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OUTLINE OF A CANDIDATE MANAGEMENT PROCEDURE FOR ATLANTIC BLUEFIN TUNA

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SUMMARY

The approach of Management Strategy Evaluation (MSE) is explained and a candidate management procedure is described for Atlantic bluefin tuna. The candidate procedure consists of an assessment model designed to utilise different types of data via data-specific likelihood functions, coupled with a simple harvest control rule that ensures that fishing mortality is reduced when the stock is reduced below an MSY-related reference point based on spawning stock biomass. The assessment model is fitted using Bayesian methods, and the posterior median of a target catch by stock is used for management purposes, via fishery-specific impact factors. The next step will be to subject this and other candidate management procedures to simulation tests involving a set of standard scenarios to be developed under the GBYP.

RÉSUMÉ

L'approche de l'évaluation de la stratégie de gestion (MSE) est expliquée et une possible procédure de gestion est décrite pour le thon rouge atlantique. Celle-ci consiste en un modèle d'évaluation conçu pour utiliser différents types de données par le biais de fonctions de vraisemblance de données spécifiques, conjointement avec une simple norme de contrôle de la ponction qui garantit que la mortalité par pêche est réduite lorsque le stock est ramené en-dessous d'un point de référence lié à la PME sur la base de la biomasse du stock reproducteur. Le modèle d'évaluation est ajusté à l'aide de méthodes bayésiennes, et la médiane des distributions a posteriori d'une capture dirigée sur un stock est utilisée à des fins de gestion, par le biais des facteurs d'impact spécifiques aux pêcheries. La prochaine étape consistera à soumettre cette procédure de gestion et d'autres procédures de gestion possibles à des tests de simulation impliquant un ensemble de scénarios standard qui seront mis au point dans le cadre du GBYP.

RESUMEN

Se explica el enfoque de evaluación de estrategia de ordenación (MSE) y se describe un posible procedimiento de ordenación para el atún rojo del Atlántico. El procedimiento candidato consiste en un modelo de evaluación diseñado para utilizar diferentes tipos de datos mediante funciones de verosimilitud de datos específicos, junto con una norma simple de control de la captura, que garantiza una reducción en la mortalidad por pesca cuando el stock se sitúa por debajo de un punto de referencia relacionado con el RMS basándose en la biomasa del stock reproductor. El modelo de evaluación se ajustó utilizando métodos bayesianos, y la mediana posterior de la captura dirigida a un stock se utilizó para fines de ordenación, a través de factores de impacto específicos de la pesquería. El siguiente paso será someter este y otros procedimientos de ordenación candidatos a pruebas de simulación que incluyan un conjunto de escenarios estándar que se desarrollarán en el marco del GBYP.

KEYWORDS

Management Strategy Evaluation, assessment model, harvest control rule, Atlantic bluefin tuna

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1. Introduction

The Management Strategy Evaluation (MSE) framework requires that the stock management process be sufficiently well defined that its performance can be evaluated by simulation under hypothetical scenarios (de la Mare 1986; Smith *et al*. 1999; Punt and Donovan 2007). The aim is to overcome uncertainty by finding management procedures that can perform robustly across a wide range of plausible scenarios. The emphasis is on achieving good and robust management performance across a range of assumptions rather than a maximally realistic assessment of the state of the stock. As noted by Rice and Connolly (2007), the fishery management process involves many more aspects than those which can be evaluated in the formal MSE framework: the term "management strategy evaluation" actually covers just some of the stages of the management cycle, but for convenience the term MSE is retained here.

The Management Strategy Evaluation process involves the following steps, not necessarily carried out in this order:

a) Construct a range of biologically plausible dynamic scenarios that are used to generate hypothetical data for testing Management Procedures. These scenarios include an Operating Model (OM) that includes the sub-models required to simulate each of the following processes:

   i) the biological processes (recruitment, growth, mortality, optionally the spatial distribution) that govern the dynamics of the fish stock or stocks;

   ii) the fishing process, including age- and size-selectivities of each fishery

   iii) the generation of the fishery-dependent and fishery-independent data used for stock assessment and management advice.

b) Specify one or more candidate Management Procedures (MPs). Each MP is an algorithm that accepts as input the data (and assumptions) on which scientific management advice is to be based, and outputs the corresponding advice. The management advice may be in the form of a recommended TAC, but other types of output are possible). The algorithm must be fully specified (i.e. a computer programme) such that it can be simulated with arbitrary inputs during the evaluation process.

c) Link the Operating Model and Management Procedure into an MSE testing framework. For each replicate of each scenario, the testing framework first uses the biological sub-model to build the initial state of the fish stock(s). Then, for each year of the simulation, the testing framework:

   i) updates the status of the fish stock(s) using the biological sub-model

   ii) applies fishing to the stock, using the fishing sub-model

   iii) generates fishery-dependent and fishery-independent data for the year

   iv) calls the Management Procedure to generate a recommended TAC for the next year (or years of a multi-year management period)

   v) stores the stock status and catch for the year

d) Specify a number of performance measures to measure the performance of the management procedure relative to management objectives.

Because of the inevitable trade-offs between opposing management objectives, performance measures that relate to stock conservation and performance measures that relate to stock utilisation are both required for meaningful evaluation. An example of a performance measure relating to stock conservation is the fraction of B_{MSY} which the stock is maintained above at least 95% of the time; an example of a performance measure relating to stock utilization is the average fraction of MSY that is realized over time.

Because both the biological processes (e.g. recruitment) and the fishing process (e.g. relationship between index of abundance and stock level) are subject to stochastic influences, the performance of a Management Procedure can only be assessed in stochastic terms. The performance relative to each measure is evaluated in probabilistic terms using multiple stochastic realizations of each scenario.

A Management Procedure can have one or more **tuning parameters**. A tuning parameter is a parameter whose value can be adjusted to shift the balance of the procedure's performance between conservation-related and utilization-related objectives. If a procedure is found to be more conservative than necessary relative to stock conservation objectives, a tuning parameter can be adjusted to allow more catch at the expense of slightly reduced conservation performance, or *vice versa*.

Contracts studies commissioned under the under the GBYP include two contracts for the development of prototype alternative assessment and advice frameworks for BFT. The intention is that these alternative frameworks will be tested under the Management Strategy Evaluation (MSE) framework under development by the SCRS. Under the MSE framework, a range of scenarios will be constructed at the ICCAT Secretariat for the simulation testing both of the existing BFT assessment and management method (to the extent that it can be formally specified), and of each alternative approach, including those developed under the two contract studies. The results of the simulation tests will be used to evaluate how well the candidate methods would be expected to perform relative to the management objectives specified by the Commission. It is of interest to the SCRS to determine how the various methods perform under both of the following sets of circumstances: (i) when supplied only with the data used for assessments to date (catch at size/age, abundance indices, growth curves); and (ii) when additionally supplied with data of the kind being collected under the GBYP (e.g. aerial surveys, electronic tagging). This will provide a means of demonstrating the value of such data for management.

2. A candidate management procedure

2.1 Summary and definitions

This paper outlines a candidate management procedure that involves a stock assessment model (SAM) and a harvest control rule (HCR), designed to work in tandem. The assessment method proposed is broadly similar to that already used for BFT. In order to be able to make use of a variety of different kinds of data, and to capture most of the main sources of uncertainty, it is cast in a Bayesian form with specific likelihood functions for each kind of data. This approach provides the advantage that a new type of data can be utilized by developing an appropriate likelihood function that captures the main properties of the new data source, without redesigning the entire management procedure.

The assessment module and the harvest control rule rely on some common quantities, which are defined as follows:

$\boldsymbol{F_{\mathrm{MSY}}}$ is the constant level of unselective fishing mortality that, if maintained, would result in the greatest long-term average catch.

$\boldsymbol{F_{0.9}}$ is the level of unselective fishing mortality, less than F_{MSY} that would result in a long-term average catch that is 90% of the average catch level under fishing at F_{MSY}.

$\boldsymbol{B_{\mathrm{MSY}}}$ is the level at which the spawning stock biomass (SSB) would currently be, if fishing had always been unselective with F=F_{MSY}.

$\boldsymbol{B_{0.9}}$ is the level at which the SSB that would currently be, if fishing had always been unselective with F=$F_{0.9}$.

$\boldsymbol{B_0}$ is the current level of SSB that would have pertained if there had never been any fishing (F=0). This definition implies that the biomass at the start of year t, B_t, always satisfies $B_t < B_0$, regardless of fluctuations in recruitment (a large year class boosts both B_0 and B_t).

A simple harvest control rule is proposed: constant $F = F_{0.9}$ when the current spawning stock biomass, B, satisfies $B > B_{0.9}$; F linearly related to $B/B_{0.9}$ when 0.1 $B_{0.9} < B < B_{0.9}$; $F = 0$ for $B < 0.1\ B_{0.9}$ (Fig. 1.). The harvest control rule is based on a notional unselective standard fishery. To convert the results to a TAC for a real mix of fisheries, weighting factors are determined for each fishery to relate the stock impact of a unit catch from that fishery to the stock impact of a unit catch from the notional standard fishery.

2.2 Age and size structure

The assessment model is age- and size-structured. There are $A_{\max}$ age classes (a = 1, …, $A_{\max}$) where the $A_{\max}$ class is a plus group, and $L_{\max}$ (l = 1,…$L_{\max}$) size classes. In the absence of size-selective mortality, the distribution of size (defined as fork length) at a given age is assumed to be log-normal.

As a group of fish grow, their relative size ranking is assumed to remain unchanged (i.e., no fish can overtake another during growth). Letting μ_{ia} , τ_{ia} denote the notional mean and CV of size at age a in stock i respectively, then in the absence of size-specific mortality, the proportion of fish aged a in stock i that are in size class l is given by:

$$P_{i,a,l} = \Phi\left(\log\left(\overline{l}/\mu_{ia}\right)/\tau_{ia}\right) - \Phi\left(\log\left(\underline{l}/\mu_{ia}\right)/\tau_{ia}\right) \quad (1)$$

Where $\underline{l}, \overline{l}$ are the lower and upper size bounds of size class l, and Φ denotes the cumulative Normal distribution. The proportion of fish in stock i in size class k at age a that moves into size class l at age a+1 is denoted $Q_{i,a,k,l}$. The entries of the array Q are calculated by solving:

$$\sum_k P_{i,a,k} Q_{i,a,k,l} = P_{i,a+1,l} \quad (2)$$

The solution is unique under the "no overtaking" assumption. The realized size distribution of fish at each age is affected by size-specific fishing and natural mortality. Within a size class, mortality is assumed to be independent of age.

The number of fish in stock i of age a in size class l in year t is denoted by N_{ialt}. The numbers by age/size class evolve with time as follows:

$$N_{i,a+1,l,t+1} = \sum_k Ni_{,a,k,t}\, Q_{i,a,k,l} \exp\left(-M_{i,k} - F_{i,k,t}\right) \quad (3)$$

Where $M_{i,k}$ is the natural mortality rate of size class k in stock i and $F_{i,k,t}$ is the fishing mortality rate of size class k in stock i in year t. The number of fish in stock i in size class l in year t is given by:

$$N_{i,l,t} = \sum_{a=1}^{A_{\max}} N_{i,a,l,t} \quad (4)$$

The growth parameters (mean and standard deviation of size by age) μ_a, τ_a {a = 1,…,$A_{\max}$} are input and treated as known. The mean weight of fish in stock i in size class l in the spawning season in year t is given by w_{ilt}. These values are also input and treated as known. Fishery-specific mean weights by size class, w_{ijlt} can also be specified for relating catch by size to weight of catch in specific fisheries.

2.3 Spawning stock and recruitment

The spawning stock biomass for stock i in year t is given by:

$$B_{it} = \sum_{l=1}^{L_{\max}} w_{i,l,t} N_{i,l,t} \phi_{i,l} \quad (5)$$

where $\left\{\phi_{i,l}; l = 1,\ldots,L_{\max}\right\}$ is a vector of size-specific fecundity factors for stock i.

The recruitment to stock i in year t is assumed given by the Beverton-Holt model:

$$R_{i,t} = \frac{R_{0i} B_{i,t}}{g B_t + (1- g) B_{0i}} \exp\left(s\, n_{i,t} - \tfrac{1}{2} s^2\right) \quad (6)$$

where the resilience γ (0<γ<1), is a measure of the steepness of the stock-recruitment relationship, and σ is a measure of variability. $\nu_{i,t}$ are annual random effects that represent the deviations of year class strength by stock from its expected value.

Prior distributions are specified for the resilience, γ, and for the ratio $D_i = B_{i,T}/B_{i,0}$ (the relative depletion of stock i) where T is the year for which an assessment is required:

$\gamma = \upsilon^p$ where υ has a uniform prior distribution on (0,1) and p>0 is a tuning parameter.

$D_i = \omega_i^q$ where ω has a uniform distribution on (0,1) and q>0 is a tuning parameter.

Given the catches and other parameters, the prior for D implies a prior for R_0. This choice of prior for D has been found to have good properties in management procedures designed for other long-lived species (Cooke, 1999).

2.4 Catch and selectivity

For each fishery *j*, the sampled catch in number in size class *l* is in year *t* satisfies:

$$C_{jlt} = s_{jt} E_{jt} \exp(\kappa \eta_{jlt}) \sum_i S_{ijl} N_{ilt} \qquad (7)$$

where s_{jt} is the sampling fraction, E_{jt} is the implied fishing effort for fishery *j* in year *t*, S_{ijl} is the selectivity of fishery *j* for stock *i* and size class *l*, κ is a variance parameter and η_{jlt} are standard normal random effects. The total catch in weight from fishery *j* in year *t* satisfies:

$$C_{jt} = E_{jt} \exp(\chi \zeta_{jt}) \sum_i \sum_l w_{ijlt} S_{ijl} N_{ilt} \qquad (8)$$

The parameters $s_{j,t}$, $E_{j,t}$, $S_{i,j,l}$ are nuisance parameters to be estimated, χ is a variance parameter and the ζ_{jt} are standard normal random effects. The weights by size w_{ijlt} are input.

2.5 Indices of abundance

A fishery-related index of abundance (standardised catch per unit effort) for fishery *j*, $\{A_{j,t}\}$, is assumed to satisfy:

$$A_{j,t} = q_j \exp(\lambda \varepsilon_{jt}) \sum_i \sum_l S_{i,j,l} N_{i,l,t} \qquad (9)$$

where q_i is a nuisance parameter, λ is a variance parameter and the ε_{jt} are standard normal random effects.

Fishery-independent indices are subject to assumptions appropriate to the index. For example, a larval index is assumed to be proportional to the spawning biomass of the stock spawning in the area.

2.6 Fitting the assessment model

The model is fitted on a Bayesian basis. Priors for all variance parameters are standard normal N(0,1) on the log scale. Priors for all nuisance parameters are uniform on the log scale. The priors for the stock-recruitment parameters γ and *D* are as specified above. The only results from the model that are directly used for management are the posterior medians of the target catch by stock, as described below.

2.7 Harvest control rule

2.7.1 Target fishing mortality and target catch

The harvest control rule **(Figure 1)**, applied to each management stock separately, is to set the target fishing mortality to $F_{0.9}$ when the current spawning biomass is above $B_{0.9}$, and for *F* to decline linearly towards zero when the current spawning biomass approaches 0.1 $B_{0.9}$:

$$F_T = F_{0.9} \text{ when } B_T \geq B_{0.9}$$
$$F_T = F_{0.9}\left(B_T / B_{0.9} - 0.1\right)/0.9 \text{ when } 0.1 B_{0.9} \leq B_T \leq B_{0.9}$$
$$F_T = 0 \text{ when } B_T \leq B_{0.9}$$

The target fishing mortality is used to derive a nominal target catch (TC) for each stock based on the assumption of unselective fishing. The posterior distribution of the target catch is computed, and the median of this distribution is taken as the target catch for management purposes. There is no 1-1 relationship between the target fishing mortality rate and a TAC, because the size-specific and stock selectivity of each fishery has to be taken into account.

2.7.2 Computation of allowed catches by fishery

The Selectivity Impact Factor of each fishery is determined as follows. First, biomass per recruit (bpr) and yield per recruit (ypr) are calculated for the current target level of fishing mortality, assumed to be unselective. Second, the level of fishing mortality is calculated for each fishery separately that would give the same biomass per recruit if that were the only fishery. The Selectivity Impact Factor for fishery *j* on a stock is given by:

$$SIF_j = \frac{\text{ypr for unselective fishing}}{\text{ypr for fishing with selectivity of fishery } j}$$

The target catch for stock *i* is considered satisfied when the weighted sum of allowed catches (AC) by fishery does not exceed the target catch by stock:

$$\sum_j \mathrm{AC}_j \times \mathrm{SIF}_i \times G_{ij} \leq \mathrm{TC}_i$$

where G_{ij} is the estimated proportion of the catch in fishery *j* that consists of fish from stock *i*.

3. Further work

The next step in this process is to develop an operating model and a range of scenarios under which the performance of the above candidate management procedure, along with others, can be evaluated by simulation.

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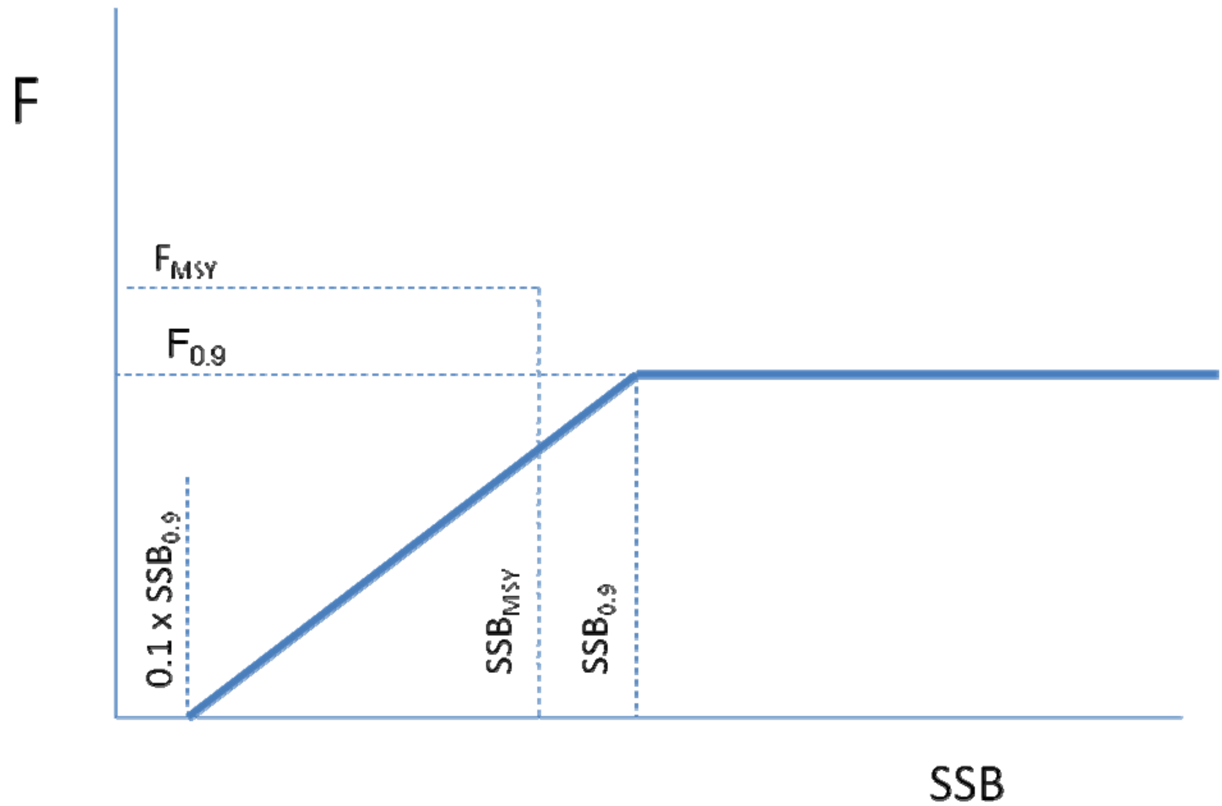

Figure 1. Harvest control rule.