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Reference points, harvest control rules and management strategy evaluation in tuna Regional Fisheries Management Organisations

FINAL REPORT

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Executive Agency for Small and Medium-sized Enterprises (EASME)
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ACRONYMS

Term	Description
ALB	Albacore tuna
B	Total biomass
BET	Bigeye tuna
BFT	Bluefin tuna
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CMM	Conservation and Management Measure
CMP	Candidate management procedure
CPUE	Catch-per-unit-effort
DFAD	Drifting fish aggregation device
EASME	Executive Agency for Small and Medium-sized Enterprises
EMFF	European Maritime and Fisheries Fund
EPO	Eastern Pacific Ocean
ESC	Extended Scientific Committee (of CCSBT)
F	Fishing mortality
FAD	Fish aggregating device
FAO	Fisheries and Agricultural Organisation of the United Nations
FFA	Pacific Islands Forum Fisheries Agency
HCR	Harvest control rule
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
ICES	International Council for the Exploration of the Sea
IOTC	Indian Ocean Tuna Commission
ISC	International Scientific Committee (for Tuna and Tuna-like Species in the North Pacific Ocean)
ISSF	International Seafood Sustainability Foundation
LRP	Limit reference point
MEY	Maximum economic yield
MP	Management procedure
MSE	Management strategy evaluation
MSY	Maximum sustainable yield
OM	Operating model
OMMP	Operating Model and Management Procedure
PBF	Pacific bluefin tuna
RFMO	Regional Fisheries Management Organisation
SAC	Scientific Advisory Committee (of IATTC)
SB	Spawning biomass
SBT	Southern bluefin tuna

Term	Description
SCRS	Standing Committee on Research and Statistics (of ICCAT)
SKJ	Skipjack tuna
SPR	Spawning potential per recruit
SRR	Stock-recruitment relationship
SSB	Spawning stock biomass
SWO	Swordfish
TAC	Total allowable catch
TRP	Target referent point
UNCLOS	United Nations Convention on the Law of the Sea
UNFSA	United Nations Fish Stocks Agreement
WCPF	Western and Central Pacific Fisheries
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean
WPTT	Working Party on Tropical Tuna
YFT	Yellowfin tuna
YPR	Yield per recruit

GLOSSARY OT TERMS

Term	Description
Biomass (B)	The total weight of all organisms in a population or a defined part of the population.
Virgin Biomass (B_0)	The theoretical carrying capacity of the recruited or vulnerable biomass of a fish stock. In some cases, it refers to the average biomass of the stock in the years before fishing started. More generally, it is the average over recent years of the biomass that theoretically would have occurred if the stock had never been fished. B0 is often estimated from stock modelling and various percentages of it (e.g. 40% B0) are used as biological reference points to assess the relative status of a stock.
$B_{CURRENT}$	Current biomass (usually a mid-year biomass).
$B_{ESCAPEMENT}$	For short-lived species, a deterministic biomass limit below which a stock is considered to have reduced reproductive capacity, including any identified additional biomass need.
B_{LIM}	Reference point to indicate stock size below which the stock is in serious danger of collapse
B_{MSY}	The long-term average biomass that is achieved by fishing at a constant fishing mortality rate equal to F_{MSY}; in other words, the average biomass able to produce maximum sustainable yield (MSY). Since it is an average, the biomass at any particular time may be different from B_{MSY} because of natural variability in productivity and breeding success, though the long-term average is maintained.
B_{TARGET}	A target is a management objective based on a level of biomass (B_{TARGET}) that should be achieved and maintained
$B_{THRESHOLD}$	A threshold is a level of biomass ($B_{THRESHOLD}$) reflecting the precautionary approach that triggers pre-agreed management actions to reduce the risk of breaching the limits. Thresholds should be set sufficiently far away from limits so that there is low probability that the limits will be exceeded.
$B_{TRIGGER}$	A trigger is a level of biomass ($B_{TRIGGER}$) that triggers a specific management action.
Catch-per-unit-effort (CPUE)	The quantity of fish caught (in number or in weight) with one standard unit of fishing effort (e.g., number of fish taken per 1,000 hooks per day, or weight of fish taken per hour of trawling). CPUE is often considered an index of fish biomass (or abundance). Sometimes referred to as catch rate.
Fishing mortality (F)	The instantaneous fishing mortality rate. This is the fraction of the population (or year class or other defined group) that is expected to be caught at any single point in time. The annual fishing mortality rate is calculated using the formula $1\text{-}e^{-F}$, where "e" is the mathematical constant known as Euler's number. For example, an F of 0.54 means that 0.417, or 41.7 percent, of the population is caught each year.
$F_{0.1}$	A biological reference point that is the fishing mortality rate at which the increase in equilibrium yield per recruit in weight per unit of effort is 10% of the yield per recruit produced by the first unit of effort on the unexploited stock (i.e. the slope of the yield per recruit curve for the F0.1 rate is only 1/10th of the slope of the yield per recruit curve at its origin).
$F_{CURRENT}$	An average fishing mortality value obtained from most recent few years and excluding the final year.
F_{LIM}	The point above which the removal rate from the stock is too high.
F_{LATEST}	A single fishing mortality value obtained in the final year of the assessment, rather than an average of recent years (i.e. F_{RECENT}).

Term	Description
F_{LOSS}	Floss is usually defined as the fishing level F which will produce a long-term spawning biomass per recruit (S/R) associated to B_{LOSS}.
F_{MAX}	A biological reference point. It is the fishing mortality rate that maximises equilibrium yield per recruit. F_{MAX} is the fishing mortality level that defines growth overfishing. In general, F_{MAX} is different from FMSY (the fishing mortality that maximises sustainable yield), and is always greater than or equal to FMSY, depending on the stock-recruitment relationship.
F_{MED}	A proxy for recruitment overfishing. F_{MED} is the equivalent of the recruits per spawning stock biomass that have been above the replacement level in half the years. The usefulness of this reference point is dependent on the level of exploitation of the stock in question. It will result underestimation of FMED if the stock has only been lightly exploited. F_{MED} is viewed as a limit reference point as fishing mortality rates higher than F_{MED} lead to stock decline.
F_{MEY}	The fishing mortality rate that corresponds to the maximum economic yield.
F_{MIN}	At low biomass levels, the fishing mortality would be as close to zero as possible (F_{MIN}) to rebuild within the maximum rebuilding time period.
F_{MSY}	A fishing mortality rate that, if applied constantly, would result in B_{MSY} and maximum sustainable yield (MSY) on average over the long term
F_{RECENT}	A single fishing mortality value obtained in the final year of the assessment.
$F_{\%SPR}$	A level of fishing mortality that reduces the spawning (biomass) per recruit to x% of the unfished spawner-per-recruit (SPR) level (e.g. F20%, F30%, F40%).
F_{TARGET}	A target is a management objective based on a fishing mortality rate (F_{TARGET}) that should be achieved and maintained
$F_{X\%}$	A fishing mortality rate that leads to X percent of the maximum spawning potential (e.g., egg production, recruits, spawners) that is obtained with no fishing.
Harvest control rule (HCR)	A pre-agreed rule that describes how the harvest is to be managed based on selected indicator(s) of stock status. Also known as a decision rule.
KOBE Plot	A four-quadrant graphic that shows the status of a stock, the trajectory of the stock through time, or both. Stock abundance is on the horizontal axis, and fishing mortality is on the vertical axis. The axes are typically divided at B=B_{MSY} and F=F_{MSY}, respectively, and hence can graphically depict whether the stock is overfished and/or subject to overfishing.
Limit reference point (LRP)	A benchmark for an indicator that defines an undesirable biological state of the stock. To keep the stock safe, the probability of violating an LRP should be very low. However, if an LRP is violated, immediate action—such as a suspension of fishing—should be taken to return the stock or fishery to the target level.
Management Procedures (MP)	A set of formal actions—usually consisting of a combination of monitoring data, analysis method, and harvest control rules—that are used to manage a fishery iteratively and adaptively. MPs are derived by simulation and chosen for their performance in meeting the specified management objectives and robustness to the presence of uncertainties.
Maximum economic yield (MEY)	The sustainable catch or effort level for a commercial fishery that allows net economic returns to be maximised. Note that for most practical discount rates and fishing costs MEY will imply that the equilibrium stock of fish is larger than that associated with MSY. In this sense MEY is more environmentally conservative than MSY and should in principle help

Term	Description
	protect the fishery from unfavourable environmental impacts that may diminish the fish population.
Management strategy evaluation (MSE)	A tool that scientists and managers can use to simulate the workings of a fisheries system and allow them to test whether potential harvest strategies or management procedures (MPs) can achieve pre-agreed management objectives. In so doing, MSE helps to determine the harvest strategy likely to perform best. That means the strategy would perform well, regardless of uncertainty, and balance trade-offs amid competing management objectives. Around the world, fisheries are moving toward management based on harvest strategies to increase long-term sustainability, stability and profitability. MSE must be an integral component of the process to ensure that the chosen strategy can achieve its objectives.
Maximum sustainable yield (MSY)	The largest long-term average yield that can be taken from a stock under existing environmental conditions and a constant fishing mortality rate.
Metiér	A group of fishing operations targeting a specific assemblage of species, using a specific gear, during a precise period of the year and/or within the specific area.
Overfished	Stocks that are below a biomass limit, such as the soft limit, are frequently referred to as "overfished" (e.g. in the United States). However, the term "depleted" should generally be used in preference to "overfished" because stocks can become depleted through a combination of overfishing and environmental factors, and it is usually impossible to separate the two.
Overfishing	Overfishing is deemed to be occurring if F_{MSY} (or relevant proxies) is exceeded on average.
Precautionary approach	A management philosophy that requires consideration of risk reduction in decision-making, so that in the absence of full information, the decision taken results in the lowest risk to the stock.
Recruitment	The amount of new fish that join a defined group of fish each year—due to growth and/or migration. The defined group may be the exploited part of a population, which is described as recruitment to the fishery. The defined group also may be the whole population (fished or unfished) older than a certain age (e.g., age 1 or the age at maturity).
Recruitment overfishing	Occurs when adults are depleted to the point that they cannot replenish themselves. Without remedy, this will lead to stock collapse.
Reference points	A benchmark against which the biomass or abundance of the stock or the fishing mortality rate (or exploitation rate), or catch itself can be measured in order to determine stock status. These reference points can be targets, thresholds or limits depending on their intended use.
Selectivity	Measures the relative vulnerability of different age (size) classes to being caught by a specific fishing gear or fleet.
Spawning potential per recruit (SPR)	The lifetime contribution of spawning output (e.g., eggs) that a recruit is expected to provide under the stated fishing mortality, relative to its lifetime production without fishing. Often expressed as a percentage. For example, $SPR_{50\%}$ means that under the specified fishing mortality rate, a recruit will on average produce half the eggs in its lifetime that it would have produced without fishing.
Stock recruitment relationship (SRR)	The relationship between the parental fish stock (spawning biomass) and the resulting recruitment (usually the number of recruits to the exploitable phase). The SRR is used to predict the average number of recruits that would be produced at different population sizes. The most frequently used stock-recruitment relationship is the Beverton and Holt equation, in which

Term	Description
	the expected number of recruits changes very slowly at high levels of spawning biomass.
$SB_{0.5R0}$	Spawning biomass corresponding to that which produces a 50% reduction in recruitment as calculated in a Beverton-Holt spawner-recruit model with steepness (h)
Spawning stock biomass (SSB)	The total weight of the sexually mature part (i.e., adults) of a population.
SSB_0	The virgin spawning stock biomass prior to fishing. SSB_0 is calculated by reconstructing the population backwards to the point where fishing mortality was absent or negligible. This can be difficult to estimate due to uncertainty in historical catches. In addition, changing environmental conditions can affect recruitment patterns and result in differing values of SSB_0.
$SSB_{CURRENT}$	An average spawning stock biomass value obtained over the last few years rather than the latest point estimate.
$SSB_{F=0}$	Spawning stock biomass in the absence of fishing. This is often estimated via models by projecting the population forwards over time in the absence of fishing mortality and under constant environmental conditions, or in practice at very low exploitation intensity.
SSB_{LIM}	Spawning stock biomass (SSB) limit reference point.
SSB_{MED}	The median spawning stock biomass over a defined period.
SSB_{MSY}	SSB_{MSY}, also known as 'spawning biomass at MSY', is the biomass of spawners that would result on average if FMSY was applied constantly year after year. It is often measured by the biomass of female spawners only.
SSB_{RECENT}	Spawning stock biomass value obtained in the final year of the assessment.
Steepness	Steepness (h) is conventionally defined as the proportion of unfished recruitment (R_0) that would be expected to be produced if the spawning biomass were reduced to 20% of unfished spawning stock biomass (SSB_0). Stocks with high steepness produce many more births than deaths on average when the spawning stock is reduced to low levels by fishing. A greater excess of births over deaths means that a stock with high steepness enables a greater number of individuals to be taken from the stock sustainably, by fishing, than a comparable stock with lower steepness. The steepness of a stock is typically both very difficult to estimate and highly influential on harvest policy and stock assessment model outputs such as maximum sustainable yield and spawning stock biomass. It therefore represents a major source of uncertainty in most comprehensive stock assessments.
Target reference point (TRP)	A benchmark for an indicator that defines the target fishery state that should be achieved and maintained. Creates a buffer zone to ensure that the limit reference point (LRP) is not breached. Can be based on one or more biological, ecological, social or economic considerations.
Yield per recruit (YPR)	The expected yield (measured by numbers, biomass, etc.) that a new recruit will produce over its lifetime under a stated fishing mortality and selectivity.

Sources:
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EXECUTIVE SUMMARY

Background

1. Management plans developed by tuna RFMOs (t-RFMOs) require the adoption of management objectives and timeframes for achieving them. These can greatly benefit from using Reference Points (RP) to develop appropriate limits, targets or trigger points and help define the parameters of the management framework. Such reference points together with detailed rules on how to define allowable catches/exploitation (i.e. Harvest Control Rules, HCRs) can then be tested under different scenarios of state of nature and uncertainty to assess their effectiveness and trade-offs among different management strategies.

2. Management Strategy Evaluation (MSE) provides a platform for simulation-testing such alternative management strategies explicitly accounting for uncertainty and has therefore been increasingly used in fisheries management to support management decisions. MSE is mainly used to test how well existing or proposed management strategies perform under different scenarios or identify the most effective management strategies from a set of candidate strategies and for a given set of objectives.

Aims and objectives

This study undertook the following four main tasks:

3. Task 1: Reference points. Provide an inventory of RPs for all tuna stocks. Use of RPs between t-RFMOs to analyse their consistency and the basis for their establishment, including the strengths and weaknesses of each individual RP. To assess the relation between different types of RPs taking into account relevant factors such as the stock status and the exploitation patterns of different fisheries. Provide several case studies as examples of different types of RPs for the same tuna stock in different conservation status and harvested by different fisheries.

4. Task 2: Harvest control rules. Provide an inventory of what types of HCRs (management procedures) have been proposed, tested or applied in t-RFMOs. Analyse the strengths and weaknesses of different types of HCR (existing and under development) for tuna stocks taking into account factors such as data availability, types of fisheries and management systems. Discuss how HCRs could be developed taking into account multispecies interactions and mixed fisheries.

5. Task 3: Management Strategy Evaluation. Review the development of MSEs across t-RFMOs, including: 1) evaluate how MSE frameworks have been planned and developed across t-RFMOs; 2) review how the MSE components (operating models, Management Procedures (MP) and performance statistics) have been developed and analyse how MSE has been used to support the adoption of HCRs; 3) identify strengths and weaknesses of the process to develop HCRs and MSE frameworks within t-RFMOs; and 4) propose alternatives for improving MSE frameworks across t-RFMOs.

6. Task 4: Three t-RFMOs (i.e. WCPFC, ICCAT and IOTC) are used as case studies to provide a more detailed picture of the MSE process and its progress. The main objectives of the case studies are to understand the MSE approaches considered, their implications, and progress so far but also consider additional options that can support the MSE process.

Task 1: Review of reference points

7. Tuna RFMOs are in the process of establishing management objectives and defining target reference points (TRPs) and limit reference points (LRPs) as part of their Harvest Strategies (HS). Management objectives include sustainability, safety, production, employment and stability and RPs aim at guiding fisheries towards achieving these objectives. However, the approach towards establishing RPs is different across t-RFMOs and each approach has its own shortcomings for fisheries management practice.

8. Various methods are available to calculate RPs, including maximum sustainable yield (MSY)-based, depletion-based, spawning potential per-recruit (SPR) and yield-per-recruit (YPR).

Each method has its own particular strengths and weaknesses although both MSY- and depletion-based methods are the most commonly used by t-RFMOs.

9. Uncertainties in the stock-recruitment relationship (SRR) steepness parameter (h), can significantly weaken the ability to provide robust estimates for MSY-based RPs with the stock assessment models currently in use. One major advantage of depletion-based RPs for management is that they remain relatively stable between each assessment and have provided the least variation in the results across a range of steepness values and stock assessment models. Where major uncertainties exist in model parameters such as the stock recruitment steepness (h) value, depletion-based RPs are considered to provide a more robust approach to setting RPs.

10. A review of LRPs across various t-RFMOs has shown a lack of consistency in the values used to support their Harvest Strategies. For example, IOTC has adopted an interim MSY-based LRP for yellowfin tuna of 40%SSB_{MSY} (which is equivalent to 14%SSB_0), whereas WCPFC has adopted a depletion-based LRP of 20%$SB_{CURRENT,\ F=0}$ (equivalent to 20%SSB_0) for the same species. This would suggest that either IOTC is less precautionary or WCPFC is more conservative in setting LRPs. In reality, this discrepancy is due to the different nature of the RPs used (MSY- and depletion-based). Further to this however, stocks in separate regions may have different levels of productivity, based on different biological or fishery characteristics. It is therefore not unexpected to observe dissimilar RPs for each t-RFMO for the same species.

11. More recently, there has been a move towards adopting MSY as a LRP rather than a TRP. It has been argued that given the uncertainties in calculating MSY and the adverse biological, social and economic consequences of exceeding this, some t-RFMOs such as WCPFC now consider MSY as a LRP, in particular F_{MSY}. This is based on the precautionary approach, UNFSA and other international instruments.

12. For the biological status, LRPs have increasingly been defined as 20% of SSB_0 using depletion-based methods, which is a precautionary RP for fisheries where the SRR remains uncertain. Further to this, it has been suggested that F_{MSY} represents an "upper bound" to fishing mortality rates, which is consistent with the definition of a LRP: "a state of a fishery and/or a resource which is considered to be undesirable and which management action should avoid".

13. It has been shown that using typical SRR steepness values (h) for skipjack between 0.7-0.9, MSY-based RPs (e.g. B_{MSY}) are just above or even below the general LRP of 20%$SB_{CURRENT,F=0}$ adopted by WCPFC. Therefore under certain conditions, a reference point typically associated "to maintain or restore stocks at levels capable of producing maximum sustainable yield" would suddenly be viewed as "outside safe biological limits". This paradox occurs specifically because the 20%$SB_{CURRENT,F=0}$ as a single depletion-based LRP has been adopted across all main stocks, irrespective of the relative productivity of the population or selectivity of the fishery. Although calculating stock-specific LRPs and their associated levels of acceptable risk would help to overcome this issue, the current LRPs are biologically "precautionary" and therefore in line with the requirements of WCPFC's Convention. To date, insufficient information is available to establish different stock-specific LRPs within the region.

14. TRPs may be set to achieve management objectives, which include social and economic objectives. There is growing evidence to suggest that managing stock biomass above B_{MSY} leads to larger fish, similar catch levels with greater economic benefit and lower ecological impact. This approach is consistent with the objectives of the CFP under article 2.2, which aims to "restore and maintain populations of harvested species above levels which can produce the maximum sustainable yield".

15. Setting TRPs equivalent to 40%SSB_0 or higher instead of MSY-based (B_{MSY}) levels can bring notable differences (or underutilisation) in the level of catch opportunities and employment (fishing effort). To date, WCPFC has adopted an interim TRP for skipjack tuna based on 50%$SB_{CURRENT,F=0}$, which despite the many uncertainties, is well above the available SB_{MSY}

estimates. While the interim TRP adopted by WCPFC might appear overly conservative, the assessment for skipjack is considered uncertain.

16. To date, the probabilities of achieving TRPs and avoiding LRPs and the timeframes for achieving management objectives is currently under debate in all t-RFMOs. In particular there is no clear definition of what constitutes 'high', 'very high', 'low' and 'very low' probabilities.

Task 2: Harvest Control Rules in tuna fisheries

17. The use of HCRs has been increasingly favoured by t-RFMOs to enable them to implement good management practice of tuna stocks and also to simplify the negotiation process of establishing fishing limits and/or catch quotas and/or implementing technical measures.

18. An inventory has been provided summarising the status of HCRs in t-RFMOs for each stock. It includes HCRs that have been recommended or proposed within t-RFMOs, as well as those that are tested or applied in some form.

19. Within ICCAT, HCRs have not been defined for skipjack, yellowfin, bigeye, southern Atlantic and Mediterranean albacore, and bluefin tuna although Recommendations 11-13 and 15-07 provide a framework for establishing them. An HCR has been defined for Northern albacore in 2017 under Recommendation 17-04. Some of the strengths identified for the Northern albacore HCR include that it will be subject to peer review by SCRS in 2018 and should exceptional circumstances occur, the Commission will review and consider a possible revision of the HCR. Further to this, clear rules regarding the types of management action to be triggered at different reference points has been established, including reduction in Total Allowable Catch (TAC). The HCRs are subject to a Management Strategy Evaluation (MSE) that indicates that the HCR is robust to uncertainties in the stock. Conversely, some of the weaknesses identified show that it is not clear if probabilities relative to the RPs or the performance indicators will integrate model uncertainty, and also that the TAC is shared among many countries where there is less control over catches.

20. Since 2016, IOTC has established an HCR for skipjack tuna based on LRPs and TRPs under Resolution 16/02. IOTC has not yet established an HCR for bigeye, yellowfin or albacore. Some of the major strengths of the IOTC skipjack HCR include management objectives along with clear definitions for LRPs and TRPs, and setting of the TAC. Res. 16/02 requires the HCR and control parameters to be evaluated using MSE approach, including a clear timeline and modification of the HCR, as necessary. A number of weaknesses were identified, including that the HCR is only recently agreed and that no meaningful evaluation can yet be made. Furthermore, the HCR does not explicitly make reference to acceptable probabilities for exceeding RPs, nor is it clear how the role of subsistence fishing will be taken into account where thresholds have been exceeded. In addition, where the biomass is estimated to fall below the LRP there is no clear timeline within which a new HCR should be implemented, putting the status of the stock at higher risk of depletion.

21. WCPFC has not yet defined an HCR for skipjack, yellowfin or bigeye tuna. CMM 2014-06 calls for WCPFC to develop and implement a Harvest Strategy approach that includes TRPs, HCRs and other elements. The Northern Committee has recommended an interim management framework for North Pacific albacore whereas in 2014 a Harvest Strategy for Pacific bluefin tuna has defined HCRs to achieve specific rebuilding targets. The rebuilding phase of the North Pacific albacore HCR is explicit how management action will be taken in relation to the rebuilding TRP, alongside an established timeline. There are also acceptable levels of risk specified, considered by WCPFC to be consistent with the UNFSA. Some of the potential weaknesses of this rebuilding HCR include that it has not yet been evaluated by MSE, although this is currently under development, and that probability of the stock declining below the LRP has not been clearly defined, as described only as 'very low'.

22. In 2016, IATTC adopted an HCR for all tropical tuna under Resolution C-16-02 based on interim LRP and TRPs. With regards to North Pacific albacore, Resolution C-13-03 requires that IATTC staff shall review work undertaken by WCPFC towards the development of HCRs. With respect to the HCR for all tropical tuna, some of the strengths of Res. C-16-02 are that

it establishes clear definitions for interim LRP and TRPs, and includes pre-agreed management actions to be taken under various stock conditions, which allows management measures, such as a reduction in TAC to be implemented quickly, where required. A number of weaknesses in the HCR include that it is only considered on an interim basis until it has been assessed, as no MSE process has yet been established with no clear probabilities related to exceeding RPs given.

23. CCSBT developed a management procedure (MP) in 2011 for southern bluefin tuna, designed to achieve the recovery target. This MP, known as the 'Bali Procedure', sets clear probability-based objectives for stock rebuilding using an interim TRP within an explicit time period. CCSBT tested a number of candidate MPs against a range of uncertainties to ensure a robust procedure was identified. The MP is also assessed regularly, including an annual review of implementation and regular evaluation of new data sources and operating models. One of the potential weaknesses of the MP is the complexity of the methods used, making it difficult to communicate to stakeholders and decision makers.

24. HCRs accounting for multispecies fisheries management can be applied using catch and effort limits. In general, when using catch limits, a real time monitoring of catch is necessary but can be difficult. For example, in the IOTC there is a time lag between landings and the effective sampling of catch. This can cause problems of non-compliance if the excess of catch is not detected or to premature closures if catch is overestimated.

25. In multispecies fisheries it is not possible to apply different levels of fishing effort to two or more species that are vulnerable to the same fishing gear and inhabit the same habitat. Provided that discarding is undesirable based on the Common Fishery Principles, when the catch limit for one stock, (e.g. yellowfin in IOTC or bigeye in ICCAT) is reached (choke species) but not for the others, fleets will stop their fishing operations. In that case, the catch limits for skipjack for example will not be reached with the associated loss of opportunities for the fishing fleets and other undesirable socioeconomic consequences. The latter include loss of food production, shortages to canneries and potentially price increases due to a lower supply at international markets.

26. In general, TAC based management requires accurate estimates of stock status, RPs and recruitment when catch limits are set. Should the biomass and recruitment be underestimated, catch limits will be reached sooner than expected and fishing opportunities would be wasted unless the choke species is discarded. On the contrary, if stock biomass is overestimated, when managing with fixed catch limits, biomass will continue to decline as fishing mortality will increase. In this regard, effort controls are a more flexible way to deal with multispecies fisheries since they can reconcile conservation objectives of two or more stocks when they are set for the most vulnerable stock, in this case bigeye.

27. Fishing effort limits are restrictions on the intensity of use of the fishing gears. These can include limits to the period of the fishing season, which is relatively easy to enforce through vessel monitoring systems (VMS), use of logbooks and other measures. Also, fishing effort control reduces the need for a real time monitoring of catch which is often difficult and expensive. Under effort control systems, it is no longer necessary to estimate the fishable biomass accurately every year, as the level of fishing mortality is restrained directly, irrespective of the continual fluctuations of stock size by controlling the level of fishing effort. In order to be effective, effort based management would require a tight control on fleets' technological capacity and catchability. In cases where fishing capacity increases, the fishing mortality produced with a given effort could be higher than expected and thus, compromise the sustainability of the stocks.

28. To date, only ICCAT uses TACs or overall catch limits for all the fleets involved in tropical tuna fisheries. IATTC and WCPFC apply output controls (TAC) only for longline fleets targeting bigeye tuna. In the Pacific, purse seine fleets activity is regulated through effort limits (the days of the fishing season). The IATTC uses an effort based pseudo-HCR to determine the number of fishing days that purse seines are permitted to fish in order to achieve MSY.

29. In 2017, IATTC attempted to introduce catch limits for bigeye and yellowfin catch from purse seine fleets operating with FADs and an additional catch limit for yellowfin from dolphin associated fisheries. In practice this proved difficult to implement as the purse seine fleet fishing on FADs had reached 80% of the total annual catch limit by mid-July. This led to the introduction of a new measure (C-17-02) after only 5 months, which prevented the FAD fishery from closing in August or early September, with dramatic consequences for purse seine fleets.

Task 3: Management Strategy Evaluation

30. The five t-RFMOs have carried out some type of MSE work, including consultation on management objectives, characterization of uncertainty of stocks' dynamics and observation, and evaluation of harvest strategies. Most of the MSE conducted to date has been developed by the RFMO science providers with seldom direct mandate from the Commissions.

31. The study provided an overview of operating models (OMs), HCRs and performance statistics used. OMs provide mathematical representations of the system that is being managed. The impact of fisheries management is evaluated before implementation in the OMs when using MSE. The OMs are considered alternative representations of the "true" dynamics of the stock and aim at covering all the uncertainties inherent to fish and fisheries' dynamics.

32. Today, MSE is being developed for single species only, with objectives of maintaining stocks at healthy levels, promoting the successful recovery of overexploited stocks and to evaluate the economic benefits of precautionary management. In order to engage third countries in the MSE process across t-RFMOs, several initiatives (workshops, capacity building, courses and projects) are being organized. This will help developing new MSE frameworks that consider alternative approaches such as multispecies interactions etc. The initiatives to promote the engagement of third countries and to develop alternative MSE approaches have been reviewed, including the impact of the Areas Beyond National Jurisdiction project on this process.

33. All five t-RFMOs have plans for evaluating MPs using MSE. In some RFMOs, the roadmap towards adopting MPs is clearly detailed and in others the process is only at an initial state.

34. The process in IOTC relies on the technical work and the interaction with the Commission. The IOTC aims at being able to adopt MPs for its most important stocks by 2020. In ICCAT, the MSE process is well advanced for North Atlantic albacore and bluefin. One of the differential aspects of ICCAT's MSE process is that it will be independently evaluated, with the evaluation of North Atlantic albacore MSE in 2018 that will contribute to the improvement of the process for other stocks. In addition, it will contemplate options for the multispecies management instead of the current single species management framework. In the WCPFC the feedback process is advanced and has made substantial progress in defining management objectives thanks to a number of dialogue workshops. In the IATTC, the MSE work consists on identifying appropriate HCRs for bigeye and yellowfin but it is still in its early stages. There is a plan for MSE development that will be presented in the 2018 Scientific Advisory Committee. The CCSBT has decided to develop a new MP to guide the setting of TACs for 2021 and onwards. The new MP will take into account changes in data availability, in particular changing the recruitment monitoring series from an aerial survey of juveniles to a juvenile gene tag/recapture program.

Task 4: Case studies of select tuna RFMOs

Harvest Strategies of WCPFC

35. WCPFC has progressed in developing Harvest Strategies incorporating the maximum economic yield (MEY) concept as well as socioeconomic and environmental objectives. WCPFC has tried to operationalise the use of MEY by explicitly accounting for economic yield (e.g. revenues) in their analysis despite concerns about completeness and viability of such work. This provides for an industry that is profitable and takes advantage of market trends and technological advances to achieve the best price and profit margins. However, higher

fish prices mean reduced access to people of lower economic income to this important source of nutrients (e.g. developing countries, coastal communities that might rely on fish for their food).

36. There are options other than those currently suggested in the Scientific Committee meetings and other working groups that could also lead to plausible Harvest Strategies that are discussed in this report. It is obvious that there is a diverse range of options that one can consider for the management of a fishery. However, it is not possible to say which of them performs better until it is clear what the strategy needs to achieve. Therefore, agreeing on management objectives including priorities and a weight assigned to each objective still remains a crucial step that, once completed, will add clarity to the process.

Development of mixed fisheries and single stock MSE for tropical tunas for IOTC and ICCAT: define options and preliminary models

37. This study represents a first step in the evaluation of management strategies for tropical tuna stocks in a mixed-fisheries framework. We have compared three different management strategies combined with different fleet dynamics. The effort-based management with a 25% reduction was translated into fleet dynamics reducing the effort of all the fleets by 25%. The other two HCRs used correspond to the HCRs proposed by ICES in the MSY framework and to a multi-stock HCR that uses fishing mortality ranges around MSY targets. These two HCRs were combined with two different fleet dynamics which differed in the condition used to restrict the effort of the fleets, the minimum effort or the effort corresponding to the TAC of bigeye.

38. The multi-stock HCR with restricted bigeye TAC produced on average sustainable biomasses for the three stocks but the probability of being below LRP (B_{LIM}) was higher than zero in some years. This type of management should be combined with strict control measures to ensure the fulfilment of the TAC advice.

39. The fleet dynamics used in this work were based on their historical behaviour. However, future work should focus first on the definition of the fleets and their métiers and afterwards identify the dynamics that better describe the fleet dynamics.

40. Simulations were based on an annual rather than quarterly time period that is used in stock assessment models. Future work should develop the simulation model in a seasonal fashion in order to provide a more accurate representation of the dynamic of the fleet and a consistent approach between the stock assessment and the simulation model.

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RÉSUMÉ EXÉCUTIF

Background

1. Les plans de gestion développés par les ORGP thonières nécessitent l'adoption d'objectifs précis et de délais d'exécution. Ceux-ci peuvent être soutenus par des Points de Références (PR) visant à développer des limites appropriées, objectifs ou points de déclenchement, et à définir les paramètres du cadre de gestion. De tels PR, ainsi que des règles détaillées précisant la manière dont les totaux autorisés de captures/exploitation (TAC) sont définis (Harvest Control Rules, HCR), peuvent être testés sous différents scénarios de l'état de nature et incertitude afin d'évaluer leur efficacité sous différentes stratégies de gestion.
2. L'Evaluation de la Stratégie de Gestion (« Management Strategy Evaluation », MSE) fournit un outil permettant la réalisation de tests de simulations. Les MSE sont de plus en plus utilisés en gestion des pêcheries. Elles sont principalement utilisées pour mesurer la performance de stratégies de gestion actuelles et proposées sous différents scénarios, ou pour identifier les stratégies les plus efficaces parmi une série de potentielles stratégies visant un ensemble d'objectifs en particulier.

Objectifs principaux

Les quatre tâches suivantes ont été entreprises durant l'étude :

3. Tâche 1 : Points de Référence (PR). Fournir un inventaire de PR pour tous les stocks de thon. Analyser la cohérence des PR entre ORGP et la base de leur définition, en précisant les forces et les faiblesses associées à chaque PR. Evaluer la relation entre différents types de PR en tenant compte de facteurs pertinents tels que l'état des stocks et le mode d'exploitation pour différentes pêcheries. Fournir plusieurs études de cas comme exemples de différents types de PR pour un même stock de thon, mais dans différents états de conservation et récolté par différentes pêcheries.
4. Tâche 2 : Règles de Contrôle de Capture (« Harvest Control Rules », HCR). Fournir un inventaire du type de HCR qui ont été proposés, testés ou appliqués dans les ORGP. Analyser les forces et les faiblesses de différents HCR (existants et en développement) pour les stocks de thon, en tenant compte de facteurs tels que la disponibilité des données, le type de pêcherie et le système de gestion. Examiner comment les HCR pourraient être développés en tenant compte des interactions multi-espèces et des pêcheries mixtes.
5. Tâche 3 : Evaluation de la Stratégie de Gestion (« Management Strategy Evaluation », MSE). Examiner le développement de MSE dans les différentes ORGP thonières, en : 1) évaluant comment les MSE ont été planifiés et développés ; 2) examinant comment les composantes de MSE (modèles d'opération, procédures de gestion, et statistiques de performance) ont été développées et comment les MSE ont été utilisés pour soutenir l'adoption de HCR ; 3) identifiant les forces et les faiblesses du processus de développement d'HCR et d'MSE dans les ORGP thonières ; et en 4) proposant des alternatives pour améliorer les MSE dans les ORGP thonières.
6. Tâche 4 : Fournir une image plus détaillée du processus de développement de MSE et de son évolution à travers trois études de cas d'ORGP thonières (WCFC, CICTA et CTOI). L'objectif principal des études de cas est de comprendre les approches de MSE considérés, leurs implications, et le progrès fait jusqu'à ce jour, mais aussi de considérer certaines options supplémentaires qui peuvent soutenir le processus de développement de MSE.

Tâche 1 : Points de Référence

7. Les ORGP thonières sont en train d'établir des objectifs de gestion et de définir des Points de Référence Cibles (PRC) et Limites de Points de Références (LPR) dans le contexte de leurs Stratégies d'Exploitation (SE). Les objectifs de gestion incluent la durabilité, la sécurité, la production, l'emploi et la stabilité des pêcheries. Les PR visent à guider les pêcheries vers l'atteinte de ces objectifs.
8. Plusieurs méthodes existent pour calculer les PR, par exemple des méthodes basées sur le rendement maximal durable (RMD, ou « Maximum Sustainable Yield », MSY), l'épuisement

des stocks, le potentiel de reproduction par recrue, et le rendement par recrue. Chaque méthode possède ses propres forces et faiblesses. Cependant, les méthodes basées sur le RMD et l'épuisement des stocks sont les méthodes les plus fréquemment utilisées par les ORGP.

9. Les incertitudes liées au paramètre de la pente de la relation stock-recrutement peuvent affaiblir de manière considérable l'exactitude de PR basés sur le RMD en utilisant les modèles actuels d'évaluation des stocks. L'un des principaux avantages de PR basés sur l'épuisement des stocks pour la gestion des pêcheries réside dans leur relative stabilité d'une évaluation à l'autre. Ces PR ont montré les variations les moins importantes dans les résultats pour une série de pentes et modèles d'évaluation des stocks. Les PR basés sur l'épuisement des stocks sont considérés comme étant les plus fiables lorsque de grandes incertitudes existent autour de paramètres tels que la pente de la relation stock-recrutement.

10. L'examen de LPR de différentes ORGP montre un manque de cohérence dans les valeurs utilisées pour appuyer leurs SE. Par exemple, la CTOI a adopté une LPR temporaire basée sur le RMD pour le thon Albacore de 40%SSB_{MSY} (équivalent à 14%SSB_0), tandis que la WCPFC a adopté une LPR de 20%$SB_{CURRENT,\ F=0}$ (équivalent à 20%SSB_0) pour la même espèce. Cela laisse à penser que soit la CTOI adopte une approche moins prudente, soit la WCPFC utilise une méthode plus conservative pour définir les LPR. En réalité, ces écarts sont dus à la nature différente des PR (basés sur le RMD ou l'épuisement des stocks). Certains stocks dans des régions différentes peuvent avoir des niveaux de productivité différents, du aux différences biologiques ou aux caractéristiques des pêcheries. Il n'est donc pas étonnant d'observer des PR différents pour chaque ORGP thonière pour les mêmes espèces.

11. De plus en plus de LPR sont aujourd'hui définies sur base du RMD plutôt que sur base des PRC. Du aux incertitudes dans le calcul du RMD et aux conséquences biologiques, sociales et économiques engendrées par son dépassement, certaines ORGP telles que la WCPFC définissent la LPR comme le RMD. Ceci est basé sur l'approche de précaution, l'Accord sur les stocks de poisson des Nations Unies, et d'autres outils internationaux.

12. Pour le statut biologique, les LPR sont de plus en plus établies à 20% SSB_0 en utilisant des méthodes basées sur l'épuisement des stocks, qui est un PR prudent pour les pêcheries pour lesquelles le SSR reste incertain. De plus, il a été suggéré que F_{MSY} représente une limite supérieure aux taux de mortalité par pêche, ce qui est cohérent avec la définition d'une LPR : « un état de pêcherie et/ou une ressource qui est considéré comme indésirable et que les mesures de gestion devraient éviter ».

13. Il a été démontré qu'en utilisant des valeurs typiques SRR de pentes pour le listao entre 0.7-0.9, les PR basés sur le RMD (B_{MSY}) sont juste au-dessus ou même en dessous de la LPR générale de 20% $SB_{CURRENT,F=0}$ adoptée par la WCPFC. Dès lors, sous certaines conditions, un PR typique défini « pour maintenir ou restaurer les stocks à des niveaux capables de produire le RMD » pourrait soudainement être vu comme « hors des limites biologiques de sécurité ». Ce paradoxe apparait car les 20% $SB_{CURRENT,F=0}$ comme seule LPR basée sur l'épuisement des stocks a été adoptée pour tous les stocks principaux, indépendamment de la productivité relative de la population ou de la sélectivité de la pêcherie. Malgré que le calcul de LPR spécifiques à un stock et leurs niveaux associés de risque acceptable pourrait aider à surmonter le problème, les LPR actuels sont biologiquement « prudentes » et ainsi en ligne avec les exigences de la Convention de la WCPFC. A ce jour, les données disponibles sont insuffisantes pour établir des LPR spécifiques à chaque stock dans la région.

14. Des PRC peuvent être définis afin d'atteindre des objectifs de gestion, comprenant des objectifs sociaux ou économiques. Il est de plus en plus suggéré que la gestion de la biomasse du stock au-dessus de B_{MSY} conduit à des poissons plus gros, à des niveaux de capture similaires avec un avantage économique plus important et un impact écologique moindre. Cette approche est cohérente avec les objectifs de la PCP en vertu de l'article 2.2, qui vise à « rétablir et maintenir les populations d'espèces exploitées au-dessus des niveaux qui peuvent produire le rendement maximal durable ».

15. Définir des PRC équivalents à 40%SSB_0 ou plus élevés au lieu de les baser sur le RMD (B_{MSY}) peut apporter des différences notables (ou sous-utilisations) dans le niveau d'effort de pêche. A ce jour, la WCPFC a adopté un PRC temporaire pour le thon listao basé sur 50% $SB_{CURRENT,F=0}$, qui, malgré les nombreuses incertitudes, est bien au-dessus des estimations disponibles de SB_{MSY}. Même si le PRC adopté par la WCPFC peut paraître fort conservateur, l'évaluation pour le thon listao est considérée comme incertaine.

16. Aujourd'hui, les probabilités d'atteindre les PRC et les objectifs de gestion dans les délais définis, ainsi que d'éviter d'atteindre les LPR, font l'objet de débats dans toutes les ORGP thonières. Il n'existe notamment pas de définition claire de probabilités « élevées, « très élevées », « faibles » et « très faibles ».

Tâche 2 : Règles de Contrôle de Capture (« Harvest Control Rules », HCR)

17. L'utilisation de HCR a été de plus en plus privilégiée par les ORGP thonières pour mettre en œuvre de bonnes pratiques de gestion des stocks et de simplifier le processus de négociation des limites de pêche et/ou de l'implémentation des mesures techniques.

18. Un inventaire a été fourni résumant l'état des HCR dans les ORGP thonières pour chaque stock. L'inventaire comprend les HCR qui ont été recommandés ou proposés dans les ORGP thonières, ainsi que ceux qui ont été testés ou appliqués.

19. Au sein de la CICTA, des HCR n'ont pas été définis pour le listao, l'albacore, le thon obèse, le germon de l'Atlantique sud et méditerranéen et le thon rouge, bien que les Recommandations 11-13 et 15-07 fournissent un cadre pour leur établissement. Un HCR a été défini pour le germon du Nord en 2017 en vertu de la Recommandation 17-04. Certaines des forces identifiées pour le HCR du germon du Nord comprennent le fait qu'il fera l'objet d'un examen par le SCRS en 2018 et que dans des circonstances exceptionnelles, la Commission examinera et envisagera une éventuelle révision du HCR. De plus, des règles claires concernant les types d'actions de gestion à déclencher pour différents PR ont été établies, y compris la réduction du total autorisé de capture (TAC). Les HCR sont soumis à des MSE qui indiquent que le HCR est robuste en cas d'incertitudes. Certaines des faiblesses identifiées montrent qu'il n'est pas clair si les probabilités relatives aux PR ou aux indicateurs de performance intégreront l'incertitude du modèle. De plus, le TAC est partagé entre de nombreux pays où le contrôle sur les captures est faible.

20. Depuis 2016, la CTOI a établi un HCR pour le thon listao sur base des LPR et des PRC en vertu de la Résolution 16/02. La CTOI n'a pas encore établi de HCR pour le thon obèse, l'albacore ou le germon. Parmi les principales forces du HCR de la CTOI, citons les objectifs de gestion ainsi que des définitions claires pour les LPR et PRC, et la définition du TAC. La Res. 16/02 exige que le HCR et les paramètres de contrôle soient évalués par MSE. Un certain nombre de faiblesses ont été identifiées, y compris le fait que le HCR n'a que récemment été accepté et qu'aucune évaluation significative n'a encore pu être réalisée. En outre, le HCR ne fait pas explicitement référence aux probabilités acceptables de dépassement des PR, et il n'est pas clair comment le rôle de la pêche de subsistance sera pris en compte lors de dépassements de seuils. Par ailleurs, lorsque la biomasse est estimée inférieure à la LPR, il n'existe pas de délais précis dans lesquels un nouveau HCR devrait être mis en œuvre, ce qui augmente le risque d'épuisement du stock.

21. La WCPFC n'a pas encore défini de HCR pour le listao, l'albacore ou le thon obèse. CMM 2014-06 demande à la WCPFC d'élaborer et de mettre en œuvre une stratégie de capture qui comprend des PRC, HCR et autres éléments. Le Comité du Nord a recommandé un cadre de gestion provisoire pour le germon du Pacifique Nord, tandis qu'en 2014, une stratégie de capture pour le thon rouge du Pacifique a défini les HCR pour atteindre des objectifs de reconstitution spécifiques. La phase de reconstruction du HCR du germon du Pacifique Nord est explicite quant à la manière dont les mesures de gestion seront prises en relation avec le PRC de reconstruction, parallèlement à un calendrier établi. Des niveaux de risques acceptables sont également précisés, considérés par la WCPFC comme compatibles avec l'Accord sur les stocks de poisson des Nations Unies. Certaines des faiblesses potentielles de ce HCR incluent le fait qu'il n'a pas encore été évalué par MSE, bien que cela soit en

cours de développement, et que la probabilité que le stock baisse en dessous de la LPR n'a pas été clairement définie, autrement que « très basse ».

22. En 2016, la IATTC a adopté un HCR pour tous les thons tropicaux en vertu de la Résolution C-16-02 sur base de LPR et des PRC intérimaires. En ce qui concerne le germon du Pacifique Nord, la Résolution C-13-03 exige que le personnel de l'IATTC examine les travaux entrepris par la WCPFC en vue de l'élaboration des HCR. Quant aux HCR pour tous les thons tropicaux, certaines des forces de la Res. C-16-02 sont qu'elle établit des définitions claires pour les LPR et PRC temporaires et qu'elle prévoit des mesures de gestion convenues au préalable dans diverses conditions de stock, ce qui permet la mise en œuvre rapide de mesures de gestion, le cas échéant. Certaines faiblesses du HCR incluent qu'il n'est considéré que provisoire jusqu'à ce qu'il soit évalué, car aucun MSE n'a encore été établie sans probabilités claires liées au dépassement des PR donnés.

23. La CCSBT a élaboré une procédure de gestion (PG) en 2011 pour le thon rouge du Sud, conçue dans le but d'atteindre l'objectif de reconstruction. Cette PG, connue sous le nom de « procédure de Bali », établit clairement des objectifs basés sur la probabilité pour la reconstitution des stocks en utilisant un PRC provisoire dans une période de temps explicite. La CCSBT a testé un certain nombre de PG liés à une série d'incertitudes afin de s'assurer qu'une procédure robuste ai été identifiée. La PG fait également l'objet d'évaluations régulières, y compris un examen annuel de sa mise en œuvre et une évaluation régulière des nouvelles sources de données et des modèles d'exploitation. L'une des faiblesses potentielles de la PG est la complexité des méthodes utilisées, ce qui rend difficile la communication aux parties prenantes et aux décideurs.

24. Les HCR prenant en compte la gestion des pêcheries multispécifiques peuvent être appliquées en utilisant des limites de capture et d'effort. En général, pour les limites de capture, une surveillance en temps réel des captures est nécessaire mais peut être difficile. Par exemple, au sein de la CTOI il y a un décalage temporel entre les débarquements et l'échantillonnage effectif des captures. Cela peut causer des problèmes de non-conformité si l'excès de capture n'est pas détecté ou engendrer des fermetures prématurées si les captures sont surestimées.

25. Dans les pêcheries multispécifiques, il n'est pas possible d'appliquer différents niveaux d'effort de pêche à deux espèces ou plus qui sont vulnérables au même engin de pêche et qui habitent le même habitat. Sachant que les rejets sont indésirables sur la base des Principes Communs de Pêche, lorsque la limite de capture d'un stock (par exemple l'albacore dans la CTOI ou le thon obèse dans la CICTA) est atteinte (« choke species ») mais pas pour les autres, les flottilles arrêteront leurs activités de pêche. Dans ce cas, les limites de capture pour le listao, par exemple, ne seront pas atteintes, avec la perte d'opportunités associée pour les flottes de pêche, et d'autres conséquences socio-économiques indésirables. Ces dernières comprennent la perte de production alimentaire, des pénuries de conserveries et des augmentations potentielles de prix en raison d'une offre plus faible sur les marchés internationaux.

26. En général, la gestion basée sur les TAC nécessite des estimations précises de l'état des stocks, des PR et du taux de recrutement lorsque les limites de capture sont fixées. Si la biomasse et le recrutement sont sous-estimés, les limites de capture seront atteintes plus tôt que prévu et les possibilités de pêche seront gaspillées à moins que l'espèce « choke » ne soit rejetée. Au contraire, si la biomasse du stock est surestimée, la biomasse continuera à diminuer alors que la mortalité augmentera. À cet égard, les contrôles de l'effort constituent un moyen plus souple pour gérer les pêcheries multispécifiques puisqu'ils peuvent concilier les objectifs de conservation de deux stocks ou plus lorsqu'ils sont fixés pour le stock le plus vulnérable.

27. Les limites de l'effort de pêche sont des restrictions sur l'intensité d'utilisation des engins de pêche. Ceux-ci peuvent inclure des limitations de la durée de la saison de pêche, qui sont relativement faciles à appliquer par le biais de systèmes de surveillance des navires (VMS), l'utilisation des journaux de bord, et autres mesures. De plus, le contrôle de l'effort de pêche réduit la nécessité d'un suivi en temps réel des captures, ce qui est souvent difficile et coûteux. Dans les systèmes de contrôle de l'effort, il n'est plus nécessaire d'estimer la

biomasse exploitable précisément chaque année, puisque le niveau de mortalité par pêche est directement limité, indépendamment des fluctuations continues de la taille du stock. Afin d'être efficace, la gestion par effort exige un contrôle strict de la capacité technologique et du potentiel de capture des flottes. Dans certains cas où la capacité de pêche augmente, la mortalité par pêcherie due à un effort donné pourrait être plus élevée que prévu et pourrait dès lors compromettre la durabilité des stocks.

28. À ce jour, seule la CICTA utilise des TAC ou des limites de capture globales pour toutes les flottilles impliquées dans les pêcheries thonière tropicales. L'IATTC et la WCPFC appliquent des contrôles de captures (TAC) uniquement pour les flottilles palangrières ciblant le thon obèse. Dans le Pacifique, l'activité des flottilles de senneurs est réglementée par des limites d'effort (durée de la saison). La CICTA utilise un pseudo-HCR basé sur l'effort pour déterminer le nombre de jours où les senneurs peuvent pêcher afin d'atteindre le RMD.

29. En 2017, la CICTA a tenté d'introduire des limites de capture pour le thon obèse et l'albacore pour les flottilles de senneurs opérant avec des dispositifs de concentration de poisson (DCP) et une limite de capture supplémentaire pour l'albacore provenant des pêcheries associées aux dauphins. En pratique, cela s'est avéré difficile à mettre en œuvre car la flottille de senneurs pêchant sur les DCP avait atteint 80% de la limite de capture annuelle totale à la mi-juillet. Ceci a conduit à l'introduction d'une nouvelle mesure (C-17-02) après seulement cinq mois, qui a empêché la fermeture de la pêcherie de DCP en août ou début septembre, avec des conséquences dramatiques pour les flottes de senneurs.

Tâche 3: Evaluation des Stratégies de Gestion (« Management Strategy Evaluation », MSE)

30. Les cinq ORGP thonières ont réalisé un certain travail sur les MSE, y compris la consultation sur les objectifs de gestion, la caractérisation de l'incertitude de la dynamique et de l'observation des stocks, et l'évaluation des stratégies de capture. La plupart des MSE réalisés à ce jour ont été élaborées par les scientifiques recrutés par des ORGP avec un mandat rarement donné par les Commissions.

31. L'étude a donné un aperçu des modèles d'exploitation (« Operating Models », OM), des HCR, et des statistiques de performance utilisées. Les OM fournissent des représentations mathématiques du système géré. L'impact de la gestion des pêcheries est évalué avant sa mise en œuvre dans les OM lors de l'utilisation de MSE. Les OM sont considérés comme des représentations alternatives de la dynamique « réelle » du stock et visent à prendre en compte toutes les incertitudes inhérentes à la dynamique du poisson et de la pêche.

32. Aujourd'hui, les MSE sont développés pour des espèces individuelles, avec pour objectifs de maintenir les stocks à un niveau sain, de favoriser le succès de la reconstitution des stocks surexploités et d'évaluer les avantages économiques de la gestion préventive. Afin d'impliquer les pays tiers dans le processus d'MSE à travers les ORGP thonières, plusieurs initiatives (ateliers, renforcement des capacités, cours et projets) sont mises en place. Les initiatives visant à promouvoir l'engagement des pays tiers et à développer d'autres approches MSE ont été examinées, y compris l'impact du projet « Areas Beyond National Jurisdiction » sur ce processus.

33. Les cinq ORGP thonières ont des plans visant à évaluer les procédures de gestion (« Management Procedures », MP) en utilisant des MSE. Dans certaines ORGP, la feuille de route vers l'adoption des MP est clairement détaillée et dans d'autres, le processus n'est qu'à ses débuts.

34. Le processus de la CTOI repose sur le travail technique et l'interaction avec la Commission. La CTOI vise à être en mesure d'adopter des MP pour ses stocks les plus importants d'ici 2020. À la CICTA, le processus d'MSE est bien avancé pour le germon et le thon rouge de l'Atlantique Nord. L'un des aspects particuliers du processus de MSE de la CICTA est qu'il sera évalué de manière indépendante, avec l'évaluation de l'MSE du germon de l'Atlantique Nord en 2018 qui contribuera à l'amélioration du processus pour d'autres stocks. En outre, il envisagera des options pour la gestion multispécifique au lieu du cadre actuel de gestion d'une seule espèce. Au sein de la WCPFC, le processus de feedback est avancé et a fait des progrès importants dans la définition des objectifs de gestion grâce à un certain nombre

d'ateliers de concertation. En ce qui concerne la CICTA, le travail de MSE consiste à identifier les HCR appropriés pour le thon obèse et l'albacore, mais il n'en est qu'à ses débuts. Un plan pour le développement de MSE sera présenté au Comité Consultatif Scientifique de 2018. La CCSBT a décidé de développer un nouveau MP pour guider l'établissement des TAC pour 2021 et au-delà. Le nouveau MP tiendra compte des changements dans la disponibilité des données, en particulier en changeant la série de surveillance du recrutement, d'une enquête aérienne sur les juvéniles à un programme de marquage génétique/recapture de juvéniles.

Tâche 4 : Etudes de cas d'ORGP sélectionnées

Stratégies de capture du WCPFC

35. La WCPFC a progressé dans l'élaboration de stratégies de capture intégrant le concept de rendement économique maximal (« Maximum Economic Yield », MEY) ainsi que des objectifs socioéconomiques et environnementaux. La WCPFC a tenté d'opérationnaliser l'utilisation du MEY en tenant explicitement compte du rendement économique (par exemple des revenus) dans son analyse, malgré certaines préoccupations sur l'intégralité et la viabilité de ce travail. Cela permet le développement d'une industrie rentable qui tire parti des tendances du marché et des progrès technologiques afin d'obtenir les meilleurs prix et marges bénéficiaires. Cependant, les prix plus élevés du poisson signifient un accès réduit à cette source importante nutriments pour les personnes à faibles revenus, dans les pays en développement ou dans les communautés côtières qui dépendent du poisson pour leur subsistance.

36. Le présent rapport examine d'autres options que celles actuellement suggérées dans les réunions du Comité Scientifique et d'autres groupes de travail qui pourraient également mener à des stratégies de capture plausibles. Il est évident qu'il existe un large éventail d'options que l'on peut envisager pour la gestion d'une pêcherie. Cependant, il n'est pas possible d'établir au préalable lesquelles d'entre elles fonctionneront le mieux jusqu'à ce que les objectifs de la stratégie soient clairement définis. Par conséquent, s'entendre sur les objectifs de gestion, y compris les priorités et la pondération attribuée à chaque objectif, demeure une étape cruciale qui, une fois terminée, apportera plus de clarté au processus.

Développement de MSE pour pêcheries multispécifiques et stocks uniques pour le thon tropical au sein de la CTOI et de la CICTA : définir des options et modèles préliminaires

37. Cette étude représente une première étape dans l'évaluation des stratégies de gestion des stocks de thons tropicaux dans un cadre de pêcheries mixtes. Nous avons comparé trois stratégies de gestion liées à différentes dynamiques de flotte. La gestion axée sur l'effort avec une réduction de 25% s'est traduite par une dynamique de la flotte réduisant de 25% l'effort de toutes les flottes. Les deux autres HCR utilisés correspondent aux HCR proposés par le CIEM dans le cadre du RMD, et à un HCR pour stocks multiples qui utilise des taux de mortalité par pêche rejoignant les objectifs de RMD. Ces deux HCR ont été combinés avec deux dynamiques de flottilles différentes de par la condition utilisée pour restreindre l'effort des flottilles, l'effort minimum, ou l'effort correspondant au TAC du thon obèse.

38. Le HCR à stocks multiples avec TAC restreint du thon obèse a produit en moyenne des biomasses durables pour les trois stocks, mais la probabilité d'être inférieur au LPR (B_{LIM}) était supérieure à zéro certaines années. Ce type de gestion doit être combiné avec des mesures de contrôle strictes pour s'assurer du respect du TAC.

39. Les dynamiques de flottilles utilisées dans ce travail étaient basées sur leur comportement historique. Cependant, à l'avenir, les études devraient d'abord se concentrer sur la définition des flottilles et de leurs métiers, puis identifier les dynamiques qui décrivent le mieux la dynamique de ces flottilles.

40. Les simulations réalisées étaient basées sur une période annuelle plutôt que trimestrielle, qui est utilisée dans les modèles d'évaluation des stocks. A l'avenir, les études devraient développer le modèle de simulation de manière saisonnière afin de fournir une représentation plus précise de la dynamique des flottilles et une approche cohérente entre l'évaluation des stocks et le modèle de simulation.

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RESUMEN EJECUTIVO

Fondo

41. Los planes de manejo desarrollados por las OROP del atún requieren la adopción de objetivos y plazos específicos. Estos pueden ser apoyados por puntos de referencia (PR) para desarrollar límites apropiados, objetivos o puntos de disparo, y para definir los parámetros del marco de gestión. Estos PR, así como las reglas detalladas que especifican cómo se definen los Totales Admisibles de Capturas (TAC), las "Harvest Control Rules" (HCR), se pueden probar bajo diferentes escenarios del estado de la naturaleza y la incertidumbre con el fin de evaluar su efectividad bajo diferentes estrategias de manejo.

42. La evaluación de la estrategia de gestión (« Management Strategy Evaluation », MSE) proporciona una herramienta para realizar pruebas de simulación. Las MPE se utilizan cada vez más en la gestión pesquera. Se utilizan principalmente para medir el rendimiento de las estrategias de gestión actuales y propuestas bajo diferentes escenarios, o para identificar las estrategias más efectivas entre una serie de estrategias potenciales para cumplir un conjunto particular de objetivos.

Objetivos Principales

Las siguientes cuatro tareas se llevaron a cabo durante el estudio:

43. Tarea 1: Puntos de referencia (PR). Proporcionar un inventario de PR para todas las poblaciones de atún. Analizar la coherencia de PR entre las OROP y la base de su definición, identificando las fortalezas y debilidades asociadas con cada PR. Evaluar la relación entre los diferentes tipos de PR teniendo en cuenta factores relevantes, como el estado del stock y los patrones de explotación para diferentes pesquerías. Proporcionar varios estudios de caso como ejemplos de diferentes tipos de PR para el mismo stock de atún, pero en diferentes estados de conservación y cosechados por diferentes pesquerías.

44. Tarea 2: Reglas de Control de Capturas (« Harvest Control Rules », HCR). Proporcionar un inventario del tipo de HCR que se ha propuesto, probado o aplicado en OROP. Analizar las fortalezas y debilidades de diferentes HCR (existentes y en desarrollo) para las poblaciones de atún, teniendo en cuenta factores como la disponibilidad de datos, el tipo de pesca y el sistema de gestión. Examinar cómo se podrían desarrollar los HCR teniendo en cuenta las interacciones multiespecíficas y las pesquerías mixtas.

45. Tarea 3: Evaluación de la Estrategia de Gestión (« Management Strategy Evaluation », MSE). Examinar el desarrollo de MSE en las diferentes OROP de atún, incluyendo: 1) evaluar cómo se han planificado y desarrollado los MSE; 2) examinar cómo se desarrollaron los componentes de MSE (modelos de operación, procedimientos de gestión y estadísticas de rendimiento) y cómo se utilizaron las MSE para apoyar la adopción del HCR; 3) identificar las fortalezas y debilidades del proceso de desarrollo de HCR y MSE en las OROP de atún; y 4) proponer alternativas para mejorar las MSE en las OROP de atún.

46. Tarea 4: Proporcionar una imagen más detallada del proceso de desarrollo de MSE y su evolución a través de tres estudios de casos de OROP de atún (WCFC, ICCAT e IOTC). El objetivo principal de los estudios de casos es comprender los enfoques de MSE considerados, sus implicaciones y el progreso realizado hasta el momento, pero también considerar algunas opciones adicionales que pueden respaldar el proceso de desarrollo de MSE actual.

Tarea 1: Puntos de Referencia

47. Las OROP de atún están en el proceso de establecer objetivos de gestión y definir puntos de referencia objetivo (PRO) y límites (PRL) en el contexto de sus estrategias de explotación (EE). Los objetivos de gestión incluyen la sostenibilidad, la seguridad, la producción, el empleo y la estabilidad de la pesca. Los PR están destinados a guiar a las pesquerías hacia estos objetivos.

48. Existen varios métodos para calcular PR, como los métodos basados en el rendimiento máximo sostenible (« Maximum Sustainable Yield », MSY), el agotamiento de existencias,

el potencial de reproducción por recluta y el rendimiento por recluta. Cada método tiene sus propias fortalezas y debilidades. Sin embargo, los métodos basados en MSY y el agotamiento de existencias son los métodos más comunes utilizados por las OROP.

49. Las incertidumbres asociadas con el parámetro de pendiente de la relación stock-reclutamiento pueden disminuir significativamente la precisión de PR en base a la MSY utilizando los modelos de evaluación de stock actuales. Uno de los principales beneficios de las PR basadas en el agotamiento de las poblaciones para la gestión pesquera es su estabilidad relativa de una evaluación a otra. Estos PR mostraron las variaciones menos significativas en los resultados para una serie de pendientes y modelos de evaluación de stocks. Los PR basados en el agotamiento de existencias se consideran los más confiables cuando existen grandes incertidumbres en torno a parámetros tales como la pendiente de la relación stock-reclutamiento.

50. La revisión de PRL de diferentes OROP muestra una falta de consistencia en los valores utilizados para respaldar sus EE. Por ejemplo, el IOTC adoptó un PRL temporal basado en MSY para atún aleta amarilla de 40% SSB_{MSY} (equivalente a 14% SSB_0), mientras que la WCPFC adoptó un PRL de 20% $SB_{CURRENT,\ F\ =\ 0}$ (equivalente a 20% SSB_0) para la misma especie. Esto sugiere que, o bien la IOTC adopta un enfoque menos conservador, o la WCPFC utiliza un enfoque más conservador para definir los PRL. En realidad, estas diferencias se deben a la naturaleza diferente de los PR (basados en el MSY o agotamiento de existencias). Algunas poblaciones en diferentes regiones pueden tener diferentes niveles de productividad debido a diferencias biológicas o características de la pesca. Por lo tanto, no es sorprendente observar diferentes PR para cada OROP de atún para la misma especie.

51. Cada vez más PRL se definen sobre la base de la MSY en lugar de sobre la base de los PRO. Debido a las incertidumbres en el cálculo del MSY y las consecuencias biológicas, sociales y económicas de su superación, algunas OROP, como la WCPFC, definen el PRL como el MSY. Esto se basa en el enfoque precautorio, el Acuerdo sobre las poblaciones de peces de las Naciones Unidas y otras herramientas internacionales.

52. Para el estado biológico, los PRL se establecen cada vez más en un 20% de SSB_0 utilizando métodos de agotamiento del stock, que es un PR prudente cuando la SSR sigue siendo incierta. Además, se ha sugerido que F_{MSY} representa un límite superior en las tasas de mortalidad por pesca, lo que es consistente con la definición de PRL: "un estado de la pesquería y / o un recurso que se considera indeseable y que las medidas de manejo deben evitarse".

53. Se ha demostrado que utilizando los valores típicos de pendiente SRR para atún barrilete entre 0,7-0,9, los valores de referencia basados en MSY (B_{MSY}) están justo por encima o incluso por debajo del PRL general de 20% $SB_{CURRENT,F\ =\ 0}$ adoptado por la WCPFC. Por lo tanto, bajo ciertas condiciones, un PR típico definido "para mantener o restaurar stocks a niveles capaces de producir MSY" podría verse de repente como "fuera de los límites biológicos de seguridad". Esta paradoja aparece porque el 20% $SB_{CURRENT,F\ =\ 0}$ como el único PRL basado en el agotamiento de existencias se adoptó para todas las poblaciones principales, independientemente de la productividad relativa de la población o la selectividad de la pesquería. Aunque el cálculo de PRL específicos de stock y sus niveles asociados de riesgo aceptable pueden ayudar a superar el problema, los PRL actuales son biológicamente "prudentes" y, por lo tanto, están en línea con los requisitos de la Convención WCPFC. Hasta la fecha, no hay datos suficientes disponibles para establecer PRL específicos de stock en la región.

54. Los PRO se pueden definir para lograr objetivos de gestión, incluidos los objetivos sociales o económicos. Cada vez más se sugiere que el manejo de la biomasa de la población por encima de B_{MSY} conduce a peces más grandes a niveles de captura similares con mayor beneficio económico y menor impacto ecológico. Este enfoque es coherente con los objetivos de la PPC en virtud del párrafo 2 del artículo 2, que consiste en "restablecer y mantener las poblaciones de especies explotadas por encima de los niveles que pueden producir un rendimiento máximo sostenible".

55. Definir PRO equivalentes al 40% de SSB_0 o más en vez de basarlas en el MSY (B_{MSY}) puede traer diferencias significativas (o subutilización) en el nivel de esfuerzo de pesca. Hasta la fecha, la WCPFC ha adoptado una PRO temporal para el atún barrilete basado en 50% de $SB_{CURRENT, F = 0}$, que, a pesar de las muchas incertidumbres, está muy por encima de las estimaciones disponibles de SB_{MSY}. Aunque el PRO de la WCPFC puede parecer conservador, la evaluación para el atún barrilete se considera incierta.

56. Hoy, la posibilidad de alcanzar los PRO y los objetivos de gestión dentro de los plazos definidos, así como la evitación de PRL, se están debatiendo en todas las OROP de atún. En particular, no hay una definición clara de probabilidades "altas", "muy altas", "bajas" y "muy bajas".

Tarea 2: Reglas de Control de Capturas («Harvest Control Rules», HCR)

57. El uso de HCR ha sido cada vez más favorecido por las OROP de atún para implementar buenas prácticas de gestión de stocks y simplificar el proceso de negociación de límites de pesca y / o la implementación de medidas técnicas.

58. Se proporcionó un inventario que resume el estado de los HCR en las OROP de atún para cada stock. El inventario incluye los HCR que se recomendaron o propusieron en las OROP de atún, así como aquellos que se probaron o aplicaron.

59. Dentro de ICCAT, HCR no se han definidos para barrilete, atún aleta amarilla, patudo, atún blanco y atún rojo del Atlántico sur y Mediterráneo, aunque las Recomendaciones 11-13 y 15-07 proporcionan un marco para su establecimiento. Se ha definido un HCR para el atún blanco del norte en 2017 según la Recomendación 17-04. Algunas de las fortalezas identificadas para el atún blanco del norte incluyen el hecho de que será revisado por el SCRS en 2018 y que en circunstancias excepcionales la Comisión revisará y considerará una posible revisión del HCR. Además, se han establecido reglas claras para los tipos de acciones de gestión para diferentes PR, incluida la reducción de la captura total admisible (TAC). El HCR está sujeto a MSE que indican que el HCR es sólido en caso de incertidumbre. Algunas de las debilidades identificadas indican que no está claro si las probabilidades de los PR o indicadores de rendimiento incorporarán la incertidumbre del modelo. Además, el TAC se comparte entre muchos países donde el control de captura es bajo.

60. Desde 2016, la IOTC ha establecido un HCR para el atún barrilete basado en PRL y PRO en virtud de la Resolución 16/02. La IOTC aún no ha establecido un HCR para el atún patudo, el rabil y el atún blanco. Las principales fortalezas del HCR de la IOTC incluyen objetivos de gestión, así como definiciones claras para PRL y PRO, y la definición de TAC. Res. 16/02 requiere que el HCR y los parámetros de control sean evaluados por MSE. Se han identificado varias debilidades, incluido el hecho de que el HCR ha sido recientemente aceptado y aún no se ha completado una evaluación significativa. Además, el HCR no se refiere explícitamente a las probabilidades aceptables de superación, y no está claro cómo se tendrá en cuenta el papel de la pesquería de subsistencia cuando se excedan los umbrales. Además, cuando se estima que la biomasa está por debajo del PRL, no existen plazos específicos en los que se deba implementar un HCR nuevo, lo que aumenta el riesgo de agotamiento de existencias.

61. La WCPFC aún no ha definido un HCR para barrilete, rabil y atún patudo. La CMM 2014-06 solicita a la WCPFC que desarrolle e implemente una estrategia de captura que incluya PRO, HCR y otros elementos. El Comité del Norte recomendó un marco de gestión provisional para el albacora del Pacífico Norte, mientras que, en 2014, una estrategia de captura para el atún rojo del Pacífico definió los HCR para alcanzar objetivos de recuperación específicos. La fase de reconstrucción del HCR del atún blanco del Pacífico norte es explícita en cuanto a cómo se tomarán las medidas de gestión en relación con los PRO, en paralelo con un calendario establecido. También se especifican niveles aceptables de riesgo que la WCPFC considera compatibles con el Acuerdo sobre las poblaciones de peces de las Naciones Unidas. Algunas de las debilidades potenciales de este HCR incluyen el hecho de que aún no ha sido evaluado por MSE, aunque esto está en desarrollo, y la probabilidad de que el stock caiga por debajo del PRL no ha sido claramente definido, que no sea "muy bajo".

62. En 2016, la IATTC adoptó un HCR para todos los atún tropicales en virtud de la Resolución C-16-02 basada en PRL y PRO provisionales. Para el albacora del Pacífico Norte, la Resolución C-13-03 requiere que el personal de la CIAT revise el trabajo realizado por la WCPFC para el desarrollo del HCR. En cuanto al HCR para todos los atún tropicales, algunos de los puntos fuertes de Res. C-16-02 es que establece definiciones claras para PRL temporales y PRO y que establece medidas de gestión previamente acordadas bajo una variedad de condiciones de existencias, lo que permite la rápida implementación de medidas de gestión, llegado el caso. Algunas de las debilidades del HCR incluyen que solo se considera provisional hasta que se evalúe, ya que aún no se ha establecido un MSE sin probabilidades claras de superar los PR dados.

63. La CCSBT desarrolló un procedimiento de gestión (PG) en 2011 para el atún rojo del sur, diseñado para lograr el objetivo de la reconstrucción. Este PG, conocido como el "Bali Procedure", establece claramente los objetivos basados en la probabilidad de reconstruir las poblaciones utilizando un PRO provisional dentro de un período de tiempo explícito. La CCSBT ha probado una serie de PG vinculados a una serie de incertidumbres para garantizar que se haya identificado un procedimiento sólido. El PG también está sujeto a revisiones periódicas, incluida una revisión anual de su implementación y evaluación periódica de nuevas fuentes de datos y modelos comerciales. Una de las debilidades potenciales del PG es la complejidad de los métodos utilizados, lo que dificulta la comunicación con las partes interesadas y los responsables de la toma de decisiones.

64. Los HCR teniendo en cuenta la gestión de las pesquerías de especies múltiples pueden aplicarse utilizando límites de captura y esfuerzo. En general, para los límites de captura, el monitoreo en tiempo real de las capturas es necesario, pero puede ser difícil. Por ejemplo, dentro de la IOTC hay un desfase temporal entre los desembarques y el muestreo de captura real. Esto puede causar problemas de no conformidad si no se detecta un exceso de captura o si se cierran prematuramente si se sobreestiman las capturas.

65. En las pesquerías de especies múltiples, no es posible aplicar diferentes niveles de esfuerzo de pesca a dos o más especies que son vulnerables al mismo arte de pesca y que habitan en el mismo hábitat. Sabiendo que los descartes son indeseables sobre la base de los Principios de Pesca Común, cuando se alcanza el límite de captura de una población (por ejemplo, el atún aleta amarilla en la IOTC o patudo en la ICCAT) ("choke species") pero no para otros, las flotas dejarán de pescar. En este caso, los límites de captura para barrilete, por ejemplo, no se lograrán, con la consiguiente pérdida de oportunidades para las flotas pesqueras y otras consecuencias socioeconómicas indeseables. Estos incluyen pérdida de producción de alimentos, escasez de conservas y posibles aumentos de precios debido a una menor oferta en los mercados internacionales.

66. En general, la gestión basada en TAC requiere estimaciones precisas del estado del stock, PR y la tasa de reclutamiento cuando se establecen límites de captura. Si se subestiman la biomasa y el reclutamiento, los límites de captura se alcanzarán antes de lo esperado y las oportunidades de pesca se desperdiciarán a menos que se descarte la "choke species". Por el contrario, si se sobreestima la biomasa del stock, la biomasa continuará disminuyendo mientras que la mortalidad aumentará. A este respecto, los controles de esfuerzo proporcionan un medio más flexible para gestionar las pesquerías de especies múltiples ya que pueden conciliar los objetivos de conservación de dos o más poblaciones cuando se establecen para el stock más vulnerable.

67. Los límites del esfuerzo de pesca son restricciones a la intensidad de uso de los artes de pesca. Estos pueden incluir limitaciones en la duración de la temporada de pesca, que son relativamente fáciles de aplicar a través de Sistemas de Localización de Buques (VMS), el uso de cuadernos de pesca y otras medidas. Además, el control del esfuerzo pesquero reduce la necesidad de monitorear las capturas en tiempo real, lo que a menudo es difícil y costoso. En los sistemas de control del esfuerzo, ya no es necesario estimar la biomasa explotable con precisión todos los años, ya que el nivel de mortalidad por pesca está directamente limitado, independientemente de las continuas fluctuaciones en el tamaño del stock. Para ser eficaz, la gestión del esfuerzo requiere un control estricto sobre la capacidad tecnológica y el potencial de captura de las flotas. En algunos casos en que la capacidad de

pesca aumenta, la mortalidad por pesca debida a un esfuerzo dado puede ser mayor de lo esperado y, por lo tanto, podría comprometer la sostenibilidad de las poblaciones.

68. Hasta la fecha, solo la ICCAT utiliza TAC o límites de captura globales para todas las flotas involucradas en las pesquerías de atún tropicales. La CIAT y la WCPFC aplican controles de captura (TAC) solo para los palangreros que pescan patudo. En el Pacífico, la actividad de la flota de cerqueros está regulada por límites de esfuerzo (duración de la temporada). La ICCAT utiliza un pseudo-HCR basado en el esfuerzo para determinar el número de días que los cerqueros pueden pescar para alcanzar el MSY.

69. En 2017, la ICCAT intentó introducir límites de captura para el atún patudo y el rabil para las flotas de cerqueros que operan con dispositivos de concentración de peces (DCP) y un límite de captura adicional para el atún aleta amarilla de las pesquerías asociadas con delfines. En la práctica, esto resultó difícil de implementar ya que la flota de cerqueros que pescaba con dispositivos de concentración de peces alcanzó el 80% del límite de captura anual total a mediados de julio. Esto condujo a la introducción de una nueva medida (C-17-02) después de solo cinco meses, que impidió el cierre de la pesquería con DCP en agosto o principios de septiembre, con consecuencias dramáticas para las flotas de cerqueros.

Tarea 3: Evaluación de Estrategias de Gestión («Management Strategy Evaluation», MSE)

70. Las cinco OROP de atún han trabajado en MSE, incluida la consulta sobre los objetivos de gestión, la caracterización de la incertidumbre de la dinámica y la observación de las poblaciones y la evaluación de las estrategias de captura. La mayoría de los MSE completados hasta la fecha han sido desarrollados por científicos reclutados por OROP con un mandato pocas veces otorgado por las Comisiones.

71. El estudio proporcionó una descripción general de los Modelos Operativos (MO), los HCR y las estadísticas de rendimiento utilizadas. Los MO proporcionan representaciones matemáticas del sistema gestionado. El impacto de la gestión pesquera se evalúa antes de la implementación de MO cuando se usa MSE. Los MO se consideran representaciones alternativas de la dinámica "real" del stock y tienen como objetivo tomar en cuenta todas las incertidumbres inherentes a la dinámica del pescado y la pesca.

72. Hoy en día, se están desarrollando MSE para especies individuales, con el objetivo de mantener las existencias a un nivel saludable, promoviendo el éxito de la reconstrucción de poblaciones sobreexplotadas y evaluando los beneficios económicos de la gestión preventiva. Para involucrar a terceros países en el proceso de MSE a través de OROP de atún, se están implementando varias iniciativas (talleres, desarrollo de capacidades, cursos y proyectos). Se discutieron iniciativas para promover la participación de terceros países y desarrollar otros enfoques de MSE, incluido el impacto del proyecto Areas Beyond Jurisdiction.

73. Las cinco OROP de atún tienen planes para evaluar los procedimientos de gestión (PG) utilizando MSY. En algunas OROP, la hoja de ruta para la adopción de los PG está claramente detallada y, en otros, el proceso está apenas en su infancia.

74. El proceso de la IOTC se basa en el trabajo técnico y la interacción con la Comisión. La IOTC pretende poder adoptar PG para sus mayores stocks para 2020. En la ICCAT, el proceso MSE está muy avanzado para el atún blanco y el atún rojo del Atlántico norte. Un aspecto particular del proceso MSE de la ICCAT es que se evaluará de forma independiente, con la evaluación de la MSE de atún blanco del Atlántico norte en 2018 que contribuirá a la mejora del proceso para otros stocks. Además, considerará opciones para el manejo de múltiples especies en lugar del actual marco de gestión de una sola especie. Dentro de la WCPFC, el proceso de feedback está avanzado y ha logrado un progreso significativo en la definición de los objetivos de gestión a través de una serie de talleres de consulta. Con respecto a la ICCAT, el trabajo de MSE es identificar los HCR apropiados para el patudo y el atún aleta amarilla, pero todavía está en su infancia. Se presentará un plan para el desarrollo de MSE al Consejo Asesor Científico 2018. La CCSBT ha decidido desarrollar un nuevo PG para guiar el establecimiento de TAC para 2021 y más allá. El nuevo PG tendrá en cuenta los cambios

en la disponibilidad de datos, en particular al cambiar las series de monitoreo de reclutamiento de una encuesta aérea de juveniles a un programa de genética / recaptura de juveniles.

Tarea 4: Estudios de casos de OROP seleccionadas

Estrategia de captura de la WCPFC

75. La WCPFC ha avanzado en el desarrollo de estrategias de captura que incorporan el concepto de máximo rendimiento económico («Maximum Economic Yield», MEY), así como objetivos socioeconómicos y ambientales. La WCPFC intentó operacionalizar el uso de MEY con una consideración explícita del desempeño económico (por ejemplo, los ingresos) en su análisis, a pesar de algunas preocupaciones sobre la integridad y viabilidad de este trabajo. Esto permite el desarrollo de una industria rentable que aprovecha las tendencias del mercado y los avances tecnológicos para obtener los mejores precios y márgenes de ganancia. Sin embargo, los precios más altos del pescado significan un acceso reducido a esta importante fuente de nutrientes para las personas de bajos ingresos, en los países en desarrollo o en las comunidades costeras que dependen de los peces para su sustento.

76. Este informe analiza opciones distintas a las actualmente sugeridas en las reuniones del Comité Científico y otros grupos de trabajo que también podrían conducir a estrategias de captura plausibles. Está claro que hay una amplia gama de opciones que se pueden considerar para la gestión de una pesquería. Sin embargo, no es posible establecer de antemano cuál de ellos funcionará mejor hasta que los objetivos de la estrategia estén claramente definidos. Por lo tanto, acordar los objetivos de gestión, incluidas las prioridades y la ponderación asignada a cada objetivo, sigue siendo un paso crucial que, una vez completado, aportará una mayor claridad al proceso.

Desarrollo de MSE para pesquerías multi-especies y stocks únicos para atún tropical dentro de la IOTC y la ICCAT: identificar opciones y modelos preliminares

77. Este estudio representa un primer paso en la evaluación de las estrategias de gestión de poblaciones de atún tropical en un marco de pesca mixta. Comparamos tres estrategias de gestión relacionadas con diferentes dinámicas de flotas. La gestión basada en el esfuerzo con una reducción del 25% dio como resultado una dinámica de la flota que redujo el esfuerzo de todas las flotas en un 25%. Los otros dos HCR utilizados corresponden a los HCR propuestos por ICES en virtud del MSY, y a un HCR de stocks múltiples que utiliza tasas de mortalidad por pesca que cumplen los objetivos de MSY. Estos dos HCR se combinaron con dos dinámicas de flota diferentes debido a la condición utilizada para restringir el esfuerzo de las flotas, el esfuerzo mínimo o el esfuerzo correspondiente al TAC de patudo.

78. La HCR multi-stock con un TAC pequeño para patudo producido biomasas sostenibles para las tres poblaciones, pero la probabilidad de estar por debajo del PRL (B_{LIM}) fue superior a cero en algunos años. Este tipo de gestión debe combinarse con estrictas medidas de control para garantizar el cumplimiento del TAC.

79. La dinámica de la flota utilizada en este trabajo se basó en su comportamiento histórico. Sin embargo, en el futuro, los estudios deberían centrarse primero en la definición de flotas y sus intercambios, y identificar las dinámicas que mejor describan la dinámica de estas flotas.

80. Las simulaciones realizadas se basaron en un período anual en lugar de trimestral, que se utiliza en los modelos de evaluación de stock. En el futuro, los estudios deberían desarrollar el modelo de simulación estacionalmente para proporcionar una representación más precisa de la dinámica de la flota y un enfoque coherente entre la evaluación de stock y el modelo de simulación.

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1 INTRODUCTION

1.1 Background

Management plans require the adoption of management objectives and timeframes for achieving them and can greatly benefit from using Reference Points (RP) to develop appropriate limits, targets or trigger points and help define the parameters of the management framework. Such reference points together with detailed rules on how to define allowable catches/exploitation (i.e. Harvest Control Rules, HCRs) can then be tested under different scenarios of state of nature and uncertainty to assess their effectiveness and trade-offs among different management strategies. Management Strategy Evaluation (MSE) provides a platform for simulation-testing such alternative management strategies explicitly accounting for uncertainty and has therefore been increasingly used in fisheries management to support management decisions. MSE is mainly used to test how well existing or proposed management strategies perform under different scenarios or identify the most effective management strategies from a set of candidate strategies and for a given set of objectives.

The MSE is a modelling-based process and its main components are (1) an Operating Model (OM) to represent the 'true' underlying dynamics of the fishery resource and to generate simulated future data, (2) an estimation model (this varies in complexity) to assess the state of the stock relative to agreed targets and reference points based on the data simulated using the operating model, and (3) one or more decision rules to determine what management actions should happen[1], i.e. the Management Strategy. The MSE process ties well with the vision of the reformed EU Common Fisheries Policy (CFP)[2] for adopting multi-annual management plans for fisheries to improve stability and robustness of management approaches. Additionally, the CFP defines that multiannual management plans should be developed for mixed fisheries when different stocks are caught jointly and that adds another layer of complexity. The latter makes the adoption of management and assessment processes that are robust to uncertainty even more important.

Early adopters of HCRs and MSE includes the USA, where MSE is already being used to identify management strategies that meet the constraints/objectives set in the Magnuson-Stevens Act and associated guidelines[3,4], Australia[5], and international organizations such as CCAMLR[6]. The joint t-RFMOs process (Kobe process) also identified the developments of MSE as an important step to address the precautionary approach and that has also led to the development of the Joint tuna-RFMO MSE Technical Working Group[7] to advance work in this area.

Although work on implementing MSE varies among the t-RFMOs, there are evidence of progress; For example the Working Party on Methods in IOTC has selected five species for MSE (albacore, yellowfin, bigeye, skipjack and swordfish) and additional work to

[1] http://www.fao.org/fishery/eaf-net/eaftool/eaf_tool_50

[2] Regulation (EU) No 1380/2013 of the European Parliament and of the Council of 11 December 2013 on the Common Fisheries Policy, amending Council regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 639/2004 and Council Decision 2004/585/EC.

[3] http://www.nmfs.noaa.gov/sfa/NSGtkgd.pdf

[4] http://www.westcoast.fisheries.noaa.gov/publications/fishery_management/groundfish/whiting/2014-stock-assess.pdf

[5] https://www.wcpfc.int/system/files/MOW3%20WP-07%20Australia%20-%20Importance%20of%20harvest%20strategies%20and%20some%20examples.pdf

[6] Management Science in Fisheries: An Introduction to Simulation-based Methods, 2016. Edited by C.T.T Edwards and D.J Dankel. Published by Routledge.

[7] http://www.iccat.int/intermeetings/Performance_rev/ENG/PER_010_ENG.pdf

develop the yellowfin and bigeye tuna MSE is expected in 2018[8]. Similarly, IATTC has already trialled MSE for Pacific bluefin tuna but just as an exercise[9] ICCAT has also developed an MSE to adopt a HCR for North Atlantic albacore in 2017 and is currently looking to develop an MSE for two BFT stocks.

1.2 Aims and objectives

This study undertook the following four main tasks:

Task 1: Reference points. The study will provide an inventory of reference points for all tuna stocks. Use of reference points between t-RFMOs will be analysed for their consistency and the basis for their establishment, including the strengths and weaknesses of each individual reference points. The relation between different types of reference points will be assessed taking into account relevant factors such as the stock status and the exploitation patterns of different fisheries. Several case studies will be given to provide examples of different types of reference points for the same tuna stock in different conservation status and harvested by different fisheries.

Task 2: Harvest control rules (HCRs). The study will provide an inventory of what types of HCRs (management procedures) have been proposed, tested or applied in t-RFMOs. The strengths and weaknesses of different types of HCR (existing and under development) for tuna stocks will be analysed taking into account factors such as data availability, types of fisheries and management systems. Besides, it will be discussed how HCRs could be developed taking into account multispecies interactions and mixed fisheries.

Task 3: Management Strategy Evaluation (MSE). A review of the development of MSEs across t-RFMOs will be carried out. For this, we will 1) evaluate how MSE frameworks have been planned and developed across t-RFMOs; 2) review how the MSE components (operating models, Management Procedures (MP) and performance statistics) have been developed and analysing how MSE has been used to support the adoption of HCRs; 3) identify strengths and weaknesses of the process to develop HCRs and MSE frameworks within t-RFMOs; and 4) propose alternatives for improving MSE frameworks across t-RFMOs.

Task 4: Three tuna RFMOs will be used as case studies to provide a more detailed picture of the MSE process and its progress (e.g. WCPFC, ICCAT and IOTC). The main objectives of the case studies are to understand the MSE approaches considered, their implications, and progress so far but also consider additional options that can support the MSE process.

[8] www.iotc.org/sites/.../01/IOTC-2016-SC19-RE_-_FINAL_DO_NOT_MODIFY_0.pdf

[9] https://www.iattc.org/Meetings/Meetings2016/SAC-07/PDFs/Docs/_English/SAC-07-07h_Research-on-Management-Strategy-Evaluation.pdf

2 TASK 1: REFERENCE POINTS

2.1 Introduction

This report presents findings from Task 1, which reviews the reference points (RP) currently used for tuna stocks. It provides a description of all RPs, including both Limit Reference Points (LRP) and Target Reference Points (TRP), which are currently applied for tuna stocks under the scope of this study and compares the consistency between the RPs used by each of the tuna RFMOs (t-RFMOs). An analysis of the relative strengths and weaknesses of the individual RPs and the correspondence between different types of RP is provided. Finally, a number of case studies on the implementation of RPs for different tuna stocks support the review.

2.1.1 Study Context

The sustainability of a fish stock is determined by the balance between the amount of biomass harvested and the capacity of the stock to respond – fisheries management decisions therefore aim to realign this balance. Following the advent of mathematical descriptions of fish stocks, the use of RPs dominates fisheries management, guiding decision makers through the provision of targets that regulate harvesting through exploitation limits (quotas) in order to maintain or restore stock biomass.

The underlying objective of many RPs is to achieve the maximum sustainable yield (MSY) (Schaefer, 1954); as reflected in the UNs' 1982 Convention on the Law of the Sea, which stipulates that "states must set an allowable catch […] designed to maintain or restore species to levels supporting a MSY." Under this definition, MSY is the maximum level at which a single fish stock can be routinely exploited without long-term depletion. The maximum level is a harvestable surplus each year through growth and recruitment and if this precise surplus is extracted - i.e. stock growth and stock removal are balanced.

In addition, two international agreements – the UN Fish Stocks Agreement (UNFSA; UN, 1995), and the FAO Code of Conduct for Responsible Fisheries (FAO, 1995) – propose a Precautionary Approach (PA) to fisheries management. In practical terms the PA requires decision-makers to determine the status of stocks relative to target reference points (TRP) and limit reference points (LRP), in order to predict the likelihood for reaching the targets while avoiding the limits. Specially, Annex II of UNFSA outlines a set of guidelines for the application of precautionary RPs in conservation and management of straddling fish stocks and highly migratory fish stocks. Under paragraph 2, it states:

Two types of precautionary reference points should be used: conservation, or limit, reference points and management, or target, reference points. Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. Target reference points are intended to meet management objectives.

To help provide consistency of advice, a common management advice framework was developed to visualise the state of exploitation of fish stocks - the Kobe Framework (De Bruyn et al., 2013). Kobe plots and the Kobe Strategy Matrix are the agreed way to report the probability of events (e.g. biomass falling below LRP) under alternative management scenarios (ISSF, 2013).

The following sections broadly describe the TRPs and LRPs currently being implemented for tuna stocks, which generally aim to maintain tuna stock biomass at levels above the point of recruitment impairment and are capable of producing MSY with high probability.

2.2 Sub-task 1.1: Inventory of reference points for tuna

Reference points began as theoretical concepts that capture the management objectives for a fishery. As such the earliest RPs were primarily targets – points at which the fishery should be maintained. However, owing to uncertainty in their calculation and the subsequent problems of overshooting TRPs, there has been a marked move towards supplementing TRPs with LRPs.

A TRP is a benchmark that should be achieved on average and corresponds to a state of a stock which is considered desirable (ISSF, 2013) – usually MSY. In general, LRPs are considered to be the benchmark that must not be breached with any substantial probability. They indicate the limit beyond which it is considered undesirable and remedial management action required to allow recovery. LRPs are therefore often based on biological points beyond which stock collapse is expected to occur. In exceptional cases where a stock is at very low abundance, LRPs have been used as an interim rebuilding target (ISSF, 2013) – for example, the CCSBT Southern bluefin stock. Caddy and Mahon (1995), defined TRPs and LRPS as such:

- Target Reference Points indicate a state of fishing and/ or resource which is considered desirable and at which management action, during development or stock rebuilding, should aim.
- Limit Reference Points indicate a state of a fishery and/ or resource which is considered to be undesirable and which management should avoid.

The majority of RPs used for tuna fisheries, whether limits or targets, are based on either biological or bio-economic models[10] that describe the balance between fishing mortality (F), stock biomass (B), and yield (Y).

Biomass RPs are often used as a benchmark to evaluate if a stock is overfished. Furthermore, population (e.g. reproduction) and ecological processes (e.g. energy flows) are related to stock biomass. Although different biomass quantities can be estimated for a stock, total spawning stock biomass (SSB) is the metric typically used. Since management actions do not directly control biomass, stock biomass relative to biomass RPs is typically used to trigger management actions that affect catch limits, fishing effort or mortality (Sainsbury, 2008). Although the biological processes relevant to a stocks sustainability are more closely related to biomass (abundance and density), fishing mortality is more directly controllable under management. Biomass may also be unpredictable due, in part, to factors beyond management control, such as environmental influences on recruitment, natural mortality and growth.

There are numerous underlying methods for describing or estimating the biomass or fishing mortality, and thus for estimating an RP. Generally, two methods are currently applied in t-RFMOs, each with varying data requirements, strengths and weaknesses: MSY-based and Depletion-based In addition, spawning potential per recruit (SPR) has been adopted by one RFMO but does not yet appear to have been applied (see section 2.4).

The original concept of maximum sustainable yield originated in the 1930s and became mainstream in fisheries during the 1950s with the advent of simple stock assessment tools (e.g. Schaefer, 1954). It was later recognised that MSY-managed fisheries often led to unsustainable and uneconomic fisheries (Larkin, 1977). A study by Hilborn (2007) reaffirmed that the traditional fisheries management objectives of fishing at MSY and high employment lead to heavily overexploited stocks.

[10] For example, a simple biological model such as a biomass production model can be used to calculate MSY (Schaefer 1954) whereas the addition of econometric data (e.g. fixed and operating costs associated with fishing effort) can be used to estimate the maximum economic yield (MEY) (Gordon 1954).

The ICES approach to advice on fishing opportunities uses an ecosystem and precautionary approach with the objective of achieving MSY. The MSY concept can be applied to an entire ecosystem, a fish community, or a single stock. ICES applies the MSY concept to single stocks as well as to groups of stocks in the context of biological interaction and mixed fisheries, where stocks are caught together in a fishery. ICES interpretation of MSY is maximization of average long-term yield from sustainable stocks. Further to this, many of the models are mathematical conceptualisations[11] used to estimate MSY and associated parameters typically assume that factors not explicitly included in the models remain constant or vary around a historical long-term mean. However, marine ecosystems are dynamic and fish stocks will change not only in response to the fisheries, but also to changes in natural environmental conditions, fishing patterns and fishing pressures on their prey or their predators. ICES considers MSY estimates to be valid only in the short term and to be subject to regular re-estimation (ICES, 2015).

In comparison to ICES, t-RFMO estimates of MSY are often not subject to regular re-estimation and can be subject to high levels of uncertainty. Fisheries scientists have therefore questioned whether MSY levels should be considered as targets or limits (Die and Caddy, 1997; Gabriel and Mace, 1999; Punt and Smith, 2001). Given the uncertainties in calculating MSY (see section 2.4.1), the WCPFC consider MSY as a LRP, particularly F_{MSY}, based on the precautionary approach, UNFSA[12] and other international agreements. To date, although WCPFC has shifted towards using SSB_{MSY} as a LRP, B_{MSY} and F_{MSY} are still used as a target in some cases by IOTC and ICCAT. Given the level of uncertainty in various stock assessments, including growth and recruitment variability, a potentially large range of biomass levels could be expected for F_{MSY} (see section 2.5.3).

Punt and Smith (2001) indicate that the reason why MSY has not been made redundant within a fisheries management framework is that it has changed from a management target to an "upper limit". Thus F_{MSY} represents an "upper bound" to fishing mortality rates, which is coherent with the definition of a LRP, which is "a state of a fishery and/or a resource which is considered to be undesirable and which management action should avoid" (Caddy and Mahon 1995). In addition, there is growing evidence to suggest that managing stock biomass above B_{MSY} leads to larger fish, similar catch levels and greater economic benefit, lower ecological impact (Pilling et al., 2012). This is consistent with the objectives of the CFP under article 2.2, which aims to "restore and maintain populations of harvested species above levels which can produce the maximum sustainable yield".

Depletion-based RPs are based on the depletion level of the total biomass (or SSB) and provide biomass based RPs (e.g. x% of SSB). Depletion estimates provide information on how much the stock has reduced and therefore, how much SSB remains, and the estimated impact on historic, current and future recruitment and yield. Most common depletion based RPs are defined as a proportion of the estimated unfished (virgin) biomass. This unfished biomass (B_0) is a conceptual (modelled) reference point, upon which we can begin to build technical reference points, such as 20% of B_0 (i.e. $0.2B_0$). The conceptual reference point is generated through back calculations using a model that is parameterised using real-life data.

It should be noted here that ICCAT calculate relative biomass (B) in terms of spawning stock biomass or total fishable biomass, depending on the stock assessment model used, such as VPA or ASPIC respectively. Similarly, WCPFC and IOTC may refer to spawning stock biomass as SB instead of SSB and IATTC refer to S as an index of

[11] An example of a mathematical conceptual model would be the relationship between fishing effort (f) and fishing mortality (F): F=q*f (where q is catchability coefficient).

12 Annex 2 of the UNFSA states "The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points".

spawning biomass. Throughout this report, we adopt the term SSB to refer to spawning stock biomass (where known) to avoid confusion.

An inventory of the types of RPs that are currently used for tuna stocks, and a brief description of them is provided in Table 1.

Table 1: Inventory of reference points used for tuna stocks.

Term	Description
B	Biomass of a stock. The total stock size, in weight.
SSB	Spawning stock biomass. The weight of the part of the stock (usually females) considered to be at- or above- the age (or size) at which 50% are reproductively mature. It is a proxy for the reproductive output of a stock. Sometimes the term spawning biomass (SB) is used instead of SSB.
F	Instantaneous fishing mortality rate, a measure of the intensity with which a stock is being exploited. The catch of a stock is roughly proportional to F multiplied by the size of the stock.
MSY	The largest average catch that can continuously be taken from a stock under existing environmental conditions (for species with fluctuating recruitment, MSY might be lower in some years).
Reference point	**Description**
FMSY	The level of fishing mortality that, if applied constantly year after year, would in theory result in MSY, while maintaining the stock at BMSY indefinitely. This assumes environmental conditions are not subject to change.
BMSY	Biomass of a stock when it is capable of producing MSY. It is based on life history traits, such as age or size at maturity, size-fecundity ratios and the rates of natural mortality (M).
BTHRESHOLD	Biomass of a stock reflecting the precautionary approach that triggers pre-agreed management actions to reduce the risk of breaching limit RPs.
B0	Biomass of virgin stock, before exploitation. This is often estimated via models, or at very low exploitation intensity.
SSB0	The virgin spawning stock biomass prior to fishing. SSB0 is calculated by reconstructing the population backwards to the point where fishing mortality was absent or negligible. This can be difficult to estimate due to uncertainty in historical catches. In addition, changing environmental conditions can affect recruitment patterns and result in differing values of SSB0.
SSBCURRENT, F=0	The average spawning stock biomass calculated from the last few years of the assessment (excluding the very last year) in the absence of fishing mortality (i.e. F=0). This is calculated by projecting the population forward in time in the absence of fishing mortality to reach equilibrium conditions under current environmental conditions.

SSBMSY	SSBMSY, also known as 'spawning biomass at MSY', is the biomass of spawners that would result on average if FMSY was applied constantly year after year. It is often measured by the biomass of female spawners only.
SSBMED	The median spawning stock biomass over a defined period.
FX%SPRo	Fishing mortality level equivalent to a percentage reduction in the per-recruit spawning potential expected under unfished conditions.

Note: Proportions or percentages of these theoretical RPs are often used for LRPs or TRPs (i.e. 0.5*SSBMSY). An overview is provided in Table 3.

ICES (who do not assess tuna stocks), has developed two types of reference points when providing fisheries advice for data rich stocks (referred to as category 1 and 2 stocks): precautionary approach (PA) reference points and maximum sustainable yield (MSY) reference points. The definition and basis of precautionary approach (PA) and MSY reference points used by ICES to assess the state of stocks and exploitation is given in the table below[13]. While B_{LIM} is the key PA reference point, other precautionary approach points (B_{PA}, F_{LIM} and F_{PA}) are all estimated from BLIM. A precautionary safety margin incorporating the uncertainty in ICES stock estimates leads to a precautionary reference point BPA, which is a biomass reference point designed having a low probability of being below BLIM. In most cases the safety margin is taken as a standard value, such that in most cases $B_{PA}=B_{LIM*1.4}$. When the spawning stock size is estimated to be above BPA, the probability of impaired recruitment is expected to be low.

In addition, all biomass reference points (e.g. B_{LIM}) are in units of spawning-stock biomass (SSB), unless otherwise indicated.

Table 2: Definition and basis of precautionary approach (PA) and MSY reference points used by ICES to assess the state of non-tuna stocks and exploitation.

PA reference point	Definition	Basis
B_{LIM}	Limit reference point for spawning stock biomass. A deterministic biomass limit below which a stock is considered to have reduced reproductive capacity.	The biomass below which recruitment reduces with spawning-stock biomass (SSB), e.g. the change point of a segmented regression.
F_{LIM}	Exploitation rate which leads SSB to B_{LIM}.	The fishing mortality rate (F) that in stochastic equilibrium will result in median (SSB) = B_{LIM} (i.e. 50% probability of SSB being above or below BLIM).
B_{PA}	Precautionary reference point for spawning stock biomass. A stock status reference point above which the stock is considered to have full	The value of the estimated SSB, which ensures that the true SSB has less than 5% probability of being below B_{LIM}, i.e. the 95th percentile

[13] This ICES framework for calculating PA and MSY reference points depend on appropriate modelling of a stock-recruitment relationship. This information is not available for stocks assessed with biomass dynamic models, where no age or length structure is considered and a few model parameters are used to estimate the combined effects of recruitment, growth and natural mortality. Further information is available ICES Advice Technical Guidelines: http://ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/12.04.03.01_Reference_points_for_category_1_and_2.pdf

PA reference point	Definition	Basis
	reproductive capacity, having accounted for estimation uncertainty.	of the distribution of the estimated SSB if the true SSB equals B_{LIM}.
F_{PA}	An exploitation rate reference point below which exploitation is considered to be sustainable, having accounted for estimation uncertainty.	The value of the estimated F, which ensures that the true F has less than 5% probability of being above F_{LIM}, i.e. the 5th percentile of the distribution of the estimated F if the true F is equal to F_{LIM}.
MSY $B_{ESCAPEMENT}$	For short-lived species, a deterministic biomass limit below which a stock is considered to have reduced reproductive capacity, including any identified additional biomass need.	B_{LIM} plus an additional biomass if the advice is based on a deterministic forecast.
F_{CAP}	A limit to F, which is used when providing catch advice without directly estimating the probability of SSB > $B_{ESCAPEMENT}$	Based on stochastic simulation that shows a less than 5% probability of SSB < $B_{ESCAPEMENT}$.

MSY reference point	Definition	Basis
F_{MSY}	The F expected to give maximum sustainable yield in the long term.	F that provides maximum yield given the current assessment/ advice error and biology and fishery parameters, constrained so that the long-term probability of SSB < BLIM is ≤ 5% when applying the ICES MSY advice rule (AR): F = F_{MSY} (if SSB≥MSY $B_{TRIGGER}$) F = F_{MSY} × SSB/MSY $B_{TRIGGER}$ (if SSB<MSY $B_{TRIGGER}$)
MSY $B_{TRIGGER}$	A lower bound to the SSB when the stock is fished at FMSY.	MSY $B_{TRIGGER}$ is defined as the 5th percentile on the distribution of SSB when fishing at FMSY.

2.3 Sub-task 1.2: Consistency on the use of reference points between tuna-RFMOs

This section describes how the five t-RFMOs implement the RPs identified, and to the extent possible the basis from which they are established is discussed. Tuna RFMOs have broad conservation objectives and stocks that are in varying states of health, and as such have equally broad RPs for the twenty three stocks of tuna that they manage (Table 6). However, all t-RFMOs implicitly combine the maximum utilisation of stocks (i.e. MSY) with the PA which aims at keeping stocks at or above the biomass corresponding to MSY with high probability and avoiding the LRPs with very high probability. ICCAT,[14] IATTC,[15] WCPFC[16] and IOTC,[17] explicitly mention MSY within their RPs, with the latter the most recent to add it to their vocabulary, while CCSBT[18] do not (largely due to the state of their stock). Tuna RFMOs have been continuing efforts to formulate effective RPs that are explicit to individual species, but this is largely still in development (IOTC have achieved this to some extent).

An overview of the currently defined LRPs and TRPs for each t-RFMO is provided in Table 3, and specific information pertaining to each RP for all tuna stocks is summarised in Table 6. The latter is taken from the ISSF Technical Report 2017-02 (ISSF, 2017) and updated accordingly from each t-RFMO. These show the definition of LRPs and TRPs vary between t-RFMOs. For example, IATTC refer to spawning stock biomass (SSB) as S, whereas WCPFC refer this is as simply SB. To further complicate matters, different t-RFMO may update the definition within Recommendations and Resolutions according to each stock. Further explanation is provided for each t-RFMO in the sections below.

2.3.1 ICCAT

Although the International Commission for the Conservation of Atlantic Tuna (ICCAT) aims to maintain tuna stocks at levels which allow the MSY, it does not currently have defined RPs for all stocks. However, Rec. 11-13 implies a target that all that stocks should be maintained within the 'green' quadrant of the Kobe plot.

To date, only the Northern albacore stock has defined interim RPs. Initially, Rec. 16-06 defined RPs in terms of the average spawning stock biomass (SSB) as either a limit (i.e. SSBLIM) or a target (i.e. SSB_{MSY}). These have subsequently been updated as stock biomass (B) only under Rec. 17-04, to establish both LRPs ($B_{LIM} = 0.4*B_{MSY}$; $F_{MIN} = 0.1*F_{MSY}$) and TRPs ($B_{THRESH} = B_{MSY}$, $F_{TAR} = 0.8*F_{MSY}$). This has been agreed, but is not yet active (as of 04/04/2018). The reported change in the definition of biomass between Rec. 16-06 and Rec. 17-04 is consistent with the outputs from the latest stock assessment advice, which includes the total biomass from production models (ICCAT, 2016c).

[14] International Commission for the Conservation of Atlantic Tuna

[15] Inter-American Tropical Tuna Commission

[16] Western and Central Pacific Fisheries Commission

[17] Indian Ocean Tuna Commission

[18] Commission for the Conservation of Southern Bluefin Tuna

Table 3: Overview of the LRPs and TRPs currently defined by tuna RFMOs (see Table 6 for more detail).

RFMO	Species	LRP	TRP	Reference
ICCAT	BET	Not yet defined	Not yet defined	Rec. 11-13
	YFT	Not yet defined	Not yet defined	Rec. 11-13
	SKJ (Eastern)	Not yet defined	Not yet defined	Rec. 11-13
	SKJ (Western)	Not yet defined	Not yet defined	Rec. 11-13
	ALB (Southern)	Under development	Under development	Rec. 11-13
	ALB (Med.)	Not yet defined	Not yet defined	Rec. 11-13
	ALB (Northern)	Interim: 0.4* B_{MSY}, 0.1* F_{MSY}	Interim: B_{MSY}, 0.8* F_{MSY}	Rec. 17-04 (where B is total biomass)
	BFT (Eastern & Med.)	Not yet defined	Not yet defined	Rec. 11-13
	BFT (Western)	Not yet defined	Not yet defined	Rec. 11-13
IOTC	BET	Interim: 0.5* B_{MSY}, 1.3* F_{MSY}	Interim: B_{MSY} and F_{MSY}	Res. 15/10 (where B is biomass level)
	YFT	Interim: 0.4* B_{MSY}, 1.4* F_{MSY}	Interim: B_{MSY} and F_{MSY}	Res. 15/10 (where B is biomass level)
	SKJ	0.2*B0, 1.5* F_{MSY}	Interim: 0.4*B0, F_{MSY}	Res. 16/02 (where B = SSB)
	ALB	Interim: 0.4* B_{MSY}, 1.4* F_{MSY}	Interim: B_{MSY}, F_{MSY}	Res. 15/10 (where B is biomass level)
IATTC	BET (EPO)	$S_{0.5R0}$, (0.08* S_0)	F_{MSY} and S_{MSY}	Res. C-16-02; SAC-05-14 (where S = SSB)
	YFT (EPO)	$S_{0.5R0}$, (0.08* S_0)	F_{MSY} and S_{MSY}	Res. C-16-02; SAC-05-14 (where S = SSB)

RFMO	Species	LRP	TRP	Reference
	SKJ (EPO)	$S_{0.5R0}$, (0.08*S_0)	F_{MSY} and S_{MSY}	Res. C-16-02; SAC-05-14 (where S = SSB)
IATTC/ WCPFC	ALB (North Pacific)	0.2*$SSB_{CURRENT, F=0}$	Not yet defined	WCPFC (2017d)
	ALB (South Pacific)	0.2*$S_{BRECENT, F=0}$	Not yet defined	WCPFC-SC11-2015/MI-WP-04
	BFT (Pacific)	Not yet defined	0.07*SSB0 (rebuilding)	WCPFC CMM 2016-04; IATTC Res. C16-08
WCPFC	BET	0.2*$SB_{CURRENT, F=0}$	Not yet defined	CMM 2017-01
	YFT	0.2*$SB_{CURRENT, F=0}$	Not yet defined	CMM 2017-01
	SKJ	0.2*$SB_{CURRENT, F=0}$	Interim: 0.5*$SB_{CURRENT, F=0}$	CMM 2015-06; CMM 2017-01
CCSBT	SBT	Not yet defined	Interim: 0.2*SSB_0	CCSBT (2011)

2.3.2 IOTC

The objective of the Indian Ocean Tuna Commission Agreement is to ensure the conservation and optimal utilisation of its stocks, while encouraging the sustainable development of fisheries. Although this objective does not specifically describe RPs in relation to MSY, recent resolutions have begun to clarify the objectives. In practice, IOTC have assumed MSY to be the management target and as such the basis for establishing RPs, while no limits had been considered. IOTC Rec. 12/14 and subsequently Res. 13/10 defined a set of interim TRPs and LRPs for tuna and tuna-like species. More importantly, IOTC Res. 12/01, has brought IOTC in line with United Nations Convention on the Law of the Sea (UNCLOS) and UNFSA by agreeing to apply the PA, and to do so it adopted stock-specific RPs, relative to fishing mortality and biomass that ensures optimal utilisation.

It should be noted that Rec. 14/07 provided guidance to standardise the presentation of RPs from scientific information in the annual Scientific Committee report and in Working Party reports. For example, a Kobe plot should include when possible "any Target and Limit Reference Points adopted by the Commission, e.g. F_{MSY} and F_{LIM}, SB_{MSY} and SB_{LIM} or B_{MSY} and B_{LIM}, depending on the assessment models used by the Scientific Committee, or proxies where available".

In 2015, IOTC adopted Resolution 15/10[19] on target and limit reference points and a decision framework. This noted that the IOTC Scientific Committee at its 17th Session made recommendations on possible alternatives to LRPs and TRPs derived from B_{MSY} and F_{MSY} when those derived from proportions of B_0, the virgin stock biomass, are considered insufficiently robust. Further to this, the Scientific Committee recommended that in cases where MSY-based RPs cannot be robustly estimated, biomass LRPs be set at 20% of the virgin biomass (B_{LIM}=0.2*B_0).

The IOTC Technical Committee on Management Procedures noted that although TRPs are established in the Res. 15/10, there is a lack of clarity between on how to reach them, or what would be deemed 'success' – i.e. "achieve Target Reference Points (TRPs) on average" (Res. 15/10; para. 2, Annex I), and "for a stock where the assessed status places it within the lower right (green) quadrant of the Kobe plot, aim to maintain the stock with a high probability within this quadrant[20]" (Res. 15/10; para. 6c). They went on to note that the objective of rebuilding and/ or maintaining a stock in 'green' implied attaining an objective of both $B>B_{MSY}$ and $F<F_{MSY}$.

It is noted that the interim fishing mortality LRPs set by IOTC were arbitrarily determined and set at 1.4*F_{MSY}, except for bigeye (1.3*F_{MSY}) and skipjack (1.5*F_{MSY}) due to differences in life-history characteristics. In 2016, Res. 16/02 on harvest control rules for skipjack adopted a biomass LRP (B_{LIM}) and TRP (0.4*B_0), where under footnote 5 indicates that the symbol B is used to refer to spawning biomass. This is highlighted in Table 3 above.

2.3.3 IATTC

The management goal of IATTC is "to keep the populations of fishes … at those levels of abundance which will permit the maximum sustained catch". This is largely used as the basis for establishing their RPs. Furthermore, appropriate IATTC TRPs should be consistent with the Antigua Convention that also aims to "maintain or restore [stocks] at levels of abundance which can produce the MSY". As such, the TRP for all stocks, is

[19] http://www.iotc.org/cmm/resolution-1510-target-and-limit-reference-points-and-decision-framework

[20] The definition of what is high, very high, low and very low probabilities and the timeframes for achieving management objectives is currently under debate in all tuna RFMOs.

considered to be BMSY and FMSY – Res. C-16-02 states that "B_{MSY} and F_{MSY} were adopted by the 87th meeting of the IATTC as interim TRPs for tropical tunas in the EPO."

However, little guidance on LRPs is given in the Antigua Convention, except that the IATTC should "apply the PA in accordance with the provisions of Article IV of this Convention." The adopted LRPs for tunas are therefore based on reduction in recruitment – i.e. depletion models. Resolution C-16-02 states that $F_{0.5R0}$ and $B_{0.5R0}$ were adopted (assuming a stock-recruitment steepness parameter, h = 0.75)[21] by the 87th meeting of the IATTC as interim LRPs (Maunder and Deriso, 2014). Indeed, in 2014 IATTC agreed to the in-house scientific staff's recommendation that the LRP for bigeye, yellowfin and skipjack stocks should correspond to the equilibrium spawning biomass which produces a 50% reduction in recruitment from the unfished level, i.e. a spawning biomass that is approximately 8% of the unfished level and that the acceptable level of risk for the stocks breaching that limit would be 10%.

In practice, IATTC has mandated rebuilding plans for several overfished stocks; in these situations the target has been to reach B_{MSY} by a given year with a probability of 50% or greater. MSY is calculated in two ways; (1) on the current age-specific fishing mortality for the stock as a whole; and (2) using the age-specific fishing mortality for each individual fishery. The selectivity of individual fleet segments may be different and alter the fishing mortality on the stock, and therefore the level of MSY.

2.3.4 WCPFC

The Western and Central Pacific Fisheries Convention requires the use of RPs in developing scientific advice and the PA for designing and implementing management measures. Key guidance from the Convention is the objective to "maintain or restore stocks at levels capable of producing MSY, as qualified by relevant environmental and economic factors".[22] This indicates that MSY-based TRPs (B_{MSY} and F_{MSY}) will be strongly featured in future management advice to the WCPF. In addition, CMM 2014-06 outlines elements of a harvest strategy that shall include target and limit reference points for each stock. Further, the adoption of the PA and in accordance with Article 6(1)(a) of the Convention, the Commission shall ensure that the risk of exceeding limit reference points is very low. The current CMM (CMM 2017-01) acts as a bridge and confirms that, pending agreement on a target reference point, the spawning biomass depletion ratio ($SB/SB_{F=0}$) is to be maintained at or above the average $SB/SB_{F=0}$ for 2012-2015.

The WCPFC has adopted LRPs for three of its four stocks, the exception being Pacific Bluefin tuna. However, it has only set an interim TRP for skipjack tuna as outlined in CMM 2015-06. The adopted RPs (both LRPs and TRPs) are based around a proportion of the equilibrium spawning biomass that would be expected in the absence of fishing under current (environmental) conditions. Given the challenges faced with calculating virgin biomass (B_0) and a number of potential regime shifts within the ecosystem during the long history of the fishery, this approach seems reasonable. MSY and associated B- and F-based RPs are estimated based on assumptions regarding stock-recruitment steepness (h parameter) and the overall age-specific selectivity of the combined fisheries, and as such do not have stock specific RPs.

In deciding on the precise RP to implement, the WCPFC follows a set of defined principles:

- Fisheries shall be managed to meet the Convention's objective;

[21] Steepness (*h*) of the Beverton-Holt stock-recruitment relationship is a common measure of stock resilience (i.e. a stock's regenerative capacity, when exploited). A higher value of steepness, means that the B_{MSY} is at lower levels of biomass relative to B_0 (i.e. the stock can regenerate at lower levels of biomass). Note that this is this is particularly evident for highly productive species such as skipjack – i.e. B_{MSY} is at a much lower stock size.

[22] https://www.wcpfc.int/doc/convention-conservation-and-management-highly-migratory-fish-stocks-western-and-central-pacific

- Fisheries are more efficient, profitable, stable and sustainable, when stocks are larger than BMSY, where MSY is a theoretical maximum that can be taken from a stock in perpetuity at larger stock sizes, and;
- Future productivity is at greater risk when stocks are reduced to a level where the recruitment of young fish relative to the portion of the stock subject to fishing declines precipitously (referred to as 'recruitment failure').

WCPFC implements a hierarchical approach using three levels to identify LRPs (Table 4). A critical analysis of using MSY-based and depletion-based RPs as LRPs is provided in section 2.5.3.

Table 4: WCPFC's hierarchical approach to defining LRPs.

Level	Condition	LRPs
Level 1	A reliable estimate of steepness is available	*FMSY* and *BMSY*
Level 2	Steepness is not known well, if at all, but the key biological (natural mortality, maturity) and fishery (selectivity) variables are reasonably well estimated.	$FX\%SPR_0$ and either X%SB_0 or X%$SB_{current,F=0}$
Level 3	The key biological and fishery variables are not well estimated or understood.	X%SB_0 or X%$SB_{current,F=0}$

2.3.5 CCSBT

The Commission for the Conservation of Southern Bluefin Tuna aims to ensure the conservation and optimal utilisation of the southern bluefin tuna. They also aim to apply the PA, as set out in the UNFSA Article 6 and the Code of Conduct for Responsible Fisheries. This implies the use of MSY as the basis for establishing its LRPs and TRPs. However, the stock is heavily overexploited (3-7% SSB_0) and therefore, management objectives focus on stock rebuilding.

In this case, the difference between the overall management objective and the specific objective is clearly appreciated. CCSBT aims at the optimal utilisation of resources but due to the status of the stock defines a temporal management objective of rebuilding by defining an interim TRP with its associated timeframes and probability.

Note that 20% SSB_0 is considered a LRP for many tuna stocks in other RFMOs. Many scientists believe that 20% $SSB_{CURRENT,F=0}$, which is used as a LRP for many tuna stocks, is inappropriate as a TRP, as more ambitious TRPs should be aimed for. However, these low TRPs are often used in a 'step-wise' rebuilding approach, with the ultimate goal to maintain stock levels to greater abundances.

The strategic plan for the CCSBT[23], in 2015, stated that the interim TRP is to rebuild the SBT stock to 20% of the original spawning biomass, with 70% probability, by 2035 and the limit below which stock size should not be allowed to fall is SSB_{2010}; and after reaching each Members' nominal catches, assess the costs and benefits of alternative rebuilding strategies, including those that favour stock rebuilding over short-term catch increase.

In general, the approaches being taken by the t-RFMOs to develop RPs vary widely. A comparison of the LRPs adopted by the five tuna RFMOs is presented below (Table 5).

[23] https://www.ccsbt.org/sites/default/files/userfiles/file/docs_english/operational_resolutions/CCSBT_Strategic_Plan.pdf

A single unit of measurement is used, the ratio of depletion compared with B_0 (unfished spawning stock biomass). The results show that t-RFMOs have adopted various biomass LRPs for a range of different stocks. These range between a low of 8% B_0 and a maximum of 20%B_0.

Table 5: Limit reference points (LRPs) adopted by the tuna regional fisheries management organizations (RFMOs) and their values as ratios of unfished spawning biomass level (B_0) (source: Valero et al., 2017).

RFMO	Stocks	Adopted biomass LRP in 2015	LRP relative to B0
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}	0.2
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 $SB_{F=0}$	0.2
	SKJ	0.2 $SB_{F=0}$	0.2
	YFT	0.2 $SB_{F=0}$	0.2
	ALB-S	0.2 $SB_{F=0}$	0.2

In addition, it was noted that CCSBT decided that the limit below which the stock size of Southern bluefin tuna (*Thunnus maccoyii*) should not be allowed to fall (which might be considered effectively to be an LRP) was the SSB in 2010, which was about 5% of SSB0 (CCSBT, 2010). Whilst this appears very low as a LRP, the value obtains for RPs will significantly differ according to the and how they are calculated.

While higher reported values (e.g. 0.2*B_0 or 20%B_0) might first appear more conservative, the reported differences may be due, however, to differences in biological characteristics of the stock (such as growth, and SRR steepness parameter) and the selectivity of the fishery on different age classes.

It is noted for IATTC, that the LRP for bigeye and yellowfin stocks corresponding to the equilibrium spawning biomass which produces a 50% reduction in recruitment from the unfished level ($B_{0.5R0}$), relates to a spawning biomass that is approximately 8% (assuming a SRR steepness parameter of 0.75) of the unfished level (B_0). Although $B_{0.5R0}$ is a level to be avoided, it can be argued that at this LRP is at a level where the stock impact has already occurred. Sainsbury (2008), highlighted that other management bodies such as ICES have taken a more conservative approach by defining a spawning biomass limit reference point such that average recruitment is not reduced, instead of 50% reduced as in 50%R_{max}.

Further critical analysis of the correspondence between different types of RPs are considered in further detail in section 2.5.

Table 6: Reference points currently applied to tuna stocks by t-RFMOs, and the basis for their establishment (adapted from ISSF, 2018).

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
ICCAT	Bigeye	LRP: Not defined. TRP: Not defined. "Green" quadrant in Kobe plot implied as target (Rec. 11-13).	The stock is estimated to be overfished and overfishing is occurring. $F_{CURRENT}/F_{MSY}$ in 2014 was estimated at 1.28. $SSB_{CURRENT}/SSB_{MSY}$ in 2014 was estimated at 0.67. 65,000 tonne TAC is specified, but the permissible catch exceeds this by a noticeable amount due to catch allowance for CPCs not included in the allocation table.	The most recent stock assessment was conducted by SCRS in 2015. $F_{CURRENT}/F_{MSY}$ from the model runs considered plausible, ranged from 0.62 to 1.85; and $SSB_{CURRENT}/SSB_{MSY}$ ranged from 0.48 to 1.20. – indicating some uncertainty in the assessment process.
	Yellowfin		The stock is considered slightly overfished, but overfishing is not taking place. $F_{CURRENT}/F_{MSY}$ in 2014 was estimated at 0.77. $SSB_{CURRENT}/SSB_{MSY}$ in 2014 was estimated at 0.95.	The most recent stock assessment was conducted by SCRS in 2016. Two main groups of abundance indicators used in the models show conflicting trends: An increasing trend in biomass with one, and a constant relative abundance since 1990 with the other.
	Eastern Skipjack		Estimated that Eastern Atlantic skipjack is not overfished and overfishing is not occurring. $F_{CURRENT}/F_{MSY}$ is likely to be below 1.0 and the $SSB_{CURRENT}/SSB_{MSY}$ is likely to be above 1.0.	The stock was assessed by SCRS in 2014, using data up to 2013. Regardless of the model used, the Committee was not in a position to provide a reliable estimate of the maximum sustainable yield and therefore nor provide quantitative advice on the state of the eastern stock. Although there are no established bases for stock assessment or management, the stock is de facto affected by Bigeye and yellowfin management.

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
	Western Skipjack		Estimated that Western Atlantic skipjack is not overfished and overfishing is not occurring. $F_{CURRENT}/F_{MSY}$ is around 0.7 and the $SSB_{CURRENT}/SSB_{MSY}$ is close to 1.3.	The most recent stock assessment was conducted by SCRS in 2014. ICCAT has not adopted conservation and management measures for this stock. SCRS has recommended that catches not be allowed to exceed MSY.
	Southern Albacore		Atlantic Albacore tuna stock is not overfished, and overfishing is not occurring. $F_{CURRENT}/F_{MSY}$ in 2014 was estimated at 0.54 and $SSB_{CURRENT}/SSB_{MSY}$ at 1.10.	The most recent stock assessment was conducted by SCRS in 2016. There is uncertainty in the models with $F_{CURRENT}/F_{MSY}$ estimated as a range from 0.31-0.87 and $SSB_{CURRENT}/SSB_{MSY}$ from 0.51-1.80.
	Mediterranean Albacore		Despite great uncertainty, FCURRENT/FMSY is thought to be less than 1.0. $SSB_{CURRENT}/SSB_{MSY}$ was estimated around 1.0 and is therefore not thought to be overfished, but near the MSY level.	The most recent stock assessment was conducted by SCRS in 2017. High uncertainty on status of the stock due to poor monitoring and lack of basic fishery statistics. Yet there are no conservation and management measures. Assessed for the first time in 2011. Data are extremely sparse and indices of abundance are lacking. In addition, there is considerable uncertainty with reported catches.
	Northern Albacore	LRP: Recently developed and accepted, (Rec. 17-04). 0.4*B_{MSY}. TRP: Recently developed and accepted, (Rec. 17-04). B_{MSY} and 0.8*F_{MSY}	The most recent stock assessment was conducted by SCRS in 2016. North Atlantic albacore stock is not overfished, and overfishing is not occurring. $F_{CURRENT}/F_{MSY}$ is estimated to be 0.54 and $SSB_{CURRENT}/SSB_{MSY}$ at 1.36.	Rebuilding plan is built around science based catch quotas. However, there is some uncertainty in the models with $F_{CURRENT}/F_{MSY}$ estimated as a range from 0.35-0.72 and $SSB_{CURRENT}/SSB_{MSY}$ from 1.05-1.78.

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
	Eastern Atlantic and Mediterranean Bluefin	LRP: Not defined. TRP: Not defined for the long term. "Green" quadrant in Kobe plot implied as target (Rec. 11-13). Interim TRP is to achieve SSB_{MSY} through 2022 with at least 60% probability (Rec. 14-04).	Stock is likely not overfished, however, considerable uncertainty on levels of abundance. The current ratio of $SSB_{CURRENT}/SSB_{MSY}$ is unknown. The TAC in place and strict controls have ended over-fishing. F_{RECENT}/F_{MSY} (using F0.1 proxy) is estimated at 0.34 (0.25-0.44). Thus, overfishing is not taking place. Catches have been reduced by over 70% since 2007 due to strict limits and controls.	The eastern Atlantic and Mediterranean bluefin stock has been the subject of a rebuilding program since 2006 (ICCAT Rec. 06-05), which has been amended every year in 2007-2010 and again in 2012 (Rec. 12-03). The plan aims to rebuild the stock to SSB_{MSY} by 2022 with at least 60% probability. The rebuilding program (Rec. 17-07) is a very comprehensive management plan that combines multiple conservation elements with enforcement ones. The TACs for 2018 through 2020 are 28,200, 32,240 and 36,000 tonnes, respectively. The latest stock assessment was conducted in 2017 applying many revisions of the historical data sets. The stock assessment is subject to considerable uncertainties due to scarcity of CPUE data and to high levels of misreporting that took place primarily in the 2000s. The SCRS was unable to estimate biomass-based reference points.
	Western Atlantic Bluefin	LRP: Not defined. TRP: Not defined for the long term. "Green" quadrant in Kobe plot implied as target (Rec. 11-13). Interim TRP is to achieve SSB_{MSY} through 2018 with at least 50% probability (Rec. 13-09).	There is uncertainty about stock status but overfishing is not occurring. The current ratio of $SSB_{CURRENT}/SSB_{MSY}$ is unknown.	An update of the 2012 and 2014 assessment was conducted in 2017, applying many revisions of the historical data sets. The Committee was unable to estimate biomass-based reference points. Stock status is highly dependent

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
			$F_{CURRENT}/F_{MSY}$ (using $F_{0.1}$ as a proxy for F_{MSY}) is estimated to be 0.59 thus overfishing is not taking place.	on the potential recruitment assumption.
IOTC	Bigeye	LRP: Interim LRP of $0.5*B_{MSY}$ and $1.3*F_{MSY}$ (Resolution 15/10). Resolution 14/03 requires a series of Science and Management Dialogue Workshops to advance work on the adoption of RP. TRP: Interim TRP of B_{MSY} and F_{MSY} (Resolution 15/10).	Overfishing is not occurring and the stock is not overfished. $F_{CURRENT}/F_{MSY}$ is estimated to be 0.76 (range 0.49-1.03), and $SSB_{CURRENT}/SSB_{MSY}$ at 1.29 (range 1.07-1.51), which is about 2.6 times above the limit SSB.	The limit reference points recommended by IOTC are not supported by scientific evidence, but as interim levels they would provide protections that limit reference points are intended to provide. The 2016 assessment conducted by the Scientific Committee (SC19) was qualitatively similar to the 2013 stock assessment but showed a lower relative biomass and higher relative fishing mortality. The estimate of MSY is 104,000 tonnes. The 2015 catch was below this level.
	Yellowfin	LRP: Interim LRP of $0.4*B_{MSY}$ and $1.4*F_{MSY}$ (Resolution 15/10). Resolution 14/03 requires a series of Science and Management Dialogue Workshops to advance work on the adoption of RP. TRP: Interim TRP of B_{MSY} and F_{MSY} (Resolution 15/10).	The stock is estimated to be overfished and overfishing is occurring due to an increase in catch levels in recent years. $F_{CURRENT}/F_{MSY}$ is estimated to be 1.11 (range 0.86-1.36), and $SSB_{CURRENT}/SSB_{MSY}$ at 0.89 (range 0.79-1.51) which is about 2.2 times above the limit SSB.	The limit reference points recommended by IOTC are not supported by scientific evidence, but as interim levels they would provide protections that limit reference points are intended to provide. In 2016, two models were applied to update the 2015 assessment, which gave qualitatively similar results. The 2016 update is somewhat more optimistic due to the use of a new composite longline CPUE series.
	Skipjack	LRP: Interim LRP of $0.2*B_0$ (Res. 16/02) and $1.5*F_{MSY}$ (Res. 15/10).	Overfishing is not occurring and the stock is not overfished.	The most recent assessment was conducted in 2017 and the model results

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
		TRP: Interim TRP of $0.4*B_0$ and (Res. 16/02) F_{MSY} (Res. 15/10).	FCURRENT/FMSY is estimated to be 0.93 (0.70-1.13). The ratio of SSBCURRENT/SSBMSY = 1.00, (0.88-1.17).	differed substantially from the previous (2014 and 2012) assessments. The limit reference points recommended by IOTC are not supported by scientific evidence, but as interim levels they would provide protections that limit reference points are intended to provide. Resolution 16/02 establishes Harvest control rules for skipjack tuna in the IOTC area of competence.
	Albacore	LRP: Interim LRP of $0.4*B_{MSY}$ and $1.4F_{MSY}$ (Resolution 15/10). Resolution 14/03 requires a series of Science and Management Dialogue Workshops to advance work on the adoption of RP. TRP: Interim TRP of B_{MSY} and F_{MSY} (Resolution 15/10).	The stock is estimated to not be overfished or subject to overfishing. However, there is considerable uncertainty associated. $F_{CURRENT}/F_{MSY}$ is estimated at 0.85 (range 0.57-1.12) and $SSB_{CURRENT}/SSB_{MSY}$ is 1.80, about 4.5 times higher than the SSB limit.	The latest assessment was performed by the SC in 2016, using data through 2014. The limit reference points recommended by IOTC are not supported by scientific evidence, but as interim levels they would provide protections that limit reference points are intended to provide.
IATTC	Bigeye (EPO)	LRP: In 2014, on an interim basis, IATTC agreed to the staff's recommendation of the equilibrium spawning biomass corresponding to that which produces a 50% reduction in recruitment from the unfished level. This corresponds to a spawning biomass that is about 8% of the un-fished level ($0.08*S_0$). TRP: In 2014, on an interim basis, IATTC agreed to the staff's recommendation of F_{MSY} and S_{MSY}.	SSB_{RECENT}/SSB_{MSY} is estimated at 1.23 (0.66-1.81), indicating the stock is not overfished; SSB_{RECENT}/SSB_0 = 0.32, which is above the LRP; $F_{CURRENT}/F_{MSY}$ is estimated at 0.87 (0.74-1.06), indicating overfishing is not taking place. However, fishing capacity of the purse seine fishery continues to increase, which is a concern.	In 2017, the IATTC conducted an update assessment of the stock, using the same model as in the previous full assessment conducted in 2013, which included several improvements in response to an external peer review. Resolution C-16-02 and minutes from the 8th IATTC meeting, state that the TRP is set on the basis of the best available information and the PA. The LRP is based on scientific literature.
	Yellowfin (EPO)		SSB_{RECENT}/SSB_{MSY} is estimated at 0.86 (0.75-0.94), indicating the stock is slightly overfished; SSB_{RECENT}/SSB_0 =	

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
			0.23, which is above the LRP; F_{RECENT}/F_{MSY} is estimated to be 0.97 (0.87-1.1), indicating that overfishing is not occurring. However, fishing capacity of the purse seine fishery continues to increase, which is a concern.	The 2017 assessment used the same methodology as the previous one, with updated data. The assessment makes an optimistic assumption that recruitment remains high when SSB is depleted. Resulting in MSY occurring at low levels of SSB and consequently the measure used to report stock status, SSB_{RECENT}/SSB_{MSY}, remains high even for low stock sizes. The assessment results are more pessimistic if a higher value is assumed for the average size of older fish, if lower rates of M are assumed for adults, and if size data from longline fisheries are given higher weight in the analyses.
	Skipjack (EPO)		Although no MSY-based RPs are available, it is very likely that the stock is above the LRP and around the TRP.	The last assessment for skipjack tuna was in 2012, based on four alternative types of analyses. In 2016 only one of the methods was updated to include data up to 2015. Stock assessment has demonstrated a high degree of uncertainty, particularly with respect to the determination of MSY RPs and biomass levels. There may also be substantial differences between regions that are not addressed.
IATTC and WCPFC	North Pacific Albacore	LRP: Not defined. WCPFC - 20% of the equilibrium spawning biomass that would be expected in the absence of fishing under current (most recent 10 years of the current assessment,	SSB_{LATEST}/SSB_{MSY} is 3.25, indicating that the stock is not overfished. $F_{2012-2014}/F_{MSY}$ is 0.61, indicating that the stock was not being overfished - fishing mortality is	The north Pacific albacore stock was reassessed in 2017.

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
		excluding the last year) environmental conditions ($0.2*SSB_{CURRENT, F=0}$). TRP: Not defined. CMM-2014-06 calls for WCPFC to develop and implement a harvest strategy approach that includes TRPs and other elements. At its 2015 meeting, the WCPFC adopted a workplan for doing so.	also lower than many commonly-used RPs that are proxies for F_{MSY}. LRP is established at $20\%SSB_{CURRENT, F=0}$. This LRP is consistent with the Annex II of the UN Fish Stocks Agreement and recent WCPFC decisions on LRPs.	Based on ISC's 2014 stock assessment advice, this stock is treated as a Level 2 stock. TRP will be determined following a comprehensive analysis. Historical fishing activity, anticipated fishing activity, and the source of increased fishing mortality will also be considered. Socioeconomic factors, as per UNFSA Article 6.3.c., will be further considered. The existing CMM for the stock (WCPFC 2005-03) establishes through limits on current effort an overall management regime for the stock.
	South Pacific Albacore	LRP: (WCPFC) 20% of the equilibrium spawning biomass that would be expected in the absence of fishing under current (most recent 10 years of the current assessment, excluding the last year) environmental conditions ($0.2*SB_{CURRENT, F=0}$). TRP: Not defined. CMM-2014-06 calls for WCPFC to develop and implement a harvest strategy approach that includes TRPs (alternatives under consideration) and other elements. At its 2015	The stock is considered to not be overfished or subject to overfishing. $SSB_{CURRENT}/SSB_{F=0}$ is 0.40 and $SSB_{CURRENT}/SSB_{MSY}$ in 2013 was 2.86. The ratio $F_{CURRENT}/F_{MSY}$ in 2009-2012 was 0.39. The estimate of MSY is 76,800 tonnes (the median across a large number of plausible model runs). LRP set at Level 2 with regard to the biomass-based LRP of 20% $SSB_{CURRENT, F=0}$, with deferral of a recommendation	In 2016 a full assessment was not conducted, but status-quo projections were calculated, which adds some uncertainty. Potential future spawning biomass levels relative to unfished levels were examined, and the probability that the south Pacific albacore stock may fall below the biomass LRP estimated to be 19%. However, the last full assessment in 2015 covers only the WCPFC Convention Area. Some other changes from the previous (2012) assessment were: having spatial structure in the model,

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
		meeting, the WCPFC adopted a workplan for doing so.	on the value of X% in the Level 2 fishing mortality-based LRP of $F_{x\%SPR}$ to SC9 (SC8 recommendation)	new datasets (age-length and tagging data) and some changes to assumed biological parameters.
	Pacific Bluefin	LRP: Not defined. TRP: CMM-2014-06 calls for WCPFC to develop and implement a harvest strategy approach that includes TRPs and other elements. At its 2015 meeting, the WCPFC adopted a workplan for doing so. WCPFC CMM 2016-04 defines an initial re-building target which corresponds to a spawning biomass of around 7% of estimated unfished spawning stock biomass ($0.07*SSB_0$). IATTC C-16-08 establishes an initial rebuilding target of SSBMED (the median spawning biomass for the period 1952-2014) to be achieved with 60% probability by 2024.	The stock is heavily overfished and the biomass is near historically low levels, with SSB estimated to be 2.6% of the unfished level. Estimated fishing mortality exceeds all calculated biological reference points except for F_{MED} and F_{LOSS}.	In 2016 ISC conducted a benchmark stock assessment (base-case model) which is considered to be a substantial improvement compared to the 2014 assessment.
WCPFC	Bigeye	LRP: 20% of the equilibrium spawning biomass that would be expected in the absence of fishing under current (most recent 10 years of the current assessment, excluding the last year) environmental conditions ($0.2*SB_{CURRENT,\ F=0}$). Adopted by the Commission in 2012.	The latest stock assessment for bigeye tuna indicates that the stock is no longer considered overfished or experience overfishing (WCPFC-SC13-2017/SA-WP-05[24]). The median ratio of F_{RECENT}/F_{MSY} is estimated at 0.83 (0.61-1.32), indicating that overfishing is likely not occurring; The median ratio of spawning	In 2017, SPC conducted a new assessment which incorporated two substantial changes: A revised growth curve (based on otolith age readings), and a new regional structure in the model. LRP set at Level 2 with regard to the biomass-based LRP of $0.2*SB_{CURRENT,\ F=0}$, with deferral of a recommendation on the value of X% in the Level 2 fishing

[24] https://www.wcpfc.int/system/files/SC13-SA-WP-05%20%5Bbet-assessment%5D%20REV1.pdf

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
		TRP: Not defined for the long term. CMM 2017-01, which acts as a bridge to the adoption of a harvest strategy, establishes that, pending agreement on a TRP, the spawning biomass depletion ratio ($SB/SB_{F=0}$) is to be maintained at or above the average $SB/SB_{F=0}$ for 2012-2015.	biomass SSB_{RECENT}/SSB_{MSY} in the model runs is estimated at 1.23 (0.63 to 1.66). There is high uncertainty in the model results. Spawning biomass is estimated to be likely above the limit reference point established by WCPFC ($SSB_{RECENT}/SSB_{F=0}$ =0.2). The median ratio $SSB_{RECENT}/SSB_{F=0}$ is 0.32. However, 16% of the model runs were below the limit, which is not insignificant.	mortality-based LRP of $F_{x\%SPR}$ to SC9 (SC8 recommendation). The most recent stock assessment has been updated following extensive peer-review. Changes include: increases in the number of spatial regions to better model size and distribution data; inclusion of catch estimates from fisheries previously missing; the use of additional longline data; improved modelling of recruitment; and a large amount of new tagging data.
	Yellowfin	LRP: 20% of the equilibrium spawning biomass that would be expected in the absence of fishing under current (most recent 10 years of the current assessment, excluding the last year) environmental conditions ($0.2*SB_{CURRENT,\ F=0}$). TRP: Not defined. CMM 2017-01, which acts as a bridge to the adoption of a harvest strategy, establishes that, pending agreement on a TRP, the spawning biomass depletion ratio ($SB/SB_{F=0}$) is to be maintained at or above the average $SB/SB_{F=0}$ for 2012-2015.	The yellowfin stock is not in an overfished state as spawning biomass is above the SSB_{MSY} level (SSB_{LATEST}/SSB_{MSY} = 1.39, range between 0.80 and 1.91 across different models). The ratio F_{RECENT}/F_{MSY} (for the period 2011-2014) is estimated to be 0.74 (range across different models between 0.54 and 1.13), indicating that overfishing is likely not occurring.	A new yellowfin assessment was conducted in 2017. LRP set at Level 2 with regard to the biomass-based LRP of 20% $SB_{CURRENT,\ F=0}$, with deferral of a recommendation on the value of X% in the Level 2 fishing mortality-based LRP of $F_{x\%SPR}$ to SC9 (SC8 recommendation) A new assessment was conducted in 2014, which had many improvements to the data and models, following recommendations during the peer review of the bigeye assessment. Changes include: increasing number of spatial regions to better model tagging and size data; additional catch estimates from fisheries previously missing; the use of longline data for multiple fleets; improved modelling of recruitment; and a large amount of new tagging data. The

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
				results were similar to those from the previous (2011) assessment. The optimistic stock status should however, be tempered by unequal patterns estimated at a sub-regional level.
	Skipjack	LRP: 20% of the equilibrium spawning biomass that would be expected in the absence of fishing under current (most recent 10 years of the current assessment, excluding the last year) environmental conditions ($0.2*SB_{CURRENT,\ F=0}$). TRP: CMM-2015-06 established an interim TRP equal to 50% of the equilibrium spawning biomass that would be expected in the absence of fishing under current (most recent 10 years of the current assessment, excluding the last year) environmental conditions ($0.5*SB_{CURRENT,\ F=0}$).	Overfishing is thought to not be occurring and the stock is not overfished. The ratio of $SSB_{CURRENT}/SSB_{F=0}$ is 0.58 and SSB_{LATEST}/SSB_{MSY} estimated at 2.56. F_{RECENT}/F_{MSY} estimated at 0.45; and recent catches are below the MSY of 1.892 million tonnes. LRP for skipjack is set at Level 3, 20% $SB_{CURRENT,\ F=0}$ (SC8 recommendation). WCPFC12 agreed to CMM 2015-06 which establishes a TRP shall initially be 50% of the estimated recent average SSB in the absence of fishing, calculated in a manner consistent with that detailed above for the LRP. This TRP shall be an interim TRP until it is reviewed in accordance with paragraph 8 of CMM 2015-06.	A new assessment was conducted in 2016, with new developments including; addressing recommendations of the 2014 stock assessment report, exploration of uncertainties in the assessment model, particularly in response to the inclusion of additional years of data, and to improve diagnostic weaknesses of previous assessments. However, the 2016 SC meeting was not able to reach consensus regarding which model runs should be used to characterize stock status.
CCSBT	Southern Bluefin	LRP: Not defined. TRP: Not defined for the long-term. 20% of the unfished biomass ($0.2*SSB_0$) is	The stock is heavily overfished. However, overfishing is not occurring	Southern bluefin tuna is assessed by the Extended Scientific Committee (ESC) of

RFMO	Stock	Reference Points	Stock status in relation to RP	Basis for establishment
		used as an interim TRP to be achieved with 70% probability by 2035.	due to measures taken in a rebuilding plan. $SSB_{CURRENT}/SSB_{MSY}$ is estimated at 0.49 (range 0.38-0.69). Spawning biomass is estimated to be between 11% and 17% of the unfished level. $F_{CURRENT}/F_{MSY}$ is estimated at 0.50 (range 0.38-0.66).	the CCSBT. The stock advice was given in 2017. Managed primarily through TACs that aim, as an interim target, to rebuild the stock to 20% of the unfished level by 2035. TACs are set through a process known as a Management Procedure, adopted in 2011, that specifies the actions to be taken depending on the outcomes of the assessment made by the ESC. This TRP is defined under the understanding that it represents a stock rebuilding target, and will increase in a step-wise manner.

2.4 Sub-task 1.3: Strengths and weaknesses of reference points

There are numerous RPs available to fisheries managers, but only a handful are used in t-RFMOs (Table 1). Equally, there are many underlying methods for describing the balance between harvesting and stock biomass, and thus estimating an RP. Generally, two variants of RPs are currently applied in t-RFMOs, each with varying strengths and weaknesses: MSY-based and Depletion-based. In addition to these, a fishing mortality LRP based on spawning-potential-per-recruit (SPR) has been adopted by WCPFC (i.e. $F_{x\%SPR}$) for 'Level 2' under their hierarchal approach, in addition to less commonly used yield per recruit (YPR) methods. While both MSY-based and Depletion-based RPs can be calculated using the same stock assessment method (e.g. SS3[25] or MULTIFAN-CL[26]) they rely on different outputs from the assessment. Meanwhile both SPR and YPR have different data requirements. The most significant difference between these types is the estimation issues and uncertainty of MSY-based RPs, which are highlighted in more detail in the following sections. As a result, Depletion-based RPs are often used in tuna RFMOs.

2.4.1 MSY-based

MSY is calculated by determining the point at which the stock dynamics (i.e. removal and replacement of fish) are in a state of balance, using the selectivity values of the current fisheries. MSY-based RPs are built into many of the legal frameworks of highly migratory fisheries (e.g. UNCLOS, 1982; UNFSA, 1995) and can be estimated as absolute quantities directly from stock assessment models (e.g. B_{MSY} or F_{MSY}) or as ratios of various kinds (e.g. $B_{CURRENT}/B_{MSY}$ or $F_{CURRENT}/F_{MSY}$). Estimates of MSY can be obtained from stock-production models or using more sophisticated models require selectivity, natural mortality, maturity (age) and estimates of the stock recruitment relationship (SRR) (Davies and Basson, 2008).

In the case of simple equilibrium surplus production models, the data requirements are minimal: a time series of both an index of abundance and catch. No information is required on gear selectivity or stock-recruitment. However, the form of the model determines at which relative depletion level (B_{MSY}/B_0) the MSY is obtained. For example, the Schaefer stock-production model has $B_{MSY}/B_0=0.5$ (Schaefer, 1954), whereas a statistical integrated age-structured model may have $B_{MSY}/B_0<0.5$ (see Figure 1).

Use of non-equilibrium surplus production (or biomass dynamic) models, rather than equilibrium surplus production models removes a key assumption that the population is at equilibrium. However, a range of issues can lead to poor fitting of the model, such as data with little or no contrast (i.e. 'one-way trip'[27] Hilborn and Walters, 1992) and increases in catchability in the fleet. For more complex age-based stock assessment models used to calculate MSY-based RPs (e.g. Multifan-CL), data requirements are much higher and include natural mortality, maturity, and weight at age and, more importantly, selectivity at age.

[25] http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm

[26] http://www.multifan-cl.org/

[27] This refers to time-series data used to assess the status of the stock, which commonly consists of a fishery with continuously increasing fishing effort and declining catch per unit effort. This type of time-series provides limited information (or contrast) in the data to parameterise stock assessment models and can lead to a biases in the results obtained.

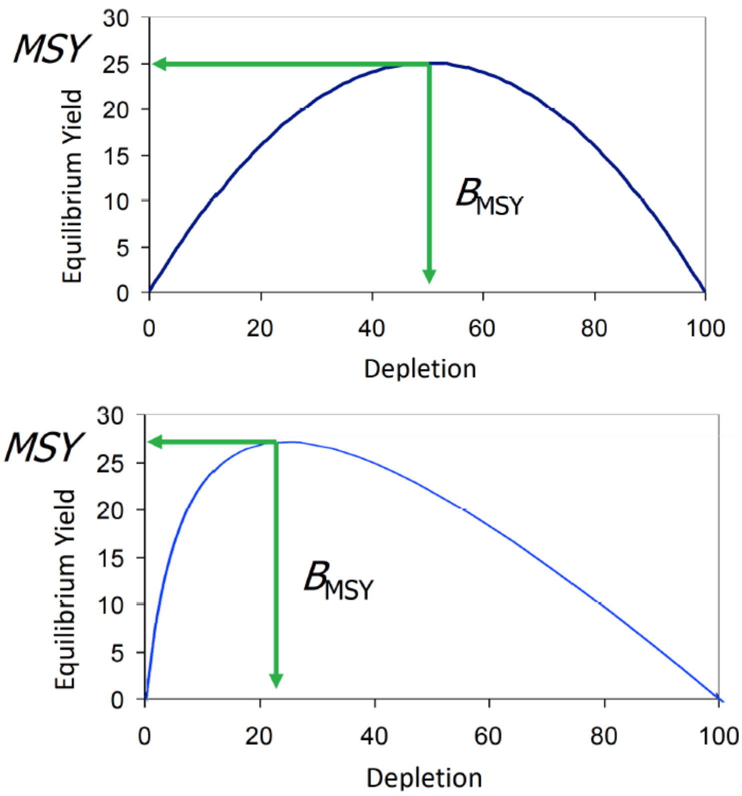

Figure 1: Example of different MSY reference points calculated using (top) Schaefer surplus production model and (bottom) a statistical integrated age-structured model (source: Valero et al. 2017).

The strength of MSY (and MSY-based RPs) is that it covers productivity directly, maximising yields while maintaining the population level at a safe and productive level. Where more sophisticated stock assessment methods are used, a number of estimation issues and uncertainty in MSY-based RPs arise. These include (i) the assumed (or estimated) steepness parameter (h) used in the SRR (ii) the selectivity of fishing gears (iii) changes in productivity (iv) recruitment variability, and (v) selection of either absolute quantities of MSY or ratios used.

(i) Steepness

The SRR steepness parameter (h) is the proportion of unfished recruitment (R0) that would be expected to be produced if the spawning biomass was reduced to 20% of unfished spawning biomass (SSB_0) and ranges between 0.2 and 1 (Figure 2). Stocks with a high steepness value (e.g. 0.9) are more productive when the stock is reduced to very low levels by fishing. This also means that more animals can be removed from the population sustainably than a population with a low steepness value, and are more resilient to high fishing pressure. The steepness value can alter between different species or within species if environmental changes were to occur (affecting growth and mortality etc.).

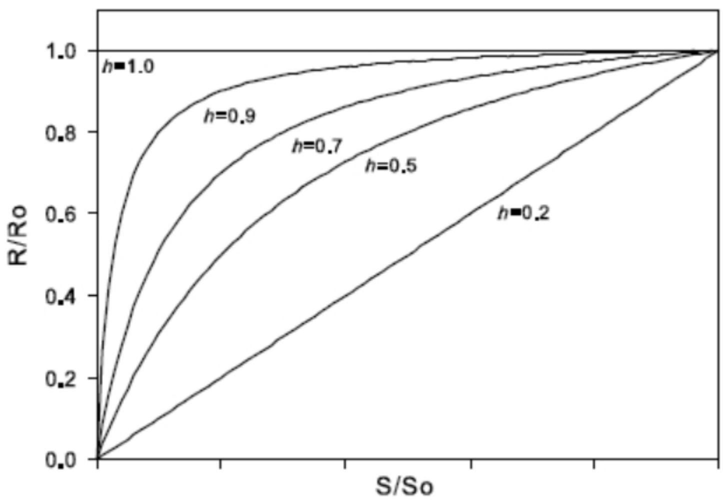

Figure 2: Beverton-Holt stock recruitment relationship with different values of steepness (h).

A key weakness of using steepness (h parameter) for MSY-based RPs is that it is often very difficult to estimate in fisheries stock assessments due to uncertainties in the model outputs in addition to environmental changes. Several examples have shown that for various levels of stock-recruitment steepness parameter (h), there is a wide range of values for MSY, and therefore, also a wide range of values for the MSY-based RPs. A Beverton-Holt SRR (Beverton and Holt, 1957) is most commonly used for marine teleost species such as tuna.

In ICES, in such situations, the recent trend in MSY estimation methods consists of considering different assumptions of the relationship model between the spawning and recruitment of a stock, via simulations. The available SRR data are used to assess the statistical likelihood of fitting each relationship, which is then used jointly in long term stochastic simulations, using for each a weight proportion to its likelihood. This way the uncertainty in the steepness is incorporated into the estimation of MSY.

The level of relative depletion is very sensitive to the value of steepness (h) used in the stock-recruit curve. At comparatively high steepness levels, the SSB_{MSY}/SSB_0 ratio will be lower than for low steepness levels. For example, the assessment of yellowfin tuna in WCPFC, calculated the ratio for SSB_{MSY}/SSB_0 to be 0.23 under the 'high steepness' (0.913) assessment model, and at 0.31 for the 'base case' or default assessment model used (steepness was 0.6215) (Langley et al., 2007).

(ii) Selectivity of fishing gears

Use of different fishing gears or exploitation pattern of a fleet segment (e.g. number and location of FADs or size of longline hooks) can select specific age-classes within the population and thus the overall productivity of the stock. Large and unexpected changes in selectivity can result in changes in MSY, which also affects other methods such as yield or spawner per recruit.

(iii) Changes in productivity and recruitment variability

Changes in productivity can refer to environmental changes or 'regime shifts' or to changes in the level of recruitment over time. Increases in recruitment over time is likely to affect the catch-at-age profile within the fishery that will result in changes in the F-at-age estimates. In turn, this can affect estimates of MSY-based RPs.

(iv) Absolute quantities of MSY or ratios used

MSY is sometimes criticised in respect to the difficulty in estimating it reliably and in using it as a TRP, from the point of view of the PA, although it may be used as an "upper limit" (Rosenberg and Restrepo, 1995). Hence, the criticism also is relevant to its precautionary proxy such as $F_{0.1}$ (see YPR). One of the fundamental issues is whether or not the current stock assessment is accurate enough in view of a large mismatch between the poor data and population analysis that requires no error in catch-at-age. Unless such issue is somehow clarified, it is not clear if $F_{0.1}$ is really robust or not. Deterministic MSY-based RPs may also be calculated that ignore system stochasticity such as recruitment and catchability (Preece et al., 2011). Under these circumstances constant fishing effort equivalent to FMSY will eventually lead to a constant yield of CMSY, i.e. ignoring the influence of variable catchability and recruitment strength. Under stochastic systems, using a long-term FMSY management strategy based on a deterministic MSY can lead to a high probability of causing permanent depletion of the spawning stock.

MSY-based RPs can use either spawning stock biomass (SSB) or total biomass (B). Use of SSB is preferable over B because recent recruitment is less well estimated than older age classes in the last few years of the stock assessment (Harley et al., 2009). However, due to data limitations, estimation of SSB may is not always be feasible. ICCAT for example, has recently assessed the Northern albacore stock using a stock-production model with associated total biomass MSY-based RPs (see Table 3). In addition, $SSB_{CURRENT}$ is defined as an average taken from the most recent years (4 years is used in WCPFC stock assessments) and excludes the most recent year in the stock assessment, which would otherwise be termed SSB_{RECENT}. The latter is preferred over $SSB_{CURRENT}$ as it provides the latest information to be used for HCR. In contrast, use of the current fishing mortality rate ($F_{CURRENT}$) as a RP is preferred over most recent estimate (i.e. F_{RECENT}) because the latter is normally over-estimated in the stock assessment, due to the last year overestimation, and decline in the following year when more data are available (Harley et al., 2009). In comparison, F_{BAR} is commonly used in ICES age-based stock assessments that refers to the average fishing mortality for a given set of age classes in the population (e.g. $F_{BAR\ 2\text{-}4}$). This can be used to monitor changes in fishing mortality against LRPs (F_{LIM}) and TRPs (F_{MSY}). This approach helps mitigate where catch and effort data are incomplete in the last year, making the most recent estimates uncertain (Langley et al., 2010). However, using only the most recent estimates of SSB and F rather than the latest creates a time-lag between the stock status advice and the implementation of management action (Preece et al., 2011).

2.4.2 Depletion-based

Depletion-based RPs are based on the depletion level of the total biomass (or SSB) and provide biomass based RPs (e.g. x% of SSB). Depletion estimates provide information on how much the SSB has been reduced since fishing began and therefore, how much SSB remains, and the estimated impact on historic, current and future recruitment and yield. Most common depletion-based RPs are defined as proportion of the initial unfished biomass (e.g. $SSB_{CURRENT}/SSB_0$).

Obtaining robust estimates of the initial unfished (virgin) biomass (B_0) can be difficult as most stock assessments use commercial data after the fishery has developed, thus already causing some level of depletion. Where no data exists for this initial period, age-based stock assessments (e.g. Multifan-CL) can be used to reconstruct the population such that it estimates 'unfished' levels without need of a SRR. Further to this, more recent environmental changes may prevent the stock from returning to similar historical unfished levels. This has been recognised by WCPFC, who calculate the current estimate of the spawning stock that would have occurred in the absence of fishing ($SB_{CURRENT,\ F=0}$), given more recent information about recruitment patterns. Unlike MSY-based RPs, reconstructing populations to estimate unfished biomass do not rely on robust estimates of the SRR steepness parameter, h.

In general, BMSY ranges between 35 and 50% of depletion but in some cases where a high stock-recruitment steepness parameter is used (i.e. 0.95) it can be as low as 14% of the equilibrium unexploited spawning stock biomass (WCPFC South Pacific albacore; Harley et al., 2015). Several Regional Fisheries Bodies and national fisheries, including International Whaling Commission and Commission for Antarctic Marine Living Resources currently use depletion LRP of 20% of SSB_0. However, the rebuilding target for SBT has been set at 20% SSB_0 as the stock is currently in a depleted state and already below what would otherwise be considered a LRP.

Some t-RFMOs including WCPFC also use the equilibrium spawning stock biomass expected in the absence of fishing under current environmental conditions (i.e. $SSB_{CURRENT,\ F=0}$), rather than that of a virgin stock. This approach accommodates environmental shifts that might be attributed to climate change, which would not necessarily occur if estimated using the virgin stock in the model (i.e. level of biomass before environmental changes). It should also be noted, that when using virgin, or unfished biomass, these are often not known from recorded measurements, but may be estimated, based on models that use historical catch records to parametrise them.

Management of the Atlantic bluefin tuna drew wide attention when the species was proposed to be listed in the Appendix I of CITES. One of the problems emerged in the meeting was estimates of virgin biomass or B_0. For example, Ravier and Fromentin (2001) demonstrated a frequent and large scale stock fluctuations caused by natural factors for the past 300 years in the Mediterranean Seas, well before the industrial fishing for bluefin started. This may indicate that the SRR does not exist or if any, fluctuation reflecting the changes in environmental carrying capacity, natural mortality, migratory routes, meta-populations and regime shift. Estimation of B_0 used to calculate RPs is also hampered by missing or very poor catch data that is required to reconstruct the population before fishing activities started. However, given the history of the fishery, potential environmental changes and uncertainty in the stock-recruitment dynamics highlighted above, estimated of virgin biomass (or spawning biomass) may be calculated based on recent biomass estimated in the absence of fishing (e.g. $SSB_{0,\ F=0}$). This overcomes the problem of obtaining large historical datasets but assumes the stock is unable to return to former levels prior to fishing activities.

Preece et al. (2011) recommend a three level hierarchical approach to setting LRPs. The first level uses F_{MSY} and B_{MSY} but only where reliable and precise estimates of the stock-recruitment steepness parameter (h) are available. The second uses FSPR and 20% of SSB0 assuming that steepness is not known well but the key biological estimates are reasonably well estimated. The third level does not provide an F-based LRP if the key variables are not well estimated or understood, but suggests that the SSB limit of 20% of SSB_0 be used. A critical analysis of the strengths and weaknesses of MSY-based and depletion-based methods is given in section 0.

2.4.3 Spawning potential per recruit

The spawning potential per recruit is the potential contribution to spawning stock biomass (SSB) over the lifetime of a single recruit. It can be calculated at any given fishing mortality level. A practical measure of the state of depletion of exploited stocks is the spawning potential ratio (SPR), which represents the ratio of the spawning potential per recruit for a given level of F, and the spawning potential per recruit in the pristine stock (SPR_0).

The information required to estimate this parameter includes natural and fishing mortality, growth, maturity and selectivity, which are often available in tuna stock assessments and can therefore represent a better method for RP than MSY, when data is limited. Some authors recommend reductions of 35%-40% in SPR_0 as LRPs (Preece et al., 2011).

Unlike MSY-based methods, spawning potential per recruit therefore does do not require an SRR, and therefore information on steepness, which highly uncertain in tuna fisheries. However, given the estimation spawning potential over the lifetime of a single recruit, reference points based on FSPR are sensitive to changes in selectivity.

2.4.4 Yield per recruit

Yield per recruit (YPR) calculations can provide fishing mortality RPs. One of the strengths of this approach is that inputs required to calculate the YPR quantities are relatively simple, including natural mortality, maturity, size (weight) and selectivity at each age. Two quantities are estimated to use as RPs: F_{MAX} and $F_{0.1}$ (Figure 3). F_{MAX} is the fishing mortality rate which corresponds to the maximum yield per recruit.

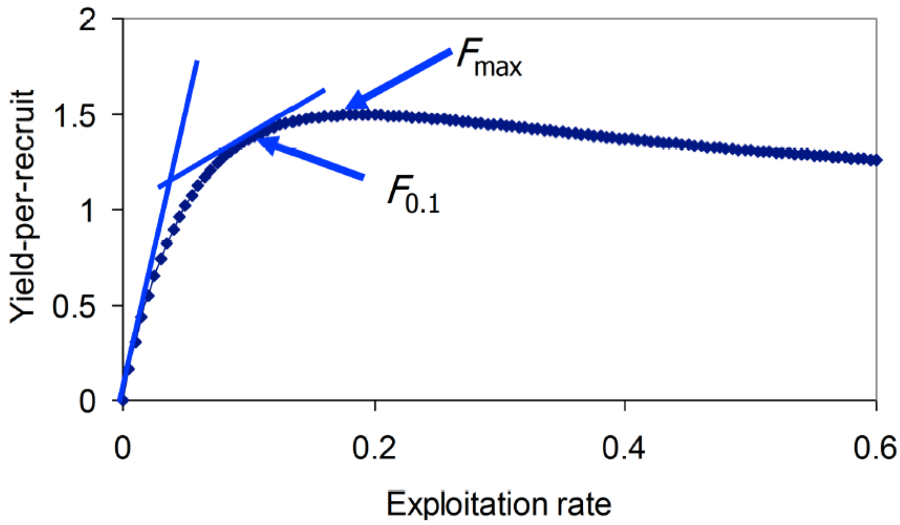

Figure 3: Example of yield-per-recruit reference points (source: Valero et al. 2017).

However, because F_{MAX} is usually greater than F_{MSY}, and that fishing at this rate over an extended period of time is liable to deplete the spawning stock and reduce future recruitment, it is generally regarded as an upper limit for F, and therefore acts as LRP (Caddy and Mahon 1995).

In cases where the YPR curve is flat and no clear maximum yield is obtained (i.e. no dome-shaped curve) a potential weakness is that it can be difficult to estimate the value of F_{MAX}. Under these circumstances the $F_{0.1}$ may be considered. This is commonly used as a TRP and corresponds to the fishing mortality rate at which the slope of the yield per recruit curve (as a function of fishing mortality) is 10% of its value at the origin (Caddy, 1998). However, $F_{0.1}$ has been found in some cases to be above FMSY so can lead to undesirable stock depletion (Caddy and Mahon, 1995).

Similar to equilibrium surplus production models used to calculate MSY-based RPs, YPR calculations do not require a stock-recruit relationship and therefore does not take into account the effect of fishing mortality on the proportion of mature fish left in the population and hence its reproductive potential. Without this information it is important to consider the implications of F_{MAX} and $F_{0.1}$ on the adult (spawning) component of the population by calculating the relative spawner per recruit (SPR) that would be implied by these harvest rates to help prevent recruitment overfishing.

The following table briefly summaries the specific strengths and weaknesses of individual RPs, taking into account the type of RP and the basis for its establishment including data requirements.

Table 7: Strengths and weaknesses of currently defined tuna RPs (source: Anon 2016; Valero et al., 2017) .

RP	Strengths	Weaknesses	Information requirements
MSY-based methods			
X% of F_{MSY}	Can be used to manage all stocks in multispecies fishery and avoids catch limits of more vulnerable species (choke species). Considers both recruitment overfishing and growth overfishing.	Calculation of MSY-based RPs are sensitive to uncertainty in recruitment variability (e.g. steepness parameter, h) and other structural assumptions used in assessment. MSY-based RPs require accurate data on SRR. It is not possible to apply different RPs to two or more species that are vulnerable to the same fishing gear in a multispecies fishery.	MSY-based RPs can be calculated using various stock assessment methods. To date, two most common methods used are Stock Synthesis (SS3) and Multifan-CL. Both require similar data requirements, including growth, fishing and natural mortality, maturity, gear selectivity, catch and effort, and SRR parameter, h. Surplus production models are used to estimate total biomass RPs only (i.e. B_{MSY}), and require less information on catch, effort and preferably an index of abundance.
X% of B_{MSY} OR X% of SSB_{MSY}	Biological MSY-based RPs can be used to monitor total biomass levels to ensure harvest strategy is effective at maintaining the stock at productive levels and above the point of recruitment impairment. Consider both recruitment overfishing and growth overfishing.	Similar to FMSY, biological MSY-based RPs are sensitive to uncertainty in recruitment variability and SRR steepness parameter, h. Difficult to manage all stocks in multispecies fisheries to MSY. Different forms of stock assessment methods (e.g. surplus production, age-based) determine the depletion level MSY is obtained (e.g. $B_{MSY}/B_0 = 0.5$ or B_{MSY}/B_0 < 0.5).	
Depletion-based methods			
X%B_0	Unlike MSY-based RPs, reconstructing populations to estimate unfished	The level of depletion (i.e. X%) at which recruitment becomes impacted is unclear	Similar to MSY-based above, depletion-based methods can be

RP	Strengths	Weaknesses	Information requirements
OR $X\%B_{CURRENT, F=0}$	biomass do not require estimates of the SRR steepness parameter, h. Unfished or virgin biomass levels can be calculated using age-structured models by projecting the stock forwards to reach an equilibrium point based on recent (e.g. 10 years) average recruitment levels (e.g. $B_{CURRENT, F=0}$). This approach can avoid uncertainties in historical environmental changes. Evidence shows depletion-based RPs are relatively stable between each assessment.	for each specific stock and values are often taken from meta-analyses of multiple stocks. Depletion levels used to set LRPs may be too precautionary and could potentially lead to foregoing potential yield. Historical environmental changes are uncertain when age-based methods are used to reconstruct the population to back-calculate unfished or virgin biomass levels (e.g. B_0).	calculated using SS3 and Multifan-CL and have similar data requirements, with exception to the SRR steepness parameter, h. Typically, depletion-based RPs can be calculated using one of two methods: reconstruction of the population backwards to a point prior to fishing mortality (e.g. B_0) or projecting the stock forwards in the absence of fishing (e.g. $B_{CURRENT, F=0}$).
Spawning potential per-recruit			
$F_{X\%SPR_0}$	SPR based RPs are not dependent on the SRR being known. Hence unlike MSY-based RPs that use a highly uncertain steepness parameter, this is not an issue that can limit the use of SPR.	SPR is very sensitive to changes in gear selectivity. Hence having appropriate information and data available for accurate estimates of selectivity is important for the calculation of SPR RPs.	Information is required on natural and fishing mortality, growth, maturity and gear selectivity.
Yield-per-recruit			
$F_{0.1}$ F_{MAX}	YPR methods do not require knowledge of the SRR, including the steepness parameter, h.	Estimates of $F_{0.1}$ can be above F_{MSY} so can lead to lower stock levels. Similarly,	Data requirements include natural mortality, growth (weight), maturity and selectivity at age.

RP	Strengths	Weaknesses	Information requirements
	Both RPs can be used to monitor growth overfishing.	estimates of F_{MAX} are always at or above FMSY so can lead to lower stock levels. YPR asymptotic curve can sometimes be flat so difficult to estimate F_{MAX}. YPR cannot account for the effect of fishing mortality on the proportion of mature fish in the population, and hence the reproductive potential.	

2.5 Sub-task 1.4: Correspondence between different types of reference points

This section provides a critical analysis of different RPs used by t-RFMOs, including use of depletion- and MSY-based RPs for establishing LRPs and TRPs. This analysis is particularly relevant to those t-RFMOs who have established MSY-based levels as a LRP, including the three tier hierarchal approach adopted by WCPFC.

2.5.1 Depletion vs MSY based RPs

Target Reference Points are defined in relation to their MSY estimates or their depletion level (relative to unexploited level). In brief, there has been substantial discussion across RFMOs on the best type of RPs that can be summarized as:

The strength of MSY (and MSY-based RPs) is that it covers productivity directly, maximising yields while maintaining the population level at a safe and productive level. MSY-based reference points align with the objective of maximizing the catch opportunities from fish stocks. The level of precaution will be implemented by increasing the probability (p) of the stock being above its B_{MSY} level. If a stock is fluctuating around its B_{MSY}, this p will be 50% whilst, for example, by establishing a management objective to be achieved with higher probability (e.g. 60% for ICCAT North Atlantic albacore) means that on average the stock will be above B_{MSY} and therefore the management objective will be precautionary in reducing the probability of the stock falling below unsustainable levels due to environmental or other fluctuations. Setting TRPs this way aims at trading small losses of catch production opportunity for reducing risks of collapse and increasing sustainability.

The limit RPs are also set in relation to B_{MSY}. F_{MSY} can be considered as a limit so that it is never exceeded. In reality, the limit fishing mortality will be that leading the stock towards the biological LRP. When using MSY-based RPs, a fraction of B_{MSY} will be set as a LRP (e.g. $0.4*B_{MSY}$, for many ICCAT and IOTC stocks). The main shortcoming of the MSY is that the use of sophisticated stock assessment models (SS3, Multifan-CL requires selectivity, natural mortality, maturity and some input on the stock-recruitment relationship. The key weakness is the difficulty in robustly estimating RPs when these parameters are not sufficiently known. Another key weakness is that it is dependent on assumptions about fisheries exploitation pattern. When using different selectivity values, the MSY estimates also vary. Therefore, MSY is not consider as robust (or stable) as depletion based RPs.

An advantage of depletion-based RPs is that they are relatively stable between assessments and, in many of the tuna stocks have provided the least variation in the range of results across a range of stock-recruitment steepness parameter (h) values used (Kolody et al., 2010). Depletion based RPs can be preferred because the unfished biomass and the depletion level estimates are similar when using different models.

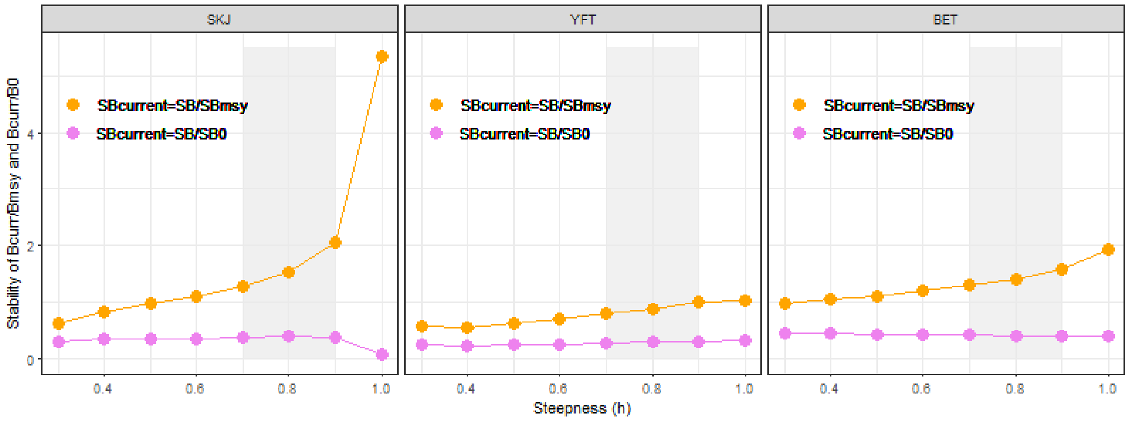

Figure 4. Robustness of SB/SB$_{msy}$ and SB/SB$_0$ estimates of the three tropical tuna stocks in the IOTC when fixing a range of steepness values (0.3-1).

Figure 4 shows that when running the stock assessment model SS (widely used in the IOTC) with different fixed levels of stock-recruitment steepness parameter (h), the estimate of the available biomass relative to its unexploited level (pink) does not differ significantly but it does when expressed relative to SSB$_{MSY}$ (orange). In reality, the range of steepness currently used in tuna RFMOs is between 0.7 and 0.9 (grey shade). In this range, the stock status is sensitive to SSB$_{MSY}$ and not that much if it is expressed in depletion level.

2.5.2 Establishment of LRPs

As defined by UNFSA, LRPs should set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce MSY. An analysis of three specific thresholds for recruitment overfishing was done by Myers et al., (1994): (1) the stock size corresponding to 50% of the maximum predicted average recruitment; (2) the minimum stock size that would produce a good year class when environmental conditions were favourable; and (3) the stock size corresponding to 20% of various estimates of virgin stock size[28]. The results indicated that the first types are generally preferable because they are easier to understand and relatively robust if only data at low stock sizes are available, and almost always end in higher level of recruitment above the threshold. However, they acknowledge that 'no single method is best for every stock and for any given analysis in practice we recommend as many diagnostic measures be examined as possible'.

In the absence of information on stock and recruitment, Caddy & Mahon (1995) highlighted that practical management advice has been based on generalisations from examination of a large number of exploited stocks. For example, a survey of 91 stock and recruitment data sets from Europe and North America suggested that for stocks considered to have an average resilience, a biomass level of 20% of the unfished level should be considered a recruitment-based LRP. Further to this, in the case where there is higher uncertainty, Caddy & Mahon (1995) suggest the LRP should be set at least 30% of the unfished level. These observations were supported by theoretical work carried out by Mace (1994) and suggest that these results may be applicable to stocks outside the North Atlantic. The results, however, were found to be highly dependent on life history characteristics, particular the degree of density dependence in the S–R relationship.

In addition, Myers et al., (1996) analysed 364 spawner-recruitment time series to determine whether fish recruitment is related to spawner abundance. In conclusion, the

[28] A reference biomass of 20% virgin or unexploited biomass (20% B_0) is the most commonly adopted 'overfishing threshold' (Beddington and Cooke, 1983; Getz and Haight, 1989).

results showed that when there is sufficient range in spawner abundance; (1) the highest recruitment occurred when spawner abundance is high; (2) the lowest recruitment occurs when the spawner abundance is low; and (3) the mean recruitment is higher if the spawner abundance is above rather than below the median. This also indicated that recruitment overfishing appears to be a common problem.

Preece et al., (2011) recommend a three level hierarchical approach to setting LRPs for WCPFC. The first level uses F_{MSY} and B_{MSY} but only where reliable and precise estimates of steepness are available. The second uses F_{SPR} and 20% of SSB_0 assuming that steepness is not known well but the key biological estimates are reasonably well estimated. The third level does not provide an F-based LRP if the key variables are not well estimated or understood, but suggests that the SSB limit of 20% of SSB_0 be used (Preece et al. 2011). The establishment of LRPs at 20% depletion is being generalized across tuna RFMOs without maybe considering the implications of such LRP when using fully integrated stock assessment models (in particular with the steepness levels currently in use). Maunder and Deriso defined a route to estimate LRPs for alternative values of steepness through the following relation (Maunder and Deriso, 2014):

$LRP = \frac{0.2\, r\, (1-h.}{0.8\, h - r(h-0.2)}$; being r=R/R0 and h=steepness. For r = R50%= R/R0 = 0.5, i.e. the LRP will be set as the point where the recruitment will be 50% of the recruitment at pristine levels. For that case, the LRP will be 20% of depletion only for steepness (h) = 0.5. The same LRP can be re-calculated for the steepness range currently used, i.e. (0.7-0.9) and the LRP will range between 9.7-2.7% of B_0, notably lower than the 20% currently being applied in IOTC, WCPFC and CCSBT. In the IATTC, the LRP is established using a steepness of 0.75, i.e. LRP=7.7%).

2.5.3 Establishment of TRPs

The TRP reflects the management objective. If this is to be above B_{MSY} with high probability, the FTRP will be lower than FMSY (which is the TRP in the IATTC but it is seen as a limit elsewhere). In contrast, if the management objective that prevails is to reduce the probability of the stock falling below the limit and this LRP is set at 20% of depletion (WCPFC), the TRP will be reasonably set far from the LRP. The problem is that when using fully structured stock assessment models, moving away from the LRP of 20% of B_0 also means moving to levels well above the B_{MSY} which is considered the TRP in many fisheries (e.g. European framework). Therefore, when using depletion based TRPs and high steepness values, the fishery will be managed towards levels notably larger than B_{MSY}. In the case of the three IOTC tropical stocks assessed using SS3 (Figure 5), the level of depletion of B_{MSY} (green) is even below the 20% depletion level (SKJ) or below 30%. This means that setting a TRP of e.g. 40% of depletion in order to reduce the probability of breaching the 20% B_0 LRP will mean reducing the use of the catch potential of fish stocks. Figure 5 shows a) the depletion level of alternative target and LRPs for a range of steepness values. The highest the steepness, the B_{MSY} is at lower levels of biomass relative to B_0. Also, the LRP set following the model by Maunder and Deriso (2014) or set as relative to BMSY (ICCAT), moves towards higher levels of depletion (lower B/B_0) for the highest steepness values. Note that this is particularly evident to very productive species such as skipjack.

Setting the TRP at 40% of depletion instead of somewhere near MSY levels can bring notable waste of catch and employment opportunities (Figure 5, bottom). This is also more apparent in highly productive species. In this case we have extracted the MSY and FMSY and compared with the Catch at 40%B_0 and $F_{40\%B0}$ levels. The loss in catch opportunities can reach 10% in the case of skipjack but the reduction of effort is more apparent as moving the TRP of 40% would mean reducing fishing effort to 50% of current levels for skipjack if a steepness value of 0.9 was used. In the case of bigeye and yellowfin the catch losses are less significant but effort reduction can reach 35%.

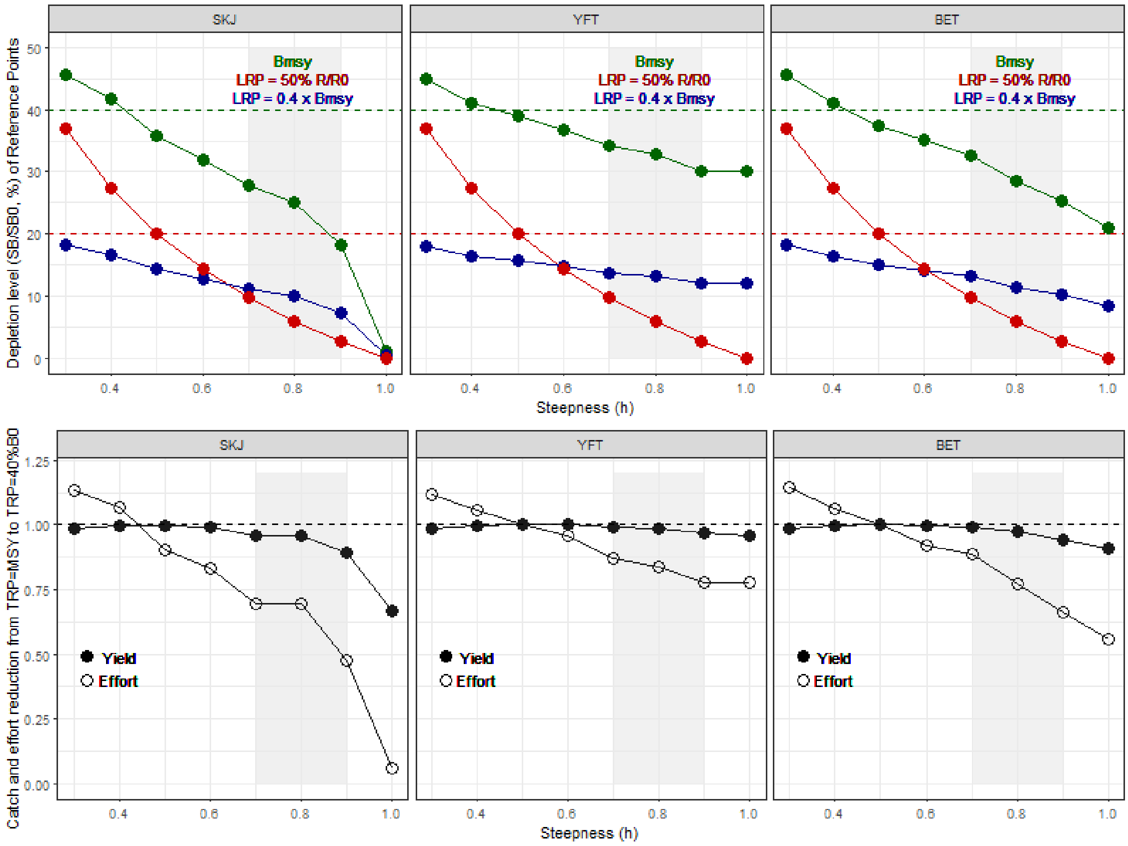

Figure 5: Robustness of different estimations of TRP (Bmsy, 50%R/R0 and 0.4* Bmsy estimates) over different levels depletion level (top) and changes in catch and employment opportunities (bottom) for the three tropical tuna stocks in the IOTC when fixing a range of steepness values (0.3-1).

In summary, the generalized use of LRP=20% of depletion together with the extended use of SS3 and MFCL type models with steepness values of 0.7-0.9 can derive in the adoption of conservative measures that can reduce the use of fisheries in terms of food and employment production. Also, current management would benefit of biological studies that help clarify the resilience of stocks to fishing and defining steepness levels accurately. For example, adopting a LRP of 20% of depletion for skipjack would mean setting the LRP at the level of SSB where the recruits are halved from pristine levels and the accepted steepness is 0.5 (red line, Figure 5). This value of steepness is not currently used in tuna RFMOs.

2.6 Sub-task 1.5: Case studies

As described in section 2.3, the five tuna RFMOs have broad management objectives, but all implicitly combine the maximum utilisation of resources with the PA. Within each RFMO a suite of specific management objectives is defined for each stock. These include ensuring the sustainability, recovery (if necessary) and profitability of fisheries. Management objectives are defined upon LRPs and TRPs by setting associated probabilities and timeframes. In the case of overexploited stocks or stocks under excessive fishing pressure, the management objective consists on the recovery and fishing mortality reduction in a given period. The definition of what is high, very high, low and very low probabilities and the timeframes for achieving management objectives is currently under debate in all tuna RFMOs.

This following section describes the recent developments to establish specific management objectives and RPs for individual stocks of the most relevant tuna species across all five tuna RFMOs.

2.6.1 Albacore

2.6.1.1 ICCAT

ICCAT aims at maintaining fish stocks at levels that will permit the maximum sustainable catch. Recommendation 16-06 recognizes that it is likely that North Atlantic albacore is not overfished and that overfishing not occurring and therefore, defines a specific operational objective for this stock (ICCAT, 2016b):

a) "to maintain the stock in the green quadrant of the Kobe plot, with at least 60% of probability, while maximizing long-term yield from the fishery, and"

b) "where the spawning stock biomass (SSB) has been assessed by the SCRS as below the level capable of producing MSY (SSB_{MSY}), to rebuild SSB to or above SSB_{MSY}, with at least a 60% probability, and within as short time as possible, while maximizing average catch and minimizing inter-annual fluctuations in TAC levels".

This recommendation specifies the probability of achieving the management objective of being in the green area of the Kobe plot but does not explicitly mention MSY as a target. The recommendation does mention the maximization of the long-term yield of the fishery as an objective while uses the 60% of probability of being in green quadrant as its implementation of the PA. Note that if a fish stock fluctuates around its MSY, it is expected to be approximately 50% of the times above and 50% below its corresponding SSB_{MSY}. Therefore, a level of biomass above SSB_{MSY} is the implicit target RP.

In the cases where SSB is assessed as below SSB_{MSY}, its rebuilding is recommended to levels above SSB_{MSY} with at least 60% probability but the time of this recovery is not specified. In order to set a time of recovery it would be expected that the recent stock assessments would indicate the level of overexploitation of the stock, which is not the case of North Atlantic albacore (ICCAT, 2016c).

This recommendation is indicative of ICCAT's determination for managing this and other stocks through Harvest Control Rules: In 2017, ICCAT has adopted a HCR for North Atlantic albacore (Recommendation 17-04, ICCAT 2017a), which aims at achieving the management objectives described in Recommendation 16-06. The HCR adopted for North Atlantic albacore specifies a maximum fishing mortality of $0.8*F_{MSY}$ when the stock is above B_{MSY} and a gradual reduction of fishing effort towards a minimum of $0.1*F_{MSY}$ when the stock is assessed to be below BMSY. Therefore, the coordinates of the HCR are: $F_{target}=0.8*F_{MSY}$, $B_{threshold}=B_{MSY}$ and $B_{lim}=0.4*B_{MSY}$.

With regards to the South Atlantic and Mediterranean albacore stocks, currently there is no management objective different maintaining populations at levels that will support MSY. RPs have not been defined for any of these stocks.

2.6.1.2 WCPFC

WCPFC seeks to ensure, through effective management, the long-term conservation and sustainable use of highly migratory fish stocks. WCPFC is undergoing discussions to setting management objectives and defining target and limit RPs for the stocks under its purview. South Pacific albacore is at relatively healthy levels but the economic performance of the fisheries within the Pacific Island Forum Fisheries Agency (FFA) has been reduced due to increased fishing effort and catch from longline fisheries. WCPFC promoted discussions on the establishment of management objectives that would serve to define target and limit RPs. A series of management objectives are being proposed for this fishery which include achieving the Maximum Economic Yield (MEY), and optimising CPUE, revenue and stability of catches. For this, WCPFC is considering options for establishing TRPs (WCPFC, 2017b). Note that none of the objectives includes maximizing long-term sustainable catch and all objectives would imply TRPs well above SSB_{MSY}, which is estimated to be at 14% $SSB_{F=0}$. The LRP for this stock is 20% $SSB_{F=0}$ (>SSB_{MSY}) and therefore, avoiding breaching the LRP with high probability would also imply setting the TRP well above the estimated SSB_{MSY}. A series of options for TRP ranging from 32% to 45% of $SSB_{F=0}$ are being proposed for this stock.

The Northern Committee from the WCPFC has in 2017 adopted an Interim Harvest Strategy for North Pacific albacore fishery (WCPFC, 2017d) that specifically defines the management objective for this stock as "…to maintain the biomass, with reasonable variability, around its current level in order to allow recent exploitation levels to continue and with a low risk of breaching the limit reference point". This resolution also specifies a LRP at 20% of depletion and recommends the adoption of TRP following the results of the incoming MSE work to be carried out for this stock. The timeframe for the recovery to levels above the LRP when the stock is assessed below this LRP will not exceed 10 years. Therefore, this Harvest Strategy aims at keeping the stock above the LRP and does not consider catch maximization or recovery to levels nearby MSY.

2.6.1.3 IOTC

IOTC aims at ensuring the conservation and optimum utilization of stocks encouraging the sustainable development of fisheries. In order to achieve this, Resolution 15/10 specifically defines a series of interim RPs for albacore, swordfish and the three tropical species. For albacore in particular, IOTC defines the following interim target and limit RPs: $B_{TARGET}=B_{MSY}$, $F_{TARGET}=F_{MSY}$, $B_{LIM}=0.4*B_{MSY}$ and $F_{LIM}=1.4*F_{MSY}$ Where the IOTC Scientific Committee considers that MSY-based reference points cannot be robustly estimated, biomass limit reference points will be set at a rate of $B_{F=0}$.

2.6.2 Bluefin tuna

2.6.2.1 CCSBT

CCSBT aims at ensuring the conservation and optimal utilization of the southern bluefin tuna (*Thunnus maccoyii*) fishery. In 2011, this stock was heavily overexploited (3-7% of the original spawning stock biomass, SSB_0) and therefore, the management objective was to rebuild the stock to acceptable levels. For this, an integrated management procedure or HCR, known as the "Bali procedure" was adopted (CCSBT, 2011). This procedure shall guide the setting of TAC from 2012 and beyond and it was tuned to ensure the SSB achieving the interim rebuilding target of 20% SSB0 by 2035 with a 70% probability.

In this case, the difference between the overall management objective and the specific objective is clearly appreciated. CCSBT aims at the optimal utilization of resources but due to the status of the stock defines a temporal management objective of rebuilding by defining an interim target RP with its associated timeframes and probability. Note that 20% SSB0 is considered a LRP for many tuna stocks in other RFMOs.

2.6.2.2 ICCAT

ICCAT, for eastern Atlantic and Mediterranean bluefin tuna (*Thunnus thynnus*) a recovery plan was established in 2007 with the aim of achieving B_{MSY} with at least 60% probability in 2022. This plan is based on fishing below the lowest estimate of MSY allowing the population to increase even in the most conservative scenario (ICCAT, 2014). This plan was reviewed in 2017 and in the light of the results of the new assessment of this stock it was decided to continue the implementation of the recovery plan through 2022, with the goal of achieving B_{MSY} with at least 60% probability (ICCAT, 2017b). However, this decision is pending further discussion and decision to change to a management plan from the recovery plan.

With regards to the Western stock, ICCAT is following a 20 year recovery plan that aims at achieving the management target of MSY with at least 50% probability by 2018. This plan was established in 1999 (Recommendation 98-7, (ICCAT, 1999)) and is updated every year, in the light of periodic stock assessments, in order to set annual quotas.

2.6.2.3 WCPFC

The Northern Committee from the WCPFC has adopted an Interim Harvest Strategy for Pacific Bluefin (*Thunnus orientalis*) Fishery (WCPFC, 2017d, Attachment F) in 2017, which specifies three management objectives for this stock: "…first, to support thriving Pacific bluefin tuna fisheries across the Pacific Ocean while recognizing that the management objectives of the WCPFC are to maintain or restore the stock at levels capable of producing MSY; second, to maintain an equitable balance of fishing privileges among CCMs; and third, to seek cooperation with IATTC to find an equitable balance between the fisheries in the western and central Pacific Ocean (WCPO) and those in the eastern Pacific Ocean (EPO)". The resolution recognizes the need of rebuilding the Pacific bluefin tuna in two stages and defines two rebuilding targets. First, an initial rebuilding target is the median SSB estimated for the period 1952 through 2014, to be reached by 2024 with at least 60% probability. The second rebuilding target is 20% $SSB_{F=0}$ to be reached by 2034, or 10 years after reaching the initial rebuilding target, whichever is earlier, with at least 60% probability. The Northern Committee also recommends developing finer target and limiting RPs through MSE and has established a work program for this. The interim Harvest Strategy adopted states the following:

Harvest controls rules during initial rebuilding period: The interim harvest control rules below will be applied based on the results of stock assessments and SSB projections to be conducted by ISC (WCPFC, 2017d, Attachment F).

(a) If the SSB projection indicates that the probability of achieving the initial rebuilding target by 2024 is less than 60%, management measures will be modified to increase it to at least 60%. Modification of management measures may be (1) a reduction (in %) in the catch limit for fish smaller than 30 kg (hereinafter called "small fish"), or (2) a transfer of part of the catch limit for small fish to the catch limit for fish 30 kg or larger (hereinafter called "large fish"). For this purpose, ISC will be requested, if necessary, to provide different combinations of these two measures so as to achieve 60% probability.

(b) If the SSB projection indicates that the probability of achieving the initial rebuilding target by 2024 is at 75% or larger, the WCPFC may increase their catch limits as long as the probability is maintained at 70% or larger, and the probability of reaching the second rebuilding target by the agreed deadline remains at least 60%. For this purpose, ISC will be requested, if necessary, to provide relevant information on potential catch limit increases.

Harvest controls rules during second rebuilding period: Harvest control rules to be applied during the second rebuilding period will be decided, taking into account the implementation of the interim harvest control rules applied during the initial rebuilding period.

2.6.3 Skipjack

2.6.3.1 IOTC

IOTC aims at ensuring the conservation and optimum utilization of stocks encouraging the sustainable development of fisheries. In 2016, IOTC adopted Resolution 16-02 to ensure the long-term sustainability of the Indian Ocean skipjack (*Katsuwonus pelamis*) fishery. The overarching goal of this resolution is to ensure the provision of jobs, food and development opportunities into the future. The specific management objective of this resolution reads as follows (IOTC, 2016):

1. To maintain the Indian Ocean Tuna Commission skipjack tuna stock in perpetuity, at levels not less than those capable of producing MSY as qualified by relevant environmental and economic factors including the special requirements of

Developing Coastal States and Small Island Developing States in the IOTC area of competence and considering the general objectives identified in Resolution 15/10 (or any subsequent revision).

This resolution combines socioeconomic objectives of employment, food and development opportunities with the PA in order to ensure the viability of fisheries in perpetuity. This resolution specifies target and limit RP for this stock in relation to the level of biomass in the absence of fishing (B_0) due to the difficulties in producing robust estimates of MSY-based RPs. Thus, a TRP of 40% B_0 and LRP of 20% B_0 are specified. However, the probabilities of achieving the management objectives and avoiding the LRP in this resolution are not specified. Skipjack is currently is estimated to be at levels above the TRP and therefore the timeframes of recovery are not specified either.

In addition to the general management objective for this fishery, this resolution sets the objective of using a HCR to maintain the stock at levels above the TRP and well above the LRP. For that, five control parameters are specified, i.e. (i) a threshold level that will trigger fishing mortality reductions (TRP=40% B_0); (ii) a maximum level of fishing intensity that will be applied when the stock is above the threshold level ($F=F_{TRP}$); (iii) a safety level, the percentage of B_0 below which non-subsistence catch will be set to zero (10% B_0, note that this is below the LRP); (iv) a maximum catch limit (900,000 t); and (v) a maximum change in catch limit (30%).

2.6.3.2 ICCAT

ICCAT, has not described specific management objectives nor developed RPs for none of the two stocks of skipjack (Eastern and Western).

2.6.3.3 WCPFC

WCPFC, following the overall objective of the long-term conservation and sustainable use of the highly migratory fish stocks, adopted an interim target reference point for the WCPO skipjack tuna stock as 50% of the estimated recent average spawning biomass in the absence of fishing ($SSB_{F=0,\ t1-t2}$) (WCPFC, 2015). Also, WCPFC adopted a LRP of 20%$SSB_{RECENT,\ F=0}$. Guidelines for defining the period corresponding to "recent" are also provided.

2.6.3.4 IATTC

IATTC is responsible for the conservation and management of tuna and other marine resources in the eastern Pacific Ocean. IATTC has established management objectives of achieving maximum long-term catch and it has also embraced the PA through the adoption of the new Antigua Convention in 2010. In 2014 the IATTC agreed to the staff's recommendation for bigeye, yellowfin and skipjack stocks target reference points should be F_{MSY} and B_{MSY}. No MSY-based target RPs are available for skipjack but it is very likely that this stock is around this TRP (SAC-IATTC, 2014). In 2014 the IATTC agreed to the staff's recommendation that the LRP for skipjack (also bigeye and yellowfin) should correspond to the equilibrium spawning biomass which produces a 50% reduction in recruitment from the unfished level (i.e. a spawning biomass that is approximately 8% of the unfished level and that the acceptable level of risk for the stocks breaching that limit would be 10%). No MSY-based limit RPs are available for skipjack but it is very likely that this stock is also above the limit. Nevertheless, IATTC adopted in 2016 interim HCRs for skipjack and the other two tropical tuna stocks (Resolution C-16-02) that specify timeframes and probabilities of achieving TRP and acceptable levels of risk for breaching the LRPs:

1) Management measures for the purse-seine fishery, such as closures, which may be fixed for multiple years, will ensure that F does not exceed the best estimate of F_{MSY} for the species that requires the strictest management.

2) If the probability that F exceeds the limit reference point (F_{LIM}) is greater than 10%, management measures that have a probability of at least 50% of reducing F to the target level (F_{MSY}) or lower, and a probability of less than 10% that F will exceed FLIM, will be established as soon as is practical.
3) If the probability that the spawning biomass (SSB) is below the limit reference point (SSB_{LIMIT}) is greater than 10%, measures will be established that have a probability of at least 50% of rebuilding S to the target level (dynamic SSB_{MSY}) or greater, and a probability of less than 10% that SSB will fall below SSB_{LIMIT} within a period of two generations of the stock or five years, whichever is greater.

For other fisheries, management measures will be as consistent as possible with those for the purse-seine fishery.

2.6.4 Bigeye

2.6.4.1 WCPFC

Until 2017, the Bigeye tuna (*Thunnus obesus*) stock was considered overexploited and the WCPFC was considering options for specifying the timeframe of recovery to levels above the LRP. The recovery time to alternative options for LRPs (20-28% $B_{F=0}$) without fishing was 2-5 years and the acceptable level of risk of not breaching the LRP would affect the recovery time and the trajectory of rebuilding. A series of potential effort reductions were estimated for achieving different LRPs in alternative timeframes. The range of timeframes being considered spans from 2 years (closure of fishery and LRP = 20% $B_{F=0}$) and >30 years (Status quo and LRP = 28% $B_{F=0}$) (WCPFC, 2017a). However, the most recent assessment (presented in August 2017) indicates that the spawning biomass is likely above the biomass limit reference point (20% $SSB_{F=0}$) and that the recent fishing mortality is likely below F_{MSY}. Based on these results, the SC of WCPFC recommends as a precautionary approach that the fishing mortality on bigeye tuna stock should not be increased from current levels to maintain current or increased spawning biomass until the Commission agrees on a target reference point (WCPFC, 2017c).

2.6.4.2 IATTC

IATTC bigeye stock is currently around the TRP of B_{MSY} and F_{MSY} (SAC-IATTC, 2014). In 2014 the IATTC agreed to the staff's recommendation that the LRP for bigeye should correspond to the equilibrium spawning biomass which produces a 50% reduction in recruitment from the unfished level, i.e. a spawning biomass that is approximately 8% of the unfished level and that the acceptable level of risk for the stocks breaching that limit would be 10%. The bigeye stock is currently above this limit. Nevertheless, IATTC adopted in 2016 interim HCRs for the three tropical stocks (Resolution C-16-02) that specify timeframes and probabilities of achieving TRP and acceptable levels of risk for breaching the LRPs (see skipjack, section 6.3).

2.6.4.3 IOTC

IOTC's Resolution 15/10 specifically defines a series of interim RPs for albacore, swordfish and the three tropical species, for achieving the overall management objective of the convention. For bigeye in particular, IOTC defines the following interim target and limit RPs: $B_{TARGET}=B_{MSY}$, $F_{TARGET}=F_{MSY}$, $B_{LIMIT}=0.5*B_{MSY}$ and $F_{LIMIT}=1.3*F_{MSY}$. Where the IOTC Scientific Committee considers that MSY-based reference points cannot be robustly estimated, biomass limit reference points will be set at a rate of $B_{F=0}$.

2.6.4.4 ICCAT

ICCAT, has not described specific management objectives for bigeye, but in Resolution 16-01 (ICCAT, 2015) it recognizes that it is overexploited and overexploitation is still undergoing, and recommends catch limits that would allow recovery to levels at or above B_{MSY} in a short period as possible.

2.7 Conclusions

Tuna RFMOs are in the process of establishing management objectives and defining target and limit reference points as part of their Harvest Strategies. Management objectives include sustainability, safety, production, employment and stability and RPs aim at guiding fisheries towards achieving these objectives. However, the approach towards establishing RPs is different across t-RFMOs and each approach has its own shortcomings for fisheries management practice.

Various methods are available to calculate RPs, including MSY-based, depletion-based, YPR and SPR methods. Each method has its own particular strengths and weaknesses although both MSY- and depletion-based methods are the most commonly used. Between the two, it has been shown that uncertainties in the steepness (h) of stock recruitment parameter can significantly weaken the ability to provide robust estimates for MSY-based RPs with the stock assessment models currently in use. One major advantage of depletion-based RPs is that they remain relatively stable between assessments and have provided the least variation in the results across a range of stock-recruitment steepness parameter (h) values and stock assessment models. Where major uncertainties exist in model parameters such as the stock recruitment steepness (h) value, depletion-based RPs are considered to provide a more robust approach to setting RPs. This is because different models usually provide similar estimates of B_0 and can produce relatively different estimates of MSY-based RPs.

A review of LRPs across various t-RFMOs has shown a lack of consistency in the values used to support their Harvest Strategies. For example, IOTC has adopted an interim MSY-based LRP for yellowfin tuna of 40%SSB_{MSY} (which is equivalent to 14%SSB_0), whereas WCPFC has adopted a depletion based LRP of 20%SSB_0 for the same species. This would suggest that either IOTC is less precautionary or WCPFC is more conservative in setting LRPs. In reality, this discrepancy is due to the different nature of the RPs used (MSY and depletion based). Further to this however, stocks in different regions may have different levels of productivity, based on different biological or fishery characteristics. It is therefore not unexpected to observe different RPs for each t-RFMO for the same species.

More recently, there has been a move towards adopting fish stocks MSY as a limit rather than a target. It has been argued that given the uncertainties in calculating MSY and the adverse biological, social and economic consequences of exceeding this, some t-RFMOs such as WCPFC now consider MSY as a limit reference point, particularly F_{MSY}, based on the precautionary approach, UNFSA and other international instruments. For the biological LRP it is increasingly been defined as 20% of SSB_0, which is a precautionary RP for fisheries where the stock recruitment relationship remains uncertain (Preece et al., 2011). Further to this, Punt and Smith (2001) argue the reason why MSY has not been made redundant within a fisheries management framework is that it has now changed from a management target to an "upper limit". It has been suggested that FMSY represents an "upper bound" to fishing mortality rates, which is coherent with the definition of a LRP, which is "a state of a fishery and/or a resource which is considered to be undesirable and which management action should avoid" (Caddy and Mahon 1995). In addition, there is growing evidence to suggest that managing stock biomass above B_{MSY} leads to larger fish, similar catch levels and greater economic benefit with lower ecological impact (Pilling et al., 2012). This approach has also been shown to be consistent with the objectives of the CFP under article 2.2, which aims to "restore and maintain populations of harvested species above levels which can produce the maximum sustainable yield".

Using typical steepness values for skipjack between 0.7-0.9 it has been shown that MSY-based RPs (e.g. B_{MSY}) are just above or even below the general LRP of 20%$SSB_{F=0}$ adopted by WCPFC (Preece et al., 2011; Maunder and Deriso, 2014). Therefore under certain conditions, a reference point typically associated "to maintain or restore stocks at levels capable of producing maximum sustainable yield" would suddenly be viewed as "outside safe biological limits". This paradox occurs specifically because the 20%$SSB_{F=0}$ as a single depletion-based LRP has been adopted across all main stocks, irrespective of the relative productivity of the population or selectivity of the fishery. Although calculating stock-specific LRPs and their associated levels of acceptable risk would help to overcome this issue, the current LRPs are biologically "precautionary" and therefore in line with the requirements of WCPFC's Convention. To date, insufficient information is available to establish different stock-specific LRPs within the region.

Setting TRPs at 40%SSB_0 or higher instead of MSY-based (B_{MSY}) levels can bring notable differences (or underutilisation) in the level of catch opportunities and employment (fishing effort). To date, WCPFC has adopted an interim TRP for skipjack tuna based on 50%SSB_0, which despite the many uncertainties, it is well above the available SSB_{MSY} estimates. TRPs may also set to achieve management objectives, which include social and economic objectives. While the interim TRP adopted by WCPFC might appear overly conservative, the assessment for skipjack is considered uncertain. In addition, WCPFC considers that fisheries are more efficient, profitable, stable and sustainable when stocks are larger than B_{MSY}.

Also, the definition of what is high, very high, low and very low probabilities and the timeframes for achieving management objectives is currently under debate in all tuna RFMOs. This means specifying the probabilities of achieving TRPs and avoiding LRPs and the timeframes for achieving management objectives.

This review has shown a range of LRPs and TRPs that have been used across different t-RFMOs, which reflects the level of uncertainty in the stock assessment and likely differences in productivity between regions for each species. In addition, a range of TRPs levels have been identified, some of which may be considered conservative. However, given the quality of information and management objectives, these are consistent with Annex II of UNFSA.

3 TASK 2: HARVEST CONTROL RULES IN TUNA FISHERIES

3.1 Sub-task 2.1: Inventory of harvest control rules in tuna RFMOs

A harvest control rule (HCR), in its broadest sense, is a set of well-defined pre-agreed rules or actions used for determining a management action in response to changes in indicators of stock status with respect to reference points. A well-designed HCR encapsulates good management of the target stock by defining clear objectives, measures of performance and appropriate management actions required to ensure fisheries meet their objectives. The use of HCRs has been increasingly favoured by tuna Regional Fisheries Management Organisations (t-RFMOs) to enable them to implement good management practice of tuna stocks and also to simplify the negotiation process of establishing fishing limits and/or catch quotas and/or implementing technical measures.

An inventory is provided below (Table 8) summarising the status of HCRs in t-RFMOs for each stock. It includes HCRs that have been recommended or proposed within t-RFMOs, as well as those that are tested or applied in some form. Further details of those HCRs that have been implemented or are under development by t-RFMOs are provided in the next section (3.2.2) where strengths and weaknesses are discussed.

The term Management Procedure (MP) is a set of formal actions, usually consisting of a combination of monitoring data, analysis method and HCRs (synonymous with a harvest strategy), which are used to manage a fishery iteratively and adaptively.

Table 8: Summary of harvest control rules that are currently being proposed, tested or applied in tuna RFMOs. HCRs/MPs currently established are shown in bold text.

RFMO	Skipjack	Yellowfin	Bigeye	Albacore	Bluefin
ICCAT	HCRs are not yet defined for skipjack, yellowfin and bigeye tuna. However, Rec. 11-13[29] and Rec. 15-07[30] provide a framework for establishing HCRs			HCRs have not yet been defined for southern and Mediterranean albacore although Rec. 11-13 and Rec. 15-07 provide a framework for establishing HCRs. An HCR has been defined for northern albacore in 2017(Rec. 17-04[31])	HCR has not yet been defined for eastern Atlantic & Mediterranean and western bluefin tuna. Rec. 11-13 and Rec. 15-07 provide a framework for establishing HCRs
IOTC	**An HCR has been in place for skipjack tuna since 2016 (Res. 16/02)[32], based on target**	HCRs are not yet defined for bigeye, yellowfin or albacore			n/a

[29] https://www.iccat.int/Documents/Recs/compendiopdf-e/2011-13-e.pdf

[30] https://www.iccat.int/Documents/Recs/compendiopdf-e/2015-07-e.pdf

[31] http://www.iccat.int/Documents/Recs/compendiopdf-e/2017-04-e.pdf

[32] http://www.iotc.org/cmm/resolution-1602-harvest-control-rules-skipjack-tuna-iotc-area-competence

RFMO	Skipjack	Yellowfin	Bigeye	Albacore	Bluefin
	and limit reference points[33]				
WCPFC	HCRs are not yet defined for skipjack, yellowfin or bigeye tuna. [CMM 2014-06](https://www.wcpfc.int/doc/cmm-2014-06/conservation-and-management-measures-develop-and-implement-harvest-strategy-approach)[34] calls for WCPFC to develop and implement a harvest strategy approach that includes target reference points (TRPs), HCRs and other elements			The Northern Committee has recommended an interim management framework for the North Pacific albacore stock[35], which includes a decision rule but falls short of a decision framework	**A Harvest Strategy for Pacific Bluefin Tuna Fisheries[36] defined HCRs in 2014 to achieve rebuilding targets[37]**
IATTC	**IATTC adopted an HCR for tropical tunas in 2016, under Res. C-16-02[38], based on interim target and limit reference points[39]**			Res. C-13-03[40] requires that IATTC scientific staff shall review work undertaken by WCPFC towards the development of HCRs for North Pacific albacore, and make recommendations to the Commission	Res. 16-08[41] requires that reference points and harvest control rules are developed for Pacific bluefin tuna by 2018, which should be comparable to those adopted by the WCPFC
CCSBT	n/a	n/a	n/a	n/a	**A management procedure has been in place for southern bluefin tuna since 2011, designed to**

[33] Interim LRP of $0.2*SSB_0$ and $1.5*F_{MSY}$; Interim TRP of $0.4*SSB_0$ and F_{MSY}

[34] https://www.wcpfc.int/doc/cmm-2014-06/conservation-and-management-measures-develop-and-implement-harvest-strategy-approach

[35] https://www.wcpfc.int/node/29863

[36] Ibid.

[37] No limit reference point is defined; WCPFC (CMM 2016-04) has defined an initial rebuilding target reference point of $0.07SSB_0$. IATTC have put forward a proposal for a new rebuilding target $20\%SSB_{current}(F=0)$ by 2030 and a limit reference point 15%SSBcurrent,F=0. (https://www.wcpfc.int/system/files/WCPFC-NC13-IP-08%20Refernce%20points%20and%20harvest%20control%20rules%20for%20Pacific%20bluefin%20tuna%20-%20IATTC%20staff.pdf)

[38] https://www.iattc.org/PDFFiles/Resolutions/IATTC/_English/C-16-02-Harvest-control-rules.pdf

[39] LRP of $0.08*SSB_0$; TRP of SSB_{MSY} and F_{MSY}

[40] https://www.iattc.org/PDFFiles/Resolutions/IATTC/_English/C-13-03-North-Pacific-albacore.pdf

[41] https://www.iattc.org/PDFFiles/Resolutions/IATTC/_English/C-16-08-Conservation-and-management-of-Pacific-bluefin-tuna.pdf

RFMO	Skipjack	Yellowfin	Bigeye	Albacore	Bluefin
					achieve the recovery target[42]

3.2 Sub-task 2.2: Strengths and weaknesses of harvest control rules for tuna stocks

This sub-task analyses the strengths and weaknesses of the five established or draft HCRs identified in sub-task 2.1, taking into account factors such as HCR specification, evaluation procedures, consideration of uncertainty and the associated management system. A non-exhaustive list of questions were developed to guide the assessment of HCR strengths and weaknesses was:

1. Have appropriate reference points been adopted, are they used appropriately in the HCR and are acceptable levels of risk of exceeding limit reference points defined?
2. Is MSE (Management Strategy Evaluation) used to evaluate the HCR, are key uncertainties included in the MSE, and is the HCR robust to these uncertainties?
3. Have explicit management measures been identified and agreed, it is clear how these will be triggered in the HCR and are these likely to be appropriate for achieving management objectives?
4. Is the performance of the HCR reviewed on a regular basis, or has a timeline been established for its review?

The assessment of strengths and weaknesses was based on expert judgement using available literature on the HCR, including technical working party reports and RFMO Commission meeting reports.

3.2.1 ICCAT North Atlantic albacore HCR

ICCAT has made significant progress in developing an HCR for North Atlantic albacore, with Recommendation 16-06[43] and more recently Recommendation 17-04[44]. The former provided a generic HCR to be tested for the stock, along with candidate reference points. A description of the proposed rule is provided in Figure 6.

[42] The recovery target for southern bluefin tuna is to rebuild the stock to an interim building target reference point of 20% of the original spawning stock biomass by 2035. https://www.ccsbt.org/sites/ccsbt.org/files/userfiles/file/docs_english/operational_resolutions/Resolution_Management_Procedure.pdf

[43] http://iccat.int/Documents/Recs/compendiopdf-e/2016-06-e.pdf

[44] Ibid.

(a) If the average spawning stock biomass (SSB) level is less than SSB_{LIM} (*i.e., $SSB<SSB_{LIM}$*), the Commission shall adopt severe management actions immediately to reduce the fishing mortality rate, including measures that suspend the fishery and initiate a scientific monitoring quota to be able to evaluate stock status. This scientific monitoring quota shall be set at the lowest possible level to be effective. The Commission shall not consider re-opening the fishery until the average SSB level exceeds SSB_{LIM} with a high probability. Further, before reopening the fishery, the Commission shall develop a rebuilding programme in order to ensure that the stock returns to the green zone of the Kobe plot.

(b) If the average SSB level is equal to or less than $SSB_{THRESHOLD}$ and equal to or above SSB_{LIM} (*i.e., $SSB_{LIM} \leq SSB \leq SSB_{THRESHOLD}$*) and

i. F is at or below the level specified in the HCR, the Commission shall assure that that applied management measures will maintain F at or below the level specified in the HCR until the average SSB is above $SSB_{THRESHOLD}$;

ii. F is above the level specified in the HCR, the Commission shall take steps to reduce F as specified in the HCR to ensure F is at a level that will rebuild SSB to SSB_{MSY} or above that level.

(c) If the average SSB is above $SSB_{THRESHOLD}$ but F exceeds F_{TARGET} (*i.e., $SSB>SSB_{THRESHOLD}$ and $F>F_{TARGET}$*), the Commission shall immediately take steps to reduce F to F_{TARGET}.

(d) Once the average SSB level reaches or exceeds $SSB_{THRESHOLD}$ and F is less or equal than F_{TARGET} (*i.e., $SSB > SSB_{THRESHOLD}$ and $F \leq F_{TARGET}$*), the Commission shall assure that applied management measures will maintain F at or below F_{TARGET} and in case F is increased to F_{TARGET} this is done with a gradual and moderate increase.

Figure 6: Extract from ICCAT Rec. 16-06 describing the HCR for North Atlantic albacore currently under consideration. It is noted that recent MSE has evaluated this as well as other 14 alternative HCR designs.[45] (ICCAT Rec. 16-06).

More recently a well-defined HCR for North Atlantic albacore has established through Recommendation 17-04. The harvest control rule (HCR) sets a 3-year constant annual Total Allowable Catch (TAC) using the following three values estimated from each stock assessment[46]. For each value the median values, as reported in the summary table of the Standing Committee on Research and Statistics (SCRS) report, shall be used:

a) The estimate of current stock biomass (B_{curr}) with respect to B_{MSY}.

b) The estimate of the stock biomass at Maximum Sustainable Yield (B_{MSY}).

c) The estimate of the fishing mortality at MSY (F_{MSY}).

A total of six control parameters are specified:

a) The biomass threshold level (B_{THRESH}) is equal to the biomass able to deliver the maximum sustainable yield ($B_{THRESH} = B_{MSY}$).

b) A fishing mortality target corresponding to 80% of F_{MSY} ($F_{TAR} = 0.8*F_{MSY}$) will be applied when the stock status is at, or above, the threshold level (B_{THRESH}).

[45] http://www.iccat.int/Documents/CVSP/CV074_2017/n_2/CV074020457.pdf

[46] It should be noted that the terminology referring to the stock biomass (B) has changed between Rec. 16-06 and Rec. 17-04. In the former, the HCR referred specifically to the spawning stock biomass (SSB), whereas Rec. 17-04 refers to the stock biomass (B). This change is most likely due to the fact that the most recent stock assessment from which management decisions are made, is based on a biomass production model that does not specify spawning biomass. The HCR in Rec. 17-04 is therefore consistent with the latest stock assessment advice.

c) If the current biomass (B_{CURR}) is estimated to be below the threshold level (B_{THRESH}) and higher than B_{LIM}, then fishing mortality will be reduced linearly for the next multiannual management period (F_{NEXT}).

d) If the current biomass (B_{CURR}) is estimated to be at, or below, B_{LIM}, then the fishing mortality shall be set at F_{MIN} with a view to ensure a level of catch for scientific monitoring.

e) The Maximum catch limits (C_{max}) recommended are 50,000 t to avoid adverse effects of potentially inaccurate stock assessments

f) The maximum change in the catch limit (D_{max}) shall not exceed 20% of the previous recommended catch limit when $B_{CURR} \geq B_{THRESH}$. The HCR described by the control parameters produces a relationship between stock status (spawning biomass relative to unfished levels) and fishing intensity (exploitation rate relative to target exploitation rate) as shown in Figure 7.

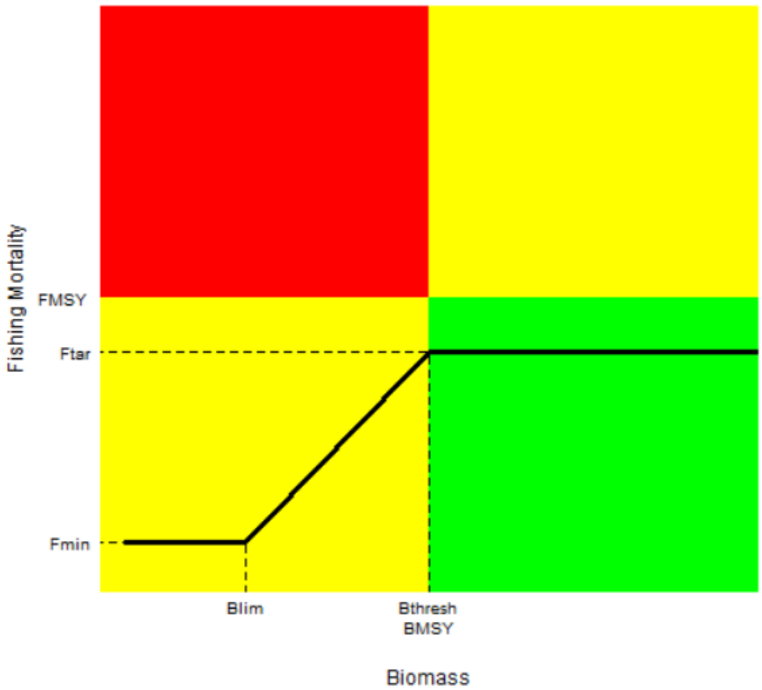

Figure 7: Relationship between stock status and fishing intensity as described by the control parameters of the ICCAT HCR for North Atlantic Albacore. (ICCAT Rec. 17-04).

Strengths

- The HCR is formally adopted through Rec. 17-04 and will be subject to a peer review by SCRS in 2018.
- Should exceptional circumstances occur, the Commission will review and consider a possible revision of the HCR.
- The proposed HCR as set out in Rec. 16-06 and adopted HCR in Rec. 17-04 establishes clear rules regarding the types of management actions to be triggered at different reference points, including when such measures would be lifted. This transparency is important as it allows stakeholders to see whether management is following its own agreed policies.
- Both Rec. 16-06 and Rec. 17-04 requires that the HCR will include pre-agreed management actions to be taken under various stock conditions. Pre-agreement on management actions is key to the successful application of a HCR, as it allows management measures such as reduction in Total Allowable Catch (TAC) to be

implemented rapidly when required, and avoiding the need for political decision making at the time.

- Both Rec. 16-06 and Rec. 17-04 explicitly requires evaluation of HCRs using a management strategy evaluation (MSE), for both the evaluation of the proposed (and alternative) HCRs[47] and testing of refined candidate reference points and associated HCRs. Furthermore, and related to MSE, Rec. 16-06 notes that the introduction of the HCR will be an iterative process of adjustments on the basis of evaluation results and taking into account scientific advice. The use of MSE to evaluate HCRs, where this incorporates the main sources of uncertainty and the latest scientific advice, is generally considered best practice.
- MSE indicates that candidate HCRs are robust to the uncertainties considered for this stock[48], including sources of information, biological parameters (natural mortality and steepness) and fishery dynamics. Also, the HCRs are considered to be robust to a range of estimates of the stock's initial state of exploitation.
- Rec. 17-04 introduces a maximum catch limit to avoid adverse effects of potentially inaccurate stock assessments and prevents increasing catches to occur when information is uncertain.
- Rec. 17-04 has a target fishing mortality rate less than F_{MSY} ($F_{TAR} = 0.8*F_{MSY}$) that is used when the spawning stock biomass is above the threshold level. This helps ensure total fishing mortality is highly unlikely to exceed F_{MSY} on the Kobe plot.

Weaknesses

- While Res. 16-06 determines that the HCR should maintain the stock in the green zone of the Kobe plot with at least a 60% probability, the accepted probability for the stock being in the red quadrant of the Kobe plot is not yet defined by ICCAT. This is an important uncertainty in evaluating and selecting harvest control rules, i.e. ambiguity on whether a given HCR will deliver management outcomes.
- It is not yet clear if probabilities relative to the reference points or the performance indicators will integrate model uncertainty.
- In terms of available management measures, the TAC is shared among many countries and control is not precise, and allowing the carry-forward of uncaught allocations effectively decreases the control over fishing mortality. However, these weaknesses may be mitigated if incorporated in the HCR as uncertainties.

3.2.2 IOTC skipjack tuna harvest control rule

A well-defined HCR for skipjack tuna has recently been established through Resolution 16/02[49]. The HCR recommends a total annual catch limit based on spawning stock biomass (referred to by IOTC as B[50]) using the following three values estimated from each skipjack stock assessment:

a) The estimate of current spawning stock biomass (B_{curr});

b) The estimate of the unfished spawning stock biomass (B_0);

[47] Ibid.

[48] Ibid.

[49] http://www.iotc.org/cmm/resolution-1602-harvest-control-rules-skipjack-tuna-iotc-area-competence

[50] It should be noted that STECF advice for skipjack tuna HCR refer to spawning stock biomass as SSB (see section 5.6, STECF 2018): https://stecf.jrc.ec.europa.eu/documents/43805/2054982/STECF+PLEN+18-01.pdf

c) The estimate of the equilibrium exploitation rate (E_{targ}) associated with sustaining the stock at B_{targ}.

Five control parameters are specified: (i) a threshold level that will trigger fishing mortality reductions (target reference point=$0.4B_0$); (ii) a maximum level of fishing intensity that will be applied when the stock is above the threshold level; (iii) a safety level, the percentage of B_0 below which non-subsistence catch will be set to zero ($0.1B_0$; note that this is below the limit reference point, $0.2B_0$); (iv) a maximum catch limit (900,000 t); and (v) a maximum change in catch limit (30%). The HCR described by the control parameters produces a relationship between stock status (spawning biomass relative to unfished levels) and fishing intensity (exploitation rate relative to target exploitation rate) as shown in Figure 8.

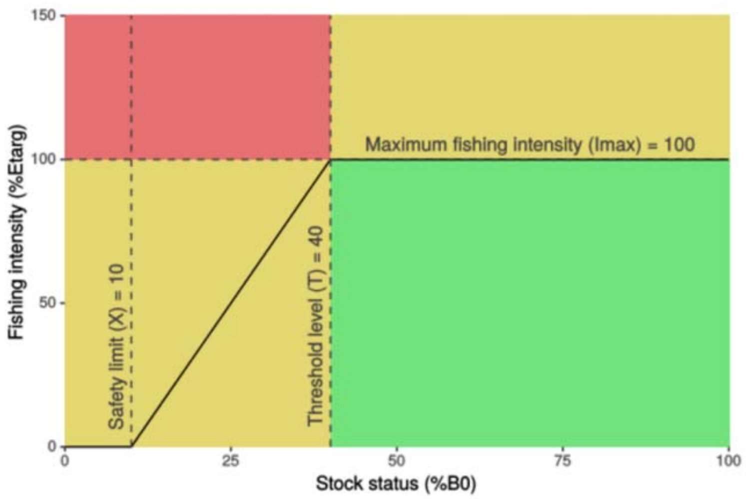

Figure 8: Relationship between stock status and fishing intensity as described by the control parameters of the IOTC HCR for skipjack (IOTC Res. 16/02).

Resolution 16/02 further defines how the recommended total annual catch limit shall be set, depending on the current spawning biomass at a given time, rules on changes in catch limits between consecutive years, and a protocol for review of the HCR using MSE.

Strengths

- The skipjack tuna HCR described in Res. 16/02 sets out clear management objectives along with clear definitions for target and limit RPs. These RPs are defined in relation to the level of biomass in the absence of fishing (B_0) due to the difficulties in producing robust estimates of MSY-based reference points.
- The relationship between the stock assessment, the HCR and the setting of total allowable catch (TAC) is clearly described. With regard to how the HCR will trigger management measures, explicit instructions are given on how total annual catch will be set according relative to different biomass-based threshold levels, with or without an allocation scheme in place[51]. This includes setting of a zero catch limit for non-subsistence fisheries at or below a safety level ($B_{curr} <= 0.1B_0$). No other technical measures are specified, e.g. area closures.
- Res. 16/02 explicitly requires evaluation of the HCR and the control parameters using MSE, including a clear timeline for evaluation and modification of the HCR, as necessary, after several iterations (but no later than 2021). Furthermore, it

[51] See setting of TAC for 2018 following the HCR: http://www.iotc.org/documents/calculation-skipjack-catch-limit-period-2018-2020-using-hcr-adopted-resolution-1602

requires a programme of work to further refine the MSE for the skipjack tuna fishery. This work will be important in refining the operating models used and reducing or better incorporating uncertainties.

- The HCR was developed and tested using Management Strategy Evaluation (MSE) that ensured that the long-term median spawning biomass (SB) was maintained at a level equivalent to $0.61SB_0$ (i.e. 61% of the unfished spawning stock biomass) and a 90% probability of maintaining SB above $0.39SB_0$[52].

Weaknesses

- The HCR is only recently agreed, with the first implementation of the HCR to be based on the 2017 skipjack stock assessment. No meaningful evaluation can be made yet on whether the target fishing intensity is being achieved and the HCR is effective.
- The HCR does not explicitly make reference to acceptable probabilities for exceeding the reference points (B_{thresh}, B_{safety}), either quantitatively or qualitatively. This is a critical step in the harvest strategy development process, i.e. choosing the level of risk that will guide future fishery decisions. Typically, managers should set low levels of risk tolerance in cases of greater uncertainty. For example, where there is a greater risk of the stock exceeding a reference point, the probability should be low (i.e. 10%).
- There remain a number of uncertainties in the HCR, including the role of subsistence fishing if thresholds are exceeded and exactly how the target rates are to be implemented.
- In the case where the estimated spawning biomass falls below the LRP, the HCR will be reviewed and consideration given to replacing it with an alternative HCR specifically designed to meet a rebuilding plan. There is, however, no clear indication of the timeframe within which a new HCR should be implemented and put the status of the stock at higher risk of depletion.

3.2.3 WCPFC Pacific Bluefin tuna rebuilding HCR

A harvest strategy for Pacific bluefin tuna was prepared in accordance with the Commission's Conservation and Management Measure on Establishing a Harvest Strategy for Key Fisheries and Stocks in the Western and Central Pacific Ocean (CMM 2014-06)[53]. Although the provisions of the harvest strategy are expressed in terms of a single stock, it is noted that they may be applied to multiple stocks as appropriate and as determined by the Northern Committee. The last stock assessment was conducted in 2016 and showed the status of Pacific bluefin tuna to be heavily overfished, with the spawning stock biomass corresponded 2.6% of the virgin spawning stock biomass (SSB_0) in the terminal year (2014) of the assessment[54]. A HCR, termed a decision rule, is described by WCPFC as follows:

[52] http://www.iotc.org/documents/management-strategy-evaluation-indian-ocean-skipjack-tuna-fishery-0

[53] https://www.wcpfc.int/system/files/CMM%202014-06%20Conservation%20and%20Management%20Measures%20to%20develop%20and%20implement%20a%20harvest%20strategy%20approach%20for%20key%20fisheries%20and%20stocks%20in%20the%20WCPO.pdf

[54] http://isc.fra.go.jp/pdf/ISC16/ISC16_Annex_09_2016_Pacific_Bluefin_Tuna_Stock_Assessment.pdf

Harvest controls rules during initial rebuilding period (i.e. between 2015 and 2024): The interim harvest control rules below will be applied based on the results of stock assessments and SSB projections[55].

a. If the SSB projection indicates that the probability of achieving the initial rebuilding target (i.e. the median SSB estimated for the period 1952 through 2014) by 2024 is less than 60%, management measures will be modified to increase it to at least 60%. Modification of management measures may be (1) a reduction (in %) in the catch limit for fish smaller than 30 kg ('small fish'), or (2) a transfer of part of the catch limit for small fish to the catch limit for fish 30 kg or larger ('large fish'). For this purpose, the International Scientific Committee (ISC) for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) will be requested, if necessary, to provide different combinations of these two measures so as to achieve 60% probability.
b. If the SSB projection indicates that the probability of achieving the initial rebuilding target by 2024 is at 75% or larger, the WCPFC may increase their catch limits as long as the probability is maintained at 70% or larger, and the probability of reaching the second rebuilding target by the agreed deadline remains at least 60%. For this purpose, ISC have been requested to provide relevant information on potential catch limit increases.

Harvest controls rules during second rebuilding period: Harvest control rules to be applied during the second rebuilding period are yet to be decided, taking into account the implementation of the interim harvest control rules applied during the initial rebuilding period.

Strengths

- The rebuilding phase HCR described by WCPFC is explicit how management action will be taken in relation to the (rebuilding) interim target reference point, which is also established alongside a specific timeline for this target being achieved. The stock of Pacific bluefin is treated as a Level 2 stock[56] under the Commission's hierarchical approach for setting biological limit reference points. This is because steepness in the stock-recruitment relationship is not well known, although the key biological and fishery variables are reasonably well estimated. The initial rebuilding target for the stock is the median SSB estimated for the period 1952 through 2014, to be reached by 2024 with at least 60% probability.
- Acceptable levels of risk are specified explicitly in the HCR, and set at a level that the WCPFC have considered to be consistent with the UN Fish Stock Agreement.[57] Until the stock is rebuilt, the Northern Committee will recommend conservation and management measures as needed to ensure rebuilding in accordance with the probabilities specified in the rebuilding targets.
- Management measures to be enacted by the HCR are clearly described by WCPFC, and consist of modifications to existing catch limits which have a reasonable

[55] Until the stock is rebuilt, the Northern Committee will work with the ISC and the Scientific Committee and consult with the IATTC to identify and evaluate the performance of candidate rebuilding strategies with respect to the rebuilding targets, schedules, and probabilities. The ISC is requested to start the work to develop a management strategy evaluation (MSE) for Pacific bluefin tuna fisheries in 2019 and have a goal of completing it by 2024.

[56] WCPFC has a 3-tier hierarchical approach (as outlined in SC7-MI-WP-03) to identify key LRPs for key target species in the WCPFC. Level 2 is defined for stocks where the stock-recruit relationship parameter for steepness (h) is not known well, if at all, but the key biological and fishery variables are reasonably well estimated (see https://www.wcpfc.int/harvest-strategy).

[57] https://www.wcpfc.int/system/files/WCPFC13%20Summary%20Report%20final_issued%202%20March%202017%20complete.pdf

expectation of being implemented effectively. This clarify on how management will respond to stock status relative to a reference point, in a pre-agreed manner, is fundamental to the successful functioning of an HCR as it allows management action to be taken rapidly and free of political influence at the time.

Weaknesses

- The HCR is not yet evaluated using MSE, although this is currently under development. The ISC periodically evaluate stock size and exploitation rate with respect to the established reference points and report to the Scientific Committee. Until 2024, while the MSE is being developed, the ISC is requested to conduct stock assessments in 2018, 2020 and 2022. With the absence of an MSE process, there remains a question of how key uncertainties have been considered in the design and implementation of the HCR, with a risk that the HCR may ultimately be ineffective.
- Once the stock is rebuilt, the Northern Committee will recommend conservation and management measures as needed to ensure that any target reference points are achieved on average in the long term, and ensure that the risk of the stock size declining below the limit reference point (once adopted) is 'very low'. However, this qualitative term is open to interpretation without clear guidelines on what 'very low' refers to in probabilistic terms.

3.2.4 IATTC tropical tunas harvest control rule

In 2016, IATTC adopted HCR for tropical tunas based on the interim target and limit reference points adopted in 2014 (Resolution C-16-02)[58]. The HCR aims to prevent fishing mortality from exceeding the MSY level for the tropical tuna stock (bigeye, yellowfin or skipjack that requires the strictest management. If fishing mortality or spawning biomass (for any of the three stocks) are approaching the corresponding limit reference point (i.e. $0.08*SSB_0$) with a probability of 10% or greater, the HCR also triggers the establishment of additional management measures to reduce fishing mortality and rebuild the stock.

The HCR recommended by the scientific staff for the purse seine fishery for tropical tunas was adopted in accordance with the following principles:

a) The scientific recommendations for establishing management measures in the fisheries for tropical tunas, such as closures, which can be established for multiple years, shall attempt to prevent the fishing mortality rate (F) from exceeding the best estimate of the rate corresponding to the maximum sustainable yield (F_{MSY}) for the species that requires the strictest management.

b) If the probability that F will exceed the limit reference point (F_{LIMIT}) is greater than 10%, management measures shall be established as soon as is practical that have a probability of at least 50% of reducing F to the target level (F_{MSY}) or less, and a probability of less than 10% that F will exceed F_{LIMIT}.

c) If the probability that the spawning biomass (S) is below the limit reference point (S_{LIMIT}) is greater than 10%, management measures shall be established as soon as is practical. These measures shall have a probability of at least 50% of restoring S to the target level (dynamic S_{MSY}) or greater. In addition, the measures shall have a probability of less than 10% that S will descend to below S_{LIMIT} in a period equivalent to either two generations of the stock or five years, whichever is greater.

d) For fisheries that use gears other than purse-seine nets, the recommendations by the IATTC scientific staff on additional management measures shall be as consistent

[58] https://www.iattc.org/PDFFiles/Resolutions/_English/C-16-02-Harvest-control-rules.pdf

as possible with those adopted for the purse seine fishery, while taking account of the impact of those fisheries on the species compared to purse seine fishery.

Strengths

- The HCR described in Res. C-16-02 establishes clear definitions for interim limit and target references points, using both fishing mortality and biomass-based reference points.
- Res. C-16-02 requires that the final adopted HCR will include pre-agreed management actions to be taken under various stock conditions. Pre-agreement on management actions is key to successful application of a HCR. It allows management measures, such as reduction in TAC, to be implemented rapidly when required, and avoids the need for political decision making at the time.
- The HCR sets out clear rules, with explicit probability thresholds, for triggering management action as the limit reference points (for F and S) are approached.

Weaknesses

- The HCR is currently established on an interim basis until it has been assessed. The scientific staff of the Commission shall carry out additional assessments of these HCRs and alternatives, which will be presented to the Scientific Advisory Committee for examination in order to allow the Commission to adopt a permanent HCR. No timeline for this is given in Res. C-16-02.
- No MSE process has been established, and the HCR has not been tested for robustness based on the main uncertainties in the assessment, such as the stock-recruitment relationship, or the ecological role of the stock. As such, there is uncertainty in how the HCR will perform in achieving management objectives, and any trade-offs between them.
- While the specifications of the HCR state that the management measures triggered by exceeding critical levels should be based on scientific recommendations relating to the species that requires the strictest management, the measures to be used are not explicitly defined.
- Not clear if probabilities relative to the RPs integrate model uncertainty.

3.2.5 CCSBT southern bluefin management procedure

Historically, southern bluefin tuna (SBT) stock has been heavily depleted. To assist in its rebuilding, CCSBT has developed a management procedure (MP), which can specify changes to the TAC for southern bluefin tuna (SBT) based on updated monitoring data. From 2002 to 2011, the CCSBT conducted extensive work to develop an MP in order to guide its global TAC setting process for the stock. The final MP, known as the “Bali Procedure”, was recommended by the CCSBT’s Scientific Committee in July 2011. The procedure is a combination of two preferred MPs, and is a representation of all the work scientists had conducted in development. Parameters of the recommended rule can be adjusted to set different time horizons for rebuilding, and to constrain the maximum TAC changes allowed every time the TAC is updated. The parameters of the MP are as follows:

a. To rebuild the status of stock to an interim building target reference point of 20% of the original spawning stock biomass by 2035;
b. The MP shall ensure a 70% probability of achieving the interim rebuilding target;
c. The minimum increase or decrease TAC change shall be 100 tonnes;
d. The maximum increase or decrease TAC change shall be 3000 tonnes;

e. The TAC shall be set for three-year periods, subject to paragraph 7 Resolution on Adoption of a Management Procedure[59]; and

f. The national allocation of the TAC within each three-year period will be apportioned according to the Resolution on the Allocation of the Global TAC.

Strengths

- The "Bali Procedure" sets clear, probability-based objectives for stock rebuilding using an interim rebuilding target reference point and within an explicit time period. The probability of achieving the interim rebuilding target has been set high (i.e. above 50%) and reduces the risk of the stock not rebuilding within the timeframe. In this respect the MP is considered conservative.
- The MP acts on a combination of longline CPUE[60] and scientific aerial survey data[61], which covers both the adult and juvenile portions of the stock respectively. The MP includes a clearly defined meta-rule process that pre-specifies what should happen in unlikely exceptional circumstances when application of the TAC generated by the MP is considered to be highly risky or highly inappropriate. This provision effectively builds greater precaution into the MP.
- The CCSBT tested a variety of candidate MPs with the aid of an operating model of the fishery that simulated the characteristics of the southern bluefin stock and fishery. The candidate MPs were tested against a range of uncertainties so that a robust procedure could be identified.
- Performance of the MP is assessed regularly, including an annual review of the implementation of the current MP and regular evaluation of new data sources and operating models.

Weaknesses

- The current Biomass Random Effects Model underpinning the "Bali Procedure" is complex, potentially making it difficult to communicate to stakeholders and decision makers.

[59] https://www.ccsbt.org/sites/ccsbt.org/files/userfiles/file/docs_english/operational_resolutions/Resolution_Management_Procedure.pdf

[60] CPUE data used in the MP is based on longline catch and effort data of Japanese, Australian (Real-Time Monitoring Program in the 1990s) and New Zealand (NZ) charter vessels at the shot-by shot resolution. Southern bluefin tuna aged 4 years or older are used in the CPUE dataset.

[61] The scientific aerial survey data are estimates of the biomass of SBT patches in the Great Australian Bight (GAB) as observed by experienced spotters. The aerial survey is conducted in January through March of each year, and consists of an aircraft flying along 15 north-south transect lines running from the coast to continental shelf (from 128E to 134E degrees longitude). The survey data consists of distance flown, location of sightings, biomass estimates of each school in a sighting, and environmental observations that might affect the number and size of sightings, such as sea surface temperature (SST), swell, haze, wind speed, and sea shadow.

3.3 Sub-task 2.3: Considerations for HCRs accounting for multispecies and mixed fisheries

Tropical tunas are candidates for the implementation of multi-species management schemes in tuna RFMOs. This sub-task provides a discussion on how HCRs might be developed considering multispecies interactions in mixed fisheries. For this, a review of HCRs used for mixed fisheries in International Council for the Exploration for the Seas (ICES) is provided. This review identifies and describes a number of HCRs that are of relevance to the development of multispecies HCRs for tuna fisheries. Also, the information available for tuna fisheries management is reviewed and, finally, three types of multispecies HCRs are presented (Catch based, effort based and fleet based).

3.3.1 Review of HCRs used for mixed fisheries in non-tuna management systems

The ICES Working Group on Mixed Fisheries Advice (WGMIXFISH) produced mixed fisheries forecasts for the North Sea, the Celtic Sea and the Iberian waters in 2017 (ICES, 2017a). All forecasts are based on the *Fcube* methodology (Iriondo et al., 2012) and a range of potential management scenarios relevant for the specific regional fisheries. The model uses the output of the single stock assessments and evaluates the consequences of different management options (e.g. TACs per stock and/or effort allocations by fleet). The model uses catch information at métier and fleet levels. *Fcube* produces catch advice for multiple stocks following a series of rules or scenarios (Table 9), including two types of multispecies HCR (Catch and effort based multispecies HCRs). These scenarios were analysed with the *Fcube* approach by the WGMIXFISH in different case studies: North Sea, Celtic Sea and Iberian waters. The main conclusion was that the most precautionary scenario impedes the maximization of fisheries potential while others cause overfishing.

Table 9: Catch advice scenarios for multi-stock management of fisheries in ICES (WGMIXFISH).

Scenarios	Abbreviation	Explanation
Maximum	max	For each fleet, fishing stops when all stocks have been caught up to the fleet's stock shares†. This option causes overfishing of the single-stock advice possibilities for most stocks.
Minimum	min	For each fleet, fishing stops when the catch for any one of the stocks meets the fleet's stock share. This option is the most precautionary option, causing underutilization of the single-stock advice possibilities of other stocks.
Stock	stock	All fleets set their effort corresponding to their hake quota share, regardless of other catches.
Status quo effort	sq_E	The effort is set equal to the effort in the most recently recorded year for which landings and discard data are available.
Economic value	Val	The effort by fleet is equal to the average of the efforts required to catch the quota of each of the stocks, weighted by the historical catch value of that stock.

† In WGMIXFISH, the term "fleet's stock share" or "stock share" was used to describe the share of the fishing opportunities for each particular fleet, which was calculated based on the single-stock advice for 2018 and the historical proportion of the stock landings taken by the fleet.

When fluctuating around MSY catch remains in a relatively low range and this is the cornerstone of the concept of Pretty Good Yield (PGY) (Hilborn, 2010). PGY refers to a range of policies that provide good yield while also producing other desired outputs. The fraction of the single stocks' MSY used to define the range of multispecies PGY is a trade-off between the maximization of total catch from a variety of stocks and sustainability objectives. The most recent WGMIXFISH tested a series of multispecies HCRs combining a range of fishing mortality levels corresponding to MSY (F_{MSY}) estimated by ICES for single stocks. For example, a HCR that generates multispecies TAC using the highest possible fishing mortalities for each stock was explored for demersal mixed fisheries off Iberian waters. Results show that the multispecies HCR makes a more adequate use of the existing fishing opportunities while the stocks biomass is maintained above reference levels.

In the Faroe Plateau mixed fisheries, the management based on TAC failed to achieve the objective of an average annual fishing mortality for three gadoid stocks (Baudron et al. 2010; ICES 2016). Baudron et al., (2010) developed a management strategy evaluation model to compare an effort-management system based on the Faroese example with a TAC system as currently applied in EU fisheries. Results show that when the stocks are considered together in mixed fisheries, effort management seems to be appropriate, and inter-annual flexibility of the system appears to be the best compromise between short- and long-term objectives, as well as between biological sustainability and economic return. Thus, in 1996, an effort based regulation system (days-at-sea) was established aiming at reducing discards and defining a simpler fisheries management administration. However, the system failed at adequately estimating effort and fishing mortality for the target stocks (Nielsen et al., 2006; Jákupsstovu 2007; Christensen et al., 2009; Baudron et al., 2010; ACOM 2012; Búskaparráðið, 2010). Nevertheless, the management system has improved in the recent years towards a global fisheries management plan aiming at achieving a multispecies MSY by modulating the overall fishing effort.

3.3.2 Overview of ICCAT tropical tuna fisheries as a paradigmatic example of multi-species management

The information available in the ICCAT website[62] is used for the characterization of Atlantic Ocean tropical tuna fisheries (bigeye, yellowfin and skipjack). The data explored include time series of catch per fishing operating mode and size distribution taken from the ICCAT website (Task II Catch and Effort statistics (T2CE) and CATDIS). The data using the fishing operating modes of Fish Aggregation Devices (FAD) or free school (FS) are from 1991 to 2015, stratified in time and space, and the data from longliners correspond to the period between 1950 and 2015. The analyses of the time series of catch per gear are done by the working groups responsible of each stock's assessments (Anon. 2015; Anon. 2016; Anon. 2017).

The annual composition of nominal catches for each of the fishing operating modes targeting tropical tunas is shown in Figure 9. Approximately 80% of the catch from purse seines using FADs corresponds to skipjack tuna, while for FS more than 75% corresponds to yellowfin. With regards to fleets using longlines, the proportion of catches has shifted since 1950s, when catch consisted mostly on yellowfin to more recent times where bigeye represents more than 75% of the total catch.

[62] www.iccat.int

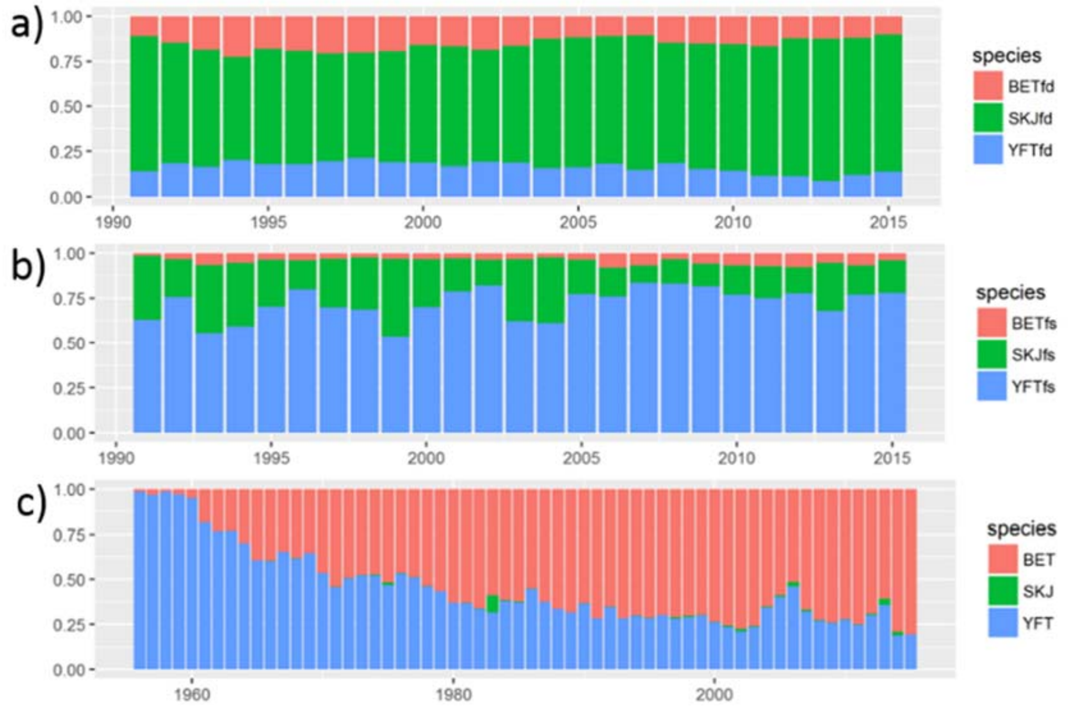

Figure 9: Yearly time series of the species catch composition with different operating fishing mode: a) purse seiners using FADs b) purse seiners fishing free swimming school and c) longliners. ***Data source: ICCAT Task II Catch and Effort statistics (T2CE) and CATDIS.***

De Finetti triangles (Figure 10) show that for purse seines using FADs catch corresponds to skipjack (60-80%), bigeye (0-10%) and yellowfin (10-30%). The plots also show that free school purse seines and longlines are monospecific, i.e. different species are not caught simultaneously. Longlines catch yellowfin or bigeye and purse seines operating over free schools catch yellowfin.

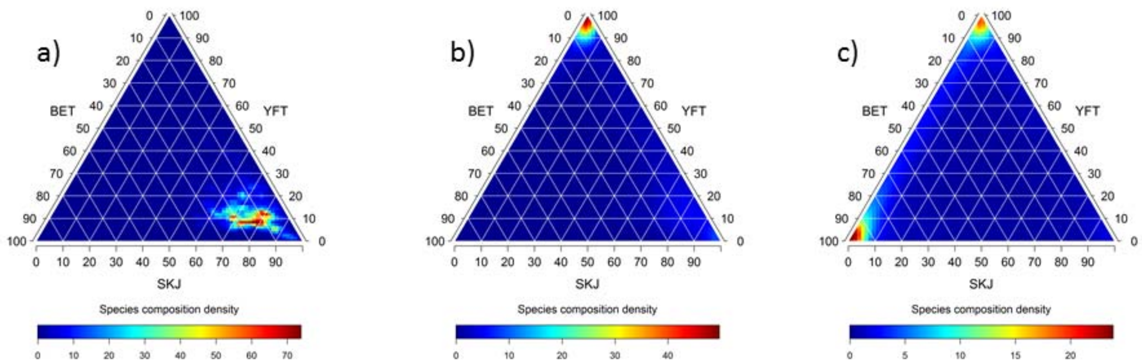

Figure 10: De Finetti triangles for: a) purse seiners using FADs b) purse seiners fishing free swimming schools and c) longline. ***Based on method described in Fonteneau et al., (2010).***

Figure 11 show the differences on the spatial distribution of the main catches of Purse seiners and longliners. The main catches of purse seiners are closer to the coast than for longliners and their catch composition is also different as it is shown in Figure 10. The purse seiners catch composition is mainly skipjack when is fishing with FADs and yellowfin tuna when is fishing with free swimming schools, while for longliners most of the catches are bigeye tuna.

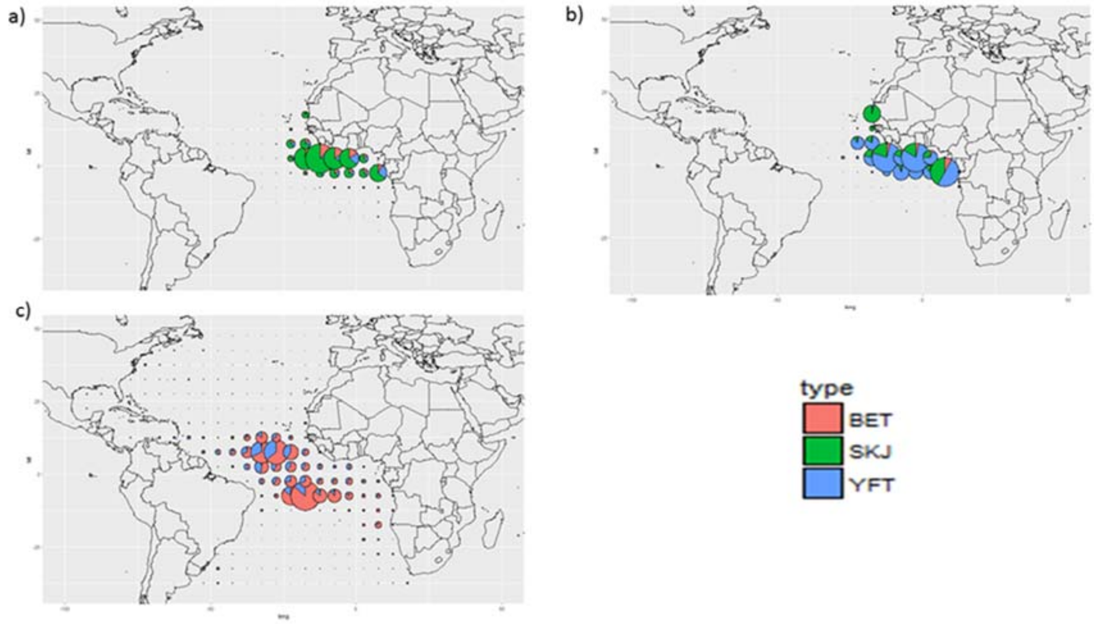

Figure 11: Geographical catch composition estimated with weighted mean (with the total landings). The size of the pie is defined with the historical total catch in each area: a) purse seiners using FADs b) purse seiners fishing free swimming schools and c) longline. Data source from ICCAT CATDIS.

Overall, purse seines using FADs catch smaller individuals of bigeye and yellowfin than purse seines targeting free schools (Fonteneau et al., 2013). The size distributions of the three species caught using Drifting FADs (DFAD) show a similar mode around 45 cm, with few individuals larger than 70 cm while individuals smaller than 40 cm observed only for skipjack (Figure 12). Longliners fish more mature bigeye than purse seiners being the mode at around 125 cm (Fonteneau et al., 2013).

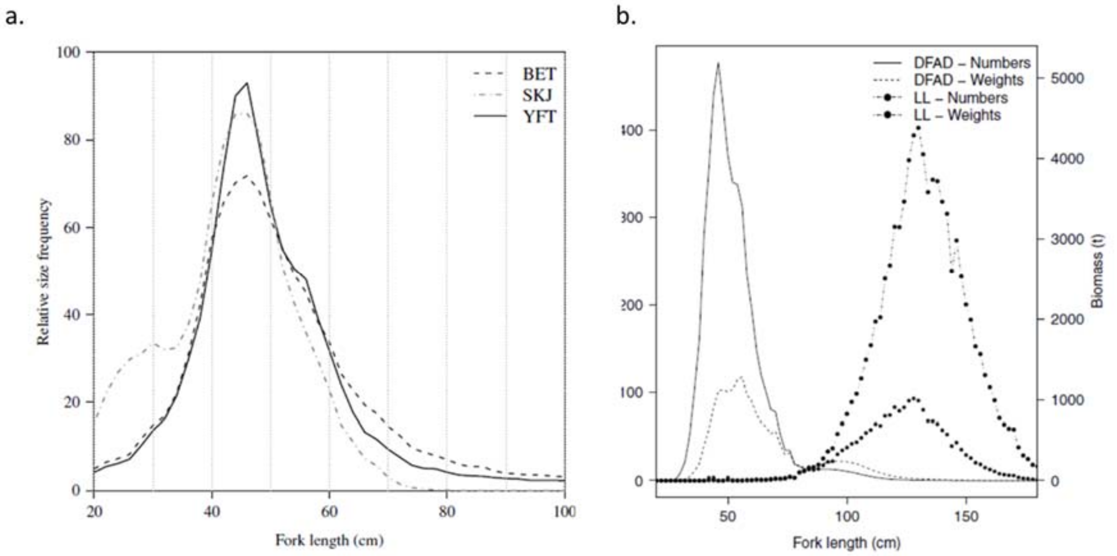

Figure 12: a) Relative size-frequency distribution (in numbers) for yellowfin, skipjack and bigeye tunas captured by purse seine fisheries on drifting FADs b) Relative size-frequency distributions of bigeye on longliners and DFAD (Fonteneau et al., 2013).

3.3.3 Options for Multispecies HCRs for tropical tunas (Catch, effort and fleet based managements)

World's tuna stocks are currently managed in single stock frameworks. When two or more stocks are caught simultaneously, the mismatch between the catch profiles of the fleets and the single stock advice can produce an incentive to generate over-quota discards (Ulrich et al., 2011). However, the mismatch between single stocks' TAC could be avoided by using multi-stock harvest control rules. In 2015 the European Commission (EC) proposed MSY fishing mortality ranges as a complement to the MSY fishing mortality point estimates to provide flexibility to the mixed-fisheries management frameworks: the objective is to produce consistent TAC advice between stocks within the fishing mortality ranges, and to avoid the presence of choke or limiting species. The range of fishing mortalities compatible with an MSY approach were defined as the "range of fishing mortalities leading to no less than 95% of MSY and which were precautionary in the sense that the probability of spawning stock biomass (SSB) falling below the limit biomass reference point in a year in long-term simulations with fixed fishing mortality was less than 5% (ICES, 2016a)".

3.3.4 Catch based management

The framework of the fishing mortality ranges defined by the EC in 2015 is the starting point for the definition of a multi-stock catch based HCR (Garcia et al., 2016). The objective of the HCR is to avoid over-quota discards and to maximize the overall catch while ensuring the sustainability of the stocks.

A multi-species HCR should fulfill the following properties:

1. Produce compatible catch advice among the stocks.
2. Take the most out of fishing opportunities (catch).
3. Result in fishing mortality levels compatible with the MSY ranges defined by the EC.

1. Compatible catch advice

A linear relationship between fishing mortality and Effort is assumed, with catchability (q) as a proportionality parameter (F = q x Effort). For a compatible fishing mortality advice (*Fadv*$_{st}$), the current fishing mortalities (*Fsq*$_{st}$) are multiplied by a parameter (μ). Mathematically:

$$\mathrm{Fadv}_{st} = \mu \cdot \mathrm{Fsq}_{st}$$

where *st* denotes each of the stocks and F_{adv} the fishing mortality that will correspond with the TAC advice. μ is defined so that the HCR fulfills the second and third properties.

2. Take the most out of fishing opportunities

If the F_{adv} of a given stock is equal or higher than the corresponding fishing mortality at MSY (F_{msy}) for that stock, all the fishing opportunities corresponding with MSY framework will be used. Then, μ_0 will be used defined as:

$$\mu_0 = \max \left(\frac{\mathrm{Fmsy}_{st}}{\mathrm{Fsq}_{st}}\right)$$

And *Fadv*$_{st}$ will be equal to:

$$\mathrm{Fadv}_{st} = \mu_0 \cdot \mathrm{Fsq}_{st}$$

3. Compatible with MSY ranges

In ICES Fmsy ranges are estimated for each of the stock defined as the range of fishing mortalities leading to no less than 95% of MSY and with a probability of 5 % of SSB falling below Blim in a year in long-term simulations with fixed. Thus, the F advice in the previous step could be higher than the upper bound of the fishing mortality range of some stocks. Hence, a second multiplier is applied to ensure that F_{adv} falls within the ranges for all the stocks, i.e.:
For any stock:

$$F\mathrm{adv}_{st} = \begin{cases} \mathrm{Fadv}_{0,st} = \mu_0 \cdot \mathrm{Fsq}_{st} & \text{if} \quad \mu_0 \cdot \mathrm{Fsq}_{st} \leq F\mathrm{upp}_{st} \text{ for all } st, \\ \mu_1 \cdot \mu_0 \cdot \mathrm{Fsq}_{st} = \min \left(\frac{\mathrm{Fupp}_{st}}{\mathrm{Fadv}_{0,st}}\right) \cdot \mu_0 \cdot \mathrm{Fsq}_{st} & \text{if for any } st \quad \mu_0 \cdot \mathrm{Fsq}_{st} > F\mathrm{upp}_{st} \end{cases}.$$

where *Fupp* is the upper bound of fishing mortality range.

In a TAC management system, $F\mathrm{adv}_{st}$ is translated afterwards in catch using the corresponding catch production function (i.e. Baranov catch equation (Baranov, 1918)).

4. Stocks without analytical assessment.

The stocks without analytical stock assessment, but subject to TAC and quota system, can be introduced in the framework of the multi-stock HCR if we assume mathematical relationship between the variation on the fishing mortality of the rest of the stocks and the variation on the catch of this stock. The simplest model is to assume that the variation in the catch of the stock decreases/increases linearly with the decrease/increase of the fishing mortality of the rest of the stocks, i.e.:

$Cadv_{st} = \mu \cdot Csq_{st}$

Then, the role of this stock in the equations in points 1, 2 and 3 is the equivalent to the role of the rest of the stocks but using catch instead of fishing mortality in status quo and target levels. Furthermore, to provide some flexibility to the system the advice of the stock should be accompanied by a catch range.

3.3.5 Effort based management

Effort based management is a potential alternative to TAC based management in mixed fisheries systems (Hauge and Wilson, 2009; Hegland and Hopkins, 2014). Effort based management overcomes the problem of multi-stocks quota mismatch and hence, with over-quota discards. However, the correct implementation of this type of management requires a series of conditions:

- The effort metric should be representative of the fishing capacity of the fleets.
- Effort based management incentives the increase of catchability, the so called technological or effort creep and therefore, this will need to be taken into account when the relation between stock status and fishing effort is defined.

The catch based HCR is also the foundation of the effort based management systems. In this case, the multiplier, μ in the formulation of the multi-stock HCR should be translated into effort using a pre-defined effort-fishing mortality relationship.

3.3.6 Fleet based management

Independently if the management is done in terms of effort or catch, the success of the harmonization of single stock TAC advices will depend on how homogeneous the fishery is in terms of fleet specific catch profiles. In a very heterogeneous fishery with very different catch profiles among fleets, consistent catch advice among stocks can only be obtained if the harmonization is performed at fleet or fishing mode level. Furthermore, when the harmonization is done at fishery level, there could be cases of unjustified favors or penalties to individual fleets. For example, let's take the case of a fishery with two fleets, one that catches only one stock and a second one that catches several stocks simultaneously. If the multi-stock HCR was applied and the TAC of the stock targeted by the single-stock fleet was decreased in order to harmonize the TACs, the catch-quota of the single-stock fleet would decrease automatically and the fleet would be penalized.

The partial fishing mortality at fleet level, i.e. the fishing mortality applied by each fleet (or fishing mode), is defined as the product of the total fishing mortality and the ratio between fleet's catch and total catch, that is:

$$F_{fl} = \frac{C_{fl}}{C_{total}} \cdot F$$

The multi-stock catch based HCR can be applied at fleet level using the partial fishing mortalities of the stocks exploited by each of the fleets and dividing the target fishing mortality among fleets for each of the stocks.

Fishing mortality is a function of fishing effort and catchability:

$$F_{st,fl} = \varphi(E_{fl}, q_{st,fl})$$

where E denotes effort and q catchability. Therefore, the fishing mortality can be modulated by both a variation of fishing effort or by a variation in catchability. Hence, a target fishing mortality could be achieved by varying any of the two variables. For example, in the case of the purse seiners operating on FADs, a reduction in the number of FADs is expected to also reduce the overall catchability of the fleet if the other conditions (e.g. FAD size, effort) remain unchanged. However, depending on the definition of the effort (e.g. fishing days, fishing days*number of FADs) the number of FADs could be part of the effort and not of the catchability. In this case, the overall selectivity of the fleet on the stocks (the component of the catchability related with the size of the individual fishes) will change and therefore their MSY-based reference points will change too (Scott and Sampson, 2011).

$$\text{Fadv}_{st} = \mu \cdot \text{Fsq}_{st} = \mu \cdot \sum_{fl} \varphi(q_{sq,st,fl}, E_{sq,fl})$$

If a linear relationship is assumed between fishing mortality and effort, i.e.:

$$\text{Fadv}_{st} = \mu \cdot \text{Fsq}_{st} = \mu \cdot \sum_{fl} q_{sq,st,fl} \cdot E_{sq,fl}$$

where q, the catchability, is the proportionality parameter. In this case varying fishing mortality by μ is analogous to vary fishing effort, given that catchability q is maintained constant. One of the problems of effort based management is the technological (Marchal et al., 2007) creeping, for example increases in catchability through increases in the number of FADs, this should be avoided to ensure a correct implementation of the fishing mortality advice. If the relationship between fishing mortality and effort were not linear and different depending on the fleet, in that case, the relationship could be described including a fleet dependent elasticity parameter on effort, α_{fl}, in the model:

$$\text{Fadv}_{st} = \mu \cdot \text{Fsq}_{st} = \mu \cdot \sum_{fl} q_{sq,st,fl} \cdot E_{sq,fl}^{\alpha_{fl}}$$

This means that the variation in effort would have different impact on fishing mortality depending on the fleet due to the α_{fl}. For example if the alfa value for a given stock and fleet1 is equal to 1 (linear fishing mortality) but 2 for fleet2 (potential relationship). Then a reduction of 10% of in the Fadv for fleet1 would mean an advice in effort of 0.9Esq, but for stock 2 it would mean an effort of sqrt(0.9)*Esq,fl2.

However, if α depends on the stock the formulation of the multistock HCR could be difficult to be implemented in an effort based management system because a common variation in fishing mortality for the stocks would not correspond to the same variation fishing effort at fleet level.

Now if we think that at the same time we want simultaneously a reduction of 10% in effort for stock 2 where the alfa value of stock 2 is lineal, that would mean a reduction of effort of 10%, so 0.9Esq,fl1. So that would means two different advices on effort to the same fleet in order to have the same impact on the F of two stocks.

3.3.7 Discussion

Multispecies fisheries management can be applied using catch and effort limits. Both types feature benefits and shortcomings. In this chapter we have focused on tropical tuna fisheries, generally captured by European purse seiners with free school and FAD sets. For example, in the Indian Ocean, purse seiners mostly capture adult individuals of yellowfin on free schools and young individuals with FADs. The catch on free schools is almost entirely composed by yellowfin whereas the catch in FADs is mostly composed by skipjack and yellowfin juveniles. Currently, Indian Ocean yellowfin is considered to be overexploited and subject to overexploitation and skipjack is estimated to be at its target RP (40% depletion). In the Atlantic, bigeye is overexploited and subject to overexploitation and there are no signs of overexploitation for skipjack.

In general, when using catch limits, a quasi real time monitoring of catch is necessary. This can be difficult however, as highlighted by IOTC's Working Party on Data Collection and Statistics and Scientific Committee in 2017 (IOTC, 2017d). This is because there is a time lag between landings and the effective sampling of catch. The problem is that until catch is monitored there is no accurate accounting of the catch of each species and therefore the catch of yellowfin can only be estimated. This can cause problems of non-compliance if the excess of catch is not detected or to premature closures if catch is overestimated. In this case, alternative management measures would facilitate the control and monitoring of tropical tuna fisheries. The difficulties in monitoring catch will also worsen the catch statistics used in tropical tuna fisheries stock assessments. Improving the monitoring of catch is possible but would require the investment of additional human and technical resources.

European purse seiners using FADs capture young individuals of yellowfin together with skipjack and, in some cases, with bigeye. However, the scientific advice in the form of stock status, reference points and catch projections are provided in a single species basis. In multispecies fisheries it is not possible to apply different levels of fishing effort to two or more species that are vulnerable to the same fishing gear and inhabit the same habitat. According to the FAO Code of Conduct for Responsible Fisheries and other international agreements, discards are generally considered a waste of fish resources and inconsistent with responsible fisheries (FAO, 1995). ICCAT, in its ICCAT Information on By-Catch of Tuna Fisheries (available via iccat.int) also calls for a reduction of discards. Also, specifically in ICCAT, according to Recommendation 17-01, it is prohibited to discard any bigeye, yellowfin or skipjack captured in the Atlantic. In the IOTC, Resolution 17/04 also bans discards of bigeye tuna, skipjack tuna, yellowfin tuna, and non-targeted species caught by purse seine vessels in the IOTC area of competence. In tropical tunas, when the catch limit for one stock, (yellowfin in the IOTC or bigeye in ICCAT) is reached (choke species) but not for the others, fleets will stop their fishing operations. In that case, the catch limits for skipjack for example will not be reached with the associated loss of opportunities for the fishing fleets and other undesirable socioeconomic consequences. The later include loss of food production, shortages to canneries and potentially price increases due to a lower supply at international markets.

Additionally, species like tunas feature a very variable recruitment. In general, TAC based management requires accurate estimates of stock status, reference points and recruitment when catch limits are set. Should the biomass and recruitment be underestimated, catch limits will be reached sooner than expected and fishing opportunities would be wasted unless the choke species is discarded. On the contrary, if stock biomass is overestimated, when managing with fixed catch limits, biomass will continue to decline as fishing mortality will increase. In this regard, effort controls are a more flexible way to deal with multispecies fisheries since they can reconcile conservation objectives of two or more stocks when they are set for the most vulnerable stock, in this case bigeye.

Fishing effort limits are restrictions on the intensity of use of the fishing gears. These can include limits to the period of the fishing season, which is relatively easy to enforce through vessel monitoring systems (VMS), use of logbooks and other measures. Also, fishing effort control reduces the need for a real time monitoring of catch which is often difficult and expensive. Effort controls represent a flexible option to seek for achieving management objectives of multispecies fisheries. Effort control is particularly adequate for stocks which assessments remain subject to uncertainty. Under effort control systems, it is no longer necessary to estimate the fishable biomass accurately every year, as the level of fishing mortality is restrained directly, irrespective of the continual fluctuations of stock size by controlling the level of fishing effort. Effort will be adjusted periodically and progressively towards meeting the target reference points. With effort controls, as biomass of the most vulnerable species fluctuates following recruitment variability, the catch obtained when applying the effort limits will change proportionally, giving automatic feedback control and allowing for meeting management objectives. Hence, when the abundance declines or increases, the catch will correspondingly decrease or increase. Also, the effort limits will facilitate the adequate management of the less vulnerable stock. For an effort control to be effective, it is important to understand and adequately estimate catchability dynamics of the fishing gears. It is particularly important and critical to adequately incorporate the impact of effort creep as a result of technological improvement. In brief, in order to be effective, effort based management would require a tight control on fleets' technological capacity and catchability. In cases where fishing capacity increases, the fishing mortality produced with a given effort could be higher than expected and thus, compromise the sustainability of the stocks.

History of TAC vs effort-based management in ICCAT, WCPFC and IATTC

IATTC's Resolution C-17-02 Conservation measures for tropical tunas in the Eastern Pacific Ocean during 2018-2020 and amendment to Resolution C-17-01, WCPFC CMM-17-01: Conservation and Management Measure for bigeye, yellowfin and skipjack tuna in the Western and Central Pacific Ocean and ICCAT Recommendation 16-01: Recommendation by ICCAT on a Multi-Annual Conservation and Management Program for Tropical Tunas.

From the above, only ICCAT uses TACs or overall catch limits for all the fleets involved in tropical tuna fisheries. That is the case for Atlantic bigeye and yellowfin that together with Indian Ocean yellowfin and skipjack are the only tropical stocks managed through an overall TAC system. Last year both yellowfin and bigeye catch limits established in ICCAT were exceeded. In this way the approach followed in ICCAT and IOTC has not been able to reduce the fishing mortality to recommended levels due to lack of compliance to catch limits. IATTC and WCPFC apply output controls (TAC) only for longline fleets targeting bigeye tuna. In the Pacific, purse seine fleets activity is regulated through effort limits (the days of the fishing season). The IATTC uses an effort based pseudo-HCR to determine the number of fishing days that purse seines are permitted to fish in order to achieve MSY.

In February 2017 the IATTC attempted to introduce catch limits for bigeye and yellowfin catch from purse seine fleets operating with FADs and an additional catch limit for yellowfin from dolphin associated fisheries. These measures aimed at mitigating the potential impact of the recent increase in capacity on the current status of bigeye and yellowfin stocks. The overall catch limit for 2017 corresponded to the average catch observed during 2013-2015 for both species combined. The attempt to introduce catch limits for the IATTC yellowfin and bigeye fisheries was shortly proven problematic and it had to be amended by a new measure, C-17-02, only 5 months after its entry into force. The reason for this was that, the purse seine fleet fishing on FADs had reached 80% of the total annual catch limit by mid-July, probably due to abnormally large recent recruitments that led to a higher than expected proportion of yellowfin and bigeye in FAD sets. If this measure hadn't been amended, the FAD fishery would have been closed by August or early September, with dramatic consequences for purse seine fleets. The new measure, adopted in July 2017, eliminated the catch limits and incorporated 10 additional days of purse seine closure which resulted in a total of 72 days of closure.

4 TASK 3: MANAGEMENT STRATEGY EVALUATION (MSE)

4.1.1 Sub-task 3.1: Provide an analysis of management strategy evaluation in tuna RFMOs

Management Strategy Evaluation (MSE), i.e. the evaluation of management strategies using simulation, is considered to be the most appropriate way to evaluate the trade-offs achieved by alternative management strategies and to assess the consequences of uncertainty for achieving management goals (Punt et al., 2016).

MSE involves using simulation to compare the relative effectiveness for achieving management objectives of different combinations of (i) data collection schemes, (ii) methods of analysis and (iii) subsequent process leading management actions (Punt et al., 2016), i.e. different MPs. MSE requires developing a series of basic steps (Punt et al., 2016; Rademayer et al., 2007):

1. Identification of management objectives and representation of these using quantitative performance statistics.
2. Selection of hypotheses of system dynamics: a range of hypotheses concerning data, biological information, environmental impact or any other factor that may be considered a source of uncertainty in relation to system dynamics.
3. Constructing Operating Models (OM): these provide a mathematical representation of the system that is being managed (fish and fisheries). The impact of the management measures decided through the HCRs in the MP will be evaluated in the OMs. These OMs are considered to be alternative representations of the "true" dynamics of the stock.
4. Defining Management Procedures (MP): this includes data used, methods of analysis and decision frameworks (e.g. Harvest Control Rules).
5. Simulation of the application of each management strategy or MP.
6. Summary and interpretation of performance statistics: this may lead to refinement of the relative weighting of the management objectives as the simulation process develops and continues to provide more refined (tuned) results to inform the quantitative trade-offs among competing goals.

The five tuna RFMOs have carried out some type of MSE work, including consultation on management objectives, characterization of uncertainty of stocks' dynamics and observation, and evaluation of harvest strategies. Most of the MSE conducted to date has been developed by the RFMO science providers with seldom direct mandate from the Commissions. However, in the recent times, all RFMOs have scheduled consultation and dialogue towards addressing the different steps required to complete the MSE process. In this section we review the steps towards the development of MSE frameworks and the adoption of MPs (also named Harvest Strategies, HSs) including HCRs in the five tuna RFMOs. Also, we review a series of recent global initiatives that are contributing to the MSE process across t-RFMOs.

4.1.1.1 International Commission for the Conservation of Atlantic Tunas (ICCAT)

SCRSs Working Group on Stock Assessment Methods (WGSAM) has fostered the development of MSE under the principles of the Precautionary Approach for tuna stocks in the Atlantic since 2010 (ICCAT 2010). This development has been followed by successive recommendations by ICCAT Commission on which the development of MSE has been requested to evaluate HCRs consistent with ICCAT Commission objectives and decision making principles (ICCAT 2015a). To date, MSE has substantially been developed for bluefin and North Atlantic albacore stocks.

ICCAT has placed a high priority on the completion of the MSE workplan for bluefin tuna. This includes developing new and/or improved assessment methods for this stock by the GBYP Core Modelling and MSE Group, which was created for this purpose in 2014 (ICCAT, 2014). This group has structured a workplan in five components: 1. data collation, management and synthesis; 2. Review and selection of alternative stock assessment models; 3. Development of MSE modeling platform; 4. Capacity building in Harvest Strategies, Reference Points and MSE; and 5. Consultation and engagement in design and evaluation of Harvest Strategies.

Also in ICCAT, a specific Call for Tenders is supporting the MSE development for the two bluefin stocks. In the specific bluefin MSE meeting (Madrid, 16-20 April) different options for Operating Models and Management Procedures were discussed. The current MSE developed so far, considers a single stock of Atlantic bluefin with mixing between the Eastern and Western regions. With regards to the MPs, only empirical indicator based MPs were preliminary tested. Currently, there are ongoing discussions on the adequacy of the current OMs and further MP tests will be carried out in September 2018.

With regards to North Atlantic albacore MSE, this has been developed specifically to allow the adoption of a HCR for this stock in 2017 as requested by the Commission (ICCAT 2016b). The preliminary and draft evaluations of HCRs were refined in 2017 using MSE (Merino et al., 2017b). The technical group that has carried out this work used a specifically tailored MSE to accommodate a Management Procedure that is comparable to the latest assessment of this stock (ICCAT 2016c), i.e. simulating the catch data and CPUE series used for the assessment together with the same model (biomass dynamic model) and model specifications (same starting values (r = 0.2, K = 10,000), shape of production function and bounds to parameter estimates). This work has also covered the uncertainty inherent to this fishery through a range of age structured population dynamics, with options for natural mortality, steepness, dynamic catchability and available information as the Operating Models (Merino et al., 2017a).

The technical work that has been produced under the SCRS has been communicated to stakeholders through the Standing Working Group on Dialogue between Fisheries Scientists and Managers (SWGSM)(ICCAT 2015b; ICCAT 2017c) and the ICCAT's Panel 2 (Northern temperate tunas) (ICCAT 2016a). These meetings have helped defining the management objectives and the performance measures to evaluate the ability of MPs to achieve them. For example, in ICCAT's Recommendation 16-06 the management objective for this stock is specified as to maintain the stock in the green quadrant of the Kobe plot with at least 60% of probability, while maximizing long-term yield from the fishery and catch and effort stability (ICCAT 2016b). Both dialogue platforms have allowed the refinement of the evaluation of HCRs for North Atlantic albacore and discussing the development of bluefin MSE. Also, the SCRS has scheduled a workplan to complete the MSEs for North Atlantic albacore, swordfish, bluefin and tropical tunas (ICCAT 2017b) that has been endorsed by ICCAT's Commission.

In November 2017, based upon the results of the HCR evaluation for North Atlantic albacore, ICCAT adopted a model based HCR for this stock (Recommendation 17-04). The control parameters of the HCR are the following: a) $B_{THRESH}=B_{MSY}$, $B_{LIM}=0.4*B_{MSY}$, $F_{TAR}=0.8*F_{MSY}$ and $F_{MIN}=0.1*F_{MSY}$. In addition, the catch limits will not exceed the 50,000 t to avoid adverse effects of potentially inaccurate stock assessments and the maximum change in the catch limit shall not exceed 20% of the previous recommended catch limit when $B_{current} \geq B_{THRESH}$. This HCR has been evaluated to achieve the management objective of maintaining the stock in the green quadrant of the Kobe plot with more than 60% probability.

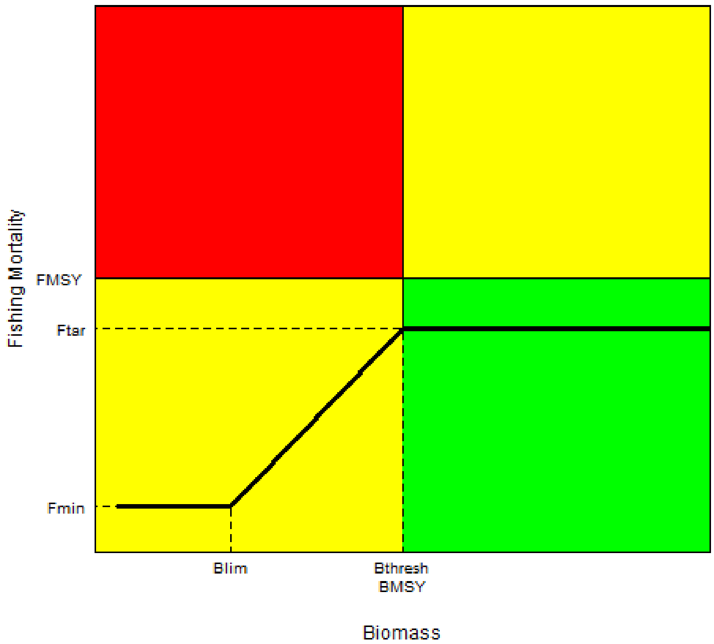

Figure 13: Harvest Control Rule adopted for North Atlantic albacore (ICCAT, 2017a).

4.1.1.2 Indian Ocean Tuna Commission (IOTC)

The Working Party on Methods (WPM) of the IOTC started a workplan to evaluate MPs for albacore, bigeye, yellowfin and skipjack in 2012. Since then, a small ad-hoc working group has been tasked to develop MSE works and to report the IOTC Commission through MP dialogue meetings specifically scheduled during IOTC Annual and Scientific Committee meetings. This ad-hoc or informal working group has annually reviewed the technical development of the MSE simulation frameworks developed in the IOTC. Also, the IOTC has established a dedicated Technical Committee of Management Procedures (TCMP) as a formal communication channel between science and management to enhance decision-making response of the Commission in relation to Management Procedures (MPs) (IOTC, 2016b). The TCMP met in May 2017 for the first time and provided a forum for discussion on the elements of MPs that require a decision by the Commission, and included the presentation of MSE results to facilitate the exchange of information and views between fishery scientists and managers.

The technical work carried out by the ad-hoc working group includes (IOTC 2017a; 2018):

A. *Progress on OMs and MPs of albacore, skipjack, bigeye and yellowfin:*
   a. The grids of OMs for these stocks are based on the latest stock assessments with alternatives for natural mortality, steepness, selectivity and dynamic catchability.
   b. The MPs considered for these stocks include model based and empirical HCRs. Overall, the skipjack MSE was used to evaluate only a series of model based HCRs and did not evaluate a complete MP.
   c. The MSEs for albacore, bigeye and yellowfin are scheduled to be completed in two or three years and they are including the current CPUE series and standardization methods used in the assessments of these stocks.
   d. The management objectives are relatively generic: i) Maintain the biomass at or above levels required to produce MSY or its proxy, and maintain the fishing mortality rate at or below FMSY or its proxy; and ii) avoid the biomass being below B_{LIM} and the fishing mortality rate being above F_{LIM} (Resolution 15-10).

   e. The performance measures used are aligned with the recommendation from IOTC's Scientific Committee (IOTC 2015a). These include measures of stock status, safety, yield, abundance and stability.
   f. The MPs evaluated for these stocks will take advantage of the recent TCMP meetings in May 2018[63] to decide on tuning parameters for achieving management objectives. Fine tuning Management Procedures is basically adapting the coordinates of HCRs in order to exactly achieve the specific management objectives defined for each stock. For example, what HCR is estimated to exactly achieved the determined probabilities in the agreed timed.

B. *Plan for developing MSE for swordfish:* the workplan identified by the Commission under Res 15/10, calls for MSE on swordfish to be completed by 2017 and presented to the Commission meeting in 2018. This plan has been delayed but endorsed in the IOTC Commission meeting in 2018.
C. *Visualization tools:* The standardised figures and tables for presentation of MSE results that were agreed at WPM07 and SC19 in 2016 were reviewed.

The work of the technical working group has been the basis for the adoption of Resolution 16-02 on Harvest Control Rules for skipjack tuna in the IOTC area of competence. This resolution indicates the procedure to be followed to establish the catch limits for this fishery for each level of SSB estimated through a stock assessment agreed by the Working Party on Tropical Tunas (WPTT) and endorsed by the Scientific Committee of IOTC (IOTC 2016a). Resolution 16-02 specifies a relationship between stock status (spawning biomass relative to unfished levels, $\%B_0$) and fishing intensity (exploitation rate relative to target exploitation rate) in Figure 14.

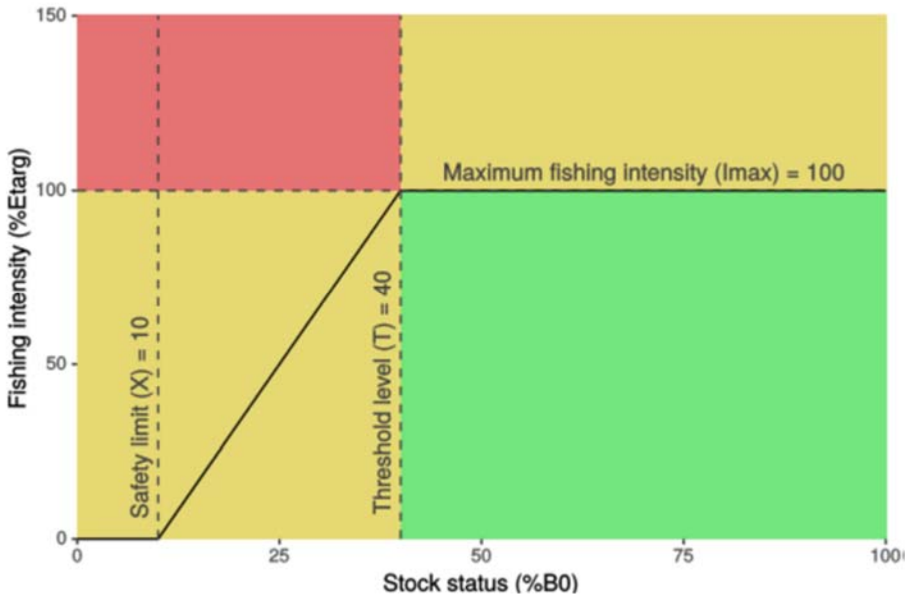

Figure 14: HCR adopted for Indian Ocean skipjack (IOTC, 2016a).

The work of the technical working group has also been the cornerstone for the Recommendation 14-07 and Resolution 15-10 on target and limit reference points for albacore, bigeye, yellowfin, skipjack and swordfish and on a decision framework (IOTC 2015b). It is important that this resolution is explicitly based on Resolution 12-01 on the

[63] TCMP (IOTC 2018) recommended that MSE tuning objectives for yellowfin (TY5) be retained and to revise a set of tuning objectives for bigeye (based on TB2; TB3 and TB4). See Appendix V for further details. www.iotc.org/sites/default/files/documents/2018/06/IOTC-2018-TCMP02-RE.pdf

implementation of the precautionary approach. Specifically, Resolution 15-10 recommends showing stock status results from stock assessments relative to limit and target RPs when available. It is also important to note that currently, despite some agreement on the management objectives, there are no timeframe or probability levels agreed for none of these stocks. Along these lines, IOTC called the TCMP to define the overarching management objectives to guide the development of management procedures for the IOTC fisheries (IOTC 2016b).

4.1.1.3 Western Central Pacific Fishery Commission (WCPFC)

The WCPFC's science provider, the Pacific Community (SPC) has developed the work towards implementing HSs or MPs. The technical work has been focused on estimating the impact of different management objectives (including specific timeframes, levels of risks and probabilities of overexploited stocks) on fisheries performance, and has included bio-economic analyses such as the estimation of the Maximum Economic Yield RP and historical catch rates for South Pacific albacore, bigeye, skipjack, yellowfin and southern bluefin tuna (Preece et al., 2011; WCPFC,2015; WCPFC, 2017a; WCPFC, 2017b; WCPFC, 2017c; WCPFC, 2017d; WCPFC, 2017e; WCPFC, 2017f). For that, alternative parameter sets have been used to condition operating model grids and account for potential sources of uncertainty.

The technical work has been communicated through specific Management Objective Workshops (MoW) since 2012, where assistance has been provided to the Commission to understand the purpose and implications of management objectives, to understand both the role of appropriate reference points and the process of evaluating potential management measures in the achievement of management objectives; and to develop a list of recommended management objectives to guide the management of fisheries by the WCPFC (WCPFC 2012a; WCPFC 2012b; WCPFC 2013; WCPFC 2014).

These workshops have allowed identifying and refining potential target RPs and proposing Conservation and Management Measures (CMM) on establishing harvest strategies for key tuna species. Overall, the adopted and proposed target reference points in the WCPFC correspond to depletion levels notably above the estimated MSY reference points (e.g. 40% SB_0). This is led by two different management objectives: 1) Setting the TRP so that the probability of breaching the 20% SB_0 LRP to a minimum and 2) recovering the stocks to abundance levels that will allow improving the economic efficiency of local fleets. The second management objective refers to leading the fishery to a biomass level that would allow longline fleets achieving the catch rates of 2008, when the fishery was at relatively acceptable levels.

4.1.1.4 Inter-American Tropical Tuna Commission (IATTC)

IATTC's Scientific Advisory Council (SAC) has led the MSE process in this RFMO and has been responsible for the technical work that has guided the adoption of target and limit reference points and it is expected to guide the adoption of HCRs in the future. In 2003, SAC organized a workshop with the aim of describing the objectives of organizations and their use of reference points, and those describing research on reference points (IATTC, 2003). After a number of consultations, in 2014, the IATTC adopted interim target and limit reference points for tropical tuna stocks. The target reference points are the biomass and fishing mortality rate corresponding to the MSY (B_{MSY} and F_{MSY}, respectively), which have been the unofficial target RPs used in managing tuna in the eastern Pacific Ocean (EPO) through a pseudo HCR. The limit reference points are those associated with a 50% reduction in recruitment from pristine levels under a conservative assumption of the stock-recruitment relationship (steepness=0.75), which is based on biological grounds to protect a stock from serious, slowly reversible, or irreversible fishing impacts. In general, this is interpreted as ensuring that recruitment is not substantially impacted, which aligns with Precautionary Approach principles.

Following the adoption of the target and limit RPs, SAC has developed MSE frameworks for evaluating more elaborated HCRs for tropical and other tunas (IATTC 2015; IATTC 2016a; IATTC 2016b; IATTC 2016c; IATTC 2017a; IATTC 2017b). In general, the OMs and the MPs for the MSEs are based on recent stock assessments carried out with the software Stock Synthesis (Methot Jr and Wetzel 2013), and are therefore conditioned to the available data. In particular, MSE efforts have been directed to the evaluation of the RPs adopted by IATTC on EPO bigeye and yellowfin tunas. SAC aims at continuing these works to identify additional harvest control rules for the management of these stocks (IATTC 2017a; IATTC 2017b). The HCR consider F_{MSY} and B_{MSY} as targets and aim at defining the length of the fishing season for tropical purse seiners (e.g. Resolution C-17/02).

4.1.1.5 Commission for the Conservation of Southern Bluefin Tuna (CCSBT)

From 2002 to 2011, the CCSBT conducted extensive work to develop a MP, known as the "Bali procedure" that was recommended by the CCSBT's Extended Scientific Committee (ESC) in order to guide its global TAC setting process for southern bluefin tuna. The development of this work was initiated by a technical group of experts through specific workshops. The initial workshops (2002-2004) aimed at the development of a work plan to focus on the specification of OMs and the evaluation of simple MPs. The results of the workshops were presented to the CCSBT through consultation meetings and the candidate MP was refined until it was adopted in 2011. The technical working group was organized to develop the different components of the MSE in the following way (CCSBT, 2002):

A. Structure of the OMs: starting from an age structure dynamic population model, alternatives for stock structure, natural mortality, steepness, growth, stock recruitment relationships, weight-length relations, maturity and catchability were considered.

B. Fishery model: the main fisheries catching bluefin tuna were identified, their selectivity estimated and a component of unknown removal was included.

C. Conditioning on historical data and identification of data and error structure used for estimating model parameters: the data used to condition the OMs were total catch, catch and age/length and three abundance indices (CPUE, tagging and aerial surveys). Also, the methods for conditioning and other technical choices were discussed in this section.

D. Candidate MPs: this includes testing alternative sources of data to be used in the MP and the proposal of decision rules. In CCSBT, since the beginning, the decision rules have been based on empirical indicators such as indices of trends in stock status, that are in general easily understood by managers and stakeholders (ISSF, 2013). In particular, the CCSBT technical working group focused on HCRs that use past catch and abundance indices to fix catch limits.

E. Testing of MPs: this comprises modelling choices for evaluating MPs, including options for dealing with uncertainty and error.

F. Initial identification of objectives and related performance measures: management objectives and performance measures need to be agreed in consultation with stakeholders, but the technical group defined three groups of management objectives including maximizing catch, safeguarding the resource (biomass, SSB, spawning potential and recruits) and stability of catch/effort.

G. Mechanics for conducting the evaluation tests: this included the organization of the work to be done between national scientists, computational language and share of files and scripts.

The work plan and advances of the technical working group were periodically discussed with stakeholders during workshops (2005) and CCSBT Commission meetings (2005-2011). In these consultations the management objectives, timeframes and tuning details were agreed before the adoption of the Bali procedure. This MP has been adopted with the aim of leading southern bluefin tuna towards the agreed objectives (2011 and updated in 2013). The MP was tuned using the following specifications:

- a 70% probability of rebuilding the stock to the interim rebuilding target reference point of 20% of the original SSB by 2035;
- The minimum TAC change (increase or decrease) will be 100 tonnes;
- The maximum TAC change (increase or decrease) will be 3,000 tonnes;
- The TAC will be set for three-year periods; and
- The national allocation of the TAC within each three-year period will be apportioned according to CCSBT's Resolution on the Allocation of the Global Total Allowable Catch.

4.1.1.6 Global initiatives

A series of global initiatives have also contributed to the development of MSE in tuna RFMOs. In particular, following international entities' engagement with the MSE process, global partnerships have promoted the dialogue between managers and scientists, and facilitated the establishment of common frameworks for simulation tests and economic incentives to adopt Harvest Strategies, the precautionary approach and sustainable fisheries management.

a. Joint Tuna RFMO Management Strategy Evaluation Working Group

At the Third Joint Tuna RFMOs meeting (La Jolla, California, July 11-15, 2011) it was recognized that MSE needs to be widely applied to implement the Precautionary Approach for tuna fisheries management. Therefore, a Joint MSE Technical Working Group was initially created to work electronically and a workshop was organized in 2016. This workshop comprised five themes: 1) Development of a dialogue with stakeholders; 2) Conditioning of Operating Models; 3) Computational aspects; 4) Global albacore case study; and 5) Dissemination.

b. Capacity building workshops and dialogue initiatives

The Common Oceans ABNJ Tuna Project[64], in collaboration with other international organizations (Food and Agriculture Organization of the United Nations (FAO), World Wide Fund for Nature (WWF) and International Seafood Sustainability Foundation (ISSF)), has organized a series of workshops to improve the understanding of better management systems for the shared tuna stocks. These workshops have specifically aimed at familiarising fisheries managers from developing States with the concepts of HSs to participate more fully in the adoption of HSs and the MSE process. These workshops have had a number of coincident specific objectives, structure and methodology. For example, all workshops have been inclusive and have requested the active participation of stakeholders in simulated management exercises and games. Five capacity building workshops have been held to date targeting officials from different t-RFMOs (ABNJ 2014; ABNJ 2016): 2014, Sri Lanka (IOTC); 2015, Panama (IATTC); 2016, Ghana (ICCAT), 2017, Sri Lanka (IOTC); 2017, Bali (WCPFC), and January 2018 in Senegal (ICCAT).

c. Marine Stewardship Council (MSC)

The MSC is an international non-profit organization addressing the problem of unsustainable fishing, and safeguarding seafood supplies for the future through certification of sustainable fisheries. MSC, under its sustainable fisheries evaluation scheme (in its first principle of evaluation), explicitly requests the adoption of limit and target reference points, the existence of a robust and precautionary harvest strategy and

[64] www.commonoceans.org/

well defined and effective HCRs. The interpretation of these criteria has been subjected to debate but it has represented an economic incentive for stakeholders to accelerate the implementation of HCRs and the development of MSE in tuna fisheries.

4.1.2 Sub-task 3.2: Provide an overview of operating models, HCRs (management procedures) and performance statistics used

4.1.2.1 Sub-task 3.2.1. Operating Models (OMs)

OMs provide mathematical representations of the system that is being managed (Rademayer et al., 2007). The impact of fisheries management is evaluated before implementation in the OMs when using Management Strategy Evaluation (MSE) (see Figure 9; Punt et al., 2016). The OMs are considered alternative representations of the "true" dynamics of the stock and aim at covering all the uncertainties inherent to fish and fisheries' dynamics. In some cases, OMs are built and conditioned from stock assessment models which are modified through different weighting of data sources, model specifications and input parameters.

The design of an OM grid aims at covering the most uncertain aspects of fish and fisheries dynamics for the stock. In general, MSE developers identify the most uncertain parameters and processes and assign a range of values from very low to very high, thus building ranges for the most important parameters and when using in a factorial design, these contribute to building the called "uncertainty grid". In general, there is agreement that most uncertain parameters in tuna stock assessments are steepness, natural mortality, migration, mixing, catchability dynamics and growth. Therefore, alternatives for these values are common to many MSE developments. In the next section we review which sources of uncertainty are considered in different stocks MSE across tuna RFMOs.

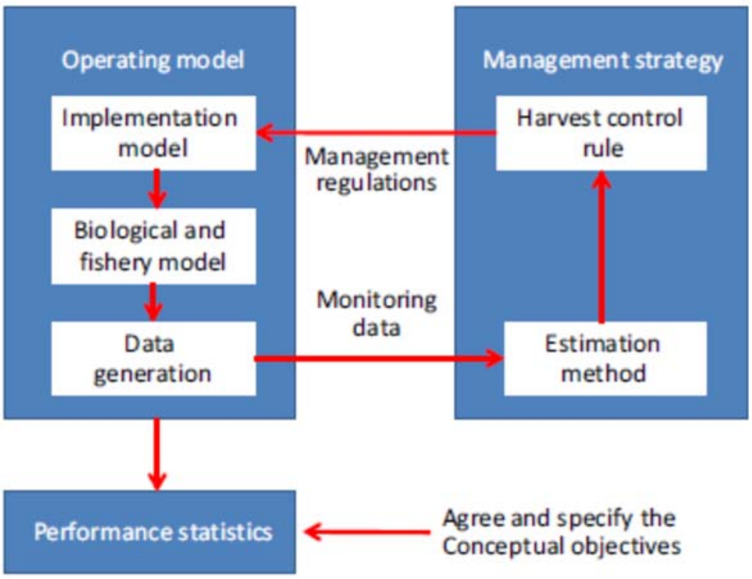

Figure 15: Conceptual overview of the management strategy evaluation modelling process (source: Punt et al., 2016).

In ICCAT, the MSE has made notable progress in the case of North Atlantic albacore and East Atlantic bluefin tuna. For the first, the OMs used to evaluate HCRs and RPs consists on 132 models derived from the 2013 stock assessment using the fully structured model Multifan-CL (ICCAT, 2013). Using 10 scenarios with alternatives on data sources and natural mortality from the 2013 stock assessment, a grid of 132 OMs was built exploring additional alternatives for natural mortality (3 options), for the steepness parameter (4 options) and temporal catchability for longline fleets (2 options) (Merino et al., 2017a). The 132 scenarios result from the 10 initial OMs multiplied by 3 mortality options and 4 steepness options plus another 12 scenarios agreed by the albacore working group with dynamic catchability.

In the case of bluefin, several initiatives have developed OMs with alternative structures (Carruthers and Butterworth 2017; Kerr et al., 2017; Morse et al., 2017). In order to test alternative MPs for Atlantic bluefin, 36 reference case and 4 sensitivity test OMs have been developed (Carruthers and Butterworth 2017). The grid of OMs is built using ranges for recruitment dynamics (high, moderate and low), recent trajectory of abundance (3 options), 2 mixing scenarios, 2 natural mortality rate scenarios and age at maturity (2 options). The fitted reference OMs span a wide range of estimates for stock status and productivity (Carruthers and Butterworth, 2017). In the most recent developments, the Atlantic bluefin OMs consist on two regions with different options for biological parameters (including mixing). However, the final set of OMs for the bluefin MSE are yet to be agreed.

In IOTC, MSE has progressed for albacore, bigeye, yellowfin and skipjack tunas. The stock assessments for this stocks are carried out using Stok Synthesis (SS3) and the uncertainty grids considered in the assessments have been the basis to build the OMs of the four stocks. With regards to albacore, the uncertainties concerning structural elements of the model formulation were considered key and they were used as the basis for the grid of OMs. The grid was built using feasible values for a number of assumptions and fixed parameters in the population model (Mosqueira, 2016). The grid of Indian Ocean albacore incorporates the main sources uncertainty identified in the estimation of population trajectories and dynamics. The factors considered in the structural uncertainty grid are seven: natural mortality (5 options), variance of the recruitment deviates (2 options), steepness (3 options), coefficient of variation of CPUE indices (4 options), effective sampling size of each length data point (3 options), catchability trends in the CPUE of longline fleets (3 options) and the form of the selectivity curve for longline fleets (2 options). The population models obtained from the complete grid of OMs included a high proportion of unrealistic estimates and plausibility criteria that were used for the final selection. The unrealistic values include estimates of MSY out of any realistic value, for example 3 orders of magnitude higher than historical maximum catch. After filtering, a total of 665 model runs were selected as part of the base case OM grid (Mosqueira, 2016).

A simulation model of the ***Indian Ocean skipjack*** tuna fishery was developed for the evaluation of alternative fisheries management procedures (Bentley and Adam, 2015; Bentley and Adam, 2016). The model partitions the population by region (South-West, North-West, Maldives and East), age and size and the fishery by region and gear (purse seine, pole-and-line, gill net, others). Prior probability distributions and sensitivity ranges are defined for a series of model parameters for use in conditioning and robustness testing. These parameters include weight-length coefficients, inflection point of the maturity ogive, steepness of the maturity ogive, proportion of mature fish spawning by quarter, virgin recruitment, steepness of the stock-recruitment relationship, standard deviation of stock-recruitment deviations from the stock recruitment relationship, proportion of total recruits by region, mean length of fish at the end of the first quarter, standard deviation of the length of fish at the end of the first quarter, instantaneous rate of natural mortality at a weight of 1kg, exponent of weight to natural mortality rate function, mean size of fish in their first quarter, standard deviation of fish in their first quarter, maximum growth rate, asymptotic length, growth variability and the proportion of fish moving between regions.

The ***Indian Ocean yellowfin*** MSE has maintained a closed relationship between the stock assessment modelling and the conditioning of OMs. The OMs were conditioned from the latest stock assessment models using SS3. The reference set OM is an ensemble of assessment models that includes several alternative plausible assumptions. In the approach to uncertainty quantification emphasis is on model structural uncertainty and stochastic recruitment uncertainty. The reference set of OM consists of an ensemble of

216 models, each differing from the base case conditioned from the stock assessment in six modelling options. The reference set OM is built with alternatives for steepness (3 options), natural mortality (3 options), tag data weighting (3 options), catchability dynamics (2 options), methods for CPUE standardization (2 options) and tag-mixing periods (2 options) (Kolody and Jumppanen, 2017).

IOTC bigeye MSE followed the same approach used with yellowfin. The 2013 assessment of Indian Ocean bigeye using SS3 (Langley, 2013) was compatible with the development of an ensemble OM configuration because a grid-based approach was used to explore alternative assumptions and their interactions (Kolody and Jumppanen, 2016). The 18 SS models' ensemble currently used for candidate MP evaluation include a factorial grid of three dimensions: steepness parameter (3 options), natural mortality (3 options) and temporal catchability trend (2 options).

In the case of the CCSBT, a grid of 432 OMs is used to evaluate the performance of the management procedure in place for this stock (CCSBT 2017a). The model is a specifically tailored age structured model that considers two regions and is fitted using fishery data and fishery independent abundance series and genetic information. A weighted set of reference operating models represents the most important uncertainties in the model structure, parameters, and data. These include alternative values for steepness (3 options), natural mortality rate at age 0 (4 options), natural mortality at age 10 (3 options), weighting of CPUE series (2 options), CPUE age range (2 options) and the power parameter on fecundity for allometric relationship between fecundity and reproductive success (3 options).

The MSE for WCPFC is under development (WCPFC, 2017h) and is addressing issues generic to all stocks. The OMs rely on the fully integrated stock assessment model Multifan-CL which is the model currently in use to provide scientific advice on tuna stocks status in the WCPFC. The current features available in Multifan-CL and the developments planned for the future (e.g. the generation of pseudo-data) are considered to be an appropriate tool for developing the OMs. As in other RFMOs, the approach used by WCPFC to capture uncertainty in the assessment results through uncertainty grids provide a starting point for capturing key uncertainties in the OMs.

In the IATTC, methods to conduct MSE using the SS3 general stock assessment program are being developed (Maunder 2014; IATTC 2016b; IATTC 2017b). MSE has supported the adoption of limit and target reference points for Eastern Pacific Ocean tropical tuna stocks (IATTC 2015; IATTC 2016a; IATTC 2017a; IATTC 2017b). In the case of bigeye, a MSE framework was built upon the results of the stock assessment made using SS3. The key structural sources of uncertainty include steepness (3 options), the average size of the oldest fish (3 options), natural mortality at age 0 (3 options) and the weighting assigned to the size composition data (2 options) (IATTC 2017b).

In the case of Pacific bluefin tuna, one MSE implementation has been developed using SS3 as the operating model. Samples from the posterior distribution of a Bayesian application of SS are used to represent the possible states of nature, allowing for uncertainty in parameters used in typical stock assessment models. Priors can be put on fixed model parameters as well as on estimated ones, to more accurately represent uncertainty. The analysis is the first step in developing a full MSE procedure to support management advice and currently considers uncertainty on natural mortality, steepness, growth and length composition data (Maunder 2014).

A summary of the information on the models used and the main sources of uncertainty considered are shown in the table below.

Table 10: Summary of the information on the models used and the main sources of uncertainty considered.

RFMO	Stock	Model	Nº of OM	Sources of uncertainty
ICCAT	North Atlantic albacore	Multifan CL	132	Steepness, mortality, catchability, data
	East Altantic bluefin	Ad hoc	36 (+4)	Recruitment, abundance, mixing, mortality and age at maturity
IOTC	Skipjack	Ad hoc	1	weight-length, maturity, steepness, maturity, virgin recruitment, standard deviation of stock-recruitment deviations, proportion of total recruits by region, mean length of fish, standard deviation of the length of fish at the end of the first quarter, instantaneous rate of natural mortality at a weight of 1kg, exponent of weight to natural mortality rate function, mean size of fish in their first quarter, standard deviation of fish in their first quarter, maximum growth rate, asymptotic length, growth variability and the proportion of fish moving between regions.
	Bigeye	SS3	18	steepness parameter (3 options), natural mortality (3 options) and temporal catchability trend
	Yellowfin	SS3	216	Steepness, mortality, tag data weighting, catchability dynamics, methods for CPUE standardization and tag-mixing periods
	Albacore	SS3	665	Mortality, variance of rec deviates, steepness, CV of CPUE, sampling size, catchability, selectivity
CCSBT	Southern bluefin	Ad hoc	432	Steepness, mortality, weighting of CPUE series, CPUE age range and the power parameter on fecundity for allometric relationship
WCPFC	Tropicals and albacore	Multifan CL	-	Under discussion
IATTC	Tropicals and albacore	SS3		Steepness, size of the oldest fish, mortality at age 0 and the weighting assigned to the size composition data

4.1.2.2 Sub-task 3.2.2. HCRs, MPs and performance statistics used.

MPs represent the series of human actions undertaken to monitor the stock, assess its state, make management decisions and implement the management advice. In MSE, the MP component describes how the true dynamics underlying fisheries exploitation are represented through stock assessment and controlled through fisheries management. Related outputs are then fed into a HCR or decision framework to provide recommendations and management actions (Rademayer et al., 2007).

Ideally, once the type of HCR is agreed, a fine tuning exercise is can help the election of a particular HCR in order to achieve a specific management objective, including exact probability and timeframes of achieving this probability. However, the current management objectives (with the exception of CCSBT) do not specifically define one probability and a timeframe. Most management objectives define a minimum level of probability of stock status and not a specific value. For example, ICCAT defines the management objective for North Atlantic albacore as of achieving at least a 60% probability of being in the green quadrant of the Kobe plot and not a specific value. Therefore, the tuning of MP is a step that is currently not being fully developed across tuna RFMOs except for CCSBT.

HCRs and MPs under investigation across tuna RFMOs

In ICCAT, the MPs tested for North Atlantic albacore contain (i) an observation error model (OEM), (ii) a simple biomass production model and (iii) a model-based HCR. The OEM reflects the uncertainties between the actual dynamics of the resource and perceptions arising from observations and assumptions by modelling the differences between the measured value of a resource index and the actual value in the OM (Kell and Mosqueira, 2016). A procedure to simulate CPUE from the OM and compare the properties of the simulated to those used in the assessment was proposed for this stock (Merino et al., 2017b; Merino et al., 2017c). One of the options explored simulates fleet specific CPUE indices using each fleet's selectivity pattern, catch and effort, and their properties are compared with the abundance indices used in the 2016 assessment of this stock. The indices generated are used to fit the biomass dynamic model "*mpb*" (Kell, 2016), which was used in the 2016 stock assessment of North Atlantic albacore. The fits are made using the same specifications and modelling choices as in 2016. Harvest Control Rules describe how harvest is automatically controlled by management in relation to the state of some indicator of stock status (ISSF, 2013).

In the case of North Atlantic albacore, when the stock level is above the precautionary threshold (B_{THRESH}), the fishing mortality applied to the stock is the target fishing mortality (F_{TAR}). When the stock falls below B_{THRESH} but above the LRP, the fishing mortality will be lower than F_{TAR}. When the stock falls below LRP, the remedial management action will be determined by F_{MIN}, which for North Atlantic albacore was fixed at $0.1*F_{MSY}$ As part of a HCR, threshold and LRPs are intended to restrict harvesting to avoid highly undesirable states of the stock, such as the impairment of the recruitment, from which recovery could be irreversible or slowly reversible. The fishing mortality applied when the stock is evaluated to be above the B_{LIM} but below B_{THRESH} is determined by the line that connects the coordinates (B_{LIM}, F_{MIN}) and (B_{THRESH}, F_{TAR}), see Figure 16 for a generic linear model based HCR such as one of many tested for North Atlantic albacore and does not correspond to that adopted by ICCAT. In addition, options for the sequential reduction or increase of catch limits above certain limits was also evaluated for this stock (ICCAT, 2017b).

At this moment, the MPs have not been tuned to achieve specific management objectives. Tuning is the process on which the MP coordinates are specifically estimated to achieve management goals. In ICCAT albacore, the management objective is to maintain the stock above certain level and not one level specifically.

A range of F_{TAR} from 0.6 to 1 F_{MSY} and a range of B_{THRESH} of 0.6-1 of B_{MSY} were evaluated for the North Atlantic albacore (ICCAT, 2017b).

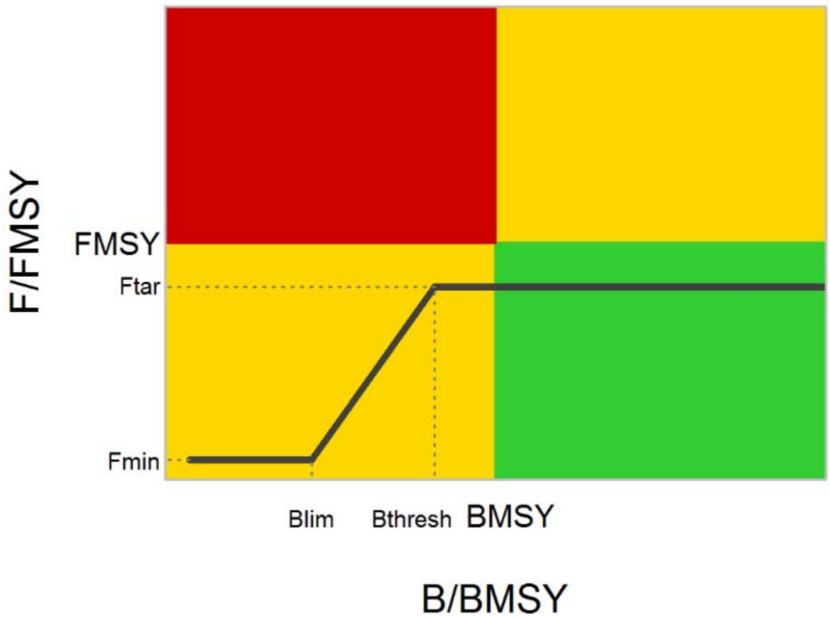

Figure 16: Generic type of HCR evaluated for North Atlantic albacore (Merino et al., 2016).

For Atlantic bluefin stocks, it was decided to initially explore management procedures that are based on empirical indicators of stock abundance rather than on model-based indicators of stock abundance as was the case for the northern albacore MSE. An initial set of relative abundance indices (three for the west and four for the east) were selected as possible candidates to be examined as part of the management procedures to be tested for the setting of future TACs (ICCAT, 2017b). However, the initial set of MPs will be extended and also evaluated over the course of 2018 to be reported in the 2018 Commission meeting (ICCAT, 2017b). In the 2018 ICCAT bluefin tuna and North Atlantic swordfish MSE meeting (Madrid, Spain), the MPs considered were initially evaluated. However, additional MPs are still to be designed, finalized and evaluated (ICCAT, 2018).

In IOTC, empirical and model-based MPs are being evaluated. For example, for ***albacore***, one MP is based on a stock assessment model, and another is driven by changes in the CPUE series. The first MP uses the results of a biomass dynamic stock assessment to inform the harvest control rule on stock status. A decision is then made on changes to the total allowable catch levels from those set on the previous year of application of the procedure. Two sources of information are generated to feed the assessment model: total catch in the fishery and an index of abundance. A Pella-Tomlinson biomass dynamics model is then fit to the data. The estimates of both depletion level, as the ratio of the spawning biomass in the last year of data to that in the first year, and of the F-at-MSY reference point, are then passed on to the harvest control rule (Figure 17, catch based 40:10 HCR where. 40:10 refers to the two biomass coordinates that delimit the HCR. At 40% of depletion catch (in Figure 17) or fishing mortality will start to be reduced. At 10% catch or fishing mortality will be reduced to a minimum.

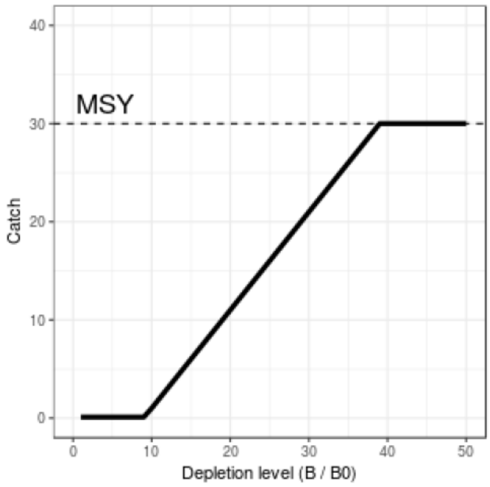

Figure 17. Catch based 40:10 type Harvest Control Rule included in the IOTC albacore MSE.

For the CPUE-trend based indicator, the only source of information for the HCR is the index of abundance provided by the generated CPUE series. The HCR takes the form TAC_t= TAC_{t+1}*(1+ƛ*b) where ƛ is a response multiplier and b is the slope of the linear model fit to the last *ny* years of data (Figure 18).

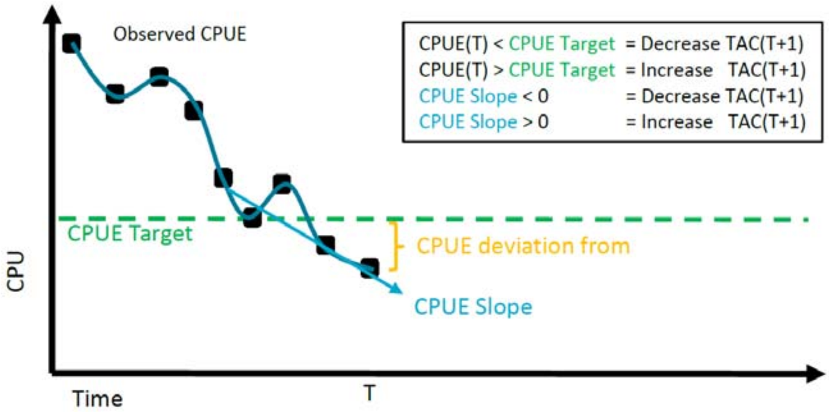

Figure 18. Diagram of the CPUE-based HCR implemented for IOTC albacore (Kolody and Jumppanen, 2016).

While the emphasis of the IOTC's yellowfin and bigeye has been to develop OMs, four types of HCRs have also been tested for these two stocks (Kolody and Jumppanen, 2016; Kolody and Jumppanen 2017). These include a catch based 40:10 type HCR coupled with a surplus production model, an F-based 40:10 type HCR coupled with a surplus production model (Figure 19), a CPUE based HCR that aims for a desirable CPUE target by increasing or decreasing the TAC, depending whether CPUE is above or below the target and whether it is trending up or down (equal to the one tested for albacore, Figure 17), and a constant catch/effort. For all the four HCRs, the projection component of the OM simulates data that are consistent with the OM conditioning assumptions, and these data are interpreted by the MP to produce the Total Allowable Catch (TAC), subject to "realistic" data and analytical errors through the HCRs (Figure 19).

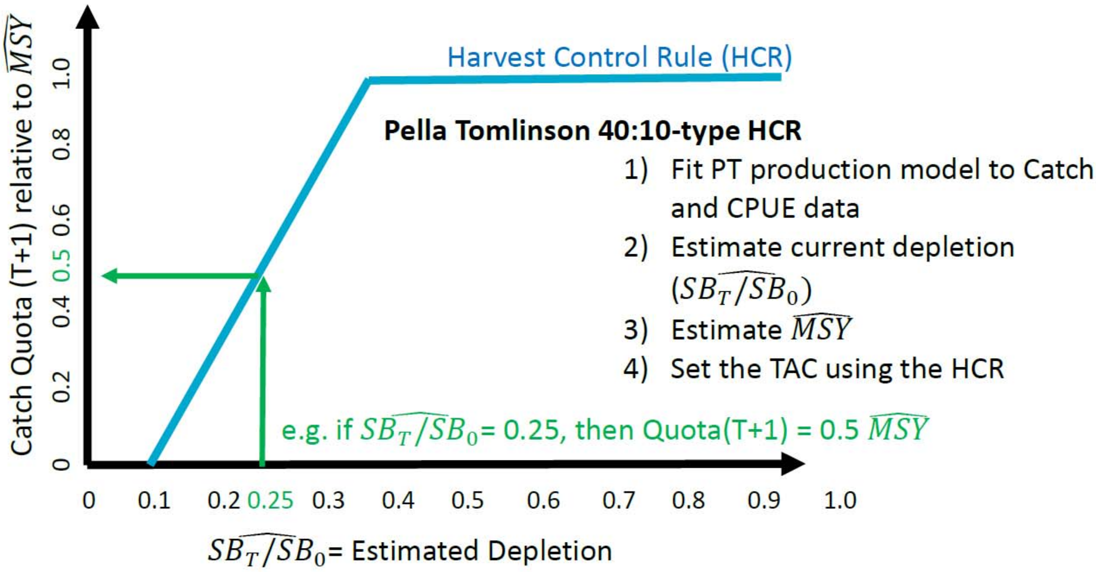

Figure 19. Schematic representation of the PT 40:10 type MP category (Kolody and Jumppanen, 2016).

The HCR shown in Figure 13 represents catch reductions relative to MSY as a response to different estimated stock levels. Identical HCRs are being evaluated that consider fishing mortality reductions instead.

Additional optional control parameters can be imposed on any MP in the MSE software developed for IOTC bigeye and yellowfin e.g., stability clauses, constrained catch/effort variations, total limits to catch.

In the case of IOTC skipjack, a series of additional MP were developed before the adoption of a HCR in 2016 (Bentley and Adam, 2016; IOTC, 2016a). The classes of MP considered for this stock are comparable to the model based and empirical HCRs evaluated for bigeye and yellowfin. In the case of skipjack, one additional type of MP was evaluated: The FRange class. FRange class seeks to maintain the fishing mortality rate within a defined range. At periodic intervals the fishing mortality is estimated and compared to the adopted range and is consequently reduced or increased if it is not within the range.

In the CCSBT, from 2002 to 2011 an MP that would determine the global catch limits was developed. In that time the CCSBT tested a variety of candidate MPs. The MPs tested in the CCSBT combine model based stock status estimations with information from two abundance indices. The agreed MP, known as the "Bali procedure", combines two MPs in one HCR. One of them uses CPUE and one aerial survey index while the other uses CPUE series and a Biomass Random Effect (BREM) stock assessment model. Also, the MP specifies the procedure to standardize the CPUE and other abundance indices. One important aspect of the MP developed in the CCSBT is that it is tuned to achieve very specific management objectives (70% of probability of achieving 20% SB_0) and in the constraints to the catch limit variation and allocation (CCSBT, 2013).

The CCSBT is currently in the process of developing a new MP to guide setting quotas for 2021 and onwards. The new MP will take into account changes in data availability: in particular, changing the recruitment monitoring series from an aerial survey of juveniles to a juvenile gene tag/recapture program. Besides, consideration is being given to the inclusion of additional data sources while maintaining the conceptual underpinning of the "Bali procedure", i.e. the combination of an index of recruitment and the harvested component or fish stock. However, a wider range of MPs can eventually be explored, including the use of a biomass production model instead of the currently used BREM (CCSBT, 2017a).

In the IATTC, the MSE research has used estimates from the OMs with error to evaluate the performance of a linear model based HCR with $F_{TAR}=F_{MSY}$ (Maunder, 2014; IATTC, 2016b; IATTC, 2016a). IATTC has designed a roadmap to develop MSE that considers further identifying candidate management strategies and coding these as management procedures (See IATTC document SAC-07-07h).

In the WCPFC, the consultation has consisted on alternative proposals to establish target and limit RPs towards designing HCR (WCPFC, 2017a; WCPFC, 2017d; WCPFC, 2017f; and WCPFC, 2017g). The technical development of MPs has consisted on developing the methodology to estimate stock status and defining a decision framework (WCPFC, 2017g). The MP can be based on empirical and model based methods. After consultation and using the skipjack stock status as example, it was decided that empirical estimation methods (CPUE trends) would be unlikely to work well in instances where purse seine fisheries account for a large proportion of catch because purse seine CPUE is difficult to interpret and unlikely to provide a reliable signal to the HCR. Therefore, for skipjack, research has focused on a model-based approach. Two alternative modelling platforms are being used to estimating stock status for WCPO skipjack. The first is based on the stock assessment software a4a that has been developed as part of the FLR project[65], to which an age-specific CPUE and a tag based index have been fitted. The second approach attempted to trim down the current MULTIFAN-CL assessment model to produce a simplified and faster running model.

In the case of North Pacific albacore, common efforts between WCPFC and IATTC scientific bodies have attempted to compare the current stock assessment with an MP comprised of simple harvest rates applied to two CPUE-based indices of abundance, one for spawners and one for recruits and a simple catch based MP (IATTC, 2016b). However, the MSE for North Pacific albacore is still very preliminary and further developments are scheduled including empirical and model based MPs (WCPFC, 2015b; IATTC, 2016b).

Performance statistics used to evaluate MPs across tuna RFMOs

In MSE, performance statistics are used to represent management objectives and to summarize the ability of MPs to achieve them. As the MSE process evolves, performance statistics can help refining the relative weighting of management objectives (Punt et al., 2016). Management objectives are often generic (e.g. catch as much as possible in a stable manner, reduce risks and ensure sustainability), and these need to be converted into operational objectives expressed in terms of the values of performance statistics (Punt et al, 2016). The conversion of conceptual objectives into operational objectives is discussed between RFMOs scientific providers and stakeholders (including policy makers) through specific meetings and dedicated workshops (e.g. ICCAT's Panel 2, Standing Working Group between Scientists and Managers (SWGSM); IOTC's Management Procedure Dialogue (MPD) and the Technical Committee for Management Procedures (TCMP); WCPFC Management Objective and Harvest Strategy workshops (MOW and HSW) and CCSBT Management Procedure Workshop (MPW)).

ICCAT Commission through its Panel 2 and the SWGSM, have established very specific performance statistics for the evaluation of HCRs of North Atlantic albacore. These consist on 15 stock status, safety, catch and stability indicators and guidelines for their specific calculation (Figure 20).

[65] http://flr-project.org

PERFORMANCE INDICATORS AND ASSOCIATED STATISTICS	UNIT OF MEASUREMENT	TYPE OF METRICS
Status		
1.1 Minimum spawner biomass relative to B_{MSY}	B/ B_{MSY}	Minimum over [x] years
1.2 Mean spawner biomass relative to B_{MSY}[1]	B/ B_{MSY}	Geometric mean over [x] years
1.3 Mean fishing mortality relative to F_{MSY}	F/ F_{MSY}	Geometric mean over [x] years
1.4 Probability of being in the Kobe green quadrant	B, F	Proportion of years that $B \geq B_{MSY}$ & $F \leq F_{MSY}$
1.5 Probability of being in the Kobe red quadrant[2]	B, F	Proportion of years that $B \leq B_{MSY}$ & $F \geq F_{MSY}$
2 **Safety**		
2.1 Probability that spawner biomass is above B_{lim} ($0.4B_{MSY}$)[3]	B/ B_{MSY}	Proportion of years that $B > B_{lim}$
2.2 Probability of $B_{lim} < B < B_{thresh}$	B/ B_{MSY}	Proportion of years that $B_{lim} < B < B_{thresh}$
3 **Yield**		
3.1 Mean catch – short term	Catch	Mean over 1-3 years
3.2 Mean catch – medium term	Catch	Mean over 5-10 years
3.3 Mean catch – long term	Catch	Mean in 15 and 30 years
4 **Stability**		
4.1 Mean absolute proportional change in catch	Catch (C)	Mean over [x] years of $\|(C_n - C_{n-1}/ C_{n-1}\|$
4.2 Variance in catch	Catch (C)	Variance over [x] years
4.3 Probability of shutdown	TAC	Proportion of years that TAC=0
4.4 Probability of TAC change over a certain level[4]	TAC	Proportion of management cycles when the ratio of change[5] $(TAC_n - TAC_{n-1})/TAC_{n-1} > X\%$
4.5 Maximum amount of TAC change between management periods	TAC	Maximum ratio of change[6]

Figure 20: Performance indicators and associated statistics requested for the evaluation of HCRs for North Atlantic albacore (ICCAT, 2016a).

Currently, ICCAT has requested the development of comparable performance statistics for the evaluation of MPs for East Atlantic and Mediterranean bluefin stock (ICCAT, 2017b; ICCAT, 2017c; ICCAT, 2017d).

In IOTC, the SC has developed a series of candidate performance statistics and types of management objectives for the evaluation of MPs for all stocks (IOTC, 2015a; IOTC, 2016c), which include status, safety, yield, abundance and stability indicators (Figure 21).

Candidate performance statistics	Performance measure/s	Summary statistic
Status: maximize probability of maintaining stock in the Kobe green zone		
Mean spawner biomass relative to unfished	SB/SB_0	Geometric mean over years
Minimum spawner biomass relative to unfished	SB/SB_0	Minimum over years
Mean spawner biomass relative to B_{MSY}	SB/SB_{MSY}	Geometric mean over years
Mean fishing mortality relative to target	F/F_{targ}	Geometric mean over years
Mean fishing mortality relative to F_{MSY}	F/F_{MSY}	Geometric mean over years
Probability of being in Kobe green quadrant	SB, F	Proportion of years that $SB \geq SB_{targ}$ & $F \leq F_{targ}$
Probability of being in Kobe red quadrant	SB, F	Proportion of years that $SB < SB_{targ}$ & $F > F_{targ}$
Safety: maximize the probability of the stock remaining above the biomass limit		
Probability that spawner biomass is above 20% of SB_0	SB	Proportion of years that $SB > 0.2SB_0$
Yield: maximize catches across regions and gears		
Mean catch	C	Mean over years
Mean catch by region and/or gear	C	Mean over years
Mean proportion of MSY	C/MSY	Mean over years
Abundance: maximize catch rates to enhance fishery profitability		
Mean catch rates by region and gear	A	Geometric mean over years
Stability: maximise stability in catches to reduce commercial uncertainty		
Mean absolute proportional change in catch	C	Mean over years of absolute (C_t / C_{t-1})
Variance in catch	C	Variance over years
Variance in fishing mortality	F	Variance over years
Probability of fishery shutdown	C	Proportion of years that C = 0

Figure 21: Candidate performance statistics and type of management objectives for the evaluation of management procedures (IOTC, 2016c).

In the IATTC, the Scientific Advisory Council has evaluated RPs and HCRs using a series of quantities to determine MP performance (IATTC, 2015). These include: (1) the frequency with which the fishing mortality drops below $F_{50\%R_0}$ (being $SSB_{50\%R0}$, a proposed criterion to establish LRPs, where R_0 is the recruitment at pristine level) (2) the frequency with which the spawning biomass depletion level drops below the LRP of $SB_{50\%R0}$ (3) the probability (uses frequency as proxy) that recruitment drops below 50% R_0 and (4) the average catch and coefficient of variation (CV) of catch from the multiple simulations. In the particular case of dolphinfish (*Coryphaena hippurus*), the SAC used total catch during the projected years (2015-2019) and the spawning biomass ratio (SBR; the ratio of the spawning biomass at that time to that of the unfished stock) for the last year in the projection (2019), as the performance statistics (IATTC, 2016c).

In the CCSBT, the new MP for SBT is currently being evaluated using the same performance statistics used in the 2011 evaluation (Davies et al., 2018). The performance measures include:

- Catch performance measures:
  - Average short term (10 year) and long term catch
  - Measure of TAC smoothness: average annual catch variability over 25 years
  - Maximum TAC decrease
  - Proportion of occurrence where initial 2 TAC changes are up and then down
  - Proportion of occurrence where initial 4 TAC changes are set up then down
  - Proportion of runs with TAC above the current catch at the tuning year.
  - Lower 10^{th} percentile in year t, e.g. in 10 years
- SSB performance:
  - SSB in medium term relative to SSB_0
  - Spawning biomass in short term relative to current
  - Spawning biomass in medium term relative to current
  - Minimum spawning biomass relative to current
  - Proportion of runs above the current biomass at the tuning year
  - Appearance that catch continues to increase while SSB stays low (ratio of catch/SSB in 2030 for a) lower 10th, b) median, c) upper 90th percentile)
  - SSB lower (10^{th}) percentile continuing to increase (no decline in period 2013-2035)
  - Lower 10th SSB percentile in year t, e.g. in 10 years
- CPUE performance:
  - CPUE relative to CPUE in the short term.

In the WCPFC, during its 2^{nd} Management Objectives Workshops (MOW) (WCPFC, 2013), a "strawman" was considered, i.e. a list of candidate management objectives and performance indicators for each major fishery. Four types of candidate indicators suggested to measure progress towards achieving the management objectives for five fisheries/stocks:

- *Biological indicators* such as fishing mortality and biomass are used at the Commission as an expression of stock status to inform decision-making and assess progress towards objectives such as optimum utilization. Biological indicators may be used to measure performance relative to an 'economic' objective – e.g. biomass as an indicator of economic yield. These are likely to provide the indicators (and basis of reference points) that will inform harvest control rules.
- *Economic indicators* can be used to monitor the economic performance of a fishery. For example, they can track progress towards the maximum economic yield, or measure whether domestic development is occurring at the rate required for employment and economic development in developing States in accordance with Article 30 2(a). Useful indicators include resource rent or economic profits, CPUE, and contributions from fisheries to the Gross Domestic Product (GDP).
- *Social indicators* are of considerable importance to coastal communities, but setting operational social objectives and indicators is challenging. Indicators include

employment in the fisheries and associated sectors, human capacity development, the maintenance of artisanal fisheries and consumption of pelagic fish by coastal communities. These indicators will be useful for monitoring, and where possible, considering the impacts of management decisions.

- *Ecosystem indicators* are at an early stage of development, as are the associated operational management objectives. Trends in bycatch rates and/or ecological community indicators derived from catches, and the biological characteristics of the species (e.g. trophic level) show promise in providing indicators of use for fisheries management.

4.1.3 Sub-task 3.3: Analyze strengths and weaknesses of the process to develop HCRs and of the process to assess HCRs through MSE frameworks within tuna-RFMOs taking into account different factors such as the capacity in third countries (information about the process), multispecies interactions and mixed nature of tuna fisheries

Today, MSE is being developed for single species only, with objectives of maintaining stocks at healthy levels, promoting the successful recovery of overexploited stocks and to evaluate the economic benefits of precautionary management. In order to engage third countries in the MSE process across tuna RFMOs, several initiatives (workshops, capacity building, courses and projects) are being organized. This will help developing new MSE frameworks that consider alternative approaches such as multispecies interactions etc. This section reviews the initiatives used to promote the engagement of third countries and to develop alternative MSE approaches.

All five tuna RFMOs have committed to a path of adopting HS or MP to achieve their general management objectives of high long-term yields whilst maintaining stocks within sustainable limits with high probability, consistent with the PA. The PA seeks to protect fish stocks from fishing practices that may put their long-term viability in jeopardy despite the many unknowns on stocks biology, response to fishing or exact state of exploitation (Garcia, 1996). In practice, the PA requires fisheries management bodies to determine the status of fish stocks relative to target reference points and limit reference points, to predict outcomes of management alternatives for reaching the targets while avoiding the limits, and to characterize the uncertainty in both cases.

In the tuna RFMOs, the MSE process has represented an opportunity to engage scientists and managers view on tuna fisheries stock assessment and management. The adoption of Harvest Strategies has been one condition for the certification of tuna fisheries by the Marine Stewardship Council and this has speeded up the process of setting management objectives, characterizing the uncertainty inherent to fisheries, developing performance measures and evaluating alternative harvest strategies, including harvest control rules.

In general, the MSE process has been led by small team of scientists within each RFMO science providers. However, one key component of the MSE process is the engagement with third countries of the contracting parties, in particular developing ones, within RFMOs. One way to do this have been through specific, manager-orientated workshops. The Common Oceans ABNJ Tuna Project[66] and other organizations (see sub-task 3.1), has organized a series of workshops to improve the understanding of better management systems for the shared tuna stocks. These workshops have specifically aimed at familiarising fisheries managers from developing States with the concepts of harvest strategies in order to allow their full participation in the adoption of harvest strategies and in the whole MSE process. In this section we will briefly review the objectives and outcomes

[66] www.commonoceans.org/

of the ABNJ workshops towards building capacity on MSE in developing countries. Note that the objectives and outcomes of the workshops are very similar.

1) *ABNJ: First Indian Ocean Tuna Management Workshop on Implementation of the Precautionary Approach and Rights-Based Management (22nd – 24th April 2014, Beruwala, Sri Lanka)*

The first tuna RFMO capacity building was held in Sri Lanka (Indian Ocean, IOTC) in 2014 (ABNJ, 2014). The medium-term goal of these workshops was to improve the capacity of developing coastal states to engage in dialogue and negotiations for the implementation of sustainable tuna management through the Indian Ocean Tuna Commission (IOTC). In particular, the first workshop was designed to increase the capacity of Indian Ocean developing coastal states to engage in:

i) Development of Harvest Strategies for Conservation Measures;
ii) Evaluation of their performance against management objectives; and
iii) Understanding their sensitivity and robustness to major sources of uncertainty.

The workshop was positively evaluated by organizers and participants. However, the participants identified a series of topics for improvement that could allow achieving the objectives of these workshops and which include:

i) further development and annotation of material for circulation to participants prior to the workshops;
ii) incorporation of gaming with simple computer simulations to demonstrate key concepts;
iii) greater use of “worked examples” from other RFMOs/fisheries to demonstrate concepts and issues associated with development and implementation;
iv) an increased focus on the policy, management and socio-economic associated with the process of development and implementation.
v) follow up dialogue on HCR, reference points and MSE;
vi) further explanation of the Kobe Matrix and its role in management advice; and
vii) further dialogue on the modelling approach and process for MSE in IOTC.

2) *ABNJ: Workshop on tuna management of Eastern Pacific Ocean coastal states (24th – 25th February 2015, Panama)*

The main objective of this workshop was to create a better understanding of Eastern Pacific Ocean coastal states on the PA, the HCR and MSE for the sustainability of tuna fisheries (ABNJ, 2015). The workshop also aimed at fostering the development of HCR for the EPO tuna fisheries considering the key elements of management for the coastal states pertaining to the G-77 group.

The workshop was organized in two days and covered the following specific topics:

i) International management of fisheries, origins of the precautionary approach, harvest control rules and MSE
ii) Precautionary approach, harvest control rules and MSE
iii) General background to Harvest Strategies and MSE in tuna RFMOs
iv) State of the art of Harvest Strategies in the IATTC

3) *ABNJ: Atlantic Tuna Harvest Strategies Capacity Building (30th-31st August, Accra, Ghana)*

This workshop had the main goal to create a better understanding among Atlantic Ocean States of the PA, HS and MSE for sustainable tuna fisheries (ABNJ 2016). The participants represented a diverse range of roles and experience in ICCAT. The workshop featured an agenda of interaction and dialogue among participants, aimed at providing hands on opportunities to learn harvest strategy concepts and run mock simulations of management strategy evaluations of harvest control rules. Attendees gained an increased understanding of the importance of HSs and significantly increased both their knowledge of HS principles and concepts. Participants expressed:

i) a strong need for Commission assistance for additional resources to enhance in-country training and engagement of managers, fishers and stakeholders,

ii) a strong need to develop national level science expertise to support Commission level HS processes.

iii) the support to a sustainable tuna management enabled by deliberate management strategy evaluation of trade-offs among potentially competing management objectives.

iv) Some concerns relative to the use of English language, which is often a barrier for a number of native French and Spanish speakers, as well as Portuguese.

4) *ABNJ: Indian Ocean Tuna Harvest Strategies Capacity Building (22nd -23rd March, 2017, Colombo, Sri Lanka)*

Similar to previous workshops, the main goal was to create a better understanding among Indian Ocean States of the precautionary approach, HSs and MSE for sustainable tuna fisheries (ABNJ 2017a). The structure of this workshop was very similar to the previous edition of the workshop in Ghana for ICCAT countries. This was also aimed at fostering the interaction and dialogue among participants and aimed at providing hands on opportunities to learn HS concepts and to run simulations of MSE and HCR.

5) *ABNJ: Western and Central Pacific Ocean Tuna Harvest Strategies Capacity Building (1st -2nd August, 2017, Bali, Indonesia)*

The main objective of this workshop was also to create a better understanding among Western and Central Pacific Ocean States of the precautionary approach, HSs and MSE for sustainable tuna fisheries (ABNJ 2017b). The workshop was designed to complement and support the capacity building that has already been delivered to WCPFC members, including through the Management Options Workshop (MOW) (WCPFC, 2015c) process and the work that the Pacific Community (SPC) is about to initiate for the countries in the region. It was specifically aimed at East and Southeast Asian countries but open to all Members, Participating Territories and Cooperating Non-member(s) the WCPFC.

During the workshop attendees gained an increased understanding of the importance of HSs and significantly increased both their knowledge of HS principles and concepts and also their confidence in being able to apply them in the Commission and in-country settings. Participants expressed a desire to learn negotiation skills applicable to use during Commission meetings, and desired more case study examples on how other RFMOs and countries are collecting data and implementing harvest strategies. There was strong support among workshop participants for the use of MSE to consider trade-offs between potentially competing management objectives and facilitate the negotiation of tuna management arrangements.

6) *ABNJ: Atlantic Ocean Tuna Management Workshop (30th -31st January 2018, Dakar, Senegal)*

Another capacity building workshop was held in Dakar, Senegal on 30-31 February 2018 with a goal to create a better understanding among Atlantic Ocean States of the precautionary approach, HSs and MSE for sustainable tuna fisheries (ABNJ 2018a). The workshop was designed to complement and support the capacity building that has already been delivered to ICCAT members in previous workshops and dialogue meetings, as well as upcoming efforts the ICCAT Scientific Committee is about to initiate for countries in the region. Following recommendations from the August 2016 ABNJ workshop in Ghana, it was specifically aimed at Francophile Contracting Party and Cooperator countries of ICCAT.

Attendees learned about the importance of HSs, significantly increasing both their knowledge of HS principles and concepts as well as their confidence in being able to apply them in the Commission and in country settings. Participants expressed a desire for more fishery-specific examples in the workshop content and an additional day of training for both the content and practical exercises. They also desired to learn more about the fundamentals of the Harvest Strategy process.

7) ***ABNJ: Western and Central Pacific Ocean Tuna Management (20th- 21st February, 2018, Nadi, Fiji)***

Another similar capacity building workshop was held in Nadi, Fiji on 20-21 February 2018 with the same goal of contributing to the understanding among Western and Central Pacific Ocean States of the precautionary approach, HSs and MSE for sustainable tuna fisheries (ABNJ, 2018b).

The workshop was designed to complement and support the capacity building that has already been delivered to WCPFC members, including through the Management Options Workshop (MOW) process and the work that the Pacific Community (SPC) is about to initiate for the countries in the region. It was open to all Members, Participating Territories and Cooperating Non-member(s) of the WCPFC.

Attendees gained understanding of the importance of HSs and significantly increased both their knowledge of HS principles and concepts and also their confidence in being able to apply them in Commission and in-country settings. Participants expressed a desire to learn more about the fundamentals of the Harvest Strategy process, particularly MSE. They also desired more fishery-specific examples in the workshop content and a training link to the national level as national interests dictate how countries behave at a regional level.

4.1.4 Sub-task 3.4: Specify what could be defined as next steps to improve the current MSE framework in different tuna-RFMOs

All five tuna RFMOs have plans for evaluating MPs using MSE. In some RFMOs, the roadmap towards adopting MPs is well detailed and in others the process is at its initial states. In this section we briefly review the work plans and provide a short comparison of the process in all tuna RFMOs.

The roadmap of IOTC towards the adoption of MPs for the main Indian Ocean stocks (IOTC, 2017b) is specific to the roles of the scientific working groups, the Technical Committee on Management Procedures (TCMP) and the Commission. The feedback between the three key players of the MSE process is well established and scheduled in yearly meetings of the WG and Scientific Committee, annual meetings of the TCMP and Commission (Table 11). The process in IOTC relies on the technical work and the interaction with the Commission. The IOTC aims at being able to adopt MPs for its most important stocks by 2020.

Table 11: Roadmap towards adoption of MPs in IOTC.

Albacore	2018	2019	2020
WP and SC			
Undertake MSE	■	■	
Evaluate candidate MP	■	■	
TCMP			
Advice to Com on MPs elements that need decision from COM	■	■	■
Commission			
Consider work from subsidiary bodies	■	■	■
Decision and adoption of MP or recommend further MSE		■	■
Skipjack			
WP and SC			
Refine HCR with MSE	■		
Apply HCR to calculate TAC			■
TCMP			
Advice to COM on the application of the HCR	■	■	
Commission			
Provide direction to refine HCR and MSE	■		
Consider work from subsidiary bodies		■	
Yellowfin			
WP and SC			
Undertake MSE	■	■	
Evaluate candidate MP	■	■	
TCMP			
Advice to Com on MPs elements that need decision from COM	■	■	■
Commission			
Consider work from subsidiary bodies	■	■	■
Decision and adoption of MP or recommend further MSE		■	■
Bigeye			
WP and SC			
Undertake MSE	■	■	
Evaluate candidate MP	■	■	
TCMP			
Advice to Com on MPs elements that need decision from COM	■	■	■
Commission			
Consider work from subsidiary bodies	■	■	■
Decision and adoption of MP or recommend further MSE		■	■
Swordfish			
WP and SC			
Develop OM and MSE (preliminary analyses)	■		
Consider recommendations from Com to develop MSE		■	■
TCMP			
Evaluate candidate MP		■	■
Commission			
Consider work from subsidiary bodies		■	■
Decision and adoption of MP or recommend further MSE			■

The roadmap for ICCAT stocks (Die, 2018) clearly lists the steps that the scientific working groups will undertake to provide the evaluations of candidate MPs to the Commission. However, it is not as specific as the IOTC in the interactions between managers and scientists (Table 12). In ICCAT, Panels and the Standing Working Group between Scientists and Managers (SWGSM) are the groups responsible of the feedback between the

Commission and MSE developers. One of the differential aspects of ICCAT's MSE process is that it will be independently evaluated. This evaluation will start in 2018 with the evaluation of North Atlantic albacore MSE and will contribute to the improvement of the process for other stocks. This independent review is not foreseen in other tuna RFMOs where the internal working groups and parties are the "reviewers" of the technical work and the process. In ICCAT, the MSE process is well advanced for North Atlantic albacore and bluefin. In addition, specific calls for tenders are being launched in 2018 to support the development of MSE for swordfish and tropical tuna stocks. A key novel aspect of the tropical tunas MSE is that it will contemplate options for the multispecies management instead of the current single species management framework.

Table 12: Roadmap towards adoption of MPs in ICCAT.

North A. albacore	2018	2019	2020	2021
Finalization of diagnostics and improvement of MP	■			
Re-evaluation of performance of MPs and exceptional circumstances	■			
Development of MPs		■		
Evaluation of MPs		■		
Independent review of MSE process	■			
Bluefin tuna (E-W)				
Development of MPs	■	■		
Evaluation of MPs	■	■		
Independent review of MSE process	■			
Documentation for stakeholders		■		
North A. swordfish				
Development of OM	■			
Development of OM alternatives	■			
Development of MPs		■		
Evaluation of MPs		■		
Independent review of MSE process			■	
Documentation for stakeholders			■	
Tropical tunas				
Development of OM	■			■
Conditioning of OM	■		■	
Development of OM alternatives		■		
Re-evaluation of performance of MPs and exceptional circumstances				■
Development of MPs		■		■
Evaluation of MPs			■	■
Independent review of MSE process			■	■
Documentation for stakeholders				■

In the WCPFC the feedback process is advanced and has made substantial progress in defining management objectives thanks to a number of dialogue workshops (WCPFC, 2012a; WCPFC, 2013; WCPFC, 2014; WCPFC, 2015b; WCPFC, 2015c; WCPFC, 2017g; WCPFC 2017f). The technical work that will support the adoption of MPs in the WCPFC is being developed by its science provide SPC. The plans for developing the technical work and agreeing on the necessary steps towards the adoption of MPs is shown in Table 13.

Table 13: Roadmap towards the adoption of MPs in the WCPFC (Santiago, 2018).

South Pacific albacore	2018	2019	2020	2021
Agree Target RP	■			
Develop HCRs and MSE		■	■	■
Adopt HCR				■
Skipjack				
Develop HCRs and MSE	■	■	■	
Adopt HCR			■	
Bigeye				
Agree Target RP		■		
Performance indicators and monitoring strategy	■			
Develop HCRs and MSE		■	■	■
Adopt HCR				■
Yellowfin				
Agree Target RP		■		
Performance indicators and monitoring strategy	■			
Develop HCRs and MSE		■	■	■
Adopt HCR				■

In the IATTC, the MSE work consists on identifying appropriate HCRs for bigeye and yellowfin but it is still in its early stages. There is a plan for MSE development that will be presented in the 2018 Scientific Advisory Committee (SAC).

The CCSBT has decided to develop a new MP to guide the setting of TACs for 2021 and onwards. The new MP will take into account changes in data availability, in particular, changing the recruitment monitoring series from an aerial survey of juveniles to a juvenile gene tag/recapture program. In the 2017 meeting of the Extended Scientific Committee (ESC), a work plan was agreed (Table 14) towards the adoption of the new MP in 2020 by the Extended Commission (EC). This work plan foresees annual consultations while the candidate MP (CMPs) are evaluated by the Operating Model and Management Procedure technical group (OMMP). The ESC acknowledged the value of having multiple groups tabling CMPs for an iterative process that refines and improves these before the final selection. For this reason, all members are encouraged to contribute to the MP development process.

Table 14: Plan for adoption of a new MP for CCSBT (source: CCSBT, 2017b).

year	month	Meeting	Objective
2018	June	OMMP9	First presentation of CMPs using new Oms
	September	ESC+1day OMMP	Evaluation of refined CMPs
	October	EC	Results on CMP to EC. Consultation with stakeholders. EC confirm or amend recovery objectives
2019	June/July	OMMP10	Recondition the OM and review initial updated versions of CMPs to develop a limited set to put forward to the ESC
	September	ESC+1day OMMP	Review and advice on set of CMPs and interaction with stakeholders
	October	EC	Aim to select and adopt MP
2020	June	Special ESC/EC meeting	Contingency placeholder in case more time is needed to complete evaluation
	September	ESC	Implementation of adopted MP to provide TAC advice for 2021
			Updated assessments including projections with adopted MP
	October	EC	Agree TAC for TAC 2021-2023

Comparative of work plans across tuna RFMO

The MSE process is being developed across tuna RFMOs through specific work plans. Each RFMO features steps that can contribute to the developments elsewhere. For example:

1) Independent expert evaluations: ICCAT's MSE process and the MSE simulation framework used to evaluate HCRs for North Atlantic albacore will be reviewed by independent experts. The review will be extended to all the Atlantic species MSE as they progress. This external review process is not foreseen in other RFMOs: however they all would benefit from that.

2) Periodical revision of the technical work at Working Groups: In the IOTC, the technical work to evaluate MPs is being developed by MSE experts under specific contracts. This work is periodically presented to the Working Party on Methods and each species working party. In ICCAT, this is carried out by scientists from the CPCs (albacore) but also by external experts through dedicated contracts (bluefin, swordfish and tropical stocks). In the WCPFC, IATTC and CCSBT, the MSE work and the evaluation of MPs is carried out by their scientific bodies. In IOTC and ICCAT the technical work is periodically presented and reviewed by the different working groups of the SCRS and SC. This is not the case elsewhere where the work is presented directly in the SC meetings. In terms of the validation of the technical work, the periodical reviews within the working groups of the RFMO could improve (but also delay) the process.

3) The feedback: In ICCAT and CCSBT the feedback between Commission and the technical works has been more productive than elsewhere. In particular, ICCAT's SWDSM and Panel 2 proved very effective in refining the HCRs to be evaluated (ICCAT, 2015b; ICCAT, 2016a; ICCAT, 2017c) for bluefin and North Atlantic albacore. The level of the concepts discussed in these forums is probably more advanced than in the other RFMOs where the dedicated dialogue meetings and workshops are used to define and clarify the MSE concepts to Commissioners. The recently established working groups in IOTC and WCPFC aims at feedbacks that will allow refining the MPs and advancing the process.

4) Multispecies options for tropical stocks: To date, there is no multispecies HCR evaluated within tuna RFMOs, even though ICCAT foresees the development of this type of HCR.

Tropical tunas represent an opportunity to explore options for multi-species management measures, such as limitations on effort or fishing gears. Tropical tuna stocks are often captured together, especially by purse seine fleets using Fish Aggregation Devices (FADs). The use and regulation of FADs is currently been discussed in all tuna RFMOs (ICCAT, 2017c). The MSE that will be developed across tuna RFMOs would allow evaluating options for FAD management, including reductions in number or usage by purse seine fleets.

5 TASK 4: CASE STUDIES

5.1 Sub-task 4.1: Harvesting strategies of the Western Central Pacific Fisheries Commission (WCPFC)

5.1.1 Introduction

This report examines the Harvesting Strategies (HS) that are proposed or being discussed in the Western Central Pacific Fisheries Commission (WCPFC). It starts with an overview of the elements of a harvest strategy, looking into the progress for each of the tuna species in scope for this study and how the harvest strategies relate to the work done under other tuna RFMOs (t-RFMOs). The overview builds upon but does not repeat the analysis and material on limit reference points (LRPs) covered in Task 1 (see section 2). The report then discusses the merits of options considered under each of the HS elements and, where possible, provides an insight on the implications of those options for the EU fleet. The last section of this report considers alternative options for a specific element of HS, the target reference points (TRPs), which is an element of HS with which more progress has been made in WCPFC.

5.1.2 Background

From 2012-2015, a series of discussions took place through the WCPFC's Management Options Workshops on increasing the understanding of management objectives and frameworks, indicators, and reference points. Although the Management Options Workshops were convened as informal meetings of stakeholders and had no formal standing within the Commission, the discussions nevertheless contributed to create a basis for the Commission to later adopt the HS approach outlined in Conservation and Management Measure (CMM) 2014-06[67]. Specifically, it was agreed that:

"the Commission shall develop and implement a harvest strategy approach for each of the key fisheries or stocks under the purview of the Commission […]"

Following the first Management Options Workshop, the Commission agreed at WCPFC9 to a process for future action on Management Objectives (Attachment X of the WCPFC9 Summary Report[68]). An expert group was then arranged to develop a candidate list of management objectives, performance indicators, and reference points (known as the 'strawman proposal') for each of the following major fisheries: tropical longline, purse seine, southern longline, Pacific bluefin tuna, and North Pacific albacore.

Following a series of comments and revisions through the 2013 Scientific Committee and Northern Committee meetings, the strawman proposal was presented to the second Management Options Workshop in 2013 for further refinement. A final draft was presented to the Commission at the WCPFC10, which accepted the strawman proposal and tasked the Scientific Services Provider with further work related to skipjack target reference point (TRP), harvest control rules (HCRs), and performance indicators.

67 https://www.wcpfc.int/doc/cmm-2014-06/conservation-and-management-measures-develop-and-implement-harvest-strategy-approach

68 https://www.wcpfc.int/meetings/9th-regular-session-commission

The Commission also agreed to hold a third Management Options Workshop in 2014. The workshop was convened immediately prior to WCPFC11 and considered a management framework based on a HS approach. While not a direct outfall of the Management Options Workshop process, the harvest strategy conservation and management measure (CMM 2014-06) was later adopted by WCPFC11.

5.1.3 Review of harvest strategy work plans and progress

In 2014, through CMM 2014-06[69], the WCPFC required that a harvest strategy approach was developed and specified that:

"The Commission shall agree a work plan and indicative timeframes to adopt or refine harvest strategies for skipjack, bigeye, yellowfin, South Pacific albacore, Pacific bluefin and northern albacore tuna by no later than the twelfth meeting of the Commission in 2015. This work plan will be subject to review in 2017. The Commission may agree timeframes to adopt harvest strategies for other fisheries or stocks."

Furthermore, paragraph 7 of the CMM established key elements to guide the development of HS:

"Each harvest strategy developed in accordance with this CMM shall, wherever possible and where appropriate, contain the following elements:

- *Defined operational objectives, including timeframes, for the fishery or stock ('management objectives')*
- *Target and limit reference points for each stock ('reference points')*
- *Acceptable levels of risk of not breaching limit reference points ('acceptable levels of risk')*
- *A monitoring strategy using best available information to assess performance against reference points ('monitoring strategy')*
- *Decision rules that aim to achieve the target reference point and aim to avoid the limit reference point ('harvest control rules'), and*
- *An evaluation of the performance of the proposed harvest control rules against management objectives, including risk assessment ('management strategy evaluation')".*

WCPFC had already approved a number of SC recommendations related to limit reference points in 2012, including a hierarchical approach for setting LRP for key species (Table 15). The approach used steepness as a key piece of information to decide on the level for each species and hence, the type of LRP to use. MSY-based indicators were proposed only for species in the most data-rich level (Level 1). Although $SB_{current,F=0}$ is recommended in the approach as one of the options for Levels 2 and 3 in practice, LRPs have been set using either $SB_{current,F=0}$ or $SB_{recent,F=0}$. WCPFC has set the time window to use to describe "recent" as a time period that starts in the last year of the stock assessment and extends back 10 years[70]. Both SB parameters refer to current spawning stock biomass ($SB_{current}$) or average spawning biomass over the recent period (i.e. using recent estimates of recruitment, SB_{recent}) and are calculated in the absence of fishing (F=0). This option is an alternative to the virgin spawning stock biomass (SB_0) so, the LRP could be calculated even if SB_0 is not known. For simplicity, this document uses the notation $SB_{F=0}$ to describe these two parameters although they are not exactly the same. In most cases presented below, SBF=0 refers to $SB_{recent,F=0}$; this is the parameter used to express the LRPs for most species except NPO albacore for which LPR has been expressed in terms of $SB_{current,F=0}$.

[69] Ibid

[70] https://www.wcpfc.int/harvest-strategy#_ftn2

Table 15: Hierarchical approach to identifying the Limit Reference Points for the key target species in the WCPFC[71]. SB: spawning stock biomass, SPR: spawning potential per recruit. F: fishing mortality.

Level	Condition	LRPs
Level 1	A reliable estimate of steepness is available	F_{MSY} and B_{MSY}
Level 2	Steepness is not known well, if at all, but the key biological (natural mortality, maturity) and fishery (selectivity) variables are reasonably well estimated.	$F_{X\%SPR0}$ and either $X\%SB_0$ or $X\%SB_{current,F=0}$
Level 3	The key biological and fishery variables are not well estimated or understood.	$X\%SB_0$ or $X\%SB_{current,F=0}$

In response to the CMM 2014-06, a work plan for adoption of harvest strategies for skipjack, bigeye, yellowfin and South Pacific albacore[72] was agreed at the 12th Regular Session of the Commission in December 2015, and was updated[73] the following year at the 13th Regular Session of the Commission. The Northern Committee is responsible for developing a schedule for Pacific bluefin and northern albacore, and has recommended a precautionary management framework for northern albacore. The sections below cover progress on the overall work plan and individual species and describes agreed or proposed options for each element of the harvest strategy. A summary of progress is also shown in Table 16.

5.1.3.1 Work plan update

As required under CMM 2014-06, the Harvest Strategy Workplan was reviewed and updated in 2017 at the 14th Regular Session of the Commission[74]. The Commission adopted an updated Workplan that included:

Extending the current workplan out to 2021 to allow for the ongoing work towards adoption of harvest strategies for the 4 key stocks;

Reframing the work on bigeye and yellowfin tuna given the recent scientific advice for the status of bigeye from rebuilding to developing a target reference point;

Proposing a dedicated discussion in 2018 by SC and the Commission of management objectives in terms of candidate target reference points for bigeye and yellowfin.

Regarding the need for clarity on whether decisions on harvest strategy elements are "interim". The proposed approach is for the workplan to not state whether a future decision will be interim or otherwise but to simply schedule the decision and then let the Commission determine its interim nature. Hence the references to 'interim' that occurred in 2017 have been removed.

Added note regarding review of skipjack TRP by 2019, according to CMM2015-06.

Commission decision on a south Pacific albacore target reference point deferred until 2018.

[71] ibid

[72] https://www.wcpfc.int/doc/supplcmm-2014-06/work plan-adoption-harvest-strategies-under-cmm-2014-06

[73] https://www.wcpfc.int/doc/supplcmm-2015-04/updated-workplan-harvest-strategies-2016-2019-and-record-outcomes-wcpfc13

[74] https://www.wcpfc.int/system/files/WCPFC14%20Summary%20Report%202017 %20Issued%2016%20March%202018 complete.pdf

5.1.3.1.1 Harvest strategies for skipjack, bigeye, yellowfin, South Pacific albacore

A proposed schedule of actions to adopt or refine HS was provided for skipjack, bigeye, yellowfin and South Pacific albacore tuna as 'an agreed work plan for the adoption of harvest strategies under CMM 2014-06'. This was adopted at the 13th Regular Session of the Commission, in December 2016.

The work plan anticipates that the Commission will agree on initial harvest strategy elements (i.e. LRPs and acceptable levels of risk of breaching a LRP) on a stock-specific basis. All other HS elements, including objectives, TRPs, HCRs and monitoring strategies, may be developed for individual stocks and/or fisheries. As such, the work plan is organised assuming that HS will be initially developed on a stock-specific basis, but the Commission may reorganise it as needed if HS elements are adopted on a fishery-specific basis. Any HCRs developed for fisheries should be designed and evaluated to achieve the TRPs for each of the main stocks caught by that fishery.

Whether harvest strategies should be established at stock or fishery level would depend on the specific element of the HS. For instance, management objectives based on biologically-determined RPs are naturally stock-focused, as too are the acceptable levels of risk associated with exceeding these reference points. Other HS elements – including HCRs, monitoring strategies and management strategy evaluation (MSE) – may be more focused on fishery operations, depending on the associated fisheries. In the case of tropical tunas, for example, where multiple stocks are harvested simultaneously, harvest strategies may be partially determined at stock level (e.g. so that a consistent management objective applies across all fisheries) and partially at the fishery level (e.g. separate HCRs established for purse seine and longline fisheries, responding to the same biological reference points).

The work plan also reflects the different level of progress amongst the four tuna stocks. The sequencing of the harvest strategy elements through the plan has been designed to allow efficient development of HSs. Under the plan, the recording of management objectives and agreement on TRPs and risks of breaching LRPs are planned to be undertaken first, followed by the development of HCRs. MSE is planned to ensure that HCRs meet objectives and TRPs. It is anticipated that MSE and the development of HCRs will be an iterative process.

It is recognised that, for south Pacific albacore and skipjack tuna, the development of TRPs early has been dependent on a substantial body of analysis and modelling to explore the candidate targets suitability and alignment with objectives. Similar preparatory analysis will be required before adoption of TRPs for yellowfin and bigeye tunas. The work plan for bigeye tuna in 2016 differed from the other stocks to reflect its reported stock status, which was below the LRP. However, at WCPCF14 the most recent assessment of bigeye indicates that it is no longer experiencing overfishing nor is considered in an overfished condition. The Commission agreed that that the work plan item for a rebuilding plan for bigeye was no longer considered relevant and was updated accordingly.

Table 16: Progress to date on the development of harvest strategies for skipjack, bigeye, yellowfin and south Pacific albacore tuna. Letters, e.g. (b), refer to harvest strategy elements listed in paragraph 7 of CMM 2014-06 and in the text above (Section 5.1.3). Commission agreements are shown in bold. Further description of the various harvest strategy elements is given in Section 5.1.3.2[75],[76]

Year	Skipjack	Bigeye	Yellowfin	SPO albacore
2015	**Interim TRP agreed by Commission (b) and CMM 2015-06**[77]	Commission tasked SC to determine a biologically reasonable timeframe for rebuilding bigeye tuna	No action	SC provided advice on implications of a range of TRPs
	Commission agreed to a work plan for the adoption of harvest strategies under CMM 2014-06			
2016	Management objectives considered by Commission (a); no progress made on agreement of objectives SC provided advice on a monitoring strategy to assess performance against reference points (d) SC provided advice on a range of performance indicators to evaluate performance of HCRs (d) **Commission agreed interim performance indicators to evaluate HCRs (d)**	Management objectives considered by Commission (a); no progress made on agreement of objectives **Commission agreed timeframes to rebuild stock to limit reference point**	Management objectives considered by Commission (a); no progress made on agreement of objectives	Management objectives considered by Commission (a); no progress made on agreement of objectives SC provided advice on a monitoring strategy to assess performance against reference points (d) SC provided advice on a range of performance indicators to evaluate performance of HCRs (d) Commission tasked SPC/SC to develop interim performance indicators to evaluate HCRs (d)
	Commission agreed on interim maximum acceptable risk level for not breaching the limit reference point (c)			
	Commission agreed to a refined work plan for the adoption of harvest strategies under CMM 2014-06			

Year	Skipjack	Bigeye	Yellowfin	SPO albacore
2017	Develop harvest control rules (e); and Management strategy evaluation (f) SC provided advice on candidate harvest control rules based on agreed reference points (ongoing). Commission consider advice on progress towards harvest control rules (ongoing).	Revised assessment showed stock was no longer overfished or had overfishing. The rebuilding plan was considered no longer relevant	Performance indicators and Monitoring strategy (d). SC provided advice on a range of performance indicators for southern longline fishery to evaluate performance of HCRs. Commission noted performance indicators for southern longline fishery to evaluate HCRs.	Performance indicators and Monitoring strategy (d). SC provided advice on a range of performance indicators for southern longline fishery to evaluate performance of HCRs. Commission noted performance indicators for southern longline fishery to evaluate HCRs.
	Considered management objectives for stocks and fisheries (a).			

5.1.3.1.2 Harvest strategy for north Pacific albacore tuna and Pacific bluefin tuna

At the Sixth Regular Session of the Northern Committee in September 2010, Canada submitted a paper[78] on the development of a precautionary fishery management regime for the northern stocks. In 2011, and building on this paper, the Seventh Regular Session of the Northern Committee agreed to a three-year work programme to develop a precautionary approach based management framework for North Pacific albacore.

In 2013, the Ninth Regular Session of the Northern Committee determined that it was best to delay discussions on the framework until the completion of the 2014 North Pacific albacore stock assessment. In July 2014, the International Scientific Committee (ISC) for Tuna and Tuna-like Species in the North Pacific Ocean concluded that the North Pacific albacore stock was "healthy and that current productivity is sufficient to sustain recent exploitation levels, assuming average historical recruitment in both the short and long term".[79] The ISC also provided further advice regarding candidate limit and target reference points.

At its 13th Regular Session of the Commission in August 2017, the Northern Committee recommended an interim management framework for the North Pacific albacore stock.

[75] https://www.wcpfc.int/system/files/SC13-WCPFC13-07%20Attachment%20N%20Agreed%20WP%20for%20Adoption%20of%20HS.pdf
[76] WCPFC14 Summary Report Attachment L (Issued March 2018)
[77] https://www.wcpfc.int/system/files/CMM%202015-06%20CMM%20on%20a%20Target%20Reference%20point%20for%20WCPO%20Skipjack%20Tuna.pdf
[78] https://www.wcpfc.int/node/2567
[79] https://www.wcpfc.int/node/19202

This replaced the "precautionary management framework for north pacific albacore" adopted at the Eleventh Regular Session. Details of this harvest strategy are described in Section 5.1.3.2.6. In December 2017, the Commission adopted an interim HS for North Pacific albacore fisheries, noting that it modifies and replaces the previously adopted precautionary management framework for North Pacific albacore and is to be recognised as a HS[80].

At the 2017 meeting of the Northern Committee, the US tabled a proposal for a HS for Pacific bluefin tuna which was agreed by the Committee[81]. However, in this case, the harvest strategy primarily focuses on rebuilding the stock given that its size has reached a very low level. The Commission agreed to adopt the HS for Pacific bluefin tuna fisheries at the WCPFC14 meeting in December 2017[82].

5.1.3.2 Harvest strategies: options proposed or under discussion

The preceding section tracks the progress to date in developing or proposing options for the harvest strategy elements for the key stocks. In this section, the agreed or proposed options are described from the information available in WCPFC session reports, working group papers and CMMs. This summary describes the elements that are applicable either across multiple stocks or fisheries (i.e. management objectives and acceptable levels of risk), or that are focused on a single stock or fishery, as shown in Table 17 below.

Table 17: Summary of progress in development of harvest strategies for the six key tuna stocks in the Pacific Ocean.

Element	Skipjack	Bigeye	Yellowfin	SPO albacore	NPO albacore	Pacific bluefin
Management objectives	Candidate management objectives				Yes	Yes
Reference points	LRP & interim TRP	LRP only	LRP only	LRP only	LRP only	Rebuilding targets
Acceptable levels of risk	Yes					
Monitoring strategy	Interim indicators	No	No	No	No	Yes
Harvest control rules	No	No	No	No	Decision rule	Rebuilding HCRs
Management strategy evaluation	No	No	No	No	No	No

80 https://www.wcpfc.int/system/files/WCPFC14%20Summary%20Report%202017_%20Issued%2016%20March%202018_complete.pdf

81 https://www.wcpfc.int/system/files/NC13%20Summary%20Report%20adopted%20-%20Final%20%28Update%29.docx

82 https://www.wcpfc.int/system/files/WCPFC14%20Summary%20Report%202017_%20Issued%2016%20March%202018_complete.pdf

5.1.3.2.1 Harvest strategy elements applicable across multiple stocks or fisheries

5.1.3.2.1.1 Management objectives

Setting management objectives gives a clear direction for the fishery, which benefits fishermen through increased transparency and predictability. When quantified, management objectives can be used to measure how well the HS performs, which helps scientists and managers evaluate the effectiveness of the program. If adopted early in the HS process, management objectives set the vision for the fishery and provide mechanisms for measuring the strategy's success over the long term.

The general objective of the WCPFC is to maintain populations of tunas and tuna-like fishes at levels that will permit maximum sustainable yield (MSY)[83]. At a more specific level, the Commission agreed at WCPFC9 to a process for future action on management objectives, and convened an expert group (i.e. Management Objectives Workgroup; MOW) to develop a candidate list of management objectives, performance indicators, and reference points, known as the 'strawman proposal'. This proposal was accepted at WCPFC10, and the management objectives contained within were considered in discussion at WCPFC13 in 2016. Using the candidate management objectives from the strawman proposal, along with an additional proposal from USA presented at the meeting (for tropical purse seine fishery only), the Small Working Group on Management Objectives drafted a list of management objectives to guide the development of performance indicators for tropical purse seine HCRs.

More recently at WCPFC14, SPC presented an updated list of proposed performance indicators based on the candidate management objectives for the tropical longline fishery[84]. Similarly, SPC presented an updated list of proposed performance indicators based on the candidate management objectives for the southern longline fishery[85]. A summary of candidate management objectives are presented in Table 18. Further details of the associated candidate performance indicators for each management objective are given in section 3.2.2. In addition, a new performance indicator, MSY, was proposed (not adopted) for bigeye and yellowfin tuna. No further discussion was given on this at WCPFC14.

Table 18: Summary of management objectives recorded for the tropical longline, southern longline and tropical purse seine fisheries. Objectives that are the same between the fisheries are merged. Based on WCPFC Circular 2016/34[86] and WCPFC14 Summary Report Attachment K[87].

Type	Tropical longline fishery	Southern longline fishery	Tropical purse seine fishery
Biological	Maintain yellowfin and bigeye (and swordfish) biomass above levels that provide fishery sustainability throughout their range	Maintain albacore, swordfish, yellowfin and bigeye biomass at or above levels that provide stock sustainability throughout their range	Maintain skipjack and yellowfin & bigeye biomass at or above levels that provide fishery sustainability

[83] https://www.wcpfc.int/convention-text
[84] WCPFC14-2017-IP04
[85] WCPFC14-2017-IP03
[86] https://www.wcpfc.int/system/files/MI-WP-03%20BET%20YFT%20Objectives%20indicators%20and%20monitoring%20strategies.pdf
https://www.wcpfc.int/system/files/WCPFC-TCC12-2016-21%20Bridging%20CMM%20and%20Management%20Objectives%20Circular%202016_34.pdf
[87] https://www.wcpfc.int/system/files/WCPFC14%20Summary%20Report%202017_%20Issued%2016%20March%202018_complete.pdf

Type	Tropical longline fishery	Southern longline fishery	Tropical purse seine fishery
Economic	Maximize economic yield from the fishery		
	Maintain acceptable catch per unit effort (CPUE)		
	Maintain bigeye and yellowfin (albacore and swordfish) stock sizes around TRP (where adopted)	Maintain albacore, bigeye, yellowfin and swordfish stock sizes around TRP (where adopted)	-
	Increase fisheries-based development within developing States' economies	-	-
	Effort predictability	Effort predictability	-
	Optimise fishing effort	-	Optimise fishing effort
	-	Maximise catch	-
	Maximize Small Island Developing States (SIDS) revenues from resource rents		
	Catch stability and continuity of market supply		
Social	Affordable protein for coastal communities		
	Employment opportunities		
	Food security in developing States (import replacement)	-	Food security in developing States (import replacement)
	Maintain/develop domestic fishery	Maintain/develop domestic fishery	-
	Human resource development	Human resource development	-
	Avoid adverse impacts on subsistence and small-scale fishers		
Ecosystem	Minimize fishery impact on ecosystem function	-	-
	Minimize catch of non-target species		

Commonalities/differences with other tuna RFMOs

ICCAT

There is a 'Convention Objective' applied to all stocks, which is to maintain them at their most productive level. The Convention Objective has led to setting total catches and fishing capacity to take stock abundance to above BMSY. Specific fishery objectives are in the form of the annual Total Allowable Catch (TAC) and national quota allocations for bigeye, yellowfin and albacore, but not skipjack. There are no explicit social or economic objectives set for any stocks, other than those implicit in the MSY objective.

ICCAT Recommendation 15-07 on the development of harvest control rules and of MSE[88] sets out first steps of MSE implementation for specific stocks. It states that the Commission shall provide guidance on, amongst other things, management objectives for northern albacore, bluefin tuna, North Atlantic swordfish, and tropical tunas. These may include objectives such as maximizing average catch, minimizing inter-annual fluctuations in TAC levels, returning or maintaining the stock in the green quadrant of the Kobe plot. Specific management objectives for the northern albacore stock are given in ICCAT Recommendation 16-06[89]:

- To maintain the stock in the green zone of the Kobe plot, with at least a 60% probability, while maximising long-term yield from the fishery; and
- Where the spawning stock biomass has been assessed as below the level capable of producing MSY (SSBMSY), to rebuild SSB to or above SSBMSY, with at least a 60% probability, and within as short time as possible, by 2020 at the latest, while maximizing average catch and minimising inter-annual fluctuations in TAC levels.

Further to this, ICCAT Recommendation 17-07[90] set out an objective for Eastern Atlantic and Mediterranean BFT to implement a 15 year Recovery Plan starting in 2007 and continuing through 2022, with the goal of achieving SSBMSY with at least 60% probability.

Management objectives have not yet been agreed for the remaining stocks in Recommendation 15-07.

The ICCAT objectives (for albacore tuna) with respect to biological sustainability are, in general terms, similar to the WCPFC's proposed biological objectives. This is expected, as both RFMOs have similar high level objectives relating to sustainable management of the stocks. However, the ICCAT objectives for albacore go further than WCPFC's proposed objectives, in their current form, by explicitly including acceptable levels of risk and timeframes. Unlike WCPFC, ICCAT have not considered social, economic or ecosystem objectives for the management of albacore tuna.

IOTC

The IOTC basic texts offers guidance and principles on which management plans might be based, with an overarching management objective to achieve MSY for all stocks. The language on agreed stock objectives is no further developed than this, although interim TRPs have been set for all stocks that imply achieving MSY as the primary management objective (Resolution 15/10; Resolution 16/02). This general MSY objective also underpins the interim rebuilding plan for yellowfin tuna (Resolution 17/01[91]). There are no explicit social or economic objectives set for any stocks, other than those implicit in the MSY

[88] https://www.iccat.int/Documents/Recs/compendiopdf-e/2015-07-e.pdf
[89] http://iccat.int/Documents/Recs/compendiopdf-e/2016-06-e.pdf
[90] https://www.iccat.int/Documents/Recs/compendiopdf-e/2017-07-e.pdf
[91] http://www.iotc.org/documents/resolution-1701

objective and the recognition of the KOBE II recommendations to avoid constraining the development of coastal States.

The IOTC has established a Management Procedures Dialogue to discuss the design and implementation of Management Procedures applied to IOTC stocks. Currently, alternative Management Procedures are being evaluated for albacore, skipjack, bigeye and yellowfin, although work is progressing at different rates. At the 3rd Management Procedures Dialogue meeting[92] in 2016 recommendations were discussed in relation to performance indicators defined by the Scientific Committee to evaluate management procedure performance against a suite of five biological/economic management objectives:

- Status: maximize probability of maintaining stock in the Kobe green zone
- Safety: maximize the probability of the stock remaining above the biomass limit
- Yield: maximize catches across regions and gears
- Abundance: maximize catch rates to enhance fishery profitability
- Stability: maximise stability in catches to reduce commercial uncertainty

The objectives proposed by IOTC are broadly similar in scope to the WCPFC's proposals, insomuch that biological, social and economic objectives are considered. The IOTC's proposed objectives are arguably presented in a more structured, coherent manner, relating each to an explicit intention of management (e.g. to provide safety, to maintain stability). Unlike WCPFC, there is no explicit consideration of coastal States in the IOTC's objectives, although they do not appear to be opposed to sustainable development goals in their current formulation.

IATTC

The IATTC Convention offers guidance and principles on which management plans might be based. There is a long-term management plan to limit fishing capacity to sustainable levels. Objectives are clearly laid out in the form of TRPs and are measurable for yellowfin, bigeye and skipjack in purse seine fisheries at least (Resolution C-2017-01).[93] The IATTC Convention includes overall considerations which not only apply to target stocks, but also to ecosystems. However, these considerations are relatively general and fall short of specific objectives. Therefore, no meaningful comparison can be made to the WCPFC's proposed objectives.

5.1.3.2.1.2 Acceptable levels of risk

One of the most critical steps in the harvest strategy development process is choosing the levels of risk that will guide future fishery decisions. When evaluating and selecting harvest control rules, managers must decide the risk level that will most appropriately deliver precautionary management. Risk is defined in terms of the likelihood of a negative outcome, such as stock collapse or breaching the limit reference point. Conversely, it can establish the probability of success, such as the chance of achieving a target reference point or not breaching the limit reference point. Typically, managers should set low levels of risk tolerance in cases of greater uncertainty.

The Commission is required to agree acceptable levels of risk for the four species covered by the Harvest Strategy work plan. Discussions on this began in plenary session at WCPFC13, in December 2016, focused around two proposals: that of the Pacific Islands Forum Fisheries Agency (FFA) members', which used interim risk levels of 5% for skipjack and South Pacific albacore with 10% for yellowfin tuna; and the USA's, which used a risk level of 20% for South Pacific albacore.

An informal small working group was formed to discuss the proposals. In particular, the group discussed option of setting a level of risk for each stock, and the integration of social

[92] http://www.iotc.org/meetings/3rd-management-procedures-dialogue-mpd03
[93] https://www.iattc.org/PDFFiles/Resolutions/IATTC/_English/C-17-01-Tuna-conservation-2017.pdf

and economic consequences into the determination of risk. There was early agreement on how to move forward for stocks south Pacific albacore, skipjack and yellowfin tuna, and later for bigeye tuna. The group proposed that, in reviewing the expected performance of harvest control rules or CMMs for these four stocks, the Commission should consider any outcome that had a risk level of more than 20% of breaching the LRP as being inconsistent with the Convention. The group also addressed how to deal with stocks currently below the limit reference point (LRP), suggesting that for those stocks the Commission should look to include a schedule and specific probabilities in rebuilding strategies[94].

After discussion of the proposals of the FFA members and the USA, and based on the recommendation of the working group, the Commission agreed – in the interim – to:

- Not specify, at this time, acceptable levels of risk of breaching the limit reference point for each stock;
- Consider any risk level greater than 20% to be inconsistent with the LRP related principle in UNFSA (as referenced in Article 6 of the Convention) including that the risk of breaching limit reference points be very low; and
- Determine the acceptability of potential HCRs where the estimated risk of breaching the limit reference point is between 0% and 20%.

In 2017, WCPFC14 agreed that the above proposal made in 2016 on acceptable levels of risk would not be reopened and agreed that papers submitted to future meetings should use language consistent with the agreed decisions of previous meetings.

Regarding the interim agreed risk levels, it is has been previously noted by the WCPFC in guidance on developing reference points[95], that harvest management strategies should ensure that the risk of exceeding the LRP under a given management strategy is "very low". The risk takes into account the possibility of the stock size falling to a low level just through chance, and defines how often that is considered allowable. It also needs to account for the fact that stock assessment is not an exact science, and there will always be some uncertainty in estimates of stock status in relation to the chosen limit. The acceptable risk is not a biological (scientific) issue, but is defined by managers and other stakeholders, and reflects the level of risk they are willing to take when managing the fish stock. In many fisheries where this approach is applied, a 10% risk of exceeding the limit reference point is used to represent the ‘very low’ risk. Therefore, the interim risk levels agreed by WCPFC fall within their own guidelines, and are reasonably precautionary.

The level of risk in breaching a LRP should also be considered in conjunction with the management objectives. It could be argued that the risk levels attributed to LRPs should be based solely on biological considerations that align with Annex 2 of the UNFSA, which states that LRPs are intended to constrain harvesting within safe biological limits and TRPs are intended to meet management objectives, including as economic and social. A highly precautionary LRP in conjunction with a very low risk (i.e. 5%) may result in overly conservative outcome. Similarly, a low precautionary LRP coupled with a high risk (i.e. 30%) could put the biological status of the resource at risk. In turn, this would also impact both economic and social objectives.

To date, the stock assessment for skipjack tuna has key biological and fishery variables that are not well understood, including information on growth and the SRR steepness parameter. Without good information on the productivity of the stock, the level of risk in breaching the LRP increases and more precautionary management necessary.

Of the four main stocks using the hierarchal approach to setting LRPs, WCPFC has established skipjack at a Level 3 and bigeye, yellowfin and southern albacore all Level 2. The latter are considered to have more reliable information on the biological and fishery

[94] https://www.wcpfc.int/doc/supplcmm-2014-06/workplan-adoption-harvest-strategies-under-cmm-2014-06

[95] https://www.wcpfc.int/system/files/MOW1-WP-06-Reference-Points.pdf

characteristics. However, it is noted that the Commission has adopted the same LRP for all four stocks, using a depletion-based methods (i.e. 20%$SB_{F=0}$). In the absence of good information on the S-R relationship, Caddy and Mahon (1995) suggested that for stocks in Europe and North America with average resilience, a biomass level of 20% of the unfished level (i.e. 20%B_0) should be considered a recruitment-based LRP. Theoretical work conducted by Mace (1994) indicates that these results are applicable outside the North Atlantic (although were sensitive to life-history characteristics). The established LRPs for all four WCPFC stocks are consistent with these findings.

Although all four WCPFC stocks have the same LRP (20%$SB_{F=0}$), it does not necessarily follow that the acceptable level of risk should also be the same. For example, skipjack tuna has been allocated Level 3 LRP, which means the results obtained from the stock assessment may be more uncertain than the results obtained from stocks allocated Level 1. Under these circumstances, as all four main stocks have the same LRP it would deem appropriate to be more precautionary for skipjack (Level 3) than say yellowfin (Level 2). The interim level of acceptable risk in breaching the LRP advocated by FFA members at WCPFC13 (5% and 10% respectively), is in accordance with the expected level of uncertainty and precaution necessary. However, the exact level of risk must be calculated for each stock based on the individual management objectives, harvest strategy, biological and fishery characteristics as part of an MSE exercise. To date, the Commission has agreed that any acceptable level of risk should be 20% or less. Currently, WCPFC is less precautionary than IATTC (10% risk level for skipjack, yellowfin and bigeye) or ICES that requires management plans to have no more than 5% probability of falling below LRPs (i.e. B_{LIM}). In the case of IATTC, the defined LRP is lower for some stocks than WCPFC (8%S_0), which is consistent with the lower acceptable risk of breaching LRP (see Task 1 report).

In addition, it is worth noting here that unlike European management frameworks, WCPFC does not utilise threshold or trigger RPs (e.g. Bpa and Fpa) that act as a brake before the LRP is reached. Without these additional RPs, it becomes more important to have robust and precautionary LRPs with a low level of risk associated with breaching them.

To date, no WCPO stocks have been defined as a Level 1 LRP (i.e. F_{MSY} or B_{MSY}). It might be expected that where more reliable information is available a higher acceptable risk to breaching the LRP might be afforded as the estimation of stock status is more robust to uncertainties. Further to this, it is noted that Level 1 stocks use MSY-based RPs as a LRP. As highlighted in section 2, in comparison to ICES, t-RFMO estimates of MSY are often not subject to regular re-estimation and can be subject to high levels of uncertainty. This has led fisheries scientists to question whether MSY levels should be considered as targets or limits (Die and Caddy, 1997; Gabriel and Mace, 1999; Punt and Smith, 2001). However, it has been noted that MSY-based RPs (BMSY) are sensitive to the SRR steepness parameter (h).

WCPFC considers that fisheries are more efficient, profitable, stable and sustainable when stocks are larger than BMSY. This is in line with Annex II of UNFSA that target reference points are intended to meet broader management objectives.

To date, with exception of the WCPFC Pacific bluefin stock rebuilding strategy, the Commission has not agreed the level of acceptable risk associated with TRPs for the four tropical tunas identified in the HS work plan. Instead the focus has centred mainly on LRPs. In comparison, ICCAT has identified management objectives for Northern albacore and Eastern Atlantic and Mediterranean bluefin that aim to maintain the stock in the green zone of the Kobe plot, or where rebuilding of the stock to or above SSBMSY[96] with at least a 60% probability. IATTC has established a lower probability of at least 50% of rebuilding the spawning stock biomass to the target level or greater. Both probabilities suggest the

[96] ICCAT assessment method used for Northern albacore refer to total biomass (B) not spawning stock biomass.

acceptable risk to rebuild or maintain the stock at or above target levels is moderately high, but significantly less than the probability of achieving the minimum amount of biomass left to spawn for WCPFC stocks (i.e. 80% or more not exceeding the LRP). In the USA, it has been shown that rebuilding plans that implemented a higher initial rebuilding probability (≥60%) for determining rebuilding fishing mortality and targets generally resulted in fewer changes to the rebuilding plans and rebuilt by the target rebuilding year, particularly for stocks with the longer rebuilding plans (Wetzel and Punt, 2016).

Commonalities/differences with other tuna RFMOs

ICCAT

ICCAT has established acceptable levels of risk for some stocks, which are less conservative than those recommended within WCPFC.

Recommendation 15-07 provides the basis for setting acceptable quantitative levels of probability of achieving and/or maintaining stocks in the green zone of the Kobe plot and avoiding limit reference points for northern albacore, bluefin tuna, North Atlantic swordfish, and tropical tunas. To date, this is seen in practice within the wording of the management objectives for northern albacore in Recommendation 16-06:

- To maintain the stock in the green zone of the Kobe plot, with at least a 60% probability, while maximising long-term yield from the fishery; and
- Where the spawning stock biomass has been assessed as below the level capable of producing MSY (SSBMSY), to rebuild SSB to or above SSBMSY, with at least a 60% probability, and within as short time as possible, by 2020 at the latest, while maximizing average catch and minimising inter-annual fluctuations in TAC levels.

The latest advice (2017) for bluefin tuna, however, appears to abandon the idea of biomass reference points because of the difficulty of modelling recruitment (poorly determined stock-recruit relationship), so Kobe plots are now only shown for fishing mortality (not biomass), and estimates of BMSY is no longer provided.

IATTC

In 2016, IATTC adopted interim HCRs for skipjack, yellowfin and bigeye (Resolution C-16-02[97]) that specify timeframes and probabilities of achieving TRP and acceptable levels of risk for breaching the LRPs:

- Management measures for the purse-seine fishery, such as closures, which may be fixed for multiple years, will ensure that F does not exceed the best estimate of FMSY for the species that requires the strictest management.
- If the probability that F exceeds the limit reference point (FLIM) is greater than 10%, management measures that have a probability of at least 50% of reducing F to the target level (FMSY) or lower, and a probability of less than 10% that F will exceed FLIM, will be established as soon as is practical.
- If the probability that the spawning biomass (SSB) is below the limit reference point (SSBLIMIT) is greater than 10%, measures will be established that have a probability of at least 50% of rebuilding S to the target level (dynamic SSBMSY) or greater, and a probability of less than 10% that SSB will fall below SSBLIMIT within a period of two generations of the stock or five years, whichever is greater.

[97] https://www.iattc.org/PDFFiles2/Resolutions/C-16-02-Harvest-control-rules.pdf

Other organisations

Australia and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) each have harvest strategy policies that require a less than 10% chance of violating the limit reference point[98]. In Canada, the Fishery Decision-Making Framework Incorporating the Precautionary Approach[99] defines quantitative levels for a series of qualitative risk designations, including defining 'very low' as less than 5%. It is worth noting also that ICES consider that management plans must have no more than 5% probability of falling below B_{lim} for the management plan to be considered precautionary[100].

5.1.3.2.2 Skipjack tuna

5.1.3.2.2.1 Management objectives

There are no species-specific management objectives for skipjack tuna. Instead, a set of candidate management objectives have been developed around three main fisheries: tropical purse seine; tropical longline and southern longline fisheries. Of these, management objectives and corresponding performance indicators for skipjack are included for purse seine fisheries only. These objectives include maintaining the biomass at or above levels that provide fishery sustainability throughout their range and to maintain stock sizes above LRPs (Annex 1). While the general objective to maintain populations that can meet MSY is not currently included as the biological objective, MSY for skipjack tuna is referred to as a performance indicator under social objectives to "avoid adverse impacts on small-scale fishers". No further updates were given at WCPFC14.

5.1.3.2.2.2 Reference points

Target reference point

In 2015, the Commission adopted an interim TRP for the WCPO skipjack tuna, which follows the overall objective of the long-term conservation and sustainable use of highly migratory fish stocks. This is described in CMM 2015-06[101], and summarised below.

- The (interim) target reference point for the WCPO skipjack tuna stock shall initially be 50% of the estimated recent average spawning biomass in the absence of fishing, ($SB_{F=0,\ t1-t2}$)
- The method to be used in estimating the recent average spawning biomass in the absence of fishing shall be the same as that adopted by the Commission for the limit reference point for WCPO skipjack tuna, i.e.
- The time window shall have a length of ten years and be based on the last ten years used in the most recent skipjack stock assessment, i.e. $t_{1=ylast-10}$ to $t_{2=ylast-1}$ where y_{last} is the last year used in the assessment; and
- The estimation shall be based on the most recent skipjack stock assessment model estimates of recruitment that have been adjusted to reflect conditions without fishing according to the stock recruitment relationship.

As stated in CMM 2017-01[102], the Commission shall review and revise the above aims in light of advice from the Scientific Committee at its 2018 annual session

[98] https://www.ccamlr.org/en/fisheries/toothfish-fisheries
[99] http://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/precaution-back-fiche-eng.htm
[100] http://ices.dk/sites/pub/Publication%20Reports/Advice/2016/2016/12.04.10_Criteria_for_defining_multi-annual_plans_as_precautionary.pdf
[101] https://www.wcpfc.int/system/files/CMM%202015-06%20CMM%20on%20a%20Target%20Reference%20point%20for%20WCPO%20Skipjack%20Tuna.pdf
[102] https://www.wcpfc.int/system/files/CMM%202017-01%20Conservation%20and%20Management%20Measure%20for%20tropical%20tunas.pdf

Limit reference point

In 2013, SC8 recommended that the LRP for skipjack be set at Level 3, i.e. key biological and fishery variables are not well estimated or understood. Under this classification, the LRP for skipjack is currently 20%$SB_{F=0}$ (see section 2 for further discussion on reference points). The method for estimating the recent period is the same as that for the target reference point described above.

Commonalities/differences with other tuna RFMOs

TRPs and LRPs are presented and discussed for stocks in other tuna RFMOs in the report that presents the work under Task 1 for this project. All tuna RFMOs implicitly combine the maximum utilisation of stocks with the precautionary approach, which aims at keeping stocks at or above the biomass corresponding to MSY with high probability, and also avoiding the LRPs with very high probability. As with WCPFC, ICCAT, IATTC and IOTC explicitly mention MSY within their RPs, while CCSBT do not. The latter is due to the heavily over-exploited status of the stock (3-7% SSB_0), which is currently undergoing rebuilding. As such an interim 'rebuilding TRP' has been identified to rebuild the SBT stock to 20% SSB0, with a 70% chance probability.

IATTC

In 2014, the IATTC agreed to the scientific staff's recommendation for yellowfin, bigeye and skipjack stocks that TRP should be FMSY and BMSY. MSY-based target reference points are not yet estimated for skipjack, but it is very likely that this stock is around BMSY. Also in 2014, the IATTC agreed to the scientific staff's recommendation that the LRP for yellowfin (also bigeye and skipjack) should correspond to the equilibrium spawning biomass which produces a 50% reduction in recruitment from the unfished level[103] and that the acceptable level of risk for the stocks breaching that limit would be 10% (see Resolution C-16-02[104]).

5.1.3.2.2.3 Monitoring strategy

A full monitoring strategy has not yet been defined for skipjack; however, in 2016 at WCPFC13, the Commission agreed interim performance indicators that should be used to evaluate HCRs. An informal Small Working Group on Management Objectives was formed to discuss, amongst other things, performance indicators for MSE for the tropical purse seine fishery. As the harvest strategies framework is set out by species, not by fisheries, the group's discussion and outputs were primarily for skipjack tuna. Using the candidate management objectives from the Management Options Workshop 'strawman proposal', along with an additional proposal from USA presented at the meeting (for tropical purse seine fishery only), the Small Working Group on Management Objectives drafted a list of suggested performance indicators against each of the proposed management objectives.

More specifically, a monitoring strategy was proposed at WCPFC13 to maintain the skipjack biomass at or above 20%$SB_{CURRENT,F=0}$ in the long-term as determined from the reference set of operating models used in the MSE. Although TRPs have not been specified under biological objectives, the USA proposal for economic management objectives to stabilise catches, highlights that skipjack tuna stock sizes should be maintained around TRPs (where adopted). To date interim TRPs have been agreed for skipjack only (50%$SB_{CURRENT,F=0}$) with a monitoring strategy that reviewed the current median adult biomass, as determined from the reference set of operating models in the MSE. No further updates were presented for skipjack at WCPFC14.

[103] These calculations need to use a Beverton-Holt stock recruitment relation with steepness of 0.75. That will lead to a spawning biomass that is approximately 8% of the unfished level.
[104] https://www.iattc.org/PDFFiles/Resolutions/IATTC/_English/C-16-02-Harvest-control-rules.pdf

Commonalities/differences with other tuna RFMOs

IOTC

At the 3rd Management Procedure Dialogue meeting in 2016, a list of candidate performance statistics and performance indicators was presented to evaluate the five proposed management objectives for all stocks for which management procedures are being developed (Figure 22). These indicators have been endorsed by the IOTC Scientific Committee, and are broadly similar to those presented being considered by WCPFC for skipjack.

Candidate performance statistics	Performance measure/s	Summary statistic
Status: maximize probability of maintaining stock in the Kobe green zone		
Mean spawner biomass relative to unfished	SB/SB_0	Geometric mean over years
Minimum spawner biomass relative to unfished	SB/SB_0	Minimum over years
Mean spawner biomass relative to B_{MSY}	SB/SB_{MSY}	Geometric mean over years
Mean fishing mortality relative to target	F/F_{targ}	Geometric mean over years
Mean fishing mortality relative to F_{MSY}	F/F_{MSY}	Geometric mean over years
Probability of being in Kobe green quadrant	SB, F	Proportion of years that $SB \geq SB_{targ}$ & $F \leq F_{targ}$
Probability of being in Kobe red quadrant	SB, F	Proportion of years that $SB < SB_{targ}$ & $F > F_{targ}$
Safety: maximize the probability of the stock remaining above the biomass limit		
Probability that spawner biomass is above 20% of SB_0	SB	Proportion of years that $SB > 0.2SB_0$
Yield: maximize catches across regions and gears		
Mean catch	C	Mean over years
Mean catch by region and/or gear	C	Mean over years
Mean proportion of MSY	C/MSY	Mean over years
Abundance: maximize catch rates to enhance fishery profitability		
Mean catch rates by region and gear	A	Geometric mean over years
Stability: maximise stability in catches to reduce commercial uncertainty		
Mean absolute proportional change in catch	C	Mean over years of absolute (C_t / C_{t-1})
Variance in catch	C	Variance over years
Variance in fishing mortality	F	Variance over years
Probability of fishery shutdown	C	Proportion of years that C = 0

Note: All the candidate performance statistics are summarised using the XXth percentiles (e.g. XX=5/10/50) of their distributions over multiple stochastic realisations. The summary will include short and long-term time windows (e.g. 1, 3, 5, 10 and 20 years).

Figure 22: List of performance indicators for evaluation of management objectives endorsed by the IOTC SC. Source: IOTC, 3rd Management Procedure Dialogue meeting report.[105]

5.1.3.2.3 Bigeye tuna

5.1.3.2.3.1 Management objectives

There are no species-specific management objectives for bigeye tuna. Instead, relevant candidate management objectives have been developed around three main fisheries: tropical purse seine (WCPFC13), tropical longline and southern longline fisheries (WCPFC14). Each fishery includes a reference to bigeye tuna, which is to maintain the

[105] http://www.iotc.org/meetings/3rd-management-procedures-dialogue-mpd03

biomass at or above levels that "provide fishery sustainability throughout their range" (Annex 1).

Similar to skipjack tuna, while the general objective of WCPFC is to maintain populations that can meet MSY, this was not specifically included as the biological objective. Instead, MSY for bigeye tuna is currently referred to under (i) the candidate social objectives of the tropical purse seine fishery as a performance indicator to "minimize impacts from other fisheries, including downstream fisheries like longline fisheries and competing fisheries like troll, pole and line and non-tropical purse seine fisheries", and (ii) .the candidate economic objective the tropical longline fishery to "minimize impacts from upstream fisheries, including the tropical purse seine fishery". No further updates were given at WCPFC14.

5.1.3.2.3.2 Reference points

Target reference point

No TRP has been agreed or proposed for bigeye tuna, although achieving F≤FMSY by 2017 is implied as an interim short-term target[106] The current CMM (CMM 2017-01) acts as a bridge and confirms that, pending agreement on a target reference point, the spawning biomass depletion ratio ($SB/SB_{F=0}$) is to be maintained at or above the average $SB/SB_{F=0}$ for 2012-2015.

The Commission at its 2018 annual session shall review and revise the above aims in light of advice from the Scientific Committee.

Limit reference point

The LRP for bigeye is set at Level 2, i.e. steepness is not known well, if at all, but the key biological (natural mortality, maturity) and fishery (selectivity) variables are reasonably well estimated. Consequently, bigeye has a depletion-based LRP of $20\%SB_{F=0}$[107].

5.1.3.2.3.3 Rebuilding timeline

In 2016, the Commission had been required, under the Harvest Strategy work plan, to agree timelines to rebuild the bigeye stock to the LRP. Discussions began in plenary session at WCPFC13 and were continued in an informal Small Working Group. Issues discussed included the risk of achieving the LRP, the measures required to get there, and impacts of a rebuilding plan. There was a general view that a 10-year timeframe to reach the LRP was reasonable. However, as with many of the decisions made under the HS work plan, the agreed timeframe was interim and intended to inform ongoing processes. At that time, the Commission agreed to an interim timeframe of up to ten years for rebuilding the bigeye tuna stock to the agreed LRP of $20\%SB_{F=0}$[108].

More recently, following the latest stock assessment for bigeye in August 2017 (SA-WP-05), the results showed that the stock was not experiencing overfishing and was not in an overfished condition. In the light of recent updates of scientific advice, the proposed work plan for rebuilding bigeye was no longer valid and would be taken into account when revising the HS work plan.

5.1.3.2.3.4 Monitoring strategy

A full monitoring strategy has not yet been defined for bigeye. In 2016, the Commission agreed interim performance indicators that should be used to evaluate HCRs (WCPFC13). More specifically, a monitoring strategy was proposed to ensure bigeye biomass was maintained at or above $20\%SB_{CURRENT,F=0}$ in the long-term as determined from the

[106] https://www.wcpfc.int/system/files/Att%20O_CMM%202016-01%20CMM%20for%20Bigeye%20Yellowfin%20and%20Skipjack%20Tuna.pdf
[107] Ibid.
[108] Ibid.

reference set of operating models used in the MSE. Similar to skipjack, although TRPs have not been specified under any biological objectives, the USA proposal for economic management objectives to stabilise catches, highlights that bigeye tuna stock sizes should be maintained around TRPs (where adopted). To date, no TRPs have been adopted for bigeye.

5.1.3.2.4 Yellowfin tuna

5.1.3.2.4.1 Management objectives

There are no species-specific management objectives for yellowfin tuna. Instead, candidate management objectives relevant to yellowfin have been identified within three main fisheries: tropical purse seine (WCPFC13); tropical longline and southern longline fisheries (WCPFC14). Each fishery included reference to yellowfin tuna, which was to maintain the biomass at or above levels that "provide fishery sustainability throughout their range" (see Annex 1).

Similar to skipjack tuna, while the general objective of WCPFC is to maintain populations that can meet MSY, this was not specifically included as a candidate biological objective. Instead, MSY for yellowfin tuna is currently referred to within the tropical longline fishery as a performance indicator under the candidate economic objectives to "minimize impacts from upstream fisheries, including the tropical purse seine fishery". No further updates were given at WCPFC14.

5.1.3.2.4.2 Reference points

Target reference point

No TRP has been agreed or proposed for yellowfin tuna. The current CMM (CMM 2017-01)[109] acts as a bridging role and confirms that that pending agreement on a target reference point the spawning biomass depletion ratio ($SB/SB_{F=0}$) is to be maintained at or above the average $SB/SB_{F=0}$ for 2012-2015.

The Commission at its 2018 annual session shall review and revise the above aims in light of advice from the Scientific Committee.

Limit reference point

The LRP for yellowfin has been set at $20\%SB_{F=0}$. The LRP for yellowfin is set at Level 2, i.e. steepness is not known well, if at all, but the key biological and fishery variables are reasonably well estimated.

5.1.3.2.4.3 Monitoring strategy

A full monitoring strategy has not yet been defined for yellowfin. At WCPFC13 the Commission agreed interim performance indicators that should be used to evaluate HCRs. More specifically, a monitoring strategy was proposed to maintain the bigeye biomass at or above $20\%SB_{CURRENT,F=0}$ in the long-term as determined from the reference set of operating models used in the MSE. Similar to skipjack and bigeye, although TRPs have not been specified under any biological objectives, the USA proposal for economic management objectives to stabilise catches, highlights that bigeye tuna stock sizes should be maintained around TRPs (where adopted). To date no TRPs have been adopted for bigeye.

[109] https://www.wcpfc.int/system/files/CMM%202017-01%20Conservation%20and%20Management%20Measure%20for%20tropical%20tunas.pdf

5.1.3.2.5 South Pacific albacore

5.1.3.2.5.1 Management objectives

There are no species-specific management objectives for southern albacore tuna. However, candidate management objectives were considered at WCPFC14 for the southern longline fishery and proposed performance indicators and monitoring strategies for the purpose of the evaluation of harvest control rules. The candidate biological objectives for the southern longline fishery aim to "maintain albacore biomass at or above levels that provide stock sustainability throughout their range".

5.1.3.2.5.2 Reference points

Target reference point

At WCPFC14, the Commission agreed to prioritise the development and adoption of TRP for South Pacific albacore through the following actions:

- All CCMs with an interest in the Southern albacore fishery jointly commit to review available scientific and economic information to inform their position about appropriate goals for the fishery and corresponding candidate target reference points;
- Regardless of the results of the 2018 stock assessment and the management advice from SC14 to WCPFC15, SC14 shall dedicate sufficient time in the Management Issues Theme to develop advice for WCPFC15 on candidate target reference points;
- CCMs will work together in advance of WCPFC15 to develop TRP proposals; and
- WCPFC15 shall adopt a Target Reference Point for South Pacific albacore.

Limit reference point

The LRP for South Pacific albacore is set at Level 2, i.e. steepness is not known well, if at all, but the key biological and fishery variables are reasonably well estimated. The LRP for South Pacific albacore has been set equal 20%$SB_{F=0}$.

5.1.3.2.5.3 Monitoring strategy

A full monitoring strategy has not yet been defined for southern albacore. At WCPFC14 the Commission noted the candidate performance indicators and monitoring strategies for south Pacific albacore commensurate with candidate management objectives for the Southern Longline Fishery to be considered in the development of harvest strategies under CMM 2014-06. This proposed a monitoring strategy to maintain the bigeye biomass at or above 20%$SB_{CURRENT,F=0}$ in the long-term as determined from the reference set of MSE operating models (updated and reconditioned periodically, as appropriate).

5.1.3.2.5.4 Decision rule

The NC has recommended a management strategy for the stock that ensures that the risk of the biomass decreasing below the LRP is low.

5.1.3.2.6 North Pacific albacore

In 2017, the Commission adopted an Interim Harvest Strategy (WCPFC-NC13-DP-13)[110], which replaced the "precautionary management framework for north pacific albacore" previously adopted at the 11th regular session of the Commission and based on the recommendation of the Northern Committee (NC) at its 10th regular session. The elements of the Interim Harvest Strategy are described below.

[110] https://www.wcpfc.int/node/29837

5.1.3.2.6.1 Management objectives

The management objective for the North Pacific albacore fishery is to maintain the biomass, with reasonable variability, around its current level (2014 assessment levels) in order to allow recent exploitation levels to continue and with a low risk of breaching the limit reference point.

5.1.3.2.6.2 Reference points

Target reference point

No TRP has yet been defined for this stock. The Northern Committee have noted that a TRP will be determined following a comprehensive analysis under a MSE approach. Historical fishing activity, anticipated fishing activity, and the source of increased fishing mortality will also be considered when evaluating a suitable TRP. Socio-economic factors will be also considered.

Limit reference point

Based on ISC's 2014 stock assessment advice, and following the hierarchical approach adopted by the Commission, North Pacific albacore is treated as a Level 2 stock, i.e. steepness is not known well, if at all, but the key biological and fishery variables are reasonably well estimated.

The LRP for this stock is established at 20%$SB_{F=0}$. This LRP is consistent with the Annex II of the UNFSA and recent WCPFC decisions on LRPs for the three tropical tuna species and South Pacific albacore. If this point is breached, management actions will be taken to return the stock to a predetermined level.

Commonalities/differences with other tuna RFMOs

ICCAT

An interim LRP of 0.4*BMSY was recently developed for the northern albacore stock (Rec. 17-04). While a target reference point has not yet been developed, ICCAT has agreed the objective "to maintain the stock in the green quadrant of the Kobe plot, with at least 60% of probability, while maximizing long-term yield from the fishery, and where the B has been assessed as below BMSY, to rebuild B to or above BMSY, with at least a 60% probability, and within as short time as possible, while maximizing average catch and minimizing inter-annual fluctuations in TAC levels". This implies the use of MSY as the basis for the establishment of reference points, but does not explicitly mention MSY as a target. Social factors do not appear to be considered in the formulation of this reference point.

IOTC

An interim LRP and an interim TRP, both expressed in terms of stock biomass (denoted as B) and fishing mortality (F), have been established for albacore tuna in the Indian Ocean, and furthermore Resolution 14/03 requires a series of Science and Management Dialogue Workshops to advance work on the adoption of reference points. It is noted that these reference points are not supported by scientific evidence.

5.1.3.2.6.3 Decision rule

The Northern Committee has recommended a management strategy for the stock that ensures that the risk of the biomass decreasing below the LRP is 'low'. In the event that the spawning stock size decreases below the LRP at any time, the Northern Committee will, at its next regular session or before if warranted, adopt a reasonable timeline, but no longer than 10 years, for rebuilding the spawning stock to at least the LRP and recommend a CMM that can be expected to achieve such rebuilding within that timeline. It is not fully documented why the rebuilding timeline is set to 10 years, although this coincides with the agreed "time window" over which depletion-based LRPs are calculated using the average unfished reference level of spawning biomass ($SB_{F=0,\ t1\text{-}t2}$)[111].

As with the development of a TRP, the Northern Committee will take into account historical fishing activity and the source of increased fishing mortality when developing management strategies to rebuild the stock, including in establishing effort reductions. The Northern Committee will consider socio-economic factors, as well as which members (if any) contributed to exceeding the LRP.

5.1.3.2.7 Pacific bluefin tuna

The proposed harvest strategy for Pacific bluefin tuna was prepared in accordance with the Commission's Conservation and Management Measure on Establishing a Harvest Strategy for Key Fisheries and Stocks in the Western and Central Pacific Ocean. Although the provisions of the harvest strategy are expressed in terms of a single stock, it is noted that they may be applied to multiple stocks as appropriate and as determined by the Northern Committee. The elements of harvest strategy[112] are described below.

5.1.3.2.7.1 Management objectives

The management objectives are:

- To support thriving Pacific bluefin tuna fisheries across the Pacific Ocean while recognising that the management objectives of the WCPFC are to maintain or restore the stock at levels capable of producing maximum sustainable yield;
- To maintain an equitable balance of fishing privileges among CCMs; and
- To seek cooperation with IATTC to find an equitable balance between the fisheries in the western and central Pacific Ocean and those in the eastern Pacific Ocean.

5.1.3.2.7.2 Reference points

The stock of Pacific bluefin is treated as a Level 2 stock under the Commission's hierarchical approach for setting biological limit reference points. This is because steepness in the stock-recruitment relationship is not well known, although the key biological and fishery variables are reasonably well estimated.

Initial rebuilding target: The initial rebuilding target for the PBF stock size is the median SB estimated for the period 1952 through 2014, to be reached by 2024 with at least 60% probability.

Recruitment scenario during initial rebuilding period: The low recruitment scenario (resampling from the relatively low recruitment period (1980-1989)) or the recent recruitment scenario (resampling from the last 10 years), whichever is lower, will be used for SB projections until 2024 or until the SB reaches the initial rebuilding target, whichever is earlier.

Second rebuilding target: The second rebuilding target for the PBF stock size is $20\%SB_{F=0}$, to be reached by 2034 or 10 years after reaching the initial rebuilding target, whichever is earlier, with at least 60% probability.

However, if: (1) the SB reaches the initial rebuilding target earlier than 2024; (2) a recruitment scenario lower than the average recruitment scenario is recommended; and (3) the SB projections indicate that the second rebuilding target will not be achieved on this schedule, the deadline for rebuilding may be extended to 2034 at the latest.

Also, if there is a recommendation from the Northern Committee that $20\%SB_{F=0}$ is not appropriate as the second rebuilding target, taking into account consideration from IATTC, scientific advice and socioeconomic factors, another objective may be established.

[111] https://www.wcpfc.int/system/files/MI-WP-02-Time-Window-LRP.pdf
[112] https://www.wcpfc.int/node/29688

Recruitment scenario during second rebuilding period: After the initial rebuilding target is reached and until the second rebuilding target is reached, the recruitment scenario to be used for the SB projections will tentatively be the average recruitment scenario (resampling from the entire recruitment period).

The Northern Committee will develop more refined management objectives as well as limit reference point(s) and target reference point(s) through MSE process.

5.1.3.2.7.3 Acceptable levels of risk

Until the stock is rebuilt, the Northern Committee will recommend conservation and management measures as needed to ensure rebuilding in accordance with the probabilities specified in the rebuilding targets. Once the stock is rebuilt, the Northern Committee will recommend conservation and management measures as needed to ensure that any target reference points are achieved on average in the long term, and ensure that the risk of the stock size declining below Blimit is 'very low' (no LRP currently defined). WCPFC13 agreed that any risk level greater than 20% to be inconsistent with the limit reference point related principles in UNFSA, including that the risk of breaching limit reference points be very low.

5.1.3.2.7.4 Monitoring strategy

The International Scientific Committee (ISC) periodically evaluates the stock size and exploitation rate with respect to the established reference points and the report will be presented to the Scientific Committee. Until 2024, while the MSE is being developed, the ISC is requested to conduct stock assessments in 2018, 2020 and 2022.

In order to cope with the adverse effects on the rebuilding of the stock due to drastic drops of recruitment: (1) all the available data and information is reviewed annually, including recruitment data provided by the ISC and in National Reports; and (2) the ISC is requested to conduct in 2019, and periodically thereafter as resources permit and if drops in recruitment are detected, projections to see if any additional measure is necessary to achieve the initial rebuilding target by 2024 with at least 60% probability.

5.1.3.2.7.5 Decision rules

Harvest controls rules during initial rebuilding period: The interim harvest control rules below will be applied based on the results of stock assessments and SSB projections to be conducted by ISC.

- If the SSB projection indicates that the probability of achieving the initial rebuilding target by 2024 is less than 60%, management measures will be modified to increase it to at least 60%. Modification of management measures may be (1) a reduction (in %) in the catch limit for fish smaller than 30 kg ('small fish') or (2) a transfer of part of the catch limit for small fish to the catch limit for fish 30 kg or larger ('large fish'). For this purpose, ISC will be requested, if necessary, to provide different combinations of these two measures so as to achieve 60% probability.
- If the SSB projection indicates that the probability of achieving the initial rebuilding target by 2024 is at 75% or larger, the WCPFC may increase their catch limits as long as the probability is maintained at 70% or larger, and the probability of reaching the second rebuilding target by the agreed deadline remains at least 60%. For this purpose, ISC have been requested to provide relevant information on potential catch limit increases.

Harvest controls rules during second rebuilding period: Harvest control rules to be applied during the second rebuilding period are yet to be decided, taking into account the implementation of the interim harvest control rules applied during the initial rebuilding period.

The Northern Committee will, through MSE development process, develop decision rules related to the limit reference points once adopted including for the case of their being breached.

Commonalities/differences with other tuna RFMOs

CCSBT

CCSBT have implemented a HCR for southern bluefin tuna[113], referred to as a management procedure (MP), which can specify changes to the total allowable catch (TAC) for southern bluefin tuna based on updated monitoring data. Parameters of the decision rule can be adjusted to set different time horizons for rebuilding, and to constrain the maximum TAC changes allowed every time the TAC is updated.

The Seventh Operating Model and Management Procedure Technical Meeting (OMMP 7) have initiated discussions about the design of a new MP to replace the current one, which uses CPUE and the aerial survey index as a fishery independent index of recruitment[114].

5.1.3.2.7.6 Performance evaluation

The Northern Committee are to work with the ISC and the Scientific Committee until the stock is rebuilt and consult with the IATTC to identify and evaluate the performance of candidate rebuilding strategies with respect to the rebuilding targets, schedules, and probabilities.

The ISC has been requested to start work to develop a MSE for Pacific bluefin tuna fisheries in 2019 and have a goal of completing it by 2024. In evaluating the performance of candidate TRPs, LRPs, and HCRs, the Northern Committee, in consultation with the ISC and the Scientific Committee, consider the following criteria to be appropriate[115]:

- Probability of achieving each of the rebuilding targets within each of the rebuilding periods (if applicable)
- Time expected to achieve each of the rebuilding targets (if applicable)
- Expected annual yield, by fishery
- Expected annual fishing effort, by PBF-directed fishery
- Inter-annual variability in yield and fishing effort, by fishery
- Probabilities of SSB falling below the B-limit and the historical lowest level
- Probability of fishing mortality exceeding FMSY or an appropriate proxy, and other relevant benchmarks
- Expected proportional fishery impact on SSB, by fishery and by WCPO fisheries and EPO fisheries

5.1.4 Review of technical analyses and implications of Harvest strategies

As indicated in the previous section, only some of the elements of a harvest strategy have been advanced in the past few years and that progress varies depending on the species. This section looks at each of those elements and discuss the science and analysis that underpins them and their implications.

5.1.4.1 Scope and approach taken

The first element of the harvest strategy is the adoption of management objectives. Candidate objectives have been proposed for some of the species and include fisheries-

[113] https://www.ccsbt.org/sites/ccsbt.org/files/userfiles/file/docs_english/operational_resolutions/Resolution_Management_Procedure.pdf

[114] Ibid.

[115] https://www.wcpfc.int/system/files/HS%202017-02%20Harvest%20Strategy%20for%20Pacific%20Bluefin%20Tuna_0.pdf

specific objectives for skipjack, bigeye, and yellowfin tuna and more general objectives such as that for NPO albacore; the latter reflects the desire of the Commission to avoid further deterioration of the stock status. The objectives are not the result of a specific technical analyses but rather a consultative and qualitative process that aimed to produce objectives that reflected the principles and spirit of the conventions, the interest of Contracting Parties, expert knowledge, and lessons from other organisations. Therefore, the focus of the section on management objectives below is merely on the candidate performance indicators and associated monitoring strategy. Furthermore, it should be noted that the list of performance indicators are based on suggestions made during the relevant working group meetings and consultation process[116].

The Commission has already adopted a hierarchical approach to identifying the LRPs for the key target species in the WCPFC[117] (Table 15). As this is an adopted approach, our analysis focuses less on the merits and technical robustness of the underpinning science. Instead, the focus is more on LRPs that have already been adopted following that approach and the science and thinking that have led to their adoption. The latest position on acceptable risk levels of exceeding LRP is also covered.

As mentioned already, limit reference points have been set for bigeye, yellowfin, SPO albacore, NPO albacore, and skipjack. They are all equal to *20%*$SB_{F=0}$ *which represents 20% of* the estimated average spawning biomass over a recent period (mainly 10 last years covered in the assessment) in the absence of fishing[118].

There is also the issue of maintaining comparability across t-RFMOs of relevance to WCPFC. In particular, there are provisional HCRs that IATTC adopted recently for purse seine fisheries catching tropical tunas (yellowfin, bigeye, and skipjack) and associated reference points (described in Annex 2). Their differences from the WCPFC ones are discussed in Section 5.1.5 that presents additional options for HCRs in WCPFC (see also Table 5 for more details on this).

The development of harvest strategies is still in progress and that includes work to develop modelling frameworks to use for management strategy evaluation (MSE)[119]. The latter component is still at an exploratory phase and as part of this work, models such as Multifan-CL are explored but recommendations for preferred models have not been made. Similarly, models and indicators that aim to incorporate ecosystem considerations into management have been explored[120] but not adopted and would benefit from further work, for example, to understand how they could be used in conjunction with more conventional models. This element of a harvest strategy is discussed in the section about HCRs but, as it is still under development, there is scope for a more detailed analysis when work on MSE has progressed further.

5.1.4.2 Reference points and Acceptable risk levels

5.1.4.2.1 LRP and risk levels

LRP have already been agreed for skipjack, bigeye, yellowfin, SPO and NPO albacore species and the majority of these species fall in Level 2 in the hierarchical approach for setting LRPs used by WCPFC. The main reason for this classification is uncertainty about the stock recruitment function that characterises each of these stocks and in particular, uncertainty in the steepness value of the recruitment function. For example, plausible values of steepness for North Pacific albacore range from 0.6 to 1; that range covers very

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[116] See SC13-WCPFC13-06

[117] https://www.wcpfc.int/harvest-strategy *Last accessed: 05/07/18*

[118] Except for NPO albacore for which the LRP is set equal to *20%*$SB_{current,F=0}$

[119] See, for example, SC13-MI-WP-04: *Developments in the MSE modelling framework*

[120] See, for example, https://www.wcpfc.int/system/files/EB-WP-02%20Ecosystem%20Indicators.pdf and https://www.wcpfc.int/system/files/EB-WP-01%20SEAPODYM.pdf *Last accessed: 05/07/18*

different levels of productivity. The stock of PBF tuna is also to be treated as a Level 2 stock, but an LRP is not used at present due to the major depletion that characterises this stock. An initial rebuilding target has been set instead, which requires that the stock size reaches the median SB estimated for the period 1952 through 2014 by 2024 with at least 60% probability[121].

The LRP for all of species has been expressed in terms of current spawning biomass relative to current or recent spawning biomass in the absence of fishing. However, depending on the categorisation, other indicators can be used including MSY- and YPR-based ones. In fact, six types of indicators were considered in the process of developing the hierarchical approach and associated reference points and those were:

i) MSY-based

ii) Yield per Recruit, YPR

iii) Historical observations

iv) Relative depletion

v) Empirical

vi) Economic

However, due to lack of direct observations of spawning biomass and recruitment and difficulties in identifying socioeconomic reference points this list was reduced to cover only MSY-, Yield-per-recruit-, Spawner-potential-per-recruit- based indicators and depletion indicators[122]. Further work put emphasis mainly on the 3 of these 4 types of indicators (mainly depletion and MSY or Spawner potential per recruit) to provide a more concise analysis[123]. A review of best practice and approaches used by other organisations and fishery management bodies showed that limits based on biomass or spawning biomass depletion were very common. Examples of such limits used to provide advice on appropriate limits for WCPFC included:

A depletion limit reference points of 20% of SSB0 used in CCAMLR, Australia and New Zealand (Preece et al., 2011). SSB_0 gives the spawning stock biomass under virgin conditions.

A limit reference point of 25%B_0 used in the US west coast groundfish management (Preece et al., 2011).

A limit of 20%SSB0 has been recommended as appropriate for cases in which recruitment declines could be observed (Beddington and Cook, 1983).

It was recognised that MSY-based indicators were also widely used but robust estimates of MSY cannot be found if there is ambiguity about the steepness parameter (which is the case for the WCPFC tuna species) even with reliable estimates of all the other key life-history and fishery parameters. It is for this reason that the hierarchical approach was designed to use MSY-based reference points only for data-rich species for which good estimates of steepness are available. Otherwise, simulation modelling and experience from other regions supported adoption of a different limit; that was SSB-based depletion reference point and specifically, 20% of the SB in the absence of fishing[124]. Even though

[121] https://www.wcpfc.int/system/files/NC13%20Summary%20Report%20adopted%20-%20Final%20%28Update%29-clean.docx *Last accessed: 05/07/18*

[122] https://wcpfc.int/system/files/WCPFC-SC6-2010-MI-IP-01_Identifying_limit_reference_points.pdf *Last accessed: 05/07/18*

[123] https://wcpfc.int/system/files/SC7-MI-WP-03%20%5BIdentification%20of%20candidate%20limit%20reference%20points%5D.pdf *Last accessed: 05/07/18*

[124] https://wcpfc.int/system/files/SC7-MI-WP-03%20%5BIdentification%20of%20candidate%20limit%20reference%20points%5D.pdf *Last accessed: 05/07/18*

such limit might lead to spawning biomass that is higher than the spawning biomass at MSY, this higher protection essentially reflects the uncertainty in stock status and any additional risks that uncertainty might bring in managing the fishery. It is also important to note that even when the MSY-based indicators are used in the adopted hierarchical approach, the biomass at MSY is seen as the limit and not the target hence biomass should not fall below that limit (i.e. MSY treated as upper limit not target, as discussed in Task 1). This approach will fulfil the precautionary approach that the CFP shall apply; specifically, as the biomass is maintained at or above the biomass at MSY, it exactly follows the direction that article 2.2 of the CFP sets about exploitation that "restores and maintains populations of harvested species above levels which can produce the maximum sustainable yield[125]"

The adopted hierarchical approach offers two options in terms of SB in the absence of fishing; one uses the SB under unfished conditions (i.e. virgin, SB_0) and the other uses the expected SB without fishing and with recruitment that reflects recent/latest productivity estimates ($SB_{F=0}$). The latter option was included to reflect the fact that in some cases, estimates of recent productivity were considered more appropriate for the calculation of the SB and could perform better in non-equilibrium conditions. For example, past stock assessment of bigeye tuna in WCPFC had used recent average level recruitment as a more realistic basis for stock projections[126]. So far, the 20% $SB_{F=0}$ has been adopted as the LRP for all the species in WCPFC for which an LRP has been established.

The acceptable level of risk of breaching the limit reference point has also been established; it has been set to no more than 20% probability of breaching the LRP[127]. The Commission has set a cap instead of choosing a single level of risk for each species because there is not enough knowledge to back a single, species-specific, level of risk.

The Commission has agreed that a risk level above 20% will be too high and will not meet the LRP-related principle in UNFSA that requires that the risk of breaching limit reference points is very low (Annex 3). This is close to risk levels considered elsewhere, but slightly higher. For example, IATTC is using 10% as the risk that is acceptable and anything above that will trigger appropriate management to reduce fishing mortality[128]. Similarly, CCAMLR uses 10% risk of falling below their biomass limit as the constraint for agreeing fishing mortality rates[129]. ICES, on the other hand, uses a smaller risk level of 5% but that refers to the probability of falling below the limit biomass B_{lim} which is the limit below which there is significant risk of reproduction being impaired. Therefore, the consequences of falling below B_{lim} could be dire and that's why ICES has actually adopted another reference point called the precautionary reference point B_{pa}, which is higher than B_{lim}, to guide management action[130]. This is used to trigger reduced fishing mortality (below F_{MSY}) once the stock size drops below MSY-$B_{trigger}$. This way, ICES ensures that the risk of their limit reference point being breached is kept low[131]. The ICES case also highlights the link between the LRP and risk of falling below it. Broadly speaking, as the LRP gets smaller relative to the unexploited biomass the acceptable risk level is also expected to become smaller (more conservative). In the case of WCPFC, we have a higher LRP and we also see

[125] https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32013R1380&from=EN *Last accessed: 05/07/18*

[126] https://wcpfc.int/system/files/SC7-MI-WP-04%20%5Breference%20points%5D.pdf *Last accessed: 05/07/18*

[127] To put it simply, this means that through stochastic simulations they can identify those levels of exploitation that will lead to a stock biomass that falls below the limit reference point more than 20 times out of 100 and thus, will not be acceptable.

[128] https://www.iattc.org/PDFFiles2/Resolutions/C-16-02-Harvest-control-rules.pdf *Last accessed: 05/07/18*

[129] http://www.afma.gov.au/wp-content/uploads/2010/06/rep_sainsbury_best-practice_jan08_20080228.pdf *Last accessed: 05/07/18*

[130] http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2016/2016/Introduction_to_advice_2016.pdf *Last accessed: 05/07/18*

[131] http://ices.dk/sites/pub/Publication%20Reports/Advice/2016/2016/12.04.10_Criteria_for_defining_multi-annual_plans_as_precautionary.pdf *Last accessed: 05/07/18*

a slightly higher level of risk allowed relative to those observed in other areas/organisations.

The LRP has been used to guide management advice in the absence of an agreed TRP and therefore, some further discussion of LRPs and their use is provided in the next section.

5.1.4.2.2 TRP

Work on defining and agreeing target reference points have progressed for skipjack, so far, in terms of adopting a TRP; the TRP adopted for this species is an interim one. The TRP has been set equal to 50% $SB_{F=0}$. For the other species, TRPs have not been adopted but some work has been done to provide a picture of possible TRPs under consideration and their relation to current stock size. While work is progressing, the Commission has set depletion levels to be maintained as a bridge to the adoption of a harvest strategy. Those are set for bigeye and yellowfin tuna and aim to maintain the spawning biomass depletion ratio at recent levels (2012-2015).

Work has focused on supporting the process for agreeing a single level of risk for each species and its links to the TRP. The following technical advice has already been provided by the SC for 4 of the key species to support the process[132]: "The lowest risk tolerance (5%) requires a larger buffer and implies minimum targets of greater than ~30%$SB_{F=0}$ for SKJ, YFT and BET and greater than 37% $SB_{F=0}$ for ALB". Furthermore, "the spawning biomass (relative to the spawning biomass under 0 fishing) required to ensure that we do not exceed a certain level of risk of falling below the LRP increases as the risk of exceeding the LRP goes from 20% to 5%". A summary of the findings of the analysis that underpinned this advice is presented in Figure 23. The acceptable range of RPs (green colour) is set equal to a bigger proportion of the SBF=0 (i.e. $SB/SB_{F=0}$) and hence, further away from the LRP, as the risk tolerance is reduced from 20% to 5%.

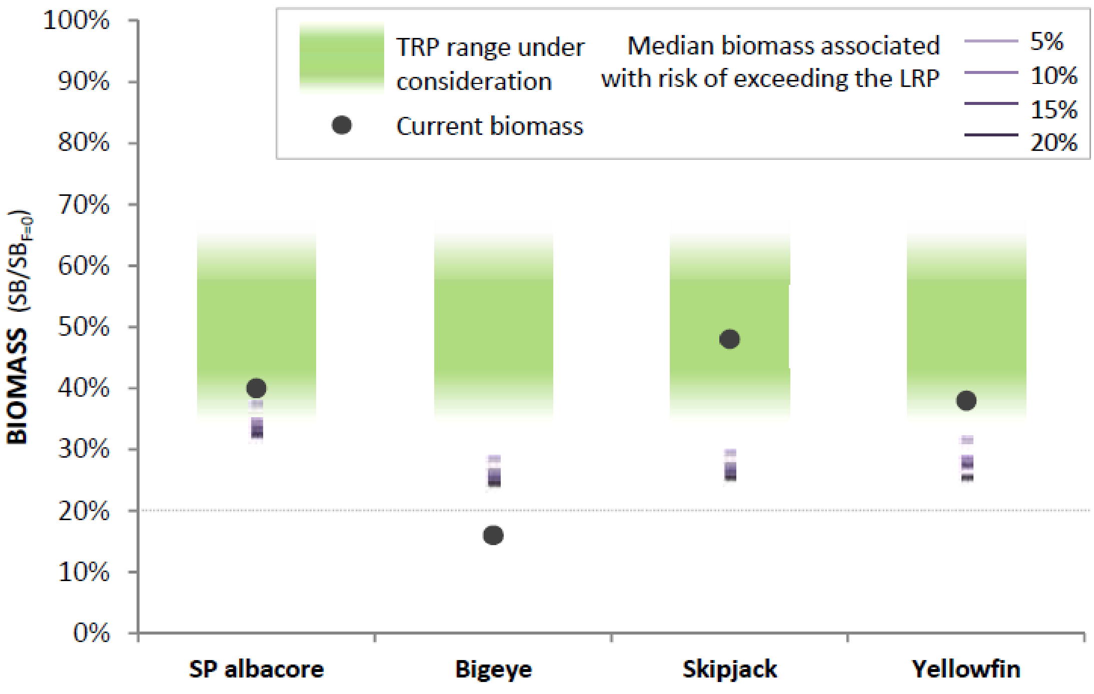

Figure 23: Relationship between the limit reference point (grey line), the spawning biomass (SB, median value) that is required to ensure that we do not exceed a certain level of risk of falling below the LRP (rectangles in grey scale), the current biomass (black

132 https://www.wcpfc.int/system/files/FINAL%20HSW%20Report%20for%20WCPFC12_1.pdf *Last accessed: 05/07/18*

dot) and the target reference point range (Source: WCPFC Harvest control workshop 2015 report)

The analysis conducted by the SC provides a good starting point for considering a TRP as it indicates that TRPs above the minimum targets (expressed as median biomass in the results presented in the graph above) will be in line with the requirements of the convention, including the precautionary principle.

The range of TRPs identified starts at 24% of the recent spawning biomass in the absence of fishing for bigeye and increase to 38% for SP albacore. Using the most recent estimates for MSY (Table 19), we can see that for species like SPO albacore, the minimum relative value of the spawning stock biomass (32%) in the range of the TRP values is well above the relative spawning biomass that corresponds to MSY (13%). Therefore, the adoption of lower risk tolerance requires targets that are above the biomass that corresponds to MSY, at least for some species. So, there are trade-offs to be made between available catches and level of risk tolerance. However, the fact that the range of TRPs identified is close or above the MSY-based equivalent is not unexpected. In fact, as mentioned already in this report and in section 2, MSY is seen as the upper limit. As such, one expects that the TRPs expressed in terms of spawning biomass will be at or above their MSY-based equivalent. Below we look at the case of skipjack to illustrate the type of considerations that are relevant for this element of the HS including catches and how they are affected by the adopted TRP. We also discuss this issue more broadly in the next section, when we look at other options for setting TRPs (Section 5.1.5).

Table 19: MSY related estimates for the 6 tuna species – values represent median estimates[133] of the probability distribution. Note, that the LRP for WCPFC species has been set to 20% of spawning stock biomass under no fishing[134].

Species	SB_{MSY}/SSB_0	$SB_{MSY}/SB_{F=0}$	MSY (1000 Mt)
Bigeye tuna	0.26	0.24	158
Yellowfin tuna	0.24	0.26	670
Skipjack	0.25	0.23	1,875
SPO albacore	0.14	0.13	85
NPO albacore	0.14	0.15	132
Pacific Bluefin tuna	Not available	Not available	Not available

The proposed minimum TRP at 5% risk level for skipjack estimated in the analysis of the SC presented in Figure 23 is less than the interim TRP already adopted which is 50% $SB_{F=0}$. This means that the adopted interim TRP leads to a low (and within acceptable levels) risk of the population dropping below the LRP. The adopted TRP has been based on analysis that takes into account both biomass depletion and fishing effort relative to the MSY levels and looked at the impacts of different possible TRPs as shown in Table 20. The adopted TRP (50% $SB_{F=0}$) achieves equilibrium yield which is very close to MSY but without producing fishing mortality that could be higher than the fishing mortality that corresponds

[133] Except for NPO albacore which are point estimates (deterministic analysis) for the base case model
[134] https://www.wcpfc.int/folder/currernt-stock-status-and-advice-key-documents Last accessed: 05/07/18 SB_0 represents the spawning stock biomass under unexploited (virgin) conditions.

to MSY. Therefore, it delivers conservation benefits with minimum compromise in terms of the amount of food that can be produced. On the contrary, as Table 20 shows, a smaller target (such as 40% $SB_{recent,F=0}$) could lead to fishing mortality that exceeds the fishing mortality associated with MSY which is not a desirable outcome.

Table 20: Expected spawning biomass, yield, and fishing mortality for different options of the target reference point for skipjack (source: WCPFC12-2015-DP06[135])

Depletion level (%SSBF=0)		Change in spawning biomass from 2012 levels	Change in effort from 2012 levels	Equilibrium yield (%MSY)		Mean size of fish (cm)	F/FMSY	
Median	Range (10-90th %ile)			Median	Range (10-90th %ile)		Median	Range (10-90th %ile)
60%	0.53–0.69	+22%	-33%	76%	68-87	54	0.40	0.29-0.56
50%	0.42-0.58	+2%	0	90%	81-98	53	0.57	0.41-0.80
40%	0.32-0.47	-18%	+50%	98%	92-100	52	0.79	0.57-1.10

As the interim TRP leads to minimum (or no) change in the fishing activity in recent years it is unlikely to have immediate negative impacts for the countries/fleets that fish for this species. However, as the TRP is seen as a RP not to be exceeded it creates a constraint that will be taken into account when calculating future catch quota.

In addition to work undertaken for skipjack, an important part of recent discussions has been devoted to making progress with the bridging CMM (Conversation management Measures) for SP albacore. In response to requests to SC for advice, a paper was prepared on the expected changes in catch rates, effort, catch and economic viability in the SP albacore fishery over a 20 year timeframe for a number of candidate TRPs. The candidate reference points ranged from MSY (14%$SSB_{F=0}$) to MEY (59%$SB_{F=0}$)[136] and the main results are presented in Table 21[137].

[135] https://www.wcpfc.int/system/files/HSW-IP-04%20FFA%20proposal%20for%20TRP%20for%20skipjack%20%28WCPFC12-2015-DP06%29.pdf *Last accessed*: 05/07/18
[136] Thirteenth Regular Session of the WCPFC Scientific Committee draft report
[137] Source: WCPFC-SC13-2017/MI-WP-01

Table 21: Expected consequences for the SPO albacore fishery of a range of potential TRPs as presented in WCPFC-SC13-2017/MI-WP-01

Option #	TRP (median SB2033/$SB_{F=0}$)	Change in Vulnerable biomass in 2033 relative to 2013 [138]	Change in effort by 2033 relative to 2013 to achieve TRP	Average change in total catch in 2033 relative to 2013 resulting from TRP	Risk of breaching 20% $SB_{F=0}$ LRP in 2033	Result for this level of TRP once fishery reaches equilibrium
1	59%	+49%	at least -75%	-59%	0%	**Maximum Economic Yield achieved**
2	45%	+17%	-47%	-41%	0%	**Allows 20% revenue margin** per average vessel over costs at US$1.10 cost per hook or **10% revenue margin** for a high cost vessel over costs at $1.30 per hook
3	42%	+10%	-39%	-38%	0%	**Allows financial break-even** per vessel if cost is $1.30 per hook
4	40%	+5%	-33%	-36%	0%	**Allows 10% revenue margin** over costs at $1.10 per hook
5	37%	-1%	-23%	-33%	4%	**Allows break-even** if cost is $1.10 per hook
6	34%	-8%	-12%	-30%	9%	**Allows 10% revenue margin** over costs at $0.90 per hook
7	32%	-14%	0% (status quo)	-28%	20%	**Achieved if no change in effort from 2013**: Allows break-even only if cost per hook is less than $0.90
8	14%	-56%	+150%	-22%	74%	**Maximum Sustainable Yield achieved**

[138] Median longline VB2033/VB2013

The results of the paper showed that a choice of any TRP which will be greater than 32%$SB_{F=0}$ is expected to lead to reduction in current fishing effort to achieve that target but all choices of TRP will also lead to lower catches in the long term (i.e. 2033). Simulation modelling was used to produce these estimates and a number of assumptions were made, including assumptions about the cost of fishing and catch price structure for this species. The SC has not recommended a TRP for SP albacore but proposals have been presented that support a TRP of 45%$SB_{F=0}$[139] based on the results of this analysis. However, those proposals use a cost of fishing that appears to be higher than that incurred by, at least, some countries, and relies on assumptions about management objectives that will be adopted for this fishery in the future.

Catches of the EU countries of SPO albacore constitute a very small proportion of the total catches of that fleet so, depending on the choice of the TRP, they might experience a negative impact on their overall catches but that will be very small.

Work on creating bridging CMM for **skipjack**, **yellowfin and bigeye** has mainly focused on the LRP to be used in the interim and has reiterated the choice of 20%$SB_{F=0}$ as the LRP to be used to guide management advice in the absence of other reference points. However, in the case of **skipjack**, the interim TRP has already been agreed and therefore, that will be used instead of LRP. For the other two species, support had been given to the adoption of current spawning biomass size as the interim target reference point and the Commission did adopted measures at its 2017 meeting to ensure that spawning biomass is maintained at recent levels.

Maintaining the **yellowfin tuna** stock at current levels (which is higher than the LRP) provides a good buffer as it remains above the median biomass associated with 5% risk of exceeding LRP (Figure 23). It is not clear how similar the economics of this fishery are to that of the SPO albacore, but that might also be of use as a guidance in terms of the TRP that can maintain a profitable sector (see discussion above and Table 21).

For **bigeye tuna**, the latest stock assessment results supported using 20%$SB_{F=0}$ as the reference point in the interim. Specifically, the results suggested that there was more than 80% probability that recent bigeye tuna spawning biomass had not breached the LRP of 0.2*$SB_{F=0}$[140]. Further exploration is needed to understand changes from the previous model used and the impacts of assumptions, such as spatial allocation of the population and the use of geostatistical approaches for CPUE standardisation, but these results lend support to the adoption of measures to maintain SSB at levels observed recently. A point of concern is the slight decline of the spawning potential in the last year of the assessment, which highlighted that close monitoring and robust harvest plans are still important.

5.1.4.3 Monitoring strategy

For this element of the harvest strategy, we consider the work that has been done recently for **skipjack** (the discussion also applies to **yellowfin** and **bigeye**) but also make reference to monitoring strategy for **PBF tuna**. This section uses the same definitions as those used in the working papers of the WCPFC and which state that: "the monitoring strategy tracks the actual performance of the selected management procedure, once it has been implemented, to see if it is performing as expected and that the actual outcomes are within the range of values predicted by the MSE". Also, the definition used for performance indicators is "Performance indicators are used to measure how well a specific harvest strategy achieves some or all of the general

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139 https://www.wcpfc.int/system/files/WCPFC-IM-SPA%20Meeting%20Report%2011%20October%202017.docx *Last accessed*: 05/07/18

140 Thirteenth Regular Session of the WCPFC Scientific Committee draft report.

objectives for management. They are interpreted in relation to defined limit or target reference points, or to management objectives"

The monitoring strategy proposed for PBF tuna focuses on a key component of the assessment analysis, which is recruitment estimates[141]. Given limited information about the steepness of the stock-recruitment relation, this element of the analysis brings uncertainty, and therefore regular review of recruitment data will allow a quick response if observations differ from the recruitment levels used for assessment purposes. This is a valid approach that responds to a key source of uncertainty and will support stock assessments and scenario modelling to consider the rebuilding potential of the stock under different assumptions about recruitment levels. The monitoring required relies on collection of data that are probably being collected already (e.g. indicators related to juvenile species). However, given the low level of the stock, monitoring needs to consider relevant indicators very frequently (note that no new relevant information on PBF tuna was presented at the SC meeting in 2017) to ensure prompt action, and that can be a challenge.

The initial list of performance indicators that have been developed for skipjack and accompany the monitoring strategy is quite comprehensive and reflects the Commission's focus on both conservation and socioeconomics. Therefore, one of the strengths of the list is that it seeks to capture a comprehensive picture of the fishery and its impacts and that is reflected on the breadth of indicators captured in the list. Another strength of the performance indicators and monitoring strategy is that it aims to build on data that are already collected, or to find proxies for indicators for which data might not be readily available. For example, for the economic management objective: "Maximise SIDS revenues from resource rents" the suggestion is that data on effort could be used to calculate the proportion of SIDS effort/catch to total effort/catch from SIDS waters and use that as an indicator of revenue for SIDs. Effort data are already available from logbooks and VMS data can help define the spatial distribution of effort even better. Therefore, this will not lead to collection of additional data and helps reduce the cost of the monitoring strategy. Similarly, the performance indicator for this management objective uses the value of catches which could be found using fish prices from public databases.

On the other hand, there are indicators that will be more difficult to calculate (e.g. Maximum Economic Yield, MEY) and that will create challenges. Concerns have already been raised about the inability of Contracting Parties to collect data to monitor all the indicators both because of costs and also other resource constraints. Furthermore, some data might be sensitive and the industry/MS might be reluctant to provide them. For example, calculation of MEY will require financial data, such as cost of fishing operations, and such information is unlikely to be readily available.

The performance indicators and monitoring strategy has followed a pragmatic approach relying mainly on data that are already available. This might lead to some indicators being crude but provides a good starting point for building a comprehensive monitoring strategy.

5.1.4.4 Harvest control rules

There is limited work done to define HCRs and it is mainly qualitative/empirical at the moment. For example, the decision rule in place for NPO albacore relates to the adopted LRP and aims to initiate prompt action in case the spawning stock falls below the LRP. The action is that the Commission needs to define a time plan for rebuilding the

[141] Northern Committee, Thirteenth Regular Session, Summary Report. https://www.wcpfc.int/system/files/NC13%20Summary%20Report%20adopted%20-%20Final%20%28Update%29-clean.docx *Last accessed*: 05/07/18

spawning stock to at least the LRP[142], and that time plan should not be longer than 10 years. That corresponds to two generation time periods and was considered appropriate for this species[143]. However, exploratory work has started for skipjack looking at alternative HCRs, and some of the HCRs considered are shown in Table 22 and Figure 24 (Scott et al., 2016)[144].

The evaluation process used for this element of the harvest strategy is underpinned by a simulation-evaluation modelling framework. The framework that has been increasingly employed recently to test the robustness of management measures under uncertainty is Management Strategy Evaluation (MSE, Punt et al., 2015). The main component of an MSE is the operating model which simulates the "true" state of the population and its exploitation. It also includes a stock assessment model that estimates the status of the stock for the species of interest using data from the operating model. Probabilistic calculations are used to reflect uncertainty in the system. A HCR can then be incorporated into the calculations to test the robustness of the management advice that it produces. Through MSE, different HCRs can be tested to evaluate their performance under alternative hypothesis about present and future states of nature using agreed performance indicators. The results for each HCR can be easily compared to each other as the calculations have been done under identical conditions.

Table 22: Control parameter settings for candidate harvest control rules (HCR) considered. Control parameters (CP) are the trigger points for management action that determine the shape of the harvest control rule. (Source: Scott et al., 2016, as above)

	CP1: SB/SBF=0	CP2: SB/SBF=0	CP3: Catches (t)	Comments
HCR2	0.4	0.2	-	-
HCR3	0.48	0.2	-	-
HCR4	0.48	0.2	-	Non-linear decline to CP2
HCR5	0.48	0.2	1,400,000	Additional trigger: effort is reduced if catch > CP3

The analysis for skipjack used a Multifan-CL model to evaluate the HCRs; the model was run forward for 30 years using the status of the stock as defined in the 2014 reference case assessment (Rice et al., 2014) as their starting point. Future effort is defined by the HCR evaluated and the assumption was that management decisions are reviewed every 3 years. Essentially, the same type of model used for stock assessment (Multifan-CL) was also used for the HCR evaluation. This is a statistical, age-structured, length-based model that can be fitted to size-frequency and tagging data in addition to more traditional data such as catches and catch rate (Davies et al., 2017). Therefore, it provides flexibility in the range of complexity one wants to incorporate into the analysis.

[142] https://www.wcpfc.int/harvest-strategy *Latest accessed: 05/07/18*
[143] https://www.wcpfc.int/system/files/MI-WP-02-Time-Window-LRP.pdf Last accessed 05/07/18
[144] Scott et al 2016. Evaluation of candidate harvest control rules for the tropical skipjack purse seine fishery. WCPFC SC12-MI-WP-06

Evaluation of the performance of these HCRs showed that the size of the stock could be maintained at TRP only if there was no effort creep[145] assumed in the future. For example, when year-to-year effort creep of 2% was used, none of the HCRs were able to maintain the stock at or close to TRP. Also, all the 4 HCRs led to a decline in catches and CPUE when effort creep was set to zero.

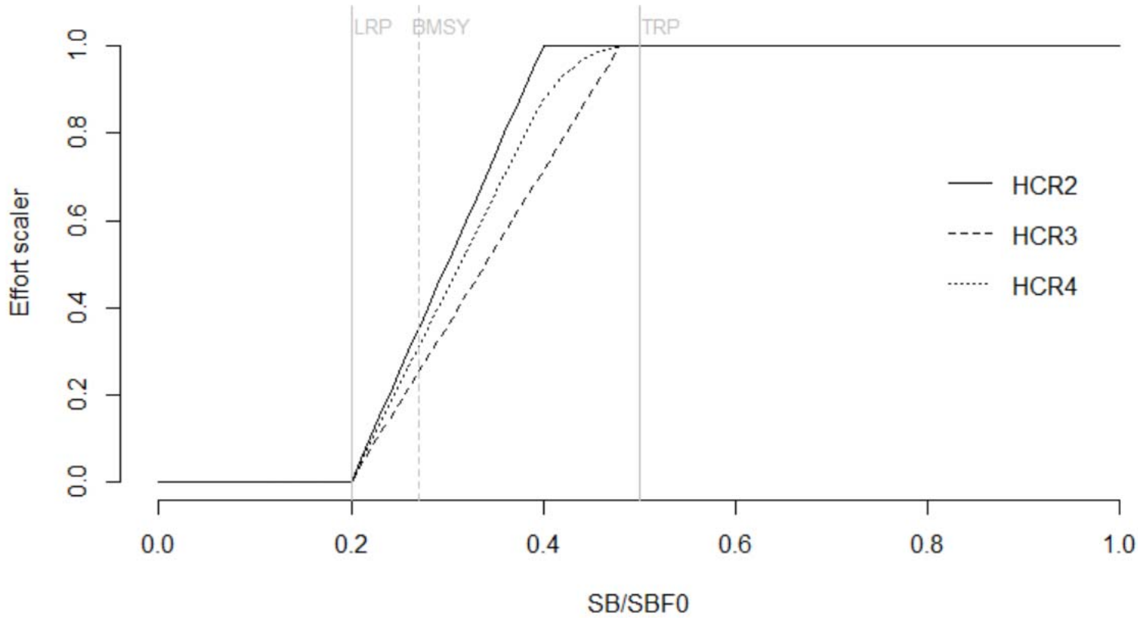

Figure 24: Candidate effort-based harvest control rules. Effort is maintained at 2012 effort levels for SB/SBF=0 above some biomass trigger point (HCR2 = 0.4; HCR3 and HCR4 = 0.48). For HCR4 effort declines progressively. HCR5 is identical to HCR3 in form, but includes an additional catch level trigger. (Source: Scott et al, 2016)

The results of this exploratory analysis on potential HCRs have highlighted the challenges involved in identifying effective HCRs and provide useful insight into alternative configurations to use to develop HCRs. However, this element of a harvest strategy is still in development and the analysis for skipjack is preliminary. The analysis does use a detailed model (Multifan-CL) but does not make use of a full MSE framework. This is because the same model was used as the operating model and the stock assessment model, which is not recommended as it can lead to underestimation of uncertainty. Next steps in this part of the MSE work will also benefit from better characterisation of the effort creep and better-defined scenarios about trends and ways to describe them as part of the fleet dynamics.

5.1.5 Additional options to consider as part of the development of Harvest strategies

As discussed above, it is the adoption of reference points that has been the main focus of technical work and policy discussions on harvest strategies so far. Therefore, this section focuses on that element and provides options for setting RPs for the different key species covered in WCPFC and for which enough information is available to allow us to express an informed opinion. There are 4 options for setting RPs that are described below; a) MSY-based RPs, b) RPs based on a min (5% or less) level of risk and c) the

[145] Effort creep describes the situation where fishing vessels improve their ability to catch fish over time within an effort-managed system, and hence catch more per fishing day. Source: Pilling et al., 2017, WCPFC-SC13-2017/MI-IP-04

maximum risk of breaching the LRP allowed by the WCPFC, and d) an ICES-style approach for setting RPs. For each of them, we discuss the resulting RP values in the context of the overall approach used in WCPFC and other t-RFMOs.

5.1.5.1 Option 1 - Compatibility with IATTC and MSY-based reference points

This option notes the recent interim HCR adopted by IATTC for yellowfin, bigeye, and skipjack (see previous sections and Annex 2) and aims to ensure high compatibility with IATTC, given that there is overlap of the areas for which each organisation is responsible. With that in mind, an option for LRP is to set it equal to the spawning biomass associated with 50% reduction in recruitment when steepness is equal to 0.75, which is what IATTC has done. Pre-defining the steepness of the recruitment functions and setting it at the same level for all species is a strong assumption and means that species-specific recruitment information is given much less weight. This reduces flexibility and the discrepancy it creates becomes apparent when one considers the assumptions about steepness of the recruitment function used in the tuna stock assessments in WCPFC. The values of steepness used for the WCPFC tuna species range from 0.65 to very close to 1 (see Figure 25 for spawning biomass that corresponds to different levels of recruitment reduction under the Beverton-Holt stock recruit relationship). This could lead to estimates for reference points that are not representative of individual stocks. Maybe of more importance though is to note that this approach will lead to values that are well below the 20% of recent spawning biomass in the absence of fishing which is the LRP adopted by WCPFC for these species at present.

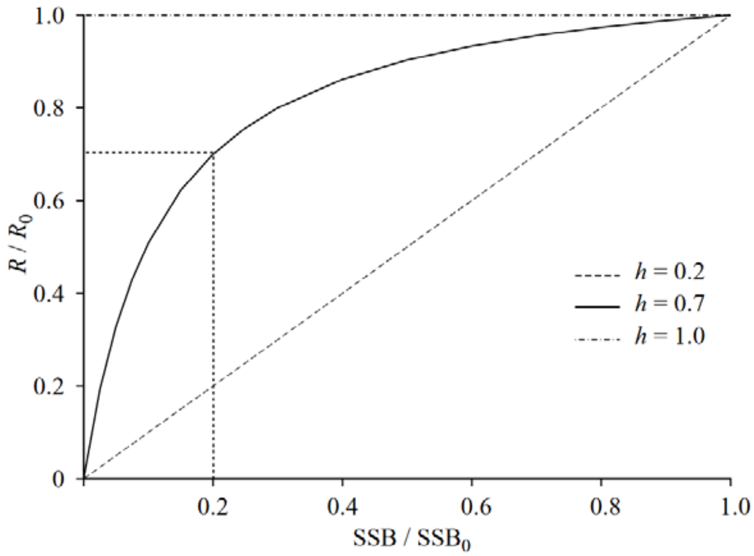

Figure 25: Recruitment curves from the Beverton–Holt stock–recruit relationship using the steepness parameter, h, for h = 0.2 (diagonal straight line), 0.7 and 1.0 (top horizontal line). R is recruitment and SSB is spawning stock biomass. The number 0 next to those symbols indicate their value under unfished conditions (i.e. virgin conditions). (Source: Beddington and Kirkwood 2005)

The HCR also defines the TRP in both fishing mortality and biomass and set them equal to those that lead to MSY. This option follows a more conventional approach as MSY is a well understood and used reference points. The BMSY relative to spawning biomass in the absence of fishing for the 6 tuna species covered in the HCR considerations in WCPFC have been presented above (Table 19). Either the MSY or fishing mortality leading to MSY can also be used to set the TRP with regards to catches or the level of fishing activity, respectively.

Although this is a conventional way to approach TRPs it does create limitations. For example, the MSY might not provide the greatest benefits with regards to the economic viability of the fleet, securing access of local communities to resources, etc. Therefore, its appropriateness depends on the socioeconomic as well as conservation objectives set for each fishery. Furthermore, this approach will breach the adopted LRP for some species; for example, for SPO albacore if the TRP is set equal to the relative MSY that will mean that the TRP will become lower than the corresponding LRP. Similarly, for some of the other species, it will be close enough to 20% of the spawning biomass in the absence of fishing that it is expected to lead to considerable risk of breaching the LRP.

5.1.5.2 Option 2: Follow species-specific calculations on risk levels to set limits for risk < 5%

Results presented already in the previous section provide information about plausible reference points for different species. One option is to choose a TRP that has 5% or less probability of breaching the corresponding LRP for each species. Using the information from Figure 23 we can see that for bigeye, skipjack, and yellowfin, such a TRP would aim to keep SB[146] at sizes greater than 28%, 29%, and 31% of SB in the absence of fishing to provide a buffer and reduce the risk of breaching the LRP to below 5%. For SPO albacore, the TRP will need to be set at higher level, at 38% or above, to create the necessary buffer. For skipjack, this TRP is less than that adopted in the interim, but the choice of the latter was made taking into account both conservation and economic factors. The values identified here are greater than those proposed by IATTC (i.e. MSY-based) which, using the values from Table 19, will be less than 30% of the unexploited spawning biomass for all 4 species.

5.1.5.3 Option 3: Follow species-specific calculations on risk levels to set limits for risk < 20%

Similar to the approach above, a higher level of risk can be assumed (that is 20%; the maximum considered acceptable by the Commission) and used to identify TRPs, as in the previous option. That approach leads to slightly lower reference points than those under Option 2 (Figure 23). For bigeye, skipjack, and yellowfin, the new reference points will be greater than 24% while for SPO albacore, that will be above 30% of the spawning biomass in the absence of fishing[147]. These values are very close to the TRP we would get if we followed the approach proposed by IATTC for the first 3 species. As above, for skipjack, this reference point is much less than that adopted as the interim TRP. Under this approach and associated TRP, catches could go up for 3 out of the 4 species (i.e. except for bigeye) because the current population of the 3 species is estimated to be above this TRP.

5.1.5.4 Option 4: The precautionary approach reference points used in ICES

Another way to define a TRP is to use the precautionary approach adopted in ICES to set precautionary limits. The approach starts with the limit reference point Blim identified for a given stock, and multiply that by a constant greater than 1. This new value is the precautionary approach limit and it is usually about 40% higher than the

[146] Here we present these reference points in terms of biomass but the same process could identify such points in terms of fishing effort. In this case (5% or less of risk), the fishing mortality relative to the fishing mortality at MSY would be 0.87 for bigeye, 1.17 for skipjack, 1.05 for yellowfin, and 0.86 for SPO albacore. https://www.wcpfc.int/system/files/MOW3%20WP-02%20Risk%20of%20exceeding%20LRP.pdf Last accessed: 05/07/18

[147] The equivalent TRPs expressed in relative fishing effort (F/Fmsy) would be 1 for bigeye, 1.36 for skipjack, 1.23 for yellowfin, and 0.95 for SPO albacore.

LRP (i.e. multiply by 1.4). However, that proportion will change depending on the uncertainty characterising the assessment estimates of current spawning biomass. This new reference point could be used as a starting point for the identification of TRP in the case of WCPFC stocks. The main difference in this case is that all key tuna stocks have (almost) the same relative LRP (i.e. $0.2*SB_{F=0}$) and therefore, the precautionary approach limit will start from the same ratio of spawning biomass relative to the unexploited one for all of them. The main difference then will come from differences in the value of uncertainty used for each species. This uncertainty can be calculated for each of the tuna species, but here, for illustrations purposes, we assume that the multiplier is the same for all of them and equal to 1.4. The resulting TRPs will be higher than the TRPs that correspond to MSY (option 1) for all 5 species but lower than the TRPs calculated under options 2 and 3. Therefore, setting TRP at that level could offer an alternative approach (possibly, an interim one) but it might not create the necessary buffer to ensure that the risk of breaching the LRP will not be exceeded.

5.1.6 Conclusions

IOTC and ICCAT have made considerable progress in developing Harvest Strategies with the adoption of Skipjack (IOTC Resolution 16/02) and Northern albacore (ICCAT Recommendation 17/04) Harvest Control Rules, respectively. Similarly, WCPFC has also progressed in developing Harvest strategies incorporating MEY concept and list of management objectives that covers socioeconomic as well as environmental objectives are components of such an approach. At the same time, their work provides an insight into complexities and challenges that such a broader view of fisheries management can entail but also the potential it has. For example, through their work, WCPFC has tried to operationalise the use of MEY by explicitly accounting for economic yield (e.g. revenues) in their analysis despite concerns about completeness and viability of such work. The results have shown that information can be found to do this type of analysis (e.g. profit/revenue maximising exploitation) if all Contracting Parties contribute constructive into the process (e.g. efficient information sharing). At the same time, the use of MEY provides for an industry that is profitable and takes advantage of market trends and technological advances to achieve the best price and profit margins. However, higher fish prices mean reduced access to people of lower economic income to this important source of nutrients (e.g. developing countries, coastal communities that might rely on fish for their food). This highlights the need for a more holistic approach and why it is important to have management objectives that ensure that there is equitable access to benefits that reflect the needs of the different communities.

There are options other than those currently suggested in the SC meetings and other working groups that could also lead to plausible harvest strategies and we have discussed some of them in this report. It is obvious that there is a diverse range of options that one can consider for the management of a fishery. However, it is not possible to say which of them performs better until it is clear what the strategy needs to achieve. Therefore, agreeing on management objectives including priorities and weight assigned to each objective still remains a crucial step that, once completed, will add clarity to the process.

5.2 Sub-task 4.2: Development of mixed fisheries and single stock MSE for tropical tunas for International Commission for the Conservation of Atlantic Tunas (ICCAT) and Indian Ocean Tuna Commission (IOTC): Define options and preliminary models

5.2.1 Introduction and review of current state

ICCAT has committed to adopt harvest strategies or MP to achieve its management objectives of high long-term yields whilst maintaining stocks within sustainable limits with high probability, consistent with the PA. The PA seeks to protect fish stocks from fishing practices that may put their long-term viability in jeopardy despite the many unknowns on stocks biology, response to fishing or exact state of exploitation (Garcia, 1996).

The current management framework of ICCAT's tropical tuna stocks is based on Recommendation 11-13, which recommends management actions for the different states of exploitation of the stocks, expressed in biomass and harvest rates relative to their corresponding Maximum Sustainable Yield RPs. The implicit target of this recommendation is to maintain the stocks in the green area ($B>B_{MSY}$ and $F<F_{MSY}$) with high probability, which adds to the traditional objective of achieving MSY. However, this recommendation relies on the interpretation of what is considered 'high probability' and 'as short a period as possible' (Figure 26).

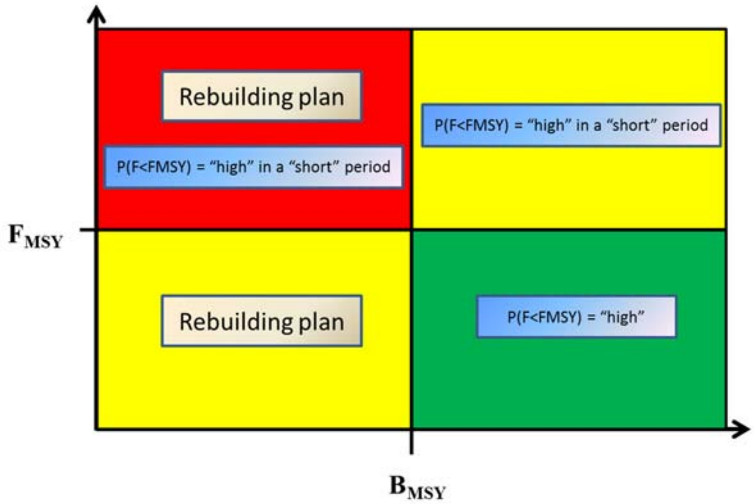

Figure 26: ICCAT's management framework based on Rec. 11-13.

ICCAT's Working Group to Enhance the Dialogue between Fisheries Scientists and Managers recommended ways to further define the current management framework building on Recommendation 11-13, in particular in relation to RPs, associated probabilities and timeframes (Rec. 15-07). Also, one of the main goals of ICCAT's SCRS Science Strategic Plan (2015-2020) is to evaluate precautionary management RPs and MPs that are robust to the many uncertainties inherent to fisheries. In this context, ICCAT also aims at adopting HCRs, i.e. a set of pre-agreed (and specific) management decisions that are used to set limits to catch or effort according to the state of some indicators of stock status with respect to reference points. Therefore, ICCAT is moving towards a scientifically sound and specific decision-making scheme that needs to be evaluated before adoption.

Bigeye tuna (BET), yellowfin tuna (YFT) and skipjack (SKJ) are the three tropical tuna stocks fished in the Atlantic. These stocks are often caught simultaneously, but are assessed independently: this might lead to undesired effects in the implementation of the single stock TAC. For example, the mismatch between the catch profiles of the fleets and the single stock advice can produce an incentive to generate over-quota discards of one of the stocks if its catch limits are exceeded but not the others' (Ulrich et al., 2011). According to the FAO Code of Conduct for Responsible Fisheries and other international agreements, discards are generally considered a waste of fish resources and inconsistent with responsible fisheries (FAO, 1995). ICCAT, in its ICCAT Information on By-Catch of Tuna Fisheries (available via iccat.int) also calls for a reduction of discards. Therefore, a responsible management of tuna stocks would avoid discards.

The mismatch between single stocks' TAC could be avoided using a multi-stock management framework, e.g. multi-stock harvest control rules. ICCAT foresees to adopt a specific management plan for tropical tunas by 2019 and for this it needs support to evaluate multi-species management measures. MSE with simulation tests can be a valuable tool to estimate different levels of probability of achieving management objectives through different management options. To support the development of a robust advice framework for tropical tuna stocks, we used a preliminary MSE framework to test a series of multi-stock harvest control rules.

In those lines, ICCAT has just funded a Call for Tenders to support the development of a robust advice framework consistent with the Precautionary Approach (PA) for the Atlantic tropical tuna stocks. The objectives of this initiative include developing a MSE framework composed by a series of OMs and MPs for tropical tuna stocks. As a main novelty, this project foresees to evaluate multispecies HCRs similar to the ones describe in this section. Therefore, the results presented here are a first step towards the evaluation of multispecies MPs in the tuna RFMO context. For now, except for fishing effort limitations, there is no MSE develop for more than one stock in any tuna RFMO.

At this moment, in IOTC there is no plans for considering multispecies MP for tropical tunas or any other stock.

According to the most recent assessments of these stocks bigeye is overfished and subject to overfishing, yellowfin is overfished but not subject to overfishing and the East and West skipjack stocks are most likely not overfished nor subject to overfishing. In this study we use MSE to explore the potential capacity of different multispecies HCRs to achieve ICCAT's management objectives. In brief, we have evaluated three types of HCR: 1) A constant TAC strategy (referred as E75 in the scenarios), 2) The ICES MSY framework HCR and, 3) A multi-stock HCR aiming at MSY ranges for the three tropical tuna stocks.

The HCRs have been evaluated under different scenarios for fleet dynamics or strategies on effort allocation, which determine how much effort is applied to each stock and how this is allocated between different *métiers* within a fleet. In this case, the *métiers* refer to the two modalities of purse seine fishing (free school and FADs). In particular, the E75 HCR assumes a 75% of the status quo effort with the current share of effort (i.e. fishing mortality reduction of 25%) between FADs and free school; the ICES multi-stock HCRs calculate effort and TAC for two different levels of effort allocation between métiers. This approach is based on the Fcube method presented in Ulrich et al., (2011) and Iriondo et al., (2012). The basis of the model is to estimate the potential future levels of effort by fleet corresponding to the fishing opportunities (TACs by stock and/or effort allocations by fleet) available to that fleet, based on how the fleet distributes its effort across its métiers, and the catchability of each of these métiers. This level of effort is in return used to estimate landings and catches by fleet and stock, using standard forecasting procedures. The inputs required to perform the forecast are: mean weight at age, the mean selectivity at age, discard ratio (3 year averages) and recruitment (geometric mean).

5.2.2 Material and Methods

We developed the MSE using the modelling platform FLBEIA, a bio-economic impact assessment model based on the MSE approach (Jardim et al., 2013; Garcia et al., 2017).

This model is written in R and requires the use of FLR libraries[148]. Figure 27 shows the structure of the MSE built with FLBEIA which includes operating and management Procedure models. The OM is composed by stock, fleet and OM covariates (environmental variables, prey, predators etc.), and the MP is composed by the data collection, stock assessment and decision making.

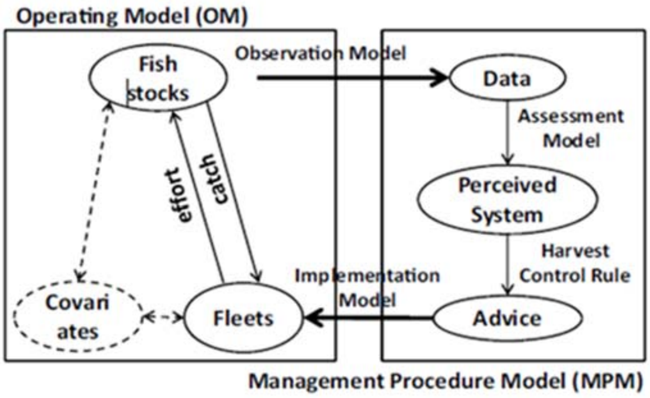

Figure 27: Conceptual representation of the main components modelled in FLBEIA (Garcia et al., 2013).

In general, MSE involves using simulation to compare the relative effectiveness for achieving management objectives of different combinations of (i) data collection schemes, (ii) methods of stock assessment and (iii) subsequent process leading management actions (Punt et al., 2016), i.e. different MPs. In this document we show preliminary results on the performance of a multi-stock HCRs which makes use of fishing mortality ranges to generate multi-stock TAC advice. To carry out this MSE, guidelines and best practices summarized in Rademeyer et al. (2007) and Punt et al. (2016) were followed.

5.2.2.1 Management objectives

The overall management intention in ICCAT is to assure the long term sustainability of the stock as well as of the fisheries, which in operational terms is translated as the highest long-term average catch with a high probability of being in the green quadrant (the target) and a low probability of being outside biological limits (the limit) (ISSF 2013).

5.2.2.2 Selection of hypotheses

We condition the MSE with the reference case of the latest SS3 stock assessments of bigeye and yellowfin. For the eastern skipjack tuna the results of a preliminary SS3 model are used (Quang, in preparation).

5.2.2.3 Operating Models

For the purposes of this study, the OMs are age structured population dynamic models conditioned from the outputs of the SS3 models available for bigeye, yellowfin and Eastern skipjack. Western skipjack was not considered in the study because there is not an age structured assessment model available actually for this stock. Biological parameters such as maturity, and natural mortality at age are taken directly from the SS3 models. A deterministic segmented regression model is assumed for the stock-

[148] www.flr-project.org

recruitment relationships and its parameters are calculated from the data series produced by the assessment models (SS3) assuming a steepness of 0.8 for the three stocks, however, in the interpretation of the results, it must be taken into consideration that in the assessment of bigeye and yellowfin tuna, different steepness value are considered between 0.7-0.9 and 0.75-0.95 respectively, and the reproductive potential of SKJ could be higher than for the other two stocks. A degree of statistical uncertainty is considered in the S-R relationship assuming a lognormal variability distribution (CV=30%).

5.2.2.4 Management Procedure

In the current set up, the MSE does not include any data collection, assessment model or implementation process. Therefore, the simulations shown here assume that the information on stock status is perfect and that management measures are implemented without error. In the future, this MSE will be developed to include observation errors, the assessment models and a detailed decision-making framework.

Fmsy ranges for each of the stock were estimated following the ICES MSY framework (ICES 2017c). The range of fishing mortalities compatible with an MSY approach to fishing were de-fined as the range of fishing mortalities leading to no less than 95% of MSY and which were precautionary in the sense that the probability of SSB falling below Blim in a year in long-term simulations with fixed F was ≤5%. Eqsim (stochastic equilibrium reference point software) function defined in the msy R package was used to provide MSY reference points based on the equilibrium distribution of stochastic projections. Productivity parameters (i.e. year vectors for natural mortality, weights-at-age, maturities, and selectivity) are resampled at random from between 2005 and 2014 for the three stocks. Recruitments are resampled from their predictive distribution which is based on parametric models fitted to the full time-series provided in this case, Ricker, segmented regression and Beverton and Holt were assumed for the three stocks.

The MP of this MSE is composed by three types of HCRs: 1) A fixed advice of constant TAC (E75) (based on effort), 2) The ICES MSY framework HCR with two options (ices_Emin and ices_Ebet) (based on catch) and, 3) A multi-stock HCR aiming at MSY ranges for the three tropical tuna stocks (multi_Emin and multi_Ebet) (based on catch), see Table 23 and sub-task 2.3 (section 3.3 of this report).

Table 23: Scenarios simulated under MSE framework.

HCR	Fleet dynamics	Abreviation	Description
Fixed advice	25% reduction in effort	E75	E75, a constant Total Allowable Catch TAC strategy based on their latest scientific advice: TAC_{BET}=65000, TAC_{YFT}=110000 t, TAC_{SKJ}=163000t†. The Reduction of 25% of the last 3 years average effort.
ICES	Fcube:min	ices_Emin	Seeks for single F_{MSY} for all stocks but fishing stops when fleet's allocated quota is reached for any stock.
ICES	Fcube:BET	ices_Ebet	Seeks for single F_{MSY} for all stocks but fishing stops when fleet's allocated quota of bigeye is reached.
MULTISTOCK	Fcube:min	multi_Emin	Aims at maintaining fishing mortality at overall MSY ranges and maximizing total catch. Fishing stops when fleet's allocated quota is reached for any stock.

MULTISTOCK	Fcube:BET	multi_Ebet	Aims at maintaining fishing mortality at overall MSY ranges and maximizing total catch. All fleets set their effort corresponding to their bigeye tuna quota share, regardless of other catches.

†Based on their latest scientific advice and for western Atlantic skipjack the most recent catch estimates 2012

5.2.2.5 First set-up of the bigeye simulation model and scenarios

For the projection of the three stocks we use an age structured population dynamic model and fleet specific fishing mortality, effort and performance indicators. The Cobb Douglas production model (Cobb and Douglas, 1928) is used to estimate the catch production per fleet. Effort and elasticity parameters are assumed equal to one, so catches per fleet depend only on the fleets' catchability and exploitable biomass. The fleets and their codes considered for this preliminary set up are shown in Table 24.

Table 24: Fleets considered in this simulation and the stocks they catch.

FLEETS	METIERS	STOCKS	Description
PS_SPFR	PS_SPFR_FS PS_SPFR_LS	YFT, BET,SKJ	Spanish and French purse seiners
PS_GH	PS_GH	YFT, BET,SKJ	Baitboat and Purse seiners Ghana
BB	BB	YFT, BET,SKJ	BET: Baitboat Portugal, Spain and Others YFT: Baitboat area2 and Dakar SKJ: Baitboat Azores, Canary and Others
LL_JP	LL_JP	YFT, BET	Japanese longliners
LL_Other	LL_Other	YFT, BET	Other longliners
Others_YFT	Others_YFT	YFT	Rod and Reel from US and Others
Others_SKJ	Others_SKJ	SKJ	Longline and others

Figure 28 shows the effort share of European purse seines. The effort share is estimated as the mean of the ratio of catches per species by each métier.

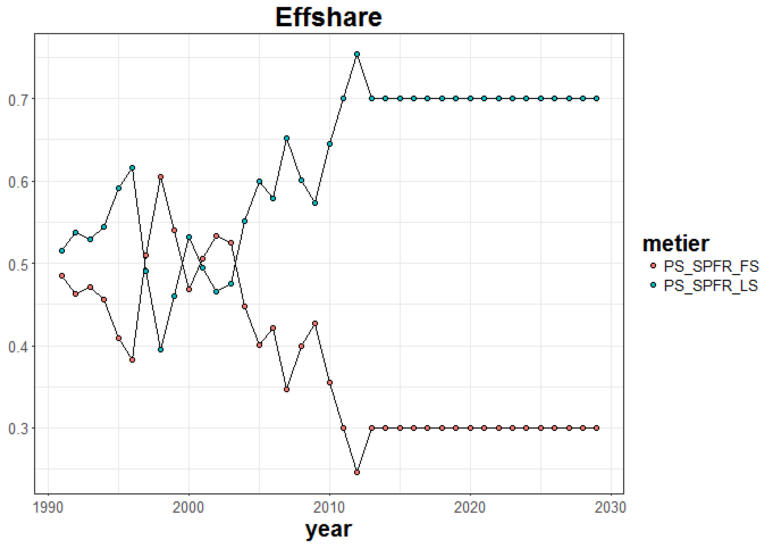

Figure 28: Effort share of European purse seine fleets: Free school (FS) and Log school or FADs (LS).

The reference points of each stock following the single stock and the multi-stock HCR are estimated following the ICES guidelines (ICES,2016b; ICES, 2017b) and are shown in Table 25.

Table 25: The reference points and control variables of the HCRs.

REFERENCE POINT (RP)		YFT	BET	SKJ	HCR
Biomass limit RP	B_{LIM}	2.60e+05	3.20e+05	2.20e+05	ICES/MULTI
Trigger biomass RP	$B_{trigger}$	3.64e+05	4.48e+05	3.08e+05	ICES/MULTI
FIshing mortality at MSY	F_{MSY}	1.10e-01	8.00e-02	6.80e-01	ICES/MULTI
Upper bound of fishing mortality rate	F_{upp}	1.30e-01	1.00e-01	9.9e-01	MULTI
Lower bound of fishing mortality rate	F_{low}	8.00e-02	6.00e-02	4.20e-01	MULTI

5.2.3 Results

The results suggest that when the effort is reduced by 25% and the advice is set fixed in the projection (E75), then the estimated median catch is higher than the TAC set in the projection for bigeye tuna in the projection, 65,000 t. This means that the differences between the TAC and catches are discarded for this stock (Figure 29). In this scenario the median fishing mortality is constant at 0.12 with a slight increase in recruitment and SSB, which is above the estimated $B_{trigger}$.

In the other scenarios, in the first years of the projection the catches and the fishing mortality decrease with different intensities, because the SSB for bigeye is below the $B_{trigger}$ and therefore the effort is reduced. After that, catches and fishing mortality increase back to higher levels, but still remain lower than the values estimated for the E75 rule; in particular, F sets at 0.08 in the ICES HCRs, which is also the estimated F_{MSY} for bigeye, while it increases up to 0.1, which is the F_{upp} value for bigeye. The simulations are very similar when E_{min} or E_{bet} are used in both single and multispecies HCRs, because the minimum effort corresponds to the effort necessary to catch the quota share of bigeye tuna.

With both HCRs (ICES and multi-stock) the increase in SSB is higher than with the fixed TAC (E75). The estimated median catches in the projection are higher when the multistock HCR is used compare to the values obtained with the ICES approach. When the E75 HCR is applied, the probability of SSB falling below Btrigger is higher than 0 (Figure 30) (Table 10), while it is equal to 0 when the ICES and multistock HCR are applied. In light of these considerations, the multistock HCR emerges as the most effective, as it provides the highest catches with no risk of falling below Btrigger.

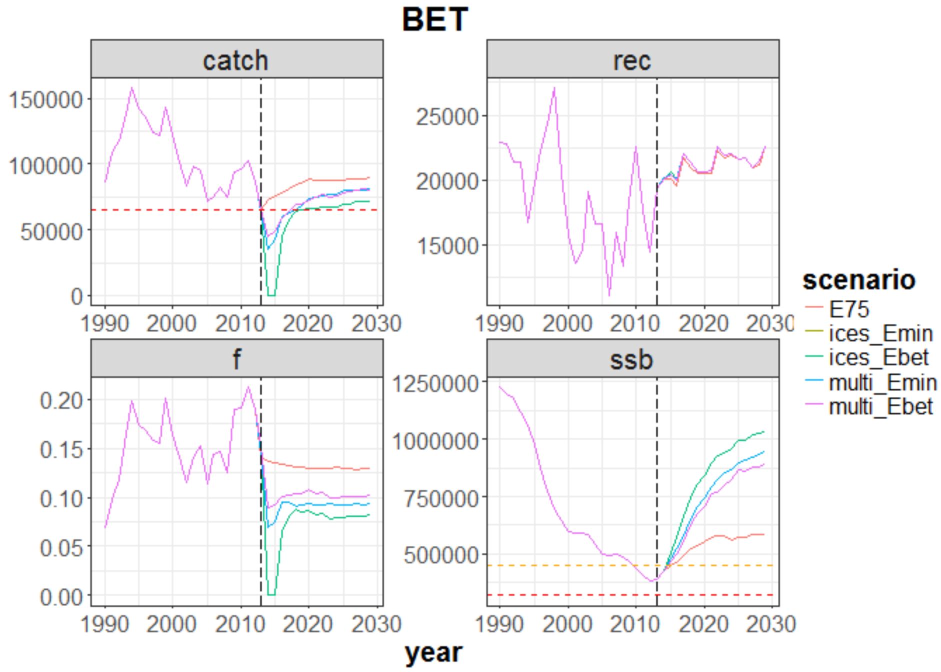

Figure 29: Figure shows the historical and the estimated median values of bigeye (BET) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal discontinuous lines are B_{lim} (red) and $B_{trigger}$ (orange).

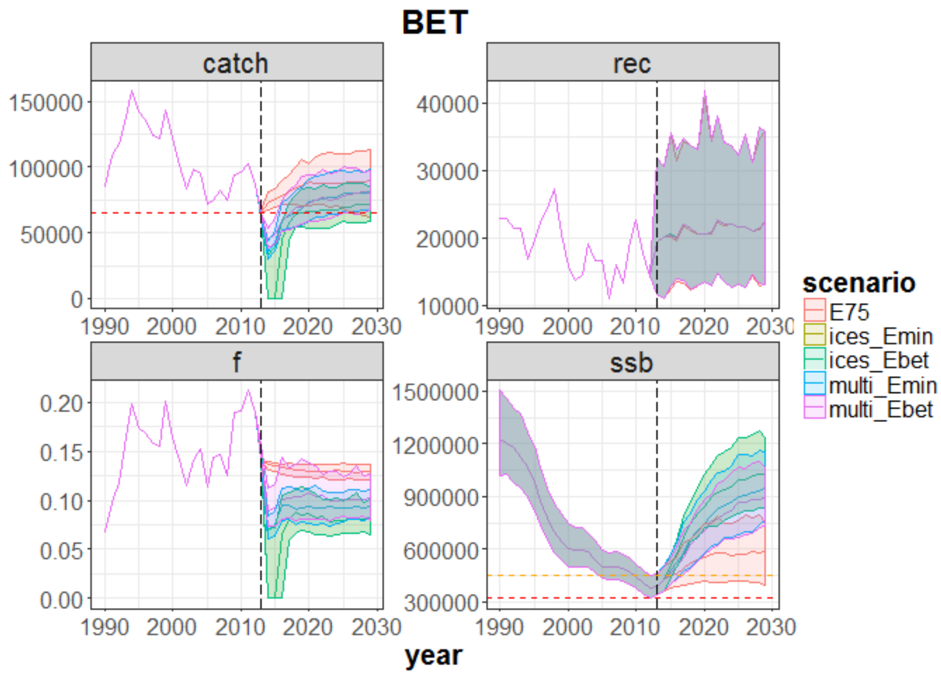

Figure 30: Historical and the estimated median, 5th and 95 quantiles, in the projection with the MSE model of bigeye (BET) catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal discontinuous lines are B_{lim} (red) and $B_{trigger}$ (orange).

Table 10: the probability of ssb of BET being below Btrigger of Blim in each of the scenarios.

BET scenario	P(ssb_{2020}<Btri)	P(ssb_{2020}<Blim)	P(ssb_{2029}<Btri)	P(ssb_{2029}<Blim)
E75	0.32	0	0.21	0
ICES_Emin	0	0	0	0
ICES_Ebet	0	0	0	0
Multi_Emin	0	0	0	0
Multi_Ebet	0.01	0	0	0

In the case of yellowfin, the highest median catch is also estimated when the E75 HCR is applied, but the catches are lower than the TAC of 110,000 t, and the fishing mortality is around 0.14, i.e. higher than the F_{MSY}, which is 0.11. The recruitment is stable around the mean and the SSB decreases in the first years of the projection, but remains stable after 2020 at levels below $B_{trigger}$ (Figure 31).

The estimated median catches with both HCRs (ICES and Multistock) fall to very low values at the start of the projection. This is because the SSB values of bigeye are below its $B_{trigger}$, therefore the fishing mortality of BET is reduced and consequently also the fishing mortality on yellowfin. The fishing mortality of multi_Ebet is the second highest and its values are close to the F_{MSY} value of 0.11; the median SSB remains stable above $B_{trigger}$. In the other scenarios, fishing mortality is lower than 0.1 but higher than F_{low}, and the SSB of all of them is higher and stable. Due to the uncertainty considered some of the iterations show that SSB can fall below $B_{trigger}$ and -on a minor extent- below B_{lim} with some probability (Table 11).

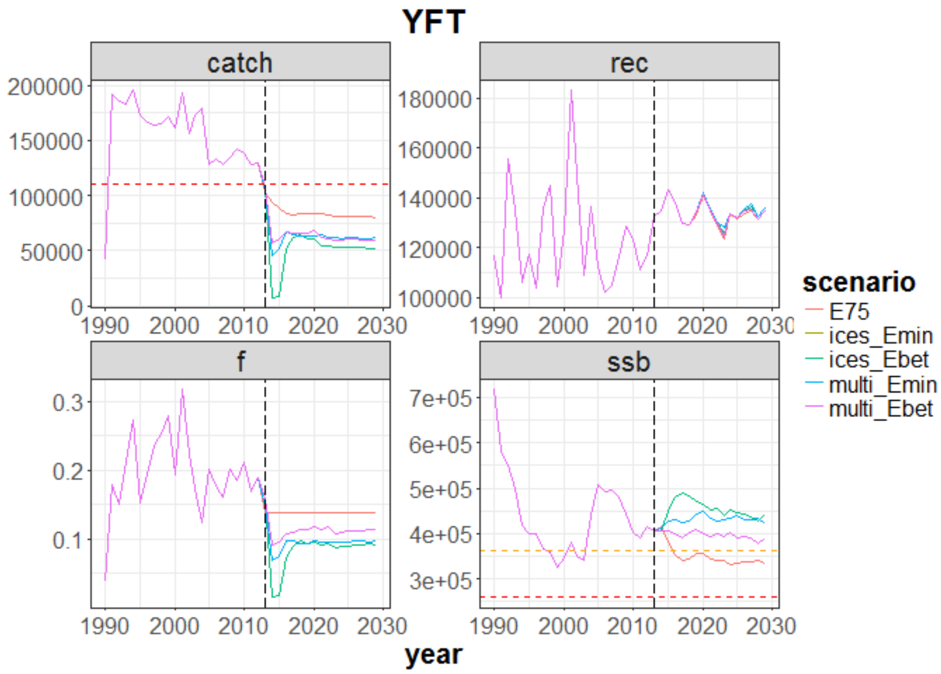

Figure 31: Historical and the estimated median values of yellowfin (YFT) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal discontinuous lines are Blim and Btrigger.

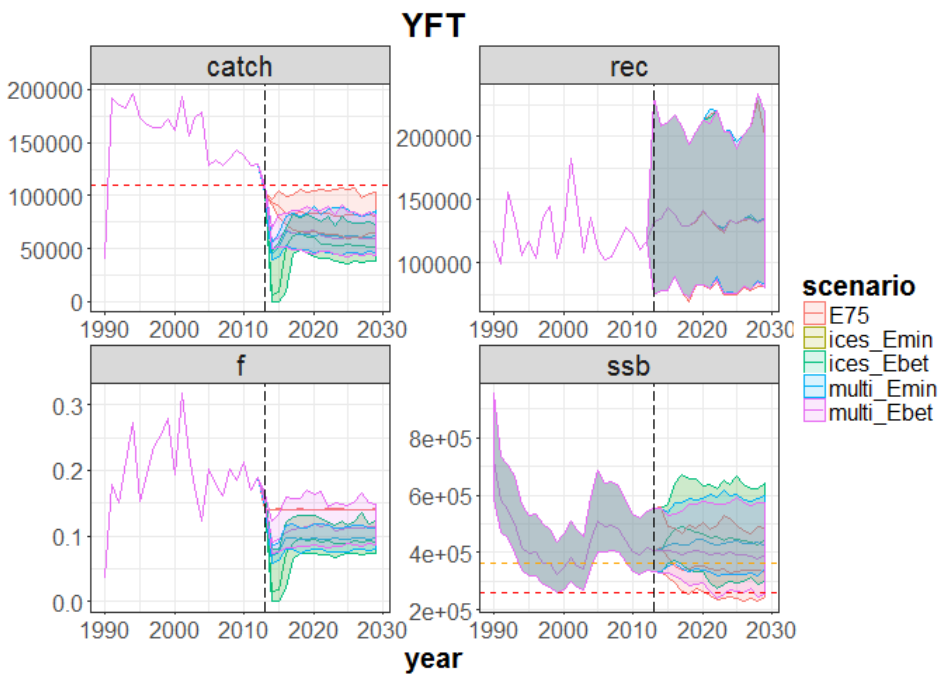

Figure 32: Historical and the estimated median values and the 5th and 95 quantile of yellowfin (YFT) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal discontinuous lines are Blim and Btrigger.

Table 11: the probability of ssb of YFT being below Btrigger of Blim in each of the scenarios

YFT scenario	P(ssb_{2020}<Btri)	P(ssb_{2020}<Blim)	P(ssb_{2029}<Btri)	P(ssb_{2029}<Blim)
E75	**0.88**	**0.38**	**0.9**	**0.38**
ICES_Emin	**0.47**	**0.05**	**0.62**	**0.05**
ICES_Ebet	**0.47**	**0.05**	**0.62**	**0.05**
Multi_Emin	**0.59**	**0.03**	**0.66**	**0.03**
Multi_Ebet	**0.74**	**0.17**	**0.74**	**0.17**

In the case of skipjack, the estimated median catch with the E75 scenario are lower than the advice of 163,000 t (Figure 33). The fishing mortality is around 0.14, which is much lower than the estimated F_{MSY} value of 0.6. The SSB decreases in the first years of the projection but it stabilizes above $B_{trigger}$ after some years. The recruitment is also stable throughout the projection. The second highest fishing mortality is estimated in the scenario multi_Ebet (0.3), which is lower than F_{low}=0.42. Figure 34 shows that the uncertainty in this stock is higher than on the others and all the scenarios show that there is some risk of falling below $B_{trigger}$. Furthermore, the multi_bet scenario shows that with some probability biomass can fall below B_{LIM} (Table 12).

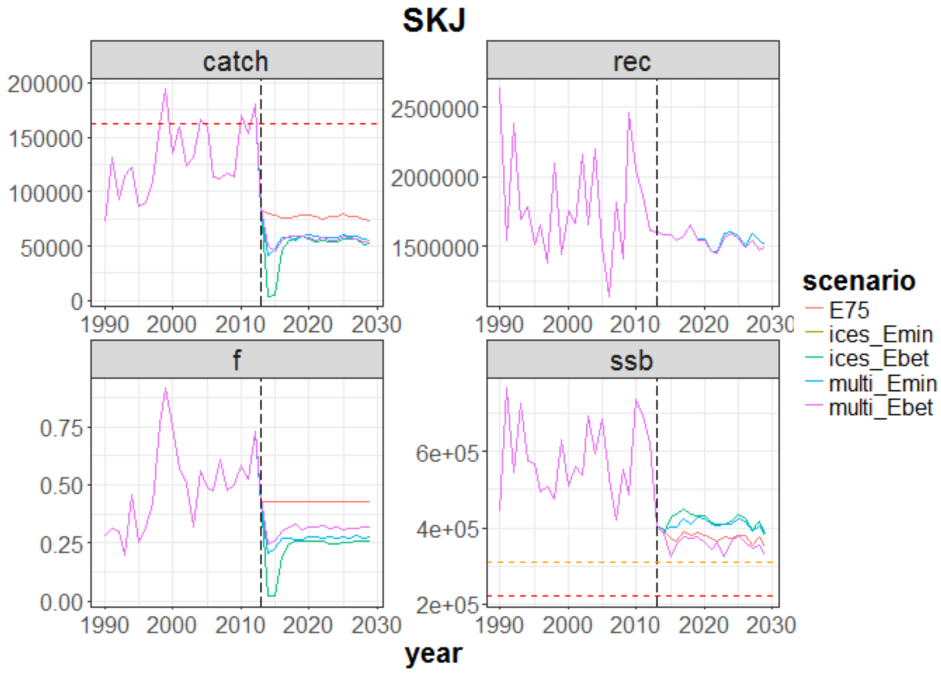

Figure 33: Historical and the estimated median values of skipjack (SKJ) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning

stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal discontinuous lines are Blim and Btrigger.

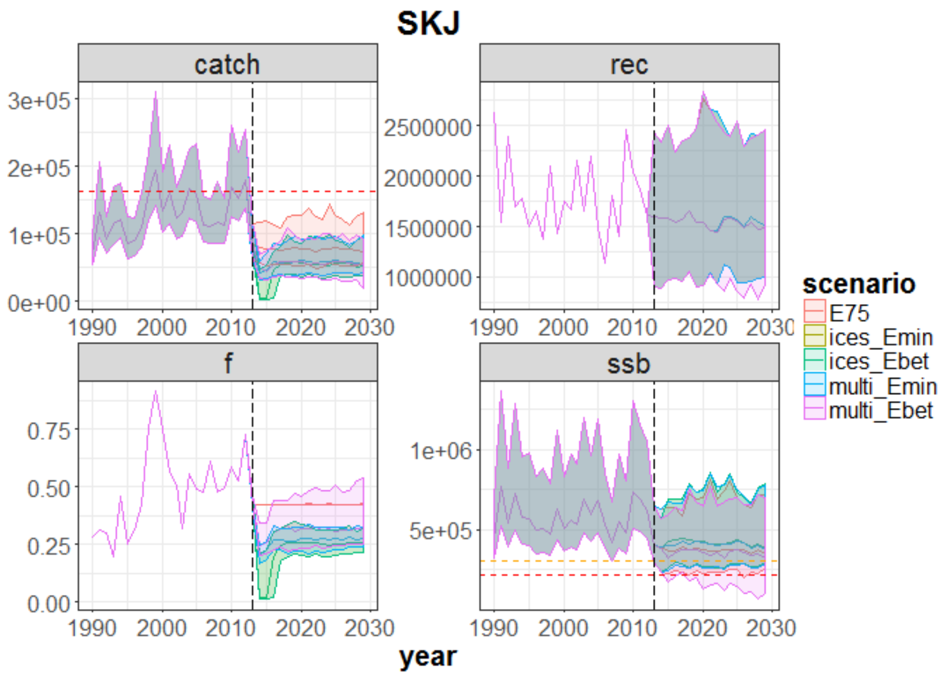

Figure 34: Historical and the estimated median values and the 5th and 95 quantile of skipjack (SKJ) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal discontinuous lines are Blim and Btrigger.

Table 12: the probability of ssb of SKJ being below Btrigger of Blim in each of the scenarios.

SKJ **scenario**	**P(ssb_{2020}<Btri)**	P(ssb_{2020}<Blim)	**P(ssb_{2029}<Btri)**	P(ssb_{2029}<Blim)
E75	**0.89**	**0.61**	**0.9**	**0.61**
ices_min	**0.88**	**0.41**	**0.88**	**0.41**
ices_Ebet	**0.88**	**0.41**	**0.88**	**0.41**
multi_Emin	**0.89**	**0.4**	**0.88**	**0.4**
multi_Ebet	**0.92**	**0.64**	**0.92**	**0.64**

Figure 35 shows the impact of the different HCRs and fleet dynamics on the catch. The estimated median catches with the E75 scenario reach the highest values for all the fleets except for the Others_SKJ, which only capture skipjack. For this fleet, the highest catches are estimated in the scenario with ICES HCRs based on single stock advice. For the rest of the fleets the highest difference between the scenarios is at the start of the projection period when the SSB of bigeye tuna is lower than $B_{trigger}$. Afterwards, following the SSB increase of bigeye, the differences in catches between the various scenarios decrease. For all of the fleets, except Others_YFT and Others_SKJ, the second highest catches are estimated with the multi-HCR type.

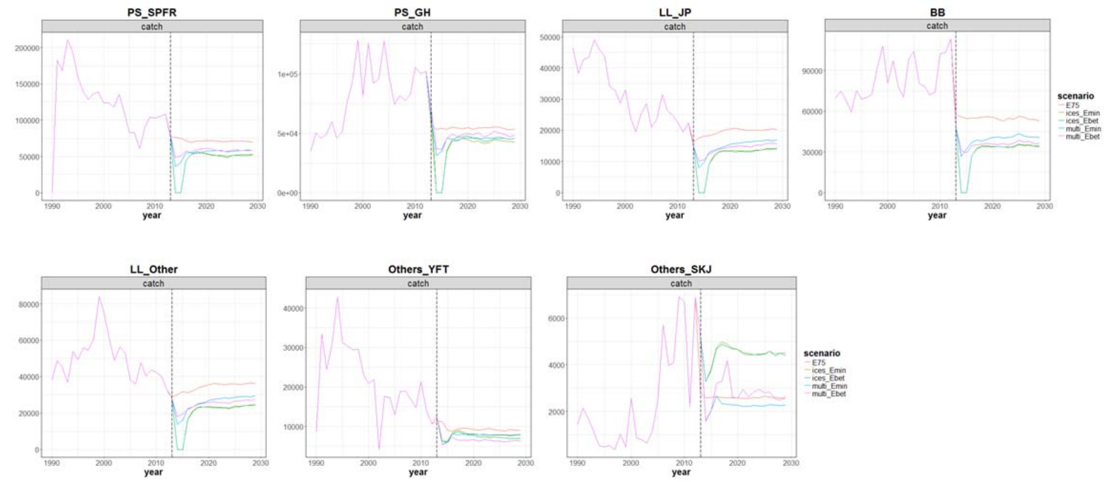

Figure 35: Historical and the estimated median values of total catches in the projection with the MSE model for each fleet.

5.2.4 Discussion

This study represents a first step in the evaluation of management strategies for tropical tuna stocks in a mixed-fisheries framework. We have compared three different management strategies combined with different fleet dynamics. The effort-based management with a 25% reduction was translated into fleet dynamics reducing the effort of all the fleets by 25%. The other 2 HCRs used correspond to the HCRs proposed by ICES in the MSY framework and to a multi-stock HCR that uses fishing mortality ranges around MSY targets. These two HCRs were combined with two different fleet dynamics which differed in the condition used to restrict the effort of the fleets, the minimum effort or the effort corresponding to the TAC of bigeye.

The SSB of bigeye is the only one that increased significantly in all the scenarios reaching MSY level in the long term, although the MSY level is below the historical maximum catch record.

The scenario with 25% reduction in effort produced the highest fishing mortality and the lowest SSB for all the stocks and years. In the ICES scenarios the "min" and "bet" options produced similar results because for most of the fleets bigeye is the most restrictive stock. The multi-stock scenario did not produce the same behavior: the reason is that when using the upper limit of the fishing mortality range bigeye is no longer the most restrictive stock.

The multi-stock HCR restricted with bigeye TAC produced on average sustainable biomasses for the three stocks but the probability of being below B_{LIM} was higher than zero in some years. This type of management should be combined with strict control measures to ensure the fulfillment of the TAC advice. In fact, this HCR and the introduction of fishing mortality ranges were defined in the light of the new landing obligation policy (Garcia et al., 2016) which forces the fleets to stop fishing when the first of the quotas has been reached; such behavior corresponds with the 'min' option. In the long term the multi-stock HCR scenario combined with 'min' behavior is similar to the ICES scenarios, but in the short term the catches were higher with the multi-stock HCR.

The fleet dynamics used in this work were based on the historical behavior. However, future work should focus first on the definition of the fleets and their métiers and afterwards identify the dynamics that better describe the fleet dynamics.

The assessment models of the stocks are quarterly based, however the simulation was run in yearly basis and this produces some inconsistencies between the models: future work should develop the simulation model in a seasonal fashion in order to provide a more accurate representation of the dynamic of the fleet and a consistent approach between the assessment and the simulation model. In the future, the development of a MSE model including the seasonal dimension is recommended in order to compare the results of both models and understand the impact of the seasonal effect in the dynamic of the stock and the fishery.

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Annex 1 MANAGEMENT OBJECTIVES AND PERFORMANCE INDICATORS

Table A.1 Management objectives and corresponding performance indicators considered at WCPFC13 for *tropical purse seine fisheries* HCRs (primarily skipjack). Objectives considered included those proposed in the strawman proposal, by the USA delegation and by the Small Working Group on Management Objectives (SWG-MO), in different columns); objectives in the same row indicate they are functionally similar to each other. The list of performance indicators is interim and may be revised when further information is available. Based on WCPFC13 Summary Report Attachment M[149] and WCPFC14.

Objective type	Management objective			Performance indicator	Monitoring strategy
	MOW proposal	USA proposal	SWG-MO proposal		
Biological	Maintain SKJ (and YFT & BET) biomass at or above levels that provide fishery sustainability throughout their range	Maintain SKJ, YFT, BET stock sizes above LRPs	-	Probability of SB / $SB_{recent,F=0}$ > 0.2 in as determined from MSE	Probability of SB / $SB_{recent,F=0}$ > 0.2 in the long-term as determined from the reference set of operating models
Economic	Maximise economic yield from the fishery	-	-	Predicted effort relative to E_{MEY} (to take account of multi-species considerations, SKJ, BET and YFT; may be calculated at the individual fishery level). B_{MEY} and F_{MEY} may also be considered at a single species level.	Observed effort in the fishery relative to E_{MEY}
	-	-	Maximise catch	Average expected catch. (may also be calculated	Observed catch information

[149] https://www.wcpfc.int/system/files/WCPFC13%20Summary%20Report%20final_issued%202%20March%202017%20complete.pdf

Objective type	Management objective			Performance indicator	Monitoring strategy
	MOW proposal	USA proposal	SWG-MO proposal		
				at the assessment region level)	
	Maintain acceptable CPUE	-	-	Average deviation of predicted SKJ CPUE from reference period levels	Observed CPUE maintained at or greater than specified levels
	Maximise SIDS revenues from resource rents	Take into account the special requirements of developing states and territories	-	Proxy: average value of SIDSs/non SIDDs catch	Observed proportion of SIDS effort/catch to total effort/catch from SIDS waters from logsheet or VMS data
	Catch stability	Stability and continuity of market supply	-	Average annual variation in catch	Observed variation in catch from logsheet data
	-	-	Effort predictability	Effort variation relative to reference period level (may also be calculated at the assessment region level).	-
	-	Maintain SKJ, YFT, BET stock sizes around TRPs (where adopted)	-	Probability of and deviation from SB/SBF=0 > 0.5 (SKJ) in the short, medium-long-term as determined from MSE (may also be calculated at the assessment region level).	Current median adult biomass, as determined from the reference set of Operating Models

Objective type	Management objective			Performance indicator	Monitoring strategy
	MOW proposal	USA proposal	SWG-MO proposal		
Social	Food security in developing states (import replacement)	-	-	As a proxy: Average proportion of CCMs-catch to total catch for fisheries operating in specific regions.	Ratio of locally marketed fish to imported fish products.
	Avoid adverse impacts on small scale fishers	Minimize adverse impacts on other fisheries, including: • Downstream fisheries like longline fisheries; • Competing fisheries like troll, pole-and-line, and non-tropical purse seine fisheries	-	MSY of SKJ, BET, YFT. Possible information on other competing fisheries targeting SKJ (may also be calculated at the assessment region level). Any additional information on other fisheries/species as possible.	Monitoring of fisheries in CCMs
Ecosystem	Minimise bycatch	Minimise adverse impacts on non-target species	-	Number of fish aggregating device sets Expected catch of other species as possible	Ratio of target species catch to catch of non-target species from observer program

Table A.2: Candidate management objectives considered at WCPFC14 for the *southern longline fishery* and proposed performance indicators and monitoring strategies for the purpose of the evaluation of harvest control rules. Based on WCPFC14 Summary Report Attachment K (Table 1)[150].

Objective Type	Management objective	Performance Indicators	Monitoring Strategy
Biological	Maintain albacore (and SWO, YFT & BET) biomass at or above levels that provide stock sustainability throughout their range.	Probability of SBrecent/SBF=0>20% as determined from the MSE.	Probability of SBrecent/SBF=0> 20% in the long-term as determined from the reference set of MSE operating models (updated and reconditioned periodically, as appropriate).
Economic	Maximise economic yield from the fishery.	Predicted effort relative to EMEY (to take account of multi-species considerations, BET and other spp; may be calculated at the individual fishery level). BMEY and FMEY may also be considered at a single species level.	Observed effort in the fishery relative to EMEY
	Maximise catch	Average expected catch (may also be calculated at the assessment region level).	Observed catch information
	Maintain acceptable CPUE	Average deviation of predicted CPUE from reference period levels.	Observed CPUE data from the longline fishery.
	Maximise SIDS revenues from resource rents	Average value of SIDS/non-SIDS catch.	Observed proportion of SIDS-effort/catch to total effort/catch in SIDS waters from log-sheet or VMS data.
	Catch stability	Average annual variation in catch.	Observed variation in catch as estimated from logsheet and other data.

[150] WCPFC14 Summary Report Attachment K

Objective Type	Management objective	Performance Indicators	Monitoring Strategy
	Effort predictability	Effort variation relative to reference period level (may also be calculated at the assessment region level).	Observed effort levels from log-sheet or VMS data.
	Maintain ALB, BET, YFT, SWO stock sizes around the TRP (where adopted)	Probability of and deviation from SBrecent/SBF=0> X in the short-medium-long-term as determined from MSE (may also be calculated at the assessment region level).	Current median adult biomass, as determined from the reference set of operating models.
Social	Food security in developing states (import replacement).	As a proxy: Average proportion of CCMs-catch to total catch for fisheries operating in specific regions.	Ratio of locally marketed fish to imported fish products.
	Avoid adverse impacts on small scale fishers.	As a proxy: Average catch for small-scale fisheries.	Monitoring of fisheries in CCMs
	Maintain/develop domestic fishery.	Levels of effort and catch in domestic fishery.	Monitoring of fisheries catch and effort in CCMs
	Human resource development.	Employment – though use catch of domestic catch as proxy.	Employment in the fishing sector monitored via number of domestic vessels and resulting catch in domestic fishery.
Ecosystem	Minimise catch of non-target species.	Expected catch of other species	Ratio of target species catch to catch of non-target species based on bycatch data from observer program.

Table A.3: Candidate management objectives considered at WCPFC14 for the *tropical longline fishery* and proposed performance indicators and monitoring strategies for bigeye and yellowfin tuna the purpose of the evaluation of harvest control rules. Based on WCPFC14 Summary Report Attachment K (Table 2)[151].

Objective Type	Management objective	Performance Indicators	Monitoring Strategy
Biological	Maintain YFT, BET (and SWO) biomass at or above levels that provide stock sustainability throughout their range.	Probability of SBrecent/SBF=0>20% as determined from the MSE.	Probability of SBrecent/SBF=0> 20% in the long-term as determined from the reference set of MSE operating models (updated and reconditioned periodically, as appropriate).
Economic	Maximise economic yield from the fishery.	Predicted effort relative to EMEY (to take account of multi-species considerations, including impacts on PS fisheries; may be calculated at the individual fishery level). BMEY and FMEY may also be considered at a single species level.	Observed effort in the fishery relative to EMEY
	Minimize impacts from upstream fisheries, including the tropical purse seine fishery.	MSY of BET and YFT.	Monitoring changes and expected changes in MSY.
	Maintain acceptable CPUE.	Average deviation of predicted CPUE from reference period levels.	Observed CPUE data maintained at or greater than specified levels.
	Increase fisheries-based development within	Amount of proportional contribution of SIDS fleet catch/catch in SIDS waters.	Amount and value of product (exported catches) from SIDS.

[151] WCPFC14 Summary Report Attachment K

Objective Type	Management objective	Performance Indicators	Monitoring Strategy
	developing states economies		
	Optimise fishing effort.	EMEY (as for Maximise economic yield) or some other economic measure. Effort consistent with specified level.	Annual monitoring through logbooks and VMS.
	Maximise SIDS revenues from resource rents.	Average value of SIDS/non-SIDS catch.	Observed proportion of SIDS-effort/catch to total effort/catch in SIDS waters from log-sheet or VMS data.
	Catch stability.	Average annual variation in catch.	Observed variation in catch as estimated from log-sheet and other data.
	Effort predictability.	Effort variation relative to reference period level (may also be calculated at the assessment region level).	Observed effort levels from log-sheet or VMS data.
	Maintain BET, YFT (and SWO) stock sizes around TRP (where adopted).	Probability of and deviation from SBrecent/SBF=0> X in the short-medium-long-term as determined from MSE (may also be calculated at the assessment region level).	Current median adult biomass, as determined from the reference set of operating models.
Social	Food security in developing states (import replacement).	As a proxy: Average proportion of CCMs-catch to total catch for fisheries operating in specific regions.	Ratio of locally marketed fish to imported fish products.
	Employment opportunities	As a proxy: Average proportion of CCMs-catch to total catch for fisheries operating in specific regions.	Numbers employed in fishing and processing sector to some target.

Objective Type	Management objective	Performance Indicators	Monitoring Strategy
	Maintain/develop domestic fishery.	Ratio of domestic catch to total catch.	Monitoring of fisheries catch and effort in CCMs
	Human resource development.	As a proxy: Ratio of domestic catch to total catch.	Monitoring of fisheries catch and effort in CCMs.
	Avoid adverse impacts on small scale fishers.	-	Monitoring of fisheries in CCMs
Ecosystem	Minimise catch of non-target species.	Expected catch of other Species based on observer data.	Ratio of target species catch to catch of non-target species from observer program.
	Minimise fishery impact on the ecosystem.	Similar to previous PI. As a proxy use the expected catch of other species based on observer data.	Ratio of target species catch to catch of non-target species.

Annex 2 PROVISIONAL HCRS THAT IATTC HAS ADOPTED

Extracts from the IATTC HCR that covers purse seine fisheries catching tropical tunas (yellowfin, bigeye, and skipjack) are presented below[152]:

Limit reference points:

The spawning biomass limit is equal to the spawning biomass associated with 50% reduction in recruitment as calculated in a Beverton-Holt spawner-recruit model with steepness of 0.75 ($S_{0.5r0}$). Fishing mortality limit is equal to fishing mortality that causes spawning biomass to be reduced to $S_{0.5r0}$

Target reference points:

Both fishing mortality and spawning biomass target points are set equal to those that produce MSY.

Action to be taken:

- […] management measures […] shall attempt to prevent the fishing mortality rate (F) from exceeding the best estimate of the rate corresponding to the maximum sustainable yield (FMSY) for the species that requires the strictest management.
- If the probability that F will exceed the limit reference point (F_{LIMIT}) is greater than 10%, as soon as is practical management measures shall be established that have a probability of at least 50% of reducing F to the target level (F_{MSY}) or less, and a probability of less than 10% that F will exceed F_{LIMIT}.
- If the probability that the spawning biomass (S) is below the limit reference point (S_{LIMIT}) is greater than 10%, as soon as is practical management measures shall be established that have a probability of at least 50% of restoring S to the target level (dynamic S_{MSY}) or greater, and a probability of less than 10% that S will descend to below S_{LIMIT} in a period of two generations of the stock or five years, whichever is greater[153].

[152] https://www.iattc.org/PDFFiles/Resolutions/IATTC/_English/C-16-02-Harvest-control-rules.pdf Last accessed: 05/07/18

[153] The generation time used for calculations for the 3 species are 5, 2, and, 3 years for bigeye, skipjack, and yellowfin respectively. https://www.wcpfc.int/system/files/MI-WP-02-Time-Window-LRP.pdf Last accessed 05/07/18. For a broader range of biological parameters and values used for these species see Mee et al (2017)

Annex 3 EXTRACTS FROM THE UN FISH STOCKS AGREEMENT[154]

Article 6(1) of the Conventions provides that the guidelines set out in Annex II of the UN Fish Stocks agreement form part of the Convention and shall be applied by the Commission.

Article 6

Application of the precautionary approach

1. States shall apply the precautionary approach widely to conservation, management and exploitation of straddling fish stocks and highly migratory fish stocks in order to protect the living marine resources and preserve the marine environment.

2. States shall be more cautious when information is uncertain, unreliable or inadequate. The absence of adequate scientific information shall not be used as a reason for postponing or failing to take conservation and management measures.

3. In implementing the precautionary approach, States shall:

(a) improve decision-making for fishery resource conservation and management by obtaining and sharing the best scientific information available and implementing improved techniques for dealing with risk and uncertainty;

(b) apply the guidelines set out in Annex II and determine, on the basis of the best scientific information available, stock-specific reference points and the action to be taken if they are exceeded;

(c) take into account, inter alia, uncertainties relating to the size and productivity of the stocks, reference points, stock condition in relation to such reference points, levels and distribution of fishing mortality and the impact of fishing activities on non-target and associated or dependent species, as well as existing and predicted oceanic, environmental and socio-economic conditions; and

(d) develop data collection and research programmes to assess the impact of fishing on non-target and associated or dependent species and their environment, and adopt plans which are necessary to ensure the conservation of such species and to protect habitats of special concern.

4. States shall take measures to ensure that, when reference points are approached, they will not be exceeded. In the event that they are exceeded, States shall, without delay, take the action determined under paragraph 3 (b) to restore the stocks.

5. Where the status of target stocks or non-target or associated or dependent species is of concern, States shall subject such stocks and species to enhanced monitoring in order to review their status and the efficacy of conservation and management measures. They shall revise those measures regularly in the light of new information.

6. For new or exploratory fisheries, States shall adopt as soon as possible cautious conservation and management measures, including, inter alia, catch limits and effort

[154] http://www.un.org/depts/los/convention_agreements/texts/fish_stocks_agreement/CONF164_37.htm

limits. Such measures shall remain in force until there are sufficient data to allow assessment of the impact of the fisheries on the long-term sustainability of the stocks, whereupon conservation and management measures based on that assessment shall be implemented. The latter measures shall, if appropriate, allow for the gradual development of the fisheries.

7. If a natural phenomenon has a significant adverse impact on the status of straddling fish stocks or highly migratory fish stocks, States shall adopt conservation and management measures on an emergency basis to ensure that fishing activity does not exacerbate such adverse impact. States shall also adopt such measures on an emergency basis where fishing activity presents a serious threat to the sustainability of such stocks. Measures taken on an emergency basis shall be temporary and shall be based on the best scientific evidence available.

ANNEX II

GUIDELINES FOR THE APPLICATION OF PRECAUTIONARY REFERENCE POINTS IN CONSERVATION AND MANAGEMENT OF STRADDLING FISH STOCKS AND HIGHLY MIGRATORY FISH STOCKS[155]

1. A precautionary reference point is an estimated value derived through an agreed scientific procedure, which corresponds to the state of the resource and of the fishery, and which can be used as a guide for fisheries management.

2. Two types of precautionary reference points should be used: conservation, or limit, reference points and management, or target, reference points. Limit reference points set boundaries which are intended to constrain harvesting within safe biological limits within which the stocks can produce maximum sustainable yield. Target reference points are intended to meet management objectives.

3. Precautionary reference points should be stock-specific to account, inter alia, for the reproductive capacity, the resilience of each stock and the characteristics of fisheries exploiting the stock, as well as other sources of mortality and major sources of uncertainty.

4. Management strategies shall seek to maintain or restore populations of harvested stocks, and where necessary associated or dependent species, at levels consistent with previously agreed precautionary reference points. Such reference points shall be used to trigger pre-agreed conservation and management action. Management strategies shall include measures which can be implemented when precautionary reference points are approached.

5. Fishery management strategies shall ensure that the risk of exceeding limit reference points is very low. If a stock falls below a limit reference point or is at risk of falling below such a reference point, conservation and management action should be initiated to facilitate stock recovery. Fishery management strategies shall ensure that target reference points are not exceeded on average.

6. When information for determining reference points for a fishery is poor or absent, provisional reference points shall be set. Provisional reference points may be established by analogy to similar and better-known stocks. In such situations, the fishery shall be

[155] Text has been underlined by us and is not part of the original document.

subject to enhanced monitoring so as to enable revision of provisional reference points as improved information becomes available.

7. The fishing mortality rate which generates maximum sustainable yield should be regarded as a minimum standard for limit reference points. For stocks which are not overfished, fishery management strategies shall ensure that fishing mortality does not exceed that which corresponds to maximum sustainable yield, and that the biomass does not fall below a predefined threshold. For overfished stocks, the biomass which would produce maximum sustainable yield can serve as a rebuilding target.

Publications Office