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Applying mixed-effects growth models to back-calculated size-at-age data for Atlantic bluefin tuna (*Thunnus thynnus*)

Nathan D. Stewart [a,*], Dheeraj S. Busawon [a], Enrique Rodriguez-Marin [b], Matt Siskey [c], Alex Hanke [a]

[a] St. Andrews Biological Station, Fisheries and Oceans Canada, St. Andrews, NB E5B 2L9, Canada
[b] Instituto Español de Oceanografía, Centro Oceanográfico de Santander, Promontorio San Martín, s/n, 39004 Santander, Spain
[c] School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195, USA

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ABSTRACT

We fit growth models to back-calculated size-at-age data for Atlantic bluefin tuna (*Thunnus thynnus*) captured in the western Atlantic management area to inform alternative growth scenarios within the current management framework of the species. The Modified-Fry function was the best-performing of three back-calculation functions based on a leave-one-out cross-validation for within-cohort comparisons. We fit multiple growth models to the back-calculated growth trajectories, and demonstrated that growth parameters were highly sensitive to whether the lack of independence between back-calculated lengths from each individual was accounted for by the model. Non-linear mixed-effects modelling provides a suitable approach for accounting for this lack of independence and the autocorrelation between back-calculated lengths from the same individual. We further demonstrated the utility of mixed-effects models for predicting future growth of individuals using a forecasting test. We used this modelling approach to demonstrate that male bluefin tuna had greater estimated asymptotic length than females, and found that there was no significant difference in growth parameters between individuals assigned to genetically distinct spawning stocks.

1. Introduction

Growth models are fundamental to most stock assessment methods, and are therefore central to the sustainable management of wild fish stocks (Methot and Wetzel, 2013). Typically, growth models are conditioned on size-at-age datasets composed of single measurements from individual fish, with the goal of describing the average size-at-age for a given stock. Parameter estimates are typically influenced by age composition. Consequently, relative under-representation of certain age classes caused by fisheries selectivity can lead to biased results (Goodyear, 2019). Back-calculation provides a method for generating data for younger age classes, which are often under-represented in size-at-age datasets for species that are primarily sampled through fisheries with size limits instead of fisheries-independent surveys. However, not accounting for the inherent lack of independence between the repeated measures, which is characteristic of back-calculated data, can potentially bias growth parameter estimates and lead to erroneous standard errors (Jones, 2000). Mixed-effects models account for this lack of independence as they estimate individual growth trajectories and can further be used to test hypotheses related to variation in growth among groups (Vigliola and Meekan, 2009; Vincenzi et al., 2020).

This study will contribute to size-at-age data products provided to assessment scientists of Atlantic bluefin tuna (ABFT; *Thunnus thynnus*) by: (1) developing and evaluating the performance of a back-calculation method using otolith growth increments; (2) fitting growth models to back-calculated data and determining how the non-independent nature of back-calculated data affects growth parameter estimates; and (3) evaluating variation in growth between sexes and genetically distinct spawning stocks for ABFT. This approach is also broadly applicable to more data-limited species where back-calculation can serve as a way to generate data for poorly represented age classes.

ABFT are a highly migratory fish of significant conservation and management concern, as they are harvested by fisheries from more than 50 countries (SCRS, 2019). Genetically distinct ABFT populations show fidelity to spawning grounds in the Gulf of Mexico and the Mediterranean Sea (Block et al., 2005; Boustany et al., 2008), although some spawning likely occurs outside of these primary locations (Richardson et al., 2016). ABFT are currently assessed and managed as

* Corresponding author.
E-mail address: nathan.stewart@dfo-mpo.gc.ca (N.D. Stewart).

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