The framework and utility of an MSE evaluation for yellowfin tuna (*Thunnus albacares*) in the Indian Ocean region

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Abstract

The Management Strategy Evaluation (MSE) framework involves the developing of an operating model to describe the underlying reality together with a model which describes the whole management process from data collection to the management advice. In this document, a method for conducting MSE for Indian Ocean yellowfin tuna is proposed, along with expected outcomes. This document intends to stimulate discussion regarding MSE for IOTC tuna, including the objectives for management and possible model specifications. Future plans for this work are also discussed and presented.

1. Introduction

One of the main objectives of any fishery management policy is to maintain adequate rates of stock regeneration to offer resilience to long-term exploitation and associated fishing mortality (Nash et al. 2009; Shelton et al. 2006). This general management objective is achieved by insuring that biomass or spawning stock biomass (SSB) is kept above a biomass reference limit, below which recruitment may be impaired, and also that fishing mortality is lower than a level (i.e. exploitation reference limit) that would reduce the RP to below this reference limit (Hauge et al. 2007; Kell et al. 2005). The conventional process for providing scientific management advice is the selection of a current "best" assessment and then to recommend a management measure such as a Total Allowable Catch (TAC) based upon those biological reference points, for example the maximum sustainable yield (MSY) or associated spawning stock biomass (B_{MSY}) and fishing- mortality (F_{MSY}) in the case of tuna RFMOs. In this sense, both the UN Fish Stocks Agreement and Code of Conduct (FAO 1995) have similar wording incorporating the principal of reference points as important instruments for the application of the Precautionary Approach to fisheries management. For example, the Annex II of the UN Fish Stocks Agreement provides guidelines for the application of precautionary reference points; which includes amongst other issues (i) the different types of reference points to be used (i.e. limit and target reference points); (ii) the risk of exceeding those references is very low; and (iii) fishing mortality corresponding to MSY should be regarded as a minimum standard for limit reference point.

Thus, it is recommended that all the uncertainties in the fishery system are taking into account when applying the precautionary approach in the fishery management process. However, current scientific advice and management is often performed in a fairly ad-hoc manner without accounting for all the uncertainty involved. Therefore, the use of Management Strategy Evaluation (MSE) have been widely recognised as a valuable tool to test the robustness of Management Procedures (MP) to the uncertainties in the fishery system (Hilborn et al. 2001; Kell et al. 2007).

The MSE approach for fishery system considers the interrelation between stock-fleet-management as the dynamic system to be studied (A'mar et al. 2009; Butterworth et al. 1997; Dichmont et al. 2008; Dichmont et al. 2006; Kell et al. 2007; Kell et al. 2005; Kell et al. 2004; Punt & Smith 1999). In that sense, 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 to fisheries management (FAO 1996). In other words, in the MSE, complex models are used primarily to test the robustness of simpler assessment–management rules before implementation, by conducting computer-based experiments that embody how the whole system reacts to a variety of possible management actions. In short, the MSE simulation approach involves the developing of an operating model to describe the underlying reality together with a model which describes the whole management process from data collection to the management advice (Fromentin & Kell 2007; Kell et al. 2007).

A convenient framework to conduct management evaluations is through the use of control rules, for which managers specify variables under their control through some functions related to the status of the stock under a pre-agreed plan for adjusting management actions. Stock assessment research is then conducted to determine the status of the stock(s), to evaluate the likely efficacy of management alternatives, to test the performance of management rules relative to precautionary targets and limits, and to characterize the uncertainty in the scientific advice for management. It is recognized that this involves continuous periodic feedback between managers and scientists with monitoring, re-evaluation, testing, and adjustment of management strategies (FAO 2001). This kind of framework is instrumental in guiding the appropriate division of responsibilities between science and management (Hauge et al. 2007).

It is also important to note that an implicit principle of the Precautionary Approach is that the level of precaution should increase with uncertainty about stock status. A major challenge is therefore to reconcile risk (i.e. of failing to meet sustainability and utilisation objectives) with uncertainty. For example the uncertainty in our knowledge of system dynamics, the data used to monitor fisheries and stocks and in implementation of management measures. Ideally the level of risk should be set by managers and be the same regardless of the level of uncertainty. This means that reducing uncertainty, by better monitoring, surveillance and control or by scientific study will have a direct benefit of decreasing the level of risk of resource mismanagement.

Therefore in this paper we propose a framework for using of Management Strategy Approach based upon MULTIFAN-CL, the current primary model used to assess the yellowfin tuna stock in the Indian Ocean. The Management Strategy Evaluation (MSE) for yellowing can be developed from a Multifan-CL assessment using the FLR open source software framework (Fisheries Library for R, http://www.flr-project.org, (Kell et al. 2007). A benefit of using FLR is that it is designed to conduct Management Strategy Evaluation (MSE) to evaluate alternative measures with respect to a range of management objectives, regulations and stock assessment methods under a variety of assumptions about resource and fishery dynamics (Fromentin & Kell 2007);(Tserpes et al. 2009). The objective of the paper is to present the advantages of the approach as well as to demonstrate several uses applied to Indian Ocean yellowfin tuna, in particular, but to other tunas in general, rather than to provide specific management advice. The provision of management advice using the MSE approach would be possible when appropriate stock hypotheses and management measures to be evaluated are discussed and agreed by the assessment group.

2. Materials and Methods

2.1. Data

The 2009 assessment of yellowfin tuna was conducted using Multifan-CL. No specific "Base-case" model was identified. Instead three plausible scenarios based on the steepness of the stock-recruitment relationship (0.6, 0.7 and 0.8) were presented to the working party on tropical tunas in Mombasa, Kenya in 2009 (IOTC 2009). In the setting up of the operating model for this study, the parameters (both fisheries and biological) from the MFCL runs can be imported directly into R thus maintaining the same assumptions and dynamics.

2.2. Management Strategy Evaluation approach

The three main elements of a MSE are:

i) 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;

ii) The 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; and

iii) Observation Error Model (OEM) that describes how simulated fisheries data, or pseudo-data, are sampled from the Operating Model.

All terminology included here is based upon that of (Rademeyer et al. 2007). Figure 1 provides a conceptual framework for the MSE. In the MSE framework, it is crucial that management outcomes from an agreed harvest control rule (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.

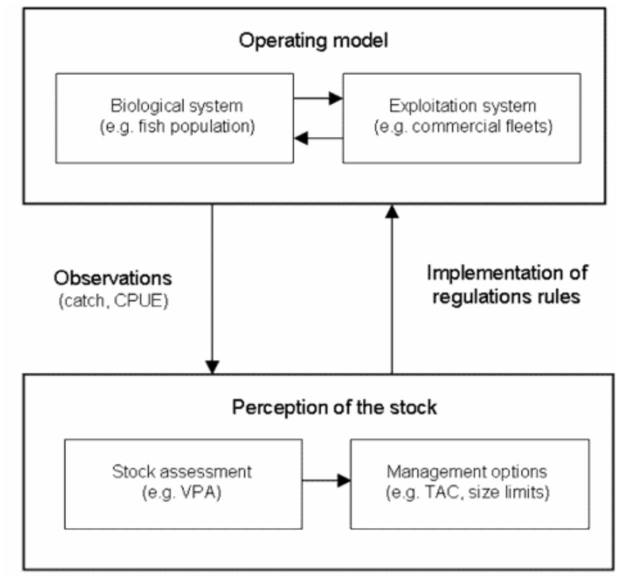

Figure 1. Conceptual framework of the simulation model.

The success of the MSE approach depends on the extent to which the true range of uncertainty can be identified and represented in operating models. These uncertainties include the following:

- process error – natural variation in dynamic processes such as recruitment, somatic growth, natural mortality, and the selectivity of the fishery;
- observation error – related to collecting data from a system (e.g. age sampling, catches, surveys);
- estimation error – related to estimating parameters, both in the operating model, and, if a model-based management procedure is used, in the assessment model within the management procedure that leads to the perception of current resource status;
- model error – related to uncertainty about model structure (e.g. causal assumptions of the models), both in the operating model and in the management procedure; and
- implementation error – because management actions are never implemented perfectly and may result in realized catches that differ from those intended.

2.2.1. Operating model

An objective of this study would be to use MULTIFAN-CL to explore alternative plausible hypotheses about stock and fishery dynamics using a simulation framework to evaluate the robustness of alternative management advice based upon stock assessment as provided by IOTC.

An OM would thus be constructed on the basis of the age-structured equation:

$$N_{a,t,q} = N_{a-1,t-1,q-1}\, e^{-Z_{a-1,t-1,q-1}}$$

where $N_{a,t,q}$ is the number of fish of age a at time t, in season q, and $Z_{a-1,t-1t,q-1}$ is the total mortality from age a–1 to age a. $Z_{a,,t,q} = M_{a,q} + F_{a,t,q}$, where $M_{a,q}$ is the natural mortality at age a in season q and $F_{a,t,q}$ is the fishing mortality at age a in year t in season q. A Beverton and Holt stock recruitment relationship (Beverton and Holt, 1956) would be assumed to close the life cycle, with parameters taken from the Multifan-CL assessments.

Various forms of uncertainty can be introduced into the OM. Historic uncertainty can be introduced into the recruitment deviates estimated by Multifan-CL. This was conducted for albacore in the Atlantic Ocean, based on the correlation matrix (Kell et al. 2009). An example of this matrix for the atlantic albacore stock is presented in figure 2. Another major source of uncertainty in Indian Ocean yellowfin stock dynamics is growth and steepness. Uncertainty in the functional growth equation (i.e. moving from a standard VBGF to a multi-stanza growth equation) and/or differences in stock-recruitment curves or steepness values can be fully investigated within the OM framework. Additionally various natural mortality estimates can be incorporated.

2.2.2. Management procedure

The Management Procedure (MP) is the specific combination of: (i) the sampling regime, (ii) the stock assessment method, (iii) the biological reference points and (iv) the management strategies. Each year an assessment, based upon Virtual Population Analysis (VPA), is being conducted and the current stock status and biological reference points estimated. Then the catch that would be equivalent to MSY in the quota year is being calculated and set as the next year´s TAC. This is a very simplistic form of harvest control rule, but can easily be modified depending on the desired management control.

2.2.3. Observation error model

The sampling regime, modelled by the Observation Error Model, corresponds to the collection of commercial catch data, the derivation of catch numbers-at-age and catch per unit effort (CPUE) and the estimation of biological parameters such as growth, maturity and natural mortality-at-age. In this example a single index of abundance covering the ages included in the MFCL is proposed. Sampling error modelled by assuming a lognormal distribution with a CV of 30% would appear to be suitable. Catch and biological parameters can be assumed to be known exactly for initial MSE runs, although uncertainty can be included at any stage during the process.

2.3. Software

Modelling is being performed using the open source R statistical environment available from cran.r-project.org. The actual code, data and any publication in the literature will be made available as part of a google project at http://code.google.com/p/mse4mfcl/.

Full details of the atlantic albacore MSE are already available on this site. The project can be accessed by non members who may check out read-only working copies or by project members to allow changes to be made, see http://code.google.com/p/glmscrs/source/checkout for more details. The project is managed using subversion and under windows TottoiseSVN provides an easy user interface; see http://code.google.com/p/mseflr/wiki/UsingTortoiseSVN for a guide on how to use tortoise.

Routines in R to read, manipulate, write, analyze, and plot the MFCL input and output files are available at http://code.google.com/p/r4mfcl/ which is based on original work by Pierre Kleiber of the US National Marine Fisheries Service, and Adam Langley and John Hampton of the SPC. The FLR framework is available to www.flr-project.org. These routines are being modified and additional routines created, in order to facilitate the reading of MFCL input and output files directly into FLR. Again, these will be made openly available.

3. **Expected outputs of the MSE**

The outputs of the MSE simulations can be used to determine possible future trends in stock status and management scenarios. Moreover, other outcomes of this approach can be to study the effects that the inclusion of various hypothesis in relation to key biological characteristics (such as growth, maturity, reproduction and stock-recruitment relationships) have on the assessment process which may lead to differing perceptions of population dynamics, biological reference points and stock status in relation to BRPs affecting the advice for fisheries management. Thus, MSE can be very valuable as it would help in prioritising research strategies, as the influence on the assessment and management process of different key processes can be determined (for example, different growth models having less impact than the reproductive biology of the species studied). In summary, in the context of the MSE framework, an evaluation of the robustness of alternative Management Procedure in relation to different sets of uncertainties (i.e. in the SR model, in the abundance indices, and in the assessment) can be carried out.

For example, the change is clearly demonstrated by (Kell et al. 2009) using a simple atlantic albacore example, where the future levels of key indices such as recruitment and spawning stock biomass is projected in relation to projected catches and harvest (figure 2). In that example, 6 different plausible MFCL model scenarios (analogous to the three different steepness scenarios currently presented for Indian Ocean Yellowfin) were projected deterministically with outputs showing historic stock estimates (prior to 2008) and projections based upon a fishing mortality of F_{MSY} subsequently.

With the addition of uncertainty in the time series of recruitment, SSB, yield and fishing mortality for assumed future recruitment scenarios projected, a clear picture of the uncertainty and, thus, the precaution to be applied can be determined (Figure 3). At the 1st “Kobe” meeting of the Joint Tuna RFMOs, it was recommended to base management decisions upon the precautionary approach and to standardise the presentation of stock assessment advice. It was also agreed that stock assessment results across all the five Tuna RFMOs should be presented in the form of a Kobe Plot. The Kobe plot (figure 4, for the same data presented in figure 3) shows stock status and fishing mortality relative to B_{MSY} and F_{MSY} where quadrants indicate stock biomass and fishing mortality relative to B_{MSY} and F_{MSY}; the red quadrant indicates the stock is overfished (i.e. $SSB<B_{MSY}$) and that overfishing is occurring (i.e. $F>F_{MSY}$), while green indicates that the stock and fishing mortality is at a sustainable level (i.e. $SSB \geq B_{MSY}$ and $F \leq F_{MSY}$ respectively). Yellow indicates either that overfishing is occurring but the stock is not overfished or conversely that the stock is overfished, but overfishing is no longer occurring. Uncertainty can also be included if a probability distribution can be estimated for the ratios of F/F_{MSY} and SSB/B_{MSY}.

While the Kobe plot is useful for summarising current stock status, management advice requires managers to be presented with alternative options for meeting management objectives, i.e. achieving MSY or ending overfishing and rebuilding overfished stocks. Therefore the Kobe Strategy Matrix (KSM) has been developed as a harmonised format for RFMO science bodies to convey advice. The K2SM is a decision table summarising the probabilities of achieving biomass or fishing mortality rate targets under different management actions, i.e. TACs. An example of a KSM is shown in figure 5. It was also strongly recommended that the results of the KSM be represented graphically (Figure 6). All of these figures can be quickly and easily presented using the MSE framework described above.

Once a suitable framework has been created, different scenarios can be proposed and explored. For a hypothetical stock a working group may currently assumes a steepness in the SRR of 0.75 with a CV of 50% (The "true" steepness is, however, 0.8 with a CV of 10%). If the working group receives additional informative data, this may allow them to adjust their perception of the steepness value they are using and assume a value of 0.8 with a CV of 30%. This reduction of uncertainty has important implications for management. The MSE will allow the determination of the robustness of the management procedure in relation to different values of steepness with the objective of maintaining a healthy stock. The reduction in uncertainty means that in theory, a larger TAC can be set while still ensuring sustainability of the stock. Additional scenarios can be to investigate the effects of varying the CV value around the CPUE series (e.g. 30%, 40% etc.)

4. Discussion

MSE applications to tuna stocks are not new. For the Atlantic Ocean, (Soto et al. 2006) analyzed the sensitivity of several reference points used in the ICCAT management process to uncertainties in the estimation of the species composition of the tropical tuna catch as well as in the total catch. This example shows how uncertainties in the observation error model affect the assessment analysis and, hence, management procedure. Errors in the species composition in the tropical tuna fishery affect the assessment of the three tropical species due to the lack of differentiation of small tunas in landings, like bigeye vs skipjack; or, regarding the total catch, the non declared catches of bigeye from the IUU fleets. In this study it was suggested that biases on catch reports are likely to be more important for stocks that are assessed through methods were total catch contains much of the signal used to explain the dynamic of the stock.

CCSBT too has utilized an MSE approach. In 2000 the Commission agreed that a Management Procedure should be developed with three components—a list of data as inputs, a model to process the data, and rules to translate the model output into a TAC. A workshop on developing a Management Procedure was first held in 2002 but efforts to refine and develop the details continued in a series of meetings ending in 2005 with the recommendation of the final management procedure (CCSBT 2005), though this was not implemented because of an overcatch problem which became apparent at about that time.

The SBT population is modelled as a single, age-structured stock. Historical trends in growth are allowed and fixed from parameters (mean and variances at age) estimated externally. The stock-recruitment relationship is given by a Beverton-Holt function with log-normal auto-correlated errors. Growth is not estimated in the model, but is fixed with assumed known length-age relationships. The most recent version of the OM (sbtmod22) includes an alternative model for the tag data, based on a Brownie model (Brownie et al. 1985). Substantial robustness testing is carried out by scientists and Management Procedure Technical Meetings by checking performance under plausible variations of the OM.

In creating this document, the authors would like to point out several caveats with regard to the methods and potential results. Firstly, the model described here requires substantial modification and discussion before it can be considered useful for management advice. It is at this stage purely a basis for initiating discussion regarding potential MSE simulations (Optimisation of model structure, realistic and desirable HCRs etc.) and the usefulness or applicability of this approach for IOTC managed stocks. The choice of Yellowfin tuna as a potential case study, is fairly arbitrary and based on the fact that it has until this stage received the most attention in terms of assessment. Another important point to consider is the fact that in this document we have proposed using the current assessment model as the operating model. In the long term this is not desirable but was done in this case in order to “jump-start” the simulations with the most accurate stock dynamics information available. In the future, however, alternate model should be sought for use as the operating model, with the stock assessment model being utilised periodically to monitor the “true” status of the stock.

In terms of future work, the model described in this document is a modification a model used for the MSE of atlantic albacore. The authors recognise, however, that in some cases the modelling platform is not optimal. To this end, work is being initiated to streamline the MSE calculations and overcome some of the deficiencies of the software proposed for use. This ad hoc project funded by the ISSF is tentatively called “biodym” and its main objective is to provide a biomass dynamic assessment model within R based upon AD Model Builder (ADMB) that can be used to provide stock assessment advice as part of a Management Procedure (MP) and evaluated within a Management Strategy Framework (MSE).

The specific objective of this work is to

i) develop a prototype interface between ADMB and FLR in order to allow the use of efficient robust solvers within R.
ii) Implement alternative ways of characterising uncertainty with a common stock assessment framework such as Bayesian and likelihood based approaches (e.g. delta method, Confidence Intervals)

The key tasks are to:

1) Implement a biomass dynamic class in FLR using the non-linear solver optim,
2) Implement in parallel a biomass dynamic routine in ADMB
3) Benchmark the two implementations using the data sets of (Polacheck et al. 1999), i.e. time to convergence, number of function evaluations, likelihood at solution, sensitivity to starting values.
4) Modify the FLR class so it calls ADMB instead of optim
5) Compare the robustness of different biomass dynamic functional forms (Fox, Schaefer, Gulland, Fletcher and Pella-Tomlinson), parameterisations (e.g. r & K and BMSY & MSY) and ways of estimating parameters (e.g. concentrated likelihoods).
6) Run simulations for different fishing histories and life history characteristics, based upon tropical tunas e.g. yellowfin and bigeye.
7) Compare uncertainty based on MCMC runs and the likelihood

This work should significantly streamline the optimisation of the model described above as well as provide powerful generic tools for use in future tropical tuna MSE work.

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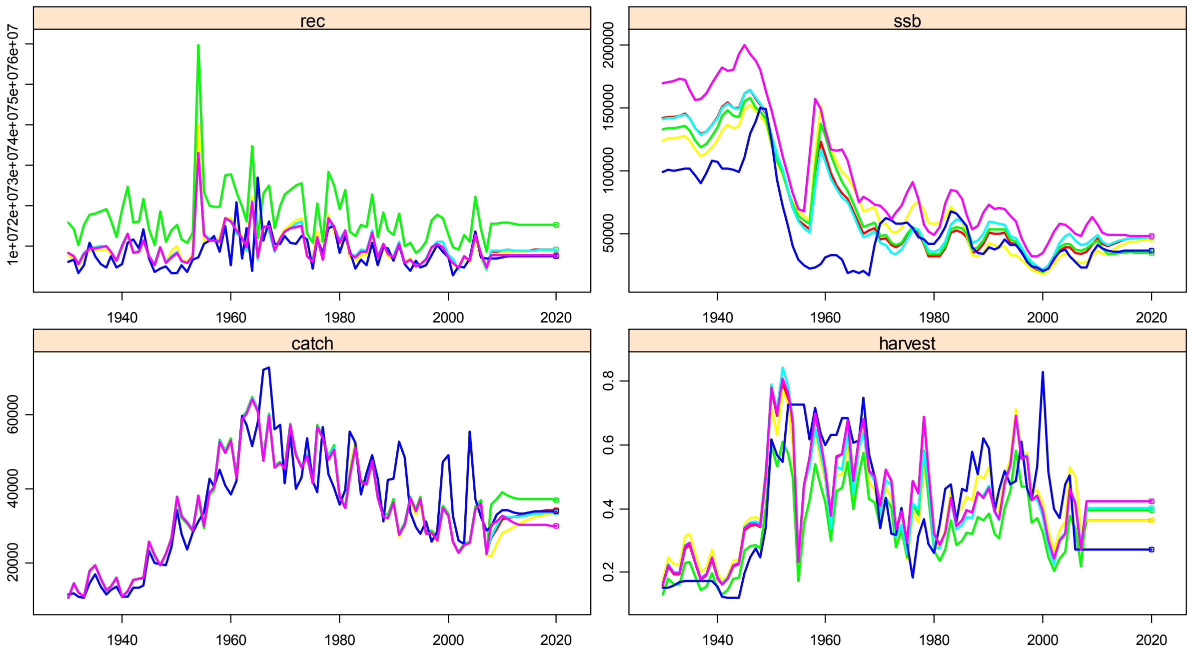

Figure 2. Historic stock estimates (prior to 2008) and projections for six alternate MFCL models for atlantic albacore based upon a fishing mortality of F_{MSY}. (Kell et al. 2009).

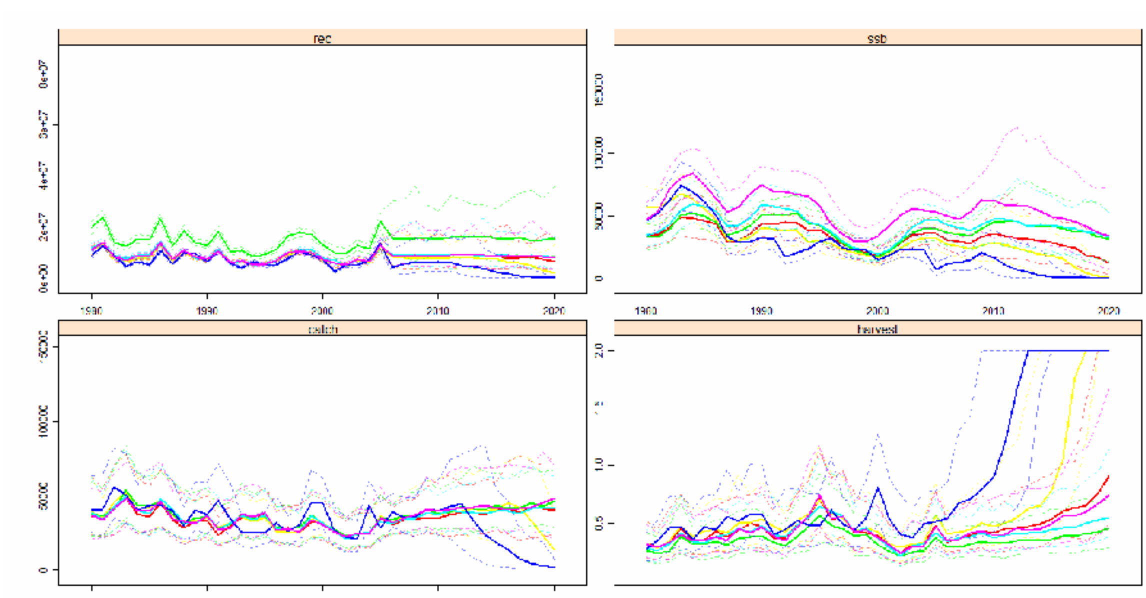

Figure 3. Historic time series (prior to 2006) with projections based upon a TAC equivalent to a fishing mortality of $F_{0.1}$.as estimated by the management procedure (Kell et al. 2009).

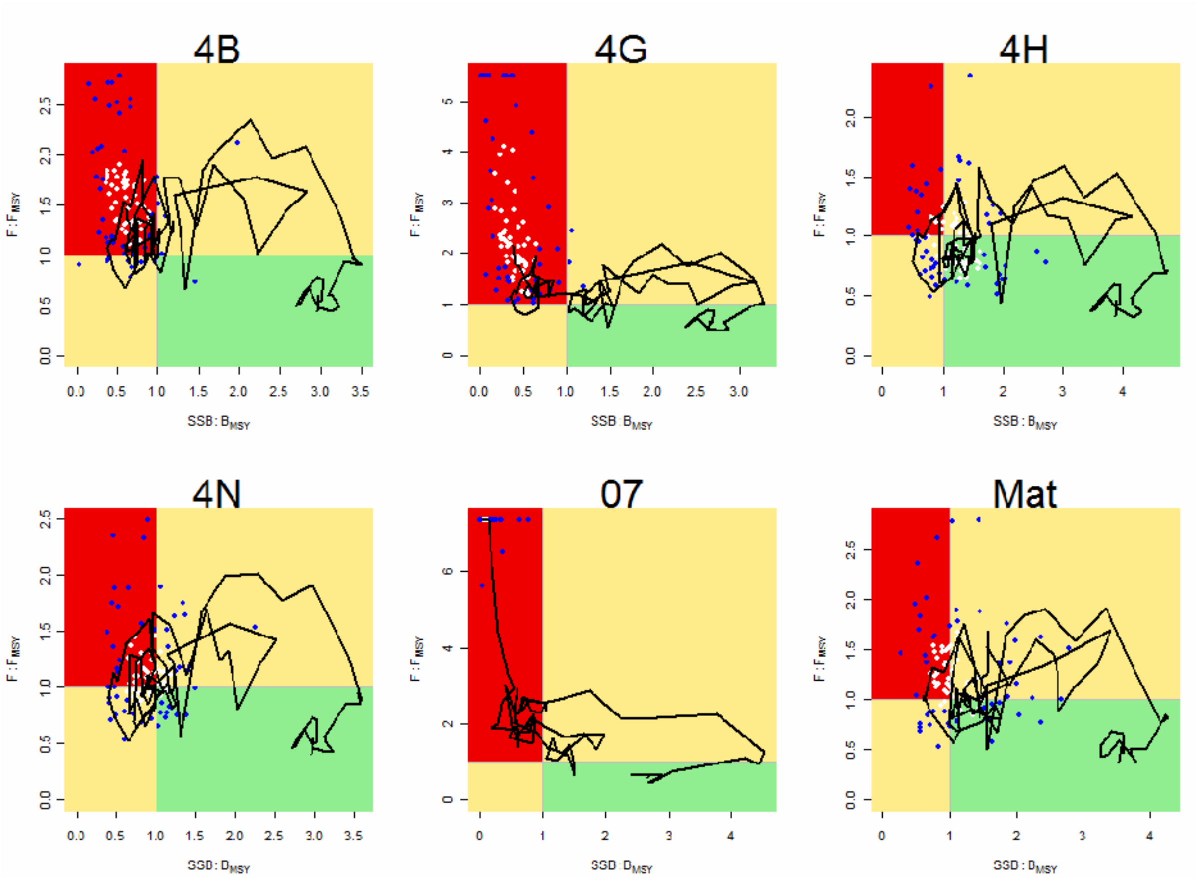

Figure 4. "Kobe plots" by scenario; points show individual realisations in 2015 (with white corresponding to the 50th bi-variate percentile). and lines the median stock trajectories for historic and projected periods. Quadrants are defined for the stock and fishing mortality relative to B_{MSY} and F_{MSY}; i.e. red SSB<B_{MSY} and F>FMSY, green SSB≥B_{MSY} and F≤F_{MSY}, yellow otherwise.

Management Target	Time Frame*	Probability of Meeting Target				Data Rich/Data Poor
		50%	60%	75%	90%	
F_{MSY}	In 1 year					
	In 3 years					
	In 5 years					

Management Target	Time Frame*	Probability of Meeting Target				Data Rich/Data Poor
		50%	60%	75%	90%	
B_{MSY}	In 5 year					
	In 10 years					
	In 15 years					

Figure 5. Example of a Kobe strategy matrix.

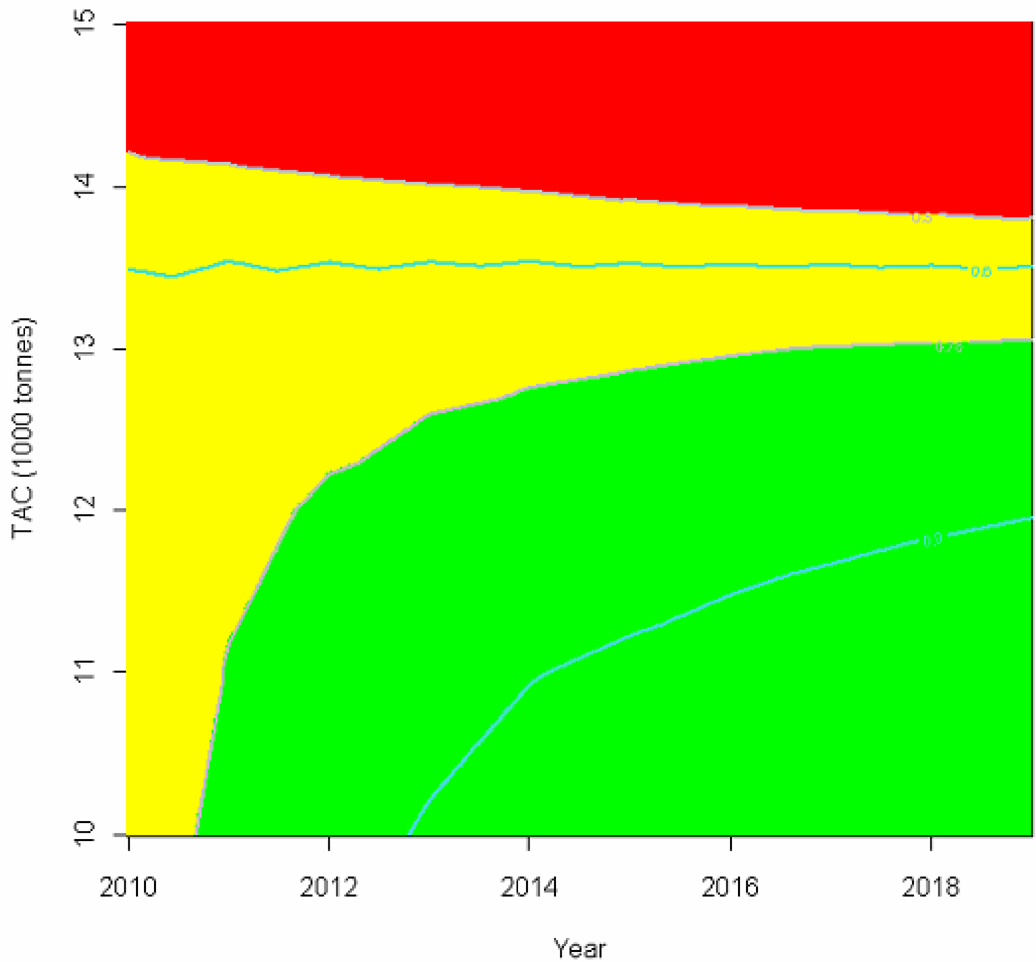

Figure 6. Example graphical illustration of the applying the Kobe II Strategy Matrix. The isolines are probability contours of B>B_{MSY} and F<F_{MSY} for constant catch scenarios over time. Red areas represent probabilities less than 50%, yellow from 50-75%, and green above 75%. The 90th, 75th and 60th probability contours are also depicted.