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Gulf Region

Information on Atlantic Salmon (*Salmo salar*) from Salmon fishing area 16 (Gulf New Brunswick) of relevance to the development of a 2nd COSEWIC status report

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

In support of the Committee on the Status of Endangered Wildlife in Canada's (COSEWIC) reassessment of Atlantic Salmon (*Salmo salar*), this document updates information and analyses for Atlantic Salmon in Salmon Fishing Area (SFA) 16 since the first review in 2010. The 39 Salmon rivers in SFA 16 are included among the rivers that COSEWIC first identified in the Gaspé-Southern Gulf of St. Lawrence Designatable Unit (DU). The largest runs of Atlantic Salmon in SFA 16 return to the Miramichi River where monitoring programs have been conducted annually since the 1950s to collect biological information on the stock and to estimate the size of the population. Several indices of abundance for adult Salmon in the Miramichi River were reviewed and all showed declines over the time series of information available including the last 16-year period which is the equivalent of three generation times for this population. While population estimation has not been attempted in other smaller rivers recently, annual monitoring programs in the Tabusintac, Kouchibouguac, Kouchibouguacis, and Richibucto rivers all indicate that runs of adult Salmon persist in those rivers. The number of adult Salmon returning to SFA 16 were estimated to have peaked at just under 130 thousand fish in 1986 and declined to less than 20 thousand Salmon in 2019, the lowest value of the time series. The rates of change in abundance for adult Salmon in SFA 16 have declined by 43% for the time series and by 68% in the last 16 years (2003-2019). Juvenile Salmon abundance determined from electrofishing surveys also showed declining trends over the last 16 years in the Miramichi River and other smaller rivers of southeastern New Brunswick. Adult and juvenile Salmon from SFA 16 continue to be widely dispersed in the freshwater and marine habitats during their different life cycle phases. Threats to Atlantic Salmon are generally poorly understood and many are likely working together to limit Salmon abundance in SFA 16.

INTRODUCTION

The Atlantic Salmon populations of Canada were first assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in 2010 (COSEWIC 2010). At that time, COSEWIC identified 16 Designatable Units (DU) of which 11 were considered at risk. The Atlantic Salmon populations reproducing in 78 rivers located between the western Gaspé Peninsula in Quebec southward and eastward to the northern tip of Cape Breton, Nova Scotia were identified as the Gaspé-Southern Gulf of St. Lawrence Designatable Unit (DU 12 of 16) and assessed as “Special Concern” (COSEWIC 2010). The Gaspé-Southern Gulf of St. Lawrence DU had not been listed on Schedule 1 of the Species at Risk Act at the time this report was prepared.

There are 39 Salmon producing rivers in Salmon Fishing Area (SFA) 16 (Fisheries and Oceans Canada, DFO Gulf Region) (Figure 1). SFA 16 is divided into a northern section (SFA 16A) that is made up of 13 rivers from the Tabusintac River to the Bay Du Vin River and a southern section (SFA 16B) that contains 26 rivers from Eel River south to the border of Nova Scotia. The Miramichi River with its complex of six major rivers and numerous tributaries is the largest Salmon producing river in SFA 16 and accounts for over 53 million m^2 of fluvial area. The other 33 rivers in SFA 16 are significantly smaller and when combined account for 7.4 million m^2 of habitat area (Appendix 1).

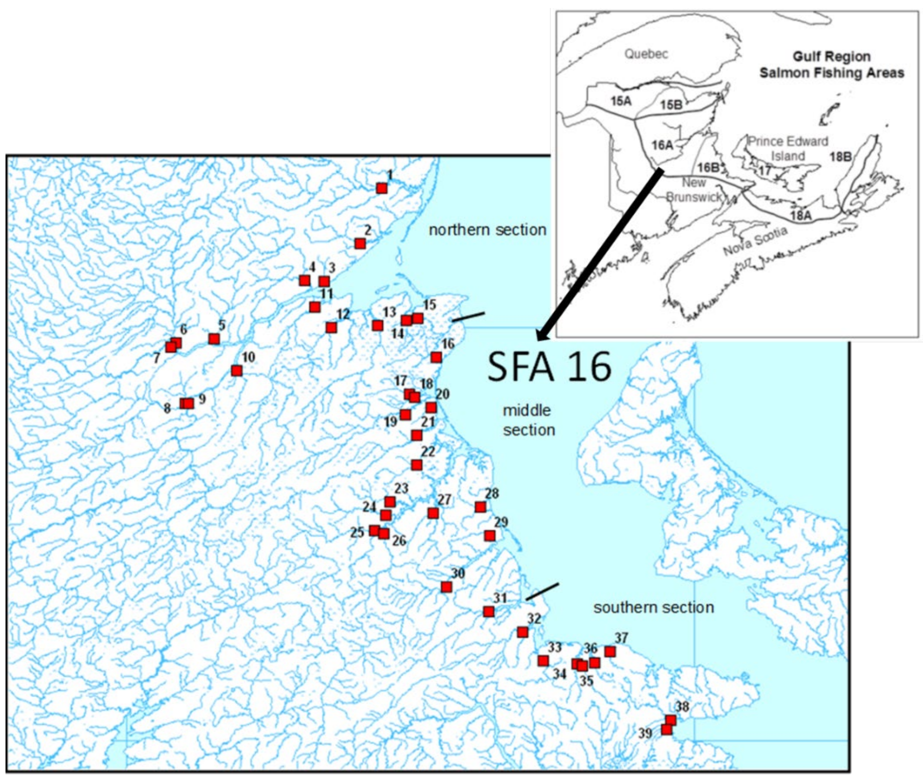


Figure 1. Salmon Fishing Areas in the DFO Gulf Region and location of rivers in SFA 16. Numbers correspond to rivers in Appendix 1. (DFO 2018a).

In support of COSEWIC’s first assessment of Canadian Atlantic Salmon populations, Chaput et al. (2010) provided information of relevance to Salmon in SFA 16. Similarly and in support of COSEWIC’s reassessment of Atlantic Salmon in 2021, the objective of this report is to provide new information collected and/or analysed by DFO since the initial assessment in 2010.

LIFE HISTORY CHARACTERISTICS

Reference is made in this section and throughout the remainder of the document to various life stages of Atlantic Salmon:

- Small Salmon: mature adult fish less than 63 cm fork length. This size group is comprised primarily of one-sea-winter maiden Salmon and a small proportion of two-sea-winter maiden Salmon and repeat spawners.
- Large Salmon: mature adult fish greater than or equal to 63 cm fork length. This size group is comprised primarily of two-sea-winter maiden Salmon but also includes three-sea-winter maiden Salmon and repeat spawners.
- One-sea-winter Salmon (1SW): mature adult Salmon that have not spawned before and have spent one full year at sea.
- Two-sea-winter Salmon (2SW): mature adult Salmon that have not spawned before and have spent two full years at sea.
- Maiden spawner: a Salmon which is on its first spawning migration.
- Repeat spawner: a Salmon which is on a second or greater spawning migration.
- Consecutive spawner: a Salmon that spawns, reconditions for a few months at sea before returning to the river to spawn in the following (consecutive) year.
- Alternate spawner: a Salmon that spawns, reconditions for more than one year at sea before returning to the river to spawn in the next (alternate) year.
- Fry: juvenile Salmon, less than one year found in fresh water.
- Parr: juvenile Salmon, older than one year and which has not migrated to the ocean.
- Smolt: juvenile Atlantic Salmon migrating to the ocean for the first time.

The longest time series of biological information on Atlantic Salmon from SFA 16 is available from the Miramichi River system. Returning adult Salmon have been systematically captured and sampled in the Miramichi River since 1971. Salmon are captured in trapnets which are fished daily over the entire migration period from the middle of May to late October. Fork length, origin (hatchery released fish are identified based on the absence of the adipose fin which was clipped from appropriate life stages prior to release), sex by external characteristics, and a scale sample is collected from up to 30 small Salmon per day and generally all large Salmon. Hayward (2001) provides an overview of all counting facilities in the Miramichi River and more details of sampling operations are in Hayward et al. (2014).

Biological characteristics of Atlantic Salmon in eastern Canada have been previously presented by Chaput et al. (2006) and O'Connell et al. (2006) and biological characteristics specific to Atlantic Salmon in the Miramichi were thoroughly reviewed by Chaput et al. (2016) and heavily relied upon for the following section.

SIZE AT AGE OF ADULT SALMON

Fork lengths of adult Atlantic Salmon increase with the number of years at sea (Figure 2). Maiden 1SW Salmon have a median fork length of about 58 cm, 2SW Salmon have a median fork length of about 75 cm, and 3SW Salmon, although rare in the Miramichi, have a median fork length of about 84 cm (Figure 2). Post spawners can return to sea to feed and grow and return to spawn in subsequent years. Salmon that spawn in consecutive years put on less length at each return migration than Salmon that spawn in alternate years. First time repeat

1SW Salmon that return in a consecutive year (1SWC) are intermediate in length between 1SW and 2SW maiden Salmon whereas first time repeat alternate 1SW spawners (1SWA) are intermediate in length between 2SW and 3SW Salmon (Figure 2). The longest Salmon recorded in the Miramichi have been 2SW repeat alternate spawners with corresponding fork lengths greater than 100 cm (Figure 2) (Chaput et al. 2016).

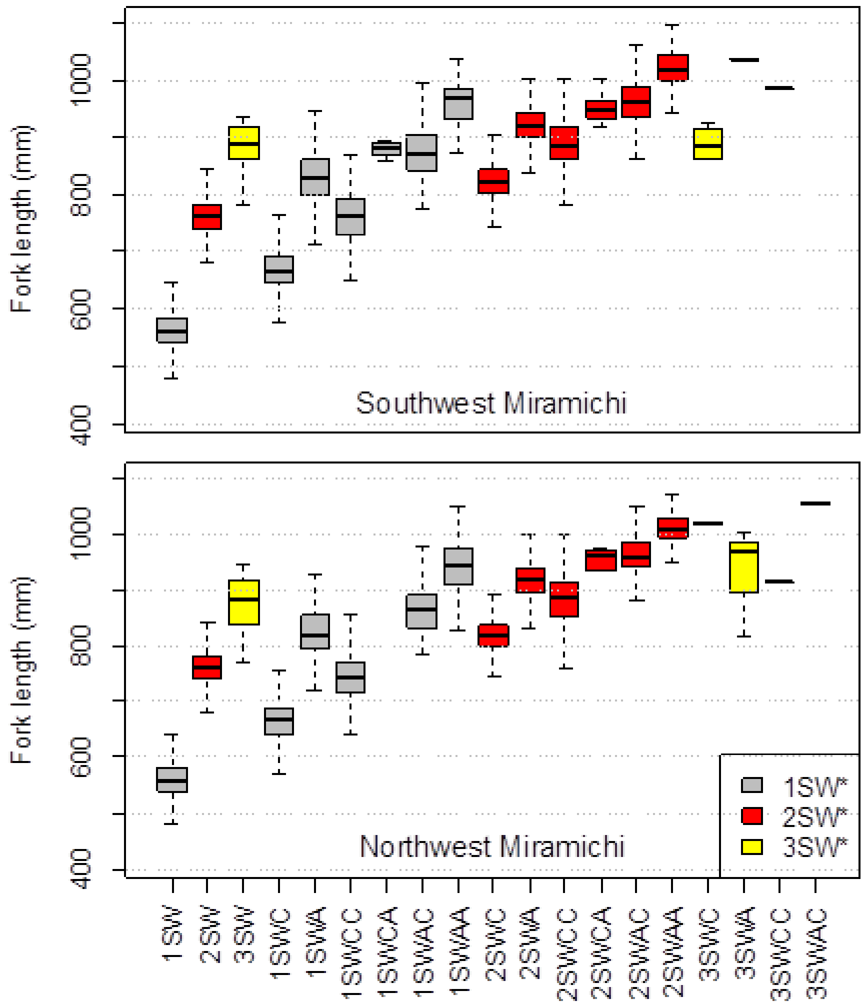


Figure 2. Boxplots of fork length (mm) distributions of wild Atlantic Salmon from the Southwest Miramichi system (top panel) and the Northwest Miramichi system (bottom panel) by spawning history type from 1992 to 2013. The 1SW, 2SW and 3SW labels are maiden first time spawners. The other categories are repeat spawners according to sea age at first spawning followed by a sequence of repeat spawner types, with C representing consecutive spawning life history and A representing alternate spawning life history. Single letters (C, A) are categories of fish on a second spawning. CC, CA, AC, and AA represent categories of fish with three or more spawning events with the first two repeat spawning histories indicated by the letter codes (Chaput et al. 2016).

An analysis of Salmon weight by sea age was possible from sacrificed samples from the index trapnet in the Miramichi prior to 1992 and from opportunistic sampling in recent years of incidental mortalities. Maiden 1SW Salmon have a median weight of 1.57 kg and 2SW maiden Salmon have a median weight of 4.50 kg. First time alternate repeat spawning 1SW Salmon have a median weight of 5.51 kg whereas first time alternate repeat spawning 2SW Salmon have a median weight of 9.00 kg (Figure 3) (Chaput et al. 2016).

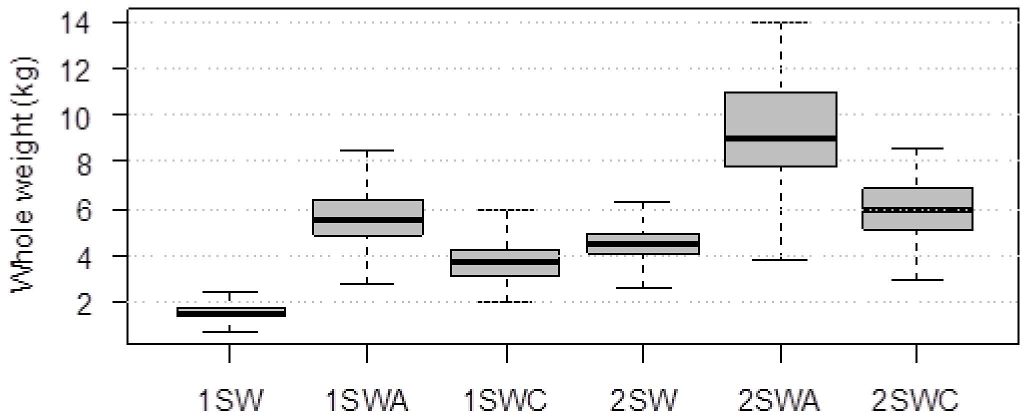


Figure 3. Whole weight (kg) of Atlantic Salmon from the Miramichi River by spawning history type. Spawning history types are limited to maiden sea ages (1SW, 2SW), first time consecutive repeat spawners (1SWC, 2SWC), and first time alternate repeat spawners (1SWA, 2SWA), over all years (1971 to 2013) and months (Chaput et al. 2016).

SEA AGE COMPOSITION

The adult Atlantic Salmon population of the Miramichi River has been characterized by an expanding spawning history structure (Chaput et al. 2016). Adult fish in the small Salmon category are comprised predominantly (> 95%) of maiden 1SW Salmon and some 2SW Salmon and repeat spawning 1SW Salmon as consecutives. The large Salmon category is comprised of a more diverse life history including 1SW maiden, 2SW maiden, 3SW maiden, and a large number of categories of repeat spawning Salmon (Table 1). Repeat spawning Salmon can be short duration migrants (consecutive) which spend a few months at sea to recondition before returning to rivers to spawn in a consecutive year, or long duration migrants (alternates) that spend more than one year at sea after spawning to recondition before returning to rivers to spawn. Since 1992 and 1995, adult Salmon on their sixth and seventh spawning migrations, respectively, have been sampled in Miramichi trapnet catches and repeat spawning Salmon have comprised 6% to 21% of the total returns of all age groups (Chaput and Jones 2006). A total of 52 unique spawning histories have been interpreted from scales of Salmon in the Miramichi and repeat spawners up to a seventh spawning migration have been sampled since the mid-1990s (Table 1). The maximum total sea age of Miramichi Salmon interpreted to date is nine years and in terms of total age (river age plus sea age plus 1 year for year of egg deposition), the oldest Salmon sampled from the Miramichi was twelve years old (Chaput et al. 2016).

Table 1. Number of samples by spawning histories of Atlantic Salmon aged from the Southwest Miramichi system and the Northwest Miramichi system, 1992 to 2013. Spawning histories are interpreted as: XSW is the maiden sea winter age at first spawning, the sequence of C (consecutive) and A (alternate) represent the at sea reconditioning history for each successive spawning event. The maximum total sea age of Salmon interpreted to date is nine years (2SWAAAC, 2SWACCCCC) (Chaput et al. 2016).

Spawning History	Southwest Miramichi	Northwest Miramichi
1SW	17,792	9,791
1SWA	631	331
1SWAA	26	16
1SWAAA	2	2
1SWAAAC	1	-
1SWAAC	6	6
1SWAACC	2	-
1SWAC	66	46
1SWACA	1	-
1SWACC	22	24
1SWACCC	11	2
1SWACCCC	1	-
1SWACCCCC	-	1
1SWC	869	393
1SWCA	10	-
1SWCAC	1	-
1SWCC	151	63
1SWCCA	1	-
1SWCCC	38	10
1SWCCCC	8	4
1SWCCCCC	3	1
1SWCCCCCC	3	-
2SW	9,043	4,479
2SWA	705	366
2SWAA	89	48
2SWAAA	8	4
2SWAAAC	1	-
2SWAAC	18	7
2SWAACC	3	-
2SWAACCC	1	-
2SWAC	314	139
2SWACA	3	-
2SWACC	121	63
2SWACCC	23	10
2SWACCCC	5	1
2SWACCCCC	1	-
2SWC	910	431
2SWCA	12	5
2SWCAC	7	1
2SWCACC	1	-
2SWCC	334	145
2SWCCA	1	1
2SWCCC	174	69
2SWCCCC	65	25
2SWCCCCA	-	1
2SWCCCCC	17	7
2SWCCCCCC	3	1
3SW	14	7
3SWA	1	2
3SWAC	-	1
3SWC	4	1
3SWCC	1	1

SMOLT PRODUCTION

Mark and recapture experiments to estimate the number of emigrating Salmon smolts have been conducted on the Northwest Miramichi River annually between 1998-2006 and again in 2011, from the Little Southwest Miramichi River between 2005 and 2011 and the Southwest Miramichi River between 2001 and 2010 (Chaput et al. 2002). The estimates of annual smolt abundance from the Northwest Miramichi and the Southwest Miramichi were highly variable and generally low relative to values expected from rivers in this area (Elson 1975; Symons 1979). Smolt abundance estimates from the Northwest Miramichi system varied from 1.0 to 4.6 smolts per 100 m² of total riverine habitat with more than half the estimates being less than 2 smolts per 100 m² (Table 2). Estimated abundances of migrating smolts from the Little Southwest Miramichi have consistently been less than 1.6 smolts per 100 m² (Table 2). Smolt production from the Southwest Miramichi system has generally been much higher than the Northwest Miramichi system, ranging from 1.0 to 6.1 smolts per 100 m², with annual estimates greater than 2.5 smolts per 100 m² since 2004 (Table 2) (Chaput et al. 2016).

MARINE RETURN RATES

Estimated return rates of Northwest Miramichi system smolts to maiden spawners (sum of 1SW and 2SW returns from a smolt class) were estimated to be as low as 0.6% to as high as 7.6% for the smolt migration years 1999 to 2006 and 2011 (Table 2). Estimated return rates for the Southwest Miramichi system were also variable, ranging from 1.7% to 11.9%, the high values for each branch being estimated from the returns of the 2001 smolt class (Table 2) (Chaput et al. 2016).

REPEAT SPAWNER RETURN RATES

The proportion of maiden Salmon in the total returns to the Miramichi has declined from over 95% prior to 1986 to about 85% since 1996 while the relative abundance of Salmon on a second spawning migration has increased from less than 5% of total returns prior to 1995 to over 10% in most years since (Figure 4). Repeat spawners have become most important in the large Salmon category as these fish grow when they return to the sea post-spawning (Figure 4).

Estimated return rates to a second spawning of both 1SW and 2SW Salmon increased between 1972 and 2010 (Chaput and Benoît 2012). Since the late 1990s, return rates to a second spawning have ranged from 8% to 25% for 1SW Salmon, and 10% to 40% for 2SW Salmon. Increased return rates to a consecutive spawning have contributed the most to the increased return rates for both the 1SW and 2SW maiden life histories (Figure 5). A higher proportion of the returns to a second spawning were of the alternate spawning history in both 1SW and 2SW Salmon prior to the 1990s but since then, the proportions of the second consecutive spawning returns have exceeded those of the alternate spawning history in both 1SW and 2SW Salmon (Figure 5). Chaput and Benoît (2012) reported on a positive association between the variations in the return rates of repeat spawners and the variations in a small fish biomass index from the southern Gulf of St. Lawrence, an area which could be used by kelts early in the reconditioning year at sea, which provides evidence that abundant food supplies at sea may be beneficial for the survival of Atlantic Salmon to a second consecutive spawning. This contrasted with the absence of an association between prey availability and return rates of alternate repeat spawners, suggesting that return rates of the alternate strategy are conditioned by high seas factors.

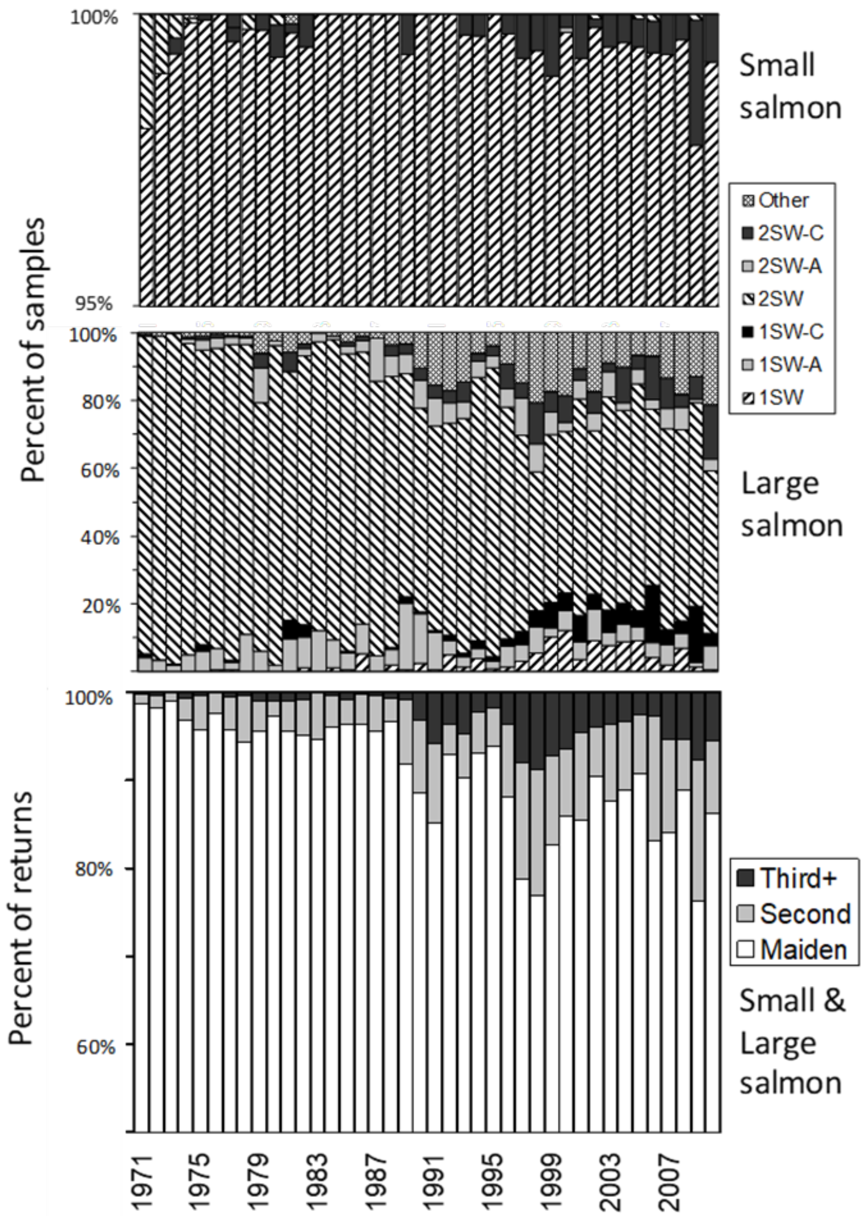


Figure 4. Percentage as maiden (1SW, 2SW), second time spawners (1SW-C, 1SW-A, 2SW-C, 2SW-A) and other spawning histories from small Salmon (upper panel) and large Salmon (middle panel) interpreted scale samples and percentage of estimated returns (size groups combined) which were maiden, second time spawners, and third plus time spawners (lower panel) in the Miramichi River, 1971 to 2010.

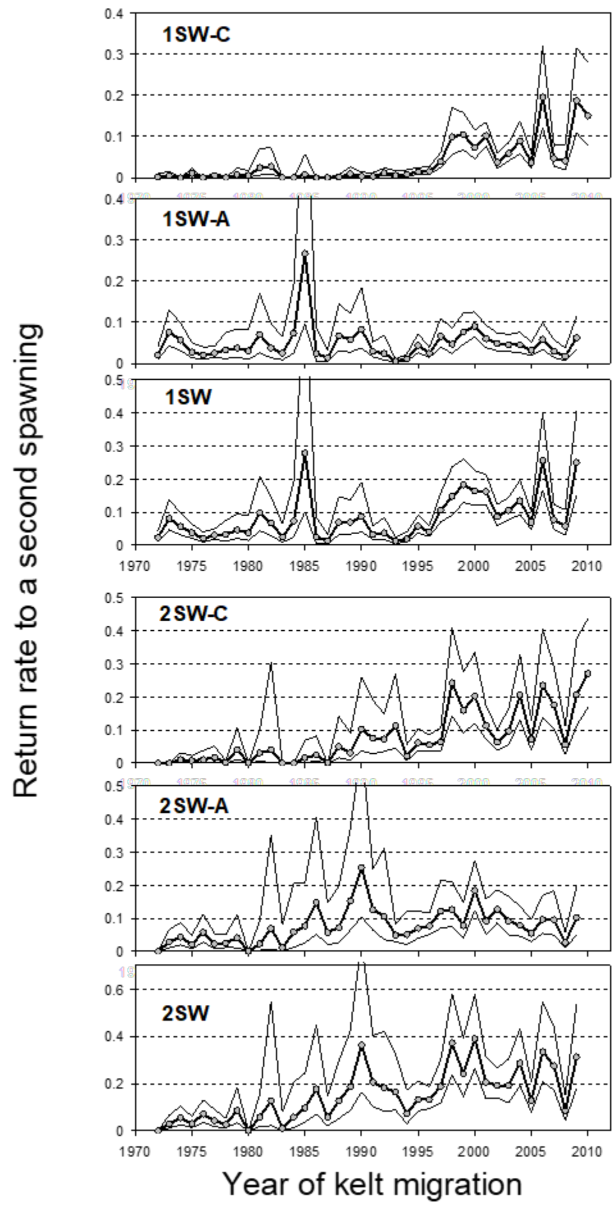


Figure 5. Return rates (median shown in black line with grey circles; 2.5 to 97.5 percentile range shown in grey lines) to a second spawning as consecutives (1SW-C; 2SW-C), as alternates (1SW-A; 2SW-A) and combined (1SW; 2SW) by year of kelt migration (from Chaput and Benoit 2012). Kelt refers to the post-overwinter condition of Salmon as they return to sea in the spring.

Table 2. Summary of smolt migration characteristics from monitoring programs in the Northwest Miramichi system, the Little Southwest Miramichi River, and the Southwest Miramichi system, 1998 to 2011. Values in grey shading are uncertain and considered to be underestimates (Chaput et al. 2016).

		Run size estimate			Smolts per 100 m²		Size (mean)		Prop. female	Prop. at freshwater age			Run timing		Return rates at maiden age		
River	Smolt year	Median	95% confidence interval		Median	95% C.I.	mm	g		2	3	4	Peak	5th perc.	1SW	2SW	Combined
Northwest	1998	-	-	-	-	-	129	21.8	0.49	0.28	0.71	0.01	16-May	15-May	-	-	-
Miramichi	1999	390,500	315,500	506,000	2.3	1.9 - 3.0	132	22.4	0.63	0.36	0.62	0.02	19-May	15-May	3.1%	1.3%	4.3%
	2000	162,000	118,000	256,000	1.0	0.7 - 1.5	131	21.2	0.58	0.34	0.63	0.03	02-Jun	18-May	5.2%	0.5%	5.7%
	2001	220,000	169,000	310,000	1.3	1.0 - 1.8	130	21.1	0.53	0.38	0.60	0.01	29-May	21-May	6.8%	0.8%	7.6%
	2002	241,000	198,000	306,000	1.4	1.2 - 1.8	128	20.7	0.57	0.52	0.48	0.00	02-Jun	24-May	2.5%	0.8%	3.3%
	2003	286,000	224,500	388,000	1.7	1.3 - 2.3	128	21.2	0.53	0.50	0.49	0.01	28-May	24-May	4.2%	1.0%	5.1%
	2004	368,000	290,000	496,000	2.2	1.7 - 3.0	131	22.1	0.57	0.41	0.58	0.01	19-May	16-May	2.6%	0.5%	3.1%
	2005	*151,200*	*86,000*	*216,000*	0.9	-	130	21.4	0.52	0.40	0.60	0.01	08-Jun	19-May	-	-	-
	2006	*435,000*	*255,000*	*1,230,000*	2.6	-	130	23.3	0.56	0.44	0.56	0.01	16-May	13-May	-	-	-
	2011	768,000	576,000	1,137,000	4.6	3.4 - 6.8	133	18.1	0.42	0.61	0.38	0.00	21-May	21-May	0.3%	0.2%	0.6%
Little	2005	*46,330*	*32,710*	*68,050*	-	-	130	-	0.58	0.22	0.76	0.02	14-May	13-May	-	-	-
Southwest	2006	87,520	41,760	665,300	1.0	0.5 - 7.6	130	-	0.51	0.51	0.49	0.00	18-May	10-May	-	-	-
Miramichi	2007	138,200	106,000	185,500	1.6	1.2 - 2.1	125	-	0.57	0.34	0.66	0.00	22-May	12-May	-	-	-
	2008	124,100	96,320	164,900	1.4	1.1 - 1.9	130	21.6	0.50	0.38	0.61	0.01	21-May	16-May	-	-	-
	2009	85,000	66,000	112,000	1.0	0.8 - 1.3	129	-	0.52	0.38	0.62	0.00	18-May	13-May	-	-	-
	2010	46,500	28,500	82,500	0.5	0.3 - 0.9	140	-	-	0.35	0.64	0.01	12-May	07-May	-	-	-
	2011	67,900	49,900	104,500	0.7	-	131	22.8	0.47	0.44	0.56	0.00	26-May	21-May	-	-	-
Southwest	2001	306,300	290,000	464,000	1.0	0.8 - 1.3	127	19.2	0.47	0.64	0.35	0.00	31-May	22-May	8.6%	3.3%	11.9%
Miramichi	2002	711,400	498,000	798,000	1.7	1.4 - 2.3	126	18.8	0.54	0.55	0.44	0.01	01-Jun	19-May	3.1%	1.4%	4.5%
	2003	485,000	393,000	615,000	1.3	1.1 - 1.7	128	19.6	0.58	0.59	0.41	0.00	22-May	22-May	6.8%	2.0%	8.8%
	2004	1,167,000	969,000	1,470,000	3.2	2.6 - 3.5	130	21.1	0.54	0.60	0.40	0.00	17-May	16-May	1.8%	0.8%	2.5%
	2006	1,332,000	983,000	1,809,000	3.8	2.8 - 5.1	131	23.1	0.55	0.54	0.46	0.00	17-May	09-May	1.5%	0.5%	2.0%
	2007	1,344,000	1,120,000	1,668,000	3.8	3.2 - 4.7	132	20.7	0.49	0.59	0.41	0.00	27-May	21-May	1.6%	0.8%	2.4%
	2008	901,500	698,000	1,262,000	2.5	2.0 - 3.6	126	19.7	0.60	0.67	0.33	0.00	28-May	22-May	1.0%	0.7%	1.7%
	2009	1,035,000	807,000	1,441,000	2.9	2.3 - 4.1	128	22.1	0.53	0.69	0.31	0.00	18-May	15-May	3.3%	2.2%	5.5%
	2010	2,165,000	1,745,000	2,725,000	6.1	4.9 - 7.7	137	23.9	0.51	0.57	0.43	0.00	21-May	07-May	1.5%	0.4%	1.8%

FECUNDITY

Separate fecundity at length relationships for large and small Miramichi Salmon were first published by Randall (1989) and have been combined with the average fork length and proportion female in the runs of each size group to estimate the number of eggs per fish for annual stock assessments (Figure 6; Douglas et al. 2015; DFO 2020a). More recently, Reid and Chaput (2012) also analyzed fecundity data for Miramichi Salmon and found that small Salmon had a lower number of eggs and that the slopes of the fecundity at length relationship for large Salmon were different than those derived by Randall (1989).

Reid and Chaput (2012) found that the number of Salmon eggs increased with both length and weight of female Salmon. Female 1SW maiden Salmon of median fork length 58 cm, had a predicted fecundity of about 2,900 eggs. Maiden 2SW Salmon of median fork length 75 cm had a predicted fecundity of 5,900 eggs and 3SW Salmon of median fork length 84 cm had a predicted fecundity of 8,000 eggs. The maximum measured fecundity was 15,500 eggs from a female Salmon measuring 104 cm fork length (Figure 7). Egg size (diameter, mm) was smallest for 1SW maiden Salmon and largest for 2SW maiden and alternate repeat spawning Salmon (Reid and Chaput 2012).

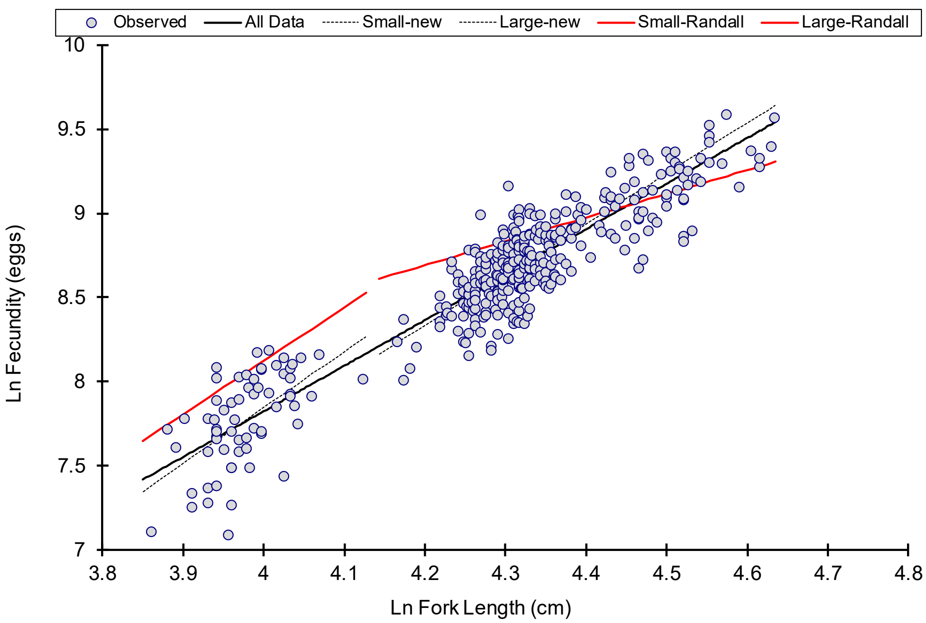


Figure 6. Length (cm) to fecundity relationships for Atlantic Salmon from the Miramichi River. The data are from egg estimations in the hatchery collected during 1991 to 1995 (J. Hayward, DFO, unpublished data). The eggs per fish were estimated by volume displacement. The red lines are the relationships from Randall (1989) based on immature eggs from Salmon sampled on entry to the river. The Randall (1989) relationships by size group are the ones used to estimate eggs in estimated returns and spawners to the Miramichi River. The parameters of the natural log of the regression of fecundity on length are: slope = 2.7075, intercept = -3.0065 (Chaput et al. 2016).

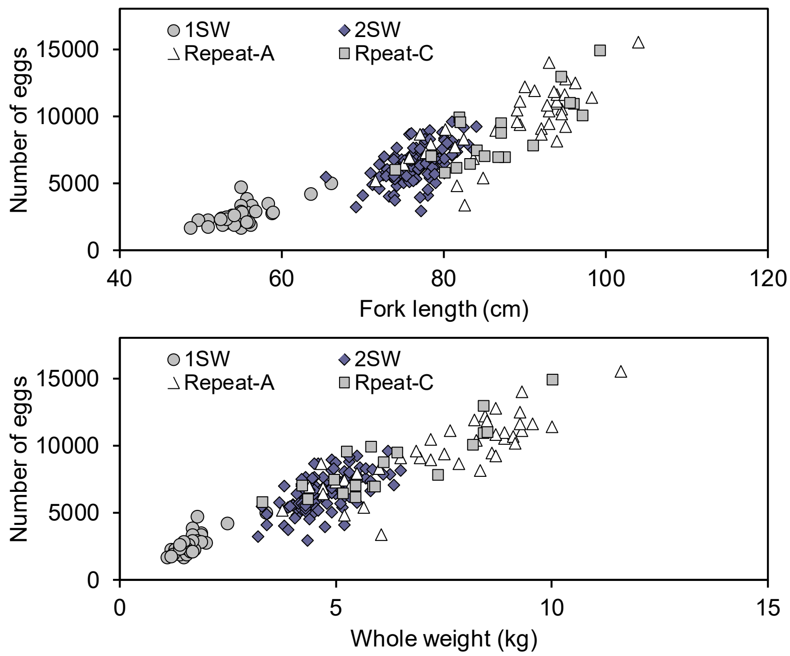


Figure 7. Fecundity (number of eggs) at fork length (cm) (top panel), and at whole weight (kg) (bottom panel) for Atlantic Salmon from the Miramichi River. Data and analyses are from Reid and Chaput (2012). The parameters of the natural log of the regression of fecundity on length are very similar to those from J. Hayward (DFO, unpublished data) (slope = 2.7005, intercept = -2.9768) (Chaput et al. 2016).

Biological characteristics of adult Atlantic Salmon, including mean fork length, proportion female, and eggs per fish for small Salmon and large Salmon to 2018, are summarized in Figure 8. Fork length of small Salmon and large Salmon increased noticeably from mean lengths prior to 1986 and reached the longest mean sizes in the mid to late 1990s (Figure 8). Although mean fork lengths of small Salmon declined from the largest mean sizes in the late 1990s, the mean lengths remain above the lower sizes recorded in the 1970s. Large Salmon do not show a decline in mean size during the 2000s (Figure 8). There is no obvious temporal trend in proportion female, however, small Salmon in the Northwest Miramichi have a higher proportion female than small Salmon in the Southwest Miramichi (Figure 8). The mean eggs per small Salmon and large Salmon are a function of the mean size and the proportion female in the runs. Mean eggs per fish by size group are highly variable over time; the mean eggs per small Salmon are higher in the Northwest Miramichi compared to the Southwest Miramichi (Figure 8).

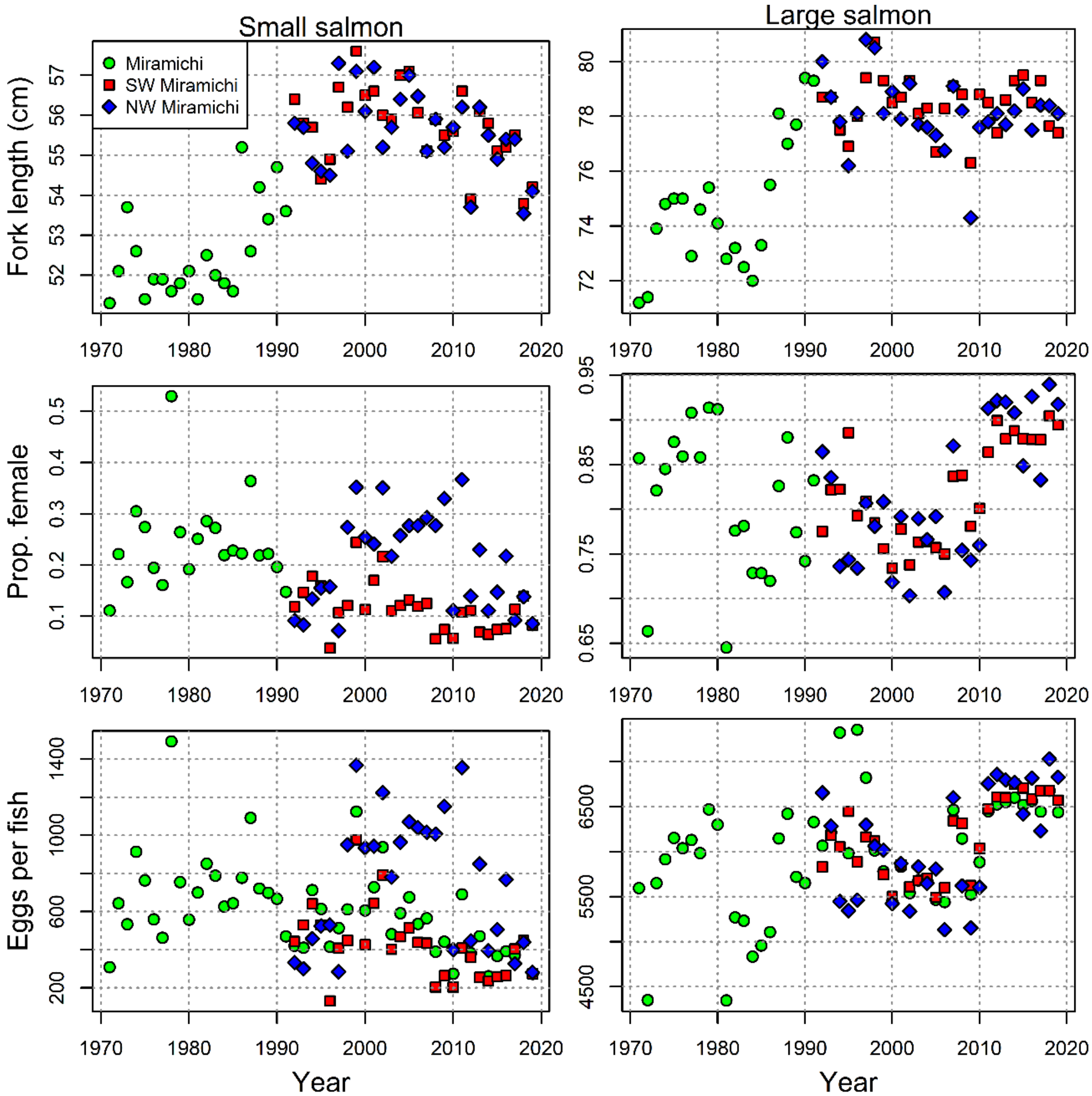


Figure 8. Biological characteristics of Atlantic Salmon by size group (small Salmon left panels; large Salmon right panels) including mean length (cm, upper panels), proportion female (middle panels), and eggs per fish (lower panels) from the Miramichi River overall (1971 to 1991) and the Southwest (SW) and Northwest (NW) Miramichi rivers, 1992 to 2019.

GENERATION TIME (MEAN AGE OF PARENTS)

Scale samples have been collected annually from adult Salmon captured in Miramichi index trapnets operated daily throughout the Salmon migration. The calculation of generation time was based on ages interpreted from scales collected between 1998 and 2013 from both the Southwest and Northwest Miramichi rivers. The mean river age and mean sea age was calculated over all samples of small Salmon and large Salmon by year. The weighted mean river age and mean sea age of all Salmon was calculated with weights based on the estimated returns of small Salmon and large Salmon to each branch annually (Table 3). The mean age of parents was calculated by adding the mean river and sea ages plus an additional year to account for the egg deposition year. Total years for three generations is calculated as three times the mean age of parents and rounded up to the nearest integer. For Atlantic Salmon from the Northwest and Southwest Miramichi, the mean age of parents is approximately 5.1 years, thus three generations is equivalent to 16 years.

Table 3. Mean river age, mean sea age, and mean age overall for Salmon from the Northwest Miramichi and the Southwest Miramichi, 1998 to 2013. The mean age of parents is calculated as mean river age plus mean sea age plus one for the egg deposition year.

	Northwest Miramichi			Southwest Miramichi		
Year	Mean river age	Mean sea age	Mean age of parents*	Mean river age	Mean sea age	Mean age of parents*
1998	2.59	1.73	5.32	2.49	1.86	5.35
1999	2.61	1.59	5.20	2.58	1.74	5.32
2000	2.53	1.49	5.01	2.49	1.57	5.06
2001	2.55	1.71	5.25	2.53	1.62	5.15
2002	2.64	1.26	4.90	2.62	1.46	5.08
2003	2.54	1.54	5.08	2.50	1.58	5.08
2004	2.58	1.34	4.93	2.51	1.49	5.00
2005	2.65	1.48	5.13	2.68	1.51	5.19
2006	2.57	1.53	5.10	2.61	1.52	5.13
2007	2.61	1.69	5.30	2.58	1.63	5.21
2008	2.52	1.43	4.95	2.44	1.47	4.92
2009	2.52	1.68	5.20	2.41	1.91	5.32
2010	2.50	1.37	4.86	2.49	1.47	4.96
2011	2.51	1.40	4.91	2.51	1.46	4.97
2012	2.44	1.64	5.08	2.44	1.80	5.24
2013	2.42	1.69	5.11	2.42	1.79	5.21
Mean over years	**2.55**	**1.54**	**5.08**	**2.52**	**1.62**	**5.14**

Based on the age interpretation of 743 scale samples collected from Atlantic Salmon in the Buctouche River between 1992 and 2000, the mean river age (ages 2 to 3) was estimated to be 2.41 years and the mean sea age (ages 1 to 6 years, maiden and repeat spawners) was estimated at 1.82 years (Atkinson 2001). Accounting for the year of egg deposition gives a mean age of parents of 5.23 years and an approximate three generation time of 16 years, similar to the Miramichi.

EARLY LIFE HISTORY CHARACTERISTICS

Eggs from Atlantic Salmon in SFA 16 are spawned in October and November and hatch the following spring in March-May. Growth rates of Salmon juveniles are highly variable among freshwater sites and years. Average size of age-0 parr (fry) is annually variable with mean fork lengths ranging between 4.0 and 5.5 cm (Swansburg et al. 2002). Age-1 parr also showed important variations in mean size between sites and among years, ranging between 7.5 cm to just over 9.0 cm in the Northwest Miramichi. Age-2+ parr, those juveniles not leaving the river as 2-year old smolts, ranged in mean size between 10.5 and 12.4 cm fork length (Chaput et al. 2016). Precocious male maturation is common in juveniles in the Miramichi system (Cunjak and Therrien 1998; Brodeur 2006).

Juvenile Salmon from the Miramichi River spend between two and five years in freshwater before going to sea. For the Northwest Miramichi system, based on sampling and run size estimates for the smolt migration years 1999 to 2006, the percentage of a yearclass going to sea after two years in freshwater varied from 29% to 61% whereas river age 4 smolts were never more than 2% of a yearclass (Table 2) (Chaput et al. 2016).

Based on characteristics of returning adult Atlantic Salmon and weighted by estimates of returns, the majority (> 95%) of a Salmon yearclass from the Northwest Miramichi spent 2 or 3 years in rivers with on average 47% of all maiden-aged returning Salmon having a river age of 2 years. A similar percentage (average 47%: range 11% to 85%) of the 1SW maiden Salmon were of river age 2. For the 2SW maiden Salmon, a slightly higher percentage was of river age 2 (average 53%; range 24% to 82%). There is a large amount of variation in the percentages of river ages in adult returns from a yearclass. This is due to the annual variations in sea survival to which a yearclass is exposed. In the case of the Northwest Miramichi, a yearclass of Salmon is at sea over four consecutive years of maiden returns (Chaput et al. 2016).

Atlantic Salmon smolts migrate from the Northwest Miramichi primarily from mid-May to early June. Date of peak catches at the estuary trapnet ranged from 16 May to 8 June over sampling years 1999 to 2011 (Table 2). The date of the 5th percentile of catches which is used as an indicator of the initiation of the smolt migration, ranged from 13 May to 24 May for the same years sampled (Table 2). Peak catches occurred in most years when water temperatures attained / exceeded 15 ºC. Run duration is generally short, occurring over a period of about three weeks.

Smolts from the Northwest Miramichi are of relatively consistent size distribution annually, ranging between 10.5 to 18.0 cm with a mean fork length of 13 cm (Table 2). Mean weight of smolts ranged between 18 and 22 g annually (Table 2). There are usually more females than males in the smolt run, the percentage female ranging between 42% and 63% with greater than 50% female in most years (Table 2).

OVERVIEW OF DESIGNATABLE UNITS

Salmon Fishing Area 16 is situated in the south and central portion of the Gulf of St. Lawrence coast of New Brunswick (Figure 1).

Life history characteristics for Salmon populations in SFA 16 are generally similar to those from other rivers in the southern Gulf area:

- relatively young ages at smoltification with predominance of smolts aged 2 and 3 years old;
- important annual returns of one-sea-winter Salmon and multi-sea-winter Salmon;
- sex ratio biased to males in small Salmon (< 63 cm fork length) and to females in large Salmon (>= 63 cm fork length); and
- predominantly fall returning Salmon with the exception of important early and late runs in the larger rivers of the southern Gulf region which include the Nepisiquit, Miramichi, and Margaree rivers. Within SFA 16, early runs of Salmon are noted in only the Miramichi River.

To support the identification of Designatable Units for Atlantic Salmon in eastern Canada, Lehnert et al. 2023, provided a genetic analysis using microsatellite markers and single nucleotide polymorphisms (SNPs) from samples of Salmon collected across their distribution in eastern Canada. The sampled Salmon populations of SFA 16 (Tabusintac, Miramichi, Kouchibouguac, Kouchibouguacis, Richibucto, Cocagne) were part of a discrete genetic group that also included sampled populations from some rivers in SFA 15 (excluding the Restigouche River), and SFAs 17-19, provisionally named the southern Gulf (Bradbury et al. 2016a, 2020; Jeffery et al. 2018; Lehnert et al. 2023).

An unpublished study by Dodson and Colombani (1997; The genetic identity of the Clearwater Brook population of Atlantic salmon (*Salmo salar*); a temporal and spatial study of Atlantic salmon population genetic structure in the Miramichi, St. John, and Margaree rivers, Atlantic Salmon Federation, Final Report) concluded that the timing of the spawning run was not genetically discrete.

From spatially intensive sampling of juveniles within the Miramichi River in 2016 and analyses of tissue samples using a 220K SNP panel, Wellband et al. (2019) were unable to identify hierarchical (spatial) structuring of Salmon within the Miramichi River using neutral genetic markers. The authors did however report on the isolation of juveniles in upper watersheds from those in the lower river and a primary role of adaptive processes in structuring populations in the Miramichi River. Specifically, Wellband et al. (2019) identified a chromosomal rearrangement characterized by a fusion between chromosomes 8 and 29 with among-population variation in the frequency of the fusion and co-varying with differences in summer precipitation and elevation within the river. Additionally, the authors reported on the association between the temperature/elevation variables and changes in allele frequency for 198 SNPs (Wellband et al. 2019).

STOCK SUPPLEMENTATION ACTIVITIES

The Miramichi River has been stocked with Salmon of various juvenile stages since the operation of a salmonid hatchery began in 1873; the Miramichi hatchery is the longest continuously operating fish culture facility in eastern Canada. Chaput et al. (2010) reported that between 1959 and 1970, experimental plantings of Restigouche origin stock (SFA 15) were distributed to the Tabusintac, Southwest Miramichi, Northwest Miramichi, and Little Southwest Miramichi rivers, as well as Rocky Brook (upper tributary of the Southwest Miramichi River). Within the past 30 years, Miramichi origin stock were distributed in the Tabusintac and Buctouche rivers of SFA 16 (Chaput et al. 2010). Otherwise, all recent enhancement activities have involved placing juvenile progeny back to tributaries from which the parents were collected, in the Miramichi, Kouchibouguacis, and Richibucto rivers (Chaput et al. 2010). The southern rivers of SFA 16 from Shediac to the Nova Scotia border have not received hatchery supplementation.

The extent of supplementation activities in the Miramichi has varied over time. Since the late 1990s when the Miramichi hatchery was divested to a non-government organization (NGO), the supplementation activities have been at a scale of less than 200 adult broodstock collected annually, with juvenile stocking in the Miramichi watershed at early stages of several hundred thousand fish per year (Chaput et al. 2010; Table 4). An example of detailed broodstock collections and juvenile distributions for the year 2000 is provided in Chaput et al. (2001) where 233,000 Salmon juveniles were distributed in 2000 and 188 adult broodstock were collected from the wild for subsequent stocking activities in 2001. Supplementation activities in recent years in the Miramichi River have occurred at similar or reduced levels (Table 4). In the years when juveniles were externally marked by ablation of the adipose fin prior to release, the proportions of the returning adults that were identified as hatchery origin were generally very low, at less than a few percent, however the proportions of the returns comprised of hatchery origin Salmon were higher in areas with more intensive tributary specific broodstock collections and juvenile distributions (Chaput et al. 2001).

Table 4. Atlantic Salmon stocked in the Miramichi watershed as first feeding fry between 2008 and 2020. First feeding fry were stocked directly to rivers in June/July or reared in satellite tanks for the summer period and released in the fall of the year.

Year	Northwest Miramichi and Sevogle	Little Southwest Miramichi	Southwest Miramichi	Renous and Dungarvon
2008	29,884	28,469	155,588	14,277
2009	1,819	1,103	57,963	-
2010	18,114	27,110	94,052	-
2011	87,375	60,401	112,745	-
2012	149,250	77,000	146,085	-
2013	92,480	46,803	140,207	-
2014	121,804	4,882	225,305	-
2015	102,671	10,508	137,494	-
2016	7,301	-	81,400	-
2017	48,441	-	141,600	-
2018	12,000	22,685	145,500	-
2019	24,000	-	33,473[a]	-
2020	-	-	33,068	-

[a] Progeny of Southwest Miramichi River females crossed with Cains River males

Stocking activities undertaken since 2008, other than in the Miramichi, occurred in the Kouchibouguacis and Richibucto rivers. Broodstock collected annually from these rivers were on the order of two to three pairs of adult Salmon per river and subsequent juvenile releases respected the origin of the stock and no cross tributary / river stocking has occurred. Egg incubation boxes have been preferentially used in the Kouchibouguacis River supplementation program.

Overall, the returns of Atlantic Salmon to rivers in SFA 16 are almost entirely from natural production. Based on available information, 99% or more of returning adults to the Miramichi River come from wild production (Chaput et al. 2001).

The hatchery activities of the recent decade are not considered to have been of sufficient scale to affect the characterization of genetic discreteness of the rivers in SFA 16 with other DUs in eastern Canada.

NEW PROPOSED STOCKING INITIATIVES

In response to the low returns of Salmon to the Miramichi River in 2014, particularly to the Northwest Miramichi River, non-governmental organizations in New Brunswick proposed a stock supplementation program which consisted of the capture of wild Atlantic Salmon smolts, rearing them in captivity, and subsequently releasing the captive-reared adults back to the river to spawn. This supplementation activity was intended to circumvent the low marine return rates of Atlantic Salmon to the Miramichi River. The proposed intervention was an important change in the supplementation programs and activities for the Miramichi River and for Gulf Region overall, which to date, have used returning adult Salmon as broodstock, spawned them in the hatchery, and stocked juveniles of various stages into freshwater. The proposed supplementation activity was the subject of two science peer reviews; the first examined the risk and benefits to population fitness of wild Atlantic Salmon from releases of captive-reared adults

(DFO 2016b), and the second, focused on advice relative to the Collaboration for Atlantic Salmon Tomorrow's (CAST) Smolt-to-Adult Supplementation (SAS) Experiment Proposal: Phase 1 (2018-2022) and mitigation measures to minimize any risks and enhance any benefits (DFO 2018b).

The NGO received permits and collected wild smolts during the springs of 2015 to 2018 from the Big Sevogle, Northwest Miramichi, and Little Southwest Miramichi rivers (Table 5). The smolts have been held and reared at the Miramichi Salmon Conservation Centre. To date, only a small number of captive-reared adults have been permitted to be released in a small upstream section of the Northwest Millstream (tidal tributary of the Northwest Miramichi system) in support of an experiment to evaluate reproduction success and juvenile survival and growth (Table 5). In 2019, some unfed fry, progeny of captive-reared adult Salmon from directed experimental crosses that were spawned and incubated in the hatchery, were released into the Little Southwest Miramichi (n = 238,000) and the Northwest Miramichi (n = 255,000) rivers. This release resulted from a misinterpretation of the Introductions and Transfers Permit which allowed the release of unfed fry from the spawning of wild broodstock in the regular Miramichi River stocking program. In 2020, approximately 30,000 fry produced from captive-reared adult Salmon were released into the Northwest Millstream for further experimentation.

In 2019, the NGO operating the Miramichi Salmon Conservation Centre applied and was authorized to collect wild smolts from two locations in the Southwest Miramichi (Table 5) for the purposes of rearing broodstock in the hatchery, spawning them, and stocking unfed fry at the locations where the smolts were originally captured. This stocking strategy was proposed as an alternative to collecting wild anadromous adult broodstock for the purpose of producing and stocking unfed fry. No releases of adults or progeny from this program has occurred to date.

Table 5. Atlantic Salmon collected and released from the Miramichi watershed for the Smolt-to-Adult Supplementation (SAS) program between 2015 and 2020. SEV = Big Sevogle River, NW = Northwest Miramichi River, LSW = Little Southwest Miramichi River, SW = Southwest Miramichi River, and DUNG = Dungarvon River.

Collected				Released			
Year	**Life stage**	**N**	**Location**	**Year**	**Life stage**	**N**	**Location**
2015	Smolt	191	SEV	2017	SAS Adult	40[a]	NW Millstream
2015	Smolt	227	NW	2019	SAS 0+	255,000	NW
2015	Smolt	1,192	LSW	2019	SAS 0+	238,000	LSW
2016	Smolt	3,132	NW	2018	SAS Adult	40[a]	NW Millstream
2016	Smolt	2,550	LSW	2020	SAS 0+	15,000[b]	NW Millstream
2017	Smolt	2,500	NW	2019	SAS Adult	40[a]	NW Millstream
2017	Smolt	2,500	LSW	2020	SAS Adult	40[a]	NW Millstream
-	-	-	-	2020	SAS 0+	15,000[b]	NW Millstream
2018	Smolt	4,927	LSW	2020	SAS Adult	40	NW Millstream
2020[c]	Smolt	482	SW	-	-	-	-
2020[c]	Smolt	368	DUNG	-	-	-	-

[a] origins from all rivers in smolt collection year
[b] contribution from NW smolts collected in 2016 and 2017 unknown but total = 30K
[c] not for SAS program

POPULATION INDICATORS AND TRENDS

ABUNDANCE INDICES OF ADULT SALMON IN SFA 16

Headwater protection barriers in the Miramichi

Salmonids have been counted through a barrier fence into three headwater refuges of the Miramichi system since the 1980s. The protection barriers have largely been operated by the province of New Brunswick (Natural Resources and Energy Development) but with the assistance of non-governmental organizations and the private sector in some years (Hayward et al. 2014). The barrier on the Dungarvon River (tributary of the Renous River which is a tributary of the Southwest Miramichi River) has operated annually since 1984, the Northwest Miramichi River barrier since 1988, and the barrier on the North Branch of the Southwest Miramichi River at Juniper between 1984 and 2013. A counting fence on Catamaran Brook (tributary of the Little Southwest Miramichi River) was operated annually between 1990 and 2000 (Hardie et al. 1998) (Figure A1).

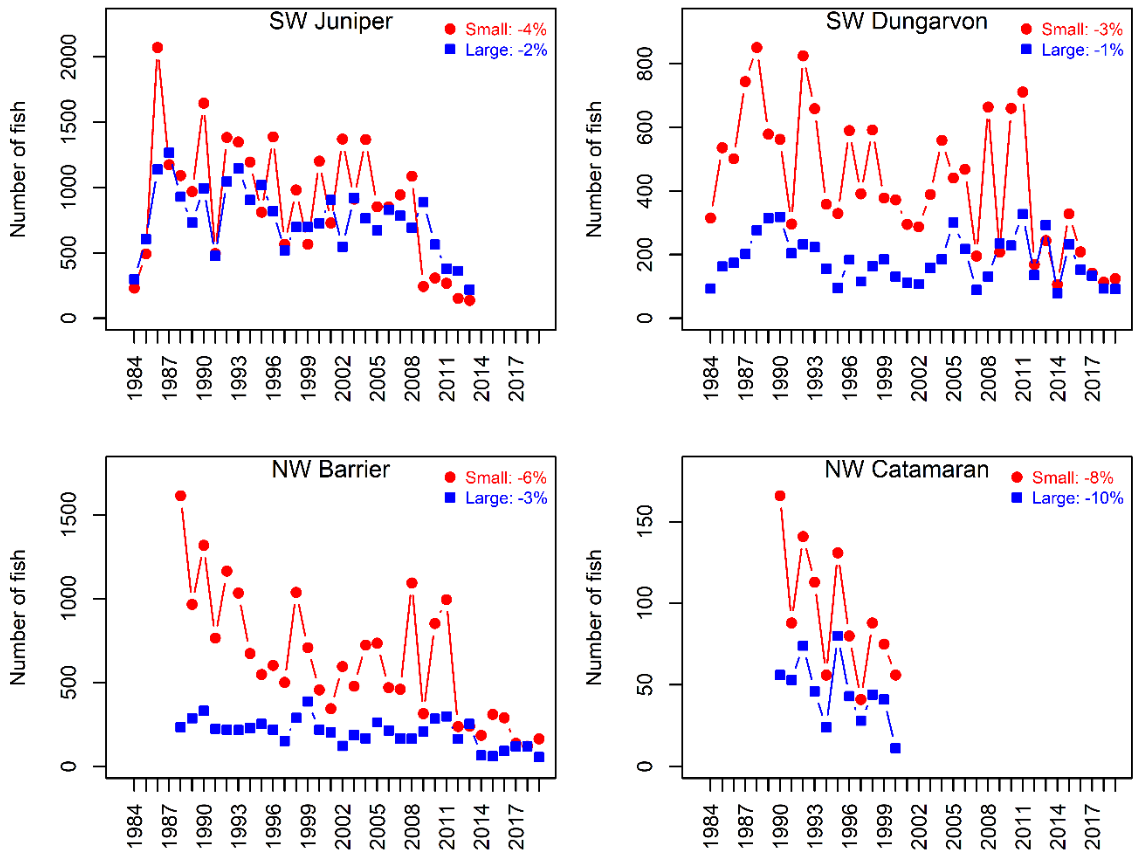


Figure 9. Indices of abundance (counts) of small Salmon and large Salmon at headwater monitoring facilities in the Miramichi River, 1984 to 2019. The annual percent change (exponential trend) over the available time series is shown in the upper right corner of each panel.

The annual catches of small and large Salmon at the headwater protection barriers or counting fence have not been adjusted for periods when the counting facilities were not operating due to maintenance, high water conditions, or suspension of activities due to high water temperatures. Counts of large and small Salmon have been annually variable at each facility and generally show a decreasing trend over the available time series at each location for both size groups (Figure 9). Although the time series is different for each facility, the annual percent change for small Salmon has declined between 3% and 8% and between 1% and 10% for large Salmon (Figure 9).

Recreational angling in the Miramichi River System

Historical angling catch data are available from two sources: FISHSYS from the New Brunswick Natural Resources and Energy Development (NRED), and from the Government of Canada Department of Fisheries and Oceans (DFO). These data are summarized in Moore et al. (1995). The FISHSYS data are based on a post-season mailout survey to a portion of the license holders of the year. Catch estimates compliled by DFO were generally lower than those compiled by NRED and were not collected after 1994. The FISHSYS survey was last conducted in 1997 and there are no angling statistics for the Miramichi River overall since 1998. Catches of both large and small Salmon showed declining trends in the Southwest and Northwest Miramichi rivers over the time series (Figure 10).

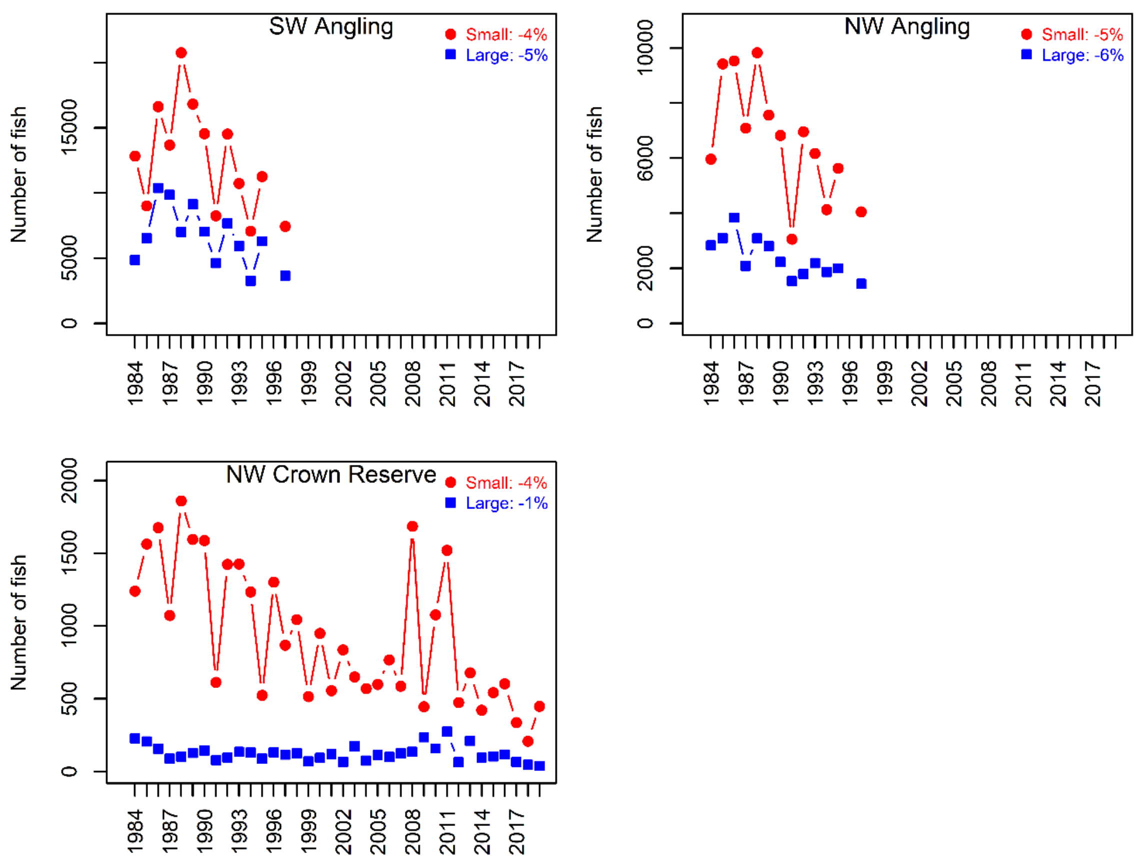


Figure 10. Indices of abundance (catches) of small Salmon and large Salmon estimated in the recreational fishery of the Southwest and Northwest Miramichi rivers (1984-1998) and the reported catches of small Salmon and large Salmon in the regular crown reserve recreational fishery of the Northwest Miramichi River (1984-2019). The annual percent change (exponential trend) over the available time series is shown the upper right hand corner of each panel.

Crown reserve stretches of the Northwest Miramichi River have been available by draw to anglers since 1973. There are 11 crown reserve stretches on the Northwest Miramichi system; five on the Northwest Miramichi River proper, two on the Little Southwest Miramichi River, and four on the Big Sevogle River. Crown reserve stretches are available from early June to mid-September and angling parties of two or four have exclusive use of the stretch for 48 hours over a three-day period (begin at 2 pm on day 1 and end at 2 pm on day 3). Anglers are required to provide catch and effort information at the end of their trip (MacEachern and Sullivan 2019).

Catch and effort from all crown reserve stretches were combined for summary purposes and no adjustments have been made for angling conditions or angler experience. The number of large Salmon caught per year (range 38 - 274) has been relatively stable over time but recorded the lowest catch of the time series in 2019 (Figure 10). The number of small Salmon caught per year has been highly variable (range 208 - 1,953) but generally declining over the time series (Figure 10).

Index trapnets in the Miramichi

The use of index trapnets to monitor the returns of Atlantic Salmon and many other species to the Miramichi River began in 1952 and has continued annually since 1954 (Chaput 1995; Claytor 1996). Trapnets are installed in the spring as soon as the freshet subsides and operated daily until the end of the Salmon spawning migration at the end of October. Between 1954 and 1992, a single trapnet was operated in the main stem of the Miramichi River at Millbank (Claytor 1996). The desire to have estimates of Salmon returns to each of the Northwest and Southwest Miramichi Rivers resulted in the operation of additional trapnets in each of those branches over the years and partnerships with both Eel Ground and Metepenagiag First Nations (Moore et al. 1992; Courtenay et al. 1993; Chaput et al. 1994). In 1994, DFO’s index trapnet on the Southwest Miramichi was moved upstream to Millerton and has operated there annually since then. Similarly in 1998, DFO’s index trapnet program expanded into the Northwest Miramichi River with the operation of a trapnet at Cassilis which has operated there annually since then (Figure A1). Trapnet operations in 2020 were delayed until September and then suspended in October so catch information is not comparable to previous years and has been omitted. Details on trapnet installations and daily operational procedures and protocols are provided in Hayward et al. (2014).

The annual catches of small and large Salmon at the index trapnets in the Miramichi River have not been adjusted for periods when the counting facilities were not operating due to maintenance, high water conditions, or suspension of activities due to high water temperatures. Catches of large and small Salmon at DFO index trapnets in the Miramichi are highly variable but show a general decline, particularly for small Salmon, over the time series of information (Figure 11). The large Salmon catches at Millerton and Cassilis in 2019 were the lowest of the time series and well below the long term average for each facility (Figure 11). Similarly, small Salmon catches in 2019 were among the lowest of the time series and well below the long term average for each trapnet (Figure 11).

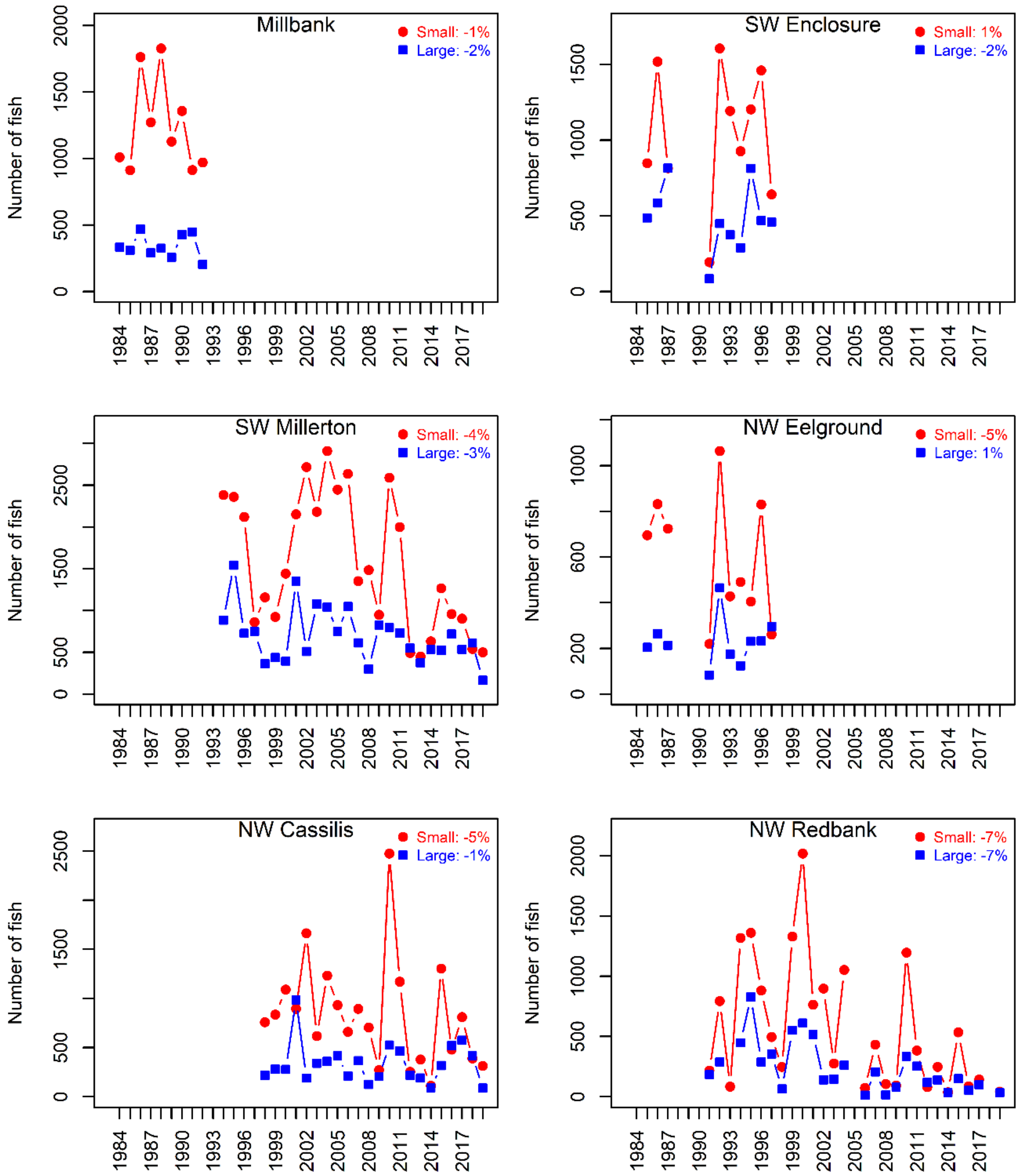


Figure 11. Indices of abundance (catches) of small Salmon and large Salmon at estuary trapnet monitoring facilities in the Miramichi River, 1984 to 2019. The annual percent change (exponential trend) over the available time series is shown in the upper right corner of each panel.

Tabusintac River

The Salmon population of the Tabusintac River has not been assessed since the 1999 return year (Douglas and Swasson 2000) but Esgenoôpetitj First Nation has continued to monitor the Salmon population entering that river with two trapnets located in the tidal portion of the river. The trapnets are usually operated for the months of September and October. Since 2002, the annual average catch has been 21 small Salmon (range 1 - 73) and 21 large Salmon (range 1 - 69).

Buctouche River

The Salmon population of the Buctouche River was last assessed in the 2000 return year (Atkinson and Peters 2001). The Buctouche River has previously been considered as an index river for rivers located in southeastern New Brunswick. Assessments of adult returns to the Buctouche River indicated that the conservation limit was met or exceeded once in eight years between 1993 and 2000. Buctouche First Nation continues to operate trapnets in the estuary but data from this program were not available.

Richibucto River

The Salmon population of the Richibucto River was last assessed in the 1997 return year (Atkinson and Cormier 1998). The Kouchibouguac National Park (2004 - 2006) and more recently Kopit Lodge (2018 - 2020) have operated multiple boxnets in the tidal portion of the Richibucto River to monitor Salmon returns. Large and small Salmon were caught in each year of operation and the total combined catch has ranged between 43 and 245 during the 2018 - 2020 period.

Kouchibouguacis River

Returns of adult Salmon to the Kouchibouguacis River have been monitored annually since 2002 (exception 2014) with the use of two boxnets operated by the Friends of the Kouchibouguacis River. Dates of operation for this program have varied over the time series but both large and small Salmon were captured in each year of operation (range 4 - 113) with 2020 marking the largest total catch (n = 113). An estimate of adult Salmon abundance or status has not been attempted for this river.

Kouchibouguac River

The Kouchibouguac National Park has used two boxnets to monitor returning adult Salmon to the Kouchibouguac River each year between 1989 and 1996, every second year between 2007 and 2019 (inclusive), and 2020. The dates of operation varied between years but generally targeted the September and October period. The mean annual catch of large Salmon in the boxnets was 29 (range 1 - 98) and for small Salmon was 16 (range 1 - 55). An estimate of adult Salmon abundance or status has not been attempted for this river.

ABUNDANCE INDICES OF JUVENILE SALMON IN SFA 16

Juvenile Salmon surveys of the Miramichi River

Backpack electrofishing surveys of the freshwater sections of the Miramichi watershed have been completed annually since 1970 (Moore and Chaput 2007; Douglas et al. 2015; DFO 2020b). Electrofishing surveys have generally occurred during the fall and sites have remained relatively consistent through time. Abundances (expressed as number of fish per 100 m^2) of fry, small parr, and large parr have been estimated using a depletion method in closed (barriered) sites or from a catch-per-unit-of-effort (CPUE) method in open (not barriered) sites (Zippin 1956; Chaput et al. 2005). On average 58 sites (range 3 - 95) have been surveyed annually since 1970. The electrofishing survey of the Miramichi watershed was not completed in 2020.

Juvenile Salmon abundances in the Miramichi River have been summarized by the four major tributaries (Southwest Miramichi [SW], Renous, Northwest Miramichi [NW], and Little Southwest Miramichi [LSW] rivers). Average juvenile densities were calculated only when four or more sites per large river system were surveyed in a given year. Size groups of juveniles (fry, small parr, large parr) were used as proxies for cohorts.

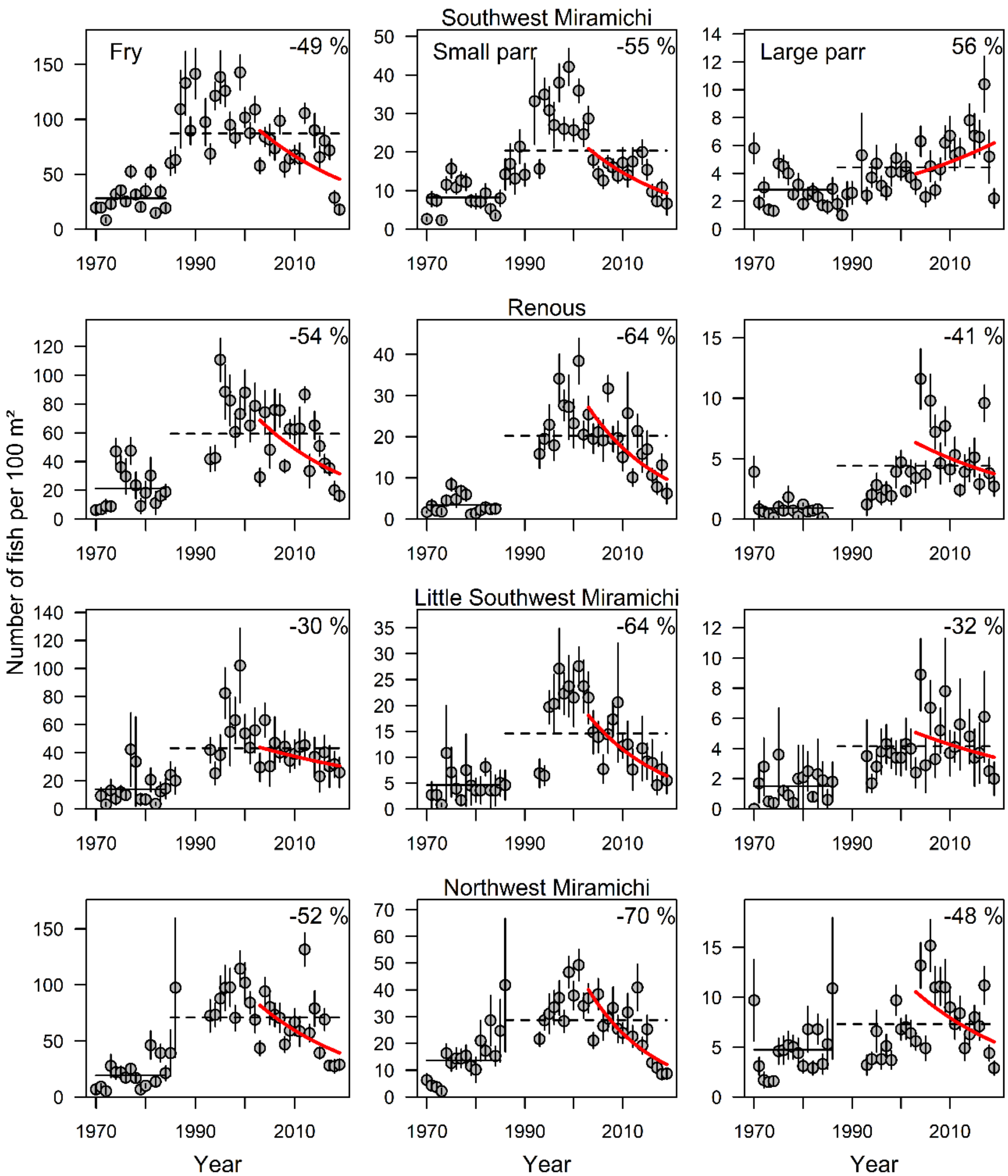


Figure 12. Annual average densities, expressed as fish per 100 m² of sampled area, for fry (left column), small parr (middle column), and large parr (right column) at sampled sites in the four major rivers of the Miramichi watershed: Southwest Miramichi (upper row), Renous River (second row), Little Southwest Miramichi (third row), and Northwest Miramichi (bottom row) for 1970 to 2019. Vertical bars are one standard error. The horizontal solid and dashed lines in each panel are the average densities corresponding to periods before and after, respectively, significant management changes were implemented to the commercial and recreational Salmon fisheries in 1984. The trend (exponential regression) over the recent 16 years (2003 to 2019) and the percent change over that time period are also shown in the upper right corner of each pane.

In response to the 1984 closure of the commercial Salmon fishery and mandatory catch-and-release of large Salmon in the recreational fishery, juvenile Salmon abundance in each of the four major tributaries of the Miramichi system increased in the 1990s from low levels observed in the 1970s - 1980s (Figure 12). The average densities of fry and small parr peaked in each river in the late 1990's while large parr abundance peaked in the 2000s. With the exception of large parr in the Southwest Miramichi, the density of all juvenile life stages has decreased in each of the four monitored rivers over the last 16 years (2003 - 2019) (Figure 12). The decrease in the average fry densities over the last 16 years has ranged from -30% (LSW) to - 54% (Renous), in small parr densities from -55 (SW) to -70% (NW) and in large parr densities from -32% (LSW) to -48% (NW) (Figure 12). While the previous 16 year trend is increasing for the large parr density in the Southwest Miramichi River, the average large parr density dropped in 2019 to levels below the pre and post-1984 average large parr density in that river (Figure 12) (DFO 2020b).

Juvenile Salmon surveys in rivers of southeastern New Brunswick

Backpack electrofishing surveys in five rivers of southeastern New Brunswick have been conducted intermittently since 1974 and most consistently since the late 1990s (Atkinson 2004). The average number of sites sampled annually has ranged from three in the Cocagne and Kouchibouguacis rivers to seven in the Buctouche River. Southeastern New Brunswick electrofishing surveys were generally completed in the fall and sites have remained relatively consistent through time.

Calibration equations between the closed site depletion method and the open site catch per unit effort (CPUE) method have not been developed for rivers specific to southeastern New Brunswick and the calculation of fry and parr densities in these rivers have relied on the linear relationships between these techniques developed from Miramichi electrofishing surveys (Chaput et al. 2005; Douglas et al. 2015). Applying the regression equations developed from Miramichi electrofishing programs to data collected in southeastern New Brunswick may not be appropriate given the differences in habitat between the two areas and the potential sampling differences among the inconsistent electrofishing crews for rivers in southeastern New Brunswick.

To evaluate the abundance and trends of juvenile Salmon in rivers of southeastern New Brunswick, the mean catch of fry and parr per unit area (CPUA number of fish per 100 m^2) and per unit effort (CPUE number of fish per 100 seconds of electrofishing effort) were summarized by river and year (Figure 13). In many cases these indices could not be calculated because electrofishing effort (seconds) was not recorded, the electrofishing site was not measured for area calculations, or both. A third index that accounted for both area and effort was developed by dividing the catches of fry and parr by the area surveyed and the effort and then standardized to number of fish per 100 m^2 per 100 seconds of electrofishing time. Similar to the CPUA and CPUE indices above, the catch per unit area effort (CPUAE) index was averaged over the number of sites in a given river and year (Figure 13).

The CPUA index was highly variable between years and showed an increasing trend for fry in all rivers and for parr in all rivers except the Buctouche and Cocagne. The CPUE index was less variable than the CPUA index but showed decreasing trends for fry in all rivers and for parr in all rivers except the Richibucto. The CPUAE index showed a declining trend for fry and parr in Buctouche and Cocagne rivers and an increasing trend for fry and parr in the Kouchibouguacis and Kouchibouguac rivers. The Richibucto River showed a decreasing trend for fry but increasing for parr (Figure 13).

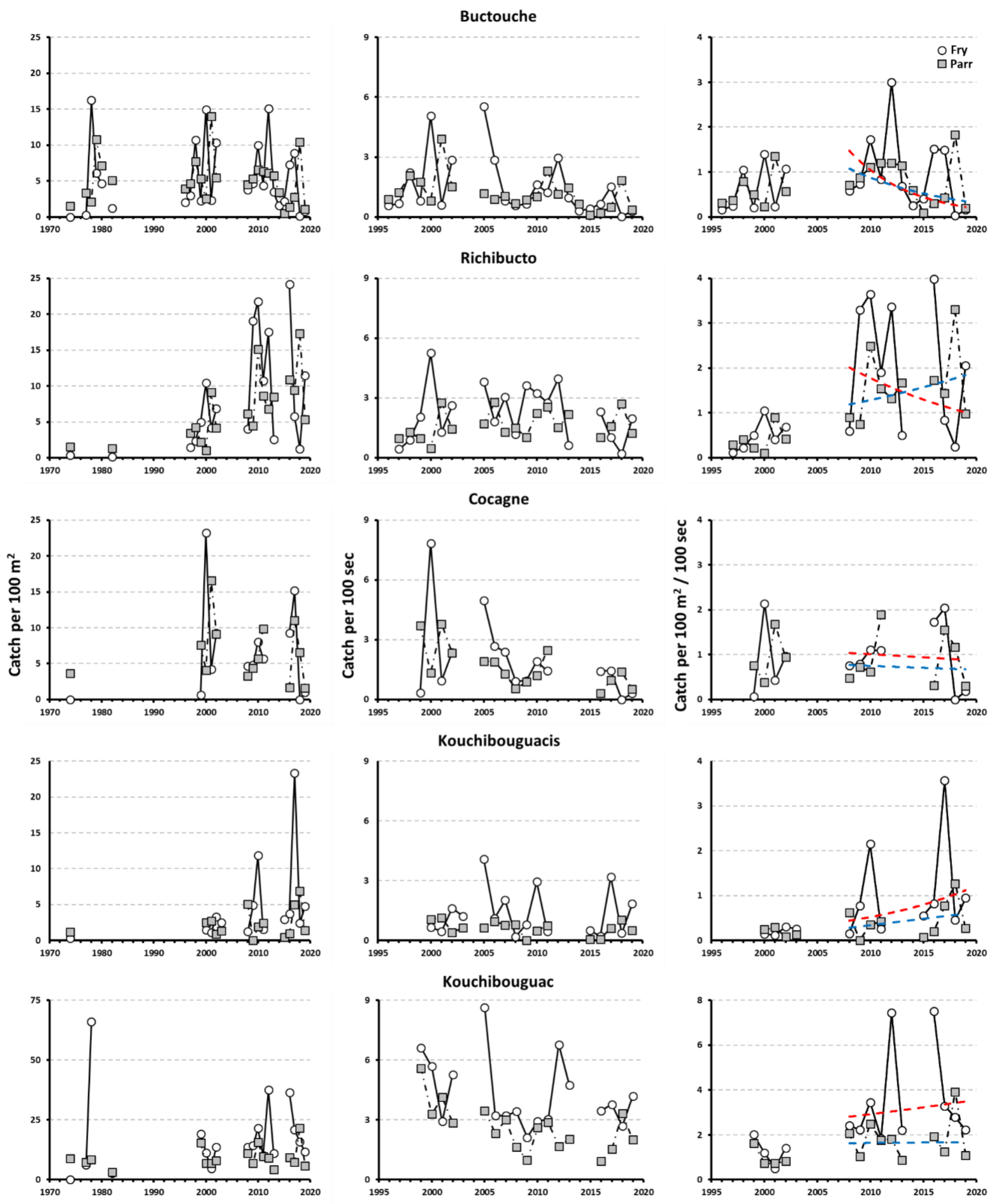


Figure 13. Catch per unit area (average number of fry and parr per 100 m^2) (left column), catch per unit effort (average number of fry and parr per 100 seconds of electrofishing effort) (middle column), and the combined CPUA and CPUE index (average number of fry and parr per 100 m^2 per 100 seconds of electrofishing effort (right column) from juvenile Salmon surveys in the Buctouche River (first row), the Richibucto River (second row), the Cocagne River (third row), the Kouchibouguacis River (fourth row), and the Kouchibouguac River (fifth row) between 1974 and 2019. Circles are fry, squares are parr. The trend (exponential regression) over the 2008-2019 period is shown in red for fry and blue for parr.

Atlantic Salmon continue to spawn in assessed rivers of southeastern New Brunswick as evidenced from catches of multiple cohorts annually. Catch indices of juvenile Salmon adjusted to the size of the site, to effort independent of area, and combined, produced conflicting results which makes interpretation of juvenile Salmon abundance in rivers of southeastern New Brunswick difficult (Figure 13). Regardless of the index, juvenile Salmon abundance in southeastern New Brunswick has been low throughout each of the river's time series. With the exception of Kouchibouguac fry in 1978, 2012, and 2016, the CPUA for fry and parr have been below 25 fish per 100 m^2 in every river and every year surveyed. Similarly, fry and parr abundance has been below 9 fish per 100 seconds of electrofishing effort in every year for each river (Figure 13).

DISTRIBUTION

FRESHWATER

There are 39 rivers in SFA 16 that extend from the Tabusintac River in the north to the New Brunswick-Nova Scotia border in the south (Figure 1). The Southwest Miramichi River is the largest river in SFA 16 and when combined with its three major tributaries (Northwest Miramichi, Little Southwest Miramichi, and Renous rivers) account for over 53 million m^2 of fluvial habitat which represents 88% of all of the habitat in SFA 16. With the exception of the Barnaby and Bartibog rivers, the remaining rivers are small with fluvial habitat areas less than 1 million m^2 (Appendix 1).

In anticipation of COSEWIC's first review of Atlantic Salmon, DFO Science conducted an extended electrofishing program to assess the distribution of juvenile Salmon in rivers of SFA 16. During the 2008 survey, juvenile Salmon were present in 77% of rivers, absent in 10% of rivers, and presence was undetermined in 13% of rivers (Chaput et al. 2010). Rivers that were not occupied by juvenile Salmon or their presence was unknown were located in the central and southern portions of SFA 16 (Figure 1; Appendix 1). Chaput et al. (2010) suggested that some rivers in SFA 16 with stream orders of 1 and 2 may not normally be expected to be occupied by Atlantic Salmon juveniles.

Electrofishing surveys since 2008 have been limited to assessment programs in the Miramichi system and five rivers of southeastern New Brunswick (see section on Population indicators and trends). Juvenile Salmon remain well distributed throughout the assessed rivers, however notable exceptions were observed in some southeastern NB rivers in 2018, possibly caused by environmental factors (DFO 2019). A broader electrofishing survey would be required to properly assess the current area of occupancy of juvenile Salmon in all non-assessed rivers of SFA 16.

MARINE MIGRATION PATTERNS

Anadromous Atlantic Salmon from rivers of SFA 16 undertake long oceanic feeding migrations to the North Atlantic. Salmon originating from the Miramichi River are annually intercepted in nearshore fisheries at West Greenland as non-maturing 1SW Salmon (from smolts in their second year at sea) and as repeat spawning Salmon (originally tagged as Salmon on their spawning migration to the river). Miramichi Salmon have also been reported from Labrador and Newfoundland coastal fisheries and from regional commercial fisheries throughout the Gulf of St. Lawrence (Saunders 1969). Four Atlantic Salmon tagged north of the Faroes Islands in their second winter at sea in February and March 1993 and 1995 were recovered in Canada in the summer following tagging; three were recovered in the Miramichi River and the fourth from the Kouchibouguac River (Hansen and Jacobsen 2000). The migrations of 1SW Salmon at sea are less known but post-smolts (first year at sea) have been reportedly captured in a number of fisheries in eastern Canada (Ritter 1989); these fish would not be available for capture in the Greenland fishery in their first year at sea due to size and timing.

More recently, Bradbury et al. (2020) analysed samples of Atlantic Salmon collected from catches in marine fisheries and research surveys in the North Atlantic. They identified the presence of Salmon from the southern Gulf reporting group in samples collected throughout the Labrador Sea, at West Greenland, and on the Grand Banks of eastern Newfoundland. Approximately half of the Salmon sampled from the Faroes fisheries with North American origin belonged to the Gulf reporting group (Bradbury et al. 2020).

TOTAL POPULATION SIZE

The Miramichi River is the only river in SFA 16 with annual published estimates of returns and spawners of Atlantic Salmon; the published time series extends from 1971 to 2019 (DFO 2020a). In 1992, the monitoring program for Atlantic Salmon moved away from the single Miramichi River assessment to branch specific assessments and estimates of returns to each of the Northwest Miramichi and Southwest Miramichi rivers and to the Miramichi River overall have been provided since then (Courtenay et al. 1993; DFO 2020a).

For the time series extending from 1998 to 2019, the catches of small and large Salmon at index trapnets in the estuaries, combined with mark and recapture data, and counts from three headwater barriers have been analysed using a Bayesian hierarchical model to estimate annual returns of small Salmon and large Salmon to each of the Northwest Miramichi and Southwest Miramichi rivers with returns to the Miramichi River overall as the sum of the branch estimates. A full description of the Bayesian assessment model used for the 1998 to 2019 assessment period is provided in Chaput and Douglas (2012). The time series analysed by Chaput and Douglas (2012), and since then, began in 1998 because that was the year when the index trapnet in the Northwest Miramichi at Cassilis began operation which also initiated the simultaneous and consistent monitoring programs on both branches of the river (index trapnet in the Southwest Miramichi at Millerton already in place since 1994).

Estimates of returns to each branch and overall to the Miramichi River between 1992 and 1997 were derived using annual monitoring data but lacked a consistent assessment model. Similarly, estimates of total returns to the Miramichi prior to 1992 were based on annual data, primarily catches at an index trapnet in the main stem of the Miramichi River and corrected by an efficiency estimate for the trapnet. Some of the annual published estimates of small Salmon and large Salmon for the period 1984 to 1997 are very high and appear anomalous, in particular for the 1992 return year, and they do not correspond to other indicators of abundance of Salmon from counting fences and protection barriers, or from estimates of catches in recreational fisheries.

The availability of hierarchical model approaches to account for disparate sources of data provides an opportunity to reanalyse the time series of information from the Miramichi River. We chose to reanalyse the time series beginning in 1984 for the following reasons:

- Important changes in fisheries management were introduced in 1984, associated with the closure of the commercial Salmon fishery in Miramichi Bay and throughout the Maritime provinces. In addition, mandatory catch and release of large Salmon (>= 63 cm fork length) in the recreational fishery was introduced in 1984.
- DFO initiated in 1985 to 1987, 1991 and 1992 a series of calibration experiments to assess the catchability of the Millbank estuary trapnet in the Miramichi, which was the primary

source of assessment data. Recapture trapnets were installed upstream in each of the Northwest and Southwest Miramichi branches.

- Two headwater protection barriers began operation in 1984 in the Southwest Miramichi (Juniper and Dungarvon) and one headwater barrier in the Northwest Miramichi began operation in 1988.

The structure and data used in the previous model (Chaput and Douglas 2012) and the treatment in this manuscript are presented in Appendices 2 to 5. The main differences between the revised model and the model of Chaput and Douglas (2012) include:

- Extending the time series for branch estimates back to 1984;
- Incorporating trapnet catches and mark/recapture data from other trapnets in use for the period 1984 to 1997;
- Incorporating angling catches when available as a proportion of the returns to the specific branches of the river to derive branch specific estimates; and
- Considering the headwater barrier and counting fences as indicators of escapement post-recreational fishery. This change is most important for the small Salmon which could be retained over the period 1984 to 2014 in contrast to mandatory catch and release of large Salmon which has been in place since 1984. The data from the Catamaran Brook counting fence are also included in the revised model.

Catches and recaptures were modelled using binomial distributions with non-informative beta priors for the probability of capture for the hyper-parameters, or in some cases the annual values if the time series was short (details in Appendix 2). The catch, marking and recapture data used in the assessment models are provided in Appendix 3 for small Salmon, in Appendix 4 for large Salmon, and recreational catch data are provided in Appendix 5; summary figures for these data are provided in Figures 9, 10, and 11. Posterior distributions of the parameter estimates from the model for the proportions of escapement that are enumerated at the headwater barriers and counting fences, the proportions of the returns intercepted at the trapnets, and estimated proportions of the returns captured in the recreational fisheries are summarized in Appendix 6.

ESTIMATED RETURNS TO THE MIRAMICHI RIVER

For the purpose of this exercise, we present the results from the revised model for returns to the Miramichi River overall of small Salmon, large Salmon, and size groups combined for the period 1984 to 2019 (Figure 14). The overall estimates to the Miramichi River are consistent with the previous model outputs for the years 1998 to 2019 (Figure 14; Appendix 7). Although estimates of returns for each of the Northwest and Southwest Miramichi for this period are also provided by the revised model, further validation of the model outputs (retrospective performance, contributions of various indicators to estimates of returns) is required before they are used in the assessments. In particular, the branch specific estimates for the period 1998 to 2019 with the revised model relative to the previous model show a consistent decrease in large Salmon estimates for the Southwest Miramichi and a systematic increase for the large Salmon in the Northwest Miramichi (Appendix 7).

There are large changes in the revised estimated abundances of small Salmon returns to the Miramichi River for the 1984 to 1997 time period from the previously published values derived using annual models (Figure 14). Specifically, the greatest change in estimated abundance of small Salmon to the Miramichi River is for the 1992 year, with revised values of 58,000 small Salmon representing a large decline from the previously published value of 151,000 small

Salmon for the Miramichi (Figure 14). The revised values are lower for the 1985 to 1995 return years and more similar for the years 1996 to 2019 with the exception of 2008. The revised values provide a more consistent estimate of the exploitation rate of small Salmon in the recreational fishery, which now is estimated to have varied from 0.30 to 0.50 per year (Appendix 7).

Small Salmon have declined from peak estimated abundances during the mid-1980s of 60 to 75 thousand fish to less than 10 thousand small Salmon during 2018 and 2019 (Figure 14). The estimated abundance has declined by 51% over 16 years based on the rate of change over the 1984 to 2019 time series but the decline over the most recent 16 year period has been more severe at 77% (Figure 14).

For large Salmon, the revised estimates for the Miramichi River are higher for the 1984 to 1989 period, lower for the 1990 to 1995 period, and either lower or higher for the 1996 to 2019 years (Figure 14). Large Salmon have declined from a peak estimated abundance in 1986 of 35,000 fish to less than 7,500 fish in 2019 (Figure 14). The estimated abundance has declined by 29% over 16 years based on the rate of change over the series 1984 to 2019 but the decline over the most recent 16 year period has been more severe at 50% (Figure 14).

Estimates of returns for small Salmon and large Salmon combined to the Miramichi have declined over the 1984 to 2019 time period from a peak in 1986 of over 110 thousand fish to the lowest estimated return of 17 thousand fish in 2019 (Figure 14). Based on the annual rate of change during the 1984 to 2019 time period, the percent change over three generations (16 years) has been 43% but the decline has been more severe over the recent 16 years at 68% (Figure 14).

The Limit Reference Point (LRP) for the Miramichi River (Southwest Miramichi system and Northwest Miramichi system combined) is 160 eggs per 100 m^2 and its attainment is assessed based on biological characteristics (mean fork length, proportion female, eggs per fish) collected annually from returning adult Salmon (DFO 2018a, 2020a). Consistent with the declining trends in the returns of adult Salmon, egg deposition rates have also declined sharply in the recent 16 years for Salmon (small and large combined) returns (47%) and spawners (42%) (Figure 15).

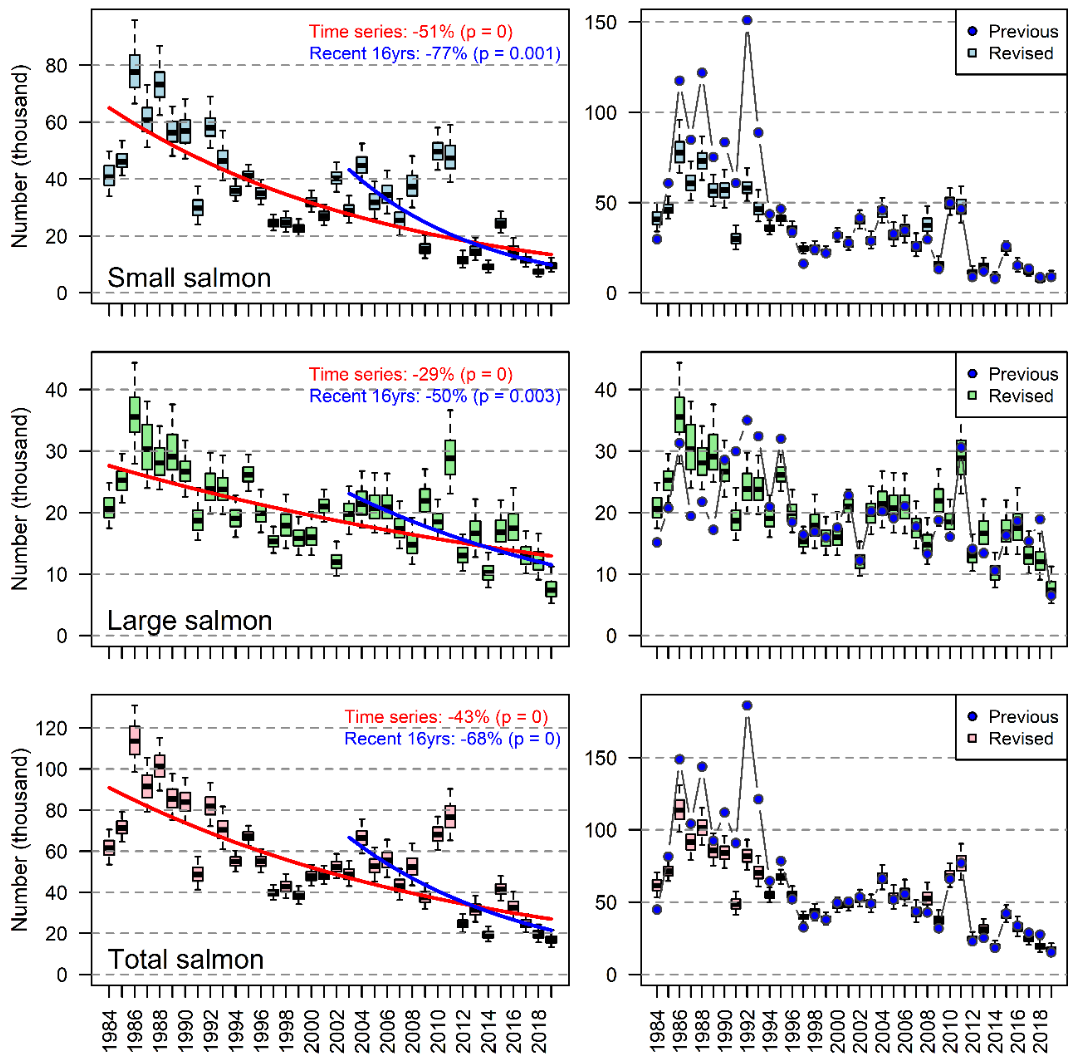


Figure 14. Estimated returns (number of fish, thousand) of small Salmon (upper row), large Salmon (middle row) and sizes combined (bottom row) to the Miramichi River for the period 1984 to 2019. The panels on the left summarize the posterior distributions from the revised assessment model with the log-linear regressions lines of the natural log of abundances plotted for the entire time series and for the most recent 16 years (approx. 3 generations). The panels on the right are the same boxplot summaries as the left panels but with an overlay plot of the point estimates of the returns published in previous assessments. The boxplots are interpreted as follows: the vertical whiskers are the 5th to 95th percentile, the box is the interquartile range, and the dash is the median. Also shown in each of the left panels are the percentage change over 16 years based on the regression for the entire time series (red; with associated p value for the slope) and for the most recent 16 years (blue; with associated p value of the slope).

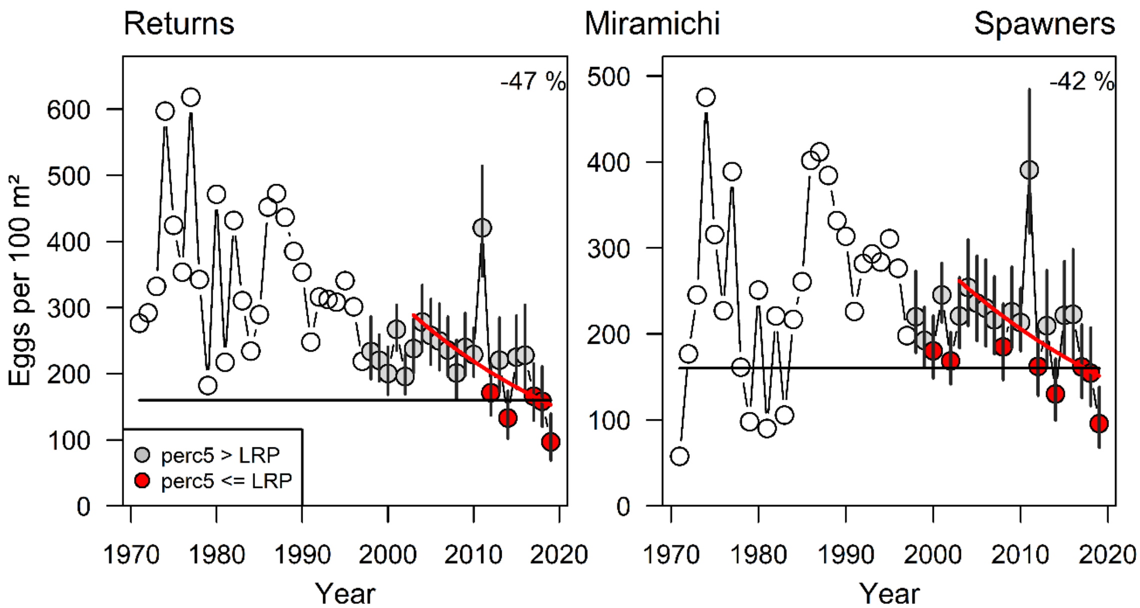


Figure 15. The estimated median (1971-2019) and 5th to 95th percentile range (1998-2019) of the number of eggs (expressed per 100 m² of habitat) from the returns (left panels) and spawners (right panels) of small and large Salmon combined to the Miramichi River overall in relation to the Limit Reference Point (solid horizontal line) (DFO 2018a). Grey symbols indicate when the 5th percentile of the number of eggs was above the LRP and red symbols indicate when the 5th percentile of the number of eggs was below the LRP. The white open circles are for years without estimates of uncertainties for egg depositions. The percent change in the number of eggs in the returns (left panels) and spawners (right panels) of large and small Salmon combined over the previous 16 year period (2003-2019) is identified in the top right corner of each panel.

ADULT SALMON ABUNDANCE IN SFA 16

In the assessment of Atlantic Salmon status for eastern Canada, the International Council for the Exploration of the Sea's (ICES) Working Group on North Atlantic Salmon has developed a run reconstruction approach that estimates the total abundance of anadromous Atlantic Salmon returning to rivers of eastern Canada. The run reconstruction approach considers catches in marine Salmon fisheries, estimates of natural mortality at sea, and estimates of abundance prior to marine fisheries on Salmon (ICES 2020). Estimates of total abundance of Salmon, by size group, for SFA 16 are used in the reconstruction of total abundance by the ICES Working Group. The estimates of abundance for SFA 16 are derived using the estimated returns to the Miramichi River raised to the total freshwater production area of rivers in SFA 16. The estimated freshwater habitat area utilized by Atlantic Salmon for the Miramichi River (four main tributaries that include Southwest Miramichi River, Renous River, Northwest Miramichi River, Little Southwest Miramichi River) equals 53.4 million m², which is 88% of the estimated 60.9 million m² for the rivers in SFA 16. A similar approach is used here to estimate the returns and spawners to all of SFA 16.

Based on the percentage (88%) of the total freshwater habitat area in SFA 16 represented by the Miramichi River, the estimated returns of Atlantic Salmon to SFA 16 were estimated to have peaked at just under 130 thousand fish in 1986 (median; 5th to 95th percentile range 112 to 149 thousand) and had declined to the lowest value in 2019 at less than 20 thousand Salmon (median; 5th to 95th percentile range 15 to 25 thousand). The rates of change in abundance of Salmon in SFA 16 are identical to the calculated rates of change for the Miramichi (Figure 16).

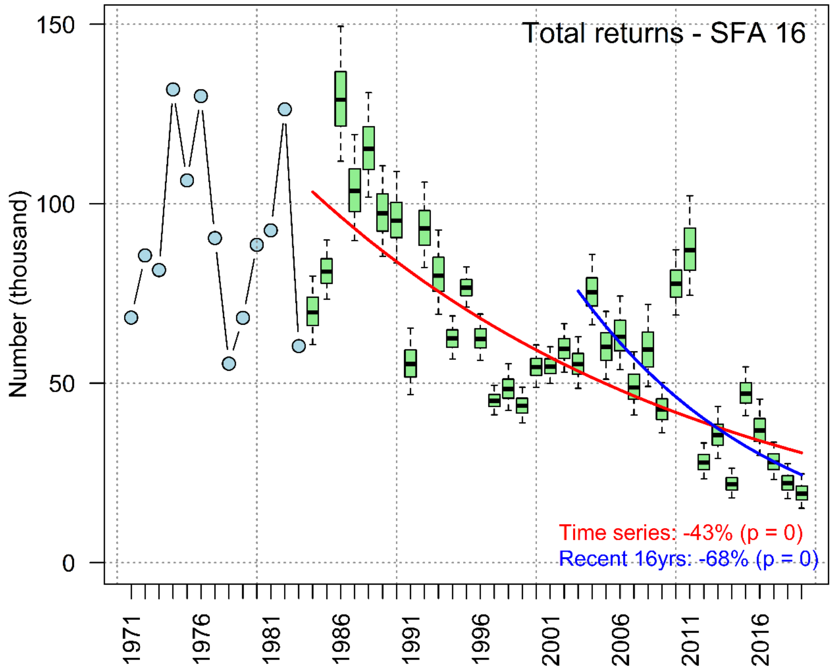


Figure 16. Estimated returns (number of fish, thousand) of Atlantic Salmon (size groups combined) to Salmon Fishing Area 16, between 1971 and 2019. The values for the period 1971 to 1983 are based on published returns of Salmon to the Miramichi River while values for the period 1984 to 2019 are based on the revised assessment model for the Miramichi. The log-linear regression lines of the natural log of abundances are plotted for the time series 1984 to 2019 (red) and for the most recent 16 years (blue). The boxplots are interpreted as in Figure 14. Also shown are the percentage change over 16 years based on the regression for the 1984 to 2019 time series (with associated p value for the slope) and for the most recent 16 years (with associated p value of the slope).

HABITAT

Concise overviews of Atlantic Salmon habitat have been previously reported for the freshwater environment (Amiro 2006), the marine environment (Reddin 2006), and overall (COSEWIC 2010). There are no special characteristics of the habitat occupied by anadromous Atlantic Salmon in SFA 16 relative to habitat utilized by Salmon in other areas of eastern Canada. In contrast to large areas of Newfoundland and some rivers in Quebec along the lower north shore of the St. Lawrence, lacustrine habitat is not used for rearing by juvenile Salmon in rivers of SFA 16. In association with a multi-year program to control non-native Smallmouth Bass in Miramichi Lake (Southwest Miramichi) using various techniques, only two juvenile Salmon were captured among a diverse and abundant community of other fish species including anadromous river herring (Biron 2018).

THREATS

A summary of threats and their associated rating of scope, timing, and severity to Atlantic Salmon in SFA 16, Gulf Region NB, is presented in Table 6; a slightly modified version of what DFO and MNRF (2009) presented previously. The ranking of the scope, timing, and severity for each threat was based on the author's current understanding of the threat in relation to Atlantic Salmon in SFA 16. When available, threat information specific to Atlantic Salmon in SFA 16 was discussed.

HOME WATER FISHERIES

Indigenous Food Social and Ceremonial

Indigenous fisheries for Atlantic Salmon are managed under communal licenses with restrictions on gear, location, season, and allocations of both small and large Salmon. The majority of Indigenous food, social and ceremonial (FSC) fisheries in SFA 16 occur in estuaries but also occur in Miramichi Bay and the crown open waters of the Miramichi, Bartibog, and Tabusintac rivers (Appendix 8). Estuarine trapnet programs with the objective of harvesting Salmon for FSC purposes as well as marking and/or recapturing Salmon for the purpose of estimating run size exist in the Tabusintac, and the Southwest and Northwest Miramichi rivers, and are conducted by Esgenoôpetitj, Natoaganeg, and Metepenagiag First Nations, respectively. Trapnet catch information is provided in each of these cases and makes a valuable contribution to the overall Salmon assessment of SFA 16. Salmon harvest information from most Indigenous FSC fisheries of SFA 16 are poorly reported.

Recreational

In 1984 the retention of large Salmon in the recreational fishery was no longer permitted and the retention of small Salmon and catch and release of large Salmon was regulated by season and both daily and seasonal bag limits. The angling season has varied slightly throughout SFA 16 but typically opened on April 15 and closed on October 15. There have been a number of reductions to the daily and possession limits of small Salmon since 1984 when two could be retained daily and ten for the season. Retention of small Salmon has not been permitted in SFA 16A since 2015, however catch and release angling persists. Since 1998, rivers in southeast New Brunswick (SFA 16B) have been closed to all directed Salmon fishing.

Harvest levels of small Salmon and catch and release statistics for large Salmon in the recreational fishery of the Miramichi River have not been available since 1997. To account for catch and release mortality in annual stock assessments for Miramichi Salmon, a 3% correction factor has been applied to an exploitation rate of 30% of the large Salmon return estimate. The same method has been applied to the small Salmon component since 2015 when mandatory catch and release of that size group came into effect (DFO 2020a).

An average of 20,120 Salmon angling licenses have been sold annually in New Brunswick since 1996 but have decreased to approximately 10,000 annually since 2015 when catch and release restrictions were implemented throughout the Gulf Region (C. Connell, NB NRED pers. comm.) (Appendix 8). A creel survey form is provided with the sale of NB angling licenses and more recently a web based tool for anglers to report angling statistics has been launched. The rate of return for angler’s catch and effort information remains low and makes meaningful analysis of catch statistics difficult.

MIXED STOCK MARINE FISHERIES

Saint Pierre and Miquelon Fishery

A marine fishery for Atlantic Salmon using gillnets takes place along the coast of the islands of Saint Pierre and Miquelon (France; SPM), off the south coast of Newfoundland. There are no anadromous Salmon producing rivers in the islands of SPM. The fishery is prosecuted by both professional license holders who can sell their catch locally in SPM and recreational license holders. Annual reported harvests have generally been less than 3 tonnes (t) with a peak reported harvest of 5.3 t in 2013; the reported harvest in 2019 was 1.3 t (Figure 17). The estimated number of fish harvested annually varies and is dependent upon the quantity of small

Salmon and large Salmon in the catches. There is insufficient information from the sampling program to reliably estimate Salmon catch numbers but based on available information, the harvest of Salmon in number of fish has ranged from a low of just under 300 fish to a high of 1,800 fish (size groups combined, Figure 17).

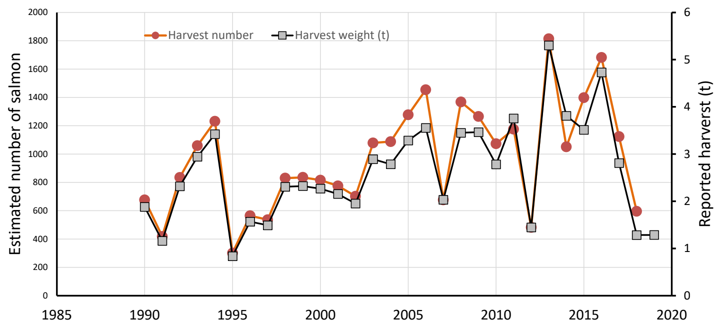
Based on genetic analyses, the Salmon sampled from the fisheries catches in SPM come predominantly from three regional groups: southern Gulf group (part of SFA 15, all of SFAs 16 to 19), Quebec (including the Gaspe regional group that includes the Restigouche River of SFA 15) and the Newfoundland regional group (Bradbury et al. 2016a). The proportions of the annual samples which were assigned to the Gulf reporting group ranged from 0.20 to over 0.50, for the period 2004 to 2017 (Figure 17). The proportions of the fishery samples assigned to the Gulf reporting group (based on a SNP panel of markers) was 0.42 in 2019 (ICES 2020).

Labrador subsistence fisheries

Historically, Atlantic Salmon originating from rivers of SFA 16 (Miramichi in particular) were recovered in the commercial fisheries of Newfoundland and Labrador. The commercial fishery in Newfoundland closed in 1992 and the commercial fishery in Labrador closed in 1998. Since 1998, there are four Indigenous communities with food social and ceremonial fisheries for Atlantic Salmon and there is a licensed subsistence food fishery for residents of Labrador in which a bycatch allocation of Salmon is provided. These fisheries take place in the estuaries and coastal areas of Labrador using gillnets.

The fishery is sampled for biological characteristics and tissue samples are collected for determination of the origin of Salmon in the catches. Over the period of analyses, 2006 to 2019, the estimated origin of the samples of the catches was dominated (> 95%) by the Labrador reporting groups. No samples have been assigned to the Gulf reporting group (Bradbury et al. 2015, 2018; ICES 2020).

A)



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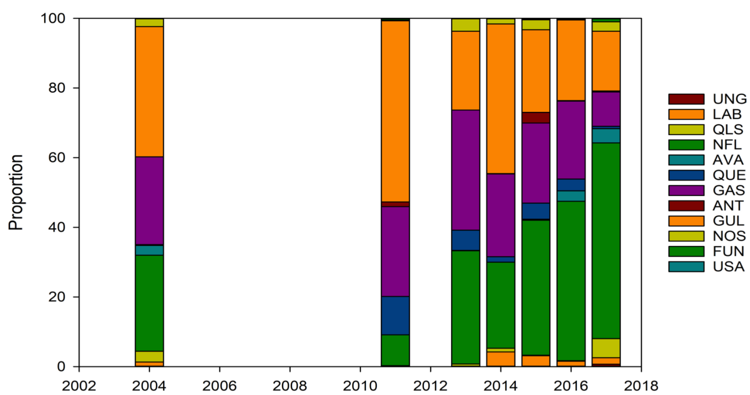

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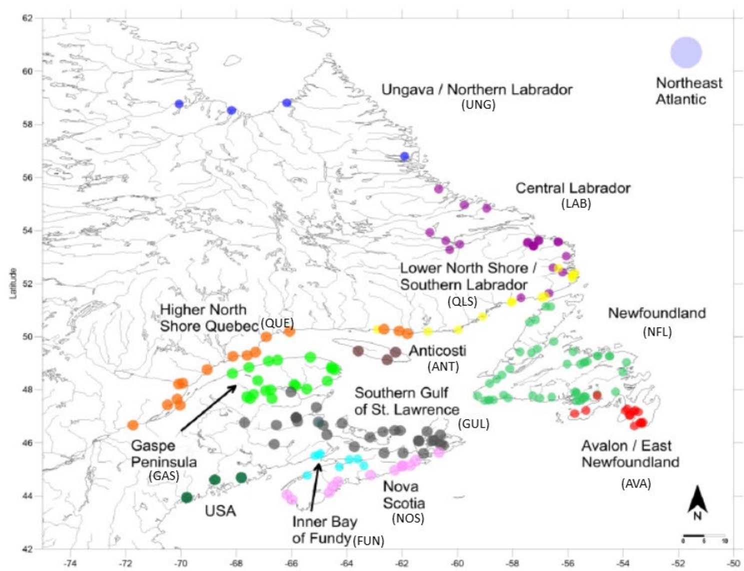

Figure 17. Panel A: the time series of reported harvested weight (t) and estimated harvested number of Atlantic Salmon in the Saint-Pierre and Miquelon fishery (ICES 2020). Panel B: the estimated proportion by regional group of Atlantic Salmon sampled from fishery catches based on microsatellite markers. Panel C: the regional groups of Atlantic Salmon assigned using microsatellite markers. Figures in panels B and C are from ICES (2018).

West Greenland

The Atlantic Salmon fishery at West Greenland takes place on mixed stocks of Atlantic Salmon originating from rivers of eastern North America and Europe, with varying annual proportions of the catches from the two continents (Bradbury et al. 2016b; ICES 2020). Atlantic Salmon originating from rivers of SFA 16 undertake high seas feeding migrations to the Labrador Sea and are intercepted in the mixed stock fisheries at West Greenland, mostly during their second summer at sea and as repeat spawners. The fishery at West Greenland had peak reported catches of 2,679 t in 1971 but the fishery catches have declined to generally less than 50 t since 1998. The number of Salmon originating from rivers of eastern North America harvested annually at West Greenland has ranged from 5,100 to 13,500 fish during the recent 10 years (Figure 18). The majority (> 95%) of the Salmon harvested at West Greenland are characterized as 1SW non-maturing Salmon, fish which would mostly have returned to rivers as 2SW Salmon if they had survived their second year at sea.

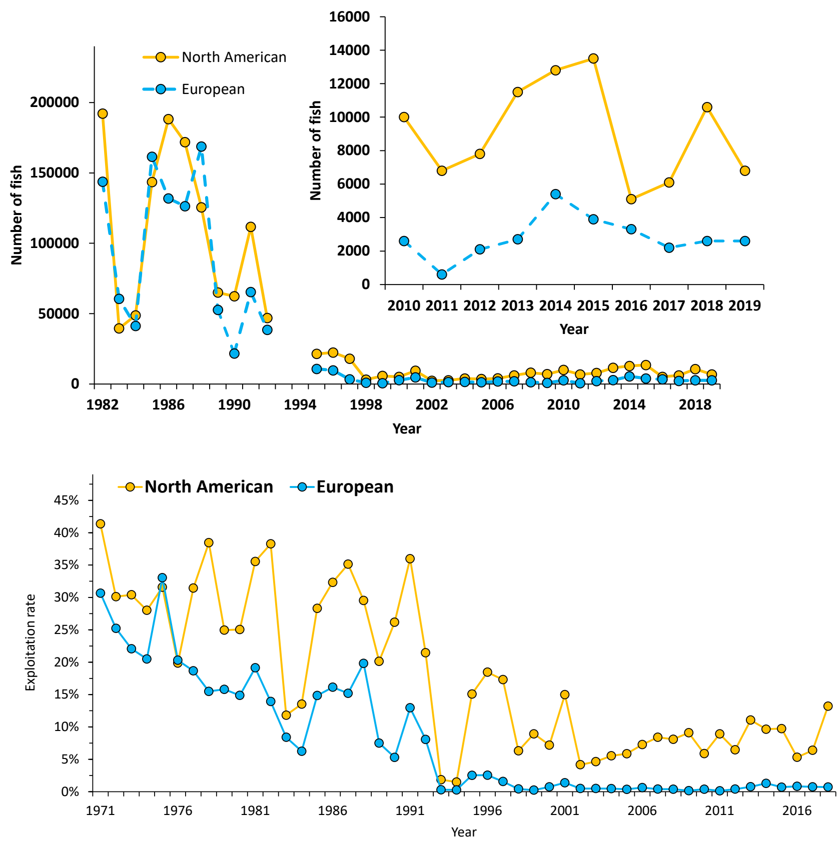

Figure 18. Estimated number of Salmon (number of fish) harvested at West Greenland by continental origin (North America, Europe) for 1982 to 2019 (upper panel) and estimated exploitation rate (bottom panel) at West Greenland by continent of origin of the 1SW non-maturing Salmon estimated alive at sea at the time of the West Greenland fishery (ICES 2020).

The exploitation rate at West Greenland on Salmon of North American origin, estimated as the ratio of the catch of 1SW non-maturing Salmon of North American origin divided by the estimated pre-fishery abundance of North American origin 1SW non-maturing Salmon in the North Atlantic just prior to the fishery (Aug. 1), declined from peak exploitation rates of just over 40% in the early 1970s to oscillating values around 10% since the early 2000s (Figure 18;

ICES 2020). The exploitation rate on North American origin Salmon for the most recent year, 2018 catches, was estimated at 13.2% (ICES 2020).

Genetic stock identification using microsatellite markers initially and SNP panels in recent years have consistently shown that the sampled catches at West Greenland originate primarily from three regions of eastern Canada, including Labrador, the southern Gulf reporting group, and the Quebec reporting group (Figure 19; Bradbury et al. 2015; ICES 2018, 2020). The southern Gulf reporting group represented between 17% and 31% of the samples from the 2015 to 2019 fisheries (ICES 2018, 2020).

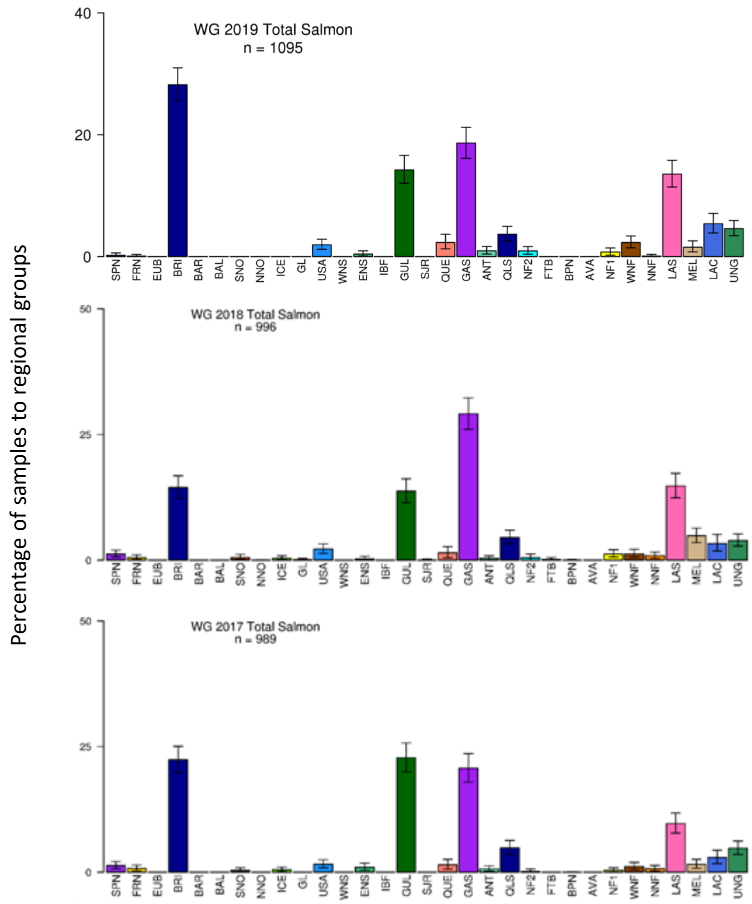

Figure 19. Estimates of mixture composition (percentages) of samples from the West Greenland Atlantic Salmon fishery for 2017 to 2019 assigned to reporting groups defined by the SNP panel baseline (ICES 2019, 2020). The reporting group of interest for Salmon of SFA 16 is labelled GUL and coloured in green.

In 2018, a 12-year agreement ("Greenland Salmon Conservation Agreement") was signed between the Atlantic Salmon Federation (ASF), the North Atlantic Salmon Fund (NASF) and KNAPK, the union who represents the professional hunters and fishers of Greenland. The agreement was for no commercial Salmon fishing in exchange for financial support for the development of scientific and economic research for educational and conservational initiatives. The agreement included a 30 tonne allowance (10 t private fishery allocation, 20 t commercial fishery allocation) as part of a subsistence fishery. There have been issues in the implementation of this agreement (2018 overharvest) but increased monitoring is reportedly occurring to better manage the fishery harvests (ICES 2020).

ENVIRONMENTAL CONSTRAINTS

Temperature and streamflow are among the most important environmental conditions determining the distribution and productivity of Atlantic Salmon in freshwater habitats. Low flow, particularly during the summer months, can contribute to high water temperature and thermal stress of all in-river life stages of Atlantic Salmon. Swansburg et al. (2002) and Swansburg et al. (2004b) showed that the growth of juvenile Salmon in the Miramichi River decreased with elevated summer water temperatures and reduced discharge, while mortality of juvenile and adult Salmon increased. Low streamflow can also impede the upstream migration of spawning adult Salmon and the downstream migration of smolts leaving the river. High discharge during early juvenile stages has been shown to negatively affect survival by displacing eggs or alevins from the riverbed (Elwood and Waters 1969; Erman et al. 1988; Swansburg et al. 2004a).

The trend in summer (July and August) air temperature has been increasing in the Miramichi area since the mid-1800s and is consistent with the expectation that the mean annual air temperature in eastern Canada will increase by 2 °C to 6 °C in the next 100 years (Parks Canada 1999) (Figure 20). Similarly, the mean air and water temperatures of the Little Southwest Miramichi River have been predicted to increase by 4.4 ºC and 3.2 ºC respectively, over the next century (Brodeur et al. 2015). Breau and Caissie (2013) demonstrated that the upper lethal temperatures for Atlantic Salmon (25 to 28 ºC) are becoming more frequent in portions of the Miramichi River. Water temperatures in the Miramichi River were in this lethal range for 10 days in 2020. The number of days where the daily maximum water temperatures recorded in the Little Southwest Miramichi River exceeded 23 °C, a temperature known to be stressful to Atlantic Salmon, were highest in 1999 (62 days) followed next by 2018 (57 days), and 2001 and 2002 (52 days) (Figure 21). The daily maximum water temperature recorded on the Little Southwest Miramichi River exceeded 23 °C on 40 days in 2020, a slight increase over 2019 (35 days).

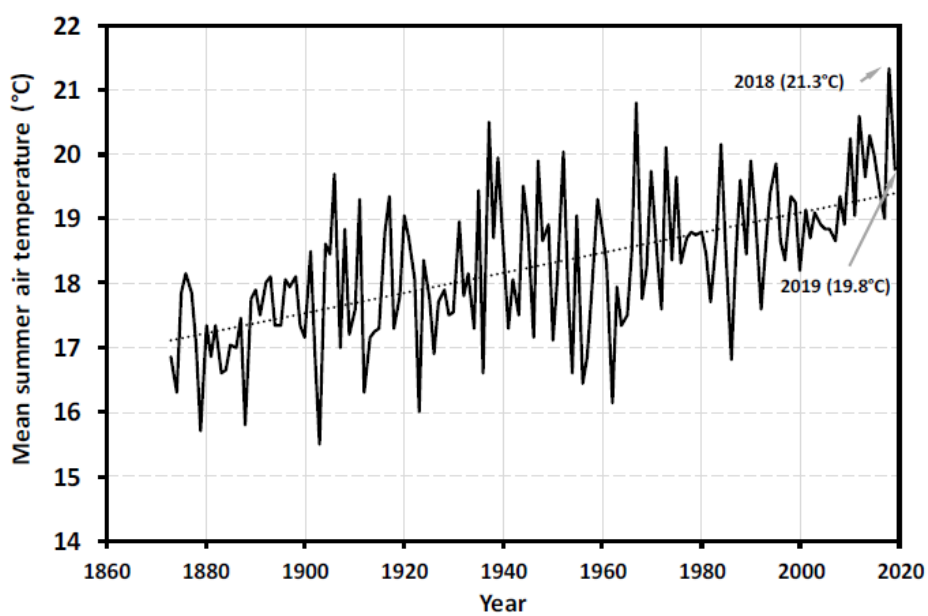

Figure 20. Mean annual summer (July and August) air temperatures and linear trend in mean temperature based on data from the Environment and Climate Change Canada meteorological station in Miramichi (station 8100989), 1873 to 2019 (DFO 2020b).

In SFA 16, real-time monitoring of the water temperature is only available in the Miramichi River and has been used by resource managers since 2012 to limit the angling pressure when water temperatures reach a level that becomes stressful to Atlantic Salmon. The ‘Warm Water Protocol’ has a series of restrictions that progress as the water temperature and duration of the heat event(s) increases. When the water temperature is above 20 °C for two consecutive days and nights, 27 cold water holding pools are closed to fishing and remain that way until the water temperature drops below 20 °C for two consecutive nights. If the water temperature is above 23 °C for two consecutive days and nights, then in addition to the closure of the cold water pools, angling is only permitted in the morning. Weather forecasts and discussions with watershed associations and fishery officers are also considered before restrictions are put in place or lifted (DFO 2012).

Since 2012, there has been an increase in the number of days that cold water pools have been closed and that morning-only angling has been implemented (Appendix 9). The highest number of days with cold water pool closures (n = 54) and morning-only angling (n = 18) occurred in 2020 and 2018 respectively (Appendix 9).

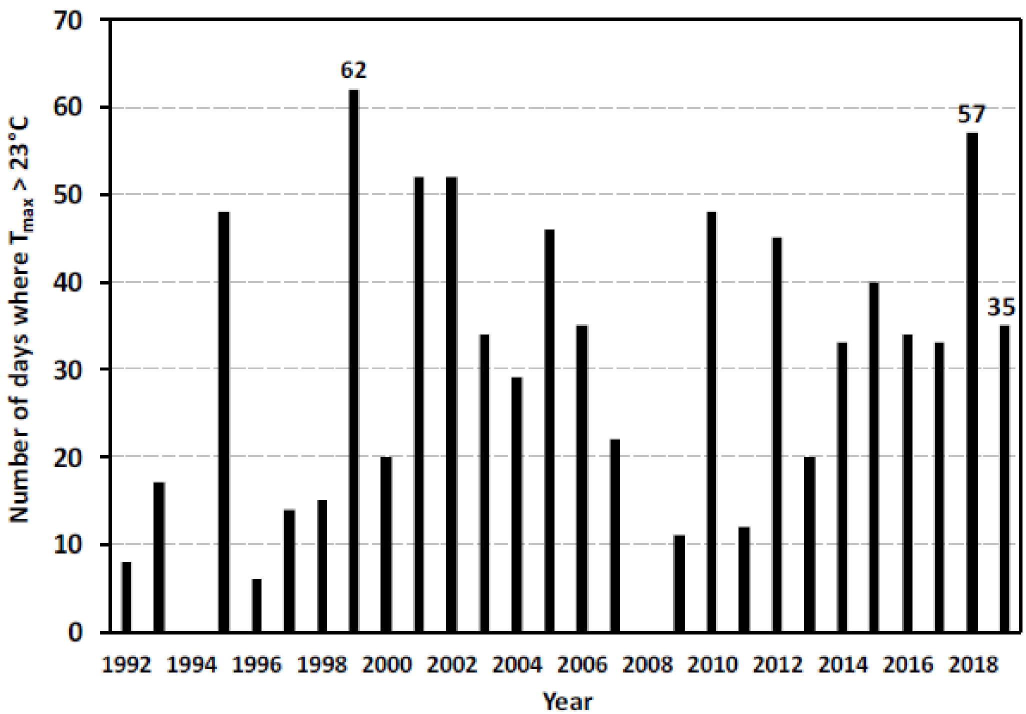

Figure 21. Number of days per year when the daily maximum water temperature exceeded 23 °C at monitoring stations in the Little Southwest Miramichi River (SFA 16) during 1992 to 2019. Data for 1992 to 2013 are from the DFO station above Catamaran Brook whereas for 2014 to 2019, the data are from the downstream Upper Oxbow site (Miramichi River Environmental Assessment Committee station).

INVASIVE SPECIES

Chain pickerel (*Esox niger*) are not native to rivers in SFA 16 but were discovered in 2001 in Despres Lake, a headwater lake that runs into the Cains River, a tributary of the Southwest Miramichi River. The piscicide rotenone was applied to the lake and the chain pickerel population was considered to have been successfully eradicated (Connell et al. 2002).

In September 2008, the non-native smallmouth bass (*Micropterus dolomieu* L) was discovered in Miramichi Lake, a headwater lake that drains into the Southwest Miramichi River via Lake Brook. A program with the objective of containing, controlling, monitoring, and removing smallmouth bass in Miramichi Lake by mechanical means (electrofishing, beach seining, fyke netting, gill netting, angling, and snorkeling) was initiated in 2009 and has been ongoing annually since then (Biron et al. 2014; Biron 2018). A physical barrier (fine meshed fence) has also been erected and maintained annually at the outflow of the lake (beginning of Lake Brook) to limit the spread of invasive smallmouth bass. To date, almost 15,000 smallmouth bass (98% young of the year) with ages ranging from 0+ to 11 years old have been removed from Miramichi Lake and 2020 recorded the highest single year removal of smallmouth bass so far (n = 3,331).

In 2019, smallmouth bass were first discovered in the Southwest Miramichi River, approximately 8.5 km downstream from the confluence of Lake Brook (outflow of Miramichi Lake). Efforts to determine the distribution of smallmouth bass in the Southwest Miramichi river by angling, electrofishing, netting, and sampling for environmental DNA (eDNA) began in 2019 and results from these methods suggested a concentration of smallmouth bass in McKiel Pond, a deep, slow moving section of river approximately 2 kms upstream from the location of the initial smallmouth bass observation in the river near the mouth of McKiel Brook. In 2020, 83 smallmouth bass of various ages were removed from McKiel Pond with the use of an electrofishing boat while three others were angled from the same area. Backpack electrofishing of Lake Brook in 2020 also yielded two smallmouth bass.

In September of 2020, a single smallmouth bass was captured in DFO's index trapnet at Millerton located in the estuary of the Southwest Miramichi, approximately 155 kms downstream from the McKiel Pond area. This was the first recorded capture of a smallmouth bass at any DFO fish sampling facility in the Miramichi River system.

A risk analysis of smallmouth bass impacts on Atlantic Salmon in the Miramichi River and an evaluation of options for and the effectiveness of mitigation measures for minimizing the risks associated with a range extension of smallmouth bass was conducted in 2009 (DFO 2009; Chaput and Caissie 2010). The science review concluded that there is a high likelihood of widespread establishment of smallmouth bass in the Southwest Miramichi River and in Gulf Region rivers generally (DFO 2009). The overall risk to the aquatic ecosystem in Miramichi Lake was considered to be high while the risk to the riverine environment was considered to be moderate (DFO 2009; Chaput and Caissie 2010). Stakeholder groups have submitted an application to DFOs Aquatic Invasive Species National Core Program for the use of the piscicide rotenone under the Aquatic Invasive Species Regulations for the purpose of eradicating smallmouth bass from Miramichi Lake, Lake Brook and a 15 km stretch of the Southwest Miramichi River. The proposal is currently under regulatory review.

The accidental discovery of two invasive species in the Miramichi River system over a span of less than 10 years (chain pickerel in 2001, smallmouth bass in 2008), suggests that the introductions of non-native fish species is a concern and a potential threat to Atlantic Salmon in SFA 16 and elsewhere.

PROBLEMATIC NATIVE SPECIES

The spawning population of Striped Bass (*Morone saxatilis*) in the southern Gulf of St. Lawrence has increased dramatically in recent years, peaking at nearly 1 million fish in 2017 (DFO 2020c). Many Atlantic Salmon fishery advocates have expressed concerns that the increase in Striped Bass is negatively affecting Salmon populations by preying upon smolts as they leave the rivers in the spring to begin ocean migrations. The concerns have been most pronounced in the Miramichi River where the majority of the adult Striped Bass population concentrates on the spawning grounds in the estuary at the same time as smolts are emigrating from the system. The predator-prey relationship between Striped Bass and Atlantic Salmon smolts in the Miramichi system has been recently and continues to be a topic of significant interest.

Over a three-year (2013-2015) study, DFO (2016a) provided direct evidence of predation by Striped Bass on Atlantic Salmon smolts in the Miramichi River. Striped Bass in the Miramichi River during the spring fed opportunistically and changed prey species as they became available (or unavailable) during different migration times. Small numbers of Atlantic Salmon smolts and in a low proportion of stomachs were identified from samples collected during a relatively brief interval of time in late May to early June in the three years of sampling and the occurrence of smolts corresponded to the timing of the smolt migration in the Miramichi River. (DFO 2016a; Hanson 2020).

Other evidence of Striped Bass predation on Atlantic Salmon smolts was inferred from an acoustic telemetry study conducted by the Atlantic Salmon Federation over multiple years between 2003 and 2016 in four rivers of the southern Gulf of St. Lawrence (Chaput et al. 2018). The survival of implanted Salmon smolts was monitored from the Southwest and Northwest Miramichi rivers where Striped Bass abundance was high and from the Restigouche and Cascapedia rivers where Striped Bass abundance was low. The survival rates of implanted smolts through Chaleur Bay (Restigouche, Cascapedia rivers) remained relatively high (67% to 95%) through time while smolt survival rates through Miramichi Bay (Southwest and Northwest Miramichi rivers) were lower (28% to 82%) and showed a decline beginning in 2010. The differences in apparent survival rates between the two neighbouring coastal embayments have been hypothesized to be in part related to differences in predation pressure on migrating smolts by Striped Bass present in the Miramichi Bay but not in Chaleur Bay (Chaput et al. 2018; Daniels et al. 2018).

There have also been a number of studies that have used acoustic telemetry to infer predator-prey interactions between Atlantic Salmon smolts and Striped Bass in the Miramichi River (Daniels et al. 2018; Daniels et al. 2019) and elsewhere (Gibson et al. 2015). Daniels et al. (2018) demonstrated smolt movements in the Miramichi River that were characteristic of Striped Bass movements, and depending on the choice of model, inferred predation rates that ranged from 2.6% to 19.9% among years and between tag release locations. In 2017, Daniels et al. (2019) implanted smolts with acoustic tags that could detect when they had been preyed upon which was reported to have occurred in 59% of the 41 smolts carrying these tags in the Northwest Miramichi River. Although the tags could not identify the predatory species, the high rate of predation inference was consistent with the high abundance of Striped Bass in the Miramichi River in the spring of 2017.

Researchers have cautioned against inferring mortality rates of wild and unmanipulated Salmon smolts from acoustically tagged and tracked individuals (Daniels et al. 2019). It is unlikely that a tagged smolt would have the same mean probability of survival as an untagged smolt as the capture, handling, and surgery would introduce stress and injury to individual animals (Ammann et al. 2013) and interrupt the migration during a particularly sensitive period of time (Riley et al. 2018). The removal of individuals from schooling with conspecifics can result in increased vulnerability to predation (Furey et al. 2016).

A recent attempt to better understand the predator-prey relationship between Striped Bass and Miramichi Salmon was provided by Chaput (2022) who modelled relative trends in sea survival rates for Miramichi smolts during their first year at sea and correlated them with annual Striped Bass abundance in the Miramichi. The hypothesis was that if predation by Striped Bass on

Atlantic Salmon smolts was intense enough during the early post-smolt phase, a signal in the relative return rates of adult Salmon should be apparent. Relative survival rates of smolts from the Southwest Miramichi were associated with variations in the Striped Bass abundance index but not so for the Northwest Miramichi smolts which were expected to be more impacted by predation considering the spatial and temporal overlap of Striped Bass spawner aggregations and the smolt migration window. The effect of Striped Bass predation on the smolt to adult dynamic for Miramichi Salmon were inconclusive (Chaput 2022).

There is direct and indirect evidence of a predator–prey relationship between the native Striped Bass and Atlantic Salmon (smolt) populations of the Miramichi River. There is inconclusive evidence that the predator-prey relationship between these two native species is driving the abundance of adult Salmon returning to the Miramichi River. Marine return rates of Atlantic Salmon to the Miramichi River, other monitored rivers in eastern Canada, and to many rivers across the species range have been declining over the past four decades, and in most cases, in the absence of any spatial or temporal overlap with Striped Bass (ICES 2020). The majority of the adult Striped Bass population of the southern Gulf occupies the Miramichi estuary each spring to spawn and therefore encounters with emigrating Atlantic Salmon smolts from other rivers are likely few.

FORESTRY PRACTICES

Forested land is intensively managed for timber production throughout all of New Brunswick, including SFA 16. Activities include widespread road building and stream crossings and mechanical timber harvests (clearcutting or select/partial harvest), followed by natural regeneration or silviculture prescriptions (planting, herbicide spraying, mechanical thinning). Forest management activities are conducted in accordance with government regulations and industry best practices, but have unquestionably altered the natural landscape on which they occur. Some concerns include potentially altered flow regimes, water temperature, increased sedimentation, soil compaction, and less mature intact forest on the landscape (if compared to natural New Brunswick forests). There is a wealth of historical and ongoing research within and outside of SFA 16 examining the impacts of forestry activities on hydrological processes and water quality within watersheds. The cumulative impact of forestry activities and the level to which they are a threat to Atlantic Salmon populations within the context of a changing climate remains uncertain.

Table 6. Summary of threats and their associated rating of scope, timing, and severity to Atlantic Salmon in SFA 16, Gulf Region NB. Threat scope (% of population affected) categories are as follows: PERVASIVE 71% - 100%; LARGE 31% - 70%; RESTRICTED 11% - 30%; SMALL 1% - 10%; NEGLIGIBLE < 1%; UNKNOWN. Threat timing categories are as follows: High – Continuing threat; Moderate – Short-term future; Low – Long-term future; Insignificant/Negligible – in past and unlikely to return. Threat severity (likelihood to destroy/reduce/degrade occurrences or habitat by "x" %) categories are as follows: EXTREME 71% - 100%; SERIOUS 31% – 70%; MODERATE 11% - 30%; SLIGHT 1% - 10%; NEGLIGIBLE < 1%; NEUTRAL or BENEFIT POTENTIAL – Not a threat; UNKNOWN.

Threat category	**Specific threat (with examples)**	**Threat Scope (% of population affected)**	**Threat Timing**	**Threat Severity (likelihood to destroy/reduce/degrade occurrences or habitat by "x" %)**	**Comments**
Residential and Commercial Development	Housing and Urban Areas	Negligible	Insignificant	Negligible	Potential for system failures or inadequate treatment systems.
	Commercial and Industrial Areas	Negligible	Insignificant	Negligible	-
	Ecotourism and Recreation	Small	High	Negligible	Construction of docks and clearing of land in the riparian zone; of greater relevance if existing mitigations measures are not followed.
	CUMULATIVE EFFECT	Small	High	Negligible	-
Agriculture and Aquaculture	Annual and perennial non-timber crops	Negligible	Insignificant	Negligible	-
	Livestock farming and ranching	Negligible	Insignificant	Negligible	Potential impacts from direct stream contact by farm animals/vehicles
	Marine and freshwater aquaculture	Unknown	Insignificant	Unknown	Although not directly relevant in SFA 16, there exists potential for interaction at sea with populations that may be affected by aquaculture (escapes from finfish facilities, disease, parasites, competition, effects on behaviour and migration, genetic introgression).
	CUMULATIVE EFFECT	Unknown	Insignificant	Unknown	-
Energy Production and Mining	Oil and Gas Drilling and Renewable Energy	Negligible	Low	Negligible	-
	Mining and Quarrying	Negligible	Low	Negligible	Historical impacts
	CUMULATIVE EFFECT	Negligible	Low	Negligible	Potential impacts from future energy or resource extraction projects

Threat category	Specific threat (with examples)	Threat Scope (% of population affected)	Threat Timing	Threat Severity (likelihood to destroy/reduce/degrade occurrences or habitat by "x" %)	Comments
Transportation and Service Corridors	Roads and railroads	Pervasive	High	Moderate	A high number of roads and stream crossings exist in most watersheds throughout the SFA. The threat severity would need to take into account the cumulative impact these roads and stream crossings have on hydrology, water quality, habitat and fish passage.
	Utility and service lines	Negligible	Insignificant	Negligible	Pipelines and cleared power transmission exist throughout SFA 16.
	Shipping lanes	Negligible	Insignificant	Negligible	Potential impacts from heavily used shipping lanes within migratory paths at sea (noise, disturbance).
	CUMULATIVE EFFECT	Pervasive	High	Moderate	-
Biological resource use	Logging and wood harvest	Pervasive	High	Moderate	Forested land is intensively managed (clear-cutting, planting, pesticide spraying) in New Brunswick for timber resource extraction. The activities are conducted with measures in place to mitigate effects on watercourses and fish habitat, but the landscape across all major watersheds is altered from a natural state as a result of clear-cutting and road construction.
	First Nations food, social and ceremonial fisheries	Small	High	Slight	There are five First Nations and one Aboriginal group that have FSC fisheries for Atlantic Salmon in SFA 16A but effort or harvests are poorly reported.

Threat category	Specific threat (with examples)	Threat Scope (% of population affected)	Threat Timing	Threat Severity (likelihood to destroy/reduce/degrade occurrences or habitat by "x" %)	Comments
Biological resource use	Recreational	Restricted	High	Negligible	There is a significant recreational fishery for Atlantic Salmon in SFA 16A which has been restricted to catch and release angling since 2015. A warm water protocol is in place for the Miramichi River which restricts angling during stressful heat events. Rivers in SFA16B have been closed to directed Salmon fishing since 1998. There is no mandatory mechanism in place to collect catch and effort information from this fishery.
	Poaching	Small	High	Slight	Poaching occurs within SFA 16; enforcement actively targets areas of known non-compliance.
	Commercial	N/A	Insignificant	N/A	Targeted commercial fisheries closed.
	Greenland / St Pierre – Miquelon mixed stock harvests	Small	High	Slight	Agreements are in place to reduce harvest in Greenland. Direct impact on this SFA may vary annually due to mixed stock fishery.
	Bycatch in other recreational fisheries	Negligible	High	Negligible	-
Biological resource use	Bycatch in commercial fisheries near shore	Small	High	Slight	Atlantic Salmon bycatch occurs in inland commercial Gaspereau traps and coastal mackerel and baitfish fisheries. Salmon bycatch is mandatory release, but some mortalities do occur.
	Bycatch in commercial fisheries offshore	Unknown	High	Unknown	-
	CUMULATIVE EFFECT	Restricted	High	Slight	-

Threat category	Specific threat (with examples)	Threat Scope (% of population affected)	Threat Timing	Threat Severity (likelihood to destroy/reduce/degrade occurrences or habitat by "x" %)	Comments
Human Intrusions and Disturbance	Recreational activities	Negligible	High	Unknown	Potential impact from disturbance by watercraft (personal or tourism related e.g. tubing operations), especially in times of stressfully warm/low water conditions. ATV and other vehicles crossing watercourse. Some efforts have been made to encourage recreational users to avoid major Salmon holding pools during stressful heat events.
	CUMULATIVE EFFECT	Negligible	High	Unknown	-
Natural systems modifications	Fire and fire suppression	Negligible	Insignificant	Negligible	-
	Dam and water management/use	Negligible	Insignificant	Negligible	-
	Other ecosystem modifications	Negligible	Insignificant	Negligible	-
	CUMULATIVE EFFECT	Negligible	Insignificant	Negligible	-
Invasive and other problematic species	Invasive non-native /alien species	Pervasive	High	Unknown	Smallmouth bass presence has been confirmed within Miramichi Lake, Lake brook and portions of the Southwest Miramichi river. There is potential for spread of this invasive species and increased threat level.
	Problematic native species	Small	High	Slight	See review of interactions between Striped Bass and other diadromous species in the Miramichi River (Chaput 2022).
	Introduced genetic material	Unknown	Moderate	Unknown	-
	CUMULATIVE EFFECT	Pervasive	High	Unknown	-
Pollution and contaminants	Household sewage and urban wastewater	Negligible	Insignificant	Negligible	Threat level assumes adequate and properly functioning systems.
	Industrial and military effluents	Negligible	Insignificant	Negligible	-

Threat category	Specific threat (with examples)	Threat Scope (% of population affected)	Threat Timing	Threat Severity (likelihood to destroy/reduce/degrade occurrences or habitat by "x" %)	Comments
	Agricultural and forestry effluents	Negligible	Insignificant	Negligible	-
	Garbage and solid waste	Negligible	Insignificant	Negligible	-
	Air-borne pollution	Negligible	Insignificant	Negligible	-
	Excess Energy	N/A	Insignificant	N/A	-
	CUMULATIVE EFFECTS	Negligible	Insignificant	Negligible	-
Geological events	Volcanoes	N/A	Insignificant	N/A	-
	Earthquakes and Tsunamis	Negligible	Insignificant	Negligible	-
	Avalanches and Landslides	Negligible	Insignificant	Negligible	-
	CUMULATIVE EFFORT	Negligible	Insignificant	Negligible	-
Climate Change	Habitat shifting and alteration	Pervasive	High	Extreme	Extreme weather events can impact hydrology and/or habitat, changing climate may have effect on short and long term conditions in freshwater and marine habitats.
	Droughts	Pervasive	High	Extreme	Extreme low flow and high water temperatures.
	Temperature extremes	Pervasive	High	Extreme	The trend in summer air and water temperatures in rivers is increasing and reaching levels lethal to Salmon more frequently. Protocols that limit angling when water temperatures are high are in place for the Miramichi River system and their use is becoming more common.
	Storms and flooding	Restricted	High	Moderate	Storms may lead to increased erosion, sedimentation (washouts, improper sized culverts, bridges).
	CUMULATIVE EFFECT	Pervasive	High	Extreme	-

MANIPULATED POPULATIONS

A summary of the stocking history of Atlantic Salmon in SFA 16 was provided in 'Overview of Designatable Units' above.

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APPENDICES

APPENDIX 1. CHARACTERISTICS OF ATLANTIC SALMON RIVERS IN SFA 16 AND ASSOCIATED LIMIT REFERENCE POINTS (LRP).

Table A1. Characteristics of rivers in SFA 16. Map index refers to numbers in Figure 1. The conservation egg requirement column is the value used in previous stock assessments and calculated as the product of 2.4 eggs per m² and fluvial area. The grey shaded cells in reference to rivers 23 to 27 include the value for the composite of five rivers collectively called Richibucto River. Fluvial area estimate references are: 1 – Anonymous (1978); 2 – Amiro (1983); 3 - Atkinson and Hooper (1995); 4 – Atkinson et al. 1995; a dash (-) indicates not available; tbd indicates to be determined; unk indicates unknown (DFO 2018a).

Map index	River	Salmon present	Conservation egg requirement (million)	Drainage area (km²)	Fluvial area (million m²)	Fluvial area estimate reference	Prop. eggs from large Salmon	LRP (eggs per m²)	LRP (eggs; million)	Reference river for biological data
1	Tabusintac	yes	1.98	704	0.824	3	0.97	1.52	1.25	Tabusintac
2	Burnt Church	yes	0.72	135	0.299	1	0.97	1.52	0.46	Tabusintac
3	Oyster	yes	-	-	tbd	-	0.97	1.52	tbd	Tabusintac
4	Bartibog	yes	2.72	512	1.135	2	0.97	1.52	1.73	Tabusintac
6	Northwest Miramichi	yes	20.1	2,138	8.230	2	0.78	1.76	14.48	Northwest
5	Northwest Millstream	yes	1.2	210	0.479	2	0.78	1.76	0.84	Miramichi
7	Little Southwest Miramichi	yes	19.7	1,345	8.070	2	0.78	1.76	14.20	system
9	Southwest Miramichi	yes	70.9	5,840	29.530	2	0.93	1.52	44.89	Southwest
8	Renous	yes	14	1,429	5.820	2	0.93	1.52	8.85	Miramichi
10	Barnaby	yes	3.1	490	1.304	2	0.93	1.52	1.98	system
11	Napan	yes	0.28	115	0.115	1	0.96	1.52	0.17	Buctouche
12	Black (Northumberland Co.)	yes	0.67	277	0.277	1	0.96	1.52	0.42	Buctouche
13	Bay du Vin	yes	0.68	284	0.284	1	0.96	1.52	0.43	Buctouche
14	Eel River	unk	-	116	tbd	1	0.96	1.52	tbd	Buctouche
15	Portage River	no	-	-	-	-	0.96	1.52	na	Buctouche
16	Riviere au Portage	yes	-	-	tbd	-	0.96	1.52	tbd	Buctouche
17	Black (Kent Co.)	yes	0.82	343	0.343	1	0.96	1.52	0.52	Buctouche
18	Rankin Brook	yes	-	-	tbd	-	0.96	1.52	tbd	Buctouche
19	Kouchibouguac (Kent Co.)	yes	1.41	389	0.588	1	0.96	1.52	0.89	Buctouche
20	Ruisseau des Major	no	-	25	-	1	0.96	1.52	-	Buctouche
21	Kouchibouguacis	yes	1.32	360	0.549	1	0.96	1.52	0.83	Buctouche
22	Saint Charles	unk	-	149	tbd	1	0.96	1.52	tbd	Buctouche
23	Molus River	yes	2.94	172	1.226	1	0.96	1.52	1.86	Buctouche
24	Bass River	yes		115		1	0.96	1.52		Buctouche
25	Richibucto	yes		449		1	0.96	1.52		Buctouche
26	Coal Branch	yes		212		1	0.96	1.52		Buctouche

Map index	River	Salmon present	Conservation egg requirement (million)	Drainage area (km²)	Fluvial area (million m²)	Fluvial area estimate reference	Prop. eggs from large Salmon	LRP (eggs per m²)	LRP (eggs; million)	Reference river for biological data
27	Saint Nicholas	yes		194		1	0.96	1.52		Buctouche
28	Chockpish	yes	0.31	129	0.129	1	0.96	1.52	0.20	Buctouche
29	Black	unk	-	-	tbd	-	0.96	1.52	tbd	Buctouche
30	Buctouche	yes	1.59	566	0.661	4	0.96	1.52	1.00	Buctouche
31	Cocagne	yes	0.68	333	0.283	1	0.96	1.52	0.43	Buctouche
32	Shediac	yes	0.52	219	0.216	1	0.96	1.52	0.33	Buctouche
33	Scoudouc	yes	0.35	159	0.146	1	0.96	1.52	0.22	Buctouche
34	Aboujagane	yes	0.29	120	0.120	1	0.96	1.52	0.18	Buctouche
35	Kinnear Brook	no	-	-	-	-	0.96	1.52	-	Buctouche
36	Kouchibouguac (Westmorland Co.)	no	-	346	-	1	0.96	1.52	-	Buctouche
37	Tedish River	unk	-	-	tbd	-	0.96	1.52	tbd	Buctouche
38	Gaspereau (Westmorland Co.)	yes	0.41	170	0.170	1	0.96	1.52	0.26	Buctouche
39	Baie Verte	unk	0.14	38	0.058	1	0.96	1.52	0.09	Buctouche

APPENDIX 2. DATA, PRIORS, AND LIKELIHOOD EQUATIONS USED TO ESTIMATE RETURNS OF SMALL AND LARGE SALMON TO THE MIRAMICHI RIVER AND TO EACH OF THE SOUTHWEST AND NORTHWEST MIRAMICHI RIVERS.

Table A2. Comparison of data used, priors, and likelihood equations for returns of small Salmon and large Salmon for the revised model and the previously published model. The symbol ∅ refers to the hierarchical dimension of the parameters when appropriate. The monitoring locations are shown in Figure A1.

Characteristic	Model of this manuscript	Model in Chaput and Douglas (2012)
Time series	1984 to 2019	1998 to 2019
Return priors		
Miramichi River	$RetMir_y = RetSw_y + RetNW_y$	$RetMir_y = RetSw_y + RetNW_y$
Southwest Miramichi	$RetSW_y \sim LogNormal(10,1)$	$RetSW_y \sim Unif(min, max)$
Northwest Miramichi	$RetNW_y \sim LogNormal(10,1)$	$RetNW_y \sim Unif(min, max)$
Trapnet catches		
Millbank	$CMill_y \sim Bin(pMill_y,\ RetMir_y)$ $pMill_y \vert \emptyset \sim Beta(\alpha_\emptyset,\ \beta_\emptyset)$ $y = 1984{:}1992$	-
Southwest Enclosure	$CSWEnc_y \sim Bin(pSWEnc_y\ \ RetSW_y)$ $pSWEnc_y \vert \emptyset \sim Beta(\alpha_\emptyset\ \ \beta_\emptyset)$ y = 1985:1987; 1991:1997	-
Southwest Millerton	$CSWMil_y \sim Bin(pSWMil_y\ \ RetSW_y)$ $pSWMil_y \vert \emptyset \sim Beta(\alpha_\emptyset\ \ \beta_\emptyset)$ y = 1994:2019	$CSWMil_y \sim Bin(pSWMil_y\ \ RetSW_y)$ $pSWMil_y \vert \emptyset \sim Beta(\alpha_\emptyset\ \ \beta_\emptyset)$ y = 1998:2019
Southwest Renous fence	$CSWRen_y \sim Bin(pSWRen\ RetSW_y)$ $pSWRen \sim Beta(1\ \ 1)$ y = 1995	-
Northwest Eel Ground	$CNWEel_y \sim Bin(pNWEel_y, RetNW_y)$ $pNWEel_y \vert \emptyset \sim Beta(\alpha_\emptyset,\ \beta_\emptyset)$ 1985:1987; 1991:1997	-
Northwest Cassilis	$NWCas_y \sim Bin(pNWCas_y\ \ RetNW_y)$ $pNWCas_y \vert \emptyset \sim Beta(\alpha_\emptyset\ \ \beta_\emptyset)$ y = 1998:2019	$NWCas_y \sim Bin(pNWCas_y\ \ RetNW_y)$ $pNWCas_y \vert \emptyset \sim Beta(\alpha_\emptyset\ \ \beta_\emptyset)$ y = 1998:2019
Northwest Red Bank	$CNWRed_y \sim Bin(pNWRed_y\ \ RetNW_y)$ $pNWRed_y \vert \emptyset \sim Beta(\alpha_\emptyset\ \ \beta_\emptyset)$ y = 1991:2019	$CNWRed_y \sim Bin(pNWRed_y\ \ RetNW_y)$ $pNWRed_y \vert \emptyset \sim Beta(\alpha_\emptyset\ \ \beta_\emptyset)$ y = 1998:2019
Fences and barriers		
Southwest Dungarvon	$CDung_y \sim Bin(pDung_y\ \ EscSW_y)$ $pDung_y \vert \emptyset \sim Beta(\alpha_\emptyset\ \ \beta_\emptyset)$ y = 1984:2019	$CDung_y \sim Bin(pDung_y, RetSW_y^{Early})$ $pDung_y \vert \emptyset \sim Beta(\alpha_\emptyset,\ \beta_\emptyset)$ $1998{:}2019$ $RetSW_y^{Early} \sim Bin(pSWEarly_y, RetSW_y)$ $pSWEarly_y \sim Beta(CSWMil_y^{Early}, CSWMil_y^{Late})$ $CSWMil_y^{Early}$ is the catch up to and including July 31 in year y
Southwest Juniper	$CJunip_y \sim Bin(pJunip_y\ \ EscSW_y)$ $pJunip_y \vert \emptyset \sim Beta(\alpha_\emptyset\ \ \beta_\emptyset)$ y = 1984:2013	$CJunip_y \sim Bin(pJunip_y, RetSW_y)$ $pJunip_y \vert \emptyset \sim Beta(\alpha_\emptyset,\ \beta_\emptyset)$ $1998{:}2010$

Characteristic	Model of this manuscript	Model in Chaput and Douglas (2012)
Northwest Barrier	$CNWBar_y \sim Bin(pNWBar_y \;\; EscNW_y)$ $pNWBar_y \| \emptyset \sim Beta(\alpha_\emptyset \;\; \beta_\emptyset)$ y = 1988:2019	$CNWBar_y \sim Bin(pNWBar_y, RetNW_y^{Early})$ $pNWBar_y \| \emptyset \sim Beta(\alpha_\emptyset, \beta_\emptyset)$ 1998: 2019 $RetNW_y^{Early} \sim Bin(pNWEarly_y, RetNW_y)$ $pNWEarly_y \sim Beta(CNWCas_y^{Early}, CNWCas_y^{Late})$ $CNWCas_y^{Early}$ is the catch up to and including July 31 in year y
Catamaran Brook fence	$CCata_y \sim Bin(pCata_y \;\; EscNW_y)$ $pCata_y \| \emptyset \sim Beta(\alpha_\emptyset \;\; \beta_\emptyset)$ y = 1990:2000	-
Angling catches		
Southwest Miramichi	$CAngSW_y \sim Bin(ERSW_y \;\; RetSW_y)$ $ERSW_y \| \emptyset \sim Beta(\alpha_\emptyset \;\; \beta_\emptyset)$ y = 1984:1995, 1997	-
Northwest Miramichi	$CAngNW_y \sim Bin(ERNW_y \;\; RetNW_y)$ $ERNW_y \| \emptyset \sim Beta(\alpha_\emptyset \;\; \beta_\emptyset)$ y = 1984:1995, 1997	-
Northwest Miramichi Crown Reserve	$CAngCRNW_y \sim Bin(ERCRNW_y \;\; RetNW_y)$ $ERCRNW_y \| \emptyset \sim Beta(\alpha_\emptyset \;\; \beta_\emptyset)$ y = 1984:2019	-
Escapement		
Southwest Miramichi	For small Salmon: $EscSW_y = RetSW_y - CAngSW_y$ 1984: 2014 $EscSW_y = RetSW_y - (CAngSW_y * 0.03)$ 2015: 2019 For large Salmon: $EscSW_y = RetSW_y - (CAngSW_y * 0.03)$ 1984: 2019 For small Salmon and large Salmon: $CAngSW_y = ERSW_\emptyset * RetSW_y$ 1996, 1998: 2019	-
Northwest Miramichi	For small Salmon: $EscNW_y = RetNW_y - CAngNW_y$ 1984: 2014 $EscNW_y = RetNW_y - (CAngNW_y * 0.03)$ 2015: 2019 For large Salmon: $EscNW_y = RetNW_y - (CAngNW_y * 0.03)$ 1984: 2019 For small Salmon and large Salmon: $CAngNW_y = ERNW_\emptyset * RetNW_y$ 1996, 1998: 2019	-
10% tagging mortality		
All locations	$M'_{y,k} \sim Bin(0.9, M_{y,k})$ k = Millbank, Miramichi (other), SW Enclosure, SW Lower (other), SW Millerton, NW Eel Ground, NW Lower (other), NW Cassilis	$M'_{y,k} \sim Bin(0.9, M_{y,k})$ k = Miramichi (other), SW Lower (other), SW Millerton, NW Lower (other), NW Cassilis
Movement of tags		
From Millbank	To NW: $pNW_y^{Mill} \| \emptyset \sim Beta(\alpha_y^{Mill}, \beta_y^{Mill})$ To SW: $(1 - pNW_y^{Mill})$	-
From Miramichi other	To NW: $pNW_y^{Mir} \sim Beta(1,1)$ To SW: $(1 - pNW_y^{Mir})$	To NW: $pNW_y^{Mir} \sim Beta(1,1)$ To SW: $(1 - pNW_y^{Mir})$

Characteristic	Model of this manuscript	Model in Chaput and Douglas (2012)
From SW Enclosure / SW Lower (other)	To NW: $pNW_y^{SWlow} \| \emptyset \sim Beta(\alpha_y^{SWlow}, \beta_y^{SWlow})$ To SW: $(1 - pNW_y^{SWlow})$	To NW: $pNW_y^{SWlow} \| \emptyset \sim Beta(\alpha_y^{SWlow}, \beta_y^{SWlow})$ To SW: $(1 - pNW_y^{SWlow})$
From SW Millerton	To NW: $pNW_y^{SWMil} \| \emptyset \sim Beta(\alpha_y^{SWMil}, \beta_y^{SWMil})$ To SW: $(1 - pNW_y^{SWMil})$	To NW: $pNW_y^{SWMil} \| \emptyset \sim Beta(\alpha_y^{SWMil}, \beta_y^{SWMil})$ To SW: $(1 - pNW_y^{SWMil})$
From NW Eel Ground / NW Lower (other)	To SW: $pSW_y^{NWlow} \| \emptyset \sim Beta(\alpha_y^{NWlow}, \beta_y^{NWlow})$ To NW: $(1 - pSW_y^{NWlow})$	To SW: $pSW_y^{NWlow} \| \emptyset \sim Beta(\alpha_y^{NWlow}, \beta_y^{NWlow})$ To NW: $(1 - pSW_y^{NWlow})$
From NW Cassilis	To SW: $pSW_y^{NWCas} \| \emptyset \sim Beta(\alpha_y^{NWCas}, \beta_y^{NWCas})$ To NW: $(1 - pSW_y^{NWCas})$	To SW: $pSW_y^{NWCas} \| \emptyset \sim Beta(\alpha_y^{NWCas}, \beta_y^{NWCas})$ To NW: $(1 - pSW_y^{NWCas})$
Tag recaptures		
At SW Enclosure	$RSWEnc_{y,k} \| \emptyset \sim Bin(pSWEnc_y, M'_{y,k})$ k = Millbank, NW Eel Ground	-
At SW Millerton	$RSWMil_{y,k} \| \emptyset \sim Bin(pSWMil_y, M'_{y,k})$ k = Miramichi (other), SW Enclosure, SW Lower (other), NW Eel Ground, NW Lower (other), NW Cassilis	$RSWMil_{y,k} \| \emptyset \sim Bin(pSWMil_y, M'_{y,k})$ k = Miramichi (other), SW Enclosure, SW Lower (other), NW Eel Ground, NW Lower (other), NW Cassilis
At SW Renous fence	$RSWRen_{y,k} \sim Bin(pSWRen,\ M'_{y\ k})$ $pSWRen \sim Beta(1\ 1)$ y = 1995 k = SW Enclosure, SW Millerton	-
At NW Eel Ground	$RNWEel_{y,k} \| \emptyset \sim Bin(pNWEel_y, M'_{y,k})$ k = Millbank, SW Enclosure	-
At NW Cassilis	$RNWCas_{y,k} \| \emptyset \sim Bin(pNWCas_y, M'_{y,k})$ k = SW Lower (other), SW Millerton, NW Lower (other)	$RNWCas_{y,k} \| \emptyset \sim Bin(pNWCas_y, M'_{y,k})$ k = SW Lower (other), SW Millerton, NW Lower (other)
At NW Red Bank	$RNWRed_{y,k} \| \emptyset \sim Bin(pNWRed_y, M'_{y,k})$ k = Millbank, Miramichi (other), SW Enclosure, SW Lower (other), SW Millerton, NW Eel Ground, NW Lower (other), NW Cassilis	$RNWRed_{y,k} \| \emptyset \sim Bin(pNWRed_y, M'_{y,k})$ k = Miramichi (other), SW Lower (other), SW Millerton, NW Lower (other), NW Cassilis

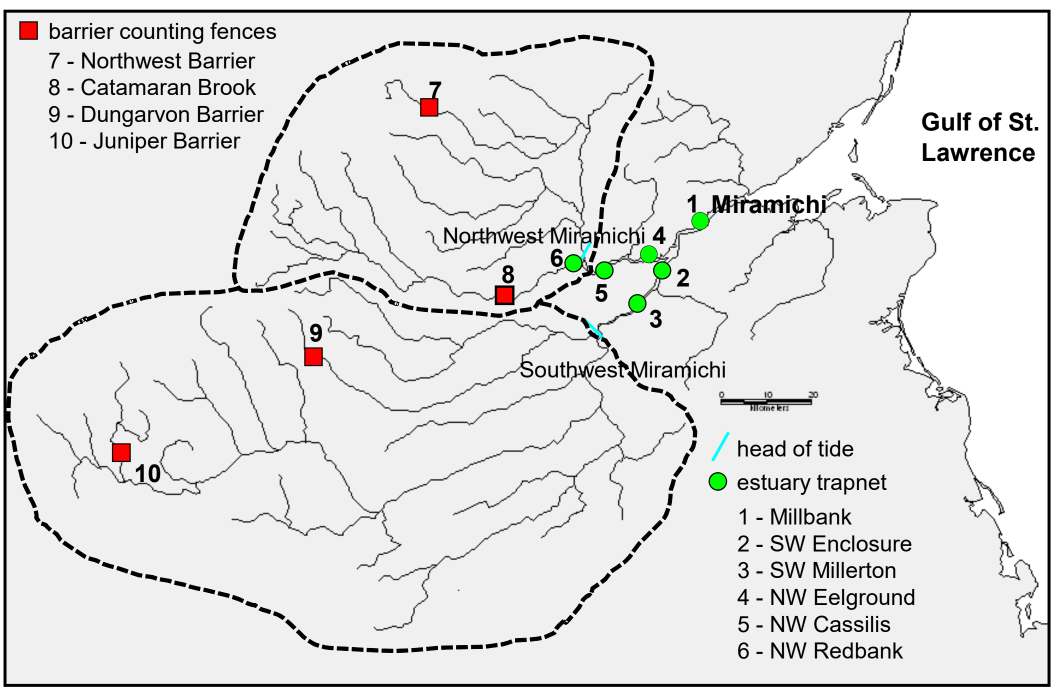

Figure A1. Location of trapnets and counting facilities in the Miramichi River used in the assessment of Atlantic Salmon returns for the period 1984 to 2019.

APPENDIX 3. CATCHES, MARKS PLACED, AND RECAPTURES OF SMALL SALMON AT MONITORING FACILITIES OF THE MIRAMICHI RIVER

Table A3. Site specific catches for small Salmon.

Year	Millbank	SW Enclosure	SW Millerton	SW Renous fence	NW Eel Ground	NW Cassilis	NW Red Bank	NW Barrier	Cata-maran	Dungar-von	Juniper
1984	1010	-	-	-	-	-	-	-	-	315	230
1985	912	848	-	-	695	-	-	-	-	536	492
1986	1763	1519	-	-	832	-	-	-	-	501	2072
1987	1272	815	-	-	724	-	-	-	-	744	1175
1988	1828	-	-	-	-	-	-	1614	-	851	1092
1989	1128	-	-	-	-	-	-	966	-	579	969
1990	1358	-	-	-	-	-	-	1318	166	562	1646
1991	913	193	-	-	220	-	217	765	88	296	495
1992	971	1606	-	-	1064	-	793	1165	141	825	1383
1993	-	1193	-	-	428	-	83	1034	113	659	1349
1994	-	927	2383	-	491	-	1317	673	56	358	1195
1995	-	1203	2362	449	405	-	1360	548	131	329	811
1996	-	1461	2121	-	830	-	882	602	80	590	1388
1997	-	642	860	-	261	-	495	501	41	391	566
1998	-	-	1158	-	-	758	246	1038	88	592	981
1999	-	-	924	-	-	835	1329	708	75	378	566
2000	-	-	1442	-	-	1090	2018	456	56	372	1202
2001	-	-	2153	-	-	893	763	344	-	295	729
2002	-	-	2718	-	-	1664	897	595	-	287	1371
2003	-	-	2182	-	-	617	275	478	-	389	912
2004	-	-	2910	-	-	1232	1052	723	-	559	1368
2005	-	-	2447	-	-	932	-	735	-	441	853
2006	-	-	2636	-	-	659	72	469	-	468	853
2007	-	-	1353	-	-	893	432	460	-	195	945
2008	-	-	1485	-	-	704	105	1094	-	664	1087
2009	-	-	949	-	-	270	91	315	-	207	242
2010	-	-	2591	-	-	2474	1196	852	-	660	307
2011	-	-	2000	-	-	1170	383	995	-	711	267
2012	-	-	491	-	-	252	80	237	-	169	152
2013	-	-	448	-	-	379	246	240	-	244	136
2014	-	-	631	-	-	111	37	185	-	106	-
2015	-	-	1266	-	-	1304	534	310	-	328	-
2016	-	-	958	-	-	479	85	290	-	208	-
2017	-	-	903	-	-	810	141	137	-	141	-
2018	-	-	539	-	-	389	-	120	-	113	-
2019	-	-	501	-	-	313	41	164	-	124	-

Table A4. Site specific marks placed at Millbank trapnet and recaptures at other facilities for small Salmon.

		Recaptured at		
Year	Millbank (tagged)	SW Enclosure	NW Eel Ground	NW Red Bank
1985	222	10	5	-
1986	404	17	9	-
1987	275	4	3	-
1988	241	-	-	-
1989	206	-	-	-
1990	391	-	-	-
1991	317	2	2	2
1992	189	11	3	6

Table A5. Site specific marks placed at other trapnet in main stem of Miramichi and recaptured at other facilities for small Salmon. The trapnet was installed and operated by the Miramichi Salmon Association for the purpose of contributing to improving the assessment of adult returns to the Miramichi River.

Year	Miramichi main stem (tagged)	Recaptured at		
		SW Millerton	NW Cassilis	NW Red Bank
2014	80	8	0	0
2015	347	17	10	1

Table A6. Site specific marks placed at Southwest Enclosure trapnet and recaptures at other facilities for small Salmon.

Year	SW Enclosure (tagged)	Recaptured at			
		SW Millerton	SW Renous fence	NW Eel Ground	NW Red Bank
1991	178	-	-	1	1
1992	1521	-	-	22	17
1993	1057	-	-	- [a]	- [a]
1994	877	68	-	10	13
1995	1170	68	8	24	24
1996	550	52	-	11	10
1997	391	27	-	1	4

[a] recapture data not available in the annual report

Table A7. Site specific marks placed opportunistically at trapnets in the lower portion of the Southwest Miramichi operated by Eel Ground First Nation for small Salmon.

Year	SW Miramichi lower trapnets (tagged)	Recaptured at			
		SW Millerton	NW Eel Ground	NW Cassilis	NW Red Bank
1996	112	4	2	-	2
1997	63	2	1	-	0
1998	508	39	-	6	4
1999	790	41	-	11	20
2000	1065	55	-	22	28
2001	613	51	-	13	7
2002	625	49	-	13	10
2003	499	42	-	3	3
2004	524	34	-	11	10
2005	109	15	-	1	-
2006	175	12	-	3	0
2007	89	3	-	1	0
2008	78	3	-	0	0
2009	38	4	-	1	0
2010	452	20	-	3	8
2011	258	10	-	4	2
2012	-	-	-	-	-
2013	11	0	-	1	0
2014	-	-	-	-	-
2015	30	3	-	0	1

Table A8. Site specific marks placed at Southwest Millerton trapnet and recaptures at other facilities for small Salmon.

Year	Southwest Millerton (tagged)	Recaptured at			
		SW Renous fence	NW Eel Ground	NW Cassilis	NW Red Bank
1994	2063	-	19	-	16
1995	2205	27	16	-	21
1996	2017	-	13	-	22
1997	847	-	7	-	5
1998	1148	-	-	9	1
1999	898	-	-	4	3
2000	1434	-	-	10	2
2001	1140	-	-	8	7
2002	1587	-	-	10	17
2003	1320	-	-	16	4
2004	2138	-	-	19	5
2005	1518	-	-	10	-
2006	1948	-	-	27	1
2007	1054	-	-	9	3
2008	966	-	-	1	2
2009	681	-	-	1	1
2010	1207	-	-	9	3
2011	1208	-	-	3	2
2012	404	-	-	0	1
2013	370	-	-	3	0
2014	586	-	-	4	0
2015	675	-	-	4	1
2016	663	-	-	4	0
2017	739	-	-	20	1
2018	343	-	-	11	-
2019	437	-	-	6	0

Table A9. Site specific marks placed at Northwest Eel Ground trapnet and recaptures at other facilities for small Salmon.

Year	NW Eel Ground (tagged)	Recaptured at		
		SW Enclosure	SW Millerton	NW Red Bank
1991	113	0	-	0
1992	981	15	-	39
1993	385	-[a]	-	-[a]
1994	438	10	22	9
1995	393	11	8	17
1996	551	6	14	27
1997	146	5	10	4

[a] recapture data not available in report

Table A10. Site specific marks placed opportunistically at other Northwest Miramichi trapnets operated by Eel Ground First Nation and recaptures at other facilities for small Salmon.

Year	NW Miramichi lower trapnets (tagged)	Recaptured at			
		SW Enclosure	SW Millerton	NW Cassilis	NW Red Bank
1994	197	2	4	-	5
1996	240	5	3	-	7
2013	39	-	1	1	0

Table A11. Site specific marks placed at the Northwest Cassilis trapnet and recaptures at other facilities for small Salmon.

		Recaptured at	
Year	Northwest Cassilis (tagged)	SW Millerton	NW Red Bank
1998	745	9	18
1999	794	7	95
2000	1076	12	140
2001	734	19	52
2002	1127	20	46
2003	594	6	22
2004	1115	13	73
2005	783	13	-
2006	646	9	10
2007	828	4	59
2008	677	6	12
2009	255	0	8
2010	1282	21	72
2011	840	6	12
2012	231	3	3
2013	331	0	10
2014	100	5	3
2015	915	19	31
2016	377	6	9
2017	671	21	16
2018	274	9	-
2019	278	4	1

APPENDIX 4. CATCHES, MARKS PLACED, AND RECAPTURES OF LARGE SALMON AT MONITORING FACILITIES OF THE MIRAMICHI RIVER

Table A12. Site specific catches for large Salmon.

Year	Millbank	SW Enclosure	SW Millerton	SW Renous fence	NW Eel Ground	NW Cassilis	NW Red Bank	NW Barrier	Cata-maran	Dungar-von	Juniper
1984	333	-	-	-	-	-	-	-	-	93	297
1985	311	486	-	-	204	-	-	-	-	162	604
1986	469	585	-	-	264	-	-	-	-	174	1138
1987	291	815	-	-	213	-	-	-	-	202	1266
1988	325	-	-	-	-	-	-	234	-	277	929
1989	257	-	-	-	-	-	-	287	-	315	731
1990	427	-	-	-	-	-	-	331	56	318	994
1991	448	84	-	-	83	-	182	224	53	204	476
1992	202	450	-	-	465	-	287	219	74	232	1047
1993	-	375	-	-	175	-	-	216	46	223	1145
1994	-	289	885	-	124	-	447	228	24	155	905
1995	-	813	1543	45	231	-	828	252	80	95	1019
1996	-	469	727	-	233	-	288	218	43	184	819
1997	-	459	749	-	296	-	353	152	28	115	519
1998	-	-	363	-	-	217	64	289	44	163	698
1999	-	-	436	-	-	280	551	387	41	185	698
2000	-	-	395	-	-	277	610	217	11	130	725
2001	-	-	1352	-	-	983	517	202	-	111	904
2002	-	-	510	-	-	188	140	121	-	107	546
2003	-	-	1080	-	-	339	146	186	-	158	920
2004	-	-	1040	-	-	358	261	167	-	185	764
2005	-	-	750	-	-	417	-	262	-	300	673
2006	-	-	1047	-	-	210	11	214	-	217	829
2007	-	-	613	-	-	365	205	166	-	88	783
2008	-	-	298	-	-	124	15	164	-	131	692
2009	-	-	824	-	-	204	80	207	-	234	889
2010	-	-	798	-	-	524	333	284	-	228	563
2011	-	-	732	-	-	464	252	298	-	327	378
2012	-	-	549	-	-	217	119	163	-	135	361
2013	-	-	373	-	-	189	140	252	-	292	219
2014	-	-	533	-	-	91	34	65	-	78	-
2015	-	-	525	-	-	316	149	60	-	232	-
2016	-	-	719	-	-	520	54	91	-	152	-
2017	-	-	536	-	-	572	100	120	-	133	-
2018	-	-	612	-	-	418	-	119	-	93	-
2019	-	-	165	-	-	87	33	55	-	91	-

Table A13. Site specific marks placed at Millbank trapnet and recaptures at other facilities for large Salmon.

Year	Millbank (tagged)	Recaptured at SW Enclosure	Recaptured at NW Eel Ground	Recaptured at NW Red Bank
1985	222	4	0	-
1986	404	3	5	-
1987	275	4	3	-
1988	241	-	-	-
1989	206	-	-	-
1990	391	-	-	-
1991	317	0	0	1
1992	189	5	2	0

Table A14. Site specific marks placed at other trapnet in main stem of Miramichi and recaptured at other facilities for large Salmon. The trapnet was installed and operated by the Miramichi Salmon Association for the purpose of contributing to improving the assessment of adult returns to the Miramichi River.

Year	Miramichi main stem (tagged)	Recaptured at		
		SW Millerton	NW Cassilis	NW Red Bank
2014	81	5	0	0
2015	170	7	2	1

Table A15. Site specific marks placed at Southwest Enclosure trapnet and recaptures at other facilities for large Salmon.

Year	SW Enclosure (tagged)	Recaptured at			
		SW Millerton	SW Renous fence	NW Eel Ground	NW Red Bank
1991	77	-	-	0	0
1992	422	-	-	4	4
1993	359	-	-	- [a]	- [a]
1994	273	10	-	2	2
1995	796	46	0	8	7
1996	462	23	-	2	7
1997	443	33	-	4	2

[a] recapture data not available in annual report

Table A16. Site specific marks placed opportunistically at trapnets in the lower portion of the Southwest Miramichi operated by Eel Ground First Nation for large Salmon.

Year	SW Miramichi lower trapnets (tagged)	Recaptured at			
		SW Millerton	NW Eel Ground	NW Cassilis	NW Red Bank
1995	356	24	3	-	8
1996	32	0	0	-	0
1997	73	7	0	-	0
1998	309	5	-	1	1
1999	357	15	-	1	13
2000	355	9	-	9	5
2001	704	57	-	20	7
2002	231	12	-	1	1
2003	345	17	-	2	0
2004	338	13	-	7	2
2005	190	11	-	4	-
2006	210	10	-	3	0
2007	279	1	-	6	0
2008	118	1	-	0	0
2009	440	19	-	6	1
2010	440	17	-	5	2
2011	417	7	-	1	1
2012	219	7	-	2	0
2013	79	4	-	0	0
2014	-	-	-	-	-
2015	99	4	-	2	0
2016	-	-	-	-	-
2017	16	2	-	1	0

Table A17. Site specific marks placed at Southwest Millerton trapnet and recaptures at other facilities for large Salmon.

Year	Southwest Millerton (tagged)	Recaptured at			
		SW Renous fence	NW Eel Ground	NW Cassilis	NW Red Bank
1994	755	-	3	-	1
1995	1480	3	10	-	10
1996	695	-	5	-	4
1997	741	-	4	-	0
1998	354	-	-	1	0
1999	403	-	-	0	1
2000	382	-	-	2	1
2001	1271	-	-	12	4
2002	494	-	-	5	4
2003	1050	-	-	10	5
2004	972	-	-	9	2
2005	705	-	-	8	-
2006	1005	-	-	7	0
2007	581	-	-	2	1
2008	281	-	-	1	0
2009	537	-	-	1	2
2010	621	-	-	1	1
2011	644	-	-	7	0
2012	418	-	-	3	0
2013	329	-	-	5	0
2014	508	-	-	2	0
2015	379	-	-	2	0
2016	565	-	-	6	0
2017	467	-	-	14	0
2018	489	-	-	16	-
2019	149	-	-	1	0

Table A18. Site specific marks placed at Northwest Eel Ground trapnet and recaptures at other facilities for large Salmon.

Year	NW Eel Ground (tagged)	Recaptured at		
		SW Enclosure	SW Millerton	NW Red Bank
1991	62	0	-	0
1992	422	6	-	13
1993	174	- [a]	-	- [a]
1994	112	0	10	2
1995	229	9	9	5
1996	226	1	3	4
1997	292	4	8	6

[a] recapture data not available in annual report

Table A19. Site specific marks placed opportunistically at other Northwest Miramichi trapnets operated by Eel Ground First Nation and recaptures at other facilities for large Salmon.

Year	NW Miramichi lower trapnets (tagged)	Recaptured at			
		SW Enclosure	SW Millerton	NW Cassilis	NW Red Bank
1994	193	1	4	-	6
1995	134	3	5	-	2
1996	112	3	3	-	3
1997	31	0	1	-	0
2012	97	-	5	0	0
2013	42	-	1	1	0
2016	36	-	2	0	0

Table A20. Site specific marks placed at the Northwest Cassilis trapnet and recaptures at other facilities for large Salmon.

Year	Northwest Cassilis (tagged)	Recaptured at	
		SW Millerton	NW Red Bank
1998	210	2	4
1999	274	2	27
2000	275	3	20
2001	946	35	33
2002	182	0	13
2003	335	9	18
2004	351	4	20
2005	387	2	-
2006	206	4	0
2007	347	12	14
2008	121	3	1
2009	197	0	5
2010	443	14	30
2011	399	3	9
2012	190	4	3
2013	168	1	4
2014	86	4	0
2015	301	3	3
2016	396	4	6
2017	515	10	7
2018	373	8	-
2019	74	0	0

APPENDIX 5. ANGLING CATCHES OF SMALL SALMON AND LARGE SALMON FOR THE SOUTHWEST MIRAMICHI, NORTHWEST MIRAMICHI, AND THE CROWN RESERVE WATERS OF THE NORTHWEST MIRAMICHI RIVER

Table A21. Angling catches of small salmon and large salmon for the Southwest and Northwest Miramichi rivers and the crown reserve waters of the Northwest Miramichi River, 1984-2019.

	Small Salmon			Large Salmon		
Year	Southwest Miramichi	Northwest Miramichi	Crown Reserve Northwest Miramichi	Southwest Miramichi	Northwest Miramichi	Crown Reserve Northwest Miramichi
1984	12827	5964	2179	4857	2828	229
1985	9007	9430	2269	6522	3098	206
1986	16616	9537	2456	10379	3836	156
1987	13670	7095	1839	9844	2088	88
1988	20753	9833	2432	6986	3082	102
1989	16814	7568	2535	9123	2805	127
1990	14547	6825	2502	7029	2229	144
1991	8244	3056	2395	4614	1533	77
1992	14522	6960	2364	7682	1794	94
1993	10727	6171	2432	5945	2186	135
1994	7072	4131	2342	3261	1868	130
1995	11258	5636	1773	6294	1998	88
1996	-	-	2607	-	-	131
1997	7440	4052	2494	3646	1432	115
1998	-	-	2488	-	-	125
1999	-	-	2177	-	-	68
2000	-	-	2619	-	-	93
2001	-	-	2298	-	-	119
2002	-	-	2566	-	-	66
2003	-	-	2601	-	-	174
2004	-	-	2565	-	-	74
2005	-	-	2637	-	-	112
2006	-	-	2579	-	-	99
2007	-	-	2574	-	-	125
2008	-	-	2558	-	-	135
2009	-	-	2755	-	-	235
2010	-	-	2208	-	-	158
2011	-	-	2336	-	-	274
2012	-	-	1919	-	-	63
2013	-	-	2289	-	-	211
2014	-	-	2423	-	-	94
2015	-	-	2197	-	-	103
2016	-	-	2229	-	-	116
2017	-	-	1963	-	-	66
2018	-	-	1655	-	-	45
2019	-	-	1772	-	-	38

APPENDIX 6. POSTERIOR ESTIMATES OF THE PROPORTION OF ANNUAL ESCAPEMENT REPRESENTED BY HEADWATER BARRIER AND FENCE COUNTS, OF TOTAL RETURNS BASED IN TRAPNET CATCHES AND CATCH RATES FOR THE RECREATIONAL FISHERY CATCH INDICATORS

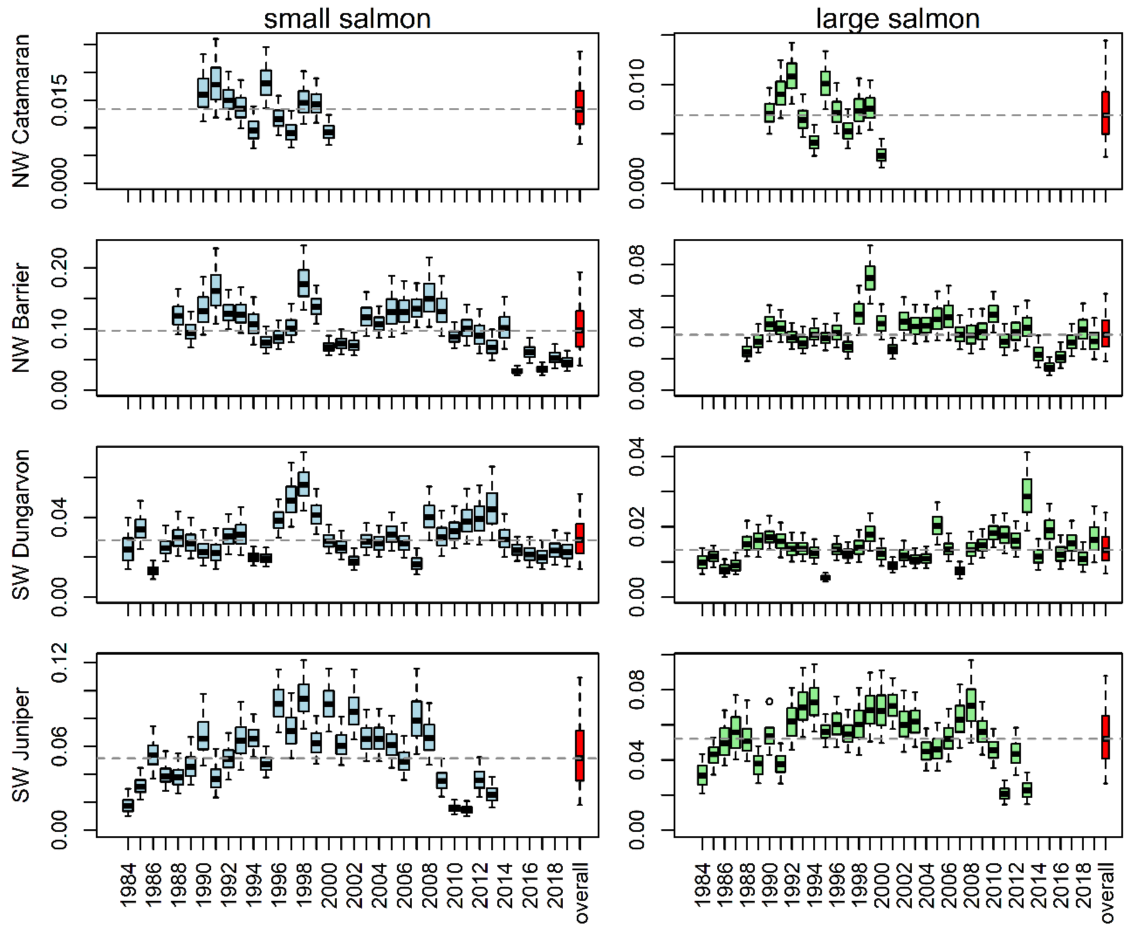

Figure A2. Posterior distributions of the annual proportions of the estimated escapement (after fisheries losses) of small Salmon and large Salmon represented at the headwater monitoring facilities in the Miramichi River, 1984 to 2019. The value labelled "overall" and shaded in red is the posterior distribution of the hierarchical proportion over all years. The boxplots are interpreted as: whiskers are the 5th to 95th percentile range, the boxes are the interquartile range, and the dash is the median. The horizontal dash line represents the median of the hierarchical proportion over all years.

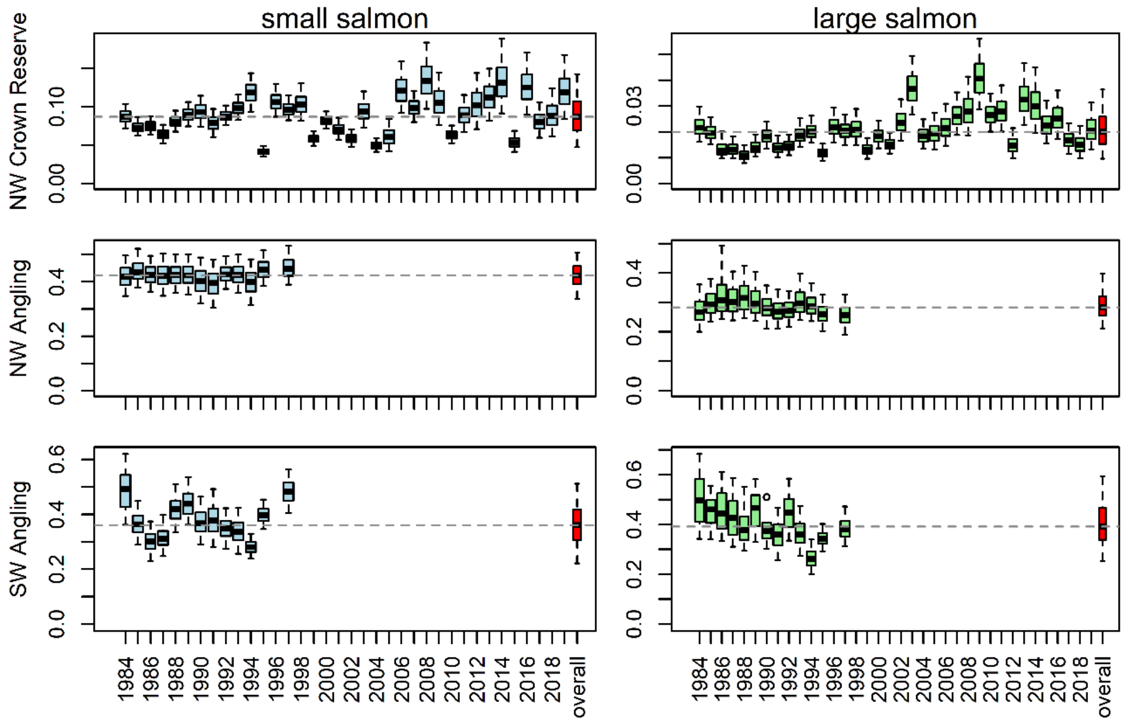

Figure A3. Posterior distributions of the annual exploitation rates in the recreational fisheries of small Salmon (left column) and large Salmon (right column). The exploitation rates refer to the proportions of the returns which are estimated to have been captured in the crown reserve waters (upper row, proportion of Northwest Miramichi returns), the Northwest Miramichi fishery (middle row, proportion of Northwest Miramichi returns), and the Southwest Miramichi fishery (bottom row, proportion of Southwest Miramichi returns). The x-axis label "overall" and shaded in red is the posterior distribution of the hierarchical proportion over all years. The boxplots and horizontal dashed lines are interpreted as described in the caption for Figure A2.

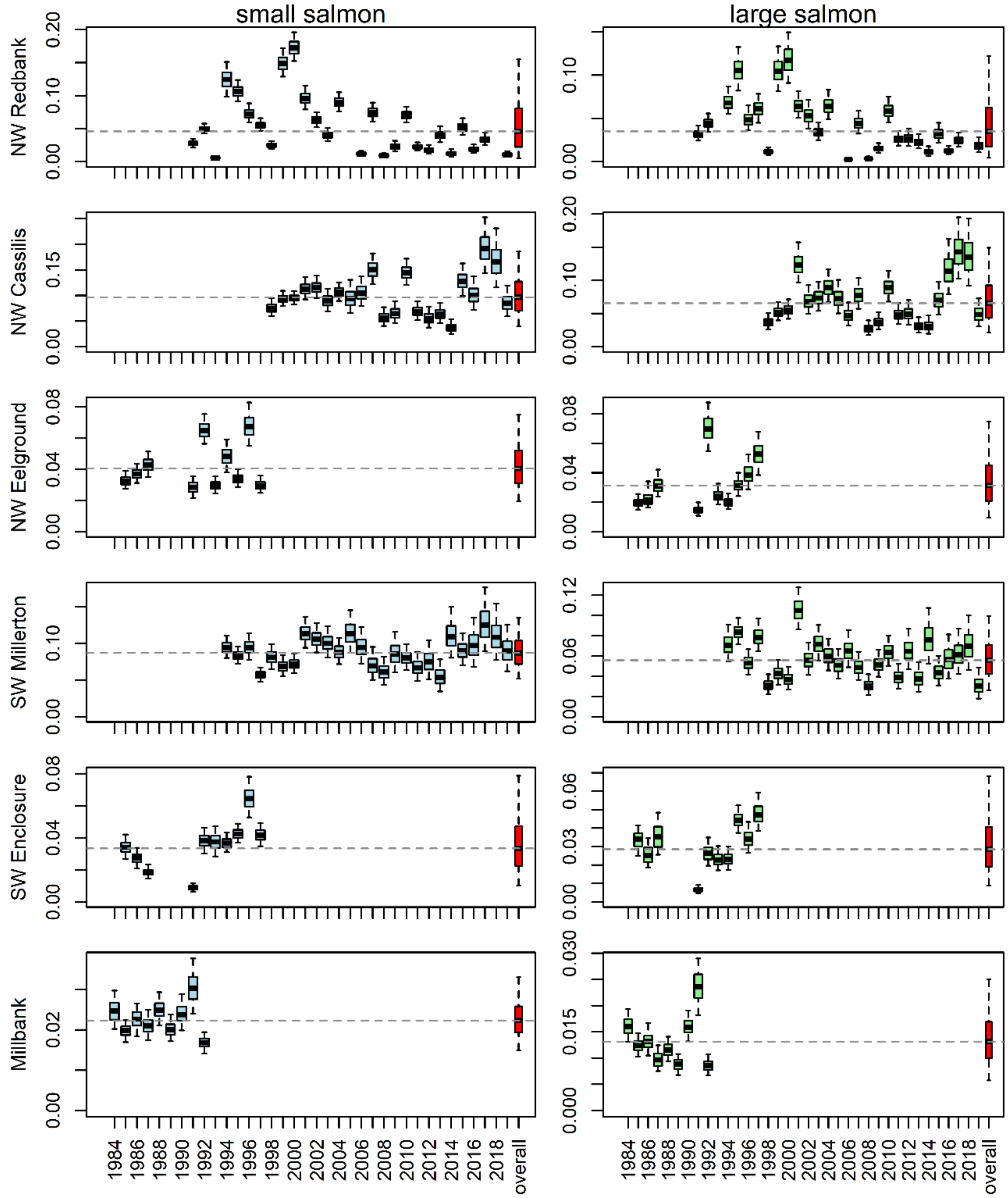

Figure A4. Posterior distributions of the annual proportions of the estimated returns of small Salmon and large Salmon for the respective components of the river intercepted at the estuary. The value labelled "overall" and shaded in red is the posterior distribution of the hierarchical proportion over all years. The boxplots and horizontal dashed lines are interpreted as described in the caption for Figure A2.

APPENDIX 7. REVISED ESTIMATES OF RETURNS OF SMALL SALMON AND LARGE SALMON TO THE MIRAMICHI RIVER AND TO EACH OF THE SOUTHWEST MIRAMICHI AND NORTHWEST MIRAMICHI BRANCHES, 1984 TO 2019

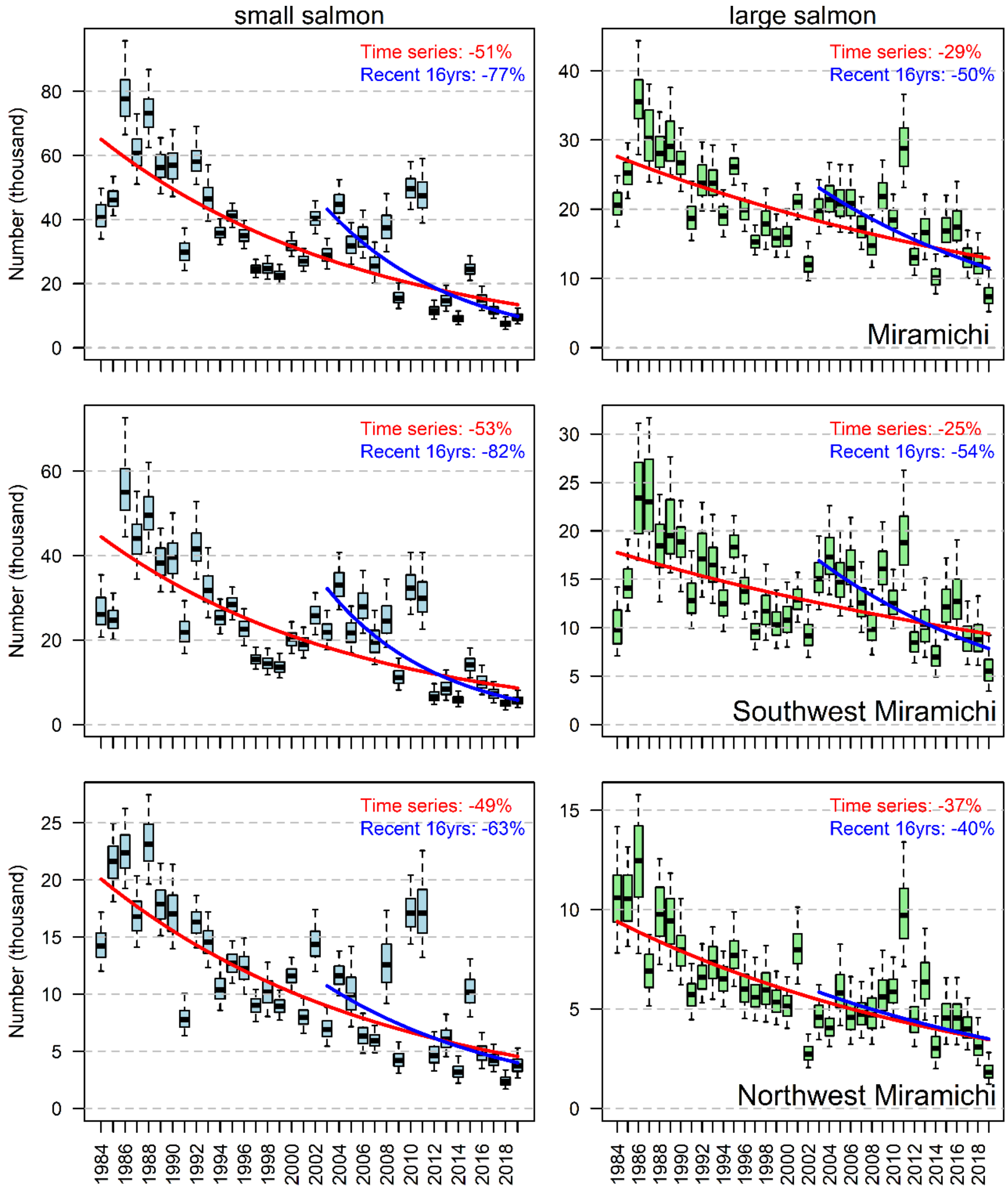

Figure A5. Posterior distributions of the estimated returns of small Salmon (left column) and large Salmon (right column) to the Miramichi River (upper row), the Southwest Miramichi (middle row),and the Northwest Miramichi (bottom row), 1984 to 2019. The percentage change over 16 years (approximately 3 generations) are shown in each panel based on the annual change in the log of abundance (median) over the entire time series or the annual change based on the most recent 16 years of return estimates.

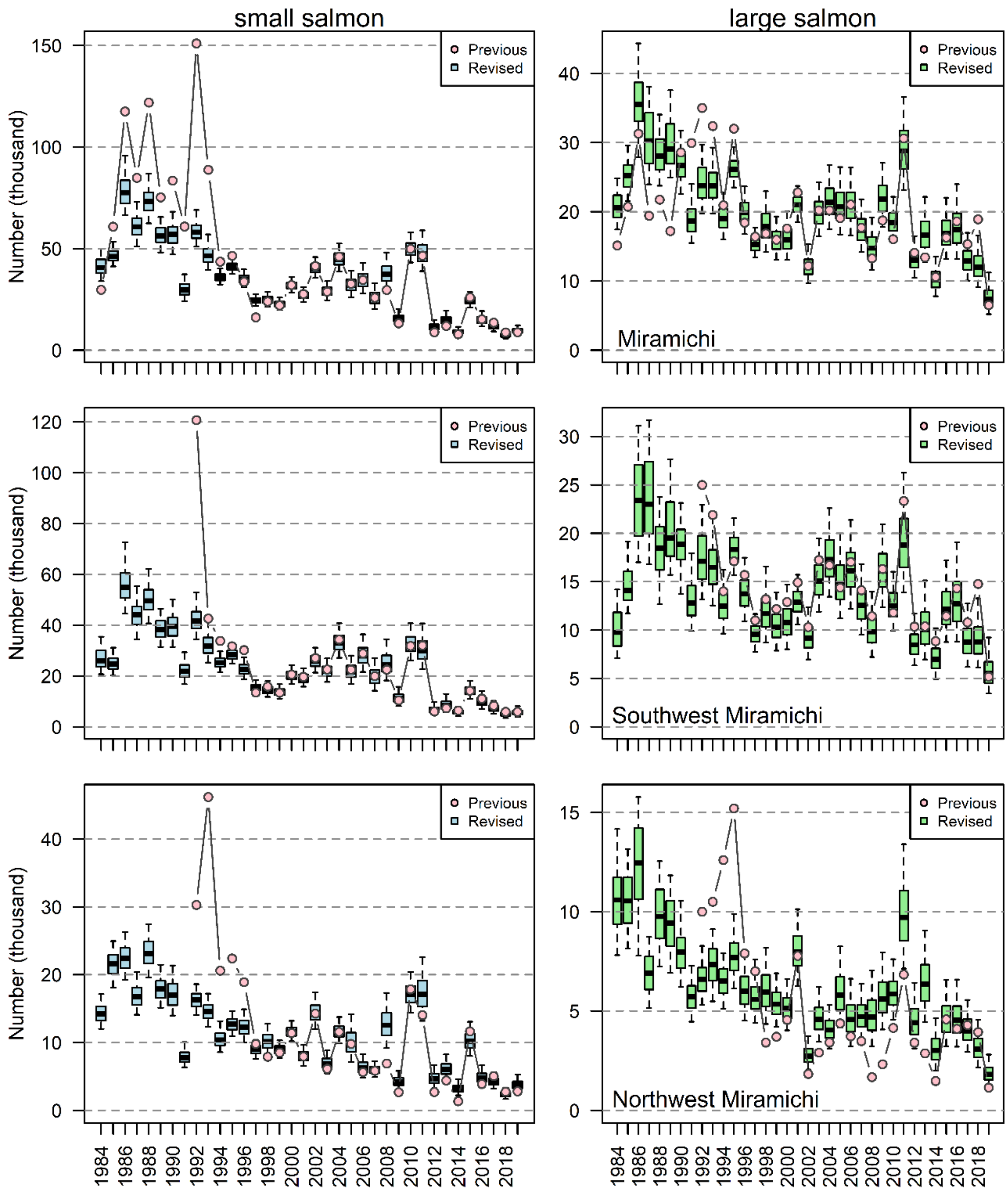

Figure A6. Posterior distributions of the estimated returns of small Salmon (left column) and large Salmon (right column) to the Miramichi River (upper row), the Southwest Miramichi (middle row),and the Northwest Miramichi (bottom row), 1984 to 2019 from the revised model and the previously published values from various annual assessment reports.

APPENDIX 8. FISHERIES

Table A22. Allocations of small and large Atlantic Salmon in SFA 16 to First Nations and Indigenous organizations according to agreements signed in 2013. Nrg refers to Native recreational gear (from Douglas et al. 2015).

				Allocation	
Aboriginal group	**Location**	**Gear**	**Qty**	**Small**	**Large**
Buctouche FN	Crown open waters of Miramichi	angling	-	110	0
Eel Ground FN	NW Miramichi	trapnet	1	2,660	185
Eel Ground FN	NW Miramichi	gillnet	11		
Eel Ground FN	Crown open waters of Miramichi and Bartibog	Nrg	-		
Eel Ground FN	NW Miramichi	fence	1	240	5
Eel Ground FN	SW Miramichi	trapnet	2	2,100	10
Eel Ground FN	SW Miramichi	gillnet	1		
Eel Ground FN	Crown open waters of Miramichi and Bartibog	Nrg	-		
Elsipogtog FN	Crown open waters of Miramichi	angling	-	200	0
Esgenoôpetitj FN	Tabusintac River	angling	-	*100	*100
Esgenoôpetitj FN	Tabusintac River	gillnet	-		
Esgenoôpetitj FN	Tabusintac River	trapnet	2	112	304
Esgenoôpetitj FN	Tabusintac River	gillnet	13		
Esgenoôpetitj FN	Miramichi Bay	gillnet	25	2,000	200
Esgenoôpetitj FN	Crown open waters of Miramichi and Bartibog	Nrg	-		
Metepenagiag FN	NW Miramichi system	trapnet	3	4,000	500
Metepenagiag FN	NW Miramichi system	gillnet	12		
Metepenagiag FN	Crown open waters of Miramichi	Nrg	-		
New Brunswick Aboriginal Peoples Council	Crown open waters of Miramichi	angling	-	280	0
New Brunswick Aboriginal Peoples Council	Crown open waters of Tabusintac	angling	-	30	0
SFA 16 total				**11,832**	**1,304**

* Kelt

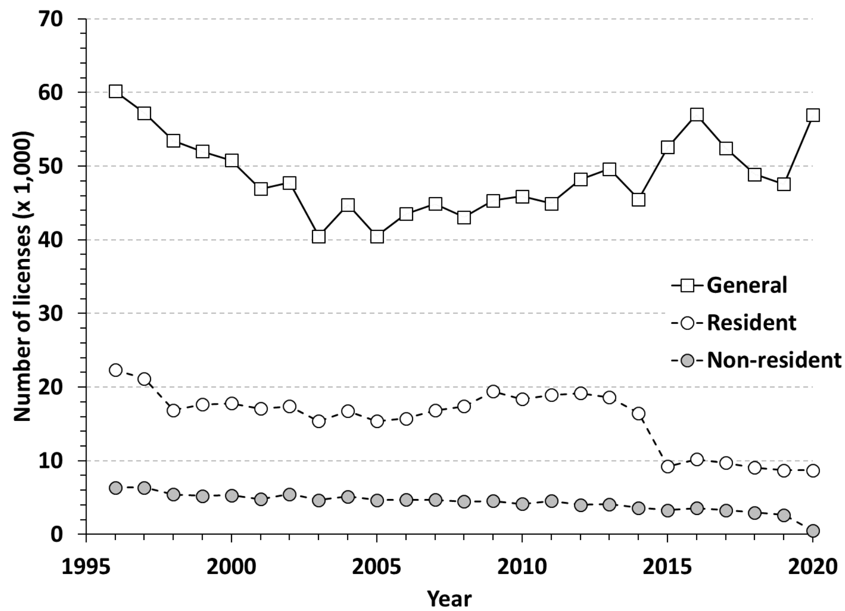

Figure A7. Angling licenses (general, resident Salmon, and non-resident Salmon) sold in New Brunswick between 1996 and 2020.

APPENDIX 9. MID-SEASON ANGLING RESTRICTIONS IN THE MIRAMICHI RIVER DUE TO WARM WATER BETWEEN 1999 AND 2019

Table A23. The number of days and type of angling restrictions invoked in the Miramichi watershed due to water conditions stressful for Atlantic Salmon between 1999 and 2020.

Year	Type of closure	No. of Pools	Start	End	No. of Days
1999	Cold water pools	2	24-Jul	10-Aug	18
1999	Morning only (6-11 am)	-	31-Jul	10-Aug	11
2001	River and pools	-	11-Aug	31-Aug	21
2010	Cold water pools	9	24-Jul	31-Jul	8
2012	Cold water pools	15	27-Jul	03-Sep	39
2012	Morning only (5-10 am)	-	05-Aug	14-Aug	10
2012	Morning only (5-10 am)	-	15-Aug	25-Aug	11
2013	Cold water pools	22	17-Jul	25-Jul	9
2015	Cold water pools	23	14-Jul	17-Jul	4
2015	Cold water pools	23	17-Aug	31-Aug	15
2015	Morning only (6-11 am)	-	20-Aug	24-Aug	5
2016	Cold water pools	26	26-Jul	15-Aug	21
2017	Cold water pools	26	20-Jul	25-Jul	6
2017	Cold water pools	26	03-Aug	09-Aug	7
2018	Cold water pools	26	05-Jul	21-Aug	48
2018	Morning only (6-11 am)	-	24-Jul	11-Aug	18
2019	Cold water pools	27	19-Jul	23-Jul	5
2019	Cold water pools	27	30-Jul	08-Aug	10
2019	Morning only (6-11 am)	-	01-Aug	07-Aug	7
2020	Cold water pools	27	23-Jun	08-Jul	16
2020	Cold water pools	27	10-Jul	17-Jul	8
2020	Cold water pools	27	21-Jul	20-Aug	31
2020	Morning only (6-11 am)	-	13-Aug	18-Aug	6