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Modelling growth in tuna RFMO stock assessments: Current approaches and challenges

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ABSTRACT

We review the approaches used to model growth in recent tuna Regional Fisheries Management Organization (tRFMO) stock assessments, and the challenges encountered. The tRFMO fisheries span vast areas, with multinational fleets operating a diverse range of gear types, and are assessed with a range of modelling methods. Despite the high volume and/or value nature of many tuna and billfish fisheries, there remain substantial data input challenges, including biased size composition sampling, conflicting age estimates from hard parts (and inconclusive validation studies), and very high error rates in some large-scale tagging programmes. There is evidence for spatial and temporal variability in growth rates, but sampling is rarely adequate to quantify this variability, and it is not described in most tRFMO assessments. Sophisticated statistical methods have been developed to combine catch length frequency distributions, age-length data and tag growth increment observations into a single estimation framework (though the data are generally not sufficient to allow the variances to be objectively partitioned). Modelling individual growth variability with random effects has the potential to greatly reduce biases from tag growth increment analyses, but this is computationally prohibitive when the growth curve is estimated within the assessment model. In contrast, the effects of size-based selectivity may not be adequately described if growth is estimated outside of the assessment model. Different species are affected by these problems to different and largely unknown degrees. We discuss options for mitigating some of these problems, but doubt that entirely satisfactory solutions can be achieved in most cases. Accordingly, we recommend that i) greater emphasis should be placed on representing the plausible growth uncertainty in the assessments (i.e. using a model ensemble approach), and ii) management strategy evaluation should be used to develop harvest strategies that are robust to the growth (and other, potentially more urgent) uncertainties, and to prioritize research investment in the context of achieving management objectives.

1. Introduction

We were invited to present an overview of current issues related to modelling growth in tuna stock assessments for the 2014 center for the advancement of population assessment methods (CAPAM) symposium: Modeling growth in fishery stock assessment models: theory, estimation, and application (this issue cite introductory paper if available), and bounded the scope to include the major industrial tuna fishery species, and swordfish (*Xiphias gladius*, the best studied of the billfishes), managed under the jurisdiction of tuna regional fisheries management organizations (tRFMOs), and assessed with age-structured assessment methods. The most important problems were identified from a review of the recent tRFMO stock assessments and peer-reviewed literature, while specific examples tend to be drawn from fisheries that we are most familiar with. Potential directions for addressing challenges are discussed individually and in the broader context of assessment and management priorities.

1.1. The stock assessment process in tRFMOs

There are five tRFMOs responsible for tuna and tuna-like species, which together account for catches exceeding 4.3 million landed tonnes annually (combined tuna estimate from FAO, 2014):

CCSBT – Commission for the Conservation of Southern Bluefin Tuna,

IATTC – Inter-American Tropical Tuna Commission,

ICCAT – International Commission for the Conservation of Atlantic Tunas,

IOTC – Indian Ocean Tuna Commission, and

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WCPFC – Western and Central Pacific Fisheries Commission.

The scientific processes within the tRFMOs vary considerably. The IATTC has a large dedicated research capacity within the secretariat. The WCPFC has a large contractual arrangement with the Secretariat of the Pacific Community Oceanic Fisheries Programme to provide stock assessments for most tropical and southern hemisphere species. The other commissions and stock assessments are largely dependent on the scientific contributions of member (and cooperating non-member) scientists (with strong oversight from a commissioned, independent scientific advisory panel in the case of CCSBT). Despite the similarities among many fisheries, the tRFMOs have a history of independently pursuing different assessment methods, including growth estimation. However, there are international initiatives to increase the flow of ideas across tRFMOs in recent years (e.g. JT-RFMO, 2007), and we hope that this review might be useful in that context.

Tuna and billfish species are generally perceived to be highly migratory, with most populations targeted by multiple nations in both domestic and international waters. Our examples are based on the main commercial species with (arguably in some cases) the most comprehensive research history. These include the (so-called) tropical tunas (bigeye, *Thunnus obesus*; yellowfin, *Thunnus albacares*; skipjack, *Katsuwonus pelamis*), temperate tunas (albacore, *Thunnus alalunga*; Atlantic bluefin, *Thunnus thynnus*; Pacific bluefin, *Thunnus orientalis*; southern bluefin, *Thunnus macoyii*) and swordfish (*Xiphias gladius*). Diverse fishing gears with very different selectivities catch most species: for example, Davies et al. (2014) illustrate that Pacific yellowfin are often caught in artisanal fisheries in the Philippines with the mode of around 40 cm, while some longline fisheries land a mode around 120 cm (a 27-fold difference in mass), which indicates the potential importance of growth and selectivity interactions in an assessment context. Fisheries catch and size composition sampling has often been limited and inconsistent, particularly for many artisanal fleets (e.g. IOTC, 2014a), while there is evidence for misreporting in some of the industrial fleets managed by quotas (e.g. Polacheck, 2012). Age composition data are routinely collected for very few tRFMO fisheries, and we are only aware of one fishery that integrates time series of direct age estimates into an assessment model (the southern bluefin spawning ground fishery). However, there have been many short-term collections of hard parts for ageing studies. There have also been several large-scale tagging programmes for the main tropical tunas and southern bluefin. Tagging programmes for other species have been limited in scale, with small numbers of returns. Most tRFMO assessments rely on commercial longline catch rates for relative abundance indices (pole and line or purse seine for skipjack), which are difficult to standardize because of changing efficiency, species targeting shifts, and spatial/temporal changes in effort (and population) distributions. The degree of assessment effort varies considerably. At one extreme, the CCSBT (the smallest tRFMO with only 9 members or cooperating non-members), is dedicated to a single species, with population structure that is thought to be well understood, and reasonable fisheries-independent data (including an aerial survey for juveniles, conventional tagging programmes, and a spawning biomass estimate based on a genetic parent-offspring mark-recapture programme, e.g. Hillary et al., 2014). At the other extreme, there are several (low value) neritic tuna populations (some with catches an order of magnitude larger than southern bluefin), which are either not assessed at all, or rely on data-poor methods (e.g. IOTC, 2014b). We do not include these latter species in this review, though any generic issues arising from growth uncertainty are also likely to be applicable to these species.

A brief summary of stock assessment and growth modelling methods used in 24 recent tRFMO assessments is provided in Table 1. Most of these assessments use age-structured models that integrate catch rates, size composition and total catch data (plus tagging data if available), often implemented with the MULTIFAN-CL (MFCL, e.g. Fournier et al., 1998) or stock synthesis (SS, e.g. Methot and Wetzel, 2013) software packages. Some tRFMO assessments use age-aggregated production models or data-poor methods (including qualitative, indicator-based descriptions) as the main or a parallel assessment (e.g. ICCAT, 2009; ISC, 2014c; Maunder, 2014), which do not use size and age data in a model-based framework. We do not consider these approaches here, except to note that they might provide a robust alternative to an individual age-structured assessment model specification if uncertainty in growth rates and/or other size/age-dependent inputs is high and not properly expressed. There have also been some explorations of length-structured models for skipjack assessment (Maunder, 2012; Hillary and Eveson, 2015). These approaches use a growth transition probability matrix to re-assign numbers of fish from one length-class to another in consecutive time-steps, and do not explicitly keep track of ages. It remains unclear whether length-structured assessments offer any real advantage for tunas over the age-structured approaches, and the general expectation would be that their potential usefulness diminishes as the quality of age information improves.

1.2. Growth equation role in tRFMO assessments

The growth equation, or size-at-age relationship, plays two key roles in most tRFMO age-structured assessments: i) the catch-at-age composition is inferred from the catch-at-size observations, and ii) biomass is calculated from the age structure (i.e. for spawning biomass or reference point estimates). For assessments that include tag dynamics (i.e. tag attrition models that estimate natural and fishing mortality, numbers-at-age and/or movement), the tag release age is estimated from the length-at-release. The length-at-age relationship is generally described by a series of normal (or log-normal) distributions at discrete points in time (i.e. quarterly or annual age/time-step mid-points). The functional form used for the mean length-at-age in most tRFMO growth models is usually derived from one of the classic parametric curves (von Bertalanffy or Richards), which are special cases of more generalized equations (e.g. see Schnute, 1981). Variances for the normal distributions are typically parameterized as a simple linear function of age or length. Most of the following discussion is qualitative in nature, but it is useful to introduce the simplest parameterization of the von Bertalanffy equation to aid the discussion:

$$L_t = L_\infty \left(1 - \exp\left(-K\left(t - t_0\right)\right)\right),$$

where mean length (L) is a monotonically increasing function of time (t), and approaches the theoretical asymptote (L_∞) at a rate determined by the parameter K, and t_0 shifts the growth equation along the time axis (i.e. to allow irrelevant early life history growth processes to be ignored, or to admit variability in cohort recruitment timing). A common alternative parameterization in assessment models is based on the length of the youngest ($L_{\min}$) and oldest ($L_{\max}$) ages in the model because these latter quantities are directly observable, unlike L_∞ which may be a theoretical abstraction.

We note that when referring to size-at-age, we are mostly referring to length-at-age in the following. For many tRFMO fisheries, mass frequency data are collected instead of (or in addition to) length, and it is assumed that there is a reliable mass-length relationship that makes the two measurements largely interchangeable. Mass predictions and observations are either used directly in the likelihood in a manner analogous to length observations, or mass is first converted to length. Mass-at-age is likely to be more variable than length at-age, and hence less reliable for inferring ages (e.g. adipose tissue can be rapidly gained or lost, unlike the