10 NORTH ATLANTIC SALMON STOCKS

10.1 Introduction

10.1.1 Main tasks

At its 2015 Statutory Meeting, ICES resolved (C. Res. 2015/2/ACOM10) that the Working Group on North Atlantic Salmon [WGNAS] (chaired by Jonathan White, Ireland) would meet at ICES HQ, 30 March–8 April 2016 to consider questions posed to ICES by the North Atlantic Salmon Conservation Organization (NASCO).

The sections of the report which provide the responses to the terms of reference are identified below.

Question		Section
1	With respect to Atlantic salmon in the North Atlantic area:	10.1
1.1	provide an overview of salmon catches and landings by country, including unreported catches and catch and release, and production of farmed and ranched Atlantic salmon in 2015[1];	10.1.5
1.2	report on significant new or emerging threats to, or opportunities for, salmon conservation and management[2];	10.1.6
1.3	provide a review of examples of successes and failures in wild salmon restoration and rehabilitation and develop a classification of activities which could be recommended under various conditions or threats to the persistence of populations[3];	10.1.7
1.4	advise on possible effects of salmonid aquaculture on wild Atlantic salmon populations focusing on the effects of sea lice, genetic interactions and the impact on wild salmon production[4];	10.1.8
1.5	provide a time series of numbers of river stocks with established CLs and trends in numbers of stocks meeting their CLs by jurisdiction;	10.1.9
1.6	provide a compilation of tag releases by country in 2015; and	10.1.10
1.7	identify relevant data deficiencies, monitoring needs and research requirements.	10.1.12
2	With respect to Atlantic salmon in the North-East Atlantic Commission area:	10.2
2.1	describe the key events of the 2015 fisheries[5];	10.2.2
2.2	review and report on the development of age-specific stock conservation limits;	10.2.3
2.3	describe the status of the stocks;	10.2.4
2.4	advise on the source of uncertainties and possible biases in the assessment of catch options for the Faroes fishery resulting from the use of samples and data collected in the fishery in the 1980s and 90s. Should it be considered that biases are likely to compromise the catch advice, advise on any new sampling which would be required to improve these assessments;	10.2.5
	In the event that NASCO informs ICES that the Framework of Indicators (FWI) indicates that reassessment is required:*	
2.5	provide catch options or alternative management advice for 2016/17-2018/19 fishing seasons, with an assessment of risks relative to the objective of exceeding stock conservation limits, or pre-defined NASCO Management Objectives, and advise on the implications of these options for stock rebuilding[6]; and	10.2.6
2.6	update the Framework of Indicators used to identify any significant change in the previously provided multi-annual management advice.	10.2.7
3	With respect to Atlantic salmon in the North American Commission area:	10.3
3.1	describe the key events of the 2015 fisheries (including the fishery at St Pierre and Miquelon)[5];	10.3.2
3.2	update age-specific stock conservation limits based on new information as available;	10.3.3
3.3	describe the status of the stocks;	10.3.4
	In the event that NASCO informs ICES that the Framework of Indicators (FWI) indicates that reassessment is required:*	
3.4	provide catch options or alternative management advice for 2016-2019 with an assessment of risks relative to the objective of exceeding stock conservation limits, or pre-defined NASCO Management Objectives, and advise on the implications of these options for stock rebuilding[6]; and	NA[†]
3.5	update the Framework of Indicators used to identify any significant change in the previously provided multi-annual management advice.	NA[†]
4	With respect to Atlantic salmon in the West Greenland Commission area:	10.4
4.1	describe the key events of the 2015 fisheries[5];	10.4.2
4.2	describe the status of the stocks[7];	10.4.3
4.3	compare contemporary indices of abundance of salmon in the West Greenland fishery to historical estimates and suggest options for improving future estimates;	10.4.4
4.4	estimate the effects of modifying the timing of the West Greenland salmon fishery, including altering the start date, with regard to harvest and exploitation of contributing stocks;	10.4.5

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4.5	advise on changes to temporal and/or spatial fishery patterns that may provide increased protection for weaker stocks;	10.4.6
	In the event that NASCO informs ICES that the Framework of Indicators (FWI) indicates that reassessment is required:	
4.6	provide catch options or alternative management advice for 2016 - 2019 with an assessment of risk relative to the objective of exceeding stock conservation limits, or pre-defined NASCO Management Objectives, and advise on the implications of these options for stock rebuilding[6]; and	NA†
4.7	update the Framework of Indicators used to identify any significant change in the previously provided multi-annual management advice.	NA†

Notes:

* NASCO informed ICES in January 2015 of the outcome of utilizing the FWI.

1. With regard to question 1.1, for the estimates of unreported catch the information provided should, where possible, indicate the location of the unreported catch in the following categories: in-river; estuarine; and coastal. Numbers of salmon caught and released in recreational fisheries should be provided.
2. With regard to question 1.2, ICES is requested to include reports on any significant advances in understanding of the biology of Atlantic salmon that is pertinent to NASCO, including information on any new research into the migration and distribution of salmon at sea and the potential implications of climate change for salmon management.
3. With regards to question 1.3, NASCO is particularly interested in case studies highlighting successes and failures of various restoration efforts employed across the North Atlantic by all Parties/jurisdictions and the metrics used for evaluating success or failure.
4. In response to question 1.4, ICES is requested to review and update the findings of the ICES/NASCO symposium on the impacts of aquaculture and the request for advice from OSPAR in June 2010.
5. In the responses to questions 2.1, 3.1 and 4.1, ICES is asked to provide details of catch, gear, effort, composition and origin of the catch and rates of exploitation. For home-water fisheries, the information provided should indicate the location of the catch in the following categories: in-river; estuarine; and coastal. Information on any other sources of fishing mortality for salmon is also requested. For 4.1 ICES should review the results of the recent phone surveys and advise on the appropriateness for incorporating resulting estimates of unreported catch into the assessment process.
6. In response to questions 2.5, 3.4 and 4.6, provide a detailed explanation and critical examination of any changes to the models used to provide catch advice and report on any developments in relation to incorporating environmental variables in these models.
7. In response to question 4.2, ICES is requested to provide a brief summary of the status of North American and North-East Atlantic salmon stocks. The detailed information on the status of these stocks should be provided in response to questions 2.3 and 3.3.

NA†: With regard to questions 3.4 and 3.5, 4.6 and 4.7, the FWI did not indicate that reassessment was required and so these questions were not posed.

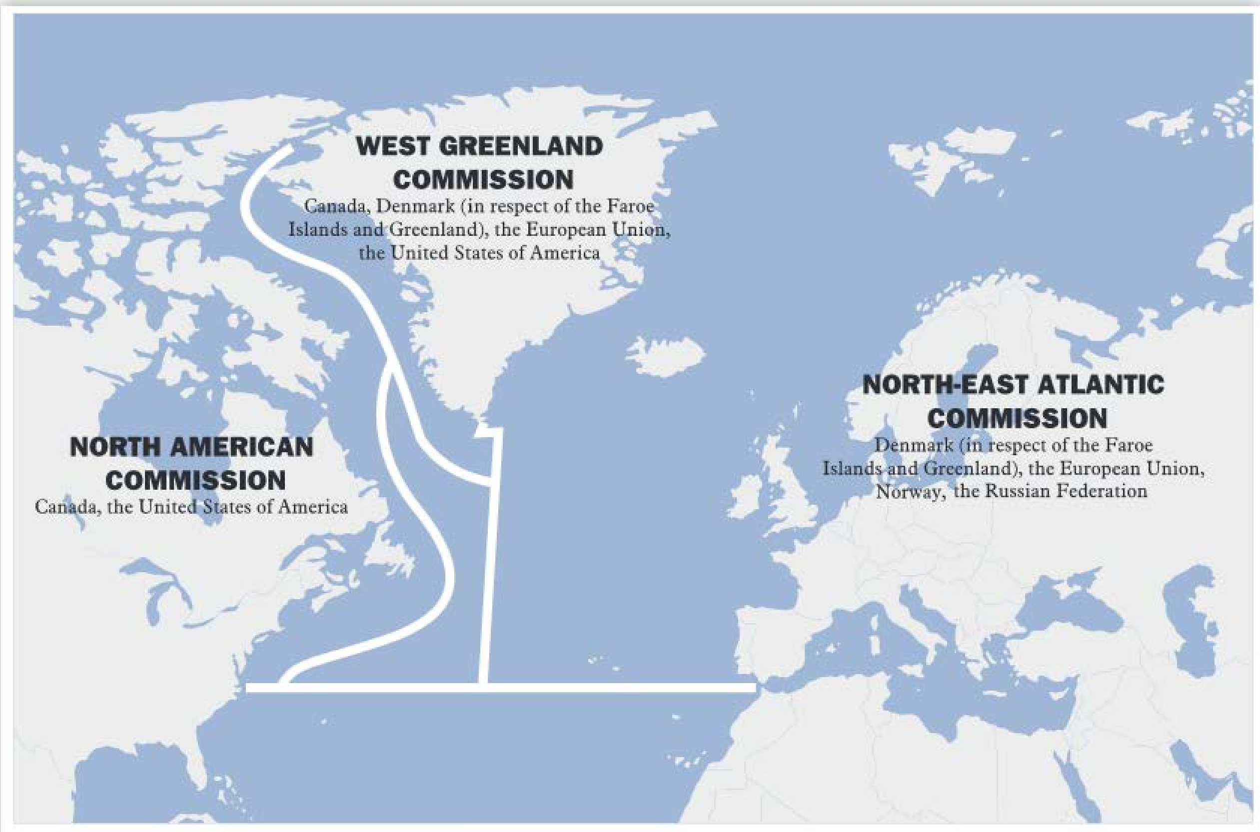
In response to the terms of reference, the working group considered 37 working documents. A complete list of acronyms and abbreviations used in this report is provided in Annex 1. References cited are given in Annex 2.

Please note that for practical reasons the tables are found at the end, immediately before the annexes.

10.1.2 Management framework for salmon in the North Atlantic

The advice generated by ICES is in response to terms of reference posed by the North Atlantic Salmon Conservation Organization (NASCO), pursuant to its role in international management of salmon. NASCO was set up in 1984 by international convention (the Convention for the Conservation of Salmon in the North Atlantic Ocean), with a responsibility for the conservation, restoration, enhancement, and rational management of wild salmon in the North Atlantic. Although sovereign states retain their role in the regulation of salmon fisheries for salmon originating in their own rivers, distant-water salmon fisheries, such as those at Greenland and Faroes, which take salmon originating in rivers of another Party, are regulated by NASCO under the terms of the Convention. NASCO now has six Parties that are signatories to the Convention, including the EU which represents its Member States.

NASCO's three Commission areas, the North American Commission (NAC), the West Greenland Commission (WGC), and the North-East Atlantic Commission (NEAC) are shown below. The mid-Atlantic area is not covered by any of the three NASCO Commissions but, under Article 4 of the NASCO Convention, NASCO provides a forum for consultation and cooperation on matters concerning the salmon stocks in this area.



10.1.3 Management objectives

NASCO has identified the primary management objective of that organization as:

"To contribute through consultation and co-operation to the conservation, restoration, enhancement and rational management of salmon stocks taking into account the best scientific advice available".

NASCO further stated that "the Agreement on the Adoption of a Precautionary Approach states that an objective for the management of salmon fisheries is to provide the diversity and abundance of salmon stocks", and NASCO's Standing Committee on the Precautionary Approach interpreted this as being "to maintain both the productive capacity and diversity of salmon stocks" (NASCO, 1998).

NASCO's Action Plan for Application of the Precautionary Approach (NASCO, 1998) provides an interpretation of how this is to be achieved:

- "Management measures should be aimed at maintaining all stocks above their conservation limits by the use of management targets".
- "Socio-economic factors could be taken into account in applying the precautionary approach to fisheries management issues".
- "The precautionary approach is an integrated approach that requires, *inter alia*, that stock rebuilding programmes (including as appropriate, habitat improvements, stock enhancement, and fishery management actions) be developed for stocks that are below conservation limits".

10.1.4 Reference points and application of precaution

Atlantic salmon has characteristics of short-lived fish stocks; mature abundance is sensitive to annual recruitment because there are only a few age groups in the adult spawning stock. Incoming recruitment is often the main component of the fishable stock. For such fish stocks, the ICES maximum sustainable yield (MSY) approach is aimed at achieving a target escapement (MSY $B_{escapement}$, the amount of biomass left to spawn). No catch should be allowed unless this escapement can be achieved. The escapement level should be set so there is a low risk of future recruitment being impaired.

ICES considers that to be consistent with the MSY and the precautionary approach, fisheries should only take place on salmon from rivers where stocks have been shown to be at full reproductive capacity. Furthermore, due to differences in status of individual stocks within stock complexes, mixed-stock fisheries present particular threats.

Conservation limits (CLs) for North Atlantic salmon stock complexes have been defined by ICES as the level of stock (number of spawners) that will achieve long-term average maximum sustainable yield. In many regions of North America, the CLs are calculated as the number of spawners required to fully seed the wetted area of the rivers. The definition of conservation in Canada varies by region and in some areas, historically, the values used were equivalent to maximizing / optimizing freshwater production. These are used in Canada as limit reference points and they do not correspond to MSY values. Reference points for Atlantic salmon are currently being reviewed for conformity with the Precautionary Approach policy in Canada and revised reference points are expected to be developed. In some regions of Europe, pseudo stock–recruitment observations are used to calculate a hockey-stick relationship, with the inflection point defining the national CLs. In the remaining regions, the CLs are calculated as the number of spawners that will achieve long-term average MSY, as derived from the adult-to-adult stock and recruitment relationship (Ricker, 1975; ICES, 1993). NASCO has adopted the region-specific CLs (NASCO, 1998). These CLs are limit reference points (S_{lim}); having populations fall below these limits should be avoided with high probability.

Management targets have not yet been defined for all North Atlantic salmon stocks. When these have been defined they will play an important role in ICES advice.

Where there are no specific management objectives for the assessment of the status of stocks and advice on management of national components and geographical groupings of the stock complexes in the NEAC area, the following shall apply:

- ICES considers that if the lower bound of the 90% confidence interval of the current estimate of spawners is above the CL, then the stock is at full reproductive capacity (equivalent to a probability of at least 95% of meeting the CL).
- When the lower bound of the confidence interval is below the CL, but the midpoint is above, then ICES considers the stock to be at risk of suffering reduced reproductive capacity.
- Finally, when the midpoint is below the CL, ICES considers the stock to suffer reduced reproductive capacity.

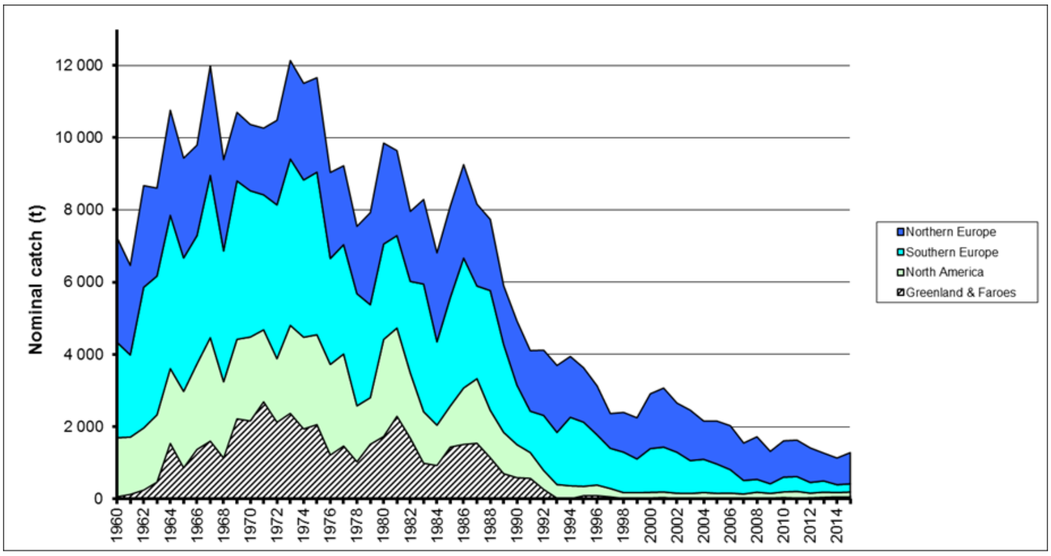
For catch advice on the mixed-stock fishery at West Greenland (catching non-maturing one-sea-winter (1SW) fish from North America and non-maturing 1SW fish from Southern NEAC), NASCO has adopted a risk level (probability) of 75% of simultaneous attainment of management objectives in seven geographic regions (ICES, 2003) as part of an agreed management plan. NASCO uses the same approach for catch advice for the mixed-stock fishery affecting six geographic regions for the North American stock complex. ICES notes that the choice of a 75% risk (probability) for simultaneous attainment of six or seven stock units is approximately equivalent to a 95% probability of attainment for each individual unit (ICES, 2013).

There is no formally agreed management plan for the fishery at Faroes. However, ICES has developed a risk-based framework for providing catch advice for fish exploited in this fishery (mainly multi-sea-winter (MSW) fish from NEAC countries). Catch advice is provided at both the stock complex and country level and catch options tables provide the probability of meeting CLs in the individual stock complexes or countries, and in all the stock complexes or countries simultaneously. ICES has recommended (ICES, 2013) that management decisions should be based principally on a 95% probability of attainment of CLs in each stock complex / country individually. The simultaneous attainment probability may also be used as a guide, but managers should be aware that this will generally be quite low when large numbers of management units are used.

10.1.5 Catches of North Atlantic salmon

10.1.5.1 Nominal catches of salmon

Figure 10.1.5.1 displays reported total nominal catch of salmon in four North Atlantic regions from 1960 to 2015. Nominal catches reported by country are given in Table 10.1.5.1. Catch statistics in the North Atlantic include fish farm escapees, and in some Northeast Atlantic countries also ranched fish.



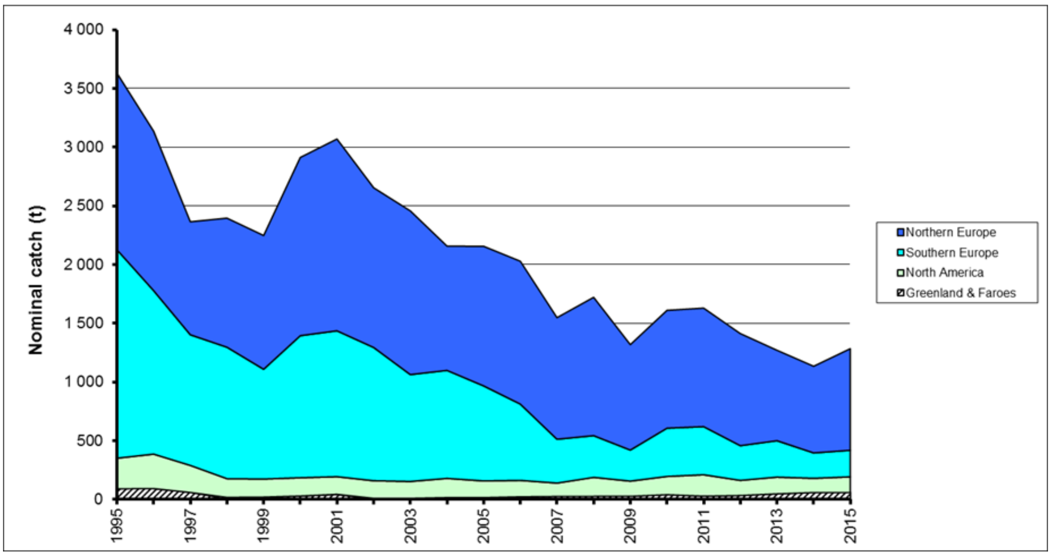


Figure 10.1.5.1 Total reported nominal catch of salmon (tonnes round fresh weight) in four North Atlantic regions, 1960–2015 (top) and 1995–2015 (bottom).

Icelandic catches have traditionally been split into two separate categories, wild and ranched, reflecting the fact that Iceland has been the main North Atlantic country where large-scale ranching has been undertaken, with the specific intention of harvesting all returns at the release site and with no prospect of wild spawning success. The release of smolts for commercial ranching purposes ceased in Iceland in 1998, but ranching for rod fisheries in two Icelandic rivers continued into 2015 (Table 10.1.5.1). Catches in Sweden are also split between wild and ranched categories over the entire time-series. The latter fish represent adult salmon which have originated from hatchery-reared smolts and which have been released under programmes to mitigate for hydropower development schemes. These fish are also exploited very heavily in home waters and have no possibility of spawning naturally in the wild. While ranching does occur in some other countries, this is on a much smaller scale. Some of these operations are experimental and at others harvesting does not occur solely at the release site. The ranched component in these countries has therefore been included in the nominal catch.

Reported catches in tonnes for the three NASCO commission areas for 2006–2015 are provided below.

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
NEAC	1866	1409	1533	1162	1414	1419	1250	1080	954	1091
NAC	140	114	162	129	156	182	129	143	122	137
WGC	22	25	26	26	40	28	33	47	58	57
Total	2028	1548	1721	1318	1610	1629	1412	1270	1134	1285

The provisional total nominal catch for 2015 was 1285 t, 151 t up on the updated catch for 2014 (1134 t). The 2014 catch was the lowest in the time-series, with the previous year (2013) being the next lowest in the time-series, followed by the catch in 2015. Catches were below the previous five- and ten-year averages in the majority of countries, except France and Greenland.

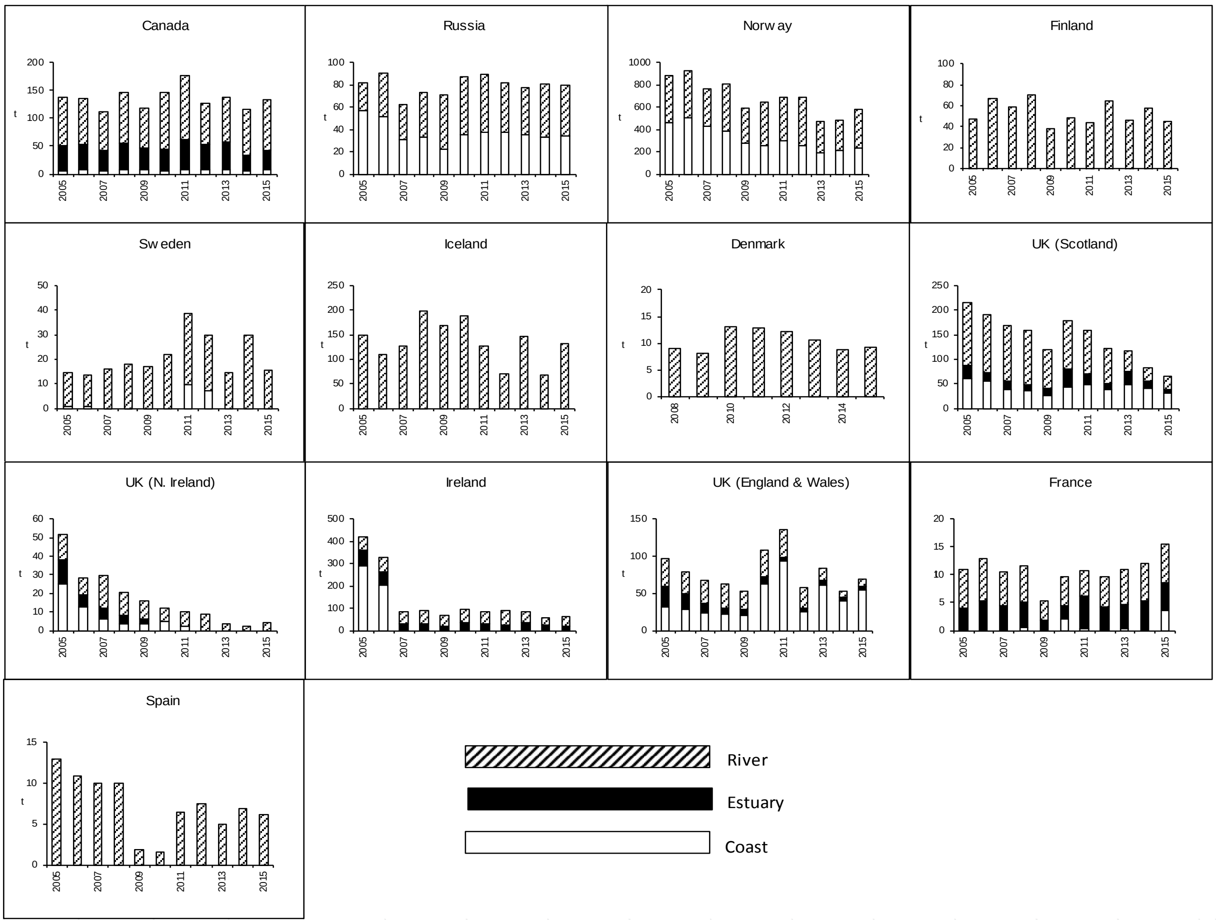


Figure 10.1.5.2 Nominal catch (t) by country taken in coastal, estuarine, and riverine fisheries, 2005–2015 (except Denmark: 2008–2015). Note that the *y*-axes scales vary.

ICES considers that mixed-stock fisheries present particular threats to stock status. These fisheries predominantly operate in coastal areas and NASCO specifically requests that the nominal catches in home-water fisheries be partitioned according to whether the catch is taken in coastal, estuarine, or riverine areas. The 2015 nominal catch (in tonnes) was partitioned accordingly and is shown below for the NEAC and NAC Commission Areas. Figure 10.1.5.2 and Table 10.1.5.2 present these data on a country-by-country basis. There is considerable variability in the distribution of the catch among individual countries. In most countries the majority of the catch is now taken in freshwater, and across the time-series the coastal catch has declined markedly. However, nominal catches in freshwater have also declined in many countries as a result of increasing use of catch-and-release in rod fisheries.

AREA	COAST		ESTUARY		RIVER		TOTAL
	Weight	%	Weight	%	Weight	%	Weight
NEAC 2015	356	33	40	4	695	64	1091
NAC 2015	12	9	35	25	91	66	137

Coastal, estuarine, and riverine catch data aggregated by region are presented in Figure 10.1.5.3 and Table 10.1.5.2. In Northern NEAC, a steadily decreasing proportion and weight of the nominal catch has been taken in coastal regions (from 44% to 31% and 522 t to 267 t, in 2005 and 2015 respectively), noting that there are no coastal fisheries in Iceland and Finland, that in-river catch has stayed fairly consistent over this time period, and that estuarine catches represent a negligible component of the catch in this area. In Southern NEAC, catches in all fishery areas have declined dramatically since 2005. While coastal fisheries historically made up the largest component of the catch, these fisheries have declined the most, reflecting widespread measures to reduce exploitation in a number of countries. Since 2007, the majority of the catch in this area has been taken in freshwater. In NAC, the total catch over the period 2005–2015 has been fluctuating around 140 t. The majority of the catch in this area has been taken in riverine fisheries; the catch in coastal fisheries has been relatively small in any year (13 t or less).

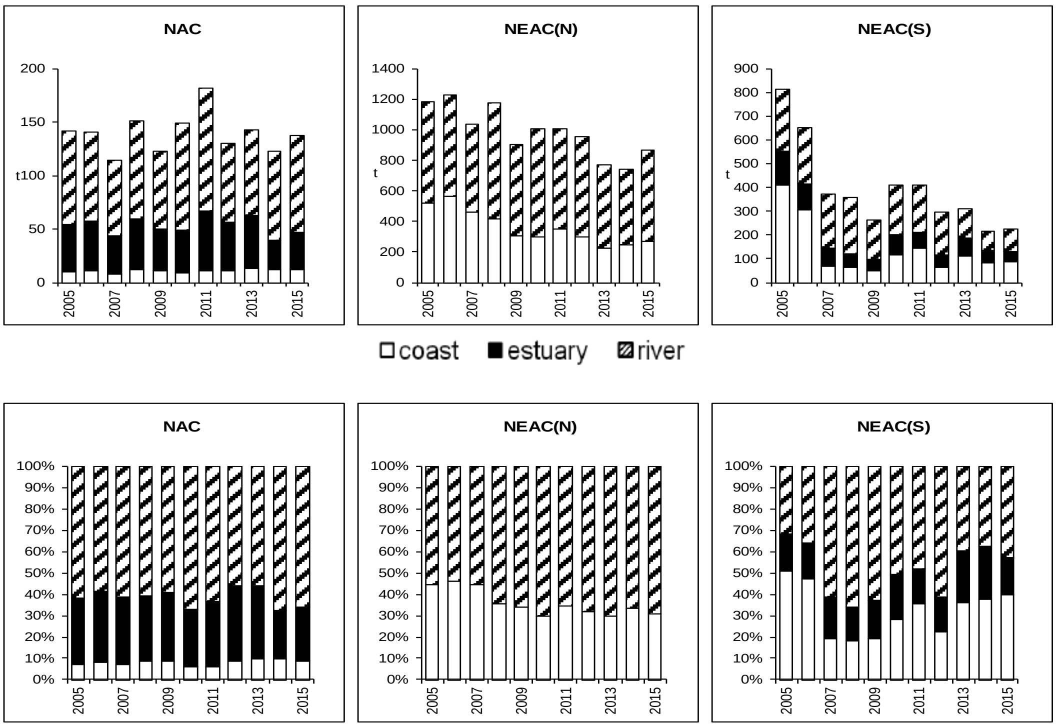


Figure 10.1.5.3 Percentages of nominal catch (top panel) and nominal catch in tonnes (bottom panel) taken in coastal, estuarine, and riverine fisheries for the NAC area, and for the Northern and Southern NEAC areas, 2005–2015. Note that scales of vertical axes vary across bottom panels.

10.1.5.2 Unreported catches

The total unreported catch in NASCO areas in 2015 was estimated to be 325 t. There was no estimate for Russia, or for Spain and St. Pierre and Miquelon, although reported catches in the latter two areas are small. The unreported catch in the NEAC area in 2015 was estimated at 298 t, and that for the West Greenland and North American commission areas at 10 t and 17 t, respectively. The following table shows unreported catch by NASCO commission areas in the last ten years:

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
NEAC	604	465	433	317	357	382	363	272	256	298
NAC	56	-	-	16	26	29	31	24	21	17
WGC	10	10	10	10	10	10	10	10	10	10
Total	670	475	443	343	393	421	403	306	287	325

The 2015 unreported catch by country is provided in Table 10.1.5.3. It has not been possible to separate the unreported catch into that taken in coastal, estuarine, and riverine areas. Over recent years efforts have been made to reduce the level of unreported catch in a number of countries (e.g. through improved reporting procedures and the introduction of carcass tagging and logbook schemes).

10.1.5.3 Catch-and-release

The practice of catch-and-release (C&R) in rod fisheries has become increasingly common as a salmon management/conservation measure in light of the widespread decline in salmon abundance in the North Atlantic. In some areas of Canada and USA, C&R has been practised since 1984, and in more recent years it has also been widely used in many European countries, both as a result of statutory regulation and through voluntary practice.

The nominal catches do not include salmon that have been caught and released. Table 10.1.5.4 presents C&R information from 1991 to 2015 for countries that have records; C&R may also be practised in other countries while not being formally recorded. There are large differences in the percentage of the total rod catch that is released: in 2015 this ranged from 19% in Norway (this is a minimum figure, as statistics were collected on a voluntary basis) to 84% in UK (Scotland), reflecting varying management practices and angler attitudes among countries. C&R rates were typically high in Russia, averaging 81% over the 17-year period 1992 to 2008; however, records since then are incomplete. Within countries, the percentage of fish released has tended to increase over time. There is also evidence from some countries that larger MSW fish are released in higher proportions than smaller fish. Overall, more than 195 000 salmon were reported to have been caught-and-released around the North Atlantic in 2015.

10.1.5.4 Farming and sea ranching of Atlantic salmon

The provisional estimate of farmed Atlantic salmon production in the North Atlantic area for 2015 was more than 1648 kt. The production of farmed salmon in this area has been over one million tonnes since 2009. The 2015 total represents a 1% increase on 2014, and a 15% increase on the previous five-year mean. Norway and UK (Scotland) continue to produce the majority of the farmed salmon in the North Atlantic (80% and 11%, respectively). Farmed salmon production in 2015 was above the previous five-year averages in all North Atlantic salmon producing countries except Canada and Russia.

Worldwide production of farmed Atlantic salmon has been in excess of one million tonnes since 2001 and has been over two million tonnes since 2012. The total worldwide production in 2015 is provisionally estimated at around 2374 kt (Figure 10.1.5.4), a 0.7% increase on 2014. Production outside the North Atlantic is estimated to have accounted for 31% of the total in 2015. Production outside the North Atlantic is dominated by Chile.

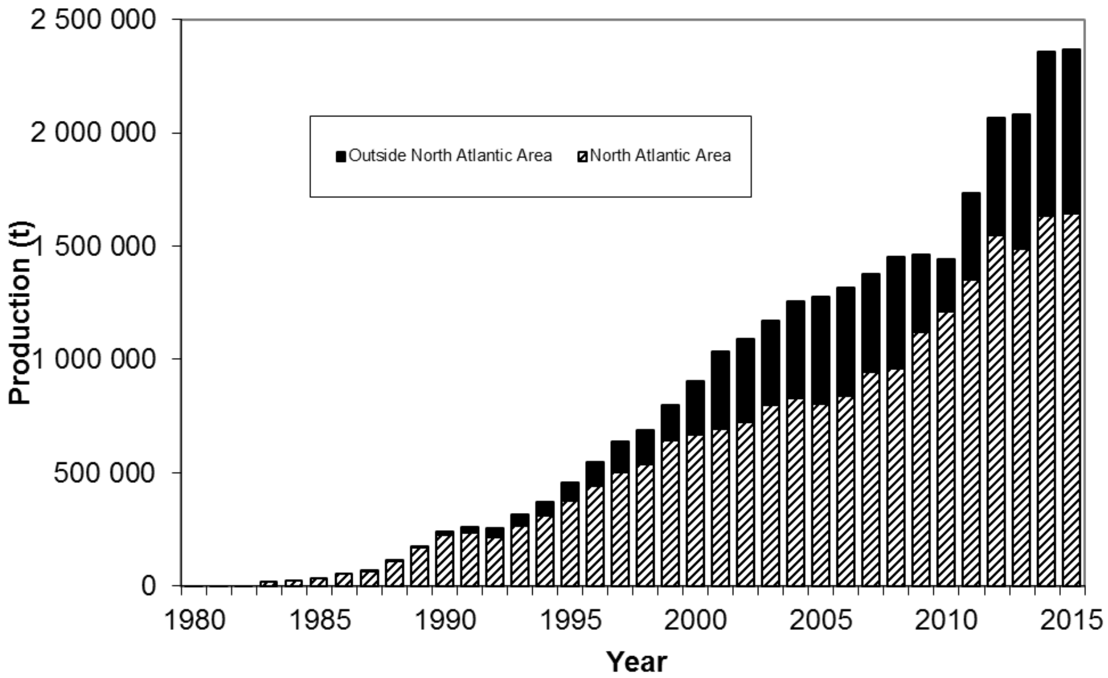


Figure 10.1.5.4 Worldwide production of farmed Atlantic salmon, 1980 to 2015.

The reported nominal catch of Atlantic salmon in the North Atlantic was in the order of 0.05% of the worldwide production of farmed Atlantic salmon in 2015.

The total harvest of ranched Atlantic salmon in countries bordering the North Atlantic in 2015 was 40 t, all taken in Iceland, Sweden, and Ireland (Figure 10.1.5.5) with the majority of the catch taken in Iceland (29 t). No estimate of ranched salmon production was made in Norway in 2015, where such catches have been very low in recent years (< 1 t), or in UK (N. Ireland), where the proportion of ranched fish has not been assessed between 2008 and 2015 owing to a lack of microtag returns.

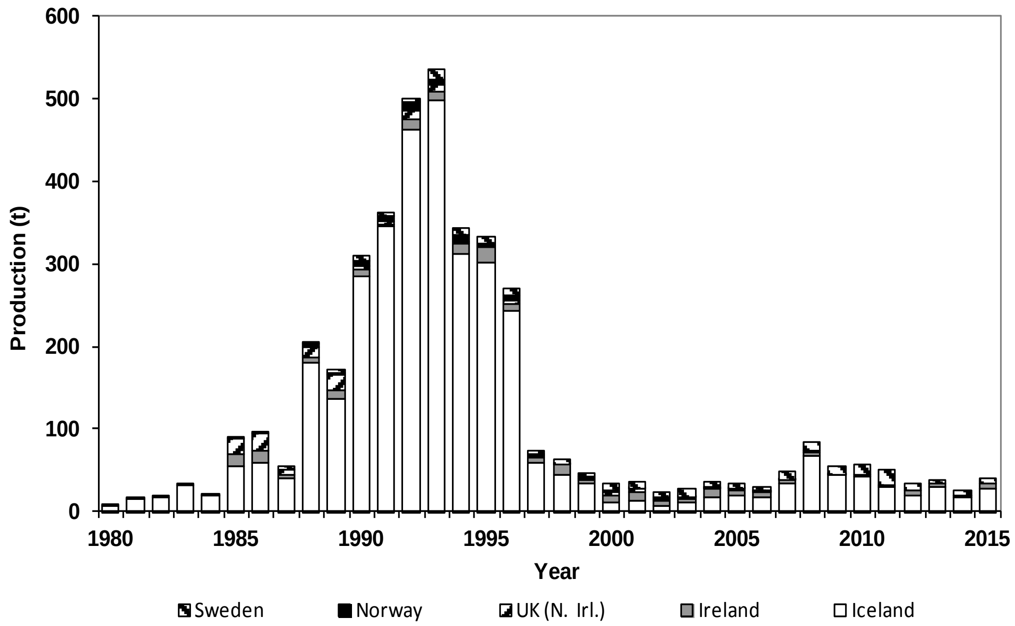


Figure 10.1.5.5 Production of ranched Atlantic salmon (tonnes round fresh weight) in the North Atlantic, 1980 to 2015.

10.1.6 NASCO has asked ICES to report on significant, new, or emerging threats to, or opportunities for, salmon conservation and management

10.1.6.1 Ocean migration and feeding areas of DST tagged Icelandic hatchery smolts

There has been little information of the the main marine feeding areas of Icelandic salmon since the closure of the ocean fishery in 1932. In 2005 and 2006, 598 hatchery smolts (weighing 60–100 g) were released in west Iceland with internal data storage tags (DST) measuring depth (pressure) and temperature at one-hour intervals (Gudjonsson *et al.*, 2015). Five tagged salmon returned in 2006 and two in 2007, and all had spent one year at sea. Six tags had complete temperature and depth profiles of their ocean migration, and one had partial measurements. Depth profiles showed the salmon stayed close to the surface for most of the time, showing some degree of diurnal behaviour by staying deeper during the day. The tagged salmon also took short deep dives (>100 m) during the latter part of their ocean migration. Temperature data indicated that salmon remained in areas where temperatures ranged from 6°C to 15°C, with warmer temperatures being experienced in the summer.

DST temperature data were compared to available sea surface temperatures (SST) (NOAA database) to estimate the location of fish at different times within the observed temperature range. All fish stayed southwest of Iceland in the Irminger Sea during the first summer before migrating east towards the Faroe Islands during the autumn and early winter (Figure 10.1.6.1). In late winter they migrated south and westward back to the Irminger Sea before returning to the river where they were released. These results show further support for the use of DST tags in studying migrations, migration behaviour, and feeding areas of salmon at sea. This will inform on locations where research activites need to be undertaken to understand factors that affect marine survival.

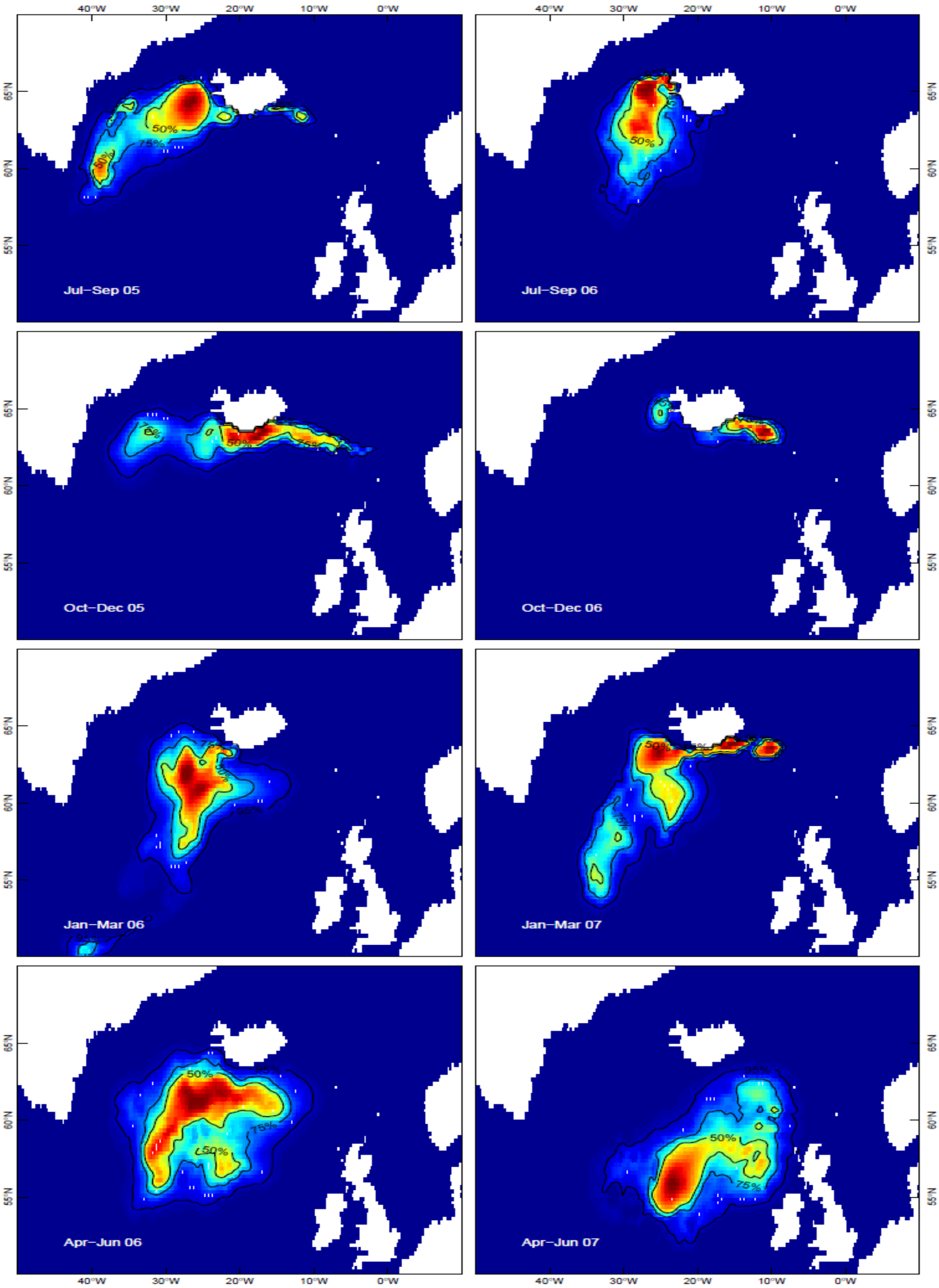


Figure 10.1.6.1 Probability density of the likely estimated location of Icelandic salmon tagged with DST tags, shown by quarter year. Five fish (5) released in 2005 are on the left, and two fish released in 2006 are on the right. The mean posterior probability is calculated for each cell, and the top 50%, 75%, and 95% areas are shown along with a more precise distribution by the colour gradient (Gudjonsson *et al.*, 2015).

10.1.6.2 Changing trophic structure and energy dynamics in the Northwest Atlantic: implications for Atlantic salmon feeding at West Greenland

Diverse population structures and management regimes are apparent across the North Atlantic. Concurrent abundance declines of these salmon populations suggest that marine mortality experienced at common marine areas may be the primary cause of population declines (Chaput *et al.*, 2005; Mills *et al.*, 2013). To investigate if altered trophic mechanisms are contributing to population declines, Atlantic salmon stomachs were collected and examined from individuals caught between 2006 and 2011 at the West Greenland feeding grounds. These contemporary data were compared to historical samples collected in the late 1960s/early 1970s from the sampled Greenland feeding areas (Templeman, 1967, 1968; Lear, 1972, 1980).

Primary prey items in both the contemporary and historical samples were capelin (*Mallotus villosus*) and amphipods (*Themisto* sp.), accounting for over 60% of the diet. Contemporary samples had 12% less biomass and 21% less capelin biomass compared to historical samples. Furthermore, from 1968 to 2008 the mean size of capelin in the Northwest Atlantic decreased by 12% and its mean energy density (kJ g^{-1} of wet weight) has decreased by approximately 34% (Figure 10.1.6.2). Energy density estimates for all identified Atlantic salmon prey were applied to the stomach contents data to estimate the total amount of energy consumed at the time of sampling. Applying prey-specific energy densities, including the high capelin energy density values for the historical samples and the low capelin energy density values for the contemporary samples, suggested lower estimates of total energy consumption (20%–58%) by Atlantic salmon over time based on historical and contemporary consumption levels (Figure 10.1.6.3).

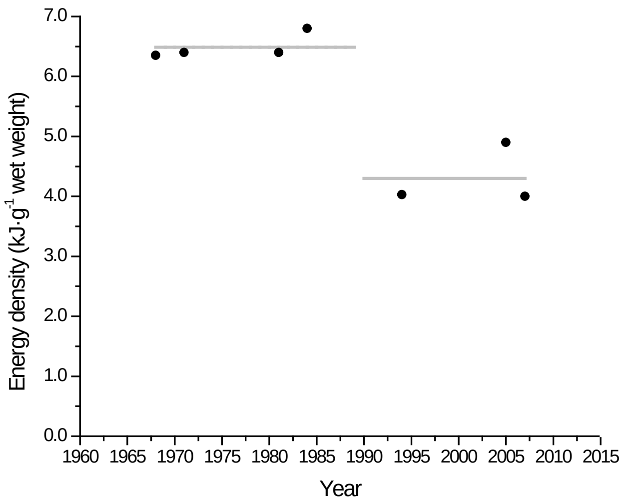


Figure 10.1.6.2 Energy density estimates (black dots; kJ·g^{-1} wet weight) of capelin and mean (grey bars) energy densities before (6.49 kJ·g^{-1}) and after (4.30 kJ·g^{-1}) the year 1990. (See Renkawitz *et al.*, 2015 for data sources used in this figure.)

Small pelagic fish are critical components in marine foodwebs, linking lower and higher trophic levels by providing a vector for energy transfer. Determining the factors that influence lower trophic level dynamics is paramount to understanding mechanisms that affect the survival, abundance, and productivity of higher trophic predators, including Atlantic salmon.

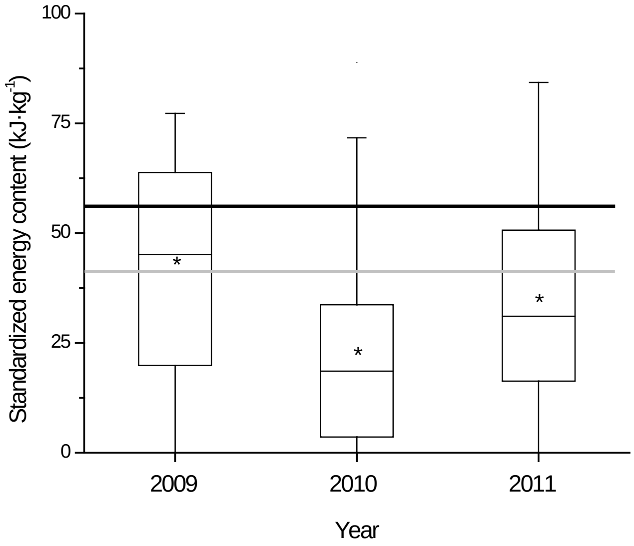


Figure 10.1.6.3 Standardized energy content (kJ·kg⁻¹ fish weight) of frozen stomach contents from Atlantic salmon sampled from West Greenland during 2009–2011. The box denotes the upper and lower quartile and the whiskers indicate the 5% and 95% confidence intervals. The horizontal line in the box is the median and the asterisk (*) indicates the mean. The grey horizontal line represents the mean standardized energy content of stomach contents from research surveys from 1965 to 1970 using contemporary energy equivalents, and the black horizontal line represents the energy equivalent adjusted for the higher energy content of capelin in historical samples.

10.1.6.3 Diseases and parasites

Update on red vent syndrome (Anisakiasis)

Over recent years, there have been reports across NEAC and NAC areas of salmon returning to rivers with swollen and/or bleeding vents (ICES, 2015). The condition, known as red vent syndrome (RVS or Anisakiasis), noted since 2004, has been linked to the presence of a nematode worm, *Anisakis simplex* (Beck *et al.,* 2008). A number of regions within the NEAC area observed a notable increase in the incidence of salmon with RVS in 2007 (ICES, 2008). Levels in the NEAC area were typically lower from 2008 to 2011 (ICES, 2009, 2010a, 2011).

Trapping records for rivers in UK (England & Wales) and France suggested levels of RVS increased again in 2013, with observed levels being the highest recorded for some monitored stocks (ICES, 2014b). Monitoring for the presence of RVS continued on three rivers (Tyne, Dee, and Lune) in UK (England & Wales). In 2015, RVS levels on the Tyne and Dee, 10% and 24% respectively, were at or close to the highest values recorded for these rivers. The level on the Lune (14%) was at the lower end of the range of observed values, although the sample size was small.

In Ireland in 2015, reports were also received of a high prevalence of red vent in fish taken in the Galway weir salmon fishery.

There is no clear indication that RVS affects either the survival of the fish in freshwater or their spawning success. Recent results have also demonstrated that affected vents show signs of progressive healing in freshwater (ICES, 2014b).

Update on sea lice investigations in Norway

The surveillance programme for sea lice infection on wild salmon smolts and sea trout at specific localities along the Norwegian coast continued in 2015 (Nilsen *et al.*, 2015). In 2015, the surveillance programme focused on further development of the model-based approach for evaluating infection pressure, where data from weekly sea lice counts at fish farms are coupled with a detailed hydrodynamic model to predict the distribution of seal lice larvae and infection pressure on wild salmonids. Model results are verified by field sampling of wild salmon and trout in the modelled areas. Predictions of infection levels from the model, and observed levels from field investigations were in good agreement for most investigated locations, demonstrating the usefulness of the model-based approach for predicting sea lice infections.

In general, the surveillance programme demonstrated varying infection pressure along the coast during the salmon smolt migration period in 2015. Even though infection levels were low at some of the field sampling stations, there was a general increase in infection levels compared to 2014. In the counties Hordaland (areas Hardanger and Nordhordland), Sogn og Fjordane (outer Sognefjord area), Møre og Romsdal (Storfjord area), and Nordland (Nordfolda area), migrating salmon smolts may have been negatively affected by salmon lice infections in 2015.

Sea lice are still generally regarded as a serious problem for salmonids (Skilbrei *et al.*, 2013; Krkošek *et al.*, 2013) and especially sea trout (Nilsen *et al.*, 2015). The use of chemicals to keep lice levels on fish below a threshold value of 0.5 mature female lice per salmon has shown a sharp increase in later years, as sea lice have developed resistance towards one or several of the most commonly used chemical agents. Multi-resistant sea lice are now present in all areas, including Finnmark County in northernmost Norway (Aaen *et al.*, 2015; www.mattilsynet.no). As chemical treatments have become less effective alternative methods, some based on mechanical removal of sea louse from the fish are being developed and increasingly put to use to try to reduce the use of chemicals. The increased application of such methods is expected to reduce the use of chemicals in the future, thus saving costs and reducing other environmental effects.

UDN in Sweden and Russia

During the summer of 2015 sick and dead salmon infected with the fungus *Saproplegnia* were observed in some northern Baltic rivers in Sweden. Skin samples were taken from salmon in the border river Tornijoki between Finland and Sweden. The Swedish National Veterinary Institute found that tissue deformations typical of UDN (Ulcerative dermal necrosis) were present in the dead fish. It was not possible to quantify the total mortality. A similar outbreak in 2014 did not reduce the number of salmon fry (0+) in 2015. These outbreaks have coincided with large spawning runs, i.e. dense populations.

In Russia in 2015 a mass mortality of adult salmon occurred in the Kola River, Murmansk region. Two hundred salmon died in a cage holding broodstock near the river's counting fence and another 500 salmon were found dead on the counting fence. Dead adult salmon were also regularly found by rod anglers over the whole catchment area. In August, the decision was taken by the Murmansk Regional Commissions on Regulation of Harvesting Anadromous Fish to close the salmon recreational fisheries in the Kola River for the remainder of the 2015 season. A sample of dead salmon was analyzed in Murmansk, Moscow and at the Norwegian Veterinary Institute, Oslo; however, no common disease agents or pathogens were identified. The outward symptoms appear similar to those often described for UDN, but no diagnostic test is available to confirm this suggestion. The total number of salmon killed by this outbreak is unknown. However, electrofishing parr surveys conducted in September showed no adverse effect on salmon juvenile densities. The impact of this event on the spawning stock will be assessed in the autumn of 2016.

10.1.6.4 Progress with implementing the Quality Norm for Norwegian salmon populations

In August 2013, a management system – The Quality Norm for Wild Populations of Atlantic Salmon ("Kvalitetsnorm for ville bestander av atlantisk laks") – was adopted by the Norwegian government (Anon., 2013). This system was based on an earlier proposal by the Norwegian Scientific Advisory Committee for Atlantic Salmon Management (Anon., 2011). A more detailed description of the Quality Norm is given in ICES (2014a). Recent progress in 2014 involved establishing a preliminary classification according to the conservation limit and the harvest potential dimension of the Quality Norm, based on assessments for the period 2010–2013. In 2016, the first classification of populations based on both dimensions (harvest potential relative to conservation limit, and genetic integrity) was conducted. An estimate of the degree of introgression from farmed Atlantic salmon in a high number of salmon populations was available, and a combined classification in both dimensions of the quality norm could be made. Of the 104 populations considered, 23 (22%) were classified as being in good or very good condition, 29 (28%) populations were classified as being in moderate condition, while 52 (50%) were in poor or very poor condition.

10.1.6.5 Progress on development of reference points for Atlantic salmon in Canada that conform to the precautionary approach

The working group was presented with an update on progress undertaken in Canada to review and revise reference points for Atlantic salmon in the context of the precautionary approach framework (PA). In 2009, Fisheries and Oceans Canada published the Sustainable Fisheries Framework (DFO, 2009a) that provides the basis for ensuring Canadian fisheries are conducted in a manner which supports conservation and sustainable use. The framework consists of a number of policies for the conservation and sustainable use of fisheries resources, including "A Fishery Decision-

Making Framework Incorporating the Precautionary Approach" (DFO, 2009b). Fisheries and Oceans Canada (DFO) Ecosystems and Fisheries Management Branch asked for science advice on the development of reference points for Atlantic salmon. The request follows on an action item associated with the implementation of the Wild Atlantic Salmon Conservation Policy (DFO, 2009c) to review benchmarks / reference points for Atlantic salmon that conform to the PA.

At present five regionally specific reference values for Atlantic salmon in eastern Canada are referred to as conservation objectives, which are considered equivalent to limit reference points. Reference points have been used informally to provide advice for Atlantic salmon fisheries management since the 1970s (CAFSAC, 1991; Chaput *et al.*, 2013) and pre-dates the development of the Sustainable Fisheries Framework (DFO, 2009b). The conservation requirement has been used both domestically and internationally to guide fisheries management actions, including the provision of catch advice for the mixed-stock Atlantic salmon fishery at West Greenland. Individual river values based on the conservation requirement have also been proposed as limit reference points that conform with the PA for stocks in the DFO Maritimes Region (DFO, 2012).

The reference points and the population dynamics of Atlantic salmon have most often been presented as a stock and recruitment diagram with spawning-stock abundance on the horizontal axis and the subsequent recruitment abundance resulting from the spawning stock on the vertical axis (Figure 10.1.6.4). The conservation requirement for Atlantic salmon is expressed in terms of a spawning stock value. This is somewhat different from the PA framework that presents stock status on the horizontal axis and the removal rate on the *y*-axis. In the PA framework, the stock status axis refers to total stock abundance or an index of total abundance prior to fishing. The single reference point and fixed escapement strategy used for Atlantic salmon can be reconciled with the PA framework by translating the recruitment indicator from the stock and recruitment plot onto the PA framework stock status indicator (Figure 10.1.6.4).

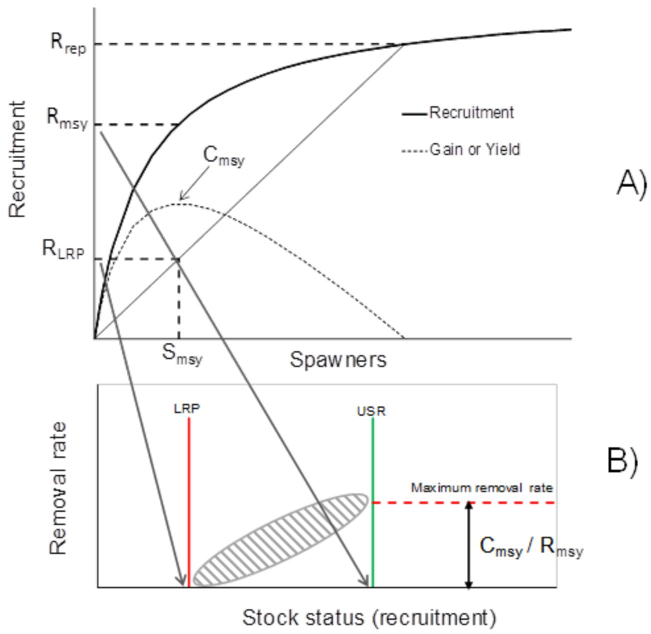


Figure 10.1.6.4 Transposing a spawning stock to recruitment relationship (upper panel A) to the removal rate and stock status axes (lower panel B) within the PA framework. The example is for an upper stock reference corresponding to R_{MSY}, a limit reference point equal to S_{MSY}, and a removal rate corresponding to F_{MSY}. The exploitation rate in the cautious zone (grey hatched oval) could be defined on the basis of a risk analysis of the chance that abundance after exploitation would be less than the LRP. R_{rep} is the abundance at replacement.

As the limit reference point (LRP) is defined as the stock level below which productivity is sufficiently impaired to cause serious harm, DFO (2015) recommended that the LRP should be defined on the basis of conservation of the salmon population rather than to fishery exploitation objectives. One approach consistent with this objective is to maintain production from freshwater to provide for sufficient numbers of adult returns, despite wide variations in environmental conditions in the marine environment, for the purpose of ensuring adequate opportunity for expression of the diversity of adult phenotypes and to maintain genetic variability. Potential candidate reference points that could satisfy this objective include:

- $S_{0.5Rmax}$: spawner abundance that produces 50% of maximum recruitment.
- S_{gen}: spawner abundance that will result in recruitment to S_{MSY} in one generation in the absence of fishing under equilibrium conditions.
- S_{LRP}: spawner abundance that results in a risk of ≤ 25% of recruitment being less than 50% of maximum recruitment.

As a minimum, the LRP should be determined based on a risk analysis of the spawning escapement that results in an agreed probability of the recruitment being less than 50% R_{max}. A risk tolerance of no greater than 25% of recruitment being < 50% R_{max} is proposed.

When establishing an LRP for small populations, conservation genetics should be considered in complement to stock and recruitment information. For conservation purposes, maintaining 90% of genetic diversity over 100 years, as used for other species, could be an appropriate objective (Frankham *et al*., 2014).

A number of candidate upper stock reference (USR) points were considered:

- $80\%B_{MSY}$: recruitment corresponding to 80% of R_{MSY} as per the PA policy.
- R_{MSY}: recruitment at S_{MSY}.
- $X\%R_{MAX}$: a percentage (X%) of maximum recruitment expected for the stock.

No recommendation for a specific USR was made as the choice depends upon the objectives of the users and the risk profile and risk tolerance of the management strategy. Upper stock reference points are best determined using full life cycle considerations as recruitment could be subject to reduced productivity and therefore increased risk of the stock abundance falling to the LRP. At a minimum, the USR must be greater than the LRP and there should be a very low probability (< 5%) of the recruitment falling below the LRP when the stock at USR is exploited at the maximum removal rate.

DFO (2009b) indicated that the maximum removal rate in the healthy zone should not exceed the value corresponding to F_{MSY}. The maximum removal rate in the healthy zone could be calculated once the upper stock reference level is defined.

Considerations for changes in productivity

Changes in productivity in either the freshwater or marine phase of the life cycle can have consequences on the derivation of reference points. The effects of lower productivity, manifest in either phase, would reduce adult recruitment. Lower recruitment rates (recruits per spawner) result in lower reference point values. Reference points based on full life cycle models may not be robust to systematic and sustained changes in the density-independent dynamics occurring at sea. Density-dependent population regulation is considered to occur during the freshwater phase; if the average productivity in freshwater has not changed, limit reference points defined on the basis of maintaining a portion of the freshwater carrying capacity (R_{MAX}) would therefore be robust to temporal changes in average conditions during the marine phase. The proposed LRP ($S_{0.5Rmax}$) as well as S_{gen} have been shown by simulation in Pacific salmon to be robust to changes in productivity (Holt *et al*., 2009).

Estimation and transport of reference points

Stock and recruitment modelling is the favoured approach for examining population dynamics and developing reference points for Atlantic salmon. Bayesian approaches that provide a framework for incorporating multiple levels of uncertainty are well developed and can be applied to single-population stock and recruitment analyses. Hierarchical Bayesian modelling (HBM) provides a framework for incorporating information from multiple stock and recruitment series, and accounts for the additional uncertainties associated with multiple stock and recruitment time-series.

Results of HBM analyses of egg to smolt time-series from 14 rivers in eastern Canada show that the stock and recruitment dynamic of Atlantic salmon is highly variable and uncertain within and among stocks (Chaput *et al*., 2015). Since it is not possible to obtain stock and recruitment data from all the rivers with Atlantic salmon populations in eastern Canada, consideration must be made to transferring reference values from monitored populations to rivers which lack such information. Scaling production and spawning stock on the basis of the amount of habitat area is the first scale of consideration for salmon. If reference points are defined in terms of rates, such as eggs or spawners per wetted fluvial area, these reference points can be transferred across a set of exchangeable rivers if the habitat areas are known. Examples of LRP values for rivers grouped by presence/absence of lacustrine habitat used for juvenile rearing, are shown in Figure 10.1.6.5. Options for transferring reference points among rivers based on exchangeability assumptions for habitat quantity, presence of lacustrine habitat, mean age of smolts, and proportions of eggs from multi-sea-winter (MSW) salmon are shown in Figure 10.1.6.5 (Chaput *et al*., 2015).

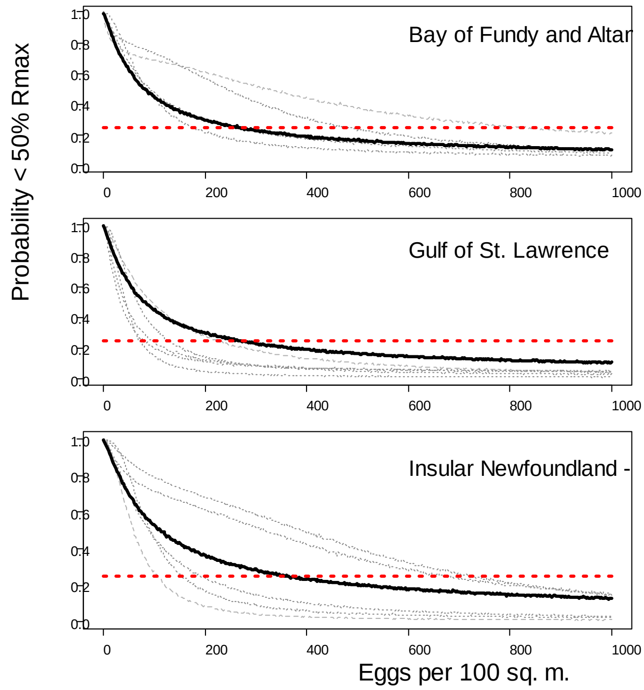


Figure 10.1.6.5 Example risk plots of recruitment being less than 50% R_{max} for different levels of egg depositions for the 14 rivers with egg to smolt data and the posterior predictions for rivers grouped by fluvial only and lacustrine habitat categories. The stock and recruitment model was Beverton–Holt with the presence/absence of lacustrine habitat modelled as a covariate of R_{max}. The light grey lines are the individual river profiles and the solid black lines are the predicted profile for rivers without lacustrine habitat (Bay of Fundy and Atlantic Coast of NS, upper panel; Gulf of St. Lawrence, middle panel) and with lacustrine habitat (insular Newfoundland, bottom panel). The dashed horizontal red line is the 25% probability risk level and the corresponding egg deposition would be SLRP.

The science advisory report on the development of reference points for Atlantic salmon (*Salmo salar*) that conform to the precautionary approach (DFO, 2015) is available on the Fisheries and Oceans Canada Canadian Science Advisory Secretariat website (www.dfo-mpo.gc.ca/csas-sccs/). Specific revisions and establishment of reference points for the PA are expected to take place in some regions over the next two years, based on regional priorities. The WGNAS will be informed of future progress on the development of the reference values that conform to the PA when they are developed.

Revised reference points for management of salmon fisheries in the province of Quebec

Conservation limits for managing Atlantic salmon fisheries in the province of Quebec (eastern Canada) were developed by Caron *et al*. (1999), based on a hierarchical analysis of adult-to-adult stock and recruitment relationships from six rivers in Quebec. In 2014, time-series of adult-to-adult stock and recruitment data from twelve rivers in Quebec, extending as far back as 1972 for some rivers were analyzed using a Ricker stock and recruitment function. The habitats of individual rivers were scaled to units of productive habitat (fluvial type, substrate, width of river, and temperature index). A full 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 Quebec. The management plan for Atlantic salmon fisheries for the period 2016 to 2026 was published in March 2016 (www.mffp.gouv.qc.ca/faune/peche/plan-gestion-saumon.jsp).

The new management measures announced in the management plan are founded on the status of Atlantic populations in individual rivers, prescribed by three status zones:

- healthy zone that defines populations not put in peril by a sustainable exploitation rate;
- cautious zone for which abundance is less than optimal but not alarming, and the exploitation rate is adjusted to favour rebuilding; and

- critical zone for which populations are at low abundance and thus in peril, and the exploitation rate would be held at the lowest level possible.

Reference values to categorize the status of populations in each zone were defined as follows:

- genetic limit reference point: the objective is for a 90% chance of maintaining genetic diversity within 100 years. Any salmon population with adult abundance less than 200 fish is considered to be in peril (in the critical zone) and no exploitation is allowed on these rivers.
- demographic limit reference point: spawner abundance (egg deposition) that results in 75% or greater chance of achieving 50% R_{max} (as described in DFO, 2015).
- upper stock reference: defined as the egg deposition rate corresponding to the 95th percentile of the posterior distribution of S_{MSY}.
- management targets: at the discretion of the managers, for example to favour catch-and-release opportunities (R_{max}) rather than yield to harvests. By default these targets must be greater than the upper stock reference.

Revised reference points for 105 rivers were defined and reference points for four rivers in the northern portion of Quebec in Ungava Bay are under development. The previously defined conservation limits for Atlantic salmon for the province of Quebec generally correspond mid-range between the demographic limit reference point and the upper stock reference point (Figure 10.1.6.6).

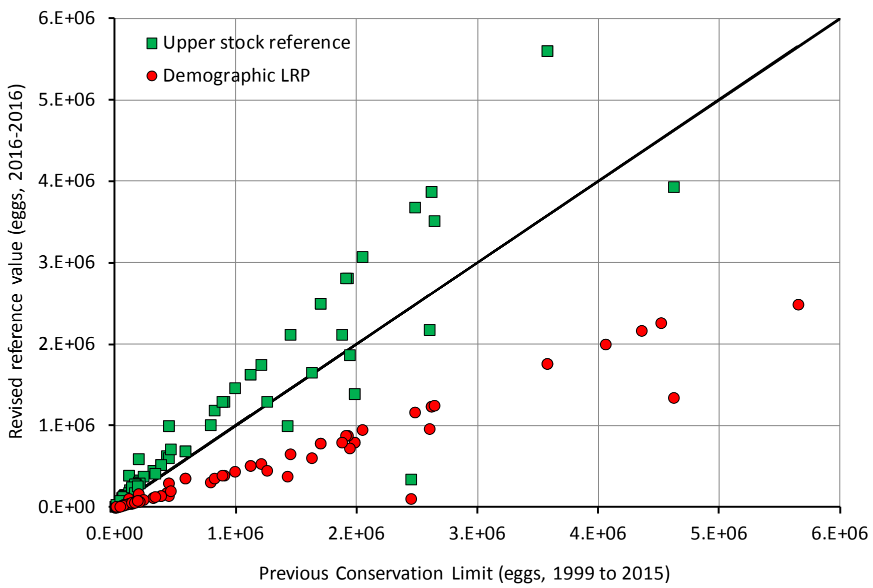


Figure 10.1.6.6 Correspondence between the previous river-specific conservation limits defined by Caron *et al.* (1999) and the new river-specific demographic limit reference points and the upper stock reference points for rivers of Quebec. Data were extracted from the table in Annex 1 of Ministère des Forêts, de la Faune et des Parcs (2016).

10.1.6.6 Review of proposed smolt-to-adult supplementation (SAS) activity in the Northwest Miramichi River, Canada

Increased marine mortality over the past two decades has contributed to declines of anadromous Atlantic salmon populations throughout the North Atlantic. Marine mortality is currently considered to be the most important threat to recovery of salmon populations in the southern regions of NAC (Section 10.3). For many populations at high risk of extinction, a number of recovery actions are undertaken, including live gene banking and adult captive-reared supplementation, to prevent extirpation and minimize loss of genetic diversity until conditions, primarily marine survival, become favorable to population persistence (DFO, 2008).

In response to particularly low returns of Atlantic salmon to the Northwest Miramichi River (New Brunswick, Canada) in 2012 to 2014, a group of non-government organizations in New Brunswick proposed a stock supplementation programme consisting of the capture of wild Atlantic salmon smolts, rearing these in captivity in freshwater to the adult stage, and subsequently releasing the adult captive-reared fish back to the river. This activity, smolt-to-adult supplementation (SAS), is intended to circumvent the low smolt-to-adult marine return rates of Atlantic salmon and to increase spawning escapement.

SAS activities consisting of the capture of wild juvenile salmon (parr, autumn pre-smolts, smolts) and rearing these in captivity with the intention of releasing the mature captive-reared adults to targeted rivers to spawn (Figure 10.1.6.7), has been undertaken by Fisheries and Oceans Canada (DFO) in the Scotia–Fundy region in support of populations of salmon at risk of extinction. However, it has not been done for the salmon populations in the Gulf region that are not considered at risk of extinction.

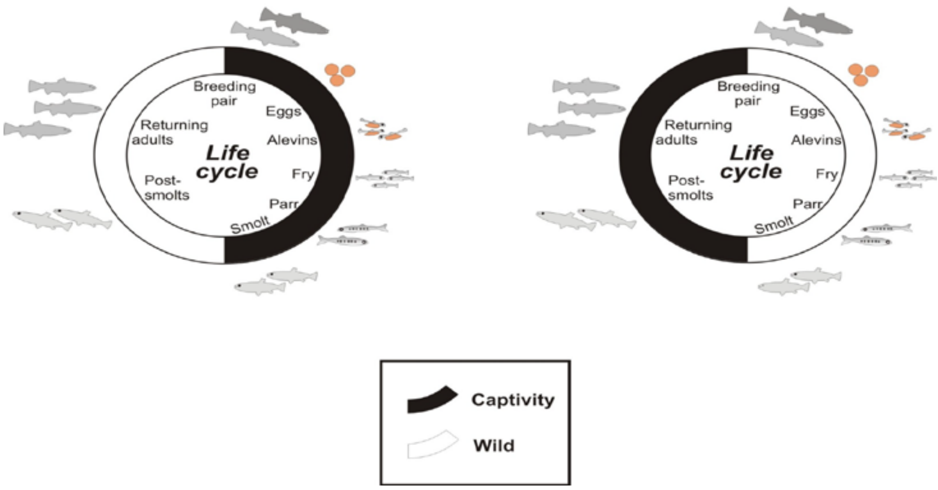


Figure 10.1.6.7 Contrasts between juvenile supplementation programmes (left panel) and juvenile/smolt-to-adult supplementation (SAS) programmes (right panel) in terms of life stages and processes which are impacted by captive rearing and those which occur in the wild. (Figure courtesy of P. O'Reilly, DFO.)

As a precedent-setting activity for supplementation of Atlantic salmon populations not considered to be at risk of extinction, a science peer review was conducted to support an assessment of risks and benefits of SAS activities to fitness of wild Atlantic salmon (DFO, 2016). The advice was provided to DFO Fisheries and Aquaculture Management, the sector responsible for issuing the permits for the collection of fish from and release to rivers. The science review addressed the following objectives:

- a review of the genetic risks of SAS to short- and long-term fitness of wild anadromous Atlantic salmon,
- the ecological risks of SAS,
- criteria and metrics for assessing risk of SAS,
- conditions under which SAS could be considered a negligible risk to wild Atlantic salmon fitness, and
- a specific assessment of risk to wild salmon of a proposed SAS activity of the Miramichi River, New Brunswick, Canada.

The science review was challenging due to the paucity of information available to assess the benefits and risks of SAS. The bulk of the scientific studies and literature regarding effects of captive-rearing and supplementation of Atlantic salmon have addressed the impacts of spawning in hatcheries and supplementation of various juvenile stages from eyed eggs to the smolt stage, though some research on SAS has been carried out on Atlantic and Pacific salmonids (Dempson *et al*., 1999; Fraser, 2008). Due to the recent development of SAS, much less empirical data are available to adequately describe the risks and benefits of SAS programmes to wild populations of Atlantic salmon. SAS is being used in areas where salmon populations are at high risk of extinction, and in cases where very low numbers of adult salmon are putting the population at risk of loss of genetic diversity which could affect long-term population viability.

Based on literature, it was concluded that adaptive genetic changes associated with captivity through unintentional selection, domestic selection, and relaxation of natural selection can occur rapidly, even within one generation. An immediate benefit resulting from an abundance of breeding/spawning of SAS fish may be offset by the expectation that mean fitness of the captive-reared progeny will be reduced relative to wild fish, in particular if survival at sea of progeny inherited from the parents is lower than that of wild fish.

Considering the presently high marine mortality rates of Atlantic salmon in eastern Canada, the anadromous salmon that are returning are likely those with the combination of fitness traits best suited to the current environment. The review concluded that any dilution of these traits via SAS activities, and particularly via SAS/wild interbred progeny, may delay the recovery in abundance of the wild anadromous phenotype which is presently subjected to strong natural selection at sea. Even worse, it may increase the risk of further declines in abundance of the anadromous phenotype due to an increased proportion of progeny which are maladapted to surviving the current marine conditions.

In-depth research, evaluation, and modelling of existing or proposed SAS activities are required. Because of the large uncertainties on the benefits and risks of SAS activities to wild Atlantic salmon fitness, it was concluded that if a SAS activity is conducted, it should be at a geographic and demographic scale that allows and includes an adequate monitoring and assessment capability to address the vast knowledge gaps on benefits and risks to wild salmon population persistence and productivity from such activities. The compilation of these additional assessment results would facilitate proper decision-making on when, where, and how SAS might provide desired, net-demographic benefits to wild salmon populations.

The science advisory report (DFO, 2016) and supporting documents for the review (Chaput *et al*., 2016; Fraser, 2016; Pavey, 2016) are available on the internet site of Fisheries and Oceans Canada Canadian Science Advisory Secretariat (www.dfo-mpo.gc.ca/csas-sccs/).

10.1.6.7 Progress in stock assessment models – Embedding Atlantic salmon stock assessment within an integrated Bayesian life cycle modelling framework

As part of the inputs to the Atlantic salmon case study within the UE-FP7 ECOKNOWS project (http://www.ecoknows.eu/), Massiot-Granier *et al.* (2014) and Massiot-Granier (2014) developed a hierarchical Bayesian integrated life cycle model which is considered to be an improvement on the stock assessment approach currently used by ICES. The model was applied to the stock units considered by ICES for stock assessment in the Southern European stock complex: France, UK (England and Wales), Ireland, UK (Northern Ireland), UK (Scotland), and Southwest Iceland. In this new approach, the stock assessment is fully integrated in an age- and stage-based life cycle model that explicitly considers the variability of life histories (river and sea ages) and the demographic link between age classes. It makes explicit hypotheses about the demography and the migration routes that are easier to interpret and critically examine than in the currently used pre-fisheries abundance (PFA) modelling approach. In addition, this is an expandable framework which offers the possibility to use additional information through the Bayesian updating framework. Finally, the model estimates trends in marine productivity and proportion maturing for the first year at sea for all stock units in Southern Europe, which forms the basis for forecasting home-water returns based on catch options for at-sea fisheries.

As a new contribution, the working group reviewed an extension of the life cycle modelling framework to the six stock units considered in North America: Labrador, Newfoundland, Quebec, Scotia–Fundy, Gulf regions, and USA. This new model now considers the dynamics of both 1SW and 2SW fish, incorporating a time trend for the proportion of fish maturing as 1SW and differing from the current model used by ICES which considers only 2SW fish in the PFA forecasting model (Figure 10.1.6.8). Partitioning the life cycle into the first and second year survivals at sea provide a model that aligns with the dynamics of the European stock units. This constitutes a critical step forward in the harmonization of the stock assessment models across stock units in the North Atlantic (Figure 10.1.6.8).

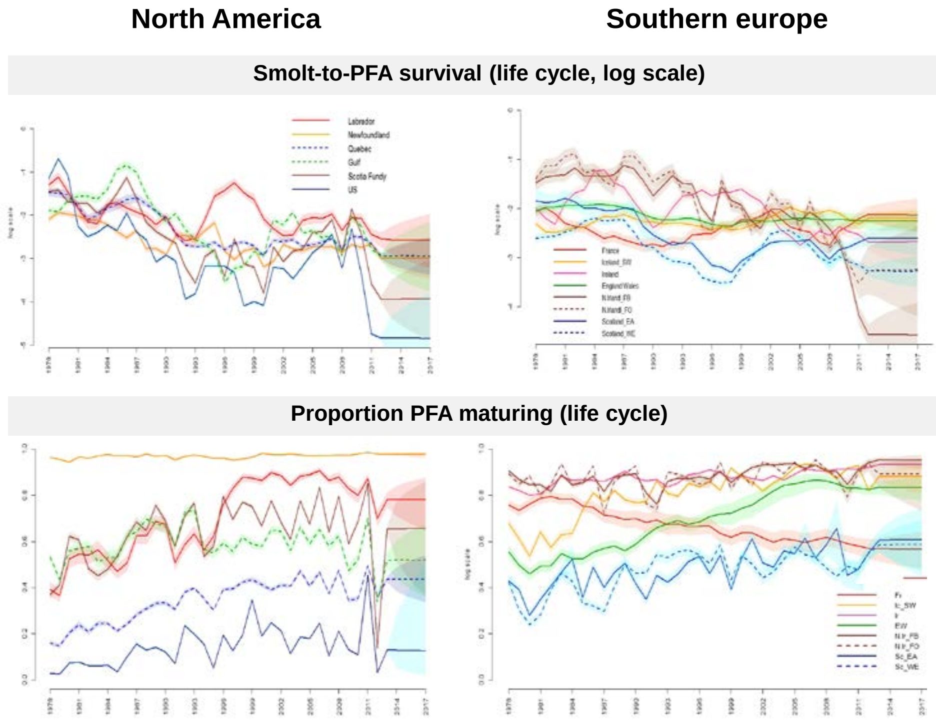


Figure 10.1.6.8 Estimates from the Bayesian life cycle models. Time-series of estimates of smolt to PFA survival (log scale; upper line) and proportion of maturing PFA (lower line) for stock units in North America (left column) and Southern Europe (right column). Lines: medians of Bayesian posterior distributions. Shaded areas: 50% BCI. Forecasting is presented for 3 years.

Cross-comparison with estimates of the PFA forecasting models show that the Bayesian life cycle approach can be applied to provide estimates and forecasts that are comparable with the PFA forecasting modelling approaches (Figure 10.1.6.9). Differences in trends in the productivity parameter for North America stock units arise from the contribution of 1SW to the total eggs deposition (more than 50% in some stock units in North America) that is considered in the life cycle approach, but not in the PFA forecasting model (only 2SW fish).

Also, by comparison with the model developed by Massiot-Granier (2014) for the Southern NEAC stock units, mathematical processes are simplified to speed up the analysis. The model can now run in a few hours (instead of several days for previous versions) and therefore has the potential to be used as a routine assessment tool by the working group.

Finally, the level of synchrony in trends in marine productivity and proportion maturing after the first year at sea can be quantified among all stock units of Southern NEAC and NAC. Taken together, the results provide a broad picture of Atlantic salmon population dynamics in the North Atlantic, providing evidence of a decline in the marine survival and an increase in the proportion of maturing PFA common to all stock units in NAC and Southern NEAC. The time-series of marine survival are negatively correlated with the AMO, a proxy of average SST in the North Atlantic. Taken together, results strongly suggest a common response to large-scale environmental changes impacting Atlantic salmon during the marine phase.

Ongoing developments include: (1) Further improvement of computational tractability of the model, including R-routines to easily pass results of the run-reconstruction as input to the life cycle model; (2) In depth comparisons of the results with those provided by the PFA forecasting models used by ICES; and (3) Extending the methodology to the stock assessment model for Northern NEAC stock units.

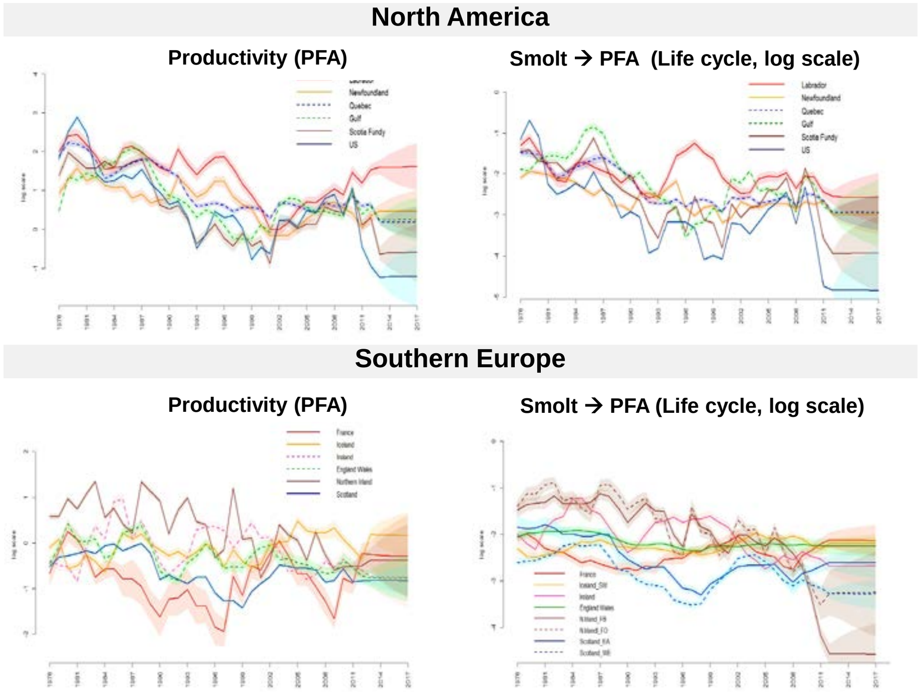


Figure 10.1.6.9 Comparison between the productivity parameter estimated from the PFA and the smolt-to-PFA survival estimated from the Bayesian life cycle model. Productivity parameter estimated from the PFA (left column) and smolt-to-PFA survival (log scale; right column) for North America (upper line) and Southern Europe (lower line). Lines: medians of Bayesian posterior distributions. Shaded areas: 50% BCI. Forecasting is presented for 3 years.

10.1.6.8 New opportunities for sampling salmon at sea

The International Ecosystem Summer Survey in the Nordic Seas (IESSNS) is a collaborative programme involving research vessels from Iceland, the Faroes, and Norway. Surveys are carried out annually in July–August and present an opportunity for improving our knowledge of salmon at sea. The time-series for abundance estimation using swept area from pelagic trawling goes back to 2007. The area surveyed (2.7 million km^2 in 2015) overlaps in time and space with the known distribution of post-smolts in the North Atlantic and, as these cruises target pelagic species such as herring and mackerel, bycatch of salmon post-smolts and adult salmon is not uncommon. In 2015 a total of 51 post-smolt and adult salmon were caught by the participating vessels in different regions of the North Atlantic (Figure 10.1.6.10). The working group has been liaising with the coordinator of the IESSNS surveys to clarify sampling protocols and a number of samples have been collected and frozen for subsequent analysis. Preparatory to conducting such analyses a plan for collecting samples from individual salmon caught in earlier years, in addition to those from last year's cruises, is currently under development at the Institute of Marine Research in Bergen, Norway.

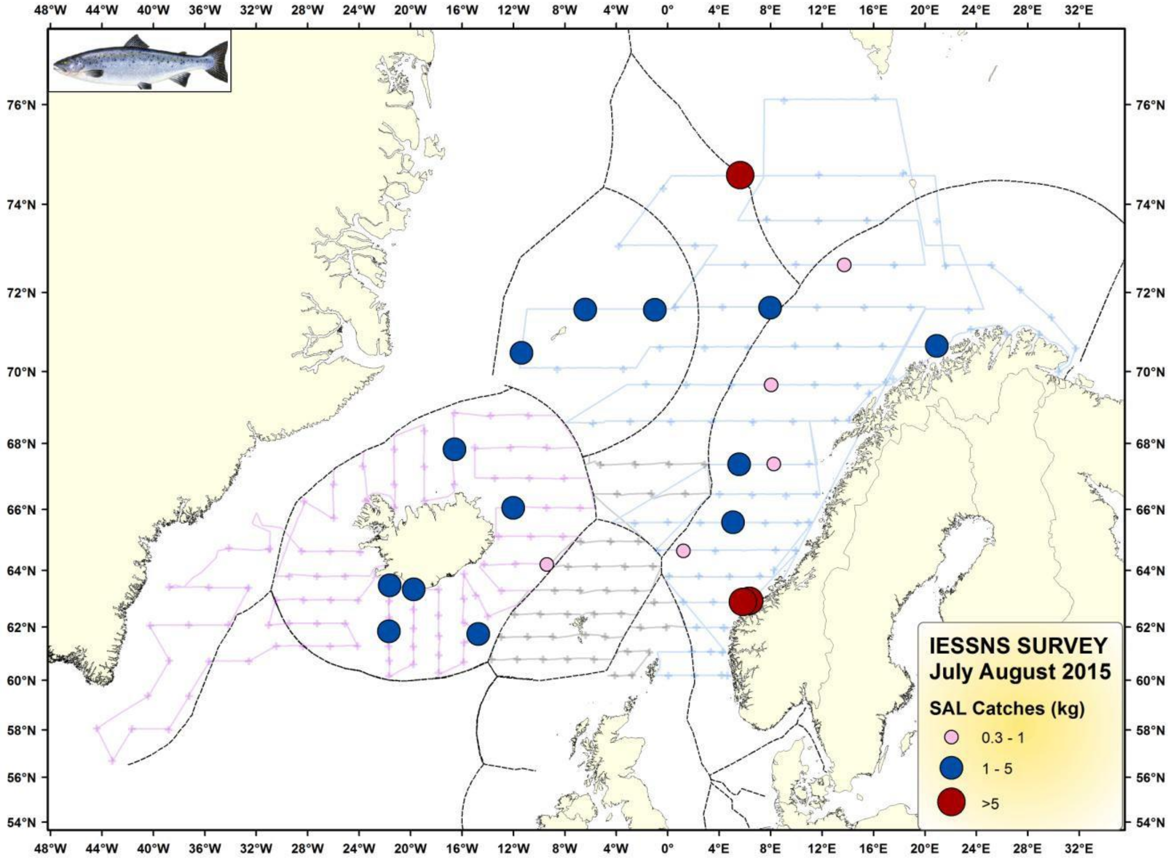


Figure 10.1.6.10 Distribution of salmon catches at surface trawl stations during the IESSNS survey in July and August 2015. (From Nøttestad *et al.*, 2015.)

The samples are expected to provide valuable information on the distribution of salmon at sea, the size, sex, and diet of individual fish, and will also enable stock origin to be investigated using genetic techniques. The IESSNS survey data will also provide information on salmon distribution in relation to other pelagic species, hydrography, and plankton abundance. It has also been suggested that some of the IESSNS research effort could be focused more on surface trawling, potentially increasing the number of salmon samples obtained from these cruises.

10.1.7 NASCO has asked ICES to provide a review of examples of successes and failures in wild salmon restoration and rehabilitation, and to develop a classification of activities which could be recommended under various conditions or threats to the persistence of populations

The Working Group on the Effectiveness of Recovery Actions for Atlantic salmon (WGERAAS) met for a third and final time 10–12 November 2015 at ICES HQ in Copenhagen.

WGERAAS has completed analysis of both the case studies and the Database on Effectiveness of Recovery Actions for Atlantic Salmon (DBERAAS). A total of 15 case studies were received, together with a total of 568 individual river stocks entered in DBERAAS (Table 10.1.7.1). Analysis of case studies and DBERAAS is ongoing. Preliminary results were presented at WGNAS 2016.

Of the 15 case studies examined, five achieved their stated goals with regard to effective recovery while nine failed to do so. One case study reported a “partial” success.

Characteristics of the successful projects included:

- A limited number of stressors acting on the population.
- Successfully addressing all stressors acting on the population.
- A river stock with moderate to high marine survival estimates.
- Good project evaluation (pre-, mid-, and post project).

Based on the analysis of DBERAAS “Stressor” entries the following stressors were most often reported as having a ***high*** or ***very high*** impact:

1. Climate change.
2. Barriers to migration.
3. Freshwater habitat degradation.

Similarly, on the basis of the analysis of the DBERAAS “Action” entries the following recovery and restoration actions were most often reported as having a high or very high benefit:

1. Improvements in connectivity.
2. Improvements in freshwater water quality.
3. Freshwater habitat restoration.

It is noted that the successful projects in the WGERAAS report concerned river stocks with moderate to high marine survival estimates, while generally it is considered that marine survival is poor for most North Atlantic stocks (Sections 10.1.6.6 and 10.3).

A final report will be submitted in 2016 to ICES for the attention of NASCO. In 2017 WGERAAS will report again to WGNAS.

10.1.8 NASCO has asked ICES to advise on possible effects of salmonid aquaculture on wild Atlantic salmon populations, focusing on the effects of sea lice, genetic interactions, and the impact on wild salmon production

Advice summary

ICES advises that there is substantial and growing evidence that salmon aquaculture activities can affect wild Atlantic salmon, through the impacts of sea lice as well as and farm escapees. Both factors can reduce the productivity of wild salmon populations and there is marked temporal and spatial variability in the magnitude of reported effects.

Effects of sea lice on wild Atlantic salmon

- The sea louse (*Lepeophtheirus salmonis*) is a parasite of salmonids that has widespread geographic distribution. Salmon farming has been shown to increase the abundance of lice in the marine environment and the risk of infection among wild salmon populations. There is considerable spatial and temporal variability in the extent of affected areas.
- Lice are also a serious problem for the Atlantic salmon farming industry and have been so since the 1970s.
- Laboratory studies show that 0.04–0.15 lice per gram fish weight can increase stress levels and that infections of 0.75 lice per gram fish weight can kill hatchery-reared smolts if all the lice develop into pre-adult and adult stages. This is the equivalent of 11 lice per smolt. This is also supported by field studies.
- Current marine mortality rates for salmon are often at or above 95%, the causes of which are largely unknown.
- There are differing perspectives on the impact of lice. In one perspective, the "additional" marine mortality attributable to lice is estimated at around 1%. In another perspective of the same data, losses are expressed at between 0.6% and 39% reduction in adult returns to rivers. The most important factor causing this variability is the level of total marine mortality. The greatest impact from lice is likely to occur on post smolts during the early period of marine migration.

Effects of escapees and genetic interactions on wild Atlantic salmon

- Farmed salmon are domesticated and display substantial differences to wild salmon in a wide range of fitness-related traits.
- Very large numbers of domesticated salmon escape from fish farms each year. Escapees are observed in rivers in all regions where farming occurs, although the number of escapees varies both spatially and temporally. The numbers of escapees have approached 50% or more of the spawning population in some rivers in some years. There is limited monitoring in rivers away from fish-farming regions.
- The spawning success of escaped farmed salmon is much lower than in wild salmon. Despite this, a large number of Norwegian wild salmon populations exhibit widespread introgression of farmed salmon genomes. Introgression has also been shown in other countries.
- The introgression of farmed salmon reduces the viability of the populations in rivers, caused by maladaptive changes in life history traits.
- The presence of farmed salmon and their offspring in a river has been shown to result in a decreased overall productivity of the wild population through competition for territory and food.
- The long-term consequences of introgression across river stocks can be expected to lead to erosion of genetic diversity and therefore to decreased resilience.

Request

1. *With respect to Atlantic salmon in the North Atlantic area:*

…

1.4 advise on possible effects of salmonid aquaculture on wild Atlantic salmon populations focusing on the effects of sea lice, genetic interactions and the impact on wild salmon production[4];

Notes:

…

[4] In response to question 1.4, ICES is requested to review and update the findings of the ICES/NASCO symposium on the impacts of aquaculture and the request for advice from OSPAR in June 2010.

The ICES Secretariat asked NASCO for further clarification via email and received the following from NASCO on 23 September 2015. These clarifications were consequently incorporated into the Terms of Reference for a Workshop to address the request for advice on possible effects of salmonid aquaculture on wild Atlantic salmon populations in the North Atlantic (WKCULEF; ICES, 2016a).

Clarification 1*: The request is referring to the most recent of the series of international symposia organised by NASCO and ICES in 2005. These symposia focused on both the scientific and management issues concerning interactions between aquaculture and wild salmon and other diadromous fish. The advice sought should focus on the effects of sea lice, genetic interactions and the impact on wild salmon production and not on the management approaches to addressing these. Furthermore, this request relates to impacts of salmonid farming and not other forms of aquaculture such as stocking. NASCO is holding a Theme-based Special Session on the topic of developments in relation to minimising the impacts of farmed salmon on wild salmon stocks and the advice will provide a very useful input to that process.*

Clarification 2*: Updating of the 2014 advice provided to OSPAR would be appreciated; there was no intention to request that ICES review its advice to OSPAR in the sense of assessing its quality but rather that ICES consider the advice already provided and update it as necessary in the light of new information. In the case of the advice to NASCO, the focus should be on the effects of sea lice, genetic interactions and impacts on wild salmon production whereas the advice to OSPAR also covered introduction of antibiotics and other pharmaceuticals; release of nutrients and other organic matter; effects on small cetaceans and introduction of non-indigenous species.*

Basis of the advice

Background

The farming of Atlantic salmon has expanded rapidly since the early 1980s. Production of farmed salmon in the North Atlantic is now approximately 1.5 million tonnes (over 2 million tonnes worldwide) and vastly exceeds the nominal catch of wild Atlantic salmon (FishstatJ; FAO, 2013). In 2014, it was estimated that farmed Atlantic salmon production exceeded the nominal wild catch in the North Atlantic by over 1900 times (ICES, 2015).

Interactions between salmon farming and wild stocks have raised concerns, in particular related to disease, parasite, genetic, and ecological interactions. Such issues have been subject to extensive research and dialogue as efforts have been made to balance current needs of industry with the need to safeguard wild stocks. The topic remains an area of continued intensive research interest.

This request for advice was addressed by a workshop, (Workshop to address the NASCO request for advice on possible effects of salmonid aquaculture on wild Atlantic salmon populations in the North Atlantic, WKCULEF). This enabled experts in aquaculture effects, wild Atlantic salmon, disease transmission, and genetic interactions to share and discuss relevant information and recent findings. WKCULEF was convened in Copenhagen, 1–3 March 2016, and was attended by 25 representatives from five ICES Member Countries.

Methods

The WKCULEF terms of reference were addressed though a comprehensive review of recent peer-reviewed literature, presentations from participants, reviews of working documents prepared ahead of the meeting, as well as the development of documents and text for the report during the meeting. It was particularly difficult to disentangle the issue of the possible impact of salmon aquaculture on wild salmon production from the sea lice and genetic interaction questions. Information pertaining to population level effects was incorporated into the sections dealing with these main issues.

The published literature with respect to the effects of lice and genetic interactions on wild salmon populations from salmonid aquaculture is inevitably focused on countries that have established salmon farming industries. This is a consequence of the importance of both farmed salmon production and wild stocks to national interests. However, relatively little is known about the scale of possible effects of lice and genetic changes on wild salmon in areas without salmon farms in the immediate vicinity.

The terms of reference for WKCULEF focus on interactions between salmon farming and Atlantic salmon. However, salmon farming activities can impact on other salmonid species, in particular sea trout, Arctic char, and species of Pacific salmon, and selected references relating to these species have been included where considered relevant.

Elaboration on the advice

The effects of sea lice on Atlantic salmon

The sea louse (*Lepeophtheirus salmonis*) has a widespread geographic distribution, is a specific parasite of salmonids, and has been a serious problem for the Atlantic salmon farming industry since the 1970s (Thorstad *et al*., 2015). Lice have a greater economic impact on the industry than any other parasite (ICES, 2010b) and control of lice levels on farms is of key importance. In recent years, lice have also developed resistance to one or more of the chemicals commonly used to manage lice levels and resistant lice have been reported in all areas of Norway, except Finnmark County in northernmost Norway (Aaen *et al*., 2015; Besnier *et al*., 2014). The high density of salmon in cages has provided a high number of potential hosts and promoted the transmission and population growth of the parasite (Torrissen *et al*., 2013). As a result, salmon farming has been shown to increase the abundance of lice in the marine environment. However, knowledge of parasite infection rates and resulting effects in wild populations of fish is relatively poor.

Historically, naturally occurring lice levels on wild salmonids have typically been low – a few (0–10) adult lice per returning salmon and sea trout (Torrissen *et al*., 2013; Serra-Llinares *et al*., 2014). Elevated levels of lice on wild salmon collected from coastal areas in the vicinity of salmon farms have been regarded as evidence that mariculture is a main source of the infections and studies have demonstrated a link between fish farming activity and lice infestations on wild salmonids (Helland *et al*., 2012, 2015; Serra-Llinares *et al*., 2014). Thus, the risk of infection among wild salmon populations can be elevated in areas that support salmon mariculture, although louse management activities can reduce the prevalence and intensity of infection on wild fish (Penston and Davies, 2009; Serra-Llinares *et al*., 2014). There is considerable uncertainty about the extent of the zones of elevated risk of infection and this will be subject to both spatial and temporal variability, for example as a result of changes in local hydrological processes (Amundrud and Murray, 2009; Salama *et al*., 2013, 2015; Jones *et al*., 2015; Johnsen *et al*., 2016).

The extent to which elevated infections of lice pose a risk to the health of wild salmon populations has been the subject of extensive research. However, there are many difficulties in quantifying effects at the population level, particularly for fish stocks that are characterized by highly variable survival linked to environmental variables, such as Atlantic salmon (Vollset *et al*., 2015; Helland *et al*., 2015). The following sections aim to summarize the current state of knowledge in relation to the impact of lice on Atlantic salmon. The literature reviewed includes some results from studies on Pacific salmon. This is considered to provide added insight, but needs interpreting with some caution since there are differences between the situation in the Pacific and the Atlantic, including in the genome of the lice themselves as well as the ecological context of the salmon. In the Pacific, salmonids are more diverse in their life-history traits, species composition, and abundance; the salmon farming industry is also smaller.

Physiological effects

Several laboratory studies have presented the effect of lice on the physiology of Atlantic salmon, sea trout, and Arctic charr smolts (reviewed in Finstad and Bjørn, 2011; Thorstad *et al*., 2015). Major primary (nervous, hormonal), secondary (blood parameters), and tertiary (whole body response) physiological effects (e.g. high levels of plasma cortisol and glucose, reduced osmoregulatory ability, and reduced non-specific immunity) occur when the lice develop from the sessile chalimus second stage to the mobile first pre-adult stage. Reduced growth, reproduction, swimming performance, and impaired immune defence have also been reported (Finstad and Bjørn, 2011). The susceptibility and response to louse infection varies among individuals, populations, and species of salmonid.

It has been shown in laboratory studies that 0.04–0.15 lice per gram fish weight can increase stress levels, reduce swimming ability, and affect the water and salt balance in Atlantic salmon (Finstad *et al*., 2000). In sea trout, the same authors found around 50 mobile lice are likely to give direct mortality, and 13 mobile lice, or approximately 0.35 lice per gram fish weight might cause physiological stress in sea trout (weight range 19–70 grams). Around 0.05–0.15 lice per gram fish weight were found to affect growth, condition, and reproductive output in sexually maturing Arctic charr (Tveiten *et al*., 2010).

Finstad *et al*. (2000) also found that infections of 0.75 lice per gram fish weight, or approximately 11 lice per fish, can kill a recently emigrated wild salmon smolt of about 15 gram if all the lice develop into pre-adult and adult stages. This is consistent with field studies on infections in salmon post-smolts in the Norwegian Sea where more than 3000 post-smolts have been examined for lice, but none observed carrying more than 10 adult lice (Holst *et al*., 2003). Fish with up to 10 mobile lice were observed to be in poor condition with a low haematocrit level and poor growth. These authors also conducted an experimental study of naturally infected migrating salmon smolts collected during a monitoring cruise. Half of the fish were deloused as a control, and the health of the two fish groups were monitored in the laboratory. Only fish carrying 11 mobile lice or less survived. The results have been further verified in the laboratory on wild-caught Atlantic salmon post-smolts infected with lice and showing the same level of tolerance for lice infections (Karlsen *et al*., in prep.).

These results have been used to provide estimates of death rates according to lice densities on migrating salmon smolts and have been adopted in the Norwegian risk assessment for fish farming (Taranger *et al*., 2015). The categories are: 100% mortality in the group > 0.3 lice per gram fish weight, 50% in the group 0.2–0.3 lice per gram fish weight, 20 % in the group 0.1–0.2 lice per gram fish weight and 0% in the group < 0.1 lice per gram fish weight. Wagner *et al*. (2008) discuss the wider factors that should be taken into account when estimating sea louse threshold levels detrimental to a host.

In practice, numerous biotic and abiotic stressors (e.g. pollutants) and ecological processes are likely to mediate the relationship between lice and the marine survival of Atlantic salmon. While laboratory estimates of lethal loads and physiological responses are attractive to predict impacts on wild populations, this is likely an over-simplified view because natural ecological processes such as predation and competition will probably remove infected fish before lice kill the fish directly. Early marine growth is important for smolts to enable them to reduce the risk of predation and to allow access to more diverse prey fields, and reduced growth rates will affect fish under resource-limited or parasitized conditions. Furthermore, studies with Pacific salmon (Peacock *et al*., 2014) have demonstrated that sub-lethal effects seen in laboratory trials may increase or decrease observed mortality in the field. As such, laboratory results ideally need to be connected with behavioural changes (e.g. migration behaviour; Birkeland and Jakobsen, 1997) in the fish that alter predator–prey interactions between the smolts and their predators as well as the smolts and their prey.

Evidence from monitoring programmes

Monitoring programmes have been implemented in a number of countries to assess lice levels to inform management decisions. Given the difficulties of sampling outmigrating wild salmon smolts, sea trout are commonly sampled and may in some cases be used as a proxy for potential levels on salmon (Thorstad *et al*., 2014).

In Norway, lice infection on wild salmonid populations is estimated through a national monitoring programme (Serra-Llinares *et al*., 2014; Taranger *et al*., 2015). The aim of the lice monitoring programme is to evaluate the effectiveness and consequences of zone regulations in national salmon fjords (areas where salmon farming is prohibited), as well as the Norwegian strategy for an environmentally sustainable growth of aquaculture.

Monitoring is carried out during the salmon smolt migration and in summer to estimate lice levels on sea trout and Arctic charr. The fish are collected using traps, fishing nets, and surface trawling (Holm *et al*., 2000; Holst *et al*., 2003; Heuch *et al*., 2005; Bjørn *et al*., 2007). Sentinel cages have also been used to investigate infestation rates (Bjørn *et al*., 2011).

The results of monitoring indicate considerable variation in the risk of lice-related mortality (low: < 10%, moderate 10–30%, and high: > 30%) between years and sampling locations. The risk for sea trout (and also Arctic charr in the Northern regions) is higher compared with Atlantic salmon post-smolts and the results show moderate-to-high risk of lice-related mortality on sea trout in most counties with high salmon farming activity.

The estimated risk of lice-related mortality for Atlantic salmon varies between years and sites. It was low at most sites in Norway in 2010 and 2013, but moderate or high at several sites in 2011, 2012, and 2014.

In Scotland, analysis of wild sea trout monitored over five successive farm cycles found that lice burdens above critical levels were significantly higher in the second year of the production cycle (Middlemas *et al*., 2010). In Norway, preliminary analysis of data from fallowing zones indicate that lice levels in farming areas are also correlated with biomass. In years with high biomass, lice epidemics are present in some zones, but such epidemics are not seen in years with low biomass (Serra-Llinares *et al*., submitted).

As noted previously, research effort on interactions between farmed and wild salmon is concentrated in areas where salmon farming is most prevalent. The same applies to monitoring efforts and little, if any, monotoring is undertaken in many areas more remote from salmon farming areas, representing a potential gap in our knowledge.

Population effects

Population-level impacts of lice infestation have been estimated in Atlantic salmon post-smolts from a series of long-term studies and analyses in Ireland and Norway involving the paired release of treated and control groups of smolts (Jackson *et al*., 2011a, 2011b; Jackson *et al*., 2013; Gargan *et al*., 2012; Skilbrei *et al*., 2013; Krkošek *et al*., 2013; Vollset *et al*., 2014, 2015). These studies assumed that the louse treatments were efficacious and that released smolts were exposed to lice during the period of the outmigration in which the treatment was effective. Furthermore, the studies were not designed to discriminate between lice from farm and non-farm sources. In addition, the baseline marine survival from untreated groups, which is used as a comparator for treated groups, is itself likely to be affected by louse abundance, introducing an element of circularity that leaves the interactive effects between lice and other factors on salmon survival poorly characterized.

Survival estimates have been based on a statistical analysis of differential survival to adults among release groups (Gargan *et al*., 2012; Jackson *et al*., 2011a, 2011b, 2013), including odds ratios (Jackson *et al*., 2013; Skilbrei *et al*., 2013; Krkošek *et al*., 2013, 2014; Torrissen *et al*., 2013; Vollset *et al*., 2015). An odds ratio is a measure of association between an exposure and an outcome and represents the odds that an outcome will occur given a particular exposure, compared to the odds of the outcome occurring in the absence of that exposure. Thus, in these studies, the odds ratio represented the probability of being recaptured in the treated group divided by the probability of being recaptured in the control group. All studies reported an improved return rate for treated versus control salmon, but all showed significant spatial and temporal variability.

Gargan *et al.* (2012) reported that the ratio of return rates of treated:control fish in individual trials ranged from 1:1 to 21.6:1, with a median ratio of 1.8:1. Similarly, odds ratios of 1.1:1 to 1.2:1 in favour of treated smolts were reported in Ireland and Norway, respectively (Torrissen *et al*., 2013). Krkošek *et al.* (2013) reported that treatment had a significant positive effect with an overall odds ratio of 1.29:1 (95% CI: 1.18–1.42). A recent meta-analysis of Norwegian data (Vollset *et al*., 2015) based on 118 release groups (3 989 recaptured out of 657 624 released), reported an odds ratio of 1.18:1 (95% CI: 1.07–1.30) in favour of treated fish. Untreated returning salmon were on average older and had a lower weight than treated fish (Vollset *et al*., 2014; Skilbrei *et al*., 2013).

The survival of Atlantic salmon during their marine phase has fallen in recent decades (Chaput, 2012; ICES, 2015). This downturn in survival is evident over a broad geographical area and is associated with large-scale oceanographic changes (Beaugrand and Reid, 2003; Friedland *et al*., 2000, 2005, 2009, 2014). For monitored stocks around the North Atlantic, current estimates of marine survival are at historically low levels, with typically fewer than 5% of outmigrating smolts returning to their home rivers for the majority of wild stocks and with even lower levels for hatchery-origin fish (ICES, 2015).

The scientific literature provides differing perspectives of the mortality attributable to lice (Jackson *et al*., 2013; Krkošek *et al*., 2013). In one view (Jackson *et al*., 2013), the emphasis is placed on the absolute difference in marine mortality between fish treated with parasiticides and those that are not. In this instance, viewed against marine mortality rates at or above 95% for fish in the wild, the mortality attributable to lice has been estimated at around 1% (i.e. mortality in treated groups is 95% compared to 96% in untreated groups). This "additional" mortality between groups is interpreted as a small number compared to the 95% mortality from the treatment groups.

The other perspective of this same example is in terms of the percent loss of recruitment, or abundance of returning adult salmon, due to exposure to sea lice. In this perspective, the same example corresponds to a 20% loss in adult salmon abundance due to sea lice; for every five fish that return as adults in the treated groups (95% mortality), four fish return as adults in the untreated group (96% mortality). In other words, one in five fish is lost to sea lice effects. These perspectives are solely differences in interpretation of the same data. Where impacts of lice have been estimated as losses of returns to rivers, these indicate marked variability, ranging from 0.6% to 39% (Gargan *et al*., 2012; Krkošek *et al*., 2013; Skilbrei *et al.*, 2013). These results suggest that a small incremental increase in marine mortality due to lice (or any other factor) can result in losses of Atlantic salmon that are relevant for fisheries and conservation management and which may influence the achievement of conservation requirements for affected stocks (Gargan *et al.*, 2012). Vollset *et al*. (2015) concluded that much of the heterogeneity among trials could be explained by the release location, time period, and baseline (i.e., marine) survival. Total marine survival was reported to be the most important predictor variable. When marine survival was low (few recaptures from the control group), the effect of treatment was relatively high (odds ratio of 1.7:1). However, when marine survival was high, the effect of treatment was undetectable (odds ratio of ~1:1). One explanation for this finding is that the detrimental effect of lice is exacerbated when the fish are subject to other stressors, and the findings of other studies support this hypothesis (Finstad *et al*., 2007; Connors *et al*., 2012; Jackson *et al*., 2013; Godwin *et al*., 2015). Potential interactive effects of multiple factors are likely to be important for explaining the result from meta-analysis where the effect of sea lice on salmon survival depends on the baseline survival of untreated fish (Vollset *et al*., 2015). In conclusion the authors cautioned that though their study supported the hypothesis that lice contribute to the mortality of salmon, the effect was not consistently present and strongly modulated by other risk factors, suggesting that population-level effects of lice on wild salmon stocks cannot be estimated independently of the other factors that affect marine survival.

Escapees, genetic interactions and effects on wild Atlantic salmon

Numbers of escapees and observations in rivers

Although aquaculture technology and fish-farm safety has significantly increased over the past decade or more, each year, large numbers of Atlantic salmon still escape from aquaculture installations into the wild. Although many of these are reported (e.g. http://www.fiskeridir.no/Akvakultur/Statistikk-akvakultur/Roemmingsstatistikk), in many circumstances, escapes go unnoticed. In Norway, the true numbers escaping from farms have been estimated to be 2–5 times higher than the official statistics (Skilbrei *et al*., 2015). The numbers of farmed escapees are also reported in Scotland (http://aquaculture.scotland.gov.uk/data/fish_escapes.aspx) and in eastern Canada and the United States (NASCO, 2015), but the degree of underreporting in these regions has not been estimated.

Farmed salmon may escape from both the freshwater (Clifford *et al*., 1998a; Carr and Whoriskey, 2006; Uglem *et al*., 2013) and the marine stages of production (Clifford *et al*., 1998b; Webb *et al*., 1991; Carr *et al*., 1997a). Most known escapes occur from sea cages (Jensen *et al.,* 2010). However, due to differences in rearing practices between countries and regions, the magnitude of freshwater escapes may differ. In some countries, such as Scotland, it is likely to be higher than, for example, in Norway. In Scotland, in the order of 20 million smolts are produced annually from freshwater pens (Franklin *et al.,* 2012). In Norway, most smolts are produced in land-based tanks from which escape is less likely. Although the probability of surviving to adulthood and maturing vary between the different life-history stages at which the salmon escape, the great majority of salmon that escape from farms disappear, never to be seen again (Skilbrei, 2010a, 2010b; Hansen, 2006; Whoriskey *et al*., 2006). Nevertheless, some escapees enter rivers where native salmon populations exist and other fish escape direct to river systems. While not all escapees are sexually mature (Carr *et al*., 1997b; Madhun *et al*., 2015), some may attempt to spawn with wild salmon (this can include both precocious parr and adults). Farmed escaped salmon have been observed in rivers in all regions where Atlantic salmon farming occurs: Norway (Gausen and Moen, 1991; Fiske *et al*., 2006), United Kingdom (Youngson *et al*., 1997; Webb *et al*., 1991; Green *et al*., 2012), eastern Canada and the United States (Morris *et al*., 2008; Carr *et al*., 1997a), and Chile (Sepulveda *et al*., 2013). Furthermore, farmed salmon can migrate great distances post escape (Hansen and Jacobsen, 2003; Jensen *et al.,* 2013), and have been observed in rivers at a considerable distance from the main concentrations of salmon farming , for example in Iceland (Gudjonsson, 1991). Still, the incidence of farmed escaped salmon in rivers has been correlated with the volume of farming in Norway (Fiske *et al*., 2006), and in Scotland (where there are differences between the east and west coasts; Green *et al*., 2012). Relatively little is known about possible levels of spawning by escapees in river systems away from centres of aquaculture production. Numbers of escapees in such areas are typically assumed to be low (ICES, 2015), but can be subject to temporal variation (e.g. higher in rivers at spawning time than evidenced from in-season catches).

The incidence of farmed escaped salmon has been investigated in a number of rivers in Norway (Fiske *et al*., 2006). A new national monitoring programme for farmed escaped salmon was established in Norway in 2014 based upon data from angling catches, dedicated autumn angling, and diving surveys. The results for 30 of the 140 rivers surveyed exceeded a frequency of 10% escapees (see http://www.imr.no/publikasjoner/andre_publikasjoner/romt_oppdrettslaks_i_vassdrag/nb-no). These studies demonstrate that the number of escapees within rivers varies in time and space (Gausen and Moen, 1991; Fiske *et al*., 2006).

Farmed salmon escapees may attempt to spawn with wild salmon or among themselves. Observations of farmed salmon spawning with wild fish have been reported in rivers in Scotland (Webb *et al*., 1991, 1993; Butler *et al*., 2005), Norway (Lura and Saegrov, 1991; Saegrov *et al*., 1997), and Canada (Carr *et al*., 1997a). However, experiments demonstrate that the spawning success of farmed salmon is significantly reduced (Fleming *et al*., 1996; Fleming *et al*., 2000; Weir *et al*., 2004), perhaps just 1–3% and < 30% of the success of wild males and females, respectively (Fleming *et al*., 1996). However, the relative spawning success is likely to also vary with the life stage at which the fish escaped (Fleming *et al*., 1997; Weir *et al*., 2005). Therefore, if a river has, for example, 10% farmed escapees observed on the spawning grounds, the genetic contribution to the next generation is likely to be significantly lower than 10%. One explanation for the wide range of estimates of the relatively low spawning success of escapees is that they originate from aquaculture stocks that have been changed the most by domestication. If so, these interbreeding events likely have more serious consequences than interbreeding events of a similar magnitude involving less domesticated stocks. This would mean that simply focusing on the rate of interbreeding will not necessarily provide a full picture of the genetic consequences of escapees (Baskett and Waples, 2013).

The life stage of the escapees affects potential impact. Escapes of smolts are believed to assume a normal migration pattern, few immature adults return to rivers, maturing fish have a higher tendancy to return to nearby rivers (Skilbrei *et al*., 2015). This is also affected by the time of year relative to migration patterns in the wild. Thus smolts that escape when natural migration is occurring in the spring have a greater tendancy to return than those escaping at other times of the year (Skilbrei *et al*., 2015).

The rate at which escapes occur may also have implications for the possible impact. Hindar *et al.* (2006) concluded that large pulses of escapes are more damaging than small amounts of gradual '"eakage". However, Baskett *et al.* (2013) reached the opposite conclusion; that constant, small-scale leakage created greater fitness losses to the wild population. The different conclusions can be largely explained by different time frames of reference: Hindar *et al.* (2006) focused on short-term effects, while Baskett *et al.* (2013) evaluated mean effects over long periods of time. However, this topic merits more detailed study. Baskett *et al.* also did not explicitly consider overlapping generations, and so more work is needed in order to evaluate results as a function of escapes across generations in Atlantic salmon. This is important to resolve, as it is convenient to ignore low-level leakage because it is very difficult to eliminate or even monitor, but some results, at least, suggest it can have extremely important effects on wild populations.

Identification of escapees

Farmed salmon escapees are typically identified using external morphological characteristics, including growth patterns on fish scales (Fiske *et al*., 2006; Lund and Hansen, 1991). In Norway, genetic methods to identify farmed escaped salmon back to their farm(s) of origin have been developed and are routinely implemented in cases of unreported escapes (Glover *et al*., 2008; Glover, 2010). By the start of 2016, the method has been used in ~20 cases of unreported escape and has resulted in initiation of legal investigations successfully resulting in fines for companies found in breach of regulations (Glover, 2010). Since 2003, all aquaculture salmon in Maine must be marked before placement into marine net pens, so that in the event of an escape the fish can be traced to the farm of origin (NMFS, 2005). Maine's marking programme utilizes a genetic pedigree-based approach to identify fish. In other countries, no formal active identification programmes are in place. There are ongoing efforts to develop other genetic and non-genetic tagging methods to permit the routine identification of escapees back to their farms of origin.

Intraspecific hybridization and introgression

Only few published studies have addressed genetic changes in wild populations following the invasion of escaped farmed Atlantic salmon. This may be due to the fact that such studies are often challenging. For example, they often require representative samples of the wild populations ideally before and after invasion, and access to representative farmed samples, as well as an informative set of molecular genetic markers (Besnier *et al*., 2011; Karlsson *et al*., 2011).

The first studies of introgression were conducted in Ireland (Clifford *et al*., 1998b, 1998a) and Northern Ireland (Crozier, 1993; Crozier, 2000), demonstrating introgression of farmed salmon in rivers as a response to escapes from local farms. These escapees originated from both cage escapes in salt water, as well as escapes from freshwater smolt rearing facilities located within rivers. The first studies in Norway demonstrated temporal genetic changes in three out of seven populations located on the west and middle parts of the country, and concluded that introgression of farmed salmon was the primary driver (Skaala *et al*., 2006). A more recent spatio-temporal investigation of 21 populations across Norway revealed significant temporal genetic changes in several rivers caused by introgression of farmed salmon, and importantly, observed an overall reduction in interpopulation genetic diversity (Glover *et al*., 2012). The latter observation is consistent with predictions of population homogenization as a result of farmed salmon breeding with wild fish (Mork, 1991). Importantly, all rivers that displayed temporal genetic changes due to spawning of farmed escapees displayed an increase in genetic variation, revealed as the total number of alleles observed in the population. This is consistent with introgression from fish of a non-local source. The final published study in Norway used recently developed diagnostic genetic markers for identification of farmed and wild salmon (Karlsson *et al.,* 2011) to estimate cumulative introgression of farmed salmon escapees in 20 wild populations (Glover *et al.,* 2013). In this study, cumulative introgression over 2–3 decades ranged from 0% to 47% between rivers. Differences in introgression levels between populations were positively linked with the observed proportions of escapees in the rivers, but it was also suggested that the density of the wild population, and therefore level of competition on the spawning grounds and during juvenile stages, also influenced introgression (Glover *et al.,* 2013). A recent study conducted in the

Magaguadavic River in eastern Canada has also demonstrated introgression of farmed escapees with the native population (Bourret *et al*., 2011).

The most recent and extensive investigations of introgression of farmed salmon were recently published as a report in Norwegian by researchers from NINA and IMR (http://www.nina.no/english/News/News-article/ArticleId/3984). A total of 125 Norwegian salmon populations were classified using a combination of the estimate of wild genome P(wild) (Karlsson *et al.,* 2014) and the introgression estimates from the study by Glover *et al*. (2013). The latter authors established four categories of introgression: green = no genetic changes observed; yellow = weak genetic changes indicated – i.e. less than 4% farmed salmon introgression; orange = moderate genetic changes documented – i.e. 4–10% farmed salmon introgression; red = large genetic changes demonstrated – i.e. >10% farmed salmon introgression. Based upon these analyses, 44, 41, 9, and 31 of the populations studied fell into categories green to red, respectively. There are no similar estimates in other countries.

Domestication and divergence from wild salmon

From the very start of the Atlantic salmon aquaculture industry in the early 1970s, breeding programmes to select salmon for higher performance in culture were initiated (Gjedrem *et al.,* 1991; Ferguson *et al.,* 2007; Gjoen and Bentsen, 1997). The largest and most significant of these programmes globally have been those initiated in Norway, based upon material originating from >40 Norwegian rivers (Gjedrem *et al*., 1991). Other programmes in Norway were also established from wild salmon, and in other countries salmon breeding programmes have also been established. Farmed salmon originating from the three main breeding companies in Norway: Marine Harvest – Mowi strain, Aqua Gen AS, and SalmoBreed AS, dominate global production although this varies from country to country. For example, in eastern Canada only the St John River domesticated strain (Friars *et al.,* 1995) is permitted for use in commercial aquaculture, and in Scotland some locally based strains, e.g. Landcatch (Powell *et al.,* 2008) are also being used.

Initially, salmon breeding programmes concentrated on increasing growth, but then expanded to include other traits that are also of commercial importance, such as flesh characteristics, age-at-maturation, and disease resistance (Gjedrem, 2000, 2010). Currently, breeding programmes have advanced to 12+ generations, and genome-assisted selection is being utilized in several of the breeding programmes. Quantitative Trait Loci (QTL)-selected sub-strains are now commercially available, displaying characteristics such as reduced sensitivity to specific diseases (Moen *et al.,* 2009) and increased growth. It is likely that full utilization of genomic selection will increase the number of traits that can be accurately targeted by selection for rapid gains in breeding. For example, the recently identified strong influence of the vgll3 locus on age-at-maturation in salmon (Ayllon *et al.*, 2015; Barson *et al.,* 2015) could represent an effective target to inhibit grilsing (i.e. early maturation) in aquaculture.

As a result of: (1) directional selection for commercially important traits, (2) inadvertent domestication selection (the widespread genetic changes associated with adaptation to the human-controlled environment and its associated reduction in natural selection pressure), (3) non-local origin, and (4) random genetic changes (drift), farmed salmon display a range of genetic differences to wild salmon (Ferguson *et al.,* 2007). Examples of these differences include growth rate under controlled conditions (Glover *et al.,* 2006; Glover *et al.,* 2009; Solberg *et al.,* 2013a, 2013b; Thodesen *et al.,* 1999), gene transcription patterns (Bicskei *et al.,* 2014; Roberge *et al.,* 2006, 2008), stress tolerance (Solberg *et al.,* 2013a), and behavioural traits including predator avoidance and dominance (Einum and Fleming, 1997). In addition, farmed salmon strains typically display lower levels of allelic variation when compared to wild salmon strains (Norris *et al.,* 1999; Skaala *et al.,* 2004), although not all classes of genetic marker reveal the same trends (Karlsson *et al.,* 2010). Looking at the level of genetic variation coding for phenotypic traits such as growth, some data are emerging that suggest a possibly reduced variation in farmed strains (Solberg *et al.,* 2013a; Reed *et al.,* 2015). The latter observation is expected given the fact that farmed fish have been selected for this trait since the early 1970s.

Fitness studies

Thus far, only three published studies have addressed survival of farmed, hybrid, and wild salmon in the natural environment. Such studies are exceptionally demanding on logistics, and require unusually long and costly experimental periods.

The first study was conducted in the river Burrishoole in Ireland, and involved planting eggs of farmed, hybrid, and wild parentage into a natural river system (McGinnity *et al*., 1997). These fish were identified using DNA profiling and followed through a two-generation experiment. The authors concluded that the survival from fertilization to adult return (life-time success) of farmed fish was just 2% of wild fish (McGinnity *et al*., 2003). The relative life-time success increased along a gradient towards the offspring of F1 hybrid survivors spawning together with wild salmon (i.e. back crosses) that displayed life-time success of 89% compared to pure offspring of wild salmon. The authors concluded that repeated invasions of farmed salmon in a wild population may cause the fitness of the native population to seriously decline, and potentially enter an “extinction-vortex” in extreme cases.

In Norway, a slightly different but complimentary investigation was conducted in the River Imsa (Fleming *et al.,* 2000). Here, the authors permitted migrating adult salmon of farmed and wild native origin entry to the River Imsa, once they had been sampled in the upstream trap. They thereafter spawned naturally and their offspring were monitored until adulthood. This study reported a lifetime fitness of farmed salmon (i.e. escaped adult to adult) of 16% compared with wild salmon (Fleming *et al.,* 2000). Important additional data from this study was the fact that productivity of the wild salmon from the river decreased, following the permitted invasion of farmed salmon, both with respect to the total smolt production and when smolt production from native females was considered alone (Fleming *et al*., 2000). This is because the offspring of the farmed and hybrid salmon competed with wild salmon for both territory and resources, and the dynamics of this may vary across life-history stages (Sundt-Hansen *et al.,* 2015).

The most recently published study to address the relative fitness of farmed and wild Atlantic salmon in a natural environment was conducted in the River Guddal in Norway (Skaala *et al*., 2012). Here, these authors used a similar design to the Irish study, releasing large numbers of farmed, hybrid, and wild salmon eggs into a river that had no native Atlantic salmon population and following their survival. The study included planting out eggs across three cohorts, and permitted for the first time comparisons of family as well as group-fitness (farmed, hybrid, and wild) in freshwater. As there were no local wild fish, salmon from the Norwegian gene-bank were used as a wild-fish proxy. While these authors reported reduced genetic fitness of farmed salmon offspring compared to the non-local wild salmon, egg size was closely related to family survival in the river. Therefore, some farmed salmon families with large eggs displayed relatively high survival rates in freshwater (higher than some wild families). When these studies were controlled for egg size, farmed salmon offspring displayed significantly lower survival in freshwater compared to the wild salmon. To illustrate this, in 15 of 17 pair-wise comparisons of maternal half-sib groups, families sired with wild males performed better than families sired with farmed fish. The study also revealed that farmed and wild salmon overlapped in diet in the river, an observation also reported from an earlier small-scale release study (Einum and Fleming, 1997) and from the full-generation study in the river Imsa (Fleming *et al*., 2000).

Studies examining the underlying details, mechanisms, and genomics of the observed survival differences between farmed and wild salmon in natural habitats have also been published (Besnier *et al*., 2015; Reed *et al*., 2015), although the exact mechanisms still remain elusive. For example, attempts at quantifying predation in the wild (Skaala *et al*., 2014), and predation susceptibility in semi-natural contests (Solberg *et al*., 2015) have not revealed greater predation of farmed salmon offspring than wild salmon offspring, despite earlier studies suggesting reduced predation awareness caused by domestication (Einum and Fleming, 1997).

Collectively, the results of the whole-river studies outlined above are supported by the widespread literature demonstrating the reduced fitness of hatchery reared salmonids, including those fish used in stocking programmes (Araki *et al*., 2007, 2009; Christie *et al.,* 2014).

Short-term (few generation) consequences of introgression for wild salmon populations

In natural habitats such as rivers, territory and food resources are typically limited, and survival is often controlled by density-dependent factors, and habitats have carrying capacities (Jonsson *et al*., 1998; Bacon *et al*., 2015). Studies have demonstrated that the offspring of farmed salmon compete with wild salmon for resources such as food and space (Skaala *et al*., 2012; Fleming *et al*., 2000). Therefore, when farmed salmon manage to spawn, and their offspring constitute a component of a given rivers´ juvenile population, the production of juveniles with a pure wild background will be depressed though competition for these resources. In addition, data from controlled studies have indicated that the total productivity of smolts in the river following introgression of farmed salmon can decrease (Fleming *et al*., 2000; McGinnity *et al*., 1997).

As discussed in the section above, farmed salmon display a range of genetic differences to wild populations, which includes various life-history and behavioural traits. In whole-river experiments with farmed and wild salmon (McGinnity *et al*., 1997, 2003; Fleming *et al*., 2000; Fraser *et al.,* 2010a; Skaala *et al*., 2012) differences in freshwater growth and body shape, timing of smolt migration, age of smoltification, incidence of male parr maturation, sea-age at maturity, and growth in the marine environment have been observed, with some variation across farmed–wild comparisons (Fraser *et al.*, 2010b). Therefore, where farmed salmon have introgressed in natural populations, it is likely that recipient populations will display changes in life-history traits in the direction of the farmed strains. Given that life-history traits are likely to be associated with fitness in the wild and local adaptation (Garcia de Leaniz *et al*., 2007; Taylor, 1991; Fraser *et al*., 2011; Barson *et al.,* 2015), these changes in life-history characteristics are likely to be associated with a loss of fitness (which will also contribute to an overall reduction in productivity). These changes will be difficult to detect against the background of natural variability in stock abundance and require long-term studies to quantify accurately. At present, there is a lack of empirical data demonstrating such changes in affected wild populations.

The short-term consequences for wild populations is expected to be dependent on the magnitude and frequency of interbreeding events. For example, in rivers where density of wild spawners is low, spawning success of escapees should increase compared with locations where density of wild spawners is high. Similarly, low density of wild juveniles with reduced ability to compete should give farm offspring better survival opportunities than they will have in locations with a high density of wild juveniles. Thus, when populations are under stress and the density of individuals goes down, impact from escapees is expected to increase. These expectations are supported both by modelling (Hutchings, 1991; Hindar *et al*., 2006; Castellani *et al*., 2015) and by studies on observed introgression rates in salmon (Glover *et al*., 2012; Heino *et al*., 2015; Glover *et al*., 2013), and also by studies on brown trout supplemented by non-local hatchery fish (Hansen and Mensberg, 2009).

Atlantic salmon river stocks are characterized by widespread structuring into genetically distinct and differentiated populations (Ståhl, 1987; Verspoor *et al*., 2005). This is conditioned by the evolutionary relationships among populations (Dillane *et al*., 2008; Dionne *et al*., 2008; Perrier *et al*., 2011) and adaptive responses to historical and contemporary environmental differences (Taylor, 1991; Garcia de Leaniz *et al*., 2007). A spatio-temporal genetic study of 21 populations in Norway revealed an overall reduction in inter-population diversity caused by interbreeding of farmed escaped salmon (Glover *et al*., 2012). It is likely that further introgression of farmed salmon will continue to erode this diversity.

Long-term (more than a few generations) consequences of introgression for wild salmon populations

The conservation of genetic variation within and among populations (as outlined in the UN Convention on Biological Diversity, 1992) is important for the resilience of local stocks to human or natural disturbances (Ryman, 1991; Schindler *et al.,* 2010), and in the long term, reduced genetic variability will affect the species' ability to cope with a changing environment (Lande and Shannon, 1996; McGinnity *et al.,* 2009). Therefore, gene flow into wild populations caused by successful spawning of farmed escapees potentially represents a powerful evolutionary force. It erodes genetic variation among these populations (Glover *et al.,* 2012), and in the long run, may also erode the genetic variation within populations under certain situations (Tufto and Hindar, 2003) as the recipient wild populations become more similar to the less variable farmed populations.

Although evolutionary theory and modelling permits us to outline general trajectories, it remains difficult to predict and demonstrate the evolutionary fate of specific wild populations receiving farmed immigrants. The severity and nature of the effect depends on a number of factors. These include:

- the magnitude of the differences between wild and farmed populations (both historical and adaptive differences),
- the mechanisms underlying genetic differences between wild and farmed salmon,
- the frequency of intrusions of farmed fish, and
- the numbers of intruding farmed fish relative to wild spawning population sizes (Hutchings and Fraser, 2008).

Furthermore, wild populations that are already under evolutionary pressure from other challenges such as diseases, lice infection, overharvest, habitat destruction, and poor water quality, etc., are more likely to be sensitive to the potential negative effects of genetic introgression and loss of fitness. Therefore, genetic introgression has to be seen in the context of other challenges.

There have been a number of attempts to model the persistence of wild salmon populations interbreeding with farmed conspecifics. Early modelling work by Hutchings (1991) predicted that the extinction risk of native genomes is largest when interbreeding occurs and when farmed fish occur frequently and at high densities. The risk is largest in small, wild populations, which is related to both demographic and genetic effects. Hindar *et al.* (2006) refined this work by using life-stage specific fitness and narrowing the modelling to scenarios based on experimental data. They found that under high intrusion scenarios the recovery of the wild population is not likely under all circumstances, even when interbreeding has not occurred for many decades. Baskett *et al.* (2013) used a model with coupled demographic and genetic dynamics to evaluate how genetic consequences of aquaculture escapes depend on how divergent the captive and wild populations are. They found negative genetic consequences increased with divergence of the captive population, unless strong selection removes escapees before they reproduce. Recent modelling work by Castellani *et al.* (2015) has focused on using individual-based eco-genetic models, which are parameterized taking processes such as growth, mortality, and maturation as well environmental and genotypic variation into account. This should allow improved power for predicting the outcome of genetic and ecological interactions between wild and farmed salmon. Further field studies would be required to verify (or otherwise) these models.

Taken collectively, existing understanding makes it clear that the long-term consequences of introgression across river stocks can be expected to lead to reduced productivity and decreased resilience to future changes (i.e., less fish and more fragile stocks).

Knowledge gaps

This advice provides a review of the current evidence based on the latest available information in the peer-reviewed literature. While these recent findings have advanced our understanding of the interactions between salmonid aquaculture and wild salmon, substantial uncertainties remain and further investigations are recommended.

Knowledge gaps in relation to impacts of lice include:

- Natural mortality. In order to put mortality from lice into context, there is a need to better understand the causes underlying the current approximate 95% natural mortality of wild salmon and their interactions.
- Transfer of lice. In order to understand better the variation in infestation rates in wild salmon, there is a need to further explore the temporal and spatial variability in the mechanisms underlying the transfer of lice from farmed fish to wild salmonids.
- Long-term effects. There have been few studies of long-term effects of lice on wild salmon populations.
- Distance effects. Little is known on impacts in areas further away from salmon farming concentrations (applies also to escapees).

Knowledge gaps in relation to impacts of farm escapees include:

- Scale of introgression. Monitoring should continue in order to characterize changes in introgression through time. In addition, further characterization of aquaculture strains would better inform management decisions.
- Factors affecting introgression. There is uncertainty around the environmental and biological factors that influence levels of farmed salmon introgression.
- Consequences of introgression and escapees. There is limited knowledge of the ecological consequences of introgression and escapees. This particularly includes effects on the productivity of fish populations in rivers.
- Effects of escapes on the genetic structure of wild Atlantic salmon populations. There is a need for a better understanding of the underlying genetic differences between farmed and wild salmon and how these affect fitness.
- Timing and pace of escapes. There is conflicting evidence surrounding the long-term differences in impact between escapes resulting from major events and gradual leakage.

10.1.9 NASCO has asked ICES to provide a time-series of numbers of river stocks with established CLs and trends in numbers of stocks meeting their CLs by jurisdiction

In this section the attainment of CLs is assessed based on spawners, after fisheries.

In the NAC area, both Canada and the USA currently assess salmon stocks using river-specific CLs (Table 10.1.9.1 and Figure 10.1.9.1).

- In Canada, CLs were first established in 1991 for 74 rivers. Since then the number of rivers with defined CLs increased to 266 in 1997 to 476 since 2014. The number of rivers assessed annually has ranged from 61 to 91 and the annual percentages of these rivers achieving CL has ranged from 26% to 67% with no temporal trend.
- Conservation limits have been established for 33 river stocks in the USA since 1995. Sixteen of these are assessed against CL attainment annually with none meeting CL to date.

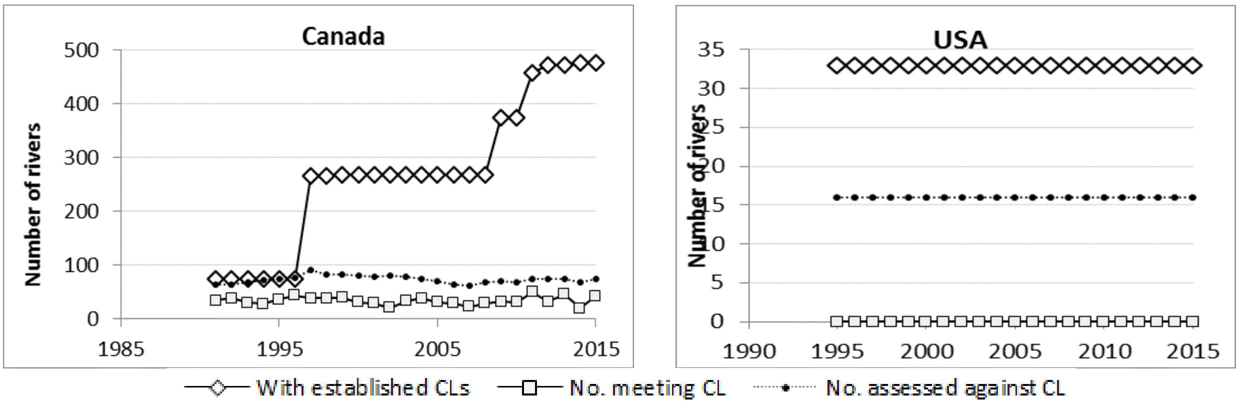


Figure 10.1.9.1 Time-series of NAC areas (Canada left; USA right) with established CLs and trends in the number of stocks meeting CLs (year on *x*-axis).

In the NEAC area, seven countries currently assess salmon stocks using river-specific CLs (Tables 10.1.9.2 and 10.1.9.3 and Figures 10.1.9.2 and 10.1.9.3).

- For the River Teno (Finland/Norway), the number of major tributary stocks with established CLs rose from 9 between 2007 and 2012 (with 5 annually assessed against CL) to 24 since 2013 (with 7 to 10 assessed against CL). None met CL prior to 2013 with 29%, 40%, and 20% meeting CLs in 2013, 2014, and 2015, respectively.
- Since 1999, CLs have been established for 85 river stocks in Russia (Murmansk region) with 8 of these annually assessed for CL attainment, 88% of which have consistently met their CL during the time-series.
- CLs were established for 439 Norwegian salmon rivers in 2009, but CL attainment was retrospectively assessed for 165–170 river stocks back to 2005. An average of 178 stocks are assessed since 2009. An overall increasing trend in CL attainment was evident from 39% in 2009 to provisionally 73% in 2015.
- In France, CLs were established for 28 river stocks in 2011, rising to 33 by 2015. The percentage of stocks meeting CL peaked in 2014 at 74%, dropping to 59% in 2015.
- Ireland established CLs for all 141 stocks in 2007, rising to 143 since 2013 to include catchments above hydrodams. The mean percentage of stocks meeting CLs is 39% over the time-series, with the highest attainment of 43% achieved in 2014. This was followed by a drop to 38% in 2015.
- UK (England & Wales) established CLs in 1993 for 61 rivers, increasing to 64 from 1995 with a mean of 46% meeting CL. In recent years, a downward trend was observed from 66% attainment in 2011 to a minimum of 20% in 2014, followed by an increase to 38% in 2015.
- Data on UK (Northern Ireland) river-specific CLs are presented from 2002, when CLs were assigned to 10 river stocks. Currently, 16 stocks have established CLs and 5 to 10 rivers were assessed annually for CL attainment over the time-series. A mean of 41% have met their CLs over the presented time-series and an upward trend is evident from 2011, with 50% of assessed stocks attaining CL in 2015.

River stocks in UK (Scotland) are not currently assessed against CLs. As part of the regulations to control the killing of wild salmon in UK (Scotland), stocks will be assessed annually at the district scale from the 2016 season onwards (Section 3.2.3). Work is continuing to extend this analysis to the river scale. Iceland and Sweden are working towards developing river stock-specific CLs. No river-specific CLs have been established for Denmark, Germany, and Spain.

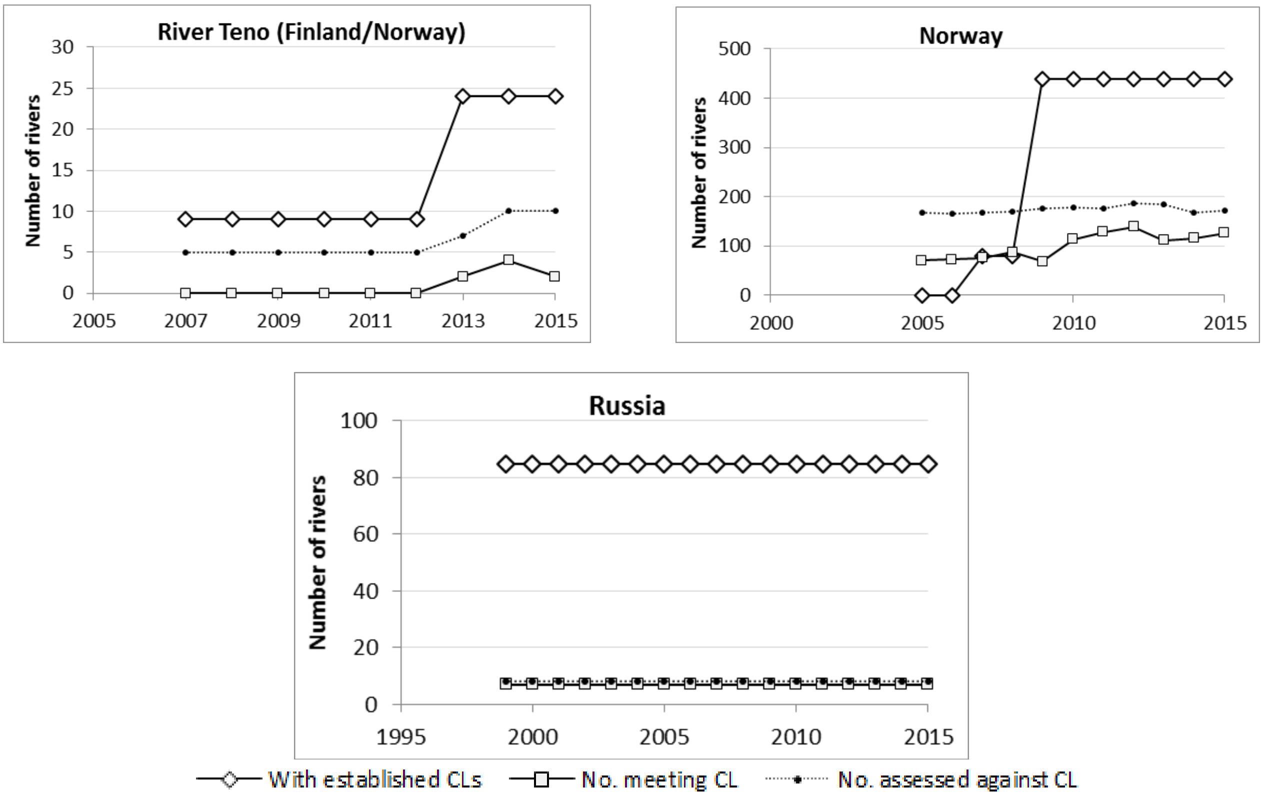


Figure 10.1.9.2 Time-series of northern NEAC area with established CLs and trends in the number of stocks meeting CLs (year on *x*-axis) (For Norway: CL attainment retrospectively assessed 2005–2008).

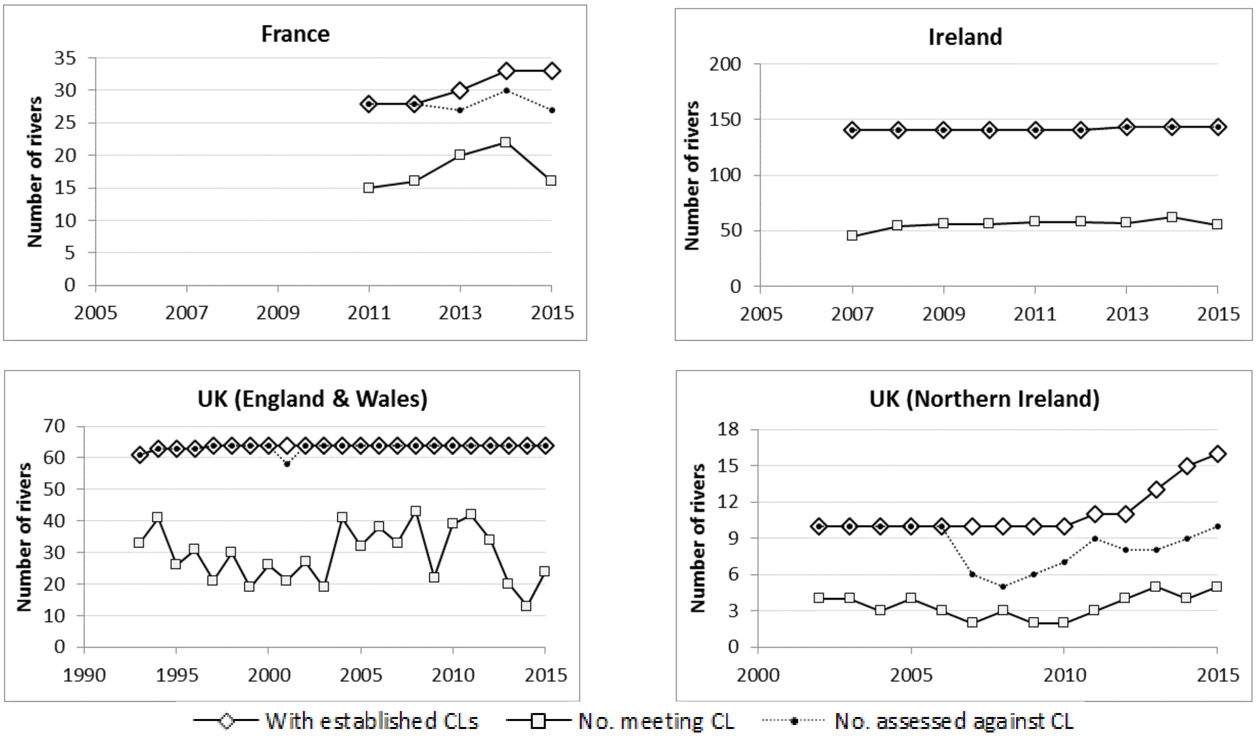


Figure 10.1.9.3 Time-series of southern NEAC area with established CLs and trends in the number of stocks meeting CLs (year on *x*-axis).

10.1.10 Reports from ICES expert groups relevant to North Atlantic salmon

WGRECORDS

The Working Group on the Science Requirements to Support Conservation, Restoration and Management of Diadromous Species (WGRECORDS) was established to provide a scientific forum in ICES for the coordination of work on diadromous species. The role of the Group is to coordinate work on diadromous species, organize expert groups, theme sessions, and symposia, and help to deliver the ICES Science Plan. WGRECORDS held an informal meeting in June 2015, during the NASCO Annual Meeting in Goose Bay, Canada. Discussions were held on the requirements for expert groups to address new and ongoing issues arising from the NASCO Annual Meeting. The annual meeting of WGRECORDS was held in September 2015, during the ICES Annual Science Conference in Copenhagen, Denmark. Updates were received from expert groups of particular relevance to North Atlantic salmon which had been established by ICES following proposals by WGRECORDS.

WGERAAS

An update of the Working Group on Effectiveness of Recovery Actions for Atlantic Salmon (WGERAAS; convener Denis Ensing (UK, N.Ireland)) is provided in Section 10.1.7.

WGDAM

The Working Group on Data-Poor Diadromous Fish (WGDAM; conveners Karen Wilson (USA) and Lari Veneranta (Finland)) met in October 2015 and will report to WGRECORDS in May 2016.

WKTRUTTA2

The ICES Workshop on Sea Trout (WKTRUTTA2; conveners Ted Potter (UK, England and Wales) and Johan Höjesjö (Sweden)) was held in February 2016 to focus on the development of models to help address key management questions and to develop biological reference points (BRPs) for use in the management of sea trout stocks and fisheries.

The decline of sea trout stocks, for example in areas where marine mixed-stock fisheries prevail (e.g. the Baltic) and where there is salmon farming, have raised concerns about our lack of knowledge of the true status of stocks. Sea trout have historically taken second place to Atlantic salmon in national fishery assessment programmes and management priorities; as a result relatively few sea trout stocks have been studied for sufficient time to allow the development of population models. Initiating such studies now will be very expensive and will take many years to provide results that will be useful for modelling. There is therefore a need to consider alternative modelling approaches, for example based on catch data or juvenile surveys, to provide information on stock status to inform management.

The workshop reviewed current national monitoring and assessment programmes. Data collection for sea trout in many countries is poor. Catch reporting is often unreliable and in some countries is not required, although this is generally improving. There are few index river studies on sea trout, and although juvenile surveys are conducted in most countries, it is unclear how representative these are of total stocks.

Relatively little population modelling of sea trout has been undertaken to date, and very little work has been undertaken to develop BRPs. A range of modelling approaches were discussed by the group, although it was recognised that their application would generally be restricted by the lack of data. BRPs would ideally be established on the basis of stock–recruitment relationships for index river stocks, and some such work has been undertaken (e.g. River Burrishoole, Ireland). But the transport of BRPs from index sites to other rivers is constrained by the limited number of studies that have been undertaken and the complex and variable nature of trout populations. Two alternative approaches were considered for setting BRPs or alternative management standards. The first, based on the use of catch data to develop “pseudo-stock–recruitment relationships”, showed promise, but its application is likely to be limited by the relatively small number of rivers throughout the northeast Atlantic for which good historical (and current) catch data are available. This work is expected to be developed further in England and Wales. The second approach was based on establishing Trout Habitat Scores for pristine/optimal juvenile trout populations. This approach is being applied in the Baltic, and the workshop recommended that a working group be established to further advance the approach, test its application more widely outside the Baltic, and develop a clearer method setting reference levels.

The final report of the workshop is expected to be produced in the summer of 2016.

In addition, theme sessions and symposia may be developed and proposed by WGRECORDS.

A theme session for the ICES ASC in 2016 has been accepted by ICES entitled:

"Ecosystem changes and impacts on diadromous and marine species productivity." Conveners Katherine Mills (USA), Tim Sheehan (USA), and Mark Payne (Denmark)

Theme session proposals for 2017 and 2018 that are being considered and which are of relevance to NASCO:

From freshwater to marine and back again – population status, life histories, and ecology of least known migratory fishes. Conveners Karen Wilson (USA) and Lari Veneranta (Finland) in 2017.

Options for mitigating against poor marine survival and low stock levels of migratory fish stocks, including endangered fish species, without jeopardizing long-term fitness of wild populations. Conveners to be announced (2018)***.***

ICES and the International Year of the Salmon

In 2002, NASCO, ICES, the North Pacific Anadromous Fish Commission (NPAFC), the North Pacific Marine Science Organization (PICES), and the International Baltic Sea Fishery Commission (IBSFC) cooperated in holding a workshop entitled "Causes of Marine Mortality of Salmon in the North Pacific and North Atlantic Oceans and in the Baltic Sea". The report of the meeting was published as an NPAFC Technical bulletin and is available on the NPAFC website (http://www.npafc.org/new/pub_technical4.html). The workshop demonstrated the benefits of, and the need to maintain and enhance cooperation and information exchange within and between the North Pacific and North Atlantic oceans and the Baltic Sea. Those attending the workshop supported holding an expanded international symposium on the marine survival of salmon. While symposia have been held in relation to the BASIS Programme in the North Pacific and the SALSEA Programme in the North Atlantic there has not, as yet, been a follow-up joint meeting or symposium.

NPAFC has now endorsed, in principle, the concept of an International Year of the Salmon (IYS) and has already held the first scoping meeting to further develop ideas for the IYS: a multi-year (2016–2022) programme centred on an "intensive burst of internationally coordinated, interdisciplinary, stimulating scientific research on salmon, and their relation to people". It considers that new technologies, new observations, and new analytical methods, some developed exclusively during the IYS, will be focused on gaps in knowledge that prevent the clear and timely understanding of the future of salmon in a rapidly changing world. It considers that the current pace of research is too slow in the face of this change and that a burst of activity is needed to develop new tools, a coordinated approach to their development and application, and field observations to close information gaps.

This first scoping workshop was held in February 2015, and ICES was identified as a key potential partner. NPAFC notes that ICES shares alignment with the goals of the IYS. The NPAFC hosted a Second IYS Scoping Meeting 15–16 March 2016, in Vancouver, BC, and invited ICES to join this meeting to advise and support in planning this initiative.

ICES recognises this opportunity to raise awareness of the salmon globally, the issues facing these species, and the considerable efforts being made to conserve and restore stocks and that it endorses the concept of an IYS. Therefore ICES is currently considering their involvement in, and contribution to, such an initiative and the resources it wishes to make available to support the IYS, so that informed discussions can be held with NPAFC.

10.1.11 NASCO has asked ICES to provide a compilation of tag releases by country in 2015

Data on releases of tagged, fin-clipped, and otherwise marked salmon in 2015 were provided to the WGNAS and are compiled as a separate report (ICES, 2016b). A summary of tag releases is provided in Table 10.1.11.1.

10.1.12 NASCO has asked ICES to identify relevant data deficiencies, monitoring needs, and research requirements

ICES recommends that the WGNAS should meet in 2017 (Chair: Jonathan White, Ireland) to address questions posed by ICES, including those posed by NASCO. The working group intends to convene at the headquarters of ICES in Copenhagen, Denmark. The meeting will be held from 28 March to 6 April 2017.

The following relevant data deficiencies, monitoring needs, and research requirements were identified:

1) Sampling and supporting descriptions of the Labrador and Saint Pierre & Miquelon mixed-stock fisheries need to be continued and expanded (i.e. sample size, geographic coverage, tissue samples, seasonal distri-

bution of the samples) in future years to improve the information on biological characteristics and stock origin of salmon harvested in these mixed-stock fisheries.

2) Additional monitoring needs to be considered in Labrador to estimate stock status for that region. Furthermore, efforts should be undertaken to evaluate the utility of other available data sources (e.g. aboriginal and recreational catches and effort) to describe stock status in Labrador.

3) Further analysis of the resulting data and continuation of the phone survey programme in the Greenland fishery should be conducted. Information gained on the level of total catches for this fishery will provide for a more accurate assessment of the status of stocks and assessment of risk with varying levels of harvest.

4) Efforts to improve the Greenland catch reporting system should continue and detailed statistics related to catch and effort should be made available to WGNAS for analysis.

5) The broad geographic sampling programme at West Greenland (multiple NAFO divisions, including factory and non-factory landings) should be continued and potentially expanded to more accurately estimate continent and region of origin and biological characteristics of the mixed-stock fishery.

Table 10.1.5.1 Reported total nominal catches of salmon by country (in tonnes round fresh weight), 1960 to 2015 (2015 figures include provisional data).

	NAC Area			NEAC (N. Area)								NEAC (S. Area)						Faroes & Greenland				Total	Unreported catches	
Year	Canada (1)	USA	St. P&M	Norway (2)	Russia (3)	Iceland Wild	Iceland Ranch (4)	Sweden Wild	Sweden Ranch (15)	Denmark	Finland	Ireland (5,6)	UK (E & W)	UK (N.Irl.) (6,7)	UK (Scotl.)	France (8)	Spain (9)	Faroes (10)	East Grld.	West Grld. (11)	Other (12)	Reported Nominal Catch	NASCO Areas (13)	International waters (14)
1960	1,636	1	-	1,659	1,100	100	-	40	0	-	-	743	283	139	1,443	-	33	-	-	60	-	7,237	-	-
1961	1,583	1	-	1,533	790	127	-	27	0	-	-	707	232	132	1,185	-	20	-	-	127	-	6,464	-	-
1962	1,719	1	-	1,935	710	125	-	45	0	-	-	1,459	318	356	1,738	-	23	-	-	244	-	8,673	-	-
1963	1,861	1	-	1,786	480	145	-	23	0	-	-	1,458	325	306	1,725	-	28	-	-	466	-	8,604	-	-
1964	2,069	1	-	2,147	590	135	-	36	0	-	-	1,617	307	377	1,907	-	34	-	-	1,539	-	10,759	-	-
1965	2,116	1	-	2,000	590	133	-	40	0	-	-	1,457	320	281	1,593	-	42	-	-	861	-	9,434	-	-
1966	2,369	1	-	1,791	570	104	2	36	0	-	-	1,238	387	287	1,595	-	42	-	-	1,370	-	9,792	-	-
1967	2,863	1	-	1,980	883	144	2	25	0	-	-	1,463	420	449	2,117	-	43	-	-	1,601	-	11,991	-	-
1968	2,111	1	-	1,514	827	161	1	20	0	-	-	1,413	282	312	1,578	-	38	5	-	1,127	403	9,793	-	-
1969	2,202	1	-	1,383	360	131	2	22	0	-	-	1,730	377	267	1,955	-	54	7	-	2,210	893	11,594	-	-
1970	2,323	1	-	1,171	448	182	13	20	0	-	-	1,787	527	297	1,392	-	45	12	-	2,146	922	11,286	-	-
1971	1,992	1	-	1,207	417	196	8	17	1	-	-	1,639	426	234	1,421	-	16	-	-	2,689	471	10,735	-	-
1972	1,759	1	-	1,578	462	245	5	17	1	-	32	1,804	442	210	1,727	34	40	9	-	2,113	486	10,965	-	-
1973	2,434	3	-	1,726	772	148	8	22	1	-	50	1,930	450	182	2,006	12	24	28	-	2,341	533	12,670	-	-
1974	2,539	1	-	1,633	709	215	10	31	1	-	76	2,128	383	184	1,628	13	16	20	-	1,917	373	11,877	-	-
1975	2,485	2	-	1,537	811	145	21	26	0	-	76	2,216	447	164	1,621	25	27	28	-	2,030	475	12,136	-	-
1976	2,506	1	3	1,530	542	216	9	20	0	-	66	1,561	208	113	1,019	9	21	40	<1	1,175	289	9,327	-	-
1977	2,545	2	-	1,488	497	123	7	9	1	-	59	1,372	345	110	1,160	19	19	40	6	1,420	192	9,414	-	-
1978	1,545	4	-	1,050	476	285	6	10	0	-	37	1,230	349	148	1,323	20	32	37	8	984	138	7,682	-	-
1979	1,287	3	-	1,831	455	219	6	11	1	-	26	1,097	261	99	1,076	10	29	119	<0,5	1,395	193	8,118	-	-
1980	2,680	6	-	1,830	664	241	8	16	1	-	34	947	360	122	1,134	30	47	536	<0,5	1,194	277	10,127	-	-
1981	2,437	6	-	1,656	463	147	16	25	1	-	44	685	493	101	1,233	20	25	1,025	<0,5	1,264	313	9,954	-	-
1982	1,798	6	-	1,348	364	130	17	24	1	-	54	993	286	132	1,092	20	10	606	<0,5	1,077	437	8,395	-	-
1983	1,424	1	3	1,550	507	166	32	27	1	-	58	1,656	429	187	1,221	16	23	678	<0,5	310	466	8,755	-	-
1984	1,112	2	3	1,623	593	139	20	39	1	-	46	829	345	78	1,013	25	18	628	<0,5	297	101	6,912	-	-
1985	1,133	2	3	1,561	659	162	55	44	1	-	49	1,595	361	98	913	22	13	566	7	864	-	8,108	-	-
1986	1,559	2	3	1,598	608	232	59	52	2	-	37	1,730	430	109	1,271	28	27	530	19	960	-	9,255	315	-
1987	1,784	1	2	1,385	564	181	40	43	4	-	49	1,239	302	56	922	27	18	576	<0,5	966	-	8,159	2,788	-
1988	1,310	1	2	1,076	420	217	180	36	4	-	36	1,874	395	114	882	32	18	243	4	893	-	7,737	3,248	-
1989	1,139	2	2	905	364	141	136	25	4	-	52	1,079	296	142	895	14	7	364	-	337	-	5,904	2,277	-
1990	911	2	2	930	313	141	285	27	6	13	60	567	338	94	624	15	7	315	-	274	-	4,925	1,890	180-350

Table 10.1.5.1 (continued).

	NAC Area			NEAC (N. Area)								NEAC (S. Area)						Faroes & Greenland				Total	Unreported catches	
													UK	UK	UK				East	West		Reported		
Year	Canada	USA	St. P&M	Norway	Russia	Iceland		Sweden		Denmark	Finland	Ireland	(E & W)	(N.Irl.)	(Scotl.)	France	Spain	Faroes	Grld.	Grld.	Other	Nominal	NASCO	International
	(1)			(2)	(3)	Wild	Ranch (4)	Wild	Ranch (15)			(5,6)		(6,7)		(8)	(9)	(10)		(11)	(12)	Catch	Areas (13)	waters (14)
1991	711	1	1	876	215	129	346	34	4	3	70	404	200	55	462	13	11	95	4	472	-	4,106	1,682	25-100
1992	522	1	2	867	167	174	462	46	3	10	77	630	171	91	600	20	11	23	5	237	-	4,119	1,962	25-100
1993	373	1	3	923	139	157	499	44	12	9	70	541	248	83	547	16	8	23	-	-	-	3,696	1,644	25-100
1994	355	0	3	996	141	136	313	37	7	6	49	804	324	91	649	18	10	6	-	-	-	3,945	1,276	25-100
1995	260	0	1	839	128	146	303	28	9	3	48	790	295	83	588	10	9	5	2	83	-	3,629	1,060	-
1996	292	0	2	787	131	118	243	26	7	2	44	685	183	77	427	13	7	-	0	92	-	3,136	1,123	-
1997	229	0	2	630	111	97	59	15	4	1	45	570	142	93	296	8	4	-	1	58	-	2,364	827	-
1998	157	0	2	740	131	119	46	10	5	1	48	624	123	78	283	8	4	6	0	11	-	2,395	1,210	-
1999	152	0	2	811	103	111	35	11	5	1	62	515	150	53	199	11	6	0	0	19	-	2,247	1,032	-
2000	153	0	2	1,176	124	73	11	24	9	5	95	621	219	78	274	11	7	8	0	21	-	2,912	1,269	-
2001	148	0	2	1,267	114	74	14	25	7	6	126	730	184	53	251	11	13	0	0	43	-	3,069	1,180	-
2002	148	0	2	1,019	118	90	7	20	8	5	93	682	161	81	191	11	9	0	0	9	-	2,654	1,039	-
2003	141	0	3	1,071	107	99	11	15	10	4	78	551	89	56	192	13	9	0	0	9	-	2,457	847	-
2004	161	0	3	784	82	111	18	13	7	4	39	489	111	48	245	19	7	0	0	15	-	2,157	686	-
2005	139	0	3	888	82	129	21	9	6	8	47	422	97	52	215	11	13	0	0	15	-	2,155	700	-
2006	137	0	3	932	91	93	17	8	6	2	67	326	80	29	192	13	11	0	0	22	-	2,028	670	-
2007	112	0	2	767	63	93	36	6	10	3	58	85	67	30	171	11	9	0	0	25	-	1,548	475	-
2008	158	0	4	807	73	132	69	8	10	9	71	89	64	21	161	12	9	0	0	26	-	1,721	443	-
2009	126	0	3	595	71	126	44	7	10	8	36	68	54	16	121	4	2	0	0.8	26	-	1,318	343	-
2010	153	0	3	642	88	147	42	9	13	13	49	99	109	12	180	10	2	0	1.7	38	-	1,610	393	-
2011	179	0	4	696	89	98	30	20	19	13	44	87	136	10	159	11	7	0	0.1	27	-	1,629	421	-
2012	126	0	3	696	82	50	20	21	9	12	64	88	58	9	124	10	7	0	0.5	33	-	1,412	403	-
2013	137	0	5	475	78	116	31	10	4	11	46	87	84	4	119	11	5	0	0.0	47	-	1,270	306	-
2014	118	0	4	490	81	51	20	24	6	9	58	57	54	2	84	12	7	0	0.1	58	-	1,134	287	-
2015	134	0	4	583	80	103	29	9	7	9	45	63	69	5	68	16	6	0	1.0	56	-	1,285	325	-
Average																								
2010-2014	143	0	4	600	84	92	29	17	10	11	52	84	88	8	133	11	5	0	0.5	41	-	1,411	362	-
2005-2014	139	0	3	699	80	104	33	12	9	9	54	141	80	19	153	10	7	0	0.3	32	-	1,582	444	-

Key:

1. Includes estimates of some local sales, and, prior to 1984, by-catch.
2. Before 1966, sea trout and sea charr included (5% of total).
3. Figures from 1991 to 2000 do not include catches taken in the recreational (rod) fishery.
4. From 1990, catch includes fish ranched for both commercial and angling purposes.
5. Improved reporting of rod catches in 1994 and data derived from carcase tagging and log books from 2002.
6. Catch on River Foyle allocated 50% Ireland and 50% N. Ireland.
7. Angling catch (derived from carcase tagging and log books) first included in 2002.
8. Data for France include some unreported catches.
9. Weights estimated from mean weight of fish caught in Asturias (80-90% of Spanish catch).
10. Between 1991 & 1999, there was only a research fishery at Faroes. In 1997 & 1999 no fishery took place; the commercial fishery resumed in 2000, but has not operated since 2001.
11. Includes catches made in the West Greenland area by Norway, Faroes, Sweden and Denmark in 1965-1975.
12. Includes catches in Norwegian Sea by vessels from Denmark, Sweden, Germany, Norway and Finland.
13. No unreported catch estimate available for Canada in 2007 and 2008. Data for Canada in 2009 and 2010 are incomplete. No unreported catch estimate available for Russia since 2008.
14. Estimates refer to season ending in given year.
15. Catches from hatchery-reared smolts released under programmes to mitigate for hydropower development schemes; returning fish unable to spawn in the wild and exploited heavily.

Table 10.1.5.2 The catch (tonnes round fresh weight) and % of the nominal catch by country taken in coastal, estuarine, and riverine fisheries.

Country	Year	Coast		Estuary		River		Total
		Weight	%	Weight	%	Weight	%	weight
Canada	2000	2	2	29	19	117	79	148
	2001	3	2	28	20	112	78	143
	2002	4	2	30	20	114	77	148
	2003	5	3	36	27	96	70	137
	2004	7	4	46	29	109	67	161
	2005	7	5	44	32	88	63	139
	2006	8	6	46	34	83	60	137
	2007	6	5	36	32	70	63	112
	2008	9	6	47	32	92	62	147
	2009	7	6	40	33	73	61	119
	2010	6	4	40	27	100	69	146
	2011	7	4	56	31	115	65	178
	2012	8	6	46	36	73	57	127
	2013	8	6	49	36	80	58	137
	2014	7	6	28	24	83	71	118
	2015	8	6	35	26	91	68	134
Finland	1996	0	0	0	0	44	100	44
	1997	0	0	0	0	45	100	45
	1998	0	0	0	0	48	100	48
	1999	0	0	0	0	63	100	63
	2000	0	0	0	0	96	100	96
	2001	0	0	0	0	126	100	126
	2002	0	0	0	0	94	100	94
	2003	0	0	0	0	75	100	75
	2004	0	0	0	0	39	100	39
	2005	0	0	0	0	47	100	47
	2006	0	0	0	0	67	100	67
	2007	0	0	0	0	59	100	59
	2008	0	0	0	0	71	100	71
	2009	0	0	0	0	38	100	38
	2010	0	0	0	0	49	100	49
	2011	0	0	0	0	44	100	44
	2012	0	0	0	0	64	100	64
	2013	0	0	0	0	46	100	46
	2014	0	0	0	0	58	100	58
	2015	0	0	0	0	45	100	45
France	1996	0	0	4	31	9	69	13
	1997	0	0	3	38	5	63	8
	1998	1	13	2	25	5	63	8
	1999	0	0	4	35	7	65	11
	2000	0	4	4	35	7	61	11
	2001	0	4	5	44	6	53	11
	2002	2	14	4	30	6	56	12
	2003	0	0	6	44	7	56	13
	2004	0	0	10	51	9	49	19
	2005	0	0	4	38	7	62	11
	2006	0	0	5	41	8	59	13
	2007	0	0	4	42	6	58	11
	2008	1	5	5	39	7	57	12
	2009	0	4	2	34	3	62	5
	2010	2	22	3	26	5	52	10
	2011	0	3	6	54	5	43	11
	2012	0	1	4	44	5	55	10
	2013	0	3	4	40	6	57	11
	2014	0	2	5	43	7	55	12
	2015	4	23	5	32	7	45	16
Iceland	1996	11	9	0	0	111	91	122
	1997	0	0	0	0	156	100	156
	1998	0	0	0	0	164	100	164
	1999	0	0	0	0	147	100	147
	2000	0	0	0	0	85	100	85
	2001	0	0	0	0	88	100	88
	2002	0	0	0	0	97	100	97
	2003	0	0	0	0	110	100	110
	2004	0	0	0	0	130	100	130
	2005	0	0	0	0	149	100	149
	2006	0	0	0	0	111	100	111
	2007	0	0	0	0	129	100	129
	2008	0	0	0	0	200	100	200

Country	Year	Coast		Estuary		River		Total
		Weight	%	Weight	%	Weight	%	weight
	2009	0	0	0	0	171	100	171
	2010	0	0	0	0	190	100	190
	2011	0	0	0	0	128	100	128
	2012	0	0	0	0	70	100	70
	2013	0	0	0	0	147	100	147
	2014	0	0	0	0	70	100	70
	2015	0	0	0	0	132	100	132
Ireland	1996	440	64	134	20	110	16	684
	1997	380	67	100	18	91	16	571
	1998	433	69	92	15	99	16	624
	1999	335	65	83	16	97	19	515
	2000	440	71	79	13	102	16	621
	2001	551	75	109	15	70	10	730
	2002	514	75	89	13	79	12	682
	2003	403	73	92	17	56	10	551
	2004	342	70	76	16	71	15	489
	2005	291	69	70	17	60	14	421
	2006	206	63	60	18	61	19	327
	2007	0	0	31	37	52	63	83
	2008	0	0	29	33	60	67	89
	2009	0	0	20	30	47	70	67
	2010	0	0	38	39	60	61	99
	2011	0	0	32	37	55	63	87
	2012	0	0	28	32	60	68	88
	2013	0	0	38	44	49	56	87
	2014	0	0	26	46	31	54	57
	2015	0	0	21	33	42	67	63
Norway	1996	520	66	0	0	267	34	787
	1997	394	63	0	0	235	37	629
	1998	410	55	0	0	331	45	741
	1999	483	60	0	0	327	40	810
	2000	619	53	0	0	557	47	1176
	2001	696	55	0	0	570	45	1266
	2002	596	58	0	0	423	42	1019
	2003	597	56	0	0	474	44	1071
	2004	469	60	0	0	316	40	785
	2005	463	52	0	0	424	48	888
	2006	512	55	0	0	420	45	932
	2007	427	56	0	0	340	44	767
	2008	382	47	0	0	425	53	807
	2009	284	48	0	0	312	52	595
	2010	260	41	0	0	382	59	642
	2011	302	43	0	0	394	57	696
	2012	255	37	0	0	440	63	696
	2013	192	40	0	0	283	60	475
	2014	213	43	0	0	277	57	490
	2015	233	40	0	0	350	60	583
Russia	1996	64	49	21	16	46	35	131
	1997	63	57	17	15	32	28	111
	1998	55	42	2	2	74	56	131
	1999	48	47	2	2	52	51	102
	2000	64	52	15	12	45	36	124
	2001	70	61	0	0	44	39	114
	2002	60	51	0	0	58	49	118
	2003	57	53	0	0	50	47	107
	2004	46	56	0	0	36	44	82
	2005	58	70	0	0	25	30	82
	2006	52	57	0	0	39	43	91
	2007	31	50	0	0	31	50	63
	2008	33	45	0	0	40	55	73
	2009	22	31	0	0	49	69	71
	2010	36	41	0	0	52	59	88
	2011	37	42	0	0	52	58	89
	2012	38	46	0	0	45	54	82
	2013	36	46	0	0	42	54	78
	2014	33	41	0	0	48	59	81
	2015	34	42	0	0	46	58	80
Spain	1996	0	0	0	0	7	100	7
	1997	0	0	0	0	4	100	4
	1998	0	0	0	0	4	100	4
	1999	0	0	0	0	6	100	6
	2000	0	0	0	0	7	100	7

Country	Year	Coast		Estuary		River		Total
		Weight	%	Weight	%	Weight	%	weight
	2001	0	0	0	0	13	100	13
	2002	0	0	0	0	9	100	9
	2003	0	0	0	0	7	100	7
	2004	0	0	0	0	7	100	7
	2005	0	0	0	0	13	100	13
	2006	0	0	0	0	11	100	11
	2007	0	0	0	0	10	100	10
	2008	0	0	0	0	10	100	10
	2009	0	0	0	0	2	100	2
	2010	0	0	0	0	2	100	2
	2011	0	0	0	0	7	100	7
	2012	0	0	0	0	8	100	8
	2013	0	0	0	0	5	100	5
	2014	0	0	0	0	7	100	7
	2015	0	0	0	0	6	100	6
Sweden	1996	19	58	0	0	14	42	33
	1997	10	56	0	0	8	44	18
	1998	5	33	0	0	10	67	15
	1999	5	31	0	0	11	69	16
	2000	10	30	0	0	23	70	33
	2001	9	27	0	0	24	73	33
	2002	7	25	0	0	21	75	28
	2003	7	28	0	0	18	72	25
	2004	3	16	0	0	16	84	19
	2005	1	7	0	0	14	93	15
	2006	1	7	0	0	13	93	14
	2007	0	1	0	0	16	99	16
	2008	0	1	0	0	18	99	18
	2009	0	3	0	0	17	97	17
	2010	0	0	0	0	22	100	22
	2011	10	26	0	0	29	74	39
	2012	7	24	0	0	23	76	30
	2013	0	0	0	0	15	100	15
	2014	0	0	0	0	30	100	30
	2015	0	0	0	0	16	100	16
UK	1996	83	45	42	23	58	31	183
England & Wales	1997	81	57	27	19	35	24	142
	1998	65	53	19	16	38	31	123
	1999	101	67	23	15	26	17	150
	2000	157	72	25	12	37	17	219
	2001	129	70	24	13	31	17	184
	2002	108	67	24	15	29	18	161
	2003	42	47	27	30	20	23	89
	2004	39	35	19	17	53	47	111
	2005	32	33	28	29	36	37	97
	2006	30	37	21	26	30	37	80
	2007	24	36	13	20	30	44	67
	2008	22	34	8	13	34	53	64
	2009	20	37	9	16	25	47	54
	2010	64	59	9	8	36	33	109
	2011	93	69	6	5	36	27	136
	2012	26	45	5	8	27	47	58
	2013	61	73	6	7	17	20	84
	2014	41	76	4	8	9	16	54
	2015	55	79	5	7	10	14	69
UK	1999	44	83	9	17	-	-	53
N. Ireland	2000	63	82	14	18	-	-	77
	2001	41	77	12	23	-	-	53
	2002	40	49	24	29	18	22	81
	2003	25	45	20	35	11	20	56
	2004	23	48	11	22	14	29	48
	2005	25	49	13	25	14	26	52
	2006	13	45	6	22	9	32	29
	2007	6	21	6	20	17	59	30
	2008	4	19	5	22	12	59	21
	2009	4	24	2	15	10	62	16
	2010	5	39	0	0	7	61	12
	2011	3	24	0	0	8	76	10
	2012	0	0	0	0	9	100	9
	2013	0	1	0	0	4	99	4
	2014	0	0	0	0	2	100	2
	2015	0	0	0	0	5	100	5

Country	Year	Coast		Estuary		River		Total
		Weight	%	Weight	%	Weight	%	weight
UK	1996	129	30	80	19	218	51	427
Scotland	1997	79	27	33	11	184	62	296
	1998	60	21	28	10	195	69	283
	1999	35	18	23	11	141	71	199
	2000	76	28	41	15	157	57	274
	2001	77	30	22	9	153	61	251
	2002	55	29	20	10	116	61	191
	2003	87	45	23	12	83	43	193
	2004	67	27	20	8	160	65	247
	2005	62	29	27	12	128	59	217
	2006	57	30	17	9	119	62	193
	2007	40	24	17	10	113	66	171
	2008	38	24	11	7	112	70	161
	2009	27	22	14	12	79	66	121
	2010	44	25	38	21	98	54	180
	2011	48	30	23	15	87	55	159
	2012	40	32	11	9	73	59	124
	2013	50	42	26	22	43	36	119
	2014	41	49	17	20	26	31	84
	2015	31	46	9	14	27	40	68
Denmark	2008	0	1	0	0	9	99	9
	2009	0	0	0	0	8	100	8
	2010	0	1	0	0	13	99	13
	2011	0	0	0	0	13	100	13
	2012	0	0	0	0	12	100	12
	2013	0	0	0	0	11	100	11
	2014	0	0	0	0	9	100	9
	2015	0	0	0	0	9	100	9
Totals								
NEAC	2015	356	33	40	4	680	63	1076
NAC	2015	8	6	35	26	91	68	134

Table 10.1.5.3 Estimates of unreported catches by various methods, in tonnes by country within national EEZs in the North East Atlantic, North American, and West Greenland Commissions of NASCO, 2015.

Commission Area	Country	Unreported Catch t	Unreported as % of Total North Atlantic Catch (Unreported + Reported)	Unreported as % of Total National Catch (Unreported + Reported)
NEAC	Denmark	6	0.4	39
NEAC	Finland	6	0.4	12
NEAC	Iceland	4	0.3	3
NEAC	Ireland	6	0.5	9
NEAC	Norway	250	17.9	30
NEAC	Sweden	3	0.2	14
NEAC	France	3	0.2	16
NEAC	UK (E & W)	13	0.9	16
NEAC	UK (N.Ireland)	0	0.0	6
NEAC	UK (Scotland)	7	0.5	9
NAC	USA	0	0.0	0
NAC	Canada	17	1.2	11
WGC	West Greenland	10	0.7	15
	Total Unreported Catch *	325	20.2	
	Total Reported Catch of North Atlantic salmon	1,284		

* No unreported catch estimate available for Russia in 2015.
Unreported catch estimates not provided for Spain & St. Pierre et Miquelon

Table 10.1.5.4 Numbers of fish caught and released in rod fisheries along with the % of the total rod catch (released + retained) for countries in the North Atlantic where records are available, 1991–2015. Figures for 2015 are provisional.

Year	Canada [4]		USA		Iceland		Russia [1]		UK (E&W)		UK (Scotland)		Ireland		UK (N Ireland) [2]		Denmark		Sweden		Norway [3]		Total
	Total	% of total rod catch	Total	% of total rod catch	Total	% of total rod catch	Total	% of total rod catch	Total	% of total rod catch	Total	% of total rod catch	Total	% of total rod catch	Total	% of total rod catch	Total	% of total rod catch	Total	% of total rod catch	Total	% of total rod catch	catch & release
1991	22 167	28	239	50.1			3 211	51															25 617
1992	37 803	29	407	66.7			10 120	73															48 330
1993	44 803	36	507	76.9			11 246	82	1 448	10													58 004
1994	52 887	43	249	95.0			12 056	83	3 227	13	6 595	8											75 014
1995	46 029	46	370	100.0			11 904	84	3 189	20	12 151	14											73 643
1996	52 166	41	542	100.0	669	2	10 745	73	3 428	20	10 413	15											77 963
1997	50 009	50	333	100.0	1 558	5	14 823	87	3 132	24	10 965	18											80 820
1998	56 289	53	273	100.0	2 826	7	12 776	81	4 378	30	13 464	18											90 006
1999	48 720	50	211	100.0	3 055	10	11 450	77	4 382	42	14 846	28											82 664
2000	64 482	56	0	-	2 918	11	12 914	74	7 470	42	21 072	32											108 856
2001	59 387	55	0	-	3 611	12	16 945	76	6 143	43	27 724	38											113 810
2002	50 924	52	0	-	5 985	18	25 248	80	7 658	50	24 058	42											113 873
2003	53 645	55	0	-	5 361	16	33 862	81	6 425	56	29 170	55											128 463
2004	62 316	57	0	-	7 362	16	24 679	76	13 211	48	46 279	50					255	19					154 102
2005	63 005	62	0	-	9 224	17	23 592	87	11 983	56	46 165	55	2 553	12			606	27					157 128
2006	60 486	62	1	100.0	8 735	19	33 380	82	10 959	56	47 669	55	5 409	22	302	18	794	65					167 735
2007	41 192	58	3	100.0	9 691	18	44 341	90	10 917	55	55 660	61	15 113	44	470	16	959	57					178 346
2008	54 887	53	61	100.0	17 178	20	41 881	86	13 035	55	53 347	62	13 563	38	648	20	2 033	71			5 512	5	202 145
2009	52 151	59	0	-	17 514	24			9 096	58	48 418	67	11 422	39	847	21	1 709	53			6 696	6	147 853
2010	55 895	53	0	-	21 476	29	14 585	56	15 012	60	78 357	70	15 142	40	823	25	2 512	60			15 041	12	218 843
2011	71 358	57	0	-	18 593	32			14 406	62	64 813	73	12 688	38	1 197	36	2 153	55			14 303	12	199 511
2012	43 287	57	0	-	9 752	28	4 743	43	11 952	65	63 370	74	11 891	35	5 014	59	2 153	55			18 611	14	170 773
2013	50 630	59	0	-	23 133	34	3 732	39	10 458	70	54 003	80	10 682	37	1 507	64	1 932	57			15 953	15	172 030
2014	41 613	54	0	-	13 616	41	8 479	52	7 992	78	37 270	82	6 537	37	1 065	50	1 918	61	445	15	20 281	19	139 216
2015	64 159	64	0		29 341	40	7 028	50	9 925	79	45 973	84	9 374	37	111	100	2 989	70	725	19	25 433	19	195 058
5-yr mean 2010-2014	52 557	56.1			17 314	32.6	7 885	47.5	11 964	66.9	59 563	75.7	11 388	37.4	1 921	46.8	2 134	57.6			16 838	14.3	180 075
% change on 5-year mean	22.1	14.1			69.5	21.2	-10.9	5.3	-17.0	18.1	-22.8	10.9	-17.7	-1.1	-94.2	113.7	40.1	21.5			51.0	34.8	8.3

Key:
[1] Since 2009 data are either unavailable or incomplete, however catch-and-release is understood to have remained at similar high levels as before.
[2] Data for 2006-2009 is for the DCAL area only; the figures from 2010 are a total for UK (N.Ireland). Data for 2015 is for R. Bush only.
[3] The statistics were collected on a voluntary basis, the numbers reported must be viewed as a minimum.
[4] Released fish in the kelt fishery of New Brunswick are not included in the totals for Canada.
[5] 2014 information based on Loughs Agency, DCAL area only.

Table 10.1.7.1 Overview of the number of case studies examined and the data base on Effective Recovery Actions for Atlantic salmon (DBERAAS) river stock entries per nation.

Nation	Region	Number rivers DBERAAS	Number Case Studies
Iceland	N/S NEAC	84	0
Faroe Islands	N NEAC	0	0
Norway	N NEAC	0	1
Sweden	N NEAC/HELCOM	77	1
Russian Federation	N NEAC/HELCOM	0	1
Finland	N NEAC/HELCOM	69	1
Poland	HELCOM	0	0
Lithuania	HELCOM	0	0
Estonia	HELCOM	12	0
Denmark	N NEAC/HELCOM	9	0
Germany	S NEAC/HELCOM	4	1
France	S NEAC	0	2
Spain	S NEAC	10	0
Ireland	S NEAC	148	4
UK (England & Wales)	S NEAC	93	2
UK (Scotland)	S NEAC	0	0
UK (Northern Ireland)	S NEAC	19	0
Canada	NAC	0	1
USA	NAC	43	1
Greenland	WGC	0	0
Total		**568**	**15**

Table 10.1.9.1 Time-series of NAC area with established CLs and trends in the number of stocks meeting CLs.

	Canada				USA			
Year	No. CLs	No. assessed	No. met	% met	No. CLs	No. assessed	No. met	% met
1991	74	64	34	53				
1992	74	64	38	59				
1993	74	69	30	43				
1994	74	72	28	39				
1995	74	74	36	49	33	16	0	0
1996	74	76	44	58	33	16	0	0
1997	266	91	38	42	33	16	0	0
1998	266	83	38	46	33	16	0	0
1999	269	82	40	49	33	16	0	0
2000	269	81	31	38	33	16	0	0
2001	269	78	29	37	33	16	0	0
2002	269	80	21	26	33	16	0	0
2003	269	79	33	42	33	16	0	0
2004	269	75	39	52	33	16	0	0
2005	269	70	31	44	33	16	0	0
2006	269	65	29	45	33	16	0	0
2007	269	61	23	38	33	16	0	0
2008	269	68	29	43	33	16	0	0
2009	375	70	32	46	33	16	0	0
2010	375	68	31	46	33	16	0	0
2011	458	75	50	67	33	16	0	0
2012	472	74	32	43	33	16	0	0
2013	473	75	46	61	33	16	0	0
2014	476	69	20	29	33	16	0	0
2015	476	74	43	58	33	16	0	0

Table 10.1.9.2 Time-series of northern NEAC area with established CLs and trends in the number of stocks meeting CLs.

Year	Teno River (Finland/Norway)				Norway				Russia			
	No. CLs	No. assessed	No. met	% met	No. CLs	No. as-sessed	No. met	% met	No. CLs	No. assessed	No. met	% met
1999									85	8	7	88
2000									85	8	7	88
2001									85	8	7	88
2002									85	8	7	88
2003									85	8	7	88
2004									85	8	7	88
2005					0	167*	70	42	85	8	7	88
2006					0	165*	73	44	85	8	7	88
2007	9	5	0	0	80	167*	76	46	85	8	7	88
2008	9	5	0	0	80	170*	87	51	85	8	7	88
2009	9	5	0	0	439	176	68	39	85	8	7	88
2010	9	5	0	0	439	179	114	64	85	8	7	88
2011	9	5	0	0	439	177	128	72	85	8	7	88
2012	9	5	0	0	439	187	139	74	85	8	7	88
2013	24	7	2	29	439	185	111	60	85	8	7	88
2014	24	10	4	40	439	167	116	69	85	8	7	88
2015	24	10	2	20	439	172	126	73	85	8	7	88

* CL attainment retrospectively assessed.

Table 10.1.9.3 Time-series of southern NEAC area with established CLs and trends in the number of stocks meeting CLs.

Year	France				Ireland				UK (England & Wales)				UK (Northern Ireland)			
	No. CLs	No. assessed	No. met	% met	No. CLs	No. assessed	No. met	% met	No. CLs	No. assessed	No. met	% met	No. CLs	No. assessed	No. met	% met
1993									61	61	33	54				
1994									63	63	41	65				
1995									63	63	26	41				
1996									63	63	31	49				
1997									64	64	21	33				
1998									64	64	30	47				
1999									64	64	19	30				
2000									64	64	26	41				
2001									64	58	21	36				
2002									64	64	27	42	10	10	4	40
2003									64	64	19	30	10	10	4	40
2004									64	64	41	64	10	10	3	30
2005									64	64	32	50	10	10	4	40
2006									64	64	38	59	10	10	3	30
2007					141	141	45	32	64	64	33	52	10	6	2	33
2008					141	141	54	38	64	64	43	67	10	5	3	60
2009					141	141	56	40	64	64	22	34	10	6	2	33
2010					141	141	56	40	64	64	39	61	10	7	2	29
2011	28	28	15	54	141	141	58	41	64	64	42	66	11	9	3	33
2012	28	28	16	57	141	141	58	41	64	64	34	53	11	8	4	50
2013	30	27	20	74	143	143	57	40	64	64	20	31	13	8	5	63
2014	33	30	22	73	143	143	62	43	64	64	13	20	15	9	4	44
2015	33	27	16	59	143	143	55	38	64	64	24	38	16	10	5	50

Table 10.1.11.1 Summary of Atlantic salmon tagged and marked in 2015 – 'Hatchery' and 'Wild' juvenile refers to smolts and parr.

		Primary Tag or Mark				
Country	Origin	Microtag	External mark[2]	Adipose clip	Other Internal[1]	Total
Canada	Hatchery Adult	0	1,904	315	1,476	**3,695**
	Hatchery Juvenile	0	38	212,180	0	**212,218**
	Wild Adult	0	4,234	0	238	**4,472**
	Wild Juvenile	0	19,390	9,303	1,061	**29,754**
	Total	**0**	**25,566**	**221,798**	**2,775**	**250,139**
Denmark	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	68,000		424,700	10,000	502,700
	Wild Adult	0	0	0	0	0
	Wild Juvenile	0	0	0	0	0
	Total	**68,000**	**0**	**424,700**	**10,000**	**502,700**
France	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile[3]	0	0	205,876	0	205,876
	Wild Adult[3]	29	0	0	0	29
	Wild Juvenile	860	0	0	0	860
	Total	**889**	**0**	**205,876**	**0**	**206,765**
Iceland	Hatchery Adult	0	102	0	0	102
	Hatchery Juvenile	32,209	0	0	0	32,209
	Wild Adult	0	92	0	0	92
	Wild Juvenile	2,406	0	0	0	2,406
	Total	**34,615**	**194**	**0**	**0**	**34,809**
Ireland	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	208,481	0	0	0	208,481
	Wild Adult	0	0	0	0	0
	Wild Juvenile	6,480	0	0	0	6,480
	Total	**214,961**	**0**	**0**	**0**	**214,961**
Norway	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	58,996	9,660	0	22,187	90,843
	Wild Adult	0	753	0	58	811
	Wild Juvenile	0	2,371	0	3,051	5,422
	Total	**58,996**	**12,784**	**0**	**25,296**	**97,076**
Russia	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	0	0	1,532,971	0	1,532,971
	Wild Adult	0	1,751	0	0	1,751
	Wild Juvenile	0	0	0	0	0
	Total	**0**	**1,751**	**1,532,971**	**0**	**1,534,722**
Spain	Hatchery Adult	0	0	0	0	**0**
	Hatchery Juvenile	0	170,920	0	0	**170,920**
	Wild Adult	0	0	0	0	**0**
	Wild Juvenile	0	0	0	0	**0**
	Total	**0**	**170,920**	**0**	**0**	**170,920**
Sweden	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	0	3999	163,870	0	167,869
	Wild Adult	0	0	0	0	0
	Wild Juvenile	0	489	0	0	489
	Total	**0**	**4,488**	**163,870**	**0**	**168,358**
UK (England & Wales)	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	0	0	23,493	0	23,493
	Wild Adult	0	613	0	3	616
	Wild Juvenile	6,468	0	9,494	10	15,972
	Total	**6,468**	**613**	**32,987**	**13**	**40,081**
UK (N. Ireland)	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	12,147	0	39,776	0	51,923
	Wild Adult	0	0	0	0	0
	Wild Juvenile	0	0	0	0	0
	Total	**12,147**	**0**	**39,776**	**0**	**51,923**
UK (Scotland)	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	0	0	183,475	2,045	185,520
	Wild Adult	0	505	0	0	505
	Wild Juvenile	3,130	0	4,758	6,288	14,176
	Total	**3,130**	**505**	**188,233**	**8,333**	**200,201**
USA	Hatchery Adult	0	488	0	2,687	3,175
	Hatchery Juvenile	0	117,628	206,182	2,480	326,290
	Wild Adult	0	0	0	0	0
	Wild Juvenile	0	0	0	50	50
	Total	**0**	**118,116**	**206,182**	**5,217**	**329,515**
All Countries	Hatchery Adult	0	2,494	315	4,163	6,972
	Hatchery Juvenile	379,833	302,245	2,992,523	36,712	3,711,313
	Wild Adult	29	7,948	0	299	8,276
	Wild Juvenile	19,344	22,250	23,555	10,460	75,609
	Total	**399,206**	**334,937**	**3,016,393**	**51,634**	**3,802,170**

[1] Includes other internal tags (PIT, ultrasonic, radio, DST, etc.)
[2]Includes Carlin, spaghetti, streamers, VIE etc.
[3] Includes external dye mark.

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Annex 1 Glossary of acronyms and abbreviations

1SW *(one-sea-winter).* Maiden adult salmon that has spent one winter at sea.

2SW *(two-sea-winter).* Maiden adult salmon that has spent two winters at sea.

ACOM *(Advisory Committee)* of ICES. The Committee works on the basis of scientific assessment prepared in the ICES expert groups. The advisory process includes peer review of the assessment before it can be used as the basis for advice. The Advisory Committee has one member from each member country under the direction of an independent chair appointed by the Council.

AMO (*Atlantic Multidecadal Oscillation*). A mode of natural variability occurring in the North Atlantic Ocean and which has its principle expression in the sea surface temperature (SST) field.

BASIS (*Bering-Aleutian Salmon International Survey*). Project, commenced in 2001 in the North Pacific, designed to establish the biological responses of salmon to conditions resulting from climate change.

BC (*British Columbia*). Canadian province on the west (Pacific) coast.

BCI *(Bayesian credibility interval).* The Bayesian equivalent of a confidence interval. If the 90% BCI for a parameter α is 10 to 20, there is a 90% probability that α falls between 10 and 20.

BRP (*biological reference point*). The spawning stock level that produces maximum sustainable yield (Conservation Limit).

C&R *(catch-and-release).* Catch-and-release is a practice within recreational fishing intended as a technique of conservation. After capture, the fish are unhooked and returned to the water before experiencing serious exhaustion or injury. Using barbless hooks, it is often possible to release the fish without removing it from the water (a slack line is frequently sufficient).

CL (or CLs), i.e. S_{lim} *(conservation limit).* Demarcation of undesirable stock levels or levels of fishing activity; the ultimate objective when managing stocks and regulating fisheries will be to ensure that there is a high probability that undesirable levels are avoided.

CWT *(coded wire tag).* The CWT is a length of magnetized stainless steel wire 0.25 mm in diameter. The tag is marked with rows of numbers denoting specific batch or individual codes. Tags are cut from rolls of wire by an injector that hypodermically implants them into suitable tissue. The standard length of a tag is 1.1 mm.

DBERAAS (*Database on Effectiveness of Recovery Actions for Atlantic Salmon*). Database output from WGERAAS.

DFO *(Department of Fisheries and Oceans).* DFO and its Special Operating Agency, the Canadian Coast Guard, deliver programmes and services that support sustainable use and development of Canada's waterways and aquatic resources.

DNA *(Deoxyribonucleic acid).* DNA is a nucleic acid that contains the genetic instructions used in the development and functioning of all known living organisms (with the exception of RNA- Ribonucleic Acid viruses). The main role of DNA molecules is the long-term storage of information. DNA is often compared to a set of blueprints, like a recipe or a code, since it contains the instructions needed to construct other components of cells, such as proteins and RNA molecules.

DST *(data storage tag).* A miniature data logger with sensors including salinity, temperature, and depth that is attached to fish and other marine animals.

ECOKNOWS *(Effective use of Ecosystems and biological Knowledge in fisheries).* The general aim of the ECOKNOWS project is to improve knowledge in fisheries science and management. The lack of appropriate calculus methods and fear of statistical over partitioning in calculations, because of the many biological and environmental influences on stocks, has limited reality in fisheries models. This reduces the biological credibility perceived by many stakeholders. ECOKNOWS will solve this technical estimation problem by using an up-to-date methodology that supports more effective use of data. The models will include important knowledge of biological processes.

EU (*European Union*)

FAO (*Food and Aquaculture Organisation of the United Nations*). Agency of the United Nations dealing with global food and aquaculture production.

FWI *(Framework of Indicators).* The FWI is a tool used to indicate if any significant change in the status of stocks used to inform the previously provided multiannual management advice has occurred.

HBM (*Hierarchical Bayesian modelling*). Statistical model written in multiple levels that estimates the parameters of the posterior distribution using the Bayesian method.

HELCOM (*Baltic Marine Environment Protection Commission*). HELCOM is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, known as the Helsinki Convention.

IASRB (*International Atlantic Salmon Research Board*). Platform established by NASCO in 2001 to encourage and facilitate cooperation and collaboration on research related to marine mortality in Atlantic salmon.

IBSFC (*International Baltic Sea Fishery Commission*). The IBSFC was established pursuant to Article V of the Convention on Fishing and Conservation of the Living Resources in the Baltic Sea and the Belts (the Gdańsk Convention) which was signed on the 13th of September 1973. The Contracting Parties undertook to cooperate closely with a view to preserving and increasing the living resources of the Baltic Sea and the Belts and obtaining the optimum yield, and, in particular to expanding and coordinating studies towards these ends. The IBSFC was closed down in 2007.

ICES (*International Council for the Exploration of the Sea*).

IESSNS (*International Ecosystem Summer Survey in the Nordic Seas*). A collaborative programme involving research vessels from Iceland, the Faroe Islands and Norway.

IYS (*International Year of the Salmon*). A concept proposal from NPAFC for a multiyear (2016–2022) programme centred on an intensive burst of internationally coordinated, interdisciplinary, stimulating scientific research on salmon, and their relation to people.

LRP (*limit reference point*). When using the Precautionary Approach in resource management the LRP represents the stock status below which serious harm is occurring to the stock. At this stock status level, there may also be resultant impacts to the ecosystem, associated species and a long-term loss of fishing opportunities. Several approaches for calculating the LRP are in use and may be refined over time. The units describing stock status will vary depending on the nature of the resource (groundfish, shellfish, salmonids or marine mammals). The LRP is based on biological criteria and established by Science through a peer reviewed process.

MSY (*maximum sustainable yield*). The largest average annual catch that may be taken from a stock continuously without affecting the catch of future years; a constant long-term MSY is not a reality in most fisheries, where stock sizes vary with the strength of year classes moving through the fishery.

MSW (*multi-sea-winter*). A MSW salmon is an adult salmon which has spent two or more winters at sea and may be a repeat spawner.

NAFO (*Northwest Atlantic Fisheries Organisation*). NAFO is an intergovernmental fisheries science and management organization that ensures the long-term conservation and sustainable use of the fishery resources in the Northwest Atlantic.

NAC (*North American Commission*).

NASCO (*North Atlantic Salmon Conservation Organization*).

NEAC (*North East Atlantic Commission).*

NOAA (*National Oceanic and Atmospheric Administration*).

NPAFC (*North Pacific Anadromous Fish Commission*). An intergovernmental organization established by the Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean. The Convention was signed on February 11, 1992, and took effect on February 16, 1993. The member countries are Canada, Japan, Republic of Korea, Russian Federation, and United States of America. As defined in the Convention, the primary objective of the NPAFC is to promote the conservation of anadromous stocks in the Convention Area. The Convention Area is the international waters of the North Pacific Ocean and its adjacent seas north of 33°North beyond the 200-mile zones (exclusive economic zones) of the coastal States.

OSPAR (*Convention for the Protection of the Marine Environment of the Northeast Atlantic*). OSPAR is the mechanism by which fifteen Governments of the west coasts and catchments of Europe, together with the European Community, cooperate to protect the marine environment of the Northeast Atlantic. It started in 1972 with the Oslo Convention against dumping. It was broadened to cover land-based sources and the offshore industry by the Paris Convention of 1974. These two conventions were unified, updated and extended by the 1992 OSPAR Convention. The new annex on biodiversity and ecosystems was adopted in 1998 to cover non-polluting human activities that can adversely affect the sea.

PA (*precautionary approach*). In resource management the PA is about being cautious when scientific information is uncertain, unreliable or inadequate and not using the absence of adequate scientific information as a reason to post-pone or fail to take action to avoid serious harm to the resource.

PFA *(pre-fishery abundance).* The numbers of salmon estimated to be alive in the ocean from a particular stock at a specified time. In the previous version of the stock complex Bayesian PFA forecast model two productivity parameters are calculated, for the *maturing* (PFAm) and *non-maturing* (PFAnm) components of the PFA. In the updated version only one productivity parameter is calculated, and used to calculate total PFA, which is then split into PFAm and PFAnm based upon the *proportion of PFAm* (p.PFAm).

PICES (*North Pacific Marine Science Organization*). PICES, the North Pacific Marine Science Organization, is an inter-governmental scientific organization that was established and held its first meetings in 1992. Its present members are Canada, People's Republic of China, Japan, Republic of Korea, Russian Federation, and the United States of America. The purposes of the Organization are as follows: (1) Promote and coordinate marine research in the northern North Pacific and adjacent seas especially northward of 30 degrees North, (2) advance scientific knowledge of the ocean environment, global weather and climate change, living resources and their ecosystems, and the impacts of human activities, and (3) promote the collection and rapid exchange of scientific information on these issues.

RVS *(red vent syndrome).* This condition has been noted since 2005, and has been linked to the presence of a nema-tode worm, *Anisakis simplex*. This is a common parasite of marine fish and is also found in migratory species. The larval nematode stages in fish are usually found spirally coiled on the mesenteries, internal organs and less frequently in the somatic muscle of host fish.

SAS (*smolt-to-adult supplementation*). Generally refers to intervention activities consisting of the capture of wild juve-nile salmon (parr, fall presmolts, smolts) and rearing theses in captivity with the intention to release the mature cap-tive reared adults to targeted rivers to spawn.

S_{lim}, i.e. CL *(conservation limit).* Demarcation of undesirable stock levels or levels of fishing activity; the ultimate objec-tive when managing stocks and regulating fisheries will be to ensure that there is a high probability that the undesira-ble levels are avoided.

S_{MSY} (*spawners for maximum sustainable yield*). The spawner abundance that generates recruitment at a level that provides a maximum exploitable yield (recruitment minus spawners).

SST (*sea surface temperatures*). SST is the water temperatures close to the surface. In practical terms, the exact mean-ing of surface varies according to the measurement method used. A satellite infrared radiometer indirectly measures the temperature of a very thin layer of about 10 micrometres thick of the ocean which leads to the phrase skin tem-perature. A microwave instrument measures subskin temperature at about 1 mm. A thermometer attached to a moored or drifting buoy in the ocean would measure the temperature at a specific depth, (e.g. at one meter below the sea surface). The measurements routinely made from ships are often from the engine water in-takes and may be at various depths in the upper 20 m of the ocean. In fact, this temperature is often called sea surface temperature, or foundation temperature.

UDN (*Ulcerative Dermal Necrosis*). Disease mainly affecting wild Atlantic salmon, sea trout and sometimes other salm-onids. It usually occurs in adult fish returning from the sea in the colder months of the year and starts as small lesions on the scale-less regions of the fish, mainly the snout, above the eye and near the gill cover. On entry to freshwater lesions ulcerate and may become infected with secondary pathogens like the fungus Saprolegnia spp. Major outbreaks of UDN occurred in the 1880s (UK) and 1960s–1970s (UK and Ireland), but the disease has also been reported from France, and in 2015 from the Baltic and Russia.

USR (*upper stock reference point*). When implementing the precautionary approach in resource management USR is the threshold point below which removals must be reduced to avoid serious harm.

WGDAM (*Working Group on Data=Poor Diadromous Fish*).

WGERAAS *(Working Group on Effectiveness of Recovery Actions for Atlantic Salmon)*. The task of the working group is to provide a review of examples of successes and failures in wild salmon restoration and rehabilitation and develop a classification of activities which could be recommended under various conditions or threats to the persistence of populations. The Working Group held its final meeting in Copenhagen in November 2015.

WGNAS (*Working Group on North Atlantic Salmon*).

WGRECORDS *(Working Group on the Science Requirements to Support Conservation, Restoration and Management of Diadromous Species)*. WGRECORDS was reconstituted as a working group from the Transition Group on the Science Requirements to Support Conservation, Restoration and Management of Diadromous Species (TGRECORDS).

WKCULEF (*NASCO Request for Advice on Possible Effects of Salmonid Aquaculture on Wild Atlantic Salmon Populations*). Workshop on the possible effects of salmonid aquaculture on wild Atlantic salmon populations in the North Atlantic. Met in Copenhagen 1–3 of March 2016 and reported by the 11 March 2016 for the attention of the ICES Advisory Committee.

WKTRUTTA2 (*Workshop on sea trout*). A workshop was held in February 2016 to focus on the development of models to help address key management questions and to develop biological reference points for use in the management of sea trout stocks and fisheries.