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Using an approximate length-conditional approach to estimate von Bertalanffy growth parameters of North Pacific albacore (*Thunnus alalunga*)

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ABSTRACT

Growth models in stock assessments can strongly influence the estimated biomass that affect the conclusion of stock status and exploitation level. Recent studies on North Pacific albacore (*Thunnus alalunga*) growth obtained age-length data from hard parts and fit the age-length data to a von Bertalanffy growth model, assuming each observation of length is a random sample for a given age. However, these previous studies may have resulted in biased growth parameter estimates because these samples were not chosen at random and hence violated the assumptions of the method. In this study, we instead use an "approximate length-conditional" approach, which assumes that each fish is a random sample from that length bin based on an equilibrium population age structure, to fit age-length data from three previous studies. Results of the length-conditional approach resulted in a sex-combined growth curve that is similar to the previous estimates over the young and mid ages (age 2–6) but with different asymptotic lengths. Estimated growth parameters were not highly sensitive to assumed mortality rates but changing the data-weighting scheme can result in differences in estimated growth parameters. Although the length-conditional approach likely result in less biased estimated length-at-ages, especially for the youngest and oldest ages, the estimated growth curves from this study may not be representative of the stock due to potential regional differences in growth, and age and sex-specific movements. In order to successfully unravel the complexities of albacore growth observed in this and previous studies, given the complex life history, ocean-basin scale movements and multiple international fisheries, a well-coordinated and designed international sampling effort will be required.

1. Introduction

Modeling the growth of fish, or how fish get bigger with age, is a key component of most fish stock assessment models (Francis, 2015). It is especially critical for stocks without large-scale production aging of hard parts because observed size compositions are converted to age compositions using a growth model. In addition to directly informing model processes like selectivity and recruitment, the age compositions can also strongly influence, albeit indirectly, key derived quantities like fishing mortality and relative population scale (Maunder and Piner, 2014). Therefore, the growth model used in an assessment can have major influences on the estimated stock status and exploitation level (Wang et al., 2014).

The stock assessment of North Pacific albacore (*Thunnus alalunga*) in 2011 (ISC, 2011) and 2014 (ISC, 2014) found that growth was a key uncertainty in the assessments and strongly influenced model estimates of population scale. The growth estimates used in the stock assessment were based on 3 recent studies (Chen et al., 2012; Wells et al., 2013 and Renck et al., 2014), which were conducted to update studies from the 1950s and 60s (Otsu and Uchida, 1959; Clemens, 1961; Yabuta and Yukinawa, 1963). These three studies obtained matched pairs of data on fish age and length (age-length data) by aging hard parts (primarily otoliths) from fish with lengths measured during sampling. These age-length data were then fit to a von Bertalanffy growth model (VBGM). Wells et al. (2013) and Renck et al. (2014) primarily used albacore samples from the eastern and central North Pacific, although smaller numbers of samples were from the western North Pacific. In con-

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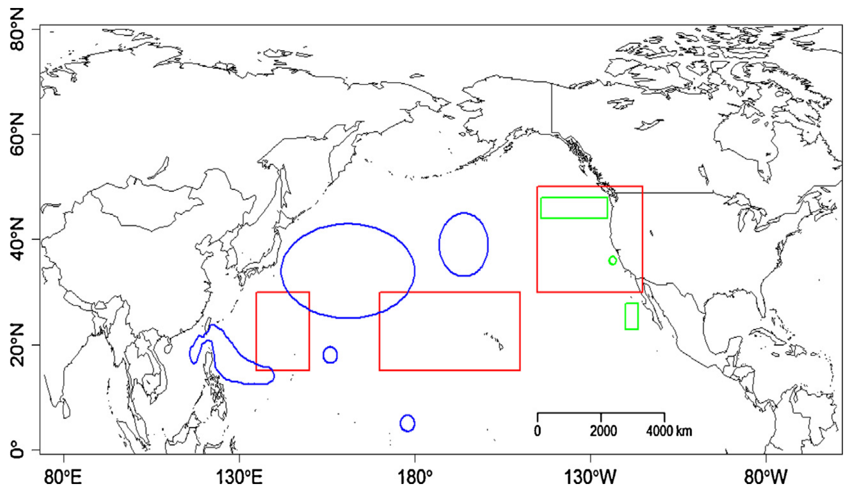

Fig. 1. Approximate regions where North Pacific albacore tuna otolith samples were collected by Chen et al., 2012 (blue), Wells et al., 2013 (red), and Renck et al., 2014 (green). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Sample sizes of age-length data from three recent studies on age and growth of North Pacific albacore used in this study.

Study	Female	Male	Unspecified sex	Total
Chen et al. 2012	125	148		273
Wells et al. 2013	34	92	360	486
Renck et al. 2014			125	125
Total	159	240	485	884

trast, Chen et al. (2012) primarily used samples from the western and central North Pacific (Fig. 1).

Similar to the vast majority of studies on fish growth utilizing age-length data from hard parts, Chen et al. (2012) and Wells et al. (2013) fit the age-length data to a VBGM, assuming that each observation of length is a random sample for a given age (random at age; Francis, 2015). Because the age of a sample can only be determined after the sample has been taken, this assumption can be met by randomly sampling from the population. However, most age and growth studies, including those on North Pacific albacore do not perform random sampling and instead sample individuals according to predefined length bins that are spread across the size range of the species. For example, Wells et al. (2013) appeared to have oversampled the largest albacore from the Hawaii longline fishery (Appendix, Fig. A1) relative to the size range available. In addition, collected samples were predominantly male, and could therefore not account for the sex-specificity of growth for these samples.

Length-based sampling can lead to bias in the estimated growth parameters (Piner et al., 2015; Taylor et al., 2005; Schueller et al., 2014). It is unclear if the estimated growth parameters from previous studies on North Pacific albacore were biased but the sampling approaches used did not meet the assumptions of the method used for fitting age-length data. One possible way of improving the growth estimates from these age-length data is to treat them as an observed distribution of ages conditioned on a length interval (random at length; Francis, 2015). Estimating growth parameters from random at length data does not assume random sampling of the population but instead assumes each fish (its accompanying observed age) is a random sample from that measured length or length bin. The need to model the expected population age-structure from which the sample was taken has typically restricted the use of this length-conditional approach to within a stock assessment model (e.g., Maunder, 2002; Taylor and Methot, 2013; Methot and Wetzel, 2013). However, Piner et al. (2015) proposed and evaluated an "approximate length-conditional" approach to fitting age-length data that is independent of a stock assessment model but is instead based on an equilibrium population age structure. It should be noted that the terms "approximate length-conditional" and "length-conditional" are used interchangeably in this paper to mean the equilibrium age-structure approach proposed by Piner et al. (2015), unless otherwise stated. Piner et al. (2015) used a series of simulations to evaluate the length-conditional approach. This study complements that study by using the length-conditional approach on real age-length data, with all its concomitant complications.

The objectives of this study are to: (1) use the length-conditional approach to fit age-length data from previous albacore growth studies and compare the growth estimates to those derived from a traditional approach, (2) study the sensitivity of the length-conditional approach to the assumed total mortality rate and data-weighting approaches, and (3) update the sex-specific and sex-combined growth model parameters from the three most recent otolith-based studies, due to a recent switch from a sex-combined to sex-specific growth models in the 2014 stock assessment.

2. Data and methods

2.1. Data

Paired age-length data ($n = 884$) from three recent North Pacific albacore age and growth studies (Chen et al. (2012), Wells et al. (2013) and Renck et al. (2014)) were used in this study (Table 1). These data included estimated ages of fish from otolith samples, measured fork lengths (cm), sampling dates, sampling regions and the sex of the fish for a portion of the samples. All data collected by Chen et al. (2012) included the sex of sampled fish (Female: $n = 125$, Male: $n = 148$). Only a quarter of data from Wells et al. (2013) specified the sex of the sampled fish, while the rest of the samples were not sex-specific (Female: $n = 34$, Male: $n = 92$, Unknown sex: $n = 360$). All samples from Renck et al. (2014) were juvenile alba-