THE SIMULATION APPROACH TO EVALUATING FISHERIES ASSESSMENT AND MANAGEMENT TOOLS: WHAT CAN IT DO FOR THE IOTC?

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ABSTRACT

The simulation approach to evaluating fisheries management tools is often referred to as management strategy evaluation (MSE). The purpose of the (MSE) approach is finding robust decision frameworks for management in the face of uncertainty, and multiple, usually conflicting, management objectives. The approach is usually employed to evaluate feedback harvest strategies, but it also embraces evaluations that do not necessarily deal explicitly with feedback harvest strategies. Such examples include evaluations focusing on robustness and performance of assessment methods, stock indicators and biological reference points.One of the key components of any such evaluations is the operating model which mimics the underlying reality, particularly of the stock and fishery dynamics. In the context of the work of the IOTC, there are three areas where simulation studies can be of great use: 1) evaluation of stock-status indicators and associated reference points, 2) evaluation of assessment methods and 3) evaluation of CPUE-standardisation. There are many issues which require careful consideration when constructing operating models and designing simulation trials.

INTRODUCTION

The use of simulation modelling to test assessment methodologies and management strategies has been used extensively in fisheries science and management. In its most complete form, the approach is used to test the entire fisheries management process, from data collection to assessment, through to management advice and implementation. In this form the approach is referred to as Management Procedure Evaluation (MPE, in southern Africa and the International Whaling Commission) and Management Strategy Evaluation (MSE, in Australia and New Zealand). Smith et al (1999) notes that the MSE approach is virtually identical to MPE in methods and philosophy, but slightly wider in scope, embracing evaluations that do not necessarily deal explicitly with feedback harvest strategies. Whether used to develop an agreed management procedure/strategy or not, it is a valuable tool, providing an objective basis for short- or long-term decision-making. One common feature, whether doing a full MSE study or a more limited evaluation, of assessment methods for example, is the operating model (or operational model, OM) which is intended to mimic reality.

Within the IOTC, the WPM recommended (at its meeting in 2001) the development of "an operating model that could be used both for understanding the properties of methods for analyses and to explore possible mechanisms behind some of the features observed in the data". The WPB (2001) was also supportive of the development of an “operational model” which could serve as a benchmark for testing new procedures for analyses and assess the performance of management procedures based on pre-agreed decision rules.

For completeness, I first briefly set out what the full MSE approach entails what it can and cannot offer. I then consider some of the aspects or subsets which could be of immediate use and value to the work of the IOTC. Finally, I consider a few philosophical issues with regard to constructing operating models.

WHAT IS THE MSE APPROACH?

The term "Management Strategy Evaluation" can mean different things to different people. It is therefore useful to briefly consider what it really is, and what it can and cannot offer in a general sense. The MSE approach is essentially a simulation exercise. The purpose of the MSE approach is finding robust decision frameworks for management in the face of uncertainty, and multiple (usually conflicting) management objectives. There is a need to have pre-defined management objectives, in order to evaluate the relative robustness of different decision frameworks. This is done by defining performance measures which can quantify the extent to which management objectives are met by each of the candidate decision frameworks under a wide range of scenarios. This process is explained in a little more detail below.

The MSE framework allows for explicitly recognising uncertainties and exploring robustness, rather than aiming for optimality, of a range of management strategies under different scenarios representing 'reality'. The trade-offs in performance of the management strategies across a range of management objectives are made transparent to decision-makers and stake-holders. Proceedings from an ICES meeting held in Cape Town in 1999 provides an excellent overview of methods, applications and current implementations (ICES, 1999).

A full MSE simulation model will contain, at least, the following set of linked model components (see e.g. McAllister et. al., 1999):

1. Operating model: mimics "reality" of the stock dynamics and of the fishery
2. Data generating model: mimics sampling and data collection, such as catch data, CPUE data, biological data (length, weight etc.), tagging data and scientific surveys.
3. Assessment model: uses the data from 2. and performs an assessment; e.g. fitting a Schaefer stock-

production model to catches and a CPUE index of abundance, or an age-structured VPA-type analysis.

4. Harvest control: specifies how results from the assessment should be used to generate advice on harvest rate (or TAC) for the forthcoming year. Some authors combine 3 and 4 into one component, particularly since some control rules perform best with certain assessment models.

5. Harvest decision: mimics the decision-making process followed by managers once they are provided with the output from the harvest control model. In some cases this component is omitted if the harvest decision follows the harvest control results exactly.

6. Implementation of management decision: simulates the application of the harvest decision to the fishery and consequently on the population simulated in the operating model. This component is important if, for example, the fishery regularly over-shoots or under-shoots a given TAC.

Loop back to component 1.

One "cycle" through all components usually reflects a year in the life of the stock, the fishery and management. The process is repeated for many "years", and a wide range of measures, and statistics, are gathered to evaluate the performance of the system against a set of management goals. So, in addition to the simulation model, a set of management objectives and a set of performance measures are required in order to evaluate the performance of different management strategies. Management objectives could be related to conservation (e.g. maintain a low probability that spawning stock biomass, SSB, will fall below 20% of unfished SSB) or utilization (e.g. maintain the annual variability in TACs below some level). Punt and Smith (1999) list performance measures that were considered for a stock of gemfish to quantify performance relative to conservation- and utilization-related management objectives. The list includes measures such as the probability that the winter biomass does not drop below 20% of virgin (unfished) biomass some time during the 20-year projection time of the model, and the median and 90% limits for the average catch over the 20-year projection period.

Several points should be noted. First, the relevance of the MSE study will be directly related to the chosen set of management goals. So, although scientist can assist in defining these, it is most appropriate and most productive for managers and stakeholders to be directly involved in the process of defining management goals. There also needs to be a candidate set of potential management tools, specified clearly enough that they can be implemented in the model framework. For example, if it is unlikely that management will be through TACs, then there is no point in testing large amounts of TAC-based harvest control rules. Again, this process should have input from managers and stakeholders, as well as scientists.

Second, it is feasible to consider a subset of the full set of model components, depending on what one is trying to evaluate. If the robustness of assessment methods is the main interest, then there is little need to simulate the entire system in the first instance. Even in a case where there are no assessments, the performance of so-called empirical indicators of stock status, can be evaluated within this framework. It should, however, be noted that the usefulness of results is greatly enhanced if the evaluations are done in the context of management objectives. Obviously, in all cases (even where there are no clearly defined management objectives) there is still a need for objectives and performance measures in order to do comparative evaluations. In the case of a pure assessment method evaluation, objectives might be low bias and high precision of parameter-estimates. Performance measures would then include the relative bias and variance (or CV) of parameter-estimates. One advantage of doing a more complete evaluation which includes an assessment method and a harvest control rule, is that it is possible to find a harvest control rule which is robust even to, say, bias in an assessment.

Third, although some view it as a complex modelling exercise which requires a vast amount of data, it should be emphasised that the approach is particularly well suited to situations where there is a great deal of uncertainty and lack of data. Applications include data-rich examples, such as the eastern stock of gemfish (*Rexea solandri*) in south-eastern Australia (Punt and Smith, 1999), and data-poor examples, such as four of the species in Australia's South East Fishery (Punt *et. al.* 2001a). Even in the case of new fisheries with no data and very little knowledge or information, the approach can be applied to assist management decisions and minimise the chances of over-exploitation (Smith, 1993).

WHAT CAN ITS OFFER, WHAT CAN IT NOT OFFER?

It is important to recognise that the approach does not guarantee an optimal management strategy, but will help eliminate ones that are not robust, or that will perform poorly relative to the pre-specified set of objectives. Similarly, if applied to assessment methods only, the approach does not guarantee a single method which performs best under all circumstances, but it will at least lie bare the strengths and weaknesses of each assessment model.

There are the obvious benefits in terms of a quantitative comparison of the performance of different management strategies under different scenarios. The extent to which the management objectives are met and the trade-offs between the objectives will be explicit. In other words, advice regarding the type of management strategy to follow will be underpinned by analyses rather than based on guess-work or a blind leap of faith.

Since the framework allows for the incorporation of uncertainty about parameters, functional relationships and structures (through considering more than one operational model and different scenarios for each OM), the approach can reveal which uncertainties dominate outcomes and which ones are secondary to the outcomes. An important by-product of the MSE approach is a basis for prioritising research. It is, however, crucial to note that the process cannot eliminate uncertainty. Also, the uncertainty reflected by outcomes is directly related to what we decide to put into the simulation system (also see Section 5 below).

The comparison of different data sources and data types used in different assessment methods also provides a basis for prioritising data collection. For example, one could compare the performance of assessment methods which include tagging data with ones that do not use tagging data. In addition, one can evaluate what type of tagging program is likely to be most effective and how often tagging should be carried out.

WHAT CAN IT OFFER IN CONTEXT OF IOTC?

As noted above, a full MSE with feedback harvest strategies, require clearly defined management objectives and realistic candidate harvest control rules. These should ideally be defined through consultation with managers and stakeholders, a process that may take time. It may therefore be premature to consider a full-blown MSE approach for any of the stocks under IOTC management at this stage. Nonetheless, there are at least 3 areas where the simulation approach could be extremely useful and informative. If done with the general MSE framework in mind, it should be relatively easy to expand the exercise to include the evaluation of harvest strategies, when appropriate.

The first key area is evaluation of stock indicators and associated reference points. Recent reports of the WPTT and WPB indicate that for many stocks there are still no stock assessments possible, and hence no estimates of stock abundance. In these situations, use of indicators of stock status for management is becoming an alternative approach. There are many candidate indicators though their performance and reliability are usually untested. The simulation approach is perfectly suited to evaluating the performance of different empirical indicators for sensitivity to changes in stock size and the relationship between changes in the indicator as a function of changes in stock size. Punt et al (2001b) performed such an evaluation for the broadbill swordfish fishery off eastern Australia. It is worth noting that this study included uncertainty about stock structure in the operating model.

The second key area is assessment methods, an area highlighted in the report of the WPM 2001. Much work has already been done to compare assessment methods (e.g. Patterson & Kirkwood, 1995; Pope and Shepherd, 1985; Punt 1993; Punt 1997; Megrey 1989), but new methods or new versions of existing methods are continually developed. In addition to new, previously untested models, the particular characteristics and quirks of data from fisheries on large pelagics may in some cases make it unreliable to extrapolate from tests performed on data from groundfish fisheries. Works on tuna- and billfish-like stocks include papers by Butterworth and Punt (1994), Prager *et.al*. (1996) and Prager and Goodyear (2001). Most of the papers in ICES (1999) involve evaluation of one or more assessment method, but in the context of a management strategy. An evaluation done independent of a management strategy would have a rather different set of performance measures, and it is worth considering this issue when designing trials. For example, Geromont et al (1999) consider Fox and Schaefer production models, an age-structured production model, but performance measures relate directly to management objectives. This is appropriate, but makes it difficult to draw conclusions in a context where performance measures are purely in terms of the assessment model performance. If stock projections form a routine part of the assessment process, it is also worth considering whether this should be included in the simulation study.

Within this exercise, it would be useful to consider the different types of data currently available, and the types of data that could be made available in future. The relative value of different types of data, for example CPUE data and tagging data, could profitably be explored.

This leads to a third area where simulation studies could play a crucial role: CPUE standardisation. Again, this was highlighted in the WPM 2001 report. There are many problems and difficulties associated with CPUE data from fisheries on large pelagics, and there are many different ways of potentially dealing with these problems. Two of the key issues are targeting of species and lack of consistent spatial coverage. Simulation studies can clearly assist in evaluating, for example, under which circumstances a "core area" or "variable area" approach performs adequately, and when they fail.

There are also many potential problems with the actual standardisation procedures, usually performed with GLMs or GAMs. For example, large datasets fitted to models which include large numbers of covariates and interaction terms could in fact lead to the removal of a substantial part of the stock abundance signal if careful thought is not given to the meaning of the included terms and included interactions. This could be a problem with any type of CPUE data, not just large pelagics. It is worth briefly explaining what I mean. Catch per unit effort is affected by (at least) two sets of factors: (i) those associated with the catchability component and (ii) those associated with stock density component. For some factors it is very obvious which component they affect. For other factors it is not so straightforward. For example, does sea surface temperature affect local stock density or catchability, or both? Which component does the Southern Oscillation Index (SOI) affect, and what does it mean if the relationship between SOI and CPUE differs by area (SOI-area interaction term)? It is fair to say that not all aspects of this problem are likely to be tractable even with a simulation study. Nonetheless, we may at the very least be able to evaluate which approaches perform best under given circumstances and whether CPUE data are likely to be "over-fitted" or not.

Clearly, the CPUE standardisation and assessment are linked, and could be viewed as a single study. The WPM 2001 report discusses results from a procedure that integrates CPUE standardisation into the assessment framework. There is clearly scope for exploring this approach further with simulations. Additional comments are made below.

Two studies currently being undertaken at CSIRO on tuna and billfish-like stocks may be of relevance here. One project is titled: “Development of an operating model for evaluation of harvest strategies for the Eastern Tuna and

Billfish Fishery". In particular, the project focuses on an operating model for swordfish. This work is an extension of that in Punt et al (2001). The other project is an evaluation of assessment models that are under development for Southern Bluefin and tropical tunas. This Simulation-Estimation Stock Assessment Model Evaluation (SESAME) project will compare a range of assessment models of varying complexity, from surplus production models to rather complicated statistical models resembling A-SCALA (Age-structured statistical catch-at-length analysis; Maunder and Watters 2000) and MultiFan-CL (a length-based, age-structured stock assessment model, Fournier et. al. 1998). Evaluations will include simulated datasets for systems resembling SBT and tropical tunas from an operating model developed in-house. An additional component of the SESAME project involves participating in the Standing Committee on Tuna and Billfish Methods Working Group, and comparing models based on the simulated datasets from an operating model developed at the SPC Oceanic Fisheries Program (and initially resembles Yellowfin-like systems of the WCPO).

CONSTRUCTING OPERATING MODELS

As noted above, the common factor in all three areas of simulation work identified above is the Operating model (OM) which is intended to mimic/simulate "reality". It is convenient to consider two components: the population dynamics, and the fishery (or fleet) dynamics. These may be treated as two linked models, or as a single large model. Several issues require careful consideration from the outset. There will be a need to take a balanced approach, particularly with regard to the level of complexity in models and the level of uncertainty built into models.

Level of detail

The WPM 2001 has already identified a set of features which should be included in the development of an OM. It is obvious that the level of detail in the OM should at least match the level of detail required in the data one intends to simulate for use as a stock indicator, in CPUE standardisation or assessment methods. This does not necessarily mean that one would simulate all data at the level it is gathered in reality (e.g. sampling of length frequency data may not have to be by vessel or port). It is also important to note the practical implications of increasing the level of detail in the OM far beyond that required for the simulated data. As the model dynamics become more detailed, more relationships and parameters need to be specified, and more sensitivity analyses need to be considered. This leads to increasing time and computational demands. It is therefore important to consider carefully whether further levels of details are warranted rather than including more detail just because one can! Having said that, the OM needs to be complex enough to capture the key features and characteristics known about the population, and capable of displaying behaviour already observed. This leads into a second major issue, that of conditioning.

Conditioning

Conditioning is the term used for the process by which the operating model is "tuned" to produce simulated data which are compatible with historic data, and to produce a plausible scenario for the current state of the stock. This step is not always essential. An OM could be a pure generic simulation model containing plausible stock dynamics, but with no attempt to generate simulated data which correspond to any real observed data. One could, for example, set up a simple operating model based on the Schaefer stock-production model with arbitrary values for the rate of increase (r) and pristine biomass (K) parameters. In this case, there is no need for conditioning. If, on the other hand, one constructs such an operating model for a specific stock where a time-series of catches and abundance indices have already been observed, then it makes sense to choose the parameters driving the OM (r and K in this example) to be compatible with the observed data. This is usually done by fitting the underlying model (Schaefer in this example) to the real data to get estimates of r and K. The operating model will then have both an historical component covering the period for which data are available, and a future component covering a period following the historical period. Stock dynamics and data for the future component will be based on the r and K estimates obtained from historical data.

It is informative to consider a few examples of conditioning in MSE studies in the literature. Kell et al (1999) construct an operating model for North Sea Plaice. They condition the historical component on the observed time series of fishery data and conditional upon an adopted assessment method. The authors note that in this way, the OM is consistent with the latest North Sea plaice stock assessment as undertaken by the relevant ICES Working Group. This approach can, however, limit the number of possible interpretations of the historic data considered in the evaluations.

A second example is that of Southern Bluefin tuna (SBT) in Polacheck et al. (1999). Assessments based on historic data provide a large range of possible estimates for the current and historic population sizes of SBT. This range reflects the uncertainty in the input parameters used. Estimates of population size from a specific set of input parameters, and assessment model fitted to the historic data (catch, size, CPUE etc.) can be considered a plausible interpretation of the history of the stock. The authors note the trade-off between ensuring that a broad range of possible interpretations (of the historic data) are considered, and keeping the number of scenarios to a modest number in order to be able to examine a broad range of management strategies and uncertainties about the processes in the operating model. The authors therefore consider a set of 24 VPA (virtual population analysis) results to determine scenarios for the historical stock sizes in the operating model.

Although the concept of conditioning makes good sense, there are difficult decisions to be made in practice. Two particular dangers are: over-conditioning and ill-conditioning. If one considers only one assessment method, and there are few plausible assessment outcomes (only a few sets of input parameters together with the data lead to acceptable fits of model to data), then there is a danger of over-conditioning by using only those few as scenarios. One should consider using alternative assessment methods and one may even need to question one's level of trust in the data. Ill-conditioning can occur if the data are essentially misleading. For example, if the operating model is conditioned with a standardised CPUE series that is not linearly related to the stock size, then the conditioned operating model could be misleading.

It could be argue that conditioning is more crucial in the context of a full MSE than in a simulation study to evaluate assessment methods or stock indicators. As noted above, evaluations can be performed in a very general way using only simulated data. Nonetheless, the issue cannot be avoided entirely, since a degree of realism in the simulations is required, particularly when performed with a particular stock in mind. Furthermore, conditioning is directly related to the level of uncertainty in the operating model.

Level of uncertainty

One of the major advantages of the simulation approach is that uncertainty - both structural and parameter uncertainty - can be incorporated in the OM. A simplistic way of explaining the difference between structural and parameter uncertainty is the following: structural uncertainty refers more to uncertainty about the shape of relationships (e.g. is recruitment governed by a Beverton-Holt or by a Ricker stock-recruit relationship?), whereas parameter uncertainty refers to uncertainty about the value(s) of the parameter(s) associated with a given relationship. Parameter uncertainty would include the fact that quantities such as natural mortality or growth rate are not perfectly known. In a model with spatial detail, and even if the timing and direction of migration is well-known, parameters governing migration rate are likely to be highly uncertain. Structural uncertainty is of key importance when it comes to stock structure and stock distribution/migration. The difference between an OM describing one stock and another describing two or more stocks with some degree of mixing, does not usually lie simply in changing the value of one parameter (though one often tries to model such issues in an elegant way!). In some cases it may be necessary to construct more than one OM to capture different likely hypotheses about the underlying system. Uncertainty about the constancy of a relationship and its parameters could also be classed as structural uncertainty. For example, if one is uncertain about whether growth has changed substantially over time, this is different from only being uncertain about the values of, say, k and Linf in the von Bertalanffy growth curve. When only simulating subsets of the full MSE structure, one should carefully consider wether a particular issue is likely to affect the subset being simulated and therefore requires inclusion or not.

Although it is possible to over-represent uncertainty by including highly unlikely hypotheses about stock and fishery behaviour, there is a real danger of under-representing uncertainty. As noted by Polacheck et al (1999), there is a direct link between what uncertainties can adequately be accommodated in the assessment framework and their incorporation into the application of the simulation framework. If this link is not recognized, apparently robust performance from a particular management strategy (or assessment method) could reflect the limits of uncertainty considered in the conditioning rather than the real properties of a particular management strategy (or assessment method).

Structure of simulation trials

Although an OM is central to all three types of simulation work mentioned above, the requirements of each are somewhat different. Take the assessment and CPUE simulations as an example. For the assessment evaluations, one could generate "standardised" CPUE directly from the OM (rather than "raw" CPUE), and in that case the fleet dynamics could be modelled in a very simple way. The simulated standardised CPUE can, of course, deliberately be biased, be non-linearly related to stock size, and have any level of variance one chooses. Doing the CPUE standardisation exercise would require some form of "raw" CPUE, but if one is mainly interested in the relationship between some underlying stock size and the standardised index, then there is no real need to model complex underlying stock migration or movement to closely match reality. Even if the simulations only approximate "reality", one can still evaluate the performance of the standardisation process. So, by considering separate OMs one could get away with simpler versions at the outset.

Having said that, at some stage it will become important to evaluate the combination of CPUE standardisation and assessment method, unless one has a very good idea of the error structure and potential bias of the CPUE series, as well as the possible non-linear relationship between CPUE and stock abundance. In this case, an OM that can generate relatively realistic raw catch and effort data would be required. Doing separate trials is likely to be less demanding, and there is merit in doing at least some separate trials to ensure that a wide enough range of scenarios are covered and that one forms a good understanding of the behaviour of the separate components (CPUE standardisation and assessment methods) before linking the two together.

The construction of an OM should obviously be done in the context of its immediate and possible future use. Even if a full MSE study is considered to be premature at this stage, it may become desirable in the future, and it would therefore be prudent to bear this in mind when designing OMs.

CONCLUSIONS

In the context of the work of the IOTC, there are three areas where simulation studies can be of great use: 1) evaluation of stock-status indicators and associated reference points, 2) evaluation of assessment methods and 3) evaluation of CPUE-standardisation. A common factor in all three areas is an operating model of the relevant stock(s). There are many issues which require careful consideration when constructing operating models and designing simulation trials. The potential advantages of using the MSE approach to develop robust management strategies in future, suggests that it would be prudent to bear the full MSE framework in mind when designing the "subset" simulation trials and operating models.

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