Fisheries Research 180 (2016) 87–91

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Estimation of growth within Stock Synthesis models: Management implications when using length-composition data

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ARTICLE INFO

Article history:
Received 10 April 2015
Received in revised form
26 September 2015
Accepted 28 September 2015
Available online 23 October 2015

Keywords:
Growth
Fisheries management
Stock Synthesis
Stock assessment
Bigeye tuna

ABSTRACT

Growth modeling is an important component of contemporary fisheries stock assessment, and is typically conducted external to assessment models. However, direct growth estimates may be problematic for some species because of difficulty in aging older individuals using hard parts. Stock assessment results and the resulting management advice can be sensitive to growth specification, particularly when fitting to length-composition data. This study evaluates the influences of mean length-at-age (mean length) and variation in length-at-age (standard deviation; SD) in relation to length composition on management advice and determines if mean length and SD can be estimated inside stock assessment models. The Stock Synthesis assessment for bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean, demonstrates that management quantities were sensitive to the assumptions of mean length and the SD of old fish. Using simulation analysis, we found that mean lengths of both old fish and young fish, and the SD of young fish, can be reliably estimated, and that the estimates were robust to the misspecification of length-based longline selectivity curve (asymptotic or dome-shaped). The SD of old fish and the growth coefficient were less reliably estimated. This study also demonstrates that equilibrium yield is robust to uncertainty in growth parameters when management is based on setting fishing mortality equal to F_{MSY}.

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1. Introduction

The growth model is an important component in contemporary fisheries stock assessment (Maunder and Piner, 2015). Mean length-at-age in combination with the length–weight relationship, maps the population dynamics, which is in numbers, to the catch, which is typically in weight. A similar mapping is needed for most management quantities (e.g., maximum sustainable yield (MSY) and corresponding stock biomass). Another important aspect related to growth is in the prediction of the length-composition of catch, which is used when fitting the observed length composition to inform the estimates of model parameters (Maunder and Piner, 2015).

Growth modeling is generally considered to be the most certain biological process in integrated stock assessment models (Maunder and Punt, 2013; Maunder and Piner, 2015). Typically, the parameters of the growth equation are estimated outside stock assessment models, i.e., they are fixed before applying the assessment model to estimate other parameters. Growth parameters can be estimated from age-length data, which is commonly available for many species, and from mark-recapture data (Aires-da-Silva et al., 2015). Unfortunately, there are a variety of problems with growth estimates. For example, estimates of age from daily ring counts on otoliths can be difficult for older individuals because the rings become too close to each other to count (e.g., bigeye tuna *Thunnus obesus*; Schaefer and Fuller, 2006). Estimates of growth from different sources (e.g. hard parts, mark-recapture data, and modes in length-composition data) may differ (Chang and Maunder, 2012), and it may not be clear which is correct.

For integrated stock assessment modeling, in the absence of age-composition data, age must be inferred using length-composition data and a deterministic growth curve. Therefore, in addition to mean length-at-age, the variation of length-at-age also must be reliably quantified to use length-composition data.

The objective of this study is to illustrate the influence of mean length-at-age (MLAA) and variation in length-at-age (VLAA) in conjunction with length-composition data on management advice, and

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http://dx.doi.org/10.1016/j.fishres.2015.09.019
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Table 1
Parameter values and longline selectivity curve for the sensitivity analysis. Base—base case value (L2 = 185.5 cm and SD-old = 12.04); Lower—10% lower than base case value; Higher—10% higher than base case value.

Model No.	L2	SD-old	Longline selectivity curve
1	Lower	Lower	Asymptotic
2	Base	Lower	Asymptotic
3	Higher	Lower	Asymptotic
4	Lower	Base	Asymptotic
5	Base	Base	Asymptotic
6	Higher	Base	Asymptotic
7	Lower	Higher	Asymptotic
8	Base	Higher	Asymptotic
9	Higher	Higher	Asymptotic
10	Lower	Lower	Dome-shaped
11	Base	Lower	Dome-shaped
12	Higher	Lower	Dome-shaped
13	Lower	Base	Dome-shaped
14	Base	Base	Dome-shaped
15	Higher	Base	Dome-shaped
16	Lower	Higher	Dome-shaped
17	Base	Higher	Dome-shaped
18	Higher	Higher	Dome-shaped

to determine if MLAA and VLAA can be estimated reliably within an assessment model. First, we conduct sensitivity analyses for growth parameters to illustrate their influences, using a full stock assessment model of bigeye tuna in the eastern Pacific Ocean (EPO). Second, we conduct a simulation analysis, using a simplified bigeye tuna assessment model to determine whether the MLAA and the VLAA can be estimated reliably within an assessment model. Finally, impacts of misspecification of growth parameters on the stock are evaluated in terms of equilibrium spawning stock biomass (SSB) and yield. We also investigate the influences in the presence of dome-shaped selectivity, since this is often an important confounding factor in estimating the catch of large individuals.

2. Material and methods

2.1. Sensitivity analysis

The von Bertalanffy growth function (VBGF) was used throughout this study. In Stock Synthesis (Methot and Wetzel, 2013), MLAA is parameterized using L1 (the size of a reference age near the youngest age, here the age at 1 quarter), L2 (the size of a reference age near the oldest age, here the age at 40 quarters), and K (the growth coefficient), and VLAA is parameterized using the standard deviation (SD) for young and adult tunas (denoted SD-young and SD-old). SDs for ages between young and adult fish are assumed to change linearly with size-at-age (Methot and Wetzel, 2013).

The bigeye tuna model of Aires-da-Silva and Maunder (2012), based on Stock Synthesis, was used to explore the sensitivity of management quantities to the values for the growth parameters. This model includes 23 fisheries and uses a quarterly time step from 1975 to 2011. The length-based selectivity curves for longline fisheries in the central and southern Pacific, which catch larger bigeye tuna, are assumed to be asymptotic (logistic) (Table 1). The length-based selectivity curves of other fisheries are assumed to be dome-shaped (i.e., double normal with six parameters defining the beginning size of the plateau, the width of the plateau, the ascending width, the descending width, the initial selectivity at first bin, and the final selectivity at last bin). The selectivity parameters of the logistic and double normal curves are estimated when fitting the model, except for the two parameters of the double normal curve defining the initial selectivity at first bin and the final selectivity at last bin, which are fixed at low values to avoid numerical estimation issues. Further details about the model configuration can be found in Aires-da-Silva and Maunder (2012).

For the sensitivity analysis, the bigeye tuna assessment model was run by fixing the growth parameters (L2 and SD-old) at different values. We focus on L2 and SD-old because previous studies have shown that the stock assessment results are very sensitive to the average size of the oldest age class (Aires-da-Silva and Maunder, 2012). For simplicity and because of lack of sex-specific data, sex-specific growth or SD was not considered. The parameter values for the base case in Aires-da-Silva and Maunder (2012) were also considered as the base case here (i.e., L2 = 185.5 cm and SD-old = 12.04). Values 10% higher and lower than the base case values were applied for the sensitivity analyses. We also considered dome-shaped selectivity assumptions for the longline fishery, configured as same as described above. Thus, the sensitivity analysis involves 18 model configurations (see Table 1). Impact on the stock assessment was evaluated, based on key model outputs relating to stock status and management quantities.

2.2. Simulation analysis

A simplified version of bigeye tuna assessment model of Aires-da-Silva and Maunder (2012) was used for the simulation analysis as simulator and estimator, and to evaluate the estimability of growth parameters of the VBGF. The simulation model included only two fisheries: purse seine and longline (1975 through 2011). Asymptotic and dome-shaped selectivity were assumed for purse seine and longline fishery respectively, configured as in the sensitivity analysis (Section 2.1). The Beverton–Holt spawner–recruitment relationship with steepness = 1.0 was assumed.

The simulation model was parameterized conditioning on the original data (i.e., a stock assessment was conducted to estimate the parameters using the original data). The model was fit to indices of relative abundance for the purse seine (1995–2011) and the longline fishery (1975–2010) under the assumption of lognormal error (log-transformed standard deviation = 0.4 and 0.15, respectively), and length-composition data for the purse seine (1994–2011) and longline fishery (1975–2008). The average sample sizes for the purse seine fishery and longline fishery are 16 and 8, respectively. Using fixed historical catch can cause the population to crash when generating simulated data with random recruitment, so the Stock Synthesis option that uses fishing mortality by fishery and year as parameters to be estimated was applied in the simulator. Other parameters estimated when conditioning the simulator include the virgin recruitment, time-series of recruitment deviations, parameters for selectivity curves, and catchability coefficient for both fisheries. The dynamics of the simulation model can also be found in Wang et al. (2014).

The parametric bootstrap feature of Stock Synthesis was used to generate the simulated data (catch, index of relative abundance and length-composition by fishery). Process error was modeled in terms of lognormal quarterly recruitment deviates with standard deviation = 0.6. Twelve scenarios, in terms of L1, L2, K, SD-young, SD-old, and the length-based selectivity curve for longline fishery (asymptotic or dome-shaped), were considered (Table 2). In the estimator, the estimability of the growth parameters and impact of misspecification of longline selectivity were systematically tested (Table 2). For simplicity, L1 and K were not separately tested because they are usually correlated when L2 is fixed. SDs for both young and old tunas was also treated as a parameter set. Sex-specific growth or SD was not considered. Scenarios with L1, L2, and K estimated and SDs fixed were not considered because this usually wouldn't occur in real applications. All other parameters (i.e., natural mortality, fecundity, length–weight relationship, stock-recruitment steepness, and recruitment variability) in the estimator were fixed at values used in the simulator. More than one hundred data sets were generated for each scenario to ensure that at least 100 had

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