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NORTH ATLANTIC SALMON STOCKS

Introduction

Main tasks

In 2016 the ICES Advisory Committee (ACOM) resolved (C. Res. 2016/2/ACOM21) that the Working Group on North Atlantic Salmon [WGNAS] (chaired by Gerald Chaput, Canada) would meet at ICES HQ, 29 March–7 April 2017 to consider questions posed to ICES by the North Atlantic Salmon Conservation Organization (NASCO). In early February 2017, NASCO informed ICES of the results of the application of the Framework of Indicators for West Greenland and Faroes which concluded that there was no need for revised catch advice for 2017. Consequently, the questions previously submitted by NASCO were revised.

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:	sal.oth.nasco
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 2016[1];	
1.2	report on significant new or emerging threats to, or opportunities for, salmon conservation and management[2];	
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];	
1.4	provide a summary of the available diet data for marine life stages of Atlantic salmon and identify key prey species at different life stages (e.g. herring at post-smolt stages, capelin in West Greenland waters and the Barents Sea)[4];	
1.5	provide a description of the potential future impacts of climate change on salmon stock dynamics;	
1.6	provide a compilation of tag releases by country in 2016; and	
1.7	identify relevant data deficiencies, monitoring needs and research requirements.	
2	With respect to Atlantic salmon in the North-East Atlantic Commission area:	sal.27.neac
2.1	describe the key events of the 2016 fisheries[5];	
2.2	review and report on the development of age-specific stock conservation limits including updating the time-series of the number of river stocks with established CL's by jurisdiction;	
2.3	describe the status of the stocks including updating the time-series of trends in the number of river stocks meeting CL's by jurisdiction;	
2.4	provide information on the size, distribution and timing of the blue whiting fishery in the North East Atlantic area and any official observer information relating to bycatch which may indicate possible impact of this fishery on wild salmon; and	
2.5	identify relevant data deficiencies, monitoring needs and research requirements.	
3	With respect to Atlantic salmon in the North American Commission area:	sal.21.nac
3.1	describe the key events of the 2016 fisheries (including the fishery at St Pierre and Miquelon)[5];	
3.2	update age-specific stock conservation limits based on new information as available including updating the time-series of the number of river stocks with established CL's by jurisdiction;	
3.3	describe the status of the stocks including updating the time-series of trends in the number of river stocks meeting CL's by jurisdiction; and	
3.4	identify relevant data deficiencies, monitoring needs and research requirements.	
4	With respect to Atlantic salmon in the West Greenland Commission area:	sal.2127.wgc
4.1	describe the key events of the 2016 fisheries[5];	
4.2	describe the status of the stocks[6]; and	
4.3	identify relevant data deficiencies, monitoring needs and research requirements.	

[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 comment on any significant changes in population dynamics (i.e. abundance, distribution, size structure, and energy density) of key prey species which may be associated with changes in salmon abundance, distribution, and marine ecology (e.g. the recently identified decreases in capelin energy density and the consequences on marine productivity of Atlantic salmon while also providing information related to fisheries which catch significant numbers of the identified key prey species (i.e. direct harvest or bycatch).

[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 homewater 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 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. The status of these stocks should be provided in response to questions 2.3 and 3.3.

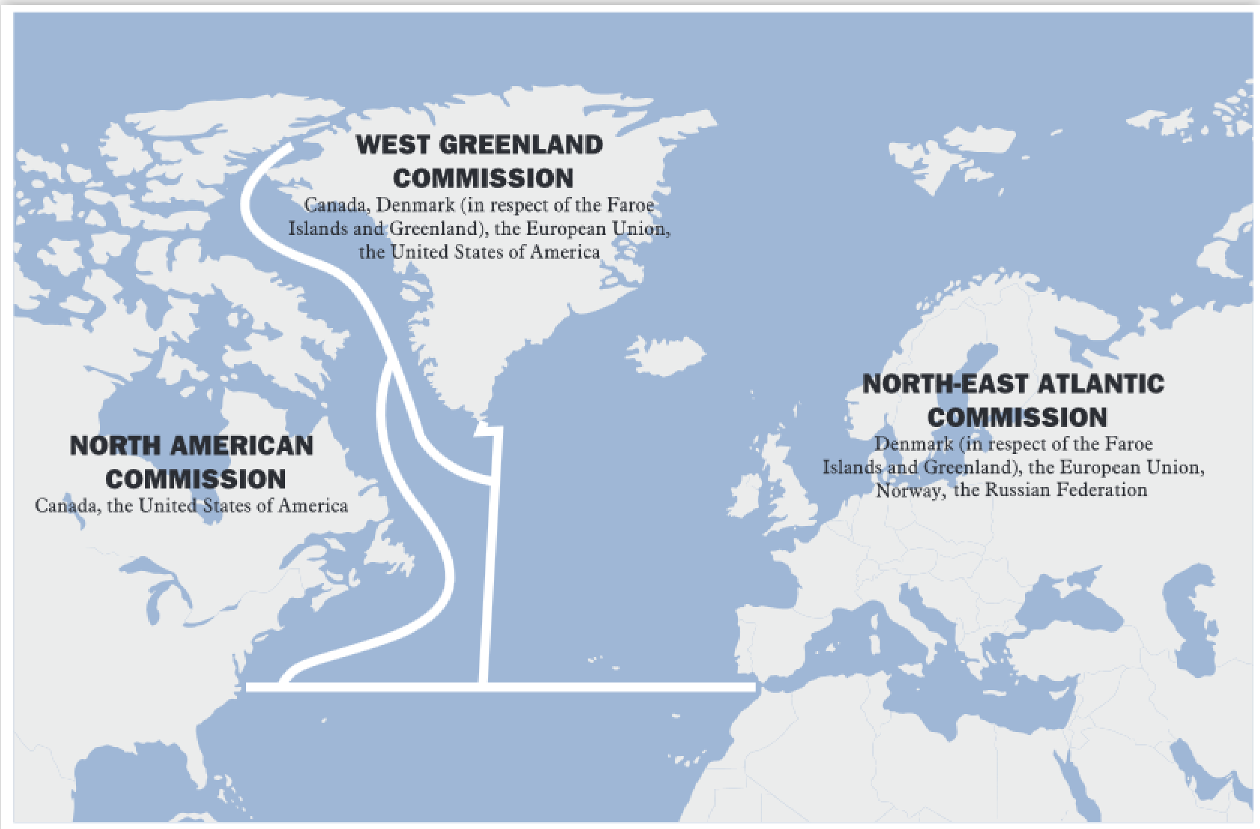
In response to the terms of reference, the working group considered 41 working documents. A complete list of acronyms and abbreviations used in this report is provided in Annex 1. References cited are given in Annex 2.

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

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.



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".

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. In addition, due to differences in status of individual stocks within stock complexes, mixed-stock fisheries present particular threats that need to be considered.

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. 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. Generally, ICES considers that full reproductive capacity is met when conservation limits are attained with a 95% probability. It should be noted that ICES is requested by NASCO to provide advice on the status of the stocks as to whether they meet these CLs.

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 limit 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 default approach 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 the country level. Tables of catch options provide the probability of meeting CLs in the individual stock complexes or countries, as well as in all the stock complexes or countries simultaneously. ICES has previously 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.

NASCO 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 2016

Nominal catches of salmon

The nominal catch of a fishery is defined as the round, fresh weight of fish that are caught and retained. Figure 1 displays reported total nominal catch of salmon in four North Atlantic regions from 1960 to 2016. Nominal catches reported by country are given in Table 4. Catch statistics in the North Atlantic include fish farm escapees, and in some Northeast Atlantic countries also ranched fish.

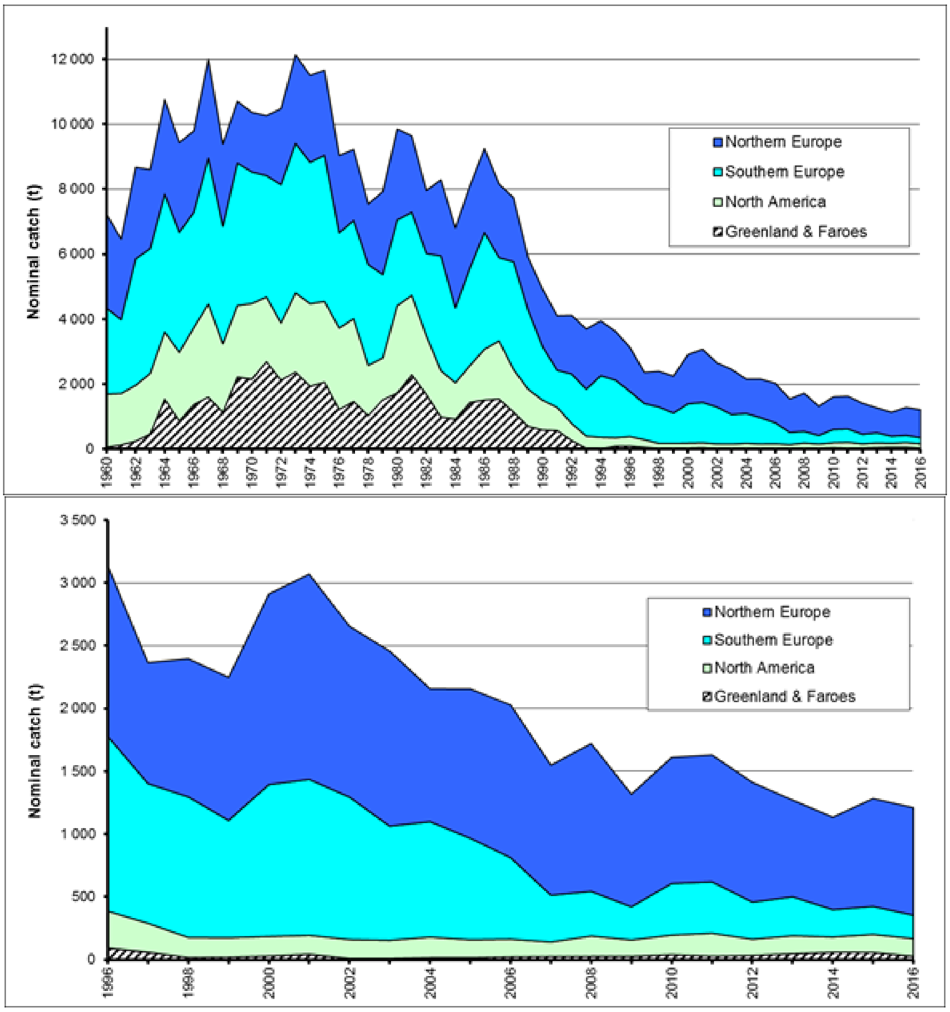


Figure 1 Total reported nominal catch of salmon (tonnes round fresh weight) in four North Atlantic regions, 1960–2016 (top) and 1996–2016 (bottom).

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 2016 (Table 4). 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.

Table 1 Reported catches (tonnes) for the three NASCO commission areas for 2007–2016.

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NEAC	1409	1533	1162	1414	1419	1250	1080	954	1081	1043
NAC	114	162	129	156	182	129	143	122	144	140
WGC	25	26	26	40	28	33	47	58	57	27
Total	1548	1721	1318	1610	1629	1412	1270	1134	1282	1209

The provisional total nominal catch for 2016 was 1209 t, 70 t below the updated catch for 2015 (1282 t). The 2016 catch was the second lowest in the time-series, after 2014. Catches were below the previous five- and ten-year averages in the majority of countries (Figure 2).

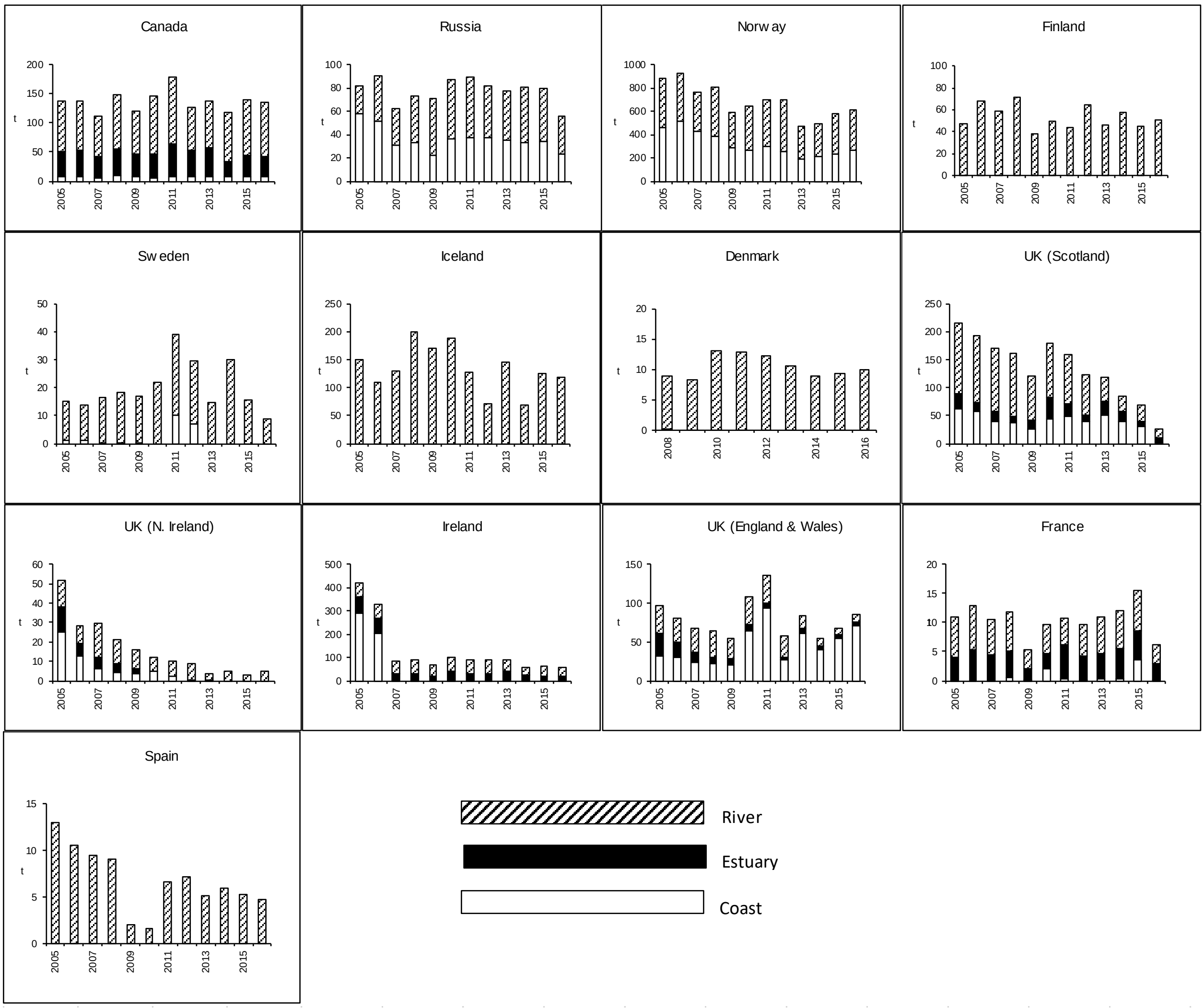


Figure 2 Nominal catch (t) by country taken in coastal, estuarine, and riverine fisheries, 2005–2016 (except Denmark: 2008–2016). Note that the scales on the *y*-axes vary.

ICES considers that mixed-stock fisheries present particular threats to stock status. Presently these mixed-stock 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 2016 nominal catch (in tonnes) was partitioned accordingly and is shown below for the NEAC and NAC commission areas. Figure 2 and Table 5 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, either partly or entirely as a result of management measures and increasing use of catch-and-release in rod fisheries.

Table 2 2016 nominal catch (in tonnes) for the NEAC and NAC commission areas.

AREA	COAST		ESTUARY		RIVER		TOTAL
	Weight	%	Weight	%	Weight	%	Weight
NEAC 2016	364	35	37	4	643	62	1043
NAC 2016	11	8	43	31	86	61	140

Coastal, estuarine, and riverine catch data aggregated by region are presented in Figure 3. In Northern NEAC, a decreasing proportion and weight of the nominal catch has been taken in coastal regions (from 46% to 34% and 565 t to 293 t, in 2006 and 2016 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 2006. 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 2006–2016 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).

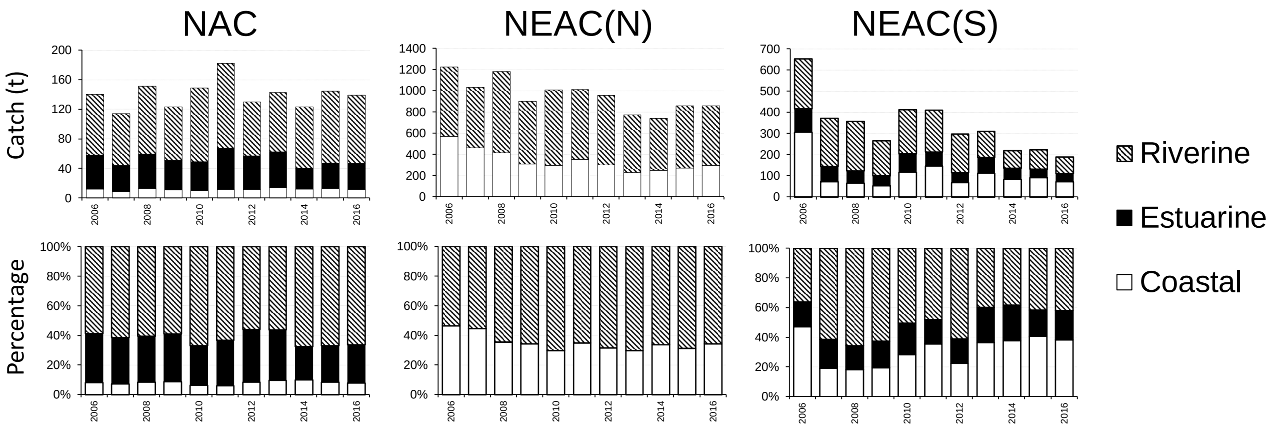


Figure 3 Nominal catches (t; top panel) and percentages of nominal catch (bottom panel) taken in coastal, estuarine, and riverine fisheries for the NAC area, and for the Northern (NEAC(N)) and Southern (NEAC(S)) NEAC areas, 2006–2016. Note that scales of vertical axes in the top panel vary.

Unreported catches

The total unreported catch in NASCO areas in 2016 was estimated at 335 t. There was no estimate for Russia, France, Spain, and St. Pierre and Miquelon in 2016, although reported catches in the latter two areas are small. The unreported catch in the NEAC area in 2016 was estimated at 298 t, and those for the West Greenland and North American commission areas at 10 t and 27 t, respectively.

Table 3 Unreported catch (in tonnes) by NASCO commission areas in the last ten years.

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
NEAC	465	433	317	357	382	363	272	256	298	298
NAC	- [1]	- [1]	16	26	29	31	24	21	17	27
WGC	10	10	10	10	10	10	10	10	10	10
Total	475	443	343	393	421	403	306	287	325	335
Total as % of reported catch	23.5	20.5	20.1	19.4	21.2	22.2	19.1	20.6	20.2	21.7

[1] Data not available for Canada in 2007 and 2008.

The 2016 unreported catch by country is provided in Table 6. 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).

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. Catch-and-release mortality is considered in some national assessments of spawner escapement, with estimates ranging from 3% to 20% among jurisdictions (ICES, 2010).

The nominal catches do not include salmon that have been caught and released. Table 7 presents C&R information from 1991 to 2016 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 2016, this ranged from 18% in Sweden to 90% in UK (Scotland), reflecting varying management practices and angler attitudes among countries. 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 2016.

Farming and sea ranching of Atlantic salmon

The provisional estimate of farmed Atlantic salmon production in the North Atlantic area for 2016 was more than 1512 kt. The production of farmed salmon in this area has been over one million tonnes since 2009. Norway and UK (Scotland) continue to produce the majority of the farmed salmon in the North Atlantic (78% and 12%, respectively). The total farmed salmon production appears to have stabilized in the last few years in the North Atlantic area.

Worldwide production of farmed Atlantic salmon has been in excess of one million tonnes since 2001, and over two million tonnes since 2012. The total worldwide production in 2016 is provisionally estimated at around 2262 kt (Figure 4), a similar level to 2015. Production outside the North Atlantic is estimated to have accounted for one third of the total in 2016, with production outside the North Atlantic dominated by Chile (81%).

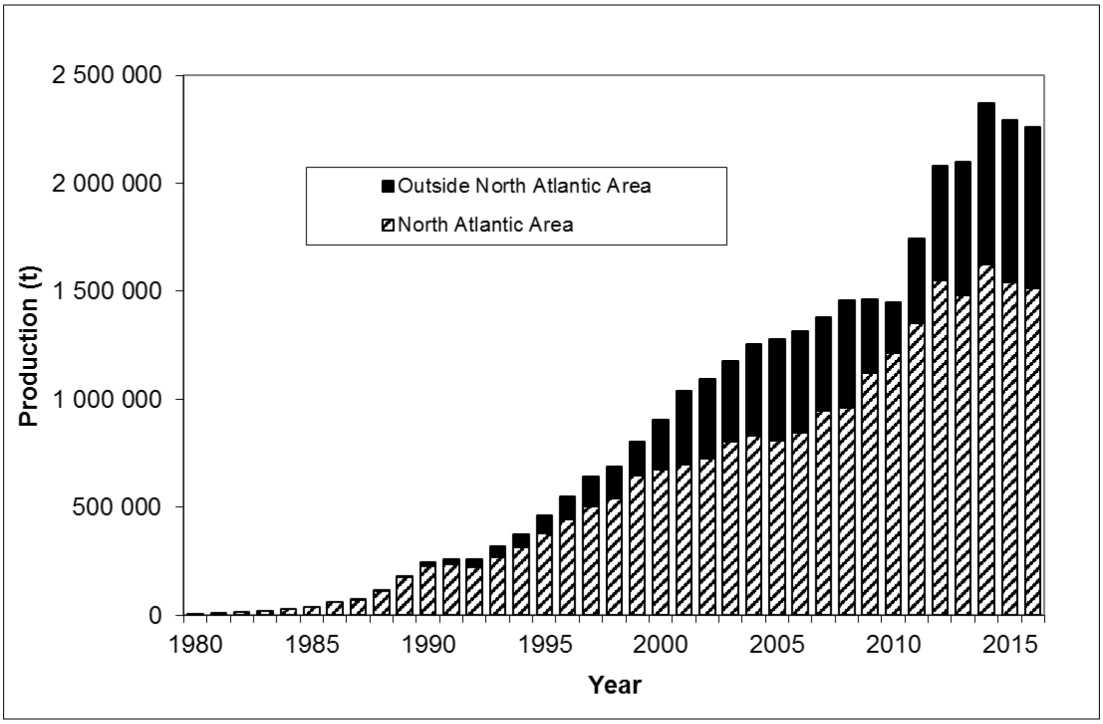


Figure 4 Worldwide production of farmed Atlantic salmon, 1980 to 2016.

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 2016.

The total harvest of ranched Atlantic salmon in countries bordering the North Atlantic in 2016 was 37 t, all taken in Iceland, Sweden, and Ireland (Figure 5) with the majority of the catch taken in Iceland (31 t). No estimate of ranched salmon production was made in Norway in 2016, 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 2016 owing to a lack of microtag returns.

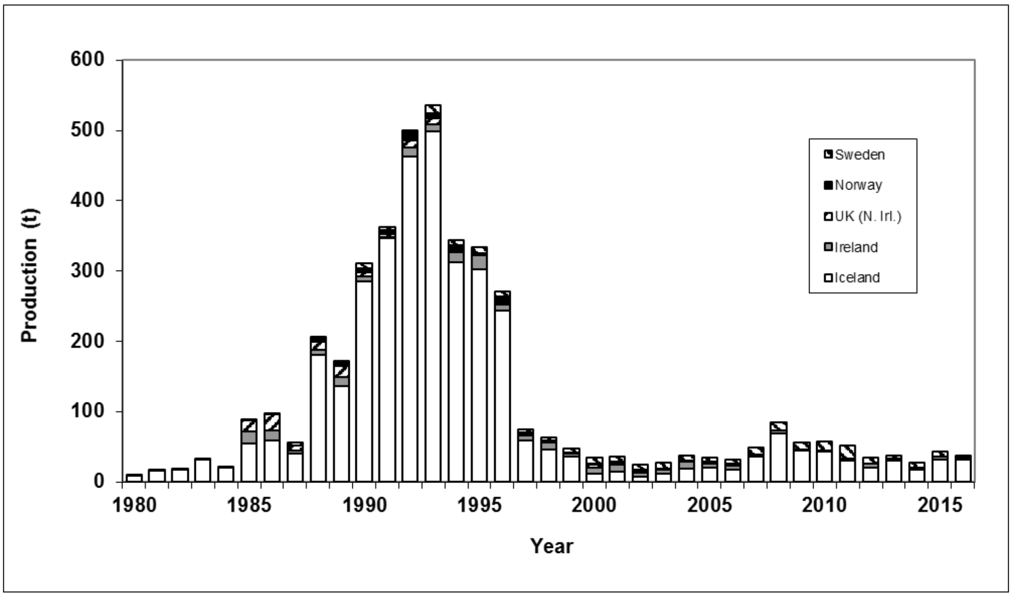


Figure 5 Production of ranched Atlantic salmon (tonnes round fresh weight) in the North Atlantic, 1980 to 2016.

NASCO 1.2 Report on significant, new, or emerging threats to, or opportunities for, salmon conservation and management

Review of major threats to Atlantic salmon in Norway

A recent paper has evaluated the major anthropogenic threats to Atlantic salmon in Norway using two-dimensional analyses (Forseth *et al.,* 2017). One dimension considered the effect of the threat and the other dimension considered the most likely development of the threat in the future (Figure 6). Escaped farmed salmon and salmon lice from fish farms were identified as expanding population threats since they scored high on both axes, with escaped farmed salmon being the largest current threat. The parasite *Gyrodactylus salaris*, acidification, and hydropower development also scored high along the effect axis, but lower on the development axis and were thus categorized as stabilized.

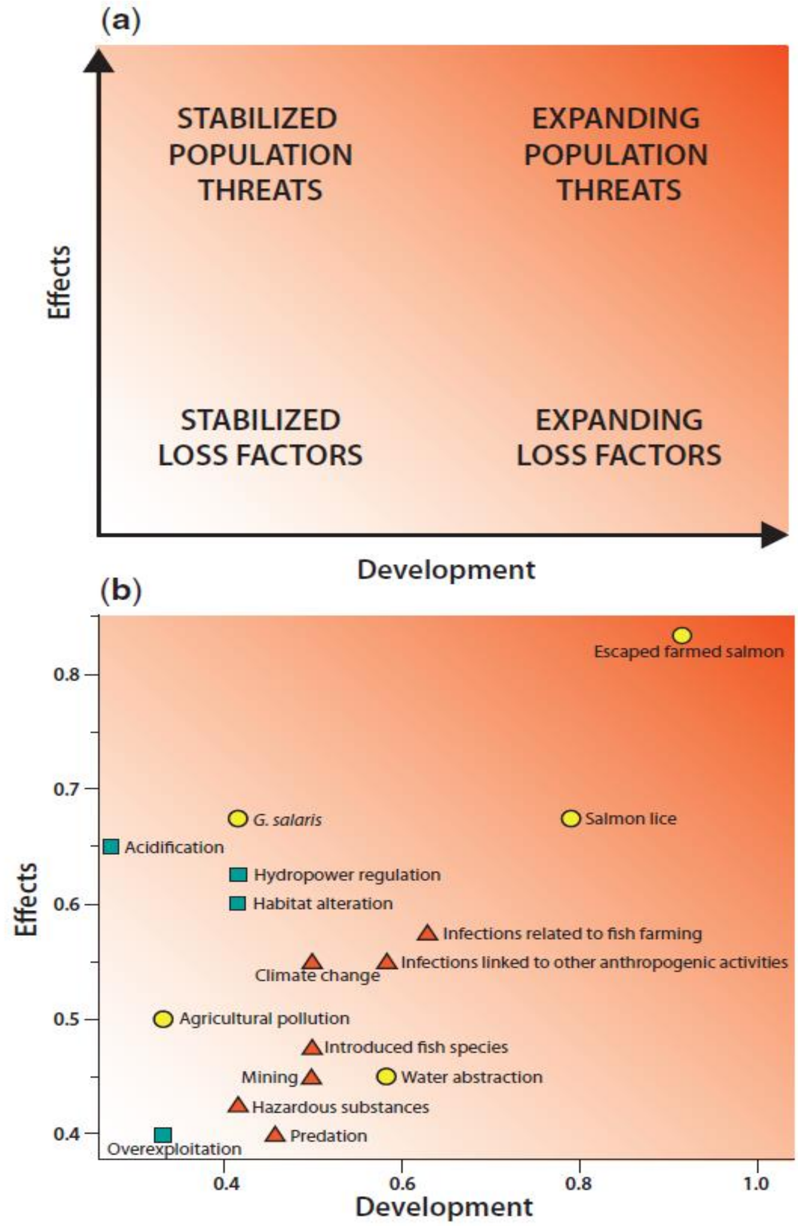


Figure 6 Panel (a) The classification system developed to rank different anthropogenic impacts on Norwegian Atlantic salmon populations along the Effects and Development axes. The four major impact categories are indicated, but the system is continuous. Background coloring indicates severity of impacts, with dark as the most severe. Panel (b) Location within the classification system of the 16 impact factors considered in 2015. For illustration, the information on each impact factor and the uncertainty of future development is indicated by the color of the markers. Green squares = Extensive knowledge and small uncertainty, yellow circles = moderate knowledge and moderate uncertainty, and red triangles = poor knowledge and high uncertainty. Figure extracted from Forseth *et al.* (2017).

Gene flow from farmed escapes alters the life history of wild Atlantic salmon

Many experimental studies have shown that farmed salmon and hybrids have altered phenotypes compared to wild salmon (reviewed in Glover *et al.,* 2017, and ICES, 2016a). In Atlantic salmon, gene flow from domesticated stocks into wild conspecific populations is well documented with introgression levels up to a maximum average of 40% (domesticated ancestry) among the spawners in some populations (Karlsson *et al.,* 2016). However, the experimental conditions and the limited number of whole-river experiments do not necessarily represent the extent or scale of the impact of domesticated introgression on natural populations. A recent study by Bolstad *et al.* (2017) together with the extensive experimental literature on the subject provides solid evidence that gene flow from escaped farmed salmon has a strong effect on important biological characteristics of wild Atlantic salmon.

Based on data from 62 salmon populations along the entire Norwegian coastline, Bolstad *et al.* (2017) showed that groups of individuals with a high level of introgression had altered size- and age-at-maturation. The effect of introgression on size- and age-at-maturation differed between sexes and among different types of populations.

In the Eastern Atlantic populations with high mean sea age, females with high levels of introgression had a higher probability of maturing after two winters at sea compared to individuals with a low level of introgression. In contrast, males with a higher level of introgression had a higher probability of maturing after one winter at sea (Figure 7). Thus, there are fewer old and large salmon with increasing levels of introgression in these populations. These effects of introgression were not observed in populations with a lower mean sea age. There was also an effect on size independent of age, which increased with increasing introgression. This effect was largest in the populations with low mean sea age.

In the Barents/White Sea populations, which are of different phylogeny from the source of domesticated salmon, the estimated effects of introgression were in several cases stronger in this phylogenetic group than in the Eastern Atlantic phylogenetic group. In particular, there was a dramatic increase in age-independent weight in the populations with low mean sea age, and the males in these populations with high levels of introgression matured after two sea winters instead of one.

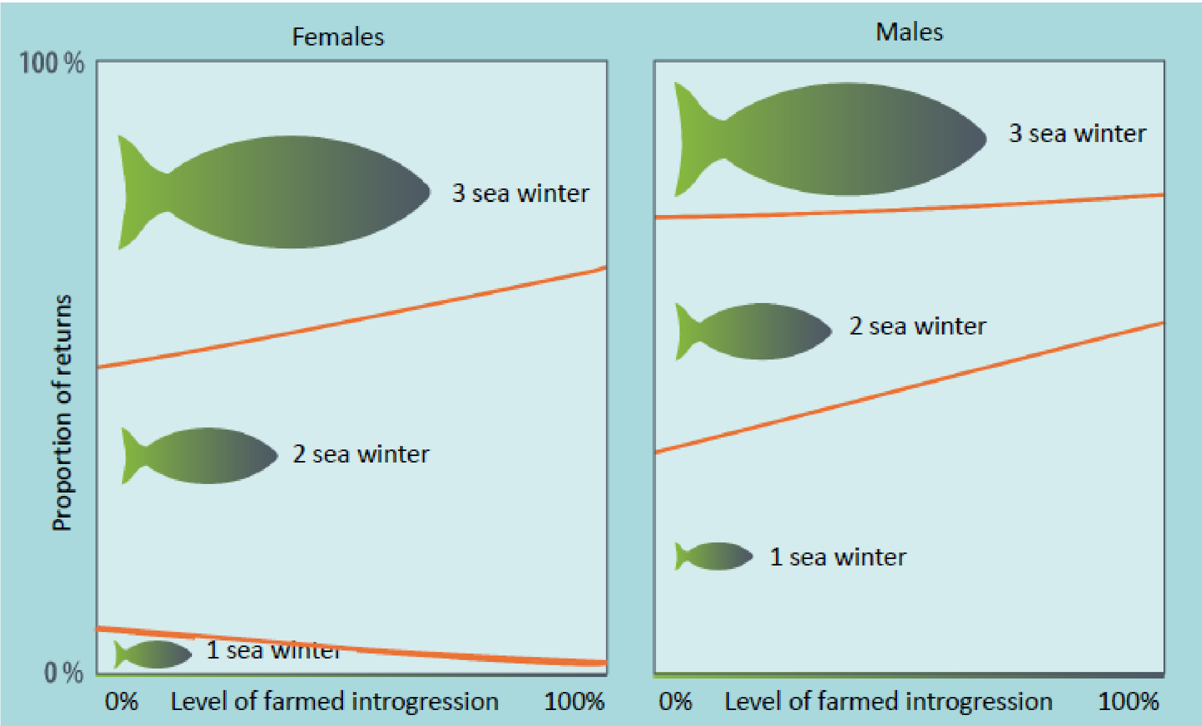


Figure 7 Changes in sea age distribution of returns with the level of farmed introgression (farmed ancestry) in 22 rivers of the Eastern Atlantic phylogenetic group, characterized by a high proportion of late maturing fish and distributed along the Norwegian coast (Bolstad *et al.,* 2017).

Diseases and parasites

Update on red vent syndrome (*Anisakiasis*)

In recent years, a number of countries in the NEAC and NAC areas have reported on salmon returning to rivers with swollen and/or bleeding vents (ICES, 2016b). The condition, known as red vent syndrome (RVS or *Anisakiasis*), has been observed since 2004 and has been linked to the presence of a nematode worm, *Anisakis simplex* (Beck *et al.,* 2008), which occurs commonly in other marine fish and marine mammals. 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 (ICES, 2009, 2010, 2011), but trapping records for rivers in the UK (England and Wales) and France suggested that levels of RVS increased again in 2013, with the observed levels being the highest in the time-series for some of the monitored stocks (ICES, 2014). Monitoring for the presence of RVS has continued on three rivers in UK (England and Wales; rivers Tyne, Dee, and Lune). In 2016, RVS levels on the Tyne and Dee, 4% and 22% respectively, were below or at the long-term average of the time-series. Similarly, the RVS level on the Lune (19%) was at the average of the observed values, although the sample size was small. In Ireland in 2016, a lower level of incidence of RVS was reported in fish taken in the Galway weir salmon fishery compared to 2015.

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, 2014).

Disease reports from Sweden

Disease and mortality issues in returning salmon and sea trout have been prevalent in a number of rivers in Sweden that drain to the Baltic Sea (ICES, 2017a). After high levels of mortality in two consecutive years (2014 and 2015), the Swedish National Veterinary Institute (SVA) conducted a sampling programme in 2016 to investigate the rivers affected: the Torneälven (northern Baltic), Umeälven (mid-Baltic), and the Mörrumsån (southern Baltic), all at a distance of approximately 200 km from North Atlantic salmon rivers. In total, 112 diseased or wounded fish were sampled in 2016. Of the 112 fish sampled, 42 (38%) had wounds typical of ulcerative dermal necrosis (UDN), but analyses showed that only 15 met criteria indicative of UDN. However, it has still not been concluded that UDN was the underlying cause of the symptoms observed, as other infections can result in similar wounds and damaged tissue. Routine analyses for viruses and bacteria gave no conclusive results, although bacteria associated with skin lesions were identified in a few individuals. Next generation sequencing indicated the presence of herpes- and irido-viruses in the population, viruses that are harder to cultivate. These viruses can cause skin lesions, but the findings need to be investigated further to ascertain the presence of virus and clarify virulence and prevalence. In summary, no outbreak of UDN was confirmed and numbers of dead salmon seem to have decreased since 2015.

Disease reports from Russia

ICES (2016b) noted that in summer 2015 a mass mortality of adult salmon was observed in Russia in the Kola River, Murmansk region, owing to disease diagnosed as UDN. In 2016, mortality of spawning fish caused by the same disease was observed in the Kola River again and in the Tuloma River, the outlet of which is located 10 km from the Kola River mouth. Both rivers drain into the inner part of the Kola Bay. The source of the pathogen was unknown, but the timing of the disease incidence in 2015 coincided with mass mortalities of farmed salmon observed in late autumn 2014 and spring/summer 2015 and with the disposal in summer 2015 of dead farmed fish on the bank of the Kola River, near the urban settlement of Molochny near the Kola River outlet. The total mortalities in these rivers from disease are unknown.

In late July 2016 a few salmon with red bellies (disease symptoms similar to those found in fish from Kola and Tuloma) were caught in the Motovsky Gulf with gillnets during surveys in the coastal areas of the Barents Sea. The Motovsky Gulf is a body of water between the northwestern coast of the Kola Peninsula and the southern coast of the Rybachy Peninsula, Murmansk region. The Bolshaya Zapadnaya Litsa, Titovka, and Ura rivers drain into the Motovsky Gulf. It was noted that salmon farms in the Titovka Bay and in the Ura Bay also suffered from mass mortality of farmed salmon in sea cages in 2015. Some further, more sporadic reports were received on individual diseased salmon caught or found in other Barents Sea rivers of the Kola Peninsula in 2015–2016.

Update on sea lice investigations in Norway

The surveillance programme for salmon lice infections on wild salmon post-smolts and sea trout at specific localities along the Norwegian coast continued in 2016 (Nilsen *et al.,* 2017). In 2016, the field activities in the surveillance programme were based on predictions from the hydrodynamic model in relation to the spreading and distribution of salmon louse larvae. In this model, data from weekly counts of sea lice at fish farms are coupled with detailed hydrodynamic modelling to predict the distribution of sea lice larvae, and the infection pressure on wild salmonids (Sandvik *et al.,* 2016). Field sampling was directed to areas where the model predicted high densities of infective salmon louse copepodites in the post-smolt migration period. The field examinations were conducted in two periods: an early period covering the migration period of salmon post-smolts, and a late period 2–3 weeks later focused on sea trout infection. In general, the surveillance programme demonstrated varying infection pressure along the coast during the post-smolt migration period in 2016. The number of sea lice observed on salmon in fish farms was generally at the same level as in 2015, but with increased levels in some regions and lower in others (Hjeltnes *et al.,* 2017). There was a significant reduction in the use of chemicals to treat salmon louse infections on farmed salmon in 2016 compared to 2015 (41% reduction). This decrease resulted from fish farmers switching to alternative methods for removal of sea lice, such as various mechanical methods, as resistance to the commonly used chemicals continues to be a serious problem (Hjeltnes *et al.,* 2017).

In 2017, a new management regime for salmonid aquaculture will be implemented in Norway (Anon., 2017a). Under this management regime, the level of aquaculture production in 13 defined production areas along the coast will be regulated and adjusted according to the estimated added mortality resulting from salmon louse infections inferred on wild salmon populations in each production area. In production areas where estimates indicate that mortality from salmon lice is >30%, salmonid aquaculture production may be reduced. Where estimates indicate that added mortality from salmon lice infections is between 10% and 30%, aquaculture production may remain at the same level. If added mortality is estimated to be below 10%, production may be allowed to increase in that area (Anon., 2015a, 2015b).

Poor juvenile recruitment in UK (England and Wales) in 2016

Densities of juvenile salmon, particularly 0+ fry, were very low in many rivers in UK (England and Wales) in 2016 and well below long-term averages. While there has been a modest decline in juvenile salmon densities since 2009, the scale of the downturn in 2016 was particularly notable and affected rivers throughout the country (Figure 8). The widespread nature of these observations suggested that factors operating at a broad scale were responsible for the declines in juvenile densities, albeit with some regional variation.

The UK Met Office described the winter of 2015/2016 as “remarkable”, with severe flooding in December from record rainfall totals, accompanied by exceptional warmth from a persistent flow of tropical maritime air. The winter was the second wettest in the UK (in a time-series dating back to 1910) and Storm Desmond on 5 December set a new 24-hour rainfall record for the UK, with 341.4 mm of rain falling in a 24-hour period. This resulted in severe and extensive flooding across many northern and western parts of the country and affected many rivers, with rivers like the River Tyne registering the highest winter flows on record. These extreme high flow events coincided with the salmon spawning period and may have caused mortality because of the wash-out of eggs and alevins from redds and/or sediment deposition in the redds.

The winter of 2015/2016 was also the warmest on record in UK (England and Wales) and temperatures in December were reported to be the warmest for both the UK and the Central England Temperature (CET) series, which dates back to 1659. The unusually warm conditions in the winter of 2015/2016 combined with the flood events may thus also have been an important factor in the observed declines in juvenile salmon recruitment.

In summary, low densities of juvenile salmon in 2016 (Figure 8) probably resulted from a combination of factors, including unusually high winter flows and unusually high winter temperatures, with relatively low numbers of spawners in some catchments. It is probable that the relative importance of different factors affected different catchments and sub-catchments to varying degrees. The impact of this event will be monitored to assess the effects on subsequent smolt (two-year-olds in 2018) and adult recruitment (1SW in 2019 and 2SW in 2020).

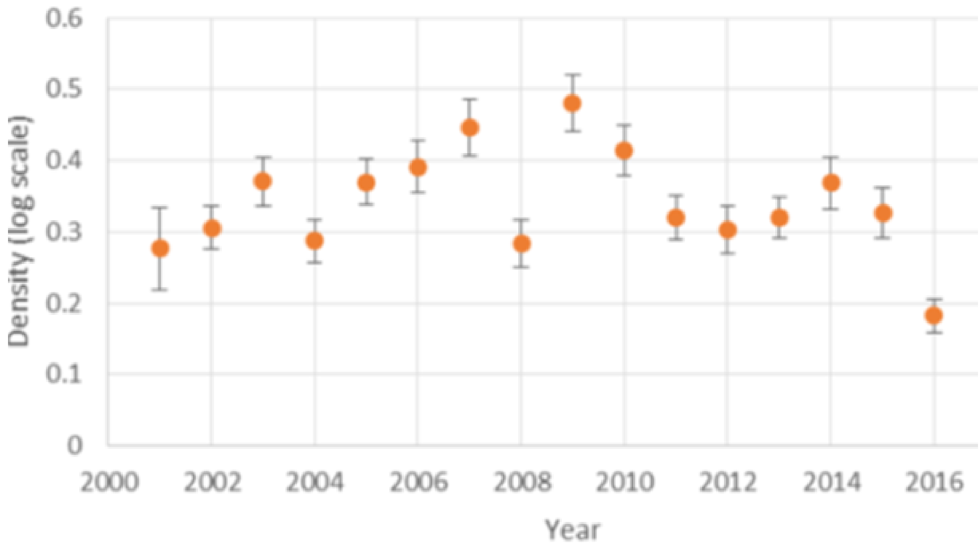


Figure 8 The density (on the log scale) of 0+ salmon fry averaged for all catchments in England where juvenile screening data were consistently available, 2001 to 2016.

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). A more detailed description of the Quality Norm is given in ICES (2014). In 2016, the first classification of populations based on both dimensions (conservation limit and harvest potential, and genetic integrity) was conducted for 104 populations (ICES, 2016b). Up to now, 148 salmon populations have been classified. These include the 104 populations classified in 2016. Updated estimates of the degree of introgression from farmed Atlantic salmon in a large number of salmon populations were available, and a combined classification in both dimensions of the quality norm was made (Anon., 2017b). Of the 148 populations considered, 29 (20%) were classified as being in good or very good condition, 42 (28%) populations were classified as being in moderate condition, while 77 (52%) were in poor or very poor condition (Figure 9).

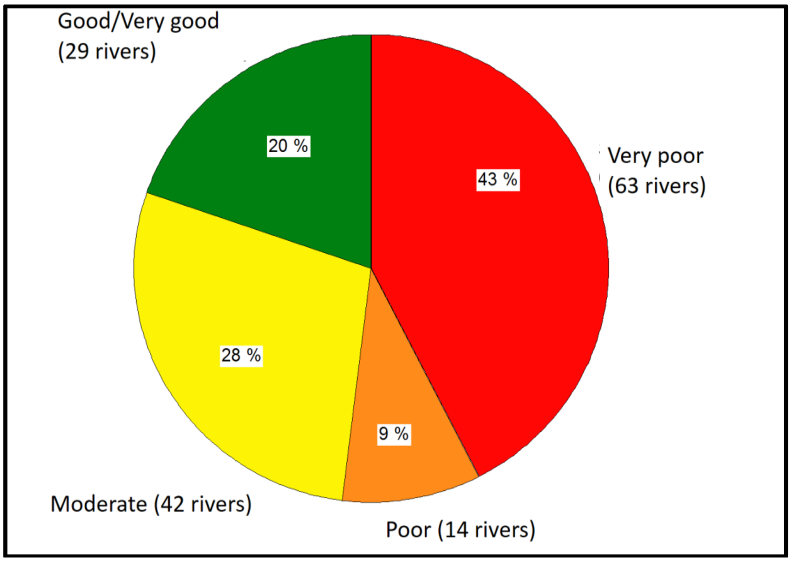


Figure 9 Final classification in the Quality Norm system for 148 Norwegian rivers. Figure translated from Anon. (2017b).

Update on opportunities for investigating salmon at sea

The International Ecosystem Summer Survey of the Nordic Seas (IESSNS)

This 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 to improve knowledge on many marine fish species, including salmon at sea. The area surveyed (3.0 million km^2 in 2016) 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 with surface trawling at predetermined locations, bycatch of salmon post-smolts and adult salmon is not uncommon. In 2016 a total of 103 post-smolt and adult salmon were caught by the participating vessels in different regions of the North Atlantic (Figure 10). The breakdown by average length (Figure 10) differentiates between locations of post-smolts and adults. This post-smolt distribution is similar to previous marine surveys for salmon at sea (Anon., 2012) and simulated distributions based on larger sample sizes from directed surveys (Mork *et al.,* 2012). 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. The Institute of Marine Research (Bergen, Norway) is developing a plan to collate all the information from the analysis of the samples of individual salmon caught in earlier years, as well as those from last year's cruises.

The samples are expected to provide valuable information on the distribution of salmon at sea, the size, sex, and diet of individual fish, and they 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.

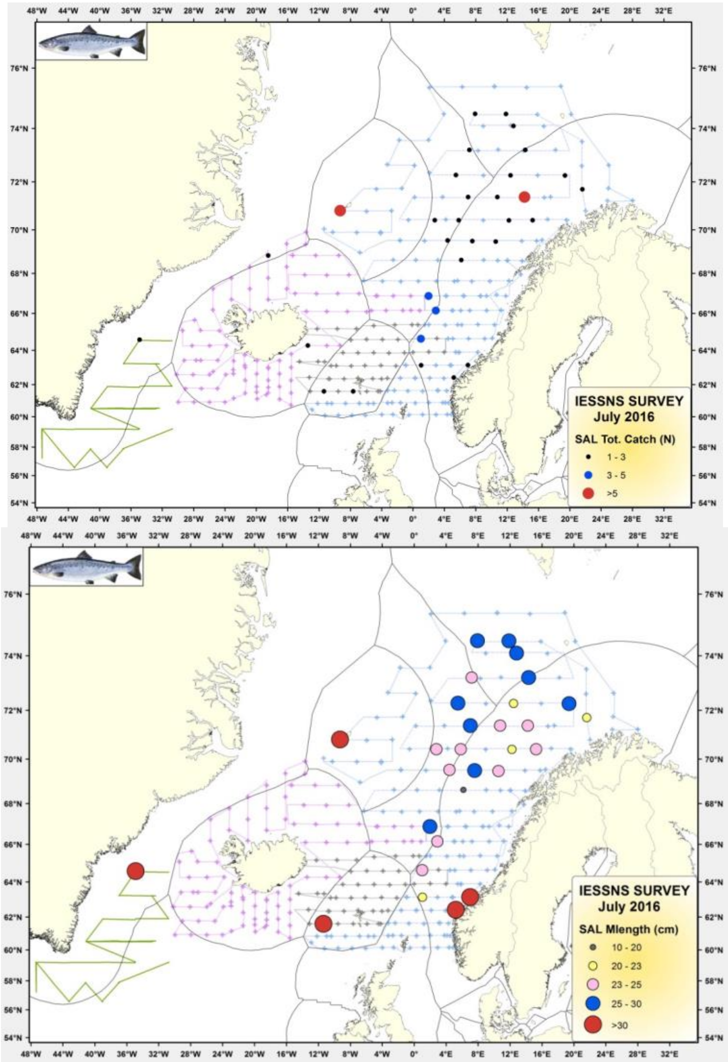


Figure 10 Locations and number of Atlantic salmon taken during IESSNS surveys in the Northeast Atlantic in July 2016 (upper panel) and the mean length of Atlantic salmon taken by location (bottom panel) during IESSNS surveys in the Northeast Atlantic in July 2016 (lower panel).

Bycatch of salmon in the Icelandic mackerel fishery

Since 2007, mackerel have been at high abundance within the Icelandic EEZ. A fishery opened in that year and the average catch of mackerel has been 163 thousand tonnes over the past five years. Mackerel are predominantly caught using midwater trawls during the summer months. Partial screening of the catch has been undertaken by the Icelandic Directorate of Fisheries to check for possible bycatch of salmon; this screening has involved both on-board inspections and screening at landing sites. In addition, salmon taken as bycatch have been voluntarily reported by the Icelandic mackerel fleet and have been recovered during surveys carried out by Marine and Freshwater Research Institute research vessels.

Between 2010 and 2014, 703 salmon have been recovered from the screening programmes and subject to investigation, including: tag recovery, collection of scales, otoliths and DNA samples, and stomach contents analysis. DNA analysis to date has enabled 186 salmon to be assigned to their area of origin (Olafsson *et al*., 2015). Eight fish, from post-smolts caught close to land, were determined to be of Icelandic origin. Of the remaining 178 samples caught further offshore, 121 individuals (68%) were from mainland Europe, the UK, and Ireland, 53 individuals (30%) were from Scandinavia and Northern Russia, and 4 individuals were from Iceland (2%) (ICES, 2016b).

Between 2010 and 2013, 107 894 tonnes of mackerel catches have been screened for salmon, resulting in a total bycatch recovery of 170 salmon. On average, the bycatch of salmon has been estimated at 5.4 fish per 1000 tonnes of mackerel caught. Over the period, this has ranged from 4.7 fish per 1000 tonnes in 2013 to 6.2 fish per 1000 tonnes in 2011. In 2016, the Icelandic Directorate of Fisheries detected 53 salmon. Of these, 50 were recovered from a mackerel catch of 9186 tonnes, again representing an average of 5.4 salmon per 1000 tonnes of mackerel. The remaining three salmon were caught in other fisheries. The data collected to date thus suggest that the proportion of salmon in the mackerel catches has been relatively stable over the time, and similar to those reported by ICES (2014). The Icelandic Directorate of Fisheries plan to continue screening for salmon bycatch in the mackerel fishery. This ongoing analysis will provide further information on the distribution and origin of salmon off the east and west coasts of Iceland.

Tracking and acoustic tagging studies

There is continued interest in the development of techniques to help investigate salmon mortality at sea and to better partition mortality between different periods of the marine phase of the life cycle. To this end, NASCO's International Atlantic Salmon Research Board (IASRB) adopted a resolution in 2014 to further support the development of telemetry programmes in the ocean.

The Atlantic Salmon Federation in Canada, in partnership with the Oceans Tracking Network and a number of collaborators have captured, sampled, and tagged with acoustic transmitters more than 3000 smolts from four rivers of the Gulf of St. Lawrence in eastern Canada over a period of fourteen years, from 2003 to 2016. Salmon smolts from additional research projects were also released with acoustic tags in 2016. Acoustic arrays to detect tagged fish were positioned at the head of tide of each river, at the exit from the bays to the Gulf of St. Lawrence (GoSL), and at the Strait of Belle Isle (SoBI) leading to the Labrador Sea, more than 800 km from the point of release.

Results to date indicate that the probability of smolt survival through freshwater was high for two rivers, while it was lower and highly variable in two others with the survival rate through freshwater negatively associated with migration duration. The survival rates from release to the outer bays leading to the GoSL varied annually, with noticeably lower survivals during the last four years for smolts from the Miramichi River release areas. The survival rates through the GoSL to the Labrador Sea were also highly variable, although some years showed very low mortality in this area.

The SoBI (between Labrador and Newfoundland) appears to be the primary route for smolts and kelts exiting the GoSL. The only other possible exit is through the Cabot Strait, and this array has been in place since 2012. Only two smolt tags were detected on the Cabot array (originating in Miramichi in 2012 and Cascapedia in 2013) although adult salmon, tagged as kelt in the preceding year, have been detected at this array. In 2016, kelts from Miramichi and Restigouche rivers crossed the SoBI array during a three-week period at end of June and early July, whereas smolts from many different stocks crossed this line together between 10 and 20 July (Figure 11).

Salmon kelts (400 in total) have been acoustically tagged in the Miramichi (since 2008) and Restigouche (since 2013) rivers. Some of these acoustically tagged kelts (53) have also been fitted with satellite tags (PSATs), since 2012 in Miramichi River and starting in 2016 in Restigouche River. There has been a high mortality of kelts in the GoSL and pop-up tags have provided data on where and how some of the kelts are dying (Strøm *et al.,* 2017). Seven of the PSAT-tagged kelts migrated beyond the Gulf of St Lawrence and into the Labrador Sea via SoBI. Of these seven, four followed the Labrador coast north towards Baffin Island, whereas three moved off the continental shelf over deep-water zones and deep dives down to 600–800 m were detected.

Additional research questions being addressed with acoustic telemetry are related to predation. Over the past four years, predator–prey interactions have been studied among diadromous species in the Miramichi River, with a focus on the spatial and temporal overlap of Atlantic salmon smolts and striped bass. Losses of acoustically tagged Miramichi smolts have been noted in areas where striped bass were known to be spawning. Preliminary modelling of acoustic tag tracks from smolts suggest that 10–19% of the smolt tracks from northwestern Miramichi and 2–20% of the smolt tracks from the southwestern Miramichi are consistent with tag tracks of striped bass, leading to the conclusion that these tagged smolts had been predated by striped bass. However, the results are highly variable over the past four years (2013–2016).

These tracking programmes provide useful information in the assessment of marine mortality on North Atlantic salmon stocks. These techniques have been proposed, and are being implemented in other areas, both in the Northwest and the Northeast Atlantic (e.g. SALSEA Track), in line with the NASCO IASRB resolution.

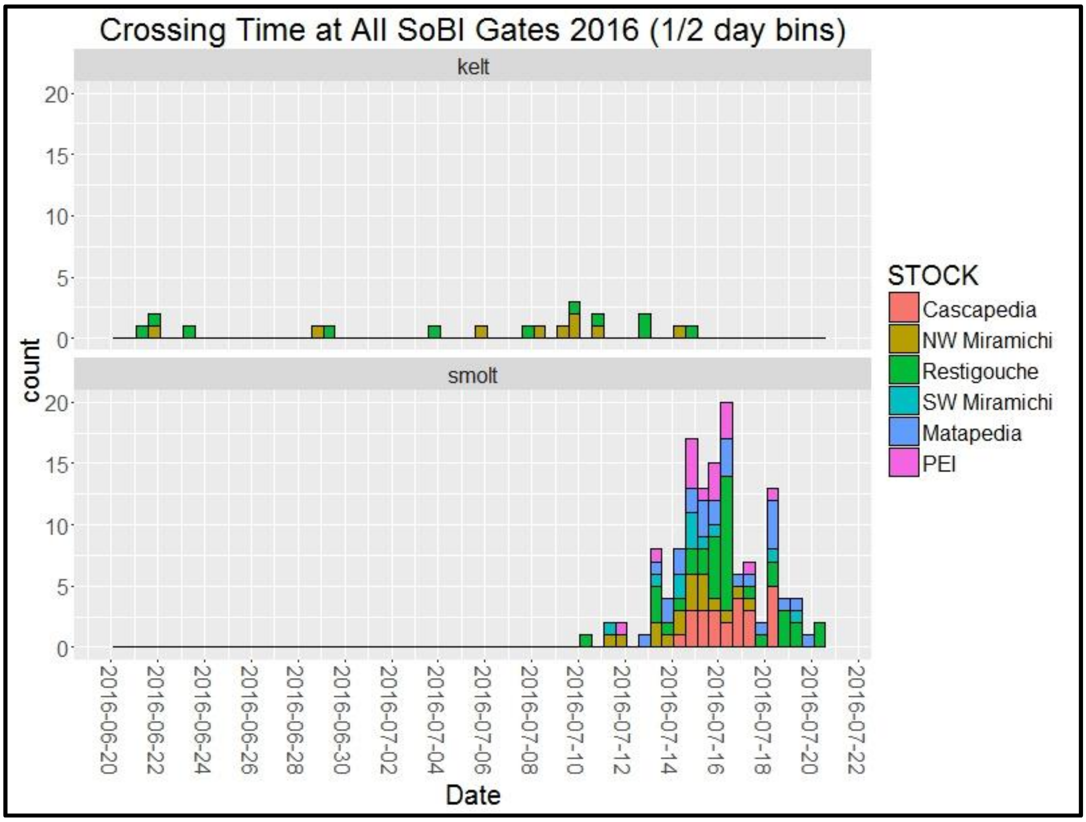


Figure 11 Counts and dates of acoustically tagged Atlantic salmon smolts and kelt from various Gulf of St. Lawrence rivers (PEI = Prince Edward Island) crossing the Strait of Belle Isle (SoBI) receiver array in 2016.

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

Developments in modelling and forecasting abundance of Atlantic salmon using life cycle models have been reported previously (ICES, 2015, 2016b). The life cycle model provides a framework to improve the understanding of the drivers and mechanisms of changes in Atlantic salmon population dynamics and productivity in the North Atlantic. An important limitation in the models currently used by ICES is that three different models are run for the three stock complexes (Northern NEAC, Southern NEAC, and NAC) and some core demographic processes, including survival in the first year at sea and proportion of the stock that matures as 1SW salmon are not harmonized among the three stock complexes. The most recent version of the life cycle model forms the basis of a graduate thesis research and considers the dynamics of the stock units in Southern NEAC and NAC complexes in a single hierarchical model where all populations follow the same life history processes, but with stock-specific parameters and data inputs (Figure 12). One of the most important changes is the simultaneous treatment of the dynamics of both 1SW and 2SW fish with estimation of the temporal variation of the proportion of fish maturing as 1SW for all stock units. Setting the dynamics of all stock units in a single hierarchical model provides the rationale for implicitly modelling covariation in the dynamics of the different populations that share migration routes and feeding areas at sea and are harvested in mixed-stock fisheries, particularly at West Greenland for NAC and Southern NEAC salmon. The approach also allows for disentangling the effects of fisheries from those of environmental and ecosystem factors in a hierarchy of spatial scales from a global effect scale shared by all populations to local effect scales for each stock unit independently.

The latest version of the life cycle model reviewed was applied to thirteen stock units (seven in the Southern NEAC stock complex and six stock units in NAC) for a time-series from 1971 to 2014. Stock units of the Northern NEAC complex were not included yet because of differences in the available time-series which only covers the 1983 to 2014 period. The life cycle model is implemented in JAGS (http://mcmc-jags.sourceforge.net/) and was run under the R platform (rjags library). The model provides estimates of trends in marine productivity (expressed as post-smolt survival rate to January 1 of the first winter at sea) and the proportion maturing as one-sea-winter for all stock units of Southern NEAC and NAC.

The initial 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 proportions of fish that mature after one year at sea, common to all stock units in NAC and Southern NEAC (Figure 13). Post-smolt survivals decreased over the time-series with a marked decline in the early 1990s, while the proportion of early maturing fish increased for almost all stocks from the 1970s to the 1990s and then decreased again for some stock units (Figure 13). For both the post-smolt survivals and the proportions of fish maturing as 1SW, common trends extracted from a Principal Component Analysis, account for more than 50% of the variance of the time-series, with only slight differences between the trends extracted from the NAC and Southern NEAC stock units separately (Figure 13).

The collective patterns observed across the thirteen stock units largely support the hypothesis of a synchronous response of populations to large-scale ecosystem changes in the North Atlantic in the last three decades that simultaneously impact distant populations during their marine migrations to and/or at common marine feeding grounds (West Greenland, Labrador, Faroes). Results also suggest some yet unknown relationships between marine survival and age-at-maturation. Although the causes and mechanisms for those changes remain unknown, results support previous studies that suggest a mechanism involving a decline in salmon prey abundance and/or quality as a response to bottom-up environmentally driven changes (Beaugrand and Reid, 2012; Mills *et al.,* 2013; Friedland *et al.,* 2014; Renkawitz *et al.,* 2015).

The life cycle model provides estimates and forecasts of variables of interest that can be compared to the ICES PFA model outputs. Estimates of stock-unit-specific PFA are similar for the Southern NEAC stock units (Figure 14). For the NAC complex, the current results indicate that there can be important differences in the posterior distribution estimates from the life cycle model compared to the previous model used by ICES. This is the result of differences in the inclusion of factors in the life cycle model, including the egg contributions of 1SW maturing salmon and the covariance structure in both the post-smolt survivals and the proportions maturing. The differences are more important for the Newfoundland stock unit, for example, in which there is an important contribution to total eggs by 1SW maturing fish, but estimates from the two modelling approaches are very close for stock units in NAC that have lower contributions to eggs by 1SW maturing salmon (Figure 14).

Anticipated improvements to model development and application

The integrated life cycle modelling framework facilitates incorporation of improvements in data inputs. Given the reported changes in smolt characteristics including proportions at age over time (Russell *et al.,* 2012), and the variations in the biological characteristics of returns of salmon to rivers (ICES, 2013), there would be benefit in improving a number of input data streams. Additionally, new stock origin data on catches in mixed-stock fisheries, based on genetic analyses, are becoming available (Bradbury *et al.,* 2016) and these inputs should be examined and compared to the current assumptions of stock composition of the mixed-stock fishery catches currently used by ICES.

The life cycle model currently models the dynamics between eggs and smolts as a density-independent function, with an average survival rate of 0.7% from egg to smolt. This value was selected based on average egg-to-smolt survival rates over a range of populations of varying status in UK (England and Wales) and UK (Scotland), as summarized in Hutchings and Jones (1998). There are consequences to the inferences on post-smolt survival rates if alternate freshwater dynamics are assumed, including compensatory density-dependent functions (Massiot-Granier *et al.,* 2014). Including more data and information on the freshwater phase of the life cycle constitutes one of the most important improvements in the modelling and for advancing the understanding of ecological inferences. Available data on monitored rivers could be used to provide better information on the egg-to-smolt survival rate dynamics, including parameterization of density-dependent survival rates as well as the variability among stock units.

The life cycle model built in a Bayesian framework provides a fully integrated method for assessing the consequences of mixed-stock fisheries (West Greenland, Faroes, Labrador, Newfoundland, and Saint Pierre and Miquelon) options on returns to rivers and to attainment of conservation limits by stock units, within a risk analysis framework. This differs from the current models used by ICES in which three independent models for Southern NEAC, Northern NEAC, and NAC are used.

The Northern NEAC stock units are not included in the current version of the model because of differences in the available time-series; the Northern NEAC complex input data begin in 1983 whereas the Southern NEAC and NAC time-series begin in 1971. Technical options could be explored to assess the feasibility of using time-series of data of different lengths between stock units as a means of integrating the Northern NEAC complex in the life cycle model without compromising the information from the longer time-series. For the objective of developing catch options, it may be sufficient to align the time-series in all the stock complexes to those of the Northern NEAC complex. This compromise would likely have minimal impact on forecasting results for the provision of advice, but it would result in an important loss of information for ecological inferences.

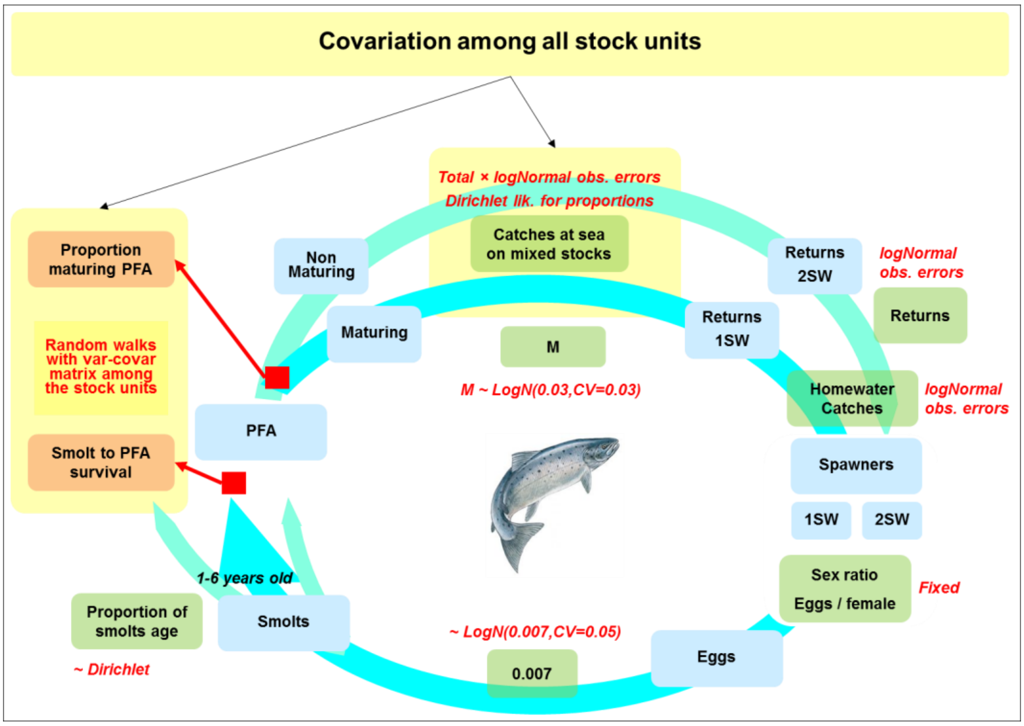


Figure 12 Schematic of the full life cycle model applied to the thirteen stock units of North America and Southern NEAC. Variables in light grey are the main stages considered in the stage-structured model. Light green boxes are the main sources of data assimilated in the model. Observation errors are introduced in returns and catches at sea. The smolt-to-PFA survival and the proportion of maturing PFA are estimated for the time-series (1971 to 2014). Yellow boxes indicate the location of the covariation among stock units.

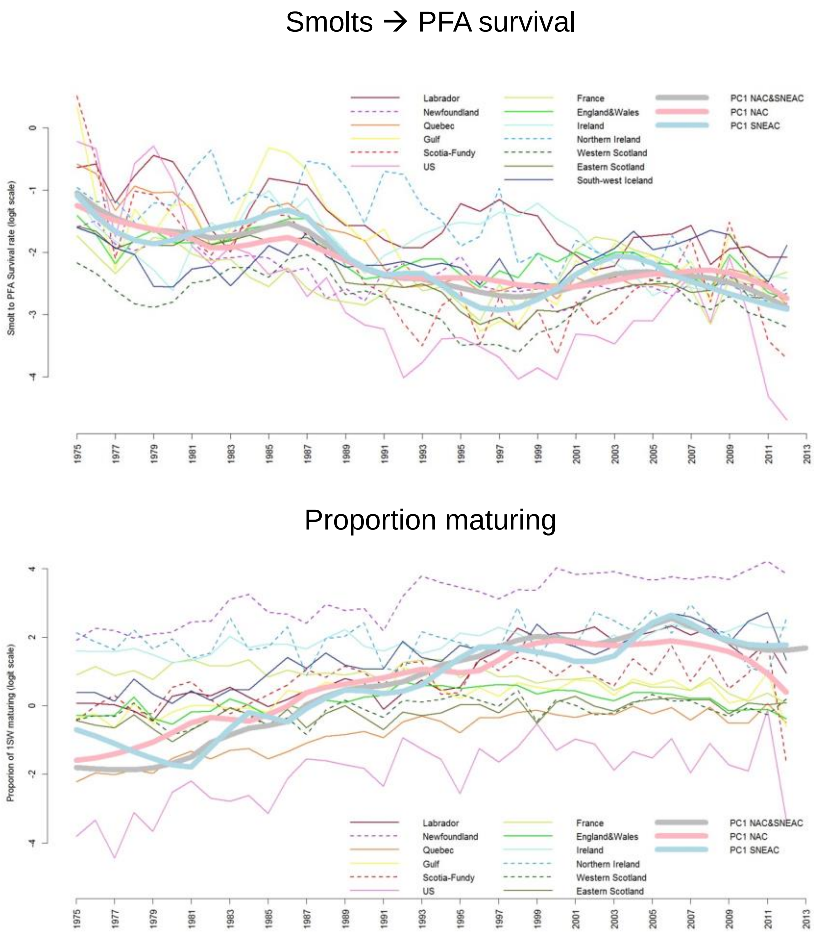


Figure 13 Time-series of estimates of smolt-to-PFA survival (top) and proportion of maturing PFA (bottom), on the logit scale, for 13 stock units in North America and Southern NEAC. Thin lines are the medians of marginal posterior distributions for the 13 stock units. Thick lines are the first principal components that indicate global trends among the 13 stock units and, separately for stock units in NAC and Southern NEAC, on the range corresponding to the logit range.

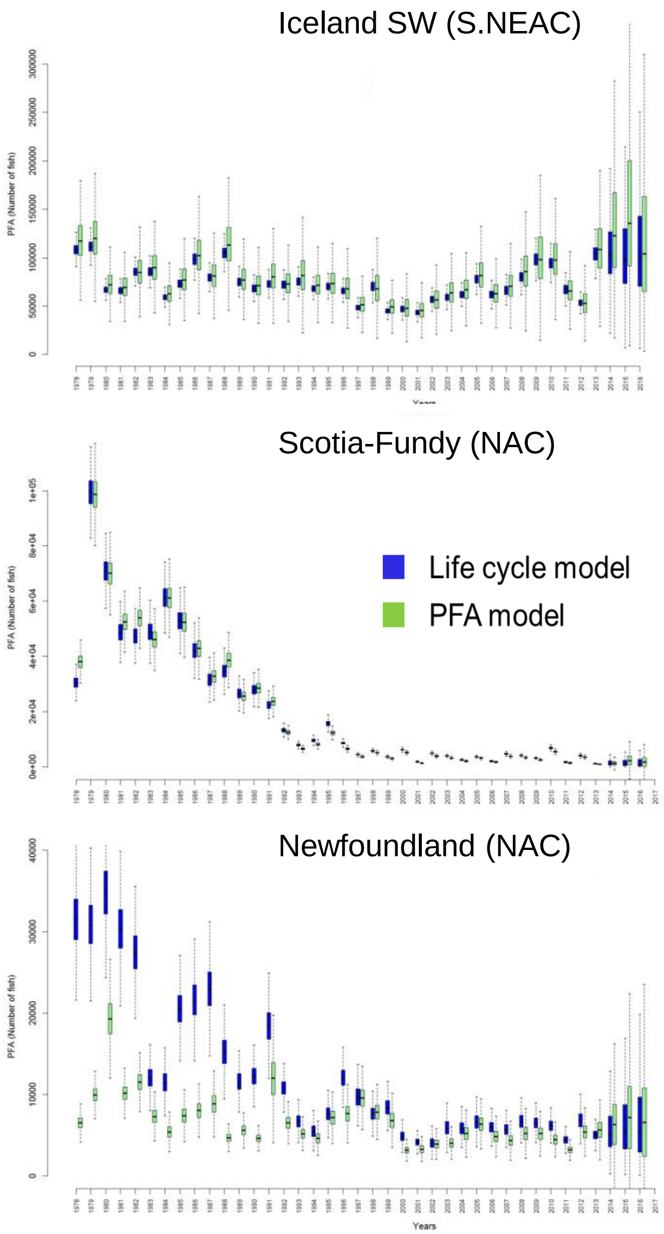


Figure 14 Comparison between the PFA estimates (non-maturing component of the PFA only) from the PFA and from the Bayesian life cycle model. Box plots are summaries of marginal posterior distributions. Forecasting is presented for the last three years. Both methods provide very similar estimates of PFA for stock units in Southern NEAC (here exemplified by Iceland), and for stock units in NAC with a low proportion of 1SW fish in returns (here exemplified by Scotia-Fundy). Differences are higher for stock units with a high proportion of 1SW in returns (here Newfoundland), with an average 90% of 1SW in returns.

NASCO 1.3 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 on 10–12 November 2015 at ICES HQ in Copenhagen to complete their 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 8). Analyses of the case studies and DBERAAS have both been completed, and the ICES report is currently being finalized.

Successful restoration and rehabilitation was characterized by:

- 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.

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;
3. Freshwater habitat degradation.

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

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

The compilation of the DBERAAS database, including the identification of the stressors that were constraining salmon population rehabilitation and recovery was completed by regional experts and based on available evidence, which is much more complete for freshwater systems. Indeed, habitat fragmentation and water quality degradation are two important stressors that have been demonstrated as having contributed to the reductions, and in some cases the loss of salmon populations in rivers. As Atlantic salmon is an obligate freshwater spawner, conditions in freshwater, particularly those associated with connectivity and barriers, are important stressors for which clear remedial actions can be undertaken to improve the probabilities of population.

Reintroduction of Atlantic salmon in the Rhine

Following the extirpation of Atlantic salmon in Germany in the 1950s, reintroducing the species was not considered for many years, mainly because of heavy water pollution and lack of river continuity in many places. In the late 1970s the first salmon reintroduction initiatives started in tributaries of Ems and Elbe, followed later by initiatives in all German river areas that flow into the North and Baltic seas (e.g. Weser, Rhine, and Oder). Some of these activities were discontinued, because prospects of success remained uncertain and/or because of insurmountable obstacles. Others resulted in more comprehensive and long-term programmes (i.e. "Salmon 2000").

Despite the numerous impediments of the international Rhine, salmon now return regularly and migrate upstream to spawn. From 1990 to 2016, around ten million young salmon were stocked in the Rhine system. Since then, 8816 adult returns were officially enumerated through various methods (control stations, fish counters, and random electrofishing campaigns or random observations and reports (Figure 10). It is possible, based on anecdotal evidence, that the actual number might be considerably higher. Fisheries on salmon are still prohibited in the entire Rhine catchment. While stocks of mixed origin were used in the early years restock the Rhine, this is now carried out with mainly local stocks from regional hatcheries, mainly produced from Rhine returns, and partially supplemented by imported ova of internationally agreed origin (Upper Rhine: Allier/France; Middle/Lower Rhine: Ätran/Sweden). Details of a coordinated genetic monitoring programme, which will monitor all stocked fish, is being prepared in 2017, with the programme running for the next two years. Because of high natural reproduction, stocking measures have been stopped in some tributaries, to investigate the development of self-sustaining salmon populations (e.g. River Agger). Ecological continuity in the main channel and tributaries of the Rhine has been further improved over the last years and the partial opening in 2018 of the Haringvliet sluices, an important access from the North Sea to the river system in the Netherlands, is on schedule.

In Germany, a complementary study on downstream migration of Atlantic salmon smolt at three hydropower stations, using different technologies to reduce negative impact on migrating fish, showed mortalities up to 25% for the whole study area. The mortality was assessed against losses in a free-flowing reference river stretch. The reservoir upstream of the power station was identified as an area of high mortality, especially in the River Sieg, with the main reason suggested as potential presence of fish predators in a slow-flowing reservoir compared to a free-flowing river stretch (Økland *et al.,* 2016).

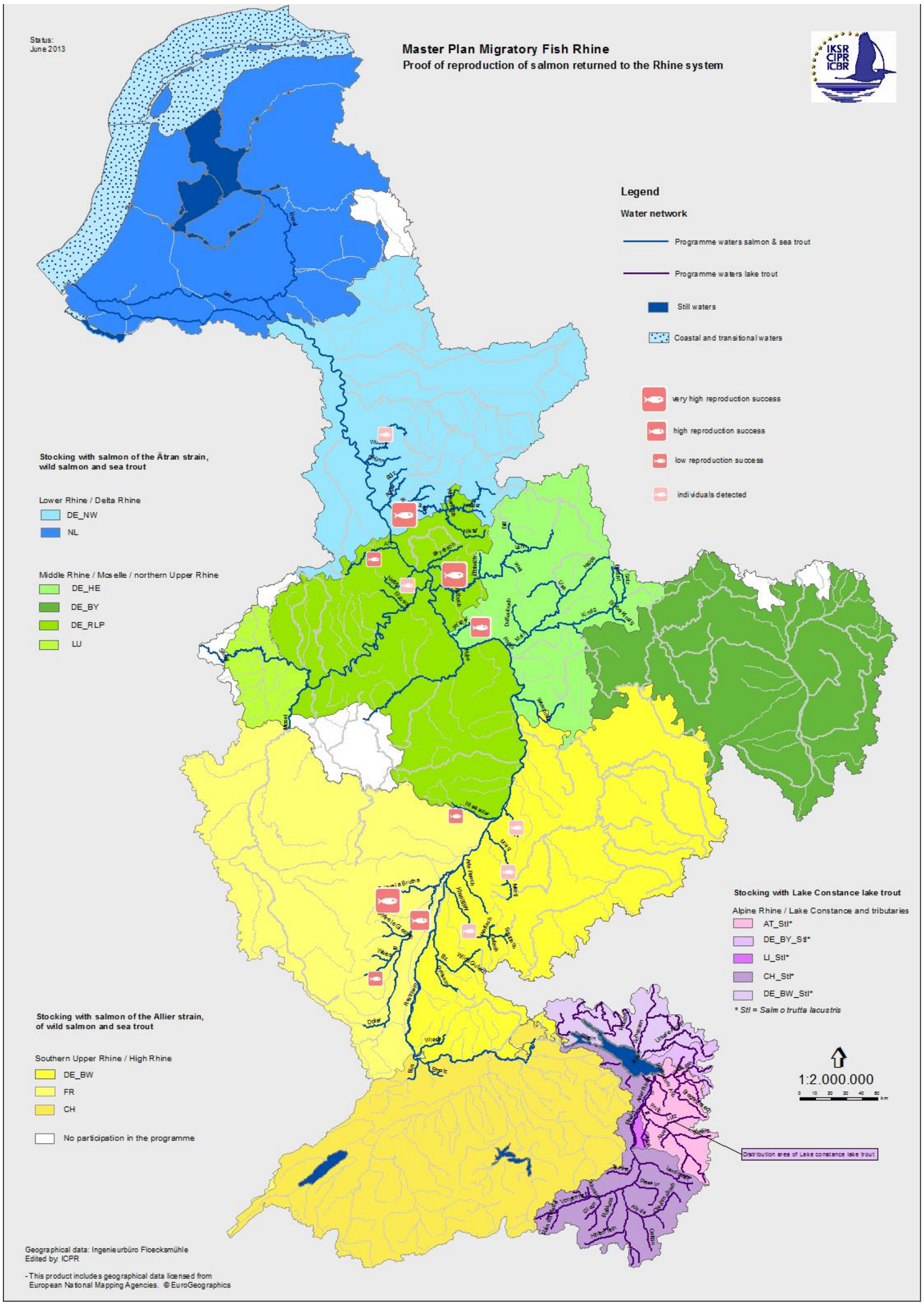


Figure 15 Summary of reintroduction of salmon in the Rhine system: stocking origins and evidence for reproductive success of returning salmon (figure from ICPR, 2013).

NASCO 1.4 Provide a summary of the available diet data for marine life stages of Atlantic salmon and identify key prey species at different life stages

Identifying key prey items of salmon at different marine life stages furthers the understanding of feeding and ecology of salmon and the identification of potential bottom–up effects on salmon abundance and population dynamics.

NASCO asked ICES to provide a summary of the available diet data for the marine life stages of Atlantic salmon and to identify key prey species at different life stages. In addition, ICES was requested to comment on any significant changes in population dynamics (i.e. abundance, distribution, size structure, and energy density) of key prey species which may be associated with changes in salmon abundance, distribution, and marine ecology (e.g. the recently identified decreases in capelin energy density and the consequences on marine productivity of Atlantic salmon), while also providing information related to fisheries which catch significant numbers of the identified key prey species (i.e. direct harvest or bycatch).

Life stage, geographic location, and water depth are useful indicators of Atlantic salmon diet at different stages during the marine phase. The marine phase of North American Atlantic salmon was partitioned into three discrete stages based on age, location, and maturity:

- post-smolt, representing the first six months at sea, either nearshore (coastal embayments, fjords, nearshore continental shelf) or offshore (shelf and oceanic waters);
- the 1SW maturing/non-maturing phases, offshore and at Greenland, Faroes, Norwegian Sea;
- the 1SW/2SW mature/maturing/kelts – nearshore phase in coastal waters.

This provided a geographic and ecological framework for grouping information (from sources covering over 85 years of intermittent data collection; 1935–2017) from which key prey items were identified. The primary prey items were determined based on historical and contemporary abundance in Atlantic salmon diets. Generally, the item was classified as a key prey species if it comprised over 20% (by weight or number) of the stomach contents, or if significant regional variation in dominant or emerging prey (i.e. increasing over time) was evident. The resulting areas, stages, and sources of information for the Northwest Atlantic are shown in Figure 16.

For the identified key prey species, summary information is provided:

- distribution and abundance (trends and current abundance when available);
- size structure and energy density/proximate composition, when available;
- fisheries interests, if any, and description of fisheries exploitation and management when available.

Diet of salmon during the marine phase

There are differences in the extent of the literature available on the diet of Atlantic salmon from the Northwest and the Northeast Atlantic, as well as some differences in diet associated with geographic differences in species composition. No information on temporal variation in diet has been collected in a consistent manner.

Northwest Atlantic

Feeding intensity and diet composition varies with life stage, gape size (Scharf *et al.*, 2000), season, and location, and there are obvious differences in diet associated with water depth. Capelin (*Mallotus villosus*), Atlantic herring (*Clupea harengus*), and sandlance (*Ammodytes* spp., referred to as sandeel in Europe) are frequently consumed at shallow depths, while deep-water fish (barracudina), amphipods (*Themisto* sp.), euphausiids (i.e. *Meganyctiphanes norvegica* and *Thysanoessa intermis*), and cephalopods (i.e. boreoatlantic armhook squid) are consumed at deeper depths (Table 9).

Some of the key prey species identified are important during multiple life stages and in multiple locations:

- Post-smolts in nearshore shallow waters: Atlantic herring (fall spawned 1+, 30% by weight, in US waters) and sandlance (94% occurrence; in Canadian waters) over shallow nearshore waters. Renkawitz and Sheehan (2011) showed differences between hatchery and wild diets, with hatchery post-smolts consuming less food and lower quality food than naturally reared smolts.
- Post-smolts in offshore waters: Switch from fish prey in nearshore waters to pelagic amphipods (39% by number) and euphausiids (49% by number). In deep waters of the Labrador Sea, post-smolts consume am-

phipods (59% by weight) and cephalopods (24% by weight), but capelin (78% by weight) were found in samples of post-smolts collected over shallow offshore banks.

- 1SW maturing/non-maturing offshore phase: On offshore banks in the Labrador Sea, sandlance (67% by weight) was abundant, whereas in deeper water, deeper water fish (i.e. barracudina; 58% by weight) were dominant.
- 1SW non-maturing at West Greenland: Forage primarily on capelin (53% by weight) with important contributions of deep-water pelagic invertebrate species such as amphipods (*Themisto* sp.; 20% by weight) and squid (*Gonatus* sp.; armhook squid, 15% by weight, but increasing over time).
- 1SW/2SW mature/maturing in the nearshore phase: As maturing adults move into shallower coastal waters during the spring of the spawning migration, a wide variety of prey are consumed with intensive feeding on capelin (76% by weight) and Atlantic herring (15% by weight but important regionally in the Gulf of Maine and Bay of Fundy) and sometimes on sandlance in smaller amounts. Returning adults, thought to cease foraging before freshwater entry (Cairns, 2002), have also been shown to forage in coastal waters on diadromous species (i.e., rainbow smelt and alewife).
- Kelt phase: Kelts are known to feed actively in rivers and estuaries in spring while migrating back to the ocean. Previous spawners at other life stages have been sampled in other studies, but details of diet have not been reported separately. They probably feed on the same spatiotemporally abundant foods that other salmon consume; at West Greenland there was no difference in the diets of 1SW non-maturing fish and previous spawners.

Northeast Atlantic

There are large temporal and spatial differences in the diet of salmon in the Northeast Atlantic (Rikardsen and Dempson, 2011). There are also differences in the diet with increasing size of the salmon (Rikardsen and Dempson, 2011; Table 10).

Post-smolts in coastal regions: Feed primarily on fish larvae. Based on studies in the early 2000s, post-smolts in the northern region mainly feed on herring larvae, sandeel larvae, and amphipods, whereas further south they feed on blue whiting larvae, sandeel larvae, and other fish larvae (Haugland *et al.,* 2006). There was, however, large interannual variability. Other fish larvae and euphausiids can also be important for post-smolts (Hansen and Pethon, 1985).

Post-smolts in fjords: Salmon are opportunistic feeders when they migrate through the fjords. The composition of the post-smolt diet varies among Norwegian fjords and among years (Rikardsen *et al.,* 2004). Feeding in the fjords was more extensive with more food and fewer empty stomachs in the north than in the south, suggesting that food availability might be higher in northern fjords. The diet in the fjords consists of a variety of organism groups (Table 10), but on a weight basis it was dominated by pelagic fish larvae (Rikardsen *et al.,* 2004; Hvidsten *et al.,* 2009), particularly sandeel, herring, and gadoids (Rikardsen *et al.,* 2004). The proportion of fish in the stomachs was higher in the outer reaches of the fjords than in the inner parts of the fjords (Rikardsen *et al.,* 2004).

Post-smolts in offshore areas: In general, post-smolts feed on large zooplankton in oceanic regions (Rikardsen and Dempson, 2011). From the SALSEA data (Anon., 2012), the main food items of post-smolts were juvenile fish and amphipods (*Themisto* sp.). Salmon also showed clear differences in diet among years; when *Themisto* sp. and fish were less dominant in their diet, salmon post-smolts seemed to have a broader diet and fed more on small prey.

As with post-smolts, there are temporal and spatial differences in the diet of larger salmon. Small pelagic fish, large zooplankton, and mesopelagic fish are important prey items. Herring and capelin have previously been reported to be the main components of the diet along the middle and central Norwegian coast (Hansen and Pethon, 1985). Of the macrozooplankton, the euphausiids and amphipods are considered to be important. Mesopelagic fish (such as *Maurolicus muelleri* and *Benthosema glaciale*) and squid (*Gonatus fabricii*) are also preyed upon by larger salmon in the Northeast Atlantic, especially during the winter (Jacobsen and Hansen, 2000). Further south, sandeel and herring were the dominant prey items in the diet of returning salmon in Scottish waters (Fraser, 1987), and blue whiting and mackerel have been important for salmon in Faroese waters in the autumn (Jacobsen and Hansen, 2000). Spatial differences in diet are apparent, considering that sprat dominated the diets in coastal Irish waters (Twomey and Molly, 1974) and herring the diets in the northern Baltic Sea (Salminen *et al.,* 1994). The general picture is that larger salmon feed on larger prey and are opportunistic predators capable of switching diet according to availability (Rikardsen and Dempson, 2011).

Key prey species characteristics and fisheries

The key prey species of Atlantic salmon fall into two general categories: harvested fish (capelin, Atlantic herring, sandeel, and other pelagic species) and unharvested prey, including fish (barracudina and sandlance), crustaceans (amphipods and euphausiids), and cephalopods (armhook squid). More information was available for commercially important fish species, but for all the other unharvested species, fish and invertebrates, very little is known besides basic life history and distribution.

Commercially important species

More information was available for commercially important fish species, but very little information was available for capelin in Greenlandic waters. The commercially important species in the Northwest Atlantic (Atlantic herring in US waters and capelin in Canadian waters) appear to be responding positively to the fishery management actions taken over the past 25 years. Spawning-stock biomass (SSB) of Atlantic herring in US waters is estimated to be well above the SSB target (Deroba, 2015) although the mean weight of Atlantic herring in the Gulf of Maine has declined drastically over the past 30 years (Golet *et al.,* 2015). The abundance indices for the Newfoundland/Labrador stock of capelin suggest that the stock is approximately 25% of the peak estimates from the 1980s, but increasing over the past few years (DFO, 2015). In contrast to the Northeast Atlantic, sandlance (*Ammodytes* sp.) are not commercially exploited in the Northwest Atlantic.

The Northeast Atlantic is generally well monitored due to the intensity of fishing for commercially important small pelagic fish species. Norwegian spring-spawning herring, blue whiting, and mackerel can each have annual landings that exceed 1 to 1.5 million tonnes. Monitoring in summertime is concentrated in the Norwegian Sea and the surrounding area (Icelandic Sea, Greenland Sea, northern North Sea), as these are the main feeding grounds for the large pelagic stocks.

- There are numerous stocks of herring in the Northeast Atlantic. The largest stocks are the Norwegian spring-spawning (NSS) herring (SSB in 2016 approximately 5 million tonnes; ICES, 2016c) and North Sea herring (SSB in 2016 approximately 2 million tonnes). In addition there are some smaller Icelandic, Norwegian, Scottish, and Irish stocks. Although all stocks can be locally important prey for salmon, NSS herring are probably the most important prey owing to the large stock size and spatial overlap with both post-smolt and larger salmon. However, NSS herring have very variable recruitment success, with roughly 10 years between each large year class (Toresen and Østvedt, 2000). There were several strong year classes in the late 1990s and early 2000s. The last strong year was in 2004. Even though the following year classes have been weak, there would have been abundant herring larvae available for post-smolts, given that recruitment failure of herring is caused by high mortality after the larval phase.
- Mackerel can be important for salmon both as prey and as a potential competitor. The mackerel stock is presently around 4.5 million tonnes and has had very good recruitment in the last 10–15 years (ICES, 2016d). The stock is expanding further north and west and is now distributed over the entire Norwegian Sea, around Iceland, and to the southeastern part of Greenland during the summer (Nøttestad *et al.,* 2016), and also into the Barents Sea. In recent years a large biomass of mackerel has migrated into the Norwegian Sea along the Norwegian coast in May. These mackerel feed to some extent on herring larvae (Skaret *et al.,* 2015) and can be an important competitor for salmon. Although several strong year classes have been produced lately, the spatiotemporal overlap with post-smolts and larger salmon is probably limited. With the expansion of feeding, mackerel, including the smaller mackerel (1- and 2-year-olds), have migrated further north and are now found over large parts of the Norwegian Sea.
- There are two stocks of capelin in the Northeast Atlantic, the Icelandic capelin and the Barents Sea capelin. The majority of capelin spawn at three to four years of age and are short-lived. The Icelandic stock utilizes feeding grounds north and west of Iceland. After low stock levels around 1980 and 1990, the stock size has been fairly stable, and well above the ICES B_{lim} (biomass limit) reference point since the early 1990s (ICES, 2016e). The Barents Sea stock has had large fluctuations since the 1970s (ICES, 2016f). The stock collapsed around 1985, 1993, and 2003, but recovered quickly again each time. The stock is presently collapsed again, but is assumed it will recover again as a high abundance of juvenile capelin has been recorded.
- Sandeel (*Ammodytes* sp.) larvae can be an important part of the diet for post-smolts (Haugland *et al.,* 2006) because of their large spatiotemporal overlap. In the northern North Sea, sandeel populations are considered to have collapsed and there are currently no fisheries in the area around Shetland. The sandeel stock in the southern and central North Sea is in good condition, although much smaller than during the 1980s and 1990s (ICES, 2016g).

- The biomass of blue whiting has increased in recent years owing to good recruitment and is presently around 6.7 million tonnes (ICES, 2016c). Blue whiting larvae can be an important part of the diet for post-smolts in the southern region (Haugland *et al.,* 2006), as the larvae are distributed north and west of the UK and Ireland in April and May. Juvenile blue whiting can also be an important part of the diet for larger salmon in the winter, as the juveniles do not migrate to the spawning areas but remain widely distributed from Portugal to the Norwegian Sea during the winter.

Non-commercially important species

Very little is known about the unharvested species although they are considered to be fairly abundant, given their prevalence in the diets of many other marine species. Small zooplankton (< 2 mm) are generally sampled with WP-2 nets hauled vertically from 200 m to the surface. Macrozooplankton, including amphipods and euphausiids, are sampled with MOCNESS (Multiple Opening/Closing Net and Environmental Sensing System) multi-nets or with macrozooplankton trawls. MOCNESS nets are not fully efficient for capturing large zooplankton as it is possible for individuals to avoid the gear. The time-series of abundance for macrozooplankton are very short and limited in geographic and seasonal distributions.

In general, there are more zooplankton in the northwestern region than in the southeastern region of the Norwegian Sea. The water masses in the western region are cold arctic waters which flow southward. As this water is too cold for most pelagic fish (< 2°C), larger zooplankton that would otherwise be vulnerable to fish predation are more prevalent in this region. The biomass of small zooplankton (< 2 mm) in the Norwegian Sea in May consists mainly of smaller copepods, with *Calanus finmarchicus* as a dominating species. The time-series (1996–2016) indicates a generally decreasing trend, but with some variation between years (ICES, 2016h). The lowest biomass was recorded in 2009, but since then the biomass has increased slightly. Although the biomass is lower than in the 1990s, the levels are still high compared to other regions such as in the Barents Sea.

As for the smaller zooplankton, abundance of large zooplankton has been decreasing over the last 5–10 years compared to the period 1991–2010 (ICES, 2016c). However, these data are uncertain and need to be quality controlled before any final conclusions are made. The spatial variation and exact decrease in abundance of large zooplankton has not been quantified to date.

Mesopelagic fish are present worldwide. They inhabit depths of 200–1000 m with diurnal migrations. The most common species in the Northwest Atlantic are myctophids (lanternfish) and barracudinas, and in the Northeast Atlantic *Maurolicus muelleri*, *Benthosema glaciale*, and *Arctozenus risso*. It is assumed that abundance decreases with latitude. The present and historical biomasses of mesopelagic fish in the North Atlantic are unknown.

Ecosystem considerations

There have been large changes in the preferred feeding areas for NSS herring, mackerel, and capelin since the mid-1990s and up to the present time. NSS herring now feed east of Iceland and further northwest towards Greenland, instead of in the central Norwegian Sea. Mackerel are found throughout the Norwegian Sea, south of Iceland, and into Greenlandic waters. Icelandic capelin are migrating further northwest than they used to during the feeding periods. These changes may be partly related to climate change and warmer waters, but may also be caused by changes in prey availability. Mackerel have shown reduced growth-at-age in the last decade, and this change is correlated with the abundance of herring and mackerel feeding in the Northeast Atlantic (Olafsdottir *et al.,* 2016).

Although much of the available information for salmon prey abundance in the North Atlantic is uncertain, the results indicate highly variable and generally less available prey for post-smolts in the last 10 to 15 years. Important fish larvae of herring and sandeel are less abundant in the Northeast Atlantic than they used to be, and there is a low spatio-temporal overlap between post-smolt and mackerel and blue whiting larvae. Furthermore, there are indications of a reduction in abundance of zooplankton in the Norwegian Sea.

There is, however, good availability of prey for larger salmon. All of the pelagic stocks feeding in the Norwegian Sea are abundant (NSS herring, blue whiting, and mackerel). In addition, the Icelandic capelin stock feeds in western Northeast Atlantic and the Greenland Sea areas. Large zooplankton are also more abundant in the western Northeast Atlantic and Greenland Sea than further to the east. Abundant juvenile blue whiting and an unknown biomass of mesopelagic fish are potential prey during the winter. Although the larval abundance of post-smolt prey species in the Northeast Atlantic has declined it is uncertain whether this reduction has resulted in reduced growth and survival.

Furthermore, it is not known whether the changes in zooplankton abundance are driven by bottom–up or top–down processes.

Altered forage conditions have been shown to have effects for some species in terms of size and body condition (Golet *et al.,* 2007*,* 2015; Sherwood *et al.,* 2007) and by inference have affected survival and population abundance via direct and indirect mechanisms (Walsh and Morgan, 1999; Dutil and Brander, 2003; Mills *et al.,* 2013; Renkawitz *et al.,* 2015) (Figure 17). Because of insufficient baselines of key metrics or time-series of monitoring information/data, it is not known if similar changes in distribution, abundance, size structure, proximate composition, or energy density of un-harvested species have also occurred.

The general picture is that Atlantic salmon are opportunistic predators capable of switching diet according to availability (Rikardsen and Dempson, 2011). However, not all prey have a similar energetic content nor is the energy value of prey constant over time (Renkawitz *et al.,* 2015). Many prey items of Altantic salmon are poorly studied and monitored because they are not of commerical importance in the North Atlantic. Consequently the impact of variations in distribution, abundance, and forage quality of these prey on Atlantic salmon growth, maturation, and survival is largely unknown, and though the trophic link through bottom–up effects is hypothesized, it is difficult to demonstrate. For example, reductions in abundance of small copepods such as *C. finmarchicus*, which themselves are not an important prey for salmon but are important prey for organisms that salmon prey upon, may be expected to lead to reduced prey for salmon, given that the ecosystem processes are largely driven by bottom–up energy flow.

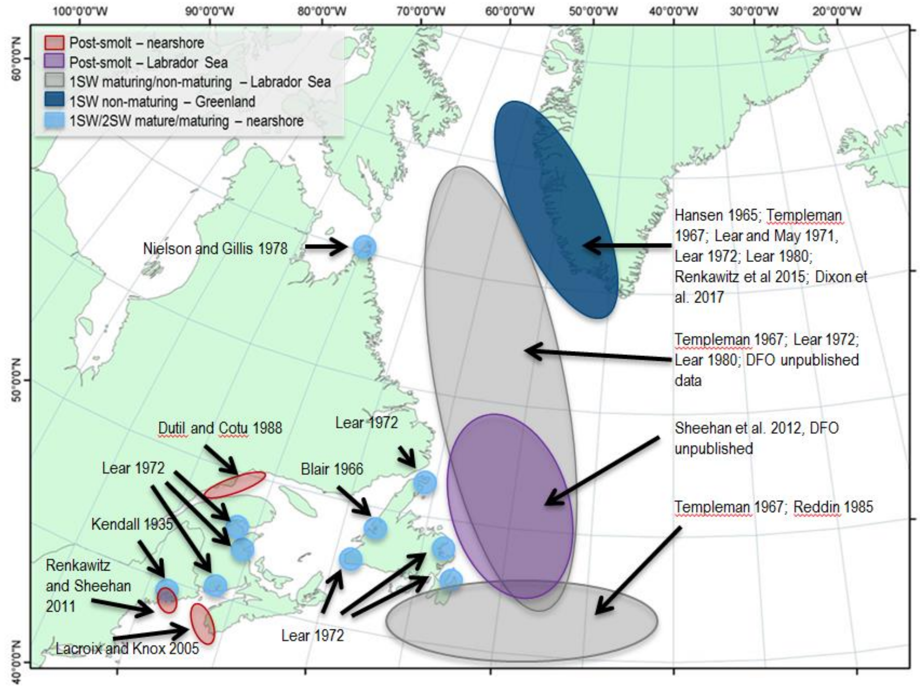


Figure 16 Approximate geographic areas, associated distinct marine phases, and literature sources of Atlantic salmon dietary information for the Northwest Atlantic.

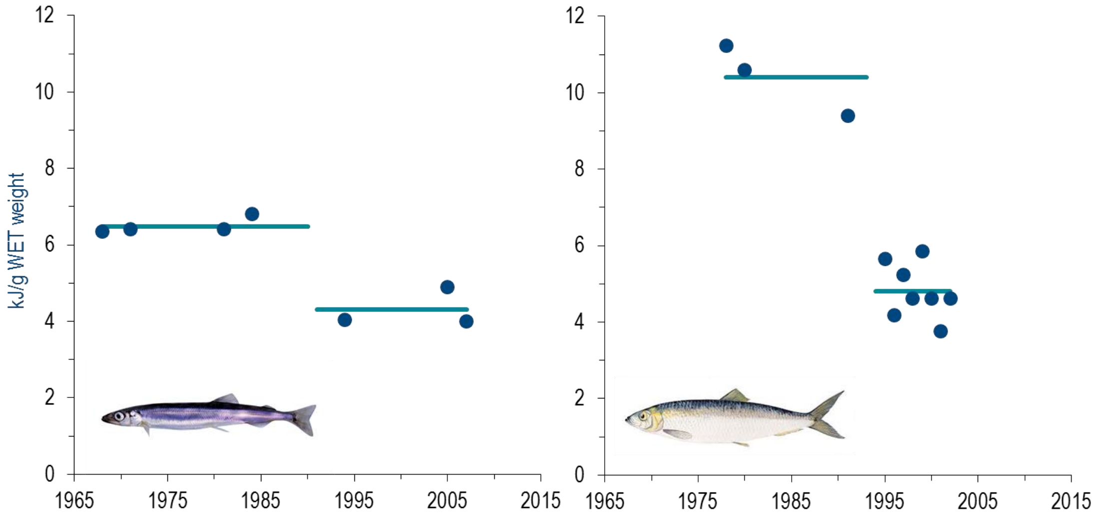


Figure 17 Energy density estimates (kJ g^{-1}) of capelin in the Labrador Sea (left) and Atlantic herring in the Gulf of Maine (right) with mean energy densities (bars) before and after the year 1990. Energy density estimates were selected that incorporated potentially large seasonal and ontogenic energy density variations. Data are reproduced from Renkawitz *et al.* (2015) for capelin and McGurk *et al.* (1980), Steimel and Terranove (1985), Lawson *et al.* (1998), and Diamond and Devlin (2003) for Atlantic herring.

NASCO 1.5 Provide a description of the potential future impacts of climate change on salmon stock dynamics

Advice summary

Climate change (CC) can be expected to impact Atlantic salmon at both the regional and Atlantic Ocean scale. Numerous biotic and abiotic factors that affect salmon survival are likely to be modified by CC, but the relative impact and interactions among these factors are poorly understood. While there will be some negative impacts, some positive impacts can also be expected for some Atlantic salmon populations. CC has the potential to affect the distribution, productivity, migration patterns, genetic variation, and other biological characteristics of the species within the range of the populations.

Invariably, projections from CC modelling suggest conditions of the atmosphere and the aquatic environment that have not previously been manifest in recorded history, and the response of Atlantic salmon populations to these novel conditions are highly uncertain.

The potential impacts of CC are discussed in the context of the fish species, Atlantic salmon (*Salmo salar*), and its populations rather than specifically on Atlantic salmon fisheries. It is evident, however, that consequences of CC on salmon stocks will likely have subsequent effects for human uses (i.e. fisheries).

<u>Climate and drivers</u>

- Before 2050, atmospheric concentrations of carbon-based emissions are neither expected to flatten out nor to be reduced. Even if emissions were to be reduced, the overturning of the ocean is at the scale of 1000 years, so the changed conditions in the ocean will persist.
- Climate variation has been large and seemingly cyclical over the past 800 thousand years of record, with annual temperature variations greater than 10°C from peak to trough. Atlantic salmon has persisted through all the climate variations of the past 500 thousand years.
- The climate projections indicate increased intra-annual variations in a number of parameters at global and regional scales; these variations are equally, if not more consequential than the changes in average values to salmon persistence. The changes that are observed and projected are very rapid and the rate of variation may well exceed the rate at which Atlantic salmon may adaptively respond.
- Changes in chemical and biological characteristics of oceans and freshwaters associated with increased atmospheric carbon include, but are not limited to, increased air and water temperatures (freshwater and marine), freshening of surface ocean layers, reduced pH (increasing acidification) of oceanic waters, and reductions in oxygen concentrations. Global warming also affects terrestrial systems, the freshwater environment of lakes and rivers, and the transitional waters between the marine and freshwater.

- Temperature and precipitation are primary drivers affecting aquatic ecosystems in general, and are major drivers for salmon in freshwater. Variations in these components influence many other environmental factors including: river discharge and level, pH, dissolved oxygen levels, water colour, and light penetration.
- Variations in biotic factors due to CC, including food availability and inter-specific competitions, are likely to occur.
- For Atlantic salmon, much of the CC research in freshwater has focused on specific drivers, while in marine waters, research has tended to examine linkages with climate forcing indices. There is much less information available for transitional waters (i.e. estuaries) as these have been much less studied.

Potential impacts

- Marine and freshwater habitat for Atlantic salmon is likely to extend further north in the future under continuing trends in global warming.
- Some loss of suitable freshwater habitat could occur, particularly in the southern part of the range, but this is unlikely to result in the loss of entire regional stock components.
- Increased stream temperatures are likely to result in increased freshwater growth in juveniles and productivity in many areas throughout the range, but this could change smolt age and run timing which might not be beneficial to survival. In the absence of thermal refugia, freshwater habitats could become limiting for some populations in areas where stream temperatures exceed lethal limits.
- Competition with, and predation by, other fish species, native and introduced, could increase in future as some of these species are currently expanding their ranges because of environmental change.
- Reduced survival may result from increased prevalence and virulence of parasites and pathogens.
- CC may alter migration routes and distribution of salmon at sea, with unknown consequences for survival.
- Environmental and genetic adaptation can facilitate adjustment to changing environmental conditions, if the rate of change in the environmental conditions does not exceed the capacity of the organism for genetic adaptation.

Request

In its request for advice , NASCO requested ICES:

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

….
1.5 quantify possible future impacts of climate change on salmon stock dynamics;
….

The ICES Secretariat indicated to NASCO on 10 November 2016 that it would not be possible to quantify possible future impacts of climate change on salmon stock dynamics. However, ICES indicated that it would be in a position to provide information on the issue and that the the request could be modified as follows:

1.5 provide a description of the potential future impacts of climate change on salmon stock dynamics;

To address the request, a Workshop on Potential Impacts of Climate Change on Atlantic Salmon Stock Dynamics (WKCCISAL, ICES 2017c) was organized.

Basis of the advice

Methods

The WKCCISAL terms of reference (ICES, 2017c) 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.

Background

Anthropogenic CC refers to the consequence of anthropogenic inputs of carbon dioxide (CO_2) and other related compounds to the atmosphere. The most frequently expressed CC response is changes in temperatures. Higher concentrations of greenhouse gases lead to increasing temperatures (global warming), because longwave radiation is reflected back to earth. This phenomenon has been observed since the mid-20th century (IPCC, 2014). Climate variation has been large and seemingly cyclical over the past 800 thousand years of record, and particularly so over the past 500 thousand years, corresponding roughly to the evolutionary divergence of *Salmo salar* and *Salmo trutta* from a common ancestor (Figure 18). Over that time period, annual temperature variations have been estimated at greater than 10°C from peak to trough, while estimates of atmospheric carbon dioxide concentration varied from approximately 150 ppm to just over 300 ppm.

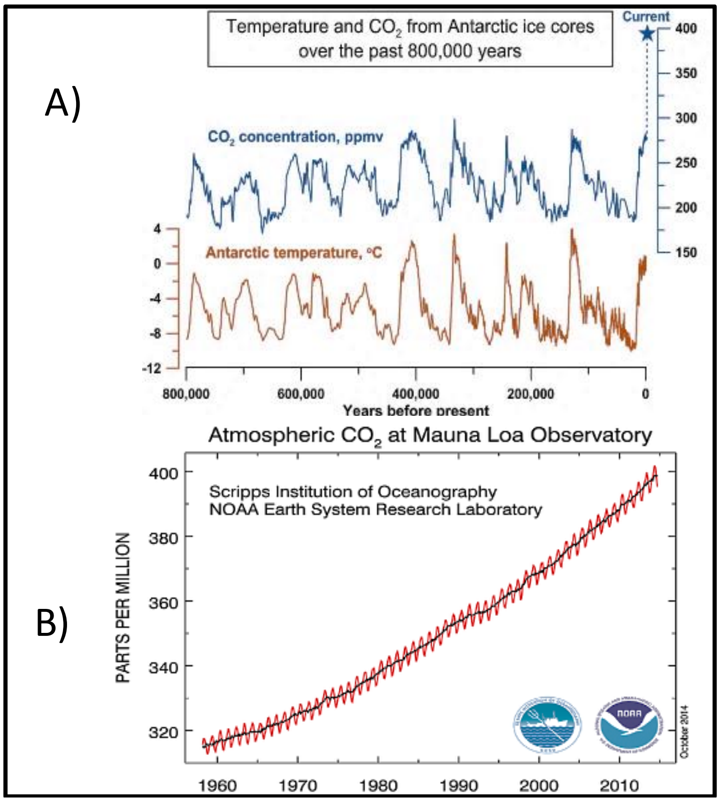


Figure 18 Upper panel A: estimated CO_2 concentrations and average temperatures inferred from ice core samples from Antarctica from 800 thousand years ago to the present. Temperature is inferred from oxygen isotope signatures which are directly related to temperature. Panel B: measured CO_2 concentrations in the atmosphere for the period 1958 to 2014.

Human-made greenhouse gas emissions "have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever", at levels that exceed 400 ppm (parts per million; IPCC, 2014) (Figure 18). The rate of increase since industrialization has also exceeded the rates of increase of any previous cycle. At present, over 60% of the anthropogenic greenhouse gas emissions are CO_2 emissions (IPCC, 2014). CO_2 emissions are partly taken up by the ocean (about 30%) and the land (about 30% via plants and soils), while about 40% remain in the atmosphere, leading to increasing CO_2 concentrations in the atmosphere (Figure 19). Air temperature changes recorded over the previous 150 years (1860+) show temperatures increasing continually on average, and in the recent period, exceeding projections of temperatures for most CC models.

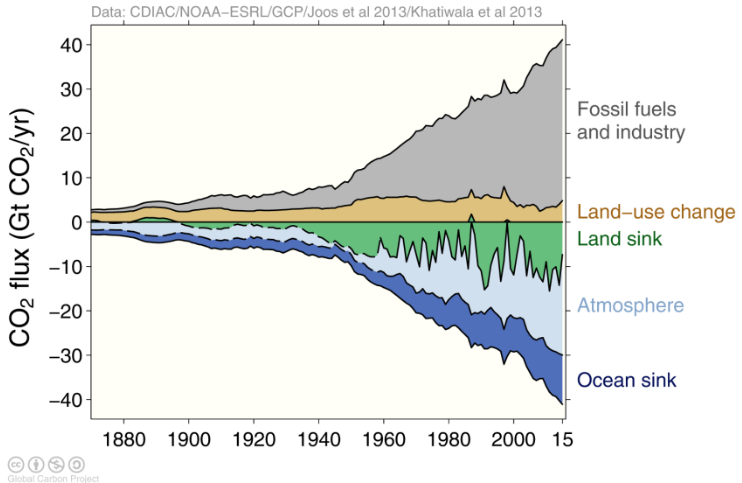


Figure 19 The fate of anthropogenic greenhouse gas emissions for the period 1870 to 2015. Illustration from the Global Carbon Project (Le Quéré *et al.,* 2016).

CC and weather are interconnected. Whereas weather refers to conditions over short time frames (days), climate is defined as average weather over longer periods (years). Observations show that there have been changes in weather (e.g. Kendon *et al.*, 2014; van Haren *et al.*, 2013), and changes in weather over time identify CC. Extremes in weather have been observed more frequently during the last few decades and when averaged out over the number of years will indicate changes in the average weather over time, thus climate. The chaotic nature of weather makes it unpredictable beyond a few days, whereas projecting changes in climate caused by changes in atmospheric composition or other factors is much more manageable, especially on large scales. These extremes in weather have been predicted by the Intergovernmental Panel on Climate Change (IPCC) in various reports (e.g. IPCC, 2014). The climate projections also indicate increased intra-annual variation at global and regional scales.

Teleconnections in the North Atlantic

One of the ways climate and weather connect to the environment of Atlantic salmon is through teleconnection patterns. Teleconnections are recurring and persistent atmospheric conditions that result from large-scale pressure and circulation variations spanning vast geographical areas. Such patterns can last from several weeks to several consecutive years, reflecting an important part of both the interannual and interdecadal variability of the atmospheric circulation. Many of the teleconnection patterns are planetary-scale in nature, spanning entire ocean basins and continents.

An important teleconnection in the Northern Hemisphere is the North Atlantic Oscillation (NAO; Barnston and Livezey, 1987). It is essentially a north–south differential in sea level pressure over the Atlantic (IPCC, 2007; Figure 20). The differential of the NAO is strongest in the winter months (December to March; Hurrell *et al.*, 2003). A high winter NAO corresponds with mild winter climate and strong storms in Western Europe (Jonsson and Jonsson, 2004).

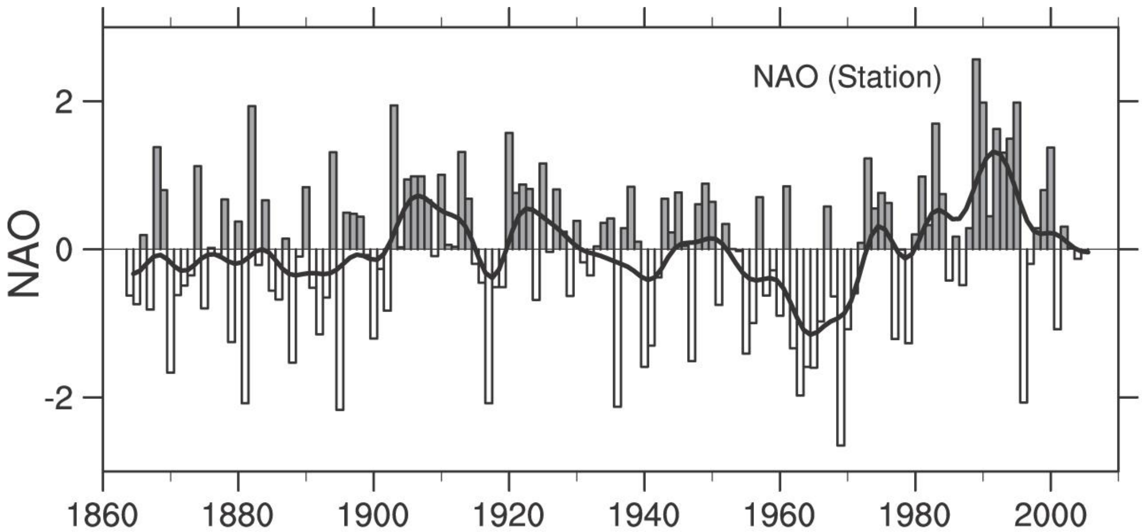


Figure 20 Normalized indices (units of standard deviation) of the mean winter (December–March) NAO developed from sea level pressure data. The index is based on the difference of normalized sea level pressure between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland from 1864 to 2005. The average winter sea level pressure data at each station were normalized by dividing each seasonal pressure anomaly by the long-term (1864 to 1983) standard deviation. The smooth black curves show decadal variations (see Appendix 3.A of IPCC, 2007). The individual bar corresponds to the January of the winter season (e.g., 1990 is the winter of 1989/1990). Updated from Hurrell *et al.* (2003); see http://www.cgd.ucar.edu/cas/jhurrell/indices.html for updated time-series. (Source: Top panel Figure 3.31 from IPCC, 2007).

An example of a longer cycle Atlantic teleconnection pattern is the Atlantic Multidecadal Oscillation (AMO). The AMO has a periodicity of approximately 20–40 years, with major oscillations between warm and cool conditions (Figure 21). Since 2000, the North Atlantic has been in a strong warm period, whereas the period between 1960 and 1990 was characteristically colder.

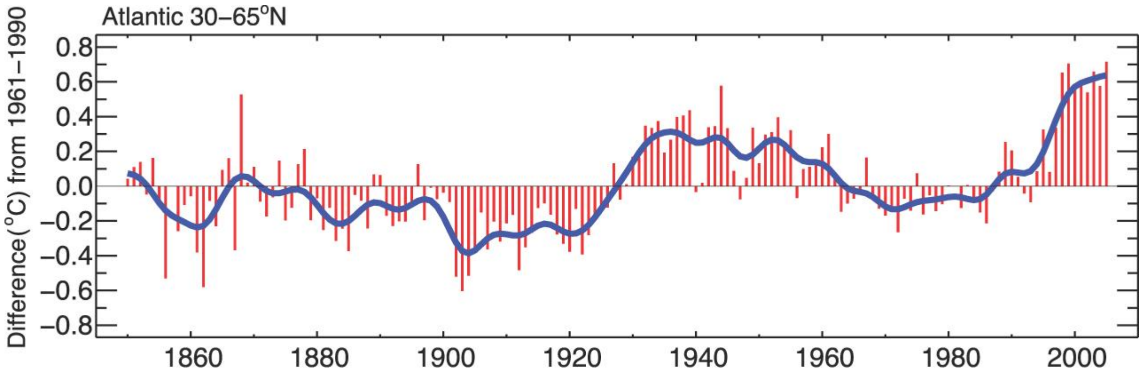


Figure 21 Atlantic Multidecadal Oscillation index from 1850 to 2005 represented by annual anomalies of SST in the extra-tropical North Atlantic (30–65°N). The series comes from HadSST2 (Rayner *et al.*, 2006) and are relative to the 1961 to 1990 mean (°C). The smooth blue curves show decadal variations (see Appendix 3.A of IPCC, 2007). (Source: Top panel Figure 3.33 from IPCC, 2007).

Elaboration on the advice

a) Changes in climate that may potentially impact wild Atlantic salmon in its distributional range based on the predictions of climate change, including those from the most recent International Panel on Climate Change

In order to estimate possible consequences of CC, the IPCC utilizes different future emission scenarios that range between being very optimistic (i.e. humankind is able to reduce emissions drastically in the future) and very pessimistic (i.e. humankind will not reduce emissions in the future). These scenarios are referred to as Representative Concentration Pathways (RCPs) and are available in the latest IPCC report (IPCC, 2014). The emission estimate for 2016 is in line with the RCP8.5 model projection (Figure 22).

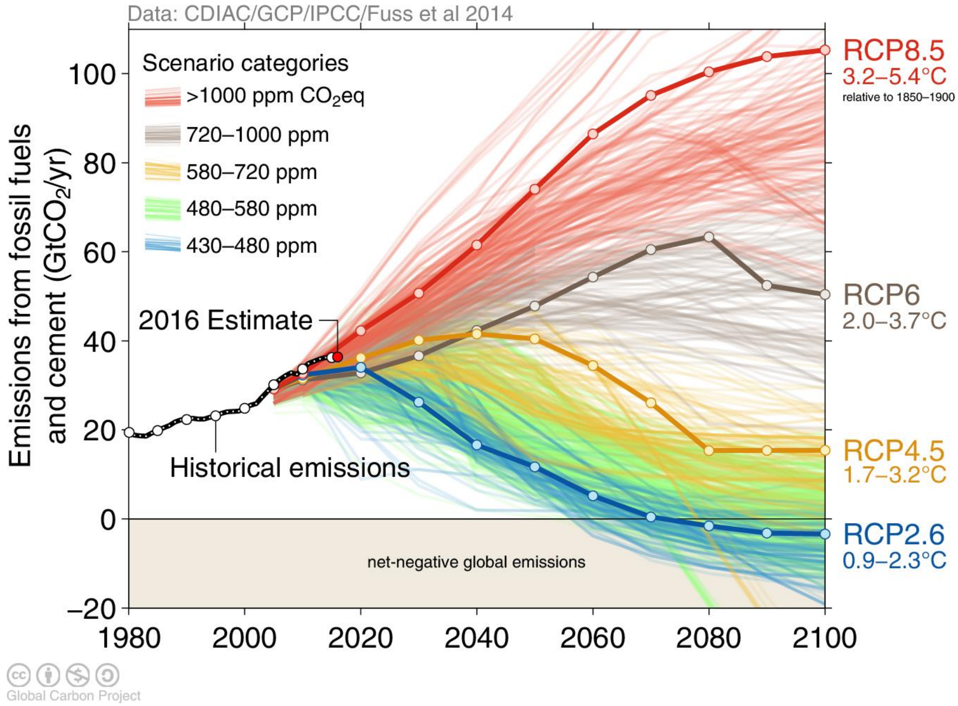


Figure 22 Representative Concentration Pathways (RCP) and their associated emissions from fossil fuels. Illustration from the Global Carbon Project (2016; www.globalcarbonproject.org/carbonbudget, published on 14 November 2016).

Before 2050, atmospheric concentrations of carbon-based emissions are not expected to reduce or flatten out. Even if emissions were to be reduced, the overturning of the ocean is at the scale of 1000 years, so the conditions in the ocean will persist. Although the global effect is for an increase in temperatures, there can be periodic declines in temperature and the occurrence of extreme weather events. The variations in certain physical and chemical responses (temperature, salinity, pH) are consistent across model scenario projections, whereas others are more uncertain (primary productivity in the ocean). The climate projections also indicate increased intra-annual variations. These variations are equally, if not more consequential to salmon persistence.

b) Review the conclusions of published literature and research on the biological and environmental drivers that impact on stock dynamics of Atlantic salmon

A review of the scientific literature was initiated for the workshop and the papers were categorized by topic and issue addressed.

Of 49 papers reviewed (ICES, 2017c), 61% addressed CC considerations in the North Atlantic and 59% addressed issues specific to Atlantic salmon. In general the publications conclude that CC will impact profoundly on the general oceanic and freshwater conditions through changing weather and teleconnection patterns. This in turn will influence growth and predation pressure, resulting in reduced marine survival for most stocks. Increased stream temperatures may result in increased growth and production in northern areas, but could reduce recruitment in southern stocks. All these interactions in marine, freshwater, and estuarine waters are very complex, not always well understood, and likely to have different outcomes for stocks on a regional scale. Some of the papers discussed mitigation options, ranging from cutting carbon emissions to reducing stream temperature and mitigating for other stressors and their synergistic effects.

c) Biological and environmental drivers that can influence Atlantic salmon abundance and distribution

Drivers are the physical, biological, and chemical controls that shape the characteristics of ecosystems across broad spatial scales (Alexander *et al.,* 2016). Since Atlantic salmon can be found in a wide range of ecosystems extending from the headwaters of river systems in eastern North America and western Europe to the northern Atlantic Ocean and Baltic Sea and habitats in between, the discussion on drivers is presented in terms of three specific aquatic environments: freshwater, transitional waters (i.e. estuaries), and marine waters. Water flows physically connect these ecosystems and since large-scale pressure and circulation patterns extend across multiple ecosystems (see teleconnection patterns in previous section), effects in one ecosystem may become apparent later in the life of salmon when they have moved and occupy the next ecosystem.

For Atlantic salmon, much of the climate-change research in freshwater has focused on specific drivers, while in marine waters, research has tended to examine linkages with climate forcing indices even though these are not causal (Link *et al.,* 2010). There is much less information available for transitional areas (i.e. estuaries) as these have been much less studied.

Freshwater

Temperature and precipitation are primary drivers affecting aquatic ecosystems in general, and major drivers for salmon in freshwater. Changes in these parameters influence many other environmental factors, including: river discharge and level, pH, dissolved oxygen levels, water colour, and light penetration. Resulting changes in biotic factors, including food availability and interspecific competitions, will also impact salmon productivity in the freshwater phase.

Temperature influences rates of organic matter decomposition by bacteria as well as rates of in-stream primary productivity. Dissolved organic carbon concentrations impact pH levels as many dissolved organic carbon compounds are organic acids (Clark *et al.,* 2005; Evans *et al.*, 2005).

Temperature has a direct effect on the survival of eggs and can also influence the size of alevins at hatching through regulating the relative proportions of the yolk sac used for metabolism and tissue growth. Oxygen requirements vary at different stages of development and are further influenced by factors such as egg size, temperature, the spatial arrangement of eggs within the redd, and the velocity of intragravel water flow (Crisp, 1996; Youngson *et al.*, 2004). Other factors affecting hatching time and egg and alevin survival include the gravel composition, light, stream bed conformation and hydraulics, patterns of discharge and mechanical shock (Crisp, 1996). Many of these factors may be modified by climatic change.

The timing of fry emergence in salmon is influenced by environmental conditions during egg development, most notably by water temperature (Elliott and Hurley, 1998; Garcia de Leaniz *et al*., 2000). It is generally accepted that spawning dates are adapted to current thermal and flow conditions such that juvenile emergence timing is optimized as a result of selection pressures (e.g. Heggberget, 1988; Jensen *et al*., 1991). Marked changes in temperature or flow during early development may create a mismatch between emergence and environmental conditions, resulting in increased levels of early juvenile mortality (Jensen *et al*., 1991).

Temperature affects physiological processes of fish at all life stages (Graham and Harrod, 2009). Juvenile salmon grow fast over a wide temperature range (10–18°C; Handeland *et al.,* 2008). Growth declines as temperature increases above the optimum, and the optimum is also affected by interaction with prey availability. Several studies have highlighted that the relative influence of temperature, water discharge and density, is highly dependent on the spatial scale and site-specific conditions.

Over the geographic range of Atlantic salmon, there is a significant negative correlation between the age of smoltification and an index of growth potential (Metcalfe and Thorpe, 1990). While temperature may be the primary determinant of systematic shifts in smolt age, other factors can influence parr growth and age at smoltification, including the hydrological and thermal regime of the nursery river, latitude, elevation, prey availability, and density of competing salmonids.

The timing of smolt and seawater entry is believed to have evolved such that smolts enter the sea in synchrony with optimal biotic and abiotic conditions (Hvidsten *et al.,* 1998). The timing of smolt migration varies with latitude, with southern populations moving out to sea earlier than northerly ones (Otero *et al.,* 2014). Migration is also correlated to body size, with larger smolts typically migrating earlier, and furthermore appears to have a genetic component (Stewart *et al*., 2006).

Estuaries

Estuaries are ecosystems that are influenced by both changing conditions upstream in freshwater and the open ocean. Although estuaries are vital for the survival of Atlantic salmon, an understanding of their ecological function is limited. Because of their location at the junction of rivers and the ocean, estuaries also tend to be sites of major human settlements, and are therefore especially vulnerable to anthropogenic stressors. Estuaries are much more than a migration corridor for salmon – they are where salmon must make the osmoregulatory adjustments necessary for survival, both when migrating to sea as smolts or kelts, and when returning to freshwater as adults. Stress during these periods can be heightened for example by large temperature differentials or by the presence of parasites and diseases.

Marine ecosystem

Numerous factors, both biotic and abiotic, affect the survival of salmon in the sea, but their relative impact and the interactions among them are poorly understood. The lack of detailed knowledge of post-smolt movements, distribution, and habitats is a key constraint in this regard (Friedland, 1998; Dadswell *et al*., 2010). The generally accepted view is that the main marine mortality events take place during the first year of sea life when survival, maturation, and migration trajectories are being defined (Hansen and Quinn, 1998; Potter and Crozier, 2000; Friedland *et al*., 2005, 2009) and when the fish are smaller (Friedland *et al*., 1996).

Marine environmental drivers include temperature (typically mean sea surface temperature is used), and various teleconnection patterns (climate forcing indices) such as the North Atlantic Oscillation (NAO) and Atlantic Multidecadal Oscillation (AMO); these indices are not causal but represent ecosystem processes that drive ecosystem dynamics (Link *et al.,* 2010). Additional environmental drivers include salinity, oxygen, and changing large-scale oceanographic patterns related to wind and turbulence (Trenkel *et al.,* 2014). Biological drivers may include density dependence and competition, prey condition and availability, top–down effects of species on their prey, bottom–up effects of species on their predators, and predator impacts on species population dynamics (Trenkel *et al.,* 2014).

Sea surface temperatures and the extent of ice cover seem to constrain Atlantic salmon distribution at sea. Surface currents are strongly dependent on surface winds (Mork *et al*., 2012), which are strongly influenced by teleconnection patterns like the NAO.

e) Predicted changes in drivers associated with climate change projections

Changes in physical, chemical, and biological characteristics of oceans and freshwaters associated with increased atmospheric carbon include, but are not limited to, increased air and water temperatures (freshwater and marine), freshening of surface ocean layers, reduced pH (increasing acidification) of oceanic waters, and reductions in oxygen concentrations. CC also affects terrestrial systems, the freshwater environment of lakes and rivers, and the transitional waters between the marine and freshwater.

Earth system models are used to study possible developments and consequences of anthropogenic CC (IPCC, 2014). Determining impacts of CC on important drivers and ultimately on Atlantic salmon requires downscaling (a procedure that takes information from a large scale to make predictions at local scales) CC scenarios from Global Circulation Models using Regional Climate Models (Figure 23). The uncertainty in model projections increases with every additional stage.

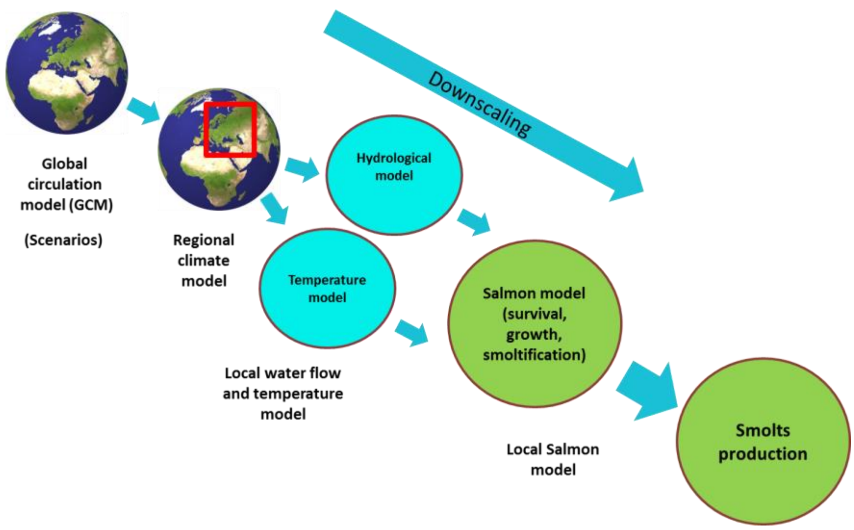


Figure 23 Schematic of downscaling climate change scenarios from Global Circulation Models to local effects (adapted from Sundt-Hansen *et al.*; in review).

Freshwater

By altering the precipitation (and therefore discharge) and temperature drivers, CC is expected to alter the freshwater habitat of Atlantic salmon.

In northern Europe and North America, CC is projected to result in warmer, drier summers and milder, wetter winters with more precipitation falling as rain and less as snow, a decrease in ice-covered periods, and more frequent extreme weather events and the severity of floods and droughts are expected to increase (IPCC, 2014; Figure 24). As a result, river systems are likely to be affected by increased runoff and earlier spring peak discharge in many glacier and snow-fed rivers (Jonsson and Jonsson, 2009). Since consequences of changing precipitation patterns vary among climate zones, projected effects on river discharge also vary among climate zones (Schneider *et al.*, 2013).

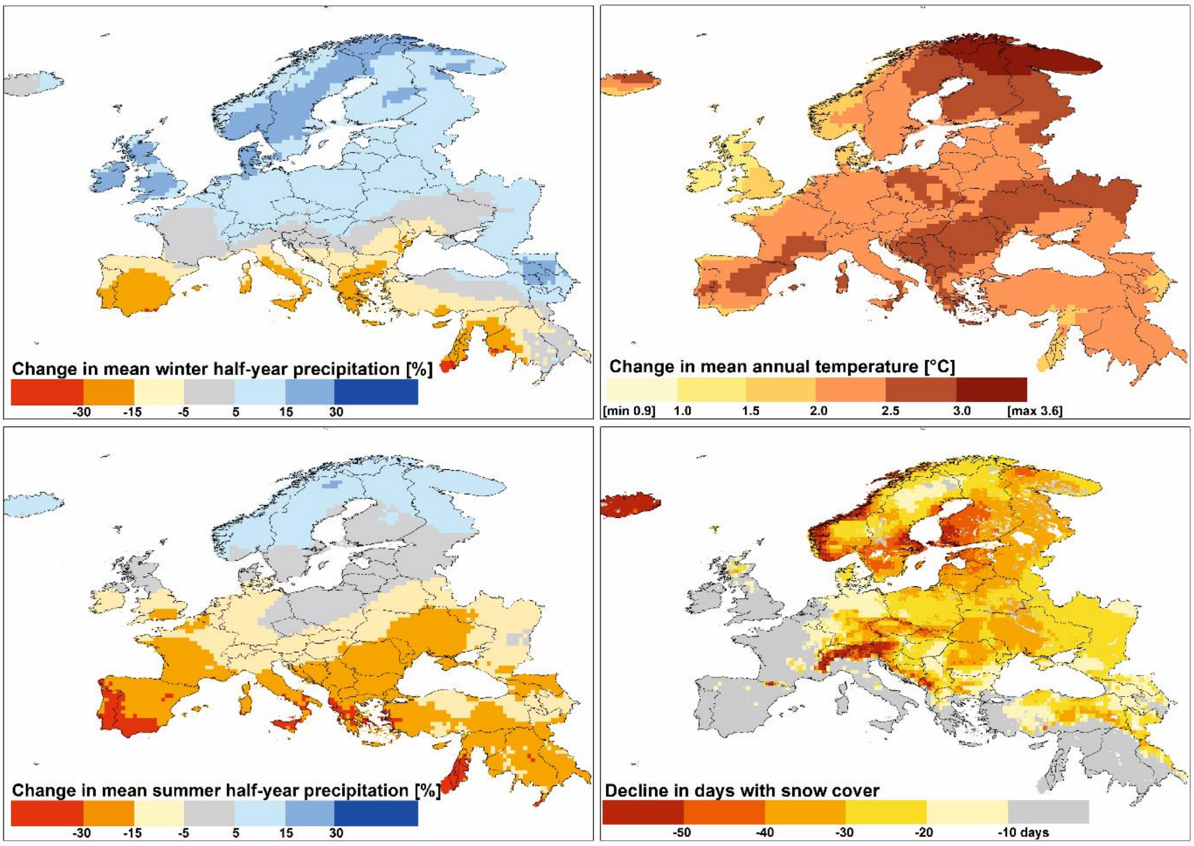


Figure 24 Changes in climate in 2050 relative to present-day climate: mean precipitation during winter (upper left) and summer (lower left), mean annual temperature (upper right), and decline in snow duration (lower right). The map represents the mean of three climate projections (Illustration from Schneider *et al.* 2013, with approval from author).

Increased air temperature may not always lead to increased water temperature. For instance, increased water temperatures over the next century in rivers in Canada are projected to be lower than the projected increases in air temperature (approximately 60–75% of the increase in air temperature; Caissie *et al.*, 2014). In other cases, for instance in Iceland, owing to complex interactions in oceanic circulation, the increase in air temperature due to CC today is associated with a decrease in water temperature in salmon-producing rivers (ICES, 2017c).

Marine

The CC projections of the marine environment indicate increases in sea surface temperature as well as increases in the amplitude of the annual cycles of sea surface temperature (Figure. 10.1.9.8), with higher temperatures in both the summer and winter. Warming is projected to result in progressive reductions in the spatial extent of sea ice in the North Atlantic, with September sea ice being essentially absent by 2080 (Figure 26). The changes in sea surface temperature are not expected to be uniform across the North Atlantic with greater warming in sea surface temperatures in the Northwest Atlantic and the Norwegian Sea than in the Northeast Atlantic, as well as south of Iceland and west of Greenland (Figure 27). Associated with loss of Arctic sea ice and glaciers, the surface waters are projected to become fresher (less saline) with the largest reductions in salinity in the northern portions of the North Atlantic (Figure 27).

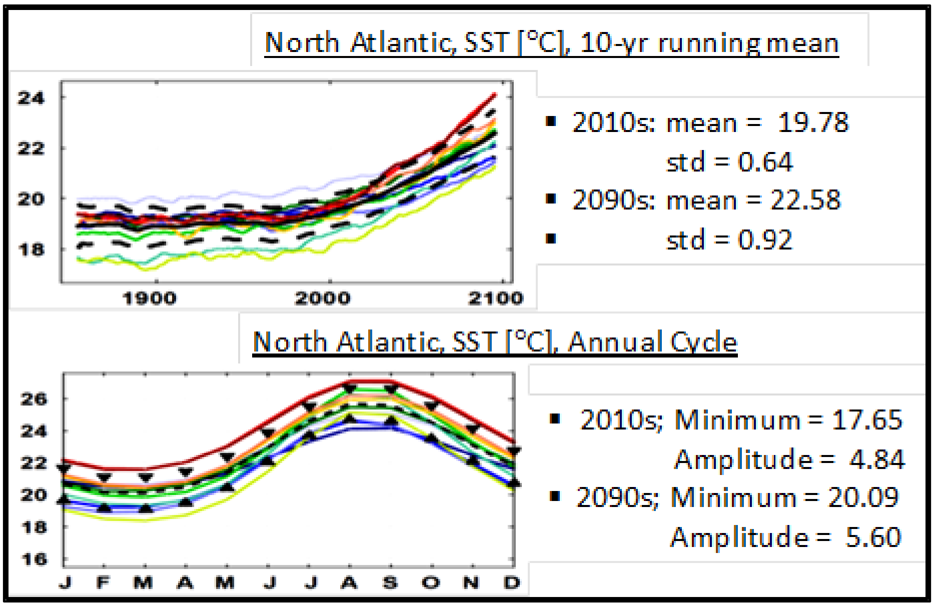


Figure 25 Projected annual mean sea surface temperature (°C) (upper panel) and annual cycle of temperatures in the 2090s for the North Atlantic, based on the RCP8.5 scenario, averaged over 12 models. Unpublished analyses from N. Goris, Uni Research Climate, Bjerknes Centre for Climate Research, Norway.

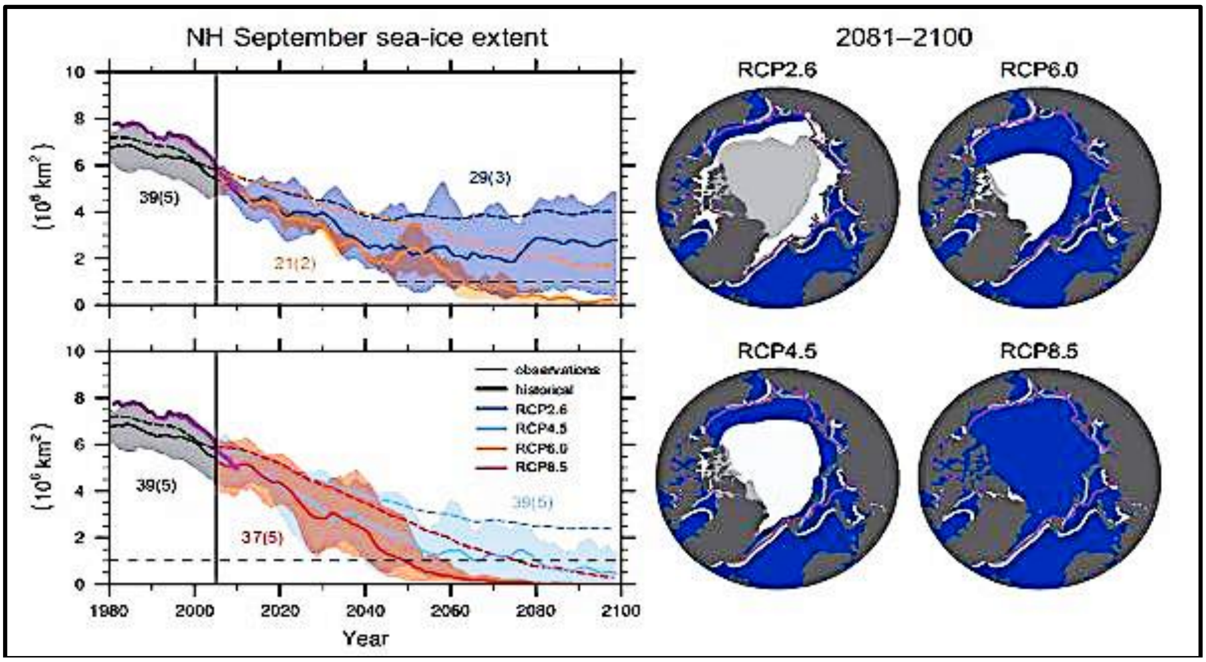


Figure 26 Current (to 2004) and projected to 2100 areal extent (km²) of sea ice in September in the North Atlantic for four climate scenarios. RCP8.5 is the scenario that more closely aligns with current emission values in 2016 (Figure 22). (Source: http://www.barentsportal.com/barentsportal/index.php/en/more/future-prospects/594-.)

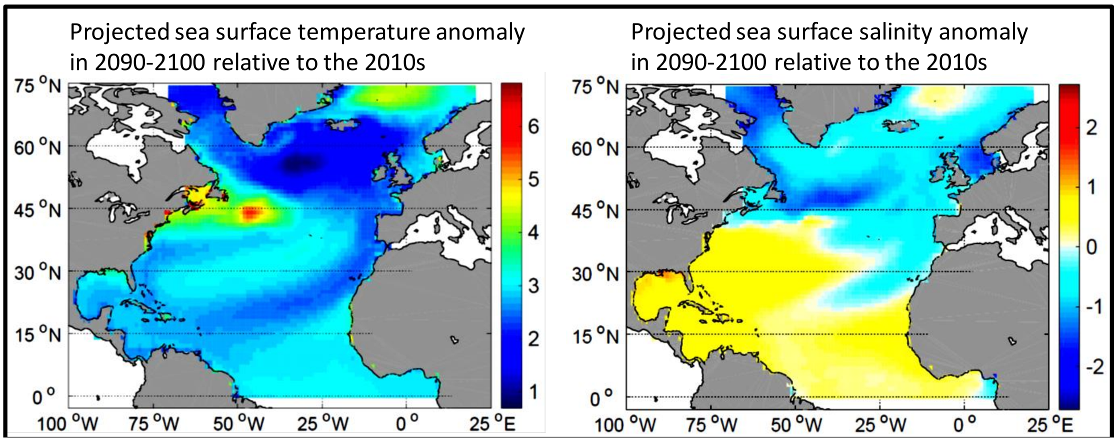


Figure 27 Projected differences (anomalies) in mean sea surface temperature (°C) (left panel) and sea surface salinity (right panel) in the 2090s relative to the 2010s, based on the RCP8.5 scenario, averaged over 12 models. Unpublished analyses from N. Goris, Uni Research Climate, Bjerknes Centre for Climate Research, Norway.

f) Potential effects of climate change on Atlantic salmon stock dynamics

Habitats – Freshwater

Climate-induced changes in precipitation patterns will result in changes in river discharge that can directly influence the amount of habitat for salmon. Increases in discharge, particularly from low levels, will increase the wetted area. The amount of shelter (interstitial spaces) in a river may limit the carrying capacity of the river, and an increase in the wetted area may result in additional habitat becoming available. Because of the relationship between discharge, wetted area, and shelter, in general the productive capacity of rivers will be reduced in areas where discharge is reduced. An increase in discharge in winter may increase habitat availability in winter, and therefore available shelter for juveniles.

Despite a general trend of lower discharges in rivers in the southern distribution range of Atlantic salmon and higher discharges in the northern distribution range, large regional differences will exist depending on factors such as altitude, gradient, groundwater influence, and topography.

With CC, new freshwater habitats may become available for Atlantic salmon in the northern areas where Atlantic salmon are presently not found.

Habitats – Estuaries

CC-related impacts in freshwater (e.g. increased temperatures, altered discharge) affecting estuarine salinity and turbidity may change the ability of salmon to successfully osmoregulate and survive. These changes may be positive or negative for Atlantic salmon. Climate-altered freshwater discharge patterns may directly affect the amount and quality of estuarine habitat used by salmon. Climate-related changes in marine teleconnection patterns may reduce upwelling, which may reduce nutrient supplies to estuaries, affecting foodwebs and young salmon (Levings, 2016).

Habitats – Marine

CC projections indicate a warming at higher latitudes, as well as an increase in amplitude of the annual temperature cycle. The primary feeding grounds of adult Atlantic salmon are at these higher latitudes (e.g. ICES, 2017b). It is not likely that sea surface temperature (SST) in the current feeding areas will be outside the thermal optimum for the species (e.g. Jonsson and Jonsson, 2009). However, together with the projected changes in other factors such as PP (primary production), SSS (sea surface salinity), pH, and dissolved oxygen, these changes are likely to impact on other components of the ecosystem that affect salmon.

With the likely event of the Arctic Ocean becoming free of ice in the summer in the next 10–20 years (Wang and Overland, 2009), currently inaccessible physical marine habitat will probably become available to Atlantic salmon. A recent peer-reviewed publication by Jensen *et al.* (2014) suggests the marine range of Atlantic salmon might already be moving northward in the east Atlantic area.

Biological characteristics – Freshwater/estuaries

Changing temperature and flow regimes resulting from CC have the potential to influence spawning success in salmon in a variety of ways, including the ability of adult fish to access suitable spawning areas, timing of spawning, and in the size and quality of eggs. Marked changes in temperature or flow during early development may create a mismatch between emergence and environmental conditions, resulting in increased levels of early juvenile mortality (Jensen *et al.*, 1991) as a result of CC.

Juvenile growth declines as temperature increases above the optimum range. The effect that predicted temperature increases might have on growth of juveniles and age at smoltification is complex and variable (Swansburg *et al.*, 2002). As mortality at sea is generally thought to be growth-mediated, particularly by factors acting during the first summer (Friedland *et al.*, 2009), this will have consequences on sea survival. The timing of smolt migration is thought to be crucial to the survival of Atlantic salmon at sea (Hansen, 1987) and is believed to have evolved such that smolts enter the sea in synchrony with optimal biotic and abiotic conditions (Hvidsten *et al.*, 1998). Changes in the run-timing of smolts due to variations in climate are, therefore, a concern due to a possible temporal mismatch with optimal conditions for early post-smolt growth and survival (Russell *et al.*, 2012).

Biological characteristics – Marine

Age-at-maturation is a key life-history trait, as the fitness of an individual is reported to be more sensitive to changes in this trait than to changes in many other life-history traits (Stearns, 1992). It has been suggested that both good and poor growth conditions can lead to delayed maturation (Jonsson *et al.*, 2016), with no mechanistic framework available to explain how seasonal growth and ocean environment combine to produce annual variability in maturation. As a result it is currently impossible to predict how CC may affect age-at-maturation.

The mean sizes of returning salmon in a number of areas are continuing to show declining trends (ICES, 2016b). However, these changes are not manifested in all populations (ICES, 2008). The decrease in growth in recent years has been linked to indirect effects of warming in areas where salmon are located at sea (Todd *et al.*, 2008) and thus could be driven by CC.

Interactions with other species – Freshwater

As a result a CC range expansion of non-native species could be expected. Two examples follow.

Pink salmon (*Oncorhynchus gorbuscha*) was introduced in northwestern Russia in the 1930s, and from around 1960 regular runs of pink salmon appeared in Norwegian rivers (Berg, 1977). It is suggested that odd-year populations appear to be benefiting from CC more than even-year populations in the Pacific (Irvine *et al.*, 2014), something that might also apply to the populations now established in northwestern Russian and northern Norway. However, as pointed out by ICES (2013), since pink salmon typically spawn in the lower reaches of rivers downstream of where Atlantic salmon spawn, and pink salmon fry have a very short freshwater residence, pink salmon may never be significant competitors with Atlantic salmon.

Smallmouth bass (*Micropterus dolomieu*) was introduced into eastern North America in the late 1800s and has subsequently been expanding northward. The presence of non-native smallmouth bass has the potential to impact Atlantic salmon through predation and competition. Given smallmouth bass prefer warmer water, incremental warming associated with CC could lead to an increase in available habitat for smallmouth bass and enhanced recruitment, survival, and dispersal northwards.

Interactions with other species – Marine

Increased freshwater growth as a result of increased stream temperatures has been reported to produce younger and smaller smolts and thus could result in higher smolt and post-smolt predation in the ocean.

Increases in inter-specific competition might occur as a result of changing distribution patterns for several marine pelagic species. For example, negative relationships have been observed between herring abundance in the Norwegian Sea and salmon catches and between herring abundance and marine survival of smolts from the River Figgjo (Crozier *et al.*, 2003). Similar correlations between survival indices and herring recruitment have been observed in the Baltic Sea (ICES, 2008).

It has been shown that higher sea water temperatures decrease generation time, and increase the rate of development and maturation in the salmon louse (*Lepeophtheirus salmonis*), resulting in higher production of salmon lice (Tully *et al.*, 1993). Mortality in Atlantic salmon as a result of salmon lice infestation may rise, especially in areas of intensive open-cage aquaculture for salmon. Other marine parasites are likely to exhibit similar increases in production with rising SST, as will virulence, transmission rates, and synergistic effects with other stressors (Marcogliese, 2008).

Migration routes

Changes in migratory pathways have been suggested as a factor affecting the survival of salmon post-smolts. Further changes in conditions that affect migratory pathways are expected under CC. It is unclear how this will affect marine survival of different Atlantic salmon stocks.

Distribution patterns

In evolutionary history, large distributional changes of Atlantic salmon have been associated with glacial (ice ages) and interglacial periods.

The effects of CC could potentially influence the distribution range of Atlantic salmon. Modelling studies (e.g. Lassalle and Rochard, 2009) have suggested the European range of Atlantic salmon could be altered markedly as a result of CC by 2100, with a disappearance of the species in river basins from Portugal, Spain, and southern France. For North America, Chu *et al.* (2005) and Minns *et al.* (1995) predict that populations of salmonids might be lost in the southern part of their ranges. However, these modelling studies do not take into account the ability of the species to genetically adapt to the changing environmental conditions. Taking such responses into consideration, Piou and Prévost (2013) conclude that in the next 30 years it is unlikely that French populations will be extirpated as a result of CC.

In contrast to possible range contraction in the southern part of the range, CC might result in a range expansion in the northern, western, and eastern parts of the range of salmon. There is much more landmass available for potential colonization in North America relative to Europe. However, it remains unclear if habitat losses in the southern part of the range would be compensated by colonization of habitats at higher latitudes for the species as a whole.

Genetic diversity and evolutionary/phenotypic responses

It is likely that there will be a net reduction in genetic diversity and genetic structure under CC. Under CC the abundance of salmon in the southern populations is expected to decline, which will result in reductions in effective population size. The southern genetic stock complexes (phylogenetic groups) have the greatest genetic diversity for Atlantic salmon and are at the greatest threat of loss caused by CC. The expected simultaneous range expansion of northern stocks with associated founder effects, will not compensate for this loss of genetic diversity.

Atlantic salmon can respond quickly to environmental fluctuations by phenotypic plasticity (variations in life history traits that are directly driven by the environment rather than genetics). But if the effects of CC are too rapid or too severe, phenotypic plasticity may be inadequate to allow populations to persist and genetic adaption to occur.

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 potential consequences of CC on Atlantic salmon, substantial uncertainties remain:

- CC is expected to increase variability of weather events, but many CC projections are at seasonal or even annual scales (e.g. river discharge, temperature). However, it is at the daily or even finer scales that the most significant deleterious consequences for survival can occur for salmon (e.g. extreme low flows combined with high temperatures).
- One of the challenges concerning earth system models is that they are computationally expensive and can therefore only be run with relatively coarse grid resolution and a limited number of variables and processes. Despite progress in refining the resolution of earth system models, the current resolution does not suffice to reproduce realistic small-scale features, which are important for coastal regions and rivers. While it is reasonable to generalize about CC effects globally, local impacts will depend on local variations in weather patterns and the frequency of episodic events.

- Projections can be made within various climate zones and hydrological models can be used to predict changes in river flow regimes at the scale of individual watersheds through downscaling. However, uncertainty is introduced at every stage of the downscaling process.
- The greatest uncertainty is the inability to predict sudden large phase-shifts in either climate, marine, or terrestrial systems. Current concentrations of CO_2 in the atmosphere exceed any levels previously estimated for the last 800 000 years. Consequences for Atlantic salmon, which have persisted for more than 500 000 years, are unknown.

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) provides a topical forum for the coordination of ICES activities relating to species which use both freshwater and marine environments to complete their life cycles, like eel, Atlantic salmon, sea trout, lampreys, shads, smelts, etc. The Group considers progress and future requirements in the field of diadromous science and management and organizes expert groups, theme sessions, and symposia. There is also a significant role in coordinating with other science and advice working groups in ICES.

A diadromous fish theme session will convene at the 2017 ICES Annual Science Conference in Fort Lauderdale, Florida, USA. This session will consider presentations on:

- Status, distribution, ecology, or biology of poorly understood diadromous fish species;
- Approaches for systematic monitoring of poorly understood diadromous species;
- Using some species as index species for environmental change;
- Lessons learned that might help management and conservation of functionally similar species.;
- Impending threats, particularly invasive species or interactions with other species undergoing range expansion;
- Physiological drivers controlling the movements of diadromous fish and addressing gaps in knowledge.

Other issues reported on included:

- Information from Portugal and the UK on fish passage and mitigation actions relevant to diadromous fish.
- The need for a host to support the DBERAAS database, a product of the ICES Working Group on Effective Recovery Actions for Atlantic Salmon (WGERAAS).
- ICES Cooperative Research Report on "Fifty Years of Marine Tag Recoveries from Atlantic Salmon" was in final editorial stages and would be published shortly (CRR 282).

ICES and the International Year of the Salmon

Further progress on developing an International Year of the Salmon event was made during 2016. Primary partners have been identified as the North Pacific Anadromous Fish Commission (NPAFC) and the North Atlantic Salmon Conservation Organization (NASCO), international intergovernmental organizations established to conserve anadromous salmon in the North Pacific and Atlantic oceans, respectively (http://www.npafc.org/new/science_IYS.html and //www.nasco.int/iys.html). 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. At the SCICOM meeting in September 2016, ICES formally accepted the invitation from the IYS Steering Committee to become a partner. ICES appointed the Head of Science Support and the SCICOM Representative for Ireland to engage with the process and be part of the North Atlantic Steering Committee and the Symposium Steering Committee.

In November 2016, NASCO held a meeting of the North Atlantic Steering Committee which ICES attended. In March 2017 SCICOM approved a resolution to support the IYS symposium in the third quarter of 2018, with an issue of the *ICES Journal* to be allocated pending discussions with the Editor-in-Chief. ICES recognised this as a high priority, given that ICES is the primary advice provider for Atlantic salmon in the North Atlantic and has been advising the North Atlantic Salmon Conservation Organization since 1983. Given the current persistent decline in salmon stocks in the North Atlantic, and a similar decline for some important Pacific salmon stocks, there is a need to share information to inform a wider research initiative to explain this decline and rational management.

It is anticipated that a wide range of participants will attend this symposium given the existing links between the Pacific, Atlantic (East and West), and Baltic and the degree of international interest in wild salmon biology and science between freshwater and marine environments. Specifically, it is anticipated that there will be involvement of scientists from ICES, NASCO, NPAFC, PICES, universities, government, state organizations, and NGOs (e.g. Atlantic Salmon Trust, Atlantic Salmon Federation). The outputs of the symposium and the research activities associated with the IYS are expected to feed into the advice process of the ICES ACOM and enhance ICES advice to NASCO. There will also be links with the ICES Science Plan through SCICOM, the Science Steering Group on Environmental Processes and Dynamics (SGEPD), and associated EGs.

NASCO 1.6 Provide a compilation of tag releases by country in 2016

Data on releases of tagged, fin-clipped, and otherwise marked salmon in 2016 are compiled as a separate report (ICES, 2017d). A summary of tag releases is provided in Table 11. About 3.2 million salmon were marked in 2016, a decrease from the 3.8 million fish marked in 2015. The adipose clip was the most commonly used primary mark (2.55 million), with coded wire microtags (0.379 million) the most common tag applied and 254 880 fish were marked with external tags. Most marks were applied to hatchery-origin juveniles (3.1 million), while 81 188 wild juveniles and 8136 adults were also marked. In 2016, 64 669 PIT tagged, Data Storage Tags (DSTs), and radio and/or sonic transmitting tags (pingers) were also reported by some countries (Table 11).

A tagging and wide-scale tag screening programme in the Northeast Atlantic was initiated in 2015, directed at pelagic species (herring and mackerel) using glass-encapsulated passive integrated transponder (PIT) tags / RFID tags (Radio Frequency Identity tags) (ICES, 2015). RFID detector systems have been installed at a number of fish processing plants in different countries, and catches landed at these plants are automatically screened for tagged fish. In 2016 more than 32 000 salmon were released with such tags. Therefore there is a potential for RFID tagged salmon as bycatch in pelagic fisheries to be detected at fish plants with the appropriate detecting equipment. A list of unknown tags detected by these detectors was received from Institute Marine Research (Bergen Norway) in 2015 and updated in 2016. The list was distributed to agencies using RFID tags for salmon. One agency confirmed that one of the detected tags had been applied to a smolt in Norway.

NASCO 1.7 Identify relevant data deficiencies, monitoring needs, and research requirements

ICES recommends that the WGNAS should meet in 2018 (Chair: Martha Robertson, Canada) to address questions posed by ICES, including those posed by NASCO. Unless otherwise notified, the working group intends to convene at the headquarters of ICES in Copenhagen, Denmark. The meeting will be held from 4 to 13 April 2018.

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

North Atlantic Salmon Stocks

1) The continuation and expansion of tracking programmes provides information that is useful in the assessment of marine mortality on North Atlantic salmon stocks. These techniques have been proposed, and are being implemented in other areas, both in the Northwest and the Northeast Atlantic (e.g. SALSEA Track), in line with the NASCO IASRB resolution.

2) In order to fully consider a life cycle model as an improvement and alternative to the current assessment and forecast model used for providing catch advice, improvements to data inputs, and the incorporation of a number of alternative life history dynamics need to occur well ahead of the 2018 ICES WGNAS meeting. As such, a workshop of jurisdictional experts is proposed before the end of the 2017 calendar year. The purpose of the meeting would be to review current national input data given reductions in fisheries particularly in the NEAC area, to incorporate improved data inputs and alternate population dynamic functions, to enable the running of the inference and forecast components, and to develop documentation related to the model. The changes to the model inputs and the model would then be reviewed at the 2018 ICES WGNAS meeting for consideration as an alternate approach for the provision of the next cycle of multi-year catch advice.

3) In 2015 ICES received information from the Institute of Marine Research (IMR), Bergen, Norway, related to a new tagging initiative and wide-scale tag screening programme in the Northeast Atlantic. The tagging programme is directed at pelagic species (herring and mackerel) using glass-encapsulated passive integrated transponder (PIT) tags / RFID tags (Radio Frequency Identity tags) (ICES, 2015). RFID detector systems have been installed at a number of fish processing plants in different countries, and catches landed at these plants are automatically screened for tagged fish. It is recommended that the list of tag detections be sent to the National Tagging coordinators (ICES, 2017d) and to the members of the WGNAS to determine if any salmon tags have been detected.

Atlantic salmon from North America

1) Sampling and supporting descriptions of the Labrador and Saint Pierre and Miquelon mixed-stock fisheries should be continued and expanded (i.e. sample size, geographic coverage, tissue samples, seasonal distribution 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 should be considered in Labrador to estimate stock status for that region, including evaluation of the utility of other available data sources (e.g. Aboriginal and recreational catches and effort) to describe stock status in Labrador.

Atllantic salmon at West Greenland

1) Continued efforts to improve the reporting system of catch in the Greenland fishery and to ensure that detailed statistics related to spatially and temporally explicit catch and effort data be provided for analyses.
2) The continuation of the phone survey programme in Greenland according to a standardized and consistent annual approach, with consideration given to surveying a higher proportion of licensed fishers and the inclusion of the non-licensed fishers. 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.
3) The continuation and potential expansion of the broad geographic sampling programme including in Nuuk (multiple NAFO divisions, including factory landings when permitted) to more accurately estimate continent and region of origin and biological characteristics of Atlantic salmon in the mixed-stock fishery.
4) Progress be made in assigning the European origin salmon from the West Greenland fishery to a sub-complex region of origin.

Table 4 Reported total nominal catches of salmon by country (in tonnes round fresh weight), 1960 to 2016 (2016 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 4 (continued).

Year	NAC Area			NEAC (N. Area)								NEAC (S. Area)						Faroes & Greenland				Total	Unreported catches	
	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)
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	18	24	6	9	58	57	54	5	84	12	6	0	0,1	58	-	1 134	287	-
2015	140	0	4	583	80	94	31	9	7	9	45	63	68	3	68	16	5	0	1,0	56	-	1 282	325	-
2016	135	0	5	612	56	87	31	6	3	9	51	58	86	5	27	6	5	0	1,5	26	-	1 209	335	-
Average																								
2011-2015	140	0	4	588	82	82	26	17	9	11	51	76	80	6	111	12	6	0	0,3	44	-	1 345	348	-
2006-2015	139	0	3	668	80	100	34	12	9	9	54	105	77	14	138	11	6	0	0,4	36	-	1 495	407	-

KEY:

1. Includes estimates of some local sales, and, prior to 1984, by-catch	9. Weights estimated from mean weight of fish caught in Asturias (80-90% of Spanish catch).
2. Before 1966, sea trout and sea charr included (5% of total).	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.
3. Figures from 1991 to 2000 do not include catches taken in the recreational (rod) fishery.	11. Includes catches made in the West Greenland area by Norway, Faroes, Sweden and Denmark in 1965-1975.
4 From 1990, catch includes fish ranched for both commercial and angling purposes.	12. Includes catches in Norwegian Sea by vessels from Denmark, Sweden, Germany, Norway and Finland.
5. Improved reporting of rod catches in 1994 and data derived from carcase tagging and log books from 2002.	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.
6. Catch on River Foyle allocated 50% Ireland and 50% N. Ireland.	14. Estimates refer to season ending in given year.
7. Angling catch (derived from carcase tagging and log books) first included in 2002.	15. Catches from hatchery-reared smolts released under programmes to mitigate for hydropower development
8. Data for France include some unreported catches.	

Table 5 The catch (tonnes round fresh weight) and % of the nominal catch by country taken in coastal, estuarine, and riverine fisheries, 2000 to 2016. Data for 2016 include provisional data.

Country	Year	Coast		Estuary		River		Total
		Weight	%	Weight	%	Weight	%	weight
Spain	2000	0	0	0	0	7	100	7
	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	5	100	5
	2016	0	0	0	0	5	100	5
France	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
	2016	0	2	3	45	3	52	6
Ireland	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
	2016	0	0	19	33	39	67	58
UK (England & Wales)	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

Country	Year	Coast		Estuary		River		Total
		Weight	%	Weight	%	Weight	%	weight
	2015	55	82	4	6	8	12	68
	2016	71	82	6	6	10	11	86
UK (Scotland)	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	45	9	14	28	41	68
	2016	0	1	10	37	17	63	27
UK (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	3	100	3
	2016	0	0	0	0	5	100	5
Iceland	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
	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	68	100	68
	2015	0	0	0	0	125	100	125
	2016	0	0	0	0	119	100	119
Denmark	2000							
	2001							
	2002							
	2003							
	2004							
	2005							
	2006							
	2007							
	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

Country	Year	Coast		Estuary		River		Total
		Weight	%	Weight	%	Weight	%	weight
	2015	0	0	0	0	9	100	9
	2016	0	0	0	0	10	100	10
Sweden	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
	2016	0	0	0	0	9	100	9
Norway	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
	2016	269	44	0	0	343	56	612
Finland	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
	2016	0	0	0	0	51	100	51
Russia	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

Country	Year	Coast		Estuary		River		Total
		Weight	%	Weight	%	Weight	%	weight
	2015	34	42	0	0	46	58	80
	2016	24	42	0	0	32	58	56
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	25	97	69	140
	2016	7	5	36	26	92	68	135
France (Islands of St. Pierre and Miquelon	2000	2	100	0	0	0	0	2
	2001	2	100	0	0	0	0	2
	2002	2	100	0	0	0	0	2
	2003	3	100	0	0	0	0	3
	2004	3	100	0	0	0	0	3
	2005	3	100	0	0	0	0	3
	2006	4	100	0	0	0	0	4
	2007	2	100	0	0	0	0	2
	2008	3	100	0	0	0	0	3
	2009	3	100	0	0	0	0	3
	2010	3	100	0	0	0	0	3
	2011	4	100	0	0	0	0	4
	2012	1	100	0	0	0	0	1
	2013	5	100	0	0	0	0	5
	2014	4	100	0	0	0	0	4
	2015	4	100	0	0	0	0	4
	2016	5	100	0	0	0	0	5
Total NEAC	2016	364	35	37	4	643	62	1043
Total NAC	2016	11	8	36	26	92	67	140

Table 6 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, 2016.

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	40
NEAC	Finland	6	0.4	10
NEAC	Iceland	3	0.2	2
NEAC	Ireland	6	0.4	9
NEAC	Norway	263	18.8	30
NEAC	Sweden	1	0.1	10
NEAC	UK (E & W)	10	0.7	11
NEAC	UK (N.Ireland)	0	0.0	6
NEAC	UK (Scotland)	3	0.2	10
NAC	USA	0	0.0	0
NAC	Canada	27	2.0	17
WGC	Greenland	10	0.7	27
	Total Unreported Catch *	335	21.7	
	Total Reported Catch of North Atlantic salmon	1209		

* No unreported catch estimate available for France and Russia in 2016.
Unreported catch estimates not provided for Spain & St. Pierre et Miquelon

Table 7 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, 1991–2016. Figures for 2016 are provisional.

Year	Canada [4]		USA		Iceland		Russia [1]		UK (E&W)		UK (Scotland)		Ireland		UK (N Ireland) [2]		Denmark		Sweden		Norway [3]	
	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
1991	22 167	28	239	50			3 211	51														
1992	37 803	29	407	67			10 120	73														
1993	44 803	36	507	77			11 246	82	1 448	10												
1994	52 887	43	249	95			12 056	83	3 227	13	6 595	8										
1995	46 029	46	370	100			11 904	84	3 189	20	12 151	14										
1996	52 166	41	542	100	669	2	10 745	73	3 428	20	10 413	15										
1997	50 009	50	333	100	1 558	5	14 823	87	3 132	24	10 965	18										
1998	56 289	53	273	100	2 826	7	12 776	81	4 378	30	13 464	18										
1999	48 720	50	211	100	3 055	10	11 450	77	4 382	42	14 846	28										
2000	64 482	56	0	-	2 918	11	12 914	74	7 470	42	21 072	32										
2001	59 387	55	0	-	3 611	12	16 945	76	6 143	43	27 724	38										
2002	50 924	52	0	-	5 985	18	25 248	80	7 658	50	24 058	42										
2003	53 645	55	0	-	5 361	16	33 862	81	6 425	56	29 170	55										
2004	62 316	57	0	-	7 362	16	24 679	76	13 211	48	46 279	50					255	19				
2005	63 005	62	0	-	9 224	17	23 592	87	11 983	56	46 165	55	2 553	12			606	27				
2006	60 486	62	1	100	8 735	19	33 380	82	10 959	56	47 669	55	5 409	22	302	18	794	65				
2007	41 192	58	3	100	9 691	18	44 341	90	10 917	55	55 660	61	15 113	44	470	16	959	57				
2008	54 887	53	61	100	17 178	20	41 881	86	13 035	55	53 347	62	13 563	38	648	20	2 033	71			5 512	5
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
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
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
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
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
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
2015	65 440	64	0	-	21 914	31	7 028	50	8 113	79	46 827	84	9 383	37	61	100	2 989	70	725	19	25 433	19
2016	69 590	65	0	-	16 643	29	10 793	76	9 192	80	49 469	90	10 280	41	230	100	3 801	72	345	18	25 198	21
5-yr mean 2011-2015	54 466	58			17 402	33	5 996	46	10 584	71	53 257	78	10 236	37	1 769	62	2 229	60			18 916	16
% change on 5-year mean	28	12			-4	-11	80	65	-13	13	-7	15	0	11			71	21			33	32

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, 2014 is for the DCAL area only; the figures from 2010 are a total for UK (N.Ireland). Data for 2015 and 2016 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.

Table 8 Overview of number of case studies and Data Base on Effectiveness of Recovery Actions for Atlantic Salmon (DBERAAS) river stock entries per country.

Country	Region	Number of rivers in DBERAAS	Number of 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 and 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	All	568	15

Table 9 Summary of key prey items in diets of salmon in the Northwest Atlantic.

Life stage	Shallow waters	Deep waters
Post-smolt nearshore	Atlantic herring Capelin	Amphipods Euphausiids
Post-smolt offshore (Labrador Sea)	Capelin	Amphipods Armhook squid
1SW maturing / non-maturing (Offshore, Labrador Sea)	Sandlance	Barracudina
1SW maturing / non-maturing (West Greenland)	Capelin	Amphipods Armhook squid
1SW/2SW mature / maturing (nearshore)	Atlantic herring Capelin	

Table 10 Atlantic salmon prey item list compiled from Rikardsen *et al.* (2004). **** = very important prey (> 50% by weight if taken); *** = prey often found in stomachs and important if less energy rich prey is assumed not available; ** = occasionally found, but in low abundance; * = rare (< 1% by weight); and – = not reported.

Prey organism	Post-smolts – estuaries	Post-smolts – fjord and coast	Post-smolts – oceanic	Pre-adults / adults oceanic
Pisces				
Ammodytidae (Sandeel)	***	****	****	****
Herring *(Clupea harengus)*	***	****	****	****
Other Clupeoids	-	-	-	**
Capelin *(Malotus villosus)*	-	***	***	****
Gadidae (Cod fishes)	***	***	***	***
Atlantic cod *(Gadus morhua)*	**	***	**	**
Saithe *(Pollachius virens)*	**	***	**	*
Blue whiting *(Micromesistius poutassou)*	-	-	***	**
Other Gadidae	-	-	**	**
Myctophidae (Lantern fishes)	-	-	**	****
Paralepididae/Barracudinas (2)	-	-	-	***
Perlside	-	-	*	***
Scorpaenidae (Redfish)	-	-	*	*
Gasterosteidae (Stickleback)	*	-	-	*
Scombridae (Mackerel, *Scomber scomber)*	-	-	-	*
Anarhichadidae (Wolffish fry)	-	-	-	*
Belonidae (Garpike)	-	-	-	*
Pleuronedidae (Flatfish)	-	-	-	*
Osmeridae	-	-	-	*
Cyclopteridae (Lumpfish)	-	-	-	*
Stichaeidae	-	-	-	*
Cottidae (Sculpins fry)	-	-	-	*
Cottunculidae	-	-	-	*
Agonidae	-	-	-	*
Crustacea				
Copepoda	**	**	**	*
Amphipoda – planktonic (Hyperiidae)	**	***	***	****
Amphipoda – Bentic (Gammaridae)	***	**	-	-
Isopoda	*	*	*	*
Mysidacea (Mysids)	-	*		
Euphausiacea (Euphausids)	*	**	**	***
Decapoda – Plantonic larvae	*	*	*	*
Decapoda – Shrimps	-	-	*	***
Other crustacean	-	*	*	*
Mollusca – Cephalopoda (Squids)	-	-	*	**
Mollusca – Gastropods (sea slugs)	-	*	*	*
Mollusca – Bivalvia (pelagic)	-	-	-	*
Insecta	****	****	*	*
Polychaetea	*	*	*	*
Chaetognatha (Arrow worm)	-	*	-	*

Table 11 Summary of Atlantic salmon tagged and marked in 2016 – '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	2,557	0	1,521	**4,078**
	Hatchery Juvenile	0	305	202,027	45	**202,377**
	Wild Adult	0	3,197	35	79	**3,311**
	Wild Juvenile	0	20,093	20,737	590	**41,420**
	Total	**0**	**26,152**	**222,799**	**2,235**	**251,186**
Denmark	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	92,450	20,000	305,100	1,903	419,453
	Wild Adult	0	0	0	788	788
	Wild Juvenile	0	0	0	0	0
	Total	**92,450**	**20,000**	**305,100**	**2,691**	**420,241**
France [4]	Hatchery Adult					
	Hatchery Juvenile[3]					
	Wild Adult[3]					
	Wild Juvenile					
	Total					
Iceland	Hatchery Adult	0		0	0	0
	Hatchery Juvenile	47,345	0	0	0	47,345
	Wild Adult	0	79	0	0	79
	Wild Juvenile	6,052	9	0	0	6,061
	Total	**53,397**	**88**	**0**	**0**	**53,485**
Ireland	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	185,891	0	0	0	185,891
	Wild Adult	0	0	0	0	0
	Wild Juvenile	6,639	0	0	0	6,639
	Total	**192,530**	**0**	**0**	**0**	**192,530**
Norway	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	22,445	6,958	0	40,797	70,200
	Wild Adult	0	1,003	0	0	1,003
	Wild Juvenile	0		0	2,638	2,638
	Total	**22,445**	**7,961**	**0**	**43,435**	**73,841**
Russia	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	0	0	1,461,482	0	1,461,482
	Wild Adult	0	1,524	0	0	1,524
	Wild Juvenile	0	0	0	0	0
	Total	**0**	**1,524**	**1,461,482**	**0**	**1,463,006**
Spain	Hatchery Adult	0	0	0	0	**0**
	Hatchery Juvenile	0	92,393	0	0	**92,393**
	Wild Adult	0	0	0	0	**0**
	Wild Juvenile	0	0	0	0	**0**
	Total	**0**	**92,393**	**0**	**0**	**92,393**
Sweden	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	0	3100	164,931	0	168,031
	Wild Adult	0	381	0	0	381
	Wild Juvenile	0	0	0	0	0
	Total	**0**	**3,481**	**164,931**	**0**	**168,412**
UK (England & Wales)	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	0	0	11,647	0	11,647
	Wild Adult	0	514	0	2	516
	Wild Juvenile	5,722	0	6,121		11,843
	Total	**5,722**	**514**	**17,768**	**2**	**24,006**
UK (N. Ireland)	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	10,230	0	57,645	0	67,875
	Wild Adult	0	0	0	0	0
	Wild Juvenile	0	0	0	0	0
	Total	**10,230**	**0**	**57,645**	**0**	**67,875**
UK (Scotland)	Hatchery Adult	0	0	0	0	0
	Hatchery Juvenile	0	0	103,141	0	103,141
	Wild Adult	0	520	14	0	534
	Wild Juvenile	2,300	0	30	10,257	12,587
	Total	**2,300**	**520**	**103,185**	**10,257**	**116,262**
USA	Hatchery Adult	0	7	22	3,293	3,322
	Hatchery Juvenile	0	102,240	215,074	2,756	320,070
	Wild Adult	0	0	0	0	0
	Wild Juvenile	0	0	0	0	0
	Total	**0**	**102,247**	**215,096**	**6,049**	**323,392**
All Countries	Hatchery Adult	0	2,564	22	4,814	7,400
	Hatchery Juvenile	358,361	224,996	2,521,047	45,501	3,149,905
	Wild Adult	0	7,218	49	869	8,136
	Wild Juvenile	20,713	20,102	26,888	13,485	81,188
	Total	**379,074**	**254,880**	**2,548,006**	**64,669**	**3,246,629**

[1] Includes other internal tags (PIT, ultrasonic, radio, DST, etc.); [2]Includes Carlin, spaghetti, streamers, VIE etc; [3] includes external dye mark. [4] Tag information for France not available for 2016.

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Annex 2 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.

ASF (*Atlantic Salmon Federation*). A non-governmental organisation dedicated to the conservation, protection and restoration of wild Atlantic salmon and the ecosystems on which their well-being and survival depend.

BHSRA (*Bayesian Hierarchical Stock and Recruitment Approach*). Models for the analysis of a group of related stock–recruit datasets. Hierarchical modelling is a statistical technique that allows the modelling of the dependence among parameters that are related or connected through the use of a hierarchical model structure. Hierarchical models can be used to combine data from several independent sources.

Blim (*Biomass limit reference point*). The minimum spawning stock biomass.

BRP (*Biological Reference Point*). The spawning stock level that produces maximum sustainable yield (Conservation Limit).

CET (Central England Temperature). Daily and monthly temperatures time-series representative of a roughly triangular area of the United Kingdom enclosed by Lancashire, London and Bristol.

CL, i.e. Slim (*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.

CPUE (*Catch per Unit of Effort*). A derived quantity obtained from the independent values of catch and effort.

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).

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.

EEZ *(Exclusive Economic Zone*)*.* EEZ is a concept adopted at the Third United Nations Conference on the Law of the Sea, whereby a coastal State assumes jurisdiction over the exploration and exploitation of marine resources in its adjacent section of the continental shelf, taken to be a band extending 200 miles from the shore.

ENPI CBC *(European Neighbourhood and Partnership Instrument Cross-Border Cooperation*)*.* ENPI CBC is one of the financing instruments of the European Union. The ENPI programmes are being implemented on the external borders of the EU. It is designed to target sustainable development and approximation to EU policies and standards; supporting the agreed priorities in the European Neighbourhood Policy Action Plans, as well as the Strategic Partnership with Russia.

FSC (*Food, Social and Ceremonial fishery*). Aboriginal fishery in Canada for food, social or ceremonial purposes.

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.

GFLK (*Greenland Fisheries Licence Control Authority*).

GLM (*Generalised Linear Model*). A conventional linear regression model for a continuous response variable given continuous and/or categorical predictors.

GoSL (*Gulf of St Lawrence*).

GUL (*Gulf of St. Lawrence*)*.*

HoT (Head of Tide). Limit of tidal influence in a river.

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.

ICES (*International Council for the Exploration of the Sea*). A global organisation that develops science and advice to support the sustainable use of the oceans through the coordination of oceanic and coastal monitoring and research, and advising international commissions and governments on marine policy and management issues.

ICPR (*International Commission for the Protection of the Rhine*).

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

IMR (*Institute of Marine Research*). Norwegian institute who provide advice to Norwegian authorities on aquaculture and the ecosystems of the Barents Sea, the Norwegian Sea, the North Sea and the Norwegian coastal zone.

IPCC (*Intergovernmental Panel on Climate Change*). The international body for assessing the science related to climate change.

IYS (*International Year of the Salmon*). An international framework for collaborative outreach and research launched by NPAFC, NASCO and other partners. The IYS focal year will be 2019, with projects and activities starting in 2018 and continuing into 2020.

JAGS (*Just Another Gibbs Sampler*). A program for analysis of Bayesian hierarchical models using Markov Chain Monte Carlo (MCMC) simulation.

LAB (*Labrador Central*).

LE (*Lagged Eggs*). The summation of lagged eggs from 1 and 2 sea-winter fish is used for the first calculation of PFA.

MCMC (*Markov Chain Monte Carlo*). Re-sampling algorithm used in (Bayesian) statistics.

MOCNESS (*Multiple Opening/Closing Net and Environmental Sensing System*).

MSA (*Mixed-stock Analysis*). Genetic analytical technique to estimate the proportions origin of fish in a mixed-stock fishery.
or

MSA (*Miramichi Salmon Association*).

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.

NAC (*North American Commission*). The North American Atlantic Commission of NASCO or the North American Commission area of NASCO.

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.

NASCO (*North Atlantic Salmon Conservation Organisation*). An international organisation, established by an intergovernmental convention in 1984. The objective of NASCO is to conserve, restore, enhance and rationally manage Atlantic salmon through international cooperation taking account of the best available scientific information.

NCC (*NunatuKavut Community Council*). NCC is one of four subsistence fisheries harvesting salmonids in Labrador.

NEAC (*North Eastern Atlantic Commission*). North-East Atlantic Commission of NASCO or the North-East Atlantic Commission area of NASCO.

NEAC – N (*North Eastern Atlantic Commission- northern area*). The northern portion of the North-East Atlantic Commission area of NASCO.

NEAC – S (*North Eastern Atlantic Commission – southern area*). The southern portion of the North-East Atlantic Commission area of NASCO.

NFL (*Newfoundland*).

NG (*Nunatsiavut Government*). NG is one of four subsistence fisheries harvesting salmonids in Labrador. NG members are fishing in the northern Labrador communities.

NOAA (*National Oceanic and Atmospheric Administration*). A scientific agency within the United States Department of Commerce.

NPAFC (*North Pacific Anadromous Fish Commission*). An international inter-governmental 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.

NSS (*Norwegian-spring-spawning*).

OSPAR (*Convention for the Protection of the Marine Environment of the North-East 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.

PFA (*Pre-Fishery Abundance*). The numbers of salmon estimated to be alive in the ocean from a particular stock at a specified time.

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 about 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.

PIT (*Passive Integrated Transponder*). PIT tags use radio frequency identification technology. PIT tags lack an internal power source. They are energized on encountering an electromagnetic field emitted from a transceiver. The tag's unique identity code is programmed into the microchip's nonvolatile memory.

PSAT (*ParkinsonSat satellite tags*)

Q Areas. (*Québec Areas*). Areas for which the Ministère des Ressources naturelles et de la Faune manages the salmon fisheries.

RFID (*Radio Frequency Identity tag*).

RR model (*Run-Reconstruction model*). RR model is used to estimate PFA and national CLs.

RVS (*Red Vent Syndrome*). This condition has been noted since 2005, and has been linked to the presence of a nematode 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.

SAC (*Special Area of Conservation*). Strictly protected site designated under the European Committee Habitats Directive.

SALSEA (*Salmon at Sea*). An international programme of co-operative research, adopted in 2005, designed to improve understanding of the migration and distribution of salmon at sea in relation to feeding opportunities and predation.

SALSEA-Merge (*Salmon at Sea Merge*). SALSEA-Merge is an international programme of cooperative research designed to improve understanding of the migration and distribution of salmon at sea in relation to feeding opportunities and predation. It differentiates between tasks which can be achieved through enhanced coordination of existing ongoing research, and those involving new research for which funding is required.

SALSEA-Track (*Salmon at Sea Track*). SALSEA-Track is the second phase of the SALSEA Programme. It employs advances in telemetry technology to precisely track Atlantic salmon along their migration routes through cooperative international research initiatives.

SE (*standard error*).

SER (*Spawning Escapement Reserve*). The CL increased to take account of natural mortality between the recruitment date (assumed to be 1st January) and the date of return to homewaters.

SFA *(Salmon Fishing Areas).* Areas for which the Department of Fisheries and Oceans (DFO) Canada manages the salmon fisheries.

Slim, i.e. CL (*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 the undesirable 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).

SNP (*Single Nucleotide Polymorphism*). Type of genetic marker used in stock identification and population genetic studies.

S–R (*Stock recruitment*).

SoBI (*Strait of Belle Isle*).

SSB (Spawning stock biomass).

SVA (*Swedish National Veterinary Institute*)

TAC (*Total Allowable Catch*). TAC is the quantity of fish that can be taken from each stock each year.

ToR (*Terms of reference*).

UDN (*Ulcerative Dermal Necrosis*). Disease mainly affecting wild Atlantic salmon, sea trout and sometimes other salmonids. 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.

UK (*United Kingdom and Northern Ireland*). Country in Europe.

VIE (*Visual implant elastomer tag*).

WGC (*West Greenland Commission*). The West Greenland Commission of NASCO or the West Greenland Commission area of NASCO.

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.

WGF (*West Greenland Fishery*). Regulatory measures for the WGF have been agreed by the West Greenland Commission of NASCO for most years since NASCO's establishment. These have resulted in greatly reduced allowable catches in the WGF, reflecting declining abundance of the salmon stocks in the area.

WGNAS (*Working Group on North Atlantic Salmon*). ICES working group responsible for the annual assessment of the status of salmon stocks across the North Atlantic and formulating catch advice for NASCO.

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).

WGWIDE (*ICES Working Group on Widely Distributed Stocks*).

WKCCISAL (*The Workshop on Potential Impacts of Climate Change on Atlantic Salmon Stock Dynamics*).

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.