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Draft revised stock annex for the North American Commission (NAC) of Atlantic salmon: data structure and methods used to define the stock units, conservation limits, reconstruct returns and spawners to stock units of eastern Canada

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BACKGROUND

Atlantic salmon (*Salmo salar* L.) is native to the temperate and subarctic regions of the North Atlantic Ocean. There are an estimated 853 anadromous Atlantic Salmon rivers in eastern Canada. The USA reports 45 anadromous Atlantic Salmon rivers historically occupied by salmon (NASCO database results). In the Northwest Atlantic, the species ranges from northeastern USA (Connecticut) to northern Canada (Ungava Bay).

Atlantic salmon has a wide range of life-history strategies. Most forms are anadromous, however, with a juvenile phase in freshwater followed by a period at sea feeding and growing, during which the fish undergo extensive migrations in the open ocean, before they migrate back to freshwater to breed. Salmon mature at various sea ages, typically returning to freshwater to spawn after one to three years at sea, but also sometimes at older sea ages; this varies widely between populations. Most Atlantic salmon return to their river of origin to spawn. This precise homing behaviour has resulted in groups of fish originating in different rivers or tributaries becoming genetically distinct as they adapt to the particular conditions that they face in their home river and along their migration routes. As a result, fish from one river or tributary can differ from fish originating in other rivers/ tributaries which have become adapted to a different set of conditions. These subgroups comprise genetically distinct 'populations' and these are regarded as the basic biological units of the Atlantic salmon species.

Large rivers and their tributaries can support several, genetically distinct populations, each with separate spawning areas within the main-stem of the river or its tributaries. In most instances, however, it is not possible to demarcate clear population boundaries within a river, and managing stocks and fisheries at this level of detail would be very complex. Thus, while there is a need to protect the sustainability of these units, the primary management unit (e.g. for reporting catch statistics and regulating fishing) is generally taken to be the river stock, comprising all fish originating in eggs laid within the river.

CHAPTER 1. OVERVIEW OF STOCK UNITS FOR ATLANTIC SALMON OF THE NORTH AMERICAN COMMISSION

1.1 INTRODUCTION

Ideally, the management of all individual river stocks, and the fisheries that exploit them, might be based upon the status of each individual population. This is not always practical, however, especially where decisions relate to the management of distant water salmon fisheries, which exploit large numbers of stocks originating in broad geographic areas. ICES has considered how populations or river stocks should be grouped in providing management advice the definition of salmon 'stocks' as 'units of a size (encompassing one or more populations) which provide a practical basis for the fishery manager' (ICES 1996). The issues around the grouping of Atlantic salmon stocks for the provision of management advice are reviewed in detail in Crozier et al. (2003). Such stock groupings have typically been referred to as stock complexes.

Salmon mature at various sea ages, typically returning to freshwater to spawn after one to three years at sea, but also sometimes at older sea ages; this varies widely between populations. Those salmon that return after one year at sea are referred to as one-sea-winter (1SW) salmon, or grilse, with older fish categorised as 2SW, 3SW, etc. In practice, however, for management purposes these older sea age fish are typically aggregated and collectively referred to as multi-sea-winter (MSW) salmon. The sea age of Atlantic salmon is important in the context of stock definition since these different groups of fish have different migration routes, return at different times and are differentially exploited in fisheries. Thus, for example, it is only potential MSW salmon that are exploited in the distant water salmon fishery that operates off the west coast of Greenland.

1.2 STOCK GROUPINGS USED BY ICES IN PROVIDING MANAGEMENT ADVICE

Atlantic salmon would, ideally, be assessed and managed on the basis of river-specific stock units. In reality, <25% of the rivers with salmon populations in the North Atlantic are so assessed (ICES 2021). Consequently, stock status is often, of necessity, assessed at broader regional, national and subcontinental scales. While there might be merit in grouping stocks according to biological criteria (which could cross jurisdictional boundaries), it has generally been considered that the difficulties of collecting data in a similar format in different jurisdictions is likely to outweigh the benefits of using such groups (Crozier et al. 2003). It is also recognised that compilations of data on stocks within each jurisdiction are of importance to regional / national managers. As such, regional / national stock groups are typically used by ICES in providing advice on the status of stocks, with additional information compiled on biological groups (e.g. sea ages) as required.

1.3 STOCK UNITS FOR NAC

The ICES run reconstruction, PFA forecast model, and the Life Cycle Model aggregate individual river abundances into six stock units representing geographic regions of North America: the USA and the five main provincial / jurisdictional regions in eastern Canada comprising Labrador, Newfoundland, Quebec, Gulf and Scotia-Fundy (Figure 1). The stock units reflect the jurisdictional boundaries of the Fisheries and Oceans Canada, the province of Quebec, and the USA. For Canada, the stock units are aggregates of management areas, termed Salmon Fishing Area (SFA) and Quebec management zones (Q) (Figure 2; Table 1). The stock units correspond in large part to the geographic structure of sea age and life history characteristics of anadromous salmon in eastern Canada (Figure 3; Porter et al, 1986; O'Connell et al. 2006).

1.3.1 Reconciling stock units with discrete genetic groups of NAC

Recently, Bradbury et al. (2021; and earlier work) reported on the identification of genetically discrete reporting groups of Atlantic salmon. Depending upon the genetic markers used and the time of the publication, the number of reporting groups and their boundaries vary. The latest iteration reported in Bradbury et al. (2021) and used by ICES (2023) uses a panel of 96 Single Nucleotide Polymorphism (SNPs) to jointly distinguish 30 stock units in the North Atlantic, 21 for NAC (including a NAC aquaculture group) and 10 for NEAC.

Five of the six NAC stock units used to date by ICES each encompass several genetic reporting groups; the exception being USA which has a single reporting group (Table 1). With few exceptions, each individual genetic reporting group is contained within a single stock unit. Exceptions to this occur along boundaries of the stock units, particularly between the Quebec and Gulf stock units, the Gulf and Scotia-Fundy stock units, and to a lesser extent between Quebec and Labrador stock units (Table 1; Figure 4).

- The Gaspe regional group includes the Restigouche River which is a border river between the provinces of New Brunswick and Quebec. In the run reconstruction, a large portion (termed Restigouche NB, excluding Matapedia River, a Quebec tributary of the Restigouche River) of the salmon returns and spawners of the Restigouche River are included in the estimates for Salmon Fishing Area 15 which is in the Gulf stock unit. If the Restigouche NB returns are added to the Quebec stock unit, the returns to Quebec would be 13% to 30% higher for large salmon, 16% to 40% higher for small salmon (years 2010 to 2019).
- The southern Gulf of St. Lawrence regional reporting group excluded the Restigouche River (NB area in SFA 15) and includes salmon from rivers of eastern Cape Breton (Salmon Fishing Area 19). The Restigouche NB returns are estimated to be 12.0% to 26.4% of the small salmon, and 10.4% to 28.9% of the large salmon of the Gulf stock unit (years 2010 to 2019) and would be reduced accordingly if the Restigouche NB returns were attributed to the Gaspe genetic reporting group. Returns and spawners to rivers in SFA 19 are included in the vector of inputs as a combined SFA 19-21 of the Scotia-Fundy stock unit. The estimated returns to SFA 19-21 are equivalent to 2% to 10% of the large salmon, 2% to15% of the small salmon estimated returns of the Gulf stock unit (excluding Restigouche NB).
- In turn, the returns to SFA 19-21 represented 36% to 88% for large salmon and 13% to 71% for small salmon of the total returns to the Scotia-Fundy stock unit (years 2010 to 2019).
- There are six rivers in the northeast portion of Quebec zone Q9 (Brador est, Ruisseau au Saumon, Ruisseau des Belles Amours, Du Vieux Fort, Napetipi, Saint-Paul) that are included in the Labrador South genetic reporting group (see Lehnert et al. 2023). The returns and spawners of these six rivers are otherwise included in the estimates for the Quebec stock unit. The return estimates of these six rivers represent 2.0% to 4.0% for large salmon and 14% to 23 % for small salmon of the total Quebec returns (including the 6 rivers). The estimated returns to these six Quebec rivers are 1.0% to 6.7% for large salmon and 1.3% to 4.5% for small salmon of the estimated returns to the Labrdor stock unit (years 2010 to 2019).

For several stock units, it would be possible to reconstruct returns and spawners to these genetic reporting groups beginning in 1984, and from 1971 to present for the regional reporting groups of Newfoundland, Gulf, Scotia-Fundy, and USA. The exceptions are:

- The Quebec estimates prior to 1984 are presently available only at the scale of the province.
- For Labrador, the reconstruction of returns and spawners from 1971 to 1998 is based on the commercial catches from the Labrador region, estimates of exploitation, and assumptions on

the proportion of the harvests of Labrador origin (see run reconstruction details). It would not be possible with the current run reconstruction data to assess the three Labrador reporting groups defined in Bradbury et al. (2021).

1.3.2 Other Issues

Prior to 1984, the coastal commercial fishery harvests from Quebec and the Maritime provinces would need to be partitioned into the regional reporting groups rather than the assumptions currently used of attributing the commercial harvests from the coastal area of a region to the stock unit. There is currently no information to partition these harvests into regional reporting groups.

There is no information with which to partition the harvests in the Newfoundland (1971 to 1991) and Labrador (1971 to 1997) commercial fisheries to either the ICES stock units or the finer scale regional reporting groups. In the PFA forecast and catch advice model, it is assumed that the stock unit contributions of these fisheries correspond to the proportions of the returns to the stock units (see commercial fisheries harvest attributions).

This could be resolved using genetics and historical scale samples.

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Table 1.1. Reconciliation of ICES North American stock units to management areas, and genetic reporting groups based on microsatellites (Bradbury et al. 2014) and on a 96 SNP baseline (Bradbury et al. 2021; ICES 2023).

Ices stock unit	Management area	Regional reporting group at ices: Micro-satellites	Regional reporting group at ices: SNP
US	US	US	US
Scotia-Fundy	SFA 23	Gulf of St. Lawrence	Outer Bay of Fundy
		Inner Bay of Fundy	Inner Bay of Fundy
	SFA 22		Western Nova Scotia
	SFA 21	Nova Scotia	Nova Scotia
	SFA 20		
	SFA 19	Gulf of St. Lawrence	Gulf of St. Lawrence
Gulf	SFA 18		
	SFA 17		
	SFA 16		
	SFA 15		
Quebec	Q1	Gaspe	Gaspe
	Q2		
	Q3		
	Q5	Quebec	Quebec
	Q6		
	Q7		Quebec Lower North Shore
	Q7		
	Q8	Quebec / Labrador South	
	Q9		
Labrador	SFA 14B		Labrador South
	SFA 2	Labrador Central	
	SFA 1B		Central Labrador
	SFA 1A		Northern Labrador
Quebec	Q11	Ungava / Northern Labrador	Ungava
	Q10	Anticosti	Anticosti
Newfoundland	SFA 14A	Newfoundland	Northwest Newfoundland
	SFA 3		
	SFA 4		Newfoundland 1
	SFA 5		
	SFA 6	Avalon	
	SFA 7		Avalon
	SFA 8		
	SFA 9		
	SFA 10		
	SFA 11	Newfoundland	Burin Peninsula
			Fortune Bay
	SFA 12		Newfoundland 2
	SFA 13		Southwest Newfoundland

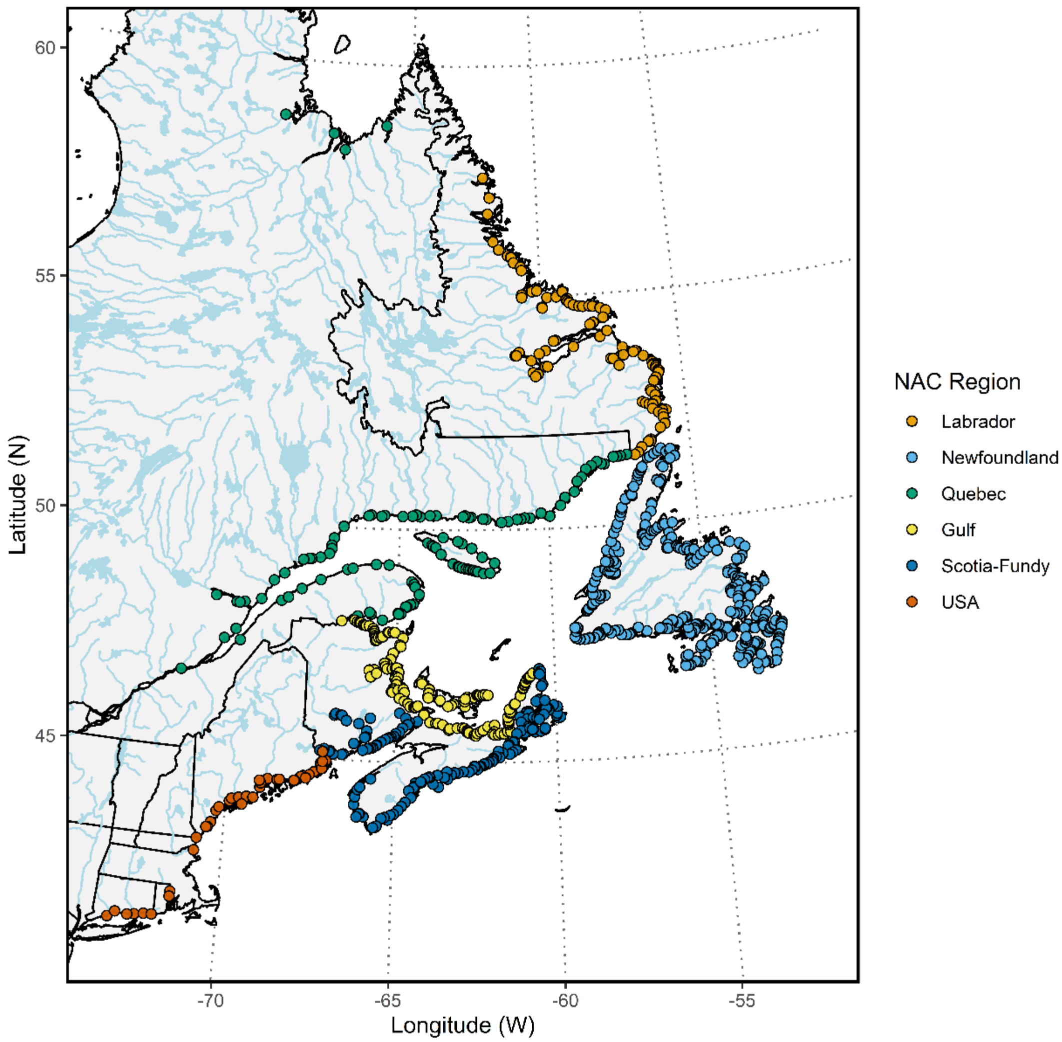

Figure 1.1. Map of stock units of the North American Commission used by ICES in the run reconstruction and forecast models of abundance of Atlantic Salmon.

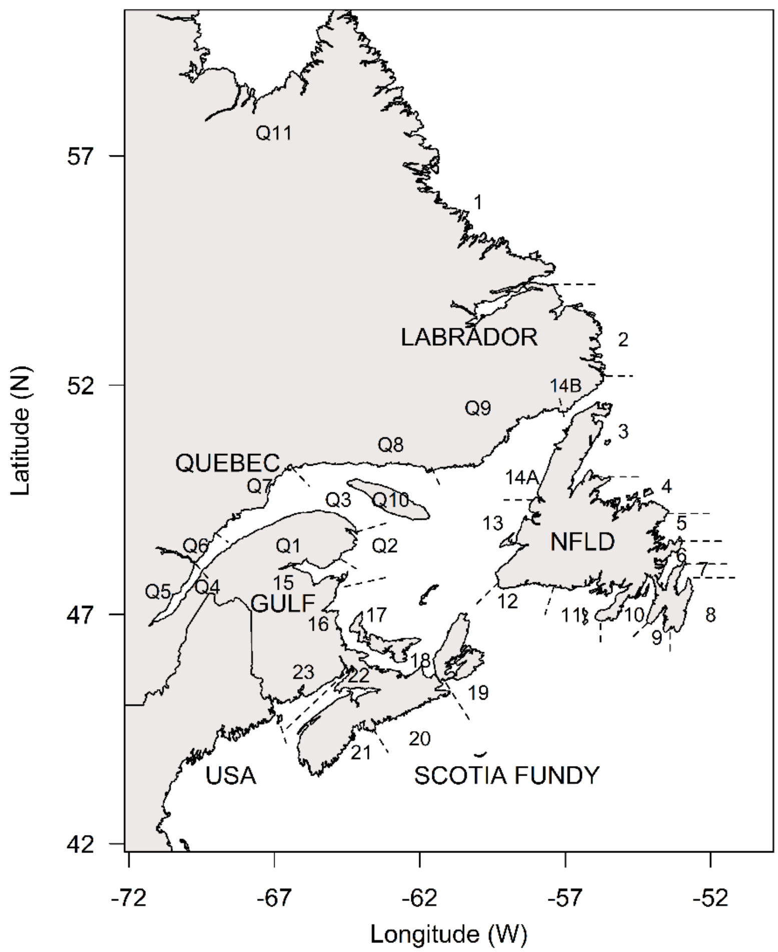

Figure 1.2. Salmon Fishing Areas (SFA) and Quebec management zones (Q) for eastern Canada.

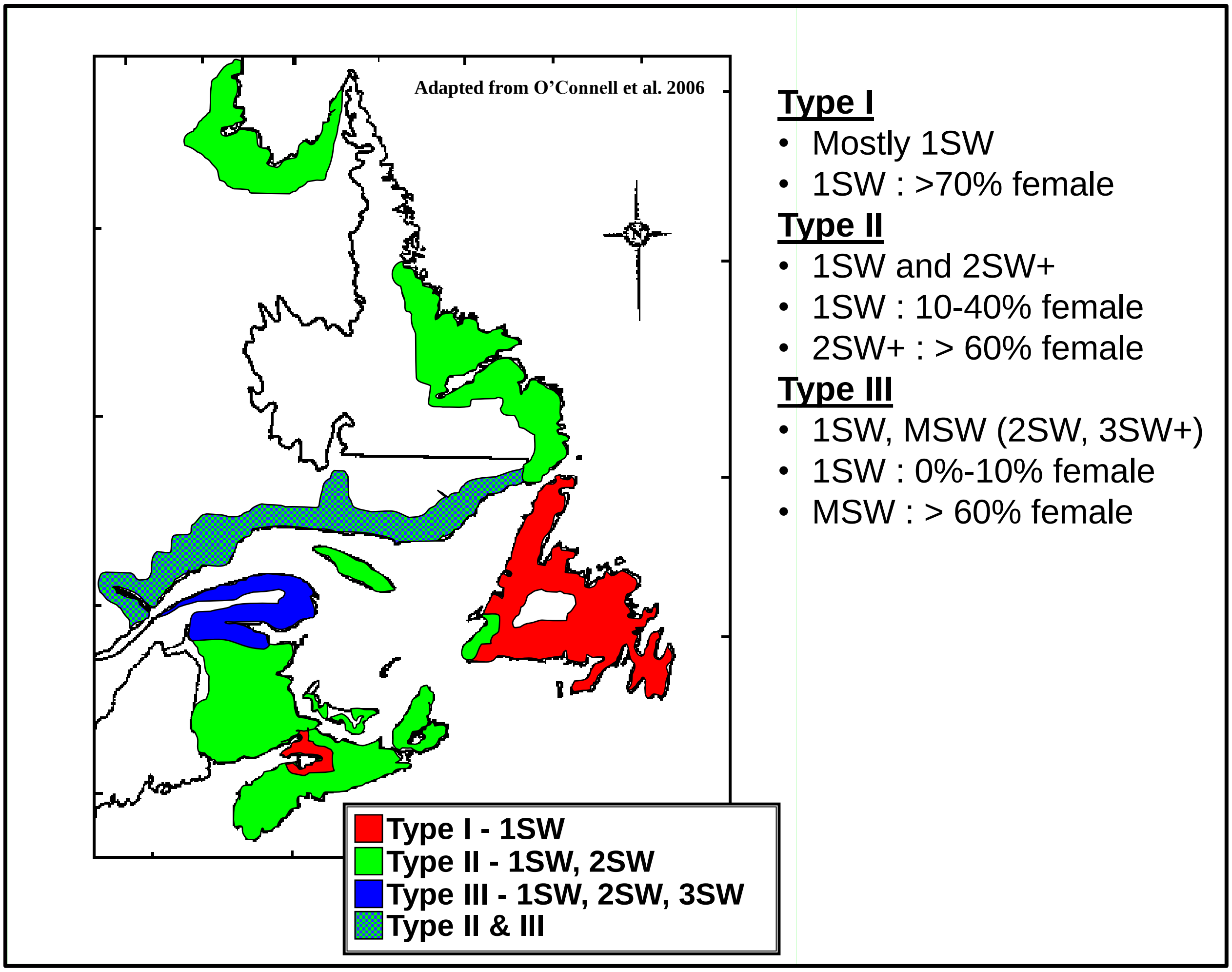

Figure 1.3. Regional characteristics of sea age at maturity and proportion female by sea age of anadromous Atlantic Salmon populations of eastern Canada. The figure is adapted from Porter et al. (1986) and O'Connell et al. (2006).

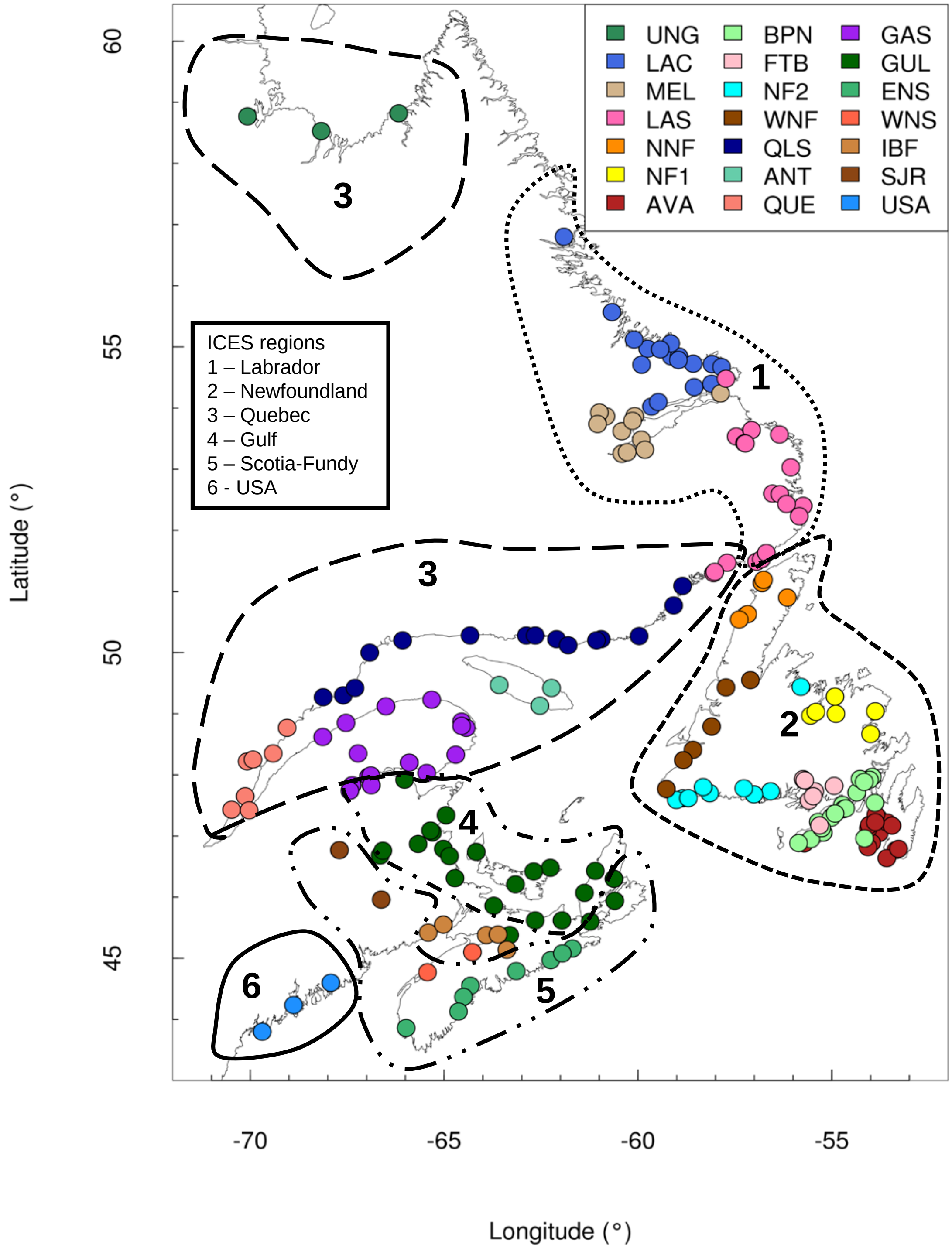

Figure 1.4. ICES regions in eastern North America which define the geographic scale for the observations and the population dynamics of salmon for the eastern North American complex compared to the regional groups defined by genetic characteristics based on SNPs (Bradbury et al. 2021; ICES 2023).

CHAPTER 2. OVERVIEW OF DEFINITION OF CONSERVATION LIMITS FOR ATLANTIC SALMON STOCK UNITS OF EASTERN CANADA

2.1 INTRODUCTION

The assessment of the status of Atlantic Salmon stocks in the North Atlantic is based on the abundance of potential spawners relative to reference points. For the provision of catch advice for the West Greenland fisheries, ICES (2002) defined the conservation limits for six North American stock units, in number of fish, for the two-sea-winter sea age component only. This was done to support the catch advice for the West Greenland fishery, which exploited primarily 1SW non-maturing salmon, the majority of which would have likely returned to North America as 2SW first time spawners. This approach makes the implicit assumption that 1SW non-maturing recruits (destined to return as 2SW salmon) are entirely determined by the abundance of 2SW salmon spawners. In addition to the Conservation Limits, ICES (2002) also provided management objectives for the two southern stock units of Scotia-Fundy and USA. The management objectives were defined in recognition that these stock units were at such low abundance that there was no probability that returns would equal or exceed the CLs even in the absence of fishing at West Greenland or in homewaters. The management objectives, in terms of 2SW salmon spawners, were described as rebuilding objectives.

Conservation limits in terms of total eggs, or in terms of small salmon and large salmon, for the six stock units of NAC have not been previously defined by ICES. In the interest to move to a life cycle model (LCM) with total eggs as the starting point of the life cycle, there is a need to define the conservation limits in units of total eggs, and to provide the equivalences of the total eggs in terms of small salmon and large salmon, accounting for the biological characteristics of the two size groups and the anticipated or desired size/sea age proportions of the spawners.

Chaput (2006) reviewed the history and process for defining Atlantic Salmon spawner requirements and variations on this leading to the definition of conservation limits and ultimately to Limit Reference Points and Upper Stock Reference Points to conform to the Precautionary Approach policy in Canada. The concern about maintaining enough spawners so as not to deplete the resource stems from the centuries of interest to fish salmon and ultimately to manage the resource sustainably for future generations. The wide recognition of the importance of spawners to recruitment also stems from the ease with which salmon can be cultured in hatcheries, had been cultured for centuries, and the broad evidence from these practices that large numbers of juveniles could be produced from a small number of spawners.

The first eastern Canadian exercise to define spawner targets (terminology of that time) for salmon producing areas of eastern Canada dates to 1978 (Anon. 1978). An Atlantic Salmon Review (1978) was mandated to respond to the Minister's intent to undertake a review of the Atlantic salmon fishery taking into account the biological realities and economic and social requirements. The Biological Conservation Subcommittee was established with terms of reference that included: identifying the major salmon production areas, and quantifying the production potential and spawning escapement requirements (Anon. 1978). The salmon producing areas in Anon. (1978) correspond in large part to the current Salmon Fishing Areas and Zones of Quebec. This exercise is referenced here as it remains the basis for defining the conservation limits used by ICES for the Newfoundland stock unit (Appendix 1). Contrasting the spawner requirements for the other stock units developed by Anon. (1978) to the current conservation limits and reference points will help position the Newfoundland values to what they could be using similar approaches to the other stock unit areas.

Conservation limits for several stock units have been periodically refined over the years with the most recent changes to the conservation limits following on the development of reference points that conform to the Precautionary Approach in Canada (DFO 2015, 2018) and a revision to the reference points for the management of salmon in Quebec (Dionne et al. 2015; MFFP 2016).

In 2016, ICES (WGNAS) provided an overview of ongoing work that Fisheries and Oceans Canada (DFO) was undertaking to refine reference points for Atlantic salmon in Canada that conformed to the Precautionary Approach (ICES 2016a). DFO Maritimes Region (Scotia-Fundy) retained the current conservation requirement based on 240 eggs per 100 m^2 as the Limit Reference Point (DFO 2012; Gibson and Claytor 2013). DFO Newfoundland Region retained the current conservation requirement based on 240 eggs per 100 m^2 of fluvial rearing habitat, and in addition for insular Newfoundland 368 eggs per ha of lacustrine habitat (or 150 eggs per ha for stocks on the northern peninsula of Newfoundland), as equivalent to their Limit Reference Point and have defined the Upper Stock Reference as 150% of the Limit Reference Point (DFO 2020). The Province of Quebec revised the Limit Reference point and Upper Stock Reference point using a Bayesian hierarchical analysis of stock–recruitment data and also defined a reference point based on conservation genetic parameters (Dionne et al., 2015; Ferchaud et al. 2016; MFFP 2016). DFO Gulf Region undertook an exercise to revise and define the Limit Reference Point in that region of Canada using the proportion of eggs from MSW salmon as a covariate in the Bayesian hierarchical model (DFO 2018). The Limit Reference Points in all cases are defined in terms of total eggs from all sizes and sea ages of salmon. In 2022, Upper Stock Reference and Target Reference points were defined for the rivers of DFO Gulf Region (DFO 2022). The definitions of the Conservation Limits (reference points) for the five Canadian regions of North America are summarized in Table 2.1.

Revised conservation limits specific to 2SW salmon for DFO Gulf Region and Quebec were presented at ICES (2019). The revised 2SW conservation limit (18,737 fish) for Gulf was a 38% decrease from the previous value whereas the revised 2SW CL for Quebec was a slight increase (9%) from the previous value. The 2SW conservation limit for Quebec was based on the Upper Stock Reference value because the management regime in Quebec could authorize a large salmon recreational fishery in cases when the anticipated spawners after fisheries met or exceeded the USR. Since the fishery at West Greenland harvests primarily 1SW non-maturing salmon, destined to return mostly as 2SW salmon, it was deemed more appropriate in the case of Quebec to use the USR value.

The definition of the 2SW conservation limit for Quebec is here revised from ICES (2019) to correspond to the defined LRP because:

- It is consistent with domestic management where the LRP rather than the USR is considered a conservation limit.
- Salmon harvests in the recreational fisheries in Quebec are now mainly directed toward small salmon (for instance in 2021, small salmon retention was allowed in 72 rivers with a reported 4446 small salmon harvested whereas large salmon retention was allowed in 18 rivers with a total reported harvest of 736 large salmon).
- The assessment presented for the other Canadian stock units uses the LRP is used as the conservation limit.

Details of the methods for deriving the conservation limits are described in the following sections, by stock unit.

2.2 LABRADOR

The method for deriving the conservation limits (referred to at the time as spawner targets) used by ICES for 2SW salmon, large salmon and small salmon were described in O'Connell et al. (1997). Habitat weighted spawning requirements were not available at the time because the resolution of the available

1:250 000 maps was insufficient to accurately estimate fluvial rearing habitat (O'Connell et al. 1997). Reference was made to spawning targets and these were used synonymously with conservation limits.

The conservation limits in terms of number of fish were defined from the ratio of spawners to recruits (in the absence of marine fisheries) of Labrador salmon. The recruits were estimated from the run reconstruction of returns to Labrador, to which was added the catch of Labrador origin 1SW non-maturing salmon at West Greenland, corrected for 10 months of mortality (at a rate of 1% per month) between the start of the West Greenland fishery (Aug. 1) and the returns to the coast of Labrador (June 1). The specifics for this calculation are as follows:

2.2.1 For 2SW salmon

- The period of returns to Labrador during 1974 to 1978 and West Greenland catches during 1973 to 1977 was chosen as the reference period to define the mean recruitment potential of the Labrador stock unit, equivalent to recruitment at Maximum Sustainable Yield (R_{MSY}).
- The returns to the coast of Labrador of large salmon, before the commercial fishery, are calculated from the commercial catches in Labrador (SFAs 1, 2, and 14B) raised by estimates of exploitation rates of large salmon (0.7 to 0.9) and included estimated catches of Labrador origin salmon in the commercial fisheries of the northeast coast of Newfoundland (Reddin et al. 2006; states this but does not show how this was done).
- The proportion of the Labrador returns to the coast of large salmon assumed to be 2SW salmon was between 0.7 and 0.9.
- The proportion of the Labrador returns of 2SW salmon considered to be Labrador origin was assumed to be between 0.6 and 0.8.
- Labrador origin catch at West Greenland was estimated from the total catch of 1SW North American origin salmon with a river age of 4 years and older, of which Labrador was assumed to contribute 70% of the total North American production of fish of river age 4 and older years. Over the period 1973 to 1977 at West Greenland, the proportion of the North American catch with a river age of 4 and older varied from 0.224 to 0.346 (ICES 2019).
- Recruits per spawner were calculated by lagging spawners by their appropriate sea age and weighting them by the river-age distribution by region. The average for Labrador-origin salmon stocks for spawning years 1974 - 1978 is 0.3 spawners per recruit and this was chosen to define the spawner target (or Conservation Limit) of 2SW salmon for Labrador (O'Connell et al. 1997); assuming that one spawner would on average generate three recruits (Reddin et al. 2006).

2.2.2 For large salmon

- O'Connell et al. (19797) indicate that the large salmon spawner requirements were derived by multiplying the 2SW salmon requirements by 1.3875 (equivalent to 2SW salmon proportion in large salmon of 0.721).

2.2.3 For small salmon

- The returns (recruits) to Labrador, before the commercial fishery, are calculated from the commercial catches in Labrador (SFAs 1, 2, and 14B) of small salmon raised by estimates of exploitation rates (0.3 to 0.5).
- The proportion of the Labrador catch of small salmon that was of Labrador origin was assumed to be between 0.6 and 0.8.

- Recruits per spawner were calculated by lagging small salmon spawners by-their appropriate sea age and weighting them by the river age distribution by region. The average for Labrador origin salmon stocks for spawning years 1974 - 1978 is 0.43 spawners per recruit and this was chosen to define the spawner target (Conservation Limit) of small salmon for Labrador (O’Connell et al. 1997).

2.2.4 Revised conservation limit egg requirement for Labrador

Reddin et al. (2006) provide background and justification for the definition of a conservation limit egg deposition rate of 190 eggs per 100 m² of fluvial parr rearing habitat for rivers of Labrador. This value is based on analysis of stock and recruitment data from the Sand Hill River and the conservation limit represents the egg deposition that corresponds to 50% of the equilibrium point (eggs in recruitment equal eggs in spawners) of a fished population (mean return rate of smolts to the river as spawners of 0.073; Reddin et al. 2006). Reddin et al. (2010) list 89 rivers in Labrador (SFAs 1, 2 and 14B) and their associated egg requirements to meet conservation limits. The total egg requirement of these 89 rivers is 239.14 million eggs (Table 2.2; Reddin et al. 2010). Converting the total egg requirement to an approximate number of fish by size group requires information on the mean eggs per fish for small salmon and large salmon as well as the expected / desired proportion of the total eggs to be contributed by small salmon and large salmon. Average biological characteristics by size group are reported in Dauphin et al. (2021). As a first estimate of the proportion of the eggs contributed by large salmon in Labrador, we considered the ratio of eggs contributed by large salmon based on the estimated recruits to Labrador as described in O’Connell et al. (1997) for the spawning years 1974 to 1978 (Table 2.3).

The average number of spawners, by size group, that would contribute the total egg requirement is:

$$N_{large} = \frac{p.Recruit\_eggs_{large} * CL_{Eggs}}{Eggs\_per\_fish_{large}} = \frac{0.705 * 239.14\ million}{4295} = 39{,}281 \text{ fish}$$

$$N_{small} = \frac{p.Recruit\_eggs_{small} * CL_{Eggs}}{Eggs\_per\_fish_{small}} = \frac{0.295 * 239.14\ million}{1262} = 55{,}806 \text{ fish}$$

2.3 NEWFOUNDLAND

The method used to define river specific egg conservation limits for rivers of Newfoundland is described in O'Connell and Dempson (1995). In summary, conservation egg requirements are defined as the product of the number of fluvial habitat units (unit = 100 m²) and an egg deposition rate of 240 eggs per unit plus the product of the number of hectares of lacustrine habitat and an egg deposition rate of 368 eggs per ha or 175 eggs per ha for the rivers of SFA 14A the Northern Peninsula of Newfoundland (Anon. 1991a; O’Connell and Dempson 1995; DFO 2015). River specific conservation requirements for Newfoundland have been defined for 71 of 312 rivers (Table 4) however O’Connell et al. (1997) provide spawner requirements in terms of small salmon, large salmon, and for 2SW sea age group for each of the SFAs in Newfoundland.

The spawner requirements by SFA tabled in O’Connell et al. (1997) have some of their source in Anon. (1978). Anon. (1978) has spawner requirements of 97,730 small salmon and 10,280 large salmon (Appendix 1) in contrast to O’Connell et al. (1997) spawner requirements of 198,160 small salmon and 15,468 large salmon (Table 2.4).

Using average eggs per fish by size group, as reported in Dauphin et al. (2021), the total egg requirement equivalent to the conservation limit for Newfoundland would be 417.78 million eggs (Table 2.5).

2.4 QUEBEC

Conservation limits for managing Atlantic salmon fisheries in the province of Quebec (eastern Canada) were originally developed by Caron *et al*. (1999) based on a hierarchical analysis of adult-to-adult stock and recruitment relationships from six rivers of Québec. Updated time series of adult-to-adult stock and recruitment data from twelve rivers in Québec, extending as far back as 1972 for some rivers, were re-analysed using a Ricker stock and recruitment function (Dionne et al. 2015). The habitats of individual rivers were scaled to units of productive habitat (fluvial type, substratum, width of river, and temperature index; Dionne et al. 2015). A Bayesian hierarchical model with reference points transported to individual rivers based on estimated habitat within the model was used to define reference points for 105 rivers in Québec. A limit reference point (LRP) was selected as the spawner abundance equivalent to the 75th percentile of the posterior distribution of $S_{0,5Rmax}$. An upper stock reference (USR) point was also defined as the 95th percentile of S_{MSY}. An additional limit reference point (LRP) was defined with the objective to preserve 90% of the genetic diversity over 100 years, corresponding to an effective population size (N_e) of 95 (MFFP 2016; Ferchaud et al. 2016). This represents an annual eggs deposition of 825 750 eggs (around 200 spawners) by river. As described by MFFP (2016), the effective values of LRP and USR are respectively approximately equivalent to 132 and 312 eggs per productive unit of habitat (100 m² of fluvial habitat adjusted using an index of habitat quality) but the river specific values may differ from this as the calculation of the percentiles depends upon the size of the river as a covariate in the model (Dionne et al. 2015). The management plan for Atlantic salmon fisheries for the period 2016 to 2026 includes a table of river specific egg requirements for the LRP and USR, summarized in Tables 2.6 and 2.7.

The egg requirements by management zone are converted to number of fish by sea age (1SW, MSW) in Table 7 based on updated biological characteristics for Quebec from those in Dauphin et al. (2021). Also considering a mean 2SW proportion of 0.449 of the total returns (as in ICES 2019), the 2SW salmon Conservation Limits is now established at 18,914.

Spawner requirements from Anon. (1978) are provided for large salmon only and total 80,400 fish (Appendix 1). This contrasts with the approximate large salmon requirement of 21,000 fish, excluding the Ungava Bay region (Q11), based on the limit reference point values from MFFP (2016). This is most likely explained by the inadequate assumption used by Anon (1978), including returns rate of 8% that have never been documented in Quebec (Appendix 1). Excluding zone Q11, the spawner requirement from Anon. (1978) totals 68,200 fish.

2.5 GULF

Spawner requirements for Gulf region rivers were first defined based on an egg deposition rate of 240 eggs per 100 m² of fluvial habitat area coming from all size / sea age groups of salmon (Anon. 1991a, 1991b). Following on a review of methods to define reference points that conform to the Precautionary Approach (DFO 2015), river specific Limit Reference Points (LRP) were defined for Gulf region Atlantic salmon rivers with estimates of fluvial areas (n = 99). The LRP was defined using egg-to-smolt relationships from 14 rivers. The LRP is defined as the egg deposition that would result in a low probability (< 25%) of the smolt production being less than half of the asymptotic production based on a Beverton-Holt stock and recruitment model with a covariate that accounts for the proportion of the eggs that would be deposited by large salmon; as the prop of eggs deposited by large salmon increases, the optimal egg deposition rate decreases. Egg deposition rates for the rivers of Gulf vary from 152 eggs per 100 m² (prop. of eggs from large > 0.90) to 176 eggs per 100 m² (prop. of eggs from large = 0.78) (DFO 2018). In a subsequent review, the Upper Stock Reference values were defined as 3.78 * LRP value (DFO 2022).

The Limit Reference Point for rivers of Gulf Region in terms of eggs is 172 million eggs whereas the USR is 649 million eggs (Table 2.8). Based on average biological characteristics of the small salmon and large salmon used to define the Salmon Fishing Area reference points, the number of spawners at LRP total 27,395 large salmon and 27,943 small salmon. The equivalent numbers of salmon for the USR point is 103,554 large salmon and 105,625 small salmon.

The number of 2SW salmon equivalents for the LRP, estimated from the average proportion of 2SW sea age group in the large salmon category by Salmon Fishing Area, were updated in ICES (2020) to 18,737 fish.

Egg depositions from small salmon and large salmon are included in the assessment of status relative to the LRP and the USR (DFO 2022). The fisheries management strategy could authorize retention fisheries on small salmon and large salmon when the expected egg depositions after fisheries exceed the LRP (or a defined harvest decision rule; DFO 2022) and the maximum exploitation rate when the egg depositions exceed the USR is set at 0.6 (Table 2.8). Catch advice of the West Greenland and homewater fisheries would be provided relative to the LRP defined in terms of eggs.

2.6 SCOTIA-FUNDY

Conservation limits for some Atlantic salmon rivers of the Scotia-Fundy stock unit were defined in Anon. 1991b based on an egg deposition rate of 240 eggs per 100 m² of fluvial habitat, unimpacted by acid precipitation. Gibson and Claytor (2O13) confirmed the conservation limit of 240 eggs per 100 m² as equivalent to the Limit Reference Point that conforms to the Precautionary Approach. The fluvial habitat area measurements exclude low gradient (< 0.12 m km^{-1}) sections (Amiro 2000).

The salmon fishing area specific estimates of egg conservation limits and the corresponding number of fish are summarized in Table 2.9.

2.6.1 Management objective for Scotia-Fundy

ICES (2002) expressed concerns that the continent wide pawning requirement used for North America to provide catch advice for West Greenland did not reflect the expected returns to the six regions, i.e. even if 172,000 2SW salmon reached the coast of North America, there would be severe under-escapement in some regions because of disproportionate under-escapement realized in the southern stock units of NAC. Based on historical data, there was no reason to expect the abundance of salmon in the North Atlantic to be proportional to the regional 2SW spawner requirements (ICES 2002).

To guide the management of the fishery at West Greenland, an alternative risk analysis was conducted that considered rebuilding objectives rather than 2SW conservation limits for the two southern regions, Scotia-Fundy and USA. The objective would be defined as a pre-agreed increase in returns relative to the realized returns of a previous period. Rates of increase could be as low as a 10% annual increase relative to the stock levels observed in the previous five years for those stocks that are approaching a stock status objective to more ambitious rebuilding rates such as 25% per year could be used for stocks that are very far from their desired state. ICES (2004) established 1992 to 1996 as the range of years to define the baseline for the Scotia-Fundy and USA regions and against which to assess the PFA abundance of NAC and fishery options. Estimated returns of 2SW salmon for Scotia-Fundy are compared to the objective of achieving an increase of 25% relative to average returns of the base period, 1992–1996, a period corresponding to the returns following on the closure of the Newfoundland commercial salmon fishery. The management objective is 10,976 2SW returns, 44% of the 2SW conservation limit (24 705) for Scotia-Fundy (ICES 2014). The definition of a revised management objective for the Scotia-Fundy region that considered advice on recovery targets identified in the recent Recovery Potential

Assessments for the three Designatable Units of Atlantic salmon in this region was not possible at the time (ICES 2014).

2.7 SUMMARY OF CONSERVATION LIMITS FOR THE STOCK UNITS OF NAC

Updated conservation limits in terms of eggs from all sea age groups and total egg conservation limits converted to number of small salmon and large salmon for the five stock units of eastern Canada are provided in Table 10. The 2SW conservation limits and the management objectives for the USA and Scotia-Fundy stock units are also shown in Table 10. Based on the revised total eggs and the biological characteristics of salmon from Labrador, a revised 2SW requirement could be considered (Table 2.10).

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2.9 TABLES

Table 2.1. Atlantic Salmon reference points that equate to conservation limits for the stock units of eastern Canada within the North American Commission area of NASCO.

NAC Region	Objective	Reference Point	Reference
Scotia-Fundy	LRP: egg depositions that result in half of maximum smolt production, Beverton-Holt function	LRP: 240 eggs per 100 m^2 of fluvial habitat	Gibson and Claytor (2013)
Gulf	LRP: egg depositions that result in a low probability (<25%) of smolt recruitment being less than 50% of maximum recruitment (Beverton-Holt function) USR: eggs in recruitment at MSY	Depends on river-specific sea age characteristics of spawners; LRP: 152 to 178 eggs per 100 m^2 of fluvial habitat USR: LRP * 3.78	DFO (2015, 2018, 2022); Chaput et al. (2023)
Québec	LRP1: egg depositions that result in a high probability (75th percentile of posterior distribution) of the adult recruitment being more than 50% of maximum recruitment (Ricker function) LRP2: eggs deposition allowing to preserve 90% of the genetic diversity over 100 years. River not reaching this genetic conservation limit are classified below all reference point USR: egg depositions that result in a very high probability (95th percentile of posterior distribution) of the adult recruitment being more than MSY (Ricker function)	LRP varies depending upon productive units of river (average 132 eggs per 100 productive units of fluvial habitat) USR: varies depending upon productive units of river (average 312 eggs per 100 productive units of fluvial habitat)	Dionne et al. (2015); MFFP (2016) ; Ferchaud et al. (2016)
Insular Newfoundland	LRP: maximum freshwater production, miscellaneous approach USR: defined as 1.5 * LRP	LRP: 240 eggs per 100 m^2 fluvial habitat + 368 eggs per ha of lacustrine habitat or +150 eggs per ha of lacustrine habitat for the Northern Peninsula (SFA 14A)	Anon. 1991a; O'Connell and Dempson (1995); USR: DFO (2020)
Labrador	LRP: eggs for 50% of adult equilibrium point for a fished population, Beverton-Holt function	190 eggs per 100 m^2 of fluvial habitat	Reddin et al. (2006)

Table 2.2 Estimated recruits of Labrador small salmon, 2SW salmon for the years 1974 to 1978 (from Reddin 2005; ICES WP2005/06), mean recruits, mean eggs per fish, and proportion of total eggs that would be contributed by small salmon and large salmon for Labrador.

Size group	Year	Recruits (Reddin 2005; ICES WP 2005/06)	Eggs per fish (Dauphin et al. 2021)	Proportion of total eggs
1SW / Small	1974	124,499		
	1975	247,117		
	1976	172,883		
	1977	153,857		
	1978	74,398		
	Mean	154,551	1262	0.295
2SW	1974	81,929		
	1975	77,845		
	1976	89,929		
	1977	79,420		
	1978	62,900		
	Mean	78,404		
Large	Mean (2SW * 1.3875)	108,786	4295	0.705

Table 2.3. The spawning requirements (conservation limits) for Labrador as reported in Anon. (1978), O'Connell et al. (1997), and estimated based on the total egg conservation limit for Labrador (Reddin et al. 2010).

Reference		Eggs (million)	Small salmon (number of fish)	Large salmon (number of fish)	Fish (2SW)
Anon. (1978)	Point estimate	182.01	63,400	12,900	na
O'Connell et al. (1997)	Min	na	23,089	35,573	25,638
	Max	na	62,435	60,843	43,851
	Mean	na	42,762	48,209	34,745
ICES (2002)	Point estimate	na	na	na	34,746
Reddin et al. (2010)	Mean	239.14	na	na	na
This manuscript	Mean	239.14	55,806	39,281	28,310 *

**2SW spawners estimated as large spawners / 1.3875*

Table 2.4. Summary of number of salmon rivers, number of rivers with defined conservation egg requirements and published spawner requirements (equivalent to conservation limits) by size and sea age group of salmon for the rivers of Newfoundland. COSEWIC compilation refers to a constructed database of rivers and characteristics taken primarily from Reddin et al. (2010), updated with information in Kelly et al. (2023) and conservation egg requirements published since Reddin et al. (2010).

	Number of rivers			Number of rivers with conservation egg requirements (total eggs; millions)			Spawner requirements in O'Connell et al. (1997) and ICES (2002) for 2SW		
SFA	O'Connell et al. (1997)	Reddin et al. (2010)	COSEWIC compi-lation	O'Connell et al. (1997)	Reddin et al. (2010)	COSEWIC compi-lation	Small	Large	2SW
3	17	32	32	0	0	0	29,000	2,000	240
4	12	31	31	12 (158.62)	10 (155.54)	13 (161.40)	66,635	4,063	488
5	8	18	23	8 (37.92)	8 (37.92)	8 (37.92)	12,687	1,945	233
6	0	16	16	0	0	0	1,000	50	6
7	0	18	18	0	0	0	800	40	5
8	0	12	12	0	0	0	400	13	2
9	10	18	19	10 (16.26)	11 (16.97)	11 (16.40)	4,736	407	49
10	8	31	31	8 (7.77)	8 (7.78)	8 (7.78)	2,054	155	19
11	18	43	43	0	2 (4.65)	3 (7.28)	19,100	800	96
12	10	12	13	0	0	0	3,500	100	48
13	19	40	40	0	7 (26.70)	22 (76.59)	44,500	5,300	2,544
14A	25	34	34	0	3 (3.51)	6 (5.17)	13,748 (10,300)	595 (1000)	292
All	127	305	312	38 (220.57)	49 (253.07)	71 (312.55)	198,160	15,468	4,022

Table 2.5. Estimated conservation limit in terms of eggs from both size groups of salmon for the Newfoundland stock unit (SFAs 3 to 14A). The estimate of total eggs to meet the conservation based on spawners from O'Connell et al. (1997) uses the mean eggs per fish by size group in Dauphin et al. (2021).

	From O'Connell et al. (1997)		
Size group	Spawners	Eggs per fish (Dauphin et al. 2021)	Total eggs (million)
Small	198,160	1782	353.12
Large	15,468	4180	64.66
2SW	4,022	-	-
Total	213,628		417.78

Table 2.6. Reference points (Limit Reference Point, LFP; Upper Stock Reference, USR) in terms of eggs from all size and sea age groups of Atlantic salmon from the rivers of Quebec, by management zone. Data are from MFFP (2016). To simplify the table and to allow a more direct comparison with other jurisdictions, the value of the genetic conservation limit was use as the LRP or USR from a river where it is superior to the values based on a stock-recruitment model, as described and applied in the management plan (MFFP 2016).

Zone	Total eggs (millions)		Comment
	LRP	USR	
Q1	10.503	27.464	Excludes 2 tributaries of the Restigouche River accounted for in Gulf CLs
Q2	6.208	7.113	Excludes 3 rivers
Q3	6.807	11.533	Excludes 2 rivers
Q5	3.320	9.902	
Q6	4.373	9.093	
Q7	12.598	26.623	
Q8	42.096	135.743	Excludes 1 river
Q9	21.358	36.348	
Q10	17.341	18.238	Excludes 3 rivers
Q11	The 4 large rivers in Ungava Bay do not have measurements of productive units of habitat		
Total	124.604	294.866	

Table 2.7. Estimated reference points in terms of eggs and spawners, by management zone, for Atlantic Salmon from the rivers of Quebec. Reference points in terms of eggs are from MFFP (2016). Mean eggs per fish by management zone are values from Dauphin et al. (2021) updated for proportion female in 2023. The proportion of eggs from large salmon is derived from the mean estimated returns of small salmon and large salmon, to each management zone over the period 1993 to 2022 based on data provided to ICES for run reconstruction) weighted by mean eggs per fish by size group.

	Total eggs (millions)		Eggs per fish (revised 2023)		Prop. of	Spawner (number of fish)			
Zone	LRP	USR	Small salmon	Large salmon	eggs from large	Small salmon (LRP)	Small salmon (USR)	Large salmon (LRP)	Large salmon (USR)
Q1	10.503	27.464	258	5862	0.958	1710	4471	1716	4488
Q2	6.208	7.113	74	6240	0.988	1007	1153	983	1126
Q3	6.807	11.533	221	5957	0.964	1109	1879	1102	1866
Q5	3.320	9.902	247	6949	0.966	457	1363	462	1377
Q6	4.373	9.093	206	5454	0.964	764	1589	773	1607
Q7	12.598	26.623	321	6342	0.952	1884	3981	1891	3996
Q8	42.096	135.743	748	5125	0.873	7147	23047	7171	23123
Q9	21.358	36.348	1065	5581	0.840	3209	5461	3215	5471
Q10	17.341	18.238	392	4214	0.915	3760	3955	3765	3960
Q11			1215	4910	0.802	-	-	-	-
Total	124.604	294.866				21,047+	46,899+	21,077+	47,014+

Table 2.8. Number of rivers, total eggs and equivalent number of small salmon and large salmon corresponding to the defined Limit Reference Point (LRP) and Upper Stock Reference (USR) point for Atlantic Salmon of the Gulf stock unit.

Salmon Fishing Area	Number of rivers	Total eggs (million)		Fish for LRP		Fish for USR	
		LRP	USR	Large	Small	Large	Small
15	19	57.177	216.128	9,971	7,400	37,690	27,971
16	24	96.530	364.880	14,202	19,112	53,684	72,242
17	25	3.048	11.520	703	321	2,659	1,215
18	31	15.060	56.928	2,519	1,110	9,521	4,197
Gulf	99	171.815	649.456	27,395	27,943	103,554	105,625

Table 2.9. Number of rivers with defined egg conservation limits and equivalences in terms of small salmon, large salmon, and 2SW salmon (subset of large salmon) for rivers of the Scotia-Fundy stock unit. Data are from Gibson and Claytor (2013).

Salmon Fishing Area	Number of rivers	Conservation limit Eggs (million)	Spawners			
			Small salmon	Large salmon	2SW salmon	2SW salmon (ICES 2002)
19	26	21.207	620	3,922	3,138	3,138
20	27	55.204	26,948	3,129	2,691	2,691
21	19	77.591	34,550	8,310	5,817	5,817
23 (partial)	6+	99.527	15,447	15,123	13,139	13,059
Total	78+	253.529	77,565	30,484	24,785	24,705
Inner Bay of Fundy (excluded from spawner requirements for ICES)						
SFA 22	23	21.176	5471	1969	531	
SFA 23 (part)	10	8.938	2167	613	80	
Total	33	30.114	7638	2582	611	

Table 2.10. Summary of conservation limits in terms of eggs from all age groups, and eggs converted to number of small salmon and large salmon equivalents for the stock units of NAC to be used in catch advice for NASCO.

Stock unit	Conservation limits				Management objective
	Eggs (million)	Small salmon (fish)	Large salmon (fish)	2SW (updated)	2SW
USA				29,999	4,549
Scotia-Fundy	253.529	77,565	30,484	24,785	10,976
Gulf	171.815	27,943	27,395	18,737	
Quebec	124.604	21,047+	21,077+	18 914	
Newfoundland	417.78	198,160	15,468	4,022	
Labrador	239.14	55,806	39,281	34,746 (28,310)	

2.10 APPENDICES

Appendix 1. Summary of data and methods from Anon. (1978) used to estimate accessible freshwater rearing area (million m²), spawner requirements and assumptions on optimal egg depositions and resulting smolt production rates and biological characteristics of Atlantic Salmon by salmon producing area of eastern Canada.

The following section summarizes the approach, input data, and estimates of spawner requirements by area used in Anon. (1978).

<u>Quebec</u>

- 1SW salmon are excluded because they were not considered to represent a significant proportion of their river stocks.
- Biological data on parr densities and recruitment rate of adults suggested 1.5 smolts per 100 m² was being produced.
- Survival rates from smolts to adults was estimated at 8%, less than for Gulf stocks because salmon from Quebec had a longer migration route and potentially exposed to more high seas fisheries
- Spawning requirements are based on 1,225 kg of female spawners at fecundity of 1m225 eggs per kg (from Elson 19XX).
- Sex ratio: 50% females

<u>Maritime Region (Gulf, Scotia-Fundy)</u>

- Divided into 14 salmon production areas delineated on the basis of similarity of biological characteristics.
- Estimates of rearing areas based on limited number of river-specific habitat surveys. For unsurveyed rivers, the rearing areas were estimated based on the ratio of habitat area to drainage area of surveyed rivers.
- Habitat classified into three categories of smolt production potential: poor = 1 smolt per 100 m², fair = 2 smolts per 100 m², good = 3 smolts per 100 m².
- Smolt to adult survival rates based on tagging studies and monitored rivers assumed to be 8 – 10%.
- Proportion large salmon derived from nine monitored rivers.
- Egg deposition rate of 240 eggs per 100 m².
- Proportion female in small salmon and large salmon from monitored rivers or samples of the angling and commercial fisheries.
- Fecundity based on data from Maritime salmon of 1,760 eggs per kg for large salmon, 2,200 eggs per kg from small salmon.

<u>Newfoundland and Labrador</u>

- Divided into 13 production areas
- Accessible rearing areas for un-surveyed (n = 255) rivers estimated from data of surveyed (n = 166) rivers as:

Drainage area	Rearing units per km²	
	Insular Newfoundland	Labrador
100 km²	12.73	16.76
100 – 500 km²	13.38	20.77
> 500 km²	14.98	13.06

- Large salmon: spent 2 or more years at sea, all fish >= 2.7 kg, mean weight = 4.09 kg

- Percentage of spawners that are large salmon estimated from inriver monitoring data adjusted for exploitation rates in marine fisheries of 0.85 for large salmon and 0.55 for small salmon.
- Small salmon: spent one winter at sea, all fish < 2.7 kg, mean weight = 2.05 kg
- Smolt production rates (smolts per 100 m^2) of 2 for relatively biologically unproductive areas A, H, I, and O. Area K is very productive with 3.5 smolts per 100 m^2 and areas L and M have ponds and lakes suitable for parr rearing with production values of 3 smolts per 100 m^2 (see Appendix 1 Table 1 for letter/SFA equivalency)..
- Eggs requirements per 100 m^2 were assigned based on smolt production rates per 100 m^2 of: 150 eggs for smolt production < 2, 190 eggs for smolt production 2 to 3, 225 eggs for smolt production > 3.
- Fecundity (eggs per kg) of large salmon female is the same as for small salmon female.

Appendix 2.10.1 Table 1. Estimates of accessible freshwater rearing area (million m²), tabulated spawner requirements and assumptions on optimal egg depositions and resulting smolt production rates and biological characteristics of Atlantic Salmon by salmon producing area of eastern Canada, from Anon. (1978).

Anon (1978) areas	SFA/Q	Stock unit	Accessible rearing area (million m²)	Spawner requirements		Objective (Eggs per 100 m²)	Expected smolts per 100 m²	Smolt-to-adult-survival (%)	Large salmon					Small salmon		
				Small	Large				% overall	% of eggs overall	% female	Eggs per kg	Mean kg	% female	Eggs per kg	Mean kg
Q1	Q1 to Q3	Quebec	36.677		18,400											
Q2	Q5 to Q8	Quebec	91.826		28,800											
Q3	Q9	Quebec	38.294		15,000											
Q4	Q10	Quebec	7.211		6,000											
Q5	Q11	Quebec	152.266		12,200											
Restigouche / Chaleur	15	Gulf	38.137	4,900	13,800	240	3	10	60	98.1	65	1760	5.4	5	2200	1.6
Miramichi	16	Gulf	53.471	40,700	25,800	240	3	10	50	95	85	1760	4.5	10	2200	1.6
PEI North	17	Gulf	1.360	300	3,300	168	1-3	10	60-65	95.0-96.2	75-90	1760	4.5	10-20	2200	1.6
Northum-berland Strait North	16 & part17	Gulf	2.864	300	300	168	1-3	10	60-65	95.0-96.2	75-90	1760	4.5	10-20	2200	1.6
Northum-berland Strait South	18 & part17	Gulf	4.448	700	700	240	2	8	10-95	23.7-98.2	70	1760	4.5	50	2200	1.6
Gulf Cape Breton	18	Gulf	8.027	800	1,500	240	1-3	2-4	90-95	99.2-99.6	75	1760	4.5	10	2200	1.8

Anon (1978) areas	SFA/Q	Stock unit	Accessible rearing area (million m²)	Spawner requirements		Objective (Eggs per 100 m²)	Expected smolts per 100 m²	Smolt-to-adult-survival (%)	Large salmon					Small salmon		
				Small	Large				% overall	% of eggs overall	% female	Eggs per kg	Mean kg	% female	Eggs per kg	Mean kg
Atlantic Cape Breton	19	Scotia-Fundy	1.335	300	500	240	0.5-3	4-10	25-80	81.3-91.2	75	1760	3.9	10-50	2200	1.9
Southeast NS	20	Scotia-Fundy	8.915	7,600	1,100	240	2-3	10	10-15	23.7-33.1	70	1760	4.5	50	2200	1.8
Halifax	21	Scotia-Fundy	3.635	2,300	700	240	2	10	10-60	23.7-80.8	70	1760	4.5	50	2200	1.8
Southwest NS	21	Scotia-Fundy	5.836	4,600	800	240	2-3	10	10-70	23.7-86.7	70	1760	4.5	50	2200	1.8
Outer Fundy NS	21&22	Scotia-Fundy	2.084	500	700	240	1-3	10	30-95	54.5-98.2	70	1760	4.5	50	2200	1.8
Inner Fundy NS	22	excluded	6.308	3,300	1,900	240	1-3	10	20-50	41.2-73.7	70	1760	4.5	50	2200	1.8
Fundy NB	22&23	Scotia-Fundy	0.640	300	400	240	3	12	50-55	69.1-73.2	70	1760	3.6	50	2200	1.8
Southern NB / Saint John	23	Scotia-Fundy	29.057	7,100	11,600	240	3		50-67	93.8-99.0	75	1760	4.5	10	2200	1.8
NFLD A	3	Newfoundland	4.910	100	3,300	150	2		10	7	0.75	0.67				
NFLD B	4	Newfoundland	25.020	2,000	18,200	190	3		25	18	0.75	0.75				
NFLD C	5	Newfoundland	6.950	800	6,100	190	3		25	19	0.75	0.75				

Anon (1978) areas	SFA/Q	Stock unit	Accessible rearing area (million m²)	Spawner requirements		Objective (Eggs per 100 m²)	Expected smolts per 100 m²	Smolt-to-adult-survival (%)	Large salmon					Small salmon		
				Small	Large				% overall	% of eggs overall	% female	Eggs per kg	Mean kg	% female	Eggs per kg	Mean kg
NFLD D, E, F	6 to 8	Newfoundland	1.980	100	1,600	190	2.5		15	9.5	0.75	0.67				
NFLD G	9	Newfoundland	4.640	300	6,700	190	2.5		15	9.5	0.75	0.67				
NFLD H	10	Newfoundland	2.670	300	3,000	150	2		25	18	0.75	0.67				
NFLD I	Part 11	Newfoundland	4.960	200	5,600	150	2		15	9.5	0.75	0.67				
NFLD J	Part 11 & 12	Newfoundland	9.360	600	15,300	190	2.5		15	9.5	0.75	0.67				
NFLD K	13	Newfoundland	15.060	3,300	17,400	225	3.5		35	26	0.75	0.33				
NFLDL	13	Newfoundland	15.220	1,600	10,200	190	3		25	18	0.75	0.67				
NFLDM	14A	Newfoundland	3.730	800	5,400	190	3		35	26	0.75	0.75				
NFLD N	14A	Newfoundland	1.520	200	4,900	190	2.5		15	9.5	0.75	0.75				
LAB O	1, 2, 14B	Labrador	121.340	12,900	63,400	150	2		45	33	0.75	0.67				

Appendix 2.10.2. Revised biological characteristics and conservation requirements of salmon by management zone for the province of Quebec.

This appendix documents the changes made in 2023 to the small and large salmon fecundities in Quebec using revised data on the proportion female. As described in Dauphin et al. (2021), small and large salmon fecundity was recently estimated based on the following data in Quebec:

female fecundity (eggs per kg) have been estimated for both small and large salmon using data from two rivers from 1982 to 2006 (Leclerc 2015).

Average weight of small and large salmons is available for 44 rivers and based on the average values from 2014 to 2018.

Percentage of females for small and large salmon are available from 22 rivers using data from 1987 to 2020.

The values for the percentage female were obtained from 22 rivers. Because some zones had too few data, the following zones had to be merged and therefore shared the same values: Q1, Q2 and Q3; Q5 and Q6, Q7 and Q8. New sex ratio data obtained from genetic analyses since 2021 allowed to update the percentage of females for small and large salmon. The new dataset includes data from 30 rivers (Appendix 2.10.2 Table 1) and provides an estimate for each zone (Appendix 2.10.2 Table 2).

There is slight decrease in the overall proportion female of small salmon and large salmon for Quebec but decreases, increases or no change are noted among the zones (Appendix 2.10.2 Table 2). The changes were most important for small salmon (Appendix 2.10.2 Table 2).

The conversion of the conservation limits in terms of eggs to number of fish for small and large salmon are updated using the revised biological characteristics (Appendix 2.10.2 Table 3).

Appendix 2.10.2 Table 1. Rivers with sex ratio data included in the new dataset.

Region	Rivers
Q1	Petite Cascapedia, Grande Cascapédia, Causapscal, Bonaventure
Q2	Saint-Jean
Q3	Matane, Madeleine, Sainte-Anne
Q5	Gouffre, Malbaie Charlevoix
Q6	À Mars, Saint-Jean Saguenay, Ste-Marguerite
Q7	Des Escoumins, Betsiamites, Godbout, De la Trinité, Aux Rochers
Q8	Saint-Jean, De la Corneille, Watshishou, Petite rivière Watshishou, Natashquan
Q9	Étamamiou, Du Vieux-Fort, Saint-Paul
Q10	Bec Scie, Jupiter, De la Chaloupe
Q11	Koksoak

Appendix 2.10.2 Table 2: Updated biological characteristics of small and large salmon in Quebec fishing areas. The changes from Dauphin et al. (2021) are for the proportion female of small salmon and large salmon and the values from Dauphin et al. are shown in parentheses (italics).

Size	Parameters	Zones										
		1	2	3	5	6	7	8	9	10	11	**Quebec**
Small	Weight per female (Kg)	1.82	1.82	1.82	2.03	2.03	1.76	1.76	1.7	1.49	1.82	
	Eggs per kg per female	2025	2025	2025	2025	2025	2025	2025	2025	2025	2025	
	Eggs per female	3682	3682	3682	4111	4111	3563	3563	3436	3019	3682	**3611**
	Proportion of female	0.07	0.02	0.06	0.06	0.05	0.09	0.21	0.31	0.13	0.33	**0.15**
	(*Dauphin et al. 2021)*	*(0.05)*	*(0.05)*	*(0.05)*	*(0.10)*	*(0.10)*	*(0.15)*	*(0.15)*	*(0.31)*	*(0.13)*	*(0.05)*	***(0.14)***
	Eggs per fish	258	74	221	247	206	321	748	1065	392	1215	**513**
	(*Dauphin et al. 2021)*	(184)	(184)	(184)	(411)	(411)	(534)	(534)	(1065)	(392)	(184)	**(496)**
Large	Weight per female (Kg)	5.42	5.42	5.42	5.04	5.04	4.98	4.98	3.9	3.45	4.4	
	Eggs per kg per female	1745	1745	1745	1745	1745	1745	1745	1745	1745	1745	
	Eggs per female	9455	9455	9455	8796	8796	8687	8687	6806	6020	7672	**8495**
	Proportion of female	0.62	0.66	0.63	0.79	0.62	0.73	0.59	0.82	0.70	0.64	**0.68**
	(*Dauphin et al. 2021)*	*(0.61)*	*(0.61)*	*(0.61)*	*(0.69)*	*(0.69)*	*(0.66)*	*(0.66)*	*(0.82)*	*(0.70)*	*(0.64)*	***(0.67)***
	Eggs per fish	5862	6240	5957	6949	5454	6342	5125	5581	4214	4910	**5708**
	(*Dauphin et al. 2021)*	*(5768)*	*(5768)*	*(5768)*	*(6069)*	*(6069)*	*(5733)*	*(5733)*	*(5581)*	*(4214)*	*(4910)*	***(5680)***
	Proportions of returns (average calculated over the whole time series)	0.23	0.07	0.13	0.03	0.03	0.08	0.17	0.17	0.06	0.04	

Appendix 2.10.2 Table 3. Estimated reference points in terms of eggs and spawners, by management zone, for Atlantic Salmon from the rivers of Quebec. Reference points in terms of eggs are from MFFP (2016). Mean eggs per fish by management zone are revised for 2023 from those in Dauphin et al. (2021). The proportion of eggs from large salmon is derived from the mean estimated returns of small salmon and large salmon, to each management zone over the period 1993 to 2022 (based on data provided to ICES for run reconstruction) weighted by mean eggs per fish by size group.

	Total eggs (millions)		Eggs per fish (revised 2023)			Spawner (number of fish)			
Zone	LRP	USR	Small salmon	Large salmon	Prop. of eggs from large	Small salmon (LRP)	Small salmon (USR)	Large salmon (LRP)	Large salmon (USR)
Q1	10.503	27.464	258	5862	0.958	1,710	4,471	1,716	4,488
Q2	6.208	7.113	74	6240	0.988	1,007	1,153	983	1,126
Q3	6.807	11.533	221	5957	0.964	1,109	1,879	1,102	1,866
Q5	3.320	9.902	247	6949	0.966	457	1,363	462	1,377
Q6	4.373	9.093	206	5454	0.964	764	1,589	773	1,607
Q7	12.598	26.623	321	6342	0.952	1,884	3,981	1,891	3,996
Q8	42.096	135.743	748	5125	0.873	7,147	23,047	7,171	23,123
Q9	21.358	36.348	1065	5581	0.840	3,209	5,461	3,215	5,471
Q10	17.341	18.238	392	4214	0.915	3,760	3,955	3,765	3,960
Q11			1215	4910	0.802	-	-	-	-
Total	124.604	294.866				21,047+	46,899+	21,077+	47,014+

CHAPTER 3. UPDATING BIOLOGICAL CHARACTERISTICS OF NORTH AMERICAN ATLANTIC SALMON STOCKS

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BACKGROUND

Each year, the run reconstruction model for NAC is updated to produce estimates of various variables such as returns, egg depositions and lagged egg depositions. This chapter documents the changes made in 2021 to replace historical values of small and large salmon fecundities in North American regions (Table 3.1) by up-to-date data. Additionally, in this document we present a method to up-scale values from individual Salmon Fishing Areas (SFAs) and Management Zones (Qs) to regional values for Quebec, Gulf and Scotia-Fundy. Some of the values are of interest for specific time-periods in the run-reconstruction model (Quebec, Scotia-Fundy) and as input to the lifecycle model (see Section 2.5 in ICES 2020).

REGION SPECIFIC DATA

In Newfoundland and Labrador, fecundity of large and small salmon was assumed to be the same due to the lack of data in Labrador. Proportions of female in the small and large size group were obtained from genetic samples collected between 2014 and 2017 for both regions (two rivers in Labrador and six rivers in Newfoundland, Table 3.2).

In Quebec, small and large salmon fecundity is estimated based on the following data:

- female fecundity (eggs per kg) have been estimated for both small and large salmon using data from two rivers from 1982 to 2006 (Leclerc 2015).
- Average weight of small and large salmons is available for 44 rivers and based on the average values from 2014 to 2018.
- Percentage of females for small and large salmon are available from 22 rivers using data from 1987 to 2020. These have not been updated based on recent analyses as described in Appendix 2.10.2.
- Adult returns by fishing zone are only available from 1984 to 2020. During this time period, fecundities are calculated for each fishing zone based on the data described above. During the older part of the time-series (1970-1983), when adult returns are only available for Quebec as a whole, the fecundities per fishing areas are weighted by their average contribution in terms of adult returns (small and large, over the 1984-2020 time-series, Table 3.3).

In Gulf, fecundity and proportion of females are available from a number of monitored rivers and these data were used to develop river-specific reference points. The reference rivers and their corresponding characteristics are presented in DFO (2018). To calculate fecundities and proportions of female at a regional scale, these river specific values are weighted by the estimated fluvial area of the reference river to the total fluvial area of the Salmon Fishing Area first and then to the relative fluvial areas of the Salmon Fishing Areas to the total fluvial area in the region (Table 3.4).

For Scotia-Fundy, biological characteristics data from reference rivers were used to calculate the region-specific values using the same approach as for Gulf. Biological characteristics of salmon in SFA 19 are provided in Taylor et al. (2012) and characteristics of populations in SFAs 20 and 21 are provided in Raab et al. (2021). For SFA 23, biological characteristics have been described in various reports including Marshall et al. (1997), Jones et al. (2014) and Reader et al. (2021). These river specific values are weighted by the estimated fluvial area of the reference river to the total fluvial area of the Salmon

Fishing Area first and then to the relative fluvial areas of the Salmon Fishing Areas to the total fluvial area in the region (Table 3.4).

In the USA, proportion of female in small and large size groups was available for the time period 2000 to 2017. Data were based on field assignments on adult returns to the Penobscot River, which were retrospectively corrected based on spawning data collected at the hatchery. Fecundity estimates of 2SW females were available from sea run broodstock spawned at the hatchery from 2000 to 2016. Estimated fecundity of 1SW was not available and the average fecundity of 1SW females in the other regions of NAC was used (Table 3.2).

- For years without estimates, mean values of the available data were used.
- From 2000 to 2019, year specific proportion of females in the large/2SW category were used.
- From 2000 to 2021, year specific fecundity of females in the large/2SW category were used.
- For the rest of the years, the average of the time-series of available data was used.
- For the whole time-series, the average proportion of female in the small/1SW category (based on data collected from 2000 to 2022) was used. The rationale behind this was that for this category there were several years with a proportion of female equal to zero and it could not be excluded that it was a sampling size issue therefore to be conservative the average was used. Fecundity of small/1SW was set at 3165 eggs.

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Table 3.1. Fecundities (in eggs per fish) as used in the run-reconstruction model until 2020

Eggs per fish	Labrador	Newfoundland	Quebec	SFA15	SFA16	SFA17	SFA18	Scotia-Fundy	USA
Small	1500	3000	468	96	640	500	353	917	200
Large	5500	4000	6402	6579	5829	3500	5846	6107	5500

Table 3.2. Updated biological characteristics of small and large salmon in Labrador, Newfoundland and USA. † indicates that the value was computed by taking the average over the other North American regions.

Size	Parameters	Labrador	Newfoundland	USA
small	Proportion of female	0.505	0.859	0.016
	Eggs per female	2500	2500	†3165
	Eggs per fish	1262	1782	48
large	Proportion of female	0.859	0.804	0.559
	Eggs per female	5000	5000	8048
	Eggs per fish	4295	4180	4497

Table 3.3. Updated biological characteristics of small and large salmon in Quebec fishing areas

		Zones										
Size	Parameters	1	2	3	5	6	7	8	9	10	11	**Quebec**
Small	Weight per female (Kg)	1.82	1.82	1.82	2.03	2.03	1.76	1.76	1.7	1.49	2.04	
	Eggs per kg per female	2025	2025	2025	2025	2025	2025	2025	2025	2025	2025	
	Eggs per female	3682	3682	3682	4111	4111	3563	3563	3436	3019	4131	**3618**
	Proportion of female	0.05	0.05	0.05	0.1	0.1	0.15	0.15	0.31	0.13	0.33	**0.14**
	Eggs per fish	184	184	184	411	411	534	534	1065	392	1363	**496**
Large	Weight per female (Kg)	5.42	5.42	5.42	5.04	5.04	4.98	4.98	3.9	3.45	4.4	
	Eggs per kg per female	1745	1745	1745	1745	1745	1745	1745	1745	1745	1745	
	Eggs per female	9455	9455	9455	8796	8796	8687	8687	6806	6020	7672	**8479**
	Proportion of female	0.61	0.61	0.61	0.69	0.69	0.66	0.66	0.82	0.7	0.64	**0.67**
	Eggs per fish	5768	5768	5768	6069	6069	5733	5733	5581	4214	4910	**5653**
	Proportions of returns (average calculated over the whole time series)	0.22	0.07	0.13	0.03	0.03	0.07	0.16	0.15	0.07	0.05	

Table 3.4. Updated biological characteristics of small and large salmon in SFAs c fishing areas

Size	Parameters	SFA 15	SFA 16	SFA 17	SFA 18	**Gulf**	SFA 19-21	SFA 23	**Scotia-Fundy**
small	Proportion of female	0.061	0.144	0.214	0.099	**0.113**	0.384	0.292	**0.35**
	Eggs per female	3017	3635	3143	2947	**3354**	3029	3479	**3194**
	Eggs per fish	184	523	673	292	**379**	1163	1016	**1119**
large	Proportion of female	0.656	0.804	0.811	0.654	**0.74**	0.927	0.824	**0.889**
	Eggs per female	8558	7492	4963	9372	**7979**	6133	6955	**6434**
	Eggs per fish	5614	6024	4025	6129	**5904**	5685	5731	**5722**
	Fluvial area (million m²)s	37.616	60.856	1.974	9.909	**110.355**	90.8905	52.6015	**143.492**

CHAPTER 4. DATA AND METHODS FOR RUN RECONSTRUCTION OF RETURNS AND SPAWNERS TO THE SIX STOCK UNITS OF NAC

The run-reconstruction model developed by Rago et al. (1993a) was originally intended to estimate the prefishery abundance (PFA) of non-maturing 1SW salmon of North American origin (beginning in 1971) for the purpose of providing forecasts of potential 2SW salmon abundance and advice for the West Greenland fishery. The focus on the non-maturing 1SW salmon component was because the West Greenland fishery exploits predominantly (>95%) 1SW non-maturing salmon (destined to return primarily as 2SW salmon). The other fish taken in the fishery represent 2SW and older non-maturing salmon and previous spawners (ICES 2023). Subsequently, estimates of returns, spawners, and prefishery abundance for all sea age groups (1SW maturing, 1SWnon-maturing, 2SW) and the two reporting size groups (small salmon, large salmon) became of interest in terms of the presentation of stock status domestically and internationally and in the evolution of the models used by ICES to summarize stock status and provide catch advice for the West Greenland and potential Faroes fisheries. The run-reconstruction approach was applied to these sea age and size groups.

The starting point for the reconstruction requires estimation of the returns and spawners to the six regions in eastern North America: Labrador, Newfoundland, Québec, Gulf, Scotia-Fundy, and USA. The annual returns and spawners for each region are estimated with the uncertainty defined by a range of stock unit specific annual minimum and maximum values based on the best information available for each region. Descriptions of how the model input data have been derived for each region of North America are presented below.

4.1 DATA INPUTS FOR USA

Total salmon returns and spawners for USA rivers are based on trap and weir catches and for the small rivers in Maine that do not have fish counting facilities, estimates of spawners were based on redd counts.

4.2 DATA INPUTS FOR SCOTIA-FUNDY

Salmon originating in rivers of the Atlantic coast of Nova Scotia and southwest New Brunswick in Salmon Fishing Areas (SFAs) 19–21 and the portion of SFA 23 outside the inner Bay of Fundy comprise the Scotia-Fundy stocks. With the exception of one stock in SFA 19, the large salmon component in other stocks of that region is assumed to migrate to the North Atlantic/Labrador Sea (Amiro et al. 2008). Inner Bay of Fundy Atlantic Salmon (SFA 22 and part of SFA 23) have been federally listed as endangered under the Canadian Species at Risk Act and are not included as inputs into the run-reconstruction model. With the exception of one population, inner Bay of Fundy stocks have a localized migration strategy that excludes high seas migrations to the Labrador Sea and Greenland and a very high incidence of maturing after one winter at sea (Amiro 2003).

Annual ranges (minimum to maximum) of returns and spawning escapement for the Scotia-Fundy stocks are provided for the run-reconstruction model. The methods used to estimate the annual total returns and spawners are described by Amiro et al. (2008). In brief, for SFAs 19–21, the annual escapement is based on the count of small and large salmon at the Morgan Falls fishway on the LaHave River from 1970 to the present year, scaled up to the region using the relationship between this count and the recreational catch data for rivers in SFA 19 to 21 from 1970 to 1997 and a catch rate for the LaHave River from 1970 to 1997. Estimates of the returns also include estimates of landings in the commercial salmon fisheries in SFA 19–21 from 1970 to 1983. The model is fitted using maximum likelihood, and the 90% confidence limits are carried forward as the minimum and maximum values.

In SFA 23 from 1970 until 1992, estimates of total 1SW and large wild-origin salmon returns are based on the estimated number of returns destined for tributaries above Mactaquac Dam on the Saint John River; this includes in-river and outer-Fundy commercial landings (1970–1971 and 1981–1983), in-river Indigenous harvests (since 1974), and counts at Mactaquac Dam. These estimates are raised by the proportion of the total accessible productive habitat in SFA 23 that is upstream of Mactaquac Dam (0.4–0.6). Hatchery-origin returns were attributed to above Mactaquac Dam only and no hatchery 1SW and MSW returns were estimated for other rivers within SFA 23 (outer Fundy). Since 1993 the estimates of 1SW and MSW returns to the Nashwaak River have been used to estimate the wild production from tributaries of the Saint John River below Mactaquac Dam. The estimated 1SW and MSW returns to the Nashwaak River (above Counting Fence), is raised by the proportion of the total production area below Mactaquac (0.21–0.3) and then added to the above Mactaquac totals.

Although estimates for unreported harvests for this stock unit are included in the report by Canada to NASCO (see ICES 2021 for example), they are not included in the run-reconstruction estimates of spawners or returns.

4.3 DATA INPUTS FOR GULF

Estimation of returns and spawners are developed for the four salmon fishing areas of Gulf Region (SFAs 15 to 18). Although estimates for unreported harvests for this stock unit are included in the report by Canada to NASCO (see ICES 2021 for example), they are not included in the run-reconstruction estimates of spawners or returns.

4.3.1 SFA 15

The major river in this area is the Restigouche River. The annual returns and spawners are estimated for the Restigouche River exclusive of returns to the Matapedia River, which is entirely situated in the province of Quebec and which are included in the returns for Quebec zone Q1. The Restigouche River stock assessment is based on estimated angling catches with assumed exploitation rates between 30% and 50%. Estuary catches in the commercial fisheries (to 1984) and the Indigenous fisheries are added back after the estimates of returns. The return and spawner estimates for SFA 15 are derived from the return and spawner estimates for Restigouche (New Brunswick); these are raised to the total for SFA 15 are based on the ratio of angling catches in SFA 15 relative to angling catches of the Restigouche River.

From 1972 to 2013, the minimum and maximum ratios of angling catch in all of SFA15 relative to angling catch in Restigouche (New Brunswick) (for small salmon, min = 1.06 to max = 1.41; for large salmon min = 1.04 to max = 1.25) are used to define the minimum and maximum values of returns. Harvests represent retained angling catch plus 6% catch and release mortality for released fish. The proportion of 2SW in large salmon numbers is based on aged scale samples from angling, trapnets, and broodstock. In the years when no scale samples analysis is available, a mean value of 0.65 is used.

From 2014 to 2020, the estimation of returns and spawners, and *in extenso* SFA 15, relies on snorkel counts. During this time period, these counts are considered more reliable than the angling catches. Snorkel counts are assumed to be an estimate of the minimum number of spawners in the Restigouche. The higher bound of the spawners estimates is obtained by adding 20% to the snorkel counts (value somewhat arbitrary but based on local technicians and biologist opinions). Spawners for SFA15 are calculated by scaling up the Restigouche snorkel counts to the ratio of habitat available (Restigouche habitat = 0.72 SFA 15 habitat).

Returns estimates for SFA 15 are obtained by accounting for catch and release mortality (6%) and assuming an exploitation rate h ranging from 0.3 to 0.5 and adding the Indigenous harvests.

$$Returns\ SFA15 = \frac{Spawners\ SFA15}{(1 - h + h * 0.94)} + Indigenous\ harvest$$

4.3.2 SFA 16

The most important Atlantic salmon river in SFA 16 is the Miramichi River which contains 91% of the total juvenile rearing area of SFA 16. Returns and spawners to the Miramichi River have been assessed annually since 1971. For 1971 to 1991, minimum and maximum values are based on capture efficiencies of the Millbank estuary trapnet representing a lower CI of -20% of the estimate and upper CI of 33% of the estimate. For 1992 to 1997, minimum and maximum are lower and upper CI and based on estimate bounds of -18.5% to +18.5%. Since 1998 to the present, the minimum to maximum range is the 5th to 95th percentile range from a Bayesian hierarchical assessment model (Chaput and Douglas 2012). Returns to SFA 16 are Miramichi returns (Minimum, Maximum) / 0.91. Proportion 1SW in small salmon is from scale ageing; proportions have varied from 0.97 to 1.0. Proportion 2SW in the large salmon category is obtained from scale ageing, these proportions have varied from 0.41 to 0.97 during 1971 to 2019. Spawners are returns minus harvests (local commercial fisheries, Indigenous fisheries, and recreational fisheries losses). The commercial fishery closed in 1984. For 1998 to present, the total loss of large salmon is estimated as the sum of the Indigenous fisheries harvests for large salmon and ~1% of the large salmon recreational catch (30% exploitation rate, 3% catch and release mortality). Prior to 1995, the harvest of small salmon is estimated as 30% of the small salmon return plus the harvest from the Indigenous fisheries. During 2015 to present, when mandatory catch and release management measures were in effect, the fisheries related loss of small salmon was estimated as the sum of the Indigenous fisheries harvests for small salmon and ~1% of the small salmon catch (30% exploitation rate, 3% catch and release mortality).

4.3.3 SFA 17

For 1970–1994, small returns are estimated from retained small salmon catch in the Morell River divided by the river-specific exploitation rate to which were added commercial harvests of small salmon from the local area. Salmon catch in the Morell River was estimated in 1970–1990 by DFO Fisheries Officers; and in 1991, 1992, and 1994 by angler mail-out surveys. The number of small retained salmon in 1993 was not recorded, so the number used is the mean for 1986–1992. For 1970–1993, exploitation rate was taken as the mean of exploitation rates estimated for 1994, 1995, and 1996 (0.317). For 1994, exploitation rate was 0.34. The min and max of small returns are calculated using exploitation +/- 0.1; e.g. 0.34 +/- 0.1 gives 0.24 and 0.44. Large returns = (number of small returns/proportion small) - number of small returns plus the commercial harvest of large salmon in the local area. For 1970–1980, proportion small is calculated from numbers of small and large salmon in the angling catch of each year. For 1981–1994, proportion small is taken from counts at the Leards Pond trap on the Morell River. Small spawners = number of small returns - number of small retained. Large spawners = number of large returns - number of large retained. In 2012, the Province of Prince Edward Island discontinued the sale of recreational fishing licences for Atlantic salmon. Instead, anglers who purchased a trout licence are authorized to also fish for Atlantic salmon. Since it was no longer possible to assemble a list of salmon anglers, the salmon angler survey was discontinued from 2012. In the absence of salmon angling data for 2012 and subsequently, catch statistics estimated for 2011 are used for 2012 and subsequent years.

Spawner estimates for 1995 to the present are derived from redd counts in 23 rivers. For years and rivers in which redd counts are unavailable, redd numbers are estimated by linear interpolation from the preceding and succeeding count year. Redd numbers in years prior to the first count are taken as the first count. Redd numbers in years after the last count are taken as the last count. Female spawners are estimated from the ratio of 3.357 redds/female spawner, measured in the West River in 1990. Total spawners are estimated from size-specific sex ratios derived from counts at Leards and Mooneys Ponds, Morell River, in 1986–2001. The proportion of large salmon is assumed to be 0.5 in the Cains, Carruthers, Trout (Coleman), Morell, Cardigan, West, and Dunk Rivers, and 0.9 in all other rivers. Spawners are presented as Min (estimated spawners -20%) and Max (estimated spawners + 20%). Returns are spawners + total estimated fisheries losses, including angler catches, catch and release mortality, and Indigenous and commercial harvests. Fish retained and caught and released are estimated from angler card surveys. Returns are presented as Min (estimated returns -20%) and Max (estimated returns + 20%). It is assumed that large salmon and 2SW salmon are equivalent.

4.3.4 SFA 18

Inriver returns and spawners to SFA 18 are derived from estimates of returns and spawners to the Margaree River, adjusted for the ratio of the SFA 18 angling catch to the Margaree River catch, a process similar to that of SFA 15. For small salmon, the ratio of SFA 18 catch to Margaree catch has varied between 1.15 and 2.71 for years 1984 to 2004. For large salmon, the ratio of SFA 18 catch to Margaree catch has varied between 1.08 and 2.32 for years 1984 to 2004. Commercial fishery harvests in marine waters of the Gulf shore of Nova Scotia are added to the inriver returns of SFA 18 to estimate the total returns to SFA 18. The commercial fishery closed in 1984.

Returns to Margaree River are estimated using various techniques.

- 1970 to 1983 angling catch divided by range of exploitation rates with maximum exploitation rate of 0.37 and minimum exploitation rate of 0.215;
- 1984 to 1986 based on annual assessments;
- 1987 to present: angling catch and effort data from logbooks and provincial licence stubs are used to derive the returns. The catchability coefficient per rod day is estimated from angling catch and effort data for the years 1988 to 1996 when mark and recapture programmes were used to estimate returns, independently from angling data (Breau and Chaput 2012).

Spawners for 1970–1983 equal returns minus removals (commercial and recreational). Spawners for 1984 to the present equal estimate inriver returns minus losses in fisheries (Indigenous fisheries and recreational fisheries as sum of retained fish plus 5% mortality for catch and release). The 2SW salmon component represents 0.77 to 0.87 of large salmon returns and spawners.

4.4 DATA INPUTS FOR QUÉBEC

In order to estimate abundance of stocks, rivers were classified into six categories (C1–C6) depending on the information available to estimate salmon returns (based on the method of Caron and Fontaine, 1999), with C1 being the most reliable evaluation and C6 the least. C1 corresponds to a river where the evaluation of the returns is based on a counting method, either from a fence or from a visual count through snorkelling or from a canoe. C2 uses the same evaluation, but without knowing the number of small and large salmon, which is then estimated from proportions reported in the sport fishing landings and, if necessary, the catch and release. Salmon returns on C3 rivers are determined based on multiple correlation factors, using catch number, fishing effort, season duration and river accessibility distance (Guillouët, 1993).

When estimation of the returns using a C1–C3 category is not possible, and when data of returns from previous years are available, the C4 category is used. C4 assumes that interannual variations in salmon returns in the targeted river are approximately the same as variations observed in the other rivers of the corresponding region. Category C5 is for rivers where only landings data are available. In these rivers the salmon run is estimated from the average regional exploitation rate. Finally, a few small rivers have essentially no available data. C6 then assumes that the run is related to the available river salmon habitat and is estimated with respect to rivers of the same area for which run estimates and salmon habitat area are known. Estimated returns from C4 to C6 cannot be used to assess status relative to attainment of conservation limits. However, they provide at least approximate numbers to estimate returns and spawners for salmon rivers in Québec.

The evaluation of the uncertainty associated with return estimates depends on the river category. For C1 and C2 rivers, the correction factor for the minimum and maximum number of returns is +5% and +10% for all rivers with a fish ladder and for all other rivers in zones Q1 to Q3 and Q10 which are C1 and C2 assessed. The correction factor for rivers with darker water from zones Q5, Q6 and Q7 is +10% and +30%. For the other categories, an uncertainty of ±25% is associated with salmon return estimates, except for category C3 where the calculation depends on the method of Guillouët (1993).

The number of spawners is obtained using the return estimate minus all river catches, which include landings and other types of removal. In most cases, river catches include landings from sport fishing only, which may be conducted by Indigenous people such as that on the Betsiamites River. The other types of removal are of limited number and include mainly natural mortality, salmon captured for hatchery use, and subsistence fishing when practiced in river.

Overall return estimates for all Québec rivers are obtained by adding in-river salmon returns, commercial fishing in Quebec waters (when operated), Indigenous people subsistence fishing when practiced in estuaries and an estimate of non-reported landings. However, little scientific data are available on non-reported landings and thus, estimates are based on good judgment, following consultations with regional biologists.

Prior to 1984, min to max ranges of inriver returns are provided for the sum of rivers by assessment category C1 to C6. Since 1984, river-specific estimates of returns and spawners are provide. These river specific estimates were developed based on the assessment data (C1 to C6) available for each river and are published annually (to 2022 see Cauchon and April 2023). In 2021, the run reconstruction for Quebec for the years 1984 to present made use of these river specific annual estimates of returns and spawners. The reconstruction begins with the calculation of min to max ranges for small salmon and large salmon returns and spawners by management zone (Q1 to Q11), as the sum of min ranges and max ranges for the rivers in the zone. The MCMC draws are then made within the min to max range by zone and the estimates by zone and for Quebec (as the sum of values over zones) are derived from these.

4.5 DATA INPUTS FOR NEWFOUNDLAND

Inputs for the run-reconstruction model for Newfoundland include estimates of small, large and 2SW returns and spawners as minimum and maximum ranges. The methods used to estimate returns and spawners to the rivers in Newfoundland are described by Reddin and Veinott (2010). In brief, inriver returns are derived from reported/estimated retained small salmon harvests in the recreational fishery raised by exploitation rates of retained small salmon derived from rivers with enumeration facilities. Exploitation rates were then applied to the sum of reported angling catches from all rivers within each Salmon Fishing area (3 to 14A; Figure 1.2). The ratios of large to small salmon from the monitoring facilities are used to estimate large salmon inriver returns. A non-parametric bootstrap technique, with replacement, was used to derive a min to max exploitation rate range and ratios of large to small salmon. The 95% confidence interval from 500 iterations of the weighted exploitation rate and ratio of large to small salmon was applied to angling catches on a Salmon Fishing Area (SFA) basis. The 95% confidence interval was used as the minimum and maximum estimate of returns of large and small salmon in each SFA. Estimates of 2SW returns are based on the expected proportion of 2SW in the large salmon category (≥63 cm). Spawners in all years were determined as the returns to rivers minus angling catches including an adjustment (10%) for catch and release mortality.

Commercial harvests in the Newfoundland coastal fisheries are excluded from the estimates of returns (inriver) to Newfoundland because of their mixed stock fishery context. The commercial harvests in Newfoundland and Labrador marine fisheries are added to the sum of the inriver returns for the six stock units of NAC to derive the returns to the coast of NAC.

Although estimates for unreported harvests for this stock unit are included in the report by Canada to NASCO (see ICES 2021 for example), they are not included in the run-reconstruction estimates of spawners or returns.

4.6 DATA INPUTS FOR LABRADOR

The information for Labrador is taken directly from a report prepared by Reddin and Poole (2010) presented as an ICES Working Document (Reddin, D., and Poole, R. 2010. Estimates of returns and spawners for Labrador, 2009. ICES North Atlantic Salmon Working Group Working Paper 2010/13).

The basis of estimates of 2SW and 1SW salmon returns and spawners for Labrador are catch data from angling and commercial fisheries. Catch and effort data from the angling fishery were collected by Department of Fisheries and Oceans (DFO) enforcement staff in conjunction with angling reports submitted by fishing camp operators and processed by DFO Science Branch personnel. Commercial catch data were collected by DFO enforcement staff from fish plant landing slips and processed by DFO Statistics and Informatics Branch personnel. Procedures for the collection and compilation of commercial and angling fishery data are described in Ash and O'Connell (1987) for fishery years 1974-96. For years 1969-74, commercial catch data came from Anon. (1978). In 1997, the angling catch statistics were converted to a licence stub system (O'Connell et al. 1998) which continues to present.

For Labrador stocks, it was considered inappropriate to estimate the inriver returns from angling catches and exploitation rates as was used for the rivers in insular Newfoundland. The problem with using angling catches to derive returns for Labrador is, that until 1994, there were no estimates of exploitation rates available other than for the salmon population of Sand Hill River and these were 20 years out of date. Also, because Labrador rivers are isolated, the exploitation rates are low and highly variable depending on the presence of an angling camp and its success in attracting guests as well as the nearness of local communities. Thus, exploitation rates would depend, and vary from one year to the next, on the success of angling camps in attracting anglers and may not be applicable to other Labrador rivers. Thus, estimates of returns until 1998 were based on commercial catches as the only source of usable continuous time-series of data.

4.6.1 Before 1998

The general approach is to use exploitation rates to convert commercial catches of small and large salmon in the Labrador fisheries to total returns to the coast of Labrador prior to the commercial fishery. River returns and spawners were estimated by subtracting the commercial catch from the estimates of returns to the coast, and accounting for non-Labrador origin salmon in the commercial harvests. The number of salmon returning to the coast of Labrador is estimated as:

$$Ret.coast_a = CC_a * u_a^{-1} \quad (1)$$

With $Ret.coast_a$ the returns to the coast of Labrador of size group *a* (*a* = small salmon, large salmon), CC_a the commercial catch in number of salmon of size group *a*, and u_a the exploitation rate on salmon of size group *a* in the Labrador commercial fishery.

Exploitation rates (u_a in equation 1) were calculated from the Sand Hill River smolt tagging study of 1969–1973 (Reddin, 1981; Reddin and Dempson, 1989). Exploitation rates of 0.28 to 0.51 for small salmon and 0.83 to 0.97 for large salmon from the tagging study were rounded to base exploitation rates of 0.3 to 0.5 on small salmon and 0.7 to 0.9 on large salmon and were assumed to apply to all of the Labrador salmon populations in SFAs 1, 2, and 14B for the period of 1969–1991 (Anon. 1993b).

Adjustment of exploitation rates due to changes in the Labrador and Newfoundland commercial fisheries

After 1991, due to the modifications of the Management Plans for the commercial fishery in Labrador and Newfoundland, several changes occurred that would have reduced exploitation of Labrador origin salmon. These changes include: (1) reductions in effort as commercial salmon fishers chose to sell their licences from a buy-out agreement begun in 1992, (2) a moratorium on commercial fishing in Newfoundland that would increase the number of Labrador salmon in Labrador coastal waters, and (3) season reductions due to the varying opening dates and early closures from the quotas applied in 1995 to 1997.

Reductions in Labrador commercial fishing effort

Fishermen reported during public consultations that in 1995 and 1996 many licensed salmon fishermen did not fish for salmon but fished for crab instead. This was verified by Fisheries Officers who reported that of the 218 licensed salmon fishermen only 132 were active in 1996. Another method of obtaining actual effort information is also available since, beginning in 1993 commercial fishing vessel (CFV) numbers have been recorded on sales receipts issued to fishermen by fish plants. Enumeration of licensed salmon fishermen actively fishing was made by determining the number of CFVs in the Statistics Branch catch records. Active effort in 1991 and 1992 was assumed to be 90% as it was in 1993 and 1994 from the CFV file (Table 4.1).

The effects of these changes were quantified in the exploitation model as follows:

$$u.e = 1 - e^{-aF} \tag{2}$$

with *a* the fraction of the 1991 licensed effort remaining in 1992 to 1996, and *F* the instantaneous fishing mortality rate at the 1991 licensed fishing effort (*F = -ln(1-u)*) with *u* = 0.3 to 0.5 for small salmon, 0.7 to 0.9 for large salmon.

Thus, the exploitation rates (*u.e*) due to effort reductions were modified in equation (2) using estimated active licences from 1991 as a base and the number of active licences in 1992 to 1997 (Table 4.2).

Adjustment for Newfoundland fishery closure

The tagging study on Sand Hill River, 1969–1973 showed that Labrador small and large salmon were not only caught in Labrador, but also in the commercial fisheries along the northeast coast of Newfoundland (both small and large) and at West Greenland (large only) (Anderson, 1985). For small salmon, out of a total of 100 (1SW) tag returns there were 24 from Newfoundland. For large salmon, out of a total of 137 (2SW) tag returns there were 41 from Newfoundland.

For 1992–1997: the moratorium on commercial fishing in Newfoundland would have released small and large salmon to Labrador. The effect of salmon released from Newfoundland in 1992 to 1996 was evaluated against the effort adjusted exploitation rates (*u.e*, eq. 2) as follows:

$$\mu.n = \left(1 - \left(\frac{24}{100} * (1 - u.e)\right)\right) * u.e \text{ for small salmon, and}$$

$$\mu.n = \left(1 - \left(\frac{41}{137} * (1 - u.e)\right)\right) * u.e \text{ for large salmon} \tag{3}$$

Adjustment for season reductions in Labrador

Season reductions due to the varying opening dates and early closures from the quotas applied in 1995 to 1997. In 1995, adjustments were made to account for the new opening date for the commercial fishery in Labrador of July 3, changed from June 20 the previous year. For 1995, the accumulative effect weighted to SFA catches was to reduce the catch so that for small salmon the current catch represents 86.0% of small salmon and 62.7% of large salmon. In 1996, the opening date reverted to June 20 but the quota levels resulted in early closures in SFA 2 of 2A - July 10, 2B - July 8, and 2C - July 2 while SFA 1 and 14B did not close. For 1996, the accumulative effect of these weighted to SFA catches was to reduce the catch so that for small salmon the current catch represents 53% of small salmon and 61% of large salmon. In 1997, the opening date remained at June 20 but the quota levels resulted in early closures in SFA 2 of 2A -July 12, 2B - July 15, and 2C - July 13 while SFA 1 closed on October 15 as the quota was not caught. For 1997, the accumulative effect of these early closures was to reduce the catch so that for small salmon the current catch represents 47% of small salmon and 64% of large salmon. The season changes reduce catches and hence lower exploitation rates:

$$u.s_a = u.n_a * SC_a \tag{4}$$

With SC_a the proportionate change in catch of the season effect for size group *a* (a = small salmon, large salmon).

The cumulative effect of the changes in active licence effort in Labrador, the closure of the Newfoundland commercial fishery, and the changes in the fishing season in Labrador is to reduce exploitation on Labrador origin salmon in the Labrador commercial fishery (Table 4.3).

Returns to the coast of Labrador origin small salmon and large salmon were derived from eq. 1 as:

$$Lab.coast_a = Ret.coast_a * p.Lab_a \tag{5}$$

With $p.Lab_a$ the proportion of the returns to the coast of Labrador that are of Labrador origin for size group *a*.

Parameter values for sea age and the proportion of salmon of Labrador origin comes from the sampling program in the commercial fishery, 1974–1991. In 1997, commercial sampling resumed with samples being collected throughout the fishery at Makkovik and Rigolet in SFA 1 and Cartwright and St Lewis/Fox Harbour in SFA 2.

River age distribution of commercial samples of small and large salmon from Labrador have been found to consist, on average, of about 75–80% river age 4 and older in SFAs 1 & 2. The commercial samples came from commercial catches sampled in Labrador at several sites along the Labrador coast including Square Islands (SFA 2) and at Nain (SFA 1) (Anon, 1993b). A total of 46,320 salmon were sampled for scales and aged. Labrador salmon stocks are thought to contribute about 70% of the total production of four year, and older, river age salmon, with the other 30% coming from northern Québec. Thus, when non-Labrador salmon are factored in at 30% applied to the river age distribution, then 60–80% of the harvest of small and large salmon ($p.c_a$) in Labrador are of Labrador origin (Anon, 1993b). In 1997, in SFA 1, the percentage of the commercial catch that was of Labrador origin was 68% for large salmon (95% C. I. 64.3–72.5%) whereas for small salmon it was 39% (95% C.I. 35.6%–41.6%). In 1997, in SFA 2, the percentage of the commercial catch that was Labrador origin was 92% for large salmon (95% C. I. 88.4–95.2%) and 80% for small salmon (95% C.I. 74.8%–85.0%).

The 2SW component was estimated separately for salmon caught in SFA 1, 2 and 14B. In SFA 1, commercial sampling at Nain of large salmon showed the proportion of 2SW was on average about 84% (n=6542), 1977–1991. Thus, a range of 0.7–0.9 was used for SFA 1. In SFA 2, commercial sampling of large salmon averaged 69% (n=4793) 2SW salmon, 1977–1991. There were no commercial samples available for SFA 14B. Thus, for SFAs 2 & 14B a range of 0.6–0.8 was used. For the 1SW component, commercial samples at Nain in SFA 1 of small salmon showed the proportion of 1SW salmon were on average about 94% (n=4757). In SFA 2 the 1SW component was on average about 97% (n=8872) of small salmon. There were no samples from commercial sampling in SFA 14B. In 1997, aged commercial samples indicated that the previous range was acceptable.

Salmon in the Labrador marine fisheries are comprised of different sea age and maturing components. In the large salmon returns to the coast, it was assumed that 0.1 to 0.3 were of the 1SW age group (p1SW), the remainder were 2SW age group. Of these 1SW salmon and for small salmon, it was assumed that a proportion of them were non-maturing salmon (p1SWnmat) that would not have returned to rivers to spawn in the year in which they were captured (or returned to the coast); these proportions were 0.1 to 0.2 (lower values of 0.05 to 0.1 are assumed for the Labrador subsistence fisheries of 1998 to present).

The estimated returns to Labrador rivers by size and sea age group are calculated as:

For large salmon: Large_rivers = (Ret.coast – Large_CC) * p.Lab * (1-p1SW*p1SWnmat)

For small salmon: Small_rivers = (Ret.coast – Small_CC) * p.Lab * p1SW * (1-p1SWnmat)

For 2SW salmon: 2SW_rivers = (Ret.coast – Large_CC) * p.Lab * p2SW

For 1SW salmon:

1SW_rivers = (Large_CC / ER_Large – Large_CC) * p.Lab * p1SW * (1-p1SWnmat) +

(Small_CC / ER_Small – Small_CC) * p.Lab * p1SW * (1-p1SWnmat)

4.6.2 Modifications for 1997

A couple of modifications were made to the estimation procedure for Labrador in 1997. First, determination of exploitation rates was calculated separately for SFA 1, 2 and 14B using the active effort individually for each SFA. For SFA 1, the active number of licences declined from 141 in 1991 to 39 in 1997. For SFA 2, the active number of licences declined from 320 in 1991 to 99 in 1997. For SFA 14B, active licences declined from 52 in 1991 to 0 in 1997 when the fishery was closed. Exploitation rates determined as in equations 2, 3 and 4 for SFA 1 were 0.0735 to 0.1399 for small salmon, 0.2221 to 0.3959 for large salmon and for SFA 2, 0.0384 to 0.0728 for small salmon, 0.1589 to 0.2799 for large salmon. Numbers of small and large salmon for SFAs 1 & 2 were estimated from the exploitation model. For SFA 14B the results of assessments on Forteau Brook and Pinware River were expanded to include all the watersheds in SFA 14B. Returns to SFA 14B were 663 to 1545 small salmon and 146 to 327 large salmon.

4.6.3 For 1998 to 2001

In Labrador, for the years 1998-2001, there was no data available with which to estimate returns and spawners because the commercial fishery had closed and there were only one or two in-river counting fence projects. Consequently, previous analyses for Labrador used raising factors estimated based on the proportion that Labrador small and 2SW salmon were to the total PFA during the years when Labrador estimates were available (Reddin 1999). These factors (1.04 to 1.49 for small salmon and 1.05 to 1.27 for large salmon) were multiplied by the PFA in 1998-2001 to provide values for returns and spawners to Labrador. At the 2009 ICES Working Group North Atlantic Salmon (WGNAS) meeting, it was decided to re-examine the Labrador data to find a new method of determining returns and spawners for the 1998-2001 period that utilized data from Labrador rather than PFA which is data from outside Labrador as was described above (Anon. 2009). The basis for estimates of 2SW and 1SW salmon returns and spawners for Labrador (SFAs 1, 2 & 14B) prior to 1998 are catch data from angling and commercial fisheries. In 1998, the commercial fishery in Labrador was closed and the model for returns and spawners utilizing commercial catch data could not be used.

From 2002–2008, there were counting projects on four salmon rivers in Labrador. Because the same four out of about 100 rivers (one in SFA 1A, Northern Labrador and three in SFA 2) were monitored annually and the return rates per accessible drainage areas were extrapolated to the un-surveyed rivers in Labrador (ICES 2005). In order to provide new estimates of returns and spawners for Labrador for 1998-2001, angling data were used with estimates of angling exploitation rates. The return estimates of small, large, and 2SW salmon for 2002 to 2008 were used to determine exploitation rates based on small retained fish and large retained and hooked-and-released in the angling fishery. The average of these exploitation rates for the years 2002-2008 were then applied to the angling catches in 1998-2001 to provide new estimates returns in those years. The spawners for Labrador were derived by subtracting the angling catches from the returns.

4.6.4 For 2002 to present

Counting projects occur on three to four Labrador rivers; out of about 100 extant salmon rivers. Because the monitoring occurs on the same rivers each year, the abundance of small and large salmon per accessible drainage areas in these monitored rivers was raised to the drainage areas of the unsurveyed rivers in the remainder of Labrador. The accessible drainage areas were 9267 km² for Lake Melville (SFA 1A), 25485 km² for Northern Labrador (SFA 1B), 28160 km² for Southern Labrador (SFA 2), and 2651 km² for the Straits Area (SFA 14B). Accessible drainage area in the counting facility rivers was 1878 km² resulting in an expansion factor of 35 to one. Not all rivers in Lake Melville were included due to a lack of information on presence of salmon populations in rivers in this region of Labrador. Lake Melville rivers whose drainage areas were included are Sebaskachu, Cape Caribou, Goose, MacKenzie, Kenamu, Caroline and Traverspine.

Abundances for SFAs 1A and 1B were derived from English River returns with maximum and minimum values developed using the observed variability of relative abundances in SFA 2. Total returns and spawners for Labrador are estimated by Monte Carlo simulation based on 10 000 random draws from the range of values assuming abundances per km² of accessible drainage were uniformly distributed. The relative abundances (per km²) for each SFA were then multiplied by the total accessible drainage area to derive total returns of small and large salmon. Ranges of values were developed to convert numbers of small and large salmon to numbers of 1SW and 2SW salmon from scale age information collected from counting fences and angling fisheries in Labrador. A bootstrap procedure was used to develop estimates of the proportions of sea age 1 salmon in estimates of small salmon returns and spawners, proportions of sea age 2 salmon in estimates of large salmon returns and spawners and proportions of sea age 1 salmon in the estimates of large salmon returns.

[This is not used in the current run-reconstruction code

Sea age correction factors were:

Small to 1SW - 96 to 100%

Large to 2SW - 60 to 71%

Small overlap in large - 12 to 21%]

4.6.5 Spawners in Labrador

Spawners of small salmon, large salmon, 1SW, and 2SW salmon were calculated as:

Large_spawners = Large_rivers – Large_ang.loss

Small_spawners = Small_rivers – Small_ang.loss

2SW_spawners= Large_spawners

1SW_spawners= Small_spawners

With Ang.loss_Large and Ang.loss_Small the losses of large salmon and small salmon, respectively, in the inriver angling fisheries calculated as the sum of retained catch plus 10% mortality of catch & released fish.

4.7 GENERATING INPUT VECTORS FOR THE PFA AND LCM MODELS

The purpose of the run reconstruction model is to generate annual estimates (midpoint, and uncertainty) for the returns of 2SW salmon for the PFA forecast model (ICES 2021) as well as estimates of returns and spawners of small salmon, large salmon, and 2SW salmon by stock unit and overall for North America for developing indicators of stock status (ICES 2023).

The estimates and uncertainties in the returns for each stock unit are calculated from Monte Carlo sampling based on defined min to max ranges of various input parameters. The inputs for each stock unit are summarized in Table 4.4.

A total of 10,000 Monte Carlo draws are performed drawing from uniform distributions between the min to max ranges of the parameters and input data. The posterior distributions of the returns, spawners for small salmon, large salmon, and 2SW salmon are summarized: for the PFA model, the mean and standard deviation by year for each stock unit are used, for the LCM the mean and standard deviation on the natural log scale are used.

4.8 SPAWNERS AND LAGGED SPAWNERS FOR THE PFA MODEL

The spawners for the six stock units of NAC are estimated from Monte Carlo sampling within provided min to max ranges for each stock unit. Spawner ranges are provided for small salmon, large salmon, and 2SW salmon. The spawners contributing to the PFA recruitment of the year of interest (first post-smolt winter or August 1 of the 1SW year) are calculated by lagging forward the spawners (lagged spawners) based on the smolt age distributions in each region (Rago 2001; Table 4.5). The lag between spawners of the year and lagged spawners for the PFA year consists of the smolt age plus two years (one for the year of egg deposition plus one for the first year at sea). The smolt age proportions are assumed to be temporally constant for each stock unit with exception of USA that has two smolt age distributions over the time series (Table 4.5). Smolt age distributions range from 1 to 6 years and it is possible to forward cast the lagged spawners for three years after the last available spawning year. Because of the older smolt ages in Labrador and the first year of spawning estimate of 1970, the first PFA year with complete lagged spawners is 1978 (Figure 4.1).

For the PFA forecast model, only the 2SW spawners and lagged spawners are considered because the PFA recruitment age group of interest is the 1SW non-maturing sea age group, destined primarily to become 2SW first time spawners. This makes the implicit assumption of perfect heritability of the age at maturity with the recruitment of 2SW salmon determined by the 2SW salmon spawners.

For the LCM, small salmon and large salmon spawners are included with the expected egg depositions calculated as the sum of eggs from small salmon and large salmon. This makes the implicit assumption that there is no heritability of age at maturity. The total eggs from a spawning year are lagged forward to produce smolts migrating at different smolt ages according to the smolt age distributions in each stock unit (Table 4.5).

The smolt age distributions by stock unit are assumed to apply to eggs from 2SW salmon in the PFA forecast model and to eggs from all sea age groups for the LCM.

4.9 ATTRIBUTION OF MARINE FISHERIES OF LABRADOR, NEWFOUNDLAND, AND SAINT PIERRE AND MIQUELON

The commercial salmon fishery in Newfoundland has been under moratorium since 1992. The Labrador commercial salmon fishery closed in 1998 but there is an ongoing coastal subsistence food fishery since 1998. There is a gillnet fishery for salmon in the territorial waters of France around the islands of Saint Pierre and Miquelon. Historically, the fisheries of Labrador and Newfoundland harvested salmon from all stock units of eastern North America. The commercial harvests are provided in numbers of small salmon and large salmon for two large areas of Newfoundland and for three Salmon Fishing Areas of Labrador (Table 4.6).

The run reconstruction of returns to the six stock units of NAC represent abundances after the marine fisheries of Newfoundland, Labrador and Saint Pierre and Miquelon, therefore the attribution of origin of the catches is not required for the run reconstruction step (except for the estimation of returns to rivers of Labrador which assumes a proportion of the commercial harvests are of Labrador origin). Attribution of the harvests in the Labrador, Newfoundland and Saint Pierre and Miquelon marine fisheries to the NAC stock units is done in the PFA forecast model, specifically for 2SW salmon based on a set of assumptions.

4.9.1 Labrador marine fisheries

- Labrador commercial fishery harvests of small salmon and large salmon for 1971 to 1997 are considered to comprise 60% to 80% Labrador origin fish, with the remainder attributed to the other five stock units in proportion to the sum of the PFA for those five stock units.
- Labrador subsistence (Indigenous Food, Social and Ceremonial fisheries, Labrador resident food fisheries) fishery harvests for 1998 to present are considered to comprise 90% to 100% Labrador origin fish, with the remainder (0 - 10%) attributed to the other five stock units in proportion to the sum of the PFA for those five stock units.
- Proportion 2SW salmon in the large salmon category is assumed 0.6 to 0.8 or 0.7 to 0.9, by SFA for 1971 to 1997. For the subsistence fisheries of 1998 to present, the proportion 2SW in the harvests is assumed to be 0.60 to 0.71.

4.9.2 Newfoundland marine fisheries

The harvest number of small salmon, large salmon are tabulated for two regions of the Newfoundland coast, the northeast region comprised of SFAs 3 to 7 and the south and west coast comprised of SFAs 8 to 14A.

- Harvests of salmon in the SFAs 3 to 7 region are attributed to the six stock units of NAC based on the proportion of the estimated stock unit PFAs, including Labrador.
- For SFAs 8 to 14A, it is assumed that no Labrador origin salmon are harvested in those fisheries and the harvests are attributed to the other five stock units in proportion to the sum of their estimated stock unit specific PFAs.

- The proportion 2SW in the large salmon category is assumed to be 0.7 to 0.9 for the harvests in SFA 3 to 7. All large salmon are assumed to be 2SW salmon in the harvests from SFAs 8 to 14A.

4.9.3 Saint Pierre and Miquelon fishery

Samples from the Saint Pierre and Miquelon salmon fishery have been attributed to all stock units of eastern North America, although few have been identified from Labrador or the USA (ICES 2021, 2023).

- It is assumed that no Labrador origin salmon are harvested in this fishery and the harvests are attributed to the other five stock units in proportion to the sum of their estimated stock unit specific PFAs.
- All large salmon are assumed to be 2SW salmon.

4.10 ESTIMATING PFA

Estimates of prefishery abundance (PFA) are derived by run-reconstruction methods. The run-reconstruction approach was first presented at ICES in 1992 and was subsequently adopted for stocks on both sides of the Atlantic (Rago et al., 1993a; Potter and Dunkley, 1993; Potter et al., 1998; 2004). The main advantage of backwards-running, run-reconstruction models over alternative forward-running approaches is that more extensive data are available on adult returns (e.g. traps, counters and catch data) than on freshwater production of juveniles. In addition, rates of natural mortality (M) were thought to be lower and less variable for large salmon after their first winter in the sea than during the post-smolt phase (Potter et al., 2003).

The models used to estimate PFA take the generalised form:

$$PFA = Nh * \exp(Mt_h) + \sum_i C_i \; * \; \exp(Mt_i)$$

with *Nh* the number of adult fish returning to homewaters, C_i the catch of fish from the stock in each interception fishery *i* (operating before the fish return to homewaters), *M* the monthly instantaneous rate of natural mortality of salmon in the sea after the first sea-winter, t_i the time in months between the PFA date and the midpoint of fishery *i*, and t_h the time in months between the PFA date and the midpoint of the return of fish to homewaters. Coastal catches, except for Newfoundland and Labrador, are included in the estimate of returns to homewaters (*Nh*).

4.10.1 PFA run reconstruction model

The run–reconstruction model developed by Rago et al. (1993a) and described in previous WGNAS reports (ICES, 2008; 2009a) and in the primary literature (Chaput et al., 2005) is used to estimate the PFA based on estimates of returns and harvests to NAC from 1971 to the present. The model takes the form:

$$PFA_i = \; (NR2_{i+1} * e^{M*1} + \; NC2_{i+1}) * \; e^{M*10} + \; NC1_i + \; NG1_i$$

with $NR2_{i+1}$ the sum of 2SW returns to six regions of North America in year *i + 1*, $NC2_{i+1}$ is the harvest of 2SW salmon in Newfoundland and Labrador commercial fisheries in year *i + 1*, $NC1_i$ is the harvest of 1SW non-maturing salmon in Newfoundland and Labrador commercial fisheries in year *i*, $NG1_i$ is the harvest of 1SW non-maturing salmon of North American origin in the Greenland fishery in year *i*, and M is the monthly instantaneous natural mortality of 0.03.

The reconstruction begins with the estimation of returns of 2SW salmon to six regions in eastern North America: Labrador, Newfoundland, Quebec, Gulf, Scotia-Fundy, and USA. For the four southern regions, the regional returns include the harvest in the coastal commercial fisheries but this is not the case for

Newfoundland and Labrador. For Labrador, the returns to rivers are estimated from the commercial harvest factored by an exploitation rate. The harvest of 2SW salmon in the Newfoundland and Labrador mixed-stock fisheries in year *i + 1* is added to the sum of the returns to the six regions (prorated backward for one month of natural mortality - equates to 1st June of year i + 1) to produce the returns to North America. Finally, the harvests of North American origin salmon in the Greenland fisheries in year *i* and the harvest of non-maturing 1SW salmon in the Newfoundland and Labrador commercial fisheries in year *i* are added to the prorated returns to North America (ten months between abundance at Greenland on 1st August year *i* and North America on 1st June year *i + 1*) to produce the pre-fishery abundance of non-maturing 1SW salmon of North American origin. An instantaneous natural mortality rate of 0.03 per month is assumed for salmon in the second year at sea for all years (ICES, 2002).

Following earlier WGNAS recommendations (ICES, 2008), the run–reconstruction model since 2009 has been developed using Monte Carlo simulations, now in R.

The PFA of the non-maturing component of 1SW fish, destined to be 2SW returns (excluding 3SW and previous spawners) is the estimated number of salmon in the North Atlantic on August 1st of the second summer at sea. As this requires estimates of 2SW returns to rivers, there is always a lag in providing this figure (PFA estimates for year *i* require 2SW returns to rivers in North America in year *i + 1*).

4.11 INSTANTANEOUS NATURAL MORTALITY RATE (M)

The natural mortality rate for salmon after they recruit to the distant water fisheries has been the subject of much discussion. ICES originally used a value of 0.01 per month, based upon Doubleday et al. (1979), but this was modified to 0.03 per month following a detailed review as part of the EU SALMODEL project (Crozier et al., 2003; ICES, 2002) on the basis of inverse-weight and maturity-schedule models. The rate is assumed to have been constant over the time-series. While mortality may be expected to vary among years and may also be different for maturing and non-maturing 1SW recruits, WGNAS has not had data on which to base the use of different values, or values that change over time. The assumption is, therefore, that the mortality of adult fish after the first winter at sea has not changed and that all the variability of marine mortality has occurred at the post-smolt stage.

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4.13 TABLES & FIGURES

Table 4.1. Licenced and estimated active licenced effort in the Labrador commercial salmon fishery, 1991 to 1997. Description of methods and data in the table are from Reddin and Poole (2010).

Commercial licences Labrador	1991	1992	1993	1994	1995	1996	1997
Licenced	570	495	288	218	218	218	205
Active	513	446	262	194	153	127	138

Table 4.2. Range of derived exploitation rates in the Labrador commercial salmon fishery for small salmon and large salmon adjusted for the estimated active licenced effort. Description of methods and data in the table are from Reddin and Poole (2010).

Size group	Range	1969-1991	1992	1993	1994	1995	1996	1997
Small salmon	Lower	0.30	0.22	0.13	0.10	0.08	0.07	0.07
	Upper	0.50	0.39	0.25	0.19	0.15	0.12	0.14
Large salmon	Lower	0.70	0.58	0.38	0.29	0.24	0.20	0.22
	Upper	0.90	0.83	0.62	0.50	0.42	0.36	0.39

Table 4.3. Range of derived exploitation rates in the Labrador commercial salmon fishery for small salmon and large salmon adjusted for the estimated active licenced effort in the Labrador fishery, the closure of the Newfoundland commercial fishery in 1992, and changes in the Labrador commercial fishery seasons (1995 to 1997). Description of methods and data in the table are from Reddin and Poole (2010).

Size group	Range	1969-1991	1992	1993	1994	1995	1996	1997
Small salmon	Lower	0.30	0.22	0.13	0.10	0.07	0.03	0.04
	Upper	0.50	0.39	0.25	0.19	0.13	0.06	0.08
Large salmon	Lower	0.70	0.58	0.38	0.29	0.15	0.13	0.16
	Upper	0.90	0.83	0.62	0.50	0.26	0.23	0.28

Table 4.4. Input data used in the run reconstruction of returns and spawners to the stock units of NAC.

Stock unit	Year range	Parameter or data	Min to max range
USA	1971 to present	Returns and spawners for small salmon, large salmon, 2SW salmon	Midpoint only (narrow range of uncertainty added, 0.99 to 1.01 of midpoint)
Scotia_Fundy	1970 to present	Returns and spawners for small salmon, large salmon, 2SW salmon for two geographic areas (SFA 19-21, SFA 23)	Provided as min to max range by geographic area
Gulf	1970 to present	Returns and spawners for small salmon, large salmon, 2SW salmon by SFA (15 to 18)	Provided as min to max range by SFA
Quebec	1971 to 1983	Annual returns and spawners for small salmon and large salmon by assessment category for all of Quebec.	Provided as min to max estimates of returns and spawners
	1984 to present	River specific annual returns and spawners for small salmon and large salmon.	Min to max range by river summed to give min to max range by zone
Newfoundland	1971 to present	Annual returns, spawners for small salmon, large salmon, and 2SW salmon by SFA - exploitation rate range and ratios of large to small salmon derived from monitored rivers	non-parametric bootstrap technique, with replacement, 95% C.I. used to derive min to max range by SFA
Labrador	1971 to 1996	Annual commercial harvests of small salmon, large salmon by SFA (Salmon Fishing Area)	NA
		Annual exploitation rates by size group by SFA similar for 1971 to 1991, then adjusted for reductions in active licences, closure of Newfoundland commercial fishery since 1992 and changes in fishing seasons in Labrador after 1994	Based on recaptures of smolts from tagging Sand Hill River
		Proportion of large salmon that are 2SW salmon	By SFA; 0.6 to 0.8 or 0.7 to 0.9
		Proportion of 1SW salmon in the large salmon category of the commercial catches	0.1 to 0.3
		Proportion of all 1SW salmon in commercial catches that are non-maturing	0.1 to 0.2
		Proportion of commercial catch of Labrador origin	0.6 to 0.8
	1997	See text above for exploitation rate estimation	
	1998 to 2001	Recreational fishery catches with exploitation rates derived from the assessment years 2002 to 2008.	Provided as min to max estimates of returns and spawners
	2002 to present	Annual return to rivers for small salmon, large salmon to Labrador - fish per drainage area of monitored rivers used to raise to all rivers of Labrador	non-parametric bootstrap technique, with replacement, 95% C.I. used to derive min to max
		Proportion 2SW in large salmon returns to rivers	0.60 to 0.71

Table 4.5. Smolt age proportions for the six stock units of NAC used to generate lagged spawner series for the PFA forecast model.

Stock unit	Years	Smolt age (years)					
		1	2	3	4	5	6
USA	1970 - 1989	0.3767	0.5200	0.1033	0	0	0
	1990 to present	0.6274	0.3508	0.0218	0	0	0
Scotia-Fundy	1970 to present	0	0.6002	0.3942	0.0055	0	0
Gulf	1970 to present	0	0.3979	0.5731	0.0291	0	0
Quebec	1970 to present	0	0.0577	0.4644	0.3783	0.0892	0.0104
Newfoundland	1970 to present	0	0.0408	0.5979	0.3237	0.0375	0
Labrador	1970 to present	0	0	0.0768	0.542	0.341	0.0401

Table 4.6a. Estimated harvests (number of fish) of large salmon in the Newfoundland commercial salmon fisheries (to 1991), Labrador commercial salmon fisheries (by SFA to 1997), Labrador subsistence food fisheries (since 1998), and the Saint Pierre and Miquelon fishery.

	Newfoundland commercial fishery		Labrador commercial fishery			Labrador subsistence fishery	Saint Pierre and Miquelon
Year	SFA 3 to 7	SFA 8 to 14a	SFA 1	SFA 2	SFA 14B	SFA 1 & 2	
1970	na	na	17633	45479	9595	0	0
1971	81152	na	25127	64806	13673	0	0
1972	43041	42861	21599	55708	11753	0	0
1973	85904	43627	30204	77902	16436	0	0
1974	73961	85714	13866	93036	15863	0	0
1975	100504	72814	28601	71168	14752	0	0
1976	79318	95714	38555	77796	15189	0	348
1977	114413	63449	28158	70158	18664	0	0
1978	64073	37653	30824	48934	11715	0	0
1979	29936	29122	21291	27073	3874	0	0
1980	86941	54307	28750	87067	9138	0	0
1981	98672	38663	36147	68581	7606	0	0
1982	46076	35055	24192	53085	5966	0	0
1983	48218	28215	19403	33320	7489	0	348
1984	44540	15135	11726	25258	6218	0	348
1985	36975	24383	13252	16789	3954	0	348
1986	48996	22036	19152	34071	5342	0	290
1987	67072	19241	18257	49799	11114	0	232
1988	36449	14763	12621	32386	4591	0	232
1989	37576	15577	16261	26836	4646	0	232
1990	31847	11639	7313	17316	2858	0	218
1991	25792	10259	1369	7679	4417	0	135
1992	0	0	9981	19608	2752	0	269
1993	0	0	3825	9651	3620	0	342
1994	0	0	3464	11056	857	0	398
1995	0	0	2150	8714	312	0	97
1996	0	0	1375	5479	418	0	182
1997	0	0	1393	5550	263	0	173
1998	0	0	0	0	0	2269	268
1999	0	0	0	0	0	1084	270
2000	0	0	0	0	0	1352	263
2001	0	0	0	0	0	1721	250
2002	0	0	0	0	0	1389	227
2003	0	0	0	0	0	2175	348
2004	0	0	0	0	0	3696	196
2005	0	0	0	0	0	2817	351
2006	0	0	0	0	0	3090	469
2007	0	0	0	0	0	2652	218
2008	0	0	0	0	0	3909	442
2009	0	0	0	0	0	3344	408
2010	0	0	0	0	0	3725	470
2011	0	0	0	0	0	4451	1031
2012	0	0	0	0	0	4228	156
2013	0	0	0	0	0	6479	1272
2014	0	0	0	0	0	3994	611
2015	0	0	0	0	0	6146	410
2016	0	0	0	0	0	5598	286
2017	0	0	0	0	0	6193	78
2018	0	0	0	0	0	4078	214
2019	0	0	0	0	0	5793	182
2020	0	0	0	0	0	6155	214

Table 4.6b. Estimated harvests (number of fish) of small salmon in the Newfoundland commercial salmon fisheries (to 1991), Labrador commercial salmon fisheries (by SFA; to 1997), in the Labrador subsistence food fisheries (since 1998), and in the Saint Pierre and Miquelon fishery.

	Newfoundland commercial fishery		Labrador commercial fishery			Labrador subsistence fishery	Saint Pierre and Miquelon
Year	SFA 3 to 7	SFA 8 to 14a	SFA 1	SFA 2	SFA 14B	SFA 1 & 2	
1970	na	na	14666	29441	8605		
1971	111518	70936	19109	38359	11212	0	0
1972	107770	111141	14303	28711	8392	0	0
1973	180966	176907	3130	6282	1836	0	0
1974	135874	153278	9848	37145	9328	0	0
1975	190557	91935	34937	57560	19294	0	0
1976	143557	118779	17589	47468	13152	0	731
1977	150491	57472	17796	40539	11267	0	0
1978	68747	38180	17095	12535	4026	0	0
1979	140844	62622	9712	28808	7194	0	0
1980	186648	94291	22501	72485	8493	0	0
1981	174222	60668	21596	86426	6658	0	0
1982	143445	77017	18478	53592	7379	0	0
1983	116592	55683	15964	30185	3292	0	731
1984	98184	52813	11474	11695	2421	0	731
1985	131360	79275	15400	24499	7460	0	731
1986	151275	91912	17779	45321	8296	0	609
1987	192308	82401	13714	64351	11389	0	487
1988	115375	74620	19641	56381	7087	0	487
1989	116375	60884	13233	34200	9053	0	487
1990	71761	46053	8736	20699	3592	0	458
1991	62331	42721	1410	20055	5303	0	283
1992	0	0	9588	13336	1325	0	565
1993	0	0	3893	12037	1144	0	717
1994	0	0	3303	4535	802	0	834
1995	0	0	3202	4561	217	0	204
1996	0	0	1676	5308	865	0	382
1997	0	0	1728	8025	332	0	363
1998	0	0	0	0	0	2988	562
1999	0	0	0	0	0	2739	566
2000	0	0	0	0	0	5323	552
2001	0	0	0	0	0	4789	525
2002	0	0	0	0	0	5806	476
2003	0	0	0	0	0	6477	731
2004	0	0	0	0	0	8385	892
2005	0	0	0	0	0	10436	926
2006	0	0	0	0	0	10377	985
2007	0	0	0	0	0	9208	458
2008	0	0	0	0	0	9834	926
2009	0	0	0	0	0	7988	857
2010	0	0	0	0	0	9867	602
2011	0	0	0	0	0	11138	145
2012	0	0	0	0	0	9977	327
2013	0	0	0	0	0	7185	542
2014	0	0	0	0	0	8958	440
2015	0	0	0	0	0	8923	988
2016	0	0	0	0	0	7638	1396
2017	0	0	0	0	0	6868	1045
2018	0	0	0	0	0	8780	382
2019	0	0	0	0	0	7061	324
2020	0	0	0	0	0	7558	382

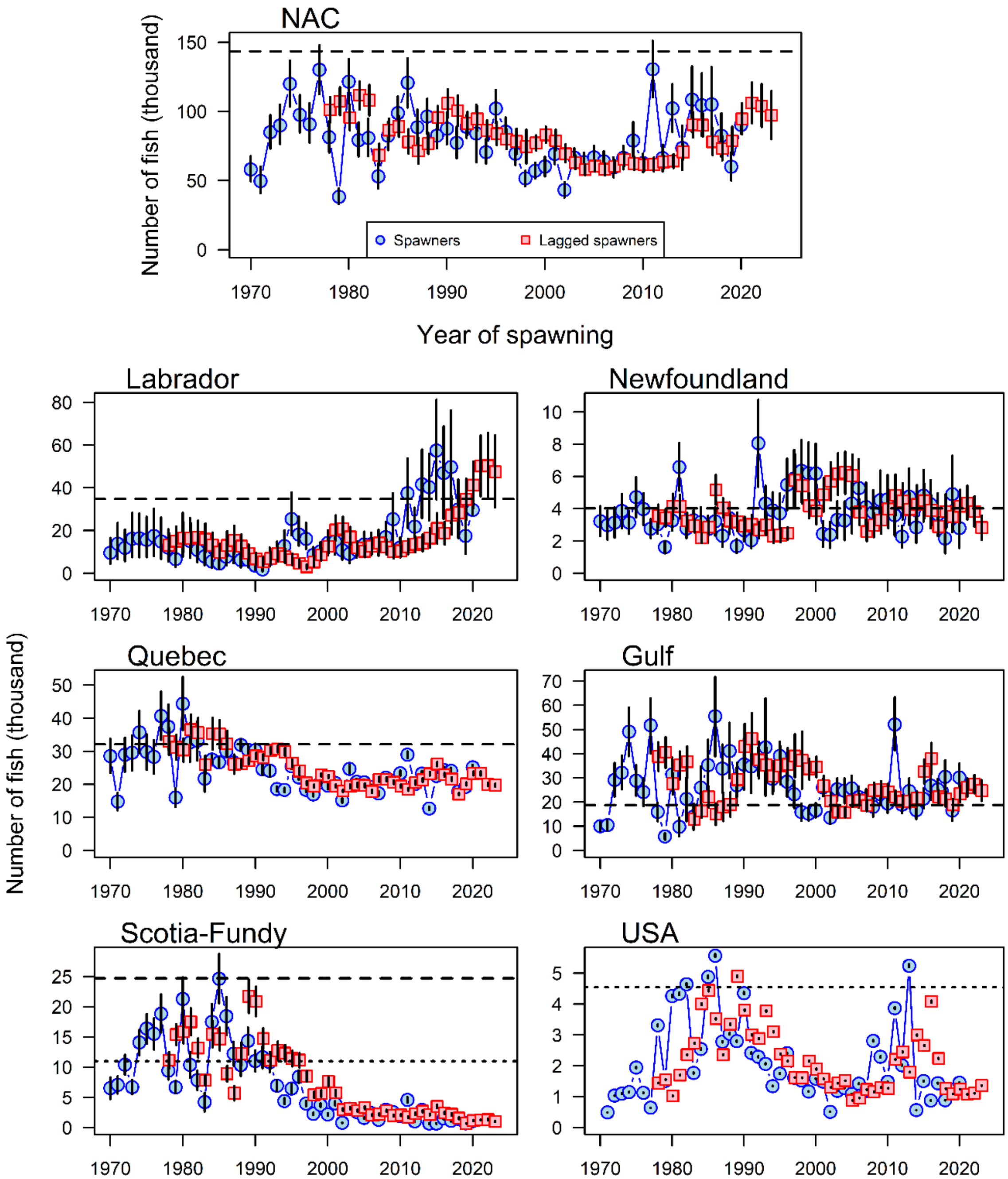

Figure 4.1. Estimated 2SW spawners and lagged spawners for the six stock units of NAC and overall for NAC, 1970 to 2023 (from ICES 2021). The dashed horizontal line in each panel is the 2SW conservation limit. The dotted line in the two lower panels is the 2SW management objective.