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Insights into mixing and movement of albacore *Thunnus alalunga* derived from trace elements in otoliths

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Summary

Information on the movements and stock structure of commercially important tunas underpins the effective management of exploited populations. For South Pacific albacore (*Thunnus alalunga*), longstanding questions remain regarding the degree of connectivity among larval pools, the migration routes of juveniles and adults and the biophysical factors influencing these processes. Using laser ablation-inductively coupled plasma mass spectrometry (LA-ICPMS), we measured trace elements (Li, Mg, Mn, Cu, Sr, Ba, Pb, Ca) in albacore otoliths collected across a broad geographical range to address these knowledge gaps. Capture locations in French Polynesia, New Caledonia and New Zealand were discriminated with high accuracy (overall 85% of individuals correctly classified), with some evidence of larval mixing for fish sampled from New Caledonia and New Zealand, but not French Polynesia. Seasonal cycles in Sr:Ca and Ba:Ca were observed along transects encompassing the full life history of individuals. These patterns may reflect migrations across ocean fronts; however, the vertical behaviours of albacore and the lack of opportunities for controlled experiments on elemental uptake complicate environmental reconstructions. Expanding the present analysis and integrating multiple data sources (e.g. commercial catches, tag returns, otolith $\delta^{13}C$ and $\delta^{18}O$, ocean circulation models) could help clarify how environmental forces shape albacore behaviour and distribution.

Introduction

Tunas are highly mobile fishes that often undertake long-range movements to track prey resources, both horizontally and vertically, and to reproduce at distant spawning grounds (Block *et al.*, 2011). In the case of albacore (*Thunnus alalunga*), fundamental questions remain regarding the number and/or location of spawning areas, connectivity and mixing between larval sources and adult populations and the biophysical forces that structure these connections. This situation has limited the spatial resolution of the population model used to assess the status of the stock. Analysis of the chemical constituents of otoliths may provide an alternative method for elucidating mixing and movement patterns in albacore. Here we examine variation in trace elements in albacore otoliths across a large spatial scale spanning ~19° latitude and 49° longitude in the South Pacific Ocean to test the utility of otolith chemistry analysis as a tool for defining movements and stock structure in the species.

Materials and Methods

Sagittal otoliths were sourced from albacore captured by longline vessels operating in waters off French Polynesia (20° 13′S–20° 38′S, 146° 40′W–146° 52′W, n=9), New Caledonia (21° 43′S–23° 16′S, 164° 10′E–165° 19′E, n=12) and New Zealand (39° 25′S–39° 44′S, 178° 24′E–178° 27′E, n=8) between September 2009 and May 2010. Otoliths were embedded in epoxy resin and sectioned transversely through the core. Transverse sections (~1-mm thick) were mounted on a circular glass disc and polished on both sides to expose (assumed) daily growth increments near the primordium. Prepared sections were rinsed in deionised water, air dried overnight, and arranged in rows on microscope slides using double-sided tape. Otoliths were analysed using LA-ICPMS. Each otolith was ablated along a transect running from the primordium to the terminal edge. A pre-ablation step was implemented and data were then acquired from a second analysis along the same transect using a 32 μm spot, with the laser pulsed at 10 Hz and scanned at 6 μm sec^{-1} with fluence of ~5 J cm^{-2}. This produced a 32-μm wide × 6-μm deep transect incorporating the full life lifetime of each fish. Otoliths were analysed for ^{7}Li, ^{25}Mg, ^{43}Ca, ^{55}Mn, ^{63}Cu, ^{88}Sr and ^{138}Ba, ^{207}Pb, and Ca was used as an internal standard. We estimated annual age and back-calculated birth year for each fish using validated methods based on counts of annual growth zones in the sectioned otoliths (Farley *et al.*, 2013a).

Results and Discussion

Our results indicate that trace element analysis of albacore otoliths can contribute valuable information on the movement and mixing patterns of the South Pacific stock at a geographic scale useful for fishery management purposes. Variation among capture locations was observed in some, but not all markers measured at the otolith edge; however, capture locations could be clearly discriminated with a multi-element signature comprising Li:Ca, Mg:Ca, Mn:Ca, Cu:Ca, Sr:Ca, Ba:Ca (MANOVA, Pillai's trace = 0.869, F = 2.435, d.f. = 12, 38, P = 0.018). Overall, 85% of fish were correctly classified to their capture location. Although based on a small dataset, the otolith core analyses provided some preliminary insights into connections between larval sources and adult populations across the South Pacific. Otolith core values from New Zealand and New Caledonia were not significantly different in any comparisons, but French Polynesian samples were higher in Mg:Ca. Our findings provide no information as to the location of spawning sites or larval sources (Nishikawa *et al.*, 1985; Farley *et al.*, 2013b), yet they do proffer questions on whether connectivity and migration patterns remain consistent under differing oceanographic/climatic conditions, for example, during El Niño Southern Oscillation (ENSO)-neutral (i.e. 2005/06), versus El Niño and La Niña years (Lu *et al.*, 1998; Briand *et al.*, 2011).

Cycling of Ba:Ca and Sr:Ca was observed in the outer growth zones of all otoliths analysed, often in near synchrony or closely correlated with annuli, but sometimes de-coupled, with no clear relationship evident between cycles (or lack of) and annulus deposition. Given the ocean circulation patterns acting during our study, it is conceivable that such cycles may reflect seasonal north-south movements across oceans fronts (Childers *et al*., 2011). However, the high mobility of albacore poses substantial challenges to disentangling the biological versus physical influences on elemental uptake into the otolith, and hence, for accurately reconstructing environmental histories. Adopting a multidisciplinary approach could benefit future efforts to understand how environmental factors influence connectivity and movement patterns in albacore.

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