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Reference point estimation for Southern bluefin tuna

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Abstract

The Scientific Committee of 2010 requested estimates of MSY, replacement yield and spawner-per-recruit reference points that are compatible with the CCSBT operating model structure and in this paper we attempt to provide estimates for all these key reference points. For MSY, to accommodate recruitment and grid-level uncertainty together, as well as the strict controls on catch allocation, the concept of Maximum Constant Yield (MCY) is employed thereby uniting MSY and replacement yield with the interim rebuilding criteria (probability of 0.7 of long-term SSB being above 0.2 B0). A target reduction ratio of 35% (relative to unfished conditions) is used to estimate the reference level of spawner biomass-per-recruit reduction ratio and, as with the MSY calculations, the catch allocation is constrained to be fixed. Estimates of MSY are lower than those coming from the previous deterministic approach, as one would expect, with higher levels of target SSB depletion and lower levels of exploitation rate.

1 Introduction

This paper details the estimation of both MSY and spawner-per-recruit reference points for the Southern bluefin tuna stock. In terms of maximum sustainable yield, previous estimates have been deterministic in nature taking no account of recruitment variability. We employ the concept of Maximum Constant Yield (MCY) [1] for the MSY reference points - which effectively unifies MSY and replacement yield - in conjunction with the probabilistic interim recovery targets defined for the management procedure work. For the spawner-per-recruit reference points we employ the well known fished-to-unfished ratio as the key reference point, using a 35% reduction ratio as the key target and ensuring that, as with the OM and MSY calculations, the catch allocation can be fixed in the calculations. For both the MSY and spawner-per-recruit analyses the population and fishery model are the same as those used in the OM.

2 Spawner-per-recruit reference points

Spawner-per-recruit reference points are a well known reference point and an indicator that has been reported in terms of a figure for the last two years (see Figure 6 in [2]). The specific indicator shown was the proportional reduction in spawning potential (biomass) per recruit (SPR) from that seen in the absence of fishing. There are a number of different "target" levels that have been used in the past but $\gamma = 35\%$ is both between the commonly observed values of 30 and 40% and one recommended for stocks of this kind [3]. It is a simple indicator of how different fisheries affect survival to the spawning stock of a given recruitment level.

There are a number of potential drawbacks with such a per-recruit analysis. The reference point does not include a stock-recruit relationship, and for fisheries that target animals after maturity (such as the spawning ground fishery), depending on the target depletion level and the relative difference between selectivity and maturity, one can tolerate harvest rates of 1 (fish out that part of the exploitable stock) and still have more than the target spawning biomass per recruit. Despite some of these issues it is still a useful measure of the survival of recruiting animals to maturity and in an SSB rebuilding scenario (such as that of SBT) this is one of the key indicators of interest.

2.1 The per-recruit population model

In terms of the per-recruit population model, let $N_{s,a}$ be the equilibrium numbers at age a (0-30) in season s (1-2). Given it is a per recruit model $N_{1,0} = 1$ and

$$N_{2,0} = N_{1,0} \exp\left(-M_a/2\right) \left(1 - \sum_{f \in F_1} \xi_f \nu_{f,0}\right) \tag{1}$$

where M_a is the natural mortality-at-age, ξ_f is the fishery-specific harvest rate, $\nu_{f,a}$ is the fishery-specific selectivity-at-age, and F_s is the set of fisheries active in season s. For ages 1 to 29:

$$N_{1,a} = N_{2,a-1} \exp\left(-M_{a-1}/2\right) \left(1 - \sum_{f \in F_2} \xi_f \nu_{f,a-1}\right) \tag{2}$$

and

$$N_{2,a} = N_{1,a} \exp\left(-M_a/2\right) \left(1 - \sum_{f \in F_1} \xi_f \nu_{f,a}\right) \tag{3}$$

For the maximum age of $A = 30$ (considered to be a plus group)

$$N_{1,A} = \frac{N_{2,A-1} \exp\left(-M_{A-1}/2\right) \left(1 - \sum_{f \in F_2} \xi_f \nu_{f,A-1}\right)}{1 - \exp\left(-M_A\right) \left(1 - \sum_{f \in F_1} \xi_f \nu_{f,A}\right) \left(1 - \sum_{f \in F_2} \xi_f \nu_{f,A}\right)} \tag{4}$$

and

$$N_{2,A} = N_{1,A} \exp\left(-M_A/2\right) \left(1 - \sum_{f \in F_1} \xi_f \nu_{f,A}\right). \tag{5}$$

The spawning potential-per-recruit is defined as follows:

$$SPR(\xi_\bullet) = \sum_{a=0}^{A} N_{1,a} \left(sw_a\right)^\kappa m_a, \tag{6}$$

where sw_a are the spawning weights-at-age, m_a is the proportion mature-at-age and κ is the non-linear fecundity-weight parameter (set to 1 for this work as in the OM and MSY calculations).

One major issue that is central to SBT is to ensure that the catch split across fisheries remains fixed so it is effectively a system of non-linear simultaneous equations to solve to get the target harvest rates, ξ_f^{spr}: the first equation to be solved is $SPR(\xi_f^{\text{spr}}) = \gamma SPR(0)$ and the other equations to be solved are $\widehat{p}_f = p_f$, where $\widehat{p}_f$ and p_f are the model-predicted and pre-specified relative catch allocation across fisheries, respectively. For the reference grid `basehupsqrt` and assuming the default MP TAC allocation scenario Table 1 summarises the estimates of ξ^{spr}, assuming a 35% SPR reduction ratio. From the summary in Table 1 the

Table 1: Summary (median and 90% CI) of the estimates of $\xi^{\rm spr}$ when restricted to ages 2-15, and the ratio of the reference level to the current exploitation rate on ages 2-15. Throughout a 35% SPR reduction ratio is assumed and we employ the default TAC allocation scenario while using the reference grid, `basehupsqrt`.

Reference point	Estimate
$\xi^{\rm spr}_{2-15}$	0.071 (0.069-074)
$\xi^{2011}_{2-15}/\xi^{\rm spr}_{2-15}$	1.06 (0.89-1.24)

estimates of $\xi^{\rm spr}_{35\%}$ are low yet very precise. They are low because of a combination of the high age at maturity and the fact the major fisheries (in terms of tonnage) select animals prior to the age-at-maturity. The estimates of the mean exploitation rate across ages 2-15 from the current OM are very close (slightly higher) to the reference level derived from the spawner-per-recruit analysis.

3 Stochastic MSY

As with the spawner-per-recruit reference point model, the population and fishery model is the same as it is in the deterministic MSY calculator and the OM, and we use the same grid files. The major difference is the inclusion of the stock-recruit stochasticity and what we actually maximise and what the sustainability criteria are. For deterministic MSY the idea is quote simple: maximise yield (via harvest rate/fishing mortality) and the sustainability condition is implicit in the assumption of an equilibrium model. The idea for stochastic MSY is an interpretation of the concept of Maximum Constant Yield (MCY) that is used sometimes in New Zealand [1] and elsewhere: project the stock forwards and estimate the maximum constant catch that satisfies the appropriate sustainability criteria.

Given the interim rebuilding target of $0.2B_0$ and the agreed target probability of 0.7 (i.e. rebuild SSB to above the target level with this probability) it seemed both sensible and relevant to use these as the sustainability criteria. The principle is this: maximise the stochastic equilibrium (500 year projection from unfished conditions) yield with the constraint that the (stochastic) equilibrium SSB has a probability of greater than or equal to $p^{\rm targ}$ of being above $0.2B_0$ and that the catch allocation remain fixed at all times. When using catch as the control variable (not harvest rate as one simply cannot constrain catch allocation at all times this way) it turns into a reasonably tractable problem. Given that the long-term quantiles of SSB decrease monotonically with increasing catch, the maximum catch that satisfies the sustainability constraints is the one that in fact solves it exactly. Let $\tilde{S}(C)$ be the equilibrium distribution of the SSB, for a given catch level C. The catch level at MSY is that which solves $p(\tilde{S}(C) > 0.2B_0) = p^{\rm targ}$ and given the MP criteria we assumed that $p^{\rm targ} = 0.7$. This makes the calculation of MSY a stochastic equation solving problem and it is implemented in C++ and uses the secant method to find the solution, making it very robust with a "good" initial guess.

In Table 2 for the updated OM the estimate of (constant) sustainable/replacement yield is 29,024t with an expected SSB depletion of 0.3. The same estimates using the previous OM

Table 2: Stochastic MSY calculations - with $p(\tilde{S}(C) > 0.2B_0) = 0.7$ as the sustainability criterion - for both the previous (`base5hsqrt`) and updated (`basehupsqrt`) OM grids. Summary includes the (constant) catch level and the expected SSB depletion at MSY.

OM	C_{msy}	$\mathbb{E}\left(B_{\text{msy}}/B_0\right)$
`base5hsqrt`	23,668	0.34
`basehupsqrt`	29,024	0.3

from last year are 23,668t and 0.34. For the deterministic MSY calculations the expected yield is 35,000t with an expected SSB depletion of 0.22. Clearly, the stochastic estimates of both sustainable yield and SSB depletion are lower than the deterministic case as one would expect. The estimator is a precautionary one, as it reacts to increasing levels of uncertainty by decreasing sustainable yield and increasing the target SSB level required to obtain it. It is therefore considered robust to recruitment uncertainty, but only in the sense that it actively accounts for it in the estimation procedure.

4 Summary

In this paper we have attempted to estimate spawner-per-recruit and MSY reference points for the stock of Southern bluefin tuna. For spawner-per-recruit reference points we used the familiar fished-to-unfished reduction ratio approach, with a level of 35% chosen as the reference reduction level given it is both between the two most common values (30% and 40%) and has been recommended for tuna stocks at a recent workshop [3]. For MSY the concept of maximum constant yield (MCY) was employed with the interim rebuilding criteria for the MPs (long-term probability of 0.7 of SSB being above 20% of B_0) being the basis for the sustainability criterion.

For the spawner-per-recruit analysis, when using the average exploitation rates from ages 2 to 15 as done previously, current levels of exploitation rate are very close to those estimated for the 35% reduction ratio reference level. For stochastic MSY the sustainable/replacement yield estimate was 29,024t and with an expected SSB depletion level of 0.3. Deterministic estimates of (expected) sustainable yield and SSB depletion were 35,000t and 0.22, respectively.

One would expect the MCY-type estimates of MSY (in terms of yield and SSB depletion) to be lower than those from a deterministic approach. A stock cannot sustain fixed levels of catch as well as they can fixed levels of exploitation rate that would give the fixed level of catch on average. The reason we did not try to maximise the expected long-term catch using exploitation rate and fishery-specific multipliers is one cannot ensure that catch allocation remains fixed across time and Monte Carlo simulations. One could maximise average yield subject to the constraint that *average* allocation remains fixed but this leads to interpretation and other issues. One can change total catch (annually or otherwise) with the expectation of obtaining the required target exploitation rate, but if allocation remains fixed there will be a disparity between what one is aiming to achieve and what actually occurs. The reference level would be estimated assuming average allocation remained fixed but in the real world it would be fixed at all times (until a change occurred and MSY would be re-estimated anyway).

Given the strong differences in selectivity between the various fisheries it is in no way clear that this disparity would be insignificant.

A final and perhaps more important issue is the overall stability of any MSY estimates. For the stochastic MSY case we see clearly that updating the previous OM to the current one resulted in around a 20% increase in sustainable yield estimates and an 11% increase in expected SSB depletion. This is not specific to the stochastic MSY estimates and the same thing happens with the deterministic estimates. This change was caused by an increase in the levels of steepness (and by correlation early-life natural mortality) being sampled by the grid, given the updated data sets [4]. Current information on steepness comes mostly from the age/length frequency data and is not consistent across fisheries [4] and in recent years we have seen the OM distributions of steepness change significantly when even an extra year of data is included. Realistically, unambiguous information on steepness will not appear until the stock abundance undergoes a data-validated period of recovery, which with current projections will not begin until later in this decade [4], thereby making it difficult to provide a robust estimate of MSY regardless of methodology.

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References

[1] Francis, R.I.C.C. (1992). Recommendations concerning the calculation of Maximum Constant Yield (MCY) and Current Annual Yield (CAY). New Zealand Fisheries Assessment Research Document. 92/8. 23 p. MAF (Fisheries). (Unpublished report held in NIWA library, Wellington.)

[2] Anonymous (2010). Report of the 15$^{\text{th}}$ Scientific Committee of CCSBT, Taipei, Taiwan.

[3] Anonymous (2011). Report of the 2011 ISSF Stock Assessment Workshop, Rome, Italy.

[4] R.M. Hillary, A. Preece, B. Barnes, C. Davies and G. Begg. (2011) Reconditioning of the SBT operating model: exploratory data analysis, fitting performance, and current stock status. CCSBT-ESC/1107/11, Bali, Indonesia.