With a range that spans from northeastern North American across the North Atlantic to southern and northern Europe, Atlantic salmon management possesses unique challenges that must be addressed internationally. Prior to the 1960's, Atlantic salmon were known to leave freshwater as juveniles, but their destinations and migration paths in the ocean were unknown. The emergence of salmon fisheries at West Greenland, the northern Norwegian Sea, and the Faroe Islands, coupled with the revelation in scientific investigations of the **true mixed-stock nature of these high seas salmon fisheries**, prompted the need for international cooperation for the science and management of Atlantic salmon stocks (Colligan et al. 2008). This need intensified as countries across the North Atlantic observed concurrent declines in harvest in both distant water and homewater fisheries as well as in adult returns to native rivers.

The Convention for the Conservation of Salmon in the North Atlantic Ocean (Convention 1982) created the North Atlantic Salmon Conservation Organization (NASCO) in 1983. The current Parties to NASCO are: Canada, Denmark (in respect of Greenland and the Faroe Islands), the European Union, Norway, the Russian Federation, and the USA (NASCO 2000). Iceland resigned from the Convention in 2009 due to domestic financial constraints, but has expressed a willingness to accede to the convention again once their economy improves and to adhere to the principles and guidelines of the organization when managing the species.

NASCO's core objective is to conserve, restore, enhance and rationally manage Atlantic salmon through international cooperation taking account of the best available scientific information (http://www.nasco.int). NASCO is organized into a Council and three individual commissions: North American Commission (NAC); Northeast Atlantic Commission (NEAC); and West Greenland Commission (WGC, **Figure 1**). The Council coordinates the activities of the three commissions and of the organization as a whole.

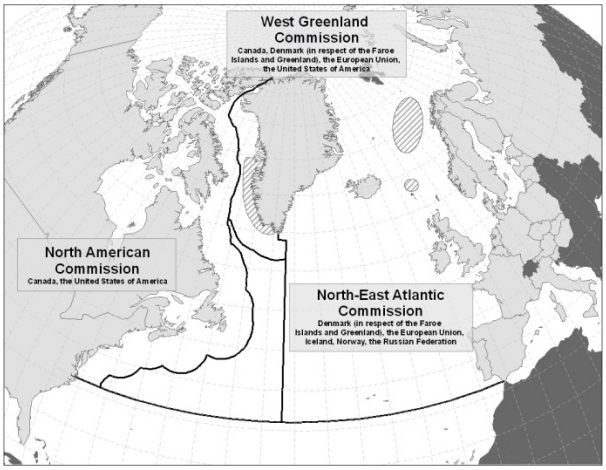

Figure 1. NASCO Convention Area and location of distant-water fishing grounds (cross hatched areas).

NASCO seeks scientific advice from the International Council for the Exploration of the Sea (ICES) to support its work and the formation of management decisions. ICES (http://www.ices.dk) is a network of scientists from 20 member countries that develops science and advice to support the sustainable use of the oceans. On an annual basis, NASCO requests scientific advice on the status of stocks, the effectiveness of management measures, monitoring and data needs, and catch options for Atlantic salmon

stocks across the North Atlantic. ICES facilitates the meeting of the Working Group on North Atlantic Salmon (WGNAS) to respond to NASCO's request for advice as described below.

INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA,

WORKING GROUP ON NORTH ATLANTIC SALMON

ICES primarily works through the use of Expert Groups (EG) to generate primary information, Review Groups (RG) who review EG work products, and finally an Advisory Committee (ACOM) that provides scientific advice back to the clients. The Science Committee (SCICOM) oversees all aspects of this process. As such, NASCO is a client of ICES.

ICES has numerous EGs that deal with diadromous fish in general and Atlantic salmon specifically. The Working Group on North Atlantic Salmon (WGNAS) and the Assessment Working Group on Baltic Salmon and Trout (WGBAST) address requests for scientific advice from clients in the North Atlantic and the Baltic Sea regions respectively. There are two separate EGs given the isolation of habitat use between North Atlantic and Baltic Sea salmon stocks.

The WGNAS addresses questions posed from NASCO to ICES. WGNAS is responsible for the annual assessment of the status of salmon stocks across the North Atlantic and specifically provides catch advice for mixed-stock fisheries operating within the three NASCO Commission Areas (NAC, NEAC, and WGC). WGNAS also provides advice on a wide range of other issues related to the conservation, restoration, enhancement, and rational management of wild salmon in the North Atlantic.

WGNAS members include scientists from all of the Parties to NASCO in the North Atlantic. Country-specific stock status reports are provided to the WGNAS annually and serve as the source material to **support annual stock assessments**. Additional reports are provided to the WGNAS to address other questions posed by NASCO that fall outside of the assessment process, but are related to salmon management. All reports are presented to and reviewed by the members of the WGNAS. The WGNAS produces a final report (ICES 2014) which is aligned with the NASCO Commission areas. Information of general interest to the management of salmon stocks is present in Section 2 (Atlantic salmon in the North Atlantic Area). Information relevant to US Atlantic salmon is found in NAC (Section 4) and the WGC (Section 5). The entire final report is reviewed by the RG and the individual sections serve as the source material when drafting the advice for the NASCO Council and its three Commissions. The WGNAS final report is available online and the supporting input data, model codes, etc. are available from ICES upon request. The current Chairman of the WGNAS provides an oral presentation of each section of

the WGNAS report to the appropriate NASCO Commission at their annual meetings (e.g. Section 2 presented to the Council, Section 3 presented to the NEAC, etc.).

US fish travel to West Greenland to feed in the Labrador Sea so the management advice for the Atlantic salmon fishery at Greenland is important to their conservation. This management advice is presented in **a risk analysis framework** consisting of five components (ICES 2012; Chaput et al. 2005). The non-maturing component of 1SW fish (fish that have spent one winter in the sea) are the life stage of interest as they are destined to become 2SW (two sea-winter salmon) returns and are exploited in the Greenland fishery. This same risk framework is used to provide management advice for the NAC. The WGC advice is dependent on the status of both North American and southern European stocks as they both are exploited in the fishery. NAC and NEAC advice are based solely on the status of North American and Northeast Atlantic stocks respectively.

The five components of the risk analysis framework for the provision of management advice are as follows:

1. estimation of the abundance of salmon prior to the fishery at Greenland (i.e. pre-fishery abundance, PFA)

A **run-reconstruction model** developed by Rago et al. (1993) and updated by Chaput et al. (2005) is used to estimate numbers of returns and spawners by size/age (small salmon, 2SW and large salmon) to six geographic regions of NAC (Labrador, Newfoundland, Québec, Gulf Region, Scotia-Fundy and USA) using Monte Carlo simulation. Pre-fishery abundance (PFA) is the estimated number of salmon in the North Atlantic on August 1st of the second summer at sea and is calculated by adjusting the estimated returns by marine harvest and adjusting for natural mortality (M=0.03) from August 1^{st} to river return.

PFA is estimated for both maturing 1SW (salmon that have spent one winter at sea and are destined to return as 1SW spawners) and non-maturing 1SW salmon (salmon that have spent one winter at sea and are destined to return as 2SW returns/spawners). However, the West Greenland fishery primarily harvests non-maturing 1SW salmon and as such, the advice for the Greenland fishery is based solely on the status of that component of the stock complex.

2. estimation of the spawning stock which would have contributed to the PFA

Estimates of the spawning escapement for 2SW salmon to North America are obtained for the same six NAC regions. Annual spawning escapement is lagged forward (smolt age plus one year for the year of egg deposition and an additional year for the first year at sea) in proportion to the smolt age distributions in each region (Rago 2001, ICES 2012). The broad assumption

inherent to this approach is that the recruitment of 2SW salmon is conditioned primarily by the 2SW salmon escapement.

3. the definition of spawning requirements for the stocks of eastern North America

The methods and the values used to derive **egg and spawner conservation limits (CLs)** for Atlantic salmon in Atlantic Canada have been described by O'Connell et al. (1997). CLs were generally derived using freshwater production dynamics translated to adult returns to estimate the spawning stock for maximum sustainable yield. Data available for a limited number of stocks were transported to the remaining rivers where only habitat area and spawner demographics were available. CLs for USA rivers were determined using a similar procedure as those of Atlantic Canada (ICES 1995). CLs for the Quebec region were defined from the adult-to-adult stock recruitment relationships for six rivers (Caron et al. 1999). The total 2SW salmon requirement for North America, calculated from the adult age structure within the regions, equals 152,548 fish (ICES 2014).

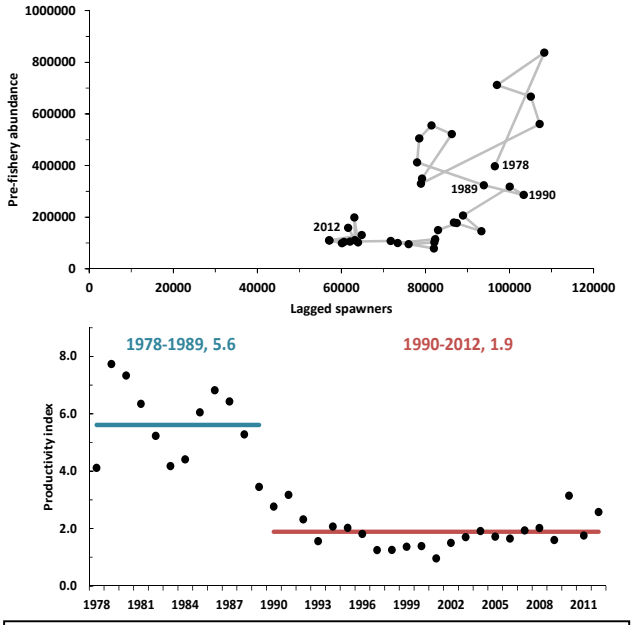

Figure 2. Time series of estimated PFA and LS (1978-2012, top) and marine productivity index (PFA/LS, bottom) identifying the significant decrease and persistence of low productivity associated with the 1990 regime shift (bottom). The last data point is 2012; 2014 returns are needed to estimate 2013 PFA.

4. the development of a model to forecast abundance of PFA in the year of interest

Forecasts of PFA for non-maturing 1SW salmon are generated via estimates of lagged spawners (LS), at sea harvest, and natural mortality to determine the corresponding returns of 2SW salmon. PFA estimates are assumed to be proportional to lagged-spawners. The current model uses regionally-disaggregated lagged spawners and returns of 2SW salmon for the six regions of North America. Models are fitted and forecasts derived in a consistent Bayesian framework under the OpenBUGS v3.0.3 software.

Chaput et al. (2005) identified a phase shift in the marine productivity of North American origin non-maturing Atlantic salmon stocks in the North Atlantic. The time series of PFA per LS suggests there has been a significant and persistent decline in the marine productivity of North American non-maturing salmon (**Figure 2**). During the high period of productivity (1978-1989) approximately 5.6 PFA fish were being produced per lagged spawner. During the low productivity phase (1990-present) approximately 1.9 PFA fish are being produced per lagged spawner. Mills et al. (2013) have since hypothesized

that **climate-driven environmental factors drove changes** in plankton communities and prey availability resulting in **poor trophic conditions for Atlantic salmon since the early 1990's** phase-shift. Within the PFA forecast model, a productivity parameter is incorporated and modelled dynamically as a random walk, to account for the different regimes in the time series of LS and PFA.

5. consequences to spawning escapement objectives of catch options at Greenland

Management advice and catch options for the West Greenland fishery are provided using the PFA and CLs of both the NAC and NEAC areas. The risk assessments for the two stock complexes in the West Greenland fishery are developed in parallel and then combined into a single catch options table. Primary inputs to the risk analysis include a PFA forecast for the year of the fishery, harvest level under consideration, and the management objectives for the contributing stock complexes. Wherever possible, input data uncertainty is accounted for.

For a given level of catch under consideration, the harvest weight is converted to a number of fish from each continent and subtracted from forecasted PFA. The remaining PFA is discounted by a previously agreed upon sharing fraction and non-Greenland fish are discounted for natural mortality for the period of time when they would leave West Greenland to the time they would return to rivers. Projected adult returns are then regionally distributed and region-specific returns are compared to the region-specific management objectives. In this manner, management objectives can be evaluated against the region-specific probability distributions for different catch options.

Management objectives for the West Greenland fishery are agreed upon by NASCO and provided to ICES. NASCO has adopted a precautionary management plan requiring at least a 75% probability of simultaneously achieving several management objectives (ICES 2012, 2014). North American objectives are:

- Meeting the CLs in the four northern regions of North America: Labrador, Newfoundland, Québec, and Gulf.
- Achieving a 25% increase in returns relative to the 1992-1996 period for the Scotia-Fundy region.
- Achieving 2SW adult returns of 4,549 or greater for the USA region.

In addition to the WGNAS, ICES also facilitates a number of other EGs in support of questions posed by NASCO or other entities on a variety of Atlantic salmon and diadromous species issues. Past EGs have focused on improving scale reading techniques, evaluating impacts of pelagic fishery bycatch, compiling and analyzing historic high seas tag recapture data from across the North Atlantic, developing a framework of indicators for supporting multi-annual

regulatory measures, evaluating trends in biological characteristics data, and evaluating the effectiveness of Atlantic salmon recovery programs from across the North Atlantic. Scientists from the US have been key participants in these additional EGs.

NORTH ATLANTIC SALMON CONSERVATION ORGANIZATION

NASCO consists of a Council and three regional commissions: NAC, NEAC, and WGC. NASCO also maintains a Finance and Administration Committee (FAC) and the International Atlantic Salmon Research Board (IASRB). The working of the entire organization is supported by a Secretariat based in Edinburgh, UK.

Generally speaking, the functions of the three NASCO Commissions are to 1) provide a forum for consultation and cooperation between members, 2) propose regulatory measures, and 3) make recommendations to the Council on scientific research. The function of the Council is to provide a forum for the study, analysis, and exchange of information on salmon, to coordinate activities of the Commissions, to establish working arrangements with other fisheries and scientific organizations, and to make recommendations for scientific research. The FAC oversees the financial administration of the organization.

Regulatory measures have been agreed upon by the West Greenland Commission for most years since NASCO's establishment. These have resulted in greatly reduced harvest in the West Greenland fishery. In all but two years since 1998, the fishery has been restricted to an internal-use fishery with commercial export of salmon not permitted.

The IASRB was established in 2001 to **promote collaboration and cooperation on research into the causes of marine mortality of Atlantic salmon**. Since its inception, the IASRB has helped facilitate, coordinate, and in many cases, fund, numerous collaborative international investigations into salmon mortality at sea. Support to date has included facilitating stable isotope studies to evaluate marine ecology of the species, evaluating historical mixed-stock fishery contributions, investigating spatial distributions and trends in historic North Atlantic high seas tag recaptures, and evaluating trends in biological characteristics data of Atlantic salmon.

One noteworthy IASRB accomplishment is the development of a comprehensive, innovative program of research on salmon at sea - the SALSEA Program. The primary focus of the SALSEA program was **coordinated marine sampling initiatives** across the North Atlantic starting in 2008. This involved three separate marine survey programs: SALSEA North America, SALSEA-Merge and SALSEA Greenland. NOAA scientist(s) served as the Principle Investigator for SALSEA Greenland and Co-Principle Investigator for SALSEA North America and coordinated closely with

the scientists overseeing SALSEA-Merge. SALSEA North America and SALSEA-Merge involved large scale, multi-year, and internationally collaborative pelagic surveys that tagged Atlantic salmon in the Northwestern and Northeastern Atlantic. SALSEA Greenland involved multi-year additive enhanced sampling in addition to the baseline-sampling program. The baseline-sampling program, coordinated by the US, annually collects biological characteristics and origin data from the Greenland fishery in support of annual stock assessments efforts by ICES. SALSEA Greenland involved additional sampling above and beyond this baseline effort. Sampling across all 3 survey programs was coordinated to collect similar data from marine captured salmon to allow for cross range comparisons. Data and samples collected involved sea lice, tissue for disease, lipid, parasite, and stable isotope analysis, and diet, among others. Numerous publications have resulted from this effort; analysis of remaining materials is ongoing.

The SALSEA Program culminated at the Salmon Summit, an international symposium co-convened by NASCO and ICES entitled **'Salmon at Sea: Scientific Advances and their Implications for Management**' held in La Rochelle, France, in October 2011. Over 130 scientists and managers from across the North Atlantic attended and a total of 35 oral and 15 poster presentations were made. US scientists made significant contributions to this symposium which produced published proceedings in the ICES Journal of Marine Science (Vol. 69 (9)).

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