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Estimating individual growth variability in albacore (*Thunnus alalunga*) from the North Atlantic stock: Aging for assessment purposes

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ABSTRACT

Length-frequency data and derived catch at age matrices are used in north Atlantic albacore (*Thunnus alalunga*) stock assessment conducted within the International Commission for the Conservation of Atlantic Tunas (ICCAT). Growth is assumed to follow the von Bertalanffy model with the assumption that growth parameters are constant over time and the same for all fish. However, individual growth variability is an important factor not considered and affecting the input into the modelling of the population. This study describes a Bayesian hierarchical model applied to model the individual variability in the parameters asymptotic length (L_∞) and growth rate (K) of the von Bertalanffy growth model for North Atlantic albacore. The method assumes that the L_∞ and K values for each individual fish are drawn from a random distribution centered on the population mean values, with estimated variances. Multiple observations of spine diameter at age for individual fish were obtained by direct reading of spine sections collected in 2011 and 2012. A suite of back calculation methods were then applied to the measurements of annuli diameters in the aged individuals observed to back-calculate lengths at each age. The von Bertalanffy model was fitted to the measured and back-calculated lengths. Models with and without individual growth variability were compared using the deviance information criterion (DIC) to find the best model. Normal and log-normal error distribution models were used to analyse the data. Additionally, subsamples of the data were used to evaluate whether an unbalanced age-distribution in the data affects estimates of growth parameters. It was found that North Atlantic albacore asymptotic length (L_∞) varies significantly between individual fish but not individual rate growth (K), for all back-calculation methods. Furthermore, negatively correlated relationships between von Bertalanffy growth parameters of asymptotic mean (L_∞) and growth rate (K) were estimated for North Atlantic albacore with the array of models explored. The overall estimated values of K and population mean L_∞ parameters were similar to values estimates in previous north Atlantic albacore growth studies.

1. Introduction

Atlantic albacore tuna (*Thunnus alalunga*) is large pelagic fish that inhabits the temperate and subtropical waters of the Atlantic Ocean. It is an economically important species that is managed under the International Commission for the Conservation of the Atlantic tunas (ICCAT). In the Atlantic, three stocks are identified for assessment purposes: North and South Atlantic separated at 5°N in the Atlantic and a third Mediterranean stock (ICCAT, 2006–2013). Commercial fisheries in the Northern Atlantic have targeted the albacore stock by surface fisheries since the 1930s and longline fleets beginning in the 1950s (ICCAT, 2013a). The surface fishery represents roughly 80% of the total catch and the longliners account for 20% in the last two decades (ICCAT, 2014). The surface fishery includes three different type of vessels according to the gears: mid-water pair pelagic trawls, trollers and baitboats. Spanish baitboats and troll landings represent an approximate participation in the fishery between 55 and 65% of the total annual surface fishery landings from the North Atlantic stock.

The last assessment of North Atlantic albacore stock, performed in 2013, reported substantial uncertainty on the current stock status considering the set of models applied, but it was concluded that the status of the spawning stock biomass was overfished (ICCAT, 2014).

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North Atlantic albacore are assessed with a variety of models, including a length based model (Multifan-CL) that requires a growth curve as input, and two other models: VPA and stock synthesis (SS) that are fitted to catch-at-age data calculated from catch-at-length data using a von Bertalanffy (von Bertalanffy, 1938) growth curve (ICCAT, 2013a). Moreover, the growth function is used to derive reference points for sustainable management (Beverton and Holt, 1957; ICCAT, 2013a).

Direct aging data have been used to study growth. A number of studies have been conducted to describe the growth of northern albacore (Bard and Compeán-Jimenez, 1980; Bard, 1981; Gonzalez-Garcés and Fariña-Perez, 1983) based on reading of the first fin ray of the first dorsal fin to determine age and fit a von Bertalanffy (von Bertalanffy, 1938) growth model, considering constant parameters for the population. The most recent study, assumed constant parameters and used the first dorsal fin ray section readings along with updated release and recapture tag data in an integrated model to fit the von Bertalanffy function (Santiago and Arrizabalaga, 2005). The analysis of the North Atlantic albacore population (ICCAT, 2014) has incorporated knowledge on the growth biology based on Bard's (1981) growth model and Santiago and Arrizabalaga (2005) growth estimates to characterize the population dynamics of the north Atlantic albacore stock. The catch-at-size data for northern stock is analyzed to derive an annual age-length key (ALK) by applying the Kimura and Chikuni iterative method (1987) and using Bard's (1981) growth parameters (ICCAT, 2014; Ortiz, 2014).

Generally, when growth models are fitted to length-at-age data, only one observation is available for each individual animal. Therefore, it is not possible to determine what fraction of the variation in measured length is due to measurement error, and what fraction is due to variation in growth between individual fish. Thus, the residual error in a fitted growth model includes both individual variation and measurement error. When multiple observations are available for each individual, for example from tag-and-recapture data, it is possible to evaluate how much individual variation exists in the growth model parameters, and to estimate the correlation between growth parameters across individual fish (Zhang et al., 2009).

None of the growth models use in the assessment of the North stock albacore incorporate individual variability in the von Bertalanffy growth function parameters. However, individual variation in growth is expected depending on physiological and environmental conditions. The first model incorporating individual variation in the K and L_∞ von Bertalanffy growth parameters was described by Sainsbury (1980); later Kirkwood and Sommers (1984) continued investigating variation in maximum length between individuals. Moreover, Hampton (1991) modified those approaches incorporating a model error component and estimates of a release length measurement error term fitted by maximum likelihood. The available North Atlantic albacore tag-release data were analysed to estimate von Bertalanffy growth parameters based on Hampton's model that incorporates individual variation in growth, release length measurement error and model error terms (Ortiz de Zárate and Restrepo, 2001).

Back calculation methods are employed to estimate length of a fish at previous age based on reading of calcified structures such as: otoliths, scales, and fin rays (spines), among other skeleton structures. This technique re-creates the life history of individual fish. This method assumes that there is a relationship between the length of the fish and the skeleton structure, either linear or allometric (Bagenal, 1978; Campana, 1990; Francis, 1990; Folkvord and Mosegaard, 2002; Ricker, 1992).

One albacore spine aging study used a linear relationship recommended by Campana (1990) to back-calculate lengths (Santiago and Arrizabalaga, 2005); meanwhile other spine studies incorporated proportional methods to back-calculate lengths (Cheng et al., 2012; Duarte-Neto et al., 2012; Kopf et al., 2011; Sardenne et al., 2014). Methods for back-calculation of length-at-age generally assume that the relationship between fish length and hard part diameter is a family of lines radiating from a common point near the origin, with different slopes for each fish (Francis, 1995). This assumption allows individual fish lengths to vary more when they are larger than when they are smaller, which is biologically reasonable and performs well in simulation studies (Schirripa, 2002). However, which back calculation method is best suited to be applied may depend on the functional form of relationship between length and annulus diameter, and other growth characteristics that may vary between stocks (Schirripa, 2002). In the thorough review of types of back-calculation methods by Francis (1990), he recommended that both regression of body length-scale to scale radius (BPH) and scale radius- to body length (SPH) be used for each fish population because neither is clearly preferable. Later, Ricker (1992) proposed the geometric mean regression using both relationships named by Francis (1990) to estimate the y-intercept for the back-calculation of length from hard structures annuli, in the absence of any biological intercept estimate. This method was applied by Pilling et al. (2002) to back-calculate lengths from otolith radius counts over the life span of a number of individuals of tropical emperor (*Lethrinus mahsena*), and the lengths were used to fit models that incorporated individual variation in growth.

The objective of this paper is to use multiple length and age reading estimates for individual albacore tuna, where lengths were back-calculated from the measured diameters of the annuli readings of cross-sections of first dorsal fin ray (spine), to evaluate how much the growth parameters vary between individual fish in the North Atlantic albacore population. Growth models were fitted and evaluated using Bayesian hierarchical models. Several alternative back-calculation models were used to determine whether the choice of back-calculation method influences the estimated growth curve parameters or the conclusions about individual variation. Finally, alternative sub-sets of the data were used to evaluate whether differences in sample sizes across ages influenced the results, and whether using back-calculated lengths gave different average results from using lengths at capture only. This study is the first attempt to use an array of back-calculated lengths from spine measured annulus to estimate growth parameters for North Atlantic albacore incorporating individual variability in the von Bertalanffy function model.

2. Material and methods

2.1. Sampling of spines (first fin ray)

As part of the monitoring of the activity of the Spanish albacore (*T. alalunga*) fisheries, biological samples are collected from the landings at the main fishing ports (Ortiz de Zárate et al., 2013, 2015; in press). A number of trips were sampled to obtain the length frequency of the catch by applying random sampling stratified according to commercial categories of catches landed at the main fishing markets. Random samples of the first fin ray (spine) from the first dorsal fin were removed during the albacore length sampling procedure. For each fish, the total fork length (FL) to the nearest centimeter, date, and catch area were noted. Spines were collected based on a length-stratified sampling protocol by 1 cm class length, covering the whole length range of albacore landings. Sampling design of spines was stratified by spatial and temporal strata. Collection of spines was done once a week at selected fishing ports, covering different geographical areas (1° × 1° degrees), during the fishing season, from June to November in the Northeast Atlantic (Fig. 1). The samples in this study were collected during the 2011 and 2012 albacore fishing seasons and no sex information