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Estimation of marine exploitation rates on Atlantic salmon (*Salmo salar* L.) stocks in Newfoundland, Canada

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Marine exploitation rates were estimated for nine Newfoundland Atlantic salmon (*Salmo salar* L.) populations, separately for small and large salmon size components. Estimates were derived using counts of salmon returning to fish counting facilities rather than from tagging studies and thus adjustments were not required to account for tag loss, handling or tagging mortality, or tag reporting rates. For all stocks combined, the overall marine exploitation rate during the period 1984–1991 averaged 45.3% (29.6–57.1%) on small salmon and 74.2% (57.7–83.7%) on large salmon. These estimates are considered minimum values. Concerns related to declining salmon abundance resulted in the closure of the Newfoundland commercial salmon fishery in 1992. Results are discussed in relation to previous estimates derived from tagging, and highlight the importance of accounting for marine exploitation when examining trends in salmon survival and return data even when commercial fisheries have been closed.

Key words: Atlantic salmon, *Salmo salar*, marine exploitation, Newfoundland, fisheries.

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Introduction

Prior to the closure of the Newfoundland commercial Atlantic salmon (*Salmo salar* L.) fishery in 1992, various measures had been introduced over the years to decrease exploitation on salmon in the region (Marshall, 1988; May, 1993). For example, the 1984 management plan was intended to reduce the interception of multi-sea-winter (MSW) salmon destined for rivers in mainland Canada, and, coincidentally through reductions in the commercial fishery, to increase escapements of small (<63 cm, 1.8–2.0 kg, mostly grilse) and large (≥63 cm, 4.0–5.0 kg, mainly previous spawners) salmon into Newfoundland rivers (O'Connell *et al*., 1992a). Salmon, however, were still harvested in mixed-stock coastal gillnet fisheries distributed among various Salmon Fishing Areas (SFAs) (Figure 1) with most of the catch occurring on the east and northeast coasts (SFAs 3–5), and along the west coast of the island in SFAs 13–14A (Figure 1). On average, about 600 tonnes were landed annually during the period 1984–1991, varying from a low of 335 tonnes to a high of 925 tonnes. This was equivalent to a harvest of 141–361 thousand fish per year (detailed summaries of catch in weight and numbers of fish by SFA are provided in Mullins and Jones, 1992; O'Connell *et al*., 1992b). Whilst landings varied annually, there were no statistically significant linear trends over the 1984–1991 period in any of the combined regional landings ($p>0.14$), or for all SFAs combined ($p>0.14$) (Figure 1). According to Pippy (1982), approximately 80% of the salmon caught in the Newfoundland and Labrador commercial salmon fishery originated from watersheds in these areas with the remainder of the catch consisting of salmon intercepted from the Maritimes, Quebec, and the eastern United States.

Despite the extent of the Newfoundland commercial salmon fishery, and the large numbers of stocks (rivers) that potentially could contribute to it (approximately 500), including those from other regions of eastern

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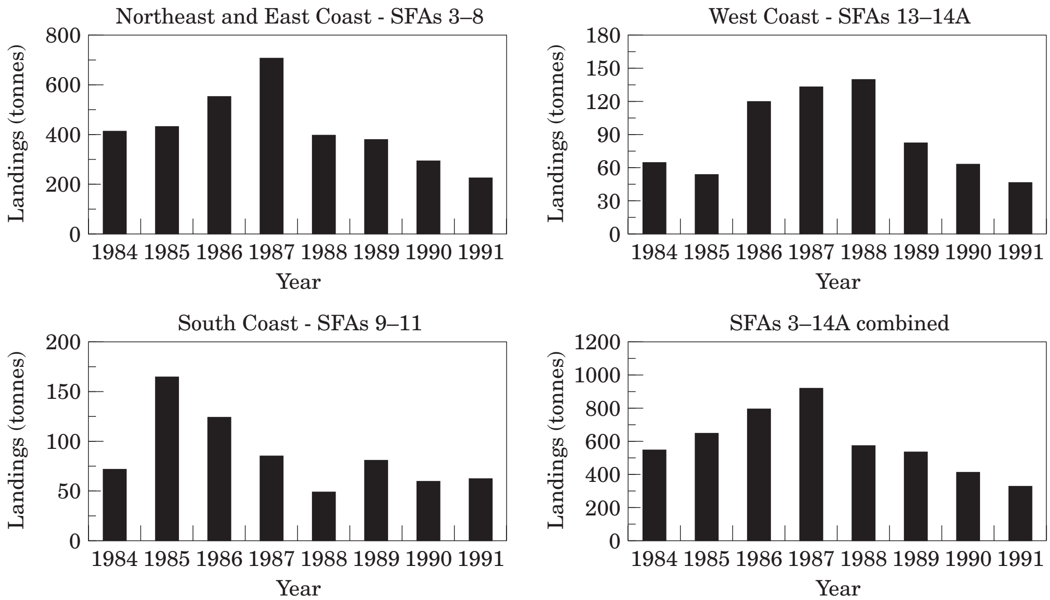

Figure 1. Commercial landings of Atlantic salmon, by weight, for regional groupings of Salmon Fishing Areas (SFAs), and for all SFAs combined, 1984–1991. Small and large sized salmon are combined.

Canada, few estimates of marine exploitation rates are available. Of those that have been derived most were based on tagging studies (Chadwick, 1993), as in Europe (Potter and Dunkley, 1993), but as Ritter (1989) and others (e.g. Hilborn and Walters, 1992) acknowledge, partitioning mortality between fishing and natural causes is often problematic owing to mixed-stock fisheries, inadequate tagging information, and problems associated in accounting for tagging reporting rates, tag loss, handling and tag mortality. In the absence of mixed-stock interception fisheries, Chadwick (1993) stated that estimates of marine exploitation may no longer be necessary. Whilst this may be true in the long term, reliable estimates are still required to evaluate the status of fish stocks. In particular, studies have shown that salmon returns to rivers are highly dependent on marine exploitation rates (Crozier and Kennedy, 1994, 1999). Thus, in comparing trends in salmon returns to rivers over time, or trends in natural survival to freshwater between periods when fisheries were operating versus when they have been closed, as in the case of Newfoundland, it is necessary to correct or adjust returns for marine exploitation in evaluating the effects of these management measures. In addition, whilst catches are quite low by comparison with historic levels, directed marine fisheries for Atlantic salmon still occur in the northeast and northwest Atlantic Ocean. Therefore, comparisons of reliable exploitation rates among individual populations can still provide insight into the effects of fishing on stock characteristics and further our understanding of the patterns associated with the utilization of the resource relative to stock conservation requirements.

This paper outlines an alternate method to infer estimates of the average marine exploitation rate for the period 1984–1991 on nine Newfoundland Atlantic salmon stocks, separately for both small and large salmon size components. Estimates are derived using actual counts of salmon returning to fish counting facilities rather than from tagging studies and thus adjustments are not required to account for tag loss, handling or tagging mortality, or tag reporting rates. Results are discussed in relation to previous studies based on tagging, and then applied in two cases to illustrate how salmon return data can be corrected or adjusted in those years prior to the start of the moratorium in 1992 to provide a more accurate evaluation of trends in salmon abundance.

Materials and methods

Sources of information

With one exception, accurate counts of Atlantic salmon were obtained at fishways or fish counting fences installed on various Newfoundland rivers (Figure 2). The exception was Humber River where estimates were derived either from mark-recapture surveys (1990–1996) or for 1984–1989, by applying angling exploitation rates to recreational salmon catches (Mullins *et al.*, 1997) as has been used in other areas (e.g. Chadwick, 1985; Porter *et al.*, 1995). When required, counts of salmon

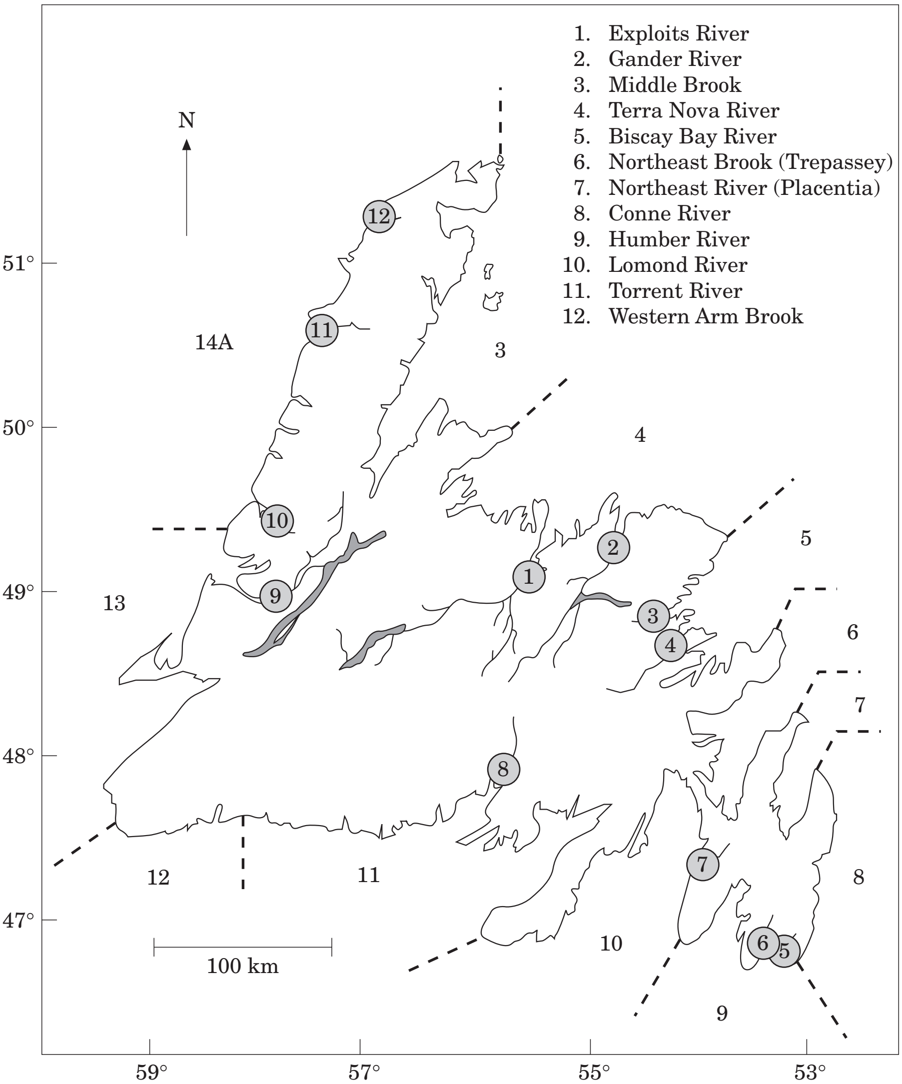

Figure 2. Map of Newfoundland, Canada, showing Salmon Fishing Areas (SFAs) 3–14A, and the location of various rivers for which marine exploitation rates were derived or for which salmon return count data were obtained.

were adjusted for any in-river losses to recreational fisheries occurring below the fish counting facilities by adding in the respective number of salmon caught and retained to determine total returns to the river. The information on recreational salmon catches below fish counting facilities was obtained either from creel surveys (e.g. Exploits River) or from angling catch statistics compiled by the Department of Fisheries and Oceans. On average, adjustments made to the actual salmon count data accounted for less than 15% of the total returns at six rivers, between 21–24% at two rivers, and 44% at Lomond River where the fishway is located about 5 km upstream and all salmon angling occurs downstream of the counting facility. Rivers from which salmon return data were available varied in size from the 11 272 km^2 drainage Exploits River in SFA 4, to Northeast Brook (Trepassey) in SFA 9 that has a drainage area of only 21 km^2 (Figure 2, Table 1). Data from the three largest rivers in Newfoundland are included (Exploits, Humber, and Gander rivers) in the derivation of exploitation rates.

The pre-moratorium period covers the eight-year interval 1984–1991, coincident with the 1984 salmon management plan which provided a moderately stable period of management measures. Details, and an evaluation of the 1984 management plan are described in O'Connell *et al*. (1992a) and highlight the fact that in general, the management plan did not result in increased escapements of either small or large salmon to Newfoundland rivers. Salmon populations in

Table 1. Summary of the mean, minimum (Min), and maximum (Max) total returns of small and large sized Atlantic salmon to various Newfoundland rivers during pre-moratorium (1984–1991) and commercial salmon fishery moratorium (1992–1996) years. SFA=Salmon Fishing Area. Drainage areas of respective watersheds are also provided.

			Small salmon						Large salmon					
			1984–1991			1992–1996			1984–1991			1992–1996		
SFA	River	Drainage area (km^2)	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
4	Exploits River	11 272	10 767	5 659	19 028	19 935	13 504	30 316	229	89	529	970	314	2 053
4	Gander River[1]	6 398	7 409	6 745	7 743	21 774	18 179	26 205	550	473	670	1 972	1 072	4 180
5	Middle Brook	276	1 169	626	1 675	1 843	1 448	2 247	22	13	57	110	43	168
5	Terra Nova	1 883	1 568	1 127	2 114	2 416	1 780	3 050	128	56	206	420	246	638
9	Biscay Bay	239	1 663	394	2 688	1 310	1 117	1 600	74	35	107	89	51	149
9	Northeast Brook (Trepassey)	21	99	62	158	76	49	99	24	9	41	14	10	17
10	Northeast River (Placentia)	94	590	350	879	968	710	1 420	20	0	44	76	46	123
11	Conne River[2]	602	6 472	2 411	10 155	2 940	1 533	4 440	355	89	516	130	100	179
13	Humber River	7 679	10 788	4 868	16 168	20 477	7 995	30 445	755	341	1 132	1 871	636	2 945
14A	Lomond River	470	720	393	986	999	794	1 365	28	12	75	76	38	101
14A	Torrent River	619	2 155	1 512	3 155	4 895	2 832	7 371	92	30	288	370	170	615
14A	Western Arm Brook	149	387	233	527	895	480	1 272	1	0	2	27	8	55

[1]Data series beginning in 1989.
[2]Data series beginning in 1986.

Table 2. Estimated marine exploitation rates for small and large sized Atlantic salmon from various Newfoundland rivers, showing the observed mean, along with the median value, coefficient of variation (CV), and the 5th and 95th percentiles obtained from 2000 realizations.

River	Small salmon					Large salmon				
	Observed mean	Median	CV	Percentiles 5th	Percentiles 95th	Observed mean	Median	CV	Percentiles 5th	Percentiles 95th
Exploits River	46.0	46.0	25.0	24.5	61.7	76.4	76.3	12.8	55.5	86.3
Gander River	66.0	66.0	3.8	61.6	69.8	72.1	72.0	11.6	55.0	82.0
Middle Brook	36.6	36.7	22.8	22.1	49.3	80.0	80.0	8.4	66.4	87.7
Terra Nova River	35.1	35.1	20.9	22.1	45.2	69.5	69.4	9.1	56.9	77.6
Northeast River (Placentia)	39.0	38.6	26.2	20.4	53.3	73.7	74.0	11.0	58.5	84.7
Humber River	47.3	47.7	25.4	23.5	62.6	59.6	59.8	20.9	33.6	72.3
Lomond River	27.9	27.4	31.8	12.3	40.9	63.2	63.0	17.6	42.2	77.0
Torrent River	56.0	55.6	15.5	39.4	66.2	75.1	75.6	12.8	56.6	86.4
Western Arm Brook	56.8	54.5	13.6	40.2	64.5	96.3	97.6	1.6	94.5	99.1
Mean		45.3		29.6	57.1		74.2		57.7	83.7

Newfoundland are characterized with a modal smolt age of 3 or 4 years (O'Connell and Ash, 1993). Thus, the first substantive returns of adult salmon produced from any potential increase in spawning escapements during the first year of the commercial salmon fishery closure (1992) would begin in 1997. Consequently, in this analysis the moratorium years were confined to the five-year period 1992–1996.

Estimation of marine exploitation

The method to estimate marine exploitation rates is appropriate where average total returns during the moratorium are higher than that for the pre-moratorium years. It is a variation of an approach used by Scarnecchia *et al*. (1989) to determine the harvest rate required to account for a change in the grilse to two-sea-winter (2SW) salmon ratio in various Icelandic rivers following the expansion of the commercial salmon fishery at West Greenland. Given the closure of the Newfoundland commercial salmon fishery, we proceed by considering the average marine exploitation rate (ME) required to account for the differences in average returns between the pre-moratorium and moratorium period for each river, separately for small and large-sized Atlantic salmon:

$$ME = \frac{\overline{Rm} - \overline{Rpm}}{\overline{rm}} \times 100 \quad (1)$$

where

Rm = average total returns during the moratorium (1992–1996)

Rpm = average total returns prior to the moratorium (1984–1991)

Estimates of the average marine exploitation rate for each river were found using the above equation and are shown in Table 2. Salmon populations, however, are often characterized by large fluctuations in annual abundance (Noakes *et al*., 1990; Dempson *et al*., 1998). Therefore, confidence intervals were computed using a non-parametric bootstrap method. For each river and size category (small or large salmon), total return values during each of the pre-moratorium (n = 8) and moratorium (n = 5) years were randomly drawn with replacement and averaged to compute Rm and Rpm with ME calculated from Equation (1) above. Thus, for each realization, eight values were randomly obtained and averaged, as above, for the pre-moratorium period, whilst five values were averaged to represent the moratorium period and a mean exploitation rate calculated. This was repeated using 2000 realizations to generate a distribution of marine exploitation rates for small and large salmon size components for each river. For Gander River, only three years were averaged for the pre-moratorium period, consistent with the actual number of years data were available (Table 1).

The exploitation rates estimated also incorporate losses in other legal (by-catch) ocean fisheries, and hence are designated as marine rather than commercial exploitation. It is assumed, however, that these losses are minimal by comparison with the amount of salmon harvested in directed commercial fisheries during 1984–1991. It is also assumed that: (a) annual variability in smolt production and natural mortality are consistent for both pre-moratorium and moratorium periods; and (b) removals due to illegal (poaching) fisheries are also consistent over the two periods. Closure of the Newfoundland northern cod fishery in 1992 was followed by cod moratoria along the south and west coasts of Newfoundland in 1993 (Myers *et al*., 1997). This would have contributed to either a reduction or elimination of salmon by-catch in cod fishing gear during the 1992–1996 moratorium.

A simple simulation model was used to examine the effect on estimating marine exploitation rates from total return data when the assumptions related to consistent smolt production and natural survival for both pre-moratorium and moratorium periods were violated. Exploitation rates were estimated in the same manner as described by Equation (1) above, but where individual values of Rm (n=5 years) and Rpm (n=8 years) were generated from:

Rpm=Smolts × natural survival × marine exploitation

Rm=Smolts × natural survival

In both cases, numbers of smolts and natural survival rates were obtained from uniform distributions with a coefficient of variation of 25%, as was the marine exploitation rate; 1000 realizations were run. The value of ME calculated from Equation (1) could then be compared with the value assigned in the simulation to see under which set of conditions the ME estimated from total return data under- or overestimated the specified marine exploitation rates in the simulation.

Results

Total returns of salmon

The average total returns of small Atlantic salmon to the largest Newfoundland Rivers (Exploits, Humber, and Gander) varied from about 7–11 thousand fish per year during the pre-moratorium period but increased to 20–22 thousand fish during the commercial salmon fishery moratorium (Table 1). With the exception of Conne River (SFA 11), annual returns in smaller systems averaged less than 2200 small salmon followed in most rivers by corresponding increases during the moratorium. Large salmon typically make up less than 10–15% of the combined return of both size categories. Prior to the moratorium, there was only one occasion when more than 1000 large salmon were counted returning to a river. This value was frequently exceeded in both Gander and Humber rivers following the closure of the commercial salmon fishery, while returns of large salmon in other systems similarly increased (Table 1).

Contrary to the above, there were three exceptions to the positive response in salmon returns to rivers resulting from the closure of the commercial salmon fishery. Average returns of small salmon to Biscay Bay River, Conne River, and Northeast Brook (Trepassey), all situated along the south coast of Newfoundland (Figure 2), declined from 55% to 21% (Table 1). Average returns of large salmon were 42% and 63% lower at Northeast Brook (Trepassey) and Conne River, respectively, whilst at Biscay Bay River, large salmon returns showed a small increase. Consequently, it was not possible to derive estimates of marine exploitation rates for these three rivers.

Marine exploitation rates

Estimates of the median marine exploitation rate on small salmon varied from 27.4%–66.0% (Table 2). Rivers in SFAs 4, 13, and with the exception of Lomond River, those in SFA 14A had higher exploitation rates than those estimated for other areas (SFAs 5 and 10). The average of the median exploitation rate for all rivers was 45.3%, with the 5th and 95th percentiles varying from 29.6%–57.1% (Table 2).

Median exploitation rates were higher on large salmon, ranging from 59.8%–97.6% (Table 2). Large salmon exploitation rates were also less variable, in general, than rates derived for small salmon. An estimate of the overall average median exploitation rate for all rivers combined was 74.2%, with the 5th and 95th percentiles of 57.7% and 83.7%, respectively.

Simulation results

Situations in which marine exploitation rates calculated from total return data underestimated the true value occurred when either natural survival, smolt production, or both parameters were lower during the moratorium years (Table 3). Alternatively, in cases where natural survival, smolt production or both were higher in during the moratorium, then calculated marine exploitation rates would overestimate the true value (Table 3). If natural survival decreased to such an extent that the estimated average total returns during period two were lower than average returns in period one, then negative exploitation rates would result using this method.

Discussion

Counts of salmon returning to fishways and fish counting fences enabled estimates of marine exploitation rates to be derived for those Newfoundland stocks where salmon returns increased during the commercial salmon fishery moratorium. With an average commercial salmon harvest from 1984–1991 of about 600 tonnes y^{-1}, salmon returns to rivers were clearly expected to increase even in the absence of any change in the overall productivity of individual stocks. Whilst traditional approaches to estimating marine exploitation rates of North American or European Atlantic salmon populations have usually involved tagging studies (Chadwick, 1993; Potter and Dunkley, 1993), they have also had to

Table 3. Results of simulations showing the effect on marine exploitation (ME) rates calculated from total returns where assumptions of consistent smolt production and natural survival between the pre-moratorium (Period one) and moratorium (Period two) were altered.

Case	Assumptions		Effect on marine exploitation rate calculated from total returns
	Smolt production	Natural survival	
1	Consistent in both periods	Consistent in both periods	Unbiased
2	Consistent in both periods	Lower in Period two	ME underestimated
3	Consistent in both periods	Higher in Period two	ME overestimated
4	Lower in Period two	Consistent in both periods	ME underestimated
5	Higher in Period two	Consistent in both periods	ME overestimated
6	Higher in Period two	Lower in Period two	ME underestimated
7	Lower in Period two	Lower in Period two	ME underestimated
8	Lower in Period two	Higher in Period two	ME underestimated
9	Higher in Period two	Higher in Period two	ME overestimated

account for problems associated with tag loss, handling and tagging mortality, tag reporting rates, and mixed stock fisheries, to name a few. The approach illustrated here was not dependent upon these considerations but was restricted to those situations in which total returns of salmon to rivers increased coincident with the closure of the commercial fishery.

Estimates of marine exploitation obtained in our study were consistent with many others, based on tagging, that indicated higher exploitation rates on the large salmon component (Table 2). The differential rates of exploitation are likely related to a number of factors including selectivity of fishing gear, run timing of the respective small and large salmon size components in the fishery, and individual fishing preferences related to directed effort. Reddin (1986) has shown that one-sea-winter (1SW) salmon are more highly selected in smaller mesh 114-mm gillnets than in larger sized gear (150 and 154-mm mesh), whereas 2SW salmon were equally vulnerable in all gear sizes studied. Use of 114-mm mesh gillnets was permitted only in SFA 10, and parts of SFAs 9, 11 and 13 (Bay of St George) on the south and south west coasts of Newfoundland (Figure 2) (Reddin, 1986). Thus, more widespread use of larger mesh gear among other SFAs could account for part of the difference in exploitation rates between small and large salmon, but does not by itself explain why the estimated median exploitation rate for small salmon at Northeast River (Placentia) in SFA 10, was generally consistent with other rivers (Table 2) rather than being somewhat higher.

With respect to timing, small salmon were found to move into an area and be caught later in the season than large salmon (O'Connell *et al*., 1992a). After targeting large salmon earlier in the fishing season, some fishers could switch to other species during the period when availability of small salmon increases. Also, logbook surveys of commercial salmon fishers indicated that because large salmon commanded a higher market price than small salmon, greater effort was often directed at the larger size component (O'Connell *et al*., 1992a).

Exploitation rates varied among rivers, with the highest rates for small salmon in SFAs 4, 13, and 14A, whilst large salmon exploitation rates were highest in SFAs 4, 5, and 14A (Table 2). The commercial harvest of salmon from 1984–1991 was also greatest along the east and northeast coasts of Newfoundland (SFAs 3–5) (Figure 1) and could, in part, account for differences in exploitation rates among SFAs.

Exploitation rates for small salmon were on average generally lower, but comparable with previous values estimated or assumed for Newfoundland stocks, while higher than those for 1SW salmon reported for New Brunswick and Nova Scotia (Table 4). For example, Pippy (1982) assumed rates of 55% and 85% for small and large salmon, respectively, in an evaluation of the extent of interception of non-Newfoundland origin Atlantic salmon in the Newfoundland commercial fishery. Exploitation rates on 1SW salmon from several New Brunswick and Nova Scotian stocks were less than 40% (Table 4). However, exploitation rates on 1SW or small salmon from North American populations were lower than rates estimated for 1SW salmon for various European stocks (Table 4).

With respect to large salmon, estimates of average marine exploitation derived here for 1984–1991 were lower than several earlier Newfoundland investigations and those obtained for 2SW or MSW salmon from New Brunswick and Nova Scotia when homewater commercial salmon fisheries still existed in the latter two areas prior to closure of fisheries in 1984 (Table 4). Given the decrease in directed effort coincident with the 1984 Newfoundland salmon management plan (O'Connell *et al*., 1992a) and corresponding decline in landings in the Newfoundland salmon fishery from approximately 1022 tonnes y^{-1} from 1974–1983 (O'Connell *et al*., 1983) to an average harvest of about 600 tonnes y^{-1} from 1984–1991, the lower exploitation rates in the

Table 4. Marine exploitation rates estimated for various Atlantic salmon stocks in North America and Europe. W=Wild; H=Hatchery origin.

Location	River	Life stage or size group	Stock	Exploitation rate (%)	Reference
North America					
Newfoundland	Little Codroy River	1SW	W	47	Murray (1968)
		2SW	W	75	Murray (1968)
	Western Arm Brook	1SW	W	62	Reddin (1981)
	Western Arm Brook	1SW	W	65	Chadwick *et al.* (1985)
	Newfoundland	Small	W	55	Pippy (1982)
		Large	W	85	Pippy (1982)
Labrador	Sand Hill River	1SW	W	33	Peet and Pratt (1972)
		2SW	W	90	Peet and Pratt (1972)
	Sand Hill River	1SW	W	36	Reddin (1981)
		2SW	W	92	Reddin (1981)
New Brunswick	Northwest Miramichi River	1SW	W	32	Saunders (1969)
		MSW	W	87	Saunders (1969)
	Northwest Miramichi River	1SW	W	34	Kerswill (1971)
		MSW	W	78	Kerswill (1971)
	Southwest Miramichi River	1SW	W	36	Kerswill (1971)
		MSW	W	92	Kerswill (1971)
Nova Scotia	Liscomb River	1SW	H	36	Semple and Cameron (1990)
		MSW	H	79	Semple and Cameron (1990)
Europe					
Northern Ireland	River Bush	1SW	H	46–95	Crozier and Kennedy (1994)
		1SW	W	62–89	Crozier and Kennedy (1994)
		2SW	H/W	36–60	Crozier and Kennedy (1994)
	River Burrishoole	1SW	H	52–90	Cited in Crozier and Kennedy (1994)
	River Erne	1SW	H	54–64	Cited in Crozier and Kennedy (1994)
Norway	River Imsa[1]	1SW	H/W	66–99	Hansen (1988)
		2SW	H/W	86–100	Hansen (1988)
	River Drammenselv[1]	1SW	H	37–81	Hansen (1990)
		2SW	H	22–70	Hansen (1990)
Iceland	Haukadalsá[2]	MSW	W	16	Scarnecchia *et al.* (1989)
	Laxá í Leirársveit[2]	MSW	W	48	Scarnecchia *et al.* (1989)
	Laxá í Kjós[2]	MSW	W	29	Scarnecchia *et al.* (1989)
	Thverá[2]	MSW	W	21	Scarnecchia *et al.* (1989)
	Nordurá[2]	MSW	W	28	Scarnecchia *et al.* (1989)
	Laxá í Dölum[2]	MSW	W	27	Scarnecchia *et al.* (1989)
	Fáskrúd[2]	MSW	W	28	Scarnecchia *et al.* (1989)

[1]Exploitation in Norwegian home waters from different tag reporting rates.
[2]Average exploitation at West Greenland required to account for differences in observed grilse:salmon ratios.

current study are not inconsistent. With the exception of Iceland, where there is no directed coastal commercial salmon fishery (Scarnecchia *et al.*, 1989), our estimates of large salmon exploitation were also generally within the range of values calculated for several Northern Ireland and Norwegian salmon populations (Table 4). This illustrates that for some stocks, the large salmon (or MSW) component has been subject to exceedingly high rates of exploitation in marine fisheries, reaching over 90% in some cases (Tables 2 and 4).

Deriving estimates of marine exploitation rates using actual counts of salmon returning to rivers represents an alternate means by which these data can be derived in the absence of tagging studies, and where accurate salmon abundance data exist prior to and following an abrupt termination of a directed commercial fishery. This method allowed us to obtain estimates for nine Newfoundland salmon stocks, separately for large and small salmon size components. The approach, however, is still subject to some limitations. For example, estimates of negative exploitation rates would occur unless the average total returns during the moratorium years were higher than in the pre-moratorium period. Note that in some tagging experiments with poor data, negative capture probabilities can be generated, and hence, negative estimates of stock size (e.g. in the Darroch or Stratified-Petersen models as outlined in Schwarz and Taylor, 1998). Similarly, the Jolly-Seber models can produce negative recruitment estimates (Schwarz *et al.*, 1993, Section 3.4). Yet, in either of these cases, it would not mean that Darroch or Jolly-Seber models were flawed and could not not be applied in other situations where sufficient data exists. With the current method, if the annual variation in natural survival was different between the 1984–1991 pre-moratorium years and the 1992–1996 moratorium period, then the estimated rates of marine exploitation could be biased as indicated by the results of the simple simulations summarized in Table 3. Similarly, these rates could be biased if salmon lost to illegal (poaching) fisheries at sea changed between the two periods. Evidence obtained to date, however, suggests that natural marine survival of salmon since 1992 has either declined or remained consistent relative to earlier years whilst the average production of smolts that gave rise to 1SW adult salmon returns from 1992–1996 has also fallen in the Newfoundland rivers for which these data are available (Dempson *et al.*, 1998). Consequently, marine exploitation rates estimated here probably reflect minimum values. The same would hold if illegal removals of salmon in the marine environment increased with the closure of the commercial salmon fishery, although there are no reliable data from which to suggest this has occurred. During the 1992–1996 period, some Newfoundland salmon could still have been harvested in commercial fisheries operating in Labrador, the Quebec North Shore, and a very small fishery at St Pierre et Miquelon. Any losses in these fisheries would similarly have reduced the potential numbers of salmon returning to their respective rivers and also contributed to underestimating the average marine exploitation rates.

The approach used in this paper is not appropriate for deriving marine exploitation rates for any specific year, as it was based on average returns from two separate time periods. However, by applying the observed range in actual salmon returns from each of the pre-moratorium and moratorium periods in the simulations, the resulting 5th and 95th percentiles of the sampling distribution of the estimated exploitation rates should adequately encompass the likely range of the mean exploitation rate. Using this method, salmon return data or estimates of marine survival can then be corrected or adjusted for those years prior to the closure of the Newfoundland commercial salmon fishery and a more accurate evaluation of trends in salmon abundance or survival can be obtained. For example, Figure 3 illustrates the trend in returns of small salmon to Middle Brook, Newfoundland, including returns adjusted for the mean marine exploitation during the 1984–1991 period. In this case, the salmon returns adjusted for the mean marine exploitation suggest that the total population size is actually rather similar between the two time periods even though returns to the river itself increased coincident with the commercial salmon fishery moratorium.

Earlier it was noted that returns of small salmon to Biscay Bay River, Conne River, and Northeast Brook (Trepassey) (Figure 2) during the moratorium were lower on average than returns in years prior to the

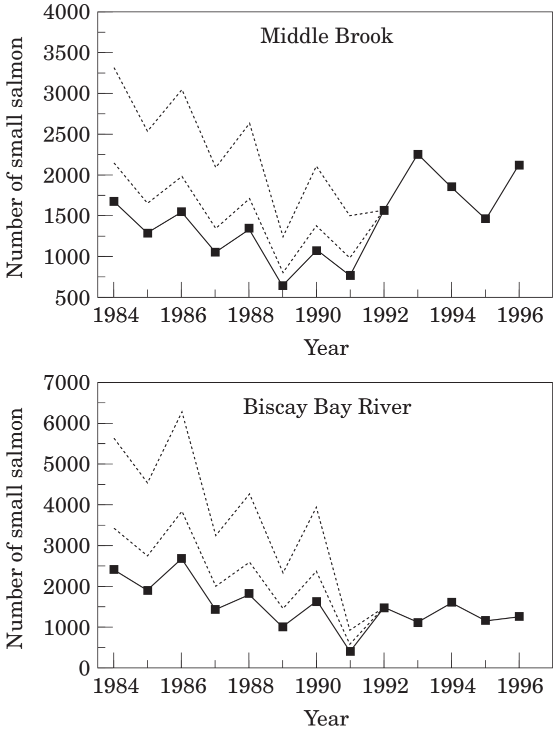

Figure 3. Total returns of small sized Atlantic salmon (solid bold line) to Middle Brook and Biscay Bay River, Newfoundland. For Middle Brook, the broken lines represent the return data adjusted for the mean marine exploitation using the 5th and 95th percentiles of the sampling distribution of the estimated exploitation rates estimated for this river. For Biscay Bay River, dashed lines represent salmon return data adjusted using the 5th and 95th percentiles of the sampling distribution of the mean exploitation rates from the average of all rivers combined.

closure of the commercial salmon fishery. Whilst this result was unexpected, specific reasons to account for this have not been identified (Dempson *et al.*, 1998). In any event, river-specific marine exploitation rates could not be determined for these populations. However, in the unlikely event that these stocks were not subject to any marine exploitation, then salmon populations in these rivers declined from 55% to 21% during the moratorium. As a second example, we applied the overall 5th and 95th percentiles of the sampling distribution of the mean marine exploitation rates for all other rivers combined (29.6% and 57.1%; Table 2) to returns of small salmon to Biscay Bay River (Figure 3). Assuming that these exploitation rates are appropriate, then as observed in Figure 3, the average salmon returns during the moratorium have more likely declined from 66% to 45%. Similar results would apply if adjustments were made to the other two rivers noted above and highlight the argument by Crozier and Kennedy (1994, 1999) that accounting for marine exploitation is necessary in examining total life cycle variation in salmon survival and return data. Thus, it is still important to have reliable estimates even when commercial fisheries are, for the most part, now closed.

The approach to derive estimates of marine exploitation rates in this paper was dependent upon accurate information on salmon returns to rivers. These data form a fundamental component of understanding the dynamics of salmon populations and their importance cannot be underestimated (see Chadwick, 1985; Chadwick, M., 1995). Whilst major management changes have now either eliminated, or greatly reduced marine fisheries for salmon in the northwest Atlantic ocean, conservation problems still exist and factors other than overfishing at sea could be responsible (Dempson *et al*., 1998; Parrish *et al*., 1998; Walters and Ward, 1998; Fairchild *et al*., 1999). With angling exploitation rates in some European and North American salmon rivers assumed or estimated to be 25%–50% (Gudjónsson, 1998; Hansen, 1990; Moore *et al*., 1995; Porter *et al*., 1995; Erkinaro *et al*., 1999), these rates approximate those derived for marine exploitation on small or 1SW salmon when marine fisheries existed. Consequently, the importance of fish counting facilities cannot be underestimated in providing the basic data required to better understand, manage and conserve salmon populations.

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