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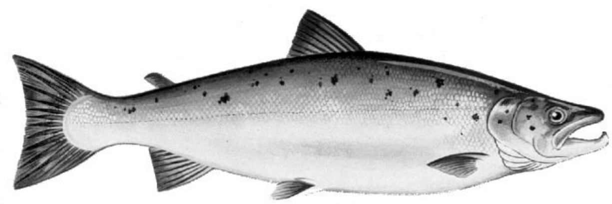
Canadian Science Advisory Secretariat
Science Advisory Report 2013/009

Maritimes Region

RECOVERY POTENTIAL ASSESSMENT FOR SOUTHERN UPLAND ATLANTIC SALMON



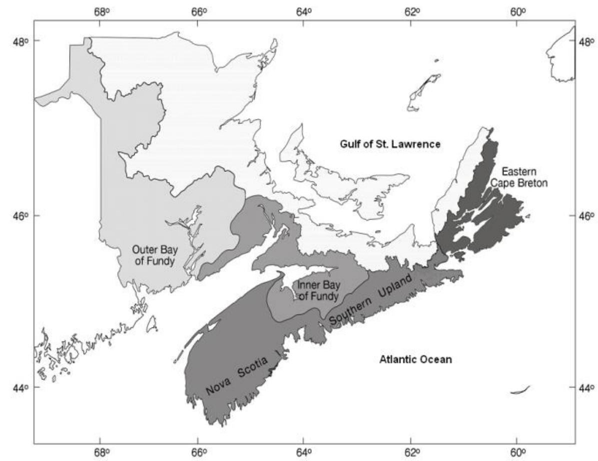


Figure 1. Map showing the location of the Southern Upland relative to the three other designatable units for Atlantic salmon in the Maritimes Region.

Context

The Nova Scotia Southern Upland (SU) population of Atlantic salmon was evaluated as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in November 2010. This population assemblage (designatable unit) occupies rivers on the mainland of Nova Scotia, including all rivers south of the Canso Causeway on both the Eastern Shore and South Shore of Nova Scotia draining into the Atlantic Ocean (Figure 1), as well as the Bay of Fundy rivers southwest of Cape Split. The unique phylogenetic history of SU Atlantic salmon, the minimal historical gene flow between the SU and surrounding regions, the low rates of straying from other regions, and the evidence for local adaption to environmental conditions in the SU region support the view that SU salmon differ from salmon in other areas.

A Recovery Potential Assessment (RPA) process has been developed by Fisheries and Oceans Canada (DFO) Science to provide the information and scientific advice required to meet the various requirements of the Species at Risk Act (SARA). The scientific information provided in the RPA serves as advice to the Minister regarding the listing of the species under SARA and is used when analyzing the socio-economic impacts of listing, as well as during subsequent consultations, where applicable. It is also used to evaluate activities that could contravene the SARA should the species be listed, as well as in the development of a recovery strategy. This assessment considers the scientific data available to assess the recovery potential of SU Atlantic Salmon.

This Science Advisory Report is from the May 22-25, 2012, Recovery Potential Assessment for Southern Upland Atlantic salmon. Additional publications from this meeting will be posted on the *Fisheries and Oceans Canada (DFO) Science Advisory Schedule* as they become available.

SUMMARY

- Available indices show that abundance of Atlantic salmon is very low in the Southern Upland designatable unit and has declined from levels observed in the 1980s and 1990s.
- Annual adult abundance in four rivers declined 88% to 99% from observed abundance in the 1980s, a similar trend is observed in the recreational catch.
- Region-wide comparisons of juvenile density data from more than 50 rivers indicate significant ongoing declines between 2000 and 2008/2009 and provide evidence for river-specific extirpations.
- Population modeling for two of the larger populations remaining in the Southern Upland designatable unit (LaHave and St. Mary's) indicates a high probability of extirpation (87% and 73% within 50 years for these two populations respectively) in the absence of human intervention or a change in survival rates for some other reason.
- Population viability analyses indicate that the loss of past resiliency to environmental variability and extreme environmental events is contributing to the high risk of extinction.
- Juvenile Atlantic salmon were found in 22 of 54 river systems surveyed in 2008/2009. Given the reductions in freshwater habitat that have already occurred and the current low population size with ongoing declines, all 22 rivers include important habitat for Southern Upland Atlantic salmon. Restoration of these populations is expected to achieve the distribution component of the recovery target. If additional rivers are found to contain salmon, the consideration of these rivers as important habitat would have to be re-evaluated.
- The estuaries associated with these 22 rivers are considered to be important habitat for Atlantic salmon as successful migration through this area is required to complete their life cycle.
- While there is likely to be important marine habitat for Southern Upland Atlantic salmon, given broad temporal and spatial variation, it is difficult to link important life-history functions with specific marine features and their attributes.
- Proposed recovery targets for Atlantic salmon populations in the Southern Upland designatable unit have both abundance and distribution components. Abundance targets for Southern Upland Atlantic salmon are proposed as the river-specific conservation egg requirements. The distribution target should encompass the range of genetic and phenotypic variability among populations, and environmental variability among rivers, and would include rivers distributed throughout the designatable unit to allow for gene flow between the rivers/populations. There is the expectation that including a wider variety of populations in the distribution target will enhance persistence as well as facilitate recovery in the longer term.
- Interim recovery targets for Southern Upland Atlantic salmon can be used to evaluate progress towards recovery. First, halt the decline in abundance and distribution in rivers with documented Atlantic salmon populations. Next, reduce the extinction risk in rivers with documented Atlantic salmon populations by increasing the abundance in these rivers. Then, as necessary, expand the presence and abundance of Atlantic salmon into other rivers currently without salmon to fill in gaps in distribution within the Southern Upland designatable unit and facilitate metapopulation dynamics.
- Recovery targets will need to be revisited as information about the dynamics of the recovering population becomes available. Progress towards recovery targets can be evaluated using survival and extinction risks metrics.
- Two dwelling places were evaluated for their potential consideration as a residence for Atlantic salmon. Of these, redds most closely match the definition of a residence because they are constructed, whereas home stones are not.
- Threats to persistence and recovery in freshwater environments identified with a high level of overall concern include (importance not implied by order): acidification, altered hydrology,

invasive fish species, habitat fragmentation due to dams and culverts, and illegal fishing and poaching.

- Threats in estuarine and marine environments identified with a high level of overall concern are (importance not implied by order): salmonid aquaculture and marine ecosystem changes.
- From analyses of land use in the Southern Upland region, previous and on-going human activities are extensive in the majority of drainage basins and have likely altered hydrological processes in Southern Upland watersheds. Watershed-scale factors have the potential to override factors controlling salmon abundance at smaller spatial scales (i.e., within the stream reach).
- River acidification has significantly contributed to reduced abundance or extirpation of populations from many rivers in the region during the last century. Although most systems are not acidifying further, few are recovering and most are expected to remain affected by acidification for more than 60 years.
- Acidification and barriers to fish passage are thought to have reduced the amount of freshwater habitat by approximately 40%, an estimate that may be conservative. However, given the low abundance of salmon at present, habitat quantity is not thought to be currently limiting for populations in rivers where barriers and acidification are not issues. Whether freshwater habitat becomes limiting in the future depends on the dynamics of recovered populations.
- Population modeling for the LaHave River (above Morgan Falls) and the St. Mary's River (West Branch) salmon populations indicated that smolt-to-adult return rates, a proxy for at-sea survival, have decreased by a factor of roughly three between the 1980s and 2000s. Return rates for Southern Upland salmon are currently about ten times higher than they are for inner Bay of Fundy salmon populations.
- In contrast with inner Bay of Fundy salmon populations, for which at-sea survival is so low that recovery actions in fresh water are expected to have little effect on overall viability, recovery actions focused on improving freshwater productivity are expected to reduce extinction risk for Southern Upland salmon.
- Remediation actions to address land use issues will not produce immediate population increases for Southern Upland salmon. However, large-scale changes are the most likely to bring about substantial population increase in Southern Upland salmon because they should have a greater impact on total abundance in the watershed rather than on localized density, and they would address issues at the watershed scale. Coordination of activities at small scales may produce more immediate effects but of shorter duration than addressing landscape-scale threats.
- Population viability analyses indicate that relatively small increases in either freshwater productivity or at-sea survival are expected to decrease extinction probabilities. For example, for the LaHave River (above Morgan Falls) population, increasing freshwater productivity by 20% decreases probability of extinction within 50 years from 87% to 21%, while a freshwater productivity increase of 50% decreases the probability of extinction within 50 years to near zero. Larger changes in at-sea survival are required to restore populations to levels above their conservation requirements.
- Sensitivity analysis examining the effect of starting population size on population viability highlights the risks associated with delaying recovery actions; recovery is expected to become more difficult if abundance continues to decline, as is predicted for these populations.
- Atlantic salmon is one of the most-studied fish species in the world. Readers are referred to the supporting research documents, which form part of the advisory package for this designatable unit, for more information than is contained in this summary document.

BACKGROUND

Rationale for Assessment

When the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) has assessed aquatic species as Threatened or Endangered, Fisheries and Oceans Canada (DFO), as the responsible jurisdiction under the *Species at Risk Act* (SARA), is required to undertake a number of actions. Many of these actions require scientific information on the current status of the species, population or designable unit (DU), threats to its survival and recovery, habitat needs, and the feasibility of its recovery. Formulation of this scientific advice has typically been developed through a Recovery Potential Assessment (RPA) that is conducted as soon as possible after the COSEWIC assessment. This timing allows for the consideration of peer-reviewed scientific analyses into SARA processes including listing decisions and recovery planning.

Southern Upland (SU) Atlantic salmon (*Salmo salar*) was assessed as Endangered by COSEWIC in November 2010 (COSEWIC 2011). DFO Science was asked to undertake an RPA for the Nova Scotia Southern Upland DU based on DFO's protocol for conducting RPAs (DFO 2007). Information on 22 Terms of Reference was reviewed at this meeting.

Southern Upland DU

The Southern Upland DU of Atlantic salmon consists of the salmon populations that occupy rivers in a region of Nova Scotia extending from the northeastern mainland near Canso, into the Bay of Fundy at Cape Split (COSEWIC 2011). This region includes rivers on both the Eastern Shore and South Shore of Nova Scotia draining into the Atlantic Ocean (Figure 1), as well as Bay of Fundy rivers south of Cape Split. Historically, it has been divided into three Salmon Fishing Areas (SFAs): SFA 20 (Eastern Shore), SFA 21 (Southwest Nova Scotia), and part of SFA 22 (Bay of Fundy Rivers inland of the Annapolis River).

Based on genetic evidence, regional geography and differences in life history characteristics SU Atlantic salmon is considered to be biologically unique (Gibson et al. 2011) and its extirpation would constitute an irreplaceable loss of Atlantic salmon biodiversity. Additional information on the genetic analysis of SU Atlantic salmon is provided in O'Reilly et al. (2012).

The exact number of rivers inhabited by SU Atlantic salmon is not known, but salmon likely used most accessible habitat in this area at least intermittently in the past. There are 585 watersheds (streams of various sizes draining directly into the ocean) in the region; 72 are considered to have historically contained Atlantic salmon populations (Figure 2).

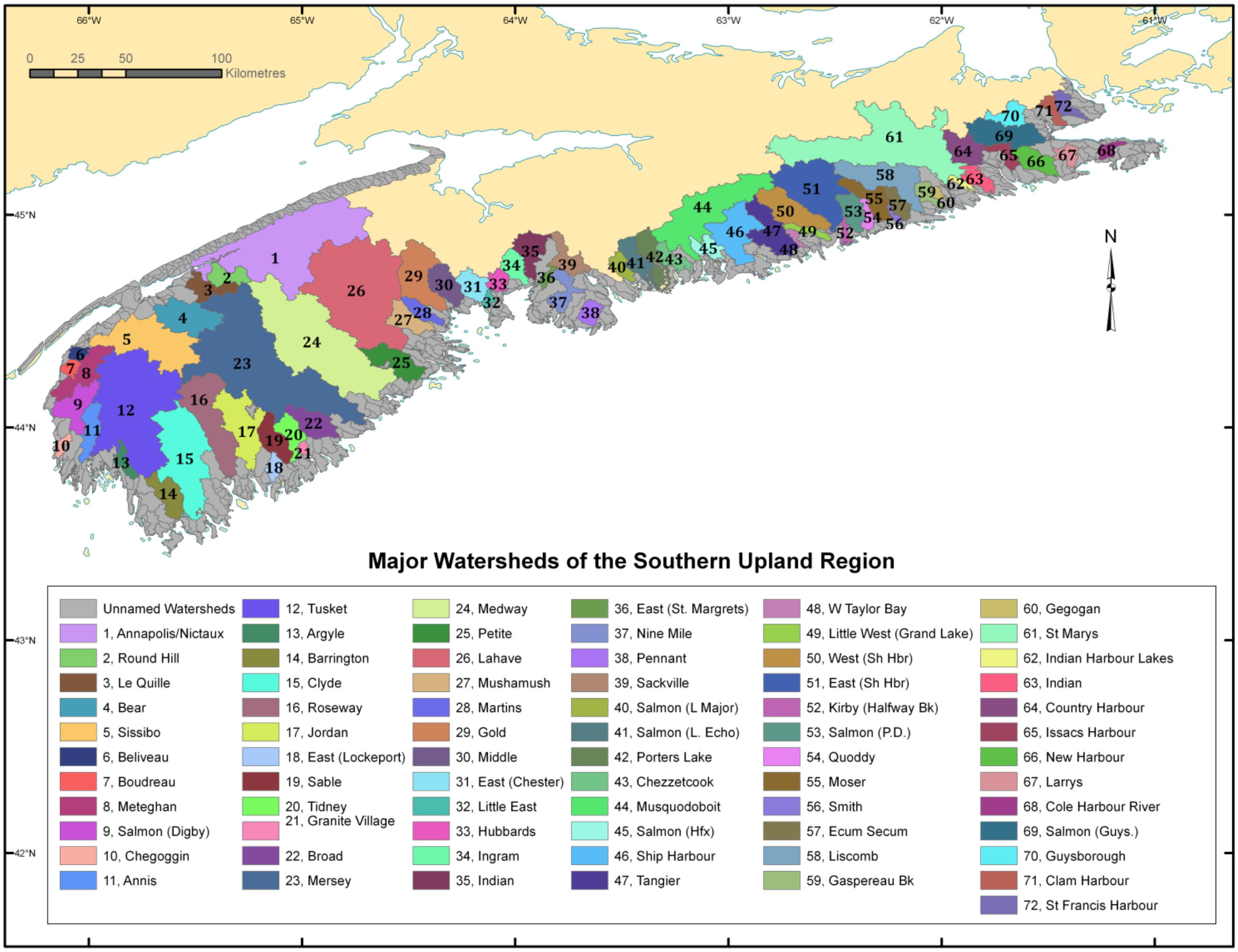


Figure 2. Map of the watersheds contained in the Southern Upland region, labelled by number and colour, where the boundaries were determined from the Secondary Watersheds layer for ArcGIS developed by the Nova Scotia Department of the Environment. Watersheds that are not labelled by number, but are still contained within the Southern Upland region are shown in grey.

Information on the life cycle of SU Atlantic salmon is contained in Gibson and Bowlby (2013). Within the SU populations, salmon mature after either one or two winters at sea (called “one sea-winter salmon” or 1SW, “two sea-winter salmon” or 2SW, respectively), although historically a small proportion also matured after three winters at sea (called “three sea-winter salmon” or 3SW). The proportion of salmon maturing after a given number of winters at sea is highly variable among populations and 3SW salmon are now very rare or absent from most populations in the Southern Upland.

Atlantic salmon is one of the most-studied fish species in the world. Readers are referred to the supporting research documents, which form part of the advisory package for this DU, for more information than is contained in this summary document.

ASSESSMENT

Status and Trends

Data available for evaluating the abundance and trends of SU Atlantic salmon include assessments of adult salmon returning to the St. Mary's River (West Branch), LaHave River (above Morgan Falls), and East River (Sheet Harbour) populations, estimates of smolts abundance for these populations, and estimates of the abundance of juvenile salmon (fry and parr) in many rivers. In the past, abundance has been assessed for the Liscomb River population as well. A detailed discussion of the abundance and trends of SU Atlantic salmon is contained in Bowlby et al. (2013a).

Adult Abundance

Available indices show that abundance of Atlantic salmon is very low in the SU DU and has declined from levels observed in the 1980s and 1990s. Annual adult abundance in four rivers declined by 88% to 99% from observed abundance in the 1980s (Figure 3); a similar trend is observed in the recreational catch time series.

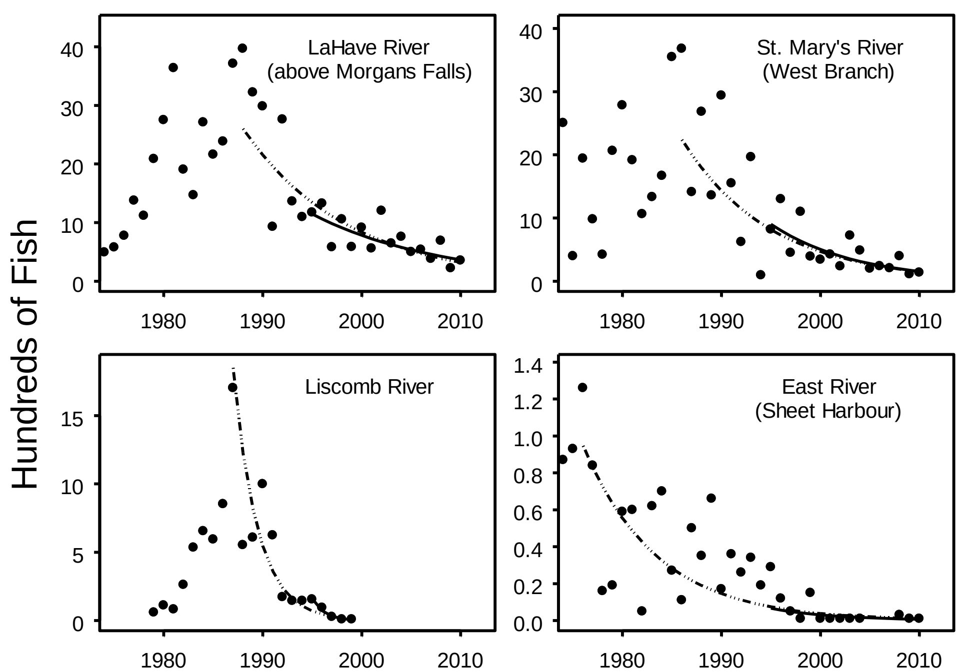


Figure 3. Atlantic salmon adult abundance time series based on adult count data (points) for four rivers in the Southern Upland from 1974 to 2010. The lines show the trends estimated by log-linear regression over the previous 3 generations (solid lines) and from the year of maximum abundance (dashed lines).

Juvenile Abundance and Distribution

Region-wide comparisons of juvenile density data (obtained by electrofishing) from more than 50 rivers indicate significant ongoing declines between 2000 and 2008/2009 and provide evidence for river-specific extirpations. In 2008/2009, juvenile Atlantic salmon were found in 22 of 54 surveyed rivers within the DU, but were not found in 4 rivers where they had been found in 2000 (Figure 4). Despite fishing effort in the two surveys being similar, only one quarter as many salmon juveniles were captured in the 2008/09 survey as in 2000 (1,019 versus 3,733).

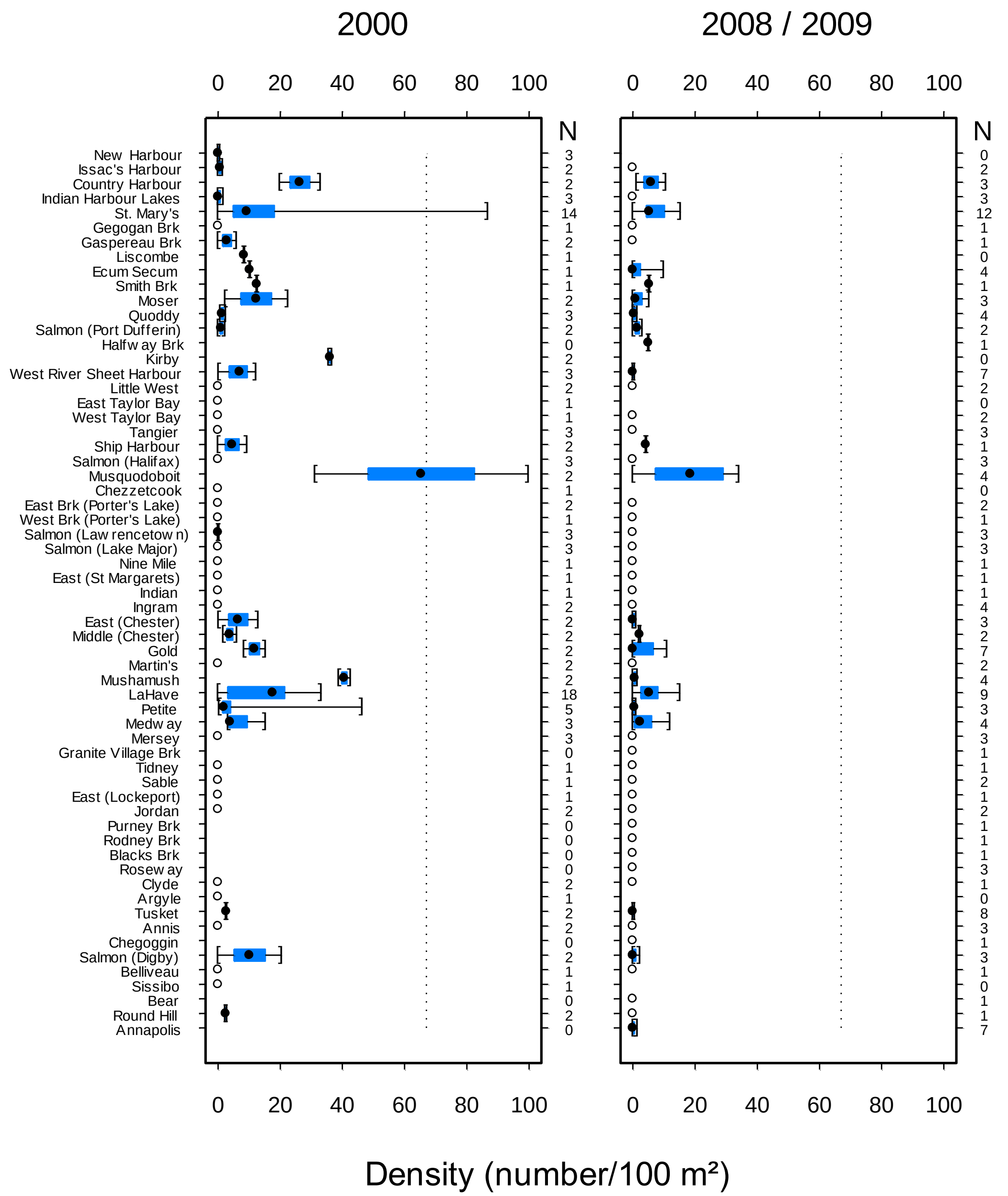


Figure 4. Boxplots of Atlantic salmon juvenile densities (age 0, age 1, and age 2+ combined) in rivers sampled by electrofishing during the survey in 2000 (left panel) and in 2008/2009 (right panel). The number of sites sampled in each river is given on the right-hand axis in both panels, and sites in which no salmon were captured are represented by open circles. The vertical dotted line shows Elson's norm for total juvenile abundance in both panels. Box plots are interpreted as follows: the black symbols are the medians, the rectangle shows the interquartile range and the whiskers the minimum and maximum values. Reprinted from Gibson et al. (2011).

Where present in 2008/2009, the observed densities of juvenile salmon ranged from 0.3 to 33.8 fish per 100 m^2 (Figure 4). Observed densities of fry (age 0) ranged from 0.3 to 28.0 fish per 100 m^2 and of parr (age 1 and age 2+) ranged from 0.2 to 16.1 fish per 100 m^2, with the highest values being recorded on the Musquodoboit River. In general, the mean density of either age class was lower than Elson's norm (30 age 0 fish per 100 m^2 and 24 age 1 and older fish per 100 m^2), values that have been used as a reference for juvenile production in fresh water.

Range and Distribution

The evaluation of range and present distribution of SU Atlantic salmon in fresh water is based on juvenile salmon surveys (Figure 4), although salmon may be present in some rivers not included in the survey. The full extent of the marine range of SU Atlantic salmon is not known, but tagging studies indicate that SU Atlantic salmon can be found along the entire coast of Nova Scotia, from the inner Bay of Fundy to the tip of Cape Breton, throughout most, if not all, of the year. Additionally, they may be found along the coast of northern New Brunswick, Newfoundland, northern Quebec, and the tip of Labrador, migrating northward until a proportion reach the Labrador Sea, Irminger Sea, or along the coast of West Greenland. For the high-seas fisheries in Labrador and West Greenland, few of the tag recaptures were assigned a latitude and longitude when recovered; therefore, it is not possible to determine how far off-shore Atlantic salmon may frequent in these areas. Assuming that these data represent general distribution patterns in the marine environment, there appears to be limited use of the Gulf of St. Lawrence (including the coastal areas around the Magdalen Islands, northern New Brunswick, or Quebec near Anticosti Island) by SU Atlantic salmon. Further details of the analysis of the tagging data are provided in Bowlby et al. (2013b).

Population Dynamics

A life history-based population dynamics model was used to evaluate population viability. The population dynamics model consists of two parts: a freshwater production model that provides estimates of the expected smolt production as a function of egg deposition, and an egg-per-smolt (EPS) model that provides estimates of the rate at which smolts produce eggs throughout their lives. These components are combined via an equilibrium analysis that provides estimates of the abundance at which the population would stabilize if the input parameters remained unchanged. This combined model is then used to evaluate how equilibrium population size has changed through time, as well as how the population would be expected to change in response to changes in carrying capacity, survival, or life stage transition probabilities. Parameter estimates from the model are used in the population viability analysis (PVA) for the recovery scenarios. Analyses are presented for the two larger rivers for which there are sufficient monitoring data: the LaHave River (above Morgan Falls), and the St. Mary's River (West Branch).

Life-History Parameter Estimates

Life-history parameter estimates were derived using a statistical, life history-based population dynamics model. Methods and results of this analysis are described in detail in Gibson and Bowlby (2013). Some key parameters are described below, including indications of where these have changed over time.

Freshwater Productivity

Analyses for LaHave River (above Morgan Falls) indicate that for the 1974 to 1985 time period, the maximum number of smolts produced per egg was 0.017 and that this value decreased to 0.013 in the 1985 to 2010 time period. Similarly, the carrying capacity for smolt production decreased from 147,700 to 119,690 (5.7 to 4.6 smolts per 100 m^2) between the two periods. For the St. Mary's River (West Branch), the carrying capacity of age-1 parr was estimated to be 11.76 parr per 100 m^2 and is considered to be low relative to other populations. The estimated number of smolts produced per egg is 0.034 and the carrying capacity for smolt is estimated to be 104,120 smolts (4.7 smolts per 100 m^2) (average values for the time period 1974 to 2010).

Details about these analyses, as well as age- and stage-specific survival rates for these populations, are provided in Gibson and Bowlby (2013).

Survival of Emigrating Smolts and Kelts in Rivers and Estuaries

The survival of emigrating SU smolts and kelts in rivers and estuaries is reasonably well studied, and provides an indication of how much survival could be changed by recovery actions that were focused on this life history event.

The survival of emigrating smolts in the LaHave, St. Mary's and Gold rivers was studied during 2010, and in West River (Sheet Harbour), during 2008, 2009 and 2010. Observed survival from release to the head of tide (the freshwater zone) ranged from 71.9% to 100%, and survival to the open ocean ranged from 39.4% to 73.5% (Table 1).

There are two studies of kelt survival in SU estuaries. In the St. Mary's River, 24 acoustically tagged kelts were detected leaving the river in the spring and all these fish survived to leave the estuary. In a study of the survival and behaviour of migrating kelts in freshwater, estuarine, and coastal habitat using LaHave River salmon, 27 of 30 acoustically tagged fish were detected leaving coastal habitat, indicating that survival was at least 90% while migrating through those environments. Further details on these studies are provided in Gibson and Bowlby (2013).

Table 1. Cumulative survival (%) and standardized survival (% per km of habitat zone length) of smolts upon exit from four habitat-zones (FW – freshwater; IE – inner estuary; OE – outer estuary; Bay / Overall). Smolts detected dead less than 1 km from release were excluded from estimates of observed survival. Reprinted from Halfyard et al. (2012).

	Observed Cumulative Survival Upon Exit			
River-Year	**FW**	**IE**	**OE**	**BAY / Overall**
LaHave	76.5% 98.9% $\cdot km^{-1}$	76.5% 100.0% $\cdot km^{-1}$	73.5% 99.7% $\cdot km^{-1}$	73.5% 100.00% $\cdot km^{-1}$
Gold	100.0% 100.0% $\cdot km^{-1}$	88.2% 92.4% $\cdot km^{-1}$	79.4% 97.8% $\cdot km^{-1}$	61.8% 97.6% $\cdot km^{-1}$
St. Mary's	79.4% 99.3% $\cdot km^{-1}$	76.5% 98.7% $\cdot km^{-1}$	73.5% 98.7% $\cdot km^{-1}$	67.6% 98.3% $\cdot km^{-1}$
West 2008	78.9% 97.0% $\cdot km^{-1}$	52.6% 83.8% $\cdot km^{-1}$	47.4% 96.5% $\cdot km^{-1}$	47.4% 100.0% $\cdot km^{-1}$
West 2009	96.0% 99.5% $\cdot km^{-1}$	76.0% 90.5% $\cdot km^{-1}$	72.0% 98.3% $\cdot km^{-1}$	68.0% 98.8% $\cdot km^{-1}$
West 2010	71.9% 95.5% $\cdot km^{-1}$	54.5% 91.0% $\cdot km^{-1}$	51.5% 98.0% $\cdot km^{-1}$	39.4% 95.0% $\cdot km^{-1}$

At-Sea Survival of Smolts and Kelts

One of the main threats to SU Atlantic salmon is thought to be the change in smolt-to-adult return rates, although estimates of the return rates for wild smolts are not available prior to the mid-1990s because smolt abundance was not being monitored before then. To resolve this issue, a model was set up to estimate past return rates using time series of estimated egg depositions, age-specific abundances of fry and parr, and the more recent age-specific smolt abundance time series.

The observed and estimated return rates of 1SW and 2SW salmon to the river mouth for the LaHave River (above Morgan Falls) population increased in the mid-1980s coincident with the closure of the commercial fisheries on Nova Scotia's coast (Figure 5). Return rates generally declined from 1985 to 1995 and have fluctuated without a clear trend since. In the 1980s, return rates varied between 2.87% and 17.60% for 1SW salmon and between 0.31% and 1.21% for 2SW salmon for the LaHave River (above Morgan Falls) population (Table 2); whereas, in the 2000s, return rates varied between 2.25% and 4.14% for 1SW salmon and between 0.31% and 1.21% for 2SW salmon. Similarly, for the St. Mary's River (West Branch) population, return rates in the 1980s varied between 1.17% and 5.52% for 1SW salmon and between 0.54% and 2.11% for 2SW salmon. In the 2000s, return rates varied between 0.18% and 2.11% and between 0.00% and 0.30% for 1SW and 2SW salmon respectively (Table 2). Return rates for Southern Upland salmon are currently about ten times higher than they are for inner Bay of Fundy salmon populations.

Population modeling for the LaHave River (above Morgan Falls) and the St. Mary's River (West Branch) salmon populations indicated that smolt-to-adult return rates, a proxy for at-sea survival, have decreased by a factor of roughly three between the 1980s and 2000s.

Table 2. A summary of the average return rates (percent) of one sea-winter and two sea-winter wild Atlantic salmon for the 1980 to 1989 and 2000 to 2009 time periods for the populations in the LaHave River (above Morgan Falls) and in the West Branch of the St. Mary's River.

	LaHave River (above Morgan Falls)		St. Mary's River (West Branch)	
	1980-1989	2000-2009	1980-1989	2000-2009
Return rates to river mouth (%)				
1SW mean	7.28	2.25	3.33	1.18
1SW minimum	2.87	1.19	1.17	0.54
1SW maximum	17.60	4.14	5.52	2.11
2SW mean	0.74	0.33	0.74	0.09
2SW minimum	0.31	0.10	0.18	0.00
2SW maximum	1.21	0.52	1.54	0.30

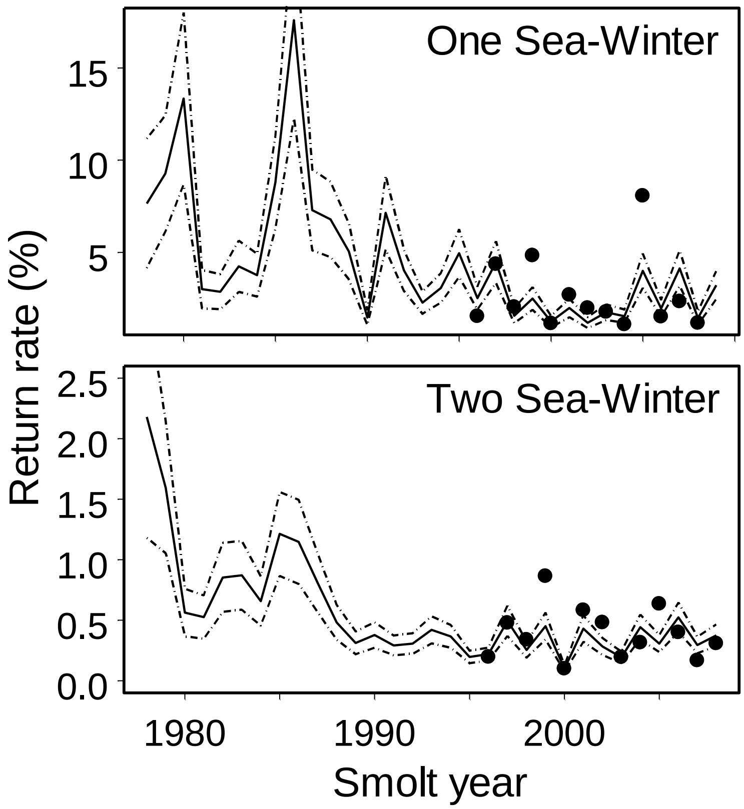


Figure 5. Observed (points) and estimated (lines) return rates for one sea-winter and two sea-winter wild Atlantic salmon for the LaHave River (above Morgan Falls) population, as estimated with the life history model. The broken lines show 95% confidence intervals based on normal approximations. Return rates are to the mouth of the river.

In addition to the changes in survival of smolts, the survival of adult salmon has also decreased since the 1980s. Details of research based on LaHave River salmon are summarized in Gibson and Bowlby (2013). The resulting estimates of mortality in the first year between spawning events increased throughout the time series, whereas mortality in the second year between spawning events increased but tended to oscillate (Figure 6). Decadal comparisons of parameter estimates indicate that mortality in the first year has continued to trend upward, indicating increasing mortality in freshwater or marine near-shore regions (near-field), whereas average second-year mortality values increased from the 1980s to the 1990s, consistent with a regime shift in the oceanic (far-field) environments. The probability of consecutive spawning varied during the time without any obvious trend in period. Fluctuations in the second-year mortality parameter matched fluctuations in the winter North Atlantic Oscillation Index (Figure 6), although this relationship was less apparent after 2000, possibly indicating a change in the regulatory mechanism in the later time period.

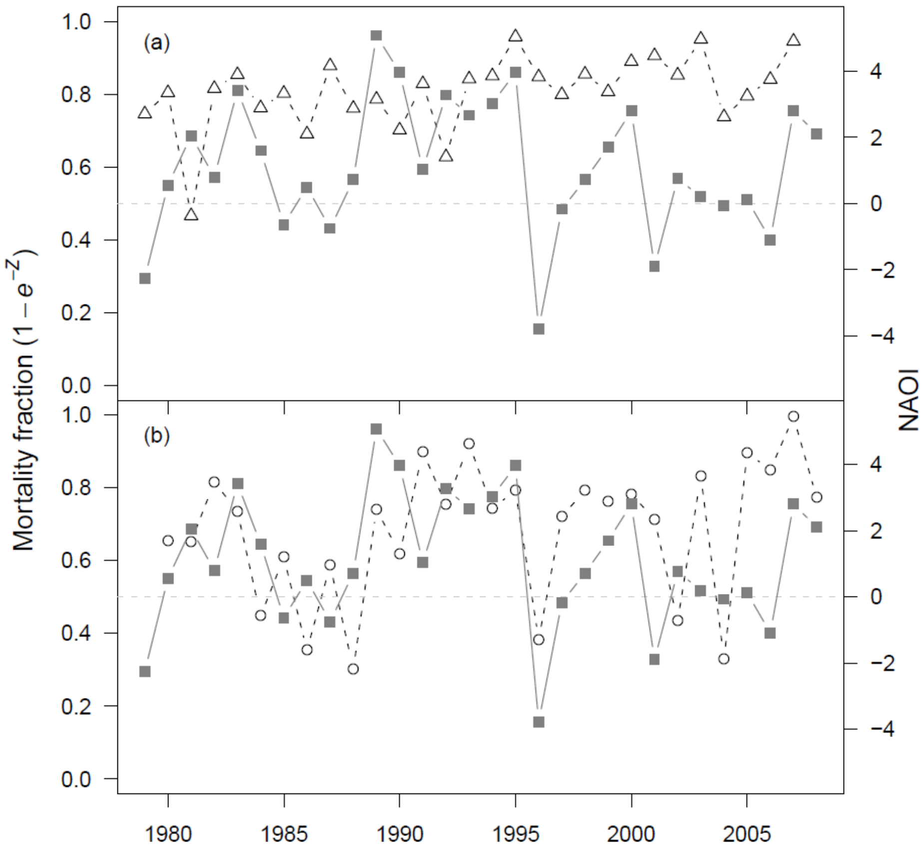


Figure 6. Annual mortality rate of LaHave River salmon as the proportion of potential mature Atlantic salmon that die in a given first year plotted alongside the winter North Atlantic Oscillation Index (NAOI) (■), an environmental variable thought to influence the marine ecology of Atlantic salmon. The NAOI is compared to mortality in the first year (Δ), which occurs mainly in freshwater (a) and mortality in the second year (○), which occurs mainly in the marine environment (b). A horizontal dashed line is provided for reference and represents an NOAI of 0 or an annually mortality rate of 50%. Reprinted from Hubley and Gibson (2011).

Population Dynamics: Past and Present

Due to the decreases in survival described above, the number of eggs expected to be produced by a smolt through its life (EPS) has also decreased. For the LaHave population, EPS values ranged between 87 and 489 eggs/smolt in the 1980s and between 29 and 111 eggs/smolt in the 2000s, a statistically significant decrease. Similar changes were estimated for the St. Mary's population, although the EPS values were generally lower.

The estimates of freshwater productivity (the rate at which eggs produce smolts) and the EPS estimates (the rate at which smolts produce eggs) were combined via an equilibrium analysis to provide estimates of the abundance at which the population will stabilize if the input parameters remain unchanged. This combined model is then used to evaluate how equilibrium population size has changed through time, as well as how the population would be expected to change in response to changes in carrying capacity, survival, or life stage transition probabilities.

The equilibrium population size for the LaHave River population varied substantially in the 1980s because of changes in the return rates and the repeat spawning component (Figure 7). However, even at the minimum values observed during that time period, the equilibrium population was greater than one. During the 2000s, the mean equilibrium for the LaHave population was zero (Table 3), indicating that the population will extirpate in the absence of human intervention or another factor that causes a change in the life history parameter values. The equilibrium population size for the St. Mary's population is slightly greater than zero (Table 4), but is low enough that the population is expected to be at high risk of extirpation due to the effects of random environmental variability.

Maximum lifetime reproductive rates for the LaHave and St. Mary's populations (Table 4) have decreased from averages of 3.59 and 4.44 in the 1980s, respectively, to averages of 0.84 and 1.02 during the 2000s. These values mean that during the 2000s, at low abundance and in the absence of density dependence (which further lowers reproductive rates), a salmon in the LaHave River produces on average a total of 0.84 replacement salmon throughout its life. Because this value is less than one (which would indicate that each spawner could replace themselves), the population is not considered viable. In the St. Mary's River, a salmon produces on average a maximum of 1.02 replacement salmon throughout its life, indicating that the population has almost no capacity to rebuild if environmental events such as floods or droughts lower survival at some point in time. Note that the minimum rate indicates that there are years of low survival, which is why this population is at risk from environmental stochasticity.

Additional information about the population dynamics of SU salmon is provided in Gibson and Bowlby (2013).

Table 3. A summary of the equilibrium population sizes and maximum lifetime reproductive rates for wild Atlantic salmon for the 1980 to 1989 and 2000 to 2009 time periods for the populations in the LaHave River (above Morgan Falls) and in the West Branch of the St. Mary's River. The values are the maximum likelihood estimates from the life history models. Two sets of values are provided: those derived using return rates to the river mouth, and those derived based on survival to the time of the assessments during the fall. The difference in the values is an indicator of the effect of the recreational fishery on the population dynamics in each time period.

	LaHave River (above Morgan Falls)		St. Mary's River (West Branch)	
	1980-1989	2000-2009	1980-1989	2000-2009
Values using return rates to river mouth				
Equilibrium egg deposition				
mean	23,188,000	0	10,651,000	71,262
minimum	3,898,900	0	1,179,800	0
maximum	63,289,000	4,378,700	21,864,000	3,428,700
Equilibrium smolt abundance				
mean	106,590	0	80,646	2,339
minimum	44,841	0	28,703	0
maximum	129,410	39,342	91,189	54,680
Max. lifetime reproductive rate				
mean	3.59	0.84	4.44	1.02
minimum	1.44	0.39	1.38	0.39
maximum	8.08	1.49	8.05	2.11

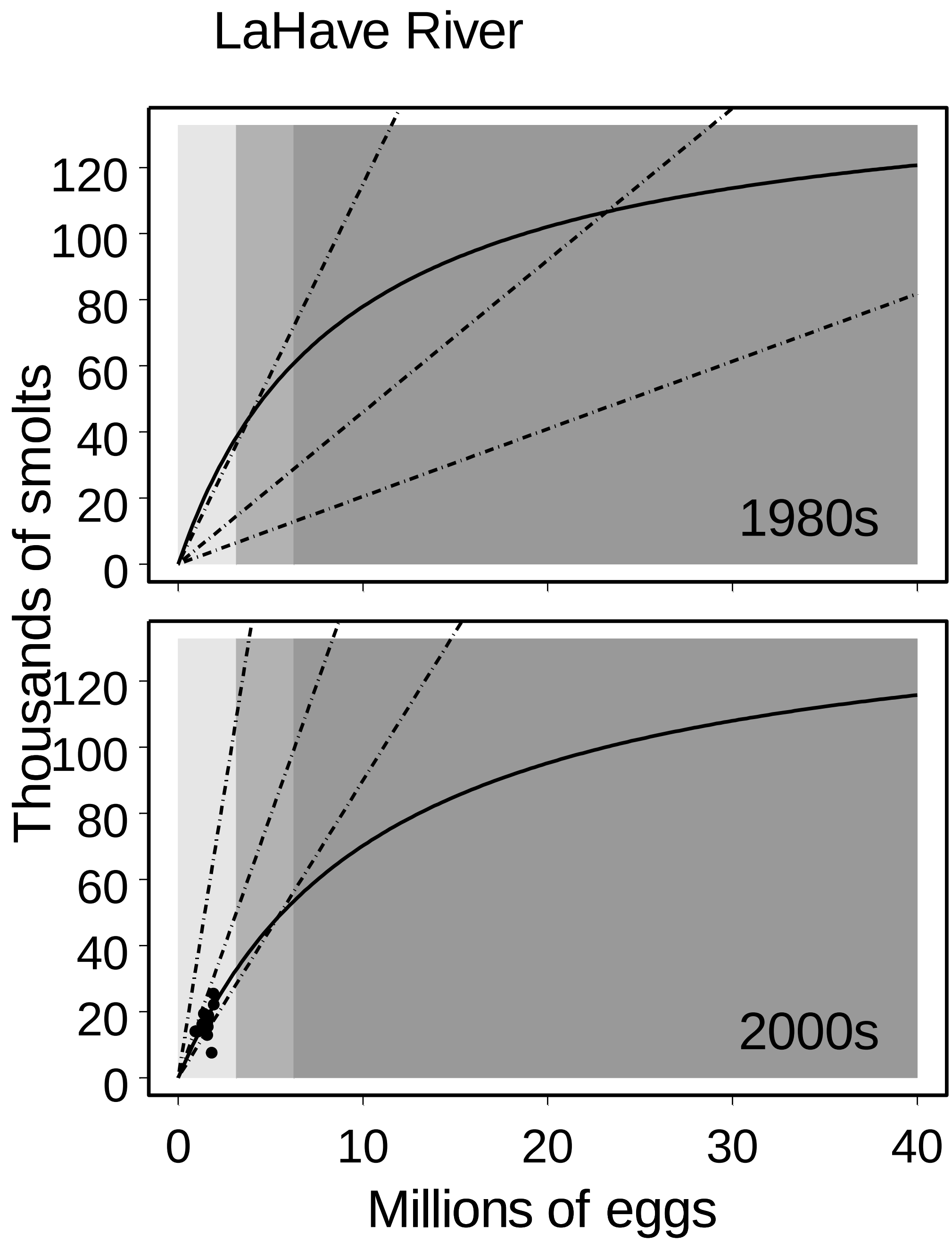


Figure 7. Equilibrium analysis of the dynamics of the Atlantic salmon population in the LaHave River, above Morgan Falls. The points are the observed egg depositions and smolt production for the 2000 to 2008 (lower panel) egg deposition years. The curved, solid line represents freshwater production. The straight, dashed lines represent marine production as calculated at the minimum observed return rates, the mean observed return rates, and the maximum observed return rates for 1SW and 2SW adults during the two time periods. Dark shading indicates egg depositions above the conservation egg requirement, medium shading is between 50% and 100% the egg requirement, and the light shading is below 50% of the requirement.

Population Viability under Present Conditions

Population viability analyses were carried out for both the LaHave River (above Morgan Falls) and the St. Mary's River (West Branch) salmon populations, using both the 1980s ("past") and 2000s ("present") dynamics. Populations are modeled as closed populations, meaning that they are not affected by either immigration or emigration. For each scenario analyzed with the PVA, 2000 population trajectories were simulated and the extinction and recovery probabilities were calculated as the proportion of populations that go extinct by a specified time. For both the past and present scenarios, the population was projected forward from a starting abundance equal to the estimated adult population size in 2010. The numbers of eggs, parr, smolt and adults, as well as their age, sex and previous spawning structure, at the start of each simulation were calculated from the adult abundance using the life-history parameter values specific to the simulation. Populations were assumed to be extinct if the simulated abundance of females dropped below 15 females for two consecutive years. When evaluating recovery probabilities, the conservation requirement was used as the recovery target.

Abundances for each life stage were projected forward for 100 years even though there is considerable uncertainty about what the dynamics of these populations will be at that time. The reason for using these projections is to evaluate longer term viability for each scenario (i.e. does it go to zero or not) and not to estimate abundance at some future time. These projections are used to determine whether the populations are viable for each combination of life history parameters, random variability and extreme events included in the scenario. In the results that follow, emphasis is placed on the LaHave River (above Morgan Falls) population.

Population modeling for two of the larger populations remaining in the Southern Upland DU (LaHave and St Mary's) indicates a high probability of extirpation (87% and 73% within 50 years for these two populations respectively) in the absence of human intervention or a change in survival rates for some other reason.

Abundance trajectories for the LaHave River (above Morgan Falls) salmon population (Figure 8) indicate that, given the present (2000s) population dynamics, this population will extirpate and has zero probability of reaching its recovery target (Figure 9; Table 4). The probability of extinction increases rapidly after about 15 years, with 31% of the simulated populations being extinct within 30 years and >95% going extinct within 60 years (Table 4). None of the 2000 simulated population trajectories met the recovery target within 100 years. This result is consistent with the maximum lifetime reproductive rate estimate of less than one (indicating that the population should continually decline under current dynamics) and the equilibrium population size of zero.

The results for the St. Mary's River (West Branch) salmon population (details in Gibson and Bowlby 2013) are similar. Even though the St. Mary's River (West Branch) salmon population has a maximum lifetime reproductive rate estimate of just over one, this population is also expected to extirpate due to the effects of natural variability in survival. Extinction probabilities also increased rapidly, with 30% of the simulated populations extirpating within 30 years, and 86% of the simulated populations becoming extirpated within 60 years. None of the 2000 simulated populations met the recovery target at any point within 100 years indicating a recovery probability of near zero based on the present dynamics.

Table 4. Probabilities of extinction and of recovery within 1 to 10 decades for the LaHave River (above Morgan Falls) Atlantic salmon population. Two scenarios are shown, one based on the 1980s dynamics (past dynamics) and one based on the 2000s dynamics (present dynamics). The same random numbers are used for each scenario to ensure they are comparable. Probabilities are calculated as the proportion of 2000 Monte Carlo simulations of population trajectories that either became extinct or met the recovery target.

	Probability of Extinction		Probability of Recovery	
Dynamics:	Present	Past	Present	Past
Year				
10	0.00	0.00	0.00	0.34
20	0.05	0.00	0.00	0.97
30	0.31	0.00	0.00	1.00
40	0.66	0.00	0.00	1.00
50	0.87	0.00	0.00	1.00
60	0.96	0.00	0.00	1.00
70	0.99	0.00	0.00	1.00
80	1.00	0.00	0.00	1.00
90	1.00	0.00	0.00	1.00
100	1.00	0.00	0.00	1.00

Population Viability under Past Conditions

In contrast, abundance trajectories using the past (1980s) dynamics (Figure 8) indicate rapid population growth. None of the simulated population trajectories extirpate within 100 years (Figure 9; Table 4) and all simulations reach the recovery target within 30 years.

As was the case with the LaHave River (above Morgan Falls) population, abundance trajectories using the past (1980s) dynamics for St. Mary's River (West Branch) indicate rapid population growth. None of the simulated population trajectories extirpate within 100 years and 97% of the simulated populations reach the recovery target within 30 years. Not all populations remain above the recovery target all of the time because of the low carrying capacity for age-1 parr estimated for this population.

Effects of Extreme Environmental Events

The population viability analyses indicate that the loss of past resiliency to environmental variability and extreme environmental events is contributing to the high risk of extinction. Extreme environmental events that markedly reduce the abundance of juvenile Atlantic salmon do occasionally occur. One such event potentially occurred in the fall of 2010 with very high water levels occurring shortly after the spawning season. Extremely high water events can lead to disturbance or destruction of redds or overwintering habitat for juveniles resulting in higher mortality. The effects of environmental variability and extreme events were investigated using the St. Mary's River (West Branch) population model. The St. Mary's example was chosen rather than the LaHave because it has an equilibrium population size greater than zero, and, therefore, would not become extinct in the absence of environmental variability. However, when random variability is added to the projections (using the same life history parameter values as in the base model), the median time to extinction becomes just under 70 years with 10% of the populations becoming extinct within 40 years. When extreme events are added, 10% of the populations are extinct in 22 years, and half of the populations are extinct within 40 years. Changing the frequency and magnitude of the extreme events changes the extinction probabilities as expected. However, when the same random variability and extreme event scenarios are modeled using the 1980s dynamics, none of the 10,000 simulated population trajectories become extinct and most met the recovery target. This highlights the resiliency that these salmon populations had in the past to environmental variability. Restoring this resiliency, resulting from distributing reproductive effort over multiple years coupled with higher survival, will be an important component of recovering SU Atlantic salmon.

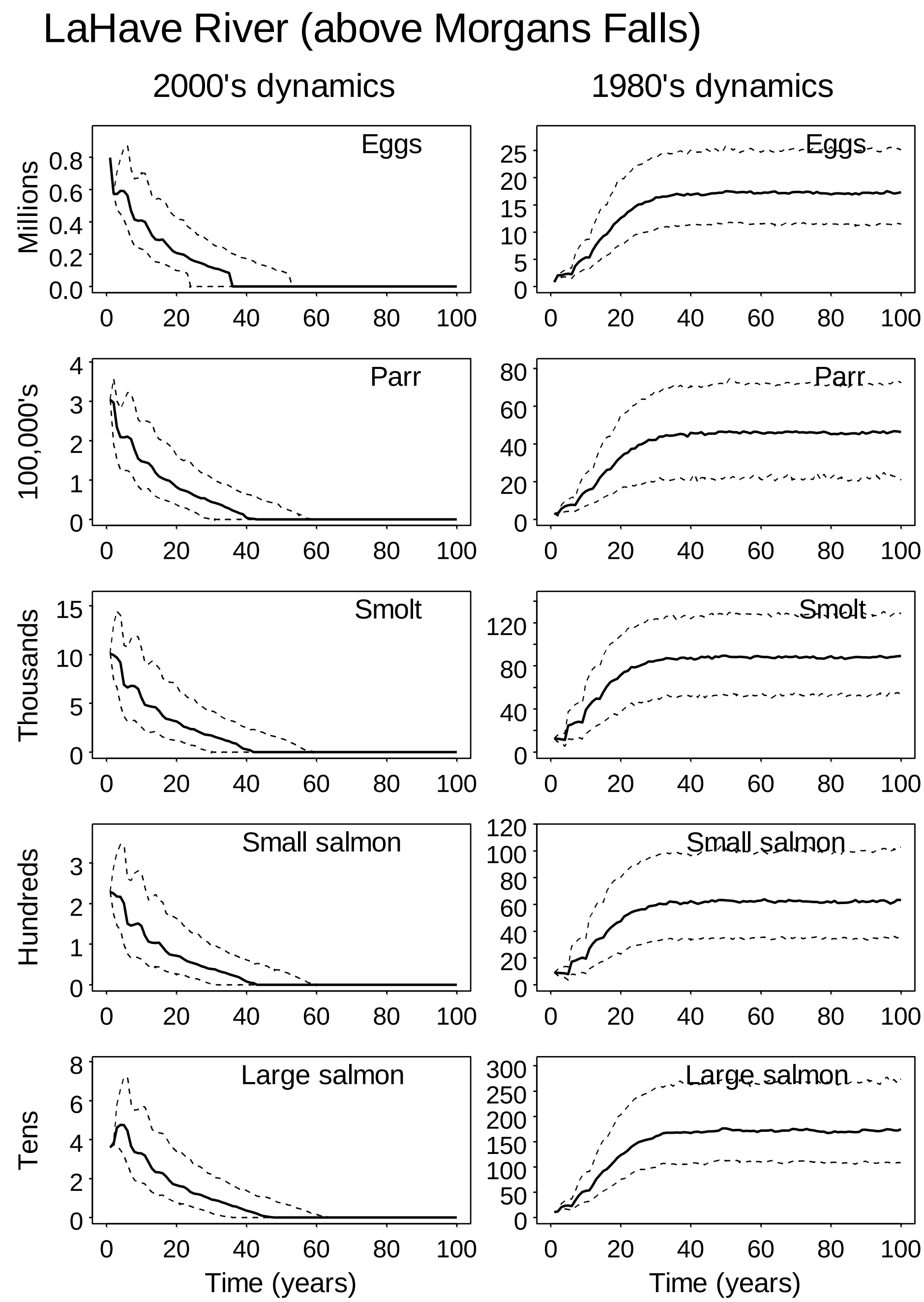


Figure 8. Simulated median abundance (solid line) with the 10th and 90th percentiles (dashed lines) for each of five life history stages from Monte Carlo simulations of the LaHave River (above Morgan Falls) Atlantic salmon population viability model. Two scenarios are shown, one based on the 1980s dynamics (right panels) and one based on the 2000s dynamics (left panels). The graphs summarize 2000 simulations for each scenario.

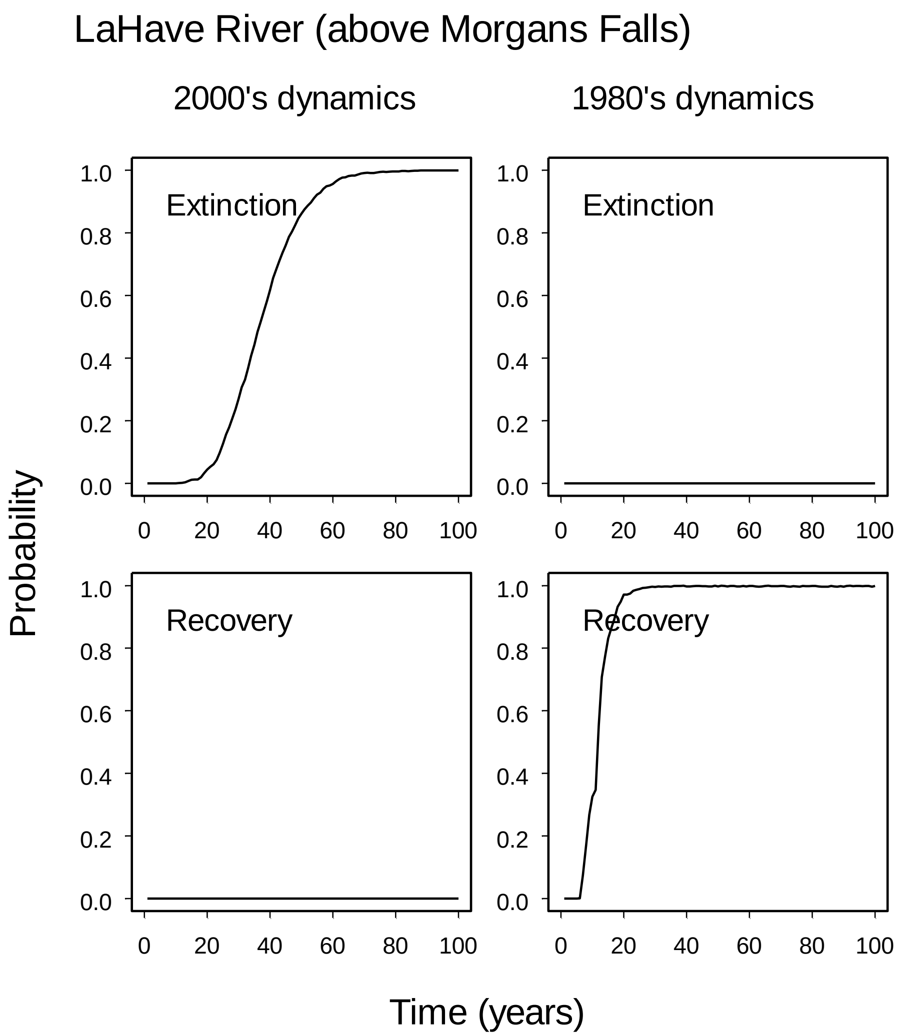


Figure 9. The probability of extinction and the probability of recovery as a function of time for the LaHave River (above Morgan Falls) Atlantic salmon population. Two scenarios are shown, one based on the 1980s dynamics (right panels) and one based on the 2000s dynamics (left panels). Probabilities are calculated as the proportion of 2000 Monte Carlo simulations of population trajectories that either went extinct or met the recovery target.

Habitat Considerations

Functional Descriptions of Habitat Properties

Detailed descriptions of aquatic habitat that SU Atlantic salmon need for successful completion of all life-history stages can be found in Bowlby et al. (2013b).

Freshwater Environment

Adult Atlantic salmon return to rivers in the SU as early as April and as late as November, but the largest proportion of the population enters the rivers in May to August, and fish can spend up to 6 to 7 months in fresh water prior to spawning. The upstream migration appears to generally consist of a migration phase with steady progress upriver interspersed with stationary resting periods, and a long residence period called the holding phase. Habitat properties required for successful migration into rivers include: appropriate river discharge (e.g. it has been suggested that upstream migration will initiate at a river discharge rate of >0.09 m^3/s per meter of river width), pools of sufficient depth and proximity in which to hold (spending weeks to months in a single pool), and unimpeded access throughout the length of the river.

Atlantic salmon in the SU spawn in October and November, with eggs incubating in redds through the winter and hatching in April. Successful incubation and hatching depends on: river discharge, water depth (e.g. generally between 0.15 to 0.76 m for redd construction) and velocity (e.g. 0.3-0.5 m/s preferred at spawning sites), substrate composition (e.g. coarse gravel and cobble with a median grain size between 15 and 30 mm forms the majority of the substrate of redds, with fine sediments found at low concentrations), water temperature (e.g. stable cold temperatures for egg development), and water quality (e.g. uncontaminated water with a pH >5.0 for development of embryos and alevins).

Juvenile SU Atlantic salmon remain in fresh water for one to four years after emergence, with most migrating to the sea two years after emergence. Habitat properties that are important for the successful rearing of juveniles (fry and parr) include: water depth (e.g. age 0 fry tend to occupy water 15-25 cm deep) and velocity (e.g. fry tend to be found in riffles with surface velocities >40 cm/s, parr are found in a wider range of velocities with an optimum between 20-40 cm/s; juvenile Atlantic salmon are rarely found at water velocities <5 cm/s or >100 cm/s, and, in the winter juveniles seek out lower velocity water, presumably to minimize energy expenditure); substrate composition (e.g. preferred substrate for age 0 salmon is in the range 16-256 mm diameter (gravel to cobble) and 64-512 mm diameter (cobble to boulder) for age 1 and older parr); the presence of cover; water temperature (typically between 15ºC and 25ºC); and water quality (uncontaminated water of pH > 5.4).

Salmon smolts do not have the same freshwater habitat requirements as parr, but rather require the environmental conditions necessary to trigger the changes associated with smoltification as well as to successfully emigrate to salt water. Environmental characteristics influencing the process of smoltification are: photoperiod, water temperature, and river discharge. The main characteristics influencing successful emigration from the river are: unimpeded access throughout the length of the river, and sufficient water discharge.

Relatively little is known about freshwater habitat use by post-spawning adult salmon (kelts) in the SU. Kelts have been shown to over-winter in deep water habitats and descend the river in the spring, although some kelts may exit the river relatively soon after spawning. Whether some SU kelts over-winter in estuaries is unknown. The proportion of the population that remains in the river during winter likely depends on the availability of pools, lakes, and stillwaters in the watershed. In a 2010 and 2011 acoustic tagging study in the St. Mary's River, all 24 of the tagged salmon left the river in spring after spawning; no kelts emigrated immediately after spawning or during the winter. The earliest observed salmon leaving the river was on March 16th, but most salmon exited the river between April 22nd and May 11th. This suggests that the proportion of adults remaining in SU rivers after spawning to overwinter in fresh water is high, particularly in rivers with suitable overwintering habitat.

Estuarine Environment

Once smolts leave fresh water, they swim actively, moving continuously through the estuary without a long period of acclimation to salt water. Migration patterns are not necessarily directly toward the open ocean, and residency times in the estuary are varied. This cyclical movement pattern has been exhibited by SU smolts. Residency patterns only suggest where and when smolts occupy estuaries, not the physical habitat characteristics that may be required. Given that smolts are thought to swim near the surface within the fastest flowing section of the water column, and use an ebb tide pattern of migration, habitat choice is unlikely to be based on physical habitat characteristics (e.g. substrate type). It is more likely that the oceanographic conditions in estuaries and coastal areas influence movement and habitat choice in estuaries.

Adult Atlantic salmon return to rivers in the SU throughout the spring, summer, and fall months. Similar to smolt use of estuaries, a variety of estuarine residency times for adults have been observed, from moving through estuaries in a matter of days to spending 3.5 months holding in an estuary before moving into the river. Estuaries appear to be mainly staging areas, and movements within them are frequently slow (<0.2 body lengths per second), following the sinusoidal pattern of the tidal currents. While holding in the estuary, adults seem to favour deep water of intermediate salinities ranging from 5 to 20 parts per thousand.

The limited information on residency times or habitat use by kelts in estuaries suggests that estuaries are used predominantly as staging areas and migratory corridors in the spring. In spring, kelts pass relatively quickly through estuaries on their way to open ocean. The one study on acoustically tagged kelts in the LaHave River found that kelts tagged in fresh water in April exited the estuary within five weeks of release. There was no typical migration pattern; one kelt exhibited non-stop migration seaward and others interspersed periods of continuous movement, residence, and backtracking.

Marine Environment

Habitat use in the marine environment for immature Atlantic salmon (individuals that have undergone smoltification, migrated to the ocean, but have not yet returned to fresh water for the first time to spawn, also known as post-smolts) has been mainly hypothesized based on physiological requirements and/or tolerances of Atlantic salmon in the marine environment. At sea, salmon tend to be found in relatively cool (4^{o}C to 10^{o}C) water, avoiding cold water (<2^{o}C), and modifying their migratory route in space and time in response to ocean temperature conditions. For example, in years where coastal water temperatures are warmer, salmon arrive at home rivers earlier. Tagging studies suggest that immature salmon are pelagic, spending the majority of their time in the top few meters of the water column, following the dominant surface currents and remaining in the warmest thermocline. Although movement patterns and distribution have been correlated with water temperature and other abiotic factors, the availability of prey and potential for growth are assumed to determine actual distribution at sea. As such, marine distribution patterns would be expected to vary in space and time as well as among years, based primarily on the distribution of suitable prey items.

Recent studies in the Northeast Atlantic demonstrate that immature salmon begin to feed extensively on marine fish larvae and to a lesser extent on high-energy crustaceans, experiencing a rapid increase in growth in the near-shore environment. Atlantic salmon are opportunistic feeders, leading to geographical differences in the type and amount of prey consumed. There is some indication that Atlantic salmon in the Northwest Atlantic have a larger proportion of insects and crustaceans in their diet than those in the Northeast Atlantic, but gadoids, herring and sand lance are also important prey items.

Growth patterns of scale circuli from two populations in the SU region combined with tag returns from commercial fishing suggest that these populations experience similar oceanographic conditions and use similar temporal and spatial routes during marine migration. A coastal or near-shore migration route along the North American continent is generally accepted (as described in the Spatial Extent of Habitat section). The location of primary feeding and staging grounds for immature salmon destined to return after one winter at sea to rivers in the SU is less well known. It may include all near-shore areas along the North American coast with suitable surface temperatures, extending northward to the Labrador Sea, but is more likely to correspond to areas of high prey density within that broad range.

After spawning, the majority of adults exit rivers in the spring of the following year for a period of reconditioning before spawning again. The length of time adults spend in the ocean between spawning events likely determines marine habitat use and distribution patterns. Consecutive spawners return in the same year as their kelt migration and have a relatively short ocean residence period (< 6 months), while alternate spawners return the following year and can spend up to a year and a half in the marine environment. Tagging studies demonstrate that alternate spawners travel as far north as West Greenland, likely following a similar migration route as immature salmon along the coastal or near-shore habitats of North America. The marine habitat use of consecutive spawning adults is less well known, but it is very unlikely that individuals would be able to reach the Labrador Sea or West Greenland in the time between spawning events. One acoustically tagged kelt from the LaHave River reconditioned over a period of 79 days before re-ascending the river, but spent this time outside the estuary. As with immature salmon, marine distribution and habitat use of adults is thought to be determined primarily by the distribution and abundance of suitable prey. Fish are the majority of the diet of adult salmon, and the species consumed include capelin, sand eels, herring, lanternfishes and barracudina. Amphipods, euphausids (krill) and other invertebrates are also consumed, and there is some indication that the proportion of invertebrates consumed increases in more southerly feeding areas.

Spatial Extent of Habitat

Freshwater Environment

Wild Atlantic salmon exhibit nearly precise homing to natal rivers, which results in significant population structuring at the river scale. There is no information which suggests that salmon do not use all available rivers in the SU at least intermittently, and assessment data demonstrates that there is no apparent minimum watershed size for occupancy. As described in the Background section, the number of watersheds that are known to have contained salmon populations is 72 (Figure 2). However, 513 additional watersheds in the SU have been identified by the Nova Scotia Department of the Environment (NS DoE), of which 256 are larger than Smith Brook (the smallest watershed known to have contained salmon). These other watersheds have a total drainage area of 6,586 km^2 (excluding coastal islands), and each has the potential to support Atlantic salmon.

Combining information from all watersheds known to have contained salmon (Figure 2), there is an estimated 20,981 km^2 of drainage area, which contains 783,142 habitat units (100 m^2) of rearing area for Atlantic salmon. The 10 largest systems contain slightly more than half of this productive area (436,572 habitat units), and only 4 watersheds have an estimated rearing area that is less than 1,000 habitat units.

Estuarine Environment

The use of particular habitat types within estuaries by smolts, adults and kelts is relatively unknown for SU Atlantic salmon, but estuarine habitat availability is not thought to be limiting.

Marine Environment

Marine distribution patterns for SU Atlantic salmon were assessed based on recovery locations of tagged smolts and adults reported by commercial and recreational fisheries.

In total, there were 5,158 recaptures of individuals tagged in the SU region (1,899 from SFA 20 and 3,259 from SFA 21). Recapture rates from groups of tagged fish were extremely low, generally less than 5% (mean = 3.9%, median = 0.8%, range: 0.02% - 73%). All of the higher recapture rates were associated with releases upstream of continuously monitored facilities, like Morgan Falls fishway on the LaHave River. There were very few release events of exclusively wild-origin fish (either adult or smolt) or of adults (either hatchery or wild. Therefore, the data presented are based entirely on recaptures of hatchery-origin or mixed-origin (wild plus hatchery in the same release group) smolts. Due to the relative scarcity of recapture information, marine distribution patterns of SU Atlantic salmon are presented as a group, although there are likely differences among populations in marine habitat use. Three time periods were evaluated: distribution in the year of release, distribution in the year following release, and distribution two years following release.

First Year Following Release (Figure 10): The majority of tagged smolts were released in fresh water in April and May. By late May and throughout June, smolts had begun leaving fresh water and moving along the coast of Nova Scotia, both in a southern and northern direction (Figure 10). By July, individuals had spread out along the entire coast of Nova Scotia, from the inner Bay of Fundy to the tip of Cape Breton, while a smaller proportion had moved substantially farther northward, to Eastern Newfoundland, Northern Quebec and the tip of Labrador (Figure 10). A similar pattern exists during August. From September until the following March, there were very few tag recaptures; these indicated that a proportion of SU salmon remained along the coast of NS during the winter months. Interestingly, there were no recaptures of immature SU Atlantic salmon off the coasts of Newfoundland, Quebec, and Labrador after September. This may suggest that immature Atlantic salmon from the SU do not over-winter this far north in their first winter at sea, or that they arrive after the close of the various fishing seasons (i.e. after November). Additionally, immature salmon were not captured in the West Greenland fishery in the first year following release (based on a total of 430 recapture events), which may indicate that they do not travel this far north in their first year or are too small to be captured by the fishing gear.

Second Year Following Release (Figure 11): In the second year, there would be salmon that return to natal rivers to spawn after 1SW as well as salmon that remain at sea for the second year (and will return as 2SW or older). The earliest recaptures in the spring were still off the coast of Nova Scotia (Figure 11), suggesting that a proportion of the individuals remained relatively localized for their entire first year at sea. Beginning in May, the largest number of recaptures was along the northern coast of NL and spread to more southerly locations in June, concentrated off the coast of Nova Scotia (Figure 10). Recaptures in the high-seas fishery off West Greenland took place from July to November (Figure 10), and the relative scarcity of recaptures in July, October and November may reflect reduced fishing effort rather than movement into or out of this area. The catch from the West Greenland fishery is thought to consist almost entirely of individuals destined to return to natal rivers as 2SW spawners, so these tag returns represent the 2SW component of populations. It is possible that the recaptures off the northern coast of Newfoundland and Labrador during the spring, summer and fall months (Figure 11) also consist of a proportion of 2SW individuals, as well as those returning to their natal rivers to spawn. It is likely that most of the recaptures of salmon off the coast of Nova Scotia in the summer months represent 1SW individuals (Figure 11). It is similarly likely that the distribution of 1SW and 2SW fish partially overlap during the summer months.

Third Year Following Release (Figure 12): In the third year, there would be salmon returning to the marine environment after spawning as 1SW salmon and salmon returning to natal rivers to spawn as 2SW adults. Based on results of kelt tagging in the LaHave River, it is likely that some portion of the marine recaptures off the coast of Nova Scotia in April and early May (Figure 12) are salmon that over-wintered in fresh water and returned to recondition in the marine environment. The other portion of the recaptures was likely first-time spawners. There were recaptures off the coast of Newfoundland from May to November (Figure 12), potentially representing two groups: salmon moving from West Greenland and the Labrador Sea on their way to natal rivers (2SW spawners) and salmon moving northward to recondition after previously spawning.

Assuming that these data represent general distribution patterns in the marine environment, there seems to be very limited use of the Gulf of St. Lawrence (including the coastal areas around the Magdalen Islands, northern New Brunswick, or Quebec near Anticosti Island) by SU Atlantic salmon. However, they do move along both coasts of Newfoundland, and they have been recaptured at locations south of where they were released. Contrary to predictions of progressive northward movement for immature individuals to over-wintering areas in the Labrador Sea or West Greenland, these tagging data suggest that SU Atlantic salmon are widely distributed in coastal marine habitats throughout their first year, particularly during the summer months.

Although it is not possible to explicitly describe the movement patterns of the various life stages of SU Atlantic salmon from these data, the inferences above highlight a crucial point when designating critical habitat in the marine environment. Although different life stages may transiently occupy similar habitats, their overall direction of movement could be in opposite directions, potentially leading to a relatively ubiquitous distribution from Nova Scotia to the Labrador Sea and West Greenland throughout most of the year. Given the variability in run-timing, both within and among populations, similar variability is likely to exist in movement of SU Atlantic salmon along the near-shore environments of the Northeast Atlantic, meaning that marine distribution (and therefore habitat use) cannot be clearly delineated on a seasonal basis.

Freshwater Spatial Constraints: Influence of Barriers and Water Chemistry on Habitat Accessibility

Assessing the impact of physical barriers on the amount of habitat in a watershed is difficult because structures can be entirely or seasonally impassable for various life stages depending on stream flow. An ArcGIS layer detailing available information on barriers in SU watersheds was compiled jointly by the NS DoE and the DFO Habitat Management (HM). This layer contains the characteristics of known barriers, including fish passage capabilities (e.g. classified as passable to fish or not). These data represent the best regional information, but data were collected over multiple years. The most recent updates to specific records span the years from 2007 to 2010 (a total of 37 out of 586 records do not list a date). Any recent changes would not have been captured in the database.

By intersecting the stream network from the National Hydrographic Service with the barrier locations, it was possible to calculate the percentage of the flow network (stream length) affected by barriers in each of the SU watersheds. There is an essentially linear relationship between the length of the flow network and the drainage area in watersheds in the SU (data not shown), so these percentages were multiplied by the amount of rearing area in a watershed to approximate the impact of barriers on habitat availability. The accessible rearing area was estimated at 57.0 million m^2 (73.2% of total rearing area) and the inaccessible area was estimated to be 21.0 million m^2 (26.8% of total rearing area).

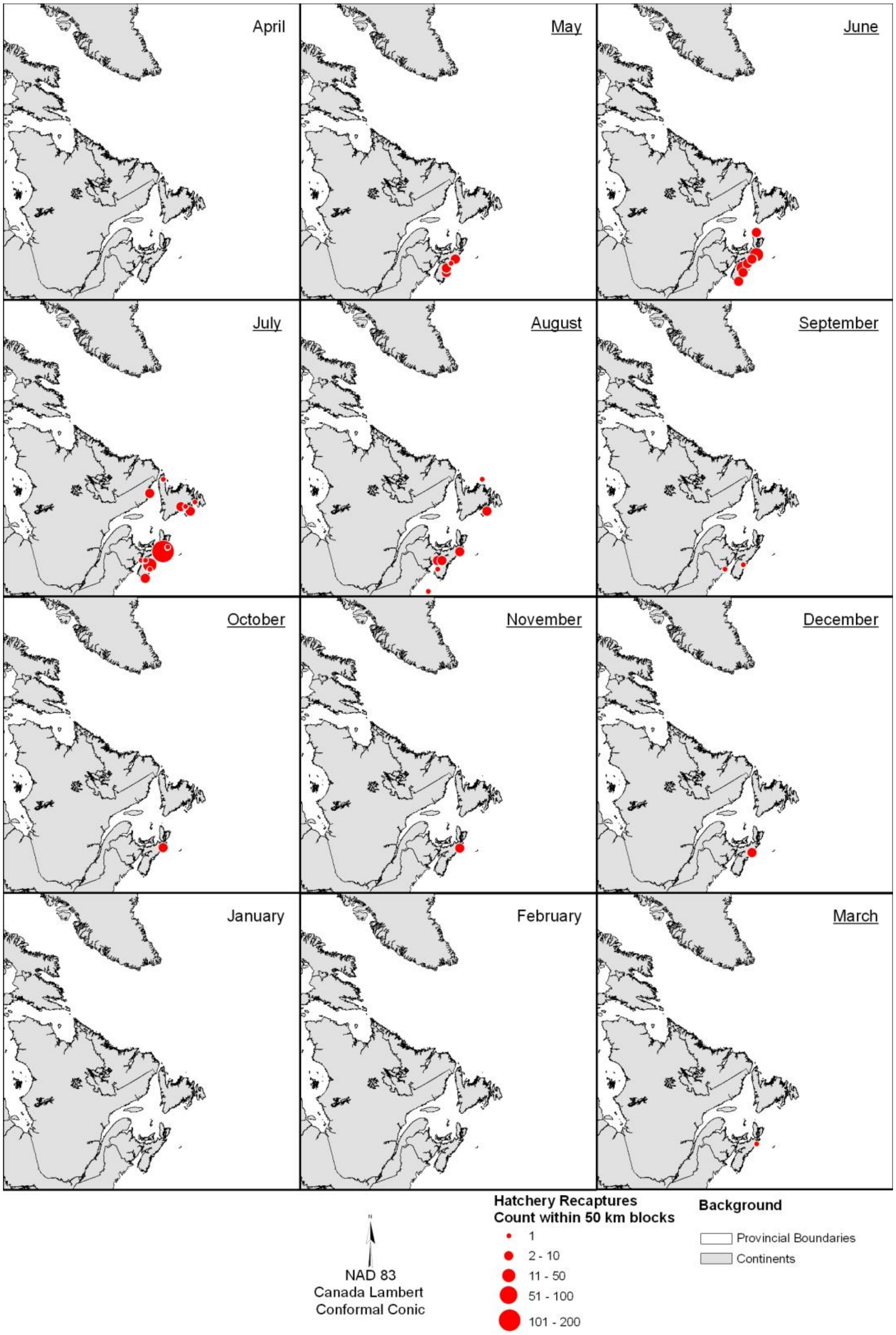


Figure 10. Recapture locations in the marine environment of individually tagged, hatchery-origin smolts in the first year following release, where the size of the point on the map is proportional to the number of recaptures within a 50 km^2 grid.

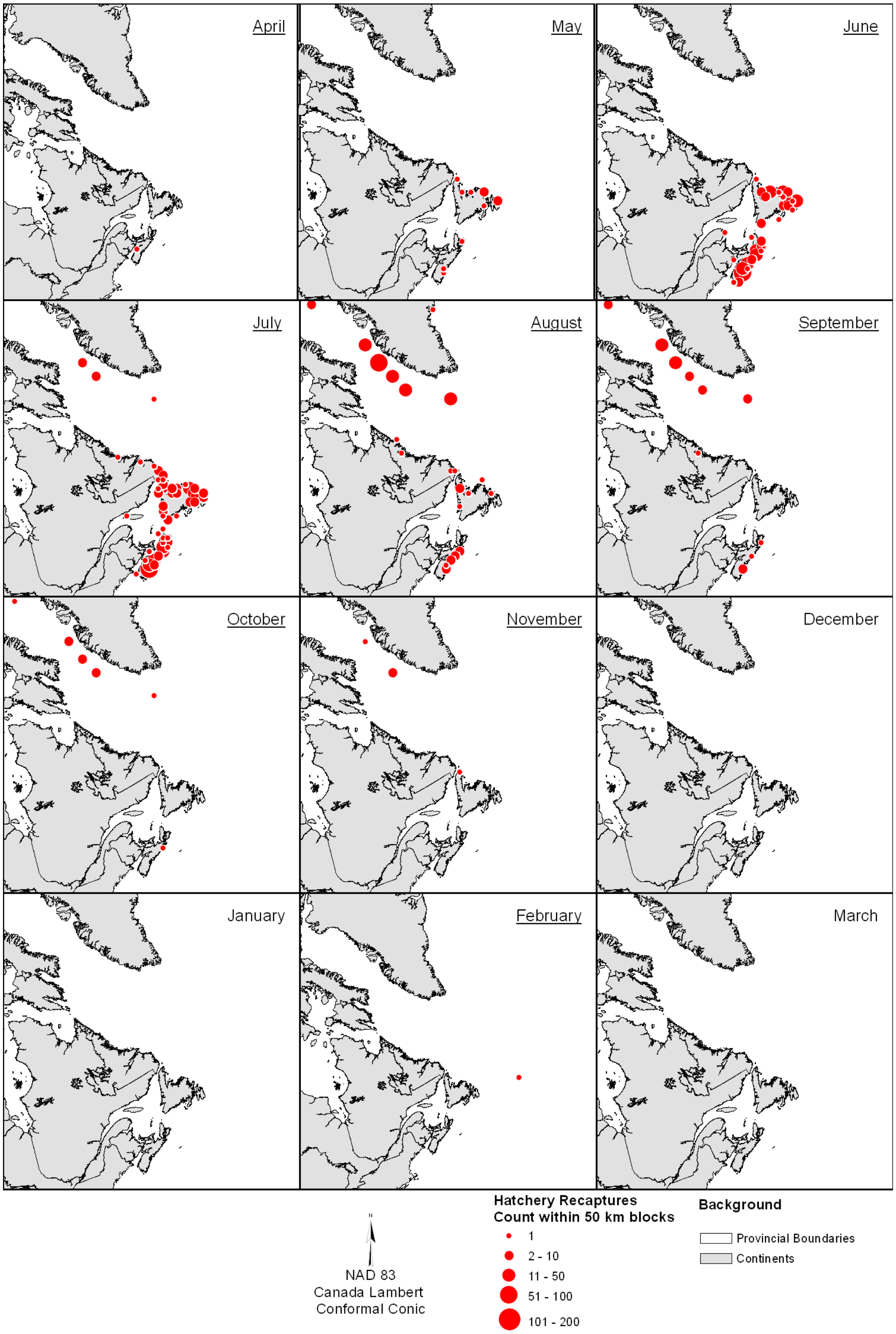


Figure 11. Recapture locations in the marine environment of individually tagged, hatchery-origin smolts in the second year following release, where the size of the point on the map is proportional to the number of recaptures within a 50 km² grid.

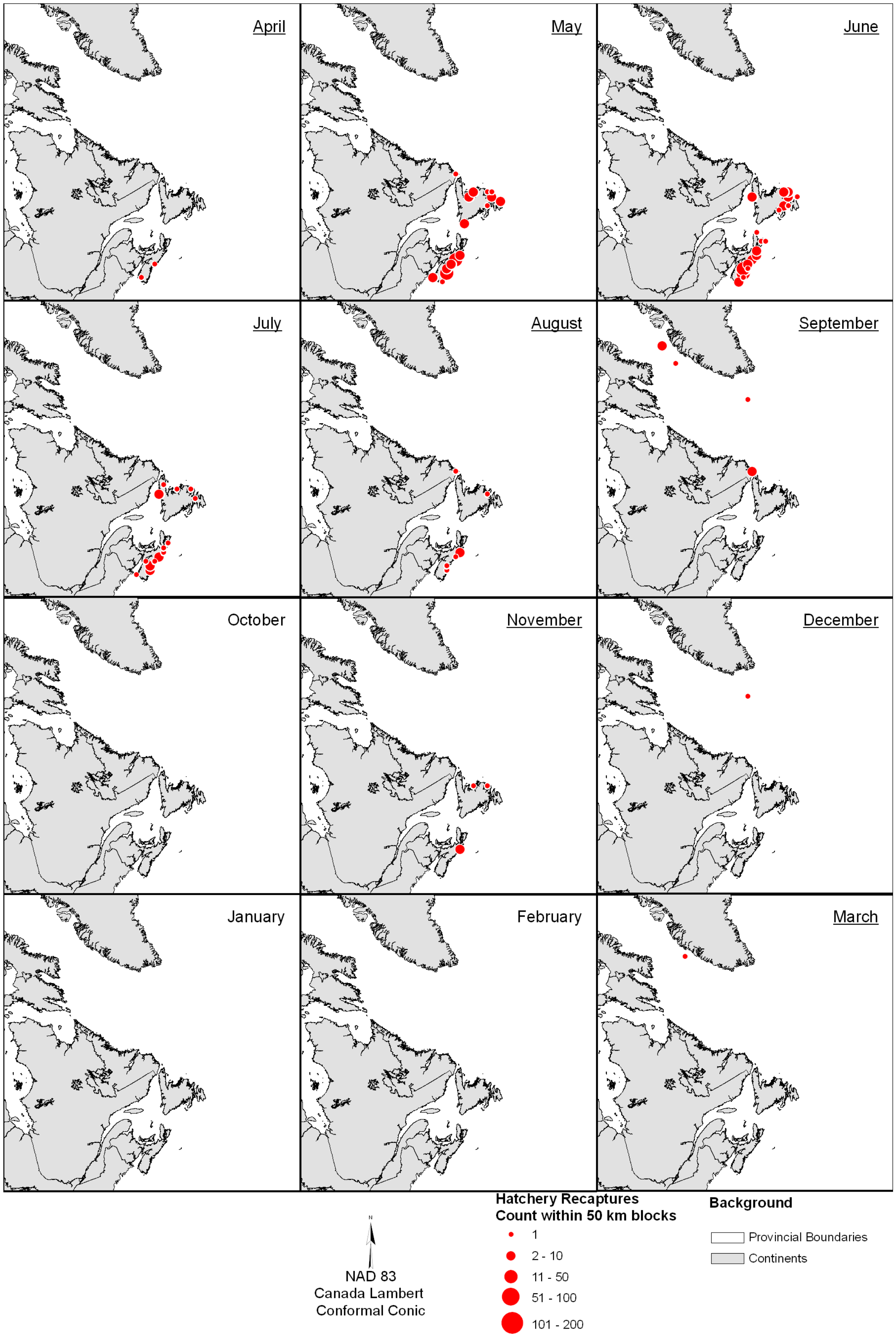


Figure 12. Recapture locations in the marine environment of individually tagged, hatchery-origin smolts in the third year following release, where the size of the point on the map is proportional to the number of recaptures within a 50 km^2 grid.

Acidification (low pH) is a major factor limiting the production of Atlantic salmon in many SU rivers. It can partially or completely eliminate suitable habitat within a watershed. Highly acidified water is not a barrier *per se* because adults can still enter the river and spawn;

however, the habitat is unsuitable because their progeny die. Thirteen rivers are considered to be unsuitable for spawning and juvenile rearing based on their acidity level (mean annual pH < 4.7), conclusion supported by the juvenile density estimates from the electrofishing surveys (0/100m^2). These 13 rivers contain a total of 100,198 habitat units (100 m^2) [or 10 million m^2] that is considered unsuitable for Atlantic salmon production.

None of the 5 watersheds that are identified as impassable due to barriers at head-of-tide are among the 13 watersheds that unsuitable for Atlantic salmon due to acidification. Thus, 18 watersheds have very little or no rearing area available for Atlantic salmon. Of the remaining 54 rivers, 25 contain total barriers that block from 0.1% to 94.5% of the watershed. There are 29 rivers that do not contain a known total barrier, and these tend to be either smaller systems or watersheds along the Eastern Shore of Nova Scotia. Of the 783,142 habitat units (100 m^2) available in rivers in the SU region, only 476,746 (61%) remain accessible to Atlantic salmon populations (Figure 13).

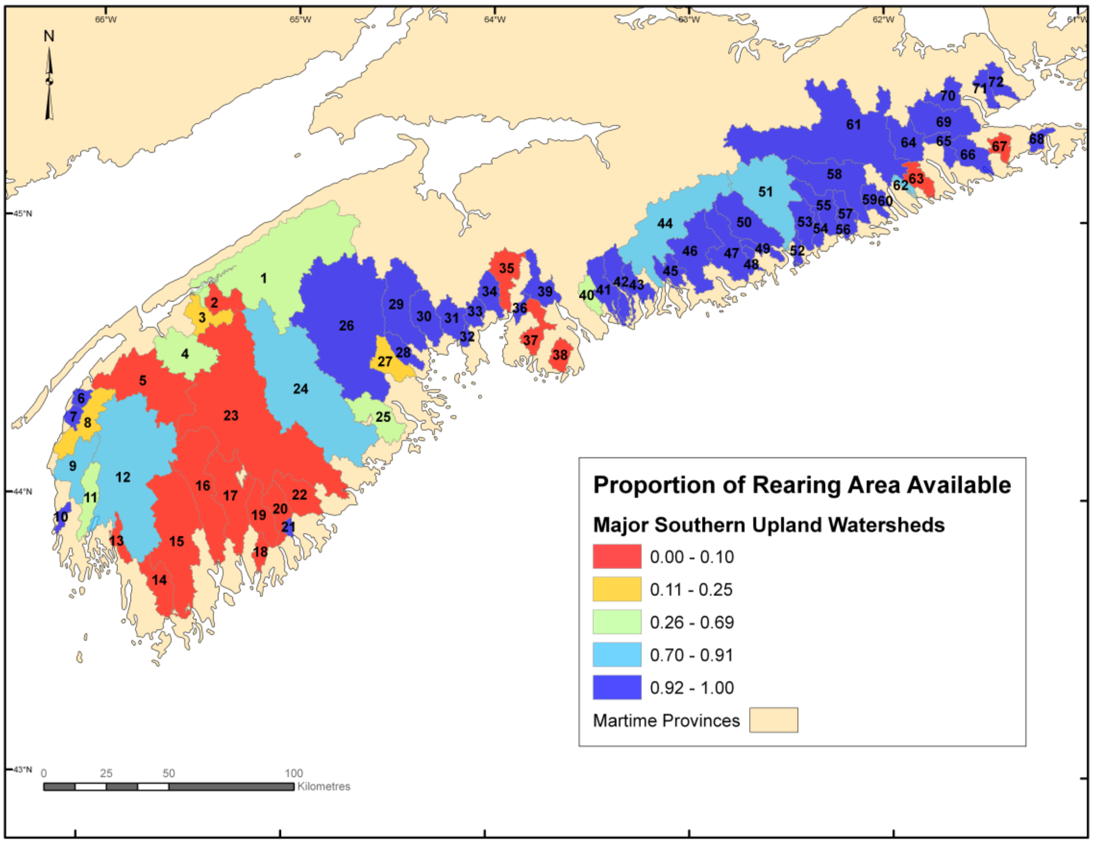


Figure 13. Proportion of rearing area available to Atlantic salmon for watersheds in the Southern Upland based on accessible habitat area (i.e. area below impassable dams) as well as pH category (where mean annual pH < 4.7 is considered unusable). Watershed numbers correspond to the legend in Figure 2.

Thus, together, acidification and barriers to fish passage are thought to have reduced the amount of freshwater habitat by approximately 40%. Thirteen individual watersheds are thought to contain essentially no useable habitat (based on acidification) and a range of 0.1% to 95% of habitat (based on stream length) is lost in other watersheds. These estimated reductions in habitat quantity are likely conservative. However, given the low abundance of salmon at present, habitat quantity is not thought to be currently limiting in rivers unaffected by barriers and acidification. .

Supply of Suitable Habitat

Current juvenile densities estimated for rivers in the SU are very low (Figure 4), particularly when compared to historical estimates of juvenile salmon production that have been used as a reference levels in the past (29 age 0 fish/100 m^2 and 38 age 1 and older fish/100 m^2: known as Elson's norm) . In other regions, where Atlantic salmon populations are thought to be meeting or close to conservation requirements, juvenile density estimates for all age classes regularly exceed Elson's norm. Although rivers in the SU may have lower productive potential than those in other areas because of their underlying geology, the amount of rearing habitat for juveniles in a given watershed (i.e. habitat of suitable gradient) is unlikely to be limiting population size for unobstructed systems and non-acid impacted systems at present. Low juvenile abundance is more likely the result of low adult abundance (in part due to low at-sea survival) and effects of human activity in these watersheds. As described above, physical barriers and water quality have likely reduced the quantity of freshwater habitat available to spawning adults by at least 40%, which would be expected to reduce adult abundance by the same amount if other life history parameters remained unchanged. In these rivers, supply of suitable habitat likely would not meet the demand.

The production of juvenile Atlantic salmon in freshwater habitats is governed by density dependent growth, survival, and habitat use. However, potential for growth is inversely related to density and, as populations become larger (with no change in the quality and quantity of available habitat), the potential rate of population growth declines. At high abundance, populations exhibit relatively constant juvenile production over a very large range of egg deposition values. In the context of habitat limitation for SU Atlantic salmon at very high abundance, this demonstrates that the productive capacity of freshwater habitats (i.e. habitat quality and quantity) will ultimately limit population size.

Regardless of the present value for carrying capacity in a specific river, the marine survival rates experienced by populations would affect whether freshwater habitat is limiting population growth at a given level of abundance. The equilibrium analysis presented earlier shows that the mean marine survival rates observed on the St. Mary's and LaHave rivers were sufficient to enable population growth in excess of the conservation requirement during the 1980s. However, under current dynamics, these populations would not be predicted to reach the conservation requirement even at the maximum observed marine survival rates during the 2000s. Ultimately, whether freshwater habitat becomes limiting in the future depends on the dynamics of recovered populations. If survival in the marine environment were to meet or exceed levels of the 1980s, freshwater habitat is not expected to become limiting until the population had reached abundance levels in excess of the conservation requirement. Conversely, if marine survival remains at current levels or undergoes a modest increase, it is predicted that increases in freshwater productivity would be necessary to reduce extinction risk or promote population increase for SU Atlantic salmon populations. The question of whether available habitat will become limiting as populations increase depends on the productive capacity of freshwater habitats as well as the mortality rates experienced by Atlantic salmon in the marine environment.

Trade-offs Associated with Habitat Allocation Options

Allocation of freshwater habitat (i.e. for consideration as critical habitat for SU salmon) can occur on at least two scales: at the watershed scale and within a watershed. At a watershed scale, freshwater habitat should be allocated to minimize extinction risk for SU Atlantic salmon populations by ensuring that the remaining genetic diversity of SU Atlantic salmon is protected, and by facilitating the re-establishment of wild self-sustaining populations in other rivers.

Specifically, watersheds that are currently known to contain Atlantic salmon and those that have a high probability of containing useable freshwater habitat are considered priorities.

Juvenile Atlantic salmon were found in 22 of the 72 (54 surveyed) river systems in 2008/2009, with knowledge of others. Given the reductions in habitat that have already occurred and the current low population size with ongoing declines, all 22 rivers include important habitat for SU Atlantic salmon. Restoration of these populations is expected to achieve the distribution component of the recovery target described below. If additional rivers are found to contain salmon, the consideration of these rivers as important habitat would have to be evaluated.

Barriers and pH are two factors that have a large effect on freshwater habitat availability and quality, respectively, and depending on the extent of each, can be difficult or costly to remediate. Therefore, rivers or parts of rivers that remain accessible to Atlantic salmon (due to the absence of total barriers) or rivers that remain mildly or un-impacted by acidification (mean annual pH that is greater than 5.0; category 3 and 4 rivers) should also be considered very important in terms of habitat allocation for SU Atlantic salmon (Figure 14). Even if the specific river does not contain Atlantic salmon at present, these areas likely contain useable freshwater habitat that could support populations in the future. Including some rivers with varying levels of pH should also help to protect the remaining genetic diversity among populations in the SU, given that there are wild populations remaining with greater tolerance to low pH (e.g. salmon in the Tusket River have a higher tolerance of low pH than other populations in Nova Scotia).

At smaller spatial scales, habitat allocation decisions can be made to ensure that habitat availability for a single life stage does not become limiting. Atlantic salmon have a complex life cycle with different habitat requirements for each life stage. Habitat for all life stages, as well as habitat connectivity, needs to be considered when identifying priority habitats for allocation, to avoid having one habitat type limiting population growth.

In addition, the estuaries associated with these rivers are considered to be important habitat for Atlantic salmon, with successful migration through this area essential to the completion of their life history.

While there is likely important marine habitat for SU Atlantic salmon, given broad temporal and spatial variation, it is difficult to link important life-history functions with specific marine features and their attributes. Further research into marine distribution patterns is unlikely to reveal distinct areas that should be considered for marine habitat allocation. Habitat allocation decisions could potentially be made at a broad scale, and the evaluation of activities likely to impact this habitat could be based on the extent to which they reduce the capacity of the larger area to provide salmon habitat.

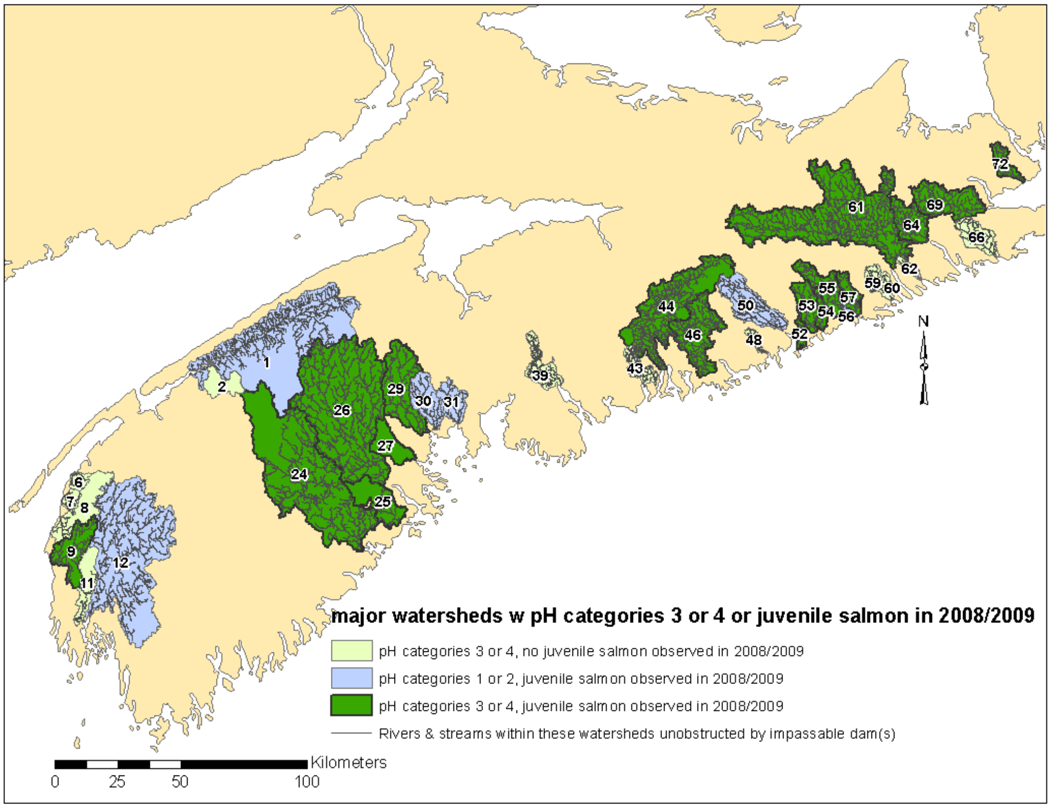


Figure 14. Location of freshwater habitats that exhibit one (or more) of three characteristics: have a pH greater than 5.0 (rivers in pH categories 3 or 4; see also Figure 16), have a high proportion of the watershed not impacted by barriers to fish passage, and/or contained Atlantic salmon in the most recent (2008/09) electrofishing survey. Watershed numbers correspond to the legend in Figure 2.

Recovery Targets

Long-term goals for the recovery of Atlantic salmon in the SU region include increasing the size and total number of populations, as well as their distribution. However, determining how many populations are needed to attain this long-term goal or how large they must be to ensure recovery of SU Atlantic salmon is not possible from a quantitative perspective because the dynamics of recovered populations of SU Atlantic salmon are not known. Previous research on abundance targets as well as theoretical research on how species distribution relates to persistence or recovery can be used as a basis for decision-making.

Proposed recovery targets for Atlantic salmon populations in the Southern Upland DU have both abundance and distribution components.

Abundance targets for Southern Upland Atlantic salmon are proposed as the river-specific conservation egg requirements, which are based on the estimated amount of juvenile rearing area and an egg deposition rate of 2.4 eggs/m^2. Attaining the conservation requirement is consistent with attaining long-term population persistence, maintaining the ecological function of the watersheds in which salmon formerly resided, and increasing the potential for human benefits if populations were recovered in as many rivers as possible. Overall population size is positively related to population persistence for a range of fish species, which suggests that increasing population size for salmon in the SU region is important for recovery. However, population size alone is not an indicator of population viability, and precisely how large populations need to be depends on their dynamics during population rebuilding.

The distribution target should encompass the range of genetic and phenotypic variability among populations, environmental variability among rivers, and include rivers distributed throughout the DU to allow for gene flow between the rivers/populations. There is the expectation that including a wider variety of populations in the distribution target will enhance persistence as well as facilitate recovery in the longer term. The following criteria can be used to help prioritize among river systems when setting distribution targets: current population size, complexity (in population life history, local adaptation and genetic distinctiveness), connectivity with surrounding populations (metapopulation structure), and the number and location of source populations.

There is population and genetic structuring within the SU region, which means all populations of Atlantic salmon cannot be considered equivalent. Furthermore, each population has the potential to contribute genetically and/or demographically to the long term persistence of SU Atlantic salmon (and possibly the species itself) so it is intrinsically important. Preserving the maximum amount of genetic variation will maximize the evolutionary potential of SU Atlantic salmon, ensuring that the DU as a whole will have the ability to respond or adapt to environmental change and a chance of re-colonizing rivers that have been extirpated. Preserving both populations with high genetic variation and populations with high genetic divergence will be important for recovery. If populations were prioritized for recovery based on within-river genetic variation, the Medway, St. Mary’s (East Branch) and Salmon River (Guysborough) would all be important populations (see O’Reilly et al 2012). If populations were prioritized based on genetic divergence, the Moser and Musquodoboit rivers would become important (see O’Reilly et al. 2012).

Local adaptation among populations is thought to result primarily from environmental heterogeneity (i.e. habitat variation), and to be maintained by the homing behavior of Atlantic salmon. A cluster analysis identified 3 main groupings of rivers and 6 subgroupings (Figure 15) that could be representative of environmental heterogeneity within the region (see Bowlby et al. 2013b for details). At a minimum, all three groups should be represented in the distribution target for SU Atlantic salmon but choosing populations representative of the six smaller groupings would further increase the diversity in the target populations. It is generally accepted that larger rivers (populations) are better source populations for emigration and colonization than are smaller rivers. Further, having as many populations included in the distribution target as is practically feasible is expected to increase the long-term persistence of the DU. Having more than one population from each group is expected to help protect against catastrophic loss.

Interim recovery targets for SU Atlantic salmon can be used to evaluate progress towards recovery. Progress towards recovery targets, particularly with respect to halting the decline, can be evaluated using survival and extinction risks metrics. Proposed interim targets are:

- First, halt the decline in abundance and distribution in rivers with documented Atlantic salmon populations.
- Next, reduce the extinction risk in the rivers with documented Atlantic salmon populations by alleviating threats in these rivers.
- Then, as necessary, expand the presence and abundance of Atlantic salmon into other rivers currently without salmon to fill in gaps in distribution within the SU DU and facilitate metapopulation dynamics.

Recovery targets will need to be revisited as information about the dynamics of the recovering population becomes available.

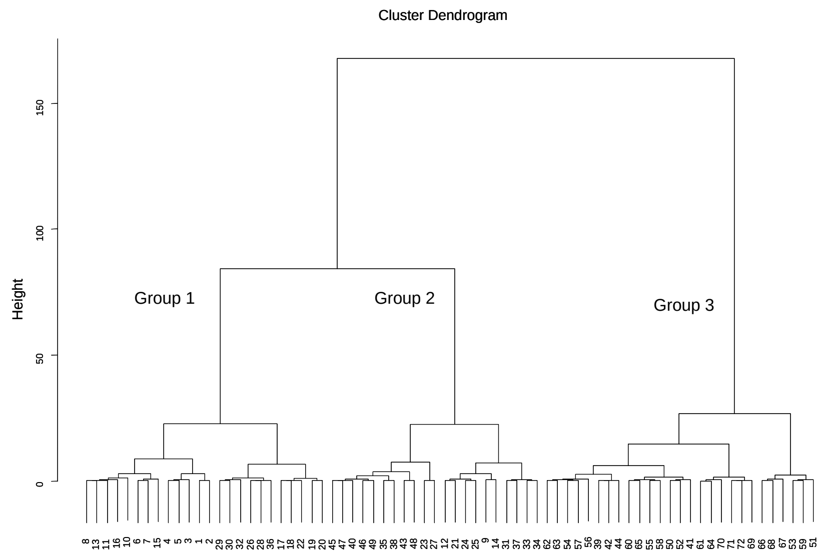


Figure 15. Dendrogram representing the degree of dissimilarity among watersheds (refer to Figure 2 for the names corresponding to each river number) as identified by the hierarchical cluster analysis. More similar watersheds are more closely joined.

Residence Requirements

Under *SARA*, a residence is defined as a dwelling-place that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating (*SARA* section 2.1). DFO's Draft Operational Guidelines for the Identification of Residence and Preparation of a Residence Statement for an Aquatic Species at Risk (DFO, unpublished report) uses the following four conditions to determine when the concept of a residence applies to an aquatic species: (1) there is a discrete dwelling-place that has structural form and function similar to a den or nest, (2) an individual of the species has made an investment in the creation, modification or protection of the dwelling-place, (3) the dwelling-place has the functional capacity to support the successful performance of an essential life-cycle process such as spawning, breeding, nursing and rearing, and (4) the dwelling place is occupied by one or more individuals at one or more parts of its life cycle.

Two dwelling places (used by three life stages) were evaluated for their potential consideration as a residence for Atlantic salmon. These were redds (used by eggs and alevins) and home stones (used by juvenile salmon in fresh water). Each of these is habitually occupied during part of the salmon's life cycle, individuals invest energy in its creation or defense, and it provides specific functions to enable the successful completion of the Atlantic salmon's life-cycle. Of these, redds most closely match the definition of a residence because they are constructed, whereas home stones are not.

Eggs and alevins reside in redds from late October/early November until spring (mid-May or early June) when fry emerge and begin feeding. Redds are essential to protect eggs and alevins from disturbance (e.g. ice scour, bedload transport, physical impact by debris), currents, changing water levels and predators. Redds provide hydraulic eddies that capture expressed eggs and, after being covered with gravel by the adult salmon, provide interstitial space for water flow and oxygen for the incubation of the eggs and development of alevins prior to emergence. As such, they minimize movement of the eggs, prevent eggs from being displaced into unfavorable habitats, and can provide protection from some predators. Redds are typically 2.3 and 5.7 m^2 in size, and consist of a raised mound of gravel or dome under which most of the eggs are located and an upstream depression or 'pot'. Burial depths are about 10 to 15 cm^2.

Redds are typically constructed in water depths of 17 to 76 cm and velocities between 26 to 90 cm/s[2].

Juvenile Atlantic salmon are territorial, remaining relatively stationary near a home stone that they actively defend from other juveniles. Occupancy (prior residency) is a key determinant for successful defense. Home stones provide eddies that shelter parr from instream currents and cover for predator avoidance, as well as influence the availability of invertebrate drift for feeding (depending on the location of the stone relative to water flow). Therefore, the choice of a territory or home stone directly impacts the potential for individual growth and successful rearing in the freshwater environment. The ability to obtain and defend a territory has been linked to growth, age-of-smoltification, and hence age-at-maturity, a key life history parameter. Although juvenile salmon may change home stones intermittently, movement is thought to be limited. For example, one study found that 61.8% of young-of-the-year salmon moved less than 1 meter during July and August. Typical home stones range from <10 cm to > 40 cm in diameter, and there is some indication that the size of stone selected increases from summer to autumn, i.e. preferred sizes increase as juveniles grow. Home stones are occupied soon after emergence from the gravel in the spring and used until juveniles return to the substrate in late autumn.

Threats

Threats are defined as any activities or processes that have, are, or may cause harm, death or behavioural changes to populations, and/or impairment of habitat to the extent that population-level effects occur. This definition includes natural and anthropogenic sources for threats. Current SU salmon populations have little ability to increase in size, so it is expected that threats that act intermittently would have longer-lasting effects on populations than when productivity was higher. Additionally, human activities that reduce Atlantic salmon populations often represent an assemblage of threats to fish and fish habitat. Thus, it is difficult to discuss a specific threat in isolation given the cumulative and correlated nature of the majority of threats.

Detailed information on each major potential threat to SU Atlantic salmon individuals and their habitat is contained in Bowlby et al. (2013b), with a summary provided here in Appendix A. The overall level of concern ascribed to a specific threat takes into account the severity of impacts on populations, how often they occur, as well as how widespread the threat is in the SU DU.

In general, there is a lot of information on how threats affect Atlantic salmon in terms of changes to growth, survival or behaviour of a given life stage (predominantly juveniles). However, comparatively little research links threats in SU watersheds with changes in adult abundance of specific Atlantic salmon populations. From analyses of land use in the SU region (Bowlby et al. 2013b), previous and on-going human activities are extensive in the majority of drainage basins and have likely altered hydrological processes in SU watersheds. Landscape factors controlling hydrology operate at hierarchically nested spatial scales (regional, catchment, reach, instream habitat), which means they often override factors controlling salmon abundance at small spatial scales.

Threats with a high level of concern are discussed below. Threats to persistence and recovery in freshwater environments identified with a high level of overall concern include (importance not implied by order): acidification, altered hydrology, invasive fish species, habitat fragmentation due to dams and culverts, and illegal fishing and poaching. Threats in estuarine and marine environments identified with a high level of overall concern are (importance not implied by order): salmonid aquaculture and marine ecosystem changes.

Acidification

Watersheds in the SU region have been heavily impacted by acidification, which has predominantly originated from atmospheric deposition (i.e. acid rain) due to industrial sources in North America. The underlying geology of the SU is such that rivers have little buffering capacity and have mildly to substantially decreased in pH. River acidification has significantly contributed to reduced abundance or extirpation of populations from many rivers in the region during the last century. In addition to ongoing effects of acidification, contemporary declines in non-acidified rivers indicate that other factors are also influencing populations. Although most systems are not acidifying further, few are recovering and most are expected to remain affected by acidification for more than 60 years. Rivers in the southwestern portion of the SU tend to be more highly acidified than those in the northeastern portion.

Low pH reduces the survival of juvenile Atlantic salmon through direct mortality or increased susceptibility to predation or disease, as well as reduced ability to compete for food or space and interference with the smoltification process. Fry (age 0) are thought to be the most severely affected life stage, with cumulative mortality curves predicting 50% mortality at a pH of 5.3. Mean annual pH values of <4.7 are considered insufficient for the continued maintenance of Atlantic salmon populations. Korman et al. (1994) developed toxicity functions by life stage based on studies available in the literature and used these to estimate egg-to-smolt mortality rates associated with pH for specific periods. Mortality estimates by life stage from these functions for surface pH values of 4.5 to 5.5 are provided in Table 5. These rates are in addition to natural mortality and mortality from other causes.

Table 5. Mortality rates (%) and toxic accumulation (TD - proportion dying weekly) of juvenile Atlantic salmon as a function of surface pH as derived from the toxicity functions in Korman et al. (1994). Values outside the interval 0-100% were assigned the limit value. Rates and pH values are specific to the time period. Mortality rates are in addition to natural mortality and mortality from other causes. Adapted from Korman et al. (1994).

Life Stage	Time Period	Rate	Average Surface pH 4.50	4.75	5.0	5.25	5.50
Egg	Nov. – Apr.	Mortality	57.1%	37.3%	17.6%	0%	0%
Alevin	May	Mortality	36.3%	16.6%	7.6%	3.5%	1.6%
Fry	June	Mortality	100%	100%	56.7%	31.7%	17.7%
Parr	All year	TD	0.19	0.017	0.0016	0.0001	0.0000
Wild smolt	May	TD	0.19	0.017	0.0016	0.0001	0.0000
Hatchery Smolt	May 15-25	TD	0.19	0.017	0.0016	0.0001	0.0000

Sixty rivers in the SU have been classified based on mean annual pH (Figure 16). Salmon populations in extremely acidified systems (pH <4.7) are thought to be extirpated (13 rivers), reduced by 90% in moderately impacted systems (pH = 4.7-5.0; 20 rivers), reduced by about 10% in slightly impacted systems (pH = 5.1-5.4; 14 rivers), and apparently unaffected when pH >5.4 (13 rivers) based on research in the 1980s. However, juvenile densities calculated in the 2008/09 electrofishing survey suggest that reductions in productivity could be even higher (95% and 58% respectively for moderately and slightly impacted systems). This means 316,726 to 334,322 habitat units (out of a total of 351,918) from moderately impacted rivers, and 19,431 to 112,701 habitat units (out of a total of 194,312) from mildly impacted rivers would be unsuitable for juvenile production.

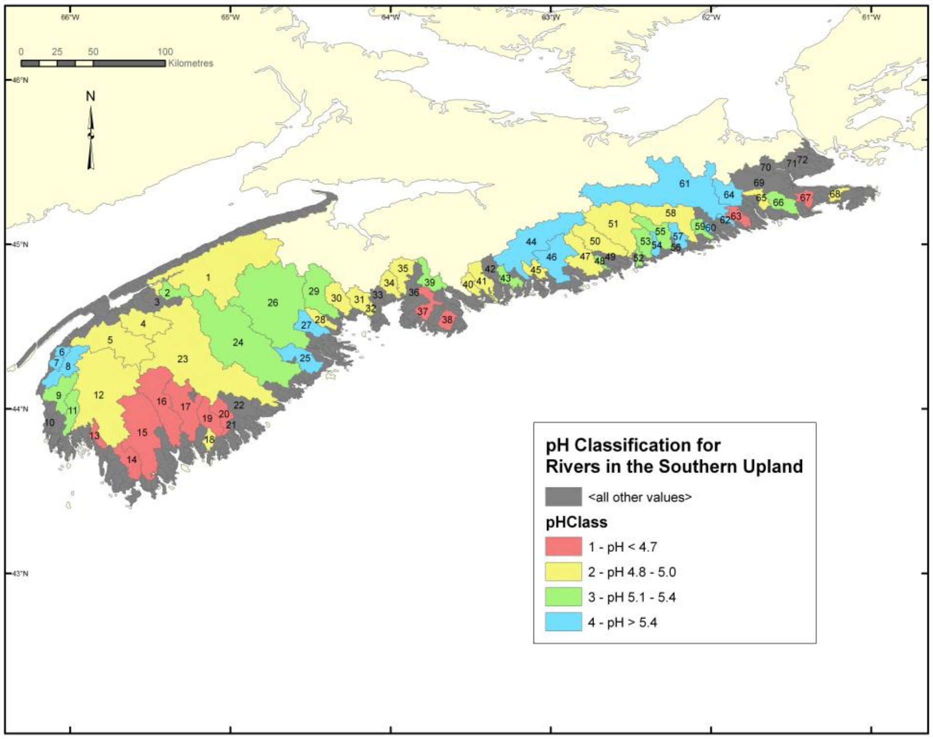


Figure 16. Classification of mean annual pH for rivers in the Southern Upland region; data are from Amiro (2006). Watershed numbers correspond to the legend in Figure 2.

Altered Hydrology

The hydrological regime of a riverine system may be altered by a large variety of human activities. These include direct withdrawal of water for industrial, agricultural or municipal purposes, intensive land use affecting overland and groundwater flow, water diversions for power generation, and an operating schedule of water release at power generating stations not consistent with the natural flow regime. These activities can have significant effects on salmon spawning and rearing habitat, especially when stream base flows are substantially reduced.

River discharge in systems of the SU DU is highly variable among years. However, natural variability may be exacerbated by intensive land use (e.g. forestry, agriculture, urbanization), which can accelerate the rate of runoff from land and entrance into stream channels. This can make a river more prone to flooding and increase the frequency and duration of both large freshets and droughts. Extreme low flows can increase the incidence of temperature extremes, reduce seasonal habitat availability in a watershed and influence food supply. The survival of eggs, alevins and juveniles has been directly linked to stream discharge, with better survival in years with higher flows during the summer and winter months. Extremely high flows can cause large scale erosion and significant changes in channel and bed morphology. All of these processes influence the quality and quantity of habitat available in fresh water. Under extremely high flows, juvenile salmon tend to seek refuge in the substrate, but can experience increased mortality from physical displacement, turbulence, abrasion, and transportation of the substrate.

Altered hydrological regimes directly affect water temperature thereby affecting the behaviour, growth, and survival of all freshwater life stages of Atlantic salmon, and can limit the amount of useable habitat in a watershed. Extreme high temperatures can lead to direct mortality of juveniles if they cannot move to cold water refugia, or can reduce survival indirectly through impacts on growth, predator avoidance responses, or individual susceptibility to disease and parasites. Extreme low temperatures during winter can result in direct mortality by freezing redds or physical disturbances from ice scour, in addition to reducing developmental rates of eggs and alevins. In addition to extreme hydrological events, loss of riparian cover, excessive groundwater extraction as well as water management at reservoirs and hydroelectric generating stations can contribute to extreme temperature events.

Additionally, returning adult spawners have been found to initiate spawning migrations as water levels rise, as well as to require sufficient water for distribution throughout the river system and to hold in pools. Spring high water is potentially a trigger for smolt migration, and survival of smolts has been shown to be higher under years of high discharge than low in some systems.

Invasive Species (Fish)

Chain pickerel and smallmouth bass have substantially increased in abundance and distribution since first being introduced into the SU region. Chain pickerel are currently found in 69 documented locations in the SU, while smallmouth bass are more widely distributed in 174 documented locations (see Bowlby et al. 2013b). Both are recognized as being significant piscivores. Chain pickerel are thought to influence Atlantic salmon populations directly through predation rather than through competition. Preliminary studies in the SU region suggest that pickerel presence in a lake substantially reduces the abundance and species richness of the native fish community. Introduced smallmouth bass influence fish communities through competition as well as predation, and their presence has been linked to community shifts and extirpations of native fishes. Atlantic salmon juveniles have been found to shift habitat use in areas where smallmouth bass are also found, although these results were dependent on water temperature and discharge conditions.

Habitat Fragmentation Due to Dams, Culverts and Other Permanent Structures

Permanent structures are often placed in or along rivers for three main purposes: water impoundment (reservoirs for hydro, municipal drinking water, or other industrial uses), bank stabilization (to prevent movement of the stream channel), or water diversion (for industrial and recreational uses or flood prevention). There are 233 dams or barrier structures identified by the NS DoE and DFO HM in watersheds in the SU region (Figure 17), 44 of which are thought to be passable to fish populations.

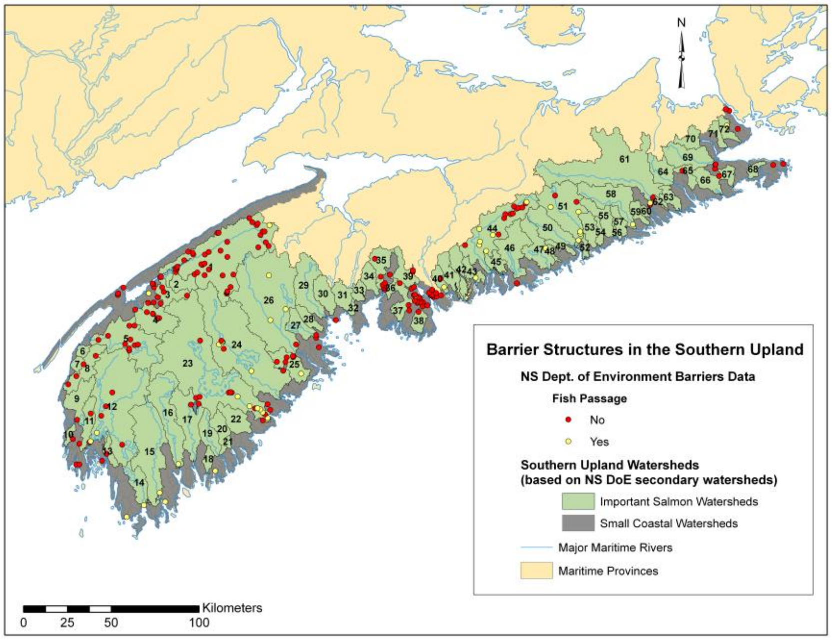


Figure 17. All barrier structures in the Southern Upland region listed on the barriers layer from the Nova Scotia Department of the Environment and DFO Habitat Management (Maritimes). Those without fish passage are shown in red, while those with at least partial passage are shown in blue. Watershed numbers correspond to the legend in Figure 2.

Due to poor design, improper installation or inadequate maintenance, culverts contribute to habitat fragmentation in watersheds by becoming seasonal or complete barriers to fish movement. Recent surveys of culverts in Nova Scotia suggest that barriers to fish passage are prevalent, with 37% assessed as full barriers and 18% assessed as partial barriers in the Annapolis watershed, and 61% assessed as full barriers from a random sample of 50 culverts in Colchester, Cumberland, Halifax and Hants Counties. Out of 62 culverts assessed on the St. Mary's River, 40 did not meet criteria for water depth, 35 exceeded velocity criteria, and 24 had an outfall drop potentially preventing passage. Similar results have been obtained for watersheds containing Atlantic salmon in Newfoundland and the continental U.S. as well watersheds containing Pacific salmon and other trout species in Alaska and British Columbia. Activities such as timber harvesting, urbanization, infrastructure (like new highways) or other land development tend to increase the number of culvert installations in a watershed. Using road crossings as a proxy for culverts (Figure 18), SU watersheds in more populated areas as well as those impacted the most heavily by forestry or agriculture had the highest road densities and thus the greatest potential for impact from culverts.

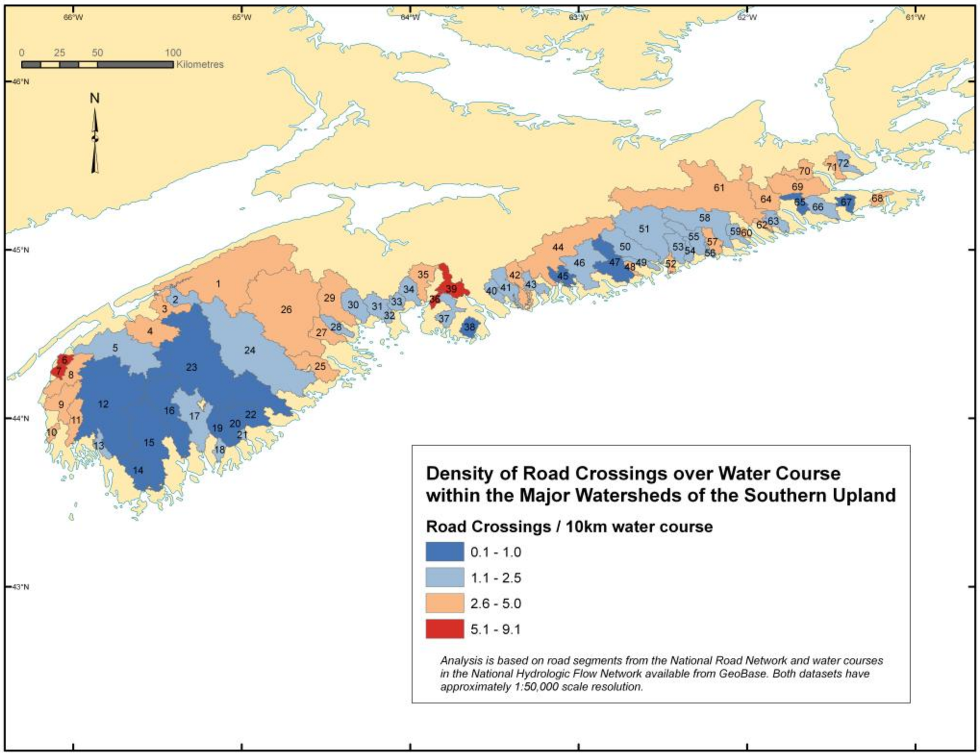


Figure 18. The density of road crossings within watersheds of the Southern Upland region. Watershed numbers correspond to the legend in Figure 2.

Illegal Fishing and Poaching

There have been many anecdotal reports of illegal fishing (e.g. targeting salmon while fishing with a general license) and harvests (i.e. poaching) of Atlantic salmon in the SU region, either using recreational fishing gear, gillnets, or other capture methods. The magnitude of this threat to specific populations is not possible to quantify; however, poaching would be expected to have the greatest impact when population sizes are small (as they are at present) because a larger proportion of the population would be affected. Additionally, the population dynamics modeling presented here indicates that populations have very little capacity to recover from any illegal removals (i.e. are not able to quickly increase in size).

Population Level Effects of Recreational Fishing

While recreational fishing is currently identified as a low threat (Appendix A) to SU Atlantic salmon, the population level effects of recreational fishing are described here.

Recreational fishing seasons, regulations and practices in the SU have changed through time from fisheries that were primarily retention fisheries for both large and small salmon, to virtually all hook-and-release fisheries, to closures throughout the SU Region in 2010.

Hook and release recreational fisheries provide an intermediate management strategy between a full retention fishery and fishery closure for populations that are below target levels. The effects are conditional on the life history and dynamics, such as freshwater productivity, survival at-sea and repeat spawning frequency. Catch and release fisheries would be expected to result in populations sizes that are higher than those in a full retention fishery, but lower than those expected to result from fishery closure. A similar relationship is expected for the lifetime reproductive rates. As such, they have the potential to slow recovery rates relative to fishery closures, although population growth is expected to be more rapid with a catch and release fishery than a full retention fishery.

Highly variable rates of fish mortality associated with a fish being hooked and subsequently released have been reported in the literature. Water temperature is cited as an important factor; angling at low temperatures (i.e. below 17-18^{o}C) generally results in lower mortalities than catch-and-release angling that occurs at higher water temperatures. In addition to temperature, fish mortality associated with catch-and-release angling is also believed to be affected by an angler's level of experience; fish mortality is believed to be lower for more experienced anglers than for less experienced anglers. Although there are several studies that show low direct mortality associated with catch-and release recreational fisheries if conducted at low water temperatures (i.e. below 17-18 C), there is little information available about other effects of catch and release salmon fishing (e.g. potential effects on migration, reproduction, habitat impacts, transfer of pathogens).

The LaHave River (above Morgan Falls) salmon population is the only SU population with sufficient data to evaluate the effects of recreational fisheries on population dynamics. In the 1980s when retention fisheries were in effect, the recreational fisheries reduced survival to spawning escapement by up to 31% for 1SW salmon, with lesser effects on 2SW in part due to the timing of the increase in recreational fishing effort and the shift to hook-and-release fisheries for large salmon. This led to a reduction in the annual equilibrium population size of up to 48% and reductions in maximum lifetime reproductive rates of up to 23%. With the switch to hook-and release fisheries, the impact of the fishery on the dynamics of the population is much less (nearly negligible), although this conclusion is conditional on the assumed 4% hook-and-release mortality rate and on the assumptions that both the non-lethal effects of hook-at-release and habitat impacts are minor. These effects would be greater if the fishing season extends into periods with warmer water temperatures. Additionally, these values should be interpreted in the context of the past impacts of the fisheries on these populations. In the future, any impacts to populations from the recreational fishery would depend on fishing intensity and management regulations with respect to timing of the fishery, as well as the associated mortality rate.

Aquaculture

Commercial aquaculture of Atlantic salmon in the marine environment of Nova Scotia typically occurs in net pens anchored in coastal estuaries or sheltered near-shore sites. Effects on wild Atlantic salmon populations from aquaculture would occur either by interaction in the immediate vicinity of the net-pens or by interactions between escaped aquaculture salmon and wild salmon. Aquaculture escapes, migration of wild salmon to or past aquaculture sites, and a combination of escapes and migration can potentially result in predator attraction, disease and pathogen exchanges, competition and genetic effects.

Rivers in close proximity to existing aquaculture lease sites include many of those that contain the larger remaining populations of Atlantic salmon in the SU region. Individuals from populations such as the Annapolis/Nictaux have the potential to pass or interact with all salmonid aquaculture sites in the SU region as they move through coastal areas, while this would be less likely for more northern populations (e.g. those near Canso).

Interbreeding between wild populations and aquaculture escapes causes reduced fitness in the hybrids as they are less adapted to local conditions and, thus, exhibit lower survival rates and less resilience to environmental change. The larger the genetic difference between wild and farmed populations, the greater these effects will be. The use of broodstock from other areas leads to greater genetic differences. Such changes can be permanent when genes from farmed fish become fixed in the wild genome (introgression). Despite poor reproductive success, the large number of escaped salmon in some areas of Canada has resulted in reports of significant numbers reproducing. For example, 20% of redds in the Magaguadavic River, New Brunswick were thought to belong to females of aquaculture origin in the 1992/1993 spawning period. Research in Europe has demonstrated that the number of farmed salmon entering rivers is proportional to the number of farms, and that escapes will enter multiple rivers in the vicinity of aquaculture sites. Aquaculture escapes in North American rivers have been reported in 54 of 62 (87%) rivers investigated within a 300 km radius of the aquaculture industry since 1984. Aquaculture escapes made up an average of 9.2% (range: 0% to 100%) of the adult population in these rivers. The prevalence of escapes suggests that farmed salmon pose a significant risk to the persistence of wild populations, and a recent meta-analysis has demonstrated that reduced survival and abundance of several salmonid species (including Atlantic salmon) are correlated with increases in aquaculture.

More direct sources of mortality to wild Atlantic salmon populations from aquaculture sites have been hypothesized to come from competition for resources, predator attraction to net-pens, as well as disease transfer from captive to wild fish. However, the available evidence suggests that growth and survival of immature Atlantic salmon in the marine environment are not limited by food, and predator attraction to net-pens has not been directly linked to increased mortality in wild populations. Similarly, there are no proven cases in Canada where disease or sea-lice outbreaks in wild populations can be directly linked to aquaculture sites, although research in epidemiology demonstrates that exposure and the frequency of exposure are important contributing factors to the spread of disease.

Aquaculture impacts would be expected to decline with distance from a specific site as well as with the recipient population size. For a given number of farmed salmon entering a river, the population-level impacts of interbreeding are expected to decrease with increases in size of the wild population, suggesting that one potentially important mitigation measure for this threat is to increase abundance of wild salmon by addressing other threats.

Marine Ecosystem Changes

The abundance and distribution of prey species and predators is thought to be an important factor affecting marine growth and survival of Atlantic salmon populations. Recent evidence of a whole ecosystem regime shift in the Eastern Scotian Shelf (ESS) demonstrates that significant change to the ecological communities experienced by wild Atlantic salmon populations at sea is likely, particularly if individuals use areas farther from the coast. The ESS ecosystem has shifted from dominance by large-bodied demersal fish, to small pelagic and demersal fish, and macroinvertebrates; a change that is also thought to be occurring in surrounding regions (i.e. Western Scotian Shelf (WSS)), albeit at a slower pace. One aspect of this shift is that strong trophic interactions between the remaining top predators, as well as fundamentally altered energy flow and nutrient cycling, appear to be maintaining the new ecological state. It has been hypothesized that changes in the abundance and distribution of small pelagic fishes affects food availability and thus marine survival of Atlantic salmon, and that increased grey seal (*Halichoerus grypus*) populations (as seen on the ESS) may lead to significantly higher predation pressure. However, empirical evidence of either impact has not been found for SU Atlantic salmon.

Large-scale changes to atmospheric and oceanographic conditions have been observed throughout the marine range of Atlantic salmon. For example, the WSS experienced a cold period during the 1960s, was warmer than average until 1998, and then significantly cooled after cold water intrusion from the Labrador Sea. The ESS cooled from about 1983 to the early 1990s and bottom temperatures have remained colder than average since. Sea-ice cover in the Gulf of St. Lawrence and off Newfoundland and Labrador in winter 2009/2010 was the lowest on record for both regions since the beginning of monitoring in 1968/1969. This lack of ice was in part due to warmer temperatures, but also to early season storms breaking up and suppressing new ice growth. The NAO has been shifting from mostly negative to mostly positive values from the 1970s to the early 2000s. Winter NAO is strongly negatively correlated with sea-surface temperature and thus could influence Atlantic salmon overwintering behaviour and mortality rates at sea. Most research that has found a correlation between Atlantic salmon catches, sea-age at maturity, or smolt-to-adult survival and recruitment with winter NAO values has been from European populations, although there are weakly correlated examples in North America. However, as discussed previously, partitioning mortality of adult salmon between spawning events into that experienced predominantly in freshwater, estuarine and near-shore environments (first year) and that experienced in more distant marine environments (second year) demonstrated a strong correlation between NAO and survival in the second year for alternate-spawning Atlantic salmon from the LaHave River.

Highest marine mortality rates are hypothesized to occur soon after immature salmon reach the open ocean while they are still in the near-shore environment. One hypothesis is that faster growth and lower mortality of immature Atlantic salmon is associated with entry into the ocean at a time when larval fish prey are abundant and at a consumable size. Thus, the environmental factors controlling primary marine production (which would determine prey availability and size) may have a large impact on early marine survival and growth.

Mitigation and Alternatives

Restoring marine or freshwater habitat quality requires the ability to quantify the impact of a given threat on a given population, something that is much more likely in fresh water than in the marine environment. Threats in fresh water are also more localized and can be addressed with remediation actions in the short term. It is likely that increasing habitat quality and quantity in fresh water will prevent further extirpations and promote self-sustaining populations at low size. Some threats (like acidification) have well-known remediation actions (liming) that can lead to population growth. In other cases, recovery actions addressing multiple threats simultaneously might be required to increase abundance. It has been suggested that watershed restoration for salmon species should focus first on reconnecting isolated fish habitats (i.e. remediating barriers) before moving on to restoring hydrologic, geologic and riparian processes at a watershed scale, and lastly to focusing on in-stream habitat enhancement. When choosing rivers for restoration, an attempt should be made to capture the range of variation among systems in the SU and to prioritize the larger remaining populations for recovery.

Remediation actions to address land use issues will not produce immediate population increases for SU Atlantic salmon. For example, it would take many years before riparian vegetation would grow to a size that would significantly reduce sediment inputs, which would be expected to increase habitat quality and reduce juvenile mortality in the river. Such large-scale changes are the most likely to bring about substantial population increase in Atlantic salmon because they should have a greater impact on total abundance in the watershed rather than on localized density, and they would address issues at the watershed scale.

Remediation of landscape-level threats to watersheds (e.g. forestry, agriculture, urbanization, roads) requires working at a much larger scale than the stream reach, and typically includes actions that are distant from the actual streambed (e.g. replanting riparian vegetation, revisiting regulations on pesticide use, community outreach on invasive species). Coordination of activities at small-scales may produce more immediate effects.

Sensitivity analysis on the effect of starting population size on population viability highlights the risks associated with delaying recovery actions; recovery is expected to become more difficult if abundance continues to decline, as is expected for these populations with the continued passage of time. Recovery actions should be initiated as soon as possible.

Mitigation and alternatives for freshwater, marine and estuarine threats were not addressed in detail at this meeting.

Assessment of Recovery Potential

The PVA described in the Population Dynamics section was also used to evaluate how the probability of extinction and probability of meeting the recovery target would be expected to vary with increased freshwater productivity and increased at-sea survival. Twenty-four scenarios were evaluated for both the St. Mary's River (West Branch) and LaHave River (above Morgan Falls) salmon populations. At-sea survival values considered in the analyses used the 1980s and 2000s dynamics as upper and lower estimates respectively, with the two intermediate scenarios evenly spaced between these (i.e. at one-third and two-thirds the difference between past and present values).

Increased freshwater production was modeled by increasing smolt production by factors of 1.0 (no increase), 1.2 (20% increase), 1.5 (50% increase) and 2.0 (double or 100% increase). This is the same as changing the parr mortality parameter by equivalent amounts. For example, the annual mortality of parr older than age-1 was estimated to be 0.72 for the LaHave River (above Morgan Falls) population. This is a survival of 28% annually. The increased freshwater productivity scenario of 1.5 equates to a survival of 42% annually.

Each combination of increased freshwater productivity and at-sea survival was modeled for a total of 16 scenarios (Table 6). In addition, eight other scenarios are presented to investigate the effects of extreme events. In these, freshwater productivity was increased by a factor of 1.5 and simulations were carried out for all four at-sea survival values. For each scenario, the probabilities of extinction and recovery were evaluated using 2000 simulated population trajectories.

Abundance trajectories, extinction probabilities and recovery probabilities for each scenario are provided in Figures 19, 20 and 21 and Table 6 for the LaHave River (above Morgan Falls) population. The results of these analyses clearly indicate how close SU Atlantic salmon are to the threshold between becoming extinct and being viable. Panel "A" in each figure shows the results using the current dynamics; as previously described, both populations will extirpate in the absence of human intervention or a change in vital rates for some other reason. Panel "B" shows the effect of increasing freshwater productivity by 20%. This improvement is not large, but it does markedly reduce extinction risk, even if marine mortality rates remain unchanged (Figure 20). For the LaHave River (above Morgan Falls) population, the probability of extinction within 30 years drops from 31% to 3% with this increase in survival. Increases of 50% (Panel C) drop the extinction probability to 0% for more than 50 years for both populations. Although small, numerically-viable populations are produced, none of the simulated population trajectories reached the recovery targets (Figures 19, 21). Small increases in marine survival (Panels G to J) have a similar effect. None of the simulated populations extirpated in the third increase scenarios and a small proportion reached their recovery targets for both populations. The proportion reaching the recovery target increases as freshwater productivity increases (Figure 21; compare Panels G to J). Recovery probabilities exceed 50% in 50 years for all scenarios that include a two-thirds increase in at-sea survival (Panels M to X) and extinction probabilities are zero. Within limits, these conclusions are robust to how the frequency of extreme events is modeled (Panels E, K, Q, W, F, L, R, X). When the frequency of the extreme events is reduced, the probability of recovery increases and extinction probability is reduced (e.g. compare Panels H and K). Results for the St. Mary's River (West Branch) salmon population are similar.

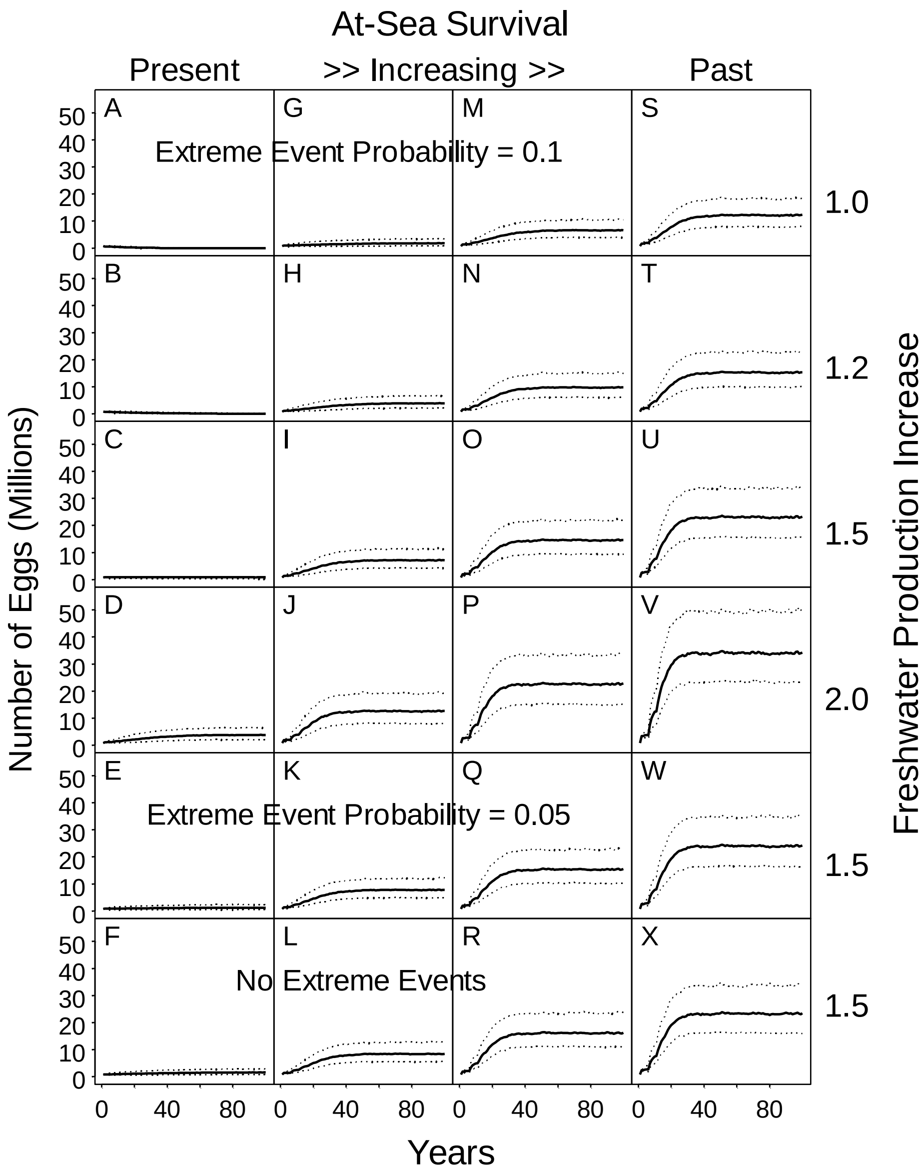


Figure 19. The effects of increasing at-sea survival and freshwater productivity on the simulated abundance of eggs for the LaHave River (above Morgan Falls) Atlantic salmon population. The graphs summarize 2000 simulations for each scenario. The median abundance (solid line), and the 10th and 90th percentiles (dashed lines) are shown. Panels on the right and the left are based on the 1980s and 2000s at-sea survival respectively, and the middle panels show scenarios using survivals increased by 1/3 and 2/3's of the difference in these values. The return rates of 1SW and 2SW salmon and survival between repeat spawning events are increased. The 2000's freshwater production is used in all scenarios. The top four rows show the effect of increasing freshwater productivity by factors of 1 (no change), 1.2 (20% increase), 1.5 (50% increase) and 2.0 (100% increase). The bottom two rows show the effect of changing the frequency of event events to an average of 1 every 20 years (5th row) and to no extreme events (bottom row).

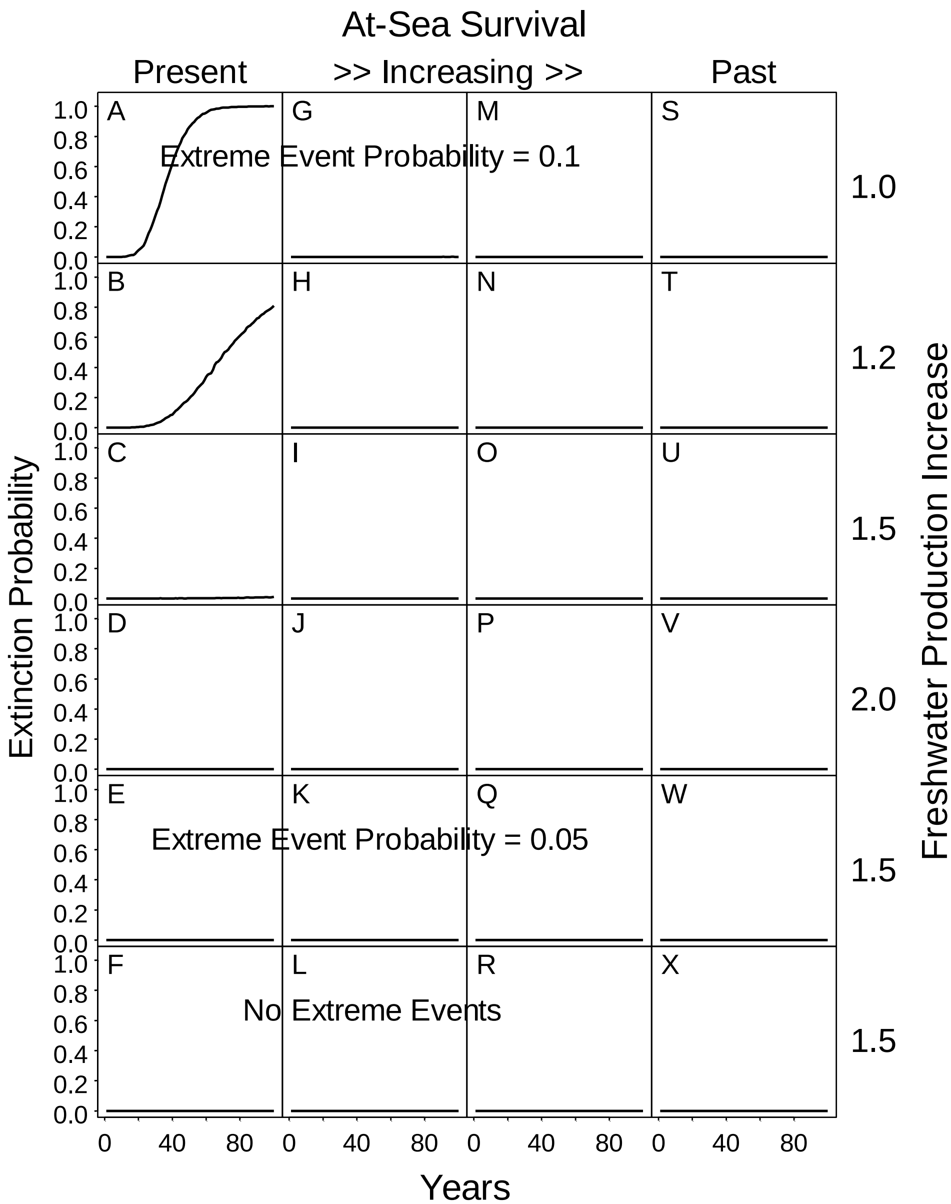


Figure 20. The effects of increasing at-sea survival and freshwater productivity on the probability of extinction for the LaHave River (above Morgan Falls) Atlantic salmon population. Panels are described in the caption for Figure 19.

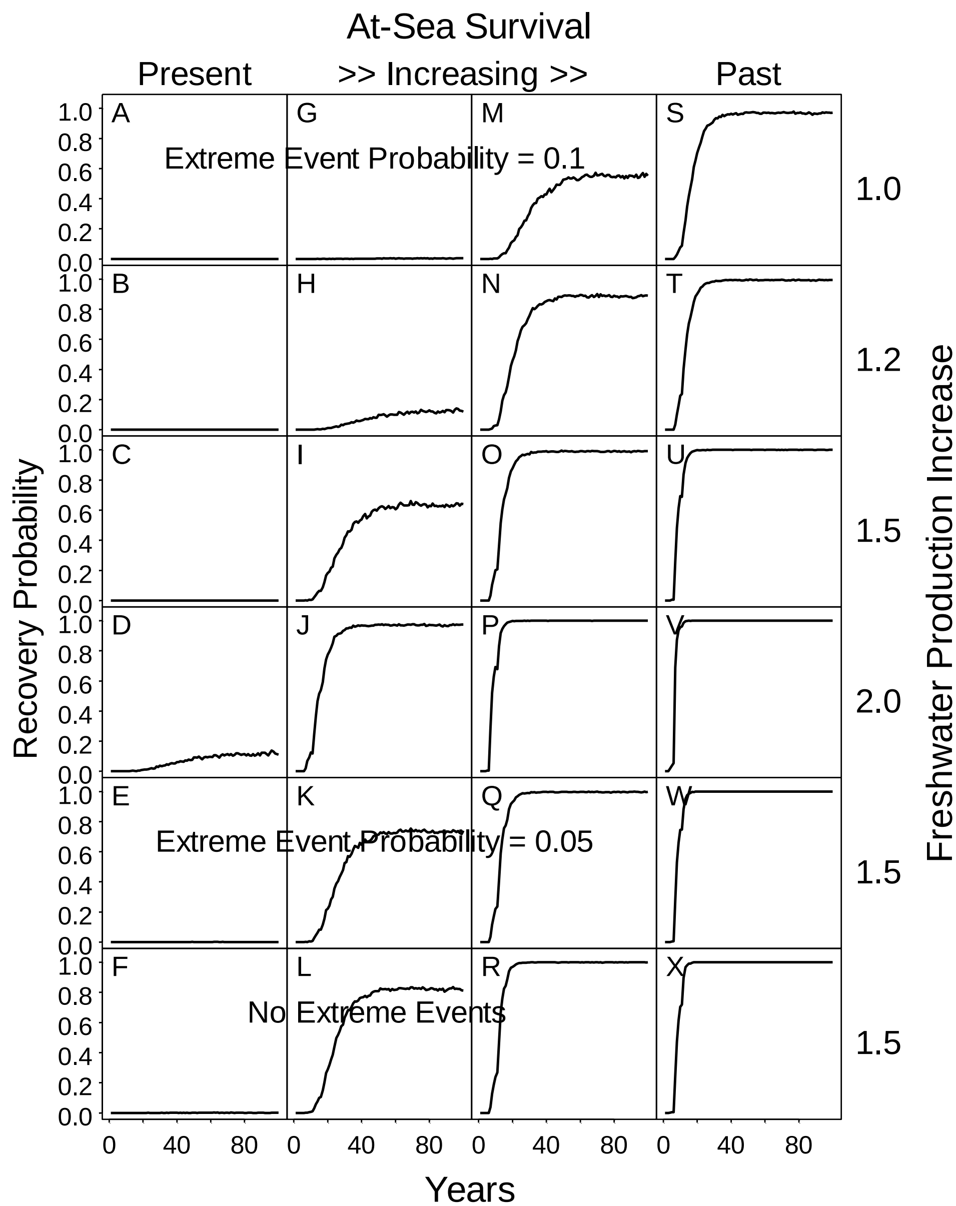


Figure 21. The effects of increasing at-sea survival and freshwater productivity on the probability of meeting the recovery target for the LaHave River (above Morgan Falls) Atlantic salmon population. Panels are described in the caption for Figure 19.

Table 6. Proportions of 2000 simulated population trajectories that either go extinct or meet the recovery target within 10, 20, 30 and 50 year time horizons based on recovery scenarios for the LaHave River (above Morgan Falls) Atlantic salmon population. The marine scenarios reflect changes from the present levels (2000s) of at-sea survival to those in the past (1980s). The freshwater scenarios reflect increases in freshwater productivity from the present level (1) to 2 times the present level. The lettering for the runs corresponds to those in Figures 19-21. Extreme event scenarios are the average frequency of extreme events and the reduction in egg to fry survival corresponding to the event.

Run	Marine Scenario	Freshwater Scenario	Extreme Event Scenario	Proportion Extinct				Proportion Recovered			
				10 yr	20 yr	30 yr	50 yr	10 yr	20 yr	30 yr	50 yr
a	present	1	10 yr; 0.2	0.00	0.05	0.31	0.87	0.00	0.00	0.00	0.00
b	present	1.2	10 yr; 0.2	0.00	0.01	0.03	0.21	0.00	0.00	0.00	0.00
c	present	1.5	10 yr; 0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
d	present	2	10 yr; 0.2	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.09
e	present	1.5	20 yr; 0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
f	present	1.5	none	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
g	intermediate 1/3	1	10 yr; 0.2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
h	intermediate 1/3	1.2	10 yr; 0.2	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.10
i	intermediate 1/3	1.5	10 yr; 0.2	0.00	0.00	0.00	0.00	0.01	0.19	0.43	0.62
j	intermediate 1/3	2	10 yr; 0.2	0.00	0.00	0.00	0.00	0.12	0.80	0.95	0.97
k	intermediate 1/3	1.5	20 yr; 0.1	0.00	0.00	0.00	0.00	0.01	0.24	0.53	0.73
l	intermediate 1/3	1.5	none	0.00	0.00	0.00	0.00	0.01	0.32	0.66	0.83
m	intermediate 2/3	1	10 yr; 0.2	0.00	0.00	0.00	0.00	0.00	0.12	0.34	0.53
n	intermediate 2/3	1.2	10 yr; 0.2	0.00	0.00	0.00	0.00	0.03	0.49	0.78	0.89
o	intermediate 2/3	1.5	10 yr; 0.2	0.00	0.00	0.00	0.00	0.21	0.90	0.99	0.99
p	intermediate 2/3	2	10 yr; 0.2	0.00	0.00	0.00	0.00	0.68	1.00	1.00	1.00
q	intermediate 2/3	1.5	20 yr; 0.1	0.00	0.00	0.00	0.00	0.24	0.94	1.00	1.00
r	intermediate 2/3	1.5	none	0.00	0.00	0.00	0.00	0.27	0.98	1.00	1.00
s	past	1	10 yr; 0.2	0.00	0.00	0.00	0.00	0.09	0.74	0.94	0.97
t	past	1.2	10 yr; 0.2	0.00	0.00	0.00	0.00	0.24	0.92	0.99	1.00
u	past	1.5	10 yr; 0.2	0.00	0.00	0.00	0.00	0.69	1.00	1.00	1.00
v	past	2	10 yr; 0.2	0.00	0.00	0.00	0.00	0.96	1.00	1.00	1.00
w	past	1.5	20 yr; 0.1	0.00	0.00	0.00	0.00	0.75	1.00	1.00	1.00
x	past	1.5	none	0.00	0.00	0.00	0.00	0.72	1.00	1.00	1.00

In conclusion, population viability analyses indicate that relatively small increases in either freshwater productivity or at-sea survival are expected to decrease extinction probabilities. For example, for the LaHave River (above Morgan Falls) population increasing freshwater productivity by 20% decreases the probability of extinction within 50 years from 87% to 21%, while a freshwater productivity increase of 50% decreases the probability of extinction within 50 years to near zero. These must be accompanied by increases in at-sea survival in order to restore populations to levels above their conservation requirements.

In contrast with inner Bay of Fundy salmon populations, for which at-sea survival is so low that recovery actions in fresh water are expected to have little effect on overall viability, recovery actions focused on improving freshwater productivity are expected to reduce extinction risk for SU salmon.

These must be accompanied by larger (value) changes in at-sea survival in order to restore populations to levels above their conservation requirements, although at present the contributing factors limiting marine survival are not known.

Sensitivity to Starting Population Size

The effect of delaying recovery activities was examined by running the PVA (base model) for the LaHave River (above Morgan Falls) population starting at 100%, 50%, 25% and 10% of the 2010 abundance estimates (300 small salmon and 53 large salmon). Using the present dynamics, further reductions in population size have the effect of shortening time to extinction. A reduction in starting population size of 50% reduced the time to which 50% of the simulated populations are extinct by about 10 years, whereas a reduction in size of 75% reduced the time to which 50% of the simulated populations are extinct to about 15 years. Similarly using the 1980s dynamics, time to recovery was similarly increased. The effects of further reductions in population size prior to the initiation of recovery are most evident in scenarios where populations are on the edge of recovery. For example, with an increase in freshwater production of 1.2 times, the probability of extinction within 25 years is 1% when the starting population size equals the 2010 abundance. This value increases to 10%, 45% and 97% for reductions in the starting population size of 50%, 25% and 10% of the 2010 abundance. The effect is not so great for an increase in at-sea survival of one third because the increase in overall survival (i.e. survival from egg to adult) is greater than for an increase in freshwater production. Additional details of this analysis are provided in Gibson and Bowlby (2013).

Sources of Uncertainty

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

As described in Gibson and Bowlby (2013) the electrofishing catchability coefficient used in the freshwater production model was for the St. Mary's River (West Branch) population could not be estimated and a value based on LaHave River (above Morgan Falls) production model was assumed. Had a different value been assumed, it is expected that the age- and stage-specific survival rates would change but the overall freshwater productivity curve would remain the same.

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

The importance of migration among rivers for ensuring numerical stability and genetic integrity within the DU is unknown; therefore, the number of populations that need to be included in the distribution component of the recovery target is also unknown.

The landscape cluster analysis used as a basis for developing distribution recovery targets is dependent on the data inputs and using additional or different environmental variables, as well as more or fewer feature classes within a variable, would affect the particular watersheds contained in the predicted number of clusters. Therefore, the watershed groupings should not be considered fixed in the sense that no other groupings are possible. However, the cluster analysis is a meaningful way of grouping landscape level patterns and demonstrates that all watersheds in the SU region cannot be considered equivalent in terms of protecting the biological diversity of Atlantic salmon populations. Diversity could also be characterized using the Eco-Districts present within the SU or using a lower level in the dendrogram presented in the Recovery Target section (e.g. the six clusters in the next tier).

PVA is a powerful and widely used technique in conservation biology to explore current conditions, assess risks and simulate how future management actions could affect a population in decline. They are known not to provide accurate estimates of the true probability of extinction or recovery, but they are useful for the relative evaluation of management actions.

The PVA models were set up with the assumption that the populations were at equilibrium abundances and age structure for the given scenario being modeled. This leads to starting abundances that can be higher than those recently observed. Short-term extinction risk would be higher if recent abundances were used for the starting values.

The PVAs were developed using a quasi-extinction threshold of 15 female salmon. Population viability analyses are known to be sensitive to the assumed threshold. This value is very low relative to the past abundances of salmon in these rivers. If depensatory dynamics exist, populations may not be able to recover from low abundances, even ones that are higher than this threshold. When scenarios were run using the 2000s dynamics, times to extinction decreased when the threshold was increased. However, this threshold has nearly no effect on time to recovery when the 1980s dynamics are used.

The PVA models were constructed such that the freshwater dynamics were independent of the marine dynamics. Marine survival rates may be improved by changes in the freshwater environment or in the freshwater population dynamics. For example, improved pH conditions may result in better marine survival of smolts as short-term exposure of smolts to low pH has been inferred to reduce early marine survival. Increased smolt production resulting in larger schools of smolts may improve early marine survival rates through prey-swamping effects when migrating through predator fields. As such, improved productivity in freshwater may directly affet marine return rates, the benefits of which will be reduced probabilities of extinction and improved probabilities of recovery. These dynamics are poorly understood in Atlantic salmon populations.

Marine distribution patterns for SU Atlantic salmon were assessed from historical tagging programs of smolts and adults combined with reported recaptures by commercial and recreational fisheries. Release data span the years from 1966 to 1998 and only include information from fish that were individually tagged (generally with numbered carlin or floy tags) and subsequently recaptured (i.e. releases with zero recaptures are not considered). Tags recovered in fisheries (or by people associated with the fishing industry such as fish plant workers) were returned voluntarily for a monetary reward. When interpreting these data, it is important to remember that sampling effort in the marine environment was non-random over space and time (i.e. the distribution of tag returns depends on the distribution of fishing effort as well as the distribution of the fish). In the Maritime Provinces and much of Newfoundland, commercial trap nets for salmon were often at fixed locations accessible from shore. For the high-seas fisheries in Labrador and West Greenland, few of the tag recaptures were assigned a latitude and longitude when recovered; therefore, recaptures were ascribed to the mid-point of each West Greenland fishing district or to locations or communities along the coast of Labrador. Therefore, it is not possible to determine how far off shore Atlantic salmon may frequent from these data and it is similarly difficult to correlate recapture locations with environmental or oceanographic variables. Furthermore, the scarcity of tag recaptures during specific months (e.g. December to March) is largely due to the lack of sampling effort and may not reflect actual distribution patterns.

Watershed characteristics and human activities within watersheds were derived using geo-spatial data, some of which is becoming outdated. While the data used are the most current, specific information may require validation.

Although home stones potentially meet the criteria to be a residence, practically there is no way to identify whether a stone in a river is being used as a home stone.

SOURCES OF INFORMATION

This Science Advisory Report is from the May 22-25, 2012, Recovery Potential Assessment for Southern Upland Atlantic salmon. Additional publications from this meeting will be posted on the *Fisheries and Oceans Canada (DFO) Science Advisory Schedule* as they become available.

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APPENDIX A

Threats tables for the freshwater, estuarine and marine environments, summarizing human activities or sources of environmental change that either negatively impact Atlantic salmon populations (i.e. cause reduced abundance) or cause reduced quality and/or quantity of habitat in the SU region.

Definition of Table Headings and Column Values

Threat Category: The general activity or process (natural and anthropogenic) that has caused, is causing, or may cause harm, death, or behavioural changes to a species at risk; or the destruction, degradation, and/or impairment of its habitat to the extent that population-level effects occur.

Specific Threat: The specific activity or process causing stress to Atlantic salmon populations in the Southern Upland DU, where stress is defined as changes to ecological, demographic, or behavioural attributes of populations leading to reduced viability.

Level of Concern: Signifies the level of concern for species persistence if a threat remains unmitigated; where a High level of concern reflects threats that are likely to lead to substantial declines in abundance or loss of populations in the absence of mitigation, a Medium level of concern reflects threats that are likely to limit populations to low abundance and thus increase extinction risk, while a Low level of concern reflects threats that might lead to slightly increased mortality but are expected to have a relatively small impact on overall population viability. This criterion is based on the evaluation of all other information in the table with an emphasis on the extent of the threat in the DU and the number of populations likely to be affected at each level of Severity (see definition below).

Location or Extent: The description of the spatial extent of the threat in the SU was largely based on the criteria developed for the Conservation Status Report Part II (DFO and MRNF 2009), where Low corresponds to < 5% of populations affected, Medium is 5-30%, High is 30-70% and Very High is > 70%. Where possible, the actual proportion of SU Atlantic salmon populations affected by a specific threat is given in brackets.

Occurrence and Frequency: Occurrence: Description of the time frame that the threat has affected (H - historical), is (C - current) or may be (A - anticipatory) affecting Atlantic salmon populations in the Southern Upland DU. Historical – a threat that is known or is thought to have impacted salmon populations in the past where the activity is not ongoing; Current – a threat that is known or thought to be impacting populations where the activity is ongoing (this includes situations in which the threat is no longer occurring but the population-level impacts of the historical threat are still impacting the populations); Anticipatory – a threat that is not presently impacting salmon populations but may have impacts in the future (this includes situations where a current threat may increase in scope). Frequency: Description of the temporal extent of the threat over the course of a year (seasonal, recurrent, continuous).

Severity: Describes the degree of impact a given threat may have or is having on individual Atlantic salmon populations subjected to the threat given the nature and possible magnitude of population-level change. See Table A1 for definitions/examples of how severity has been evaluated.

Table A1. Definitions/examples of how severity has been evaluated.

Category	Definition/Examples
Negligible	• Habitat alteration within acceptable guidelines that does not lead to a reduction in habitat quality or quantity. • No change in population productivity.
Low	• Minor or easily recoverable changes to fish habitat (e.g. seasonal or changes <1 year). • Little change in population productivity (< 5% decline in spawner abundance)
Medium	• Moderate impact to fish habitat with medium term for habitat recovery (3-5 years). • Moderate loss of population productivity (5-30% decline in spawner abundance)
High	• Substantial damage to fish habitat such that the habitat will not recover for more than 5 years. • Substantial loss of population productivity (> 30% decline in spawner abundance)
Extreme	• Permanent and spatially significant loss of fish habitat • Severe population decline with the potential for extirpation.

Causal Certainty: Two-part definition. Part 1: Reflects the strength of the evidence linking the threat (i.e. the particular activity) to the stresses (e.g. changes in mortality rates) affecting populations of Atlantic salmon in general. As such, evidence can come from studies on any Atlantic salmon population. Part 2: Reflects the strength of the evidence linking the threat to changes in productivity for populations in the Southern Upland DU specifically. See Table A2 for definitions/examples of how causal certainty has been evaluated. Note: Does not apply to threats that are anticipatory.

Table A2. Definitions/examples of how causal certainty has been evaluated.

Causal certainty	Description
Negligible	Hypothesized.
Very Low	< 5%: Unsubstantiated but plausible link between the threat and stresses to salmon populations.
Low	5% - 24%: Plausible link with limited evidence that the threat has stressed salmon populations.
Medium	25% - 75%: There is scientific evidence linking the threat to stresses to salmon populations.
High	76% - 95%: Substantial scientific evidence of a causal link where the impact to populations is understood qualitatively.
Very High	> 95%: Very strong scientific evidence that stresses will occur and the magnitude of the impact to populations can be quantified.

Table A3. Threats to Atlantic salmon populations in the freshwater environment of the SU DU.

Threat Category	**Specific Threat**	**Level of Concern**	**Location or Extent**	**Occurrence and Frequency**	**Severity**	**Causal Certainty**	
		for the DU as a whole	of the threat in the DU	of the threat in the DU	of population level impacts	evidence linking the threat to stresses in general	evidence for changes to viability of SU salmon populations
Freshwater Environment							
Water quality and quantity	Acidification	**High**	Very High (78% of assessed populations affected)	H, C and A Continuous and recurrent	Extreme	Very High	Very High
	Extreme temperature events	**Medium**	High to Very High (anecdotal information suggests the majority of rivers are affected)	H, C and A Seasonal	High	High	Medium
	Altered hydrology	**High**	High to Very High	H, C and A Seasonal	High	High	Medium
	Water extraction	**Low**	Low	H, C and A Recurrent	Negligible to High (dependent upon timing and magnitude of extraction/alteration)	High	Low
	Chemical contaminants	**Low**	Unknown (anecdotal information suggests the majority of populations affected)	H, C and A Seasonal	Negligible to High (dependent upon concentration (dose) and time of exposure (duration)	High	Low
	Silt and sediment	**Medium**	Very High (100%)	H and C Continuous	Negligible to High (dependent upon concentration (dose) and time of exposure (duration)	High	Low
Changes to biological communities	Invasive species (fish)	**High**	Medium (22% of assessed populations)	H, C and A Continuous	High	High	Medium

Threat Category	**Specific Threat**	**Level of Concern**	**Location or Extent**	**Occurrence and Frequency**	**Severity**	**Causal Certainty**	
		for the DU as a whole	of the threat in the DU	of the threat in the DU	of population level impacts	evidence linking the threat to stresses in general	evidence for changes to viability of SU salmon populations
Freshwater Environment							
	Invasive species (other)	**Low**	Low	A Continuous	Low to High	Medium	Very Low
	Stocking for fisheries enhancement using traditional methods	**Medium**	Very High	H and C Continuous	Medium to Extreme (dependent upon number of fish stocked and length of period of stocking)	High (rate of fitness recovery after stocking ends is unknown)	Low
	Stocking (current)	**Low**	Low (several Fish Friends projects; educational programs)	C and A Continuous	Low to High (dependent upon number of juveniles stocked and size of recipient population)	High	Low
	Other salmonid stocking (rainbow, brown, & brook trout)	**Low**	Medium	H, C and A Continuous	Low to High (dependent upon number stocked and type of recipient waterbody (lake vs. river))	Medium	Low
	Salmonid aquaculture (commercial)	**Low**	Low	H, C and A Continuous	Medium	High	Low
	Avian predators	**Medium**	High	C and A Seasonal	High	Medium	Medium
	Genetic effects of small population size	**Medium**	Medium (mostly focused in southwest area of DU)	H, C and A Continuous	Negligible to High (dependent upon length of time at small population size, stocking history, and site specific conditions)	High	None (Not evaluated)
	Allee (small population size) effects	**Medium** (abundanc e specific)	Very High (abundance is low in all rivers)	H, C and A Continuous	Low to High (dependent on population-specific abundance)	Medium	Low

Threat Category	Specific Threat	Level of Concern	Location or Extent	Occurrence and Frequency	Severity	Causal Certainty	
		for the DU as a whole	of the threat in the DU	of the threat in the DU	of population level impacts	evidence linking the threat to stresses in general	evidence for changes to viability of SU salmon populations
Freshwater Environment							
	Scientific activities	**Low**	Low (Two Index Rivers and occasional surveys/sampling of other rivers)	H, C, A Seasonal	Low	Low	Low
Physical obstructions	Habitat fragmentation due to dams, culverts and other permanent structures	**High**	Medium to Very High	H, C and A Continuous	Low to Extreme (Dependent upon design of structure and location within watershed)	Very High	Very High
	Reservoirs	**Medium**	Medium	H, C and A Continuous	Low to High (Dependent upon size of individual reservoirs and number in series on a system)	High	Medium
Habitat alteration	Infrastructure (roads)	**Medium**	Very High (all rivers)	H, C and A Continuous	Low to High (dependent upon road density within watershed or sub-watershed)	Medium	Low
	Pulp and paper mills	**Low**	Low (only two known pulp mills in DU)	H and C Continuous	Medium to High (Dependent upon process used and effluent discharge quality)	High	Low
	Hydro power generation	**Medium**	Medium	H, C and A Continuous	Medium to Extreme (dependent upon facility design and operating schedule)	High	Medium

Threat Category	Specific Threat	Level of Concern	Location or Extent	Occurrence and Frequency	Severity	Causal Certainty	
		for the DU as a whole	of the threat in the DU	of the threat in the DU	of population level impacts	evidence linking the threat to stresses in general	evidence for changes to viability of SU salmon populations
Freshwater Environment							
	Urbanization	**Medium**	Medium	H, C and A Continuous	Low to High (dependent upon density of urbanization and infrastructure development)	High	Medium
	Agriculture	**Medium**	High	H, C and A Seasonal	Low to High (dependent upon extent within watershed and practices used)	Medium	Low
	Forestry	**Medium**	High	H, C and A Continuous	Low to High (dependent upon extent within watershed and practices used)	Medium	Low
	Mining	**Medium**	Unknown	H, C and A Continuous	Low to High (dependent upon type of mine, processes used, and susceptibility to Acid Rock Draiange)	Medium	Low
Directed salmon fishing (current)	Aboriginal FSC fishery	**Low**	Low	H, C and A Seasonal	Negligible	Very High	High
	Recreational fishery (angling)	**Low**	Low	H and A Seasonal	Negligible	Very High	High
	Illegal fishing and poaching	**High**	Unknown (but potentially high)	H, C and A Seasonal	Low to High (dependent on number of salmon removed and size of impacted population)	High	High
By-catch in other fisheries	Aboriginal or commercial fisheries	**Low**	Low	H, C and A Seasonal	Low	High	High

Threat Category	**Specific Threat**	**Level of Concern**	**Location or Extent**	**Occurrence and Frequency**	**Severity**	**Causal Certainty**	
		for the DU as a whole	of the threat in the DU	of the threat in the DU	of population level impacts	evidence linking the threat to stresses in general	evidence for changes to viability of SU salmon populations
Freshwater Environment							
	Recreational fisheries	**Low**	High	H, C and A Seasonal	Low	High	High
	Recreational fishery: illegal targeting of Atlantic salmon while fishing under a general license	**Medium**	High	H, C and A Seasonal	Low to High (dependent upon angling pressure)	High	High

Table A4. Threats to Atlantic salmon populations in the marine or estuarine environments of the SU DU.

Threat	**Specific Threat**	**Level of Concern**	**Location or Extent**	**Occurrence and Frequency**	**Severity**	**Causal Certainty**	
		for the DU as a whole	of the threat in the DU	of the threat in the DU	of population level impacts	evidence linking the threat to stresses in general	evidence for changes to viability of SU salmon populations
Marine or Estuarine Environment							
Changes to biological communities	Invasive species	**Low**	Very High (all populations)	C and A Continuous	Low	Low	Low
	Salmonid aquaculture	**High**	Very High	H, C and A Continuous	Medium to High (dependent upon location of aquaculture facilites and operating practices)	High	Low
	Other species aquaculture	**Low**	Very High (all populations)	H, C and A Seasonal	Negligible to Medium (dependent upon species under culture, location of fsaacility, and operating practices)	Low	Low
	Diseases and parasites	**Medium**	Very High (all populations)	H, C and A Continuous	Low to High (dependent upon irruptive behavior of disease/parasites resulting in outbreaks)	Low	Low
Changes in oceanographic conditions	Marine ecosystem change (including shifts in oceano-graphic conditions and changes in predator/prey abundance)	**High**	Very High (all populations)	H, C and A Continuous	Low to Extreme (dependent upon magnitude of change and sensitivity of salmon to change)	Medium	Low

Threat	Specific Threat	Level of Concern	Location or Extent	Occurrence and Frequency	Severity	Causal Certainty	
		for the DU as a whole	of the threat in the DU	of the threat in the DU	of population level impacts	evidence linking the threat to stresses in general	evidence for changes to viability of SU salmon populations
Marine or Estuarine Environment							
Physical or abiotic change	Shipping, transport, noise, seismic activity	**Low**	Very High (all populations)	H, C and A Seasonal	Uncertain; likely Negligible to Low (dependent upon proximity of salmon to source of noise/activity)	Low	Low
	Contaminants and spills (land- or water-based)	**Low**	Very High (all populations)	H, C, A Episodic	Low to Extreme (dependent upon identity and magnitude of contamination, and efficacy of cleanup)	Low	Low
	Tidal power	**Low**	Low	C and A Seasonal	Medium to High (dependent upon facility design and operating schedule)	High	Medium
Directed salmon fisheries	Subsistence fisheries (Aboriginal and Labrador residents)	**Low**	Low	H and A Seasonal	Negligible	High	High
	International fisheries (Greenland; St. Pierre-Miquelon)	**Medium**	Very High (MSW component of all populations)	H, C and A Seasonal	Negligible to High	High	Medium
By-catch in other fisheries	Commercial fisheries	**Low**	Very High (all populations)	H, C and A Seasonal	Low	High	High
Fisheries on prey species of salmon	Commercial fisheries	**Low**	Very High (all populations)	H, C and A Seasonal	Low to High (dependent upon reduction of prey species and availability of other forage species)	Low	Low

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