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Get the biology right, or use size-composition data at your own risk

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ABSTRACT

Weighting of size-composition data (length or weight composition of the catches) can have a large influence on the results of contemporary integrated stock assessment models in the presence of model misspecification. Model misspecification leads to conflicting information among data sets, and the choice of data weighting will determine the results. Information content on absolute abundance and abundance trends contained in size-composition data is particularly susceptible to misspecification of the biological processes. Biological processes are often misspecified in assessment models for exploited fish stocks due to lack of information. The misspecification can be in a functional form (e.g., the growth curve) or in the values assumed for pre-specified parameters. Our application to bigeye tuna in the eastern Pacific Ocean shows how one needs to "get the biology right", i.e. minimize model misspecification, to reduce the dependency of stock assessment results on the weighting of the various data components. The stock assessment results are sensitive to the conversion from processed weight to total weight, a common, but often overlooked, component of model specification, and to the asymptotic length of the growth curve. The results are also sensitive to the weighting of the composition data. Application of the Age-Structured Production Model diagnostic shows that recruitment variation must be taken into account to interpret the absolute abundance and trend information contained in a CPUE-based index of relative abundance. Unfortunately, recruitment cannot typically be estimated from the relative index of abundance alone, so composition data are needed. The abundance estimates from an age-structured production model with estimated recruitment deviates are too uncertain (i.e., have wide confidence intervals) to be of use for management advice. Therefore, there is a trade-off between using composition data to estimate recruitment and its influence on estimates of absolute abundance through a catch-curve type process. We conclude that (i) integrated analysis, the current approach for assessing fish stocks, is supported by our results; (ii) composition data are needed to estimate recruitment; and (iii) addressing key model misspecifications should be a major component of integrated analysis.

1. Introduction

Many contemporary integrated fishery stock assessment models are fit to size-composition data (i.e., either length- or weight-composition data) to provide information on fishery selectivity and annual variation in recruitment (Maunder and Punt, 2013; Punt et al., 2013). The size-composition data can have an undesirable dominant influence on the estimates of absolute abundance and abundance trends because the interpretation of these data can be highly sensitive to model misspecification (Maunder and Piner, 2015). This has led to the recommendation that assessments should be implemented in such a way that information on abundance from indices of relative abundance is not overwhelmed by information from composition data (Francis, 2011) and to the development of appropriate diagnostics (Francis, 2011; Wang et al., 2014; Lee et al., 2014; Maunder and Piner, 2015; Carvalho et al., 2017).

Information on abundance from age-composition data with low aging error is much less susceptible to model misspecification than size-composition data. Length-composition data also relies on both

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the specification of the growth model and the variability of length-at-age. Weight-composition data rely additionally on the length-weight relationship. Unfortunately, due to the practical (e.g., the need to collect hard parts, such as otoliths, and the time aging takes) and economic constraints of obtaining age data, many assessments, e.g. Aires-da-Silva et al. (2016), rely predominantly or solely on size-composition data.

There are two major approaches to ensure that information about absolute abundance from size-composition data does not overwhelm that from the indices of relative abundance, especially when the model is misspecified. The first, and arguably the most common, is to reweight (typically downweight by reducing the sample size used in the multinomial likelihood) the composition data as recommended by Francis (2011). The second is to model additional process, as recommended by Maunder and Piner (2017). Sharma et al. (2014) also suggested using an "iterative approach" to avoid the over influence of unreliable length–frequency data, in which the composition data are used only to estimate the selectivity parameters and not when estimating the remaining parameters.

Preferably, the model structure would be correct and the weighting of the different data sets would not matter except for the overall estimates of uncertainty or, in extreme cases, where the model unsuitably follows random sampling variation in the data (Wang and Maunder, 2017). Maunder and Piner (2017) argue that down-weighting data is not desirable, unless it better represents the sampling error, because the model is still misspecified and it is unknown how the misspecification influences the model results. Data weighting deals with the symptom, rather than underlying cause (Wang et al., 2014). However, accounting for all the error, including correlation caused by model misspecification and non-modelled process variation, is important for statistical inference (Francis, 2017).

Here we use known misspecifications in the assessment for eastern Pacific Ocean bigeye tuna *Thunnus obesus* (Lowe, 1839) (Aires-da-Silva et al., 2016) to illustrate the importance of "getting the biology right", i.e. minimizing key model misspecification, to reduce the dependency of the stock assessment results on the weighting of different data components for an integrated stock assessment that is fit to size-composition data. Specifically, we investigate the influence of misspecification in the growth curve, the weight-length relationship, and the conversion factor from processed weight to whole weight. These biological processes are known to be misspecified, but the true specifications are uncertain, so we use sensitivity analyses based on alternative parameter values to illustrate the possible effects of model misspecification and data weighting. We then apply the Age Structured Production Model diagnostic (Maunder and Piner, 2015) and alternative weighting runs to gain insights into how to appropriately weight composition data.

2. Methods

2.1. Stock assessment model

The stock assessment of the bigeye tuna in the eastern Pacific Ocean (Aires-da-Silva et al., 2016) is conducted using Stock Synthesis (Methot and Wetzel, 2013). It is an age-structured integrated model with a quarterly time step and has multiple fisheries defined on the basis of gear type (purse seine, pole-and-line, and longline), purse-seine set type (on floating objects, unassociated schools, and dolphins), time period, length-frequency sampling area or latitude, and unit of longline catch (in numbers or weight). The model starts from an exploited condition in the year 1975 and runs through 2015. It is fit to indices of relative abundance based on catch-per-unit-of-effort (CPUE) data for longline fisheries and length-composition data for most fisheries (Supp. Fig. A.1). The length-composition data are assumed to follow a multinomial distribution. The multinomial sample size for the purse-seine fisheries is assumed to be equal to the number of wells sampled and for the longline fisheries is assumed to be equal to the number of fish sampled multiplied by a constant set to a value such that the average sample size is equal to the average sample size of the main purse-seine fishery. The number of wells was used because a single well often contains fish from mostly one purse-seine set or multiple sets from similar locations and the fish in each set are typically similar in size. This is probably a low estimate of the sample size, but is in line with the recommendation of limiting the influence of composition data (e.g., Francis, 2011). The weighting for the longline data is intended to give similar influence to the longline and purse seine composition data. The model estimates 241 parameters that include the virgin recruitment in log scale, an offset for the initial recruitment, initial fishing mortality rate, quarterly recruitment deviates, parameters that parsimoniously represent the initial age structure, and selectivities for each fishery (Suppl. Table A.1).

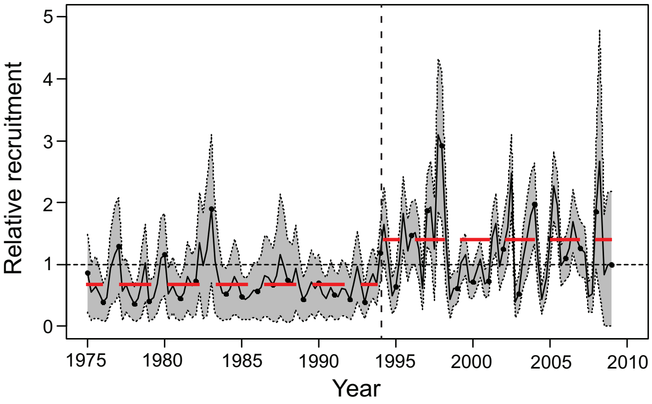

Fig. 1. Estimated quarterly recruitment of bigeye tuna in the eastern Pacific Ocean. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0. The continuous line depicts the maximum likelihood estimates of recruitment, and the grey area illustrates the uncertainty around those estimates (±2 standard deviations). The thin dashed horizontal line represents the average recruitment for the period of that assessment (1975–2008); the thick dashed horizontal lines indicate the average recruitment for two consecutive periods: 1975–1993 and 1994–2008. The vertical dashed line marks the start of the expansion of the purse-seine fishery on floating objects in 1994. From Aires-da-Silva et al. (2010a).

One concerning characteristic of the assessment is the apparent regime change in recruitment that occurs simultaneously with the expansion of the purse-seine fishery on floating objects, which catches juveniles, around 1993 (Fig. 1, Aires-da-Silva et al., 2010a). This is most likely due to a misspecification in the model, and correction of this issue could be used to identify model misspecification. Several hypotheses about the causes of the pattern are explored by Aires-da-Silva et al. (2010a). The only analyses that "corrected" the trend at that time were those that had assumed unrealistically high natural mortality for the medium and large bigeye (Aires-da-Silva et al., 2010a), and spatial changes in the fishery (Aires-da-Silva and Maunder, 2010). However, results from a cohort analysis (Aires-da-Silva et al., 2010a) failed to support the hypothesis that the trend in recruitment was caused by spatial changes. Rather, the analysis indicated that recruitment associated with the catch by the longline fishery remained fairly constant over time, while that associated with the catch by the purse seine fishery increased as the floating object fishery expanded (Aires-da-Silva et al., 2010a). Recruitment associated with the catch by the purse seine fishery after 1993 is higher than that associated with the catch