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David Righton [1], Auden Rikardsen[2], Richard Hedger[3], Cedar Chittenden[2], Jan Davidsen[3], Finn Okland[4], Tor Naesje[4], Patrick Gargan[5], Eva Thorstad[4], Elina Halttunen[2], Kim Aarestrup[6],R. Scott McKinley[7]

[1]Centre for Environment, Fisheries and Aquaculture Science (Cefas), Cefas Laboratory, Pakefield Road, Lowestoft, Suffolk, NR33 0HT, UK, [2]Department of Arctic and Marine Biology, University of Tromsø, N-9037 Tromsø, Norway, [3]Museum of Natural History and Archaeology, Norwegian University of Science and Technology (NTNU), N-7491 Trondheim, Norway, [4]Norwegian Institute for Nature Research (NINA), N-7485 Trondheim, Norway, [5]Inland Fisheries Ireland, Swords Business Campus, Co. Dublin, Ireland, [6]Technical University of Denmark, National Institute of Aquatic Resources, Silkeborg, Denmark, [7]The University of British Columbia, 2329 West Mall Vancouver, B.C. V6T 1Z4 - Canada. Contact email: david.righton@cefas.co.uk

Summary

Catches and survival of Atlantic salmon in the North Atlantic have declined by ~70% since the 1970s. The cause of the decline has been attributed to overfishing and reduced marine survival that, in the latter case, links to ocean climate. However, the links between ocean processes, habitat occupation and marine survival of salmon are only poorly understood. We used pop-up satellite archival tags (PSATs) to observe the behaviour and oceanic migration of more than 150 kelt salmon from eight different Atlantic salmon populations within the North Atlantic. We show that the primary migration routes of different populations aligned with surface ocean currents, with the result that kelts moved rapidly northward and/ or westward after release to productive frontal areas off Greenland. Populations were spatially segregated during the feeding season, with more northerly populations exploiting latitudes higher than 70N during the Arctic summer, while more southerly populations exploited feeding grounds further south. Mixing of northern populations occurred at high and medium latitudes, while southern populations mixed in waters to the east of Greenland. Predicted changes in the location and strength of the polar front due to a more variable and changing climate are likely to impact the feeding migrations of kelt salmon, with consequent effects on population mixing with consequences for the interpretation of genetic sampling programmes.

Introduction

Catches and survival of Atlantic salmon (*Salmo salar*) in the North Atlantic have declined by ~70% since 1970s. Similar situations have also been reported for several Pacific salmon species. Furthermore, the scale of the decline is not homogeneous: some southern populations have been virtually extirpated, while the decline of northerly stock components risks further loss of population diversity. This decline has been linked to low marine survival rates and stimulated interest in the spatial and temporal distribution of Atlantic salmon during marine feeding. Despite being one of the worlds most studied fish species, knowledge of detailed movement patterns, residence locations, environmental conditions, and the behavior of Atlantic salmon while at sea is generally very limited. We assessed migration routes, spatial overlap and at-sea behaviour of Atlantic salmon from populations

in northern Europe to gain a greater understanding of environmental and population influences on oceanic space use.

Materials and Methods

We used pop-up satellite archival tags (PSAT) and archival data storage tags to study the marine migrations of Atlantic salmon kelts from six river systems in Europe (spread from 51°N in southern Ireland to 70°N in northern Norway) and from North American maiden salmon tagged at the coast of West Greenland. Tags were programmed to pop-off after periods between 90 and 300 days. In total, we received data from 125 PSATs and 24 data loggers, which together yielded >22,000 days of data. All time-series data received from the tags were combined into a database and summarised to provide daily estimates of mean, maximum and minimum depth and temperature. Daily estimates of geographic location were made using a bespoke geolocation method that used sunrise/sunset data, maximum depth and sea surface temperature as inputs.

Results and Discussion

Tagged kelts travelled from river release to reside during summer in productive frontal zones where Atlantic surface currents meet south-flowing Arctic waters. Populations from northern river systems (Norway, Denmark) occupied overlapping but spatially segregated foraging areas at high latitudes, while populations from more southern rivers (Iceland, Ireland) occupied lower latitudes off the coast of Greenland. Individuals from the same river tagged in different years showed fidelity to the same oceanic regions. Kelts spent the majority of their time in surface waters when migrating, with occasional dives to great depth (Figure 1). Maximum dive depth was greater when salmon were within foraging areas, and they spent significantly more time at 50-100m than during the migratory phase. Maximum dive depth also increased as the year progressed, with the consequence that average or median occupied depth also peaked in late summer in northern latitudes. The spatial segregation of eastern and western populations helps to explain previously described variation in productivity between northern and southern European salmon populations. Our results help to shed light on important ecological process that shape Atlantic salmon population dynamics, and which may help to identify measures that will help set and refine management targets.

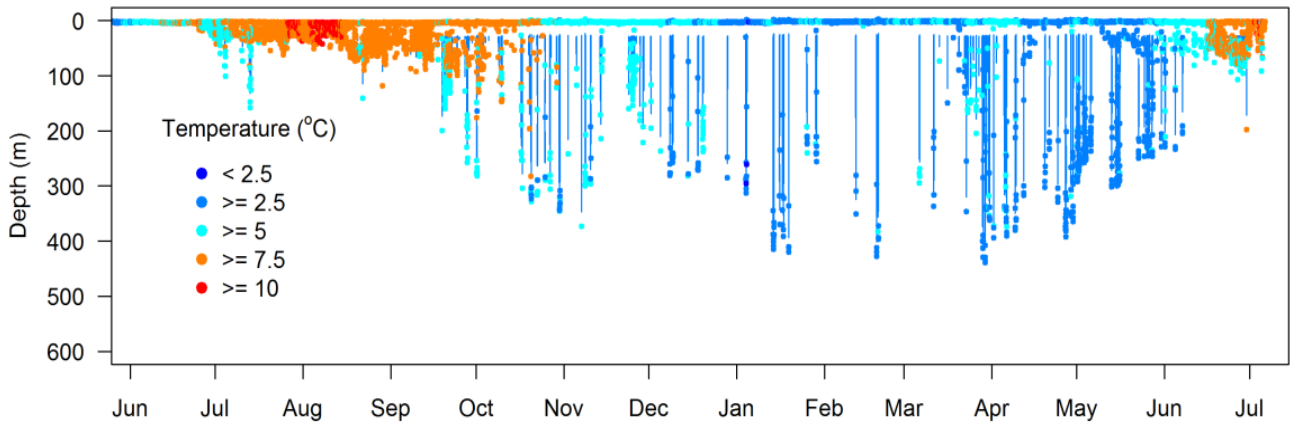

Figure 1. Depth and temperature profile of a kelt salmon that migrated to polar waters from the Alta river before recapture one year after release.