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An Evaluation of a Harvest Control Rule using Limits and Target Reference Points: An Atlantic Yellowfin Example

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Abstract

Managing the risks associated with uncertainty is a key concept of the precautionary approach to fisheries management. An important tool is there Management Strategy Evaluation which is able to incorporate the main sources of uncertainty into the scientific advice. A simple harvest control rule incorporating both a target F and Biomass trigger was tested for the Atlantic yellowfin tuna population using an MSE framework. The operating model was based on the 2008 ADAPT-VPA base case assessment model. The MSE framework included two scenarios related to stock dynamics (OMs), two levels of data quality (OEMs) and two harvest control rules (MPs). The model simulations indictaed that the major impact on the model outputs was due to value uncertainty, i.e. choice of natural mortality (M). Relatively minor changes in assumed M resulted in stock collapse. This is a matter of concern given that M is poorly known in most assessments. The MSE evaluations also demonstrated that the use of a $B_{trigger}$ resulted in better performances in all cases. This would indicate that good management can compensate for defficiencies in the stock assessment. In addition, the MSE showed that under a harvest control rule, variations in advice on fishing effort and TACs are likely to occur. Future HCR development should take this into account, possibly restricting inter-annual variability in TACs and fishing effort. Although this work is considered preliminary and much additional effort is needed, the benefit of the MSE process is clear. It must be noted however, that the process is usually an iterative one where certain sources of information/uncertainty can be shown to be less important than others, and thus excluded from further analysis, effectively streamlining the evaluations.

KEYWORDS

Harvest Control Rule, FLR, Management Strategy Evaluation, VPA, Yellowfin

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1 Introduction

The main management objective of ICCAT is to maintain the populations of tuna and tuna-like fishes at levels which will permit the maximum sustainable catch. Commonly interpreted as using an analytical estimate of maximum sustainable yield (MSY) as a target, derived from either yield per recruit analysis combined with a stock recruitment relationship or directly or from a biomass dynamics model. However Rickers (1975) original definition is defined as the largest average catch or yield that can continuously be taken from a stock under existing environmental conditions. Even if you can calculate MSY based reference points from an assessment model does not mean that you can achieve that level of yield in practice due to uncertainty.

As well as target reference points the Precautionary Approach (FAO, 1996) requires limit reference points and harvest control rules (HCRs). Where the HCR specifies in advance what actions should be taken when limits are reached. Although harvest control rules may include several precautionary elements, it does not necessarily follow that they will be precautionary in practice (Kirkwood and Smith 1996). This is because many harvest control rules are not evaluated formally to determine the extent to which they achieve the goals for which they were designed, given the uncertainty inherent in the system being managed (Punt in prep). Therefore simulation, and Management Strategy Evaluatiomn (MSE) in particular, has increasingly been used to evaluate the impact of the main sources of uncertainty inherent in the system being managed (Kirkwood and Smith 1996, Cooke 1999, McAllister et al. 1999, Kell et al.).

MSE allows uncertainty beyond just the assessment process has to be considered; since under active management uncertainties about management decisions, their effects and their implementation also affect management outcomes. However, Fisheries management advice has traditionally been based on a reductionist approach, where tasks are considered in a linear fashion e.g. collect the data, perform the assessment, compute reference points, then set the quota. However, just as in ecology where it is argued that inappropriate use of reductionism limits our understanding of complex systems,we need to understand how systems work and in particular how feedback loops influence those systems. Management Strategy Evaluation (MSE) has therefore become an important tool for evaluating manangement advice.

2 Material and Methods

2.1 Management Strategy Evaluation Framework

An important aspect of the MSE approach is that the management outcomes from the HCR are fed back into the operating model so that their influence on the simulated stock and hence on the future simulated fisheries data is propagated through the stock dynamics (Figure 1). A reason for this is because stock assessment mainly considers only uncertainty in observations and process (e.g. recruitment) and uncertainty about the actual dynamics (i.e. model uncertainty) has a larger impact on achieving management objectives (Punt 2008).

All terminology is based upon that of Rademeyer et al. (2007).

The most rigourous use of MSE is when a Management Procedure (MP) is simulation tested prior to implementation. Where a Management procedure is the combination of pre-defined data, together with an algorithm to which such data are input to provide a value for a TAC or effort control measure. A flowchart describing the MP development process is given in figure 1.

Operating Model (OM); that represents alternative plausible hypotheses about stock and fishery dynamics, allowing integration of a higher level of complexity and knowledge than is generally used within stock assessment models;

Management Procedure (MP); or management strategy which is the combination of the available pseudo-data, the stock assessment used to derive estimates of stock status and the management model or Harvest Control Rule (HCR) that generates the management outcomes, such as a target fishing mortality rate or Total Allowable Catch.

Observation-error Model (OEM); a part of the MO that describes how simulated fisheries data, or pseudo-data, are sampled from the Operating Model; and

Complex models are used primarily to test the robustness of simpler assessmentmanagement rules before implementation, by conducting computer-based experiments that embody how the whole system reacts to a variety of possible management actions (Hilborn, 2003). Population and fleet dynamics are deduced from a range of plausible hypotheses and available data sets, rather than being based on a singular set of assumptions, because the objective is to develop strategies that are robust to our uncertainty about the true dynamics and, hence, to meet the requirements of the precautionary approach. The challenge is no longer to build (and then justify) a single best model but to identify an appropriate of range of plausible models, parameterise and assigning weights to them (Punt, 2008). There is also a need to explore alternative model structures and ways of assigning weights or probabilities to them for example using Bayesian and meta-analytic techniques (Michielsens and McAllister, 2004).

All modelling was done using FLR (Kell et al.) which was designed to be be used to build simulation models representing alternative hypotheses about stock and fishery dynamics. Thereby allowing a higher level of complexity and knowledge than used by stock assessment models and to explicitly include a greater range of uncertainty.

It is important to consider appropriate sources of uncertainty; traditional stock assessments mainly considers only uncertainty in observations and process (e.g. recruitment). However, uncertainty about the actual dynamics (i.e. model uncertainty) has a larger impact on achieving management objectives (Punt 2008). Therefore when providing management advice it is important to consider appropriate sources of uncertainty. Rosenberg and Restrepo (1994) catagorised uncertainties in fish stock assessment and management as:

- Process error; caused by disregarding variability, temporal and spatial, in dynamic population and fisheries processes;
- Observation error; sampling error and measurement error;
- Estimation error; arising when estimating parameters of the models used in the assessment procedure;
- Model error; related to the ability of the model structure to capture the core of the system dynamics;
- Implementation error; where the effects of management actions may differ from those intended.

Sources of uncertainty related to *Model Error* include

- structural uncertainty; due to inadequate models, incomplete or competing conceptual frameworks, or where significant processes or relationships are wrongly specified or not considered. Such situations tend to be underestimated by experts (Morganand Henrion, 1990). and
- value uncertainty; due to missing or inaccurate data or poorly known parameters.

2.2 Operating model

Setting up and conditioning Opertaing Models depends on the objectives of a particular study but if uncertainties in the resource assessment are large, the construction of a reference set of OMs is preferable to the use of a single reference case OM. In the last assessment 13 VPA-Adapt runs were considered; which explored different hypotheses about the data and the stock dynamics conditioned upon the VPA assumptions. However, in this study we constructed a single OM based on the base case from 2008 since we are mainly concerned in illustrating the utlity of the approach; Varying some of the assumptions about the data and knoweldge used in the stock assessment.

Biological parameters were taken from the last ICCAT assessment; however, these can easily be changed to consider other life-history traits

- annual spawning (1 cohort per year),
- 50% maturity at age 4, 100% maturity at ages 5+ (i.e. immature before age 4),
- fecundity is linearly proportional to weight,

- growth following the von-Berttalanffy equation used in the ICCAT working group (with the following parameters: L = 318.85, k=0.093, tO=-0.97),
- length-weight relationship used in the ICCAT working group (W=2.95.10-5*L2.899),
- lifespan of 20 years.
- age-specific, but time-invariant, natural mortality based on tagging experiments on the southern bluefin tuna and used in the ICCAT working group (i.e., M=0.49 for age 1, M=0.24 for ages 2 to 5, M=0.2 for age 6, M=0.175 for age 7, M=0.15 for age 8, M=0.125 for age 9 and M=0.1 for ages 10 to 20).
- Recruitment given by Beverton and Holt stock recruitment relationship with a steepness of 0.75

Given the selection pattern (s) of a fishery, and the catchability (q) of a population for a given effort (E), the fishing mortality rate (Fa,y,j) for age a, year y, and population j is given by:

2.3 Management Procedure

The Management Proceedure is linked to the operating model by the data and assumed level of knowledge, this is modelled by the Observation Error Model (OEM) and the dynamics assumed in the Stock Assessment Procedure (SAP). Then depending upon the perceive stock status and reference points by the HCR which determines management action.

The SAP chosen was VPA which requires total catch-at-age and assumptions about natural mortality and CPUE as data inputs and estimates numbers and fishing mortality-at-age from which time series of stock trends and stock recruitment relationships and reference points can be estimated. Process and measurement error were modelled as a lognormal error with a CV of 30% on the CPUE. All other data were considered to be know exactly by the working group unless stated otherwise.

The Harvest Control Rule (figure 2) was based on that described in the Report of the 2010 ICCAT Working Group on Stock Assessment Methods (Anon. 2011). HCR incorporates limit and target reference points into a ruke that dictates the action to be taken in terms of defining fishing mortality rates depending on the estimated biomass level (x-axis) (Figure 2). The $B_{trigger}$ causes F to be reduced if the stock falls below this level, otherwise fishing is at the target F level.

In this example the target fishing mortality was 75% of F_{MSY} and the $B_{trigger}$ 75% of B_{MSY},

2.4 Scenarios

Three scenarios were considered i.e.

1. No Bias, in that the data (other than the CPUE) used in the assessment were sampled without error from the OM.
2. As 1 but recruitment declined by 25% in the future
3. As 1 but M is assumed to be 25% greater in the MP than the OM

and compared to a stock projection.
Two harvest control rules were evaluated,

1. A constant F.
2. Constant F above a biomass limit below which F declines.

3 Results

Figure 3 shows the results from a single scenario in the form of a worm plots for fishing mortality, recruitment, spawning stock biomass and yield. These show the annual medians and interquartiles (thick and thin blue lines) with two example trajectories (red and green). This shows that half the time a trajetory will be outside of the inter-quartile range and that the realised trajectories will be much more variabke than that suggested by the median.

The MSE outcomes for constant F (*orange*) MP are compared with a projection in figure 4 (all quantities are relative to MSY benchmarks). The first column is for the projection with constant F where only recruitment varied (i.e. process error). The second column presents the results from an MSE where the assessment model was VPA (i.e. the same assumed dynamics as the OM) and all data and parameters used in the MP were known without error, i.e. as well as process error estimation and measur error were modelled. In the third column a regime shift (i.e. OM recruitment reduced by 75%) occurred, and the final column evaluates the outcomes when natural mortlaity was assumed to be greater than 25% in the MP than the OM, i.e. model error in the form of value uncertainty.

These show that even where the assumed assessment dynamics are identical to those used to simulate the stock in the OM, differences are seen between the projection and MSE (columns 1 & 2), mainly due to the variablity of the MSE being greater due to the inclusion of measurement and estimation error in the MSE. A regime shift casues at first F to be greater than the target since the productivity of the stock is overestimated and so the TAC is set too high, however after 2020 the F is reduced as reference points take into account the reduced recruitment. The bias in M has the largest effect causing the stock to collapse.

Figure 5, presents the same scenarios for a HCR with a bimass limit, after which F is reduced. These show that the limit is effective in stablising fishing mortality and stock biomass. This is particularly important in the case of the mis-specification of M. Another feature of the HCR is that oscilations are seen due to lags, i.e. it takes a few years before the stock recovery is detected and F can increases.

Figures 6 to 10 show the same data in the form of a kobe phase plot for five year intervals, clockwise from teh top left panel.

The projection is noticably less variable than the results from the MSE. Inspection of the MSE with no bias shows that in the 1st few years of operation of the HCR cycling is seen, i.e. a decline followed by a recovery, In the case of the constant F such fluctuations are not seen. In the case of the regime shift no cycling is seen although in the case of the constant F MP F ncreases above F_{MSY} and stock declines, although the HCR maintains F at the target level and SSB ust below B_{MSY} and little yield id forgone. The most striking result is in the case of a bias in the assumed M; although this was relatively small if a $B_{trigger}$ is not used in the HCR the stock collapses.

4 Discussion

This study is not intended to be a definitive MSE for yellowfin tuna. It is a simple demonstration of how an MSE models greater uncertainty than a traditional stock assessment and how reference points should be evaluated, e.g. as part of a HCRs.

Although this example was not intended to be a definitive analysis, it did incorporate a greater range of uncertainty than is normally considered within stock assessment. The simulations conducted in this study clearly demonstrate that considering more realistic sources of uncertainty is important when providing probablistic management advice.

The main sources of uncertainty considered were process error (i.e. recruitment variability), uncertainty about the true dynamics of the stock being evaluated (e.g. M), measurement error (CPUE CV) and estimtion error. As mentioned above, this is more uncertainty than considered with an ICCAT stock assessment.

The model simulations indicated that the major impact on the model outputs was due to value uncertainty, in that just a 25% mis-specification of M caused stock collapse. A very important result given that M is poor known in most assessments. However, using a $B_{trigger}$ as part of a HCR resulted in much better performance in all cases. Showing that good management is more important than stock assessment.

The so called "worm plots" clearly indicate that in reality, catches, harvest (and hence fishing effort) and stock trends will not follow the smooth trends suggested by the medians and logically 50% of the time will be outside of the range given by the inter-quartiles. This example showed that under a harvest control rule variation in advice on fishing effort and TACs is likely to occur. Therefore it will be important to consider other components when designing HCRs, e.g. to reduce inter-annual variability in TACs and fishing effort.

5 Future Work

As with all work in progress, it is important to map out future directions and opportunities for building on the methods detailed in this document. Although this was a preliminary example and the sources of uncertainties considered were meant to be illustrative rather than realistic, it did show the importance of considering a broader range of uncertainty when designing HCRs than is traditionally considered with performing stock assessments. The MSE process is an inclusive process that is amplified by incorporting all stakeholders. This is also however a time consuming process. In the short term, the scientific aspects of the process can be addressed fairly quickly. It is important that before managment advice can be provided based on such an MSE as described above, the main sources of uncertainty as well as realistic plausible values for this uncertainty must be considered, discussed and agreed upon. The most convenient forum to achieve this, is in the relevant Working Parties, where a range of experts are available. The use of MSE is also likely to be an iterative process where, through simulation testing, certain sources of information/uncertainty can be shown to be less important than others and so excluded from further analysis, stream-lining future work.

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