Fisheries Research 158 (2014) 158–164

Contents lists available at ScienceDirect

Fisheries Research

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

Evaluation of virgin recruitment profiling as a diagnostic for selectivity curve structure in integrated stock assessment models

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ARTICLE INFO

Article history:
Received 8 August 2013
Received in revised form 6 December 2013
Accepted 7 December 2013
Available online 18 January 2014

Keywords:
Virgin recruitment
Likelihood profile
Stock assessment
Selectivity
Diagnostic
Bigeye tuna

ABSTRACT

Virgin recruitment (R_0), the equilibrium recruitment in the absence of fishing, is an often used parameter in fisheries stock assessment for scaling population size. We describe and evaluate the use of the R_0 likelihood component profile to diagnose selectivity misspecification, using simulation analysis for bigeye tuna in the eastern Pacific Ocean. The profile is evaluated under two types of selectivity misspecification: (1) misspecified shape and (2) misspecified temporal variation. The results indicate that length-composition data can provide substantial information on R_0 estimation when the model is correctly specified, but can substantially bias estimates of absolute abundance when selectivity is misspecified. Although contradictory profiles for length-composition and abundance index data result from selectivity misspecification, they may not be useful in determining which survey or fishery selectivity is misspecified. The R_0 profile selectivity diagnostic is based on the influence of composition data on absolute abundance. However, perhaps a more problematic and difficult to detect issue is the impact of length-composition data on biomass trends. The age-structured production model diagnostic could be applied to identify bias in both absolute biomass and biomass trend caused by age- or length-composition data in the presence of model misspecification.

1. Introduction

Contemporary stock assessment methods integrate multiple data types in a single analysis (Fournier and Archibald, 1982; Maunder and Punt, 2013; Punt et al., 2013). There are several general computer programs (e.g. Methot and Wetzel, 2013) that implement these methods. In addition to catch data, the two main types of data used in these models are indices of relative abundance and catch age/size composition. These have historically been used in independent analyses. For example, indices of relative abundance have been used to fit surplus production models (Schaefer, 1954; Pella and Tomlinson, 1969), and catch-at-age data have been used in Virtual Population Analysis (VPA) (Fry, 1949) or cohort analysis (Pope, 1972). Catch-at-age data have also been used in catch-curve analyses (i.e. linear regression of log abundance on age) to estimate total mortality rates and thus fishing mortality if good estimates of natural mortality are available. Relative abundance and composition data provide information on absolute abundance. The decrease in an index of relative abundance caused by a known level of catch provides information on absolute abundance. The decline in the logarithm of the proportion of catch-at-age with age (the catch curve) provides information on fishing mortality (natural mortality assumed known), and when combined with catch data provides information on abundance.

However, both data types require information or assumptions (either explicit or implicit) about population (e.g. growth, natural mortality, and the stock-recruitment relationship) and fisheries (e.g. selectivity) processes. Surplus production models simplify the population dynamics into a single production function that aggregates fishery and biological processes and relies on strong modeling assumptions. Catch curve analysis used to estimate mortality rates generally assumes that recruitment and fishing mortality are in equilibrium, and that selectivity is constant for the ages used in the analysis. There may be information about these processes in data external to the stock assessment model (e.g. growth estimates from age-length data obtained from hard parts or from tag-recapture

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0165-7836/$ – see front matter © 2014 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.fishres.2013.12.009

studies) or information used in the model (e.g. information on natural mortality from catch-at-age data; see Lee et al., 2011). Integrated analyses allow simultaneous extraction of information from both indices of abundance and catch-at-age data, with the advantage that assumptions are relaxed through the estimation of parameters based on information from ancillary data external to the assessment or explicitly stated (Maunder and Punt, 2013). Integrated analysis relaxes these assumptions by estimating recruitment, fishing mortality, and selectivity when fitting to the catch-at-age data.

A major issue in the application of contemporary integrated analyses is the influence of different types of data (i.e. catch composition, survey, etc.) on estimates of absolute abundance and population trends (Francis, 2011). Based on the logic of catch curve-analysis, catch composition data should provide information on abundance. However, the information provided by the data is highly sensitive to selectivity curves, particularly when these are assumed to be asymptotic. For example, fishing mortality must be very high if fewer old fish than expected are caught given natural mortality. The issue is even more complicated when using length-composition data, since the estimates will be sensitive to the assumed or estimated length of old individuals. Therefore, misspecification of selectivity can bias stock assessment results. The influence of age- or size-composition data on abundance estimates has led to recommendations to de-emphasize age- or size-composition data in stock assessments and, instead, emphasize indices of abundance (Francis, 2011).

Theoretically, it is possible to use statistical approaches to determine the weight assigned to each data set (McAllister and Ianelli, 1997; Maunder and Starr, 2003; Deriso et al., 2007; Maunder, 2011), but these are based on the model being correctly specified. Unfortunately, this is rarely the case and the misspecification can lead to bias, particularly for composition data. Therefore, alternative methods should be used to weight the different data sets and determine model misspecification.

Lee et al. (2014) proposed profiling across a set of levels of a scaling parameter to evaluate the relative contribution of data components and model structure to the estimation of population scale (also see Francis, 2011). Virgin recruitment (R_0) or biomass (B_0) is the scaling parameter in most contemporary stock assessments. In Lee et al. (2014) approach, profiles of negative log-likelihood of each data component are created and the model is restructured or data down weighted until the change in negative log-likelihood across a reasonable range of virgin recruitment for composition data is low compared to a reliable index of relative abundance. They suggested adding model processes or re-evaluating data weighting to emphasize the data considered most appropriate to provide information on population scale.

This study extends Lee et al. (2014) to include the diagnosis of selectivity pattern misspecification. The R_0 profile is used to explore the contribution of data components for a population exploited under known selectivity patterns when selectivity is either correctly or incorrectly specified in the assessment model. The simulation analysis is based roughly on bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean (EPO) and is used to evaluate the R_0 profile diagnostic under two types of selectivity misspecification: (a) asymptotic selectivity when selectivity is dome-shaped and (b) time-invariant selectivity when this is not the case.

2. Materials and methods

The most recent assessment of bigeye tuna was carried out using Stock Synthesis (SS) (Methot and Wetzel, 2013; details of the application can be found in Aires-da-Silva and Maunder, 2012).

The definitions of the fisheries in the assessment are based on data collection areas and similarities in catch and length

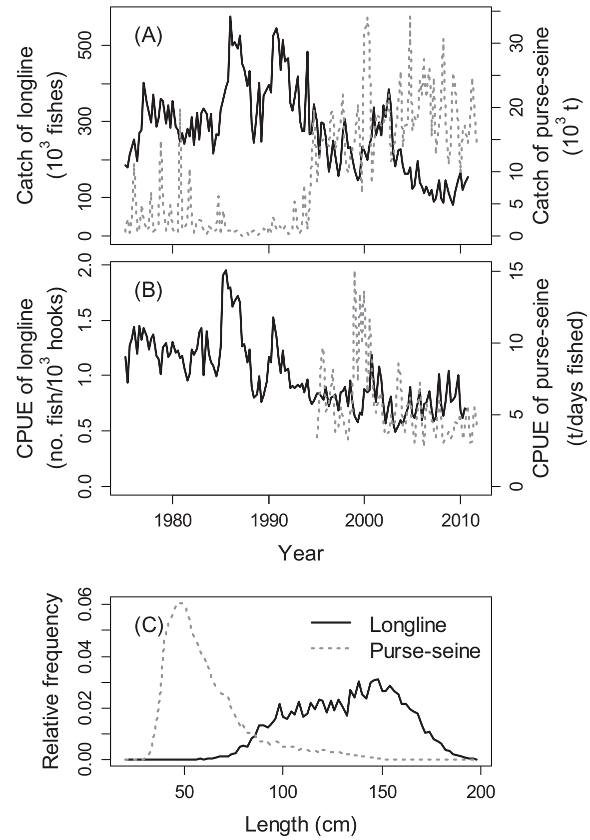

Fig. 1. The data series of catch, CPUE, and length-frequency of bigeye tuna caught by longline (solid line) and purse-seine (dashed line) fisheries in the eastern Pacific Ocean. Length-frequency data are aggregated across years in lower panel to present overall patterns for different fisheries.

frequency of catch. Fishery definitions take into account several factors, including gear type (purse-seine, pole-and-line, and longline), purse-seine set type (fish associated with floating objects, fish in unassociated schools, and fish associated with dolphins), time period, the IATTC length-frequency sampling area or latitude, and whether the catch is reported as numbers or weight (Aires-da-Silva and Maunder, 2012). However, the fisheries definition is simplified here into two categories: longline and purse-seine fisheries to reduce the computational demands of the simulation analysis.

2.1. Model structure

A simplified version of the stock assessment model of Aires-da-Silva and Maunder (2012) was used in the simulation analysis as both the simulator and estimator. The model is implemented in SS (version 3.24f) and the parametric bootstrap feature of SS was used to generate the simulated data. The application included two fisheries from 1975 to 2011, and used a quarterly time step. Selectivity for the longline fishery was assumed to be logistic and length-based, while that for the purse-seine fishery was assumed to be a dome-shaped (double normal) and length-based. The data used included catch, catch per unit of effort (CPUE) and length-composition (Fig. 1). The CPUE of the longline fishery has a declining trend before early 2000s, but is relatively flat thereafter. The model is fit to an index of abundance based on longline CPUE and to length-composition data for both fisheries.

Growth, variation in length-at-age, natural mortality, and the steepness of the Beverton–Holt stock-recruitment relationship