International Atlantic Salmon Research Board

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Application for partial funding by the IASRB
'Effects of recent ocean warming on growth and migration of Southern NEAC 1SW salmon'

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Application for partial funding by the IASRB – 'Effects of recent ocean warming on growth and migration of Southern NEAC 1SW salmon'

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SUMMARY
In collaboration with Marine Scotland Science (MSS), we have collated measurements of scale circuli for 3,400 adult 1SW salmon returning to Scotland. The data include a single river stock (River North Esk, E Scotland; 1993-2011) and a mixed-stock interceptory fishery (Strathy Point, N Scotland; 1993-2007). Our overall objective is to assess growth performance of Southern NEAC salmon that are known to migrate to the Norwegian Sea, and which have encountered major environmental change over the past 3 decades. The Norwegian Sea has undergone marked surface warming since the turn of the millennium and the size and quality of return adult 1SW and 2SW salmon has fallen markedly. In addition, we now have developed a simple method of estimating dates for all marine circuli deposited on a scale as the fish grew. From these data, we now can attribute dates, or calendar months, to growth hiatuses (e.g. "growth checks") which will better inform our understanding of the spatial and temporal incidence of environmental challenges to salmon at sea. Perhaps most intriguing is that we now are able to estimate the start and end dates of the period of markedly reduced growth rate manifest on a scale as the winter annulus. The mean duration of winter experienced by these cohorts of 1SW adults shows considerable year-to-year variation and preliminary analyses show strikingly strong correlation with sea surface temperature anomalies in the Norwegian Sea. Moreover, by making simple assumptions regarding the causal factor of the winter growth annulus – that is, reduced light availability for foraging at high latitude in midwinter – we will be able to affirm shifts in over-wintering latitude of annual cohorts in response to recent climate warming. Our preliminary results also indicate that smolt length explains a significant proportion of the variation in final adult size. Such information would be of positive value to freshwater managers in encouraging not only the maximization of numbers of emigrant smolts, but also of their size and quality because larger return females will have higher ultimate fecundity. All the empirical measures and data now are compiled, and the funding sought from IASRB will permit comprehensive modelling and analysis of the data. This will result in two major publications (with all due acknowledgment of NASCO). The outputs will enable a strong case to be made for a funding application to be made to Natural Environment Research Council, UK for a major project (in collaboration with MSS) to undertake more extensive analyses of their scale archives for multiple river systems, ranging back to 1963. Moreover, with appropriate staff and infrastructure support from a major grant we also would be able to undertake comparable analyses of MSW adults which are known to migrate either to the Norwegian Sea or West Greenland.

BACKGROUND

The surface waters of the North Atlantic presently are warming at a rate approximately four times that of the global average ([1]). Large-scale changes in plankton communities, or regime

shifts, have been well documented in the Northern Hemisphere ([2]), and pelagic and demersal fish species in the eastern North Atlantic have shown particularly striking responses in recent years to ocean climate change. Thus, for example, changes in depth distribution ([3]) and latitude ([4]) have been noted, and the pelagic fish species assemblages of the eastern North Atlantic in particular have undergone sufficient change to now be characterised by so-called "sub-tropicalization" ([5,6]) as colder-water species (e.g. sprat, herring) give way to warmer water species (e.g. horse mackerel) shifting poleward. In concert with anomalous warming of the eastern North Atlantic over the past two decades, we have shown clear negative responses of wild salmon populations to this trend ([7, 8, 9]). Specifically, the size and condition factor of multiple populations of 1SW salmon returning to Scotland has fallen as the surface waters of the Norwegian Sea have warmed. The mean weight of 1SW adults returning to the River North Esk (E Scotland) presently is approximately 40% lower than at the turn of the millennium (unpubl. Marine Scotland Science data). A marked shift in marine growth success for Southern NEAC salmon occurred in Spring 2005. 1SW adults returning during the summer of 2005 were of poor condition, but it was summer 2006 before this became apparent to commercial netsmen and freshwater managers. 2006 saw 1SW adults of equally poor condition as in 2005, but in 2006 the grilse were significantly shorter. Hence, 2006 in Scotland became known colloquially as the "year of skinny grilse". Whilst the data that we presently are working with will affirm spring 2005 as having been a critical tipping-point for growth success of Southern NEAC salmon at sea, our previous analyses of Scottish salmon time-series ([9]) pointed to anomalous warming of the Norwegian Sea specifically in January exerting an indirect effect on salmon: that is, we concluded the decline in condition factor (and size) to be a consequence of changed feeding conditions for salmon at sea, rather than a direct physiological response of salmon individuals and populations to ocean warming. Notwithstanding additional concerns regarding salmon abundance trends, it remains problematic that there is no evidence − from continued monitoring of 1SW adults returning to the North Esk − of adult size or condition factor improving significantly from the 2005-2006 low. The Norwegian Sea feeding areas of Southern NEAC fish continue to show persistent anomalous warming.

PRESENT AND AVAILABLE METHODS AND DATA

Salmon are very effective "data loggers" in recording much information concerning their life history. Specifically, the otoliths and scales comprise sources of detailed information on the growth history and environment experienced by the fish throughout its lifetime. From observation, measurement and analysis of the growth circuli on scales there is a long history of biologists assessing the river age, sea age and spawning history of individuals. Moreover, additional quantitative information is derivable from scale circuli by back-calculation. Thus, if one knows the length of the fish at capture, and by assuming isometric growth of the scale radius with fish length, one can estimate the length of the smolt at river emigration, and of the pre-adult fish at sentinel points in the marine phase (e.g. length at the end of each sea winter). We recently published a simple method ([10]) for estimating a date for every marine circulus. This additional facility therefore permits an observer to estimate the growth rate ($cm.day^{-1}$) and specific growth rate ($cm.cm^{-1}.day^{-1}$) for individual fish throughout their marine migration. Furthermore, it now is possible to estimate the seasonal incidence and temporal duration of growth hiatuses (e.g. growth "checks") and also of the winter(s) experienced at sea. Winter is manifest on the scale as an annulus of tightly-spaced circuli. The circulus spacing is indicative of a marked, and more or less protracted, period of reduced growth rate of the fish. In deriving our scale-dating method we make the assumption that the annulus arises not from low temperature, but from reduced feeding. Being visual predators of macrozooplankton and nekton at the ocean surface, it is intuitive that at high latitude in winter the fish will encounter markedly reduced light availability for foraging.

CDT has a long-standing collaboration with Marine Scotland Science (MSS) and has been given access to all their monitoring data – both of return adults captured in numerous commercial fisheries, and of emigrant smolts from the River North Esk. Our previous analyses of time-series change in size and condition of Scottish 1SW salmon (1993-2006) involved a correlative approach ([9]), in that mean annual condition factor at migratory return to Scotland was correlated with sea surface temperature (SST) anomalies in the Norwegian Sea. Whilst those results (based on annual average final adult condition) are statistically very robust, it would be extremely important if those data could be reinforced, confirmed and further informed by the extraction of specific and detailed historical information from individual fish. To this end we have measured all the marine circuli on a total of 1,900 1SW grilse from the River North Esk over the period 1993-2011. These data have taken four years to be compiled and now will permit the calculation of specific growth rate at each circulus on the scale. Our proposed analyses will focus on the influence – on final individual size/quality – of oceanographic variables and of individual river age, smolt length, length at the marine winter, sex and date of migratory return. For the River North Esk comprehensive additional data are available because the emigrant smolt population has been quantified each year, and the return adults have been routinely sampled from the in-river net and coble fishery since 1963. For every cohort of 1SW adults we therefore have available (for scale dating purposes) the median date of emigration of smolts in the previous year, and comprehensive samples and dates of the return adult cohorts. By applying the dating methodology, we now can interrogate individual fish for changes in specific growth rate throughout the marine phase. Those data will permit confirmation of the post-winter marine growth period being the key time at which final adult condition is determined because our previous correlative analyses showed that final adult condition at return [May-August] was linked to the January SST anomaly in the Norwegian Sea.

Furthermore, as a novel addition to our understanding of the biology of salmon at sea, we will focus specifically on our estimates of duration of the marine winter for two independent time-series of 1SW adult salmon (detailed below). Marked individual (and between-year) variation in the number of circuli comprising the marine winter annulus is indicative of fish experiencing a winter of very different durations. A longer winter will arise for fish that over-wintered at higher latitude. We therefore have initiated analyses of time-series changes in the mean winter duration, and thence over-wintering latitude, experienced by North Esk 1SW adults and also for 1SW fish from a mixed stock fishery. These analyses will be based on assumptions regarding ambient light levels available to salmon at varying latitudes, on solar data, and inferences on light penetration of the ocean surface: the preliminary results show that the inferred latitudes are biologically realistic in terms of the known (or suspected) distribution of Southern NEAC salmon at sea. A comprehensive assessment of whether or not further-northward migration has consequences for individual growth and survivorship will be a specific research objective.

The strong and varied pattern in mean winter duration that we have found for the River North Esk begged the question as to whether or not this is exclusive to that one river stock. As for our previous analyses of time-series change in condition factor, we chose here to obtain comparable scale data for a mixed stock. The data for Strathy Point (N Scotland) that we have now compiled are ideal for this purpose in comprising a mixed stock fishery for salmon largely originating from the North and West coasts of Scotland. Data are available for the period 1993-2007 (up to closure of the fishery) and we now have measured scales for 1,500 1SW grilse from that fishery. Preliminary analyses of the data show a very close concordance between

Strathy Point and River North Esk. That is, the patterns shown for the North Esk are indicative of a Scotland-wide response of salmon; specifically, this evidence confirms that it is the common (marine) environment that is driving this trend, and that influences in freshwater have no bearing on this variation in marine migration.

PROJECT PROPOSAL

The present request is for partial funding to support an experienced post-doctoral assistant for 3 months (August-October 2016) to complete the analyses and to prepare and submit the results for publication. Dr Mendo has considerable expertise in modelling using the R platform and these data require some complex modelling to be undertaken. Models will assess as many explanatory factors and variables as possible, but one fundamental problem is to ensure independence of variables and no co-linearity thereof. Some variables (such as the duration of the first marine growth period and the duration of the one marine winter) are not independent and thus both cannot be included in a single model. CDT does not have the necessary modelling expertise to fully interrogate and analyse this large data resource, and hence the assistance of Dr Mendo is essential to the full exploitation and ultimate publication of the results from the MSS data. Because data ownership remains the property of MSS all papers will be published jointly with MSS co-authors.

The University of St Andrews acknowledges the status of NASCO, and the limitations on funds available to support research projects of this kind. The sums requested (£10,000), therefore, are solely to support the salary of Dr Mendo for 3 months (1 August – 31 October 2016) and include an in-kind contribution from the University of £17,081. Publication costs and recurrent costs attributable to this project will be supported by CDT.

OUTPUTS AND DELIVERABLES

These data are unique for Southern NEAC salmon. For no other river system is there such comprehensive information available on the emigrant smolts and the return adults. The large sample sizes will provide statistically very robust outcomes: the 'signal' does clearly emerge from the inevitable 'noise' in the data. These model analyses will result in two major publications, 1. on the seasonal timing of the growth period crucial to determining final adult size and condition factor, and 2. on variation in winter duration (and thence marine migration) of salmon at sea. With respect to an effective contribution to management of salmon in freshwater, it is already clear from preliminary analyses that we can show a significant effect of smolt size on the size of the return adult 1SW fish. That is, we will be able to provide freshwater managers with clear evidence of the beneficial effects of maintaining and enhancing not only the numbers, but also the size and quality, of emigrant smolts. Moreover, given our access to all of the MSS monitoring data we will be able to further interrogate our estimates of emigrant smolt length of our scale-sampled adults against the observed sizes of smolts of varying river age that actually emigrated. Thus, for example, we will be able to determine whether or not there is any size-related bias in survivorship of emigrant smolts. The SALSEA project showed the critical importance of integrating all available information and data for salmon at sea in furthering our understanding of the complex environmental challenges confronting salmon both in the marine and freshwater environments. Successful completion and publication of the present analyses will be complementary to SALSEA and permit St Andrews to construct a strong case for further substantial funding from national or international funding bodies to support a larger and broader project, to extend our analyses of the MSS archives back to 1963 and to include 2SW salmon.

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