The 'Salmon Summit'

Salmon at Sea: Scientific advances and their implications for management

ABSTRACTS

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SEVENTH FRAMEWORK PROGRAMME

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Please note the corresponding author for each abstract is shown in bold. E-mail addresses are given in the List of Participants.

Session 1: Introductions and Scene Setting Overviews

Global challenges in sustainable utilization of marine ecosystems

D. Pauly

The principal challenge that humanity is faced with regards to the "sustainable utilization of ecosystem", particularly marine ecosystems, is that we have hardly ever been exploiting anything 'sustainably'. Thus, sustainable utilization is a concept that still needs inventing. This is here illustrated by the expansion (geographic, bathymetric and taxonomic) that has characterized marine fisheries in the last 60 years, which implies a complete lack of 'sustainability', if the concept is accepted to mean - as it should - the notion that something sustainable is something that can be done over the long term (because we can't expand 'sustainably'!). Sustainability utilization of ecosystems thus implies rebuilding the resources embedded in the ecosystems that we have depleted, which also implies reducing our footprint on these same ecosystems. For marine ecosystems in Europe, this implies a massive reduction of effective fishing effort, the phasing out high-impact gears such as bottom trawls, the setting up of marine reserves, and the export and sharing of all these approaches to those areas and countries from which we imports much of our fish supplies. This sounds trite and unoriginal, but the fact is that this would be quite exciting, being the closest we can get to time travel, which, in this case, would takes us back to the time where we still had some of the bounty that we have now depleted. Once this bounty is re-established, we may then learn to value it correctly, and to utilize it… sustainably.

Overview of the status of Atlantic salmon (*Salmo salar*) in the North Atlantic and trends in marine mortality

G. Chaput

Atlantic Salmon, compared to other marine fish species, has and can sustain generally high annual mortality rates at sea. The several thousand rivers with anadromous Atlantic Salmon populations in the North Atlantic have in the past three decades produced annually less than 10 million adult sized fish, a minor component of the marine pelagic ecosystem. Ideally, Atlantic salmon would be assessed and managed on the basis of river-specific stock units, the scale which corresponds best to the spawner to recruitment dynamic. In reality, comparatively few river-specific assessments are available. Since the early 1980s, the ICES Working Group on North Atlantic Salmon has collated and interpreted catch data, exchanged on research initiatives, and provided advice to fisheries management in support of conservation efforts for Atlantic salmon. Marine return rates for this species are generally low and based on assessments of smolt to adult returns from monitored rivers, have declined since the mid to late 1980s. Abundance has declined more severely for the multi-sea-winter components and especially in the southern areas of the species range. Common patterns in abundance inferred at the stock complex level in the North Atlantic suggest that there are broad-scale factors affecting productivity and abundance and that these are acting throughout the salmon's time at sea. Stock assessment, which is essentially bookkeeping and not flashy, is the foundation that supports the research to explore hypotheses of factors that determine species abundance and population dynamics.

Both predation and feeding opportunities may explain changes in survival of Baltic salmon post-smolts

*S. Mäntyniemi, **A. Romakkaniemi**, J. Dannewitz, S. Palm, T. Pakarinen, H. Pulkkinen, A. Gårdmark, and O. Karlsson*

The post-smolt survival of wild and hatchery-reared salmon in the Baltic Sea has declined since the 1990s. Direct observations on the processes affecting survival are, however, lacking. In this paper we analyse the importance of food-availability and of predation for variation in post-smolt survival. Based on previous studies, we selected the following explanatory variables: availability of herring recruits in the Gulf of Bothnia (Bothnian Sea, Bothnian Bay) in the northern Baltic Sea, sprat and herring abundances in southern Baltic Sea, and the abundance of grey seal along the post-smolt migration route. We used Bayesian analysis to estimate the relative probability of each of the 32 combinations of these variables, and show that the model including grey seal abundance and herring recruits per post-smolt had the highest posterior probability, and a high degree of determination. Our results indicate that the declining trend in survival is explained by the increased number of grey seals, whereas the annual variation in survival coincides with variation in recruitment of Bothnian Sea herring. However, it still remains uncertain whether the observed correlations arise from direct causalities or from other mechanisms.

Overview of the status of salmon in the North Pacific and trends in marine mortality

L-L. Low

The North Pacific Anadroumous Fish Commission (NPAFC) has served as a common forum for compiling Pacific salmon stock status for the North Pacific Ocean. The Party States of Canada, Japan, the Republic of Korea, the United States, and the Russian Federation maintain specific details of their catches and trends by finer geographical regions. The status of the stocks are generally measured by catches of the six main species as escapement data of the individual stocks by river destinations are not extensively compiled. In general, escapement goals of the major river systems of returning salmon have been set to perpetuate the stocks. Thus, this report on catch data of the species by country do provide good indicators of the status of the stocks . The data go back to 1925. The positions of the catches by species have generally remained fairly stable over time. The species dominance of the catches are pink, chum, sockeye, coho, Chinook, and masu salmon. Pink and chum salmon clearly dominate the catches. The total catches of all species combined have been increasing and appear to be continuing. There are obviously some stocks that have declined and remained low. Most of these stocks are dependent on fresh water habitat of heavily populated urban areas where conflicts of land and water use are clearly evident with human dependence on power generation, agricultura;, and industrial developments. The NPAFC scientists who study salmon mainly in their ocean phase of the salmon life cycle have generally attributed the high level of abundance since 1977 to better ocean survival associated with favorable regime shifts for salmon production. Hatchery operations that breed salmon to migrate into the ocean to forage and compete with naturally spawned salmon also play an important role for the high level of abundance, particularly on pink and chum salmon. The Japanese salmon industry,

for example, of chum salmon production is based virtually on hatchery operations. The United States and Russian are next in order of hatchery-produced fish. The NPAFC scientists have implemented new ocean cruises (the BASIS program) that began in 2003 aimed at studying the juvenile salmon distributions, migrations, and their ocean survival. The studies seem to need many more years of sampling to gather the data needed to link ocean conditions and food supplies to ocean survival for the current high level of abundance of Pacific salmon in the North Pacific Ocean.

The North Atlantic in the era of global change

B. Hansen *and H. Hátún*

The physical conditions in the North Atlantic are governed by the interplay between its three circulation systems: the subpolar gyre (SPG), the subtropical gyre (STG), both of which circulate horizontally, and the thermohaline circulation (THC), which also has a vertical component. The upper layers are in the south dominated by warm and saline water masses, carried by the STG, whereas colder and fresher waters dominate the SPG in the northern parts. The two gyres are not isolated, however. In the SPG, atmospheric cooling of the ocean makes surface water sufficiently dense that it can sink to large depths from where it flows southwards and spreads throughout the depths of the World Ocean. This is the deep branch of the THC, which carries water from the SPG to the STG at depth. To compensate, water from the STG has to flow into the SPG in the upper layers. Due to the earths rotation, this northward flow of warm and saline water is mainly in the east, where it extends far to the north and makes parts of the Nordic Seas an exceptionally warm region considering its latitude. As long as these circulation systems are stable, physical conditions in the ocean depend mainly on the atmosphere but during the last decades, the circulation systems have changed. Since the mid-1990s, the SPG has retracted, which allowed a warmer component of STG water to propagate northwards where it induced strong warming and affected the ecosystem at many levels. During the 21st century, global warming will affect the ocean as well as the atmosphere, but not necessarily only by increasing temperatures. Most climate models also predict a weakening of the North Atlantic THC due to anthropogenic climate change, although the regional effects of this weakening are not well described by the models. Long-term measurements indicate that the currents feeding the eastern part of the SPG have not weakened as yet, but in the Labrador Sea, deep convection has been weak since the mid-1990s, which is one reason that the SPG retracted westwards. Present-day models do not allow unequivocal attribution of observed changes to anthropogenic versus natural causes and their ability to predict future conditions in the various parts of the North Atlantic is limited, but changes are to be expected.

A discussion of the processes behind the correlation between declining North Atlantic salmon and increasing Northern Hemisphere temperature

P. C. Reid*, G. Beaugrand and P. Helaouët*

In 2003 the first two authors above showed that long-term changes in North Atlantic salmon were significantly correlated negatively with Northern Hemisphere temperature (NHT) even after autocorrelation was taken into account. The changes in sea surface temperature in the

North Atlantic differ regionally and were also correlated with the North Atlantic Oscillation, but less strongly. The link with salmon is likely to be via North Atlantic sea surface temperature (SST), the trend of which was correlated positively with NHT and was reflected geographically by a pronounced increase from ~1975 to 1997 to the south of an oblique line extending from ~Bergen, Norway at 60°N to 40°N, 45°W in the Atlantic. Salmon of course are equally affected by temperatures above and below a threshold in rivers, which may have contributed to the correlations. Marine ecosystems in the eastern North Atlantic have responded by a change to a warmer dynamical regime reflected in a regime shift after the mid 1980s. A step decline in the total nominal catch for salmon in the North Atlantic coincided with this change. At approximately the same time a progressive northerly biogeographic shift of warm water plankton and fish in the eastern North Atlantic occurred, which has continued to the present day. An update of the multivariate analysis of SST and its correlations with NHT and the NAO to 2010 shows that the boundary of warmer water has shifted even further north into the subpolar gyre. The processes behind all these changes, the extent to which they are forced by climate change and the prognosis for the future status of salmon stocks in the North Atlantic will be discussed.

Beaugrand, G. and Reid, P.C. 2003. Long-term changes in phytoplankton, zooplankton and salmon related to climate. *Global Change Biology* 9, 801-817.

The SALSEA Programme – unraveling the life of the Atlantic salmon at sea

K. Whelan

Over the past two decades, an increasing proportion of North Atlantic salmon are dying at sea during their oceanic feeding migration. The specific reasons for the decline in this important species are as yet unknown. Deeply concerned about this reduction in survival, the North Atlantic Salmon Conservation Organization (NASCO) established an International Atlantic Salmon Research Board (IASRB) in 2001. The objective of this Board is to promote collaboration and co-operation on research into the causes of marine mortality of Atlantic salmon and the opportunities to counteract this mortality. The Board identified as a key priority research to improve our understanding of the migration and distribution of salmon at sea in relation to feeding opportunities and predation. They concluded that only by better understanding where the salmon are at sea, and how they get there, will it be possible to identify the factors that are influencing their survival. To facilitate the required research the Board commissioned the development of an international programme of cooperative research on salmon at sea. This £14m initiative was named the 'Salmon at Sea' or *SALSEA* Programme and was developed by scientists from all of NASCO's Contracting Parties. *SALSEA* had lofty objectives: it sought to increase understanding of how Atlantic salmon use the ocean; where they go; how they use ocean currents and the ocean's food resources; and what factors influence migration and distribution at sea. It further sought to draw together intellectual and scientific resources in a unique concerted cooperative effort to identify the factors influencing mortality of salmon at sea and the opportunities to counteract them. Ten years on from the formation of the Board it is timely to review progress in achieving SALSEA's key objectives. This paper traces the history of salmon research at sea; the development of bespoke sampling tools designed to tackle the breath and scale of the challenges faced by the researchers; a summary of the innovative research undertaken by

teams across the north Atlantic, a critical overview of what has been achieved to date and an outline of exciting future prospects in understanding the complex marine life of the Atlantic salmon.

Session 2: Distribution and Migration of Salmon

Analysis of historical tagging data from the salmon fisheries at West Greenland and the Faroe Islands

J. A. Jacobsen, *D. G. Reddin, L. P. Hansen, V. Bakkestuen, I. Russell, J. White, E. C. E. Potter, T. F. Sheehan, N. Ó Maoiléidigh, J. B. Dempson, G. W. Smith, A. Isaksson, M. Fowler, L. Karlsson, S. Oskarsson, K. A. Mork, P. Amiro and S. Pedersen*

A database consisting of 9,210 tag recaptures at Greenland and the Faroes, of which 7,879 had recapture positions, was used to describe the distribution and growth of salmon of different origins and sea-age in time and space. The proportion of recoveries from east Greenland suggested that potential multi-sea winter salmon from northern Europe have a more easterly distribution than those from southern Europe. The recovery of North American origin salmon differed from that of European salmon at west Greenland. Salmon from Canada and USA were more commonly captured in northern locations, while European origin salmon tended to be caught further south. A significant proportion of the salmon caught in the Northeast Atlantic during late autumn originated from southern European countries while fish from northern regions were more abundant later in the winter period. A spatial shift among the various origins and sea-ages was observed, and Norwegian salmon was taken at higher latitudes and longitudes, were of larger size and had spent a longer time at sea, compared to salmon originating from countries. Recoveries from Ireland and UK (Scotland) had an opposite trend. Management could use the results to manipulate the location of fishing so as to reduce the catch of salmon from populations at risk.

GRAASP: a genetic tool for advancing understanding of the marine ecology of Atlantic salmon in the Eastern Atlantic Ocean.

E. Verspoor, *P. McGinnity and the SALSEA-MERGE Consortium*

The inherent potential of molecular genetic variation to serve as a marker for natal population of origin has been recognised for decades, based on theory and studies of population differentiation in model species. In species that are structured into highly reproductively isolated local populations, evolved differences in variant frequencies mark the geographic region, river and, in some cases, tributary to which individuals belong. In widespread anadromous species such as Atlantic salmon, with reproductively isolated, locally adapted populations, knowledge of origin is essential to understand the species' marine ecology, given that marine migrations may vary in ways that affect marine mortality. This inherent potential has been exploited in the EU SALSEA-MERGE project to create the GRAASP (**G**enetically-based **R**egional **A**ssignment of **A**tlantic **S**almon **P**rotocol) tool. GRAASP exploits heritable variation at nuclear microsatellite DNA loci. Its creation involved a unique calibration and integration of national data bases across Europe, the identification of regional biogeographhical stock groups, and the optimization and validation of alternative assignment algorithms. The tool has been applied to the assignment of marine post-smolts from contemporary and historical collections to defined regional groups. This information has been merged with ecological and biological data to provide a preliminary assessment of migration

heterogeneity among regional stock groups and its biological implications. The potential for increasing the cost-effectiveness and resolution of GRAASP using other molecular markers to provide higher definition regional or river specific assignment was also explored.

Extending understanding of marine migration, ecology and mortality of Atlantic salmon post-smolts using oceanographic modeling, recaptured tagged salmon and SALSEA-GRAASP

***K. A. Mork**, J. Gilbey, L. P. Hansen, A. J. Jensen, N. Ó Maoileidigh and the SALSEA-MERGE Consortium*

The migration of Atlantic salmon post-smolts in the North East Atlantic the first months at sea is modeled with a particle drift model. The migration is decomposed into both passive drift from surface currents, taken from an ocean model, and active swimming behavior where swimming speed is a function of body length. The active swimming speed was estimated from recaptured tagged post-smolts. In the model, particles were released at several key locations in Ireland and Norway where the post-smolt enters the sea and represent the different stock origins based on the SALSEA-GRASSP information. The drift model simulations provide likely migration routes, post-smolt distribution as function of time, ambient sea surface temperatures, etc., and differences between the different stocks are explored. Differences in migration patterns for different years are revealed, where the impacts of interannual variation in oceanographic conditions on the migrations are examined.

Marine distribution of regional Atlantic salmon post-smolt stocks in the NE Atlantic ascertained by microsatellite DNA based assignment

***J. Gilbey**, J. Coughlan and the SALSEA-MERGE Consortium*

Atlantic salmon stocks, although quintessentially anadromous, can display heritable heterogeneity in their migratory behaviour. Even among anadromous stocks, patterns of marine migration are known to differ as evidenced by the restricted migrations of Baltic and Inner Bay of Fundy stocks, and by differences among stocks within the Baltic. Variation among anadromous salmon stocks in Atlantic European rivers is indicated but poorly understood. A genetic analysis and regional assignment of fish was carried out on 4179 post-smolts collected in the NE Atlantic between the years of 1997 and 2009 using the microsatellite based GRAASP tool developed under the EU SALSEA_MERGE project. Spatial and temporal samples were analysed for evidence of heterogeneity in regional stock group composition associated with differences in the marine distribution of fish from different regional stock groups. The analysis found evidence for significant differences that suggest that salmon from different regions may have important differences in their migratory patterns. The extent to which differences might be conditioned by the geographical relationship of river of origin to the feeding grounds, or to inherent differences in migratory patterns or timing, is considered.

SALSEA North America: A pelagic ecosystem survey targeting Atlantic salmon in the Northwest Atlantic

***T. F. Sheehan**, D. G. Reddin, G. Chaput and M. D. Renkawitz*

Pelagic ecosystem surveys were conducted in the Labrador Sea during in 2008 and 2009 as part of SALSEA North America. A total of 107 Atlantic salmon (*Salmo salar*) were captured using a pelagic surface trawl and multi-panel surface gillnets. Surface trawling provided a broad spatial sampling of the fish and macro-invertebrate communities in the upper 10m of the water column, but caught few salmon (23). Gillnetting was more effective at capturing post-smolt (60) and adult (24) salmon. Multiple smolt cohorts were captured indicating that post-smolts and returning adults have similar autumnal habitat requirements. Postsmolts were caught at night and in water temperatures exceeding 10°C, both novel results. Postsmolts and adults consumed similar and diverse prey species, except that adults also consumed white barracudina (*Arctozenus risso*) and northern krill (*Meganyctiphanes norvegica*). Intestinal macroparasite loads were substantial and could be a significant source of mortality. Concurrent planktonic assemblage and oceanographic conditions were also quantified. A full exploration of these data, historical datasets, and parallel data collected during SALSEA Greenland and SALSEA-Merge will further our understanding of the ecology of marine phase Atlantic salmon and inform investigations into stock-specific differences in marine productivity.

Sonic tracking of Atlantic salmon smolts to sea: correlates of survival and lessons on the migration pathway

F. Whoriskey

Sonic telemetry documented North American Atlantic salmon smolt migration patterns and survival from fresh water river release sites to: 1) the head of tide, 2) the estuary, and 3) across the Gulf of St. Lawrence to the Strait of Belle Isle. The rivers studied (Miramichi, Restigouche, Cascapedia and St. Jean (North Shore) Rivers) fell on an approximately 600 km south-to-north gradient. Survival patterns in fresh water and through the estuary were generally similar among years for a given river. Consistent differences among rivers occurred in survival to the head of tide and across the estuary; however, these differences did not clearly correlate with latitude. Heavy losses occurred in most river estuaries, and were correlated with smolt size classes. Typically, twenty to 30% of the smolts that exited the estuaries of the Miramichi, Restigouche and Cascapedia Rivers passed through the Strait of Belle Isle en route to Greenland. Travel rates in the Gulf were estimated as 17- 25 km/d, and survivals and travel speeds were not correlated with fish body lengths. The smolts moved across the Gulf in synchrony with kelts tagged in the Miramichi River suggesting that experienced adult salmon may "teach" the migration route to naïve juveniles.

Tracking Atlantic salmon migration at sea by use of pop-up satellite tags - surprises, world records and mysteries..!

***A. H. Rikardsen**, C. M. Chittenden, D. Righton, F. Økland, T. F. Næsje, P. Gargan, M. D. Renkawitz, T. F. Sheehan, B. Ådlandsvik, O-P. Pedersen, E. B. Thorstad, J.G. Davidsen, E. Halttunen, R. S. McKinley, B. Finstad and K. Aarestrup*

Recent advancements in pop-up satellite archival tags (PSATs) offer the opportunity to observe real-time behaviour of adult salmon and its relation to oceanographic patterns. Through the SALMOTRACK-project, we have for the first time been able to describe oceanic migration routes and behavioural patterns of individual Atlantic salmon (*Salmo salar*) from different stocks in the open ocean. During 2008-2011, we have used more than 150 PSATS and 400 standard archival tags to tag kelts (post-spawners) that departed from Norway (three areas; north-east, north-west and middle part), Ireland, Denmark and Iceland. In addition, we also tagged 1SW non-maturing salmon in the West-Greenland Sea with PSATS. The project has during this period revealed new and unique information on salmon migration behaviour at sea, including new feeding areas, behavioural patterns and locations and reasons for mortality. For example, the populations exhibited differing migratory routes, but individuals consistently used the polar fronts as primary foraging habitats and travelled with oceanic currents and gyres, some reaching latitudes almost up to 80ºN, until now the northernmost recording. Some populations appeared to mix at the feeding areas while other did not. The salmon also regularly dived fast to deep water, including depths between 400-900 m, a feat previously unknown. These data will have management implications and help explaining why survival and growth of salmon at sea often varies among stocks from different regions, as well as how environmental factors and changes in climate may influence salmon migration and feeding patterns in the oceans.

Locating adult salmon at sea using stable isotopes

***K. M. MacKenzie**, C. N. Trueman, M. R. Palmer, A. Moore, A. T. Ibbotson and W. R. C. Beaumont*

Locating and differentiating adult salmon feeding grounds at sea has long posed a problem. For example, despite tagging almost 4 million fish in English & Welsh rivers since the 1950s, <3000 have been recaptured at sea, with capture locations limited by the presence of fishery or research vessels. We present an alternative method to identify adult location at sea based on natural stable isotope tags. The isotopic composition of tissues is intrinsically linked to the environmental conditions in the feeding grounds, and time series of tissue isotope data will co-vary with environmental conditions. Using the relationships between temporal trends in stable carbon isotopes measured in archived salmon scales and sea surface temperature, we create maps identifying the oceanic areas where adult salmon are most likely to have spent their last summer of growth before return migration. We show an east/west division in feeding areas between salmon originating from the south and north of the UK respectively, and separation in marine feeding areas between grilse and MSW returning fish. All returning fish thus carry information relating to their particular marine feeding area. Identifying marine feeding areas on a stock-specific basis will allow targeted management efforts within high seas fisheries.

The spatial and temporal distribution of salmon and the pelagic fisheries in the North-East Atlantic: A potential for by-catch?

***M. Holm**, Á. Ísaksson, J. A. Jacobsen, L. P. Hansen, S. Guðjónsson, N. Ó Maoileidigh and S. Óskarsson*

The spatial and temporal distribution of postsmolt and adult salmon is presented based on salmon capture data from dedicated salmon surveys at sea, research surveys of marine fish, historical and recent salmon tagging experiments and reported salmon captures in the commercial marine fisheries in the North East Atlantic (NEA). The overlap in time and space of salmon with some major commercial fisheries for other pelagic species do pose a risk of by-catches of salmon in certain areas and at certain times in the NEA. The potential for by-catch of salmon is discussed with reference to the findings from ICES Study Group on By-catch of Salmon in Pelagic Fisheries (SGBYSAL 2004 and 2005) and from screening programmes in the recently developed fisheries targeting mackerel in the Nordic Seas. Implications for salmon management are discussed and recommendations for further investigations provided.

Identifying freshwater and oceanic environmental signals from centennial Atlantic salmon catches off the North-East Atlantic

***J. Otero**, T. Rouyer, A. J. Jensen, J. H. L'Abée-Lund, J. D. Armstrong, J. C. MacLean, A. F. Youngson, S. Guðjónsson, G. Gudbergsson, N. C. Stenseth, G. O. Storvik and L. A. Vøllestad*

Atlantic salmon production has declined gradually over the last thirty years. The largest component of this decrease has been attributed to poor marine survival, mainly related to thermal conditions, though several other factors affect the juvenile production during the freshwater phase of the life cycle. The variability of harvested organisms results from complex combinations of population dynamics, environmental forcing and exploitation. In addition, these factors interact with each other and might be spatio-temporal dependent. Whereas most of the previous research addressing the factors affecting the multidecadal trends of salmon production has focused on analyzing single or only a few populations, here we present an analysis that compiles information on adult catches, from decadal to centennial scales, covering much of the distributional range of this species within the North East Atlantic. Using wavelet analysis, a time-frequency decomposition that is especially powerful for analyzing nonstationary, aperiodic, and noisy signals, we studied the long-term fluctuations in the time series and their spatial variability. Furthermore, using cross wavelet analyses allowed us to investigate the associations between the catch time series and multiple environmental factors both during the freshwater and oceanic phases of the life cycle, so as large-scale climatic indices.

Are post-smolts running on empty? - Migration and survival in the Atlantic

***C. Byron**, J. Stockwell, A. Pershing and H. Xue*

Atlantic salmon (*Salmo salar*) spawning returns to Maine, USA, rivers continue to decline despite intensive restoration programs. Most management and research efforts have focused on freshwater life-stages and conservation of freshwater habitat. Little is known about the marine phase of post-smolts but recent work suggests a potential bottleneck at this life-stage. In this presentation, we use dynamic modeling to examine growth and survival of post-smolts as they migrate through the Gulf of Maine to the Scotian Shelf. We couple an ocean circulation model and a bioenergetics model to explore post-smolt energetic costs during this migration over observed ranges of hydrographic variability. The model can serve as a template on which we can layer other hypothesized factors (e.g., shifting predator and prey fields, climate change scenarios) to evaluate their relative importance, singularly or interactively.

Environmental conditions affecting North American and Penobscot River populations of Atlantic salmon (*Salmo salar*)

***K. Mills**, A. Pershing, D. Mountain and T. F. Sheehan*

North American Atlantic salmon populations experienced substantial declines in the early 1990s, and many populations have persisted at low abundances into recent years. The coherence of declines across multiple populations suggests a shift in marine survivorship, rather than the influence of river-specific factors. While the processes controlling marine survival of Atlantic salmon are poorly understood, concurrent shifts in the Northwest Atlantic ecosystem have been documented. We use time series analyses to identify and quantify the influence of oceanographic and environmental conditions on Atlantic salmon during their marine migration, overwintering, and feeding stages. Analyses are conducted at two spatial scales: (1) the North American region based on pre-fishery abundance estimates and (2) the Penobscot River (Maine), a hatchery-dependent run that represents the largest population in the United States. Findings provide insights into environmental factors controlling Atlantic salmon populations at regional and local levels, and management implications of the results will be discussed.

The decline and fall of Fraser River sockeye salmon and their immaculate resurrection from an intervention of oceanic origin

S. McKinnell

Three years with no fishery on Fraser River sockeye salmon from 2007-2009 provided sufficient justification for the Prime Minister of Canada to establish a judicial inquiry (Cohen Commission) into the cause(s) of their decline. PICES was invited to prepare a chapter on the relationships between Fraser River sockeye salmon, the ocean, and marine ecology. In addition to an extensive overview of what is known of the biology and ecology of Fraser River sockeye salmon at sea, the report considered the oceanic cause(s) of very low returns in

2009, and lower productivity generally during the last 15 years. As the chapter was being written in the summer of 2010, the largest return of sockeye salmon in 97 years arrived at the Fraser River. Ocean/climate was involved in ways that cannot be described until the Cohen Commission releases the chapter (one of 12) to the public in the summer of 2011.

Session 3: Food Production, Growth, Trophic and other Ecological Interactions

How climate and post-smolt growth control marine mortality in Atlantic salmon; the potential effects of a changing climate on the marine survival of Atlantic salmon

K. D. Friedland

In addition to the obvious differences that separate continental sub-species of Atlantic salmon, *Salmo salar*, such as genetics and migration behavior, it is now recognized that the sub-species are also governed by differing mechanisms of recruitment control or more specifically how climate variation controls post-smolt survival. European Atlantic salmon recruitment appears to be governed by factors that affect the growth of post-smolts during their first summer at sea including warming sea surface temperatures and shifting forage abundances. In contrast, North American Atlantic salmon recruitment appears to be governed by variation in predation pressure during the first months at sea and not shaped by variation of post-smolt growth. Additionally, a phenological mismatch between the cues that stimulate smolt migrations and ocean conditions may exacerbate the survival problem for North American stocks. An ensemble of climate projection models were examined to develop prognoses in regard to the pattern of marine survival we may see from continental groupings of salmon stocks. Increased sea surface temperature in key ocean regions are expected to continue to erode marine survival for southern tier stocks from both continental groups. The phenology of smolt migration in North America may be further unsynchronized by a differential shift in transitional temperatures in the juvenile rearing areas and the coastal ocean. The persistent range of Atlantic salmon in North America and Europe may be redefined by the dynamics of ocean thermal conditions in combination with stressors associated with other segments of its life history.

Regional and temporal variation in marine growth of Atlantic salmon (*Salmo salar*, L.) from North-East Atlantic populations – links to marine survival and oceanographic conditions

***N. Ó Maoiléidigh**, A. J. Jensen, K. Thomas, J. White, S. M. Einarsson, J. Erkinaro, P. Fiske, K. D. Friedland, J. C. Holst, A. Peyronnet, D. Cotter, A. K. Gudmundsdottir, J. Haantie, J. G. Jensås, J. Kuusela, G. M. Østborg and C. Garcia de Leaniz*

Recent advances in digital technology allow for fine scale temporal estimates of growth rate of salmon from fish scales and have been used to identify growth anomalies associated with prevailing oceanographic conditions. In this study, archive scale samples of salmon from rivers in Ireland, Norway, Finland and Iceland have been analysed to identify changes in growth at key periods from 1970 to present with some limited information for certain stocks extending back to earlier periods. In particular, the number of circuli laid down in specific periods and the distances between the circuli were measured and compared between stocks, over years and for specific monthly periods during the first year at sea. Growth parameters including total and monthly post smolt growth indices showed clear temporal differences

between rivers. Growth trajectories were compared to prevailing oceanographic conditions to highlight any growth anomalies in specific periods. Information from this historical material provides a unique insight into periodic changes in the species use of the marine ecosystem, and the probable link between marine growth and survival of North east Atlantic salmon populations.

Ocean climate impacts on growth condition of 1SW and 2SW salmon returning to Scotland

***C. D. Todd**, J. C. MacLean, M. E. Lonergan, A. J. Howe and L. Boehme*

The surface waters of the North Atlantic have shown widespread and persistent anomalous warming since the mid-1990s. Ocean warming commonly has pervasive and widespread impacts on pelagic ecosystems, manifest as changes in the distribution and abundance of zooplankton and nekton and thereby the success or failure of populations of top consumers (e.g. piscivorous fish and seabirds). 1SW grilse returning to Scottish coastal waters have shown recent and marked declines in growth condition and we can show identical time-series patterns of response for the Rivers Spey, North Esk, Tay and Tweed dating back to the early 1960s: the effect primarily is attributable to the marine environment and is not a response to systemic changes in freshwater catchments. We show that contrasting growth condition responses of 1SW grilse, summer 2SW salmon and early-running spring 2SW salmon are variously attributable to ocean climate changes identifiable at their migratory destinations both in the eastern and western North Atlantic. Long-term variations in adult salmon size, growth condition and lipid energy reserves of the magnitude that we have observed will have major impacts upon fecundity and egg quality of successfully spawning females. Moreover, these variations in ocean climate and feeding/growth success are reflected also in run-timing of grilse returning to Scottish rivers. All of the foregoing will have management and conservation implications.

Prey quality affects the production of wild Pacific salmon in the northern California Current Ecosystem

***M. Trudel**, D. Mackas, and A. Mazumder*

The marine survival of salmon has been observed to covary with climate and ocean conditions at small and large spatial scales. Several competing hypotheses have been proposed to explain these patterns. Although the specific mechanisms affecting the marine survival of salmon differ among these hypotheses, all generally agree that lower marine survival of Pacific salmon is associated with lower marine growth during their first year at sea. In this study, we examined the effects of ocean conditions on the growth and survival of Pacific salmon in the northern California Current System (CCS) and Alaska Costal Current (ACC), and developed forecasting models for the marine survival of Pacific salmon. Our work shows that, while plankton productivity and temperatures tend to be higher in the CCS, salmon are generally larger and fatter, and have higher growth in the ACC. The poorer growth and condition of salmon in the northern CCS appears to be related to a calorie-deficient diet rather than to lower rates of food consumption or to higher metabolic rates. This indicates that ocean conditions affect salmon production through changes in prey

community composition and quality, which in turn are induced by the effects of climate on ocean circulation, and on the local success of different zooplankton life history strategies (year round activity vs seasonal dormancy and lipid accumulation).

Characterizing trophic status and shift in Atlantic salmon, *Salmo salar*, from freshwater to marine life-cycle phases

*H. Dixon, **M. Power**, J. B. Dempson, T. F. Sheehan and G. Chaput*

Atlantic salmon, Salmo salar, marine survival and recruitment are commonly thought to be influenced by linkages between marine temperature and growth. Salmon are opportunistic feeders and, therefore, likely to be influenced by trophic factors that condition the quality and quantity of prey available for consumption. During the marine phase, salmon often target prey in the upper end of the size spectrum with a preference for fish over crustaceans. European salmon recruitment appears linked with forage abundance which critically affects post-smolt growth during the first summer at sea. Similar linkages have not been shown for North American populations. Here questions related to trophic differences within and among populations and life-stages of Atlantic salmon during the freshwater and marine residency phases are addressed. Stable isotope methods were used to characterize variations and changes in trophic status by sampling smolts and returning adult survivors from rivers spanning a broad geographic range in Canada (southern Labrador to the Bay of Fundy) as well as non-maturing salmon sampled at West Greenland. Isotopic analyses indicate that salmon undergo a dramatic change in feeding flexibility as they migrate from freshwater as generalists and feed more as specialists in the marine environment with a high reliance on pelagic oceanic foodwebs.

Stable isotope evidence for the effect of climatic variations on salmon diet and marine mortality.

***C. N. Trueman**, K. M. MacKenzie, M. R. Palmer, A. Moore, A. T. Ibbotson and W. R. C. Beaumont*

Salmon populations respond to human interventions and natural climate fluctuations. For (cost) effective interventionist management of populations, these influences on population dynamics must be distinguished at a stock or even cohort specific level. Natural stable isotope markers as measured in salmon scales record ecosystem effects during marine feeding. Carbon isotopes reflect phytoplankton community dynamics, while nitrogen isotopes reflect the number of trophic steps between primary production and the sampled animal. Long-term records of C and N isotope variation in salmon scales thus reflect temporal variations in phytoplankton communities and their subsequent effects on trophic level. Using a 20 year record from Atlantic salmon migrating to different feeding grounds, we show that ocean circulation modes induce decadal scale variations in phytoplankton dynamics. Salmon feeding in different regions are distinguished by their differing temporal records. growth rates experienced by salmon differ between populations. The fluctuations in plankton community dynamics suggested by the stable isotope values are co-incident with fluctuations in estimates of marine mortality in 1SW-returning fish feeding in the Norwegian Sea, but not in those feeding further west towards the Iceland Basin. Marine mortality in salmon feeding

in the Iceland Basin is thus likely to be more strongly influenced by factors other than bottom-up control. Time series analysis of stable isotopes in salmon tissues aids understanding of how ocean climate influences population dynamics on a stock-specific basis.

The diet of Atlantic salmon post-smolts during their first feeding season in the North-East Atlantic

***W. Melle**, K. Thomas, J. A. Jacobsen, C. Broms, N. Ó Maoileidigh, M. Haugland, M. Holm and J. C. Holst*

Atlantic salmon (*Salmo salar*) post-smolts were collected by surface trawling during a series of scientific cruises in the Northeast Atlantic Ocean in 1991-2003, 2008 and 2009. The surveys covered the time period from June to August. In the laboratory 2836 stomachs were analyzed for prey composition (numbers and dry weight) and total stomach content weight. The data were analysed in relation to environmental data, geographical location, water mass, fish size, condition and other biological features. The diet was dominated by 0-group fish and Themisto spp. 0-group fish dominated some years and particularly in the continental shelf regions, while Themisto was the dominant prey in offshore and Arctic regions. The growth of the post-smolt peaked during years when 0-group fish dominated the diet. Krill were also a common prey along with the epipelagic copepod *Anomalocera pattersoni*. The prevalence of the latter prey demonstrates the epipelagic feeding behavior of the post-smolt. The post-smolts diet was compared to the diet of their co-occurring competitors for food, herring and mackerel.

Atlantic salmon foraging ecology in the Northwest Atlantic

***M. D. Renkawitz,** T. F. Sheehan, D. G. Reddin and G. Chaput*

Atlantic salmon *Salmo salar* L. are considered opportunistic generalist predators that forage on locally abundant food items. However specific dietary requirements at various life stages may be necessary to promote growth and survival. Consequently, changes in ocean productivity that influence the spatial and temporal abundance of key forage items may have population level effects. Since 1987, stomachs from postsmolts and immature adults have been collected in coastal North American waters, at feeding grounds in the Labrador Sea, and along the West Greenland coast to gain insight into the feeding ecology of marine phase salmon. In coastal waters postsmolts consumed Atlantic herring and euphausiids, while in the Labrador Sea hyperiid amphipods were the dietary staple. Contemporary diets at West Greenland are dominated by capelin and amphipods, and despite annual variability in diet these findings are consistent with historical data. Retrospective analysis of historical time series may provide clues as to whether changes in diet is one of the casual mechanisms responsible for decreases in marine survival documented across most North American populations.

Session 4: Implications for Salmon Management

The influence of the freshwater environment and the biological characteristics of Atlantic salmon smolts on their subsequent marine survival

***I. Russell**, M. Aprahamian, J. Barry, I. Davidson, A. T. Ibbotson, R. Kennedy, J. C. Maclean, A. Moore, J. Otero, E. C. E. Potter and C. Todd*

The past 20-30 years has seen a marked decline in the abundance of Atlantic salmon across its distributional range. Much of the focus for this decline has been on factors operating in the marine environment. However, salmon occupy freshwater, estuarine and marine environments during their life-cycle and factors contributing to salmon mortality in these habitats do not operate independently. This paper focuses on the role that the freshwater environment plays in influencing the biological characteristics of smolts leaving freshwater and the impact this may have on the subsequent behaviour and survival of salmon at sea. In many rivers, juvenile salmon are growing faster and smolts are migrating to sea at a younger age and, typically, smaller sizes. This is particularly apparent for rivers in the southern part of the north-east Atlantic. A possible consequence is a damping of the impact of increased marine mortality, assuming that higher in-river survival prior to smolting is not outweighed by increased mortality of the smaller smolts at sea. Smolt run-timing is also occurring earlier across the geographic range, with increasing concerns that this might result in a mismatch with optimum marine conditions - the environmental "smolt window". A range of contaminants and other factors operating in freshwater have also been shown to have marked effects on smolt quality, with implications for subsequent life stages and ultimately adult returns. The findings are discussed in the context of climate change and with regard to potential implications for management.

Minimising the impact of climate change on Atlantic salmon populations in freshwater

P. McGinnity

The assessment report of the 4th International Panel on Climate Change suggests that Global warming is strongly affecting biological systems and that many species and their constituent populations will be negatively impacted by future increases in water temperature. It is essential that conservation measures taken to address climate mediated declines are appropriate. For example the release of captive bred animals to augment wild populations is a widespread management strategy for the enhancement of vulnerable Atlantic salmon populations. Data are presented here that show that deliberately or inadvertently releasing captive bred salmon into the wild can disrupt the capacity of natural populations to adapt to higher freshwater temperatures associated with climate variability. It will be argued here that rather than imposing an additional genetic load on wild populations by introducing captive bred animals into natural environments, that conservation efforts should focus on optimising conditions for adaptation to occur by reducing exploitation and protecting critical habitats.

Determining the continent-of-origin (COO) and region-of-origin (ROO) of Atlantic salmon collected at West Greenland 1995-2010: A review of the findings and a look at what the future holds for molecular genetics methods of mixed-stock assignment

***T. L. King**, T. F. Sheehan, B. Lubinski, and D. G. Reddin*

A significant Atlantic salmon (*Salmo salar*) mixed-stock subsistence fishery exists off the western coast of Greenland composed of both western and eastern Atlantic origin one-sea-winter age fish. Proper management of this valuable resource on both continents relies on robust estimates of the relative contributions of these diverse stocks to the west Greenland fishery. U.S. NOAA-Fisheries, U.S. Geological Survey, and DFO Canada have partnered for the molecular genetics-based assignment to continent-of-origin among 12,500 *S. salar* landed from 1995-2010 at seven west Greenland locations ranging from Sisimiut to Qaqortoq. The mixed-fishery is evenly distributed between eastern and western Atlantic origins among salmon landed in the southern-most portion of the study area. However, western Atlantic fish constitute the majority of the fishery as collections move north and west along the coast. To identify the effects of fishing on western Atlantic stocks within the multi-stock fishery complex, a probabilistic-based genetic assignment model has been developed to estimate the contribution of salmon from individual North American rivers. This presentation will provide a summary of the COO and ROO findings and discuss progress in the standardization of microsatellite DNA genotyping among the North American laboratories participating in the SALSEA.

What tools are left in the manager's toolbox – challenges to conservation of Atlantic salmon in eastern Canada.

S. Rocque

This paper describes the present and emerging challenges of managing access to Atlantic salmon among the varied human interests while ensuring conservation of the populations and the species. Fisheries management played a dominant role from the early 1900s to the late 1980s in conserving Atlantic salmon in Canada. In the early 1990s, it became clear that management of marine and freshwater fisheries was insufficient for sustaining and rebuilding salmon runs and many of these fisheries were further curtailed. The recognition of aboriginal rights to fish represented a further allocation challenge. The science base remains insufficient to manage individual river populations using river-specific quotas. The adoption by Canada of the precautionary approach (PA) and the ecosystem approach necessitates a further consideration that Atlantic salmon does not trump other species and diversity considerations. Management efforts are now focused on reducing the impacts on salmon at all stages in the life cycle, particularly those in freshwater, these being direct, measurable and recognizing the imperative of sustaining healthy freshwater environments. The manager's tools now include preserving and restoring river habitat, minimizing and eliminating fish passage constraints, eliminating habitat fragmentation, and managing land use activities.

Ramifications of persistent low marine survival to Atlantic salmon management in the US

R. Saunders *and M. A. Colligan*

The US is at the southern edge of the Atlantic salmon's range on the western side of the Atlantic. As such, it is anticipated that marine survival would be low for US stocks when compared to more northerly stocks with shorter migration routes. In addition, anthropogenic changes to the Atlantic salmon's freshwater habitat (e.g., dam construction) have greatly diminished the Atlantic salmon's capacity to withstand periods of sustained low marine survival. Consequently, many stocks in the US are now listed as endangered while others are extirpated. Recent population viability modeling efforts have elucidated the importance of later life stages (smolts and later) to overall demographic patterns. In the US, the major impediments to these later life stages occur in the form of dam-related mortality and low nearshore and offshore marine survival. Management regimes in the US are shifting toward a greater focus on these later life stages. This shift poses new challenges to managers first to determine what to do and then effectively implementing actions at a sufficient scale to affect survival. While effecting change in these later life stages is very challenging, it is necessary to ensure that the range of the Atlantic salmon does not recede completely from the US.

Use of marine ecosystem productivity indicators along the US west coast to forecast annual returns of Pacific salmon and improve harvest management: a role for long term observations

J. Ferguson*, E. Casillas and W. Peterson*

Successful prediction of early marine survival of salmonids and recruitment into older age classes requires knowledge of ocean residency patterns and annual variability in the productivity of key habitats that juvenile salmon occupy. Over the past 13 years we sampled the continental shelf off Oregon and Washington and monitored climate conditions, hydrography, zooplankton, and juvenile salmon abundance. We developed 16 indicators of ocean conditions and ecosystem productivity that relate to the early marine survival of juvenile salmon and subsequent adult escapement. These indicators are based on physical factors, and biological indicators that index the quality of food within the food chain and catches of juvenile salmon during May, June and September trawl surveys. These indicators represent an "ecosystem approach" to providing advice to harvest managers. The values are displayed in a 'stoplight' diagram (shown below) where 'poor ocean conditions' are assigned a red color, 'good ocean conditions' get a green color, and 'average ocean conditions', yellow. The indicators are being incorporated into adult return forecast models to improve harvest management. Detailed information on these indicators can be found at: http://www.nwfsc.noaa.gov> by clicking on "Ocean Conditions and Salmon Forecasting" in the box on the right-hand side of the page.

Environmental Variables	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
PDO (December-March)	12	4	2	8	5	13	7	10	9	6	3	1	11
PDO (May-September)	10	2	4	5	7	12	11	13	9	8	1	6	3
MEI Annual	12	1	3	5	11	10	8	9	6	4	2	7	
MEI Jan-June	13	2	3	4	9	10	7	11	5	8	1	6	12
SST at 46050 (May-Sept)	10	8	3	4	1	6	12	9	5	11	2	7	9
SST at NH 05 (May-Sept)	8	4	1	6	2	5	13	10	7	12	3	11	9
SST winter before (Nov-Mar)	13	10	3	5	6	9	11	8	7	2	1	2	12
Physical Spring Trans (UI Based)	3	6	12	11	4	8	10	13	8	1	5	2	7
Upwelling Anomaly (Apr-May)	7	1	12	3	6	10	9	13	7	2	4	5	11
Length of upwelling season (UI Bas	6	2	12	9	1	10	8	13	5	3	7	3	11
Deep Temperature at NH 05	13	4	6	3	1	9	10	11	12	5	2	8	7
Deep Salinity at NH05	13	2	6	4	5	11	12	8	7	1	3	9	10
Copepod richness	12	2	1	5	3	9	8	11	10	6	4	7	11
N.Copepod Anomaly	12	9	3	6	2	10	7	11	8	5	1	4	
Biological Transition	13	7	5	3	6	11	7	12	10	4	1	2	8
Copepod Community structure	13	3	4	6	1	8	9	12	11	10	2	5	7
Catches of salmon in surveys													
June-Chinook Catches	12	2	3	10	7	9	11	13	8	6	1	4	5
Sept-Coho Catches	9	2	1	4	3	5	10	12	7	8	6	13	11
Mean of Ranks of Environmental Da	10.6	3.9	4.7	5.6	4.4	9.2	9.4	11.1	7.8	5.7	2.7	5.7	9.0
RANK of the mean rank	12	2	4	5	3	9	11	13	8	6	1	7	10

Managing salmon stocks and fisheries in a changing environment

E. C. E. Potter

Over recent decades, there have been marked changes in the patterns of growth and mortality of Atlantic salmon (*Salmo salar*) during both the freshwater and marine phases of their lifecycle and consequent effects on the structure and status of populations. In some cases, these changes have been due to factors that are within our control and can be alleviated by appropriate management action. Taking such action should clearly be given a high priority. However in other circumstances, such as modifications to the marine environment caused by climate change, there may not only be little that can be done to reverse the pressures but the severity of the impacts may also be expected to increase in the future. These changes, along with our management responses, will have implications for the optimal life-history strategies of the fish and thus how populations change. As a result, maintaining current management approaches, which generally involve trying to restore historic stock structures, may no longer be appropriate. There is therefore a need to determine how managers should both plan for and respond to these changes in relation to the protection and restoration of stocks and the management of fisheries. Methods are required to forecast the likely impacts on habitats and the consequent effects on stocks in order that the best ameliorative actions can be taken at an early stage. Managers will also need to determine whether it is likely to be practical (or even possible) to maintain favourable environments for salmon in specific areas in the face of major climatic changes and engage with stakeholders in developing procedures for deciding when protection and restoration is no longer tenable. Environmental change adds another dimension of complexity to the effective management of environmental goods and services and the development of good governance through the interplay between society, science and government.

Poster Presentations

Distribution and Migration of Salmon at Sea

A preliminary evaluation of use of nuclear SNPs for the assignment to origin of marine post-smolt Atlantic salmon captures in the NE Atlantic

***J. Coughlan**, P. A. Prodohl, S. Lien, P. Berg, J. Carlsson, P. McGinnity, T. F. Cross and the SALSEA-MERGE Consortium*

Preliminary studies show that the analysis of nSNP loci is capable of regional stock structuring for anadromous Atlantic salmon stocks in Europe, and in this study we investigate the usefulness of these loci for assignment of marine captured smolts to region of origin. The baseline used was composed of 333 individuals sampled from across the species range and screened for 325 nSNP loci which resolved into six major genetic clusters (Iceland, Northern Norway/Kola peninsula/White Sea, Western Norway/Sweden, Denmark/British Isles/Northern France and Southern France/Spain) of direct interest to the SALSEA-merge project. Efficacy of this baseline for correct assignment was tested with 112 'blind-test' samples of known origin collected from Norway and the British Isles. The results indicated that 98% of these samples were correctly assigned to region of origin and that mis-assigned individuals tended to have lower assignment scores. Analysis of Irish farmed Atlantic salmon also showed that these would assign to the western Norway cluster rather than the British Isles which will have implications for attempting to correctly identify migration patterns of any farm-origin fish. A subsample of the marine captured post-smolts (n=170) were also screened for the nSNP loci and each was assigned to one of the six regions in the NE Atlantic area (average assignment score 98%). These results were compared to the assignments and assignment scores revealed by 14 microsatellite DNA loci alone. Because the usefulness of individual nSNPs varies considerably among loci, assignment of these fish was also undertaken with a panel of approximately 30 markers (10% of the total) (selected following hierarchical F_{ST} analysis) in order to assess the potential for changes in assignment or decreasing assignment scores when an ascertainment panel of loci is utilised. However, the work carried out to date indicates that given the current number of available nSNPs (>5000), a considerable potential exists to identify a cost-effective suite of SNPs that can provide both regional and potentially finer scale (population specific) assignment of migrating Atlantic salmon to origin.

Geographical differentiation and structuring of European Atlantic salmon stocks at microsatellite DNA loci to enable the regional assignment of marine fish

***J. Gilbey**, J. Coughlan and the SALSEA-MERGE Genetics team*

During the marine phase of the salmons life history stocks from different origins in the Eastern Atlantic can be found mixed in the northern seas of the North Atlantic. Regional genetic differentiation of stocks, a legacy of post-glacial recolonisation, can be exploited to

assign the geographical origin of marine caught fish using Genetic Stock Identification techniques. As part of the EU SALSEA-MERGE project, the regional differentiation of European salmon stocks was assessed in relation to variation at a suite of 14 microsatellite loci using an integrated project database of 26,813 fish from 466 locations on 284 rivers from across the species Eastern Atlantic range. Regional patterns of differentiation of the samples were examined resulting in a hierarchical regional subdivision of stocks to which marine caught fish could be assigned. European salmon were genetically divided into 3 well defined geographical groups at the top level (Iceland, Scandinavia and Northern Russia, and Mainland Europe, Britain and Ireland) and 18 regional subdivisions at the lowest level. Finer scale regional structuring was apparent within all these subdivisions but was not further explored as levels of differentiation were not optimal for the robust assignment of marine fish to region of origin.

Geographical structuring in Atlantic salmon as revealed by nuclear SNPs: potential for application in the assignment of origin of marine fish

***J. Coughlan**, J-P. Vähä, S. Lien, P. Berg, J. Carlsson, P. McGinnity, T. F. Cross and the SALSEA-MERGE Consortium*

Genetic structuring of anadromous Atlantic salmon into regional stock groups has been identified and variously resolved by allozyme, mitochondrial and microsatellite DNA variation. Studies with these classes of variation have also shown significant structuring into distinct breeding stocks and populations on a highly local scale among and within rivers. Genetic differences at microsatellite loci are sufficient to allow the assignment of salmon caught at sea to distinct regional stock groups. Recent technological developments (automated/high-throughput genotyping platforms) have lead to an increased interest in distribution of nuclear gene single nucleotide polymorphism (nSNP) loci. However, presently there have been few large scale Atlantic salmon nSNP studies, therefore very little is known about the amount and scale of the genetic structure that will be revealed by analysis of large numbers of SNP loci. Similarly, not much is known in terms of both identifying population structure and regional groups, and ascertaining the usefulness of specific loci or locus combinations for assignment to origin. The extent of regional differentiation was explored using a set of 388 nSNPs screened for variation for 333 fish from 52 rivers (one to 22 individuals per river) across the Atlantic salmon range. The study revealed that 325 of these nSNPs worked consistently and were variable in at least some portions of the geographic range. Using Bayesian clustering methods, ten highly distinct and geographically discrete regions were identified among the population samples including eight major clusters which were comprised of North America, Iceland, Baltic Sea, Northern Norway/Kola peninsula/White Sea, Western Norway/Sweden, Denmark/British Isles/Northern France and Southern France/Spain. Two clusters comprised of one population each were also identified (Seal Cove river [Newfoundland] the Pechora river [far eastern Russian distribution]) which indicates that the addition of increased numbers of samples from the rivers used here and from different rivers will resolve further and finer genetic structures. In some cases individual samples taken from rivers located between identified geographic regions (particularly North-western Norway and Northern France), appeared to show evidence of admixture or introgression between these major groups. Patterns of variability revealed by different loci showed considerable heterogeneity in terms of both polymorphism and allele frequencies among the different genetic clusters indicating strong ascertainment bias in this

panel of loci. Attempts to capitalise on this finding used a hierarchical ascertainment approach and indicated that as few as 30 (10%) loci from this panel of 325 are required to resolve the maximum genetic structure revealed by all the markers in combination.

Microsatellite standardization and genotyping error in a large multi-partner research programme for conservation of Atlantic salmon (*Salmo salar* L.)

J. S. Ellis, J. Gilbey, A. Armstrong, T. Balstad, E. Cauwelier, C. Cherbonnel, S. Consuegra, J. Coughlan, T. F. Cross, W. Crozier, E. Dillane, D. Ensing, C. Garcia de Leaniz, E. García-Vázquez., A. M. Griffiths, K. Hindar, S. Hjorleifsdottir, D. Knox, G. Machado-Schiaffino, P. McGinnity, D. Meldrup, E. E. Nielsen, K. Olafsson, C. R. Primmer, P. A. Prodöhl, L. Stradmeyer, J-P. Vähä, E. Verspoor, V. Wennevik and ***J. R. Stevens***

We present a massive cross-laboratory microsatellite calibration study which underpins the microsatellite-based genetic baseline used in the SALSEA-Merge research programme for Atlantic salmon. Many of our findings and the lessons learned have only become apparent because of the breadth and detail in the study, and statistics relating to factors such as scoring error rates, now have meaning in the broader context. Since different alleles are sized relative to internal size-standards, laboratories must calibrate and standardize allelic designations when exchanging data. This interchange of microsatellite data is often considered to be problematic. Here, sixteen loci were calibrated and standardized, across twelve laboratories. Although inconsistencies were observed, particularly due to differences between migration of fragments and actual allelic size, inter-laboratory calibration was successful. Standardization also allowed an assessment of the degree and partitioning of genotyping error. Notably, the global allelic error rate was reduced after calibration. Most errors were found to occur during analysis (i.e. when size-calling alleles; mean proportion of error across loci decreased to 0.58 after calibration). The microsatellite calibration between laboratories presented is important for genetic analysis of in-river populations and assignment of marine-caught Atlantic salmon. This work is published as Ellis *et al.* (2011) *Genetica*, on-line at: http://www.springerlink.com/content/q53114553698k6q7/.

Regional mtDNA SNP differentiation in European Atlantic salmon (*Salmo salar*): an assessment of potential utility for determination of natal-origin

E. Verspoor*, S. Consuegra, O. Fridjonsson, S. Hjorleifsdottir, D. Knox, K. Olafsson, S. Tompsett and C. Garcia de Leaniz*

The Atlantic salmon, *Salmo salar*, shows geographically structured differentiation at various classes of molecular genetic variation, among and within river stocks. Nuclear microsatellite locus variation at multiple loci has been exploited as a marker for the continental origin of fish caught at sea in high seas fisheries for over a decade. However, a simpler, more cost-effective, but still accurate, assignment can be obtained using a single microsatellite locus in combination with a mtDNA restriction enzyme detected polymorphisms. Following on from this, a preliminary study was made of the potential for using mtDNA SNP variation to enhance the resolving power and cost-effectiveness of within continent assignment of

European salmon based on microsatellites. Variation in 20 mtDNA regions, encompassing ~43% of this genome in 330 individuals from 29 rivers across Europe, was analysed. High levels of inter-individual and inter-river variation were found as well as evidence of regional differentiation paralleling observed microsatellite differentiation. The observations indicate scope for using mtDNA SNPs along with microsatellites for genetically-based assignment of European salmon to region and river of natal origin but further study is needed.

Revisiting the marine migration of US Atlantic salmon with historic Carlin tag data.

***A. S. Miller**, T. F. Sheehan, R. C. Spencer, M. D. Renkawitz and A. L. Meister*

The discovery of non-native Atlantic salmon (*Salmo salar* L.) off Greenland prompted the initiation of a US tagging program in 1962, revealing vast ocean transits to Canada and Greenland. Since its inception, over one million fish from New England rivers, primarily hatchery reared smolts, were tagged and released. Overall tag recovery rate was 0.5%, with slightly more than half of the recoveries in US waters (52.7%), the majority as river returns, and the rest distributed in distant waters off of Canada (25.6%) and Greenland (21.7%). Given the marked decline in marine survival of Atlantic salmon in the Northwest Atlantic in recent decades, this database is a valuable resource for salmon researchers. Revisiting this extensive database can improve our understanding of the marine migration of US Atlantic salmon stocks, allowing for a more comprehensive investigation of the environmental and physical factors driving the species' marine survival patterns.

The migration and survival of Atlantic salmon kelts in estuarine and coastal regions of Canada

J. Carr

Sonic telemetry documented Miramichi River Atlantic salmon kelt migration patterns and survival within the estuary and Atlantic Ocean from 2008 to 2010. Survival in the estuary was high (>90%) where fish spent fewer than 20 days, mostly near the head of tide, before entering the Gulf of St. Lawrence. Eleven percent of the tagged kelts spent 44 to 68 days in the Gulf before returning as consecutive spawners. Another 3% of the tagged fish spent one winter reconditioning in the Atlantic Ocean before returning as alternate year spawners. No kelts overwintered in the estuary. Travel rates in the Gulf ranged from 10 - 69 km/day between the New Brunswick coastline and the Strait of Belle Isle (SOBI). The percent of kelts moving past the SOBI en route to Labrador Sea and possibly Greenland varied from 14 - 44% minimum. Kelt movements through the SOBI were synchronized with smolts that had been tagged in multiple rivers throughout the Gulf region. This suggests that naïve smolts may 'learn' the migration route from experienced adult salmon. Results from this study suggest that a high mortality rate occurs for reconditioning kelts in the Gulf of St. Lawrence and in the Atlantic Ocean.

The effects of dispersal at sea, local adaptation and stocking on the hierarchical genetic structure of Atlantic salmon populations

C. Perrier, J-L. Baglinière and ***G. Evanno***

Migration among Atlantic salmon (*Salmo salar*) populations can only occur through dispersal at sea. While the salmon homing behaviour is not strict, the dispersal distance among populations is largely unknown. Here we investigated the spatial genetic structure of 34 French Atlantic salmon populations to infer the level and spatial scale of dispersal among rivers. 975 individuals were genotyped at 17 microsatellite loci. A Bayesian analysis revealed a pattern of hierarchical genetic structure into five geographically distinct clusters. Coastal distance among estuaries was a strong predictor of population structure ($r = 0.55$) and the effect of river length was also significant ($r = 0.37$). However the latter was mainly due to one population having both the farthest spawning grounds off the river mouth (900 km) and the highest level of differentiation. This population also exhibited very particular morphological (large size) and behavioural traits (run timing), suggesting a role for local adaptation to river length. We also detected highly variable genetic impacts of stocking: from a strong admixture among non-native and wild populations to a complete lack of introgression in certain populations. Overall these results suggest that dispersal at sea is higher among neighbouring populations from the same cluster than among distant rivers located in different regions. In the case of populations located in very large rivers, behavioural and morphological traits linked to migration in freshwater are probably locally adapted. Finally, the high levels of genetic admixture observed in some populations may lower the accuracy of population assignment for fish caught at sea.

Evidence of positive selection acting on the Atlantic salmon mitochondrial DNA: implications for assessing the impacts of climate change

E. John, ***C. Garcia de Leaniz****, E. Verspoor and S. Consuegra*

Mitochondria produce 95% of the energy in the eukaryote cell through the production of ATP by means of oxidative phosphoralation. It is therefore expected that the 13 genes that make up the mitochondrial genome may have evolved in response to the energy requirements of the organism, or to environmental conditions that affect metabolic processes, including the effects of temperature. We identified SNPs from the partial mt genome (encompassing 9 mitochondrial genes) of 330 Atlantic salmon from 29 rivers across Europe (6 to 12 individuals per river). The rate of synonymous and non-synonymous loci was estimated using likelihood-based methods and genes with signs of positive selection were analysed. Positive selected sequences were also identified based on the peptide chemo-physical changes that would be expected from the observed amino acid substitutions. We found evidence of positive selection on the ND4 gene, a gene that codes for a peptide in the NADH dehydrogenase complex 1 and which is involved in the electron transport system (ETS). A panel of 30 SNPs (including those with signals of selection) were identified, SNaPshot multiplexes were designed, and are currently being used to screen extant and historical scale samples from wild Atlantic salmon populations. This new set of molecular markers may help to address the impacts of climate change and other stressors that affect metabolic processes in migratory salmon and related species.

Food Production, Growth, Trophic and Other Ecological Interactions

Use of storage tags to study the behavioural ecology at sea of Newfoundland Atlantic salmon smolts and kelts

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For migratory fishes, such as Atlantic salmon, temporal variation in the utilization of habitats in the marine environment is likely to occur at both broad and fine scales, reflecting both ecological and metabolic factors. To test this, we implanted 26 Atlantic salmon kelts descending Campbellton River, Newfoundland, with data storage tags that recorded date/time, internal and external temperatures, pressure, and light. The salmon that returned to Campbellton River after an average of 62 days at sea were consecutive spawning kelt. Detailed data were recovered from eight of these fish and revealed distinct patterns in their utilization of thermal and depth habitats. Water temperatures experienced over the period at sea showed a wide range for all fish (<0 to nearly 20°C), however, there were two clear frequency modes; one at 6-7°C and the other at 11-12°C. The cooler mode was indicative of daytime profiles and the warmer mode of night-time profiles. This corresponded with the depth profiles, which indicated that salmon dove more frequently below 5 m (mean ± sd = 23 ± 0.9 dives per day) and spent less time (ca. 18%) near the sea surface (< 1 m) during the day than during the night (4 ± 0.4 dives per night; ca. 45% time < 1m). The diurnal pattern may be indicative of a reliance on vision for feeding at depth and the short duration of dives (< 10 min) may be a strategy that allows salmon a metabolic advantage (e.g. swimming capacity) over their prey living constantly at depth in cool waters.

Evidence for bottom-up trophic effects on return rates to a second spawning for Atlantic Salmon (*Salmo salar*) from the Miramichi River, Canada

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Increased return rates of consecutive spawning Atlantic Salmon (*Salmo salar*) have been noted in the past two decades and their short time period for reconditioning at sea places them within the southern Gulf of St. Lawrence (sGSL) ecosystem. We use a 40 year time series of observations to examine linkages between return rates to a second spawning of Atlantic Salmon and changes in the small fish community of the sGSL, which are potential prey to adult salmon. The positive association between the variations in return rates of repeat spawners and the variations in the small fish biomass index in the reconditioning year at sea provides evidence that food supplies in the early period of return at sea may be beneficial to survival to a second spawning of Atlantic Salmon. This provides evidence for bottom-up effects of prey availability on adult fish survival.

Spawning history influence on fecundity, egg size and egg survival of Atlantic salmon (*Salmo salar*) from the Miramichi River, New Brunswick, Canada

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There is an increasing abundance of repeat spawning individuals in salmon populations, which due to their increased size can be expected to increase egg depositions and offspring survival compared to primarily maiden spawning populations. Currently, there is little information on repeat spawning salmon, and less information on fecundity, egg size and survival of the two types of spawning strategies within the repeat group; consecutive and alternate. We examined the fecundity, egg size and egg survival from 235 wild female Atlantic salmon over three years, which consisted of 1SW and 2SW maiden, and repeat spawning individuals. Relative fecundity was not different among the large-bodied Atlantic salmon in this study but the consecutive repeat spawners had a predicted higher fecundity than maiden 2SW salmon and alternate repeat spawning salmon. Egg diameter also scaled positively with body size but consecutive repeat spawning salmon had significantly smaller eggs in absolute terms and relative to their body size than the maiden 2SW and the alternate repeat spawners. The survival rate of consecutive repeat spawners was significantly lower than of 2SW maiden and the alternate repeat survival rates. Repeat consecutive spawning Atlantic salmon are different in that egg diameter and egg survival does not follow the general trends of increasing with female size, which is likely due to the short time that is spent reconditioning in the ocean and subsequent energy stores.

Smolt age and fine scale marine growth of Atlantic salmon post-smolts in the North-East Atlantic

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Twelve surveys with surface trawls, covering a large part of the Northeast Atlantic, were carried out in 2002, 2003, 2008 and 2009 to collect samples of Atlantic salmon post-smolts during their marine feeding migration, and altogether 2 242 post-smolts were captured. The predominating smolt age of post-smolts of wild origin was two years, followed by one and three years, and a few four years old fish. The average rate of circuli formation in the marine zone of scales was estimated to be 6.3 days per circulus. Both age structure and number of marine circuli in the scales suggest that the majority of the post-smolts caught belong to populations of southern European origin. Further, applying intercirculi distances in scales as a proxy variable of growth rate, the results suggest that marine growth rates varied among years, with highest growth rates in 2002, followed by 2003 and 2009, and lowest growth rates in 2008. Also, the first marine intercirculi distances were narrowest in one year old smolts, successively increasing with smolt age, indicating that growth rates during the first period at sea were lowest for salmon of southernmost origin. These growth indices were linked to prevailing environmental and biological conditions.

Implications for Salmon Management

The large landings of Atlantic salmon along the coast of Finnmark, northern Norway; origin from Norwegian or Russian rivers?

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A multi-stock Atlantic salmon (*Salmo salar*) sea-fishery operates off the coast of Finnmark, the northernmost county in Norway, with 200-300 tons in annual landings over the last decades. The annual harvest from the sea-fishery is similar to that of the total riverine harvest in the 40 salmon rivers in Finnmark, which together contribute to ca. 50 % of the total wild Atlantic salmon catch in Norway. While the salmon sea-fishery in Finnmark has long cultural traditions, it has recently been under strong debate due to the complexities arising from the mixed stock harvest, targeting not only Finnmark salmon, but potentially also Russian salmon originating from more than 60 Kola rivers. To investigate any population-specific migration patterns, and the composition of the mixed stock fishery, we genetic stock identified 2 000 salmon (1SW-4SW) samples from 21 fishing localities along the coast of Finnmark. Comparisons were made with a genetic baseline constructed by samples from more than 60 rivers covering northern Norway and North-West Russia. The results are discussed in relation to the complexities of migration patterns, mixed-stock fishery, conservation and future management of Atlantic salmon.

DNA parentage assignment to improve restoration programmes for Atlantic salmon in the Garonne and Dordogne French rivers.

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Atlantic salmon restoration programmes, involving stocking and improvements to habitat and fish passage, have been conducted over the last thirty years in the Garonne and Dordogne rivers. During this period there has been a marked decline in marine survival of salmon and this is a challenge to initiatives to conserve and restore salmon stocks. To date, little effort has been made to evaluate the effectiveness of the stocking programmes but DNA fingerprinting techniques offer the possibility of assigning returning salmon to their parents allowing estimates to be made of stocking success and identification of biological and physical factors affecting the effectiveness of stocking practice. Since 2007, MIGADO has been using DNA parentage assignment in support of the stocking programme. Thirty to 60 wild salmon (F0) are captured every year then electronically tagged and reared in the hatchery in Bergerac together with F0 salmon captured in previous years. F0 salmon are mated to produce F1 families that are then held in two other hatcheries. Each year, approximately 1,500 F1 parents are crossed at each hatchery to produce F2 progeny that are released to the wild together with a limited number of F1 individuals. Since 2007, F0 and F1 parents have been genotyped using 9 microsatellites (LABOGENA genotyping laboratory). The results of the assignment of the first return of 2+ salmon collected in 2010 will be presented.