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APPROACHES FOR IDENTIFICATION OF APPROPRIATE REFERENCE POINTS AND IMPLEMENTATION OF MSE WITHIN THE WCPO

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EXECUTIVE SUMMARY

1. Following an overview of a range of factors, including estimation issues, biological and fishery characteristics, we can see no strong reason for not using reference points based on maximum sustainable yield (MSY) as 'default limit reference points' for the key WCPFC fish stocks. These quantities have already been identified in the convention and the UN Fish Stocks Agreement as, appropriately (e.g. Caddy, 1998), limit reference points.

2. Much technical development has already been done to estimate the relevant quantities needed to evaluate stock and fishery status relative to these reference points, including approaches for taking uncertainty into account. Estimates are in fact available for the past several yellowfin and bigeye assessments (Langley et al. 2007; Hampton et al. 2006a, b). We recommend the approaches used in these assessments, particularly use of the ratio of current values to the MSY values (for biomass and harvest rate) as reference points, and quantifying the probabilities of biomass and harvest rates being below or above the reference points.

3. We also suggest that a modest amount of work is undertaken, using existing, and as many past assessments as possible, to confirm whether MSY-based reference points are suitable as default limit reference points (when used as ratios, i.e. Fcurrent/Fmsy=1 and Bcurrent/Bmsy=1), by comparing them with a range of other candidate reference points. In particular, harvest rates based on spawner per recruit considerations should be calculated, or estimated, with their expected implications for relative biomass and spawning biomass.

4. Target reference points are likely to be more difficult to set, so we suggest that default target reference points be based on limit reference points with an associated 'buffer' (e.g. the biomass target reference point (TRP) would be set some distance above the biomass limit reference point (LRP); the harvest rate TRP would be set some distance below the harvest rate LRP). The size of the 'buffer' should take into account the uncertainties in the assessments and the limit reference points.

5. It is as important to define agreed management action when stock and/or fishery status is estimated to be outside the limit reference points, as it is to define the reference points themselves. We illustrate two examples for decision rules as a starting point for discussion. If a stock is above or near its target reference points, a decision rule can relatively simply be constructed on the basis of the reference points (see text and Figure 1 for detail).

6. However, if a stock is already near or outside its limit reference points and if a harvest strategy is being implemented for the first time, the approach to defining a decision rule will need to be pragmatic and probably case-specific. Projections (along the lines already done as part of stock assessments) can be used to explore which sequences of reductions in catch or effort would achieve a desired reduction in harvest rate and rebuilding of the biomass with acceptable probability after a specified time-period.

INTRODUCTION

During the Third Regular Session of the Scientific Committee (SC3) in August 2007, the Committee discussed a consultancy paper on “A brief review of the use of the precautionary approach and the role of target and limit reference points and Management Strategy Evaluation (MSE) in the management of highly migratory fish stocks” (WCPFC-SC3-ME-WP-3).

Following this discussion, the Committee recommended to the Commission that a future work programme, including a scoping paper and draft work plan, be prepared during 2008 to inform both the SC4 and the Fifth Regular Session of the Commission (WCPFC5) on the potential costs, benefits and difficulties of alternative approaches for identification of appropriate reference points within the WCPO. This recommendation was adopted by the Commission at WCPFC4 held in December 2007.

Objective

The objective of this paper is to present, for the consideration of the WCPFC Scientific Committee and Commission, options for appropriate reference points and the use of Management Strategy Evaluation (MSE) to evaluate the relative performance of alternative harvest strategies (or Management Procedures) as part of the implementation of the precautionary approach in the management of WCPO tuna and billfish stocks. The terms of reference for this project are provided at Appendix 1.

Outline

This report is structured into two substantive sections which each address the main components of the objective:

1. Identification of appropriate “default reference points” for target stocks of the WCPO, and;

2. Alternative approaches to the development and implementation of MSE to target stocks of the WCPO.

The first section provides a brief background on the definition and role of target and limit reference points in fisheries management systems, including the importance of pre-agreed “decisions rules” for management action. The remainder of the section focuses on alternative forms of limit reference points and their appropriateness for use in the management of tuna and billfish stocks in the WCPO. As noted in this section, the majority of the requisite reference points, or quantities required to estimate them, are to be found in previous and current assessments for the major target species in the WCPFC, and therefore will be familiar to the SC and Commission. It follows with a brief consideration of two examples of decision rules, which are used to determine management action based on the outcomes of an assessment of the status of the stock and fishery relative to the reference points. It concludes with recommendations on the next steps that should be taken to select appropriate reference points. Appendix 2 provides a more detailed definition and technical consideration of potential reference points.

In section three we briefly review the concept of MSE and outline an initial work-plan for the development and implementation of MSE as part of applying the precautionary approach to the management of targeted fisheries in the WCPO. Following the proposal of Davies and Polacheck (2007) we structure the work-program into three main components: 1) consultation and communication; 2) Identification and specification of MSE components, and 3) technical implementation. These three components are then drawn together into a single time line to demonstrate the linkages, dependencies and important decision points for the SC and Commission.

Finally, we summarise our major conclusions and recommendations.

REFERENCE POINTS AND DECISION RULES

In this section we start with introductory comments on the advantages and need for reference points, and clarify the concepts of target and limit reference points. The setting of 'default' reference points is then discussed using the MSY-based reference points listed in the WCPFC Convention as a starting point. We consider their general and estimation properties, and ask whether there are strong reasons why they may not be appropriate for use with large pelagics. Following that, we consider how they could be used in practice and how target reference points could be set. Finally we discuss two examples for approaches to developing decision rules to inform management action depending on stock and fishery status relative to the reference points as a starting point for discussions on "interim arrangements", should the SC and Commission decide to embark on an MSE process.

There is, of course, a wide range of possible reference points. These alternative options are covered in Appendix 1, and further comments about choice of reference points are made under 'Conclusions' at the end of this section.

The descriptions and discussion in this section (and the Appendix) are deliberately not highly technical; technical details can adequately be handled in the relevant forums, such as the Methods and Stock Assessment Working Groups or dedicated inter-sessional workshops. Rather, the intention is to provide general explanations of concepts, and summaries of the relative merits and potential pitfalls of using alternative reference points in various ways, with a view to assist the SC and the Commission in their considerations on selecting interim reference points.

The advantages of reference points

In their review of the use of the precautionary approach and the role of reference points and management strategy evaluation (MSE) in the WCPFC, Davies and Polacheck (2007) recommend that *"the 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 for their formal evaluation by MSE."* They note, however, that the development and evaluation of management strategies will take some time to complete (3-5 years) and that decisions on the management of the fisheries are likely to be required during this period. We agree with their conclusion that, in this respect, it would seem prudent and consistent with the precautionary approach and the Convention to develop 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.

Davies and Polacheck (2007) identify two contexts for the use of reference points: (i) as a benchmark for interpreting the results from stock assessments 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. In this section, the discussion is focused primarily on the first context, but many of the issues and approaches will also be relevant in the second context.

It is also worth noting the comment by Caddy (1998) that "*TRPs (target reference points) and LRPs (limit reference points) alone do not lead to a responsible or precautionary management response"*. He adds: *"Reference points can only be effective if appropriate management responses (and by the same token, agreement with the fishing industry) are pre-negotiated and effectively implemented."* This again emphasises the need for agreed action (i.e. a decision rule) to use in combination with reference points.

It only takes a quick review of recent working papers on yellowfin and bigeye stock assessments submitted to the WCPFC's Stock Assessment Working Group (e.g. Langley et al. 2007, Hampton et al. 2006a and 2006b) to recognise that a large amount of high quality groundwork has been completed with regard to estimating candidate reference points, dealing with uncertainty in their estimation and establishing stock status relative to these reference points. For completeness we raise some of the issues which these papers have already dealt with, and we refer to the solutions and approaches they have used.

The concepts and use of target and limit reference points

It may be useful to repeat the general definitions for target and limit reference points here (taken from Caddy and Mahon, 1995):

*"A **Target Reference Point (TRP)** indicates a state of a fishing and/or resource which is considered to be desirable and at which management action, whether during development or stock rebuilding, should aim."*

*"A **Limit Reference Point (LRP)** indicates a state of a fishery and/or resource which is considered to be undesirable and which management action should avoid."*

We use the 'limit' and 'target' concepts with the generic notation of B_{lim} and F_{lim} for limit reference points, and B_{targ} and F_{targ} for target reference points.

Reference points are usually defined in pairs; one reference point defined in terms of total biomass (B) or spawning biomass (SSB), and the other defined in terms of the harvest rate (i.e. fishing mortality, F). The reason for defining two limit reference points, and two target reference points, is related to the distinction between *'overfished'* and *'overfishing'*.

An 'overfished' stock is one where the biomass (or spawning biomass in particular) is below an acceptable level[1]. This is generally defined as being a biomass at which there is a high risk of below-average, or impaired, recruitment. 'Overfishing' occurs if the harvest rate is above an acceptable level, with an associated high risk of reducing the biomass to below its acceptable level. It is obvious that there needs to be some compatibility between the fishing mortality and biomass reference points.

How do these reference points get used as benchmarks relative to results from an assessment? In its simplest form, and using just B_{lim} for this example, the procedure could be as follows. The first step is usually to agree on a 'conceptual' definition for B_{lim}; for example, the biomass where maximum sustainable yield occurs, B_{msy}. This step does not define an actual number, but defines the quantity that will be estimated each year (or other time-interval). A stock assessment is run each year and B_{msy} is estimated, i.e. a number is obtained[2]. The next step is to compare the estimate of current biomass with the estimate of B_{msy} to evaluate whether it is above or below. The final step is to identify the management action associated with the outcome of the previous step (i.e. whether $B_{current}$ is above or below B_{msy}). We emphasise that this is a hypothetical example to illustrate a simple version of how the process could work. There are two weaknesses in this example. First, it ignores uncertainty. The estimate of current biomass from the stock assessment will (should) have some estimate of its uncertainty, and it is sensible to take this into account when making the comparison with B_{msy}. There is also some uncertainty in B_{msy}, the reference point itself. The second weakness is that absolute quantities such as B_{msy} are usually more sensitive to assessment assumptions or new data, and can therefore vary substantially from one years' assessment to the next, than ratios such as $B_{current}/B_{msy}$. Both these issues are considered in the next sections.

Setting default reference points

In this report we use the term 'default reference points' to indicate the notion that they would not necessarily be based on a detailed case-specific analysis and/or management strategy evaluation prior to setting, but rather on the basis of broad collective fisheries knowledge and experience,

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[1] The term 'unacceptable level' is used in the generic definitions of the terms overfished and overfishing; in practice these would usually equate to the limit reference points, though it may depend on the actual definition used in different forums.

[2] In some cases, assumed inputs and point estimates are used to calculate MSY-quantities so there are no estimates of uncertainty; in other cases uncertainty around point estimates are taken into account, in which case there will be estimates of uncertainty for the MSY-quantities. We first discuss the simplest case where there is no assumed uncertainty in the reference point.

meta-analyses[3] and/or theoretical considerations. Together with this is the implicit understanding that they may be replaced by more appropriate and better performing reference points following further work on reference points and management strategy evaluation.

MSY-based limit reference points

The biomass (B_{msy}) and harvest rate (F_{msy}) coinciding with maximum sustainable yield (MSY) are listed in the WCPFC Convention as limit reference points, and are therefore good candidates for default reference points. We start by considering these quantities and their estimation characteristics. Given that many RFMO's still appear to use MSY-based quantities as target reference points (Davies and Polacheck, 2007), it is worth commenting further on this. MSY was widely used as a target for management by fishery commissions in the 1960s and 1970s, but developments in the theory and practical experience in fishery management cast doubts on the appropriateness of MSY as a safe TRP. It is therefore now commonplace to treat MSY-based reference points as LRPs (see Caddy and Mahon, 1995; Caddy, 1998; Mace, 2001). It is in recognition of this that the WCPFC has listed F_{msy} and B_{msy} as limit reference points in its convention.

MSY quantities can either be obtained from stock-production models or from stock assessment models with built-in stock-recruit relationship (or from a stock-recruit relationship estimated outside the assessment). The common quantities are MSY (i.e. a catch level), the harvest rate at which MSY is achieved (F_{msy}), and the biomass at which this occurs (B_{msy}). In the case of the simplest production models, the form of the model determines at which relative depletion level (B_{msy}/B_0) the MSY is obtained. For example, the Schaefer stock-production model has $B_{msy}/B_0=0.5$, whereas the Fox stock-production model has $B_{msy}/B_0=\exp(-1)=0.37$.

In an age-based stock assessment, the stock-recruit curve and the assumed (or estimated) steepness play a crucial role in determining this ratio. At higher steepness levels, B_{msy}/B_0 will be lower than for low steepness levels. For example, in Table 8 of Langley et al. (2007), the yellowfin ratio for SB_{msy}/SB_0 is estimated at 0.23 for the 'high steepness' assessment model, and at 0.31 for the 'base case' model. The other inputs required in an age-based calculation of MSY-quantities are mortality at age, maturity at age, weight at age and, importantly, selectivity at age. Selectivity is important because in a multi-gear fishery (e.g. purse seine and longline gears) as the selectivity depends on the mix of gears. This means that if there is a large change in the relative catches of (or allocation to) the different gears, the reference points will be affected and need to be re-estimated. It is important to note that this does not necessarily mean that, say, B_{msy} is no longer appropriate as the biomass LRP, but since the value of B_{msy} will change, it could mean that current biomass is suddenly very different relative to the new reference point.

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[3] 'Meta-analyses' is the analysis of data from, for example, a wide range of fish stocks to identify general patterns and draw general conclusions which can then be applied to data poor situations, or prior to doing case-specific analyses.

Estimation issues and uncertainty in MSY-based reference points

Many of the estimation issues associated with MSY-based reference points are clearly listed in the yellowfin and bigeye stock assessment papers that have been submitted to the WCPFC Stock Assessment Group. From (for example) Langley et al. (2007) we list the following:

- steepness
- selectivity (mix of gears)
- changes in productivity
- recruitment variability
- absolute quantities vs ratios of various kinds

Steepness of Stock recruitment relationship

Steepness is commonly poorly defined and impossible or very difficult to estimate in fisheries stock assessments. This is not just an issue for large pelagics, such as tuna and billfish. Since steepness plays an important role in determining MSY-based quantities, any assumptions about steepness will have follow-on effects for MSY-based reference points.

Our response to this difficulty would be to:

(a) explore how sensitive results are to the assumptions (or priors) about steepness and, ideally, carry this uncertainty forward in calculations; and

(b) consider the use of spawner per recruit harvest rates, possibly in combination with F_{msy} as reference points.

We discuss point (b) further below. We note that Langley et al. (2007) and Hampton et al. (2006a,b) take uncertainty in steepness into account when calculating the posterior probabilities of current biomass and harvest rate relative to the MSY quantities for a given assessment model. By calculating the posterior probabilities for different assumptions about priors on steepness, additional model uncertainty can also be taken into account, though this is a somewhat more complicated issue. We discuss this further below.

Fishery Selectivity

Regarding selectivity, the existing stock assessment results and reference point calculations are again done with explicit awareness to the assumed selectivity patterns. Difficulties primarily arise when there are proposed, or unanticipated large changes in selectivity, and this would in fact also affect other types of reference points, such as ones based on yield or spawner per recruit considerations (see Appendix 1). It is therefore, again, not something that makes MSY-based reference points inappropriate, but rather an issue to be aware of.

Equilibrium assumption

MSY concepts are based on the notion of 'equilibrium', i.e. the long term expected level of biomass and yield under a constant harvest rate, and implicitly, constant recruitment. If actual recruitment (i.e mean recruitment and its annual deviations) varies substantially then comparisons between equilibrium quantities (such as B_{msy}) and the (non-equilibrium) current biomass could vary substantially from year to year. This is likely to be of greater importance when there are relatively few age classes in the population, for example, for relatively short-lived species (e.g. skipjack), or for heavily depleted stocks. It is, however, very likely that the severity of this problem can be reduced by careful and informed choices of how the target is set relative to the limit reference point, the definition of how the comparison is made, and the choice of associated probabilities for exceeding the LRP (e.g. when using the probability of, say, (current Biomass)/B_{msy} <1; this is discussed again further below).

Changes in Productivity and recruitment variability

Changes in productivity can refer to substantial changes in the level of recruitment over time rather than necessarily as a function of changes in the spawning stock. The term 'regime shift' is sometimes used (implying a step change from one 'regime' to another), but it can also simply be a case of an extended sequences (several years) of above average recruitment, before the system appears to return to average again. The main problem, in our view, arises when calculating the absolute yield rather than in the calculation of F_{msy} or B_{msy}. If all else remains equal, a higher recruitment level should simply scale up the yield. In the context of an assessment this is, of course, over-simplistic, since above-average recruitment is likely to affect the catch-at-age profiles which can have an impact on the F-at-age estimates (and recent recruitment estimates) which can then potentially affect all the MSY-based quantities. This is again, in our view, not sufficient reason for not using MSY-based reference points, at least in the interim, since the sensible kinds of sensitivity analyses seen in Langley et al. (2007) and Hampton et al. (2006a,b) can easily be used to evaluate implications of apparent changes in recruitment. (For example, different assumptions about recruitment can be made when doing forward projections under different catch options). We also note that this issue will affect reference points based on historic estimated stock and recruit series (see Appendix 2).

Absolute estimates or ratio reference points

It is important to consider both the precision of the estimate (the variance, or CV) and the year-to-year variability of the estimate. Some assessments can be rather sensitive to the addition of even just one year's data, and this can imply large year-to-year changes in the estimated B_{msy} and/or F_{msy} and the estimated state of the fishery relative to the reference points. In addition, structural changes in the model or new analyses of, for example CPUE indices, can often change the absolute levels of estimated biomass and recruitment from one year's assessment to the next. It is often the case that ratios, for example $B_{current}/B_{msy}$ or $F_{current}/F_{msy}$, are more stable and have lower variance than absolute quantities. Langley et al. (2007) further distinguish between three types of ratios: (i) ratios comparing measures for a particular time period with the corresponding equilibrium measure; (ii) ratios comparing two equilibrium measures and (iii) ratios comparing two measures pertaining to the same time period. $B_{current}/B_{msy}$ and $F_{current}/F_{msy}$ fall in the first category which Langley et al. (2007) have found to be less robust than those in category (ii). An example of a category (ii) ratio is $B_{Fcurrent}/B_{msy}$ - the expected equilibrium total biomass at $F_{current}$ relative to equilibrium total biomass at MSY.

Notwithstanding this point, comparison of results for $B_{current}/B_{msy}$ and $F_{current}/F_{msy}$ over several previous assessments also show remarkable similarity. We strongly support a preference for working with the ratios rather than absolute estimates, and commend the effort that has been put into quantifying underlying uncertainties by formally estimating the probabilities that $B_{current}/B_{msy} < 1$ and that $F_{current}/F_{msy} > 1$ for the current SPC assessments. In the current context, therefore, it seems sensible to continue using these quantities until the use of the category (ii) type quantities as reference points have been tested in simulations (i.e. via an MSE exercise).

There will inevitably be differences in characteristics and outcomes of stock assessments for different species. Some assessments will be more 'stable' from year to year and possibly have lower uncertainty in estimates of important outcomes. Also, the estimated historic time-series of stock and recruitment for some species may suggest that changes in productivity need to be considered whereas for others it may not be an issue. While much can be learnt from general exploration of the behaviour of different reference points and types of assessment models, there will always be the need to consider these issues for each particular species in the context of the specific data, ancillary information etc available for the assessment. We consider that this is best done by the stock assessment practitioners and members of the SAWG. The work already done by Langley et al (2007) and others (e.g. Kolody et al 2006, 2008) provides a sound basis for the WCPFC SC to do this.

Particular considerations for tropical tunas and billfish.

There are essentially three factors that could imply that the common reference points, including MSY-based reference points, are not applicable to tunas and billfish:

- life-history characteristics
- exploitation pattern (selectivity of gear)
- migration patterns
- stock structure

Life history characteristics

In terms of life-history characteristics, it is species that are at the extremes of longevity (very short-lived, or very long-lived and late-maturing) that may be of concern since much of the experience with reference points, and meta-data analyses, have been concerned with stocks of intermediate longevity – albeit a wide range. In this regard, the shortest lived stock of relevance here is probably skipjack tuna. If most, or a large proportion, of the harvest consists of juveniles, then the main concern is to ensure that enough survive to mature and spawn, and to maintain multiple age-classes in the spawning population. In this case it is important to set reference points in terms of spawning biomass rather than (just) fishable or total biomass.

At the long-lived end of the spectrum, it is the species which also mature late that need to be considered with caution if much of the harvest occurs on juveniles as well as young spawners. In the case of long lived species, it is often the case that the older year classes contribute disproportionately to the total spawning success of the stock. Therefore maintaining sufficient older reproductive year classes may be important in maintaining long-term productivity, particularly if there are temporal trends in recruitment (e.g. Kritzer and Davies 2004). It is not a case of finding different reference points, but again rather a case of being cautious about maintaining sufficient spawning biomass and sufficient age classes in the spawning biomass.

Regarding exploitation pattern, the points made above about juveniles and immature or young adults are again relevant. The implications of changes in selectivity and/or in the mix of gear types (e.g. purse seine and longline gears) for estimation of reference points have already been discussed. It is again, worth noting that other types of reference points (e.g. ones based on yield per recruit and spawner per recruit considerations) will also be sensitive to changes in selectivity.

Caddy (1998) notes that, from a technical point of view, reference points for straddling or highly migratory stocks do not differ from those for shared stocks (Gulland 1980, Caddy 1982), or for those occurring entirely within an EEZ, but that the feasibility of application of individual reference points may differ, due to the multijurisdictional nature of the resources, rather than their biological characteristics.

The most difficult situation is that of sequential exploitation along a migratory route. The main difficulty is, in our view, more related to allocation issues than to finding suitable reference points. According to Caddy (1998), the best overall reference point in a sequential fishery for a highly migratory species is one which ensures that a target spawning biomass survives all fisheries to replace the stock. Caddy uses a simple example to illustrate that this can be achieved by many different combinations of national (or spatial) allocations, which all result in the same cumulative risk of death prior to spawning. It should be possible to achieve this through MSY-based limit reference points provided that $SSB_{current}/SSB_{msy}$ is also monitored, together with some attention to the ratio of fished to unfished spawning biomass (e.g. through spawner per recruit, or relative SSB, considerations under F_{msy}).

Uncertainty in stock structure will always cause some concerns and difficulties for the calculation of reference points. The same uncertainties can obviously cause difficulties for stock assessments too. It is also difficult to second-guess how reference points will be affected, other than relatively obvious observations (e.g. if multiple stocks are included in an assessment, then absolute reference points, e.g. B_{msy}, will estimate some combined reference point which would be an over-estimate for each of the component stocks). The issue of stock structure uncertainty is, in our view, best dealt with in the context of a simulation model and management strategy evaluation. This would allow for explicit evaluation of alternative hypotheses about stock structure with a view to designing a robust management system. In addition, data collection which takes place on appropriate spatial scales to allow for ‘local’ monitoring can act as an important safeguard in cases where uncertainty in stock structure is considered to be a potential problem. Given the existence of stock assessments for WCP stocks, it seems reasonable to assume that stock structure issues have already been considered, and that the most sensible assumptions about what can be treated as a ‘unit stock’ (based on currently available information and data) have been made in this regard. As a starting point it would therefore make sense to use the same ‘stock’ definitions currently used in the stock assessments for the purposes of estimating and using reference points.

Other considerations

There are two additional considerations which may affect how reference points are set for tunas and billfish:

- technical interactions
- ecological considerations (e.g. bycatch)

We include in technical interactions the fact that a single gear (be it purse seine or longline) can catch species other than the target species. For example, bigeye and yellowfin are taken incidentally in purse seine sets aimed at catching skipjack. This means that if reference points are calculated for each species independently (even if the ‘incidental’ harvest rate is taken into account), it may not be possible to remain above the LRP for each fishery totally independently. It is also likely that management action for one species could negatively impact on another, and this obviously needs to be considered. There may need to be additional considerations for adjusting single-species reference points to take such technical, or ecological, interactions into account. On the other hand, it may be possible to achieve objectives by more detailed management actions such as time-area closures to minimise the catch of non-targeted species, or bycatch. Langley and Hampton (2006) provide an example of an approach to try to achieve the objectives for the individual fisheries.

The most practical approach for now, in our view, is to start by defining single-species reference points. There may be a need to define an additional management steps to evaluate the implications of management actions triggered by the single-species comparisons of stock status relative to reference points. Subsequent tasks can then be defined to investigate where and whether there is a need for adjustments to reference points, or whether more sophisticated management tools, than just total catch or total effort, are required to give an appropriate probability of management objectives can be met.

Conclusions regarding default limit reference points

From the overview and discussion provided above, we can see no strong reason for not using MSY-based reference points as ‘default LRP reference points’ for the key WCPFC fish stocks. It goes without saying that, in common with all candidate reference points, MSY-based reference points are not perfect and there are weaknesses. However, much technical development has already been done to estimate the relevant quantities needed to evaluate stock and fishery status relative to these reference points, including approaches for taking uncertainty into account. Estimates are in fact available for the past several yellowfin and bigeye assessments (Langley et al. 2007; Hampton et al. 2006a, b). In addition, these quantities have already been identified in the convention and the UN Fish Stocks Agreement as, appropriately (e.g. Caddy, 1998), limit reference points. We consider it would be more in keeping with the precautionary approach, and having lower associated risk to the stocks, to define and adopt reference points with associated management actions than to wait (do nothing) until sufficient further work has been completed in order to set the 'ideal', or 'perfect' reference points for each stock.

Operationalising limit reference points

It is beyond the scope of this document to provide a full technical review of the approaches used in recent yellowfin and bigeye stock assessments (Langley et al. 2007, Hampton et al. 2006a, b). However, we recommend that those approaches be used to estimate the probability of current (total) biomass being above B_{msy} and current harvest rate being above F_{msy}. We agree with the use of ratios and associated probabilities rather than the use of absolute values in this regard. In additional we recommend that, in line with the precautionary approach, and given the potential for a large proportion of juveniles being harvested, similar estimates of the probability that spawning biomass is above that at MSY ($SB_{current}/SB_{msy}$) be considered.

From an operational point of view there are two issues which would need some discussion regarding reference points. Both issues relate to the definition of whether the stock is in the category 'overfished' and/or 'being overfished'. It is important to recall that the whole idea behind establishing this is to take appropriate action, and in this sense operationalising reference points becomes directly related to the decision rule and management action.

There are, at least, two ways in which the action can be defined on the basis of the probability that the stock is 'outside' its limit reference points. For simplicity just take the harvest rate measure for now. One approach is to define the status and action as follows:

> if $P(F_{current}/F_{msy} > 1) \geq$ x% then stock is 'being overfished' - take action associated with 'being overfished' status
>
> if $P(F_{current}/F_{msy} > 1) <$ x% then stock is 'not being overfished' – take action associated with 'not being overfished' status

In this case it is clear that there needs to be some agreement about what the 'x%', which we'll refer to as the cut-off probability, should be. The very definition of limit reference points as something to 'avoid' suggests strongly that 'x' should be a very low percentage – say 5% or 10% at the most; the exact choice is one the Commission needs to make on the basis of the level of risk they (stakeholders, managers, society) are prepared to take. Also, the action required is – again in the spirit of the precautionary approach – supposed to be prompt and severe (Caddy, 1998) to ensure that the stock and fishery return to within the limit reference points and, ideally move towards and above the target reference points. More will be said about target reference points below.

Another approach is to use the estimated probability as a sliding scale to define action. This suggestion should not, however, be confused with the 'sliding scale' for action when the stock or harvest rate is between the limit and target reference points (see 'Decision rules' and Figure 1 below). Regarding limit reference points, we would still argue that there should be a cut-off point; for example, action may be less severe if the probability (of $F_{current}/F_{msy} > 1$) is between 1 and 5%, but when it is above 5% there should be one option for action which would be prompt and severe. It is worth noting that in many illustrations of conceptual decision rules, the action is for no targeted harvest, i.e. TAC=0, when the stock is deemed to be outside its limit reference points (e.g. Figure 1; Smith et al. 2007; Australian Government 2007).

The second issue that requires discussion is how probability estimates from several assessment models could be used to determine stock status. There are many reasons why it is (at least nowadays) common to conduct and present results for several assessments. In some cases different datasets (particularly CPUE data series) may be included; in other cases different structural assumptions or assumptions about parameter values (or priors) might be made. It is also often the case that there is no direct way of comparing models, or of ranking or obtaining relative weights for them. One option is to consider combining results from the set of models; if this is the choice then there are various ways to do so. An implicit equal weighting of models and taking averages is often an obvious, but not always sensible, approach. A more risk averse approach would be to consider the maximum estimate for $P(F_{current}/F_{msy} > 1)$ and the minimum estimate for $P(B_{current}/B_{msy} < 1)$, but this is likely to be rather sensitive to the set of models. A percentile or quantile could be used instead, particularly if there are a large number of models. Although percentiles are likely to be less sensitive to the suite of models than the minimum or maximum, the potential problem remains.

If there is already an established philosophy of “a base case” run and “sensitivity” runs, then this distinction can be used without a need to combine results. We note that this distinction tends to carry an implicit understanding of the ‘base case’ being the most likely or most plausible scenario, and the others (possibly) less likely or less plausible. The base case can then be used to provide the estimate of stock status relative to reference points (i.e. $P(B_{current}/B_{msy} < 1)$ and $P(F_{current}/F_{msy} > 1)$), but the actual probability level (i.e. the x% in the example above) can be informed by the full set of models at the time that the reference points and decision rule are defined. This is an important point; the cut-off percentage (value of x) need not (and should not) be re-set every time an assessment is run, though it should of course be reviewed when appropriate. The probability of the stock being outside its limit reference points should be, however, estimated every time an assessment is conducted.

Target reference points

In some ways it is simpler to discuss target reference points separately from decision rules (which define the management action to be taken, depending on where fishing and the resource are relative to the limit and target reference points). We note, however, that the setting and performance of target reference points does interact with the choice and design of the decision rule, which is discussed in the next section.

As noted above, target reference points are meant to indicate a state of a fishing and/or resource which is considered to be desirable and at which management action should aim. In order to avoid frequently fishing above or the stock being below its limit reference point, and recognising that estimates of stock status from assessments are uncertain, the target reference points should be set far enough from the limit reference point. In ICES, so-called 'precautionary[4] reference points' (B_{pa} and F_{pa}) have been used as a mechanism for managing the risk of the stock falling below B_{lim} or the fishing mortality exceeding F_{lim} (ICES, 2007). B_{pa} is set above B_{lim} and F_{pa} is set below F_{lim}; the buffer between the two is designed to safeguard against natural variability and the uncertainty in the assessment. In broad terms, the notion is that if the precautionary reference points are exceeded, it implies that the limit reference points are being approached, so action needs to be taken to move away from the limit reference points. In the ICES context the size of the buffer depends on the accuracy of the assessment and the risk managers and society are prepared to accept that the true SSB is blow B_{lim} and true F is above F_{lim}.

The relationship between the two types of reference point is sometimes defined, in general terms, as:

$$F_{pa} = F_{lim}.\exp(-2S) \qquad \text{and} \qquad B_{pa} = B_{lim}.\exp(+2S)$$

where S can be based on estimates of precision from an assessment, or established through simulations to achieve desirable probabilities for biomass and harvest rates being above the 'pa' reference points (Caddy, 1998). ICES (2007) stresses that the precautionary reference points should not be treated as management targets, but as lower bounds on spawning biomass and upper bounds on fishing mortality. Nonetheless, we note that this general approach can be useful in defining default target reference points, particularly if generous buffers are set. Much of the information for doing this is already available within existing stock assessment results (e.g. Langley et al. 2007, Hampton et al. 2006a,b).

It is also useful to note that, in some cases a fraction of MSY or of F_{msy} is used as a TRP. For example, Doubleday (1976) postulated that fishing at the effort level that corresponded to 2/3 of the effort needed to produce MSY would allow a very large fraction (about 80%) of the MSY to be harvested with a significantly reduced risk of stock collapse.

Raynes (2007) outlines the key elements of the Australian Governments Harvest strategy policy (HSP). Under this policy, minimum standards for target reference points are as follows. The biomass target should be equal to or greater than B_{mey} (Biomass where maximum economic yield is obtained), but when B_{mey} is unknown, a proxy of $1.2B_{msy}$ is to be used. The harvest rate target should be less than or equal to the harvest rate which would keep B at B_{targ}. The reason for noting this is primarily with regard to the use of B_{msy} to construct a target reference point. As discussed in Appendix 1, we consider that economic-based reference points, beyond those based on simple stock and fishery proxies (likely long-term yield, average catch rates) are unlikely to be practical in the context of the WCPFC, at least as default reference points. Simply put, MEY is based on the concept of maximising the economic return from the surplus yield of a stock, which equates to the value of the catch (tonnes x price) less the cost of harvest and getting product to market (including capital, opportunity cost etc). In making the translation from (relatively) simple measures of potential long-term yield and catch rate to an economic measure, such as MEY, a range of assumptions have to be made about the values of and trends in costs, prices, fleet

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[4] The term precautionary essentially refers to how the reference point is used as a component for precautionary management strategy rather than to the way in which is derived.

structures, markets and currency exchange rates etc. Many of the relationships among these measures vary according to factors outside the "fishery system" and also between member countries involved in the fisheries. Hence, we consider it more useful to implicitly provide for the highest long-term economic return from the resource as proposed by Doubleday (1975), i.e. aim to keep the stock above MSY (or appropriate level of depletion), where catch rates (income) will be higher and costs of fishing, inter-annual variability in catches, and the need for and cost of management interventions are likely to be lower. Notwithstanding this, estimates of net economic return from the fishery and other "firm related" economic measures are useful performance indicators, for the past and current economic performance of the fishery, that can be used to determine whether current or future management measures require adjustment to improve the economic performance of the fishery.

Given the existence of stock assessments and the facility to do projections, it may in fact be feasible to, relatively quickly, use projections to evaluate the likely performance of different choices of target reference points – for example, different multipliers on B_{msy} and fractions of F_{msy} - at least under scenarios with constant future harvest rate. (Projections do not provide information on the performance of a feed-back decision rule; simulation models are required to do this).

Results from the stock assessments can also inform the appropriate choice of probabilities associated with the question of whether current biomass (or harvest rate) is above or below its target or limit reference points. Two points are worth noting. First, although the probability of being outside the limit reference points (biomass below; harvest rate above) should be very small since it is a state to avoid, the probability of being outside the target reference point can be higher. For example, Table 1 in Davies and Polacheck (2007) shows that CCAMLR uses a probability of less than 10% of being below the limit biomass reference point (20% of unexploited SSB), and a probability of less than 50% of being below the target biomass reference point (50% of unexploited). This highlights the need of setting the target reference points carefully. The target reference point needs to be sufficiently above the limit reference point so that a 50% probability of $SSB<SSB_{50}$ does not imply a 10% or greater probability of $SSB<SSB_{20}$.

Decision rules

The final, but crucial, component of the management strategy based on reference points is the decision rule, or the definition of agreed management action that should be taken when the stock and fishery are at different positions relative to the limit and target reference points.

There are, of course, many ways in which a decision rule can constructed. Two examples are considered here for information and as starting points for discussion. We should, however, note that it is more in keeping with the precautionary principle to actually take action when the fishery or resource exceeds the limit reference points than to delay action in order to find the 'ideal' decision rule.

A common type of decision rule (Smith et al. 2007, Australian Government 2007) is schematically illustrated in Figure 1. In this example, the estimated current biomass is compared to its reference points (horizontal axis), and the decision rule generates a harvest rate (vertical axis) which can be used to set the appropriate effort or TAC level for the coming year. For example, if current biomass is above B_{targ}, the decision rule indicates that the harvest rate be set at its maximum value, which is usually the same as F_{targ}. In our version of the schematic F_{lim} is only drawn on the graph to indicate that it is a value above the maximum generated by the decision rule[5]. When current biomass is between the target and limit reference points the decision rule indicates that harvest rate decreases linearly from F_{targ} to 0 (or some very low value). The reduction is meant to allow the biomass to increase back to a level above B_{targ}. If the biomass is below B_{lim}, there is no fishing (or possibly a very small harvest rate to allow for some monitoring on the fishing grounds). In this example, it is implicit that whenever the current harvest rate is above F_{targ}, the decision rule will recommend a reduction to F_{targ}. On the other hand, it also implies that if the current F is below F_{targ}, the decision rule will recommend an increase to F_{targ}.

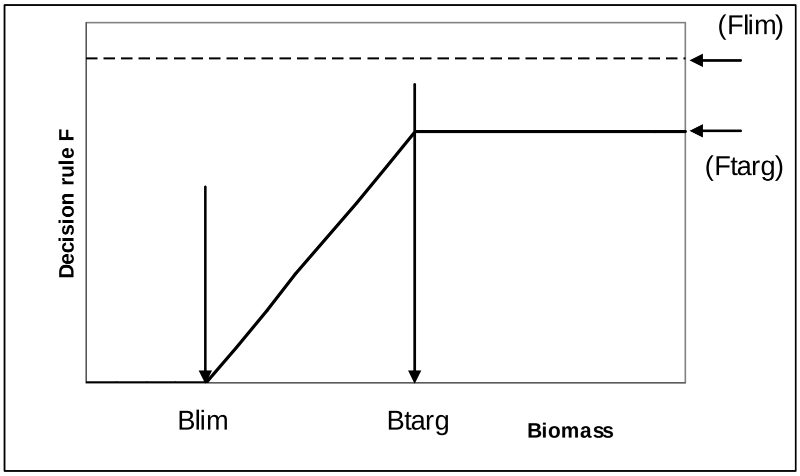

Figure 1. Schematic illustration of a commonly used decision rule which defines the harvest rate (solid line) as a function of current biomass relative to its target and limit reference points. F_{lim} (dashed line) is only drawn in to show that it is above F_{targ}; also see text.

Although the decision rule above is formulated in terms of the harvest rate F, it would of course be possible to convert that harvest rate to a coinciding level of effort (or an estimated catch) based on a stock assessment.

It would be easy to construct a similar rule with probabilities of biomass being above or below its reference points on the horizontal axis rather than the absolute biomass. One advantage of this type of rule is that once reference points have been set, the decision rule is essentially defined. The only word of caution is that if B_{targ} is set as some ‘buffer’ value above B_{lim}, it would be prudent to check (using projections) whether a harvest at F_{targ} has a high probability of keeping the biomass above B_{targ}. Also, care should be taken that B_{targ} is far enough away from B_{lim}, so that the management action is unlikely to ‘jump’ between the two extremes of F=0 and $F=F_{targ}$ from one time-step to the next (as noted in section 1.6).

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[5] In some versions (e.g. Smith et al. 2007) a second line is drawn starting at zero at B_{lim}, increasing to F_{lim} at some point below B_{targ}. We omit this line which can be confusing since it is not intended to form the basis for the harvest rate generated by the decision rule.

An alternative approach would be to determine an appropriate harvest rate (catch, or effort level) on the basis of projections, but with pre-agreed constraints or requirements. For example, if current biomass is between the target and limit reference point, then find the harvest rate which implies a "z% probability that B would be above B_{targ} after (say) 3 years". This approach requires more quantities to be defined (z%, the number of years) and, again, the projections will not reflect the feedback nature of the system. If this kind of approach is used, it would be very important to pre-agree the specifics of the stock assessment model and assumptions that would be used in such calculations.

There is, however, one situation where there is an advantage of this approach over that illustrated in Figure 1. If the stock is near or below B_{lim} and the harvest rate is near or above F_{lim}, and a harvest strategy is being implemented for the first time, it may be unrealistic to achieve the sudden level of cut-back required by the type of rule in Figure 1. Instead, projections can be used to explore which sequences of cut-backs (for example, 20% in each of 3 years, say) would achieve a desired reduction in F and rebuilding of the biomass with acceptable probability after a specified time-period. We stress the importance of agreeing on the time-frame and acceptable probability in advance. The time-frame will be related to the life-history of the stock and the current age structure; the acceptable probability will to some extent depend on the precision of the assessment and the way in which the target reference points are set, as well as the level of risk inferred in the Convention and that the Commission (managers, stakeholders, society) are prepared to take. In the medium to longer term, and once F and B are close to their target levels, it may then be feasible to adopt the Figure 1 type decision rule.

Other candidate reference points

Although we concluded above that there are, in our view, no obvious and serious reason for not using the MSY-based reference points as 'default limit reference points', we have listed other candidate reference points in Appendix 1. One reason for doing this is for completeness (though the list in Appendix 1 is not exhaustive). The other reason is that it is often informative to calculate a range of candidate reference points for a given stock. In our experience, the values of and therefore implications of the different candidate reference points are often very similar. In other words, if the harvest rate is considered to be close to or above F_{msy}, it is often also the case that the harvest rate is close to or above the candidate limit reference point based on, say, spawner per recruit considerations. Although it is inappropriate and risky to base the choice of reference points on the result of its calculation, we consider that it is nonetheless an informative exercise. Many of the candidate reference points are already available in the assessments presented to the WCPFC SC; others (notably the spawner-per-recruit based reference points and those based on historic stock and recruit estimates) can easily be calculated from the stock assessment inputs and/or results.

It would be particularly useful to extract estimates of candidate reference points from several recent assessments and to assess how much the estimates have varied or changed from one year's assessment to the next. This exercise will also include changes in the sets of assessment models (or scenarios) considered over time.

One set of reference points that are not currently in the assessment summaries (as far as we know) are spawner-per-recruit based harvest rate reference points. These quantities are based on 'forward' (equilibrium) calculations of the expected spawning biomass per recruit under a given harvest rate, relative to that which would be achieved under no harvest (see Appendix 1). The calculations do not include assumptions about a stock-recruit relationship and, therefore, are not sensitive to uncertainty about steepness. They take a recruit as the starting point, so care needs to be taken with this type of reference point if the spawning stock is already at a low relative level (i.e. SSB/SSB_0 is small). A meta-analysis of 91 stocks in Mace and Sissenwine (1993) suggests that a harvest rate which implies relative spawner per recruit of 30% may be appropriate as a limit reference point. Note, however, that this selection of stocks does not include any tuna stocks, and should therefore be interpreted with some caution in the context of tunas and billfish. It may, in fact, be possible and informative to do a similar analysis for just tunas. In any case, calculation of $F_{spr30\%}$ and higher values (eg $F_{spr35\%}$, $F_{spr40\%}$) and comparisons of these values with those obtained for F_{msy} under different steepness assumptions, could help confirm whether F_{msy} would be appropriate as a limit reference point.

USE OF MANAGEMENT STRATEGY EVALUATION AS PART OF IMPLEMENTING THE PRECAUTIONARY APPROACH IN THE MANAGEMENT OF FISHING IN THE WCPO

Brief background on the MSE approach

Management Strategy Evaluation is a formal approach to dealing with the inherent uncertainty in natural resource management systems. Davies and Polacheck (2007) reviewed the background to MSE and its relationship with reference points and implementation of the precautionary approach in the context of the WCPFC. In this section we provide a more operational overview of the necessary steps for implementing the MSE approach. The leads is intended as a general introduction to the two potential "case studies" provided in the subsequent section on potential work- plan for MSE. The case-studies suggested encapsulate the potential range from the relatively "straight forward" to "complicated and challenging": i) SW Pacific Swordfish, and ii) the multi-species, multi-gear skipjack, yellowfin, big-eye fisheries. As noted they are made as suggestions for the SC and Commission to consider and there are a range of potential options that fall in between these extremes. First, however, we provide a very brief reminder of the components of an MSE and the general technical steps involved in implementation.

The MSE approach uses Monte Carlo simulations to encompass the important components of the fishery system, including the uncertainty in current understanding, in a "virtual fishery". That is, it involves an iterative process of simulating the underlying population dynamics of the stock, the fishery, the collection of data, the assessment process, the management decision making process (i.e. the "decision rule") and the specification of the subsequent management action which leads into the subsequent cycle of stock and fishery dynamics.

An important advantage of the approach is that it is possible to evaluate the relative performance of different management strategies in meeting the objectives of fisheries management before they are implemented. Hence, it is an objective, quantitative approach for selecting between potential strategies based on their likely performance, cost and management complexity, and their robustness to major uncertainties. Put simply, if a strategy does not perform adequately in a well constructed "virtual fishery", what basis is there for assuming that it will work in a real one?

A second important advantage of the MSE approach is that it provides for evaluation and refinement of "feedback management". That is, as the process involves iterative simulations of the (usually) annual fisheries monitoring, assessment, decision-making (including setting of total catch or effort) cycle, it allows the behaviour and performance of different feedback management strategies to be evaluated, including their robustness to uncertainty and response to potential future changes in the fishery system. In the MSE context, the primary question is: "Which management strategy[6] is most likely to meet the objectives of fishery management in the long-term (20-30 years), given what we do know and, importantly, don't know about the state, productivity and dynamics of the fishery?" This is in contrast the current use of stock assessments to provide short-term (1-3 years) estimates of future stock status and potential yields based on constant levels of fishing mortality. In the latter case the question is: "What catch/effort level can be taken in the fishery over the next year (s) and maintain the stock (or move the stock toward) the target reference point and above the limit reference point, assuming all else remains constant?

In the MSE context the focus becomes the relative trade-offs among measures such as:

- "average long-term catch" vs "average long-term catch rate";
- "average long term catch" vs "probability of the stock being below the limit reference point";
- "average long term catch" vs "probability of the stock being above/below the target reference point";
- "average long-term catch (or catch rate)" vs "inter-annual variation in catch (or catch rate)";
- "average long-term catch" vs "size/frequency of management interventions";

Measures such as these can be more readily and directly related to the higher level management and policy objectives of the Commission and the Convention. A simple example is provided in table 1. Specific examples for the WCPF of the potential tradeoffs between the sort of measures given above can be found in Kolody et al (2007) in the context of the SW Pacific swordfish. Other relevant examples and recent reviews are provided by Basson and Polacheck (2004), Punt (2006) and Butterworth et al (2007).

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[6] Recalling that a management strategy (harvest strategy, management procedure) is defined as the combination of monitoring, assessment, decision-making and management implementation (e.g. effort control, catch control, time area-closures, etc).

Table 1: Common examples of how higher level policy and management objectives can be translated into quantitative performance measures for the purposes of MSE. For a more detailed consideration in the context of the WCPFC see Davies and Polacheck (2007).

Formal goal/objective	Short-hand	Performance measure
"*to ensure long-term sustainability*"	Risk to stock	Proportion of years stock is below limit reference point over period of evaluation (e.g. 2008-2038)
	Productivity of stock	Realised catch as a proportion of "true" MSY over evaluation period.
"*promote optimum utilization*"	Economic performance[7]	
	e.g. operational cash flow	Long-term average catch rate
	e.g. harvesting and processing capacity	Long-term average catch
	e.g. Revenue	Long-term average value of catch

General technical steps for implementing an MSE approach

At the technical level, the simulation modelling associated with an MSE 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[8] that uses the data from the sampling model to provide estimates of resource status;

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[7] Note: These economic measures are provided as examples of the "translation" of high level objectives into potential performance measures for an MSE exercise. Naturally, the definition of specific quantities to be used in any particular MSE exercise would need to include appropriate consideration of discount rates etc, in which the authors profess to not having the appropriate expertise.

[8] Which can even simply be a time-series of a stock status indicator, such as CPUE, if there is no formal quantitative stock assessment

4. a harvest strategy component that determines management actions (e.g. setting a quota, effort level) based on the results of the assessment and a specified decision rule;

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. This process is referred to as conditioning.

In the following section we elaborate on each of these components in the context of developing an MSE work program the WCPFC. These general steps are further elaborated for each of the suggested case studies.

Scoping and specifying the management objectives, performance measures, monitoring, assessment, management options and operating model

This first step can be thought of as the detailed project or problem specification. It should be designed to be consultative and interactive and include participants from all aspects of the fisheries management system; including , but not limited to, policy makers, fisheries managers, fishers, NGO interest groups, stock assessment and fishery scientists and MSE practitioners. The purpose of this stage is to identify and specify in conceptual form, not necessarily in technical detail:

1. The specific management objectives and issues that will be addressed by the MSE exercise;

2. The form and specification of the monitoring (data collection), assessment and management measures that are considered realistic and feasible for operational management of the fishery;

3. The performance measures that will be used to summarise and report the results of the evaluation;

4. At least, conceptual specification of alternative models of the dynamics of the target stock(s) and the fishery(ies) that harvest them. These “conceptual models” should be sufficiently detailed to allow them to be translated into dynamic mathematical and statistical models of the fisheries system;

5. Identification and agreement on the form of modelling platform to be used for the Operating Model, and;

6. The process for development, operating model conditioning, harvest strategy specification and evaluation, technical review and reporting and consultation for the delivery of the MSE.

In our experience, some of the specifications from this first step may well change somewhat through the iterative process of modelling, presenting preliminary results, or finding problems or difficulties with initial specifications.

Conditioning the Operating Model to available data

The process of conditioning the operating model(s) to the available data is a technically demanding task somewhat analogous to an integrated stock assessment. Hence, participation at this stage is largely limited to MSE practitioners and stock assessment and fisheries scientists with expertise in the particular fishery. However, regular opportunity for consultation and feedback with other participants in the MSE process is essential.

The aim of the conditioning phase is to develop a range of population dynamics and fisheries models which are broadly consistent with the current understanding of the dynamics of the fishery system, including important sources of observation, process and implementation uncertainty (*sensu* Francis and Shotton, 1998). This involves fitting of alternative models to the available data and exploring the implications of alternative parameter assumptions and scenarios. This process can be used to identify the set of models to be used for the projection and evaluation phases of the MSE. In other cases, the outcome of the conditioning phase has been a set of “most plausible models” referred to as the Reference Set and a set of “less plausible” but not impossible models, referred to as the Robustness Set (e.g. Basson et al 2005, MPWS report). The former set of models are used for the main evaluation phase to identify as “short list” of candidate management strategies (i.e. decision rules) and refine, or “tune”, their performance relative to the specific management objectives. The Robustness Set is used to test the performance of the final set of management strategies for robustness against the set of less plausible but not impossible scenarios, to see whether their relative performance is acceptable under these circumstances.

At the completion of the conditioning phase there should be a set of agreed simulation models that incorporate the current understanding and uncertainties of the fishery system that can be used to start the ‘forward simulations’ for evaluating different “feedback” decision rules under a range of future scenarios for the fishery. The implications of different levels of constant future catch or effort can obviously also be evaluated using the agreed set of models from the conditioning phase.

Projections of future scenarios based on uncertainties in OM

The conditioning phase provides a set of models that encapsulate the dynamics and uncertainties in the fishery. This can be used as starting points for simulating future stock dynamics under different harvest strategies. As noted above, the main difference between ‘projections’ in the context of MSE and those currently done in the context of stock assessments is the fact that, in the MSE context, the catch or effort is established (and can change) each year depending on the simulated "collected data" and the decision rule.

Some assumptions in, or parameter estimates from, the conditioned models can be used to simulate future stock dynamics. For example the recruitment variability estimated in the conditioning phase of each model can be used to generate future recruitments. It is also, however, important and relevant to ask whether there may be a need to make different assumptions or use different parameter values for the projection phase. For example, if there are concerns of 'regime shifts' in future recruitment (e.g. where the level of recruitment may be different from that estimated in, say, a stock-recruit curve), then this can be built into the projections. It is, however, important, both for practical reasons (i.e. to keep the number of models, scenarios and results to consider to a minimum) and plausibility or realism to be able to justify the need for considering such scenarios.

The same set of models can, of course, also be used to provide advice on the implications of future constant catch or effort levels under a range of potential future scenarios. While the results of such projects should be treated with caution beyond the short-term, they provide a sound basis for short-term management advice in the absence of evaluated management strategies. As noted in the section on Reference Points, the MULTI-FAN CL stock assessments currently considered by the WCPFC SC and Commission include all the necessary reference points (or information to calculate them) for the SC to be able to provide the Commission with management advice relative to default reference points. What is currently not available is a more comprehensive exploration of the uncertainty in each of the respective assessments (although we note that significant progress is being made in this regard) and agreed decision rules relating the outcomes of the assessments to reference points.

Design and evaluation of decision rules

Formal decision rules are the basis for converting the outcomes of the monitoring and assessment components of a management strategy into management actions (i.e. increasing or decreasing levels of fishing) aimed at meeting management objectives. The decision rule is a necessary component of a feedback management system. In the absence of agreed decision rules, management decisions tend to be made in an *ad hoc* manner and it is difficult, if not impossible, to predict the medium to long-term performance of the management system. As such, formal decision rules linking outcomes of assessments of the fishery to management action are recognised as an integral component of implementing the precautionary approach (Anon 1995 Annex II; FAO, 1997; Anon, 2008; Rayns, 2007).

The design of decision rules should be informed by the particular nature and circumstances of the fishery and the growing body of experience with implementation and evaluation of different types of rules. In the WCPFC context, particular consideration will need to be given to the nature (e.g. single/multi species, single/multi gear, single/simple/complex stock structure) and the current state (developed/developing, overfishing/overfished etc) of the fishery.

It is probably worth noting that the 'assessment' model used in the conditioning phase (i.e. conditioning of the operating model to historic data) can be used as the 'assessment' model for the decision rule in the projection phase, but it does not have to be used here. For example, a much simpler 'assessment', such as a stock production model[9], can be used as a basis for the decision rule. It is, of course, even possible to base a decision rule directly on an indicator (e.g. standardised CPUE) (e.g. Kolody et al., 2007). Also, reference points can be directly and explicitly built into a decision rule, but do not have to be as long as the decision rule can be shown, through the evaluation process, to achieve the objectives implied by the reference points.

The design and evaluation of decision rules should be done in a similar fashion to the initial step in the MSE process described above. That is, it should include representatives of all participants in the fisheries management system, and be interactive and iterative. While some characteristics of a decision rule will be determined by technical requirements, to a large extent, the most important issues associated with the design of decision rules have to do with "operational requirements" or "desirable behaviours" related to the management of the fishery or the operation of fishing fleets. For example, relatively straightforward issues such as how often to run the assessment and decision rule, minimum or maximum values for changes in levels of catch or effort, the number of years between management changes (e.g. annual process vs catch or effort levels set for multiple years) and target levels for average catches or catch rates, all have significant effects on the behaviour (e.g. year to year variation in catch/effort levels, speed of development/rebuilding) of a management strategy and its performance against different objectives (e.g. level of long-term catches and catch rates). Hence it is essential that there is a strong and regular consultative process between the technical evaluation, the broader SC process and the Commission to ensure that the design and evaluation process results in a suite of candidate strategies that are likely to meet the different objectives of decision makers.

When considering the development and implementation of decision rules in this context, it is worth noting, that while the evaluation component of an MSE is necessarily considers long term (i.e. 20-30 years) performance, this does not necessarily mean that, in reality, a single decision rule should be selected and used over that period. For example, in the case of a stock that is currently assessed to be at, near, or outside its limit reference point, it would be appropriate, and consistent with the precautionary approach, to identify decision rules that are designed to reduce the risk to the stock and the returns from the fishery in the short-term and result in some rebuilding, while developing and evaluating management strategies that may provide for improved performance against economic and social objectives when the stock is at higher levels of abundance. That is, much can be learnt from previous experience and implemented, without waiting for the outcomes of a formal MSE exercise.

Implementation and review

The outcome of the design and evaluation phase is the selection of a preferred management strategy for implementation. Part of the design process would have included discussion and agreement on a range of details associated with the operational implementation of the strategy. For example, the nature and timing of monitoring, data exchange, pre-analyses of data etc, to ensure that each component of the management strategy is implemented as closely as practically

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[9] The use of multiple gears (longline and purse seine) in some tuna fisheries obviously complicates this approach, but see Butterworth and Mori, 2003 and 2005.

possible to the way it was evaluated. Regardless, however, of how carefully and comprehensively the previous steps have been completed, there will inevitably be issues that arise during implementation that were not foreseen in the design phase and lessons learnt that can improve implementation and, perhaps, future management performance. For these reasons, it is important to have a formal implementation and review plan for the management strategy once the evaluation phase is complete. Ideally this would form part of the formal Management Plan for the fishery (FAO, 1996).

Such an implementation plan should include the following:

1. Full specification of the management strategy and implementation procedures;
2. Annual schedule of events;
3. Agree criteria and rules for situations that may arise that are outside the scope of what was considered in the evaluation phase (*alla* meta-rules, Basson and Polacheck 2005);
4. Schedule for full stock assessment and review of management strategy

A commonly cited advantage of the implementation of formally evaluated management (harvest) strategies is that they will reduce the overall level of resources dedicated to the annual scientific process associated with assessment of stock and management advice. While this can be true, in our view it will depend on the particular nature of the management strategy, in particular its complexity, the state and stage of development of the fishery and the stage of development of the scientific and management processes. In the context of the WCPFC, we would expect that the development and implementation of MSE processes for the major target species would result in an increase in the resources required during the development phase and during implementation, but may result in a small reduction in the total resources dedicated to assessment and provision of management advice in the longer-term.

Regarding step 4 above, we note that the role of a ‘stock assessment’ in this regard is two-fold: First, to do a full evaluation of current stock and fishery status and ii) review whether the assumptions, models and parameters used for the evaluation of the MP are still valid. The need for, or frequency of, a ‘full stock assessment’ will depend somewhat on the choice of decision rule. If the decision rule is based on an integrated assessment (e.g. Multifan CL) then this step would clearly be less critical. If the decision rule is much simpler, say, based on fitting a stock production model, then there would be more of a regular (though usually not annual) need for an integrated assessment which uses as much relevant data as are available, and which explores the uncertainties in a more rigorous manner. The second role of the assessment lies more in the context of reconditioning the operating model with any new information or data and, if considered necessary, re-evaluating and retuning the implemented decision rule.

DRAFT WORK PROGRAM FOR IDENTIFICATION OF REFERENCE POINT AND IMPLEMENTATION OF MSE IN THE WCPFC

In the following section we outline the main components and schedule for a work program for: i) The refinement and adoption of limit and target reference points and decision rules that would be used to guide management in the short term, and;

ii) The implementation of the MSE approach for two case studies in the WCPO: Broadbill swordfish and the complex multi-species skipjack, bigeye, yellowfin tuna fishery.

As noted above, these case studies have been selected to represent the range of potential applications within the WCPFC and, in doing so, provide the SC and Commission with the specific ideas of the scope, time and resources associated with each. These are not intended to represent the definitive options, but to serve as a basis for discussion and decision on future directions.

Identifying and agreeing interim reference points

Suggested tasks towards defining reference points and a process for management action are listed below. The sections of text in italics are meant as suggestions, or examples, rather than as prescriptive instructions.

1. Use existing, and as many past assessments as possible, to confirm whether MSY-based reference points are suitable as default reference points when used as ratios (limit reference points $F_{current}/F_{msy}=1$ and $B_{current}/B_{msy}=1$) and evaluated using estimates of the probability that current ratios are less than, or greater than, 1. Consider candidate target and limit reference points and identify appropriate probabilities to be associated with them, where relevant.

Include, for example, tables of the changes in these and other candidate reference points from one year's assessment to the next, and estimates of CVs where possible/ relevant; calculate other harvest rate reference points and their implications for relative SPR, relative SSB and relative B where appropriate; compare these with Fmsy and its implications for SPR, SSB and B. Document any major concerns about the use of MSY-based reference points and any major advantages of using a different type of reference point.

2. On the basis of 1, propose limit and target reference points for the main stocks, together with their associated (suggested) probabilities where relevant, for consideration by the Commission.

Include reasoning for proposal and, where target reference points are based on limit reference points with some buffer, explain the choice of buffer. Comment on the reasons for the suggested probabilities, including asymmetries in probabilities associated with LRPs vs TRPs.

3. Suggest ways in which management action can be specified or obtained from the stock assessments results and reference points (eg a decision rule or projections).

For stocks which are already near its limit reference points, a flexible approach is likely to be required, suggesting that projections may play an important role. Any illustrations/examples of a staged or stepped management response are likely to be useful. There will most likely be a need for several iterative discussions between the SC and the Commission and it may be useful to consider the use of special meetings depending on the current status of the different stocks.

Options for application of MSE in the WCPO

Broadbill swordfish - Single species management with uncertain stock structure, productivity and fishery dynamics

The targeted fishery for Broadbill swordfish is a new fishery relative to the main tuna fisheries in the WCPO. While swordfish have been taken as a bycatch of tuna operations since the commencement of longlining, the targeted fishery developed in the mid-late 1990's in the SW WCPO and is rapidly expanding to other regions of the western South Pacific (see Kolody et al. 2008 and related papers for this meeting.). We suggest SW Pacific swordfish represents a useful case study for of MSE for the SC and Commission to pursue for the following reasons:

1. It is a single species, single gear fishery. There is considerable experience and available expertise with MSE in this context and, therefore, there are no immediately obvious insurmountable technical challenges to implementation.

2. There is current work underway that will provide the much of the necessary data and modelling foundations for an MSE application to swordfish in the broader WCPFC. Kolody et al., 2007 presented an outline and initial results of an MSE project for swordfish focussed on the Australian Eastern Tuna and Billfish Fishery, which included connectivity to the south-west WCPO. Kolody et al., 2008 and related papers, provide an updated integrated stock assessment for this region of the WCPO and a comprehensive summary of the data and information requirements (including current availability). The work of Kolody et al,. 2007 has proceeded as planned and a fully conditioned and tested operating model (using the 2008 assessment results) will be complete before the end of 2008.

3. Finally, the most plausible model ensemble from the 2008 swordfish assessment indicates that for the south-west WCPO stock that it is not likely that overfishing is currently occurring or that the stock is overfished. Hence, an MSE study on swordfish could be completed in a strategic context aimed at improving the economic performance and flow of benefits from the fishery; and without the pressure often associated with situations where there is a high short-term risk to the stock.

Given the above, a case study on swordfish could be initiated in the 2009 calendar year, with a relatively small additional contribution of resources for technical support and consultation, and reasonably be expected to be completed by the end of the 2010 calendar year. The exact schedule would depend on the additional resources available for the case study and the schedule and availability of the SC and Commission for consultation.

Skipjack, bigeye and yellowfin tuna - Multi-species management with mixed gear and species productivity

Skipjack, bigeye and yellowfin tuna collectively represent the largest and most valuable fisheries in the WCPO, and in the case of skipjack, the largest volume tuna fishery in the world. In contrast to the swordfish example provided above, this is a complex fishery and considerable assessment and management challenge. Nevertheless, we consider that there is much to be gained from initiating an MSE approach in a carefully considered and staged manner. The main advantages we envisage for the SC and Commission engaging in an MSE approach for these three major fisheries are:

1. There are strong, direct technical interactions among the three fisheries (e.g. juvenile bigeye and yellowfin are taken as a bycatch of purse seine fishing for skipjack). Therefore, management measures for one fishery will very likely have a direct impact on the other fisheries. An MSE framework would provide a more formal (qualitative or quantitative) basis to examine the nature of these interactions and the potential trad-offs amongst social, economic and stock sustainability objectives.

2. In our view, the formal and informal consultation processes associated with the scoping stage of an MSE exercise has the potential to benefit the current considerations of the SC and the Commission on potential management measures for bigeye and yellowfin. If designed correctly and facilitated well, this stage of an MSE assist in clarifying objectives of different parties and the "conceptual models" they use to interpret and understand the fishery. In turn, this can assist in identifying management options that may not have been considered previously (and that may be more parsimonious) and provide a "reality check" on what is feasible, in terms of likely effectiveness and outcomes of different strategies[10].

3. While not as advanced as the swordfish examples described above, initial work has been done to explore the technical aspect of an MSE for these species (e.g. data structures and spatial/stock structure of operating models for the individual species, as part of an MSE project focussed on the ETBF (Davies at al 2006[11]). Hence, while considerably more resources would be required to complete a full quantitative MSE for these species, than for swordfish, the process would not be starting from scratch and it would benefit considerably from the experience gained from this current project. Recently, there has also been considerable work done by the OFP of SPC in exploring the uncertainty

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[10] For example, the MSE work undertaken in the CCSBT was central to the SC and Commission revising its original rebuilding objective when it was demonstrated that it could not be met by any of the management procedure being considered (including zero catches) due to the current state and productivity of the stock.

[11] Note this is a collaborative project between CSIRO and the OFP of the SPC funded by the Australian FRDC.

associated with the assessments for each of these species. Again, much of this work would directly inform the development and implementation of an MSE.

4. There are existing integrated assessments for each of these species and there is the potential to use the MULFIFAN-CL software as a basis for the conditioning stage of the MSE. Again this means that a significant component of the technical work required to implement an MSE has to some extent been done (but not completed) and the expertise with the assessment models, data etc exists within the current WCPFC science community. In our experience this is a significant advantage.

Given the above, we recommend that the SC and Commission proceed with three streams of work:

1. Identification, refinement and adoption of reference points;

2. Focused MSE case study on broadbill swordfish in the southern WCPO;

3. Formal consultations and technical design study for an integrated MSE for skipjack, bigeye and yellowfin tuna.

Table 2 outlines potential tasks and schedule for each stream of work for an MSE work-program.

Stream	**2008**	**2009**	**2010**
Reference Points	SC recommend options to Commission Commission agree on options	SAWG refine and test reference points at inter-sessional ws. SC review, consider, and recommend reference points Commission adopt default reference points, in lieu of MSE	
Swordfish case study	SC review outcomes of assessment and inter-sessional workshop SC recommend case study MSE on swordfish Presentation to Commission of detailed project proposal and budget.	Inter-sessional consultations as part of "scoping" phase of MSE with interested parties Inter-sessional technical work to complete conditioning of operating model and preliminary results for selected decision rules– presented to SC and Commission for consideration.	Inter-sessional technical work to complete formal evaluations and final results for selected decision rules– presented to SC review and Commission for decision. Commission decides on whether or not to adopt the MSE outcomes.
Consultations and technical design study for integrated tuna MSE	Presentation to Commission on proposal, including budget for initial consultations and design study	Inter-sessional technical workshop to scope MSE and identify technical and procedural issues that would need to be addressed in a full MSE Workshop report to SC with recommendations on whether or not to proceed with full MSE, and if so, in what form. Proposal and SC recommendation to the Commission	Initiation of full MSE if agreed by SC and Commission

Table 2: Outline of a potential tasks and schedule for each stream of work for an MSE work-program.

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APPENDIX 1 – ORIGINAL TERMS OF REFERENCE

Objective

Develop a scoping paper and draft work plan to inform both the SC and the Commission on the potential costs, benefits and difficulties of alternative approaches for identification of appropriate reference points and the implementation of the precautionary approach in the management of WCPO tuna stocks.

Scope and Tasks

Scoping paper:

The Scoping paper will address, *inter alia,* the following issues:

- A review of current assessment methods and reference points used to provide management advice to the WCPFC and the sensitivity of this management advice to the key uncertainties in the current assessment process. Note that this should provide the SC and the Commission with a 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 would be required in the MSE context;
- A review of alternative biological reference points (MSY-based and otherwise) for potential application in the WCPO tuna fisheries including a discussion of risk-management strategies associated with the potential reference point approaches;
- Consider the general nature of potential management strategy options (i.e. data needs, assessments, performance indicators, limit and target reference points, and decision rules) for the management of fisheries in the WCPO consistent with the provisions of the WCPF Convention. Performance indicators considered should include considerations for both stock conservation and socio-economic benefits derived from fisheries, including the distribution of benefits;
- Technical and organizational issues, and any associated difficulties related to undertaking an MSE in the WCPO, including consideration of interim management strategies (including reference points and decision rules) while a full MSE is underway; and
- Potential costs, benefits and difficulties of alternative approaches for identification of appropriate reference points (e.g. MSE) within the WCPO.

Work Plan:

The Work Plan will address, *inter alia,* the following issues:

- A specific plan for the development and implementation of MSE for WCPO tuna fisheries, including consideration of the following:
  - Methodological research and development requirements;
  - Data requirements;
  - Stakeholder involvement;
  - Approaches for the identification of appropriate reference points, decision rules and performance measures;
  - Implementation approaches, e.g. full multispecies MSE vs. a staged approach involving initially a single species
  - Time schedule, costs and appropriate organisational and institutional arrangements if an MSE project was to be undertaken.

Outputs

A report for consideration at the Fourth Regular Session of the Scientific Committee to be held at Port Moresby, Papua New Guinea, 11-22 August 2008 and the Fifth Regular Session of the Commission to be held at Busan, Korea, 8-12 December 2008.

APPENDIX 2

There is a large body of scientific literature about biological reference points for fisheries management (see e.g. Smith et. al. 1993 and references therein). We base much of our summary on Caddy and Mahon (1995), Caddy (1998). The list considered here is not exhaustive, but includes the most commonly used reference points and those we consider most appropriate for consideration in the context of the WCPFC.

Table A2.1 provides a list of potential limit and target reference points and the sections that follow provide further comments on their characteristics and suitability in various situations.

Table A2.1 Potential candidates for limit (LRP) or target reference points (TRP) (see Table A2.2 for full definitions). YPR=yield per recruit; SPR=spawner per recruit; h=steepness in the stock-recruit relationship.

Reference points based on YPR and SPR considerations			
F reference	*type of reference*	*B reference*	*type of reference*
F_{max}	LRP	implied %SPR (and B/B_0 with h)	LRP
$F_{0.1}$ (sometimes $F_{0.2}$)	TRP	implied %SPR (and B/B_0 with h)	TRP
$F_{spr\ x\%}$	LRP or TRP depending on x	implied %SPR (only =%B if steepness is high)	coincides with type for F
Reference points based on historic estimates of S and R			
F_{low}, F_{med}, F_{high}	F_{med} as TRP F_{high} as LRP	implied %SPR	coincides with type for F
(implied F_{mbal})	(LRP)	MBAL (actually SSB)	LRP
Reference points based on MSY considerations			
F_{msy} (or MSY)	LRP	B_{msy} (and/or SSB_{msy})	LRP
y.F_{msy} (or y.MSY)	TRP	y*.B_{msy} (and/or y*.SSB_{msy})	TRP
Quantities based on relative spawning biomass (or total biomass)			
implied Fz%	LRP or TRP depending on z	Bz% (B/B0=z) e.g. SSB20% (LRP) SSB40% (TRP)	LRP or TRP depending on z

(e.g. x = 30% or 35%, see text)
(e.g. y=2/3, y* the coinciding proportion implied by harvesting at y.F_{msy}; see text)
(e.g. z=20%, then F20% is the F that would lead to B/B0=20%)

Reference points based on Yield per recruit and Spawner per recruit considerations

Yield per recruit (YPR) calculations can provide fishing mortality reference points. The classical quantity is F_{max}, the fishing mortality rate which corresponds to the maximum yield per recruit. This quantity is now regarded as an LRP, with a lower harvest rate, often $F_{0.1}$, commonly used as the corresponding TRP (Caddy, 1998). $F_{0.1}$ is the fishing mortality rate at which the slope of the yield per recruit curve (as a function of fishing mortality) is 10% of its value near the origin (see Table A1).

The inputs required to calculate the YPR quantities are natural mortality, maturity, size (weight) and selectivity at each age. It is important to note that YPR calculations do not require a stock-recruit relationship. Because of this, it is important to consider implications of F_{max} and $F_{0.1}$ on the spawning component of the population by calculating the relative spawner per recruit (SPR, see below) that would be implied by these harvest rates. It is also worth noting that in some situations there is no clear maximum yield; the curve of yield as a function of fishing mortality rises to an asymptote. In such cases it is particularly important to use the implied relative biomass and/or SPR as guidance to defining F_{max}.

Spawner per recruit (SPR) analysis is an extension of YPR analysis, but in this case the expected spawning biomass per recruit is calculated as a function of different fishing mortalities. Also, whereas YPR shows a maximum with increasing F, SPR decreases monotonically. Note that under SPR-based reference points we consider the theoretically calculated values rather than those calculated directly from time-series of SSB and R estimates obtained via a stock assessment. The latter are considered under the next section. SPR analysis requires the same inputs as YPR analysis. It is common to express SPR at a given harvest rate relative to that obtained under no fishing (SPR/SPR_0). The harvest rate that would lead to $SPR/SPR_0=0.3$, for example, is then referred to as $F_{spr30\%}$. This type of analysis is particularly useful in situations where there are no estimates of stock and recruitment and, or, where the stock-recruit relationship is very uncertain. However, note that if the stock-recruit curve is very uncertain (i.e. steepness is essentially unknown), it is clearly prudent to use a relatively high percentage for setting F_{spr} (say, 40% rather than 20%).

Caddy (1998) notes that for $F_{spr35\%}$ and $F_{spr30\%}$, calculations based on data sets for stock and recruitment have shown that these fishing rates are likely to maintain SSB/R at safe levels. We note, however, that it would be important to establish the characteristics of the stocks which form the basis for this statement to assess whether generalisation to tuna and billfish stocks is likely to be warranted. Details of this study can be found in Mace and Sissenwine (1993).

Finally, note that for a given harvest rate, the relative depletion (SSB/SSB_0 calculated with an assumed or estimated stock-recruit curve) will only be similar to the relative SPR (SPR/SPR_0, which is not based on a stock-recruit curve) if steepness is high. If there is reason to believe that steepness may be below, say 0.9, then it would be prudent to calculate the expected relative depletion (SSB/SSB_0) for a range of steepness values, rather than simply relying on relative SPR.

Reference points based on historic spawning biomass and recruit estimates

There is another class of 'spawner per recruit' reference points which are based on the relationship between recruits and spawning biomass, obtained from pairs of stock-recruitment observations, and the expected spawner per recruit for a given harvest rate. This potentially has the advantage of moving away from the notion, or implicit assumption, of constant recruitment underlying the theoretical SPR considerations (above). Caddy and Mahon (1995) provide a useful illustration of how the harvest rate reference points F_{low}, F_{med} and F_{high} are obtained (their Figure 7, p16). In graphic terms, the process is as follows. Estimates of recruitment in numbers are plotted against spawning biomass. Straight lines are then drawn through the origin and with slopes such that, for example, 50% of the points are above the line, and 50% below. The reciprocal of the slope is the spawner per recruit value, and the harvest rate that coincides with that SPR is easily found from SPR analysis (discussed above). The harvest rate coinciding with this example (50% of points above and 50% of points below the line) is referred to as F_{rep} ('replacement'; Sissenwine and Shepherd, 1987), or F_{med} (by ICES, 1993b), and corresponds to the line representing an average survival ratio at which the stock replaces itself. F_{low} is based on a line with 90% of points above and 10% of points above; F_{high} is based on a line with 10% of points above and 90% of points below.

Sissenwine and Shepherd (1987) argued that F_{med} could serve as a target reference point since at or below F_{med}, the stock should, on average, replace itself. At values above F_{med}, however, the risk of recruitment failure increases and F_{high} should be viewed as an indicator of danger, to be avoided, making it a possible candidate LRP.

As Hart and Reynolds (2002) point out, this approach is potentially risky since it depends on the history of the stock. If the stock has only been lightly exploited, the resulting reference harvest rates could be over-conservative and hence limiting. On the other hand, if the stock has been overfished for some time, F_{med} may estimate a critical level of fishing rather than a safe level. Finally, high recruitment variability could lead to F_{high} being inflated and therefore risky as a LRP.

The ‘minimum biological acceptable level’ (MBAL) is based on the observed (i.e. estimated) spawning biomass and recruitment patterns, but does not rely on an actual stock-recruit relationship having been fitted to the data. MBAL, is a spawning biomass level below which observed spawning biomasses over a period of years, are considered unsatisfactory and the associated recruitments are smaller than the mean or median recruitment. A coinciding ‘F_{mbal}’ could be calculated, but is not commonly done (as far as we know). It is not obvious what the best assumption about recruitment would be for such a calculation. One option would be to use the low recruitments associated with the low SSB values, but this could imply an F value that is less than candidates for F_{target} obtained from other considerations and when the stock is above MBAL.

Reference points based on Maximum Sustainable Yield considerations

A relatively detailed description of maximum sustainable yield (MSY) reference points is given in the main text. A brief summary is repeated here for completeness.

MSY quantities can either be obtained from stock-production models or from stock assessment models with built-in stock-recruit relationship (or from a stock-recruit relationship estimated outside the assessment). The common quantities are MSY (i.e. a catch level), the harvest rate at which MSY is achieved (F_{msy}), and the biomass at which this occurs (B_{msy}). In an age-based stock assessment, the stock-recruit curve and the assumed (or estimated) steepness play a crucial role in determining this ratio. At higher steepness levels, B_{msy}/B_0 will be lower than for low steepness levels. The other inputs required in an age-based calculation of MSY-quantities are mortality at age, maturity at age, weight at age and, importantly, selectivity at age. Selectivity is important because in a multi-gear fishery (e.g. purse seine and longline gears) the selectivity depends on the mix of gears. This means that if there is a large change in the relative catches of (or allocation to) the different gears, the reference points will be affected.

Changes in productivity, particularly recruitment, can affect the interpretation of, and appropriate estimation of, these equilibrium quantities.

Although MSY-based reference points were used extensively in the 1960’s and 1970’s (and still are in some cases) as target reference points, developments in the theory and practical experience in fishery management cast doubts on the appropriateness of MSY as a safe TRP. It is therefore now commonplace to treat MSY-based reference points as LRPs (see Caddy and Mahon, 1995; Caddy 1998; Punt and Smith, 2002)

Reference points based on relative depletion

In the absence of information on spawning biomass and recruitment for the stock of interest, the choice of reference points can be informed by generalisations based on examination of a large number of exploited stocks for which such estimates are available (referred to as meta-analysis). As noted in Caddy and Mahon (1995) a survey of 91 stock and recruitment data sets for Europe and North America suggest that for stocks considered to have average resilience, a spawning biomass level of 20% of the unfished level should be considered a recruitment-based LRP. In the case of little known stocks, the LRP should be set at 30% of the unfished spawning biomass level. The theoretical analysis by Mace (1994) supported these recommendations and suggested that these results may be applicable to stocks outside the North Atlantic.

In cases where stock production models are used and total rather than spawning biomass is estimated, care needs to be taken when there is substantial harvesting of juveniles (i.e. immature animals) to avoid situations where the relative spawning biomass is well below the relative total biomass. In such cases a more conservative ratio would be prudent.

Empirical approaches

Empirical approaches essentially use historic trends in biomass, recruitment, and any other indicators of stock and/or fishery status to identify a period with reasonably stable and satisfactory recruitment. This is used to guide the choice of a reference target for spawning biomass. The basis for selecting a level/(time in the past) is based on direct observations, and as such there is no theoretical underpinning for the selection of a reference level.

This approach can be particularly useful if there have been apparent changes in stock dynamics (for example spatial contraction) which are not reflected in the stock assessment and conventional reference points, and which might indicate the need for caution in applying the conventional reference points. The rebuilding objective for Southern Bluefin Tuna was essentially determined using this approach (see Basson and Polacheck, 2004).

Although approaches which use historic fishery yields to determine reference points are also sometimes listed as ‘empirical approaches’, we caution strongly against the use of these approaches, given the potentially misleading nature of yield (or catch) information used on its own. In the context of the WCPFC where there are stock assessments for all the major species, there should be no need to use historic yield in this way.

Economic considerations

In some cases, for example in the recently developed Australian Commonwealth Fisheries Harvest Strategy Policy (Australian Government, 2007), the concept of maximum economic yield (MEY) is used as a basis for setting (target) reference points. The notion is that economic efficiency in a fishery implies that the fish stock is protected and that the net returns to the community are maximised. This occurs when the sustainable catch or effort level for the fishery as a whole maximises net returns, and this point is referred to as maximum economic yield.

In our view, economic-based reference points are unlikely to be practical as reference points for management of straddling and migratory resources given the international nature of the fisheries. It is particularly unlikely to be practical as a basis for limit reference points. Even as target reference points it may be difficult to define. For example, F_{mey} (the harvest rate corresponding to the maximum economic yield), is not easy to define for fisheries which involve several fleet components with different gears and fishing practices (Caddy and Mahon, 1995). The ongoing work to develop bio-economic models for tunas in the WCP region may prove this wrong in future (http://www.spc.int/oceanfish/Html/SAM/index.htm), though for the immediate needs of the WCPCF, we consider that biologically-based reference points are likely to be more practical. It is for this reason that we have not discussed economic-based reference points in this report. This does not, however, mean that the economic implications of reference points should be ignored.

Table A2.2. Definitions of candidate reference points. See text for discussion

Reference point	**Description**
%SPR	spawner per recruit as a percentage of the unfished spawner per recruit - usually set in terms of the harvest rate that implies this
B/B_0	biomass relative to unexploited biomass (or often defined in terms of spawning biomass).
B_{msy}	the biomass which corresponds with maximum sustainable yield
MBAL	(Minimum Biological Acceptable Level) a spawning biomass level below which, observed spawning biomasses over a period of years, are considered unsatisfactory and the associated recruitments are smaller than the mean or median recruitment.
F_{max}	Fishing mortality rate which corresponds to the maximum yield per recruit (as a function of fishing mortality)
$F_{0.1}$	fishing mortality rate at which the slope of the yield per recruit curve (as a function of fishing mortality) is 10% of its value near the origin. (Similarly defined $F_{0.2}$ has been used in some cases; see Caddy, 1998)
$F_{spr.x\%}$	fishing mortality rate which corresponds to spawner per recruit being x% of unfished spawner per recruit (values of 30%, 35%, 40% have been used; see e.g. Mace and Sissenwine, 1993)
F_{low}	fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the 10th percentile of the observed R/SSB
F_{med} (F_{rep})	fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the median (50th percentile) of the observed R/SSB
F_{high}	fishing mortality rate on an equilibrium population with a SSB/R equal to the inverse of the 90th percentile of the observed R/SSB
F_{msy}	fishing mortality rate which corresponds to the maximum sustainable yield as estimated by a production model (or age-based model with stock-recruit curve)

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