2013 ISSF Stock Assessment Workshop: Harvest Control Rules and Reference Points for Tuna RFMOs

San Diego, California, USA, March 6-8, 2013

Summary. Management strategies include monitoring, stock assessment, harvest control rules, reference points and management actions. The International Seafood Sustainability Foundation convened a workshop to review the current status of the adoption of these elements into the decision-making process by five the Tuna RFMOs and to make recommendations for harmonizing and facilitating the process among RFMOs. Of the five RFMOs, CCSBT has formally adopted a management strategy (management procedure) for decision-making. The other four RFMOs are making substantial progress to identify and test key elements of management strategies, such as reference points (limit and target) and harvest control rules. This work is being done primarily by the RFMO science bodies, sometimes without a formal Commission mandate. The workshop reports on key issues that should be kept in mind when developing and testing management strategies: Data and models, the treatment of F_{MSY} as a target or a limit, testing of the strategy, and implementation. The workshop concluded that management strategies have worked quite well elsewhere in fisheries, and that there is no technical constraint to advance them in the tuna RFMOs. This could be done in many cases with relatively simple, existing tools. The report contains specific recommendations on limit and target reference points, harvest control rules, and other considerations for management strategy evaluations. A glossary of terms is also included.

Suggested citation:

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1. BACKGROUND, OBJECTIVES AND ORGANIZATION

Target and limit reference points, and harvest control rules, and how they are used in a management framework, are very important tools in modern fisheries management. The five Tuna Regional Fishery Management Organizations (RFMOs) have been conducting work on these tools, either at the scientific or at the Commission level, or both, for several years. In some cases the Conventions require the Commissions to adopt these tools. The International Seafood Sustainability Foundation (ISSF) convened this workshop to review the current situation in the tuna RFMOs and to make recommendations for moving forward. The emphasis of this report is on the principal tuna target species, although much of the discussion is applicable to other target or bycatch species. It is hoped that these recommendations will help improve consistency between RFMOs.

The workshop was held at the Manchester Grand Hyatt hotel in San Diego. Participants included members from the ISSF Scientific Advisory Committee, as well as other experts on the topics being discussed: Alex Aires de Silva, Robin Allen, Anthony Beeching, Guillermo Compeán, Laurent Dagorn, Campbell Davies, Rick Deriso, Francesca Forrestal, William W. Fox, Jr., Richard Hillary, Jim Ianelli, Susan Jackson, Laurie Kell, Katie Matthews, Mark Maunder, Mikihiko Kai, Carolina Minte-Vera, Iago Mosqueira, Hilario Murua, Ana Parma, Graham Pilling, Victor Restrepo (Chair), Keith Sainsbury, Gerry Scott, Rishi Sharma, Dale Squires, Daniel Suddaby, Shuhei Uematsu , Juan Valero, Deirdre Warner-Kramer, Sheng-Ping Wang and Meryl Williams.

A number of participants made background presentations intended to inform the discussions, which are summarized in **Appendix 1**. In addition, a number of scientific publications were made available as references (**Appendix 2**). **Section 4** summarizes the current situation relating to the workshop's theme in tuna RFMOs. **Section 5** elaborates upon some of the key issues discussed by participants and **Section 6** lists the main recommendations.

2. NOTES ON TERMINOLOGY

The scientific literature related to the workshop's theme is populated with terms and acronyms. **Appendix 3** provides a Glossary of some commonly-used terms. It is important to keep in mind that harvest control rules and reference points are only part of the broader "management strategy" or "management procedure", which also includes monitoring and how the data are analyzed (perhaps a stock assessment) for use in decision making.

3. PRESENTATIONS

Twelve presentations were made by meeting participants. They included talks specific to the current status of work on harvest control rules, reference points and management strategies in the five tuna RFMOs, in addition to other presentations relevant to the workshop theme. The presentations are summarized in **Appendix 1**.

4. SUMMARY OF CURRENT STATUS IN T-RFMOS

A summary of the current status of the tuna RFMOs in terms of elements considered as part of management strategies is given in **Table 1**. The five tuna RFMOs have broad conservation objectives. IATTC, ICCAT and WCPFC conventions make explicit mention of MSY levels, while the other two do not.

Of the five RFMOs, only CCSBT has a formal management strategy (management procedure) in place, which is used to set TACs in 3-year intervals. The strategy's objective is to rebuild the SBT population, which is currently depleted, to an interim rebuilding level of 20% of the unfished biomass ($20\%SSB_0$) with a probability of 0.7 estimated via MSE. Thus, the management strategy does not yet contain a long-term target. The other four RFMOs are at different stages in terms of formally adopting various elements of management strategies:

Limits. WCPFC has adopted biomass-based limits and is considering the adoption of F-based limits in the future. IOTC has adopted non-binding interim limit reference points for its tuna stocks, and ICCAT has requested the development of a limit for one of its albacore stocks.

Targets. IOTC has adopted non-binding interim targets. ICCAT has an implied target to be in the "green" zone of the Kobe plot and IATTC uses F_{MSY} as an implied target. WCPFC is developing targets through a series of Management Objective Workshops.

Harvest Control Rules. ICCAT Recommendation 11-13 is a framework for a HCR but it has not yet been parameterized for any stock. The four RFMOs are conducting work to identify candidate HCRs, but this work is being done primarily at the scientific level mostly without a formal mandate from the Commissions (except IOTC, Res. 12-01 requires the SC to do this work). In terms of management controls, most RFMOs use a combination of input and output measures (CCSBT uses TACs only).

Management Strategy Evaluations. All of the RFMOs conduct some type of projections that are used to inform managers about the consequences of alternative options, and these could be considered as being pseudo-MSE. However, a full MSE involves a feedback mechanism through the operating model to account for the impacts of catches on the stock, monitoring and advice. Similar to HCRs, most of the MSE work being conducted is by the RFMO science bodies/providers, without a very direct mandate from the Commissions (except for IOTC, Res. 12-01 instructs the SC to evaluate the performance of reference points and potential HCRs through MSE).

Table 1. Summary of current status of management strategies in RFMOs.

Element	IATTC	ICCAT	IOTC	WCPFC	CCSBT
Management Objectives (Convention and CMMs)	Population level that can produce MSY. Apply the Precautionary Approach.	Maintain population at level that can permit maximum sustainable catch.	Conservation and optimum utilization of stocks. Adoption of PA in 2012 (Res. 12-01). "Dialogue initiated" on identifying clear management objectives.	Long-term conservation and sustainable use of HMS. Maintain stocks at levels capable of producing MSY, as qualified by environmental, economic and SIDs considerations. Includes guidelines for RPs based on best science.	Ensure, through appropriate management, the conservation and optimum utilization of SBT. The 2011 Commission meeting requires TAC setting to also take PA into account.
Limit Reference Points	None yet.	None yet. ALB: Under development by SCRS (Rec. 11-04)	Interim, non-binding limits: SKJ: $0.4B_{MSY}$, $1.5F_{MSY}$ BET: $0.5B_{MSY}$, $1.3F_{MSY}$ YFT and ALB: $0.4B_{MSY}$, $1.4F_{MSY}$	BET, YFT, ALB: $20\%SB_{current,\ F=0}$ and $F(x\%SPR_0)$ SKJ: $20\%SB_{current,\ F=0}$ Currently investigating F-based LRPs for SC9 in 2013	20% SSB_0 is an interim rebuilding target, but would also become a limit at the end of the rebuilding program. The 2011 decision identifies the lowest observed stock size as the limit
Target Reference Points	None in place yet. Though F_{MSY} is an implied TRP.	None in place yet Though the "green" quadrant of the Kobe plot is implied as a target region in Rec. 11-03	Interim non-binding targets: SKJ, BET, YFT, ALB: B_{MSY}, F_{MSY}	None in place yet. 2013 MOW goal: developing TRPs. CMM-2012-01 indicates TRP ≤ F_{MSY} for BET, SKJ, YFT	"Interim rebuilding objective": 20% SSB_0 A long-term TRP will be considered once stock is rebuilt to $20\%SSB_0$.

Element	IATTC	ICCAT	IOTC	WCPFC	CCSBT
HCRs	None formal. "Informal" rule based on FMSY applied by Secretariat	Principles of Decision-making (Rec 11-13) provides HCR framework but parameters not defined ("high" or "low" probability, timeframes)	None formal. HCR development mentioned in the PA Resolution. "Informal" rule based on F_{MSY} or B_{MSY} being exceeded	None yet but SPC conducting PNA-requested review of alternative HCRs for SKJ. "Informal" rule based on F_{MSY} when it or B_{MSY} is exceeded	Harvest rules via a TAC, that is the average catch value from two formulas designed to achieve the recovery target and tuned to juvenile surveys and CPUE. 0.7 probability of rebuilding to 20%SSB_0.
Management Strategies / Procedures	None formal. Staff uses stock assessment results to determine how current F should be changed to obtain FMSY (e.g. change closure length).	None formal. SCRS advice via Kobe framework (Res 11-14) and strategy matrices.	None formal. SC provides management advice based on stock assessment and recommends catch limits to the Commission.	None formal. SPC provide stock assessments and projections to the SC, and ISC provides them to the SC and Northern Committee	Adopted in 2011. Sets TAC in 3-year intervals. An interim plan to rebuild the stock to the limit level.
Management Strategy Evaluations (MSEs)	None	Under SCRS development for BFT (Mediterranean) and ALB (N. Atlantic).	Under development SC for SKJ, ALB.	"Pseudo-MSE" (without feedback control) under development by SPC.	Completed for the measure adopted in 2013

5. DISCUSSION OF KEY ISSUES

This section summarizes the key issues addressed by the workshop during and after the presentations.

5.1 Data and model issues

Level of information richness

The information available to develop management strategies may differ substantially between different stocks. In some "data-poor" situations, the available data may be only a series of annual catch estimates. For some stocks, sophisticated integrated stock assessment methods make use of all the information available, while other stocks are assessed using only series of catch and CPUE. And, some stocks such as skipjack maybe relatively "data-rich" but are difficult to assess because of their complex population dynamics.

The development of management should take the above differences into account. For example, in developing LRPs, WCPFC has been using a three-tier hierarchical system where the reference points are defined based upon the level of information available (Preece et al. 2011). Similar systems have been used elsewhere (e.g. Australia and Alaska), where the control rules defined in each tier may increase in precaution as the level of information worsens. In any case, MSE testing is used for each tier.

Methods for quantifying uncertainty in stock status

Various methods are used to quantify uncertainty. FAO (2001) summarized these conceptually as a 4-step process quoted below:

> "1. For each potential source of error, a set of hypotheses must be developed. (It should be noted that a set of hypotheses does not have to be a group of discrete alternatives, as it can be represented by a continuous distribution.);
> 2. For each hypothesis in Step 1, a relative weight or probability must be determined;
> 3. For all combinations of hypotheses in Step 1, the likelihood of the resulting estimate (e.g. the fit of the data) must be determined;
> 4. The results from Steps 2 and 3 must be integrated to provide an overall assessment of the uncertainty or risk."

In practice, the approach used to estimate uncertainty varies between (and sometimes within) RFMOs. For example, many assessments use an "uncertainty grid", whereby individual combinations of alternative parameter values (e.g. steepness, growth, natural mortality) are run separately (step 1 above). In some cases, these are combined (step 4), while in other cases the range of results are shown, e.g. on the Kobe plot. It is not a trivial matter to properly determine the probability for each model run (step 2); see Maunder et al. 2012.

A consistent characterization of uncertainty is particularly important when considering how to measure the risk of exceeding LRPs each year during the implementation of a management strategy. For this reason, when setting an LRP and defining the tolerable risk of exceeding it, it is also useful to consider how that probability will be estimated. Probabilities relative to reference points should integrate model uncertainty to the extent practical.

Dealing with environmental changes

Environmental changes sometimes occur that change the productivity of a stock, and hence the relevant biological reference points. These changes cannot usually be addressed through the assessment process as they are taking place. More often, historical changes are addressed by, for example, considering different periods within the data separately. In developing harvest strategies, it is useful to test through MSE if the strategy can indeed identify such changes and adapt accordingly, or more generally whether the strategy is robust to environmental changes that might reasonably be expected. This may be tested by MSE or by simple robustness trials, e.g., with shifts in the underlying stock-recruitment relationship. It may be interesting to consider models such as SEAPODYM (a spatially-explicit age-structured ecosystem model developed for investigating spatial tuna population dynamics, forced by both commercial fishing data, tagging information and physical ocean variables) as the operating model in cases where environmental change can have important consequences for fishery productivity.

Empirical vs model-based HCRs

There are multiple examples of both empirical and model-based HCR in management strategies. In a sense, model-based ones are attractive because they may be linked to the stock assessment results and generally have a greater capacity to "learn" about stock productivity. In some cases, however, the model used as part of the HCR is a much simpler model than the one used for actual assessments. Sometimes HRCs may be based on empirical indicators that follow trends in stock status or other variables of interest reliably, and which may be more easily understood by managers and stakeholders. Using the more complex model-based indicators will not necessarily ensure a more robust management procedure. In addition, the MSE does not always need to rely on a very complex operating model; often a relatively simple operating model will provide a good idea of what management procedures are likely to perform well. To properly evaluate robustness, however, HCRs need to be tested under a wide range of models or even hypothetical situations. Further, there are examples where the MSE process (i.e. identification of potential strategies for testing, agreement on performance measures to compare strategies, predicting the performance measures for each potential strategy) has been successfully applied without modeling at all – a wide range of expert judgments were used instead of a quantitative Operating Model to make these predictions and describe their uncertainty.

Single species modeling in multispecies fisheries

Some multi-species fisheries produce technical interactions that affect the various species differently. For example, bigeye, yellowfin and skipjack are caught together in purse seine fisheries

that set on floating objects, but the status and productivity of the three species is not the same. Therefore, if management strategies are developed for these, it is important to recognize that the same objective cannot always be achieved to the same degree for all species: MSY from the most productive species in the complex may not be achievable if overfishing of the least-productive ones is to be avoided. For example while the LRPs for the species in a multispecies complex may be the same as their single species values, so as to protect the stocks biologically, the TRPs could be altered so as to provide the desired returns from the complex as a whole. As a specific example, work by SPC evaluating target reference points and harvest control rules for the Parties to the Nauru Agreement will examine the implications of a range of TRPs and HCRs for species such as bigeye and yellowfin tuna. A management procedure that performs well in a multispecies setting needs to respect the limit reference points for all species in the complex while meeting as closely as possible the targets.

Changes in assessment models

Innovation is an important component of the scientific process. Stock assessment methods and models can change regularly as a result of research or newly available data. But changes are not very desirable when a management procedure is in place. Once a management procedure is adopted by managers, it is important that the underlying model and indicators are transparent and reasonably stable. During development of the management procedure sources of uncertainty should have been identified and the robustness to those uncertainties evaluated. So unless the new information conforms to the 'exceptional circumstances' agreed when adopting the management procedure then the management procedure should continue to be applied until it is re-evaluated formally. The assessment model used in an agreed management procedure is an integral part of that procedure and it should not be altered in isolation from the other parts of the procedure without formal re-evaluation of the procedure as a whole. Sometimes the management procedure does not include a stock assessment model but rather has its control rule directly driven by measured indicators (e.g. CCSBT and IWC management procedures), which highlights this distinction between a stock assessment and the analysis in the management procedure that is used to inform the control rule of that procedure For this reason, it would be very complicated to link a management procedure to an assessment model that may change from year to year. Ongoing development of assessment models to improve understanding is to be expected and encouraged outside on an agreed management procedure, but this development must be recognized as being different from the application or further refinement of an accepted management procedure.

5.2 Treatment of F_{MSY} as a limit or target

The workshop devoted considerable time to this important issue. Several RMFOs (and/or RFMO members) have adopted Precautionary Approach elements of UNFSA[1] in their conventions or as management measures or legislation. Annex II of the UNFSA provides guidance that states that "The fishing mortality rate (F) which generates Maximum Sustainable Yield (MSY) should be

[1] The United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks

regarded as a minimum standard for Limit Reference Points (LRPs)" and "the risk of exceeding LRPs is very low". However, many of the tuna RFMOs refer to MSY, or a stock size that can produce MSY, as an objective (see Table 1 in Section 4). This apparent contradiction between UNFSA guidelines and the tuna RFMO Conventions has caused considerable confusion as to whether F_{MSY} is a limit or a target.

UNFSA sets a general intention on limit and target reference points as well as providing some guidance for the limit.

> "Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits". Safe biological limits are interpreted as relating to highly undesirable states that are irreversible or slowly reversible, such as impaired recruitment (recruitment overfishing). Avoiding irreversible or slowly reversible impacts in the context of uncertainty is also the objective in applying the Precautionary Approach.
>
> A general target in UNFSA is to "maintain or restore stocks at levels capable of producing maximum sustainable yield" while also recognizing uncertainty in understanding and variability of biological systems. The associated target is recognised as being a management related issue.

Thus, the overall intention is to maintain the highest long-term average catch (the target) with a low chance of being outside safe biological limits (the limit).

In common current practice, MSY is the largest average long-term yield from application of a constant F (F_{MSY}) or from application of a variable F (harvest control rule where F varies as a function of stock size). In common practice MSY is estimated in this way taking realistic account of uncertainties/variability in productivity, stock status and fishery selectivity. However, in some cases, F_{MSY} may be determined assuming perfect knowledge and ignoring important sources of uncertainty, and the workshop recognised that this way of calculating F_{MSY} was more common at the time that UNFSA was negotiated.

The workshop noted:

> In situations where there is little or no quantitative analysis of uncertainty, and particularly where F_{MSY} is determined assuming perfect knowledge, the estimate of F_{MSY} should be used as a limit reference point as suggested in the UNFSA Annex II Guidelines. Consequently, the target F should be less than F_{MSY} so as to provide the precautionary buffer envisaged by the Guidelines. The use of F_{MSY} as a limit in most situations is expected to be very cautious because F_{MSY} is not usually associated with being beyond biologically safe limits, though a wide range of biomass outcomes for some stocks can be experienced at F_{MSY} because of variability in productivity (e.g. recruitment) and this should be examined on a case by case basis.
>
> Where uncertainty has been well considered and built into selection of a harvest control rule that has both a low probability of exceeding safe biological limits and providing a high

average long-term catch, then the F-Stock vs size relationship from that control rule could be treated as a target. Similarly the limit reference point can be defined from such considerations so as to recognise and maintain the stock within biologically safe limits (i.e. the limit RP can also be defined so as to have a low chance of breaching the actual biological limit despite uncertainties in assessing current status, similar to the precautionary limit reference points defined for some time in the ICES process).

What about B_{MSY}?

Unfortunately, the UNFSA guidelines do not mention B_{MSY}. In considering this, the workshop offered the following:

> In a long term sense, B_{MSY} is the average biomass that results from fishing constantly at F_{MSY}. But, given that there is considerable variability in the stock-recruitment relationship, in practice stock biomass will fluctuate above and below the equilibrium B_{MSY} level when fished at F_{MSY}. Therefore, if F_{MSY} is set as a target, for example after MSE testing, it is problematic to also set B_{MSY} as a limit because the latter will be exceeded 50% of the time (which is not a "very low probability"). A target F that is close to F_{MSY} is also likely to result in biomass outcomes below B_{MSY}, although less than 50% of the time. The biomass limit that corresponds to F_{MSY} should be lower than B_{MSY} by an amount that depends primarily on recruitment variability and estimation error (Restrepo 2008). In some countries a default of $0.5B_{MSY}$ or $0.2B_0$ is used as B_{LIM}. If a stock's biomass falls between B_{MSY} and an adequate B_{LIM}, while being fished at F_{MSY} or less, it will likely be within safe biological limits.

5.3 The management strategy

Do HCRs have to be part of a tested MP/MS?

It is arguable that, from a best practice perspective, the answer to this question is yes. However, one can explore under what circumstances this requirement – which may not be achievable in all cases – can be relaxed. To do this it is perhaps useful to classify the issue into two broad categories: (i) where the HCR is based on a quantitative stock assessment model; (ii) where the HCR is based on empirical indicators (which may have models involved but is not what one would classify as a more conventional stock assessment). In either case, the discussion below assumes that the management system can respond appropriately if there was good evidence of the stock status and trends in order to achieve the targets and avoid the limits, and in this situation the need for a tested MP/MS depends on the reliability of the assessment.

HCRs driven by stock assessment output

If the stock assessment can be shown to be suitably robust (retrospective trends, precision of key estimated variables, statistically sound) and has either been shown to be robust to the relevant uncertainties in a simulation evaluation, or is done using a suitably tested stock assessment package, then it may not need to be part of a fully evaluated MP. Obviously, it would be preferable to test the assessment, monitoring process and the HCR in a full feedback loop, but if the

assessment has been shown to be able to robustly estimate the key HCR inputs from the relevant monitoring data this would be a reasonable compromise. In many cases the assessment model may be too computationally demanding to be fully tested using MSE. This is perhaps most relevant to the complex and computationally demanding assessments used for many tuna species.

If an assessment is preliminary in nature, or does not show the kind of stability or rigor described above, it would be assumed to be unlikely to provide the kind of robust population and fishery variables to feed say an MSY-based F/SSB harvest control rule of the general form seen in this meeting. In this case, it may be important to fully test the HCR using MSE. Due to computational demands, the stock assessment model or other analysis methodology used in the HCR might need to be simplified (as for example was done in the case of SBT, where the full assessment model was not used to give the parameters of the HCR but rather the direct measurements of CPUE and the recruitment index were used to drive the HCR).

HCRs driven by indicators

For a HCR that is driven by indicators derived from key monitoring data (e.g. CPUE, mark-recapture, surveys, catch composition), whether the HCR is purely empirical or has some kind of simple model embedded within it, then it should always be a requirement that the HCR is tested in a full MSE. Given the wealth of information now available on the performance of these kinds of MPs, it is highly unadvisable to simply implement a rule without a rigorous MSE. Even for complex systems simple indicator-driven HCRs can be highly effective, but their very nature (often ignorant of SSB depletion or fishing mortality and the like) means that they do need a significant amount of testing and subsequent adaption to be effective.

How additional data can change the performance of management (and how we can get closer to the target)

A comprehensive MSE should consider the type of data collected and used in the assessment, and perhaps even evaluation of the benefit of collecting additional or new data. This is a wide-ranging issue but perhaps the focus here should be on data that may improve the estimates of the key quantities (namely natural mortality, steepness) that strongly effect estimates of key management variables such as MSY. However the "test" for the value of the currently available or any new data is their effect on the performance of the harvest strategy or management procedure – for example improved understanding of steepness may not be as valuable in this sense as developing a more accurate and precise direct measure of the abundance of a part of the stock that can be used directly in an empirical HCR.

Natural mortality

Mark-recapture data are still the most informative data source on mortality rates, both fishing and natural. Many estimates of natural mortality for tunas have come from models that use tagging data (and sometimes catch data also). An implicit requirement for using tag data to estimate both fishing and mortality rates concurrently is estimates of the reporting rate of tags through the key return platforms; estimates of total mortality can be obtained with information on the temporal

changes in reporting rate without having to know absolute reporting rates. Data coverage would be a key issue in this particular regard: to obtain estimates of M over a wide range of fished ages requires the release and recapture of tags across the age range. This can be challenging for tunas, as it is far easier to release tags on smaller, younger fish than on larger adult fish. A final issue would be treatment of the data, as there are a number of options employed across the various models and stock assessment packages. In an age-based setting, the best way to estimate mortality rates is to follow release along cohorts, and preferably with multiple releases along a cohort (so-called Brownie formulation). This is done in the southern bluefin tuna operating model (where M is estimated over the tagged age range).

Steepness

This is perhaps a more intractable issue than natural mortality. The estimation of steepness requires good contrast in the time-series of SSB and recruitment, preferably with strong declines and subsequent recovery of the SSB and some related signal in the recruitment estimates. This is, perhaps, at odds with the general wish to avoid strong declines in SSB in the first place but unfortunately this does aid in the estimation of key density-dependent quantities such as steepness. A large amount of tuna CPUE indices show one-way trip dynamics already indicating that the robust estimation of both SSB_0 and steepness will not be feasible without additional information.

Working on the assumption that one has at least one relative abundance index (like CPUE) and associated catch and composition data (i.e. most tuna assessments) it is possible that additional information on the absolute abundance of the mature population (or at least some subset of it) may assist in estimating steepness, albeit with the condition that we still require some contrast in the SSB and recruitment. If we still see no apparent change in average recruitment for changes in SSB then there is probably little one can do, but this kind of information may at least avoid the issue around a given abundance decline being possibly due to higher steepness/lower SSB_0 or lower steepness/higher SSB_0. A recent project to estimate adult absolute abundance using DNA fingerprinting to find parent-offspring pairs in genetic samples of juveniles and mature adults has been completed for southern bluefin tuna. The results of this are currently being included in the SBT operating model and may improve the CCSBTs current highly uncertain estimates of steepness.

5.4 Management implementation

Management objectives and defining acceptable levels of risk

Managers and scientists would clearly benefit from a set of well-defined management objectives, and this is usually considered an essential requirement for developing formal harvest strategies through MSE. Management objectives should arise out of a dialogue between managers, deciding on economic, fishery and conservation targets, and the acceptable levels of associated risk, and scientists, able to explore the limits and trade-offs imposed by biological and ecosystem considerations. Exploration and elaboration of this is an iterative process between managers and scientists. For example managers cannot be expected to make statements about acceptable risk without understanding the consequences of different options but scientists cannot well target their

analysis of consequences without guidance on what options might be considered feasible and what performance measures might relate to overall management objectives. In practice this usually requires one group or the other to 'break the ice' and start the iterative process by putting forward some opening suggestions.

While the definition of acceptable levels of risk is a policy decision, the role of science is to quantify the risks and trade-offs associated with alternative management choices. This requires models that adequately represent the uncertainty in the assessments (including not only process and parametric uncertainty but also structural uncertainty) and the different hypotheses considered plausible about future stock trajectories and implementation of alternative management measures. The admission of greater uncertainty has a direct impact on the risks estimated, which makes the choice of models difficult, especially when acceptable levels of risk have been specified in advance by managers. Acceptable risk levels are better selected after the operating models have been identified, and trade-offs involved between different management objectives have been quantified. In particular, the costs in foregone yield associated with different levels of risk aversion need to be evaluated and understood by decision makers. This requires iterations between evaluation of performance of HCRs and consultation with managers.

Risks for the stock are quantified as probabilities of going below some given stock size or reference point. Normally these are selected to correspond to stock levels below which the productivity of the stock may be compromised, and so they are considered limit reference points to be avoided with high probability. The level of probability of going below a reference point that is tolerated should be smaller the lower the limit selected (as a fraction of the target). However, the use of small probability levels (e.g., less than 15% or so) to specify risk tolerance is problematic because estimates of probabilities in the tails of distributions are too sensitive to the level of uncertainty admitted. Therefore, for defining risk tolerance, it is preferable to choose biomass limits that are less extreme and not as far from the target so that the probability of exceeding the limits that can be tolerated is higher, and therefore more robustly estimated.

There are other risk measures associated with different objectives (CPUE, F, etc.), but the same concept above applies.

Can HCRs allow for flexibility?

Development of Harvest Control Rules can be structured to allow flexibility in management actions, but having too much flexibility would result in undermining success in achieving objectives. Evaluating and communicating the trade-offs in use of different HCR 'parameterizations' (*e.g.* time frames, acceptable risk of failure, tolerable inter-annual change in fishery controls, *etc.*) which reflect a range of options and flexibilities for achieving objectives is a critical part of the dialogue required between tRFMO science bodies and Commissioners in HCR development. These discussions should be held as much as possible prior and during the process of developing and testing prospective HCRs. Understanding the boundaries of flexibility in an agreed management procedure, including in the HCR, is a part of the iterative process to develop mutual understanding about expectations from adopting a management procedure. Specifically, this includes defining the exceptional circumstances for change in an agreed management procedure.

Trade-offs among management objectives

Fisheries management typically involves trade-offs across four main dimensions: average long term catch, stability of quota/effort, average CPUE and stock depletion. For example, higher average catch generally result in greater stock depletion and lower average CPUE. In addition these trade-offs are complicated in multispecies fisheries where the optimum for the individual species is not necessarily the optimum for the species complex, and any multispecies optimum may not be the same for different regions/participants in the fishery. The nature and extent of these trade-offs will vary among fisheries and exploring the particular nature of these trade-offs is an important part of the development and selection of formal harvest strategies/management procedures. Ideally, this should occur in two phases: early on in the development/consultation phase, to develop a common understanding of the likely decision/outcome space for the fishery and specify quantitative management objectives and performance measures, and; in considerable detail at the HS/MP evaluation and selection stage of a management strategy evaluation. The final selection of an HS/MP is based on what is considered an acceptable trade-off among these multiple objectives and will be particular to the context of each fishery.

The role of dialogue between managers-industry-scientists

Development of operating models and management advice depends on managers first communicating their preferred management objectives, timeframes, and acceptable risk levels and feasible forms of management strategies to scientists. But these in turn must be informed by an understanding of the underlying concepts from scientists and the operational reality from industry. Finally, the scientific rationale for management advice needs to be communicated to managers in a way that conveys the most important aspects but minimizes technical detail, and managers in turn need to be able to articulate this rationale to industry. As mentioned above, this will be an iterative process - initially to mutually explore options and consequences and then to support greater clarity of objectives, management approaches and the scientific focus of effort.

Capacity Building

To support RFMOs in determining, negotiating, implementing and monitoring HCR and RP systems, the regional management-industry-science system needs to function at the regional (RFMO) level and also at the national level. In some countries, the national management system is not linked to a formal science advisory process. Thus, some Commissioners to RFMOs may not be sufficiently familiar with the management procedure process (and the related technical terminology, which can be onerous) to engage fully in this form of decision-making, frequently lowering trust among the parties.

In recent years, tuna RFMOs have made important advances in capacity building at the level of individuals and institutions. The majority of these efforts have focused on monitoring, compliance and participation in meetings. Tuna RFMOs should also consider how to further bridge national gaps in the science-management system if they are to progress fully to management strategies. Therefore, focused capacity development investments are needed.

6. CONCLUSIONS AND RECOMMENDATIONS

Workshop participants agreed that the experience available worldwide (not just for tunas) demonstrates that well designed management strategies can work very well in achieving high yields while avoiding recurrent overfishing. Such management strategies are increasingly common and associated with the better performing fisheries in the world.

There are no technical constraints to prevent the tuna RFMOs from making progress rather quickly (say, during the next 2-3 years) in testing and adopting management strategies. In many cases, perhaps with the exception of a multispecies context, the performance of alternative management procedures can be assessed with relatively simple operating models, and there is plenty of scientific and technical expertise within the RFMOs to achieve this. What is needed, then, to start the iterative management-science dialogue? A natural start is to begin clarification of management objectives and to identify some options and performance measures for assessment. This will raise further questions to be addressed in this iterative process, such as the embedded issues of allocation in some management options and the treatment of multispecies complexes. But there is no technical constraint on making progress.

Recommendations on limits, targets and HCRs:

- LRPs for F should be based on quantitative analysis that shows an undesirable outcome can be avoided with a high probability based on agreed-upon objectives. These undesirable outcomes may be described in terms of LRPs for biomass depletion or similar (e.g. SPR related depletion). LRPs for F may be higher than F_{MSY} and be reasonably sustainable (e.g., F_{loss}). There should be a high probability of not breaching a LRP.
- The target is a point that optimizes management objectives and ensures a reasonable chance of avoiding stock status that leads to poor fishery performance.
- The target should be designed to provide the maximum long-term average annual yield under realistic levels of uncertainty but also include other factors which affect the fishery (e.g., yield and population variability).
- The target F should be lower than the limit F.
- Consideration of a harvest control rule (HCR) should be kept separate from assessments (e.g. stock assessment models) and presentations that summarize stock status (e.g., Kobe plot).
- Regarding F levels, the reference points (limit and target) should be displayed as part of a fishery performance metric and can be independent from biomass reference points and HCRs. If the Kobe plots are used to define Overfished and Overfishing status, the cross lines should represent limit reference points.
- Probabilities relative to reference points should integrate model uncertainty to the extent practical.

Considerations for future Management Strategy Evaluation:

The primary objective of MSE is to evaluate the relative performance and robustness of alternative management strategies. Performance relates to the ability of a management strategy to meet the specified objectives. Robustness relates to the sensitivity of the strategy to circumstances/events/processes that the strategy has not been specifically designed/tuned to cope with[2]. The level and extent of the evaluations should reflect the particular context and need of the RFMO and the species/stocks under consideration, in particular:

- The availability (or not) of a quantitative stock assessment and its relative maturity and robustness;
- The quality and form of the monitoring data sets and understanding of stock biology, status, productivity;
- The technical and management capacity available for the evaluation and implementation;
- A pragmatic assessment of the feasible management measures;
- The time frame in which the MSE needs to be completed;

In this context, an MSE may range from relatively simple, unconditioned simulations, or even conceptual, expert-opinion exercises, which take weeks to months to complete, (e.g. Davies et al 2008; Smith et al. 2009, Prince et al 2010; Dichmont and Brown 2010) to highly data conditioned simulation evaluations and model-based HCR that require considerable technical expertise and resources, and may take several years to complete (e.g. CCSBT 2012, Kolody et al 2008; Butterworth 2008).

The working group on MSE created through the Kobe process is a good mechanism through which efforts by the RFMO science providers can be harmonized, and to minimize some costs in cases where the same software can be reutilized.

Other recommendations:

- It is important that scientists communicate with decision-makers at a non-technical level, especially during the initial stages of development. At first, there is a need to focus on the "big picture" and too many details will not be useful.
- It is important to support the development of coordinated efforts on capacity-building around the issues discussed in this report, both at technical and managerial levels.

7. ADJOURNMENT

Most of the report was adopted during the meeting and final adoption was done by correspondence. The Chair thanked participants for their excellent contributions and the meeting was adjourned.

[2] In the CCSBT context, the Reference Set was used to tune and evaluate performance of procedures. A subset with acceptable performance were then tested against the Robustness Trials to examine their relative sensitivities.

APPENDICES

Appendix 1. Presentation summaries

A1.1 Reference points and harvest strategies in Australian fishery management, including MSY, MEY, data-poor and by-catch considerations. Keith Sainsbury

The experience with the development and use of reference points and harvest strategies in Australian federally managed fisheries was described and discussed. The move to adopt formal reference points and harvest strategies was motivated by deteriorating stock status and economic performance, and their introduction was accompanied by complimentary management actions to better align fishing capacity to sustainable production, to increase the use of spatial management and to address IUU (Illegal, Unreported and Unregulated) fishing. Default reference points and harvest strategies and guidance for their use and performance requirements, are provided through the Harvest Strategy Policy. A harvest strategy in this context is a combination of monitoring, analysis of monitoring data, and use of this analysis through a control rule to determine management measures (e.g. allowed catch or effort). The reference points and performance to be achieved through application of a harvest strategy are:

- Biomass target reference point – maximum economic yield B_{MEY}
- Fishing mortality target reference point - F_{MEY}
- Biomass limit reference point – half B_{MSY}
- Fishing mortality limit reference point – F_{MSY}
- The control rule should progressively reduce fishing mortality between B_{MSY} and B_{LIM}, and below B_{LIM} there should be no targeted fishing
- There should be less than a 10% chance of the stock falling below the limit per generation time under application of the harvest strategy

Default proxies are provided for situations where reference points cannot be estimated:

- B_{MSY} is 40% of unfished level
- So B_{LIM} is 20% of unfished level
- B_{MEY} is 1.2 x B_{MSY} = 48% of unfished level.

MSY is the maximum average long-term catch from a constant F (F_{MSY}) or from a variable F given by a catch control rule. F_{MSY} as a limit reference point is consistent with UNFSA. F_{MSY} is a suitable precautionary limit when uncertainty is not well accounted for, and especially if F_{MSY} is calculated assuming perfect knowledge, as was common at the time UNFSA was adopted. However if the harvest control rule has been shown to achieve the MEY target and avoid the biomass limit across a realistic range of uncertainties, for example by Management Strategy Evaluation (MSE), then the Fs from the harvest control rule should be treated as targets rather than limits. The biomass trajectories for realistic levels of natural variability in recruitment when fishing at F_{MSY} and F_{MEY} include significant fluctuations below B_{MSY}. The boundaries of the Kobe plot would be better defined as the limit reference points rather than F_{MSY} and B_{MSY}.

Several approaches to applying the requirements of the Harvest Strategy Policy in data poor fisheries have been developed. These include:

- Tiered control rules, similar to those applied in Alaskan fisheries, for different levels of available information with an increasing 'discount factor' applied for decreasing information.
- Use of empirical harvest strategies that are based on direct use of measured indicators (catch rate, length distributions, etc.) and shown by MSE to achieve the performance required by the Harvest Strategy Policy.
- Tiered Ecological Risk Assessment methods, from qualitative through semi-quantitative to qualitative. These can be applied to all species and habitats to identify and focus on high-risk situations for targeted and Risk Management. The risk criteria for the high-risk category is analogous to a limit reference point, and the risk management response is analogous to a control rule in a harvest strategy.

Application of these approaches from 2005, combined with the other accompanying management measures, has given a considerable and measurable improvement to both stock status and economic performance. The formal use of reference points and harvest strategies has been a significant contributor to this improvement. More globally it can be observed that where these approaches have been applied (e.g. USA, New Zealand, Canada, several of the CCAMLR fisheries) there has been improvement or maintenance of stocks. Where these approaches are not used, or are used with lax settings, fisheries continue to deteriorate. There is a very good case that these approaches should be more widely used and recognised as part of good fishery management – as was suggested in 1995 by the FAO Code of Conduct for Responsible Fishing. The development of suites of methods that can be applied for different levels of information availability, and MSE methods to test prospective harvest strategies, make wider application feasible.

Some remaining challenges, and the focus of current further development, include better approaches to multispecies fisheries, formally accounting for spatial closures and protected areas in assessments and harvest strategies, further development of data-poor harvest strategies and MEY harvest strategies.

A1.2 Indian Ocean Tuna Commission-Its past, present and future. Where we are with respect to reference points, and where do we go from here. Rishi Sharma

An overview of the Indian Ocean Tuna Commission (IOTC) management was presented. The IOTC is one of five global RFMOs that manages Tuna. It was established in 1997 and follows in large part the principles UNFSA. However, the precautionary approach was not part of the original convention because IOTC was formed before the formulation of the precautionary approach. Thus, The commission discussed two resolutions in 2012 that would include the Precautionary Approach to management in the mandate of the Commission. One of these passed a binding Resolution (Res. 12-01) that involved setting up principles of Precautionary Approach (launching an MSE process). The second resolution, involving the setting up of interim reference points was turned into a non-binding recommendation.

Interim limit and target reference points were presented for different stocks. All targets are either S_{MSY} or F_{MSY}. Limits are based on the Schaefer surplus production model estimates (0.2*K) or 0.4 S_{MSY} for most tropical tuna (other than bigeye tuna which was 0.5 S_{MSY}). For F, limits were arbitrarily

determined and set at $1.4F_{MSY}$, except for bigeye ($1.3F_{MSY}$) and skipjack ($1.5F_{MSY}$) due to differences in life-history characteristics.

Stock status estimated within the IOTC process indicates that all stocks are currently healthy (other than albacore) with respect to target and limit reference points. The IOTC Scientific Committee process (involving the Working Parties on different species) accounts for parameter, data, structural and derived parameter uncertainty. In addition, deterministic catch projections are made using these sources of uncertainty to assess Kobe-II strategy matrices. Finally, the dialogue on MSE process and objectives has been initiated and operating models for both Albacore and Skipjack are currently being developed. However, conveying these objectives and results to the Commission will be a challenging process, and will need to be dealt with in the future.

A1.3 Reference points and harvest strategies for ICCAT: Development and future work. Laurie Kell

The presentation summarized the implementation of the Kobe process in the International Commission for the Conservation of Atlantic Tunas (ICCAT). A range of stock assessment methods are used by the Standing Committee of Research Statistics (SCRS), i.e. ASPIC, Bayesian Surplus Production Models, Adapt, Multifan-CL, Stock Synthesis.

The main management objective of ICCAT is to maintain the populations of tuna and tuna-like fishes at levels that will permit the maximum sustainable catch. Originally interpreted as using MSY as a target. ICCAT was formed before the Precautionary Approach and the EAFM (Ecosystems Approach to Fisheries Management), so neither is mentioned in the convention. However, stock assessments routinely consider a range of uncertainties and assessment are conducted for bycatch species (e.g. seabirds, turtles) and sharks. Recovery plans are in place for both the Eastern and Western Bluefin (as well as for other stocks), and work on developing an Operating Model under the GBYP (an ICCAT research program for bluefin) is commencing this year. Limit Reference Points (LRPs) are being developed for North Atlantic Swordfish and Albacore by conducting a Management Strategy Evaluation (MSE) to evaluate the performance of reference points as part of HCR.

A1.4 Progress in developing an agreed framework for management within the WCPFC. Graham Pilling

The presentation provided an overview of the legal framework of the Western and Central Pacific Fisheries Commission (WCPFC), based on key Articles of the Convention. These refer to Annex II of the UNFSA and help guide a process to identify appropriate reference points for WCPO (western and central Pacific Ocean) stocks.

The current status of the development of reference points and harvest control rules for WCPO stocks was presented. A framework for key tuna species limit reference points has been adopted, using a hierarchical approach where different limit reference points are selected based on available biological knowledge of each species. Work on the acceptable levels of risk and identification of F-based limit reference points is ongoing. The WCPFC ran a Management Objectives Workshop in 2012 which had a capacity-building focus. The workshop's outputs included recommended management objectives from which an initial list of target reference points and performance

measures may be derived. A roadmap to continue the development of management objectives (to include work on target reference points and ultimately harvest control rules) during 2013 was described.

A1.5 The evolution of governance, science advice and management measures for southern bluefin tuna (SBT). Campbell Davies

Southern Bluefin tuna is a highly migratory tuna species whose range spans three oceans in the southern hemisphere. Historically, the stock has been heavily harvested by longline and surface fisheries and is currently depleted (3-8% SSB). The Commission for the Conservation of Southern Bluefin Tuna (CCSBT) was established in 1994, following informal tri-lateral arrangements between Japan, Australia and New Zealand. Subsequent members include Taiwan, Korea, Indonesia and a number of Cooperating Non-Members.

Early stock assessments and associated scientific advice was characterized by divergent views of stock status and productivity and conflicting management advice. Appointment of independent Chairs, an Expert Advisory Panel and initiation of a Management Procedure development and evaluation process in 2002 were central to resolving these earlier disputes and providing a framework to evaluate and select a formal rebuilding strategy for the stock. An MP was recommended by the Scientific Committee and adopted by the Commission in 2005. However, revelation of large unreported catches and farming anomalies resulted in suspension of the MP program while the implications of these events were investigated. The MP program resumed in 2009 and a final MP was adopted and implemented by the Commission in 2011.

General lessons for other contexts include: MSY is an important policy goal but not necessarily a useful technical objective; Independent chair and technical support, a dedicated work plan and appropriately resourced consultation program for Commission and members are essential to successful outcomes; Work plan should include agreement on schedule and criteria for conditioning of the Operating Model; poorly estimated but influential parameters, in particular M and steepness, should be included as bracketed ranges in a “reference set”, rather than selecting a “best model”; pre-MSE simulation testing of empirical decision rules is valuable for identifying convergence and fitting behavior of candidate MPs; and continuity of scientists and managers through the development and MP/HS selection process is important to successful implementation. While the SBT experience is particular amongst tuna RFMOs, in that is a single species fishery, it is hoped that the experience and lessons from this process will have value for the reference point, HCR, MSE processes underway in the larger multi-species RFMOs.

A1.6 Practicalities of reference points, decision rules, and management strategy evaluation for tunas and associated species in the eastern Pacific Ocean. Mark Maunder, Alexandre Aires da Silva, and Rick Deriso.

Management objectives outlined in the IATTC Antigua Convention include “… maintain or restore the populations of harvested species at levels of abundance which can produce the maximum sustainable yield …”, “… adopt, as necessary, conservation and management measures and recommendations for species belonging to the same ecosystem … with a view to maintaining or

restoring populations of such species above levels at which their reproduction may become seriously threatened …", and "apply the precautionary approach …". The United Nations Fish Stocks Agreement (UNFSA) states that reference points and decision rules should be used and the guidelines set out in Annex II state "The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points.", "Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low.", and "For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield". The IATTC does not have any formal reference points or harvest control rules, however, F_{MSY} is the operating target reference point and harvest control rule, which is not consistent with Annex II of the UNFSA. The fishing mortality rate may be set lower than F_{MSY} due to multiple species being caught in the same fishery and management being based on the most vulnerable species.

Developing reference points and harvest control rules is a complex process and many issues need to be considered including: F_{MSY} is not the same for all species caught by the same gear, $F > F_{MSY}$ can be sustainable (sustainable overfishing); reference points are conditional on the fishing method (selectivity); the yield curve can be flat if the steepness of the stock-recruitment relationship is high resulting in a high F_{MSY}; the years used to average recruitment and selectivity can influence results; effort based strategies may be less risky than catch based strategies in the presence of assessment error; biomass estimates have a double effect on catch from biomass triggered decision rules (on the F that is used and on the catch when the F is applied to biomass). Many of these issues in the context of tuna management in the EPO are addressed by Maunder (2013), Maunder and Aires-da-Silva (2012); Maunder and Harley (2006), and Maunder et al. (2012).

Calculation of the Kobe Strategy Matrix requires the estimation of uncertainty. The Stock Synthesis based stock assessment models used by the IATTC staff for assessing tunas in the EPO are computationally intensive and it is currently impractical to apply Bayesian MCMC methods while including all sources of uncertainty. Uncertainty estimates based on normal approximation confidence intervals for alternative model structure assumptions are combined with a priori weights to evaluate F based harvest levels with respect to F_{MSY} and B_{MSY}. Risk curves are used rather than the Kobe Matrix because they present all the possible harvest strategies that generally need to be calculated if a Kobe Matrix is implemented correctly. The Kobe Plot is also used to provide management advice, but it is recommended that the Kobe Plot be based on limit reference points rather than targets and that F_{MSY} and B_{MSY} should not be used as limit reference points in the sense that there should be a low probability of exceeding them.

A1.7 Kobe's tRFMO Working Group on Management Strategy Evaluation: Quantification and presentation of risk. Laurie Kell

The Third Joint Tuna RFMOs meeting[3] recognized that a Management Strategy Evaluation (MSE) process needs to be widely implemented in the tRFMOs in order to implement a precautionary approach for tuna fisheries management. It was therefore recommended that a Joint MSE Technical Working Group be created and that this Joint Working Group work electronically, in the

[3] http://www.tuna-org.org/Kobe3.htm

first instance, in order to minimize the cost of its work. Three activities are currently being conducted: A review of the Kobe Advice framework, MSE tools and the use of parallel and cloud computing.

A1.8 The development of a management procedure for southern bluefin tuna. Richard Hillary

The most recent work on the development of an operational management procedure (MP) for Southern bluefin tuna within the CCSBT was summarized. The key issues covered relating to the process were: operating model development and the characterization of uncertainty; what data were used in the candidate MPs; targets, operational constraints, and performance measures; and finally, how the process occurred in actuality. Although the MP adopted by the CCSBT differs from the more explicitly MSY-based approaches seen in other tuna RMFOs - in that the MP acts on estimated trends in the long-line CPUE (catch per unit effort) and juvenile survey information - some general observations were made:

The MP process is likely to take a number of years, so scientists and managers/commissioners should plan accordingly. There should be meaningful and continued communication between scientists and managers/commissioners throughout the process to avoid issues around overly-specific, unattainable, or equivalent options relating to the relevant targets of the MP. The definition of what constitutes "exceptional circumstances" (when the dynamics are outside the tested range or new relevant information becomes available) should, to the extent possible, be discussed and codified at the same time as MP development and testing. Collaborative development of the MPs should be encouraged, to ensure not only a wide range of plausible candidate MPs are explored but that MP itself is more a product of the whole developmental group, thereby increasing the probability of acceptance and eventual adoption.

A1.9 The Usefulness of historically-based limit reference points: Application to North Pacific tuna stocks. Mikihiko Kai

We examined the usefulness of historically-based Limit Reference Points (LRPs) such as F_{loss} to Pacific bluefin tuna (northern) stocks using operating model and contrasted these with maximum sustainable yield MSY-based LRPs such as F_{MSY} proposed for Western and Central Pacific southern tuna (southern) stocks. The numerical simulations indicated that historically-based LRPs are appropriate for northern stocks when recruitment compensation is high (i.e. when "steepness" in the stock recruitment relationship is high). In contrast, MSY-based LRPs often have a high risk of allowing recruitment overfishing of northern stocks when process errors are large. Based on these results, we suggest that LRPs set with reference to historical stock sizes are worthy of consideration for temperate tunas in the North Pacific.

A1.10 Why tuna RFMOs need to get Harvest Control Rules and Harvest Strategies in place; WWF approach to achieve this. Daniel Suddaby

The World Wildlife Fund (WWF) can provide the support needed to implement harvest strategies and harvest control rules. Our focus on tuna reflects the need to overcome the key challenges of

lack of effective stock management, overcapacity by-catch and IUU. In order to assist we use the tools of:

- Governance: utilizing our large geographic spread we are able to bring about a groundswell of political support through 'classical advocacy. In addition and often very effectively we partner with industry to drive change
- Markets: Using the 'pull' of sustainable markets to demand sustainable tuna
- Fishers: Working with fishers to reduce their impact and create political push for sustainable tuna
- Financial markets: Working with the financial sector to recognize ecological risk as financial risks as well as financing positive transitions and defining this as an investment opportunity

It is hoped that by using these tools WWF, in conjunction with others, is able to assist in adoption by tRFMO of harvest strategies and harvest control rules.

A1.11 The role of Reference Points and Harvest Control Rules in the MSC certification scheme. David Agnew (presented by Keith Sainsbury)

A brief presentation was provided that outlined the Marine Stewardship Council (MSC) requirements in general and discussed some of the performance requirements that have been discussed extensively in the context of tuna assessments.

MSC fishery assessments score 31 performance indicators across the three MSC Principles – stock condition, ecosystem effects and the management system. To pass MSC assessment, each performance indicator must score at least 60 out of 100, and any score less than 60 results in a failure. To pass MSC assessment, the average of the performance indicators scores for each Principle also must be at least 80, so it is not possible to pass with a lot of indicators just over a score of 60. For any performance indicators that score between 60 and 80 a 'condition' is placed on the fishery. The conditions are designed to raise the score to 80 in the 5-year period of an MSC certification, but there are situations where a longer time is acceptable (e.g. if it is not biologically possible to achieve the necessary change in 5 years).

The MSC performance requirements are very strongly based on international fishery agreements, especially the Code of Conduct for Responsible Fisheries and the FAO Guidelines for Ecolabelling of Fish and Fish Products.

The target reference point in the MSC scoring relates to achieving MSY, and is the case for international agreements such as UNCLOS (United Nations Convention on the Law of the Sea) and UNFSA. The limit reference point relates to avoiding recruitment overfishing.

Across all the MSC certified fisheries the performance indicator that most often results in a condition is the requirement for a harvest control rule. This reflects the reality that while there is good evidence for harvest control rules being good practice in fishery management there are still many fisheries without them. The 60 score for the harvest control rule performance indicator can be met without a formal rule being adopted, provided that there is evidence that there is an implicit rule that is generally understood and has been applied in practice. To score 80 the rule

must be well defined, which usually means formally written and agreed, with evidence of its effectiveness.

The MSC requirements for management as they relate to cross-jurisdictional fisheries are strongly based on the need to effectively cooperate, as outlined especially in UNFSA.

A1.12 Precautionary Pragmatism: Putting it all in Practice in RFMOs. Deirdre Warner-Kramer

Scientific advice that stipulates a single outcome can be too easy for managers to ignore if they do not fully understand the underlying basis for the recommendation. This is even more the case when the advice would entail large changes in catch levels or implementation challenges. Advice that presents a set of options to achieve comparable conservation outcomes can instead give managers the room to find a negotiated outcome that is consistent with convention objectives.

To work well, the process must include ongoing, circular communication between managers and scientists. Managers need sufficient information to know which questions to ask of scientists, and scientists need specifics to provide advice that managers can use. Most importantly, the results of the scientific process need to be conveyed in a way that managers can understand. As much as possible, advice should be clear and simple, using standardized formats such as the Kobe Plot. More complex details about underlying uncertainties and methodologies should be minimized in the initial summary of advice.

ICCAT's principles for decision-making (*Recommendation by ICCAT on the Principles of Decision Making for ICCAT Conservation and Management Measures* [Rec. 11-13]) is an example of an overall harvest control framework that can further facilitate this process. This measure calls for overall management responses to specific stock situations, which managers and scientists are then able to work with together to refine, taking into account such considerations as the biology of the stock, the nature of the fishery, or the overall management goal. T-RFMOs should also devise new means to test and evaluate whether agreed management measures are the optimal way to meet management goals. The broader use of Management Strategy Evaluations would be an important step, though only a part of the solution.

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Appendix 3. Glossary of terms

A3.1 Reference points mentioned in this report

B Stock biomass or stock abundance. In determining stock status relative to reference points, spawning stock biomass (SSB; SB) is more commonly used. SSB is that part of B corresponding to mature individuals.

B_{LIM} The limit reference point for biomass (synonymous with LRP).

F The fishing mortality rate. It is roughly the proportion of the fishable stock that is caught in a year.

F_{loss} A reference point sometimes used as a limit. The fishing mortality corresponding to the lowest observed spawning stock and associated recruitment.

F_{MEY} The fishing mortality rate that produces MEY.

F_{MSY} The fishing mortality rate that produces MSY.

h **Steepness** defines the degree of dependence of average recruitment on spawning biomass. For most tunas, steepness is poorly known and difficult to estimate, but has an important influence on the estimates of stock status (see Anonymous 2011).

K Carrying capacity (maximum population size). A parameter in production models, analogous to SSB_0.

LRP Limit reference point (see Section A2.2).

M Natural mortality rate. A stock's total mortality rate is given by F+M.

MEY Maximum Economic Yield. The value of the largest positive difference between total revenues and total costs of fishing (including the cost of labor, capital, management and research).

MSY Maximum Sustainable Yield. (1) The largest average long-term yield that can be obtained by applying a constant F (F_{MSY}) or a variable F (in the case of a formal harvest control rule where F varies as a function of stock size). (2) The largest constant yield that can be obtained year after year. The second definition was prevalent in the early days of fisheries science; current practice refers to the latter as MCY (maximum constant yield).

S Stock size. Used as an alternative term for B.

SPR Spawning potential-per-recruit. The amount of spawning output (e.g. SSB or another appropriate measure of reproductive output) obtained from the average recruit under a given value of fishing mortality, conditional on age-specific values of selectivity, growth, maturity, and natural mortality. $SPR_{F=0}$ and SPR_0 are used to the note the maximum SPR, in the absence of fishing; $X\%SPR_0$ would be used to indicate X% of the maximum.

SSB Spawning stock biomass. The total weight of sexually mature fish in the population (usually males and females combined, but sometimes only female SSB is used).

SSB_0 Spawning stock biomass in the absence of fishing (usually before fishing started). This reference point is difficult to estimate reliably as it is strongly correlated with steepness (*h*) and natural mortality (M), although it is a parameter in many stock assessment models as the initial stock biomass before fishing began. Alternative estimators such as $SB_{current,\ F=0}$ may be more robust.

$SB_{current,\ F=0}$ An estimator of the unfished biomass in which a stock's current (or recent) productivity conditions are assumed in order to calculate the level that SSB would reach in the absence of fishing.

SSB_{MSY} The equilibrium spawning stock biomass that results from fishing at F_{MSY}. In the presence of recruitment variability, fishing a stock at F_{MSY} will result in a biomass that fluctuates above and below B_{MSY}.

TRP Target reference point (see Section A2.2).

A3.2 Terms commonly used in Management Strategy or Management Procedure literature

Conditioning

The process of fitting/conditioning an Operating Model (OM) to data as part of a Management Strategy Evaluation (MSE). The level of conditioning of the OM can vary substantially depending on the context and purpose of the MSE and the data and information available for the fishery in question. The aim of conditioning the OM is to develop a set of plausible models/hypotheses of the stock and fishery that are consistent with the data, as distinct to identifying a "best assessment".

Decision Analysis

A formal analysis to aid decision-making in the face of uncertainty. A decision analysis usually evaluates the relative likelihood that alternative management actions (e.g. average catch, constancy of catch, probability of rebuilding to a given biomass target, etc.) will achieve the expected outcomes. Decision analysis can also address management consequences under different plausible assumptions about the status of the stock or under different monitoring programs.

Harvest Control Rule (HCR) (also Decision Rule)

An agreed rule (algorithm) that describes how harvest is intended to be controlled by management in relation to the state of some indicator of stock status. For example, a harvest control rule can describe the various values of fishing mortality which will be aimed to be achieved at corresponding values of the stock abundance. Constant catch and constant fishing mortality are two types of simple harvest control rules.

Kobe Plot

The "Kobe Plot" was identified by the joint meetings of tuna RFMOs (the "Kobe process") as a useful way to graph stock status. Stock abundance (SSB) is on the X-axis and fishing mortality on the Y-axis. The plot is used to either show the trajectory of a stock over time, or its current status, or both. The Kobe plot is usually divided into four quadrants by using a vertical line at $B=B_{MSY}$ and a horizontal line at $F=F_{MSY}$.

Kobe Strategy Matrix

The Kobe strategy matrix was recommended by the joint meetings of the RFMOs as a useful way to report the probability of something happening (e.g. biomass falling below B_{MSY} or F going over F_{MSY}) under alternative management actions (e.g., different levels of TAC). The Kobe strategy matrix is similar to a decision table of the types used in operations research.

Management Objective

A formally-established, more or less quantitative target that is actively sought and provides a basis for management action. Management objectives need to consider both the manner in which the benefits from the fishery are to be realized, as well as the possible undesirable outcomes that are to be avoided. It is desirable that both the timeframe and likelihood for achieving the target (or avoiding a limit) is included in the formal specification of each management objective. Broad objectives include considerations of long-term interests and the avoidance of irreversible or slowly reversible impacts (e.g. large reductions in recruitment below average levels). Typically, the catches are to be as large as possible, so long as the probability of substantial stock depletion is below an acceptably low level, catches can be kept reasonably steady and catch rates remain profitable. Management objectives are often conflicting (e.g., maximizing yield while avoiding stock depletion) and therefore tradeoffs need to be understood. Management Strategy Evaluation provides a valuable framework for exploring these trade-offs and building understanding between managers, stakeholders and scientists.

Management Plan

In a broad fisheries context, it is the strategy adopted by the management authority to reach established management objectives. The management plan generally includes the policy principles and forms of management measures, monitoring and compliance that will be used to regulate the fishery, such as the nature of access rights, allocation of resources to stakeholders, controls on inputs (e.g. fishing capacity, gear regulations), outputs (e.g. quotas, minimum size at landing), and fishing operations (e.g. calendar, closed areas, and seasons). Ideally, the Management plan will also include the formal management/harvest strategy for the fishery or a set of principles and guidelines for the specification, implementation and review of a formal management strategy for target and non-target species.

Management Procedure (MP)

The formally specified combination of monitoring data, analysis method (which may be an assessment) and harvest control rule (decision rule) that are used to calculate the value for a TAC or effort control measure. MPs are derived by simulation and chosen for their performance in meeting the specified management objectives and robustness to the presence of uncertainties. Management Strategy Evaluation is commonly used to evaluate and select MPs. Two types of MP may be distinguished:

- **Empirical MP**: An MP where resource-monitoring data (such as survey estimates of abundance, or standardized CPUE) are input directly into an algorithm (the HCR) that generates a control measure such as a TAC/effort level without an intermediate (typically population-model based) assessment model;
- **Model-based MP**: An MP where the analysis used to generate a control measure, such as a TAC (this process is sometimes termed a catch limit algorithm or CLA), is a combination of an assessment model (which may be more or less complex) and an HCR.

Management Strategy (also Harvest Strategy)

Is a combination of monitoring, assessment, harvest control rule and management action designed to meet the stated objectives of the fishery. The management actions include choices regarding all or some of the following: limited access, allocation of access rights to stakeholders, controls on inputs (e.g. fishing capacity, gear regulations, seasonal or spatial closures), or controls on outputs (e.g. quotas, minimum sizes). The level of detail specified in the each of the components of a management strategy can vary according to the fishery and the context in which it is being used, in particular the stage of development of the fisheries monitoring and management system. An important characteristic of a management strategy is that it is the performance of the individual components and the propagation of uncertainty among them that determines overall performance of the strategy. Hence, careful consideration of the interaction between monitoring, assessment, HCR and management measures is a major focus of management strategy evaluation (MSE).

Management Strategy Evaluation (MSE) (Also MP Approach)

The process of evaluating the relative performance of a range of management strategies or options and presenting the results in a way that demonstrates the tradeoffs in performance and robustness across a range of management objectives. MSE usually involves simulation using (1) a model or models (the "operating model(s)") to represent the true underlying dynamics of the resource, the fishery and to generate future monitoring data, (2) an estimation model to assess the state of the stock relative to agreed target and limit reference points based on the data simulated by the operating model, and (3) a harvest control rule to determine management actions (e.g., the TAC) given the results of the estimation model. MSE is a general framework aimed at designing and testing Management strategies. It can be applied at a range of levels from high level harvest policy evaluation to detailed testing of fishery specific operational management procedures. The terms MSE and MP Approach are often used interchangeably, although the latter generally refers to simulation testing of specific management strategies.

Operating Model (OM)

The part of the MSE that represents the true underlying status and dynamics of the population, the fishery and the monitoring regime, including the full range of uncertainty pertinent to that fishery. May include a "Reference Set" of most plausible situations/hypotheses and a "Robustness Set" of unlikely, but not impossible situations/hypotheses

Performance Measure

Measures of performance used during management strategy evaluations. These are interpreted in relation to reference points and management objectives. For example, performance measures under a given management strategy can measure the probability that the limit reference point is exceeded over a defined period, the expected long-term yield, etc. In the MSE context, they are used to summarize different aspects of the simulation results and to evaluate how well a specific strategy achieves some or all of the general objectives for management for a particular scenario.

Precautionary Approach (PA)

A set of agreed cost-effective measures and actions, including future courses of action, which ensures prudent foresight, reduces or avoids risk to the resource, the environment, and the people, to the extent possible, taking explicitly into account existing uncertainties and the potential consequences of "being wrong". The MSE (MP approach) is a transparent, rigorous way to incorporate uncertainty into the fisheries management process and demonstrate whether a strategy is precautionary.

Reference Points

Benchmarks against which the abundance of the stock, the fishing mortality rate or economic and social indicators can be measured in order to determine its status. These reference points can be used as limits or targets, depending on their intended usage.

- **Limit Reference Point (LRP):** A benchmark that should not be exceeded with any substantial probability according to a given set of management objectives. It indicates the limit beyond which the state of a fishery and/or a resource is not considered desirable and remedial management action is required. When a stock is at very low abundance, LRPs are often taken as interim rebuilding targets.
- **Target Reference Point (TRP):** A benchmark that should be achieved on average according to a given set of management objectives. It corresponds to a state of a fishery and/or a resource which is considered desirable.

Risk Analysis

Analysis (and comparison) of the probability of negative outcomes of alternative actions foreseen in development, harvesting or management strategies.

Uncertainty

Uncertainty results from a lack of perfect knowledge of many factors that affect stock assessments, estimation of biological reference points, and management. Sources of uncertainty include:

- Measurement error (in observed quantities)
- Process error (or natural population variability, e.g. in future recruitment),
- Model/structural error (misspecification of assumed values or population model structure)
- Estimation error (in population parameters or reference points, due to any of the preceding types of errors)
- Implementation error (or the inability to implement management controls for whatever reason).

Often, it is useful to distinguish between uncertainty that can be quantified, and uncertainty that can only be addressed qualitatively, or through scenario modeling.