

# Using $\delta^{18}\text{O}$ to assess the migratory route of Scottish two sea-winter wild Atlantic salmon

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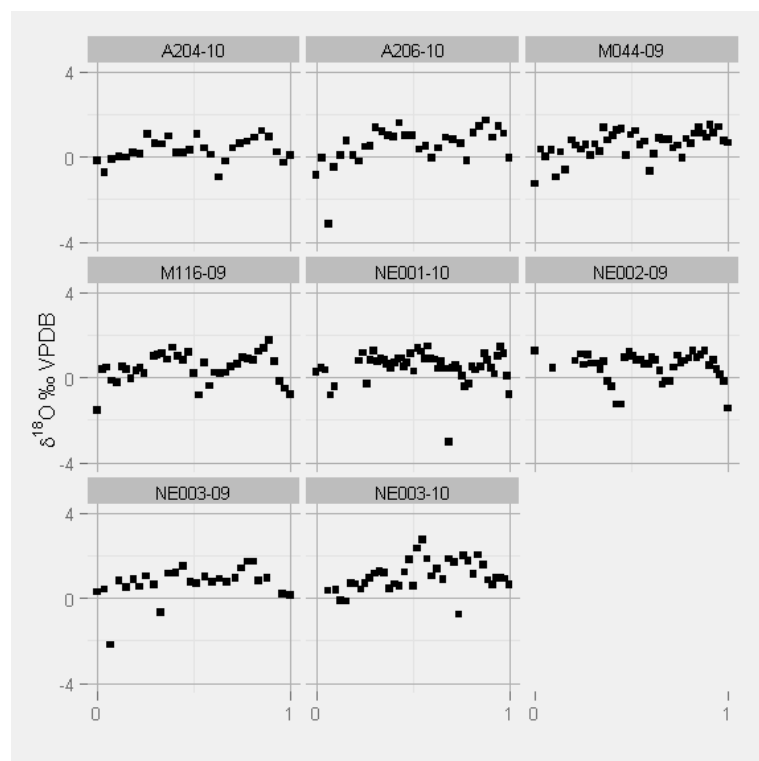
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## Background

Despite increased marine mortality and declines in growth condition of wild Atlantic salmon [1-3], the details of their marine migration remain largely unknown. Strong concordance between time series of growth condition for one sea-winter (1SW) and two sea-winter (2SW) Scottish salmon suggest that both groups occupy the same ocean area during their final months at sea. However, present migratory models place 2SW fish in the warm North Atlantic Current during return migration [4]. Electronic tagging of salmon to monitor details of their entire marine migration is currently unfeasible but otoliths, the tiny calcium carbonate 'bones' in the fish ear, can be used as retrospective 'natural tags'.  $\delta^{18}\text{O}$  values of otolith aragonite are deposited at or near equilibrium with the ambient water and the temperature during otolith deposition can be estimated provided that  $\delta^{18}\text{O}$  values of ambient water are known. We sought to use high resolution SIMS profiles of otolith  $\delta^{18}\text{O}$  values from 2SW salmon to infer latitudinal migration paths and test our hypothesis of shared residency in the Norwegian Sea with 1SW fish.

## Results & Discussion

Between 27 and 50  $\delta^{18}\text{O}$  analyses per otolith were obtained ( $n = 8$  individuals, 148 separate analyses). All profiles (Fig. 1) were scaled such that  $x=0$  refers to the freshwater/marine emigration transition and 1 refers to the otolith edge (i.e. time nearest to capture). For all salmon,  $\delta^{18}\text{O}$  profiles were characterised by two periods of increased values at  $\delta^{18}\text{O} \sim 0.7 - 0.9\%$  in the first instance and  $\sim 1-1.1\%$  in the second. These rises correspond to the two winters (at lower temperatures) spent at sea, as described below. The overall mean  $\delta^{18}\text{O}$  was  $0.57(\pm 0.18)\%$  and there were significant differences in mean  $\delta^{18}\text{O}$  values between fish – most notably, NE003-10 had a mean value of  $0.72\%$ . However, the majority of the variation in  $\delta^{18}\text{O}$  values occurred within individual profiles ( $\sim 94\%$  variance; linear mixed effects model).



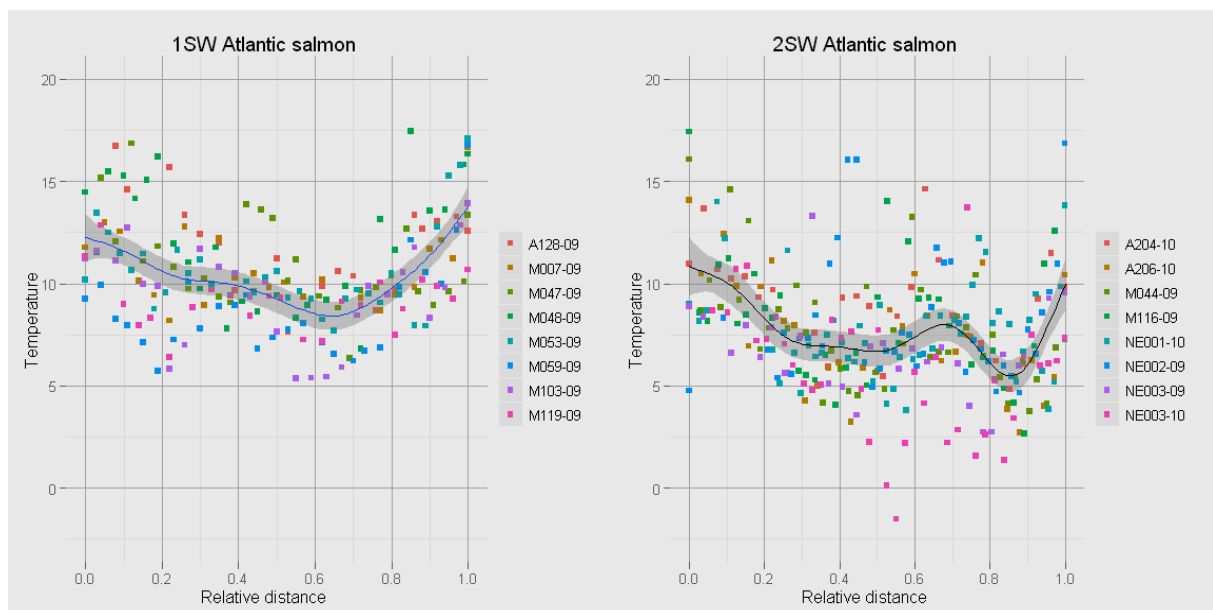
**Figure 1:** Intra-otolith  $\delta^{18}\text{O}$  values from eight individual wild Atlantic salmon. Standard error on measurements determined by repeat analyses of a known standard (see Appendix) was  $0.19\%$ . The x-axis is scaled such that  $0 =$  smolt emigration to saltwater and  $1 =$  capture ( $\sim 2$  years after emigration).

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$\delta^{18}\text{O}$  values of otolith aragonite are inversely related to water temperature. Several 'otolith thermometry' equations have been developed empirically; here, we use an equation derived from previous SIMS work described in [5]. Four of the eight individuals were captured off the north coast of Scotland in summer 2009 and four were caught in the same location during the summer 2010 netting season. These represent two separate cohorts of 2SW salmon, but for simplicity their results are grouped in Figure 2.

[4] suggest that from December to May of the second winter, 2SW salmon of southern European origin (incl. Scotland) follow the currents of the Labrador Sea eastward to the North Atlantic Current and onwards to the North Atlantic sub-polar gyre. If this were true, salmon migrating in these waters would have encountered markedly higher sea surface temperatures (SST) corresponding to  $\delta^{18}\text{O}$  values approximately 1-2‰ (or 4-8°C) higher than in the previous winter. However, the thermal conditions experienced by salmon during each winter period were similar and varied by only  $\sim 1^\circ\text{C}$ , suggesting that these fish did not migrate within the North Atlantic Current on their return migration.

When compared with thermal profiles estimated from eight 1SW salmon, the present profiles show that salmon returning after two winters at sea consistently occupied significantly lower water temperatures than those returning after only one year. This suggests that while any shared residency between age cohorts is accompanied by active thermal selection and occupation of rather different waters within the broader Norwegian Sea area known to be exploited by salmon.



**Figure 2:** Estimated temperatures and GAM smooths of 1SW and 2SW wild Atlantic salmon caught in north Scotland. Temperatures were estimated using an equation derived for 1SW fish from [5], although it is the relative, rather than absolute, temperatures which are of interest here.

## References

1. ICES, "Report of the Working Group on North Atlantic Salmon (WGNAS)" (2010).
2. C. D. Todd *et al.*, *Global Change Biol.* **14**, 958 (2008).
3. P. J. Bacon *et al.*, *ICES J. Mar. Sci.* **66**, 844 (2009).
4. M. J. Dadswell, A. D. Spares, J. M. Reader, M. J. W. Stokesbury, *J. Fish Biol.* **77**, 435 (2010).
5. N. Hanson, PhD, University of St Andrews (2012).