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A brief review of the use of the precautionary approach and the role of target and limit reference points and Management Strategy Evaluation in the management of highly migratory fish stocks

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CAMPBELL C. DAVIES AND TOM POLACHECK[1]

[1] CSIRO, Hobart, Australia.

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Campbell Davies[1]
Tom Polacheck

Pelagic Fisheries and Ecosystems
CSIRO Marine and Atmospheric Research
Castray Esplanade, Hobart, Tasmania 7001, Australia

[1] Corresponding author: campbell.davies@csiro.au

Important Notice

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Table of Contents

List of Tables

List of Figures

Executive Summary

The Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (WCPO) entered into force in June 2004. The second regular session of the Commission's Scientific Committee (SC) adopted a work programme for 2007 to investigate alternative stock status reference points, including identification of appropriate target and limit reference points. The UN Fish Stocks Agreement provides the legal framework for new approaches to the management of fish stocks world wide. In particular, Article 6 and Annex II of the 1995 UN Fish Stocks Agreement and Articles 5 and 6 of the WCPFC Convention provide for the application of the precautionary approach and guidelines for its application to fisheries management of highly migratory species.

This review aims to do five things: i) provide the background and rationale to the development of reference points and Management Strategy Evaluation as separate but related approaches to dealing with uncertainty and risk in the management of fisheries; ii) briefly outline the relevant sections of international law that enable and require the implementation of the precautionary approach in the management of highly migratory fish stocks; iii) review the current application of the precautionary approach across international tuna RFMOs; iv) provide a framework and examples of how high level policy and management goals can be logically distilled into specific operational objectives and related directly to reference points in the context of the WCPFC and the Management Strategy Evaluation approach, and v) provide guidance on the issues that will need to be considered in the development of a work program for implementing the MSE approach in the WCPFC.

On the basis of this review we concluded the following:

- Provisions of international law and WCPFC require application of precautionary approach, including the use of target and limit reference points and pre-agreed management measures (i.e. decision rules)
- There are two contexts for the use of reference points: i) as a benchmark for interpreting result of stock assessment and providing advice on short-term management actions, and ii) informing the development of operational objectives and performance measures for management strategies as part of a management strategy evaluation process.
- MSE provides a formal approach for evaluating whether the performance of a management strategy is likely to be consistent with the precautionary approach and to compare relative performance among alternative strategies.
- Review of current application of precautionary approach in tuna RFMOS, including use of target and limit reference point and MSE, indicated that none appear to be currently applying the precautionary approach in practice as per WCPFC, UNFSA, FAO Code of Conduct.
- The WCPF Convention provides specific guidance and requirement for the development of formal management plans that meet the requirements of the precautionary approach.
- Operationalising the Commission's objectives along with defining appropriate performance measures and reference points is one key component of implementing the precautionary approach. This needs to be done based on realistic expectation of what is possible and in light of the feasible management measures that the Commission may utilise.
- The Commission and SC should initiate a work program for: i) a consultative process to develop formal management strategies for a small number of case studies spanning the size and complexity of the WCPFC fisheries; and ii) a technical process to evaluate the robustness of the current and alternative assessment and reference points and determine the specific technical requirements and costs associated with undertaking a management strategy evaluation process for specific fisheries.
- Other key issues in the implementation of the precautionary approach that need to be addressed include development of a program for the reliable collection of the fishery data with appropriate levels of independent verification and a research program to address priority information gaps;
- The resourcing of this process should be commensurate with the relative priority and likely impact of the outcomes on the decisions of the Commission. It is essential that the development of any future work program for stock status reference points and MSE is done with full consideration of the priority of and resources available for other elements of the precautionary approach that will be central to its effective implementation.

1. Introduction

The Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean (WCPO) entered into force in June 2004 with the effect that all major tuna fisheries are now covered by international fishery conventions. The objective of the Convention is to ensure, through effective management, the long-term conservation and sustainable use of highly migratory fish stocks in the western and central Pacific Ocean. For this purpose, the Convention established the Western and Central Pacific Fisheries Commission (WCPFC) and the Secretariat is based in Pohnpei, Federated States of Micronesia.

The completion of WCPFC is significant in that it is the first regional fisheries management organization to have been negotiated and established since the adoption of the UN Fish Stock Agreement. The UN Fish Stocks Agreement provides the legal framework for new approaches to the management of fish stocks world wide. In particular, Article 6 and Annex II of the 1995 UN Fish Stocks Agreement and Articles 5 and 6 of the WCPFC Convention provide for the application of the precautionary approach and guidelines for its application to fisheries management of highly migratory species. These Articles also identify the need to determine, on the basis of the best scientific information available, stock-specific reference points and the action to be taken if they are exceeded, as part of implementing a precautionary approach to management.

To date, the WCPFC has not agreed to any specific management objectives. It has largely relied on estimates of current stock size in relationship to MSY-based biological reference points for interpreting the current status of target stocks and the implications for future constant catches (e.g. SC2 2006). The second regular session of the Commission's Scientific Committee adopted a work programme for 2007 to investigate alternative stock status reference points, including identification of appropriate target and limit reference points. This work program was endorsed by the Commission in December 2006 and a consultancy commissioned in April 2007 to prepare a discussion paper for the 2007 meeting of the SC and make presentations to the methods working group of the SC and the plenary of the SC.

Objective

The objective of the paper is to provide an overview of the development and application of the precautionary approach in the context of the management of highly migratory stocks of tuna and tuna like species for the third meeting of the Scientific Committee. In particular the review focuses on the history and role of target and limit reference point and Management Strategy Evaluation in the practical implementation of the precautionary approach. The latter sections highlight issues and considerations relating to the identification and evaluation of appropriate target and limit reference points for the application of precautionary approach in the management of tuna resources within the WCPFC Convention Area, including the use of management strategy evaluation to formally evaluate the robustness of potential alternative management strategies.

2. General review of stock status reference points in the context of precautionary approach to fisheries management of highly migratory fish stocks

Over the past 10 to 20 years the focus of fisheries science and management has moved from approaches based on deterministic "best estimates" to approaches that recognize the need to explicitly incorporate uncertainty into the formal scientific advice and decision-making processes. This has resulted in a change in emphasis from optimality to robustness in developing management policies and strategies and the need for the development of management frameworks that can effectively make decisions in the face of the inherent risks and large uncertainty associated with fisheries (Hilborn and Walters 1992; Smith et al 1993; Kirkwood and Smith 1996; Francis and Shotton 1997; Caddy 1999; Punt 2006). Failure to account for uncertainty was seen as one major factor contributing to the continuing over-fishing and depletion of many fishery resources world wide (Stephenson and Lane 1995; Lauck et al. 1998; Smith 1998). The development of a precautionary approach was seen as a solution to these problems and represented a fundamental shift in the how uncertainty was incorporated into the provision of scientific advice.

The precautionary approach embedded two fundamental concepts into fisheries management with respect to the current review: (1) the use of reference points, and (2) the development of management strategies, in relationship to these references points, that account for inherent uncertainties and risks.

Reference Points

With respect to the first of these concepts, reference points are quantifiable measures of a stock or fishery that provide a measure of operational performance with respect to the underlying management objectives. They provide useful benchmarks, or standards, for assessing the performance of management actions, but by themselves are neither the objectives of management nor the determinate of management actions. A simple example illustrates the distinction between these concepts. A common management objective is minimizing inter-annual variability in quotas. A reference point for this object could be whether the inter-annual changes in TAC are less then 15%. Thus, a reference point 15% variation provides a straight forward basis for assessing how well this objective is being met (e.g. how frequently quotas changes are in excess of 15%). The reference point is neither the objective of management (i.e. there is no *a priori* reason for a particular percentage) nor does the reference point necessitate a specific management action (i.e. how recommended quota levels should be moderated if they exceed the 15% levels). Nevertheless, if management objectives are to be realized, there needs to some underlying (but not necessarily direct, or explicit) relationship, "on average", between management actions and the status of the stock or fishery to agreed references points.

Within the context of the precautionary approach, there has developed a large literature on reference points with a primary focus on the stock conservation and sustainability objectives of fishery management. Within this context, reference points commonly take two forms: (1) those that provide guidance on the status of the stock (e.g. B_{MSY}, B_{MEY}, B_{targ}, B_{lim},…B_t/B_0) and (2) those that reflect the sustainability of current and future levels of fishing (e.g. F_{MSY}, F_{MEY}, F_{targ}, F_{lim}…) (e.g. Mace 1994; Caddy and Defeo 1996; Caddy and McGarvey, 1996). These broad categories of reference points reflect, at least in part, the multiple objective nature of fisheries management (i.e. stock conservation and catch utilization) and the need to set biological limits for stock conservation as well as targets.

The concept of defining reference points for management, not only with respect to a target to aim for, but with respect to limits to be avoided is a fundamental component of the precautionary approach. The inclusion of, and emphasis on, limit reference points within the precautionary approach constituted a fundamental shift in perspective for fishery management – avoidance of "undesirable consequences" is given a priority. In essence, because of the inherent limitations and uncertainty in our ability to understand and estimate stock dynamics, as well as our limited ability to estimate the current status of a resource, the precautionary approach recognizes that management needs to adopt a two fold strategy in operationalising its objectives. That is, there is a need to determine states that are unacceptable to be in, due to associate risks to the stock and the fishery, as well as those states where, ideally, a stock and fishery should be at. This two fold approach stems from the recognition of the failure of the traditional approach of using maximum sustainable yield (MSY) as a single "optimal" management objective (Punt and Smith 2001).

Reference points can form a basis for constructing specific quantifiable objectives for a fishery from higher level management goals and guidance for interpreting the outcomes of an assessment to form the basis management advice. For example, the current stock assessments conducted by the SPC for target species in the WCPFC, use output of an assessment model (MULTIFAN-CL) to estimate the quantitative value for a range of reference points relating to stock status and current levels of fishing mortality (Hampton et al. 2006a and b). The reference points include B_{MSY} and F_{MSY}. The stock assessment results are used to provide estimates of the current stock size and most recent catches in relationship to these estimated values for the reference point. These estimates of current status relative to the estimated values of the reference points are used by the Scientific Committee to provide general management advice to the Commission (SC2, 2006). In the case of B_{MSY} and $F_{MSY,}$ they are presented as limit reference points not to be exceeded. At present however, there is no agreement on the management action that should be taken when the stock assessment results estimate that reference points have been exceeded, nor the appropriate level of confidence associated with the estimation of the particular reference point being used.

It should be noted that while reference points can form a basis for constructing specific quantifiable objectives for a fishery from higher level management goals, their primary focus has been in relationship to the biological conservation objectives of fishery management (i.e. prevention of over-fishing and over-fished resources). The more directly related economic and social goals of fishery management have generally not been included within general discussions of reference points. However, ensuring that reference points are defined with respect to these goals is also important in the development of robust management approaches. Explicit recognition and enunciation of objectives for these other important dimensions of fisheries management is important when developing management approaches for it provides recognition of the need to balance what are essentially competing objectives and of the impossibility of simultaneously maximizing them all.

Finally, it should be noted that the definition of appropriate target and limit reference point *per se* is not sufficient to achieve management that is consistent with the precautionary approach. The precautionary approach also requires that appropriate and timely management actions are taken in relation to the status of the stock and fishery relative to these reference points as part of a comprehensive management plan for the fishery (FAO 1997).

Management Strategies

A second key concept in the precautionary approach is the use management strategies in relation to reference points. The UN Fish Stock Agreements specifies that management strategies will be used as a basis for management decisions to ensure that "the risk of exceeding limit reference points is very low" and that "target reference points are not exceeded on average". The precautionary approach defines a direct link between reference points and management decisions, in that "reference points shall be used to trigger pre-agreed conservation and management action" and management strategies "shall include measures which can be implemented when precautionary reference points are approached".

While the precautionary approach specifically mandates the use management strategies involving pre-determined management responses relative to defined reference points, its provides little guidance on how these should be developed and how to evaluate whether the strategies are in fact likely to be consistent with the precautionary approach in practice (e.g. that the risk of exceeding limit reference points are low or that target references points on average will not be exceeded).

Separate, but parallel and consistent with the development of the precautionary approach, has been the development of approaches to formally evaluate the potential performance of management strategies, or management procedures, through simulation. That is, through simulation modelling of the stock and fishery dynamics, data monitoring, assessment and decision-making processes (e.g. Smith 1981, 1994; Butterworth et al. 1994; Constable and de la Mare 1994; Cochrane et al. 1998; Cooke 1999; Butterworth and Punt 1999; Polacheck et al. 1999). This approach, known as Management Strategy Evaluation (MSE) or, alternatively, as Management Procedures, provides an integrated approach for the development of a management strategy for a fishery that has a reasonable probability of achieving management objectives. The MSE approach provides a robust method for assessing the likely performance of a pre-determined set of management actions taking into account uncertainties with respect to both the data and the underlying dynamics of the resource. As such, the MSE provides the necessary link to ensure that the combination of reference points and harvests strategy defined for a fishery are in fact consistency with the basic principles of the precautionary approach (Kirkwood and Smith 1996; Punt 2006).

An important, but not always full appreciated problem, in the use of reference points for defining management strategies, is the potential confounding between the estimation of a status of a resource in relationship to a reference point and the actual true status of resource in relationship to the reference point. Of course, it is the latter that is of critical interest and importance for management, while it is only the former that, at best, is directly available for use in the decision making process. Simply using a single estimate from one particular stock assessment of where a resource is in relationship to target and limit reference points without regards to the uncertainty associated with the estimate can lead to poor (un-precautionary) and unstable management performance. For example, even in the situation of a relatively informative stock assessment without major model uncertainty (an unlikely situation in most cases, particularly for highly migratory species), estimates of stock status in relationship to whether a limit reference point has been exceeded are likely to be highly variable when the resource is in the vicinity of the reference point simply due to sampling variability in the data available stock assessment. In such situations, there is likely to be high inter- annual variability in the assessment of whether the limit reference point has been exceeded or not and the extent to which a management response is required. The MSE approach is intended to avoid this kind of problem by facilitating the development of management strategies that provide acceptable performance with respect to the “actual” or “true” status of the stock and fishery with respect to defined reference points, despite the uncertainty in the data ad assessment process.

The MSE approach involves the following four components:

1. The specification of operational objectives from higher level management goals;
2. Identification of performance measures for each objective;
3. Specification of management or harvest strategy (i.e. a decision rule, monitoring and assessment programs); and
4. A method of evaluation that provides an assessment of likely performance for any proposed management strategy as well as a basis for comparing the relative performance of possible alternatives (commonly done by simulation modelling).

These four components range across the roles and responsibility of policy-makers, managers, stakeholders and scientists. To be effective the MSE approach requires that there is a shared understanding and respect for these varying roles and responsibilities. It is important to establish a process for communications between the managers, primary stakeholders and scientists throughout the process to ensure that technical aspects of any management strategy are in fact logistically feasible, consistent with managers/stakeholders’ objectives, well understood and that there is joint ownership of the process and results.

The MSE approach was developed in recognition of the inherent uncertainty in our knowledge of the past and current status of the fish stocks, their response to different levels (and types) of harvest and their current and future productivity and, therefore, the range of uncertainties associated with scientific estimates of quantities such as biomass, productivity and sustainable yield. In this context, the focus has shifted from attempting to provide the "best estimate" of sustainable yield, given current knowledge of stock status and dynamics, to one that focuses on the evaluation of strategies that are likely to meet specified objectives of management (and by default, higher level objectives of enabling policy or legislation) in spite of our uncertain knowledge of the system. In other words, the focus of MSE is to identify management strategies that are "robust" to known and plausible sources of uncertainty in the assessment and management of the fishery.

Operational Objectives

An essential and important step in the application of a MSE approach is the articulation of the operational objectives. An operational objective is a specific, unambiguous statement of what management aims to achieve. Ideally, this should include an iterative process of consultation between policy, management, stakeholders and science (Sainsbury et al 1999, Mapstone et al 2004). The need for iteration and consultation is twofold. One, objectives defined in the abstract may not be feasible to achieve in reality, or difficult for policy-makers, managers and stakeholders to relate to. For example, in the case of southern bluefin tuna, the CCSBT defined recovery of the spawning stock to its 1980 level by 2020 as one of its primary management objectives. However, by 2000 when it was attempting to develop a management strategy for the stock, all analyses indicated that even under zero catches it was highly unlikely that this rebuilding objective would be achieved. As such, there was little point in attempting to design a strategy to meet this objective. The second reason for consultation and iteration in the process is that different management objectives are likely to conflict (e.g., objectives for catch stability will tend to conflict with objectives for catch maximization). As such, it is important that the trade-offs are well understood and that a satisfactory balance in achieved in the specification of multiple objectives.

In some instances, an operational objective will ideally include a statement of the state to be achieved/avoided, the desired level of confidence/risk and the time period over which it should apply. For example, "to maintain, on average, the spawning stock biomass above 50% of its average unfished level" or " to ensure that the probability that fishing mortality exceeds F_{MSY} is not greater than 20% in any one year". In doing so, this provides a basis, in principle at least, to incorporate the elements of the precautionary approach (uncertainty, risk, reversibility) directly into the objectives (Kirkwood and Smith 1996). However, when multiple objectives are involved, it can be difficult or impossible to pre-specify operational objectives with this level of specificity that can all be simultaneously met. Either, it will be require the priority to be given to different objectives to be determined (i.e. ensure that one specific operational objective is met and the others met to the extent possible) or more general specifications will need to be used and the trade-offs evaluated to provide a procedure that give acceptable balance among competing objectives.

An early example of operational objectives in the MSE context comes from the International Whaling Commission's process of evaluating and selecting a Revised Management Procedure (IWC 1994). In this case, the objectives agreed by the IWC were:

1. Stability of catches;
2. Acceptably low risk of stock depletion to below 54% of carrying capacity; and
3. Making possible the highest continuing yield from the stock.

The general concepts underlying these objectives, that is (1) stability of catches, (2) minimization of the risk of recruitment over-fishing and (3) potential to realize the highest sustainable yield over the long term, are often considered as the three basic classes of objectives underlying fishery management (particularly at the international level).

Note that there are other objectives that can, and frequently are, also important but do not fit directly into one of these categories. For example, profit maximization, net economic return to the national economy, economic efficiency, employment maximisation, social equity or minimization of by-catch are all common objectives for fisheries management in different contexts. However, to our knowledge there has been limited application of MSE approaches to this broader suite of objectives (but see Fulton et al. 2007 for recent examples) and some judgment needs to be made as to whether it is appropriate or possible to address particular issues in a quantitative MSE framework. As important, decisions need to be made about which actual objectives management intends to actively pursue. At the international level many of these objectives would appear to be intractable because of the competing interest among the parties and differing goals and priorities in the short and long term.

Performance Measures

Performance measures are simply quantitative measures of how well management objectives are being met. They form an essential component of the MSE process as they are the basis for assessing the performance of a management strategy (e.g. is it consistent with precautionary approach) and comparing/selecting among different potential strategies. There needs to be at least one performance measure for each objective, but multiple measures are often relevant to the same objective. For example, with respect to catch stability, the frequency that TAC changes as well as the magnitude of the inter-annual variability may be two performance measures of interest. Performance measures provide the direct link between the MSE approach and the reference points in the context of the precautionary approach. The reference point provides the standard or benchmarks for assessing whether the performance measure expected to be realized from a particular strategy is acceptable – i.e. how frequently and to what extent a performance measure exceeds any given reference point.

Management Strategy

Within the context of the MSE approach, the management or harvest strategy is a fully specified and agreed set of rules that specify what data will be collected, how they will be analysed and “assessed” and the criteria for how the results of the “assessment” will be used to determine the next set of management actions (e.g. setting of TAC). Figure 1 provides an example of a very simple form of harvest strategy illustrating the three main components of the data, assessment and criteria. Note that the “assessment” in this context need not necessarily be equivalent to the best conventional stock assessment. The goal of the assessment in this case is to extract an informative signal to guide the next management decisions (e.g. level of annual TAC, TAE) based on the results of past experience. This contrasts with conventional stock assessment approaches which aim to provide the best estimate of current stock status and the short term implications of different constant catches. Experience has shown that relatively simple assessments used in this context may often provide better performance then highly complex ones (Hilborn and Walters 1992). It should be noted that the criteria used to translate the results of the assessment into a management decision will inevitably involve the specification of one or more parameter values. For example, in the illustrative example contained in Figure 1, the parameter “*a*” can range from 0 to 1.0 and controls the extent that the previous quota will be carried over into the next year’s quota or the extent that new data can affect a change in the TAC.

A key characteristic of a management strategy in this context is its complete specification (including the data to be collected and the analysis methods to be used). Without a complete specification, it is not possible to evaluate the performance of a strategy and, hence, assess whether in fact there is a high likelihood of achieving management objectives. Additional advantages of having a fully specified set of rules is that the assessment and decision making process become more transparent, it reduces conflicts at the time when decisions need to be made and it prevents uncertainty being used to delay decisions or marginally compromise them. Nevertheless, while the full specification of the management strategy is intended to provide coverage the full range of eventualities, in practice exceptional and unforeseen circumstances can arise. This should be explicitly allowed for in the specification of the strategy so that there is a well defined procedure for the automatic decision making process to be over-ridden in circumstances that have been pre-agreed as exceptional.

Evaluation Process

The evaluation step is a fundamental component of the MSE approach. Without a comprehensive process for evaluating performance there is no objective basis for assessing whether a particular management strategy has a high likelihood of achieving management objectives, favouring one set of decision rules over another, or determining the extent to which a particular strategy is likely to be truly precautionary in practice. The evaluation process is designed to provide an objective and scientific approach to assess likely performance. Ideally this could be an empirical experimental approach, but realistically this is not feasible (i.e. there are not replicate resource/fishery systems upon which to perform the experiments, particularly in the case of highly migratory species). Instead, the approach that has been developed and increasingly widely applied is to use a Monte Carlo simulation, which attempts to mimic all the important components (including the important uncertainties) of the process (i.e. it involves an iterative process of updating the underlying stock, the fishery, the collection of data, the assessment process, the decision rule, the specification of the subsequent management action which leads into the subsequent cycle of stock and fishery dynamics). The advantage of doing the evaluation in a virtual world is that there are no negative consequences for utilizing poor strategies. If a strategy does not perform adequately in a well constructed simulated system, what basis is there for assuming that it will work in the real one?

The evaluation process for an MSE is technically complex and demanding. The simulations need to contain alternatives for the underlying stock and fishery dynamics in order to ensure that a strategy is robust and provides adequate performance in light of the basic uncertainties about the system. As such, an essential part of the evaluation process is ensuring that the simulation models appropriately account for and incorporate the full uncertainty about the real stock, its dynamics, the sampling processes and the implementation of management actions. If the uncertainty is under-represented, the evaluation process will result in unrealistic expectations of performance. However, if it is over-represented it will result in undue pessimism about accomplishing anything. Additionally, it is important that the simulation model for the underlying stock and fishery dynamics is consistent with the available historic data. For example, there is little point in testing a management strategy for a stock which could have produced a maximum of X tones over the last 25 years when in fact twice that amount was taken from the stock over the same period. The process of ensuring that the underlying modelled stock and fishery dynamics are both consistent with the historic data and also adequately represent the main underlying uncertainties is referred to as “conditioning” of the operating model.

At the technical level, the simulation modelling consists of five main components:

1. an operating model that simulates the population and fishery dynamics;
2. a sampling model that generates the data available for assessing the resource from the ‘‘true’’ state of the resource as simulated in the operating model;
3. an assessment model that uses the data from the sampling model to provide *estimates* of resource status;
4. a harvest strategy component that determines management actions (e.g. setting a quota) based on the results of the assessment and a specified decision rules;
5. a component for the calculation of an appropriate set of performance statistics.

The first four of these components are sequentially iterated to simulate a time series of future population sizes, management actions, and catches. The results can then be used to evaluate the performance of a particular management strategy for a specific set of assumptions about the dynamics of the resource. Finally, a component is required to determine a range of initial starting values for the operating model that are consistent with the available historical information on the stock being evaluated. As noted already, this process is referred to as conditioning. Figure 2 provides a schematic representation of the overall framework and the interrelationship between the different components.

Reference Points Revisited

At this point, it is worth further elaboration on the distinction between the role of reference points in relationship to the precautionary approach and provision of management advice. As noted, reference points can form a part of an operational objective for an MSE and they can be a benchmark for the status of the stock and fishery estimated as part of regular stock assessment process.

In the context of an MSE, the evaluation process is used to assess whether in fact a proposed management strategy will provide behaviour that is consistent with the precautionary approach (e.g. “the risk of exceeding limit reference points is very low” and that “target reference points are not exceeded on average”). Performance measures from the evaluation process summarise the performance of a harvest strategy relative to each operational objective including those which are expressed in terms of target and limit reference points. For example, the proportion of years over a time period of a simulation that the biomass drops below the limit reference point is a commonly used performance measure for a stock conservation objective. In an MSE, the state of the stock, and all other quantities of interest, are known perfectly, as they are generated by the operating model. Hence, there is no uncertainty in calculating the performance measure as there is no uncertainty in the state of the stock in each year relative to the reference point. Nor is there any uncertainty in what the “true” value of the actual reference points (e.g. B_{MSYi}), due to uncertainties about the stock biology and dynamics (e.g. age of maturity, stock productivity, weight-at-age) as this value is also known. As such, conditional on the evaluation process, it is straight forward to assess whether in fact a management/harvest strategy is consistent with the precautionary approach in terms of target and limit reference point.

Note that within the MSE framework, the management strategy is relied on to ensure that the precautionary approaches requirements with respect to reference points are satisfied. Annual estimates of the stock status relative to these references points are not required components of the process or necessarily direct inputs into the annual decision making process (although such estimates from the MSE “assessment” can be a component of the decision rule). In the MSE context, a wide range of target and limit reference points can be incorporated into the evaluation process. This allows for a reduced emphasis or need to select the “best” reference point for the stock in question. Moreover, it has been frequently found there is relatively high correlation in the performance of a management strategy with respected to reference points within a similar class (e.g. stock status).

In contrast to the MSE approach, the annual stock assessment approach attempts to use the results directly from the annual assessments to ensure that management decisions will be consistent with the precautionary approach’s requirements with respect to reference points. Thus, the results from stock assessments are used to estimate the current stock status relative to agreed reference points and short term management actions evaluated (generally in terms of constant catch projections) to attempt to ensure that limit reference points are unlikely to exceeded and that target reference points are not exceeded on average. This approach depends upon the stock assessments providing sufficiently reliable measures of the status of the stock and fishery with respect to agreed reference points and from these that it is straightforward to determine what are the subsequent decisions required to ensure that the precautionary approaches requirements are met.

However, in any stock assessment, there is considerable uncertainty in the estimate of the current state, and the actual value for a particular reference point (e.g. F_{MSYi}, B_{MSYi}). There can be considerable estimation uncertainty in the form of bias and precision but generally even greater uncertain as a result of model and structural uncertainty (Kolody et al. 2004). The potential extent of bias and precision will depend on the nature of the reference point, the data, assessment method, the stock in question and its history of exploitation (e.g. estimation of stock productivity from “one way trips” is notoriously poor). It has been demonstrated through simulation studies, however, that the form of biases associated with different classes of reference points and assessment methods means that some are more less sensitive to violations of underlying assumptions and data inputs than others (Polacheck et al 1993, Punt 1994, Kolody 2004). Furthermore, in light of model uncertainty and data which are not highly informative with respect to key parameters for the estimation of a reference points (e.g. steepness in terms of B_{MSY}), estimates of stock status with respect to reference points and their confidence intervals can be very sensitive to assumptions, priors and weights for alternative hypotheses. This can result in large amount of discord and disagreement within the Scientific Committees responsible for producing advice to management and the results contested by parties who have interests in specific outcomes.

In addition, best estimates of whether a reference point has been exceeded or not can be highly unstable between years as a result of inherent sampling variability in the input data, combined with adjustments to assessment model. In this context, it has been demonstrated that while particular reference points and associated management strategies may appear to be precautionary in principle, it does not mean they are necessary precautionary in practice (e.g. Smith 1993; Punt 2000; Punt et al 2000). What this means in the context of the stock assessment approach is that it is not possible to determine whether a particular reference point (and/or associated confidence interval) is precautionary or not without having formally evaluated its use in decision making under known conditions, i.e. via management strategy evalution (Kirkwood and Smith 1996).

It should also be noted that within the stock assessment context, the choice of reference point can often be a major issue. This is because, in contrast within the MSE approach, the choice of the specific reference points used (and how they are calculated) can have substantial direct impacts on short term management decisions and on the perception about whether current management is consistent with the precautionary approach.

Notwithstanding these point, while there are problems in using the stock assessment approach, the results from stock assessments should not simply be ignored in terms of the estimates they produce of current stock status in relation to reference points. In particular, when stock assessments indicate that limit reference points have been exceeded this should be considered as evidence that past and recent management practices have not been consistent in practice with the precautionary approach. Especially in the case where a stock has been highly depleted, stock assessment in spite of all their problems will leave little doubt that limit reference points have been exceeded and thus provide a clear signal of the need for a recovery strategy. However, even in this situation, it is difficult to specify a particular recovery strategy, or to assess whether it would be consistent with the precautionary approach, outside of a MSE framework.

In conclusion, in our opinion, the use of the MSE approach provides the most robust and objective basis both for identifying reference points for use in a management decision making framework and ensuring that management strategies are appropriately linked to reference points in a manner that yields long term performance consistent with the precautionary approach.

3. Brief overview of relevant provisions of international law relating to the application of precautionary reference points in the fisheries management of tuna and tuna-like species

The United Nations Convention on Law of the Sea, 1982, is the over-aching instrument of international law for management of fisheries. It provides for the sustainable use and conservation of marine resources and defines the rights, responsibilities and obligations of States. The precautionary approach has its formal origin in the United Nations Conference on the Environment and Development, in particular Chapter 17 of Agenda 21. It has subsequently been refined for the particular context of fisheries and incorporated in the UNFSA (Article 6 and Annex II, the FAO Code of Conduct for Responsible Fisheries and Article 6 of the WCPFC.

Common principles underpinning the application of the precautionary approach to fisheries management include:

- The approach should be applied widely to conservation, management and exploitation to protect living marine resources and preserve the marine environment;

- Caution in the face of uncertain, unreliable or inadequate information;
- Consideration of the level and distribution of fishing effort and the structure and distribution of the target stocks and non-target and dependent and associated species;
- The collection and sharing, in a timely manner, of complete and accurate data concerning fishing activities;
- The establishment of appropriate cooperative mechanisms for effective monitoring, control, surveillance and enforcement;
- The development of reference points and decision rules on the basis of the best available scientific advice;
- Timely implementation of measures to ensure that when reference points are approached they will not be exceeded, preferably as part of a formal management plan for each fishery;
- Avoiding over-capacity;
- Increasing monitoring when the status of target stocks, non-target or dependent species is of concern to improve the efficacy of conservation and management measures;
- Implementing measures that do not allow effort in new and developing fisheries to expand faster that the availability of information and implementation of management measures to ensure conservation and sustainable use; and
- The adoption of emergency management measures to ensure that fishing does not exacerbate the effects of natural or non-fishery human phenomenon on the long-term sustainability of the stocks.

From this it is evident that the application of the precautionary approach extends beyond the selection and use of reference points to include the design of stock assessments, monitoring, targeted research, management measures and decision rules in relation to underlying assumptions about the structure and state of the target and non-target populations and marine environment.

Furthermore, there is the explicit expectation that the implementation of the precautionary approach involves the use of prudent foresight and timely decision making to avoid the risk of fishing reducing stocks to undesirable levels (i.e. below limit reference points), including limiting the level and rate of development of fishing capacity to be commensurate with the uncertainty in the productivity of the target stocks. As outlined above, the MSE approach provides a formal basis for evaluating whether management strategies are likely to be consistent with the precautionary approach.

These issues are revisited in more detail in Section 5 in the specific context of the WCPFC.

4. Overview of the current applications of the precautionary approach in major tuna RFMOs, addressing their management objectives and technical methods to achieve them.

Section two provided an overview of the background to the development of reference points and management strategy evaluation and some of the issues associated with their application. This section focuses on the application of the precautionary approach in the context of the Regional Fisheries Management Organisations (RFMOs) responsible for the management of highly migratory stocks. It is based on a necessarily brief review of the most recent reports of the working groups, scientific committees and commissions of major tuna RFMOs, as well as a number of relevant workshop reports addressing the use of reference points and MSE approaches for management of tuna and billfish (e.g. SCTB 1998, IATTC 2003, 2006).

In addition to the major tuna RFMOs, we have also included the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) as an international regional body responsible for the management of fishing of stocks that cross multiple jurisdictions and a recognized example of implementation of the precautionary approach to international fisheries (Kirkwood and Smith 1996; Anon 2007).

The results of the review across RFMOs for the major target species of tuna and billfish and elements of the precautionary approach are summarized in Table 1.

A number of general points are worthy of note:

- With the exception of their implicit use by the WCPFC, (and arguably CCSBT), tuna RFMOs have not adopted formal limit reference points;
- All tuna RFMOs, with the exception of WCPFC and CCSBT, use MSY or B_{MSY} as a target reference point for the status of the stock and F_{MSY} for a target fishing mortality;
- None of the tuna RFMOs appear to have formally agreed confidence levels associated with estimates of current stock size in relation to limit or target reference points for use in providing management advice or making management decisions;
- With the single exception of BBL in ICCAT in a rebuilding situation, none of the stocks managed by tuna RFMO have implemented any pre-agreed decision rule for management action;
- There are a wide range of assessment models in use; running the full spectrum from relatively simple to highly complex with the model relied on by WCPFC being the most complex;
- The extent to which assessments have attempted to quantify the uncertainty associated with them and the approaches for doing this vary greatly among RFMOs and among stocks within RFMOs;
- The extent to which estimation and model uncertainties are incorporated as an integral part of the stock assessment process and the presentation of management advice varies substantially among RFMO and assessments of individual stocks;
- Within the tuna RFMOs , many species and stocks have either: 1) no formal assessment available; or ii) no agreed assessment;
- The primary data informing the stock assessment was fishery-dependent catch, effort and size information. For a proportion of stocks, generally the high value fisheries, conventional and/or electronic tagging data are available for use in the assessments (either directly, or to inform assumptions about stock structure);
- All of the assessments conducted by tuna RFMOs are highly dependent upon CPUE indices of abundance and the problems with this are well known;
- Formal evaluations of harvest strategies/management procedure were rare. Notable exceptions being the CCSBT management procedure process (but see Basson et al 2006, and Polacheck et al 2006) and the early example for Antarctic Krill in CCAMLR;
- There are, however, a number of MSE processes either in progress (CCAMLR, ICCAT) or in development (IATTC).

On the basis of this brief review, it is difficult to conclude that any of the tuna RFMOs are currently implementing the precautionary approach in practice. None of them have both agreed target and limit reference points for their major target species or have implemented defined management strategies that are designed to ensure that “the risk of exceeding limit reference points is very low” and that “target reference points are not exceeded on average”. Thus, the most basic aspects of the precautionary approach, in terms of reference points and their use in the decision making process, are not part of the management process, much less are many of the other broader requirements of the precautionary approach (as outline in Section 3 above) incorporated into the current management and scientific processes.

While the precautionary approach appears not to be being implemented in practice within the tuna RFMOs, it must be acknowledged that the time available for this review did not allow an exhaustive review of the available literature nor direct consultations. Hence, it is possible that more effort and progress is being made towards actually implementing the precautionary approach than was evident from the information available for this review.

It should be noted that a governance problem for a number of the tuna RFMOs with respect to the precautionary approach is that the conventions under which they were constituted pre-date the development of the precautionary approach and the UN Fish Stock Agreement (e.g. Restrepo, In IATTC 2003). In several cases, B_{msy} and/or F_{msy} are built into their enabling conventions as target reference points (in contrast to the UN Fish Stock Agreement in which these are effectively defined as minimum standards for limit reference points). Thus, it is perhaps not surprising that these RFMOs struggle in implementing the precautionary approach. As such, the current practices in these RFMOs appear not to provide useful guidance for the WCPFC with respect to reference points and the precautionary approach.

Among all of the tuna RFMOs, the CCSBT is the only one that has attempted to embrace and develop a fully specified management strategy based on the MSE approach outlined in Section 2 and is the one tuna RFMO that has abandoned the use of the reference point based stock assessment approaches in recent years. In this context, it is the only one of the tuna RFMOs that has attempted directly (but not necessarily explicitly) to implement the precautionary approach. The MSE approach adopted by the CCSBT was “technically” successful. Out of the process the CCSBT Scientific Committee was able to recommend a fully specified decision rule or management procedure that had been tested and demonstrated to provide “acceptable” performance (i.e. having some reasonably probability of achieving some stock rebuilding over the next 20 years) (SC-CCSBT 2005). The CCSBT adopted “in principle” the results from this MSE process (CCSBT 2005). However, before being implemented the primary catch and effort data, which were to be used in the decision rule and which were also an integral part of the evaluation process, were shown to be gravely compromised by 15 years or more of previously unknown Japanese IUU fishing (Polacheck et al, 2006;Basson et al 2006; SC-CCSBT 2006). In short, the CCSBT process demonstrated that the implementation of the precautionary approach in terms of reference points and management strategies is feasible within the context of tuna RFMOs. However, even more fundamental to the implementation of the precautionary approach than reference points and management strategies is ensuring the availability of an accurate information base for making decisions. In this regard, the CCSBT failed and has demonstrated that data monitoring and enforcement will be critical for the successful implementation of the precautionary approach in RFMOs (see Polacheck and Davies 2007).

The review of reference points and stock assessments in CCAMLR provides examples of how the stock assessment approach for the use of reference points has been successfully adopted. This approach has included the formal specification of decision rules based on estimates of current stock status in relationship to estimates of agreed reference points. Based on our review, there is nothing that would indicate that a similar approach could not also be adopted by tuna RFMOs. Although, the management strategy for each of the target species includes the used of fisheries independent estimates of abundance, generally in the form of stratified trawl surveys, something which has is difficult to obtain for highly migratory pelagic stocks.

While the general approach being used by CCAMLR would appear to be precautionary in principle, it does not clear whether any of the specific applications is actually precautionary in practice. As noted above, this requires an objective evaluation process, which has not been undertaken to date (but a process in which CCAMLR is currently engaged).

In summary, it can be said that for all of the tuna RFMOs and for the majority of species for which they are responsible, the current management arrangements in terms of reference points and management strategies cannot be considered precautionary in the context of the criteria stipulated in current international agreements, as outlined in the previous sections.

5. Identifying operational specification of the Commission's management objective for key tuna species in the WCPO and selecting appropriate target and limit reference points

This section attempts to provide a framework for the development of formal management strategies (including operational objectives, reference points, decision rules and monitoring strategies) for the WCPFC. As already noted, it is essential that the actual process of developing specific objectives and management strategies is an inclusive, iterative process between the policy-makers, managers, stakeholders (industry and NGOs) and scientists involved in the fisheries. That is, in the case of the WCPFC, the Commission, Scientific Committee (including appropriate specialist working groups), and stakeholders.

The development of management strategies will require a number of related processes. One of the first of these should be the refinement of into more specific operational objectives for the high level goals and guidance provided by the convention. This needs to be followed by the definition of agreed performance measures and reference points (bench marks) for each operational objective. The WCPFC is, in some respects, fortunate to have a Convention that provides relatively specific guidance on the principles and considerations to guide the development of more specific management objectives as part of formal management plans for each fishery. We elaborate on this point below, purely by way of example, to illustrate the linkages between higher level policy objectives and more technical specifications. However, the size, number and complexity of the fisheries and diverse group of interests in the WCPFC raise some considerable challenges in terms of the consultative and technical processes required. In light of this, we recommend that it may be most effective to approach this important task in a series of case studies that address the spectrum of fisheries management complexity that the Commission is charged with managing.

As noted, the Convention is unusual, relative to most other tuna conventions, in that it provides quite specific guidance on the relationship between its high level objective and the development of conservation and management objectives and associated reference points for fisheries management plans. This is not surprising given its origins under the UNFSA and the international scientific and management shifts the preceded it (see section 2). The examples provided below are aimed at illustrating this relationship. Naturally, it is the role of the Commission, in consultation with the Scientific Committee, to make the formal interpretation as part of developing formal management strategies. A process that this paper is designed to facilitate.

The objective of the WCPFC is "*... to ensure, through effective management, the long-term conservation and sustainable use of highly migratory fish stocks in the western and central Pacific Ocean in accordance with the 1982 Convention and the Agreement.*"

Article 5 of the Convention provides further guidance for the interpretation of the objective of the Convention through "*Principles and measures for conservation and management*". These include, *inter alia:*

i. *"to **ensure long-term sustainability**" and to "**promote optimum utilization**";*

ii. *"**ensure** that such measures are based on the **best scientific advice** and are designed **to maintain or restore** stocks at levels **capable of producing maximum sustainable yield, as qualified by relevant environmental and economic factors, including the special requirements of developing states in the Convention Area, particularly small island developing States**.."*

iii. *"apply the **precautionary approach**.."*

iv. *assess the **impacts of fishing, other human activities and environmental factors** on target stocks, non-target species, and dependent and associated species;*

v. *"take measures **to prevent or eliminate overfishing and excess fishing capacity** and **to ensure that levels of fishing effort do not exceed those commensurate with the sustainable use** of fisheries resources";*

vi. *"take into account the* ***interests of artisinal and subsistence fishers";***

vii. ***Collect and share, in a timely manner complete and accurate data*** *concerning fishing activities on, inter alia, vessel position, catch of target and non-target species and fishing effort…"*

These guiding principles allow for more specific interpretation of the objective of the Convention in developing specific objectives for management strategies. For example, the emphasis on *"ensure long term sustainability… of stocks"* and *"to promote... optimum utilization"* can be interpreted to reflect that the latter is conditional on the former. That is, that optimum utilization is conditional on the long-term sustainability of the stocks. This is consistent with the concept of limit reference points for stock conservation (Annex II, UNFSA). In addition, the choice of word "ensure" can be interpreted to indicate that there should be a high probability of this objective being achieved while "promote" implies less stringent performance criteria. Another example, relating to measures designed to prevent over-fishing and limit the development of over-capacity, is paragraph (g) of Article 5: *"take measures to prevent or eliminate over-fishing and excess fishing capacity…."* This implies that management measures should have a very high likelihood of avoiding over-fishing and preventing excess investment in fishing capacity.

In relation to situations when a reference point is approached Article 6, paragraph 3, states: *"Member of the Commission shall take measures to ensure that, when a reference point is approached, they will not be exceeded. In the event that they are exceeded, members of the Commission shall, without delay, take the action determined under paragraph 1(a) to restore the stocks."* Again, this consistent with the use of F_{MSY} as a limit reference point for fishing mortality and the requirement to have pre-agreed management measures to reduce fishing mortality when the reference point is approached and, ideally, to prevent it from being exceeded.

The application of the precautionary approach (Article 5(c), and Article 6 provides further guidance on interpretation, given the specific reference to Annex II of the Agreement (UNFSA 1996). Article 6 paragraph 1(a) states: "*In applying the precautionary approach, members of the Commission shall:*

a) *apply the guidelines set out in Annex II of the Agreement, which shall form and integral part of this Convention, and determine, on the basis of the best scientific information available, stock-specific reference points and the actions to be taken if they are exceeded;*

b) *"take into account, inter alia, uncertainties relating to the size and productivity of the stocks, reference points, stock condition in relation to such reference points, levels and distribution of fishing mortality…"*

The above clearly demonstrates the requirement to define and agree specific management objectives, and associated reference points, decision rules and performance measures required to develop and implement formal management plans.

Some of these examples have been used in Table 2 to illustrate the relationship between the high level objective of the Convention and more specific objectives and reference points. In other cases, the intent in terms of defining a specific operational objective is less clear. An important example is *"optimum yield"*. Given that the factors that contribute to this concept include operational and fixed costs, capital investment, price and interest rate variations and the like, it is a challenging task to specify operational objectives and reference points in the context of an MSE, as opposed to indicators that may be used to monitor relative performance across time in the real world.

Another example, Article 5 paragraph (h) *"Take into account the interests of artisanal and subsistence fishers"* could reasonably be interpreted to imply a desire to avoid situations that directly or indirectly impact on the catches of artisanal and subsistence fishers. In this context, issues such as local depletion due to concentration of fishing effort may need to be taken into account. However, refining a more specific objective for this issue would, to a very large extent, depend on the specific nature of the artisanal fisheries and their interaction with target stock and industrial fisheries. Furthermore, as noted in the section 2, there has been very limited experience with the application of reference points and the MSE approach to this broader context.

In addition, when considering operationalising objectives and defining reference points, it is critical to be aware of the management measures that are actually available, the interaction among individual objectives and at what level it is realistic to consider that the scientific process can help inform the process. For example, with respect to stock conservation, optimum utilization and maximization of catches, the concept of maximum sustainable yield is dependent upon the mix of gears (i.e. selectivities) operating in the fishery. Given a gear mix, reference points such as B_{msy} and F_{msy} are relatively straight forward in principle to estimate from a population/fishery dynamic model and the consequences of different management strategies for setting a global catch limits can be evaluated. The results will be conditional upon the gear mix assumed. Thus, a strategy for setting the global TAC that performs well under one combination of fishing gears may perform poorly under a different (consider the extreme of shifting to either a pure purse seine or longline fishery). However, for any particular combination of fishing gears, there will be management strategies that will yield approximately equivalent performance in terms of stock conservation but will have different implications in terms of catch performance. Thus, operational objective such as a maximization of catch and the appropriate reference point for it will be dependent upon whether allocation among gears is considered to be within the scope of management measures that are available to the Commission and if so, the objective and performance measures under which changes in gear allocations are to be assessed.

In summary, operationalising the Commission's objectives along with defining appropriate performance measures and reference points is one key component of implementing the precautionary approach. This needs to be done based on realistic expectation of what is possible and in light of the feasible management measures that the Commission may utilize. This process needs to be consultative and iterative involving the policy-makers, managers, stakeholders (industry and NGOs) and scientists.

6. Issues to be resolved in applying the precautionary approach to the management of WCPO fisheries, including the need of an MSE approach.

There are a range of issues that need to be considered in the context of implementing the precautionary approach in the management of fishing in the WCPO. While the focus of this review has been on the role of reference points and MSE in the implementation of the precautionary approach, the scope of the precautionary approach is much broader than these two elements and incorporates the full spectrum of the fisheries management system (see section 3).

A future work program to implement the precautionary approach

We recommend that the a primary component of a future work program to implement the precautionary approach should be the formal specification of limit and target reference points for target stocks, with agreed decision rules (i.e. formal management strategies) and the development of a simulation environment (Figure 2) for their formal evaluation by MSE. This would provide the Commission with the necessary information to objectively assess the likely performance of alternative management strategies and decide on the most appropriate measure for implementing a precautionary approach that is consistent with the objective and guiding principles of the Convention.

There is, however, the fact that the development of decisions rules, which have been adequately evaluated using the MSE approach, will take some time to complete (3-5 years) and that decisions on the management of the fisheries will be required during this period. In this respect, it would seem prudent, and consistent with the precautionary approach and the Convention, to develop and adopt decision rules for management action based on the current default reference points (i.e. UNFSA, Annex II) and assessment methods (i.e. MULTI-FAN and/or readily available suitable alternatives (see Table 1)).

An important part of this process would be to examine the sensitivity of the management advice, arrived at using the current combination of reference points and assessment methods, to the uncertainties in the assessment inputs and the underlying model uncertainty (e.g. Kolody et al 2004; Kolody et al 2006). This would provide the Scientific Committee and the Commission with a more comprehensive understanding of the full range of uncertainty in the current estimates of stock status and sustainability of the current levels of fishing, as well as a more informed basis for constructing the operating model that will be required in the MSE context.

As already noted, the precautionary approach entails more than the development of reference points and robust management strategies. It is critical that these other components are also built into any work plan intended to put into effect the precautionary approach. In particular, as the recent CCSBT experience demonstrates, there is a critical need to ensure that the fishery data collection, monitoring and verification issue, which are an integral part of the precautionary approach, are a central part of any work plan. In addition, it is also essential that the basic information requirements for providing meaningful management advice are addressed through research and fishery independent monitoring (e.g. tagging).

It is beyond the scope of this review to identify and discuss a comprehensive set of research issues. Nevertheless, the following appear to be particularly relevant for further consideration by the SC and the Commission in the general context of the fisheries resources of the WCPO and the development of operating models in particular:

- The stock structure and spatial dynamics of target species and how these relate to historic, current and future potential distributions of fishing effort;
- The nature of technical and trophic interactions among target species and dependant and related species;
- Direct fishery-independent measures of fishing mortality rate or abundance
- Quantification of uncertainty associated with the current assessment including the robustness and sensitivity of the general conclusions to model uncertainty.

In addition to the above, there are also issues that need to be considered that are not directly within the formal purview of the SC. In particular, systems for ensuring that levels of fishing capacity do not exceed those commensurate with long-term average yields and an effective system for ensuring compliance with any management measures. These are issues that the SC can provide technical advice for consideration but they are ultimately issues for the Commission.

In summary, we consider that there are at least 5 primary components that need to be include in a work plan for implementing precautionary approach:

1. development and evaluation of a management strategy using the MSE approach including the formal specification of limit and target reference points for target stocks and decision rules;

2. interim decision rules based on estimates of current stock status relative to "default" target and limit reference points using current or readily available assessment methodology;

3. development of a comprehensive and reliable program for collection of the fishery data with appropriate levels of direct independent verification;

4. development of a research program to provide fishery independent measures of fishing mortality rates and/or abundance and to address priority information gaps; and

5. development of the required management system, including one for ensuring effective compliance and another to address the management of fishing capacity.

As part of the implementation of precautionary approach, it will be important to consider the relative priority of the various elements. This should include consideration of their respective costs and the expected impact of their successful implementation on the effectiveness of management.

The outcome of considering the relative priority of addressing these other aspects of implementing the precautionary approach in the context of finite resources of the Commission and members should inform the focus, timeframe and level of investment in any future MSE process and/or sensitivity analysis of the current default reference points and assessment process.

Issue to Consider in a MSE Work plan

There are three basic parts to an MSE work program. These are:

- The consultative and communication process between the SC and the Commission;
- The scientific process of identifying and specifying the components of the MSE system; and
- The technical implementation of the MSE and provision of results.

Below we identify some of the issues that will need to be considered by the SC and the Commission in relation to each component of the work plan. The level of resources and complexity of each component should be determined by the nature of the specific questions being addressed by the MSE and, as noted above, the relative priority of the MSE process in the work program of the SC and the Commission.

Consultative and communication process between the SC and the Commission

As noted above, the first issue to be considered is the focus and scope for the MSE in the first instance. While it is, in principle, possible to undertake an MSE for all of the fisheries of the WCPFC as a whole, this would be an enormous undertaking and it would be very questionable whether it was feasible or useful in practice. Hence, the fist step in the process would be to identify one or more management issues that would most benefit from an MSE approach.

While the identification of options, and decisions on which should be initiated first, is best considered by the SC and Commission, from our limited knowledge of the fisheries of the WCPFC, initial candidates could include:

- single species MSE for the main target species with bigeye and yellowfin tuna being obvious first choices
- multi-species (bigeye, yellowfin and skipjack tuna) and the technical interactions among fisheries and gears;
- regional case studies of single or multi-species.

Other issues to be considered in this context include:

- Clarification of the roles and responsibilities between Commission, SC and Working Groups and the modes and schedule of communications as part of the work plan (i.e. will completing the work program in a reasonable timeframe require inter-sessional meetings?);
- Development and confirmation of terms of reference for the project team(s);
- Whether the technical project team(s) will be chaired and constituted by member scientists and or independent consultants
- Likely costs for different alternative options (including the use of consultants) and how these costs will be met (i.e. Commission and/or member funded participation)

Once the work program has been developed the principle task of the Commission should be a series of consultations on the MSE approach to ensure the Commission clearly understand the rationale and benefits of the approach and the important stages of the process that it will need to provide guidance and direction to ensure that the outcomes are relevant and useful to the it. This would generally be followed a series of iterative consultations between the SC and the Commission to specify and agree on objectives, potential management measures to be included in the MSE process and associated performance measures.

The scientific process of identifying and specifying the components of the MSE system

The principal role of the SC and its working groups in an MSE process would be to communicate with and advise the Commission on the process and to provide direction to the project team(s). In particular, the SC would:

- identify options for, and select, a simulation platform appropriate for the requirements of the MSE (i.e. operating model, assessment model, conditioning etc. See Figure1);
- Identify and specify the full range of uncertainties that should be included in the operating and sampling models to ensure that, to the extent feasible, the MSE includes all the important sources of uncertainty relevant to the particular management issue.
- Selection of and testing of assessment models and reference points
- Technical specification of the Commissions objectives, management strategies and performance measures;
- Identification of “base case” and “robustness” trials for the evaluations
- Interpretation and communication of MSE results for the Commission

As noted above, an important procedural question to consider is the appointment of Chairs and membership of the working groups and/or project teams responsible for the scientific direction and technical implementation of the work program. Experience in other cases has demonstrated that there are advantages and disadvantages of having independent chairs/panels to provide oversight of the process as an alternative to having both the scientific oversight and technical tasks done by member scientists. An obvious advantage of having these roles filled by member scientists is the reduced cost relative to retaining consultants and familiarity with the detail of the issues. However, the reduced costs can be offset by potential or real bias and contribution among members. Hence, the choice between the two alternatives, or a combination of the two, really will depend on the specifics of the situation and, in particular, the technical capacity of the member scientists (i.e. the extent to which specialist external expertise may be required to facilitate the process).

Technical implementation of the MSE and provision of results

Implementation of the simulation models required for an MSE process involves the development of relatively complex and sophisticated simulation models and data management and analysis routines. The complexity and resources required to develop the simulation models will depend on the nature and complexity of the questions being addressed, in particular, the complexity of the management strategies.

The amount and complexity of programming involved in building the simulation models for an MSE is considerable. It is also highly desirable to have consistent, reliable software that is flexible and accessible for member scientists, maintained, archived and documented. Experience elsewhere has demonstrated that having dedicated independent programming support can be very effective. This does not preclude member scientists contributing to the programming; however, it does provide considerable efficiency and an element of technical transparency and confidence in the process.

There are many other technical aspects to the implementation process that are beyond the scope of this review. However, it is worth noting that there is a growing body of experience with the application of the MSE approach in national and international fisheries, which can and should be drawn upon should the SC and Commission decide to initial an MSE process (e.g. CCSBT, CCAMLR, and IWC). It is of particular interest that both the IATTC and ICATT have initiated, or are considering initiating, MSE processes for their major target species. While the fishery specific nature of MSE requires it to be tailored to the specific questions, details and requirements of the particular application, there are potential efficiencies and benefits from investigating the potential for collaboration and/or sharing of experience.

7. Conclusions

In summary, our conclusions from this review are:

- Provisions of international law and WCPFC require application of precautionary approach, including the use of target and limit reference points and pre-agreed management measures (i.e. decision rules)
- There are two contexts for the use of reference points: i) as a benchmark for interpreting result of stock assessment and providing advice on short-term management actions, and ii) informing the development of operational objectives and performance measures for management strategies as part of a management strategy evaluation process.
- MSE provides a formal approach for evaluating whether the performance of a management strategy is likely to be consistent with the precautionary approach and to compare relative performance among alternative strategies.
- Review of current application of precautionary approach in tuna RFMOS, including use of target and limit reference point and MSE, indicated that none appear to be currently applying the precautionary approach in practice as per WCPFC, UNFSA, FAO Code of Conduct.
- The WCPF Convention provides specific guidance and requirement for the development of formal management plans that meet the requirements of the precautionary approach.
- Operationalising the Commission's objectives along with defining appropriate performance measures and reference points is one key component of implementing the precautionary approach. This needs to be done based on realistic expectation of what is possible and in light of the feasible management measures that the Commission may utilise.
- The Commission and SC should initiate a work program for: i) a consultative process to develop formal management strategies for a small number of case studies spanning the size and complexity of the WCPFC fisheries; and ii) a technical process to evaluate the robustness of the current and alternative assessment and reference points and determine the specific technical requirements and costs associated with undertaking a management strategy evaluation process for specific fisheries.
- Other key issues in the implementation of the precautionary approach that need to be addressed include development of a program for the reliable collection of the fishery data with appropriate levels of independent verification and a research program to address priority information gaps;
- The resourcing of this process should be commensurate with the relative priority and likely impact of the outcomes on the decisions of the Commission. It is essential that the development of any future work program for stock status reference points and MSE is done with full consideration of the priority of and resources available for other elements of the precautionary approach that will be central to its effective implementation.

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9. References

Anon (2007). Final Report of the Expert Workshop on Ecosystem-Based Management of the Oceans. United Nations Informal Consultative Process on Oceans and Law of the Sea, UN, New York, June 2006.

Butterworth, D.S., Gluckman, G.R., Thomson, R.B., Chalis, S., Hiramatsu, K. and D.J. Agnew. 1994. Further computations of the consequences of setting the annual krill catch limit to a fixed fraction of the estimate of krill biomass from a survey. CCAMLR Science 1: 81–106.

Butterworth, D. S. & Punt, A. E. (1999). Experiences in the evaluation and implementation of management procedures. ICES Journal of Marine Science, 56, 985-98.

Caddy, J. F. (1999). Fisheries management in the twenty-first century: will new paradigms apply? Reviews in Fish Biology and Fisheries, 9, 1-43.

Caddy, J. F. & Defeo, O. (1996). Fitting the exponential and logistic surplus yield models with mortality data: some explorations and new perspectives. Fisheries Research, 25, 39-62.

Caddy, J. F. & McGarvey, R. (1996). Targets or limits for the management of fisheries? North American Journal of Fisheries Management, 16, 479-87.

Cochrane, K. L., Butterworth, D. S., De Oliveria, J. A. A. & Roel, B. A. (1998). Management procedures in a fishery based on highly variable stocks and with conflicting objectives: Experiences in the South African pelagic fishery. Reviews in Fish Biology and Fisheries, 8, 177-214.

Constable, A.J and W.K. de la Mare. 1994. Revised estimates of yield for *Electrona carlsbergi* based on a generalised version of the CCAMLR krill yield model. Paper WG-FSA-94/21 presented to the CCAMLR Scientific Committee, October 1994.

Deriso, R. B. (1980). Harvesting strategies and parameter estimation for an age-structured model. Canadian Journal of Fisheries and Aquatic Sciences, 37, 268-82.

Deriso, R. B. (1982). Relationship of fishing mortality to natural mortality and growth at the level of maximum sustainable yield. Canadian Journal of Fisheries and Aquatic Sciences, 39, 1054-8.

Deriso, R. B. (1987). Optimal $F_{0.1}$ criteria and their relationship to maximum sustainable yield. Canadian Journal of Fisheries and Aquatic Sciences, 44 (Supplement 2), 339-48.

Fournier, D.A., Hampton, J., and Sibert, J.R. 1998. MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. Can. J. Fish. Aquat. Sci. 55: 2105−2116.

Hampton, J., Kleiber, P. 2003. Stock assessment of yellowfin tuna in the western and central Pacific Ocean. WP YFT-1, SCTB 16, Mooloolaba, Australia, 9−16 July 2003.

Hampton, J., Kleiber, P., Langley, A., Hiramatsu, M. 2004. Stock assessment of yellowfin tuna in the western and central Pacific Ocean. WP SA-1, SCTB 17, Majuro, Republic of Marshall Islands, 9−18 August 2004.

Hampton, J., P. Kleiber, A. Langley, Y. Takeuchi, and M. Ichinokawa. 2005. Stock assessment of yellowfin tuna in the western and central Pacific Ocean. WCPFC SC1 SA WP 1, Noumea, New Caledonia, 8−19 August 2005.

Francis, R. I. C. C. & Shotton, R. (1997). “Risk” in fisheries management: A review. Canadian Journal of Fisheries and Aquatic Sciences, 54, 1699-715.

FAO. 1995. Precautionary approach to fisheries. Part 1:Guidelines on the precautionary approach to capture fisheries and species introductions. FAO (Food and Agriculture Organisation of the United Nations) Fisheries Technical Paper, 350/1.

Fulton, E.A., Smith, A.D.M. and Smith, D.C. (2007) Alternative Management Strategies for Southeast Australian Commonwealth Fisheries. Stage2. Quantitative Management Strategy Evaluation. Report to the Australian Fisheries Management Authority and the Fisheries Research and Development Corporation.

Goodyear, C. P. (1996). Variability of fishing mortality by age: Consequences for maximum sustainable yield. North American Journal of Fisheries Management, 16, 8-13.

Hilborn, R. & Walters, C. J. (1992). Quantitative Fisheries Stock Assessment. London: Chapman and Hall.

IATTC (2003). Workshop on Reference Points for tuna and billfishes. 27-29 October 2003, La Jolla, California (USA), 10pp.

IATTC (2006a). 74th Meeting of the IATTC, Busan, Korea. Document no: IATTC-74-04, Tunas and Billfishes in the eastern Pacific Ocean in 2005, 100pp.

IATTC (2006b). Workshop on Management Strategies. 17-20 October 2006, La Jolla, California (USA), 16pp.

Kirkwood, G. P. & Smith, A. D. M. (1996). Assessing the precautionary nature of fishery management strategies. FAO (Food and Agriculture Organisation of the United Nations) Fisheries Technical Paper, 350/2, 141-58.

Kolody, D.S., Jumppanen P.C., Ricard, D.G., Hartog, J.R., Preece, A.L., and T. Polacheck. 2004. SESAME: a simulation-estimation stock assessment model evaluation project focused on large pelagic species. CSIRO Marine Laboratories Report 241.

Kolody, D.S., R.A. Campbell, and N. Davies. 2006. South-West Pacific swordfish stock assessment (year 2). Final report for Australian Fisheries Management Authority (Canberra), project R04/0995.

Lauck, T. C.W. Clark, M. Mangel and G. R. Munro. 1998. Implementing the precautionary principle in fisheries management through marine reserves. Ecological Applications 8 (Supplement): S72-S78.

Mace, P. M. (1994). Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. Canadian Journal of Fisheries and Aquatic Sciences, 51, 110-22.

Mace, P. M. (1996). Limited access for Atlantic highly migratory fish stocks: Changing the ground rules. Fisheries, 21(4), 20.

Myers, R. A., Rosenberg, A. A., Mace, P. M., Barrowman, N. & Restrepo, V. R. (1994). In search of thresholds for recruitment overfishing. ICES Journal of Marine Science, 51, 191-205.

Myers, R. A. & Barrowman, N. J. (1996). Is fish recruitment related to spawner abundance? Fisheries Bulletin, US, 94, 707-24.

Polacheck, T., Hilborn, R. & Punt, A. E. (1993). Fitting surplus production models: comparing methods and measuring uncertainty. Canadian Journal of Fisheries and Aquatic Sciences, 50, 2597-607.

Punt, A. E. (1994). Assessments of the stocks of Cape hake Merluccius spp. off South Africa. South African Journal of Marine Science, 14, 159-86.

Punt, A. E. (2000). Extinction of marine renewable resources – a demographic analysis. Population Ecology, 42, 19-27.

Punt, A. E. & Hilborn, R. (1997). Fisheries stock assessment and decision analysis: A review of the Bayesian approach. Reviews in Fish Biology and Fisheries, 7, 35-63.

Punt, A. E. & Smith, A. D. M. (1999). Harvest strategy evaluation for the eastern stock of gemfish (Rexea solandri). ICES Journal of Marine Science, 56, 860-75.

Punt, A. E., Campbell, R. A. & Smith, A. D. M. (1998). Evaluation of performance indicators in the eastern tuna and billfish fishery – a preliminary study. Report to the Australian Fisheries Management Authority, Canberra.

Punt, A. E., Pribac, F., Walker, T. I., Taylor, B. L. & Prince, J. D. (2000). Stock assessment of school shark Galeorhinus galeus based on a spatially-explicit population dynamics model. Marine and Freshwater Research, 51, 205-20.Myers, R. A., Rosenberg, A. A., Mace, P. M., Barrowman, N. & Restrepo, V. R. (1994). In search of thresholds for recruitment overfishing. ICES Journal of Marine Science, 51, 191-205.

Myers, R. A. & Barrowman, N. J. (1996). Is fish recruitment related to spawner abundance? Fisheries Bulletin, US, 94, 707-24.

Polacheck, T., Hilborn, R. & Punt, A. E. (1993). Fitting surplus production models: comparing methods and measuring uncertainty. Canadian Journal of Fisheries and Aquatic Sciences, 50, 2597-607.

Punt, A. E. (1994). Assessments of the stocks of Cape hake Merluccius spp. off South Africa. South African Journal of Marine Science, 14, 159-86.

Punt, A. E. (2000). Extinction of marine renewable resources – a demographic analysis. Population Ecology, 42, 19-27.

Punt, A. E. & Hilborn, R. (1997). Fisheries stock assessment and decision analysis: A review of the Bayesian approach. Reviews in Fish Biology and Fisheries, 7, 35-63.

Punt, A. E. & Smith, A. D. M. (1999). Harvest strategy evaluation for the eastern stock of gemfish (Rexea solandri). ICES Journal of Marine Science, 56, 860-75.

Punt, A. E., Campbell, R. A. & Smith, A. D. M. (1998). Evaluation of performance indicators in the eastern tuna and billfish fishery – a preliminary study. Report to the Australian Fisheries Management Authority, Canberra.

Punt, A. E., Pribac, F., Walker, T. I., Taylor, B. L. & Prince, J. D. (2000). Stock assessment of school shark Galeorhinus galeus based on a spatially-explicit population dynamics model. Marine and Freshwater Research, 51, 205-20.Punt, A. E., Pribac, F., Walker, T. I., Taylor, B. L. & Prince, J. D. (2000). Stock assessment of school shark Galeorhinus galeus based on a spatially-explicit population dynamics model. Marine and Freshwater Research, 51, 205-20.

Sainsbury, K. (1998). Living marine resource assessment for the 21st century: What will be needed and how will it be provided? In Fishery Stock Assessment Models, ed. F. Funk, T. J. Quinn II, J. Heifetz, J. N. Ianelli, J. E. Powers, J. F. Schweigert, P. J. Sullivan & C-I. Zhang, pp. 1-40. Alaska Sea Grant College Program Report No. AK-SG-98-01, University of Alaska Fairbanks.

Sainsbury, K. J., Punt, A. E. & Smith, A. D. M. (2001). Design of operational management strategies for achieving fishery ecosystem objectives. ICES Journal of Marine Science, 00, 00-00.

Smith, A. D. M. (1993). Risks of over- and under-fishing new resources. In Risk Evaluation and Biological Reference Points for Fisheries Management, ed. S. J. Smith, J. J. Hunt & D. Rivard, pp. 261-7. Canadian Journal of Fisheries and Aquatic Sciences (Special Publication) 120.

Smith, T. D. (1994). Scaling fisheries: The science of measuring the effects of fishing. Cambridge: University of Cambridge Press.

Smith.T. D. 1998. Simultaneous and Complementary Advances: Mid-century Expectations of the Interaction of Fisheries Science and Management. Reviews in Fish Biology and Fisheries 8: 335-348.

Smith, S. J., Hunt, J. J. and Rivard, D. (ed.) 1993. Risk Evaluation and Biological Reference Points for Fisheries Management. Canadian Journal of Fisheries and Aquatic Science (Special Publication) 120.

Smith, A. D. M., Sainsbury, K. J. & Stevens, R. A. (1999). Implementing effective fisheries management systems – management strategy evaluation and the Australian partnership approach. ICES Journal of Marine Science, 56, 967-79.

SCTB. (1998) Report of the 11th meeting of the Standing Committee on Tuna and Billfish, 28 May – 6 June 1998, Honolulu, Hawaii (USA), 107pp.

Stephenson, R. L. & Lane, D. E. (1995). Fisheries management science: a plea for conceptual change. Canadian Journal of Fisheries and Aquatic Sciences, 52, 2051-6.

Table 1: *Comparison of implementation of the precautionary approach in tuna RFMOs as evidenced by: formal adoption of target and limit reference points and decision rules, assessment methods, primary monitoring data and formal evaluation of the robustness of management strategies for target for selected Regional Fisheries Management Organisations.*

Organisation	**Taxon**	**LRP**	**TRP**	**Decision rule**	**Assessment method**	**1° monitoring data**	**Evaluated**
WCPFC[2]	SJT	B_{MSY}, F_{MSY}		N	MULTIFAN-CL[3]	C&E + Size + tagging	N
	YFT	B_{MSY}, F_{MSY}		N	MULTIFAN-CL [4]	C&E + Size + tagging	N
	BET	B_{MSY}, F_{MSY}		N	MULTIFAN-CL [5]	C&E + Size + tagging	N
	ALB	B_{MSY}, F_{MSY}		N	Preliminary MULTIFAN-CL [6]	C&E + Size	N
	BBL	B_{MSY}, F_{MSY}		N	Preliminary MULTIFAN-CL & Pella-Tomlinson [7]	C&E + Size	N
	STM	B_{MSY}, F_{MSY}		N	Preliminary MULTIFAN-CL	C&E + Size	N

[2] Note: In this case the reference points have been interpreted by the authors to represent limit reference points, while recognising that the Commission has not formally agreed to them as such. This decision was based on the manner in which the reference points have been used by the Scientific Committee to provide management advice to the Commission and their definition as such in Annex II of the UNFSA and Article 6 of the WCPFC.

[3] Hampton et al 200

[4] Hampton et al 2006

[5] Hampton et al 2006

[6] Langley and Hampton 2005

[7] Kolody et al 2006

IATTC	SJT		F_{AMSY}, SB_{AMSY}	N	Preliminary A-SCALA[8]	C&E + Size	Preliminary[9]
	YFT		F_{AMSY}, SB_{AMSY}	N	A-SCALA	C&E + Size+ tagging	Preliminary[††]
	BET		F_{AMSY}, SB_{AMSY}	N	A-SCALA	C&E + Size + tagging	Preliminary[††]
	PBT		F_{AMSY}, SB_{AMSY}	N	No formal Assessment	C&E	N
	NP-ALB		F_{AMSY}, SB_{AMSY}	N	VPA	C&E + Size	N
	NP-BBL		F_{AMSY}, SB_{AMSY}	N	Preliminary MULTIFAN-CL	C&E + Size	N
	SP-BBL		F_{AMSY}, SB_{AMSY}	N	Preliminary SSII	C&E + Size	N
	BML		F_{AMSY}, SB_{AMSY}	N	Deriso-Schnute Preliminary MULTIFAN-CL	C&E + Size	N
	STM		F_{AMSY}, SB_{AMSY}	N	Pell-Tomlinson Deriso-Schnute	C&E + Size C&E + Size	N
IOTC	SJT		MSY, F_{MSY}	N	No formal assessment	C&E + Size	N
	YFT		MSY, F_{MSY}	N	Preliminary ASPM, Bayesian ASPM, CATAGE-Trend, PROCEAN[10]	C&E + Size	N
	BET		MSY, F_{MSY}	N	Preliminary ASPM, CASAL, SSII, Pella-Tomlinson, ASPIC[***]	C&E + Size	N
	ALB		MSY, F_{MSY}	N	No current assessment[†††]	C&E + Size	N
	BBL		MSY, F_{MSY}	N	Preliminary production model[11]	C&E + Size	N

[8] IATTC 2006a
[9] IATTC 2006b, Maunder and Harley 2006
[10] IOTC 2006a
[11] IOTC 2006b

ICCAT	SJT		F_{MSY}, B_{MSY}	N	No current assessment	C&E + Size	N
	YFT		F_{MSY}, B_{MSY}	N	APSM, VPA	C&E + Size	N
	BET		F_{MSY}, B_{MSY}	N	Range of Production Models	C&E + Size	N
	ALB		F_{MSY}, B_{MSY}	N	APSM, VPA for three stocks	C&E + Size	N
	ABT		F_{MSY}, B_{MSY}	N	ADAPT - VPA	C&E + Size	In development[12]
	BBL		F_{MSY}, B_{MSY}	Y – for rebuilding	Production Model	C&E + Size	N
	BML		F_{MSY}, B_{MSY}	N	Production Model	C&E + Size	N
	WML		F_{MSY}, B_{MSY}	N	No formal assessment	C&E + Size	N
CCSBT[**]	SBT	SSB_{2004} [13]	SSB_{1980} [***]	Y-but not implemented	SCAA[14] (current applicability in doubt)	C&E + Size + Age + tagging + Biology	Y[15]
CCALMR	TOP	SSB_{20}; Pr<0.10	SSB_{50}; Pr=0.50	Y	GYM & CASAL	FI Survey + tagging biology + C&E	In Progress[16]
	TOA	SSB_{20}; Pr<0.10	SSB_{50}; Pr=0.50	Y	GYM & CASAL	Tagging + C&E	In progress
	MIF	SSB_{20}; Pr<0.10	SSB_{50}; Pr=0.75	Y	GYM + bootstrap	FI Survey + C	N
	KRL	SSB_{20}; Pr<0.10	SSB_{50}; Pr=0.75	Y	GYM	FI Survey + Size + C	Y[17]

[12] SCRS 2006
** The status of the CCSBT reference points and the SBT stock assessment are problematical because of large and recently detected Japanese IUU catches (ESC-SC-CCBT 2006; CCSBT 20006)
[13] More explicitly SSB2022/SSB2004 >= 1; Pr=0. 9 as assessments indicated that SSB is likely to decline in the short term even under zero catches
*** since the 1980s the CCSBT (and its predecessor) have had the 1980 SSB has a rebuilding target. Since 1994, the agreed timeframe has been 2020. However, it is currently recognized that this is unachievable but it has not formally been change rebuilding target.
[14] ESC-SC-CCSBT 2004
[15] ESC–SC-CCSBT 2005 & 2006; CCSBT 2005 and 2006.
[16] SC-CCAMLR/WG-FSA 2006
[17] Butterworth et al 1984

Table 2: *Framework for developing operational objectives and reference points with examples for target stocks and fisheries of the WCPFC.*

Category	**Conceptual Objective**	**Operational objective**	**Potential Reference Points**	**Level of Confidence**	**Ref. in Convention**
Stock Conservation	Ensure long-term conservation of target stocks, or Ensure that stocks are not overfished	Ensure that there is a very low probability of the spawning stock biomass declining below a level where the risk of recruitment collapse increases substantially	$0.20*SSB_o$ SSB_{MSY}	High confidence that stock is above reference point (e.g. 0.90)	Article 2, 5a
	Prevent or eliminate overfishing	Ensure there is a high probability that fishing mortality does not exceed F_{MSY} in any year	F_{MSY}	High confidence that F is below F_{MSY}	Article 2, 5g
Optimum utilisation	Maximise sustainable yields		B_{MEY}, F_{MEY}		Article 2, 5a
	Minimise variation in catches				
	Maximise net economic return from the fishery				

Example of a Simple Harvest Strategy

Conceptual Specification:

TAC next year = TAC this year + an adjustment based on change in CPUE

(i.e. adjust TAC upward if CPUE goes up
and adjust downward if CPUE goes down)

Mathematical Specification (determines the exact response):

$$TAC(t+1) = aTAC(t) + (1-a)TAC(t)\,[(CPUE(t)/CPUE(t-1)]$$

Where a is a parameter that determines the extent of adjustment

Key Concepts:

DATA: log books from fleet(s)   ASSESSMENT: standardization of CPUE

CRITERION: above mathematical specifcation plus a specific value for a

Figure 1: Illustration of a very simple management or harvest strategy (Note performance is unlikely to be acceptable in practice.

Simulation system structure

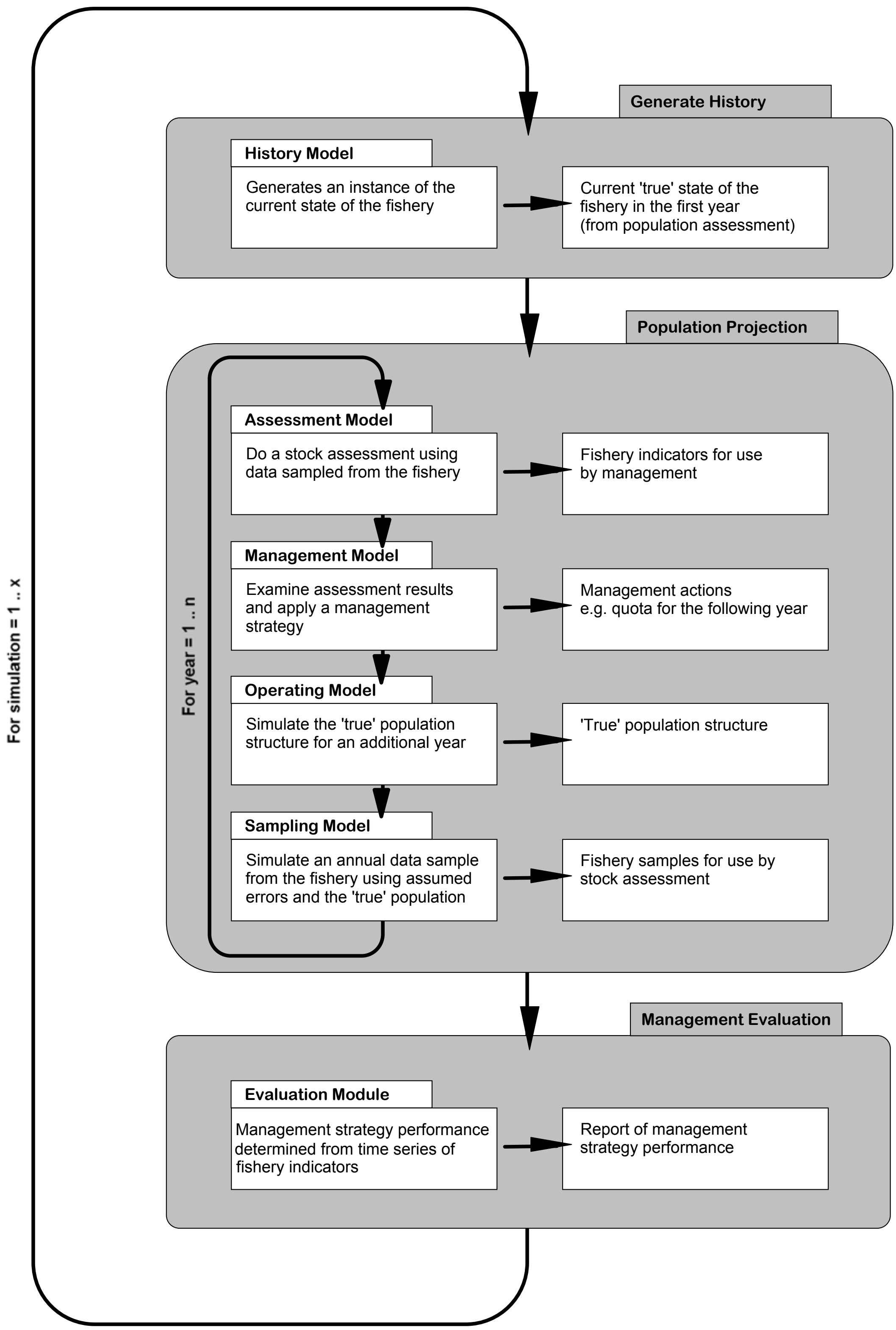

Figure 2: Schematic representation of the simulation framework involved in evaluation of management strategies (taken from Polacheck et al 1999).