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The effect of length bin width on growth estimation in integrated age-structured stock assessments

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ABSTRACT

Analysts conducting stock assessments using integrated, age-structured models must discretize length data into a limited number of bins (data bins). Furthermore, some modeling frameworks also allow users to specify a distinct structure for how lengths of fish are represented in the model (model bins). The effect of choices regarding the number and width of these bins on model output is unclear, and these choices are made inconsistently in assessments across regions and species. Here, we used the stock synthesis modeling framework, and the ss3sim stock assessment simulation package, to explore the effects of choices about length discretization on stock assessment performance for three fish life-history types and four data cases. We found that, with all other aspects of a model fixed, increasing the model bin width tended to increase estimates of spawning biomass, but this effect depended on the shape of length-based processes (e.g., growth, maturity, and selectivity). Thus, we suggest analysts using model bins wider than 1 cm explore the effect of this decision on derived management quantities. In the context of estimation, there generally was a predictable tradeoff between estimation accuracy and model run time, with finer model and data bins always improving estimation accuracy and model convergence, but increasing run time. In some cases, wider data bins reduced run time (by up to 50%) with little sacrifice in model estimation performance, particularly those using conditional age-at-length data. This study identifies key aspects to consider when binning length, and provides pertinent information for stock assessment best practice guidelines.

1. Introduction

Integrated, age-structured fisheries stock assessment models are complex, powerful, and flexible tools for analyzing the status of a fish stock (Hilborn and Walters, 1992). However, this complexity often requires an analyst to make a variety of subjective biological, statistical, and modeling decisions, the effects of which are often poorly understood (Maunder and Piner, 2015). One such decision is how to discretize fish length measurements into 'bins' for analysis. In reality, growth is a continuous process, yet in assessment models, length data, and processes which depend on length, must be broken into discrete bins. Length bin specification is of central importance when constructing size-structured models (Drouineau et al., 2008), but it also is important in age-structured models because many important biological and fishery processes are a function of length (e.g., growth, maturity, and selectivity). In addition, lengths, which are easier to measure than ages, are a common source of data used to inform estimates for key processes like growth.

Within some types of age-structured stock assessment models, analysts must specify two distinct types of length bins. First are 'data bins,' which specify the resolution of the observed length data (e.g., length compositions). For example, length measurements

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Table 1
The three life-history operating model configurations, including minimum and maximum length bin (measured in cm), growth parameters, and the parameters natural mortality (M), steepness (h), and recruitment variability (σ_R).

Life history	Min. bin	Max. bin	L_{min}	L_{∞}	CV_{young}	CV_{old}	k	M	h	σ_R
Cod	10	190	20.0	132.0	0.10	0.10	0.20	0.20	0.65	0.40
Flatfish	2	102	12.7	47.4	0.20	0.20	0.35	0.20	0.76	0.80
Rockfish	10	110	18.0	62.0	0.13	0.13	0.05	0.08	0.44	0.50

from a fishery may be recorded to the nearest 1 cm, and bins must span the observed length range (i.e., 10–50 cm). Second are 'model bins,' which define the length dynamics within the model. For the same example, the model bins may need to range from 5 to 100 cm to appropriately capture fish in the population that are too small to be selected by the gear, and larger fish which were previously available to fishermen. The choice of data bins is limited by the properties of the observed data, whereas the choice of model bins may be based on prior observations or may be a subjective decision. In many age-structured stock assessment modeling frameworks, the data and model bins match. The common bin width is decided upon based on the bins in which the length measurements are collected, or some aggregation subjectively chosen by the analyst. For cases where the data and model bins do not match, model bins need to be mapped to the data bins (typically via aggregation) to calculate the likelihood of the expected proportions at length, conditional upon the observed data. Distinct bin types are possible for any custom-built model, as well as the widely-used age-structured population modeling framework stock synthesis (SS; Methot and Wetzel, 2013). Therefore, depending on the modeling framework, an analyst must decide the minimum length, maximum length, and bin width (together the 'bin structure'), and whether to have distinct model and data bins.

The choice of bins represents a tradeoff between model performance and accuracy. Increasingly, fine model bins characterize length-based processes at a finer scale, but also increase computational requirements. Finer bins are therefore expected to increase accuracy, but may increase model run time (i.e., slower estimation). Conversely, increased bin width may reduce the accuracy of model estimates, but reduce model run time. Reducing model run time may free up time for analysts to conduct sensitivity tests or perform Bayesian analyses (e.g., Stewart et al., 2013). However, guidelines on best practices for binning strategies (i.e., setting the width and thus the number of bins) to balance this tradeoff are not readily available. Consequently, decisions are typically *ad hoc* and likely based on factors such as preferences from personal or colleague experience. A non-exhaustive survey of stock assessments from the U.S. West Coast, Gulf of Mexico, South Atlantic, mid-Atlantic, and Australia found a wide variety of bin widths were used in assessments, with little relation to maximum length or other life-history characteristics (Fig. 1).

Szuwalski (2015) used simulation to explore the effects of increasing bin width on the precision and run time of a size-structured stock assessment model. He found biases in mature biomass and tradeoffs between precision, model stability, and run time, and recommended setting the bin width based on the goal of the analysis. Simulation testing has also been used to study age-structured stock assessment models for a wide range of topics, such as selectivity (Crone and Valero, 2014), steepness of the stock–recruit relationship (Conn et al., 2010), the value of data (Ono et al., 2014), retrospective patterns (Hurtado-Ferro et al., 2014), and time-varying natural mortality (Johnson et al., 2014). Here, we explore tradeoffs between run time and accuracy of growth and management quantities with increasing length bin widths for three life histories and two types of data (age vs. conditional-age-at length) in an age-structured stock assessment model.

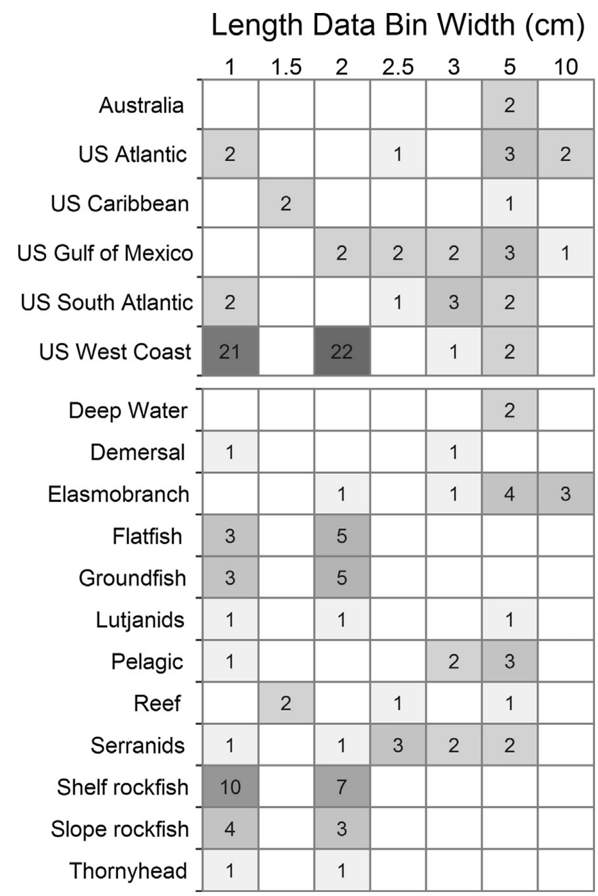

Fig. 1. Frequency of data length bin widths used by region (top panel) and by species grouping (bottom panel). Columns represent bin widths in cm, and cells contain counts with darker shading indicating higher counts. Results are from a non-exhaustive survey of stock synthesis models in the U.S. and Australia.

2. Materials and methods

2.1. Overview

We generated true population and fishery dynamics from an operating model (OM), and then ran stock assessments via an estimation model (EM). The OMs and EMs were parameterized from actual assessments and modified to generate and assess simplified, but realistic, dynamics. Process and sampling error were added to the OM values to simulate variable dynamics and data collection. During model development, we verified that under base conditions (i.e., the same model structure between OM and EM and unbiased data sampling) the EM parameter estimates were unbiased. This ensured any observed bias was caused by the hypothesis under investigation. We then varied the data and model length bin structures in the EMs and investigated how these differences affected the precision and bias of estimated growth and management quantities.

We conducted our analysis in R (version 3.2.2; R Core Team, 2015) using the stock assessment simulation framework ss3sim