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Bayesian hierarchical modeling of eleven years of inter-stage survival rates of wild Atlantic salmon smolt and post-smolt from three rivers of eastern Canada

Gerald Chaput(1) Jonathan Carr (2), Fred Whoriskey(3), and Ian Jonsen(4)
(1) Department of Fisheries and Oceans; (2) Atlantic Salmon Federation, P. O. Box 5200, St. Andrews, NB, Canada, E5B 3S8. Presenter contact details: Tel.: 506-529-1385, Fax: 506-529-4985, Email: jcarr@asf.ca; (3) Ocean Tracking Network, Dalhousie University; (4) Macquarie University.

Summary

Mortality of Atlantic salmon post-smolt has been assumed to be highest in the first few months of migration at sea due to their small body size and the stress associated with acclimation to the marine environment. We report on research undertaken to estimate the location and timing of mortality of smolt during the first 2 months at sea. More than 1,700 wild Atlantic salmon smolt from three rivers of the Gulf of St. Lawrence (Canada) were acoustically tagged and released from 2003 to 2013. Acoustic arrays were first installed and monitored at the head of tide of each river, and at the exit of these rivers to the Gulf of St. Lawrence. In 2007 an array became fully operational in the Strait of Belle Isle (SoBI), the Gulf of St. Lawrence exit leading to the Labrador Sea, about 800 km from the point of smolt release. A Bayesian state-space model variant of the Cormac-Jolly-Seber model was used to disentangle the imperfect detection of tagged smolt on the acoustic arrays from apparent survival during their out migration. The model reduced uncertainty in expected values of the annual and river specific detection probabilities at the head of tide and bay exit arrays, however, it was not possible to independently resolve the detection probabilities at the SoBI array and the probability of survival through the Gulf of St. Lawrence. This telemetry research provides useful guidance in the design of such experiments and the treatment of data.

Introduction

Migration routes of juvenile (post-smolt) anadromous North American Atlantic salmon during the period after their entry to the ocean are poorly documented (Thorstad *et al*. 2011). Tag recaptures and scale analysis suggest that North American salmon post-smolt arrive at the Labrador Sea and Western Greenland by the early autumn of their first year at sea (Ritter 1989, Reddin and Friedland 1999). Many of North America's most productive Atlantic salmon rivers drain into the Gulf of St. Lawrence. To get from the Gulf of St. Lawrence to the Labrador Sea and Western Greenland, they must enter into the Atlantic Ocean through either the Strait of Belle Isle or the Cabot Strait.

In this study we used 11 years (2003 to 2013) of sonic telemetry to document Atlantic salmon smolt movements from three rivers draining into the Gulf of St. Lawrence, Canada (Miramichi, Restigouche, and Cascapedia Rivers). For each river, acoustic arrays were monitored for variable numbers of years at the head of tide, at the exit from the bays to the Gulf of St. Lawrence and at the Strait of Belle Isle leading to the Labrador Sea. A Bayesian state-space model variant of the Cormac-Jolly-Seber model was used to model survival and disentangle the imperfect detection of tagged smolt on the sonic arrays from apparent survival during their out migration.

Materials and Methods

Smolt were captured primarily in rotary screw fish traps, and occasionally by counting fences, or trap nets. Selected animals (>13 cm fork length) were tagged and released at the site of capture. Smolt were anesthetized (clove oil, 40 mg/l), and VEMCO V9-6L sonic pinger tags surgically implanted in the body cavity through a small ventral surface incision. The incision was closed by two-to-three Ethilon sutures, and the fish were allowed to recover for a few hours in a holding pen in the river before being released.

Tagged animals were detected by strategically deployed VEMCO (Halifax, Nova Scotia) VR2, VR2W, or VR4 receivers. The choice of the model of the receiver used at a given site was dictated by the availability and suitability of the receiver for a particular site. The extent of the acoustic arrays expanded regularly during the early period of the study. For each river during our study (2003-2013), complete receiver coverage was positioned across the head of tide (HoT) and near the exits to the Gulf of St. Lawrence (Miramichi and Chaleur Bays). Beginning in 2007, the northern exit from the Gulf of St. Lawrence was covered with an array positioned at the Strait of Belle Isle (SoBI) between Green Island Cove Newfoundland, and L'Anse a Loup, Labrador. A partial array was in place across the Cabot Strait (southern exit from the Gulf) beginning in 2010 (completed by 2012). Spacing distances among receivers was a maximum of 800 m. Both the Cabot and Strait of Belle Isle arrays were equipped with sentinel tags that were programmed to signal at regular intervals, and provided an independent measure of detection efficiencies of these arrays.

A Bayesian state-space implementation of the Cormack-Jolly-Seber (CJS) model (Gimenez *et al*. 2007, Royle 2008) was used to disentangle the sonic array's imperfect detection (p) of tagged smolt from their apparent survival (ϕ) during their out migration. The CJS model can be parameterized with constant or time-varying parameters, a combination of the two, and individual effects on these parameters.

Results and Discussion

The detection probabilities at the HoT arrays were estimated to be consistently high, with annual median values ranging from 0.73 to 0.99 for Miramichi, 0.74 to 0.89 for Restigouche, and 0.86 to 0.98 for Cascapedia Rivers, respectively. Annual detection probabilities were lower at the bay arrays, ranging from 0.58 to 0.93 for the Miramichi, and 0.36 to 0.76 for Chaleur Bay rivers. It was not possible to independently resolve the detection probabilities at the SoBI array and the probability of survival through the Gulf of St. Lawrence.

Modeled survival probabilities were highest in the area above the HoT arrays for all rivers. The annual survival probability median values ranged from 0.71 to 0.95 for Miramichi, 0.77 to 0.91 for Restigouche and 0.91 to 0.97 for Cascapedia. Survival differences among rivers may be best explained by the variable distances among these rivers that the smolt had to travel from their release points to the head of tide. Annual survival probabilities from the HoT to ocean entry were lower than survival from release to the HoT for fish from all rivers, and annually ranged from 0.80 to 0.91 for the Miramichi , 0.70 to 0.89 for the Restigouche, and 0.72 to 0.89 for the Cascapedia animals. The establishment of precise survival estimates is the first step in establishing correlations with potential mortality causes. This information, in turn, will contribute to our understanding of the drivers of the current declines in wild Atlantic salmon populations.

References

Gimenez, O., Rossi, V., Choquet R., Dehais, C., Doris, B., Varella, H., Vila, J.-P., and Pradel,. 2007. State-space modelling of data on marked individuals. Ecological Modelling 206:431–438

Reddin, D. G., and Friedland, K. D. 1999. A history of identification to continent of origin of Atlantic salmon (Salmo salar L.) at west Greenland, 1969-1997. Fisheries Research, 43: 221-235.

Ritter, J. M. 1989. Marine migration and natural mortality of North American Atlantic salmon (Salmo salar L.). Canadian Manuscript Report of Fisheries and Aquatic Sciences 2041, Halifax.

Royle, J.A. 2008. Modeling individual effects in the Cormack-Jolly-Seber model: a state-space formulation. Biometrics 64:364-70.

Thorstad, E. B., Whoriskey, F., Rikardsen, A. and Aarestrup, K. 2011. Aquatic nomads: the life and migrations of the Atlantic salmon. In Atlantic Salmon Ecology, pp 1- 32. Ed. by Ø. Aas, S. Einum, A. Klemetsen and J. Skurdal. Blackwell Publishing Ltd., Oxford. 467 pp.