ISSF Technical Report 2015-06

2015 ISSF Stock Assessment Workshop
"Characterizing uncertainty in stock assessment and management advice"

March 16-18, 2015
Board Room, Monterey Bay Aquarium, Monterey California, USA

SUMMARY

This Workshop was convened by the International Seafood Sustainability Foundation (ISSF) to review progress made recently by tuna Regional Fishery Management Organizations (tRFMOs: CCSBT, IATTC, ICCAT, IOTC and WCPFC) towards the formal adoption of harvest strategies for the management of the stocks under their jurisdiction, with a special focus on the treatment of uncertainty and the estimation of risk. This progress involves improved data collection, adoption of target and limit reference points, and analyses of the performance of alternative harvest control rules through management strategy evaluations. This report summarizes what the tRFMOs have adopted and also highlights related work that supports the RFMO processes. The workshop concluded that good progress is being made overall, especially through the processes of dialogue between scientists and managers that have been initiated in ICCAT, IOTC and WCPFC. The report also makes recommendations for furthering these efforts.

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1. BACKGROUND, OBJECTIVES AND ORGANIZATION

Over the last few years, tuna RFMOs have been moving progressively forward towards the adoption of integrated harvest strategies for the management of their stocks. This progress involves improved data collection, adoption of target and limit reference points, and analyses of the performance of alternative harvest control rules through management strategy evaluations.

Quantifying uncertainty in stock status results can be very important when it comes to implementing harvest strategies. For example, if an RFMO decides on what constitutes an unacceptable level of risk of exceeding a Limit, then the methods used to quantify that probability of exceeding the limit may be highly influential.

The purpose of the 2015 ISSF Stock Assessment Workshop was to review recent progress made by the tuna RFMOs towards adopting harvest strategies, with particular emphasis on the methodologies used to quantify and express uncertainty in stock status results. Discussions will aim to highlight the pros and cons of different approaches, and recommendations for harmonization will be made where appropriate.

The workshop was held at the Monterey Bay Aquarium in Monterey, California. Participants included members from the ISSF Scientific Advisory Committee, as well as other experts on the topics being discussed: Alejandro Anganuzzi, Anthony Beeching, Shui-Kai (Eric) Chang, Laurent Dagorn, David Die, Chuck Farwell, Jean-Marc Fromentin, John Hampton, Shelton Harley, Jim Ianelli, Ana Justel-Rubio, Laurie Kell, Zang-geun Kim, Dale Kolody, Josh Madeira, Steve Martell, Carolina Minte-Vera, Robin Pelc, Graham Pilling, Victor Restrepo (Chair), Josu Santiago, Eric Schwaab, Gerry Scott, Rishi Sharma, Dale Squires, Yukio Takeuchi, Steve Teo, Deirdre Warner-Kramer 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**) and the Glossary created during the 2013 ISSF Harvest Control Rules and Reference Points for Tuna RFMOs Workshop (Anon., 2013) was revised and included as **Appendix 3** in this report. **Section 2** summarizes the current situation relating to the adoption of harvest strategies in tuna RFMOs. **Section 3** elaborates upon the discussion by the participants on treatment of uncertainty and estimation of risk and **Section 4** lists the main conclusions and recommendations derived from the workshop.

2. UPDATE ON THE ADOPTION OF HARVEST STRATEGIES IN TUNA RFMOs

The Workshop reviewed progress made recently by the RFMOs on the adoption of harvest strategies and their main components (reference points, harvest control rules, and the evaluation of how they work together -MSE-). It was noted that substantial work is going on particularly at the level of the scientific committees and Secretariats and also at the political level. **Table 1** summarizes the elements that have actually been adopted formally by the five tuna RFMOs. Other work of a more informal nature is also mentioned in **Sections 2.1 to 2.4**. In addition, there are individual countries and sub-regional organizations that are also conducting relevant work which may well feed into the RFMO processes. Some examples are highlighted in **Section 2.5**.

Table 1. Summary of elements of harvest strategies that have been formally adopted by the five tuna RFMOs.

Element/ RFMO	**CCSBT**	**IATTC**	**ICCAT**	**IOTC**	**WCPFC**
Management Objectives (Convention and other decisions)	CCSBT Convention. Art. 3: "... ensure, through appropriate management, the conservation and optimum utilisation of southern bluefin tuna." The Commission decision requires TAC setting to also take the Precautionary Approach into account	Antigua Convention. Art. II: "... to ensure the long-term conservation and sustainable use of the fish stocks covered by this Convention, in accordance with the relevant rules of international law." Art. IV: Apply the Precautionary Approach.	ICCAT Convention. Preamble: "... maintaining the populations of these fishes at levels which will permit the maximum sustainable catch for food and other purposes..." NOTE: ICCAT has a Working Group that is drafting amendments to the Convention which may include wording about the Precautionary Approach.	IOTC Agreement. Art. V: "... ensuring, through appropriate management, the conservation and optimum utilization of stocks covered by this Agreement and encouraging sustainable development of fisheries based on such stocks."	WCPFC Convention. Art. 2: "... ensure, through effective management, the long-term conservation and sustainable use of highly migratory fish stocks" (in accordance with the Law of the Sea Convention.
Limits	None	For tropical tunas: $F_{0.5R0}$ and $B_{0.5R0}$ evaluated assuming a steepness of 0.75 (adopted at the 87th Meeting as interim limits). The B limit corresponds to a depletion level of $0.077B_0$. Using the 2014 assessment results, the corresponding F/F_{MSY} values are 2.4 and 1.6 for yellowfin and bigeye.	For N. Atlantic swordfish: 0.4 B_{MSY} (interim limit; Rec 13-02)	Biomass: Tropical tunas: 0.4 B_{MSY} (0.5 B_{MSY} for BET) 1.4 F_{MSY} (1.3 F_{MSY} for BET & 1.5 F_{MSY} for SKJ)-(interim limits; Res 12/01 and 13/10)	For tropical tunas and S. Pacific albacore: 0.2 $SB_{F=0}$ ($0.2B_0$) evaluated using recent recruitment levels (adopted at the 2012 annual meeting)

Element/ RFMO	CCSBT	IATTC	ICCAT	IOTC	WCPFC
Rebuilding targets	$0.2B_0$ (with 70% probability) in 25 years *	None	Western Atlantic bluefin: 20-year program to rebuild to BMSY (recs. 98-07 and 14-05). Eastern Atl. and Mediterranean bluefin: A 15-year recovery program to reach BMSY with at least 60% probability (Recs 07-05 and 14-04). Past Recommendations: Rec 06-02 established a 10-year rebuilding program for N. Atlantic swordfish to achieve B_{MSY} with greater than 50% probability. Rec. 09-05 established a rebuilding program for N. Atlantic albacore with the implied rebuilding target of B_{MSY} in 10 years.	None	For BET, reducing F to FMSY by 2017 is an implied rebuilding target under CMM 2014-01
Targets	None	B_{MSY}/F_{MSY} (adopted as interim at the 87th annual meeting)	Rec. 11-13 suggests that the "green" quadrant of the Kobe plot is a target zone, but no specific target reference points have been adopted.	For tropical tunas, albacore and swordfish: B_{MSY} and F_{MSY} (adopted as interim in Res 13/10)	None
Harvest Control Rule	Empirical Based (Juvenile survey & CPUE)	For tropical tunas: Reduce F to F_{MSY} if it exceeds this value (adopted as interim at the 87th annual meeting)	None	None	None

2.1 Limit Reference Points (LRPs)

Most tuna stocks managed by RFMOs are in a healthy state (ISSF, 2015), and three of the five RFMOs have interim (IOTC and IATTC and ICCAT) or adopted (WCPFC) LRPs.

For WCPFC, limits are based on a proportion of estimated unfished total or adult stock biomass, while the rebuilding target of CCSBT is couched in similar terms of unfished total biomass. Different methods have been used to estimate that unexploited biomass level (in WCPFC, the value represents the average unexploited adult biomass level calculated over a recent 10-year period). For IOTC and ICCAT, limits are expressed relative to B_{MSY}. The Workshop noted that the value of MSY is a function of selectivity (reflecting the overall mix of gears/fisheries) and assumed steepness value, and hence will change over time. For IATTC, limits are expressed relative to the maximum level of equilibrium recruitment.

Because the adopted limits are often expressed in different units which can be difficult to compare, the Workshop decided to also present them on a common scale, relative to the unfished level (**Table 2**). Note that these values may change with every new assessment. Still, Table 2 provides insight into the main differences in the LRPs adopted by the RFMOs.

Table 2. Comparison of biomass Limit Reference Points (LRPs) adopted by tuna RFMOs. The last column expresses the LRPs on a common scale, relative to the unfished spawning biomass level (B_0).

RFMO	Stocks	Adopted biomass LRP	LRP relative to B_0
CCSBT	SBT	None	N/A
IATTC	BET	$B_{0.5R0}$	0.077
	YFT	$B_{0.5R0}$	0.077
ICCAT	SWO-N	0.4 B_{MSY}	0.20
IOTC	BET	0.5 B_{MSY}	0.14
	YFT	0.4 B_{MSY}	0.14
	SKJ	0.4 B_{MSY}	0.14
WCPFC	BET	0.2 $SB_{F=0}$	0.20
	SKJ	0.2 $SB_{F=0}$	0.20
	YFT	0.2 $SB_{F=0}$	0.20
	ALB-S	0.2 $SB_{F=0}$	0.20

The Workshop also noted that the tuna RFMOs have become quite used to the so-called "Kobe plots" to represent status relative to MSY. However, with the recent adoption of limit reference points, there is as of yet no standard way of representing stock status relative to both MSY levels and LRPs. An example for WCPFC (2014) is given in **Figure 1a** (see also MacDonald, 2013, for other examples). In this case, (called a "Majuro plot" because it was produced at the 2014 WCPFC SC meeting in Majuro, RMI), the color Red is use to indicate the biomass level below the biomass LRP; On the F scale, Red and Orange show F levels above F_{MSY}. **Figure 1b** shows a different depiction from IOTC (2014). In this case, the Orange/Red/Green levels are more aligned with a traditional Kobe plot, and the LRPs are shown by additional horizontal and vertical lines. There is no "right" or "wrong" way to depict these results, but it would be useful if tuna RFMOs agreed on some standard to minimize confusion.

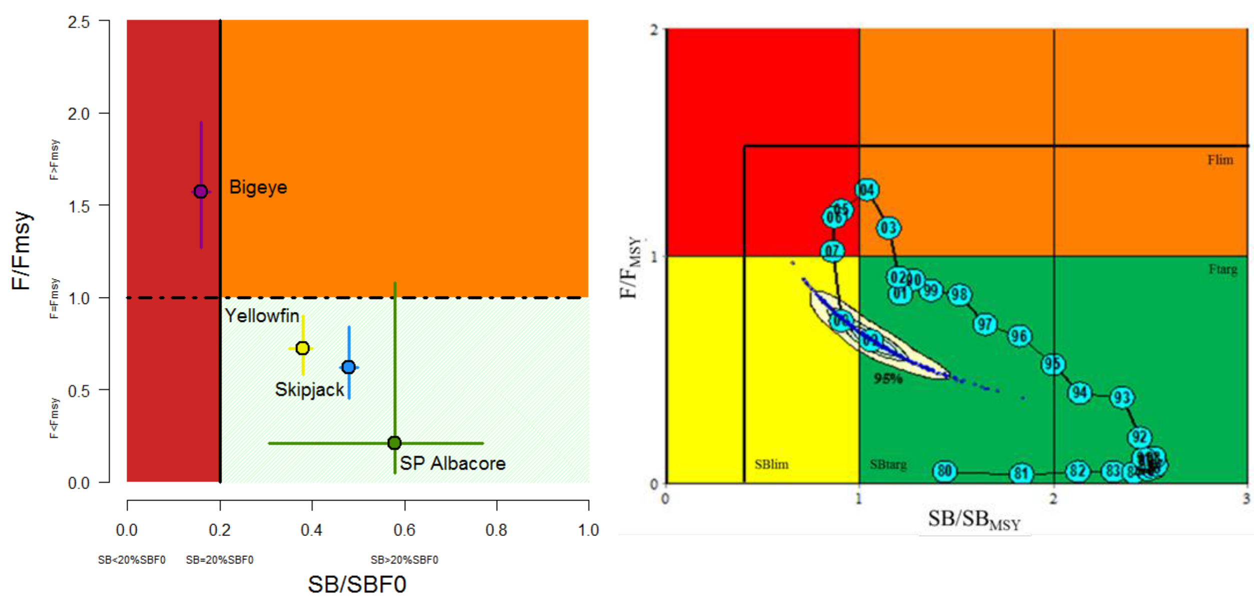

Figure 1. (**a**, left): "Majuro plot", with a coloring scheme that depicts stock status as Red at the biomass LRP (from WCPFC, 2014). (**b**, right): Traditional "Kobe Plot" with LRPs indicated by additional horizontal and vertical lines (from IOTC, 2014).

2.2 Target Reference Points (TRPs)

Tuna RFMO Convention management objectives are based on concepts such as "optimal utilization" or "long term conservation and sustainable use" (**Table 1**). As a result, TRPs adopted or being discussed are around fishing mortality levels that achieve high yields or high catch rates, while being distant from the LRPs. At the 2013 ISSF Workshop (Anon., 2013), there was considerable discussion on whether F_{MSY} should be viewed as a target or a limit. Where there was little or no quantitative analysis of uncertainty, the workshop's opinion was that F_{MSY} should be used as a limit. However, where there was good knowledge, the use of F_{MSY} as a target had potential, with appropriate considerations of risk:

> *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 vs Stock 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).

(Anon., 2013)

Separate rebuilding targets have also been identified for stocks that have been depleted (**Table 1**). In CCSBT, where the southern bluefin stock was severely depleted in the early 2000s, the identified interim target is to rebuild the stock to $0.2B_0$ by 2035. In WCPFC, the aim to reduce fishing mortality on the bigeye tuna stock to F_{MSY} levels is via a step-by-step approach through 2017 (CMM 2014-01). Similarly, ICCAT has identified B_{MSY} as a rebuilding target for bluefin, albacore, marlins and swordfish stocks, with varying timelines.

2.3 Harvest Control Rules (HCRs):

The workshop noted that, beyond the empirical HCR within the Management Procedure for CCSBT, HCRs have not yet been formally adopted by any other tuna RFMO. However, the development of HCRs for individual fisheries has begun, largely driven by Marine Stewardship Council (MSC) certification conditions.

Relevant frameworks for the development of reference points and harvest control rules have been developed within Commission documents, including CMM 2014-06 (WCPFC), Resolution 13/10 (IOTC) and Recommendation 11-13 (ICCAT). However, at present there are no explicit statements on how to achieve targets or to avoid limits, which might reflect Commission harvest control rules.

The workshop discussed whether harvest control rules need only be formulaic recipes, but could potentially be more flexible. As an example, Recommendation 11-13 by ICCAT indicates that the stock should remain in the green quadrant of the Kobe plot ($F \leq F_{MSY}$ and $B \geq B_{MSY}$) with high probability. And, if the stock is in the red or yellow zone of the Kobe plot, management should drive the stock back to the green zone 'in as short a period as possible'.

In turn, the potential for the Kobe II strategy matrix to be considered as a form of HCR was discussed, given that ICCAT uses this to guide subsequent harvest levels. It was noted that this is not really an 'autopilot'-style HCR in the ICCAT context, and that simulation testing such a 'rule' is not straightforward (although testing of the implicit management procedure has been performed for ICCAT (Kell et al., 2000). However, constant catch projections are often tested alongside, and compared with, more complicated feedback-based HCRs in MSE, in part to demonstrate the benefits of feedback (e.g. CCSBT).

The workshop also noted the importance of wider stakeholder involvement in the development, and particularly the evaluation, of HCRs, with successful examples from CCSBT and outside the tuna RFMO arena demonstrating wide stakeholder engagement.

2.4 MSE work

Management Strategy Evaluation (MSE) is an important way to characterize and evaluate uncertainty and risk for fisheries management purposes (**Figure 2**). A fundamental principle of this approach is to test harvest strategies under a series of simulated plausible scenarios to obtain some understanding of relative benefits and risks.

Additionally, MSE can play an important role in prioritizing research and data collection. The evaluation and quantification of stock assessment uncertainties has developed in recent years and are being increasingly well expressed within assessment results. However, quantification of how new research and data collection programs will translate into improved decisions and management outcomes is rare. The MSE approach can help since, if specified (from the operating model), the new information can be tested directly within a harvest strategy and evaluated against performance indicators. For example, given a choice between investing in a new absolute abundance survey, or doubling the size composition sampling in a fishery that is already randomly sampled, MSE would presumably indicate that the HCR with an additional survey can be expected to result in a lower risk of violating biomass limit reference points.

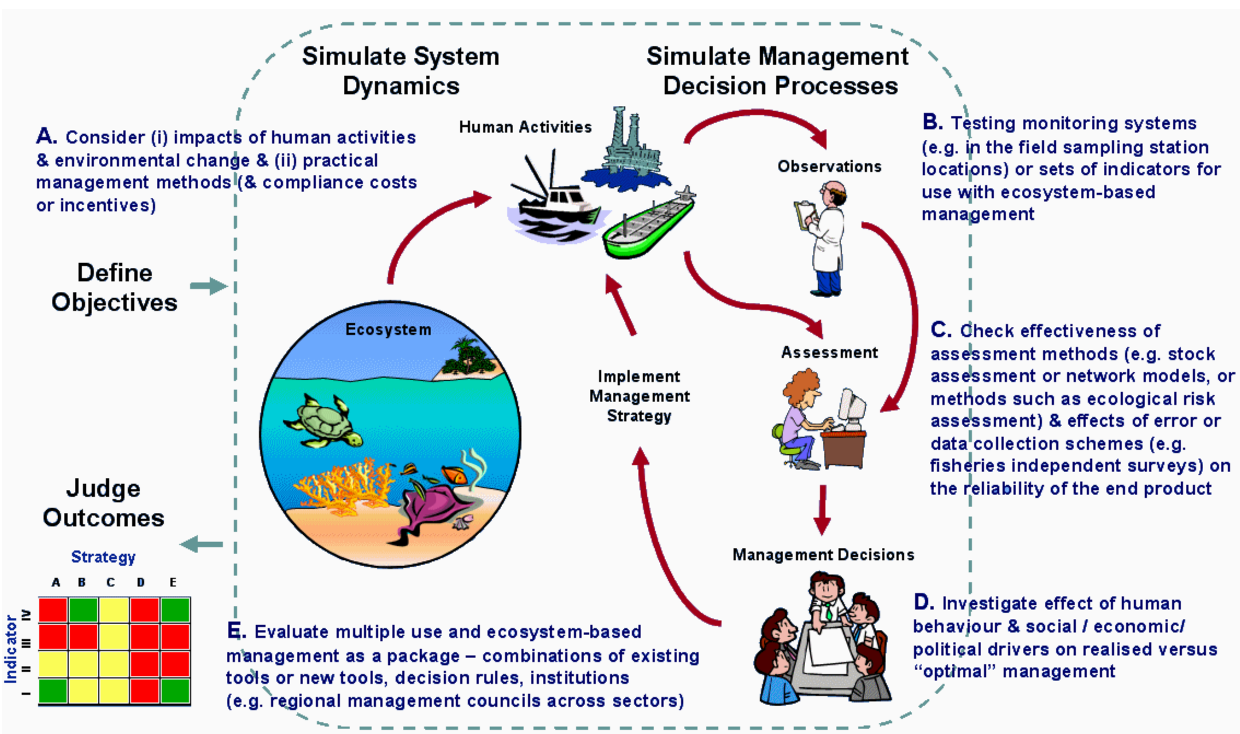

Figure 2. Depiction of a general MSE approach for resource management (adopted from CSIRO).

The Workshop discussions focused on how the "*management strategy evaluation"* process is being used by tuna RFMO to inform management. All tuna RFMOs are engaged in developing or using components of the MSE process. However, the level of integration of MSE activities in management differs between RFMOs (**Table 3**). Components of the MSE process to support stock assessments and management advice are being developed within all tuna RFMOs, but only CCSBT has formally used MSE to test and evaluate the adopted "*management procedur*e" that is used to determine TAC for the southern bluefin stock. Other RFMOs have developed full MSE processes, including testing of management procedures. However, these management procedures are sometimes designed by scientists and have had limited feedback from stakeholders and commissioners. The group discussed the importance of establishing this interaction and dialogue and specifically in regards to the setting of objectives. It was noted that while some RFMO scientists have developed components of the MSE (i.e., operating models) the development of harvest control rules (HCR or management procedures) have been limited (**Table 4**). In other settings, HCRs may be applied without having being formally tested against management objectives.

Table 3. Components of the MSE process in use by tuna RFMOs.

	CCSBT	**IATTC**	**ICCAT**	**IOTC**	**WCPFC**
Operating model	ADMB	SS3			
Simulation of data generation	Yes	Yes	Yes	Yes	MULTIFAN-CL
Assessment model	Same as OM		ASPIC		No
Harvest strategy evaluated	Adopted HCR	Hypothetical HCRs	Hypothetical HCRs	Hypothetical HCRs	Constant catch/effort, hypothetical HCRs
Implementation error in the harvest strategy	No	No	No	No	No

The current level of integration of MSE processes in the management also differs between RFMOs. In CCSBT, the MSE was formally used to develop and test alternative Harvest Control Rules. An HCR has been adopted and the MSE process is currently the process by which modifications of this HCR can be evaluated. CCSBT has also recognized the need to continuously monitor this process as management objectives or the fishery change. In the other RFMOs, the process of integration of the MSE in management is at a much earlier stage of development. However, all tRFMOs recognize that the MSE process is a tool to be used in support of management. IOTC, ICCAT and WCPFC have instituted formal dialogue processes where the MSE is part of the agenda of this process. Few RFMOs have reached the point where the Commission has agreed to the management objectives that need to be considered as part of the MSE. Fewer yet have had formal agreements on the performance indicators that are to be used to evaluate whether such objectives are reached given any particular harvest strategy. Such agreements are essential if MSE applications are truly going to be used to inform management. Even if most RFMOs have not reached such agreements, many RFMO scientists have already developed lists of hypothetical objectives, performance indicators and harvest strategies that they are using to test their ability to run

MSE processes. Such tests have sometimes been used by scientists to evaluate performance of alternative assessment models in order to improve stock assessments.

The range of species to which MSE is been applied is broad and includes all major species of tunas and two billfishes. The number of scientists developing MSE applications tends to be small for each RFMO because of the level of programming skills required to implement such simulations, and depending on the RFMO, may include members of the secretariat, an independent science provider, or working groups made up of scientists from member countries. In some RFMOs, expertise to run MSE is contracted by the tRFMOs to science providers like the Secretariat of the Pacific Community (SPC), the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) or certain universities. At least one RFMO (ICCAT) actively collaborates with another non-tuna RFO (International Council for the Exploration of the Sea, ICES) to enhance its capacity to develop and apply MSE in the management context. This is done by an agreement to hold joint meetings of the working group on methods of ICES and ICCAT that will focus on MSE. Although currently all applications of MSE are done for individual stocks there is strong recognition that multi species applications are desirable, especially for tropical tunas.

Table 4. Level of integration of MSE in the management process.

	CCSBT	**IATTC**	**ICCAT**	**IOTC**	**WCPFC**
Explicitly used MSE to evaluate adopted HCR	Yes	No	No	No	No
Explicit resolution exists saying that MSE is to be used to support management	Yes	? Yes for tropical tunas	yes	Yes	yes
MSE is topic of discussion of formal dialog meeting	Not applicable, MSE is operational	There is no formal dialog group	yes	Yes	yes through the WCPFC MOW process
Resolution exists that defines management objectives to be considered by the MSE	Yes for SBT	No	Yes BFT East	No	No
Performance indicators used in MSE agreed by Commission	Yes	No	No	No	No
MSE used to evaluate performance of assessment process	MSE already operational	No	Yes	Yes	No
Case studies for MSE	SBT	Dorado, N. Pacific Bluefin[1]	N Albacore, N Swordfish, Bluefin	Albacore, SKJ	SKJ
Who is involved in running MSE	Sci. Committee	Secretariat staff and ISC[2]	Secretariat, Methods Working group, contracted expert	Secretariat, Working group on methods	Scientists from two member countries, ISC, SPC
Multispecies MSE	N/A	Desired for tropical tunas	Desired for tropical tunas	Desired for tropical tunas	Desired for tropical tunas
Collaborating with other RFMO to conduct MSE	N/A	No	ICES	No	No

[1] N Albacore and N Pacific Bluefin are jointly managed by WCPFC and IATTC with the support of the ISC scientists.
[2] ISC provides science products to both IATTC and WCPFC.

MSE can also be a useful approach in which new data and research programs are considered for evaluating the potential benefits of fisheries-independent monitoring methods. This could include a comparison of tagging studies (e.g. episodic or continuous tagging programs; conventional, electronic or genetics-based tagging methods), or potentially the impacts of new technologies, like transponding sonar buoys. One of the challenges in this process in tuna RFMOs is providing a reliable estimate of the quality of existing fisheries data (e.g. if the quality of the CPUE data is currently assumed to be better than it really is, the simulated improvement from fisheries independent data may be under-estimated).

There are various forms of software being used by groups running MSEs. These include applications, code, packages and libraries for the conditioning of Operating Models (OMs), running simulations, building Management Procedures (MPs) and presenting results and summary statistics. Existing stock assessment applications such as Multifan-CL and Stock Synthesis are being used to construct operating models conditioned on data for the stock, while others such as ASPIC are being used to inform the management procedures. A github repository at http://rfmo-mse.github.io/ has been developed by the tRFMO-MSE Working Group where updates on the list provided below will be kept. Much of the software is available from *github* repositories or from *CRAN*. **Appendix 4** is a compilation of the software used by each tRFMO as well as other RFMOs and institutions.

2.5 Relevant work by other groups

As mentioned above, there is related work going on by individual countries that are members of tuna RFMOs or by sub-regional organizations. Examples are given below.

The PNA skipjack fishery

The seven Parties to the Nauru Agreement (PNA) along with Tokelau, have notable leverage over the skipjack resource within the Western and Central Pacific Ocean. The catch from their EEZs represents >70% of the skipjack caught within the region.

Following the WCPFC agreement of a Limit Reference Point for WPCO skipjack (0.2 $SB_{F=0}$), the Parties identified objectives for the management of the fishery (see PNA and Tokelau, 2014). Analyses against these objectives led to the development of a candidate Target Reference Point of 0.5 $SB_{F=0}$, which was submitted to the WCPFC 11th Commission Meeting and included a narrative on how the proposed TRP met the objectives:

- resource sustainability, noting that this TRP is sufficiently distant from the LRP to ensure the population does not fall below the LRP and is well above SB_{MSY}, with SB_{MSY} estimated at 0.26 $SB_{F=0}$;
- economic goals, noting the current profitable performance of the major fisheries for skipjack, and that this TRP is designed to maintain the volume, size composition and value of catches in real terms at around the current levels;

- promoting stable conditions in the fisheries for skipjack by maintaining the volume, size composition and value of catches at around the current levels;
- being risk adverse, noting the substantial uncertainty about projected outcomes from changes in effort levels significantly distant from current effort levels, because of the poor understanding of the relationship between CPUE and abundance in the purse seine fishery;
- avoiding additional impacts on artisanal fisheries for skipjack, and impacts on fisheries for skipjack at higher latitudes possibly resulting from range contraction; and
- avoiding additional impacts on other target stocks and non-target species (see PNA and Tokelau, 2014).

Using the candidate TRP, the process of examining potential Harvest Control Rules has begun (e.g. Kirchner et al., 2014) using what SPC calls 'pseudo MSE'[3]. The performance of those candidate HCRs are evaluated using performance measures relevant to the management objectives, including catch value, the level of fishing effort change between management periods, and estimated CPUE.

The Australian Eastern Longline Fishery.

Australia has developed a harvest strategy to manage the domestic catches of swordfish and striped marlin within the WCPFC, developed under the guidance of the domestic Harvest Strategy Policy (HSP, see **Appendix 1**). In this mixed species fishery, Australia is responsible for the large majority of the swordfish and striped marlin catch in the western region of the southern convention area, and likely has a substantial effect on the stock status in this region. However, the population connectivity with more eastern sub-populations remains unclear, and it is recognized that Australia has limited capacity to influence the stock status of the broader region defined in the most recent assessments. A main objective for the harvest strategy was to rebuild to, and then maintain, profitable CPUE. Accordingly, a historically profitable CPUE was adopted as the target reference point (and was subsequently updated to the CPUE equivalent of the B_{MEY} proxy (0.48 B_0) defined in the HSP). The simulation-tested Harvest Control Rule was designed to try and stabilize CPUE at the target level through annual TAC adjustments. The limit reference point was also adopted from the HSP as 0.2 B_0, with the expectation that there was less than 10% chance that biomass would violate this limit reference point in a medium term time-frame.

The Maldives pole-and-line fishery

The Maldives pole-and-Line fishery for skipjack tuna became certified by the MSC in 2012. As part of the certification, various Conditions were set, including the need for a regional (IOTC) management strategy that includes a harvest control rule. To achieve this, the

[3] This process represents a series of 3-year projections to mimic the period between assessments under constant fishing levels defined by the candidate HCR. At the end of each 3-year period, uncertainty is added to the actual stock status to mimic assessment uncertainty, and the fishing level for the following 3-year period defined through the HCR based on that uncertain status. It does not include a feedback loop or specific operating model, and hence cannot be termed MSE based upon the definition involving operating models, estimation models, HCRs and feedback.

government of Maldives has contracted a consultant to undertake Management Strategy Evaluations (MSE) that would allow for the testing of alternative management strategies and their robustness to major sources of uncertainty. To support this effort, ISSF established an Advisory Committee, comprised of several scientists with expertise in MSE that would provide advice and oversight. The Report of the 2014 Meeting of the Indian Ocean Skipjack MSE Advisory Committee (Anon., 2014) provides a summary of aspects specific to the MSE simulation work undertaken and planned, as well as aspects related to the process of establishing management objectives and adopting harvest control rules at the IOTC level.

The Kobe MSE Working Group

At the Third Joint Tuna RFMOs meeting (i.e. Kobe III) it was recognized that Management Strategy Evaluation needs to be widely implemented in the tRFMOs in order to implement a Precautionary Approach for tuna fisheries management (FAO, 1996). It was therefore recommended that a Joint MSE Technical Working Group be created to work electronically in the first instance. While the working group has been recommended as good mechanism through which tRFMO efforts could be harmonized, thus far the working group has had limited success in this regard. With the advent of the ABNJ project (see below), an opportunity exists to facilitate some of the working group activities, including those that can minimize costs in cases where the same software can be reutilized.

The GEF-ABNJ Tuna Project

The project "Sustainable Management of Tuna Fisheries and Biodiversity Conservation in the Areas Beyond National Jurisdiction (ABNJ)", also known as the ABNJ Tuna project, carries out capacity-building workshops and provides support for the science-management dialogues and preparation of the MSE in certain cases. The World Wide Fund for Nature (WWF) is the lead partner for the implementation of the capacity building workshops which are designed to increase capacity of RFMO member countries to engage in: development of Harvest Strategies as a tool to improve the sustainability of tuna fisheries; including the evaluation of their performance against management objectives through a Management Strategy Evaluation (MSE) process; and understanding the sensitivity and robustness of different strategies to uncertainties. To date, workshops have been held in Sri Lanka (IOTC region) and Panama (IATTC region). On the support of the science-management dialogues, implemented through FAO, there has been support to the dialogues in IOTC, WCPFC and ICCAT. The Project has also provided support for some of the preparatory work, including continuing development of the MSE, in the case of IOTC. The Project can also provide support for a global meeting of the Kobe Joint WG on MSE.

3. TREATMENT OF UNCERTAINTY AND THE ESTIMATION OF RISK IN TUNA AND OTHER FISHERY STOCK ASSESSMENTS

Treatment of uncertainty is routinely incorporated in some form in tRFMO assessments. Examples of how uncertainty is currently characterized are given in **Table 5**, below.

Table 5. Examples of how uncertainty is currently characterized in different tuna RFMOs. This is not an exhaustive list.

Characterization of uncertainty in the assessment of stock status and harvest strategies	CCSBT (SBT)	IATTC (BET – full assessment)	ICCAT (N-ALB)	IOTC (ALB)	WCPFC (SKJ)
Multiple structural models (states of nature)					
a. One-off from base		Yes			
b. Fully factored	Yes	No	Yes	Yes	Yes
c. Typical factors	Steepness, M, catch levels, CPUE interpretation, selectivity form, CK data, tag mixing, sample size	Steepness, M, L_{max}, CPUE interpretation, selectivity variation	CPUE, 7 scenarios	Steepness, M, recruitment var, CPUE var, size data weight, catchability trend, selectivity form	Steepness, tag mixing
d. Typical number of models	320	24	7	648	6
Statistical uncertainty in each structural model				No	
a. Hessian	Yes	Yes (base only)	No		Yes (base only)
b. MCMC	Possible		No		
c. Bootstrapping	N/A		Yes, 500 replicates		
Process error in projections for each model					
a. Recruitment	Yes, with auto-correlation[2]	Yes [1]	No	Yes, with auto-correlation	Yes (200 replicates)
b. Catchability	Sensitivity in testing	Yes [1]	No	No	No
c. Starting N(age)	Yes	Yes [1]	No	No	No
d. Selectivity	No	Yes [1]	No	No	No
e. Implementation uncertainty	No	No	No	No	No

[1] IATTC includes projections in the model estimation; therefore statistical uncertainty is propagated for all estimated parameters

[2] Auto-correlation in recruitment for SBT is presently set to start after the last year of data (i.e., unlinked from current estimated high recruitments). Previously it was linked.

It is useful to distinguish between the portrayal of uncertainty in the estimation of current stock status, and uncertainty in how particular harvest strategies might meet their objectives. For current stock status, uncertainty is usually portrayed by plotting stock status estimates from alternative models on a Kobe plot or similar. Outcomes may also be expressed as a distribution where the individual models may be weighted for plausibility. The alternative models capture uncertainties due to structural issues, such as spatial structure, selectivity forms, temporal variability in selectivity and catchability, etc; how the different data sources are weighted in the overall objective function; and alternative parameter settings for processes such as natural mortality and growth, where these are fixed and not estimated internally in the models. It is common to explore full combinations of models factored across all of the axes of uncertainty. While less common, the statistical uncertainty of individual models, which may be estimated using techniques such as the hessian-delta method, bootstrapping or MCMC, may also be incorporated into the overall uncertainty framework.

Projections of stock status into the future are often used to evaluate harvest strategies (which may or may not incorporate feed-back to HCRs) against target and limit reference points and other management objectives. Such evaluations are best done in a full, closed-loop MSE framework; however, a simpler approach is often taken whereby the projections from a range of structural models are undertaken to assess the long-term performance of harvest strategies.

A portrayal of the range of possible uncertainty treatments in projections is shown in **Figure 3**. The best treatment of uncertainty in such projections is as per the third case shown in Figure 3, whereby a range of alternative models are employed, and additional uncertainty in the future projections is recognized by stochastic resampling of future recruitment, catchability and possibly other processes that are considered important to reflect. The statistical uncertainty in individual models may also be reflected in such schemes, for example by bootstrapping, or by reflecting uncertainty in the starting population for the projections using a hessian-based covariance matrix.

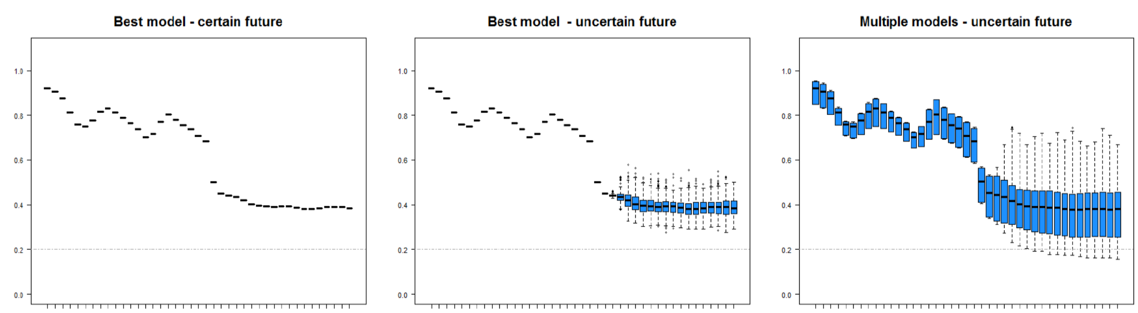

Figure 3. Example of the impact on estimation of risk that different ways of treating uncertainty can have (adopted from WCPFC). The horizontal line represents the biomass LRP. Different ways of treating uncertainty (increasing sources of uncertainty from left to right) affect the probability that future stock size will breach the LRP.

When uncertainty is reflected in the ways described above, management advice can be provided as a probability of meeting or not meeting a given management objective, such as avoiding a limit reference point. Managers are then able to evaluate harvest strategies in terms of these probabilities and what they consider to be an acceptable risk. Ultimately, the extent to which uncertainty is included in fisheries models is somewhat subjective. Also, the interpretation of risk will to some extent depend on the extent to which uncertainty is treated.

It is therefore recommended that uncertainty characterization and choice of acceptable risk levels be considered together, and that there be consistency in the interpretation of uncertainty and risk over time.

4. CONCLUSIONS AND RECOMMENDATIONS

The Workshop concluded that the tuna RFMOs are making progress towards the adoption of harvest strategies. While only CCSBT has a formal management procedure, the other RFMOs have adopted elements of harvest strategies for some stocks (e.g. limit reference points). In addition, ICCAT, IOTC and WCPFC are engaged in dialogue processes between scientists and managers to advance the work. The Workshop also recognized that substantial work is going on in individual member countries of RFMOs (e.g. Australia and Maldives), by sub-regional organizations (e.g. PNA) and by other projects (e.g. ABNJ and related work by NGOs such as WWF and ISSF), which can also help facilitate the work of the RFMOs.

The Workshop made the following general recommendations for the process leading to the adoption of harvest strategies in the tuna RFMOs to be successful.

Commit and understand different roles. It is essential that the Commissioners, as well as other key stakeholders at the national level, be fully committed to the completion of the process. The role of the scientific community is to assist by providing the technical work, and assisting the management bodies of the tRFMOs to become familiar with the concepts, but the responsibility of adoption returns to those management bodies.

Broaden participation. The dialogue meetings should also support the meaningful participation of stakeholders, and particularly those from industry, in addition to scientists and government managers. While challenging, given the number of involved parties, such practices have been shown elsewhere to increase communication and transparency, particularly with respect to uncertainties. Workshop participants particularly noted the success realized through the International Pacific Halibut Commission (IPHC) and its MSE process in improving collaboration around desired outcomes, better appreciation and prioritization of uncertainties, and improved acceptance of selected management strategies. Workshop participants noted the high value of having visits to individual t-RFMO members during which it is possible to brief not only government representatives, but other stakeholders such as industry, Civil Society Organizations (CSOs), NGOs, etc.

Make dialogue an important part of the process. A key ingredient is to have a fluid dialogue between managers and the scientific community, both to discuss the management objectives to be included in the MSE, and, later on, to discuss results of the on-going MSE until a final management procedure is agreed. This dialogue may represent a new way for managers, stakeholders and the scientific community to work jointly to develop management actions, as it would be extended beyond the initial process of developing management procedures by assessing performance of the adopted harvest strategies in the future. The terms of reference for these dialogues should enable continuity, even if participants from various member delegations may change, and set realistic workplans and schedules that recognize the process of developing and refining MSE is iterative and on going.

Consider informal format and expert facilitators. In the iterative process represented by the dialogues, an informal environment is more conducive to a fruitful discussion. The process should involve both open discussions where participants engage directly and on an even footing, and reversion to member delegations in order to finalize specific decisions and recommendations. This format is gaining preference in a number of tRFMOs and other fishery management organizations pursuing MSE as a guide for adopting management procedures. Dialogue sessions run by a skilled facilitator who can present the ideas in a non-technical way and move the process forward are highly desirable. Where possible, the formal process should have co-Chairs from the scientific community and from the management body, who work together to plan agendas and work plans.

Carry out capacity building. Capacity building is crucial as many of the stakeholders would not have previous experience with the elements of the process, and they might be unsure about the role that they are expected to play in the process. It is important to support the development of coordinated efforts on capacity-building around the issues discussed in this report, at technical, managerial, and stakeholder levels. Harmonization of terminology and curriculum for capacity building should be accelerated to avoid unnecessary confusion amongst and between tRFMOs, especially noting that many countries are parties to more than one tRFMO and lack of consistent messaging and terminology introduces unnecessary confusion.

Develop good communication tools. It is important that communication between those involved in dialogue is at a non-technical level, making use of common currencies based on familiar analogy, especially during the initial stages of development (the Kobe MSE Working Group and/or the ABNJ Tuna Project could assist in producing these materials). At first, there is a need to focus on the "big picture" and too many details are not useful. In addition, to be most effective, dialogue on the topic should be taken on in small bites in informal settings with regular frequency, and be designed to engage key stake-holders interactively, rather than to lecture. A good example is the set of communications tools used in the International Pacific Halibut Commission.

Communicate uncertainty in a way that helps decision-making. Clear communication about the sources, treatment and impacts of uncertainties allows scientists, managers and stakeholders to make better choices from among various investments and strategies intended to reduce the impacts of uncertainties and achieve improved management outcomes. Depending on the management processes developed, the tRFMOs should develop structured and transparent methods, such as tables and checklists, to identify the sources of uncertainty, the consequences for decisions and how the uncertainty is addressed in the decision-making process. Decision support tools such as the Kobe 2 Strategy Matrix used by some tRFMOs should evolve to include information on both fishery and stock performance with respect to agreed objectives. The decision table used by IPHC (**Table 6**) provides a good example of how KB2SMs could be structured to include such information.

Consider potential ecosystem changes. Harvest strategies should be robust to the impacts of environmental forcing/shift and species interactions. This requires Operating Models to be conditioned on datasets and assumptions other than those typically used in stock assessment models. Empirical MPs based on observation systems that allow integrating variations in stock sizes due to environmental forcing and/or species interactions between species need to be evaluated.

Table 6. Decision table of 2015 yield alternatives (rows) and risk metrics (columns). Values in the table represent the probability, in "times out of 100" of a particular risk (table produced following the IPHC Annual Meeting on 30 January, 2015.)

				Stock Trend				Stock Status				Fishery Trend				Fishery Status
				Spawning biomass				Spawning biomass				Fishery CEY from the harvest policy				Harvest rate
				in 2016		in 2018		in 2016		in 2018		in 2016		in 2018		in 2015
2015 Alternative	Total removals (M lb)	Fishery CEY (M lb)	Fishing intensity	is less than 2015	is 5% less than 2015	is less than 2015	is 5% less than 2015	is less than 30%	is less than 20%	is less than 30%	is less than 20%	is less than 2015	is 10% less than 2015	is less than 2015	is 10% less than 2015	is above target
No removals	0.0	0.0	$F_{100\%}$	<1/100	<1/100	<1/100	<1/100	5/100	<1/100	1/100	<1/100	<1/100	<1/100	<1/100	<1/100	0/100
FCEY = 0	13.1	0.0	$F_{73\%}$	<1/100	<1/100	<1/100	<1/100	5/100	<1/100	2/100	<1/100	<1/100	<1/100	<1/100	<1/100	<1/100
	20.0	7.7	$F_{64\%}$	<1/100	<1/100	1/100	<1/100	6/100	<1/100	3/100	<1/100	<1/100	<1/100	<1/100	<1/100	<1/100
	30.0	16.5	$F_{54\%}$	3/100	<1/100	17/100	4/100	7/100	<1/100	5/100	<1/100	3/100	2/100	3/100	2/100	4/100
Blue Line	38.7	25.0	$F_{46\%}$	19/100	<1/100	40/100	23/100	8/100	<1/100	8/100	<1/100	37/100	22/100	36/100	23/100	50/100
status quo	41.4	27.5	$F_{45\%}$	26/100	1/100	47/100	30/100	8/100	<1/100	9/100	1/100	57/100	37/100	51/100	38/100	50/100
Final adopted	42.8	29.2	$F_{44\%}$	30/100	1/100	54/100	34/100	8/100	<1/100	10/100	1/100	69/100	47/100	60/100	46/100	78/100
Maintain 2014 SPR	43.3	29.5	$F_{43\%}$	31/100	1/100	56/100	36/100	8/100	<1/100	10/100	1/100	73/100	51/100	63/100	49/100	88/100
	50.0	36.0	$F_{39\%}$	44/100	5/100	75/100	51/100	9/100	1/100	13/100	1/100	99/100	91/100	95/100	84/100	>99/100
	60.0	45.8	$F_{34\%}$	65/100	22/100	96/100	82/100	11/100	1/100	23/100	2/100	>99/100	>99/100	>99/100	>99/100	>99/100
				a	b	c	d	e	f	g	h	i	j	k	l	m

5. ADJOURNMENT

Participants were grateful to the Monterey Bay Aquarium for hosting the meeting at the Aquarium. The report was adopted by correspondence. The meeting was adjourned.

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Appendices

Appendix 1. Presentation summaries

A1.1 The CCSBT harvest strategies and how it addresses uncertainty. Jim Ianelli

In 2001 the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) adopted a plan for rebuilding the stock that was then at historically low levels. As a viable alternative to a full fishery closure, the CCSBT adopted a scientifically tested, adaptive rebuilding strategy for the depleted southern bluefin tuna (*Thunnus maccoyii*) stock. The Management Procedure (MP) adopted involves a harvest control rule that fully specifies the total allowable catch as a function of key indicators of stock status, adjusting future harvest levels every three years so as to meet the rebuilding targets agreed by CCSBT. It was chosen from a subset of candidate MPs selected following extensive simulation testing. This involved first selecting a wide range of plausible scenarios for stock status and input data, ranging from pessimistic to optimistic, against which the alternative candidate MPs were tested to ensure that they were robust to important uncertainties. The operating model used for testing the MPs characterized uncertainty based on broad range of structural uncertainty that involved a grid of 320 configurations. In July 2014 a sub-group of the Scientific Committee met to update data to complete an "assessment" using this original operating model. A key outcome of this work was to determine if the stock was "on track" or whether there were exceptional circumstances. In the presentation to the workshop, several examples of how structural uncertainties over many dimensions were demonstrated, along with the newly developed examination of within-grid estimation uncertainty. An issue with projecting recruitment for SBT was noted and auto-correlation in future years was de-linked from the terminal year of the assessment model. This case study represents the first time that a comprehensively evaluated MP has been adopted for an internationally managed tuna stock. Both the process and the outcomes have broad applicability to other internationally managed stocks.

A1.2 Progress to advance harvest strategies and addressing uncertainty in IATTC. Carolina Minte-Vera

At its 2014 annual meeting, the Inter-American Tropical Tuna Commission adopted as interim the target and limit reference points proposed by the scientific staff for the tropical tunas. The target reference points are S_{MSY} and F_{MSY}. The limit reference points are $S_{0.5R0,h=0.75}$ (the spawning biomass corresponding to that which produces a 50% reduction in recruitment as calculated using a Beverton-Holt spawner-recruit model with steepness of 0.75) and $F_{0.5R0,h=0.75}$ (fishing mortality that causes spawning biomass to be reduced to $S_{0.5R0,h=0.75}$). The operational harvest control rule (HCR) used by the IATTC has been to reduce fishing mortality to that corresponding to MSY if fishing mortality exceeds the MSY level for either YFT or BET. For the last ten years the reduction on fishing mortality has been achieved by reduction in effort mainly through temporal closures for purse-seiner and catch limits for longliners, combined with limits on fleet capacity, spatial closures and full retention measures. As the fisheries are multispecies, temporal closures based on the most harvested stock, benefit all species. The scientific staff proposed that this rule be adopted by the commission. The commission agreed that "this recommendation should be linked to the one about the adoption of reference points, and that additional evidence and controls were necessary" [Minutes of the iattc-87 meeting]. This implies testing the reference points and harvest control rule using management strategy evaluation (MSE). The HCR should also specify the action to be taken if the limit reference point is exceeded. An illustration of using the stock synthesis 3 model as a platform for MSE was carried out by the scientific staff for the Pacific Bluefin tuna (PBT) stock. Other MSE works in progress are MSE for the dorado stock, development of MSY-seeking harvest control rules, testing of the robustness of the limit reference points and MSE for Northern Albacore (N ALB) and PBT in collaboration with the ISC.

Indicators are used to monitor the SKJ stock. Indicators have also been developed for bycatch species such as silky sharks and dorado, bases on observer data (100% coverage). The assessments of YFT and BET are carried out using an age-structured population dynamic model (SS3) fitted to length-frequency and CPUE indices. The models use the "areas-as-fleets" approach. The uncertainty in the model estimates are based on the assumed sampling error of the main longline CPUE indices and the length frequency sample sizes and percolates into the projections of abundance. Uncertainty is presented as asymptotic confidence intervals. The assessment cycle is annual. Full assessments are done about every three years, in other years update assessments are carried out. In update assessments, a base-case and a single sensitivity case (assuming steepness of the stock-recruitment relationship equal to 0.75) are presented. The point estimates of the base-case model are used to provide advice to the commission. Uncertainty is presented, but not fully integrated into management. Recruitment variation is taken into consideration through the use dynamic reference points. Structural uncertainty if further explored in the full assessments. The main axes of uncertainty are: steepness of the stock-recruitment relationship, natural mortality, mean size of old individuals. Kobe plots are always presented to the commission. Kobe strategy matrix and decision tables have been computed as scientific exercises, but are not habitually used.

A1.3 Progress to advance harvest strategies and addressing uncertainty in ICCAT. Laurie Kell

Management by the Commission is based on which quadrant of the Kobe II Phase Plot (K2PP) the stock is in (Rec 11 -13), where the quadrants are defined using F_{MSY} and B_{MSY} or their proxies. The Commission then looks at the Kobe 2 Strategy Matrix (K2SM) which shows the combinations of TAC levels and number of years required to achieve rebuilding with different probabilities, and picks one of the combinations, taking into account social and economic factors. For North Atlantic Albacore and Swordfish Interim LRP have also been set at $0.4B_{MSY}$ (Recs 13-02, 13-05). In the case of albacore the final LRP will be established through further analysis using MSE. Nine out of twelve K2SMs prepared for the 5 main tuna stocks and swordfish are based on biomass dynamic stock assessment models. A generic MSE framework has been developed and used to determine under what conditions biomass dynamic models can be used to provide robust advice, i.e. that meets management objectives. This framework is intended to help enhanced dialogue to allow the

Commission to focus on the establishment of management frameworks that take into account LRPs and TRPs, associated level of risks and related Harvest Control Rules consistent with the PA.

A1.4 Progress to advance harvest strategies and addressing uncertainty in IOTC. Rishi Sharma

An update on the Indian Ocean Tuna Commission (IOTC) Management Strategy Evaluation (MSE) process was presented. The background of how the Precautionary Principle was introduced in the IOTC arena was presented and three CMMs namely Resolution 12/01, 13/10 and 14/03 that are relevant to the following; i) implementing the precautionary approach, ii) the adoption of interim target and limit reference points, and the development of harvest control rules that insure that stocks remain in healthy status with a high probability or are brought from an overfished status to a healthy stock status with a high probability in as short a time period as possible, and iii) initiating the dialogue at the Commission to develop and implement these rules. As far as the technical work regarding development of an OM, an integral part of MSE process, two approaches were being pursued by the Working Party Methods (WPM) of the IOTC. The first uses the assessment model as the basis for developing the OM for Albacore, by varying numerous parameters (structural uncertainty) used in the assessment. Management Procedures (MP) using a CPUE based rule, and a model based rule (Biomass driven) are being pursued for Albacore. The second approach builds an assessment model from first principles accounting for biological and spatial characteristics of the skipjack fishery. The model is conditioned on the pole and line, and purse seine CPUE, as well as length based samples from the primary fleets. MPs based on CPUE based rules, biomass based rules and target Fs are evaluated. Performance measures that evaluate trade-offs between different management objectives were presented, and the need for providing clear objectives and performance measures at the Commission were discussed. Problems related to operational design, management controls, capacity of countries to understand and implement a MSE, and M&E measures that may impede progress on the MSE were discussed.

A1.5 Progress to advance harvest strategies and addressing uncertainty in WCPFC. Tony Beeching and Graham Pilling

The presentation provided an overview of the Western and Central Pacific Fisheries Commissions (WCPFC) process in developing reference points and harvest control rules for WCPO stocks. Following adoption of a Limit Reference Point of $0.2SB_{F=0}$ for key tuna species (skipjack, bigeye, yellowfin and south Pacific albacore), the Kobe phase plot has been modified (the 'Majuro' plot). Capacity building activities have been undertaken within the Management Objectives Workshop process and a Harvest Strategy Conservation and Management Measure was adopted in 2014, which provides a framework for activities within the Commission on target reference points and harvest control rules. Largely driven by the Parties to the Nauru Agreement, candidate TRPs for skipjack have been evaluated, which incorporate objectives for biological sustainability, economic benefits and multispecies considerations. Candidate TRPs for south Pacific albacore have focused on economic objectives for the fishery. These TRPs have been phrased in terms of $SB_{F=0}$; F-based reference points are still being discussed.

Analyses of the consequences of candidate permissible risks of falling below the LRPs (risks being 5-20%) have been undertaken. The uncertainty included within these evaluations for management advice is under consideration. The WCPFC Scientific Committee has selected 6-9 stock assessment runs reflecting alternative parameter settings. These are used within the evaluations for each species, capturing one aspect of uncertainty. Future uncertainty is currently included through modelled recruitment variability. However, this underestimates uncertainty, and a consistent approach to more fully capture uncertainty is needed when considering risk. This conversation is ongoing.

A1.6 Management Strategy Evaluations and the Kobe Process. Laurie Kell

Management Strategy Evaluations and the Kobe Process, summarised the work of tRFMO-MSE Working Group (http://www.tuna-org.org/). There are various current activities, i.e. Quantification and Presentation of Risk, and actions related to capacity building.

A1.7 The FAO/GEF ABNJ (Common Oceans) Tuna Project: a global partnership for sustainability. Alejandro Anganuzzi

The Common Oceans (ABNJ) Tuna Project, supported by the Global Environmental Facility and coordinated by FAO, aims to achieve efficiency and sustainability in tuna production and biodiversity conservation in the Areas Beyond National Jurisdiction (ABNJ), working with a large and diverse array of partners, amongst others, the five tuna Regional Fisheries Management Organizations (t-RFMOs). Amongst its activities, the Project includes support to workshops dedicated to increase the capacity of developing states to participate effectively in MSE processes (an activity led by WWF), and support to science-management dialogues to advance MSE and the adoption of harvest strategies (led by FAO).

Scheduled to be in operations until 2019, the Project aims at facilitating existing processes in each of the RFMOs, to encourage and support the communication between RFMOs to exchange experiences, innovative approaches in communication, empower developing states to participate fully in the process, and to provide technical assistance in order to accelerate the adoption of harvest strategies in all RFMOs

A1.8 Addressing Uncertainty in Fisheries Science and Management. Eric Schwaab

This presentation summarized a recently issued report, *Addressing Uncertainty in Fisheries Science and Management* (aqua.org/fisheries). Understanding uncertainty, communicating it, reducing it where practical and accounting for it in science and management decisions are critical ongoing challenges. This report focused primarily on US domestic management challenges and explored multiple aspects of uncertainty. Based on the work of an expert panel, the report conveys a wide range of conclusions, findings, best practices and recommendations useful to scientists, managers and stakeholders. The Panel organized its work under four overarching areas of recommendation:

Identifying Uncertainty - Better educate and inform stakeholders, managers, scientists and policy-makers about the nature, scope and management implications of uncertainty, and enhance communication, particularly at the science-policy interface. Better define the roles of various participants in addressing uncertainty issues in the management process.

Reducing Uncertainty - Expand and support efforts to reduce uncertainty wherever possible through strategic investments in fisheries-dependent and fisheries-independent data, and improved modeling and assessment processes. Regularly evaluate and communicate the limits to – and costs and benefits of – reducing uncertainty.

Managing Fisheries in the Context of Environmental Change - Develop new and improved tools and processes to better understand, communicate, reduce and account for uncertainties due to ecosystem changes. There is need to place increased emphasis on broader ecosystem trends and their effects on fisheries science and management decisions.

Managing Risk - Develop and test existing and new methods that prioritize management responses to uncertainty, including Management Strategy Evaluation. Prioritize the use of adaptive management techniques that allow for more regular interaction among scientists, managers and stakeholders to adjust to changing understanding of fisheries conditions. Incorporate considerations of risk (both likelihood and severity of consequences) into management actions and explicitly communicate risk decisions.

A1.9 Management Strategy Evaluations for Pacific Halibut. Steve Martell

In 2013, the International Pacific Halibut Commission (IPHC) formed a Management Strategy Advisory Board (MSAB) with the objectives of leading a stakeholder driven approach in exploring alternative management procedures for the Pacific halibut fishery. The composition of the MSAB consists of commercial, recreational and tribal fishermen, managers, halibut buyers (processors) and one commissioner from each of the two participating countries. The role of IPHC in this process is to facilitate discussion during MSAB meetings, provide quantitative support and web-based tools for stakeholders and MSAB members to design and explore alternative management procedures and training in the use of these tools. The IPHC's MSE process actively engages stakeholders and decision makers and the process is truly stakeholder driven. The development of web-based tools (e.g. https://iphc.shinyapps.io/MSAB/) for designing and exploring alternative management procedures was a critical component for engaging stakeholders in the MSE process.

Recently, the IPHC has adopted a decision table framework for conveying advice to the Commission. The IPHC provides a risk assessment framework that integrates over structural uncertainty by producing decision tables from each of the alternative assessment models and taking the (weighted) average over all tables. This process eliminates the need to choose a single base model and accommodates alternative hypotheses.

A1.10 Review of Australia's Harvest Strategy Policy. Keith Sainsbury, Dale Kolody and Meryl Williams

An overview of the Australian Harvest Strategy Policy (HSP 2007) was presented as potentially useful background for the tuna-RFMO MSE development discussion. The HSP provided operational guidance to achieve the legislative objectives that all federally-managed Australian (targeted) fisheries be managed consistent with the general principles of "ecologically sustainable development" and "maximizing the net economic returns". The HSP included the obligation to develop and adopt simulation-tested harvest strategies, defined to include the monitoring requirements, modelling methods and Harvest Control Rules for specifying management actions (e.g. setting quota limits). The HSP recommended default target (B_{MEY}, F_{MEY}) and limit ($0.5B_{MSY}$, $0.5F_{MSY}$) reference points, recognizing that suitable proxies may be more practical to estimate and implement (e.g. $B_{MEY} \sim 0.48B_0$, $0.5B_{MSY} \sim 0.2B_0$). The harvest strategies were expected to apply the precautionary approach, such that the level of risk (probability of violating limit reference points) should be roughly equivalent regardless of whether the stock was data rich or data poor (i.e. all other things being equal, stocks with more uncertain status should generally have lower quotas). In an international context, Australia's position should be consistent with the HSP, but recognize that RFMO decisions are a negotiated outcome. The HSP provides guidance, but leaves considerable freedom for different fisheries to achieve the management objectives in different ways, provided that the approach is consistent with the intent of the HSP. The HSP is currently under review, and future iterations are expected to cover by-product (valuable, non-target) and by-catch species, using a range of methods developed for Ecological Risk Assessment.

A1.11 Swordfish harvest strategy work in Australia. Dale Kolody

A description of the Eastern Australian longline fishery harvest strategy for swordfish was presented as an example of MSE developed for a domestic fishery operating within the jurisdiction of the WCPFC (Kolody et al. 2010). The harvest strategy was developed (under the direction of HSP 2007) to regulate the swordfish catch of the Australian domestic fleet, while recognizing that the targeted population is also harvested by the adjacent international fleet to an unknown extent. Key features of the Harvest Control Rule included:

- It is a simple empirical (data-based) decision rule, based on commercial fishery observations (Prince et al. 2011).
- The key element is an annual TAC calculation that aims to stabilize the CPUE of "prime-sized" fish (the 25th-75th percentiles of the catch size distribution) at an economically desirable target level (which is well above the biological limit)
- The initial TAC based on prime-sized CPUE is potentially reduced if there are signals of poor recruitment or poor spawning biomass relative to 40% SPR equilibrium conditions.
- The harvest strategy is applied at a local scale, but would be expected to be robust to population spatial connectivity uncertainty if all fisheries applied a

similar HCR (and provided that a number of standard fisheries stationarity assumptions hold).

The HS was simulation-tested against a range of operating models derived from the 2008 assessment. These models represented a range of stock status estimates, and included different levels of stock-recruit steepness, growth, natural mortality, maturity, and spatial connectivity. The HCR appeared to provide sensible behaviour that was robust to the simulated uncertainties. Preliminary attempts to re-evaluate the HS with the updated 2013 assessment suggest some potential problems, including a mismatch between CPUE-based and SSB-based reference points, and a potential increase in the importance of the international fishery. However, since the first application of the HS in 2011, there have been no surprises in the real world application to indicate that the fishery has fallen outside of the range of dynamics encompassed by the original testing.

A1.12 Ecosystem considerations. Jean-Marc Fromentin and Laurent Dagorn

The great majority of stock assessment and management procedures are based on fisheries information and sometimes scientific surveys, but no or few environmental or ecosystemic data/considerations (except by-catch) are included. Nonetheless, growing gaps between stock assessment procedures and very recent knowledge, in particular concerning:

- Recruitment and productivity
- Synergy between fishing and climate
- Trophic interactions

Indeed, environment appears to more strongly influence recruitment than SSB for many stocks.

Environmental fluctuations can generate substantial changes in stock productivity and then the conditions for overexploitation under an otherwise acceptable fishing effort. Several regional examples, such as the Barent Sea, show that fish stocks need to be managed at a multispecies/community level because of strong interactions (i.e. predation or competition) beween species.

A paradigm shift would be to maintain the structure/functioning of the ecosystem to determine the exploitation schemes and not the reverse, as currently; i.e. moving from an ecosystem approach to fisheries to ecosystem-based fisheries.

Appendix 2. Background documents distributed prior to the meeting

WCPFC. CMM 2014-06. Conservation and management measure on establishing a harvest strategy for key fisheries and stocks in the Western and Central Pacific Ocean

Mosqueira, I. and R.Sharma. IOTC-2014-WPM05-06. Base operating model for Indian Ocean albacore tuna, scenarios included and model conditioning

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SPC-OFP. MOW3 WP-03. Current and projected stock status of skipjack tuna to inform consideration of Target Reference Points

SPC-OFP. MOW3 WP-05. Multi-species implications of reference points: what might a target reference point of 50%SBF=0 for skipjack tuna mean for bigeye and yellowfin tuna

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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.

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

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.

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 (Decision Table)

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.

Appendix 4. Computer tools

CCSBT. The MSE process was fully completed in custom-made software programmed in ADMB which include the operating model (for assessments), projections, and management procedures. The source code and R-package for evaluating outputs is maintained through a private (available to members) *git* repository. The main link for the commission for reports etc can be found at http://www.ccsbt.org.

IATTC. SS3 is used as a platform to generated operating models conditioned on data. The procedure is described in details in Maunder (2014) in an application for Pacific bluefin.

http://www.iattc.org/PDFFiles2/StockAssessmentReports/SAR15/7-Management-Strategy-Evaluation.pdf

ICCAT. "Kobe" is a CRAN package for summarizing results in Kobe II Framework http://cran.r-project.org/web/packages/kobe. **Albacore MSE** http://rscloud.iccat.int/mse/papers/SCRS2013-34.pdf

FLR Generic MSE software http://flr-project.org/doku.php

IOTC
Skipjack https://github.com/iotcwpm/SKJ
Albacore Use of SS for conditioning OMs https://github.com/iagomosqueira/SS3forOM
FLR Generic MSE softwarehttp://flr-project.org/doku.php
IOTC Working Party on Methods Working Group Report
http://iotc.org/science/wp/working-party-methods-wpm
WCPFC
R4MFCL https://http://code.google.com/p/r4mfcl/source/checkout
Multifan-CL http://www.multifan-cl.org
IPHC
IPHC MSE Tool https://iphc.shinyapps.io/MSAB/
Links to Software for conducting MSE

- iSCAM (software in development for the Halibut MSE) https://github.com/smartell/iSCAM/tree/IPHC-developer
- Delay Difference Model from ADMB Course in Hawaii https://github.com/smartell/PIFSC/tree/master/opaka/DelayDiff
- Shiny Applications for R http://shiny.rstudio.com
- Using C++ in R http://www.rcpp.org

Version Control and Code Repositories

- git http://git-scm.com

High power computing CPU & GPU and using makefiles for spawning parallel jobs

- using OpenCL in R http://cran.r-project.org/web/packages/OpenCL/OpenCL.pdf
- Example of using OpenCL in R https://github.com/smartell/DPSAM/blob/master/R/openCL/openCLeg.R
- Makefiles "http://www.gnu.org/software/make/manual/make.html
- pthreads

Other
MSE Framework for data poor stocks: http://cran.r-project.org/web/packages/DLMtool/DLMtool.pdf
SS3 http://nft.nefsc.noaa.gov/SS3.html
R4SS http://cran.r-project.org/web/packages/r4ss
NOAA MSE http://nft.nefsc.noaa.gov/MSE.html
SS3SIM An R package for fisheries stock assessment simulation with Stock Synthesis
http://arxiv-web2.library.cornell.edu/pdf/1312.6450.pdf