Council

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Presentation of the ICES Advice to the Council

sal.oth.nasco

North Atlantic Salmon Stocks

ICES CIEM

Science for sustainable seas

Terms of Reference

With respect to Atlantic salmon in the North Atlantic area

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;

1.2 report on significant new or emerging threats to, or opportunities for, salmon conservation and management;

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;

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;

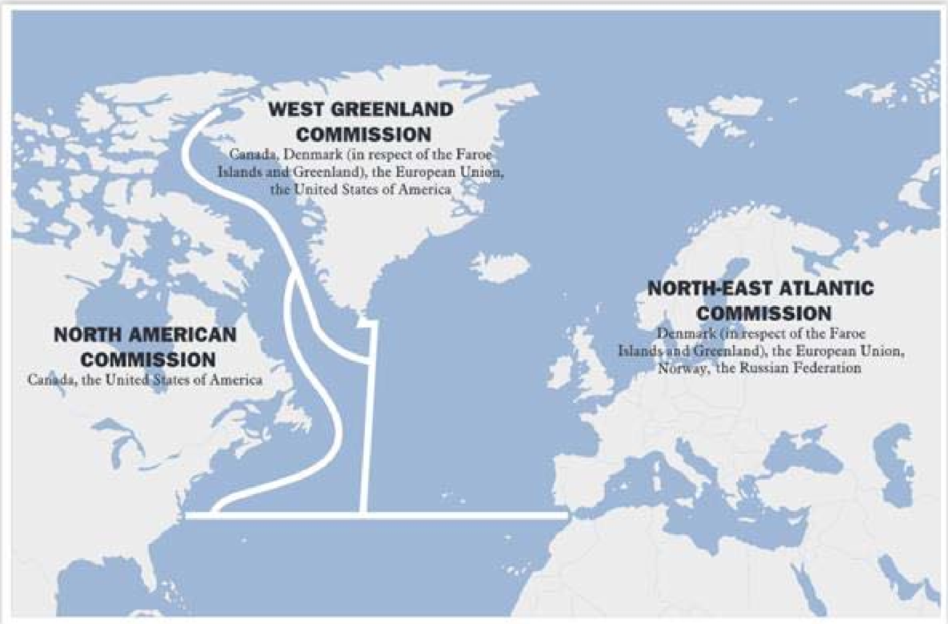
1.5 provide a description of the potential future impacts of climate change on salmon stock dynamics;

1.6 provide a compilation of tag releases by country in 2016; and

1.7 identify relevant data deficiencies, monitoring needs and research requirements.

Background

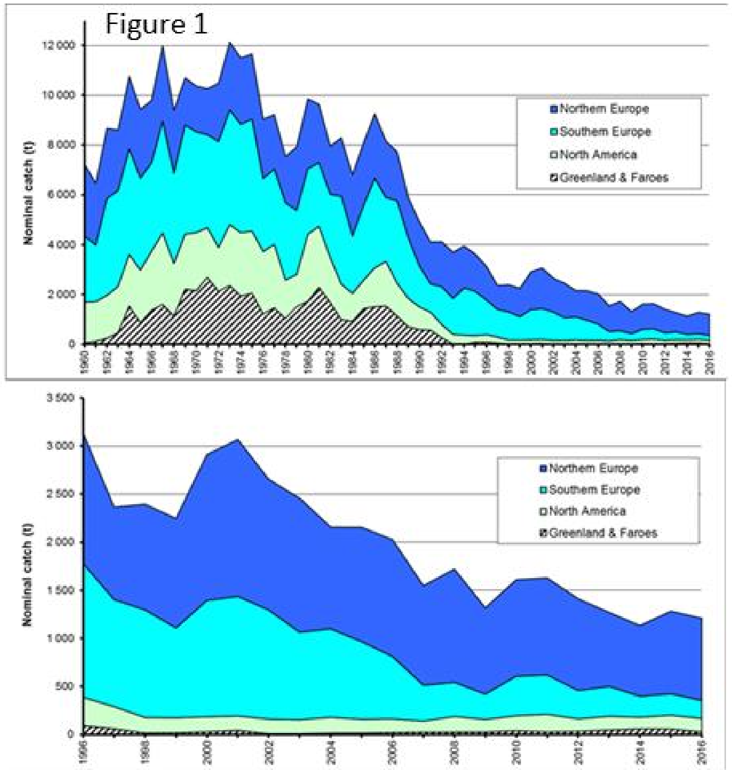
- Management framework for salmon in the North Atlantic
- Reference points and application of precaution



1.1 overview of salmon catches and landings, unreported catches, catch and release, and production of farmed and ranched Atlantic salmon in 2016

- nominal catch : round, fresh weight of fish caught and retained
- total nominal catch for 2016: 1209 t
  - second lowest in the time-series, after 2014

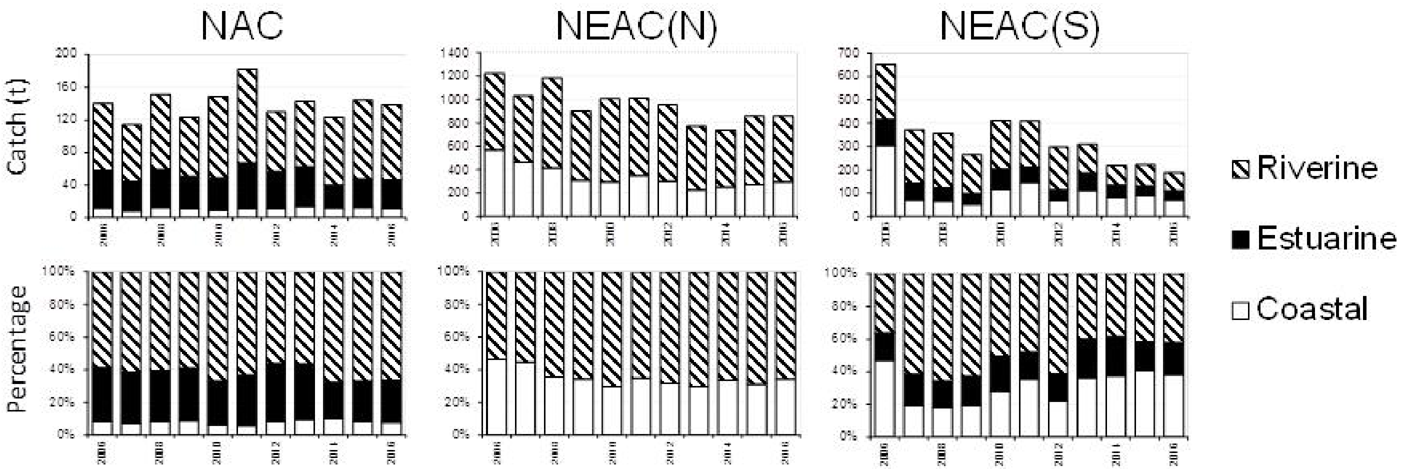
Area	Catch (t)		
	2014	2015	2016
NEAC	954	1081	1043 (86%)
NAC	122	144	140 (12%)
WGC	58	57	27 (2%)
Total	1134	1282	1209



1.1 overview of salmon catches and landings,

Location of catches (Figure 3):

- NEAC : 62% in-river , 4% estuarine, 35% coastal.
- NAC: 61% in-river, 31% estuarine, 8% coastal.
- WGC: 0% in-river, 0% estuarine, 100% coastal



Location of catches by country (Figure 2)

1.1 overview of salmon catches and landings, **unreported catches**, catch and release, and production of farmed and ranched Atlantic salmon **in 2016**

- Total unreported catch in NASCO areas in 2016 was estimated at 335 t (22% of total nominal catch)
  - 298 t from NEAC; 27 t from NAC; 10 t from WGC
  - no estimate for Russia, France, Spain, and St. Pierre and Miquelon in 2016

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.

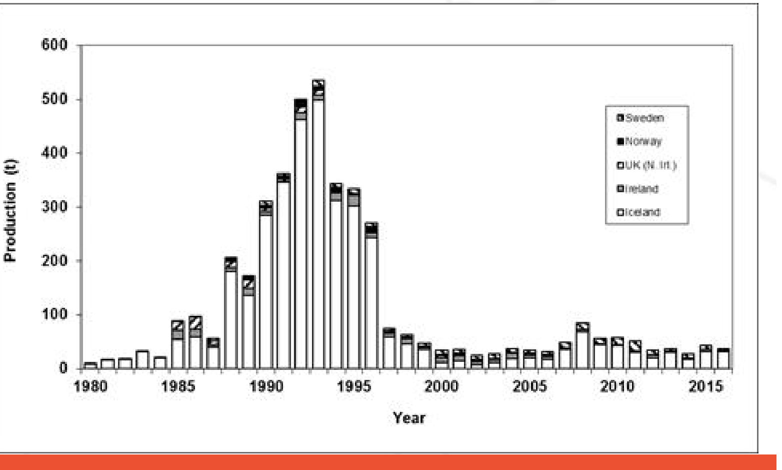
1.1 overview of salmon catches and landings, unreported catches, catch and release, and production of farmed and ranched Atlantic salmon in 2016

- The nominal catches do not include salmon that have been caught and released.
- Practice of catch-and-release (C&R) in rod fisheries has become increasingly common in light of the widespread decline in salmon abundance in the North Atlantic.
- Catch-and-release mortality is considered in some national assessments of spawner escapement, with estimates ranging from 3% to 20% among jurisdictions.
- Table 7 presents C&R information from 1991 to 2016 for countries that have records.
- In 2016, total number of catch and released fish reported was 195 000 fish.
- Percentage of handled fish released ranged from 18% in Sweden to 90% in UK (Scotland), reflecting varying management practices and angler attitudes.
- The percentage of fish released has tended to increase over time.

1.1 overview of salmon catches and landings, unreported catches, catch and release, and production of farmed and ranched Atlantic salmon in 2016

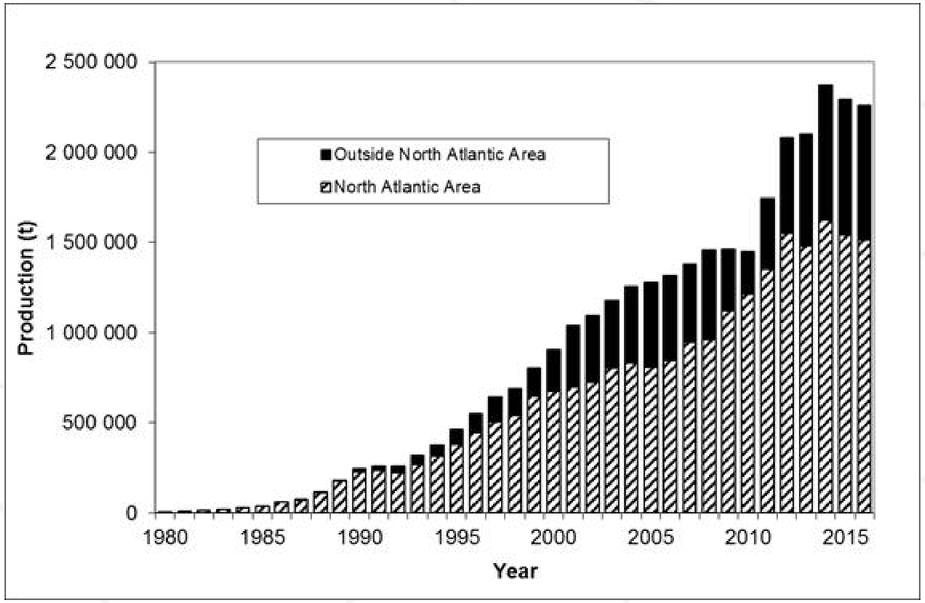
- Sea ranching is release of fish with the specific intention of harvesting all returns at the release site and with no prospect of wild spawning success.
- Iceland: ranching for rod fisheries in two rivers.
- Sweden: adult salmon originated from hatchery-reared smolts, released under programmes to mitigate for hydropower development schemes, exploited in home waters with no possibility of spawning naturally.

- Total harvest of ranched salmon in 2016 = 37 t (Iceland, Sweden, and Ireland); with 31 t from Iceland.



1.1 overview of salmon catches and landings, unreported catches, catch and release, and production of farmed and ranched Atlantic salmon in 2016

- Provisional estimate of farmed salmon production in North Atlantic area for 2016 was > 1512 kt.
  - Norway (78%) and UK (Scotland) (12%).
- Worldwide production of farmed Atlantic salmon in 2016 is provisionally ~ 2262 kt; in excess of one million tonnes since 2001, and over two million tonnes since 2012.
  - production outside the North Atlantic dominated by Chile (81%).

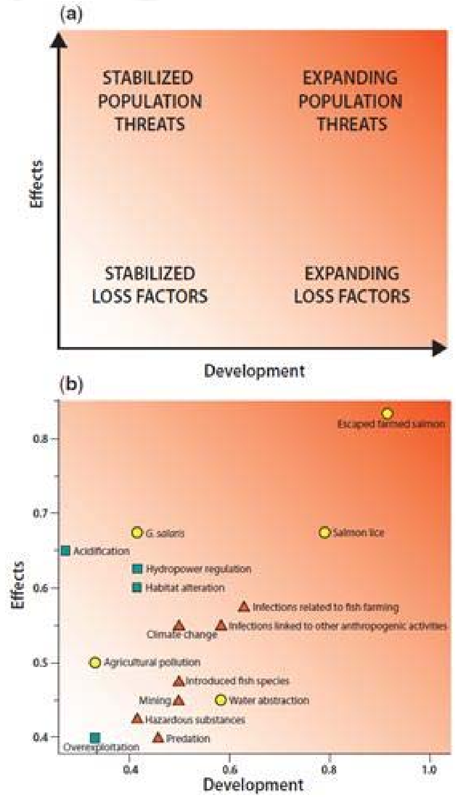


- nominal catch of Atlantic salmon in the North Atlantic was 0.05% of worldwide production of farmed Atlantic salmon in 2016

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

- Evaluation of 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, escaped farmed salmon being the largest current threat.
- *Gyrodactylus salaris*, acidification, and hydropower scored high along the effect axis, but lower on the development axis; categorized as stabilized.

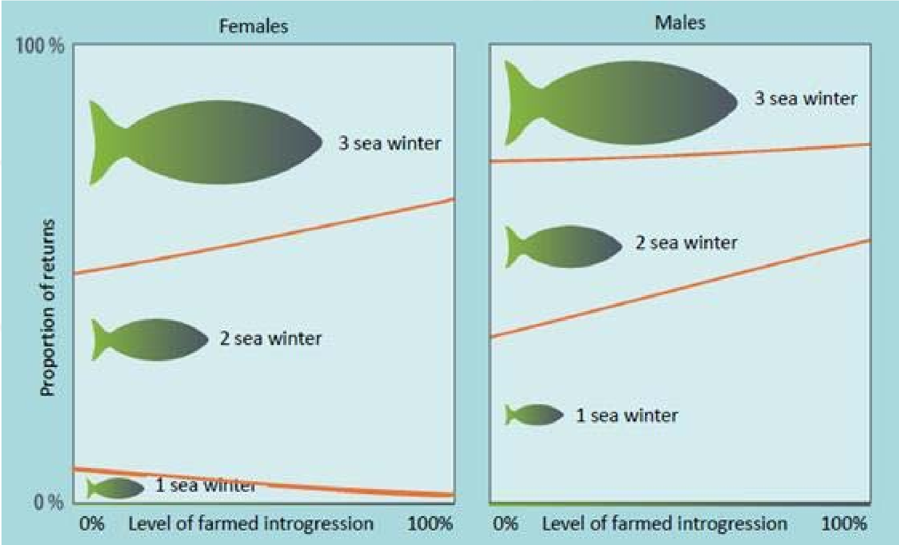


1.2 report on significant new or emerging threats to, or opportunities for, salmon conservation and management

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

- Gene flow from domesticated stocks into wild conspecific populations is well documented with introgression levels up to a maximum average of 40%.
- Farmed salmon and hybrids have altered phenotypes compared to wild salmon.

- Recently published study of 62 salmon populations along the entire Norwegian coastline, Bolstad *et al.* (2017)
- Eastern Atlantic populations: fewer old and large salmon with increasing levels of introgression.
- Barents/White Sea populations, which are of different phylogeny from the domesticated salmon: the estimated effects of introgression were in several cases stronger.



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

Diseases and parasites

- **Update on red vent syndrome (*Anisakiasis*)**

Red vent syndrome (RVS or *Anisakiasis*), observed since 2004, linked to nematode worm, *Anisakis simplex*, persists in monitored rivers into 2016 at average or below average levels. No clear indication that RVS affects either the survival of the fish in freshwater or their spawning success.

- **Disease reports from Sweden**

High levels of mortality in 2014 and 2015 in returning salmon and sea trout in a number of rivers in Sweden that drain to the Baltic Sea. In 2016, 112 fish were sampled and 38% had wounds typical of ulcerative dermal necrosis (UDN). It has not been concluded that UDN was the underlying cause of the symptoms observed. Numbers of dead salmon seem to have decreased since 2015.

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

Diseases and parasites

- **Disease reports from Russia**

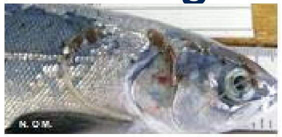
In summer 2015 a mass mortality of adult salmon was observed in the Kola River, owing to disease diagnosed as UDN. In 2016, mortality of spawning fish caused by the same disease was observed in the Kola River again and in the Tuloma River; both rivers drain into the inner part of the Kola Bay.

- 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.

In late July 2016 a few salmon with disease symptoms similar to those in fish from Kola and Tuloma were caught in the Motovsky Gulf, Barents Sea. 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.

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

- **Update on sea lice investigations in Norway**



Surveillance programme for salmon lice infections on wild salmon post-smolts and sea trout continued in 2016 (Nilsen *et al.,* 2017).

- varying infection pressure along the coast during the post-smolt migration period in 2016.
- 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).

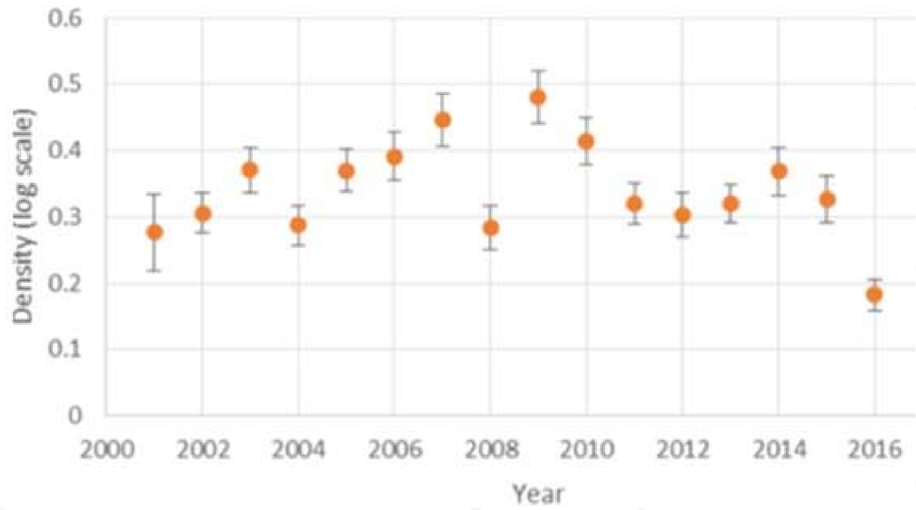
In 2017, a new management regime for salmonid aquaculture will be implemented in Norway (Anon., 2017a).

- 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.

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

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; scale of the downturn was particularly notable and affected rivers throughout the country (Figure 8).



- Low densities of juvenile salmon in 2016 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. 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).

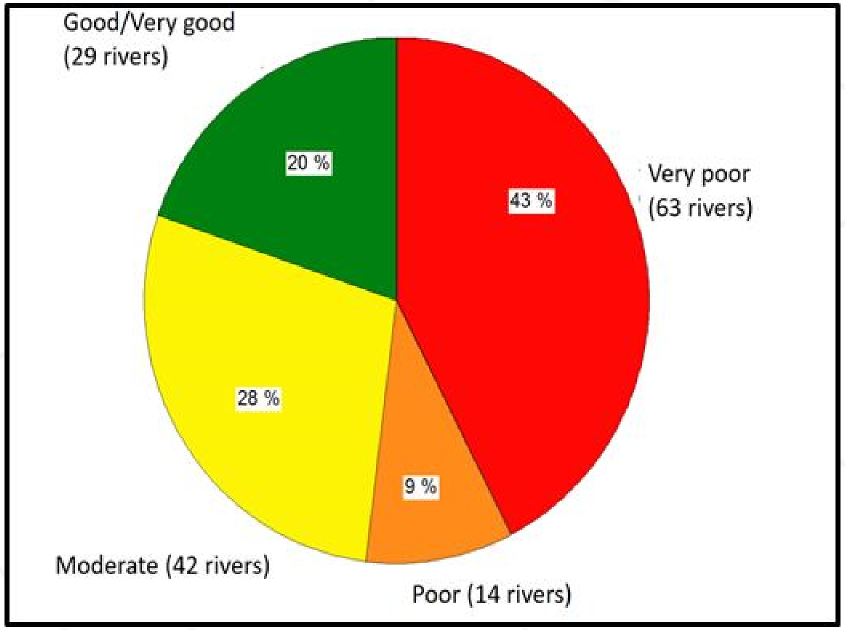
1.2 report on significant new or emerging threats to, or opportunities for, salmon conservation and management

- **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.

148 salmon populations have been classified based on both conservation limit and harvest potential, and genetic integrity dimensions.

Of these, 29 (20%) were classified as being in good or very good condition, 42 (28%) were classified as being in moderate condition, while 77 (52%) were in poor or very poor condition (Figure 9).



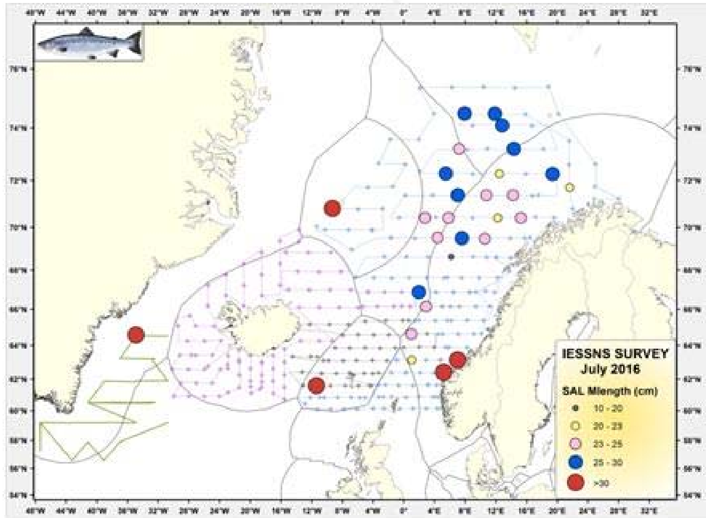
1.2 report on significant new or emerging threats to, or opportunities for, salmon conservation and management

Update on opportunities for investigating salmon at sea

- **International Ecosystem Summer Survey of the Nordic Seas (IESSNS)**

Collaborative programme involving research vessels from Iceland, the Faroes, and Norway; surveys are carried out annually in July–August, 3.0 million km^2 surveyed in 2016, surface trawling. Surveys overlap in time and space with the known distribution of post-smolts.

- In 2016, 103 post-smolt and adult salmon were incidentally captured (Figure 10).
- 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 from all years.
- IESSNS survey data will provide information on salmon, and distribution in relation to other pelagic species, hydrography, and plankton.



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

Update on opportunities for investigating salmon at sea

- **Bycatch of salmon in the Icelandic mackerel fishery**

Since 2007, mackerel have been at high abundance within the Icelandic EEZ.

- Partial screening of the catch, by onboard inspections and at landing sites, has been undertaken by the Icelandic Directorate of Fisheries.
- Salmon taken as bycatch have been voluntarily reported by the Icelandic mackerel fleet.
- Salmon recovered during surveys by Marine and Freshwater Research Institute vessels.

Between 2010 and 2014, 703 salmon have been recovered from the screening programmes and sampled (tags, scales, otoliths, DNA, stomach contents). 186 salmon assigned to their area of origin including Iceland, mainland Europe, UK, Ireland, Scandinavia and Northern Russia.

On average, bycatch of salmon has been 5.4 fish per 1000 tonnes of mackerel (4.7 to 6.2) caught with the proportion of salmon in the mackerel catches relatively stable over years, and similar to those previously reported by ICES (2014).

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

Update on opportunities for investigating salmon at sea

- **Tracking and acoustic tagging studies**

Atlantic Salmon Federation in Canada, in partnership with the Oceans Tracking Network and collaborators have captured, sampled, and tagged with acoustic transmitters more than 3000 smolts and 400 kelts from rivers of the Gulf of St. Lawrence in eastern Canada over the period 2003 to 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 or Cabot Strait to the Atlantic Ocean.

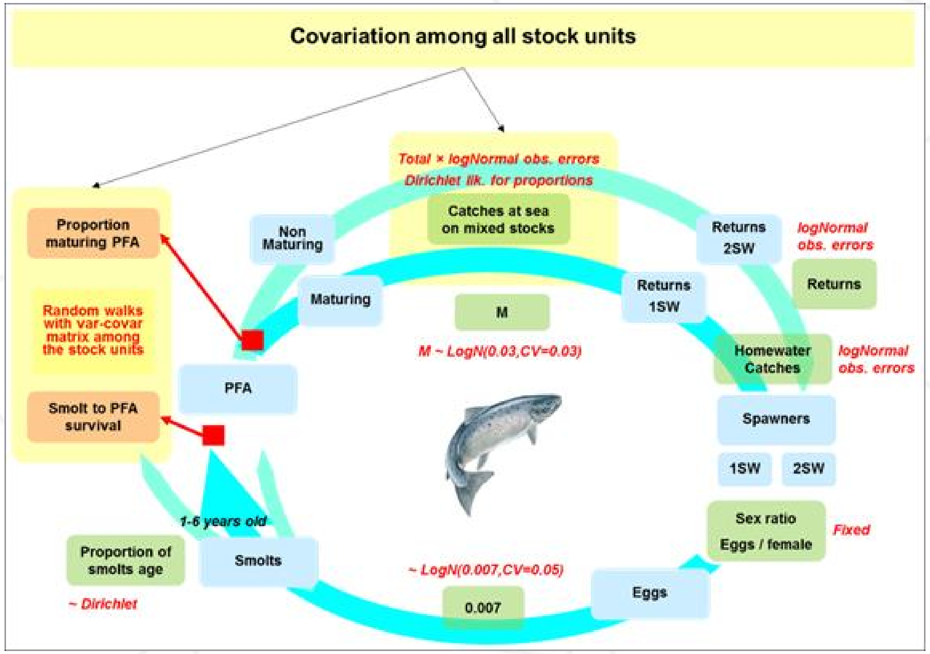
What has been learned:

- Information on survival rates in freshwater, through estuaries and through Gulf of St. Lawrence.
- Fixed migration paths and synchronized timing of smolt migrations into Labrador Sea.
- Additional research questions being addressed related to predator–prey interactions.

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

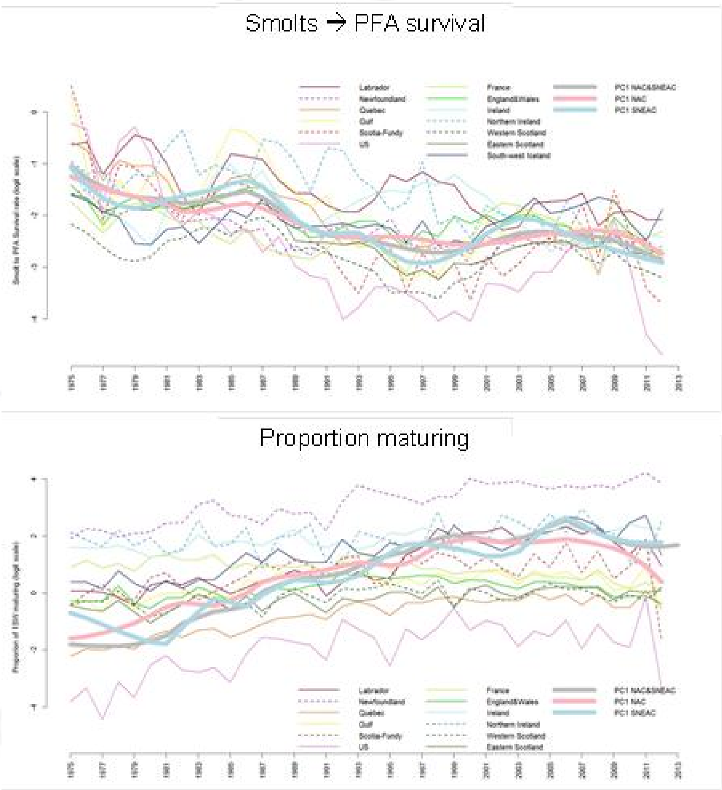
Progress in stock assessment models – Embedding Atlantic salmon stock assessment within an integrated Bayesian life cycle modelling framework

- Important limitation of models currently used by ICES is that three different models are run for the three stock complexes (NNEAC, SNEAC, and NAC).
  - Survival in the first year at sea and proportion of the stock that matures as 1SW salmon are not harmonized among stock complexes.
- Current life cycle model considers the dynamics of the stock units in SNEAC and NAC complexes in a single model where populations follow the same life history processes, but with stock-specific parameters and data inputs (Figure 12).



1.2 report on significant new or emerging threats to, or <u>opportunities</u> **for, salmon conservation and management**

- Initial results provide a broad picture of Atlantic salmon population dynamics in the North Atlantic.
- 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).
- Collective patterns observed across thirteen stock units support the hypothesis of a synchronous response 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).



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

Anticipated improvements to model development and application

- incorporation of changes in smolt characteristics including proportions at age over time and the variations in the biological characteristics.
- improving a number of input data streams including new stock origin data on catches in mixed-stock fisheries based on genetic analyses.
- including more data and information on the freshwater phase of the life cycle (data on monitored rivers, egg-to-smolt survival rate dynamics, density-dependent survival) for advancing the understanding of ecological inferences.
- incorporation of the Northern NEAC stocks in a full North Atlantic complex model.

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

Working Group on the Effectiveness of Recovery Actions for Atlantic Salmon (WGERAAS) met for a third and final time on 10–12 November 2015.

- Analyses of the case studies and DBERAAS have both been completed, and the ICES report is currently being finalized.

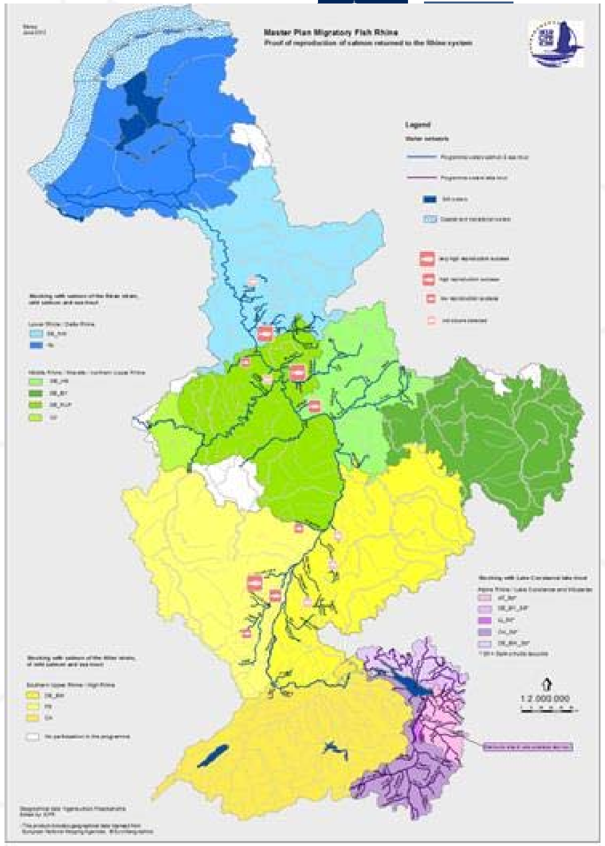
Habitat fragmentation and water quality degradation are two important stressors that have been demonstrated as having contributed to the reductions, and in some cases the loss of salmon populations in rivers.

- 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.

1.3 Provide a review of examples of successes and failures in wild salmon restoration and rehabilitation

Reintroduction of Atlantic salmon in the Rhine

- Extirpation of Atlantic salmon in Germany in the 1950s.
- First salmon reintroduction initiatives started in late 1970s
- Despite ongoing impediments, salmon now return regularly and migrate upstream to spawn.
- From 1990 to 2016, around ten million young salmon were stocked in the Rhine system.
- 8816 adult returns were officially enumerated through various methods.
- Because of natural reproduction, stocking measures have been stopped in some tributaries, to investigate the development of self-sustaining salmon populations.
- Study on downstream migration of Atlantic salmon smolt at three hydropower stations; reservoir upstream of the power station identified as an area of high mortality.



Reports from ICES expert groups relevant to North Atlantic salmon

WGRECORDS - Working Group on the Science Requirements to Support Conservation, Restoration and Management of Diadromous Species

- 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.
  - Diadromous fish theme session will convene at the 2017 ICES Annual Science Conference in Fort Lauderdale, Florida, USA.
  - 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).

International Year of the Salmon (IYS)

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

- Feeding intensity and diet composition varies with life stage, gape size, season, location, and water depth.
- Key prey species from the Northwest Atlantic:
  - Post-smolts in nearshore shallow waters: juveniles Atlantic herring, sandlance.
  - Post-smolts in offshore waters: switch to pelagic amphipods, euphausiids, cephalopods, and capelin.
  - 1SW maturing/non-maturing offshore phase: sandlance, deeper water fish (barracudina).
  - 1SW at West Greenland: capelin, amphipods and squid.
  - 1SW/2SW mature/maturing in the nearshore phase: capelin, Atlantic herring, sandlance.

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

- Key prey species from the Northeast Atlantic:
    - Post-smolts in coastal regions: herring larvae, sandeel larvae, blue whiting larvae and amphipods, euphausiids.
    - Post-smolts in fjords: opportunistic feeders, varies among Norwegian fjords and among years, dominated by pelagic fish larvae (sandeel, herring, and gadoids).
    - Post-smolts in offshore areas: large zooplankton, juvenile fish and amphipods.
    - Larger salmon: small pelagic fish (sprat, herring, capelin, mackerel, blue whiting), sandeel, large zooplankton, (amphipods and euphausiids), mesopelagic fish, and squid.
    - Larger salmon feed on larger prey and are opportunistic predators capable of switching diet according to availability.

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

Key prey species characteristics and fisheries

Key prey species 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.

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

Commercially important species

- 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.
  - in contrast to the Northeast Atlantic, sandlance (*Ammodytes* sp.) are not commercially exploited in the Northwest Atlantic.
- Northeast Atlantic is generally well monitored due to the intensity of fishing for commercially important small pelagic fish species (herring, blue whiting, and mackerel)
- Norwegian spring-spawning (NSS) herring are probably the most important prey owing to the large stock size and spatial overlap with both post-smolt and larger salmon.
  - very variable recruitment success.
  - last strong year was in 2004; even though following year classes have been weak, there would have been abundant herring larvae available for post-smolts.

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

Commercially important species

- Mackerel can be important for salmon both as prey and as a potential competitor.
  - mackerel stock presently around 4.5 million tonnes, very good recruitment in the last 10–15 years.
  - stock is expanding north and west and is now distributed over the entire Norwegian Sea, around Iceland, and to the southeastern part of Greenland during the summer and into the Barents Sea.
  - mackerel feed on herring larvae 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.

- Two stocks of capelin: Icelandic and Barents Sea.
  - After low stock levels around 1980 and 1990, the Icelandic stock size has been fairly stable.
  - Barents Sea stock has had large fluctuations since the 1970s, stock collapsed around 1985, 1993, and 2003. The stock is presently collapsed again, but high abundance of juvenile capelin has been recorded.

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

Commercially important species

- Sandeel (*Ammodytes* sp.) larvae can be an important part of the diet for post-smolts 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 .
- Biomass of blue whiting has increased in recent years owing to good recruitment and is presently around 6.7 million tonnes.
  - blue whiting larvae can be an important part of the diet for post-smolts.

  - juvenile blue whiting are part of the diet for larger salmon in the winter, as the juvenile whiting remain widely distributed from Portugal to the Norwegian Sea during the winter.

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

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) and macrozooplankton (amphipods and euphausiids): time-series of abundance for macrozooplankton are very short and limited in geographic and seasonal distributions.


Northeast Atlantic

- In general, more zooplankton in the northwestern region than in the southeastern region of the Norwegian Sea.
  - water masses in the western region are too cold for most pelagic fish thus larger zooplankton that would otherwise be vulnerable to fish predation are more prevalent in this region.
  - biomass of small zooplankton (< 2 mm) in the Norwegian Sea in May consists mainly of smaller copepods. Time-series (1996–2016) indicates a generally decreasing trend. Although the biomass is lower than in the 1990s, the levels are still high compared to other regions such as in the Barents Sea.

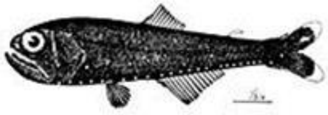
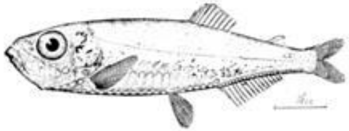
1.4 Provide a summary of the available diet data for marine life stages of Atlantic salmon and iden-tify key prey species at different life stages

Non-commercially important species

- Abundance of large zooplankton has been decreasing over the last 5–10 years compared to the period 1991–2010. 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.

  - most common species in the North Atlantic are myctophids (lanternfish; *Maurolicus muelleri*, *Benthosema glaciale*) and barracudinas.
  - it is assumed that abundance decreases with latitude.
  - the present and historical biomasses of mesopelagic fish in the North Atlantic are unknown.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Ecosystem considerations

- Large changes in the preferred feeding areas for NSS herring, mackerel, and capelin since mid-1990s.
- 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, change correlated with the abundance of herring and mackerel feeding in the Northeast Atlantic (Olafsdottir *et al.,* 2016).
- <u>Post-smolt prey</u>
    - highly variable and generally less available prey in the last 10 to 15 years.
    - larvae of herring and sandeel are less abundant in the Northeast Atlantic than previously.
    - low spatio-temporal overlap between post-smolt and mackerel and blue whiting larvae.
    - indications of a reduction in abundance of zooplankton in the Norwegian Sea.
    - although the 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.

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

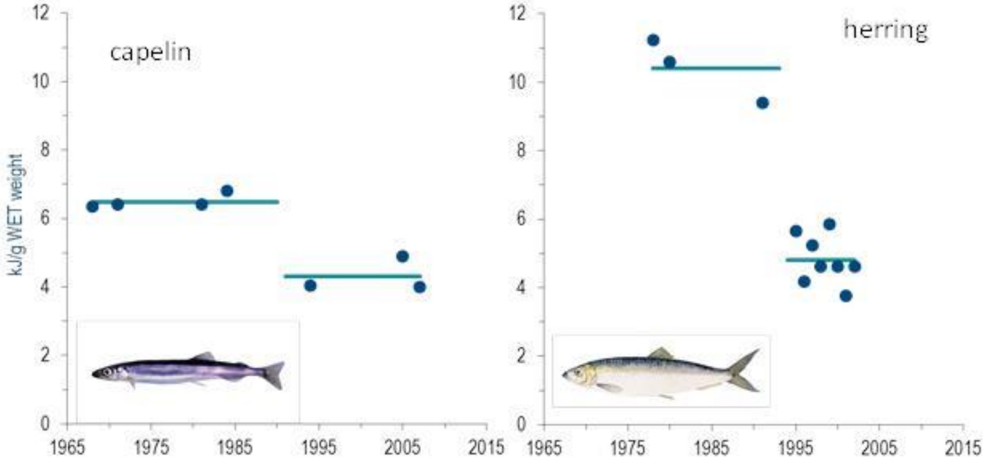
Ecosystem considerations

- Good availability of prey for larger salmon.
  - All the pelagic stocks feeding in the Norwegian Sea are abundant (NSS herring, blue whiting, and mackerel).
  - 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.

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

Atlantic salmon are opportunistic predators capable of switching diet according to availability

- Altered forage conditions have been shown to have effects for some species in terms of size and body condition and by inference have affected survival and population abundance via direct and indirect mechanisms
- Not all prey have a similar energetic content nor is the energy value of prey constant over time.



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

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- Many prey items of Atlantic salmon are poorly studied and monitored because they are not of commercial importance in the North Atlantic.
- Impact of variations in distribution, abundance, and forage quality of these prey on Atlantic salmon growth, maturation, and survival is largely unknown.
- The trophic link through bottom–up effects is hypothesized but 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.

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

To address the request, Workshop on Potential Impacts of Climate Change on Atlantic Salmon Stock Dynamics (WKCCISAL, ICES 2017c) held March 27 and 28, 2017
Co-chair: D. Ensing (UK (N.Ireland)) and J. Irvine (Canada)

WKCCISAL task to review predicted climatic changes over the range of wild Atlantic salmon, literature and research on biological and environmental drivers affecting stock dynamics and describe potential impacts upon:

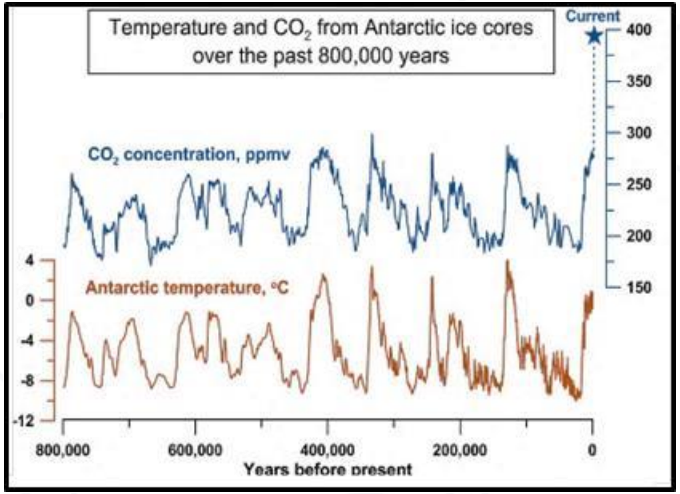
- Biological characteristics (growth, condition, maturity, fecundity, time at sea, survival, etc) that may affect the productivity of stocks
- Riverine, estuarine and marine habitat and potential consequences for salmon
- Interactions with other species (parasites, predators, preys and competing species including invasive species)
- Migration routes used by salmon, the timing of migration and implications of such changes
- Inter-population genetic diversity

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

Background

- Anthropogenic Climate Change (CC) refers to the consequence of anthropogenic inputs of carbon dioxide (CO_2) and other related compounds to the atmosphere.
- 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.

- Climate variation has been large and seemingly cyclical over the past 500 thousand years, corresponding roughly to the evolutionary divergence of *Salmo salar*
- Mean annual temperature variations have been greater than 10°C from peak to trough, while estimates of atmospheric CO_2 concentration varied from 150 ppm to just over 300 ppm.



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

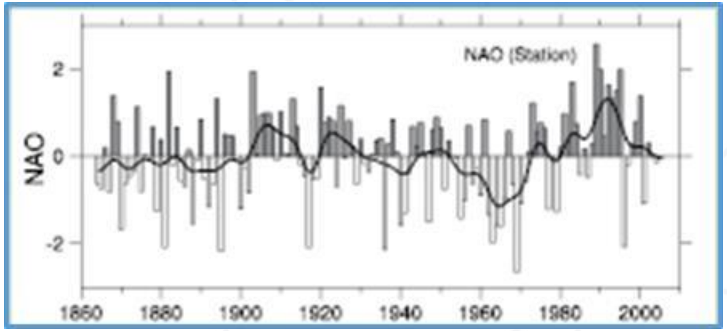
Background

- CC and weather are interconnected.
- Weather refers to conditions over short time frames (days), climate is defined as average weather over longer periods (years).
- 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.
- 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.
- 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.

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

Background

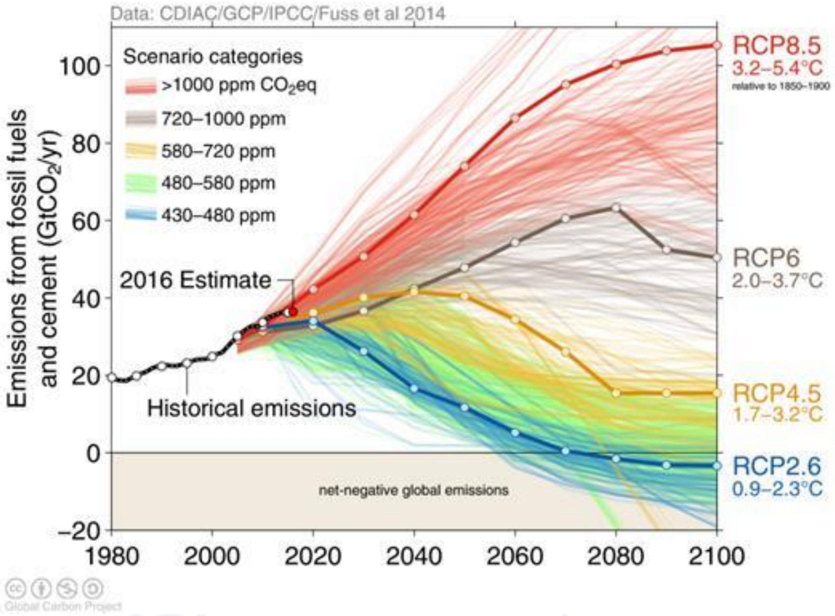
- One of the ways climate and weather connect to the environment of Atlantic salmon is through teleconnection patterns (recurring and persistent atmospheric conditions that result from large-scale pressure and circulation variations spanning vast geographical areas).
- Many of the teleconnection patterns are planetary-scale in nature, spanning entire ocean basins and continents.
- An important teleconnection is the North Atlantic Oscillation (NAO): north–south differential in sea level pressure over the Atlantic. A high winter NAO corresponds with mild winter climate and strong storms in Western Europe.



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

Climate and drivers

- Before 2050, atmospheric concentrations of carbon-based emissions are neither expected to flatten out nor to be reduced. Current emission trajectories are consistent with RCP8.5.
- 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.



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

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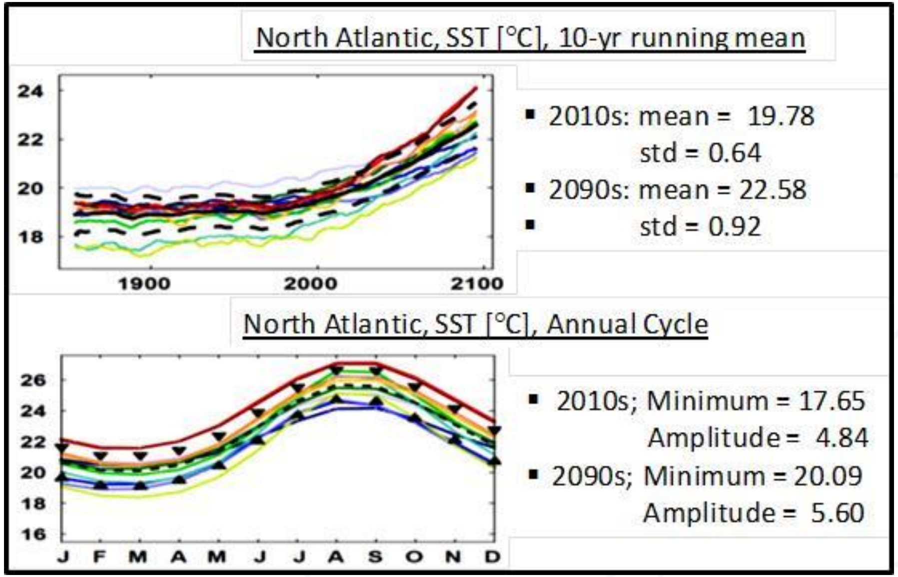
Climate and drivers

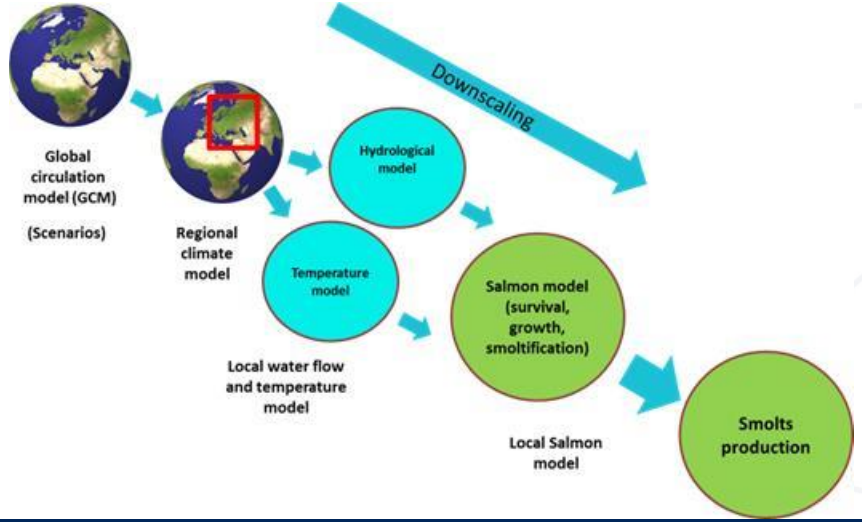
- Climate projections indicate increased intra-annual variations in a number of parameters at global and regional scales; these variations are equally, if not more consequential than the changes in average values to salmon persistence.



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

Climate and drivers

- 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
- The uncertainty in model projections increases with every additional stage.



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

Climate and drivers

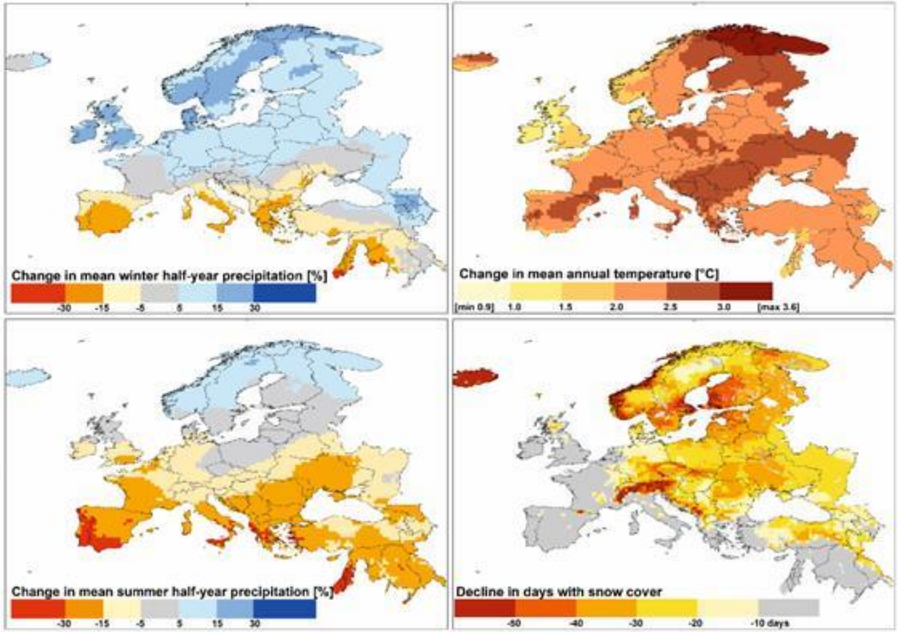
- Changes in chemical and biological characteristics of oceans and freshwaters associated with increased atmospheric carbon include, but are not limited to:
  - increased air and water temperatures (freshwater and marine),
  - freshening of surface ocean layers,
  - reduced pH (increasing acidification) of oceanic waters, and
  - reductions in oxygen concentrations.

  Also affects terrestrial systems, the freshwater environment of lakes and rivers, and the transitional waters between the marine and freshwater.

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

Climate and drivers

- 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.



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

Potential impacts

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

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

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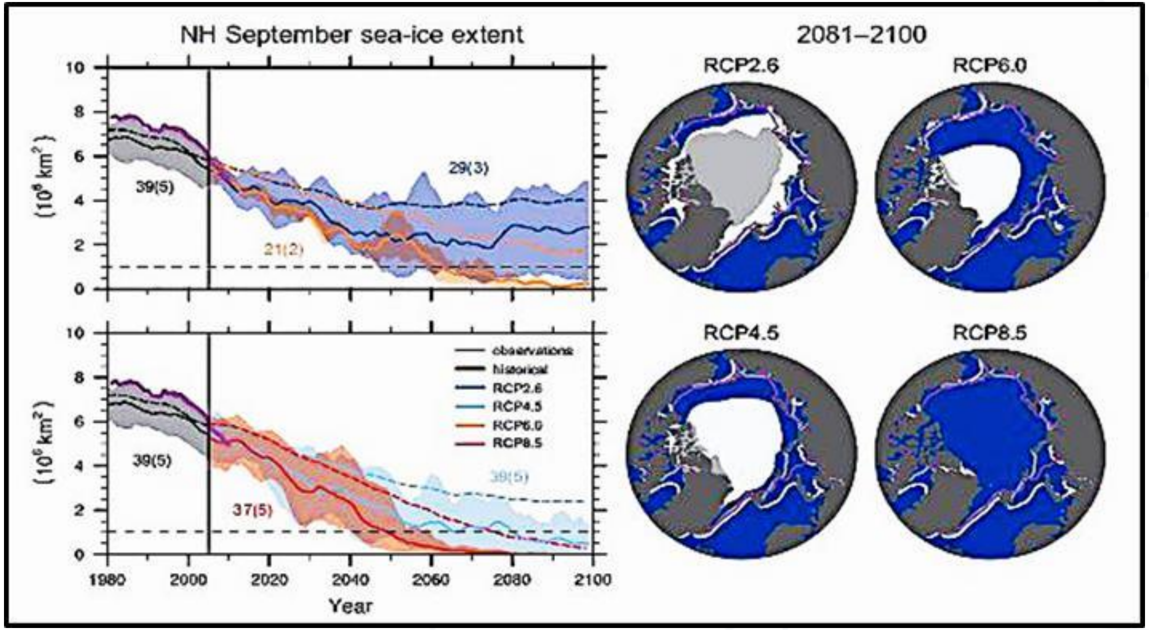
Potential impacts

Marine and freshwater habitat for Atlantic salmon is likely to extend further north in the future under continuing trends in global warming.



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

Potential impacts

- 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.

1.5 Potential future impacts of climate change on salmon stock dynamics

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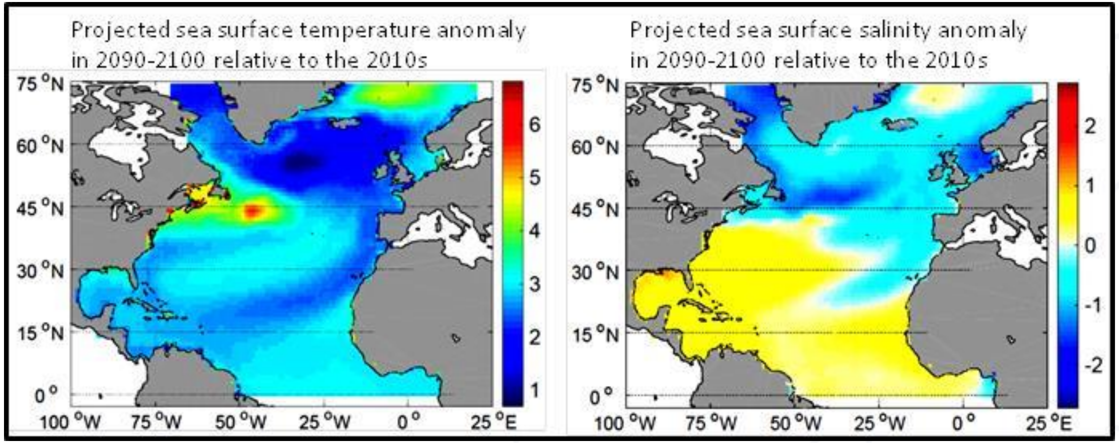
Potential impacts

- 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 which are strongly influenced by teleconnection patterns like the NAO
- CC may alter migration routes and distribution of salmon at sea, with unknown consequences for survival.



Projected differences (anomalies) in mean sea surface temperature (°C) (left panel) and sea surface salinity (right panel) in the 2090s relative to the 2010s,

1.5 Potential future impacts of climate change on salmon stock dynamics

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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).
  - 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.

1.5 Potential future impacts of climate change on salmon stock dynamics - Conclusions

- 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.
- 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).

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

- 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.
- 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.
- 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.

Workshop report is available at ICES website :

ICES. 2017. Report of the Workshop on Potential Impacts of Climate Change on At-lantic Salmon Stock Dynamics (WKCCISAL), 27–28 March 2017, Copenhagen, Denmark. ICES CM 2017/ACOM:39. 90 pp.

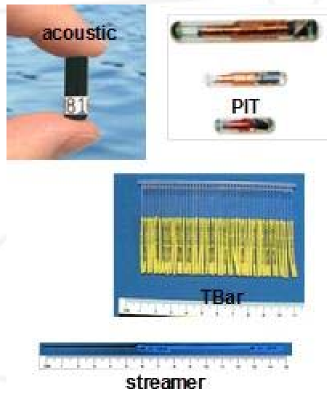
Acknowledgements

- Co-chairs of the workshop: Dennis Ensing and Jim Irvine
- Participants at the workshop and contributors to the report and advice

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) (summary in Table 11)
- ~ 3.2 million salmon were marked in 2016
- 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.

- In 2016, 64 669 PIT tagged, Data Storage Tags (DSTs), and radio and/or sonic transmitting tags (pingers) were also reported by some countries.



1.6 Provide a compilation of tag releases by country in 2016

- Tagging and wide-scale tag screening programme in the Northeast Atlantic
  - initiated in 2015, directed at pelagic species (herring and mackerel)
  - using glass-encapsulated passive integrated transponder (PIT) tags / RFID tags (Radio Frequency Identity tags).
- RFID detector systems installed at 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; 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 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.

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

North Atlantic Salmon Stocks

- 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.
- 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. A workshop of jurisdictional experts is proposed before the end of the 2017 calendar year. 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.
- (PIT) tag / RFID tag detector systems have been installed at a number of fish processing plants 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.

Annexes

- Annex 1: references
- Annex 2: glossary of terms

Acknowledgements

- Members of the ICES Working Group on North Atlantic salmon from 17 countries in the North Atlantic, and supporting scientific staff