Fisheries and Oceans Canada | Pêches et Océans Canada
Ecosystems and Oceans Science | Sciences des écosystèmes et des océans

Maritimes Region

Canadian Science Advisory Secretariat
Science Advisory Report 2020/027

INNER BAY OF FUNDY (IBOF) RETURNING ADULT ATLANTIC SALMON POPULATION ABUNDANCE ESTIMATE

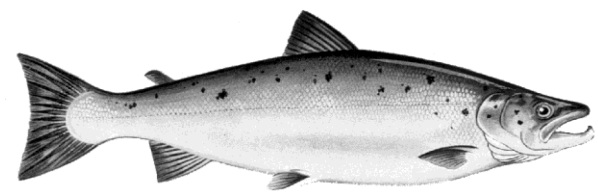

Image: BIO, Technographics

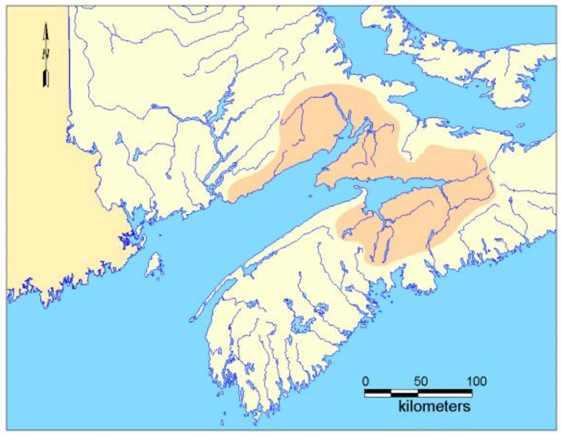

Figure 1. Map showing the region within the Maritimes Provinces where inner Bay of Fundy (iBoF) Atlantic salmon are found. The highlighted area indicates the location of iBoF Designatable Unit (DU).

Context:

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) identified the inner Bay of Fundy (iBoF) Atlantic Salmon assemblage as a Designatable Unit (DU) and assessed this population as Endangered in May 2001 (COSEWIC 2006). Furthermore, this population was included as Endangered on Schedule 1 of the Species at Risk Act (SARA) when the Act was passed in 2002. A Recovery Potential Assessment (RPA) for iBoF Atlantic Salmon was conducted in 2008 (DFO 2008), which includes information on population abundance for iBoF Atlantic salmon available at that time. A Recovery Strategy for the iBoF salmon was developed and published on the Species At Risk Public Registry as final in May 2010 (DFO 2010). Updated abundance information that incorporates data since the 2008 RPA is needed to update the Population Abundance section of the draft amended Recovery Strategy under development, and to inform the regulatory and management decisions made by Fisheries and Oceans Canada.

This Science Advisory Report is from the October 19, 2018, Inner Bay of Fundy Atlantic Salmon Population Abundance Estimate meeting. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule](#) as they become available.

SUMMARY

- Even with the uncertainty in the annual population estimates for the inner Bay of Fundy (iBoF) Atlantic Salmon Designatable Unit (DU), current estimates consistently remain below the 1999 estimate of less than 250 returning adults.
- The iBoF DU population abundance has not improved and may have further declined since the late 1990s despite supplementation efforts. The 1999 population estimate was comprised primarily of wild-origin fish, whereas the current estimates (adult returns less than 105 in 4 of 5 years) predominantly originate from Live Gene Bank (LGB) program support.
- The egg-to-smolt survival rates used in this analysis were derived from adult releases from 2003–2005. Given the shift in program release strategies from smolts and parr to unfed fry and mature adults, updated egg-to-smolt survival rates would provide more accurate population abundance estimates, which could be used to inform recovery action decisions.
- Under current conditions, it is highly unlikely that adult returns to these rivers can be maintained without the support of the LGB program, and given the lack of juvenile production from natural spawning.
- IBoF rivers that are not supported by LGB releases may contain remnant populations of Atlantic Salmon; however, their contribution to the DU adult abundance estimate has not been included in this assessment. Additional assessment work is needed before they can be incorporated into the full iBoF DU estimate.

INTRODUCTION

Wild anadromous Atlantic salmon populations have been in decline throughout their native range over the past three decades, in large part as a result of poor marine survival (DFO 2008; Jones et al. 2018). In 1999, the inner Bay of Fundy (iBoF) Designatable Unit (DU) was estimated to have declined to less than 250 adults returning to approximately 50 rivers (Figure 2) (Amiro 2003; COSEWIC 2006). Since the iBoF population is known for its distinctive local migration in most river-specific sub-units and is genotypically discrete from other regional groups of Atlantic Salmon in Canada (and elsewhere), efforts were made to conserve the population. Fisheries and Oceans Canada (DFO) developed a Live Gene Bank (LGB) program that includes three distinct live gene banks using individuals primarily from three rivers—Gaspereau, Nova Scotia (NS); Stewiacke, NS; and Big Salmon, New Brunswick (NB)—to conserve the unique genetics and maintain the population until marine survival improves (Gibson et al. 2008). The LGB program consists of captive-rearing and spawning through pedigree-based mating plans (to conserve genetics) and adult and juvenile supplementation components (population maintenance).

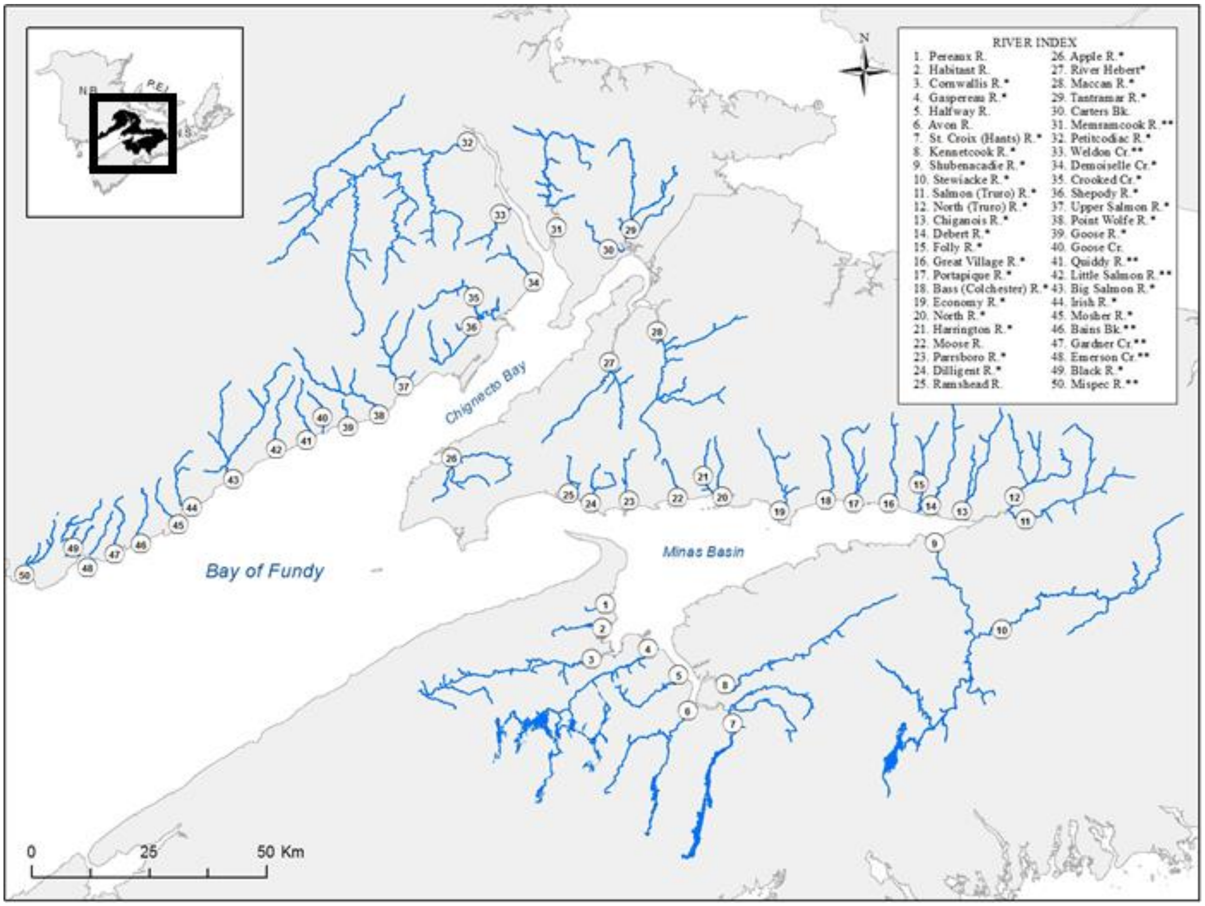

Figure 2. Inner Bay of Fundy (iBoF) Designatable Unit (DU) rivers identified by the iBoF Recovery Potential Assessment.

Biodiversity facilities in Nova Scotia (Coldbrook [CBF] and Mersey [MeBF; closed in 2013]) and New Brunswick (Mactaquac [MBF]) have been responsible for rearing and releasing the fish, both adults and juveniles, associated with the captive-breeding and supplementation components of the LGB program. The CBF maintains the Gaspereau River and Stewiacke River LGB populations, while MBF preserves the Big Salmon River population. Captive-breeding of these populations results in adults and juveniles that are distributed into iBoF rivers to complete their life cycle in a wild environment. In a given year, during the captive-breeding process, more salmon are produced through its specific LGB program than can be released into their river of origin (i.e., Gaspereau, Stewiacke, and Big Salmon rivers). These surplus fish are distributed to other LGB-supported rivers.

Adaptive management has occurred throughout the lifespan of the LGB program. In particular, changes in release strategies from juveniles of various life stages (i.e., unfed and 6-week feeding fry, Age-0 and Age-1 parr, and Age-1 and Age-2 smolts) to unfed fry have occurred to reduce the effects of domestication on the population (Jones et al. 2018). Previously, immature, mature, and post-spawned adults (kelts) were released into LGB-supported rivers; however, the emphasis is now placed on releasing mature adults and kelts.

River-specific adult abundance assessments in all rivers that receive LGB support are not feasible due to the size of the program and the extent of the program's geographic area between release-rivers. Currently, adult salmon assessments are only conducted annually on two of the LGB-supported rivers (Gaspereau and Big Salmon) and two non-DFO program rivers (Upper Salmon and Point Wolfe in Fundy National Park, NB). Additionally, adult assessment surveys were completed on the Pollet River (a tributary of the Petitcodiac River, NB) from 2014 to 2016 in partnership with Fort Folly Habitat Recovery (FFHR) (Jones et al. 2018) and are used for model validation only. Throughout the lifespan of the LGB program, there have been at least 15 LGB-supported rivers that have not had annual adult assessments. Not all of these are reported in this document since fish releases and corresponding adult return estimates are outside of the considered time frame of 2013 to 2017.

In 1999, it was estimated that less than 250 iBoF adults had returned to their natal rivers to spawn. Given the continued low abundance of adult returns to the assessed iBoF rivers (i.e., Stewiacke, Gaspereau, Big Salmon, Point Wolfe, and Upper Salmon rivers; Gibson et al. 2008; Jones et al. 2018; C. Clarke, unpublished data), it is unlikely that abundance has increased. Two decades have passed since the population abundance for the entire iBoF Salmon DU was quantified and the current estimate of the returning adults to all iBoF rivers is unknown. Furthermore, the 2014 Broadscale Electrofishing Survey demonstrated that very few rivers (5 of the 34 surveyed rivers), outside of those receiving contributions from the LGB programs (n=2), had any indication of remnant wild populations, thus this report focuses on LGB-supported rivers within the iBoF DU (Jones et al. 2018).

This Science Advisory Report (SAR) focuses on the adult and juvenile supplementation component of the LGB program with the objective of developing a current returning adult population abundance estimate for the LGB-supported rivers within the iBoF DU over the past five years (2013–2017).

ANALYSIS

Data Acquisition

Where available, actual counts (or estimates, i.e., Big Salmon) were used to quantify adult abundance for LGB-supported rivers from 2013 to 2017. If adult counts were not available, the number of fish released into LGB-supported, non-assessed rivers were used to derive quantitative estimates. Data for both juvenile and adult salmon releases were acquired from the CBF, MeBF, and MBF through the DFO Distribution Database (Figures 3 and 4). Biological data (i.e., sex and length) for LGB program adult salmon used in the pedigree-based mating plan were obtained from comprehensive LGB program datasets and applied to LGB adult release information to obtain sex ratios and mean lengths used for egg deposition estimates. This information was captured during seasonal distributions and annual spawning of target and non-target salmon (target salmon: used in the pedigree-based LGB program and released into rivers of origin; non-target salmon: individuals not required for the LGB program are released into other iBoF rivers). Adult return estimates from LGB non-supported rivers were analyzed but not included in the estimate, as only one year of data is available (i.e., 2014 Broadscale Electrofishing parr densities). LGB-supported and non-supported rivers are identified in Table 1, which includes information regarding age, LGB program, current adult assessment status, and source (actual count versus estimate) of adult abundance.

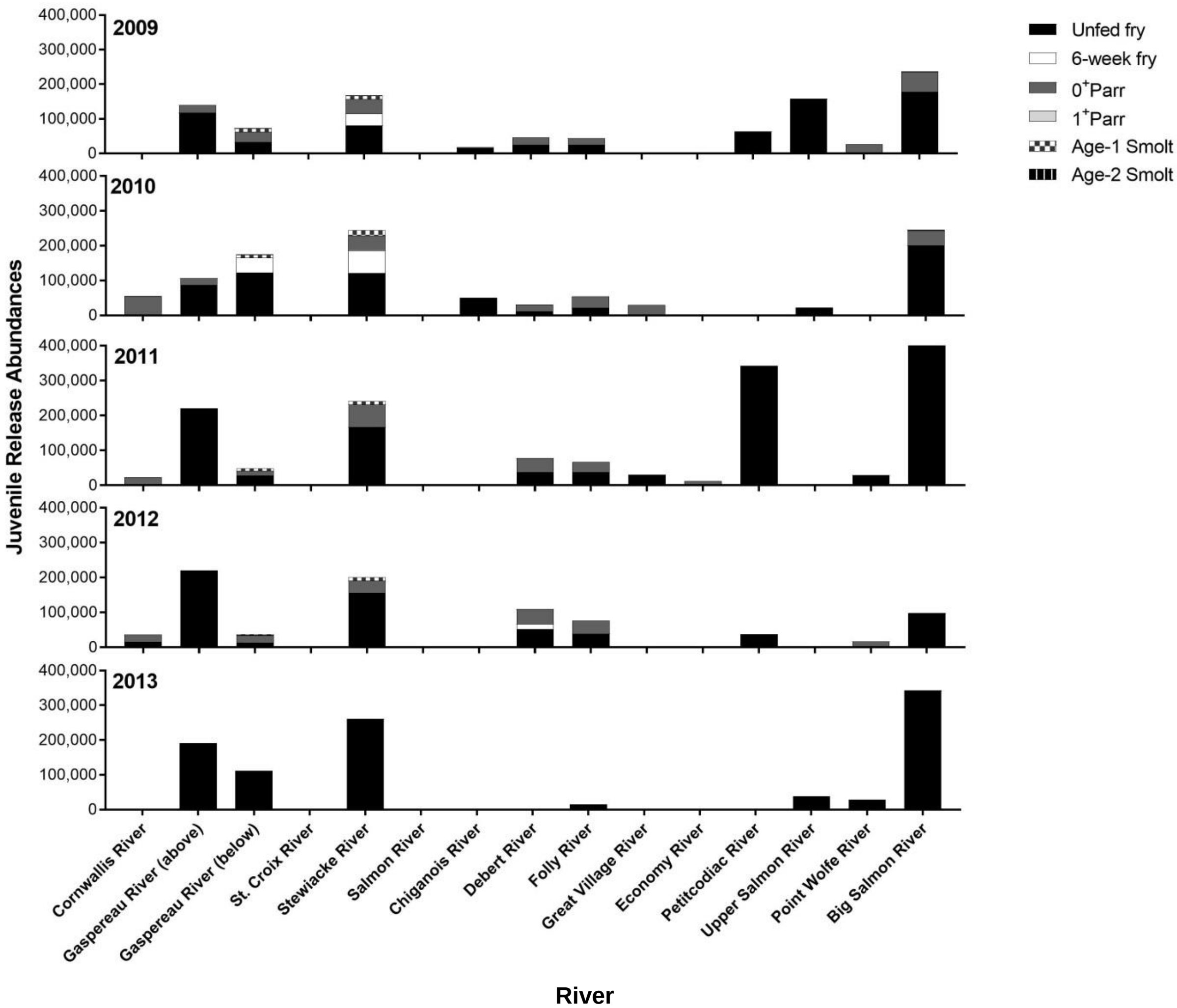

Figure 3. Coldbrook, Mersey, and Mactaquac Biodiversity Facility Live Gene Bank juvenile Atlantic Salmon releases from 2009 to 2013.

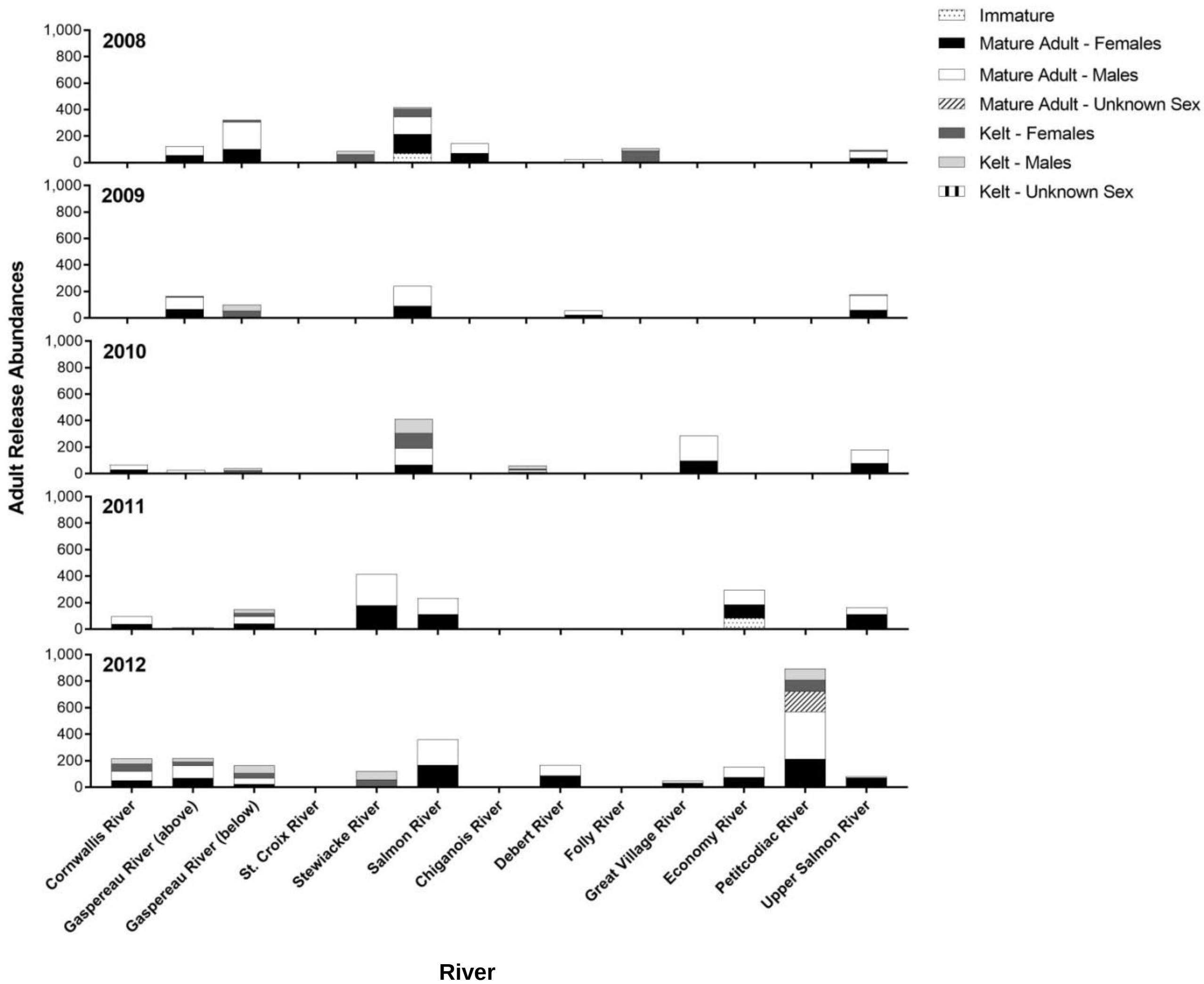

Figure 4. Coldbrook, Mersey, and Mactaquac Biodiversity Facility Live Gene Bank adult Atlantic Salmon releases from 2008 to 2012.

Table 1. The iBoF rivers referred to in this report for estimating the Atlantic Salmon adult return abundance, their distributions from the LGB program (since 2008), the presence and source, and method of deriving the adult salmon abundance data used in this report.

River	River No. from Figure 2	LGB-Supported	LGB Population	Current Adult Assessment	Estimated vs. Actual Adult Abundance	Source of Adult Abundance Data
Cornwallis	3	Yes	Gaspereau	No	Estimated	LGB distribution
Gaspereau (above White Rock)	4	Yes	Gaspereau	Yes	Total count	Fishway
Gaspereau (below White Rock)	4	Yes	Gaspereau	No	Estimated	LGB distribution
St. Croix	7	Yes	Gaspereau	No	Estimated	LGB distribution
Stewiacke	10	Yes	Stewiacke	No	Estimated	LGB distribution
Salmon (Colchester)	11	Yes	Stewiacke	No	Estimated	LGB distribution
Chiganois	13	Yes	Stewiacke	No	Estimated	LGB distribution
Debert	14	Yes	Stewiacke	No	Estimated	LGB distribution
Folly	15	Yes	Stewiacke	No	Estimated	LGB distribution
Great Village	16	Yes	Stewiacke	No	Estimated	LGB distribution
Portapique	17	No	None	No	Estimated	2014 Electrofishing
Economy	19	Yes	Stewiacke	No	Estimated	LGB distribution
Petitcodiac	32	Yes	Big Salmon/ Point Wolfe/ Nova Scotia LGBs*****	No	Estimated	LGB distribution
Upper Salmon	37	Yes	Big Salmon/ Upper Salmon	Yes	Partial count	Dive Counts
Point Wolfe	38	Yes	Big Salmon/ Point Wolfe	Yes	Partial count	Dive Counts
Big Salmon	43	Yes	Big Salmon	Yes	Partial count (Estimated Observation Rate)	Dive Counts
Irish	44	No	None	No	Estimated	2014 Electrofishing
Mosher	45	No	None	No	Estimated	2014 Electrofishing
Black	49	No	None	No	Estimated	2014 Electrofishing
Mispec	50	No	None	No	Estimated	2014 Electrofishing

* Various LGB crosses from the 2013 Crossbreeding Experiment (see Jones et al. (2018) for more details).

Model Development

In this report, the smolt productions from 2012 to 2016 and the resulting potential adult abundances from 2013 to 2017 of non-assessed LGB-supported rivers were estimated using freshwater survival rates and smolt-to-small salmon return rates from the Big Salmon River. The Big Salmon River has been used as the benchmark population since all required biological information (i.e., juvenile and adult survival rates) has been well-documented within this lineage (Jones et al. 2018, see sections 3.4.1.1 and 3.4.2.1). Some preliminary freshwater survivals and smolt-to-adult return rates have also been determined for the Gaspereau River (above White Rock dam) LGB-supported assessed population (Jones et al. 2018). However, these survival and return rates are likely influenced by the hydro dam facilities located throughout the river, which alter various hydrological parameters (e.g., water flow, level and temperature). Until a more robust dataset can be developed from other LGB-supported river subunits, the Big Salmon River remains the reference population.

To estimate adults from non-assessed LGB-supported rivers for the 2013 to 2017 return years, estimates of smolt production in 2012 to 2016 are required; these are developed using juvenile releases to which freshwater survival parameters of various juvenile stages are applied. The freshwater survival data from the Big Salmon River for the most recent five years were used. Freshwater survival rates are assumed to be variable among rivers within a year as well as among years. Accordingly, the annual freshwater survivals for the LGB-supported rivers were assumed to have varied between the minimum to maximum values of the most recent five years of Big Salmon River data. Juvenile life stage at release and Big Salmon River freshwater survival rates used in this report are summarized in Table 2.

Table 2. Minimum and maximum freshwater survivals used to estimate smolt output from the non-assessed LGB-supported iBoF rivers (data from Jones et al. 2018; Tables 20, 21 and 22 or Appendix 1). All survival rates are derived from the Big Salmon River data series. Min.: minimum rate observed, Max.: maximum rate observed for those release years, N/A: data borrowed from another life stage.

Release Stage	Smolt Age	Applicable Years Released	Min. to Max. survival rate over release years	Table No. From Jones et al. 2018
Captive-reared eggs	to Age-2	2003 to 2005	0.11% to 0.65%	22
Captive-reared eggs	to Age-3	2003 to 2005	0.02% to 0.22%	22
Unfed fry	to Age-2	2010 to 2014	1.20% to 1.68%	20
Unfed fry	to Age-3	2009 to 2013	0.05% to 0.87%	20
6-week fry	to Age-2	N/A	N/A	N/A
6-week fry	to Age-3	N/A	N/A	N/A
Age 0+ parr	to Age-1	2007 to 2011	0.38% to 0.93%	21
Age 0+ parr	to Age-2	2007 to 2011	3.30% to 6.75%	21
Age 1+ parr	to Age-2	N/A	N/A	N/A

Uncertainties in the freshwater survival rates applied to the non-assessed LGB-supported rivers were characterized by random draws from a uniform distribution (1000 Monte Carlo draws) between the minimum and maximum values shown in Table 2. The resulting distribution of the survival rate for a given release stage was applied to the life-stage specific numbers released in each year to calculate annual smolt output in non-assessed LGB-supported rivers.

Stocking of 6-week old fry and Age-1 parr has also occurred in non-assessed LGB-supported rivers. In the absence of specific data from the Big Salmon River, it was assumed that survival rates of 6-week old fry to smolts were identical to those of unfed fry. Age-1 parr survival rates to Age-2 smolts were assumed to be similar to those of Age-0 parr to Age-2 smolts.

In contrast to the freshwater survival rates, it was assumed that annual variability in the at-sea survival rates of smolts from non-assessed LGB-supported rivers was similar to the annual survival rates of smolts from the Big Salmon River, since all the smolts would have shared a common and annually variable marine environment. Annual estimates of smolt-to-adult salmon return rates from Big Salmon River, for the smolt years 2012 to 2016, were applied to the annual estimates of smolt production to derive the annual estimates of adult returns. The uncertainty in the annual smolt to adult return rate was derived by incorporating the uncertainties of the annual smolt production estimates and the annual adult return estimates from Big Salmon River. For both of these, the uncertainty was assumed to be equivalent to a coefficient of variation (CV) of 20%. This CV value corresponds approximately to the uncertainty of the smolt production estimates of the Big Salmon River in 2015 and 2016; 95% confidence intervals of 7,680 to13,080 and 5,860 to 9,240, respectively (Table 3). For the adult returns, the estimates are based on fish counted and an assumed observer efficiency of 0.57 (Gibson et al. 2004). A similar CV of 0.20 was assumed for the adult estimates, a reasonable value given the data used to derive the efficiency parameter from the mark and recapture experiment of 2003 (Gibson et al. 2004). The input values and corresponding uncertainties for smolt output, small salmon returns, and estimated return rates, grouped by smolt year for the Big Salmon River are summarized in Table 3.

Table 3. Smolt output, small salmon returns, and estimated return rates for the Big Salmon River for smolt year classes 2012 to 2016.

Smolt Year	Smolt output (95% C.I. assuming CV = 20%)	Small salmon in year + 1 (95% C.I. assuming CV = 20%)	Return rate % (95% C.I.)
2012	13,020 (8,855–17,546)	7 (5–9)	0.054% (0.033%–0.086%)
2013	10,890 (7,583–14,581)	13 (9–17)	0.119% (0.075%–0.183%)
2014	4,510 (3,151–5,950)	28 (18–37)	0.621% (0.389%–0.976%)
2015	9,690 (6,474–12,746)	14 (9–19)	0.144% (0.089%–0.242%)
2016	7,180 (4,798–9,680)	16 (11–21)	0.223% (0.136%–0.376%)

Incorporating uncertainty

A Monte Carlo simulation, programmed in R (R Core Team 2018), was used to derive the adult abundance estimate statistics. The Monte Carlo simulation used random draws from a uniform distribution to incorporate the uncertainties (defined by minimum to maximum values) in freshwater parameters, resulting smolt production, and return rates to derive estimates of adult returns with uncertainties. Annual production for the freshwater life stages was also calculated outside of the estimation model using the mean survival rates of each life stage, and these results are presented below.

Estimating Adult Returns (2013–2017)

Live Gene Bank-Supported Assessed Rivers

Gaspereau River (Above White Rock Dam)

Adult salmon ascending the Gaspereau River encounter several migration barriers, although both upstream and downstream passage exists at the White Rock Hydro Station. Since 1995, salmon have been enumerated annually at a fishway located within the facility, which now includes an assessment trap after retrofitting in 2002. Individuals caught in the trap were held for incorporation into the Gaspereau LGB program or released upriver to spawn naturally if catches were greater than ten adults. The 2013 to 2016 adult return counts for Gaspereau River above White Rock were taken from Jones et al. (2018), while the estimated returns for 2017 are provided by DFO Science (R. Jones, unpublished data).

Upper Salmon and Point Wolfe Rivers

Adult counts have been conducted annually since 2002 in late September or early October and involve one or two diver surveys of the key sections of river expected to be holding returning adult salmon (C. Clarke, pers. comm.). In 2017, a Passive Integrated Transponder (PIT) array was setup in the Upper Salmon River to determine the number of repeat spawning adult returns from captive-reared virgin mature adults released in 2016. Any repeat-spawning salmon originally released as maiden spawners are included in the count data for the Upper Salmon River.

Big Salmon River

Adult abundance assessments occur annually using similar methods, including an early season (August) diver count of salmon holding in the largest pools, a mid-season count (September) usually of those same pools followed by a seining/marking activity, and finally a three-section swim survey in October. The adult abundance estimates were derived by applying a single census mark-recapture value of 0.57 (Gibson et al. 2004) to the largest observed count for that year. The 2013 to 2016 adult return estimates for the Big Salmon River were taken from Jones et al. (2018), while the estimated returns for 2017 are provided by DFO Science (R. Jones, unpublished data).

Live Gene Bank Supported Non-Assessed Rivers

Treatment of Live Gene Bank Distribution Data

The annual total number of unfed and 6-week feeding fry released between 2009 and 2014 were obtained from the DFO Distribution Database (Appendix 2). As mentioned above, ranges of freshwater survival rates were applied to the numbers of both unfed and 6-week feeding fry released to determine the estimated abundance of Age-2 and Age-3 smolts leaving the non-assessed rivers. Similar to the age of smoltification for the Big Salmon River population, it was assumed that very few, if any, Age-4 smolts were produced from the unfed fry and/or 6-week feeding fry releases (Jones et al. 2018). To date, no survival rates specific to the 6-week feeding fry stage have been developed.

Annual totals of Age-0 and Age-1 parr released between 2010 and 2015 were also obtained from the DFO Distribution Database (Appendix 2) and corresponding ranges of freshwater survival rates were applied to the number of parr released to determine the number of Age-1 and Age-2 smolts emigrating from the non-assessed LGB-supported rivers. As with 6-week feeding fry, a freshwater survival rate has not been developed for Age-1 parr, so the freshwater survival rates for Age-0 parr were applied to the number of Age-1 parr released to determine the number of emigrating Age-2 smolts.

Mature adults, specifically females, released between 2008 and 2013 were included in the egg deposition estimates to assess their contributions to the 2013 to 2017 adult returns, assuming successful spawning in the wild. The number of females released and their respective fork lengths came from data collected during LGB pre-spawning sex identification activities. If fork length at release was not recorded, then the mean fork length of all females released in a given year was used for that particular individual. Individual egg depositions were calculated using the respective fork lengths and river-specific fecundity-length relationships (Appendix 3). In the case where LGB program individuals surplus to spawning requirements (i.e., lifetime captive-reared F1 offspring not required for pedigree-based matings) were released and individual biological data (i.e., sex and length) were not available, the proportion of females and mean fork length from known LGB adults released the same year were applied to estimate the number of eggs deposited. Total estimated egg depositions from all mature LGB adults were calculated by year for all non-assessed rivers (Appendix 2). Immature adult salmon releases were not included in the estimated returning adult salmon abundance, as phenotypic data, maturation, and freshwater survival rates are unknown.

Very few adults were thought to contribute to the iBoF population estimate from the spring smolt releases (2012 to 2016) since only five adults (three returning adults confirmed from LGB smolt releases and two unconfirmed (no genetic data) since the LGB program inception in 2001) have been captured or observed on the Big Salmon River during the years when large numbers of adipose-clipped LGB smolts were released in the spring (Jones et al. 2018).

Kelt marine survival rates were developed for releases in 2008, 2009, and 2011 (returning in 2009, 2010 and 2012, respectively) using kelt releases and returns to the Gaspereau River (above White Rock dam).

$$\frac{Live\ Gene\ Bank\ kelt\ returns\ (current\ year)}{Live\ Gene\ Bank\ kelt\ releases\ (previous\ year)}$$

However, kelts were not included in the estimated returning small salmon abundance due to their low estimated marine survival to date and lack of contribution to the analyzed years.

Electrofishing Data (2014) – Live Gene Bank Non-Supported and Non-Assessed Rivers

A Broadscale Electrofishing Survey for 34 (30 non-LGB-supported rivers) of the 50 iBoF rivers was conducted in 2014, which indicated the presence of juvenile salmon at very low densities in 5 iBoF LGB non-supported rivers (Portapique, Irish, Mosher, Black and Mispec) (Jones et al. 2018). For these 5 rivers (r), the estimated smolt production in 2015 was estimated from parr densities of 2014 as per the described method below:

$$Total\ Parr\ (2014) = \sum\nolimits_r Parr\ density(2014)_r \cdot Habitat\ units\ (100\ m^2)_r \cdot BSR\ HabScalar$$

$$Total\ Smolts\ (2015) = Total\ Parr\ (2014) \cdot Parr - to - Smolt\ Mortality$$

When the productive habitat was unknown, established river-specific watershed areas (Canadian Rivers Institute Database 2017; L. Savoie, pers. comm.) relative to the known productive habitat/total watershed area ratios for the Big Salmon River (reported by Jessop [1986]) were used to estimate river-specific habitat units for the river. The Big Salmon River Habitat Scalar (BSR HabScalar = 2790/9093 = 0.31) and the parr to smolt mortality rate (0.623) used to derive the smolt estimates are from Gibson et al. (2008). These were applied to the

2014 Broadscale Electrofishing Survey data to determine an estimated total parr abundance for the non-LGB-supported rivers with residual parr populations in 2014. The smolt-to-small salmon return rate (Table 3) was then applied to the estimated smolt output in 2015 to estimate the 2016 adult returns.

Results

Estimated Smolt Output

Live Gene Bank Supported Non-Assessed Rivers

IBoF DU Smolt Outputs. Annual smolt outputs (ages 1 to 3) from LGB releases in the non-assessed rivers ranged from 18,300 to 26,670 individuals (Figure 5). The contributions from various release stages varied annually.

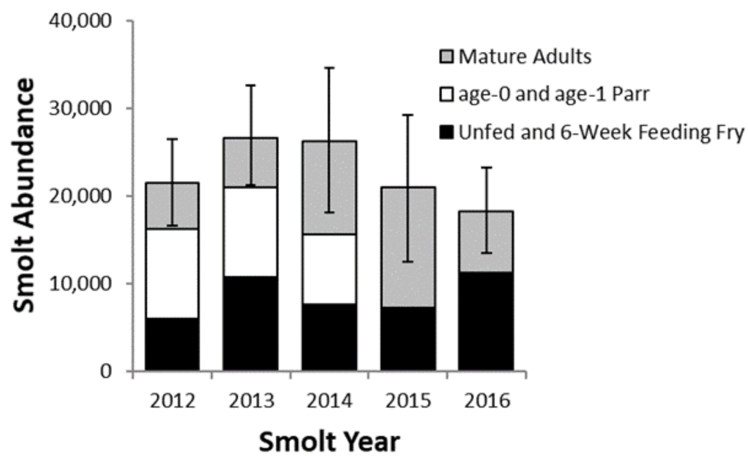

Figure 5. The estimated number (with 2.5 and 97.5% percentile ranges) of Atlantic Salmon smolts, by release strategy, emigrating from non-assessed iBoF rivers that have been supported by releases through the LGB program.

Unfed Fry and 6-week Feeding Fry Contributions. The estimated number of smolts produced from the unfed and 6-week fry released between 2009 and 2014 contributed to a range of 5,960 (2012) to 11,260 (2016) smolts in various LGB-supported non-assessed rivers between 2012 and 2016 (Figure 5). Unfed fry have the greatest contribution to smolt production (5-year mean = 8,520 fish) compared with all other release strategies (Figure 5).

Age-0 and Age-1 Parr Contributions. Annual smolt output from parr releases range from 140 (2015) to 10,300 (2013), with a 5-year mean of 5,730 fish (Figure 5). No smolts were estimated from this release group in 2015 or 2016 due to the small numbers of parr released after 2012 (Figure 3).

Mature Adult Contributions. The mean annual contribution of smolt production from mature adult releases was 8,460 fish, ranging from 5,260 (2012) to 13,740 (2015) smolts, from the various LGB-supported non-assessed rivers (Figure 5).

Live Gene Bank Non-Supported and Non-Assessed Rivers

A Broadscale Electrofishing Survey of 30 non-LGB supported iBoF rivers in 2014 indicated that only 5 rivers had juvenile salmon present and at very low densities (highest density was Black River; 7.2 parr per 100m^2). Since these electrofishing surveys did not take place annually, it is not possible to estimate the contribution of the non-supported rivers for the 2013 to 2017 time period. Due to these low densities, substantial smolt production or adult return from these rivers is not anticipated (Table 4).

Table 4. Estimated number of Atlantic Salmon smolts produced in 2015 potentially contributing to adults in 2016 based on the 2014 Broadscale Electrofishing Survey of rivers in the iBoF DU not supported by releases through the LGB program. Number of sites sampled in brackets after Mean Parr Density.

River	Habitat Units ($100m^2$)	Habitat or Watershed Reference	Mean Parr Density ($/100m^2$)	Total Parr In River (2014)	Estimated Smolts (2015)
Portapique River	3,309	DFO 2008	0.45 (n=4)	457	172
Irish River	9,142	CRI 2017	0.28 (n=4)	785	296
Mosher River	517	L. Savoie	0.50 (n=1)	79	30
Black River	3,190	CRI 2017	7.20 (n=2)	7,047	2,657
Mispec River	5,332	CRI 2017	2.10 (n=1)	3,436	1,295
Total	**21,490**	**na**	**na**	**11,804**	**4,450**

The greatest proportion of smolts emigrating from non-LGB supported rivers came from the Black and Mispec rivers. These two iBoF rivers border the Saint John River, which is in the outer Bay of Fundy (oBoF) DU. It has been shown that the majority of the fish captured during the 2014 Broadscale Electrofishing Survey from the Black and Mispec rivers were of oBoF genetic origin (Jones et al. 2018).

Estimated Adult Returns

Live Gene Bank-Supported Rivers

IBoF DU Adult Abundance Estimate. Even with the uncertainty in the annual population estimates for the DU, current estimates consistently remain below the 1999 estimate of less than 250 returning adults (Table 5). Despite supplementation efforts, the iBoF DU population abundance has not improved and may have declined further since the late 1990s. Of note, the 1999 estimate of less than 250 adults in the iBoF DU was comprised primarily of wild-origin fish, whereas the current estimated returns (adult returns <105 with the exception of 2015 when the smolt to adult return rate was above average) are predominantly composed of adult Atlantic Salmon of LGB-origin.

Unfed Fry and 6-Week Feeding Fry Contributions. As a result of the shift in release strategies, unfed and 6-week feeding fry contribute a significant amount to the returning adult abundances. Estimated adult abundances ranging from 3 (2013) to 47 (2015) have been attributed to unfed fry releases in non-assessed rivers (Table 5).

Age-0 and Age-1 Parr Contributions. Age-0 and Age-1 parr accounted for maximum of 49 adult returns (2015) and a minimum of 6 (2013) to iBoF LGB-supported rivers (Table 5). Due to the low number of parr released since 2012, no adult returns were estimated to have originated from this release strategy in 2016 or 2017 (Table 5).

Table 5. Inner Bay of Fundy DU breakdown of estimated Atlantic Salmon adult returns to LGB-supported rivers from 2013 to 2017.

Life Stage	Returning Adults to LGB-Supported Rivers				
	2013	2014	2015	2016	2017
Mature Captive-reared Adults	3	7	64	19	15
Unfed and 6-week Feeding Fry	3	13	47	10	25
Age-0 and Age-1 Parr	6	12	49	0	0
Total (Non-Assessed Rivers)	**12**	**32**	**160**	**29**	**40**
2.5% C.I.	**6**	**18**	**80**	**13**	**21**
97.5% C.I.	**21**	**59**	**309**	**61**	**80**
Adult Returns (Assessed Rivers)	25	18	45	36	64
Total (LGB-supported Rivers)	**37**	**50**	**205**	**65**	**104**

Mature Captive-reared Adult Contributions. Mature captive-reared adults are estimated to contribute a similar proportion to returning adults of the LGB-supported non-assessed rivers as unfed and 6-week feeding fry. Using the egg-to-smolt survival rates derived from adult releases on the Big Salmon River from 2003 to 2005, the estimated adult returns derived from mature adult releases in previous years ranged from 3 (2014) to 64 (2015) (Table 5).

Kelt Contributions. Based on an estimated mean survival of 4.42% (2009: 6.67%, 2010: 4.72%; 2012: 1.89%) and the number released into LGB-supported rivers, kelts were not expected to contribute substantively to the adult abundance estimate in any of the years analyzed, likely as a result of low marine survival.

Potential Adult Returns to Non LGB-supported Rivers (2016 Only)

Applying the smolt-to-adult return rate for the 2015 Big Salmon River smolt class to the smolt abundance estimate from the non-supported rivers could potentially add another 6 small salmon to the 2016 overall estimate of 65 adults. The Black and Mispec rivers were expected to be the most productive and potentially yielded 4 and 2 adult returns, respectively, in 2016 (Table 6). Based on the genetic analysis of parr captured in 2014, these potential adults would most likely resemble oBoF salmon genotypically.

Table 6. Estimated small salmon returns from LGB non-supported iBoF rivers from contributions of parr observed during the 2014 Broadscale Electrofishing Survey and smolts estimated in 2015 (presented in Table 4).

River	Estimated Adult Returns (2016)
Portapique River	0
Irish River	0
Mosher River	0
Black River	4
Mispec River	2

Model Verification

For three of the analyzed years (2014 to 2016), adult count data based on adult swim surveys are available for the Pollet River (Petitcodiac River) (Table 7). The initial swim survey was completed on September 29 and 30, 2014, which covered 20 km of river containing all the major holding pools (Jones et al. 2018). Similar surveys were completed in subsequent years, with the exception that a second survey was completed in 2015. Origin (LGB versus wild) and life stage at release, if LGB origin, are unknown since these adults were not captured and, therefore, not genotyped. To assess the consistency of different data types, the outputs for the estimated adult abundance can be compared with counts observed during these adult assessment activities (Table 7).

Table 7. Adult swim survey counts and estimated Atlantic Salmon adult returns on the Pollet River (Petitcodiac River) during 2014 to 2016.

Assessment Year	Adult Count	Estimate Adult Returns from the model
2014	1 small salmon	6
2015	4 small salmon	14
2016	1 small salmon and 1 large salmon	0

The adult count data from the Pollet River surveys from 2014 to 2016 confirm low returning adult abundances to the Petitcodiac River, similar to the overall trend observed in the iBoF DU returning adult population estimate to LGB-supported non-assessed rivers.

Sources of Uncertainty

A variety of sources were used for data collection and input into the adult population estimate, including: 1) actual estimates and counts from DFO and Parks Canada Salmon conservation programs, 2) DFO’s Distribution Database containing numerical and some qualitative (i.e., life stage and locations) data on salmon releases, 3) comprehensive life-history (e.g., spawning, growth, release) and genetic databases (Excel-based) for each of the LGB programs, and 4) data from the 2014 iBoF Broadscale Electrofishing Survey integrated with methods from Gibson et al. (2008).

The analysis incorporates uncertainty at a number of levels: in the numbers of fish released into rivers, estimated smolt abundances, smolt age proportions, smolt origin (when genetic information is insufficient for distinction), and number of adults returning. The Big Salmon River assessment has been conducted over two decades and is used as the benchmark river for assessing other LGB-supported and non-supported rivers within the DU. Thus, in this report, when other LGB program-specific (i.e., Gaspereau and Stewiacke) ecological parameters are unavailable, Big Salmon River is used as the proxy population. However, the Big Salmon River is expected to have better production per unit area of habitat and fewer negative freshwater-related factors that may influence survival to the smolt stage compared to other LGB supported rivers. Applying the Big Salmon River freshwater survival rates to a system with less productive habitat such as the Cornwallis River (Figure 5; DFO 2008) or Great Village or Chiganois rivers, which both have fish passage issues, could produce an overestimate of outgoing smolts and/or returning adults. The Big Salmon River population also has specific life-history characteristics (Jones et al. 2018) that were assumed to be representative of other rivers. For example, most juveniles were expected to leave after 2 or 3 years in river (smolt ages 2 and 3, few Age-1) (depending on age and life stage released) and return as small salmon (one seawinter [1SW]). Therefore, only Age-2 and Age-3 smolts were taken into account for smolt abundance estimates for released juveniles and adults and any Age-4 smolts were excluded.

The population abundance estimates presented in this report were derived from rivers that are LGB-supported. There are a number of other rivers, including those presented in this document as LGB non-supported rivers, that may contribute adults. A small number of rivers were identified by the 2014 Broadscale Electrofishing Survey as having remnant salmon populations; however, their contribution to the DU adult abundance estimate has not been included and is expected to be very small.

To provide an estimate of uncertainty around adult returns, a minimum to maximum range of freshwater survival rates from all the years analyzed was used as opposed to annual ranges directly. Given that the minimum and maximum survival values were used as bounds, annual smolt abundance estimates could be higher or lower than reported. Furthermore, a combined annual smolt-to-small salmon return rate was used representing all origins of smolts, including smolts produced from unfed fry, parr, and wild adults. Smolts produced from unfed fry and wild adult spawners have been shown to have higher survival (6X; Jones et al. 2018) than smolts produced from parr releases, which could bias the returning adult estimate. Finally, stock-specific captive-reared fecundity-length relationships were used in this model to estimate potential egg depositions. These fecundity-length relationships were derived between 2006 and 2008 and may not be representative of adults released annually from 2008 to 2013. Also, the relationship for the Big Salmon River is not stock-specific but derived from captive-reared Tobique River fish.

LGB smolts released from hatcheries in the spring at ages 1 or 2 were not incorporated into the returning adult abundance estimates, as they have been shown to contribute very few Atlantic Salmon returns in the past (Jones et al. 2018). Similarly, post-spawned LGB kelts that are no longer required in the LGB program may be released into LGB-supported rivers, but they are not expected to contribute to overall abundance. A kelt survival rate was developed from the Gaspereau River LGB data and applied to all iBoF kelt released between 2007 and 2011. Few, if any, of the estimated adult returns were estimated to have been from these kelt releases due to the estimated poor marine survival. However, kelt survival rate values were derived from releases in the Gaspereau River, a system that has a number of limiting factors that could impact survival rates, and they may not be representative of all rivers (i.e., Petitcodiac River, NB and Stewiacke River, NS) where kelts are also being released.

Due to the pedigree-based spawning design of the LGB program, excess fish are produced that are genetically surplus to requirements. Furthermore, a component of the program contains solely captive-reared fish that: 1) are used within the pedigree-based spawning only if an individual with similar genetics from a wild-exposed or wild-produced collection is unavailable, and 2) provides a safeguard against a catastrophic event in the wild. Some of these fish may be released as immature (may or may not be genotyped) or mature adults. Immature adults that were released in the spring were not incorporated into the model since sex and return rates are unavailable, thus a quantitative estimate of adult returns could not be derived.

Given that the LGB programs are designed to maintain the iBoF salmon population in supported rivers, it is expected that returning adults will spawn successfully. For simplicity, this report does not consider the contributions of returns in subsequent years (i.e., repeat-spawners) for the non-assessed rivers. For example, returns in 2009 from LGB releases could contribute to returns in 2013 and 2014 through natural spawning activities. Given the low marine survival, repeat spawners are expected to contribute minimally to iBoF adult abundance. The iBoF salmon population has a distinctive local migration and adults typically employ a consecutive repeat-spawning life-history tactic. Adults will migrate to the marine environment in the fall or spring after spawning and spend a few to several months at sea reconditioning before returning to spawn in a consecutive year. Interestingly, the Gaspereau River population is unique to the DU in that a portion of the population undergo a distant migration and return to spawn as two-sea-winter (2SW) adults. This analysis assumes that all salmon are returning as grilse (1SW, small salmon); however, a portion of the Gaspereau River (below White Rock dam) population may be returning as 2SW salmon, which would lead to an overestimate of returning adults in one year (e.g., 2013) and an underestimate in the next (e.g., 2014).

Regarding the actual count data for returning adult salmon, both the Gaspereau and the Big Salmon are the only rivers with total count data or estimates for the entire river. Count data from the Upper Salmon, Point Wolfe, and Pollet rivers are simply raw counts obtained from swim surveys and have not been extrapolated to represent the whole system since observation rates were not derived for these rivers. Therefore, these counts may be underestimates of the actual adult abundance returning to the Upper Salmon, Point Wolfe, and Pollet rivers.

Release data for this report was extracted from the DFO Distribution Database. This database has been actively used as a repository for release information; however, it has not been maintained by a single user throughout its lifespan and numerical discrepancies were identified during the analyses. Where possible, discrepancies were adjusted; however, a complete dissection of the database is required to ensure data is accurate for future use. These discrepancies were identified after Jones et al. (2018) was published, thus distribution values are similar between the two documents but not identical.

CONCLUSIONS AND ADVICE

Even with the uncertainty in the annual population estimates for the DU, current estimates of adult Atlantic Salmon in the iBoF DU consistently remain below the 1999 estimate of less than 250 returning adults. Abundance of Atlantic Salmon in the iBoF DU has not improved and may have further declined since the late 1990s despite supplementation efforts. Abundance estimates for 2013 to 2017 are less than 105 returning adults, with the exception of 2015 when the smolt-to-adult return rate was above average. The 1999 estimate of less than 250 adults in the iBoF DU was comprised primarily of wild-origin fish, whereas current annual adult estimates predominantly originate from LGB program support.

Based on the recent review of the iBoF population genetics (Jones et al. 2018; O'Reilly et al. 2018), it is expected that most of the Atlantic Salmon adults are of LGB-origin. Due to low marine survival, recovery activities have emphasized supplementation activities that increased the chances of wild-spawning (i.e., mature adult releases) and wild-exposure of progeny (i.e., unfed fry releases). This report also identifies the expected lack of contribution from kelts released into LGB-supported rivers due to low return rates associated with decreased marine survival.

The Big Salmon River appears to be producing the greatest number of returns compared to all other LGB-supported rivers (ranging between 11 [2013] and 32 [2015]); however, without an adult assessment, the contribution of the Stewiacke River to adult returns cannot be quantified. Additional adult assessments are required on LGB-supported rivers to determine definitive adult return estimates, which would aid with overall assessment and adaptive management of the LGB program. The egg-to-smolt survival rates used in this analysis were derived from adult releases from 2003–2005. Given the shift in program release strategies from smolts and parr to unfed fry and mature adults, updated egg-to-smolt survival rates would provide more accurate population abundance estimates, which could be used to inform recovery action.

Given that the LGB program consists of salmon from a variety of origins (i.e., captive-reared, wild-exposed and wild-produced), development of origin-specific survival and other biological parameters (e.g., fecundity-length relationships) would reduce uncertainties in the assessments of the iBoF population and LGB program.

Variations in marine survival can have a significant impact on returning adult population abundances. Evidence for this is apparent in the 2013 and 2015 adult return estimates, where marine survival of 0.05% produced estimated returns of 37 adults in 2013 to the entire DU (LGB-supported rivers, both assessed and non-assessed), compared to a marine survival of 0.62%, which resulted in an estimated return of 205 adults in 2015 despite similar LGB juvenile and adult inputs to supported rivers. Under current conditions, it is highly unlikely that adult returns to these rivers can be maintained without the support of the LGB program, given the lack of juvenile production from natural spawning.

IBoF rivers that are not supported by LGB releases may contain remnant populations of Atlantic Salmon. The production of these rivers is not included in this assessment. Additional assessment work is needed before they can be incorporated in the full iBoF DU estimate.

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Tuziak, Sarah	DFO Science, Maritimes Region
Bennett, Lottie	DFO Science, Maritimes Region
Bowlby, Heather	DFO Science, Maritimes Region
Chaput, Gerald	DFO Science, Gulf Region
Dauphin, Guillaume	DFO Science, Gulf Region
Epworth, Wendy	Fort Folly Habitat Recovery Program
Jones, Ross	DFO Science, Maritimes Region
MacDonald, Alyx	The Confederacy of Mainland Mi'kmaq
Reader, Jeff	DFO Science, Maritimes Region
Robichaud-Leblanc, Kim	DFO Species at Risk Management Division, Maritimes Region
Samms, Adam	New Brunswick Aboriginal Peoples Council
Sark, Roger	Maliseet Nation Conservation Council

SOURCES OF INFORMATION

This Science Advisory Report is from the October 19, 2018, Inner Bay of Fundy Atlantic Salmon Population Abundance Estimate meeting Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

Amiro, P.G. 2003. Population Status of Inner Bay of Fundy Atlantic Salmon (*Salmo salar*). Can. Tech. Rep. Fish. Aquat. Sci. 2488.

COSEWIC. 2006. COSEWIC Assessment and Status Report on the Atlantic Salmon *Salmo salar* (Inner Bay of Fundy Populations) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa.

Canadian Rivers Institute Database. 2017.

DFO. 2008. Recovery Potential Assessment for Inner Bay of Fundy Atlantic Salmon. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2008/050.

DFO. 2010. Recovery Strategy for the Atlantic Salmon (*Salmo salar*), Inner Bay of Fundy Populations [Final]. In: Species at Risk Act Recovery Strategy Series. Ottawa: Fisheries and Oceans Canada. xiii + 58 pp. + Appendices.

Gibson, A.J.F., Jones, R.A., O'Neil, S.F., Flanagan, J.J., and Amiro, P.G. 2004. Summary of monitoring and Live Gene Bank activities for inner Bay of Fundy salmon in 2003. DFO. Can. Sci. Advis. Sec. Res. Doc 2004/016, 49pp.

Gibson, A.J.F., Bowlby, H.D., Bryan, J.R., and Amiro, P.G. 2008. Population Viability Analysis of Inner Bay of Fundy Atlantic Salmon With and Without Live Gene Banking. DFO. Can. Sci. Advis. Sec. Res. Doc. 2008/057.

Jessop, B.M. 1986. Atlantic salmon (*Salmo salar*) of the Big Salmon River, New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 1415.

Jones, R.A., Anderson, L., Flanagan, J.J., and Goff, T. 2006. Assessments of Atlantic salmon stocks in southern and western New Brunswick (SFA 23), an update to 2005. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/025.

Jones, R.A., Ratelle, S.M., Tuziak, S., Harvie, C., Lenentine, B., and O'Reilly, P.T. 2018. Review of the Inner Bay of Fundy Atlantic Salmon Monitoring Activities Associated with the Live Gene Bank. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/043.

O'Reilly, P.T, Harvie, C.J., and McWilliams-Hughes, S.M. 2018. Genetic Change in Inner Bay of Fundy Atlantic Salmon Across Three Generations of Captive Breeding and Rearing. DFO Can. Sci. Advis. Sec. Res. Doc. 2018/044.

R Core Team. 2018. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

APPENDIX

Appendix 1. Freshwater survival estimates to smolt stage (by age) of unfed fry, Age-0 fall parr and egg released into the Big Salmon River (taken from Tables 20, 21, and 22 from Jones et al. 2018).

*Estimated survival of LGB **unfed fry** released into the Big Salmon River to the smolt stage from 2009 to 2014 (taken from Table 20).*

Release Year	Number Released	Percent Survival to Smolt Stage			
		Age-2	Age-3	Age-4	Total
2009	177,971	1.3%	0.9%	0.0%	2.2%
2010	200,378	1.3%	0.3%	0.0%	1.6%
2011	401,486	1.2%	0.1%	0.0%	1.3%
2012	97,209	1.3%	0.7%	0.1%	2.0%
2013	341,995	1.7%	0.6%	-	2.3%$^{+}$
2014	255,386	1.4%	-	-	-

*Estimated survival of LGB **Age-0 parr** released into the Big Salmon River to the smolt stage from 2007 to 2011 (taken from Table 21).*

Release Year	Number Released	Percent Survival to Smolt Stage				
		Age-1	Age-2	Age-3	Age-4	Total
2007	87,088	0.8%	4.5%	0.5%	0.0%	5.9%
2008	87,786	0.8%	6.7%	1.0%	0.0%	8.6%
2009	56,984	0.8%	3.3%	0.1%	0.0%	4.2%
2010	43,140	0.4%	3.9%	0.1%	0.0%	4.4%
2011	15,137	0.9%	5.9%	0.2%	0.0%	7.1%

*Estimated **egg-to-smolt** survival from LGB adults released in Big Salmon River from 2003 to 2005 (taken from Table 22).*

Release Year	Estimated Eggs	Percent Survival to Smolt Stage				
		Age-1	Age-2	Age-3	Age-4	Total
2003	156,720	-	0.65%	0.22%	0.04%	0.90%
2004	138,814	-	0.11%	0.08%	0.00%	0.19%
2005	283,646	-	0.16%	0.02%	0.00%	0.18%

Appendix 2. Applicable years of Live Gene Bank (LGB) release for each life stage and subsequent smolt Age-2 and Age-3 output year.

Life Stage of LGB Release (Age of Smolts Produced)	**Applicable Year of LGB Release for Each Life Stage**				
Mature Adults (Age-2 Smolts)	2009	2010	2011	2012	2013
Mature Adults (Age-3 Smolts)	2008	2009	2010	2011	2012
Unfed Fry (Age-2 Smolts)	2010	2011	2012	2013	2014
Unfed Fry (Age-3 Smolts)	2009	2010	2011	2012	2013
6-week Feeding Fry (Age-2 Smolts)	2010	2011	2012	2013	2014
6-week Feeding Fry (Age-3 Smolts)	2009	2010	2011	2012	2013
Age-0+ Fall Parr (Age-1 Smolts)	2011	2012	2013	2014	2015
Age-0+ Fall Parr (Age-2 Smolts)	2010	2011	2012	2013	2014
Age-1+ Spring Parr (Age-2 Smolts)	2011	2012	2013	2014	2015
	Numbers released				
Eggs Mature Adults (Age-2 Smolts)	918436	1208144	2459436	2869342	952338
Eggs Mature Adults (Age-3 Smolts)	1544082	918436	1208144	2459436	2869342
Unfed Fry (Age-2 Smolts)	217250	640060	310521	386450	658050
Unfed Fry (Age-3 Smolts)	245049	217250	640060	310521	386450
6-week Feeding Fry (Age-2 Smolts)	107757	0	14950	0	0
6-week Feeding Fry (Age-3 Smolts)	34245	107757	0	14950	0
Age-0+ Fall Parr (Age-1 Smolts)	183518	157932	2694	0	0
Age-0+ Fall Parr (Age-2 Smolts)	176734	183518	157932	2694	0
Age-1+ Spring Parr (Age-2 Smolts)	3000	653	0	170	0
Corresponding Smolt Class Year	**2012**	**2013**	**2014**	**2015**	**2016**

Appendix 3. Captive-reared length-fecundity equations for specific Live Gene Bank (LGB) rivers (i.e., Gaspereau, Stewiacke and Big Salmon rivers) used in this study to determine mature adult egg depositions for 2008 to 2013 releases.

LGB Population	**Length-Fecundity Relationships**	**Reference**
Gaspereau River	$\text{Eggs} = 309.8 * e^{(0.045*\text{Fork Length})}$	B. Lenentine, unpublished data
Stewiacke River	$\text{Eggs} = 324.84 * e^{(0.045*\text{Fork Length})}$	B. Lenentine, unpublished data
Big Salmon River	$\text{Eggs} = 337.93 * e^{(0.0436*\text{Fork Length})}$	Jones et al. 2006 *

***** derived from Captive-reared adults of Tobique River origin

THIS REPORT IS AVAILABLE FROM THE:

Center for Science Advice (CSA)
Maritimes Region
Fisheries and Oceans Canada
1 Challenger Drive, PO Box 1006
Dartmouth, NS B2Y 4A2

Telephone: 902-426-7070
E-Mail: MaritimesRAP.XMAR@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

ISSN 1919-5087

Correct Citation for this Publication:

DFO. 2020. Inner Bay of Fundy (iBoF) Returning Adult Atlantic Salmon Population Abundance Estimate. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2020/027.

Aussi disponible en français :

MPO. 2020. Estimation de l'abondance de la population adulte du saumon atlantique revenant frayer à l'intérieur de la baie de Fundy (IBF). Secr. can. de consult. sci. du MPO, Avis sci. 2020/027.