REPORT

PRESENCE OF ATLANTIC SALMON (SALMO SALAR) OF UNGAVA BAY, NUNAVIK, IN THE KOKSOAK SYSTEM : PHASE 2, FIELD VALIDATION OF THE DELAY RIVER SUB-WATERSHED

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512 Route 167 S, Chibougamau, QC G8P 2X8
Tel.: (418) 748-4441 Fax: (418) 748-1110
www.faunenord.org

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BACKGROUND

The Ungava Bay watershed represents the northernmost range in North America of the Atlantic salmon (*Salmo salar*). Wildlife in Ungava Bay area is under the management of the *Direction de la gestion de la faune Nord-du-Québec*, part of the *Ministère des Forêts, de la Faune et des Parcs* (MFFP-DGFa-10; Fishery zone 23). Wildlife management is handled in a concerted fashion through the Hunting, Fishing and Trapping Coordinating Committee (HFTCC). The HFTCC was created under the provisions of Chapter 24 of the James Bay and Northern Quebec Agreement (JBNQA) and has been in existence since 1976. The Agreement established a specific hunting, fishing and trapping regime for the territory covered by the JBNQA. Under this regime, members of the signatory Native people were granted certain rights regarding the exploitation of wildlife in the Territory. Chapter 24 also established a special Outfitting Regime for the Territory. The HFTCC was given the responsibility to review, manage, and in certain cases, supervise and regulate the regimes. It also participates with the responsible minister of Canada or Québec in the management of wildlife species in the Territory, either through decisional or consultative recommendations as called for in each case. In the words of the JBNQA, the HFTCC is “the preferential and exclusive forum for Native people and governments jointly to formulate regulations and supervise the administration and management of the Hunting, Fishing and Trapping Regime.” This means that the responsible ministers of Canada or Québec are required to consult the Coordinating Committee on all questions within its mandate before making decisions or proposing new regulations affecting the Territory. The Coordinating Committee brings together representatives of the Quebec Government, the Canadian Government, the Cree Regional Authority, Makivik Corporation (Inuit), and the Naskapi Landholding Corporation, as well as a non-voting observer-member appointed by la *Société de développement de la Baie James* (the James Bay Development Corporation).

There are a dozen outfitters spread throughout the territory of the Ungava watershed. Outfitters offer fishing packages for salmon as well as several other species found in Northern Quebec (for example brook trout (*Salvelinus fontinalis*), Arctic char (*Salvelinus alpinus*), lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*). There are no ZECs or wildlife reserves in the territory and unlike in the South, there is no legally incorporated watershed organization.

Atlantic salmon frequent four great rivers that feed into Ungava Bay – the Leaf, Koksoak, Whale and the George rivers. Salmon rivers in the Ungava are quite different from rivers in southern Quebec. The Ungava region is noteworthy for a brief summer growth period. Moreover, the drainage basins of the northern rivers are much larger than for other salmon rivers in the province, and so the salmons have to travel great distances to reach their spawning sites.

Provincial and federal bodies officially recognize and regulate a certain distribution of the species in some sections of these four rivers. However, there are still significant knowledge gaps about the species, particularly in terms of its presence in the tributaries of the four rivers and the southern limits of its distribution. This lack of knowledge was noted in 2010 by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). In fact, while five Quebec populations of Atlantic salmon were added to Appendix I of the Species at Risk Act (SARA), the Nunavik population retains the status of "insufficient data". This category applies when there is insufficient information available to (a) determine the eligibility of a wildlife species for assessment, or (b) assess the risk of extinction of the species.

In this context, and to adequately ensure the conservation of the species, it is imperative to initiate projects aimed, among other things, at accurately determining the distribution of the species in the tributaries of the four main systems of Ungava Bay. Of these, the Koksoak River system deserves special attention. Linked to the Caniapiscau and Aux Mélèzes rivers, the Koksoak network and its tributaries have high habitat potential for salmon, and are also subject to the greatest fishing pressures in the Ungava Bay area.

The regulatory boundaries of the section of the Koksoak network described as a "salmon river" were defined several years ago. This delimitation was carried out using rudimentary hydrogeomorphological criteria with the tools available at the time, and with no field validation other than an analysis of the sport fishing data from a few outfitters who used certain sections of the system. A first phase of the project carried out in 2015 involved the analysis of historical data collected from interviews with outfitters to determine quality indices for theoretical habitat, targeting areas not currently recognized as "salmon rivers" but which offer good potential for the species. **The goal of the second phase of the project is to validate *in-situ* the interpretation of that theoretical data. Such validation has never been done for the great rivers of the North, which is a major constraint to the establishment and validation of a Habitat Quality Index model.** HQI data are critical to achieving reliable values in stock-recruitment models and to improve management of salmon rivers in the Ungava. Given the expected development of Northern Quebec in the near future, it is important that these data be obtained as soon as possible to ensure the species is properly managed.

Ultimately, this project will lead to a set of recommendations that can be used by the region's key stakeholders in the conservation and management of the species. All data collected on species distribution in the study area and the resulting recommendations will be used by Makivik Corporation, the project partner and a member of the HFTCC. In addition, this project will help develop regional expertise by adapting theoretical concepts that were developed based on salmon rivers in the south to our large northern rivers and identifying, from a species conservation perspective, other needs regarding the salmon rivers of Nunavik. Finally, field validation of the parameters derived from satellite imagery and the IQH will be of utmost importance and will ultimately allow for better management of salmon rivers in Northern Quebec.

OBJECTIVES

This project had three main objectives:

1- Field validation of the presence of salmon in the habitats identified in Phase 1 (2015);
2- Physicochemical characterization of the habitat;
3- Participate in the development of a conservation strategy for the Koksoak River system.

METHODOLOGY

STUDY AREA

The field phase of this project was carried out in the Koksoak River system, which includes the watersheds of the Koksoak River and the Aux Mélèzes (Kuuvik) River. The Koksoak system is located southwest of Ungava Bay near the town of Kuujjuaq, Nord-du-Québec, Quebec (58.10304°N, 68.41881°W, NAD83, Figure 1). However, as this area is too large to cover in its entirety, the first phase of the project targeted the Delay River area (56.51939° N, 71.07586° W; Figure 1) not only because it showed a strong theoretical potential for salmon, but also because it is under greater fishing pressure than the rest of the Koksoak system. In addition, the Delay River is located in a sector that is targeted for the creation of a conservation area and is the subject of a study request from the Inuit regarding the possibility of creating sanctuaries where fishing would be prohibited.

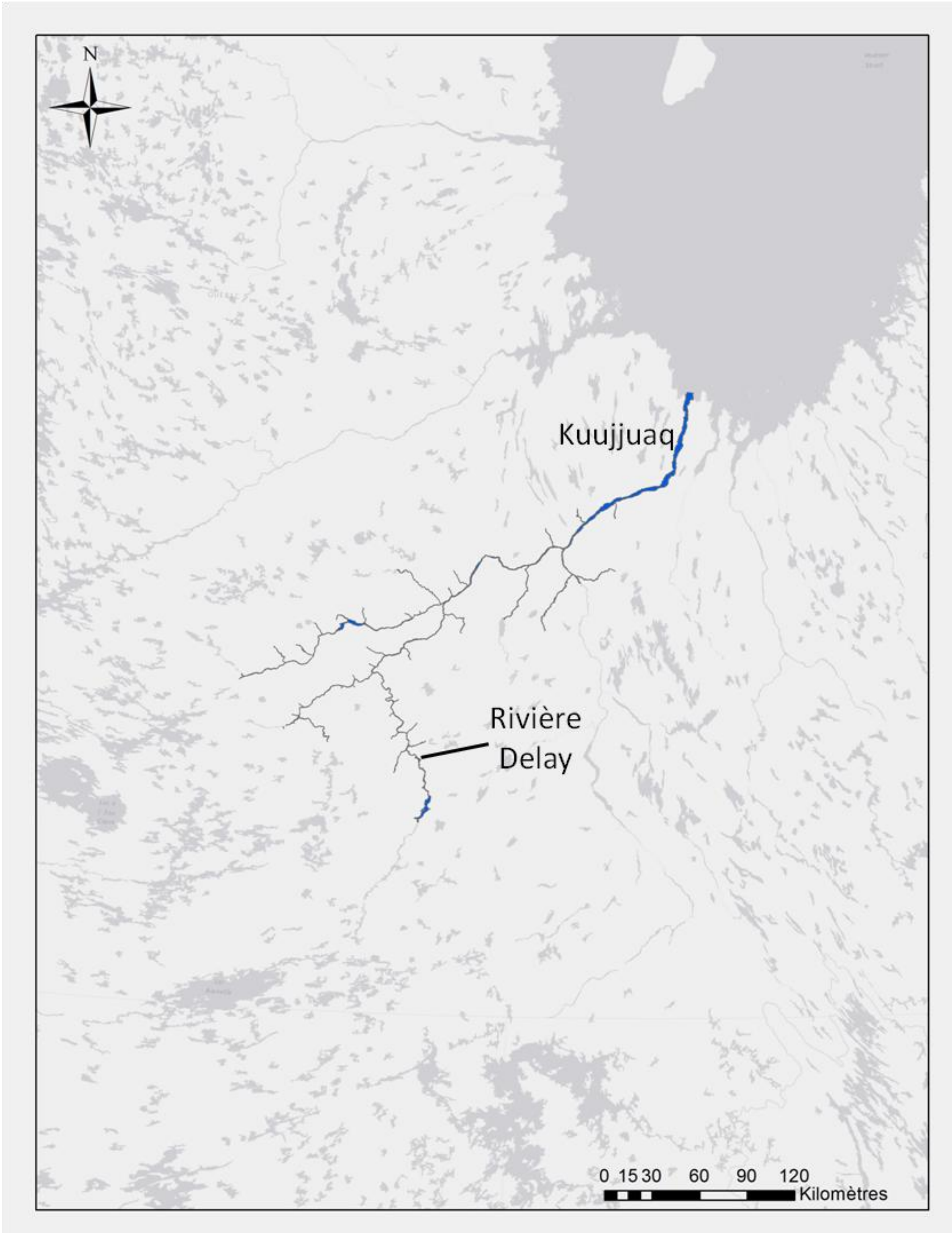

Figure 1. Location of the Delay River within the Koksoak River system (in blue). Note that the Koksoak system is not shown here in its entirety.

Within the Delay sector, 12 rivers or river segments had been previously identified as priorities based on the results of the first phase of the project (Figure 2). Of these, we hoped to be able to inventory 11. However, the sampling of certain segments was dependent on the field results obtained at stations farther upstream. Basically, for logistical reasons, some segments would not be sampled if salmon were found further upstream.

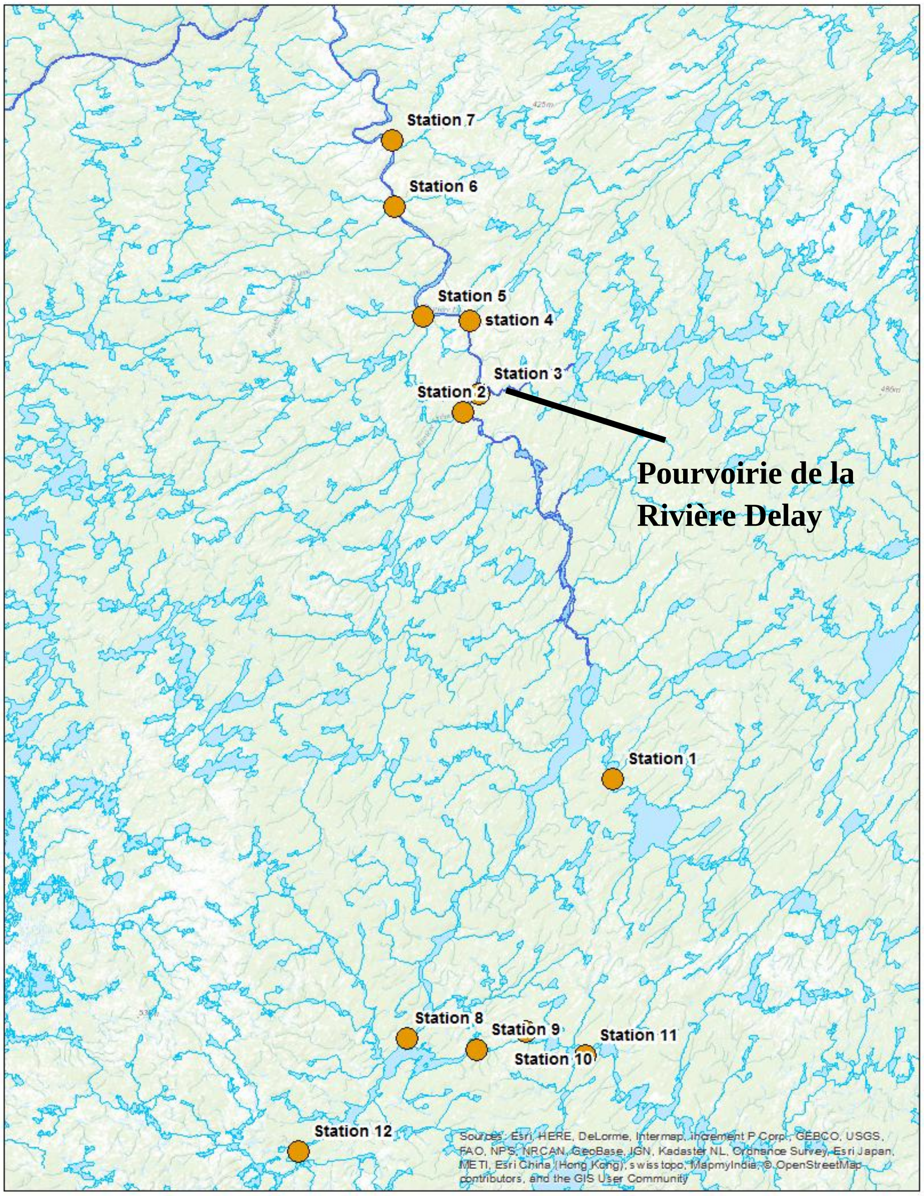

Figure 2. Locations of previously identified rivers or river segments.

DATA COLLECTION

The data collection took place between August 29 and September 4, 2016. Using the Delay River Outfitters camp as their base (56.51939 ° N, 71.07586 ° W), the field team travelled by helicopter, by boat and on foot to the previously identified sampling sites on the different rivers (Figure 3). Each of these rivers or river segments could have more than one sampling station.

Figure 3. An example of the rivers sampled.

Field validation of the presence of salmon

Because at the outset the field reality was not well known, various fishing and observation techniques had been planned to check for the presence of salmon in the targeted rivers or river segments, including electro-fishing, seining, gill nets, hook-and-line and snorkelling. In the end, electro-fishing (Figure 4) and hook-and-line (Figure 5) proved to be the most effective techniques (see results section). As authorized under permit SEG # 2016-07-18 -150-10-GP, the captured salmon were sacrificed and their otoliths harvested for analysis to determine whether they were anadromous or resident salmon.

Figure 4. Field team trying to catch Atlantic salmon parr using electro-fishing.

Figure 5. Fishing with hook-and-line for Atlantic salmon parr.

Physicochemical characterization of the habitat

At each sampling station, as many habitat characterization measurements were collected as possible. For most stations, this included measurement of the width of the watercourse, its average depth, the type of substrate, water temperature and the nature of the banks. For logistical reasons, the current velocity and pH were measured at only some of the stations (see Results section).

DIFFERENTIATION OF LANDLOCKED AND ANADROMOUS SALMON

The ouananiche (landlocked salmon) is the resident form of the Atlantic salmon. Like the anadromous form, it migrates to a river to reproduce but its feeding areas are in lakes. The adults are easily differentiated from anadromous salmon by their colour, but it is impossible to differentiate between the two forms in the pre-smolt stages without further analysis.

One way to differentiate the parrs is to analyze the chemical composition of their otoliths. During growth, the otolith retains a chemical signature of the environment, making it possible to deduce which environments the individual inhabited at certain stages of its life. The center of the otolith begins to form in the larva during the absorption of the yolk sac. The chemical composition of the yolk is inherited from the mother and reflects the environment in which she fed before spawning. Because anadromous Atlantic salmon do not feed, or feed very little, during their river migration, the chemical signal transmitted to the eggs is characteristic of the marine environment and can be found in the center of the offspring’s otolith (Rieman *et al*, 1992).

The microchemical composition at the center of the otoliths from the sampled parrs was obtained by ICP-MS laser ablation. The concentration of Strontium (Sr) was used because it is strongly influenced by saline environments. The ratio of this element to Calcium (Ca), used as an internal standard due to its abundance in the chemical composition of the otolith, makes it possible to determine the mother's anadromous or freshwater origin. This Sr/Ca ratio has been in common use since the 1990s to determine whether an anadromous individual developed in a marine environment at different life stages. The analysis of the microchemical composition of otoliths was carried out by the aquatic sciences laboratory of Dr. Pascal Sirois at the Université du Québec à Rimouski.

RESULTS

In total, 9 out of the 11 rivers or river segments were sampled (#1, 2, 4, 5, 6, 7, 8, 11 and 12, Figure 2). Although this total was less than the target, we do not consider it disappointing because salmon were found in sector 11 upstream of river sections 9 and 10. Since the salmons have to pass through sections 9 and 10 to reach the upstream station, the downstream stations were considered less important, and were deliberately abandoned. If the team had had an unlimited time in the field, it would have been interesting to sample these areas as well. However, when we arrived, most of the tributaries targeted in the project were not navigable by boat, and so the team had to travel long distances on foot, which slowed the work. In that context, sacrificing two stations was justified. As for river # 3, much of length of the Maricourt River is already legally recognized as a salmon river. Again, due to the short time available, this river was sacrificed since the detection of salmon upstream of the legally recognized portion was considered less important than the detection of salmon in rivers which, at present, have no legal status.

Table 1. Stations targeted and sampled in the study area.

Station	Global co-ordinates	Sampled (Y/N)	Substation	Latitude	Longitude
1	See substation	Y	1.1	56.175	-70.8234
			1.2	56.17402	-70.80485
2	See substation	Y	2.1	56.43354	-71.17722
			2.2	56.39695	-71.20649
			2.3	56.50028	-71.10218
			2.4	56.50195	-71.09853
			2.5	56.503128	-71.097369
3	56.525221° N 71.066832° W	N	-	-	-
4	See substation	Y	4.1	56.62244	-71.05065
5	See substation	Y	5.1	56.5897	-71.19638
			5.2	56.594906	-71.191783
			5.3	56.596353	-71.191331
			5.4	56.58521	-71.20342
			5.5	56.587973	-71.199965
6	See substation	Y	6.1	56.7048	-71.25938
7	See substation	Y	7.1	56.78119	-71.23411
8	See substation	Y	8.1	55.85236	-71.15926
9	55.847498° N 71.027652° W	N	-	-	-
10	55.867984° N 70.938147° W	N	-	-	-
11	See substation	Y	11.1	55.85492	-70.80305
12	See substation	Y	12.1	55.73959	-71.34708

FIELD VALIDATION OF SALMON PRESENCE

Since little was known about the field reality, the research team had planned various inventory techniques. However, only electro-fishing and hook-and-line fishing yielded interesting results. It appeared that the large salmon had not begun their run up the tributaries sampled, and so efforts were directed at capturing parr. Gillnets were not appropriate for parr, and the stream configurations and coarse substrate meant that seining did not work well either. Finally, snorkelling was used a few times, but the water in the rivers was much less clear than expected, which greatly reduced visibility. Nonetheless, this technique enabled us to observe salmon parr in two different rivers, as well as brook trout (Figure 6) and white suckers. However, it was much less effective than angling or electro-fishing.

Figure 6. Brook trout observed by snorkelling in one of the sampled rivers.

In total, the field team was able to capture salmon in seven of the nine rivers or river segments sampled (Figure 7). Despite the absence of salmon in Sector 8, salmon have to pass through it to reach Sector 11. Sector 12 was therefore the only sector for which the presence of salmon was not confirmed at this time.

Nearly 80 salmon parrs were captured in all, with a total length varying between 42 and 195 mm (Figure 8).

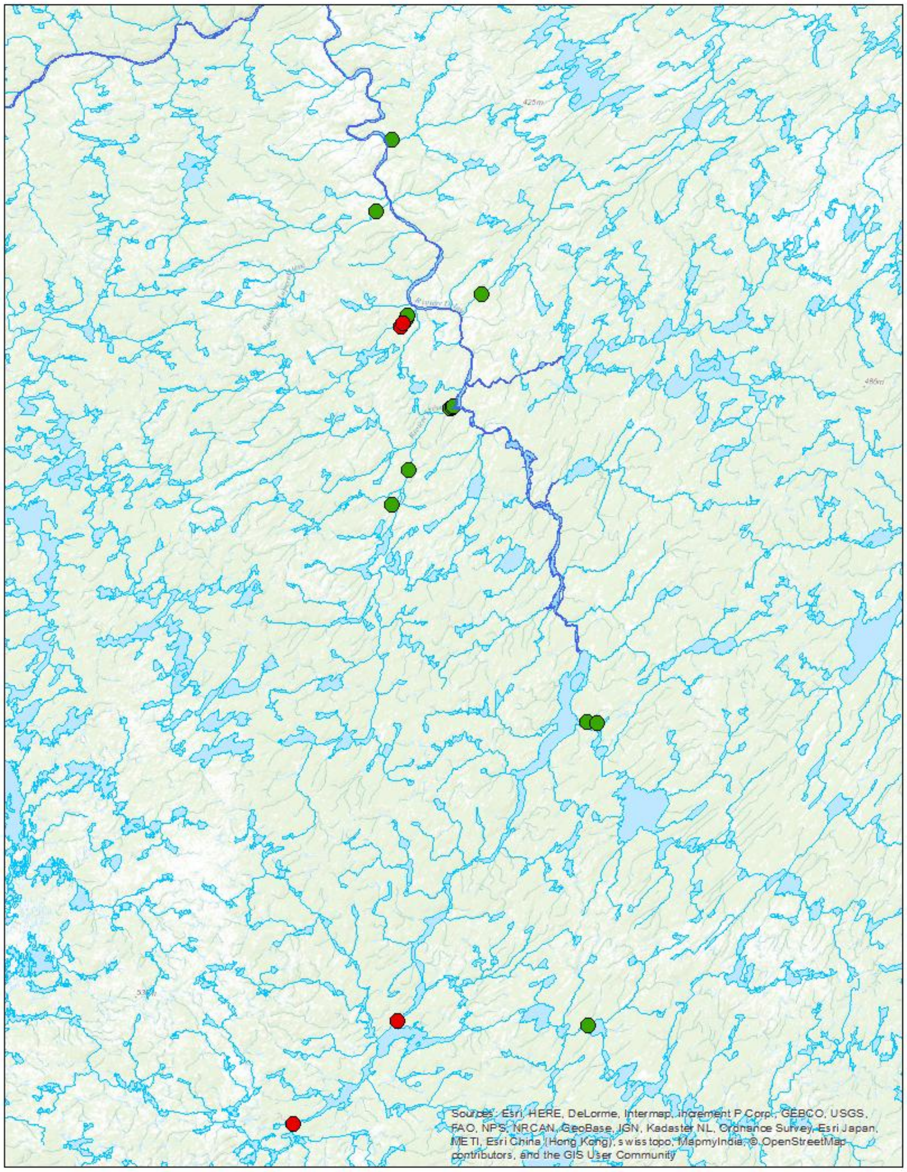

Figure 7. Locations of stations with salmon (green) and with no salmon (red).

Figure 8. Atlantic salmon parr.

PHYSICOCHEMICAL CHARACTERIZATION OF THE HABITAT

As mentioned above, to the extent possible, a physicochemical characterization was performed at each of the sampling stations. However, on several occasions a full characterization could not be completed due to lack of time. In this particular project, salmon detection was more important than habitat characterization, and thus when time was limited, salmon detection was given priority at the expense of a full characterization. In addition, since it was impossible to access the targeted tributaries by boat, the sampling equipment had to be reduced so that the field team could transport it on foot. Thus, for those sampling stations reached without the aid of the helicopter, we did not use the current meter or the multi-parameter probe used for measuring the pH.

Nevertheless, for most stations, we were able to collect data on width, depth, temperature, substrate (Figure 9) and riparian vegetation. Physicochemical and current velocity data were collected (Figure 10) and aerial photographs of the site were taken for most of the helicopter sampling stations (Figure 11). The characterization data are reported in Table 2.

Figure 9. Photo of substrate at one of the sampling stations.

Figure 10. Measuring current velocity.


Figure 11. Aerial photo of one of the sampling stations.

Table 2. Physico-chemical characterization data from the various sampling stations.

The data recorded includes geographic coordinates, date, river dimensions (width, length and depth), configuration (straight or winding), substrate (bedrock, boulder, stones, pebbles, gravel, sand, silt), organic debris, physico-chemistry (temperature, pH, $\%O_2$, and nature of banks (rocky, trees and shrubs), grassy, erosion).

					Segment size							Configuration			Substrate type (%)									Physico-chemical			Bank characteristics (%)			
Station	Latitude	Longitude	Date	Type of stream	Width (m)			Length (m)	Depth (cm)			Straight (%)	Sinuous (%)	Current speed (m/s)	Rock	Large block	Block	Pebble	Stone	Gravel	Sand	Silt	Organic debris	Temperature (°C)	pH	O_2 (%)	Rock	Trees and shrubs	Herbaceous	Erosion
					min	max	avg		min	max	avg																			
1.1	56.175	-70.8234	30-08-16	river	-	103	-	-	5	70	-	100	-	-	-	50	20	20	10	-	-	-	-	14.96	6.8	-	-	50	50	-
1.2	56.17402	-70.80485	04-09-16	river	-	220	-	122	5	-	-	5	95	0.95	-	15	35	30	20	-	-	-	-	11.9	6.8	-	5	50	45	-
2.1	56.43354	-71.17722	29-08-16	river	60	125	75	50	-	-	30	100	-	0.6	-	15	70	15	-	-	-	-	-	-	-	-	X	X	X	-
2.2	56.39695	-71.20649	29-08-16	river	20	100	50	300	-	-	30	80	20	0.23	-	15	55	15	5	5	5	-	-	-	-	-	5	85	10	-
2.3	56.50028	-71.10218	02-09-16	river	-	-	74	400	-	-	50	90	10	-	-	10	15	55	10	5	5	-	-	12	-	-	-	X	X	-
4.1	56.62244	-71.05065	31-08-16	river	-	46	-	111	3	50	-	90	10	-	-	5	70	25	-	-	-	-	-	13	-	-	50	15	35	-
5.1	56.5897	-71.19638	01-09-16	river	-	-	32	-	10	250	50	100	-	-	10	35	30	25	-	-	-	-	-	14	-	-	-	100	-	-
5.4	56.58521	-71.20342	03-09-16	river	-	63	-	-	5	40	-	80	20	0.39	-	25	25	35	15	-	-	-	-	13	-	-	10	-	90	-
6.1	56.7048	-71.25938	03-09-16	river	-	27	-	-	5	50	-	100	-	0.35	-	40	50	10	-	-	-	-	-	12.7	6.5	-	15	40	45	-
7.1	56.78119	-71.23411	03-09-16	river	-	-	20	-	5	50	-	10	90	0.43	-	5	-	30	50	15	-	-	-	10.7	6.2	-	5	40	50	5
8.1	55.85236	-71.15926	30-08-16	river	-	180	-	-	30	300	-	100	-	-	-	-	50	50	-	-	-	-	-	15	6.9	-	-	60	40	-
11.1	55.85492	-70.80305	30-08-16	river	145	250	-	-	10	60	30	100	-	0.3	-	5	50	30	5	5	5	-	-	14.32	6.64	92	X	X	-	-
12.1	55.73959	-71.34708	30-08-16	river	-	-	-	-	-	-	-	80	20	-	-	15	20	65	-	-	-	-	-	-	-	-	-	40	60	-

Discrimination of landlocked and anadromous salmon

Analyses of otolith microchemistry were carried out on 50 individuals representing all capture sites (Appendix 1). The mean concentration of Strontium (Sr) in the samples was 1,237 ppm with a minimum and maximum of 779 ppm and 1,787 ppm, respectively. High concentrations of Sr generally correspond to a signature of maternal growth in salt water (Rieman *et al*., 1994).

The mean Sr/Ca ratio was 3.09x10-3 with a minimum and maximum of 1.95x10-3 and 4.47x10-3, respectively. Several studies (Rieman *et al*., 1992, Friedland *et al*., 1998, Zimmerman & Reeves, 2000, Zimmerman, 2004) have identified Sr/Ca ratios greater than 1.1x10-3 in the center of anadromous salmonid otoliths, whereas resident individuals typically showed values below 1.0x10-3.

Given the strength of the Strontium signal in the samples tested, we can conclude that the individuals caught are of anadromous origin. However, it is not possible to distinguish between individuals of estuarine and marine origin (Robitaille *et al*., 1984) because the sample is too small to see the emergence of two distinct groups in the Sr/Ca ratios.

Recommendations

Changing the limits of the salmon rivers

According to Schedule 6 of the Quebec Fishery Regulations, the current boundaries of the salmon rivers in the study are defined as follows:

- 46 (1.1) a) Delay River. The downstream limit is determined by its confluence with the river named Rivière du Gué, marked off by a straight line joining points 56° 56′42″N., 71° 28′18″W. and 56° 56′24″N., 71° 28′18″W.
  The upstream limit is determined by a straight line between points 56° 14′59″N., 70° 50′19″W. and 56° 14′47″N., 70° 50′35″W.

- 46 (1.1) a) (i) Maricourt River. The downstream limit is determined by its confluence with the river named Rivière Delay, marked off by a straight line joining points 56° 31′38″N., 71° 04′40″W. and 56° 31′42″N., 71° 04′40″W.
  The upper limit is determined by the point 56° 33′04″N., 70° 55′00″W.

Based on the results obtained in this project, we recommend that new limits be adopted (Figure 12). The proposed limits are defined as follows:

- 46 (1.1) a) Delay River. The downstream limit is determined by its confluence with the river named Rivière du Gué, marked off by a straight line joining points 56° 56′42″N., 71° 28′18″W. and 56° 56′24″N., 71° 28′18″W.
  The upstream limit is determined by a straight line between points 55°49’54" N., 70°46’26" W. and 55°49’56" N., 70°46’31" W.

- 46 (1.1) a) (i) Maricourt River. The downstream limit is determined by its confluence with the Delay River, marked off by a straight line joining points 56 ° 31′38″N. 71° 04′40″W and 56° 31′42″N. 71° 04′40″W.
  The upper limit is determined by the point 56° 33′04″N. 70° 55′00″W.

- 46 (1.1) a) (ii) Fremin River The downstream limit is determined by its confluence with the Delay River, marked off (zone 23) by a straight line joining points 56° 30’29"N., 71° 05’33"W. and 56° 30’30"N., 71° 05’36"W.
  The upper limit is determined by the point 56°22’27" N., 71°12’33" W.

- 46 (1.1) a) (iii) Unnamed river. The downstream limit is determined by its confluence with the Delay River, marked off (zone 23) by a straight line joining points 56°47’06" N., 71°14’56" W. and 56°47’09" N., 71°14’55" W.
  The upper limit is determined by the point 56°47’05" N., 71°12’09" W.

- 46 (1.1) a) (iv) Unnamed river. The downstream limit is determined by its confluence with the Delay River, marked off (zone 23) by a straight line joining points 56°43’00" N., 71°14’03" W and 56°42’58" N., 71°14’03" W.
  The upper limit is determined by the point 56°41’41" N., 71°15’36" W.

- 46 (1.1) a) (v) Laperottière Stream. The downstream limit is determined by its confluence with the Delay River, marked off (zone 23) by a straight line joining points 56°36’19" N., 71°10’30" W and 56°36’17" N., 71°10’26" W.
  The upper limit is determined by the point 56°33’58" N., 71°14’55" W.

- 46 (1.1) a) (vi) Unnamed river. The downstream limit is determined by its confluence with the Delay River, marked off (zone 23) by a straight line joining points 56°35’56" N., 71°05’24" W and 56°35’55" N., 71°05’23" W.
  The upper limit is determined by the point 56°38’13" N., 71°01’22" W.

- 46 (1.1) a) (vii) Unnamed river. The downstream limit is determined by its confluence with the Delay River, marked off (zone 23) by a straight line joining points 56°10’43" N., 70°50’38" W. and 56°10’20" N., 70°50’46" W.
  The upper limit is determined by the point 56°08’23" N., 70°47’23" W.

- 46 (1.1) a) (viii) Unnamed river. The downstream limit is determined by its confluence with the Delay River, marked off (zone 23) by a straight line joining points 55°50’22" N., 71°07’50" W and 55°50’47" N., 71°07’43" W.
  The upper limit is determined by the point 55°49’49" N., 70°46’35" W.

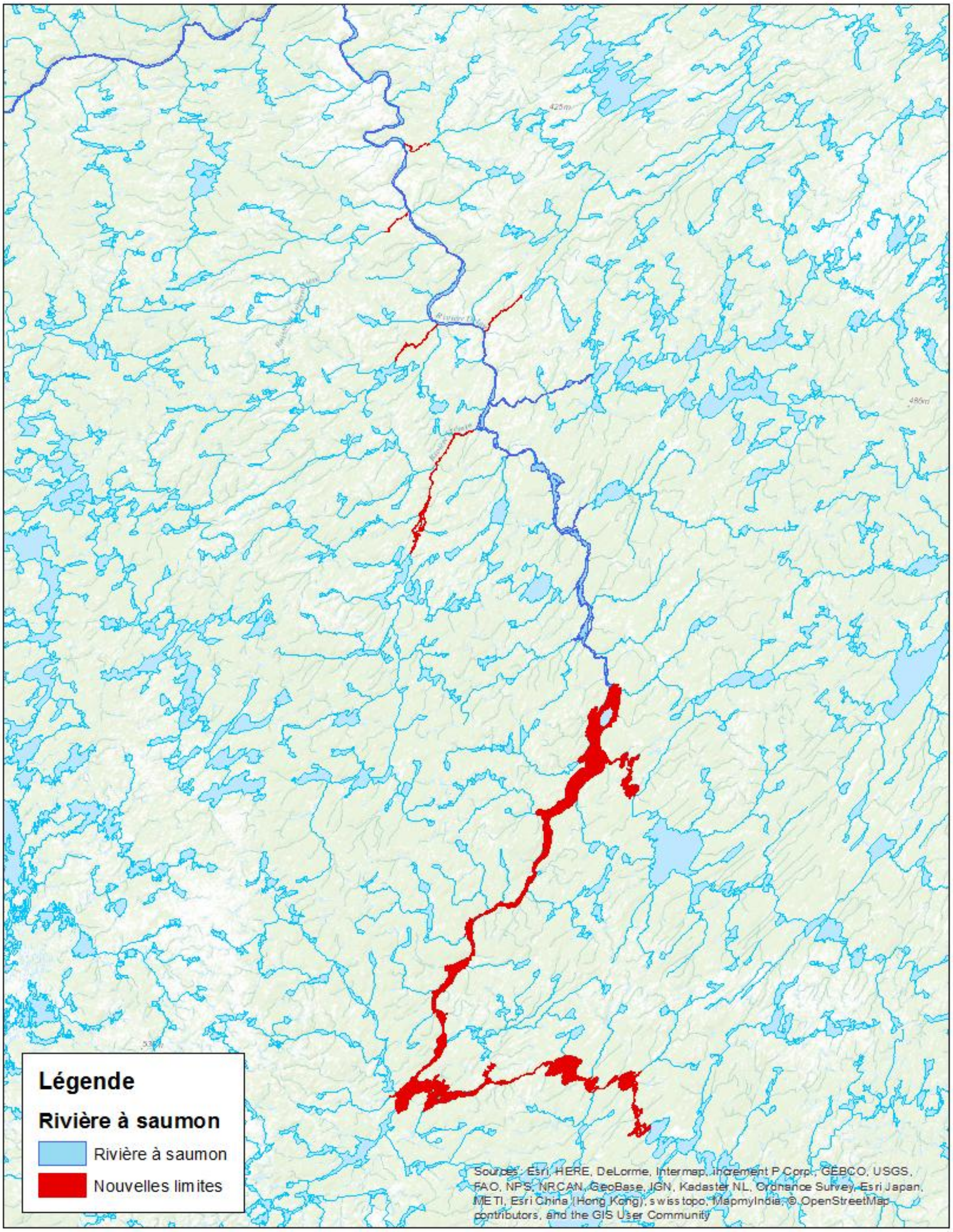

Figure 12. Existing limits (blue) and proposed limits (red) of the salmon rivers in the Delay River sector.

SALMON FISHING IN NUNAVIK

Due to the vastness of the territory and the high costs of conducting inventories in Nunavik, there is very little data on the Atlantic salmon in Ungava. At this point, data from the sport fishery remains the best tool for assessing the health of northern salmon populations. However, over the years, the MFFP has been able to determine that the data from independent fishermen, which is compiled using the Info-Salmon line, are partial and imprecise, even though registration of salmon catches is compulsory. At present, the only data considered reliable are those provided by outfitters. Outfitters also provide the Ministry with scales from their catches, making it possible to determine the age structure of the spawning stock and the return rate of spawning adults. These data are necessary for the implementation of management measures. Thus, in order to respect the precautionary principle in a context where the productivity of northern populations is lower and stock data is fragmented, we recommend that it be mandatory for non-beneficiaries of the JBNQA to use an outfitter operating on a salmon river in order to fish for Atlantic salmon in Nunavik. Adopting this recommendation would not only improve the quality of data available for sound salmon management, it could also reduce poaching.

MANDATORY INVENTORIES OF SALMON RIVER TRIBUTARIES

Our results showed that, despite their small size, the tributaries feeding into salmon rivers can be important habitat for Atlantic salmon. However, the Ungava Bay basin is far too large for all of these tributaries to be inventoried so that they can benefit from the protection associated with salmon river status. In light of this, we recommend that prior to any development project, the tributaries feeding directly into recognized salmon rivers and likely to be impacted by the project be the subject of a thorough inventory to determine whether they are used by anadromous Atlantic salmon, and thus should benefit from the regulatory procedures that apply to salmon rivers.

ASSESSING THE NEED FOR AND FEASIBILITY OF A WATERSHED APPROACH FOR THE MANGEMENT OF SALMON STOCKS

Southern salmon rivers are often managed using a single-river approach when the rivers in question show singular characteristics. In a similar vein, it would be advisable to assess the need for and feasibility of managing each of the watersheds of the large Ungava salmon rivers independently. There is reason to believe that each of these watersheds has its own specific characteristics that may influence the management approach to its salmon stocks. For example, the Koksoak Watershed is the only one with estuarine salmon, i.e., salmon that stays in the estuary rather than heading out to sea to grow. Salmon management in the Ungava is already relatively complex, but we recommend that the feasibility of such a management scheme be assessed.

FUTURE NEEDS

This project provided important insights into the distribution of Atlantic salmon in the Delay River watershed and documented the salmon's use of the river's small tributaries. But although these results mark a step in the right direction, knowledge about Atlantic salmon in Ungava rivers remains fragmented, including how salmon use the territory. Thus, in order to be able to effectively manage these salmon stocks, it will be necessary to continue acquiring knowledge about all the major salmon river watersheds in Ungava.

VALIDATING THE HQI MODEL

The physico-chemical characterization data collected during this project should enable the MFFP to validate, at least partially, the theoretical HQI model that has been developed for the salmon rivers of the North. Our capture results showed that salmon are indeed found in areas identified by the HQI as having good potential for the species. However, it is important that all future field campaigns to collect data on Atlantic salmon in Ungava also include the collection of physicochemical data in order to further improve the HQI model.

IDENTIFICATION OF SPAWNING GROUNDS

Protection of spawning grounds is an important part of Atlantic salmon management, particularly in the northern context where productivity is lower. We know very little about the locations of Atlantic salmon spawning grounds in northern rivers. Work to specifically locate and map the Atlantic salmon spawning sites in the Ungava Bay basin could help in establishing the necessary conservation measures.

IMPLEMENTING SALMON RUN MODELS

As part of Phase I of this project, we worked with MDDELCC geographer Dr. Daniel Blais to try to determine the limits of the salmon runs in the Koksoak watershed. However right now, the Digital Elevation Model (DEM) is not sufficiently accurate in northern regions to allow for reliable identification of the limits of the Atlantic salmon run. In the coming years it might be feasible to employ LIDAR technology in these areas, which would make it possible to calculate the run limits. Knowledge of these limits would be an important asset in reducing the inventory time required at the limit of these salmon rivers. It would also make it possible to better target future field work on Atlantic salmon in the Ungava Bay basin.

Upstream and downstream migration counts

Systematic upstream and downstream migration counts are conducted on several salmon rivers in the south of the province. However, no such count has even been done on the salmon rivers of Northern Quebec. Conducting such a count in the Ungava Bay basin would provide important information on the status of spawning stocks and ensure that stocks are monitored over time. In addition, these counts could provide a better understanding of migratory phenomena that are unique to northern salmon. The acquisition of such data would contribute to more sophisticated decision-making on the management of Ungava's salmon stocks.

Conclusion

This project has revealed the presence of anadromous Atlantic salmon in tributaries (Strahler number 5-7) of the Delay River watershed. The relative importance of these tributaries for the reproduction and growth of Atlantic salmon remains to be assessed, but our results show that the species indeed use many of them. This phenomenon is unlikely to be unique to the Delay River area and the number of tributaries used by Atlantic salmon in the entire Ungava Bay watershed is potentially very large. At present, the only tributary that benefits from the legal protection associated with salmon river status is a 10-km segment of the Maricourt River (Strahler number 7) located near the Delay River. Our findings therefore show that there are gaps in the current protection of important Atlantic salmon habitat in the Ungava Bay area. We are well aware of the challenges of salmon management in northern rivers, but in light of our findings, we believe that the recommendations presented in this report, particularly the first three, can serve as a good starting point for improving the management and protection of the species in Northern Quebec. In order to maximize the impact of this project, the results will be disseminated to the following entities: Quebec's Ministry of Forests, Wildlife and Parks, Makivik Corporation, the Hunting, Fishing and Trapping Coordinating Committee, the Atlantic Salmon, Conservation Foundation, and Environment and Climate Change Canada.

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APPENDIX 1.

Concentration of Strontium (Sr) and Strontium/Calcium ratio contained in the centre of otoliths from captured Atlantic salmon parr.

ID	Date	Station	Sr (ppm)	Sr/Ca[1]
1	2016-08-30	1.1	1142	2.86E-03
2	2016-09-04	1.2	1330	3.33E-03
3	2016-08-29	2.1	1170	2.93E-03
4	2016-08-29	2.2	1194	2.99E-03
5	2016-09-02	2.3	1380	3.45E-03
6	2016-09-02	2.3	1246	3.12E-03
7	2016-09-02	2.3	1167.6	2.92E-03
8	2016-09-02	2.3	1162	2.91E-03
9	2016-09-02	2.3	1161	2.90E-03
10	2016-09-02	2.3	1254	3.14E-03
11	2016-09-02	2.3	1240	3.10E-03
12	2016-09-02	2.3	1294	3.24E-03
13	2016-09-02	2.3	1196	2.99E-03
14	2016-09-02	2.3	989	2.47E-03
15	2016-09-02	2.3	996	2.49E-03
16	2016-08-31	4.1	1417	3.54E-03
17	2016-08-31	4.1	1373.9	3.43E-03
18	2016-08-31	4.1	1231	3.08E-03
19	2016-08-31	4.1	1216	3.04E-03
20	2016-08-31	4.1	1384	3.46E-03
21	2016-08-31	4.1	1131	2.83E-03
22	2016-08-31	4.1	1243	3.11E-03
23	2016-08-31	4.1	1099	2.75E-03
24	2016-08-31	4.1	1048	2.62E-03
25	2016-08-31	4.1	1458	3.65E-03
26	2016-08-31	4.1	1300	3.25E-03
27	2016-08-31	4.1	1294	3.24E-03
28	2016-08-31	4.1	1206	3.02E-03
29	2016-09-01	5.1	1585.7	3.96E-03
30	2016-09-01	5.2	1215	3.04E-03
31	2016-09-01	5.2	1265	3.16E-03
32	2016-09-01	5.2	1513	3.78E-03
33	2016-09-01	5.2	1188	2.97E-03
34	2016-09-01	5.2	1159	2.90E-03
35	2016-09-01	5.2	1787	4.47E-03
36	2016-09-01	5.3	1449	3.62E-03
37	2016-09-03	6.1	1138	2.85E-03
38	2016-09-03	6.1	995.3	2.49E-03
39	2016-09-03	6.1	1154	2.89E-03

40	2016-09-03	6.1	779	1.95E-03
41	2016-09-03	7.1	1063	2.66E-03
42	2016-09-03	7.1	1079	2.70E-03
43	2016-09-03	2.3	962	2.41E-03
44	2016-08-30	2.3	1017.1	2.54E-03
45	2016-08-30	11.1	1217	3.04E-03
46	2016-08-30	11.1	1026	2.57E-03
47	2016-08-30	11.1	1642	4.11E-03
48	2016-08-30	11.1	1453	3.63E-03
49	2016-08-30	11.1	1467	3.67E-03
50	2016-08-30	11.1	1398	3.50E-03

[1] The otolith is a carbonate ($CaCO_3$), and by mass it is 40% Ca. Therefore, a concentration of 400,000 ppm is assumed for calculation of the Sr/Ca ratio.