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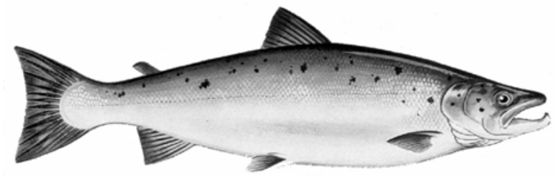
RECOVERY POTENTIAL ASSESSMENT FOR THE ANTICOSTI ISLAND ATLANTIC SALMON METAPOPULATION



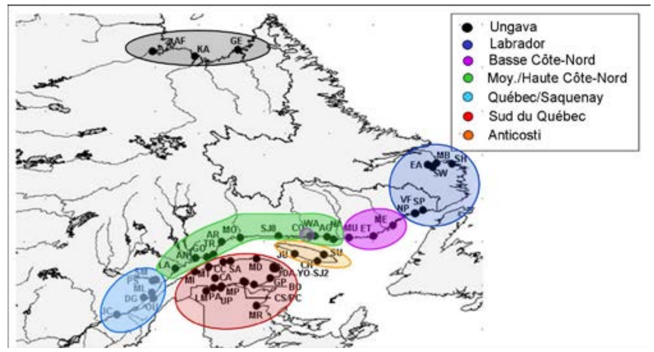


Figure 1. Genetically distinct regional groups, including the Anticosti Island group (from Dionne et al. 2008)

Context:

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the Anticosti Island Atlantic salmon population as Endangered in November 2010. “Small (one-sea-winter) and large (multi-sea-winter) fish have both declined over 3 generations, approximately 32% and 49% respectively, for a net decline of all mature individuals of about 40%. The population size is small, about 2,400 individuals in 2008. As is the case for most populations of the species, poor marine survival related to substantial but incompletely understood changes in marine ecosystems is a concern.”

In order to provide the information and scientific advice needed to meet the various requirements of the Species at Risk Act (SARA) and, if necessary, develop a recovery strategy and an action plan, Fisheries and Oceans Canada (DFO) Science has implemented a Recovery Potential Assessment (RPA). As part of this process, a peer review was held December 4 and 5, 2012 in collaboration with Quebec’s ministère du Développement durable, de l'Environnement, de la Faune et des Parcs (MDDEFP), the ministère des Ressources naturelles du Québec (MRN), the Société des établissements de plein air du Québec (SEPAQ), the Fédération Québécoise pour le Saumon Atlantique (FQSA) and the Atlantic Salmon Federation (ASF). The available information on the Anticosti Island Atlantic salmon population was reviewed at the meeting: its abundance, range, recent trajectory and projections, habitat requirements and potential threats, mitigation measures and alternatives, as well as allowable harm.

SUMMARY

- Atlantic salmon inhabit 25 rivers in the Anticosti Island Designatable Unit (DU 9). Over half (53%) the Anticosti Island Atlantic salmon population is concentrated in the Jupiter (28%), De la Chaloupe (13%) and Aux Saumons (12%) rivers.
- A stochastic state model was used to study the renewal dynamics of the Anticosti Island metapopulation. The study of the Anticosti Island metapopulation's trajectory from 1993 to 2007 confirmed the decrease in the number of adults indicated by COSEWIC, with an average overall decrease of 43% in that time period. However, the study of the trajectory over the last three generations (1997 to 2011) appeared to indicate the trend was reversing. Abundance estimates for recent years showed an increase in numbers since 2006, although the abundance of adults returning to Anticosti rivers decreased in 2011 and 2012. Overall, the metapopulation remained fairly constant at about 3 500 adults between 2006 and 2012.
- A Ricker model stock-recruitment relationship, based on specific metapopulation data was used to estimate a reference point (S_{MSY}) equivalent to the level of stock that will achieve maximum sustainable yield (MSY). A recovery target equivalent to the 95th percentile of the S_{MSY} was established. The target is a population of 2 100 spawners and should allow both the survival of the metapopulation and maximum sustainable yield for sport fishing.
- Based on current parameters of the metapopulation's renewal dynamics, the probability that broodstock producing adult returns from 1990 to 2017 was greater than or equal to the recovery target (2 100 individuals) is between 0.55 and 1. With respect to spawners producing returns from 2018 to 2032, uncertainty regarding abundance increases with time and this probability therefore decreases. The probability remains above 0.50 regardless of the assumption on the metapopulation's productivity and the recreational fishery's exploitation pattern. Based on current metapopulation parameters and in the worst case scenario (management measures in force before 2000), the probability that the stock will drop below the recovery target within the next 15 years is about 0.30.
- The connectivity of the various types of habitats used by salmon throughout their life cycle is essential. In freshwater, the whole river appears crucial. The Anticosti Island productive freshwater habitat is assessed at 4 463 368 Production Units (PU). The Anticosti rivers are rarely disturbed by human activities. However, strong natural variations in the water level and the particular geological structure of this area could be limiting factors for the metapopulation.
- A lower survival rate during the maritime phase may be one of the main causes of decline. Widespread changes throughout the North Atlantic ecosystem, which are still not fully understood, remain a major concern. Similar patterns in large groups of stock or throughout the North Atlantic Ocean bring to mind global factors affecting all stocks during their time at sea.

BACKGROUND

Biology and ecology

Atlantic salmon (*Salmo salar*) is an iteroparous species that returns to spawn in its natal river after a large-scale migration in the marine environment. Spawners returning to their rivers consist of varying percentages of “maiden salmon” (first time spawners) and “repeat spawners.” Maiden salmon consist of smaller fish (grisle) that return to spawn after one winter at sea (1 SW) and larger fish that return after two or more winters at sea (MSW). Between May and November, adult salmon leave their feeding and resting areas at sea and return to their natal river. They generally deposit their spawn in gravel nests in October and November. Both adult males and precocious parr can fertilize the eggs. Eggs incubate over the winter months and usually begin to hatch in April. The alevins remain in the gravel beds for several weeks subsisting on their yolk sacs. Once this food supply is exhausted, in late May or early June, the alevins leave the nest. At the parr stage, they swim freely and feed actively. The early-stage salmon feed primarily on invertebrates. After a period of one to eight years (usually 2 to 5), and a series of behavioural and physiological changes, parr become smolts and migrate to sea. Atlantic salmon have relatively short lifespan, between 4 and 8 years, with maximum age ranging from 12 to 14 years. Variations in freshwater smolt age and sea age at maturity contribute to major variations (2 to 14 years) in spawning age.

Description of the fishery

Commercial fishing has been banned in Canadian waters since 2000. However, salmon of Canadian origin is still harvested in marine fisheries in the waters of Saint-Pierre and Miquelon and west of Greenland. Labrador Aboriginal groups and residents engage in certain subsistence fisheries in what are considered Labrador coastal waters.

In Quebec, the recreational fishery is currently managed by river, based on conservation thresholds, expressed as the number of eggs required annually (Caron et al. 1999). This threshold is designed to preserve the species while ensuring an abundance level that allows optimal long-term exploitation of the resource (MRNF 2012). When it is anticipated that a river’s conservation threshold cannot be achieved, fishers are required to release large salmon (> 63 cm) or fishing is prohibited.

The Anticosti Island Designatable Unit (DU 9) is equivalent to Quebec salmon fishing area 10 (Q 10) and home to 22 recognized salmon rivers. Until 1999, sport fishing was permitted in about 15 rivers. As a result of the decline of salmon stocks in these rivers over the last 20 years, fishing was restricted to a few rivers. Since 2002, recreational salmon fishing is allowed only in the De la Chaloupe, Aux Saumons, Ferrée, À la Loutre and Jupiter rivers (MRNF 2012). A daily quota of two grilse is allowed (except for the Jupiter River where the quota is limited to one grilse per day at the end of the season) and large salmon (> 63 cm) must be released. However, based on age readings from previous years, salmon more than 58 cm long are considered multi-sea-winter salmon in this fishing area, which explains their presence in recreational catches.

RECOVERY POTENTIAL ASSESSMENT

Assess the current/recent status of Anticosti Island Atlantic salmon

1. Evaluate present status for abundance and range and number of populations.

It has been established that there is high gene flow between Anticosti Island rivers, whereas this gene flow is lower between this group of rivers and other salmon rivers in Quebec and Labrador (Figure 1; Dionne et al. 2008). Individuals that spawn in Anticosti Island rivers can be thus be regarded as belonging to a metapopulation consisting of several interconnected populations. Although it has its own genetic identity, the Anticosti Island metapopulation has a certain level of connectivity with other Canadian populations.

There are currently 22 recognized salmon rivers in the Anticosti Island Designatable Unit (DU 9). (Figure 2). Since 1993, the Du Brick, Natiscotek and Aux Loups-Marins rivers no longer have that status under the Quebec Fishery Regulations. However, since some individuals were present in these rivers before 1993, they were included in the analyses. As a result, 25 rivers were considered in the modelling work.

A Bayesian model was used to estimate the annual numbers of adults from 1984 to 2012, which has hovered around 3 500 individuals since 2006 (Brun and Prévost 2013). According to this model, the average number of adult returns in 2012 was estimated at 2 804.

2. Evaluate recent species trajectory for abundance (i.e., numbers and biomass focusing on mature individuals) and range and number of populations.

A stochastic state model was used to study the renewal dynamics of the Anticosti Island salmon metapopulation (Brun and Prévost 2013). This type of model consists of two processes, an observation process and a dynamic process. The two processes are coupled to reconstruct the information from the data to estimate the number of individuals and the parameters of the dynamic process, in a single coherent framework. This methodological approach was used to estimate the changes in the metapopulation from 1984 to 2012 and the metapopulation's trajectory from 1993 to 2007 and 1997 to 2011, about three generations in terms of total abundance of adults. A Ricker model stock-recruitment relationship was used to describe the metapopulation's renewal dynamics.

The study of the trajectory from 1993 to 2007 confirmed the decrease in the number of adults indicated by COSEWIC, with an average overall decrease of 43%. However, the trajectory study of the last three generations (1997 to 2011) appeared to indicate the trend was reversing. Abundance estimates for recent years showed an increase in numbers since 2006, although the abundance of adults returning to Anticosti rivers decreased in 2011 and 2012 (Figure 3).

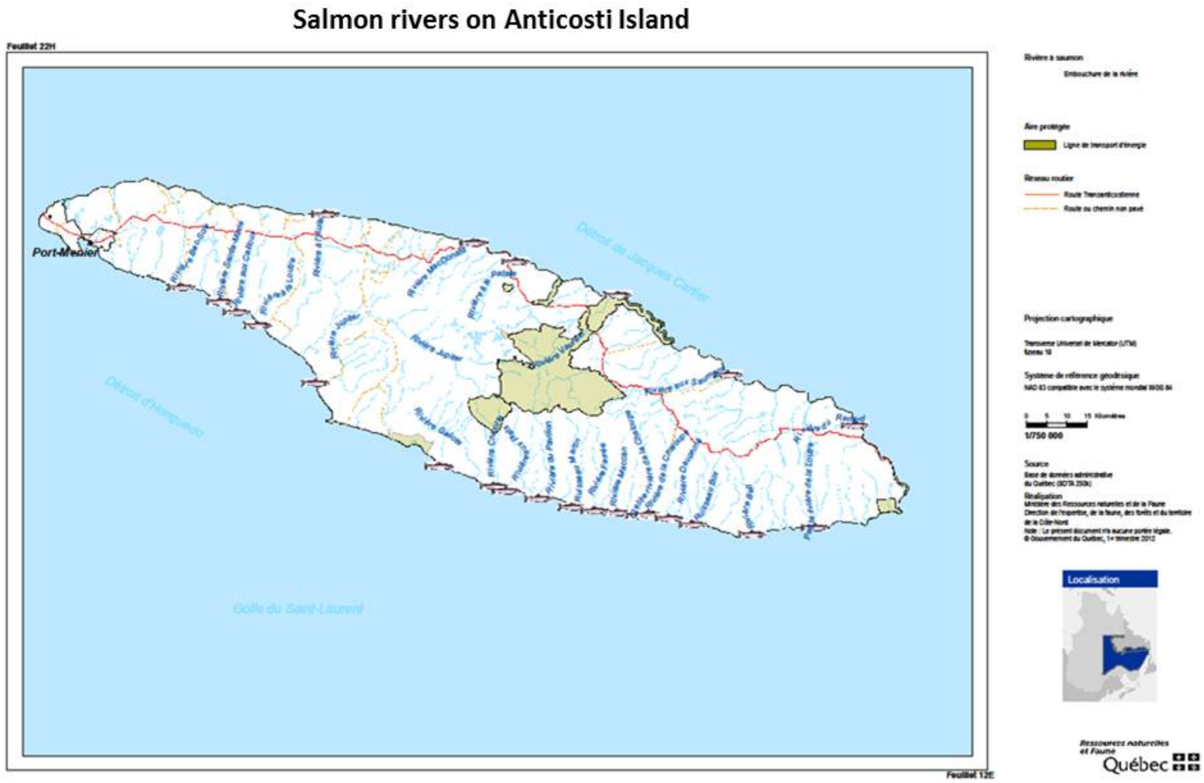


Figure 2. Salmon rivers on Anticosti Island.

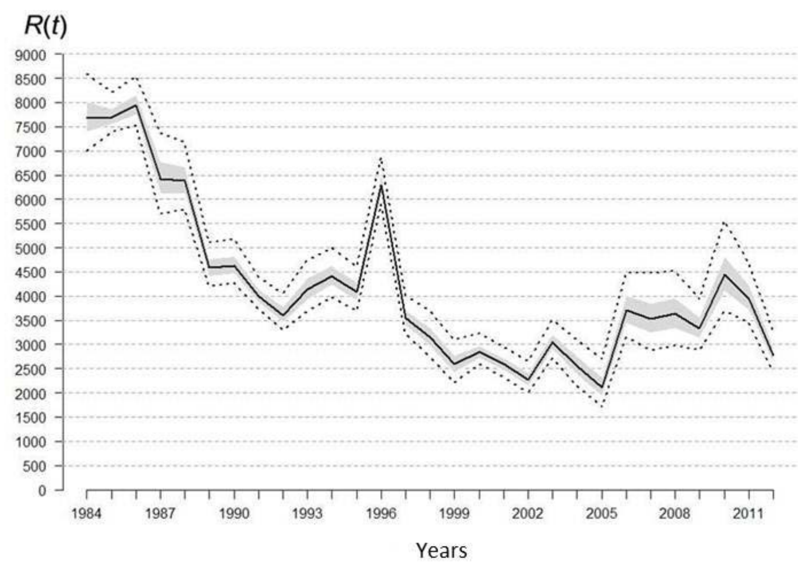
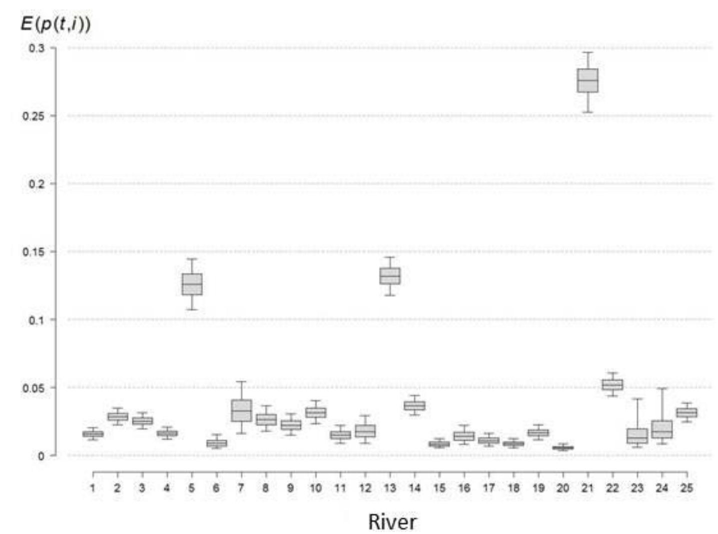


Figure 3. Summary of posterior marginal ranges of the total annual number of adults (R) from 1984 to 2012. The continuous bold line represents the median, the grey area represents the 25th and 75th percentiles and the dotted bold lines represent the 5th and 95th percentiles of the ranges.

Throughout the 1984–2012 study period, the average annual number of adults ranged from 2 148 in 2005 and 7 979 in 1986 (Figure 3). The number of adults declined from the mid-1980s until 2005 and increased to 3 746 individuals on average in 2006. Since 2006, the population has consisted of approximately 3 500 individuals.

The distribution of adult returns was estimated for each of the 25 rivers (Figure 4). The rivers that received the most adults were rivers 5 (Aux Saumons), 13 (De la Chaloupe) and 21 (Jupiter), with about 12%, 13% and 28% of adult returns respectively. Other rivers received fewer and more similar numbers of adults (between 0.6% and 5% of adults returned to each of the 22 remaining rivers). River 20 (Du Brick) received the fewest adults. This result was not surprising because it is a small river. It was also one of the reasons it lost its status as a salmon river.



Rivers

1. *À l'huile*
2. *MacDonald*
3. *À la Patate*
4. *Vauréal*
5. *Aux Saumons*
6. *Du Renard*
7. *Pet. riv. de la Loutre*
8. *Bell*
9. *Ruisseau Box*
10. *Dauphiné*
11. *Pet. riv. De la Chaloupe*
12. *Maccan*
13. *De la Chaloupe*
14. *Ferrée*
15. *Ruisseau Marin*
16. *Du Pavillon*
17. *Aux Plats*
18. *Chicotte*
19. *Galiote*
20. *Du Brick*
21. *Jupiter*
22. *À la Loutre*
23. *Aux Cailloux*
24. *Sainte-Marie*
25. *Bec-Scie*

Figure 4. Summary of posterior distribution (in percentage) of adult returns in the various Anticosti Island rivers. The box plots represent 5th, 25th, 50th, 75th and 95th percentiles of the posterior distribution.

3. Estimate, to the extent that information allows, the current or recent life-history parameters (total mortality, natural mortality, fecundity, maturity, recruitment, etc.) or reasonable surrogates; and associated uncertainties for all parameters.

Most individuals in the Anticosti Island metapopulation spend three years in a river before their time at sea, which lasts for a year for grilse or two or more years for multi-sea-winter salmon. The fertility rate of grilse and multi-sea-winter salmon used in this RPA are 2 430 and 1 600 eggs / female / kg respectively. An average weight of 1.50 kg for grilse and 3.45 kg for multi-sea-winter salmon were used for years and rivers for which average weights were not available. 14% and 68% of grilse and multi-sea-winter salmon respectively are supposed to be females except for the Bec-Scie River where the proportions were 19% and 63% respectively. The production rate (recruits per spawner) between the spawning stock (i.e. weighted sum of individuals that reproduced in years t-5 and t-6) and recruitment (i.e. adult returns for year t) with low stock values, averaged 3.31 (median: 2.70 and 90% Bayesian credibility interval of 1.45 to 7.24). The value of stock producing the maximum number of recruits averaged 4 178 (median: 3 627 and 90% Bayesian credibility interval of 2 095 to 7 560).

4. Estimate expected population and distribution targets for recovery as well as reference points developed under the Precautionary Approach Framework.

A Ricker model stock-recruitment relationship was used to describe the metapopulation's renewal dynamics. The model was also used to set reference points, including the S_{MSY}, equivalent to the level of spawners that will achieve maximum sustainable yield (Brun and Prévost 2013). For assessing recovery potential, it is proposed that the S_{MSY} be used as a recovery target, whose average value is estimated at 1 566 spawners. However, due to the uncertainty in estimating this parameter, the recovery target was set at the 95th percentile of the range of the S_{MSY}, i.e. 2 100 spawners. This level should allow both the survival of the metapopulation and maximum sustainable yield for sport fishing (Figure 5). The stock-recruitment slope is far greater than 1, meaning the population is viable and quite productive. The probability that the level of spawners producing adult returns from 1990 to 2017 was greater than or equal to the recovery target is between 0.55 and 1 (Figure 7).

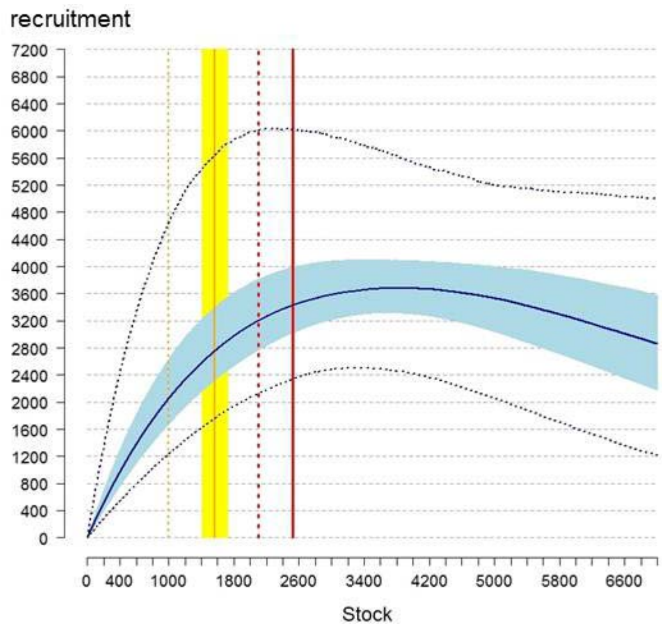


Figure 5. Summary of estimates of the stock-recruitment curve (blue) and the conservation limit (S_{MSY} in yellow). The solid blue and orange lines represent the medians. The coloured areas represent the 25th and 75th percentiles and the dotted lines represent the 5th and 95th percentiles of the posterior marginal distributions. The 95th percentile of the posterior marginal range of S_{MSY} (dotted bold red line) is the recovery target set in this advisory report. The solid red line represents the sum of the number of spawners required by river (2 525 spawners) under the current Anticosti Island Atlantic salmon management framework.

5. Project population trajectories for Atlantic salmon over at least three generations, and trajectories over time to the recovery target (if achievable), based on current population dynamics parameters and associated uncertainties.

A stochastic state model was used to predict the metapopulation's evolution over three generations, from 2013 to 2027 (Figure 6). The abundance of adult returns from 1984 to 2012 fluctuated sharply between about 2 200 and 8 000 fish during the observation period, whereas the abundance of spawners ranged between 2 100 and 6 000 fish for the same period (Figure 6). The average predictions on abundance of adult returns during the next 15 years was approximately 3 670 adult returns (90% Bayesian credibility interval of 2 050 to 5 360) (Figure 6, Table 1). If sport fishing were closed in all rivers, the average predicted abundance of spawners in the next 15 years would be about 3 640 spawners (90% Bayesian credibility interval of 2 090 to 5 280) (Figure 6, Table 1).

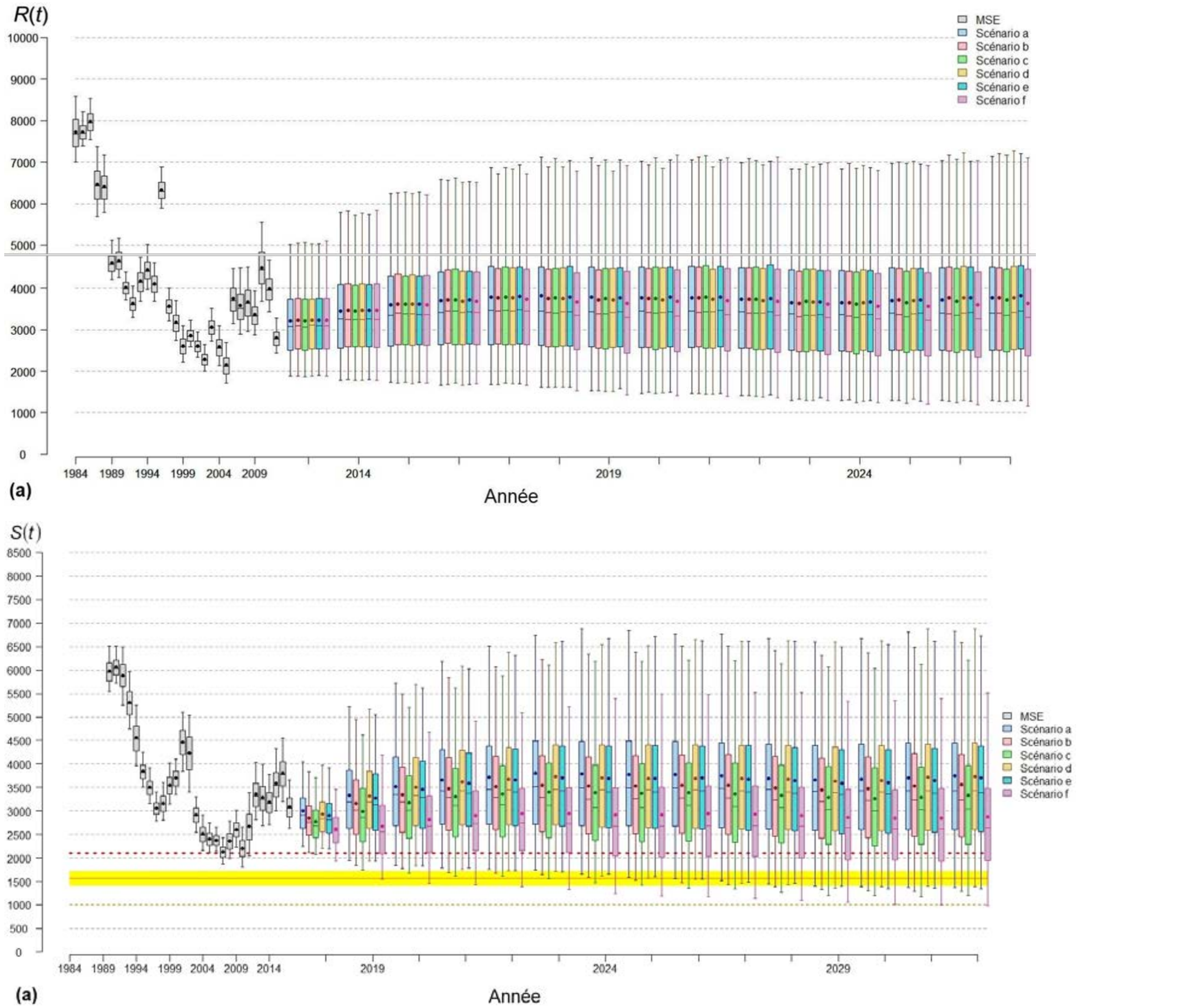


Figure 6. Summary of posterior marginal distributions for return estimates (top chart) for 1984 to 2012 and spawner estimates (bottom chart) for the 1990 to 2017 return years, and for return predictions (2013 to 2027) and spawner predictions (2018 to 2032). The predictions were based on different sport fishing management scenarios (Table 2) with the current values of the parameters of the metapopulation's renewal dynamics parameters. The box plots represent the 5th, 25th, 50th, 75th and 95th range percentiles. The points represent the range averages. The solid orange lines in the bottom chart represent the median posterior marginal distributions of the recovery target (S_{MSY}). The coloured areas represent the 25th and 75th percentiles and the dotted lines represent the 5th and 95th percentiles. The point value for the recovery target is the dotted red line (95th percentile of the S_{MSY}). The grey shaded rectangles are the estimates for the observation years (SSM: Stochastic State Model).

Metapopulation trajectories were also assessed based on high and low productivity assumptions at the levels estimated for the observation period. A multiplication factor was applied to the Ricker model stock-recruitment relationship to study different productivity assumptions, i.e. changes in the metapopulation's survival and carrying capacity (salmon density that the unit area of production is likely to accommodate). The following three multiplication factors were tested:

- **A**. No change in survival and carrying capacity;
- **B**. 25% increase in survival and carrying capacity;
- **C**. 25% decrease in survival and carrying capacity.

As expected, the average abundance of returns and spawners was directly related to productivity parameters (Table 1). The uncertainty of the average predictions was lower (25% to 26% coefficient of variation depending on the management scenario) based on the assumption of increased productivity, intermediate for recent productivity (29% to 32%) and higher for reduced productivity (33% to 36%).

Table 1. Predicted abundances of returns and spawners for the next 15 years (mean, median, 90% Bayesian credibility interval) for three productivity assumptions and two sport fishing management scenarios. The management scenarios are described in Table 2.

Assumption	Returns		Spawners	
	Sport Fishery Closed	Current Sport Fishery Management Measures	Sport Fishery Closed	Current Sport Fishery Management Measures
A: Recent productivity	3 674 3 610 2 054 to 5 356	3 663 3 585 2 018 to 5 455	3 641 3 581 2 085 to 5 278	3 269 3 200 1 843 to 4 834
B: Increased productivity	4 513 4 476 2 699 to 6 401	4 514 3 585 2 603 to 6 471	4 450 4 410 2 705 to 6 265	4 022 4 004 2 350 to 5 696
C: Decreased productivity	2 701 2 612 1 396 to 4 278	2 663 2 553 1 350 to 4 296	2 704 2 622 1 447 to 4 222	2 403 2 309 1 269 à 3 835

The impacts of sport fishing on the abundance of returns, spawners and the likelihood of achieving the recovery target over the next 15 years were assessed using the stochastic state model and recent metapopulation productivity parameters. Six sport fishing management scenarios were assessed (Table 2). Fishing effort was assumed to be constant for all years from 2013 to 2027, but different for each river. Scenario **(a)** is total stoppage of fishing or catch and release of all salmon with 0% mortality associated with catch and release. Although extreme, this scenario is used to study the metapopulation's evolution without any fishing in the river, which provides a good benchmark. Scenario **(b)** is a 50% reduction in fishing effort compared to the current average since 2002, i.e. scenario **(c)**. Scenarios **(d)** and **(e)** are intermediate scenarios between scenarios **(a)** and **(c)**, where catch and release of all salmon is mandatory with respective 5% and 15% mortality rates associated with catch and release. Finally, scenario **(f)** is the average situation before 2000, i.e. conservation of all target individuals and fishing effort equal to the average fishing effort until 1999 (except for the Brick River).

Table 2. Sport Fishery Management Scenarios Assessed.

Scenarios	Management Measures	Target Individuals	Catch and Release Mortality
(a)	Fishery closed		
(b)	Fishing effort decreased by half compared to scenario (c)	Retention of grisle only	0%
(c)	Current situation, fishing allowed in 5 rivers	Retention of grisle only	0%
(d)	Scenario (c) but mandatory catch and release	All salmon	5%
(e)	Scenario (c) but mandatory catch and release	All salmon	15%
(f)	Situation before 2000	Retention of all salmon	

Broodstock producing adult returns from 2018 to 2032 differ by management scenario (Figure 6). Regardless of the productivity assumption, the order of management scenarios, in ascending order of the number of spawners, remains the same: **f**, **c**, **b**, **e**, **d** and **a**. If we consider that the survival and carrying capacity will remain the same (assumption **A**, recovery target = 2 100), the probability that the stock will be greater than or equal to the recovery target in the next 15 years ranges from 0.69 to nearly 1 based on the management scenario (Figure 7). As the predictions move forward in time, uncertainty increases and thus this probability decreases (Figures 6 and 7). Maintaining the current management measures (scenario **c**) would produce an approximate probability of 0.80 that the recovery target would be achieved at the end of the period. A 50% reduction in fishing effort slightly increases the probability (0.83) while mandatory catch and release of all salmon would produce 86% and 85% probabilities of achieving the target within 15 years based on 5% and 15% mortality rates respectively (Figure 7). Finally, closing the sport fishery would produce an 86% probability of achieving the spawner target recovery within 15 years (Figure 7).

6. Evaluate residence requirements for the Atlantic salmon, if any.

SARA defines the term “residence” as follows: dwelling-place, such as a den, nest or other similar area or 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.

In at least four stages of their lives, Atlantic salmon use places considered essential to achieving critical functions: gravel nests for eggs and alevins, shelters used by juveniles in freshwater, as well as pits frequented by adults. However, the concept of residence also means that individuals invest in the residence and (or) protecting the site and structures that form the residence. From this standpoint, only nests seem to fit the concept of residence.

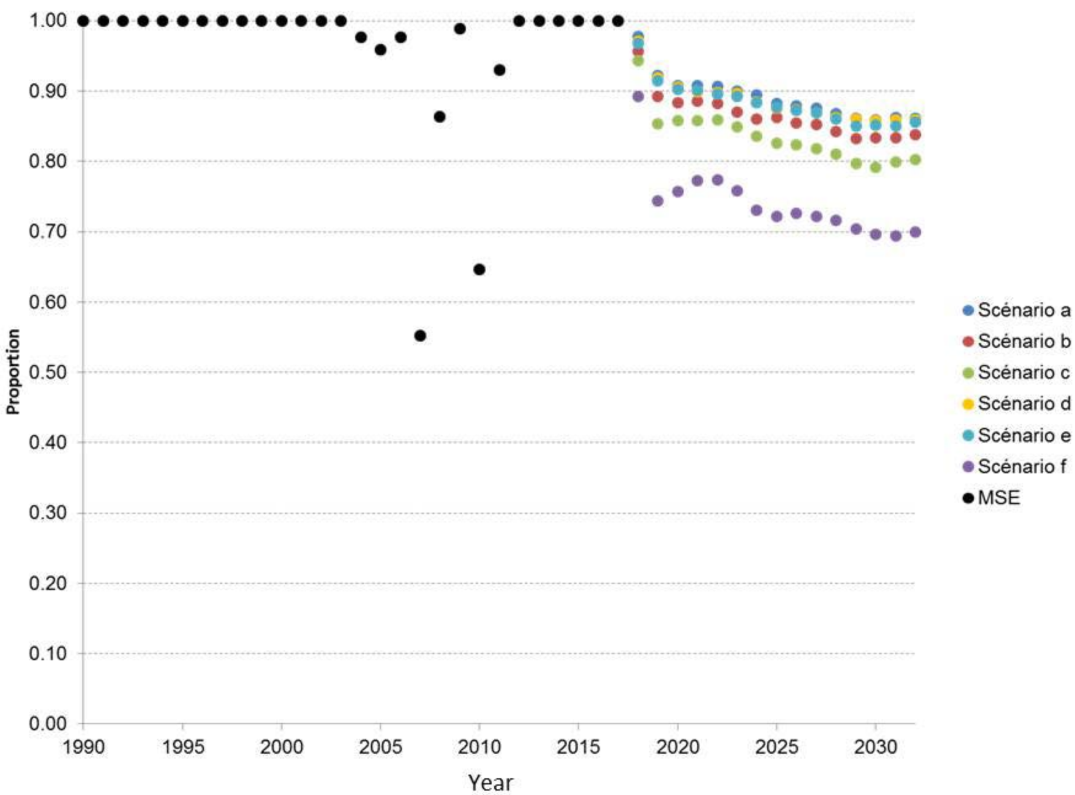


Figure 7. Probability that broodstock producing adult returns in year t is greater than or equal to the recovery target (2 100 spawners) with the current values for parameters of the metapopulation's renewal dynamics. From 2013, various sport fishery management scenarios are tested (scenarios ***a*** *to* ***f;*** *Table 2; MSE = Stochastic State Model).*

Assess habitat use

7. Provide functional descriptions (as defined in DFO 2007) of the required properties of the aquatic habitat for successful completion of all life-history stages.

As an anadromous species, Atlantic salmon can adapt to various habitats and conditions. While they grow, their habitat needs change. However, Atlantic salmon only spawn in freshwater and this habitat must be available for the species to survive. The following sections provide a description of the different types of habitat salmon need to survive. References have been removed to simplify the text, but are presented in Dubé (2012).

Freshwater habitat

Salmon need freshwater habitat to spawn. Atlantic salmon also need freshwater habitat for the early stages of growth and suitable habitat for downstream migration, upstream migration and spawning. Rivers with Atlantic salmon are generally clear, cool and well-oxygenated, with low (2 m / km) to moderate (11.5 m / km) gradient, a moderate current (25 cm / sec.), bottom substrates of gravel, cobble and boulder, low silt loads (less than 0.02%) and a pH greater than 5.5. The optimal temperature for growth of juvenile salmon is between 16 and 20ºC and the incipient lethal temperature is 27.8ºC. Adult salmon prefer to migrate in water temperatures between 14 and 20ºC although migrations occur below this temperature in spring and fall. The incipient lethal temperature for adult salmon is probably about 25ºC.

Habitat for spawning, incubation and early stages of development

Eggs are deposited in nests built by females in stable, permeable, uncompacted gravel substrate, often in riffles. Incubation occurs in winter with the alevins hatching in April or May. After hatching, the alevins remain in the gravel substrate for several weeks before emerging. Several factors influence the choice of spawning sites, including water flow in the substrate, particle size, the quantity and quality of water and the presence of shelters. Egg and alevin survival depend mainly on temperature and oxygen supply.

Juvenile habitat

Juveniles establish and defend their territory. The area of a territory depends on biotic and abiotic factors, including the morphology of the river, the substrate, gradient, quantity and quality of water, availability of shelter and food, and abundance of predators and competing species. Salmon alevins and parr generally prefer a riffle habitat. They may move to deeper waters as they grow and during winter and periods of drought. Juveniles may also occupy lakes, ponds and still water areas. The requirements for this stage of life include interconnected freshwater areas that provide fresh, clean and well-oxygenated water, adequate food (mainly invertebrates) and shelter against predation, sun and severe weather.

Juvenile and adult migration

Given the species' migratory behaviour, Atlantic salmon habitats need to be connected not only for adults migrating to spawning areas and parr and smolts migrating dowstream to the estuary and the sea, but also for the seasonal movements of juveniles. Smolt begin to migrate downstream when the weather warms up in spring and the water temperature nears 10ºC. The river's flow and the date on which the weather warms up also have an influence. Smoltification is chiefly synchronized with water temperature, which is strongly related to the photoperiod. Smolt migration in estuaries and coastal areas occurs mostly at night, at low tide and along the surface. Tidal currents and winds affect migration. At sea, the factors that trigger the return migration of adults are less well known. However, sea surface temperature and ice distribution appear to influence salmon distribution in the Northwest Atlantic and run timing. Entry into the river seems to be driven by increased water flow, but other factors may also be involved (temperature and water chemistry, light, tide and the season). Both during their migration upstream and near spawning grounds, adult salmon need areas to rest and recuperate. Deep pits of freshwater provide them with shade and protection against predation and severe weather.

There is little detailed information on the migration routes of the various salmon populations and their distribution at sea. They do, however, appear to overlap in the North Atlantic. All age groups of salmon at sea are represented in the Labrador Sea, where they also probably spend the winter. Salmon that will become multi-sea-winter salmon upon their return to freshwater are also observed every year in the Greenland area. Post-smolts from the north shore of the St. Lawrence estuary, the North Shore, Anticosti Island and the Gaspé, leave the Gulf of St. Lawrence through the Strait of Belle Isle. They reach the Labrador Sea in the area north of the Grand Banks in late summer and early fall. Post-smolts may take a different path than adults do when they return to freshwater.

Sea habitat

The low marine survival rate throughout the Atlantic Salmon range has been cited as a primary cause of declines. However, marine habitat needs are still poorly understood because there is little detailed information on the migration routes and marine distribution of the various salmon populations, particularly on post-smolt salmon behaviour and distribution. Temperatures in marine environments inhabited by adult salmon range from 1 to 13ºC, with an optimal range between 4 and 10ºC. The temperature range seems to be narrower in post-smolts, between 5 and 8°C, and appears crucial to their survival, because it regulates their metabolic rate. Salmon feed primarily on invertebrates in the early stages of marine life, but also consume fish as they grow. Their diet varies in time and space, suggesting they are opportunistic feeders.

8. Provide information on the spatial extent of the areas that are likely to have these habitat properties.

Freshwater environment

The extent of freshwater habitat with the desired properties is considered the limiting factor for production in freshwater and is used as a criterion to determine the densities needed for conservation of the species. In order to establish conservation thresholds, a habitat quality index (HQI) model was used to identify production units in rivers, i.e. the number of productive habitats (Caron et al. 1999). The model took into account the following environmental variables: particle size, flow regime and river width, as well as a growth index used to consider the “temperature” component. The HQI was measured for each river segment and multiplied by the area of the segment to calculate the amount of available habitat (m^2), known as a “production unit (PU).” The PU values for each segment were then added to calculate a total PU value per river. Based on this approach, Anticosti Island’s productive freshwater habitat (for 21 salmon rivers) was estimated to be 4,063,942 PUs (Table 3). The total value was 4,463,368 PUs if the areas estimated by Brun and Prévost (2013) for four rivers without PU measurements were included: Petite rivière de la Chaloupe (106,134), Maccan (115,434), Ruisseau Martin (91,115) and Du Brick (81,743). Thus, freshwater habitat does not appear to be a limiting factor in terms of productive area. However, certain natural factors could affect the availability of freshwater habitat (See step 11.).

It is also important to keep in mind that some rivers have more production units (productive habitat) and greater salmon concentrations (probability of returning adults). Table 3 compares PUs and adult returns in the various rivers. Over half (53%) of the Anticosti Island Atlantic salmon metapopulation is concentrated in the Jupiter (28%), De la Chaloupe (13%) and Aux Saumons (12%) rivers. In addition, the connectivity of the various types of habitats used by salmon throughout their life cycle is essential (i.e.: spawning grounds, habitat for alevins and juveniles, downstream migration corridor). Thus, the whole river appears crucial. We should also note the importance of providing access to all rivers and ensuring that each region of the island is represented to maintain the structure of the Atlantic salmon metapopulation in this designatable unit.

Marine environment

The marine environment range, estimated at over 20,000 km^2, includes a large portion of the North Atlantic (COSEWIC 2010). The lack of correlation between the number of adult salmon and the rate of return to counting facilities, compared to the number of smolts leaving rivers, suggested that carrying capacity in the Northwest Atlantic does not limit the abundance of salmon.

9. Identify the activities most likely to threaten the habitat properties that give the sites their value, and provide information on the extent and consequences of these activities.

A semi-quantitative assessment of the impacts of threats to salmon habitat in proposed designatable units (DU) in Canada indicated that the Anticosti Island DU was one of the least affected areas (DFO and MRNF 2009). In short, the area is seldom disturbed by human activities. There are few logging operations in the salmon river watersheds and appropriate steps have been taken to protect these habitats. However, oil and gas exploration activities on the island raise some concerns. The low marine survival rate, which may be linked to substantial but still poorly understood changes in marine ecosystems, appears to be a major concern. It is also important to consider that the Anticosti Island Atlantic salmon population is small, making it more vulnerable to potential threats.

Table 3. Production Units (PUs) in Anticosti Island rivers (MRNF, unpublished data) and breakdown of returns to these rivers.

River	Productive Habitat (PU m²)	Percentage of Adult Returns (%)
Petite rivière de la Loutre	135,871	3.4
Bell	119,414	2.6
Ruisseau Box	97,817	2.3
Dauphiné	242,728	3.4
De la Chaloupe	331,119	12.7
Ferrée	92,933	3.6
Du Pavillon	68,722	1.5
Aux Plats	99,591	1.2
Chicotte	113,614	1.0
Galiote	222,687	2.0
Jupiter	1,186,836	27.6
À la Loutre	137,147	5.1
Aux Cailloux	108,829	1.8
Sainte-Marie	94,790	2.1
Bec-Scie	82,495	3.1
À l'Huile	107,262	1.5
MacDonald	108,849	2.8
A la Patate	67,124	2.5
Vauréal	79,669	1.7
Aux Saumons	453,875	11.8
Du Renard	117,570	1.1
Ruisseau Martin	91,115*	1.0
Maccan	115,434*	2.0
Petite rivière de la Chaloupe	106,134*	1.6
Du Brick	81,743*	0.6
TOTAL	4 463 368	100

**Values estimated by Brun and Prévost 2013*

Oil and gas exploration and development

Since the early 1960s, several oil and gas exploration projects have been completed on the island. These projects included more than 1,410 km of seismic surveys, 19 exploration wells and several core sampling operations. In 2012, almost all of Anticosti Island was leased for oil exploration. Exploration operations come under various provincial laws, including the *Mining*

Act, the *Environment Quality Act* and the *Act Respecting the Conservation and Development of Wildlife*, because it is an activity that must comply with the Regulation respecting wildlife habitats. However, there are still concerns about future exploitation and its potential impact on the habitat: encroachment on aquatic habitat, potential contamination of groundwater and rivers, and intensive water use. Water is commonly used for fracturing because of its low cost and availability. In addition, chemicals are added to the water to produce fracturing fluids. This water is usually from local freshwater sources. Given Anticosti Island's particular hydrological regime, river water use could affect natural variations in water levels, particularly extremely low flows. The amount of water used can vary from zero to tens of thousands of cubic metres based on geological characteristics and specific reservoir characteristics.

Also, seismic operations in the Gulf of St. Lawrence produce acoustic waves that can affect fish populations and interfere with salmon migration patterns. Sublethal physical harm and physiological problems can occur near airguns and may cause delayed mortality or chronic effects. The Gulf of St. Lawrence's unique topography affects sound propagation (inland sea, shallow but highly stratified waters and the Laurentian Channel) and increases the degree of uncertainty regarding the impact on marine resources. The risk of an accidental oil spill in the area is also a concern, whether it involves an oil tanker accident or a leak from an oil well.

Climate change

In terms of climate change, observed variations in physical and chemical parameters (temperature, salinity and currents) and the composition and distribution of aquatic species (including salmon prey and predators) can affect the biology and ecology of salmon at various stages of their life cycle, both in freshwater and marine environments.

The recent period of poor marine survival occurred in tandem with many widespread changes in the North Atlantic ecosystem. These changes are still poorly understood and appear to be a major concern. Changes in ocean temperatures could have a direct impact on the survival of post-smolts, as well as indirect impact through the availability of prey. Return run timing could also be affected.

In freshwater, changes in seasonal temperatures and flow regimes could, for example, affect age at smoltification and sea-run timing. These changes could also increase the impact relating to natural variations in Anticosti river water levels.

The difficulty of assessing populations' ability to adapt to climate change is also a significant source of uncertainty. Data from monitoring two control salmon populations for nearly 30 years, in two separate genetic and geographic areas (St-Jean River in the Gaspé and Trinité River on the North Shore), suggested each river had its own population dynamics and each population could be affected differently by environmental changes (Dionne et al. 2012). It should be noted that there is growing scientific evidence on local adaptation in Atlantic salmon, but the speed at which Atlantic salmon can adapt to changes in its habitat is a source of uncertainty.

Others threats

There are other potential threats such as aquaculture and the presence of invasive species (i.e.: Rainbow trout). For the time being, they do not seem to be a direct threat to the Anticosti Island salmon metapopulation. However, the aquaculture industry continues to cause a great deal of controversy. The industry's growth in Canada coincided with significant declines in some wild populations. The concerns are related to potential interactions that can lead to inter-breeding and subsequent loss of reproductive success, competition for food and space, disruption of breeding behaviour, and disease transmission. Predation on salmon, in particular by seals (related to concerns of constantly increasing populations of grey seals and harp seals) and predatory birds, is also considered a potential threat. The Common Merganser is among the most important potential predator of juvenile salmon. In addition, salmon could be more vulnerable to it during low water periods.

Assessment of human threats to habitat

In order to assess the main human threats that may affect the habitat of Anticosti Island salmon, they were classified in terms of probability of occurrence (known, likely, unlikely or unknown) and their level of impact (high, medium, low or unknown) (Tables 4 and 5). This classification was peer-reviewed at the Recovery Potential Assessment meeting held December 4 and 5, 2012. However, the cumulative effect of the various threats was not considered. We should also note that this is a small population, making it more vulnerable to these threats.

Table 4. Definition of classes used to assess threat probability and impact

Probability of Threat Occurrence	
Known	This threat has been observed.
Likely	There is more than a 50% chance that this threat will be observed.
Unlikely	There is less than a 50% chance that this threat will be observed.
Unknown	There are no data or information available indicating that this threat could be observed.
Threat Impact Level	
High	The presence of the threat endangers the survival or recovery of the species.
Medium	The presence of the threat is likely to endanger the survival or recovery of the species.
Low	The presence of the threat is not likely to endanger the survival or recovery of the species.
Unknown	There are no data or information available indicating that this threat could endanger the survival or recovery of the species.

Table 5. Assessment of human threats to habitat

Potential Threats	Probability	Impact Level
Climate Change in Rivers	Known	Unknown
Climate Change at Sea	Known	Unknown[1]
Oil and Gas Exploration and (Future) Development	Known	Unknown[2]

[1] The recent period of poor marine survival occurred in tandem with many widespread changes in the North Atlantic ecosystem. These changes, though still poorly understood, are a major concern regarding the recovery of the Anticosti Island salmon population.
[2] The impact this activity will have is unknown but troubling.

10. Quantify how the biological function(s) that specific habitat feature(s) provide to the species varies with the state or amount of the habitat, including carrying capacity limits, if any.

The Anticosti Island productive freshwater habitat for the 25 salmon rivers is estimated to be 4,463,368 Production Units (PU). According to the stock-recruitment model used to establish certain benchmarks, the average carrying capacity (R_{max}) in Anticosti Island rivers would be 4,083 individuals based on the number of recruits from 1990 onwards. Thus, freshwater habitat does not appear to be a limiting factor in terms of productive area. However, certain natural factors could affect the availability of freshwater habitat (See step 11.). It is also important to keep in mind that some rivers have more production units (productive habitat) and greater salmon concentrations (probability of returning adults) and are particularly crucial in supporting this metapopulation.

11. Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.

The connectivity of the various types of habitats used by salmon throughout their life cycle is essential. The Anticosti Island's unique hydrology, especially the large natural variations in river water levels, could be a limiting factor. The island rivers have a torrential flow regime. There are very few lakes and water levels vary greatly depending on precipitation. Anticosti Island rivers can experience very low and high flows within short periods of time. River mouths can also move during a year or be blocked (spits) for a while. Karst phenomena, involving dissolution of the limestone forming the bedrock of Anticosti Island, may cause rivers to disappear from the surface and reappear several metres or hundreds of meters away (resurgence phenomenon). River configurations can therefore change from year to year. It is a very dynamic environment.

On the Jupiter River, for example, there have already been reports of dry, eroded spawning grounds. The low egg to alevin survival rate observed during three years of monitoring is mainly associated with extremely low flows in late March, early April. In addition, low summer flows can greatly reduce the breeding habitats of juvenile salmon and slow their growth. On the Jupiter River, a correlation was also observed between annual salmon runs and the minimum summer flow recorded in the two (grilse) and three (two sea-winter salmon) previous years (Hydrotech inc. 1989). The level of adult return runs would appear to be partially determined by hydrological history.

12. Provide advice on how much habitat of various qualities / properties exists at present.

See step 8. More detailed information is not available.

13. Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present, and when the species reaches biologically based recovery targets for abundance and range and number of populations.

The productive freshwater habitat, estimated at 4,463,368 PUs, does not appear to be a limiting factor for population recovery. However, the large natural variations in Anticosti river water levels could limit access to these habitats (See step 11.). Carrying capacity in the Northwest Atlantic does not seem to be a limiting factor either. However, the low marine survival rate, which may be linked to substantial but still poorly understood changes in marine ecosystems, is a major concern.

14. Provide advice on the feasibility of restoring habitat to higher values, if supply may not meet demand by the time recovery targets would be reached, in the context of all available options for achieving recovery targets for population size and range.

The availability of freshwater habitat does not appear to be a limiting factor in terms of productive area. However, the obstruction of some rivers may limit access to quality habitat. Steps could be taken to minimize obstruction of these river mouths.

15. Provide advice on risks associated with habitat “allocation” decisions, if any options would be available at the time when specific areas are designated as critical habitat.

To reduce risk, allocation decisions will have to reflect the fact that some rivers have more production units (productive habitat) and greater salmon concentrations (Table 2). Over half (53%) of the Anticosti Island Atlantic salmon metapopulation is concentrated in the Jupiter (28%), De la Chaloupe (13%) and Aux Saumons (12%) rivers (Brun and Prévost 2013). Failing to consider the rate at which rivers contribute to the metapopulation would therefore constitute a risk. In addition, the whole of the river should be considered in allocation decisions given the importance of ensuring the connectivity of the various types of habitats used by salmon throughout their life cycle (i.e.: spawning grounds, habitat for alevins and juveniles, downstream migration corridor). We should also note the importance of providing access to all rivers and ensuring that each region of the island is represented to maintain the structure of the Atlantic salmon metapopulation in this designatable unit.

16. Provide advice on the extent to which various threats can alter the quality and/or quantity of habitat that is available.

See step 9.

Scope for management to facilitate recovery

17. Assess the probability that the recovery targets can be achieved under current rates of parameters for population dynamics, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters.

See step 5.

18. Quantify to the extent possible the magnitude of each major potential source of mortality identified in the pre-COSEWIC assessment, the COSEWIC Status Report, information from DFO sectors, and other sources.

For the entire Anticosti Island designatable unit, the estimate of salmon sport catches (retained) decreased from 1,596 specimens in 1984 to 463 in 2011, with a maximum value of 1,904 fish in 1985 and a minimum value of 162 in 2004 (MRNF 2012). The 2006–2010 average was 336 catches, which was 10% of average adult returns, about 3 500 adults since 2006 (Figure 3). The 463 salmon caught in 2011, distributed among the five rivers where fishing was permitted (Jupiter: 231; Aux Saumons: 118; De la Chaloupe: 89; À la Loutre: 14; Ferrée: 11 (MRNF 2012)) accounted for 12% of the estimated average returns for 2011.

The West Greenland commercial fishery is a mixed stock interception fishery that harvests fish of North American and European origin. Note that this fishery primarily targets multi-sea-winter salmon. The 2011 data estimate the North American share at 91.5%, compared to 8.5% of European origin, which is equivalent to 25 tonnes (6 800 fish) (ICES 2012). Between 1995 and 2006, regional contributions ranged from less than 1% (Maine) to 40% (southern Quebec) and the Anticosti area accounted for only 1% (Gauthier-Ouellet et al. 2009). No regional group was overrepresented in landings compared with their respective productivity. Saint Pierre and Miquelon also operated a mixed stock and interception fishery. The 2011 catch was estimated at 3 756 kg.

Labrador Aboriginal groups and residents engaged in certain subsistence fisheries in what were considered Labrador coastal waters. These fisheries were moved closer to the river mouths and probably harvested few salmon from outside the area, but the origin of salmon caught in these fisheries was unknown.

Bycatch associated with monitored commercial fisheries, which must be released, was not considered significant. Management measures were introduced during the last decade (mesh size, net position and fishing period) to reduce salmon bycatch in the pelagic mackerel, herring and capelin fisheries.

Illegal salmon fishing was reported in marine and freshwater areas. However, this source of mortality was difficult to quantify. On Anticosti Island, there was not enough staff to produce a clear picture of the situation, even if indications of illegal fishing (increased boat traffic at the mouths of rivers and the presence of prohibited fishing gear (spoons) at the bottom of rivers) were occasionally observed. Given their low relative abundance in some rivers, illegally harvesting a few salmon could have a significant impact on the recovery of local populations.

The probability of occurrence and the impact associated with various sources of mortality were peer reviewed at the Recovery Potential Assessment meeting held December 4 and 5, 2012 (Table 5). See Table 4 for class definitions.

Table 5. Assessment of sources of mortality

Source of Mortality	Probability	Impact Level
Sport fishing in rivers[1]	Known	Low[2]
Illegal fishing in rivers	Known	Low[3]
Illegal fishing at sea	Known	Low
Marine mixed stock and interception salmon fishery	Known	Low
Commercial fishery bycatch	Known	Unknown

[1] This potential threat was estimated in the context of current management measures and based on modelling results (Brun and Prévost 2013).
[2] The level of impact associated with the sport fishery was estimated to be low, but given the status assigned to the population by COSEWIC, caution should be exercised and existing management measures should be maintained and enforced.
[3] The level of impact associated with illegal fishing was estimated to be low for the entire production unit, but it may be more significant on a smaller scale, if the catches are concentrated in one river in particular or a smaller river.

19. Quantify to the extent possible the likelihood that the current quantity and quality of habitat is sufficient to allow population increase, and would be sufficient to support a population that has reached its recovery targets.

See step 13.

20. Assess to the extent possible the magnitude by which current threats to habitats have reduced habitat quantity and quality.

See step 9.

Scenarios for mitigation and alternative to activities

21. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all feasible measures to minimize/mitigate the impacts of activities that are threats to the species and its habitat (steps 18 and 20).

See next step (22).

22. Using input from all DFO sectors and other sources as appropriate, develop an inventory of all reasonable alternatives to the activities that are threats to the species and its habitat (steps 18 and 20).

To minimize and mitigate the impacts of activities that are threats to the Atlantic salmon metapopulation, mitigation measures and alternative solutions are proposed (Table 6). They were peer-reviewed at the Recovery Potential Assessment meeting held December 4 and 5, 2012.

Table 6. Mitigation measures and alternative solutions

Threat	Mitigation Measure and Alternative Solution
Sport fishing in rivers	• Maintain and enforce existing management measures. • Monitor the effectiveness of management measures. • Raise fishers' awareness of catch and release and best practices to increase survival of released salmon. • Allow catch and release fishing during periods where environmental conditions favour survival of released salmon.
Illegal fishing in rivers and at sea	• Strengthen monitoring. • Awareness.
Marine mixed stock and interception salmon fishery	• Conduct further research to increase knowledge on the migration profile, marine range and origin of salmon caught outside the Anticosti area in Canada and outside Canada (impact of these fisheries).
Commercial fishery bycatch	• Enforce mandatory catch and release and educate fishers on this practice. • Enforce restrictions on fishing gear, fishing zones and fishing seasons. • Document bycatch in pelagic fisheries (mackerel, herring and capelin).
Oil and gas exploration and development	• Comply with standards that govern these activities. • Adjust the timing of oil and gas activities to minimize impacts.

23. Using input from all DFO sectors and other sources as appropriate, develop an inventory of activities that could increase the productivity or survivorship parameters (steps 3 and 17).

See step 22.

24. Estimate, to the extent possible, the reduction in mortality rate expected by each of the mitigation measures in step 21 or alternatives in step 22 and the increase in productivity or survivorship associated with each measure in step 23.

The information needed for a direct answer to this question is not available. However, in the case of sport fishing in rivers, steps 5 and 27 provide a basic overview of the impact that closing the fishery, reducing fishing effort or taking other management actions will have on achieving the recovery target.

25. Project expected population trajectory (and uncertainties) over three generations (or other biologically reasonable time) and to the time of reaching recovery targets when recovery is feasible; given mortality rates and productivities associated with specific scenarios identified for exploration (as above). Include scenarios which provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.

See step 5 regarding sport fishing in rivers.

26. Recommend parameter values for population productivity and starting mortality rates, and where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts of listing the species.

Current parameters of the metapopulation's renewal dynamics indicate the metapopulation is productive (survival when stock values are low is much greater than 1). In the past, the probability that the spawning stock was greater than or equal to the recovery target was generally high, i.e. greater than 0.85, except for stocks that produced returns in 2007 (0.55 probability) and 2010 (0.65 probability) (Figure 7). In the worst proposed sport fishing management scenario, there was a 30% risk that the broodstock would be less than the recovery target in the near future (15 years). If long-term productivity were to increase or decrease, the recovery target for this metapopulation would have to be reviewed. If productivity were to increase by 25%, the recovery target for this stock and recruitment scenario would be 2,622 spawners, but if productivity were to decrease by 25%, the recovery target would be 1,648 fish.

Allowable harm assessment

27. Evaluate the maximum human-induced mortality which the species can sustain and not jeopardize survival or recovery of the species.

According to the results presented in step 5, the probability that broodstock producing adult returns from 1990 to 2017 was greater than or equal to the recovery target is between 0.55 and 1.

The impacts of various sport fishing management scenarios on spawner abundance for the next 15 years were estimated. Based on current metapopulation productivity parameters, there is very little difference in the likelihood of achieving the recovery target within 15 years if the fishery is closed (scenario (**a**); 86%) or if fishing is permitted in the five main rivers, but with mandatory catch and release of all salmon (scenarios (**d**) 86% and scenario (**e**) 85%) (Figures 6 and 7). This probability decreases to 79% if current management measures are maintained (scenario (**c**)).

No other human activity causing Atlantic salmon mortality could be estimated.

Sources of uncertainty

The Bayesian statistical approach was selected to estimate the parameters of the metapopulation's renewal dynamics and to predict its evolution over 15 years (about three generations). This approach is used to quantify the uncertainty in quantities in an intuitive but mathematically rigorous manner by using probability distributions. There are several sources of uncertainty in the study of ecological processes. The stochasticity of the processes (not described by probability distributions) reflects random noise, which is impossible to predict given the knowledge available. Random observation errors are inherent in the sampling and measurement methods. The stochasticity of the processes as well as measurement errors make it impossible to accurately determine the unknown quantities of a model, which leads to uncertainty in estimating these quantities. It is also difficult to know exactly what relationships govern natural processes, and their complexity obliges us to simplify reality in order to represent it. Thus, several models can be used to represent the same phenomenon. Finally, when a management measure is introduced, it may be difficult to implement, which causes random implementation errors. The predictions did not consider this final source of uncertainty.

Gaps in knowledge and research needs were identified at the Recovery Potential Assessment meeting. The factors responsible for the mortality at sea, which could partially explain the decline of the population, are still poorly understood. Based on current knowledge, it is not possible to properly assess the causes of low abundance of post-smolts. The pursuit of scientific research to increase knowledge of the migration profile, marine range and origin of salmon caught off Canada appears justified. It would also be useful to better document salmon bycatch in pelagic fisheries and better measure the impact of salmon catch and release. The difficulty of assessing populations' ability to adapt to climate change also remains a significant source of uncertainty. In connection with these changes, it would be useful to take a closer look at the historical changes in Anticosti river flows and temperatures, as they may heighten the impact of natural variations in water levels. Mention had also been made of gaps in the available data on monitoring spawners in rivers. It was also suggested that a control Anticosti river be established and that individuals in that river be closely monitored. Assessment of smolt production associated with available habitat would include assessing egg to smolt survival (river survival) and smolt to adult survival (survival at sea), essential information that would be used to better characterize salmon population dynamics, and by extension that of other rivers concerned. With respect to modelling work performed as part of the Recovery Potential Assessment (Brown and Prevost 2013), it might be appropriate to differentiate grilse from multi-sea-winter salmon, which would help refine the model by taking age structure into account.

SOURCES OF INFORMATION

This Science Advisory Report is from the December 4 and 5, 2012 meeting on the recovery potential assessment of Anticosti Island Atlantic salmon. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada Science Advisory Schedule as they become available.

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