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Salmon at Sea: Scientific Advances and their Implications for Management: an introduction

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Concerns about increased mortality of salmon at sea resulted in the development and implementation of a major internationally coordinated, public- and privately funded programme of research, the SALSEA programme. Major research surveys were conducted in the Northeast and Northwest Atlantic in 2008 and 2009, and there was enhanced sampling of the Atlantic salmon (*Salmo salar*) fishery at West Greenland. The findings from these surveys and sampling programmes, and from important new analyses of historical data, stable isotope and genetic stock assignment studies, recent tagging experiments, and other research, were reviewed at an international symposium organized by North Atlantic Salmon Conservation Organization and ICES and held in La Rochelle, France, 11–13 October 2011. This well-attended symposium, entitled "Salmon at Sea: Scientific Advances and their Implications for Management", highlighted advances in our understanding of the migration, distribution, and survival of salmon at sea, possible causes of the recent increased mortality, future research priorities, and the management actions that might be undertaken to mitigate the increased mortality of salmon at sea.

Keywords: management implications, marine mortality, migration, research requirements, salmon.

Introduction

The abundance of Atlantic salmon (*Salmo salar*) at sea before any fisheries has declined from ~10 million fish in the early 1970s to around 3.5 million fish in recent years. Marine survival indices in the North Atlantic have declined and remain low, and factors other than marine fisheries are contributing to continued low abundance of wild Atlantic salmon (ICES, 2011). Lack of understanding of the factors responsible for this decline is an obstacle to rational management. In 2001, and in response to this situation, the North Atlantic Salmon Conservation Organization (NASCO) established an International Atlantic Salmon Research Board (IASRB) to promote collaboration and cooperation on research into the causes of marine mortality of Atlantic salmon and the opportunities to counteract it. The IASRB initially developed and then reviewed an inventory of research related to the mortality of salmon at sea and decided that its immediate priority would be studies into the distribution and migration of the species at sea in relation to feeding opportunities and predation. A comprehensive, innovative programme of research, the SALSEA programme, was developed and implemented with public and private sector funding. The programme included internationally coordinated marine surveys in both the Northwest and Northeast Atlantic in 2008 and 2009 and enhanced sampling of the West Greenland fishery in 2009, 2010, and 2011. These initiatives were complemented by other research in fresh, estuarine, and coastal waters conducted by jurisdictions around the North Atlantic and by non-government organizations. Further information on the SALSEA programme is available at www.nasco.int/sas/salsea.htm.

The so-called "Salmon Summit", an international symposium entitled "Salmon at Sea: Scientific Advances and their Implications for Management", was co-convened by NASCO's IASRB and ICES and was held at l'Aquarium, La Rochelle, France, from 11 to 13 October 2011. The objectives of this symposium were to:

(i) review recent advances in understanding of the migration, distribution, and survival of salmon at sea and the factors influencing them;

(ii) consider the management implications of recent advances in understanding of the salmon's marine life;

(iii) identify gaps in current understanding and future research priorities; and

(iv) increase the awareness of recent research efforts to improve the understanding of salmon at sea and encourage support for future research.

In all, 128 participants from 14 countries attended the symposium. Although the focus of the meeting was on the marine phase of salmon in the North Atlantic, there were also presentations on salmon in the North Pacific and the Baltic Sea. The symposium comprised both oral (35) and poster (15) presentations under the themes (i) introduction and scene-setting overviews, (ii) distribution and migration of salmon at sea, (iii) food production, growth, trophic, and other ecological interactions, and (iv) implications for salmon conservation and management and future research.

This introduction to the published suite of papers outlines briefly, in a bullet fashion, the findings from the symposium relating to possible causes of the recent increased mortality of salmon at sea, their implications for salmon populations, possible management actions, and future research priorities.

Overview of scientific and management findings

Scene setting

(i) Common patterns in abundance of Atlantic salmon, inferred at the stock-complex level, suggest that broad-scale factors are influencing productivity and abundance, with the decline in abundance greatest for multi-sea-winter (MSW) salmon in southern areas.

(ii) Post-smolt survival has declined over the past 30 years in both the Baltic Sea and North Atlantic. In contrast, in recent years, salmon production in the North Pacific has been at near-record highs, particularly for pink (*Oncorhynchus gorbuscha*) and chum (*O. keta*) salmon, although some southern (North Pacific) stocks are also experiencing reduced abundance.

(iii) Most climate models predict a weakening of the North Atlantic thermohaline circulation, although the regional effects are poorly described by current models. Long-term measurements indicate that the currents feeding the eastern part of the Subpolar Gyre have not yet weakened, but in the Labrador Sea, deep convection has been weak since the mid-1990s. The effects of these changes on salmon remain unknown.

(iv) Long-term changes in North Atlantic salmon are significantly negatively correlated with northern hemisphere sea temperature and the North Atlantic Oscillation (NAO), after accounting for autocorrelation. Marine ecosystems in the eastern North Atlantic have responded with a change to a warmer regime, particularly since the mid-1980s. There have been increases in phytoplankton production, but reductions in zooplankton production and salmon catches in the North Atlantic, associated with increasing air and sea temperatures since the late 1980s.

(v) A northward movement of fish species and key salmon zooplankton prey has been detected in the North Atlantic. In North America, the southern edge of the range of Atlantic salmon has already shrunk by 2° latitude, and remnant stocks of Atlantic salmon in Maine are critically endangered.

(vi) Perhaps climate affects local environmental dynamics differently and has contrasting effects on different life stages and age classes of salmon.

(vii) In the Baltic Sea, grey seal (*Halichoerus grypus*) predation of salmon post-smolts may determine trends in marine survival, whereas the availability of herring (*Clupea harengus*) of uitable size, and other prey, may determine short-term variation in survival.

Distribution and migration of salmon at sea

(i) Valuable new information on the distribution and migration of salmon at sea has been obtained through re-examination of historical tagging data. For example, tag recoveries at West Greenland indicate that North American salmon have a more northerly distribution than European-origin salmon. In the Northeast Atlantic, MSW salmon from northern Europe appear to have a more easterly distribution than those from southern Europe, and tags from northern European and US salmon stocks are more frequently recovered at East Greenland. Around the Faroes, a significant proportion of the salmon caught in late autumn originated from southern European countries, whereas fish from northern regions were more abundant there in winter.

(ii) Acoustic tagging provides a reliable and effective method of deriving quantitative estimates of survival at points along the migration pathway both for salmon smolts/post-smolts and kelts. Detection arrays have extended progressively farther out to sea. For rivers entering the Gulf of St Lawrence (Canada), mortality rates (expressed as % mortality per day) of post-smolts were highest typically in freshwater or estuaries. For kelts, conversely, mortality rates in the estuary were low, but were high during reconditioning in the Gulf of St Lawrence and North Atlantic. Kelt and smolt migrations were synchronized.

(iii) "Smart" tags can be used to determine the areas frequented and the conditions experienced by salmon at sea. Pop-up satellite tags have shown that Polar Fronts are often primary foraging habitats for Atlantic salmon that tend to travel with the main ocean currents and may utilize deeper water than previously known. Data-storage tags applied to kelts have shown that salmon dive more frequently and spend less time at the surface by day than by night, possibly indicating a reliance on vision for feeding at depth.

(iv) Methods are now available to sample post-smolts and adult salmon at sea using gillnets and surface trawls. Marine surveys conducted in the Northwest Atlantic indicate that post-smolt and adult salmon have similar autumnal habitat requirements and a similar diet. Also, intestinal parasite loads are substantial and may be a significant source of marine mortality.

(v) Migration models provide valuable new insights into the distribution and migration of salmon at sea. In the Northeast Atlantic, a particle-drift model, simulating post-smolt distribution during the first 4 months at sea, has shown that the strength and direction of flow can transport post-smolts towards areas with favourable feeding conditions. However, in some areas, the direction of migration is sensitive to interannual changes in windforcing, leading the post-smolts to areas with different environmental conditions and prey. Inclusion in the swimming behaviour of a preference for water with higher temperature and salinity displaced the northward migration more offshore, away from coastal areas. Coupled ocean circulation and bioenergetics modelling allows for the identification of potential marine mortality bottlenecks, identification of areas for field research, and a tool for testing hypotheses relating to the impacts of predators and climate-change scenarios.

(vi) The calibration and integration of baseline microsatellite genetic data across Europe and the validation of assignment methods provide a powerful tool for assignment of salmon caught at sea to region of origin. European Atlantic salmon stocks are genetically divided into three well-defined geographical groups (Iceland; Scandinavia and northern Russia; and mainland Europe, the UK, and Ireland). Finer-scale regional structuring was apparent within all groups. Other molecular markers, single-nucleotide polymorphisms, are being developed that offer potential as cost-effective methods to provide finer-scale regional or river-specific assignment. Studies indicate that as few as 30 loci from a panel of 325 tested are required to resolve the maximum genetic structure. Preliminary investigations are beginning to answer questions about stock-specific patterns of marine habitat utilization, the origin of salmon taken as bycatch in fisheries for mackerel (*Scomber scombrus*) and herring, and the origin of escaped farmed salmon.

(vii) Stable isotope analyses can supplement other methods of investigating the distribution and migration of salmon at sea and allow for retrospective investigations of marine diet, location, and migration at the stock- and cohort-specific levels. Studies have shown that adult fish from different natal origins within the UK feed in different oceanic regions before their return; that one-sea-winter (1SW) and MSW salmon returning to some rivers in the UK are separated in their marine feeding areas, whereas those from others are not; and that salmon from the rivers sampled are not feeding in the same regions of the Northwest Atlantic as 1SW salmon returning to rivers in Newfoundland.

(viii) Minimum estimates have been derived of the bycatch of salmon in fisheries for mackerel and herring in the Northeast Atlantic. The quantification of bycatch remains challenging; furthermore, non-catch fishing mortality of salmon in these fisheries has not been assessed.

(ix) In the North Pacific, the 2009 returns of sockeye salmon (*Oncorhynchus nerka*) to the Fraser River were the lowest since quantitative monitoring began, but in 2010, the returns were the highest in 97 years (~25 million salmon). This extreme range in returns was attributed to a combination of variability in spawner abundance and oceanic conditions, and it underscores the importance of maintaining freshwater production so that salmon can benefit from any improvements in ocean conditions that may arise.

Food production, growth, trophic, and other ecological interactions

(i) For some North Atlantic salmon stocks, both the abundance and the condition of fish returning to spawn have declined. Atlantic salmon of southern European origin migrating to the Norwegian Sea currently encounter anomalously high sea surface temperatures, and returning adults have low mean condition factor, with implications for both the number and quality of eggs produced. There is evidence of a possible trans-generational, or maternal, influence (poor somatic condition of spawners) driving reduced quality of emigrant S2 smolts in one Scottish River (the North Esk). This effect is concurrent with an influence of freshwater climate (as indicated by the NAO Index). Moreover, the condition factor explains a significant proportion of the variation in run-timing. In years of poorer adult condition, 1SW salmon are staying at sea longer.

(ii) In the Miramichi River (Canada), there has been an increase in the number of repeat-spawning salmon, both consecutive- and alternate-year repeat spawners, with implications in terms of egg production and quality. Consecutive repeat spawners differ in that their egg diameter and survival do not follow the general trends of increasing with female size. The increase in return rates of repeat spawners is positively associated with variations in an index of small fish biomass in the reconditioning year at sea, suggesting bottom–up effects of prey availability on adult fish survival.

(iii) In the Northeast Atlantic, post-smolt diet was dominated by 0-group pelagic fish, the hyperiid amphipod *Themisto*, and the epipelagic copepod *Anomalocera pattersoni*. The post-smolt diet was directed more towards the epipelagic community than the diet of herring and mackerel. Salmon feeding in the Norwegian Sea appear to be more sensitive to climate-induced changes in the phytoplankton community than those feeding farther west in the Iceland Basin.

(iv) In the Northwest Atlantic, stomach contents of post-smolts decreased in volume from 2002/2003 to 2008/2009. Post-smolts consumed Atlantic herring and euphausiids in nearshore waters in the Gulf of Maine, whereas hyperiid amphipods were the dominant dietary item in the Labrador Sea. The diet of 1SW salmon at West Greenland was dominated by capelin (*Mallotus villosus*), amphipods, and squid (*Gonatus fabricii*).

(v) Stable isotope signatures from Atlantic salmon scales can be used to identify temporal fluctuations in diet. For Canadian salmon populations, there is considerable variation in the diet of smolts, but much less variation in the diets of 1SW and 2SW salmon. This reduced range of variation reflects a significant narrowing of feeding opportunity with respect to the ecosystems inhabited, although within the foodweb in which they function, salmon continue to source prey from multiple trophic levels.

(vi) North American and European Atlantic salmon respond to warming ocean conditions in different ways at different stages of their life history. Southern North American post-smolts are entering a warmer ocean, with different predator species and greater predator abundance, suggesting that recruitment is controlled by changes in predation pressure associated with the warmer conditions. For southern European stocks, marine survival and adult recruitment depend on post-smolt growth, particularly during summer and early autumn, and declining marine survival is linked to warming conditions in the Northeast Atlantic during the same period. Ocean thermal conditions in key post-smolt nursery areas are expected to continue to change and may make marine survival unsustainable for some segments of salmon stock complexes from both North America and Europe.

(vii) Growth rates in the first year at sea for an Irish Atlantic salmon stock were high in the period 1963–1981 and generally low thereafter, with growth in recent years being among the lowest in the time-series. This poor growth rate correlates with low marine survival for this stock. Comparisons with survival rates from other European rivers and environmental conditions revealed a number of factors which could be correlated with growth in the first year at sea. Comparison of post-smolt growth rates in the Northeast Atlantic in four different years indicated that the growth rates were highest in 2002, followed by 2003 and 2009, and were lowest in 2008. Furthermore, there was evidence that growth rates were lowest for post-smolts from the southernmost regions of Europe.

(viii) Information from the Pacific indicated that Pacific salmon production is not a simple function of plankton production in the California Current and Alaska Coastal Current systems, but that salmon growth and survival are affected by foodweb quality.

Implications for salmon conservation and management and future research priorities

(i) There have been significant advances in our understanding of the biology of salmon at sea as a result of the implementation of the SALSEA programme, and full analysis of the findings should assist the identification of future research needs and support rational management. For example, in the North Pacific, improved knowledge of juvenile salmon abundance at sea and the ocean conditions they experienced has allowed better predictions of salmon runs in support of rational management of the fisheries there.

(ii) Incorporation of pelagic trawling in existing fishery-independent sampling programmes might provide a lower-cost approach than dedicated salmon surveys to permit continued sampling of Atlantic salmon at sea in future.

(iii) Salmon occupy freshwater, estuarine, and marine environments during their life cycle, and factors affecting their mortality in these habitats do not operate independently. Temperature changes in some rivers in the North Atlantic increase growth rates, resulting in younger salmon smolts and earlier seasonal migration to sea, possibly resulting in a mismatch with ocean conditions. Contaminants in freshwater can also influence the subsequent survival of salmon at sea.

(iv) There have been enormous reductions in fishing effort for salmon around the North Atlantic in response to declining abundance, so fishing mortality is now a minor component of marine mortality. Management needs to aim to maximize the number of healthy wild salmon smolts going to sea by focusing on all the impact factors affecting the resource in freshwater and estuarine and coastal waters, including habitat degradation, fisheries, aquaculture, and bycatch.

(v) Salmon habitats in freshwater are more amenable to management than marine habitats, but uncertainty about future climate-change scenarios is a major challenge. Long-term planning and a catchment/ecosystem-based management approach involving all stakeholders will be needed in future.

(vi) To minimize the negative impact of climate change on wild salmon populations, managers need to aim to maximize their evolutionary potential. There is increased interest in stocking, but this activity may have potentially serious implications for natural gene pools. Rational management involves the assessment of the risks and possible benefits of stocking.

(vii) Major new tools have been developed that can assist rational management in future. For example, the establishment of new genetic baselines and advances in genetic stock assignment should assist *inter alia* in rational management of salmon fisheries and in identifying stocks exploited as bycatch in fisheries for mackerel and herring. Genetic techniques are already being used to assign returning hatchery-origin salmon to their parents, to improve the effectiveness of the stocking programme.

(viii) Re-examination of historical tagging information and genetic assignment of archived samples can provide valuable information to support the provision of assessment advice concerning the management of the distant-water fisheries.

(ix) Advances in modelling techniques support predictions of the distribution and migration patterns of salmon at sea and can assist in planning future research and in forecasting returns. A bioenergetics framework could assist understanding of the effects of ocean conditions on salmon growth in the marine environment.

(x) There is a need to consider both quantitative and qualitative aspects in assessing attainment of conservation limits and other biological reference points, because there have been changes in condition and life-history strategy (e.g. increased abundance of repeat spawners) that have consequences for egg-deposition levels. Changes in run-timing may have implications for exploitation rates where closed seasons are set by statutory regulation.

(xi) Ideally, Atlantic salmon would be assessed and managed based on river-specific stock units, the scale that best corresponds to the spawner–recruitment dynamic. In reality, however, comparatively few river-specific assessments are available in either the Northwest or the Northeast Atlantic, and they should be maintained and expanded.

(xii) Further assessments of bycatch of salmon in fisheries for mackerel and herring and of the level of non-catch fishing mortality associated with trawls are required, e.g. through surveys at processing plants, screening of catches on board commercial fishing vessels, and experiments involving commercial fishing gear.

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Reference

ICES. 2011. Report of the Working Group on North Atlantic Salmon. ICES Document CM 2011/ACOM: 09. 286 pp.