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

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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

Term	Description
SBT	Southern bluefin tuna
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

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[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

As specified in the Terms of Reference, a separate document with the results and conclusions has been written to address task 1 (see Wakeford et al., 2018).

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 1) 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 1: 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[10] and Rec. 15-07[11] 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[12])	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**	HCRs are not yet defined for bigeye, yellowfin or albacore			n/a

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

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

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

RFMO	Skipjack	Yellowfin	Bigeye	Albacore	Bluefin
	(Res. 16/02)[13], based on target and limit reference points[14]				
WCPFC	HCRs are not yet defined for skipjack, yellowfin or bigeye tuna. CMM 2014-06[15] 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[16], which includes a decision rule but falls short of a decision framework	**A Harvest Strategy for Pacific Bluefin Tuna Fisheries[17] defined HCRs in 2014 to achieve rebuilding targets[18]**
IATTC	**IATTC adopted an HCR for tropical tunas in 2016, under Res. C-16-02[19], based on interim target and limit reference points[20]**			Res. C-13-03[21] 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[22] 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,**

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

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

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

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

[17] Ibid.

[18] 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)

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

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

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

[22] 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
					designed to achieve the recovery target[23]

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[24] and more recently Recommendation 17-04[25]. 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 1.

[23] 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

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

[25] 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 1: 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.[26] (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[27]. 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}).

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

[27] 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 2.

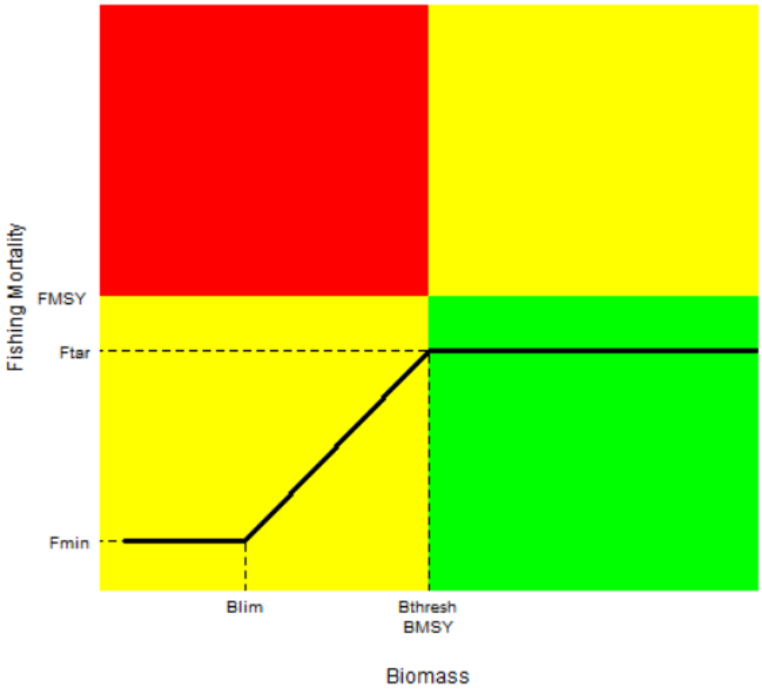

Figure 2: Relationship between stock status and fishing intensity as described by the control parameters of the ICCAT HCR for North Atlantic Albacore. (ICCAT Rec. 17-04).

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[28] 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[29], 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[30]. The HCR recommends a total annual catch limit based on spawning stock biomass (referred to by IOTC as B[31]) 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);

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

[28] Ibid.

[29] Ibid.

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

[31] 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

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 3.

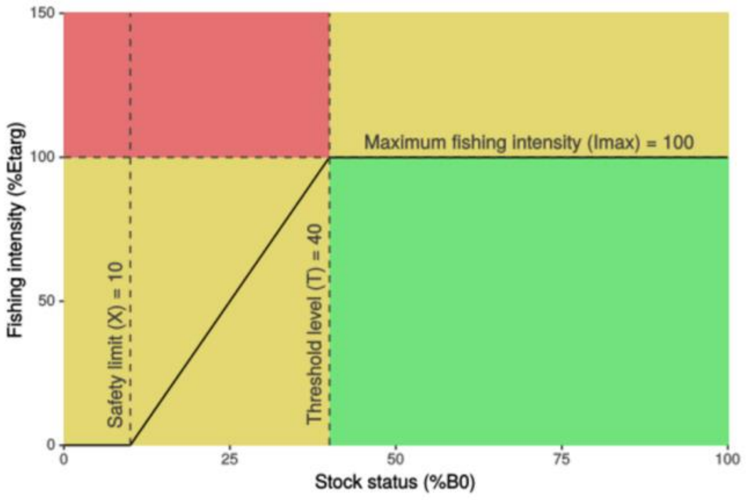

Figure 3: Relationship between stock status and fishing intensity as described by the control parameters of the IOTC HCR for skipjack (IOTC Res. 16/02).

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[32]. 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 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.

[32] 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

- 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 $0.39SB_0$[33].

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)[34]. 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[35]. A HCR, termed a decision rule, is described by WCPFC as follows:

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[36].

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

[34] 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

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

[36] 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.

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[37] 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.[38] 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 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

[37] 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).

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

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)[39]. 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 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

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

- 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[40]; and

40 https://www.ccsbt.org/sites/ccsbt.org/files/userfiles/file/docs_english/operational_resolutions/Resolution_Management_Procedure.pdf

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[41] and scientific aerial survey data[42], 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.

[41] 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.

[42] 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 2), 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 2: 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[43] 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 4. 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.

[43] www.iccat.int

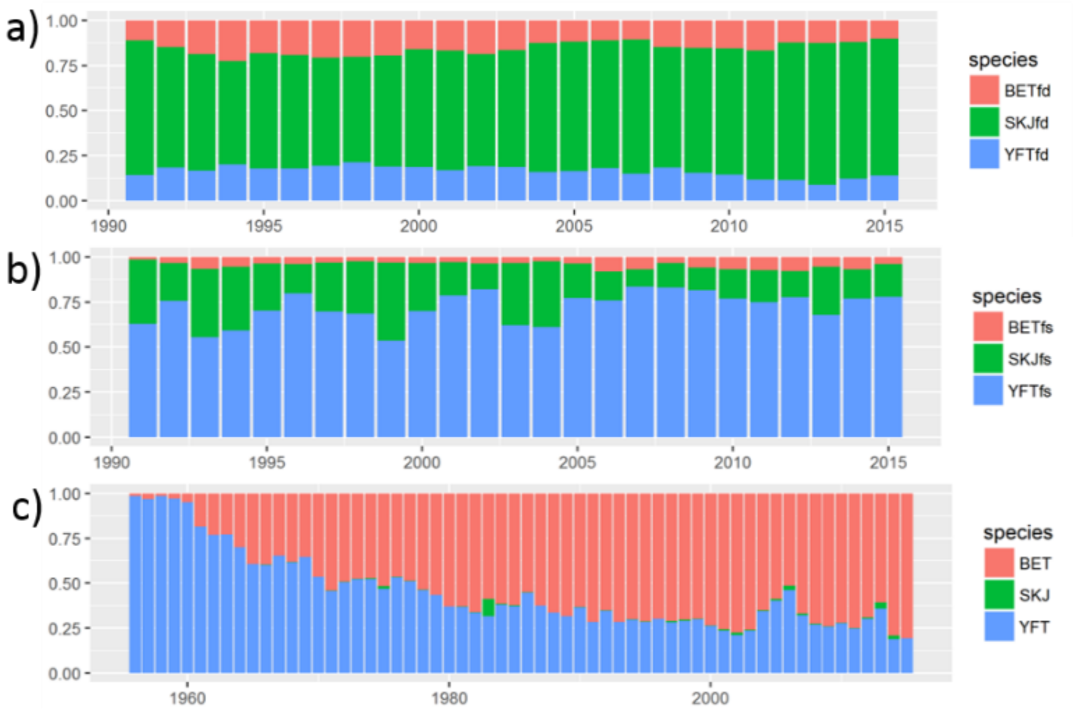

Figure 4: Yearly time series of the species catch composition with different operating fishing mode: a) purse seiners using FADs b) purse seiners fishing free swimming school and c) longliners. ***Data source: ICCAT Task II Catch and Effort statistics (T2CE) and CATDIS.***

De Finetti triangles (Figure 5) 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.

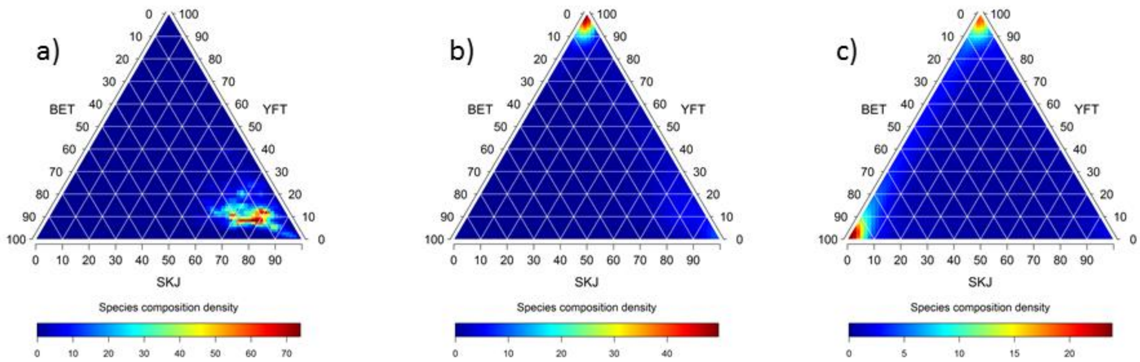

Figure 5: De Finetti triangles for: a) purse seiners using FADs b) purse seiners fishing free swimming schools and c) longline. ***Based on method described in Fonteneau et al., (2010).***

Figure 6 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 5. 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.

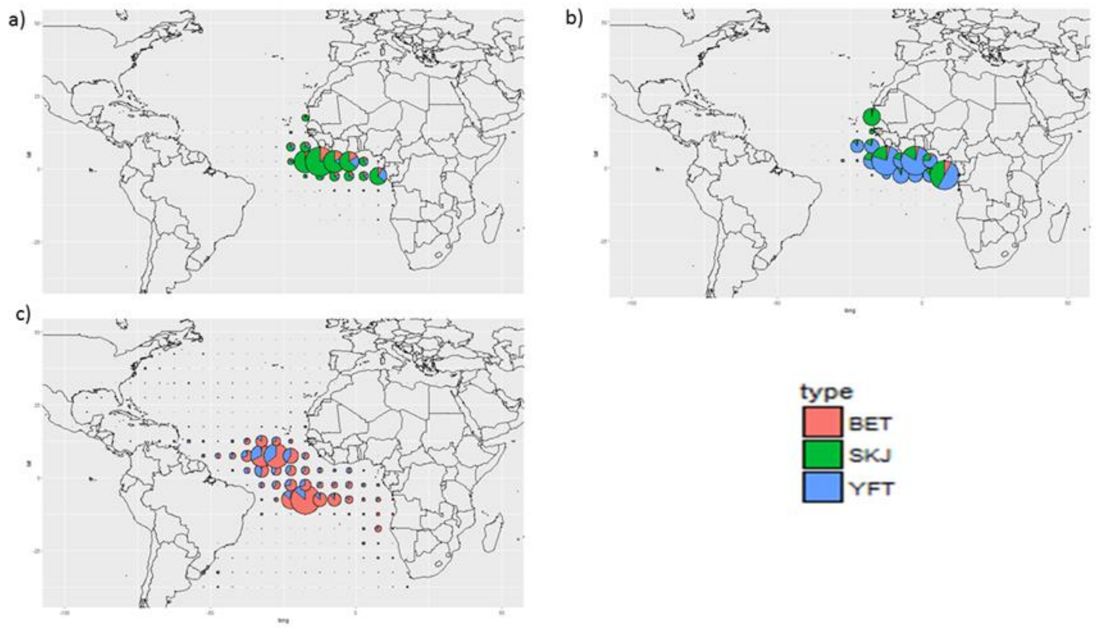

Figure 6: Geographical catch composition estimated with weighted mean (with the total landings). The size of the pie is defined with the historical total catch in each area: a) purse seiners using FADs b) purse seiners fishing free swimming schools and c) longline. Data source from ICCAT CATDIS.

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 7). Longliners fish more mature bigeye than purse seiners being the mode at around 125 cm (Fonteneau et al., 2013).

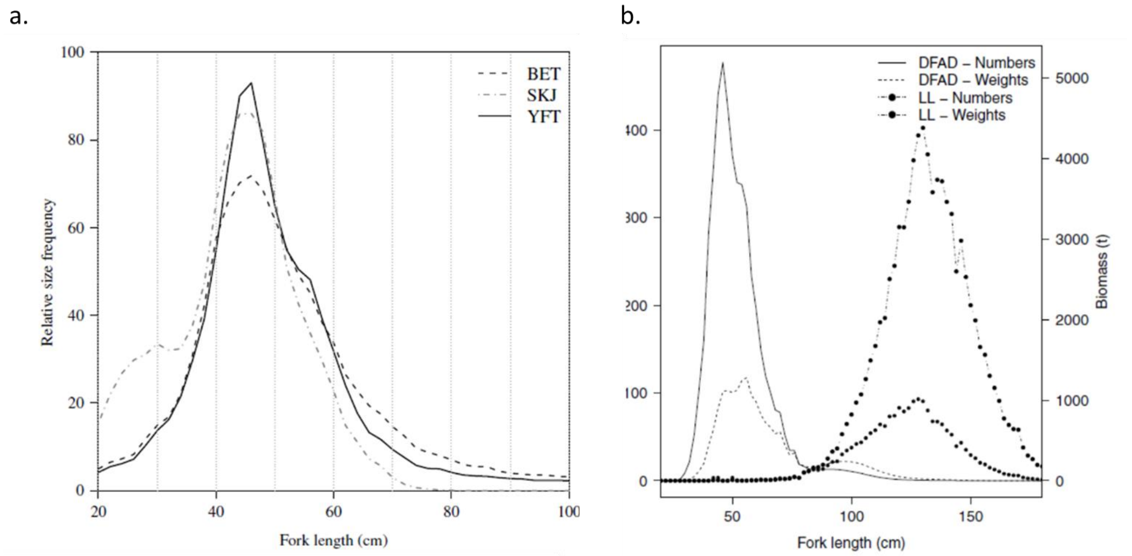

Figure 7: a) Relative size-frequency distribution (in numbers) for yellowfin, skipjack and bigeye tunas captured by purse seine fisheries on drifting FADs b) Relative size-frequency distributions of bigeye on longliners and DFAD (Fonteneau et al., 2013).

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:

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

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).

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

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.

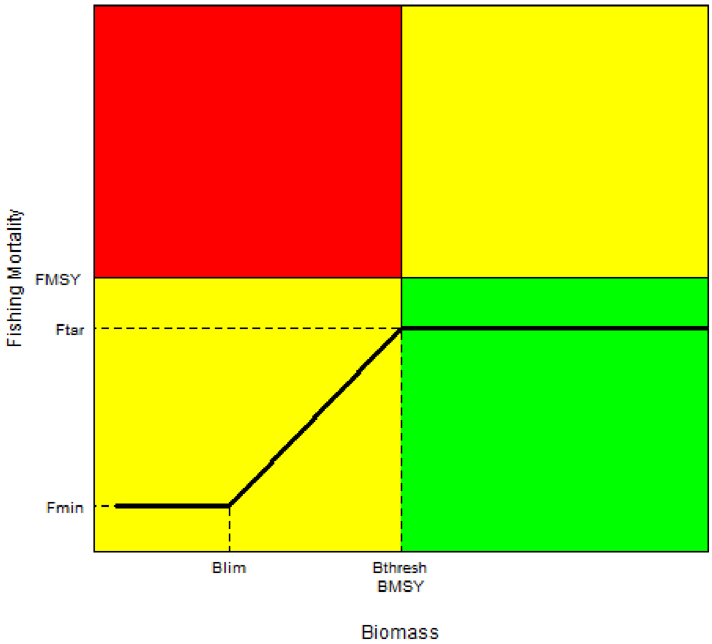

Figure 8: Harvest Control Rule adopted for North Atlantic albacore (ICCAT, 2017a).

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[44] 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 9.

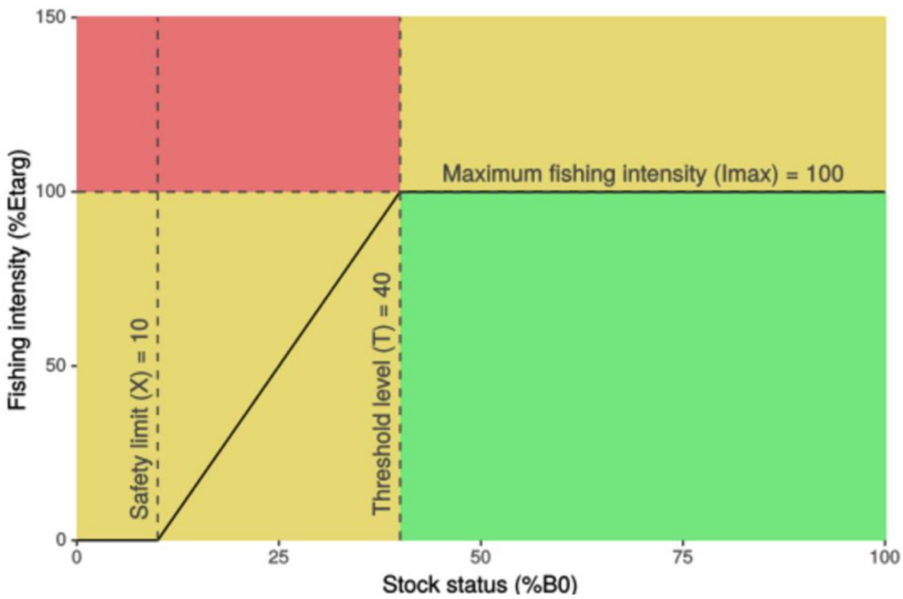

Figure 9: HCR adopted for Indian Ocean skipjack (IOTC, 2016a).

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 implementation of the precautionary approach. Specifically, Resolution 15-10

[44] 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

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[45], 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 well defined and effective HCRs. The interpretation of these criteria has been

[45] www.commonoceans.org/

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.

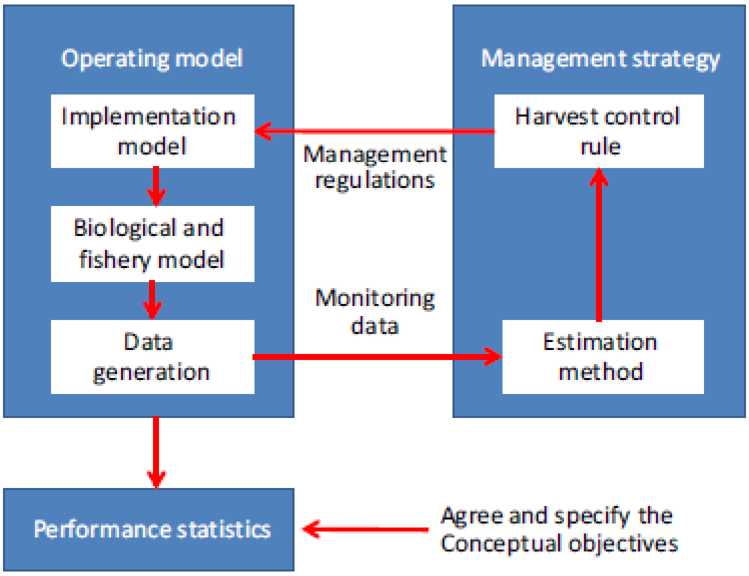

Figure 10: Conceptual overview of the management strategy evaluation modelling process (source: Punt et al., 2016).

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 3: 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 11 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).

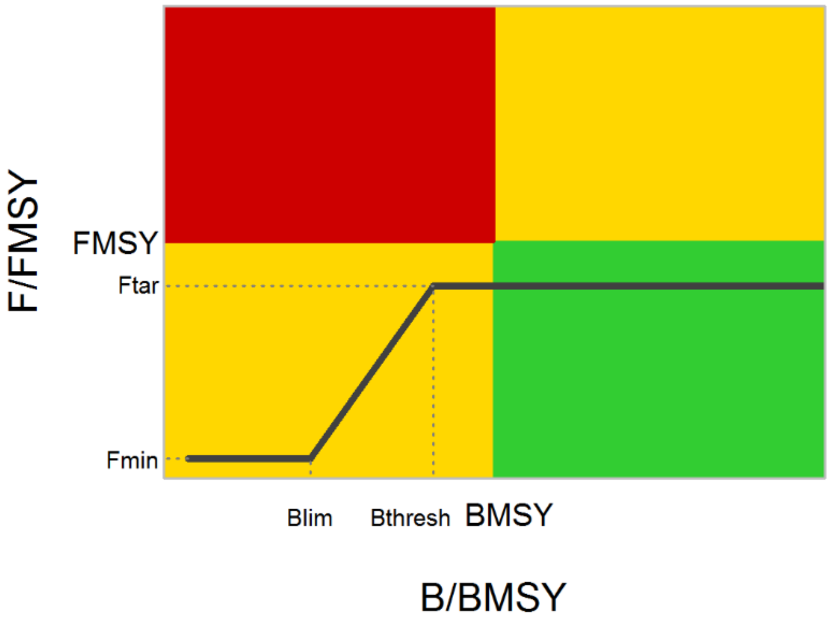

Figure 11: Generic type of HCR evaluated for North Atlantic albacore (Merino et al., 2016).

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 12, 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 12) or fishing mortality will start to be reduced. At 10% catch or fishing mortality will be reduced to a minimum.

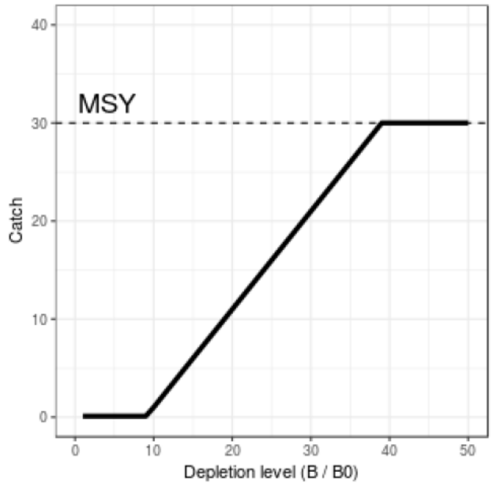

Figure 12. Catch based 40:10 type Harvest Control Rule included in the IOTC albacore MSE.

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 $TAC_t = TAC_{t+1}*(1+λ*b)$ where λ is a response multiplier and b is the slope of the linear model fit to the last *ny* years of data (Figure 13).

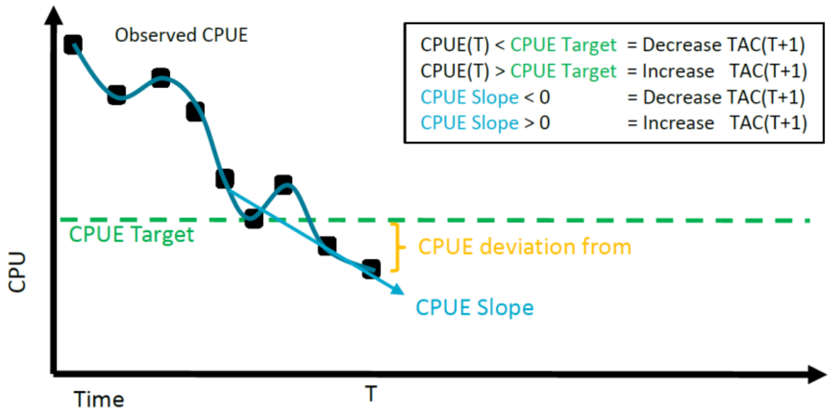

Figure 13. Diagram of the CPUE-based HCR implemented for IOTC albacore (Kolody and Jumppanen, 2016).

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 14), 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 12), 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 14).

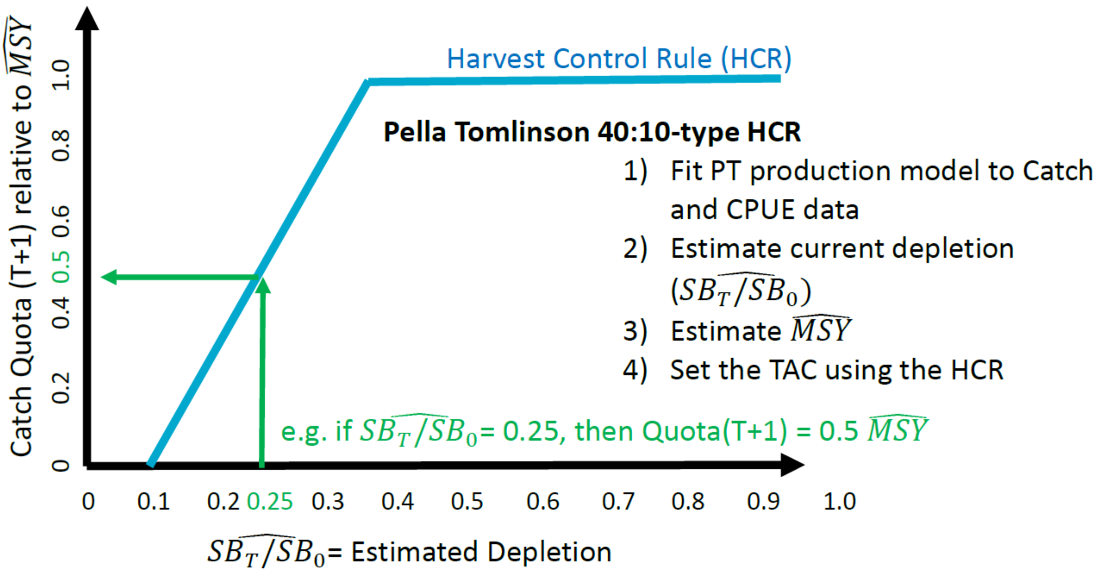

Figure 14. Schematic representation of the PT 40:10 type MP category (Kolody and Jumppanen, 2016).

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[46], 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 15).

[46] 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 15: 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 16).

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 16: 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[47] 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 of the ABNJ workshops towards building capacity on MSE in

[47] www.commonoceans.org/

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 4). 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 4: 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 5). 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 5: 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 6.

Table 6: 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 7) 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 7: 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)

As specified in the Terms of Reference, a separate document has been written to address task 4.1 (see Apostolaki et al., 2018).

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 17).

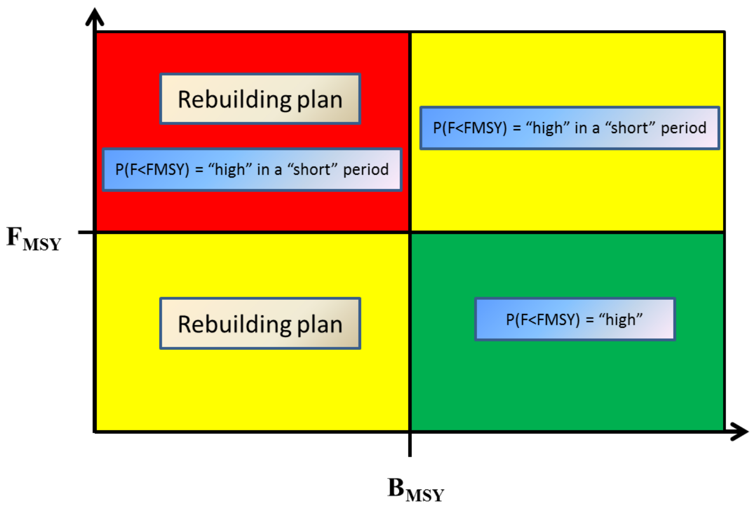

Figure 17: ICCAT's management framework based on Rec. 11-13.

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[48]. Figure 18 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.

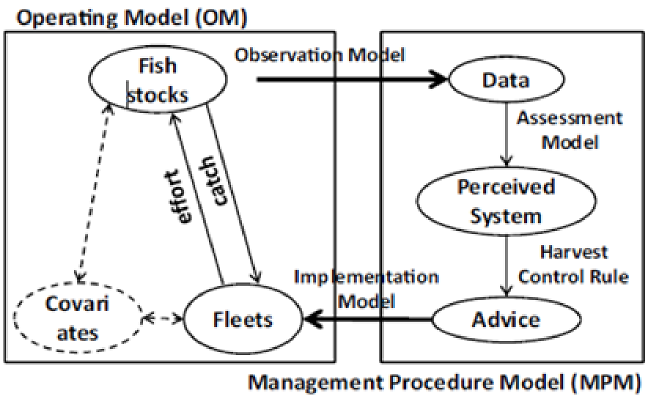

Figure 18: Conceptual representation of the main components modelled in FLBEIA (Garcia et al., 2013).

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).

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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-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 8 and sub-task 2.3 (section 3.3 of this report).

Table 8: 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 9.

Table 9: 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 19 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.

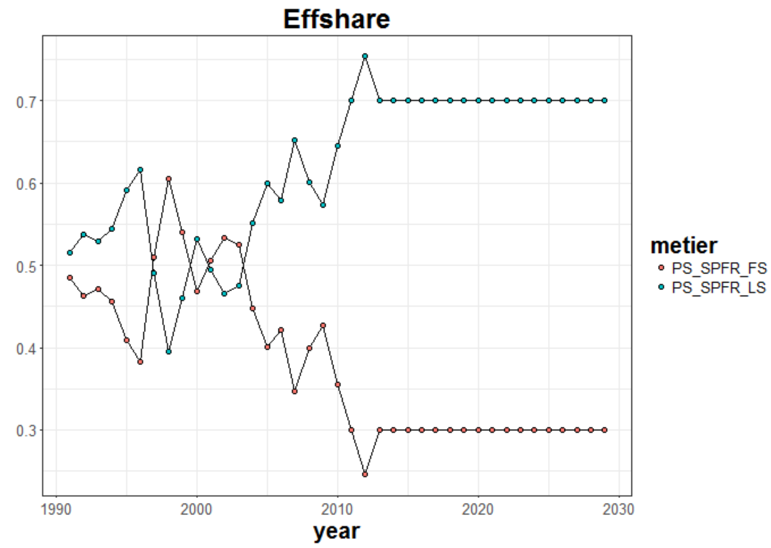

Figure 19: Effort share of European purse seine fleets: Free school (FS) and Log school or FADs (LS).

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 10.

Table 10: 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 20). 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 21) (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.

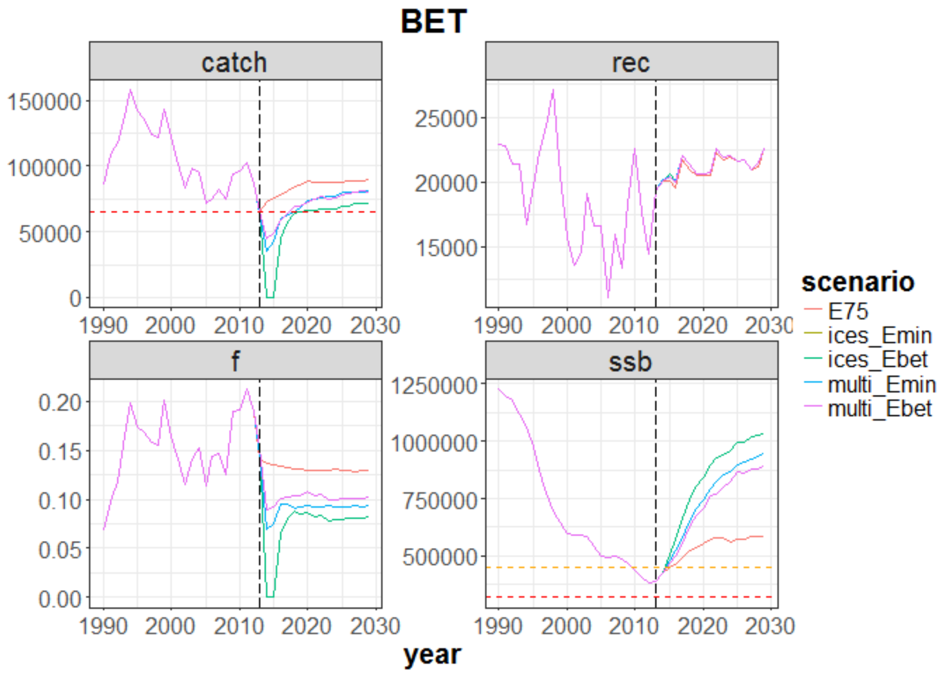

Figure 20: Figure shows the historical and the estimated median values of bigeye (BET) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal discontinuous lines are B_{lim} (red) and $B_{trigger}$ (orange).

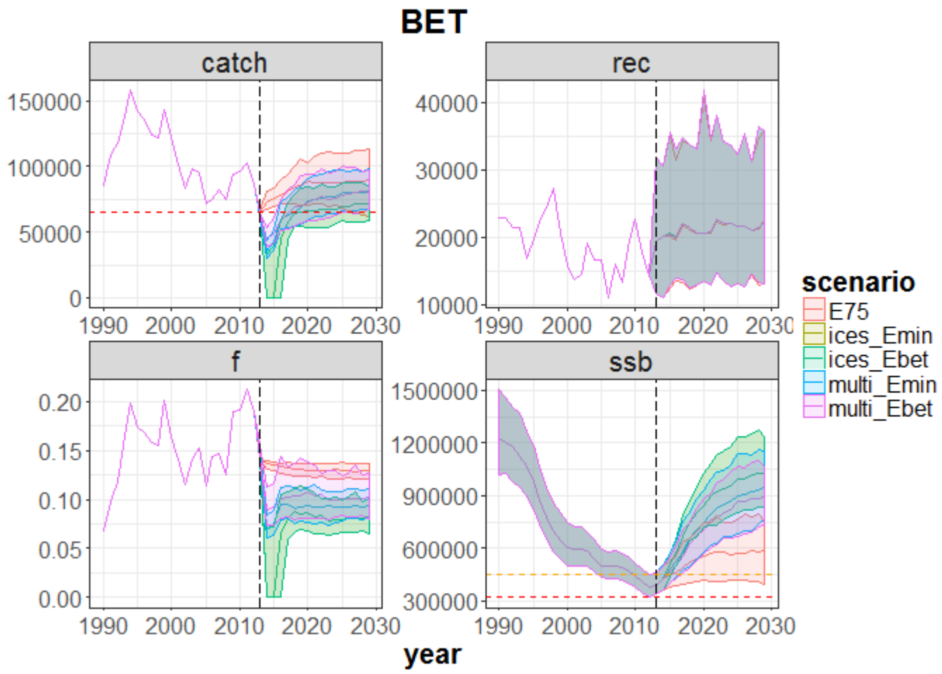

Figure 21: Historical and the estimated median, 5th and 95 quantiles, in the projection with the MSE model of bigeye (BET) catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal 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 22).

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).

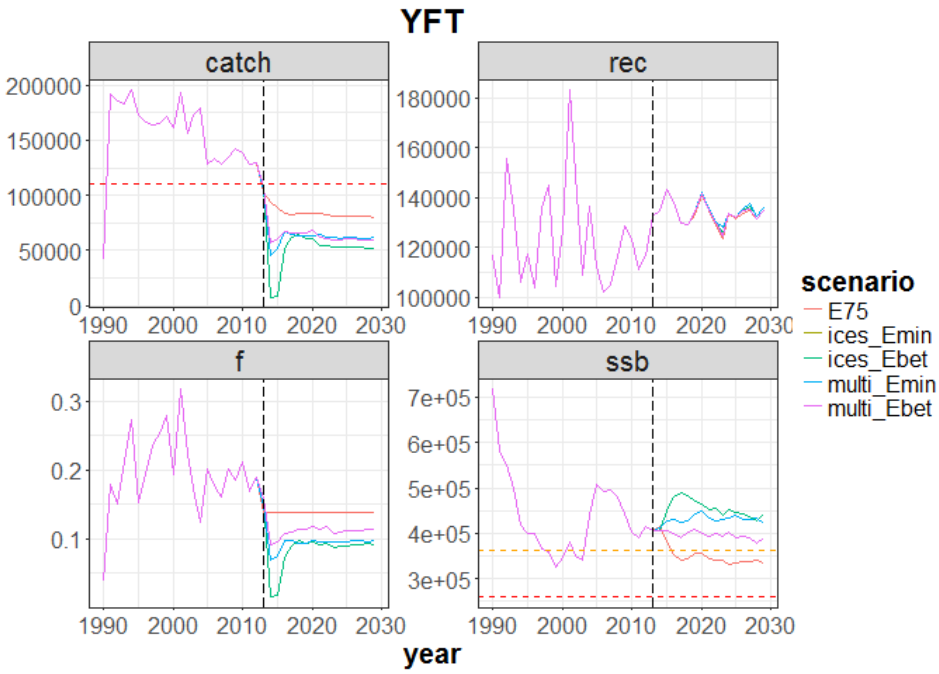

Figure 22: Historical and the estimated median values of yellowfin (YFT) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal discontinuous lines are Blim and Btrigger.

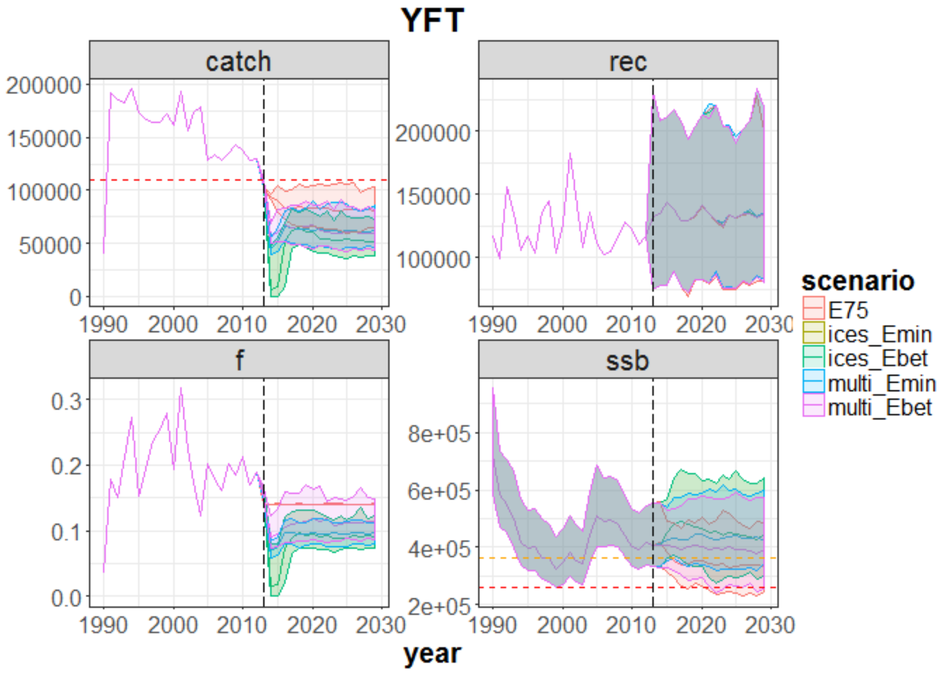

Figure 23: Historical and the estimated median values and the 5th and 95 quantile of yellowfin (YFT) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 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 24). 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 25 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).

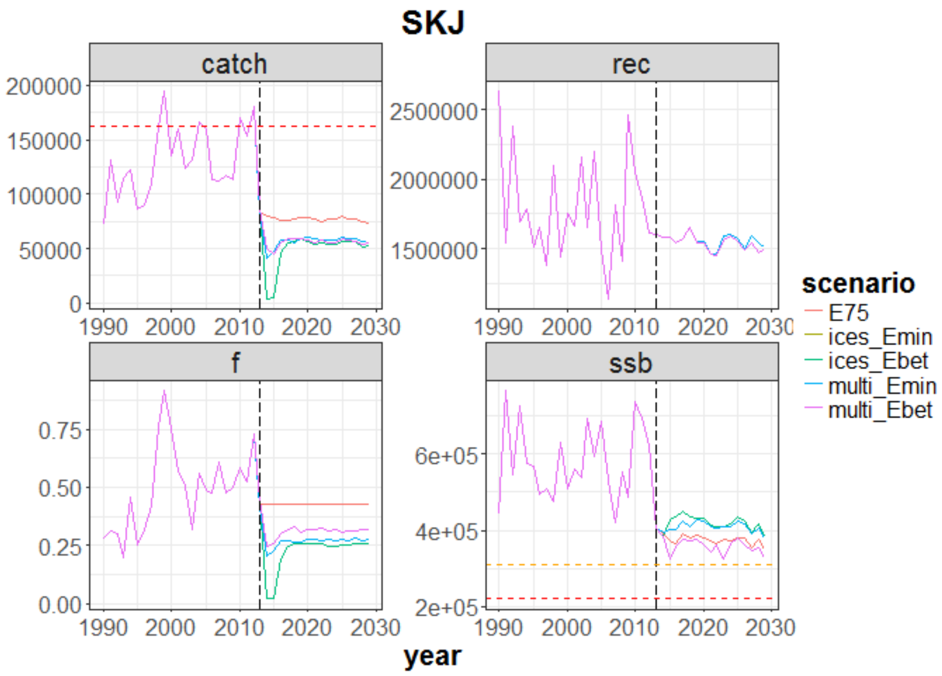

Figure 24: Historical and the estimated median values of skipjack (SKJ) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 2013 and the horizontal discontinuous lines are Blim and Btrigger.

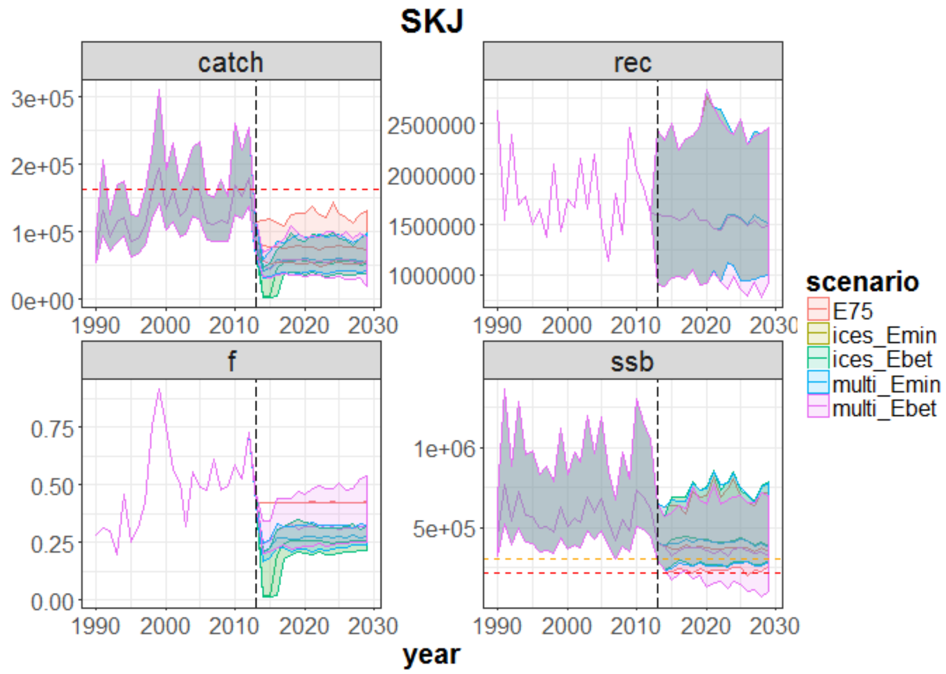

Figure 25: Historical and the estimated median values and the 5th and 95 quantile of skipjack (SKJ) in the projection with the MSE model of catch, recruitment, fishing mortality (f) and spawning stock biomass under different scenarios. The vertical discontinuous line is the year starts the projection 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 26 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.

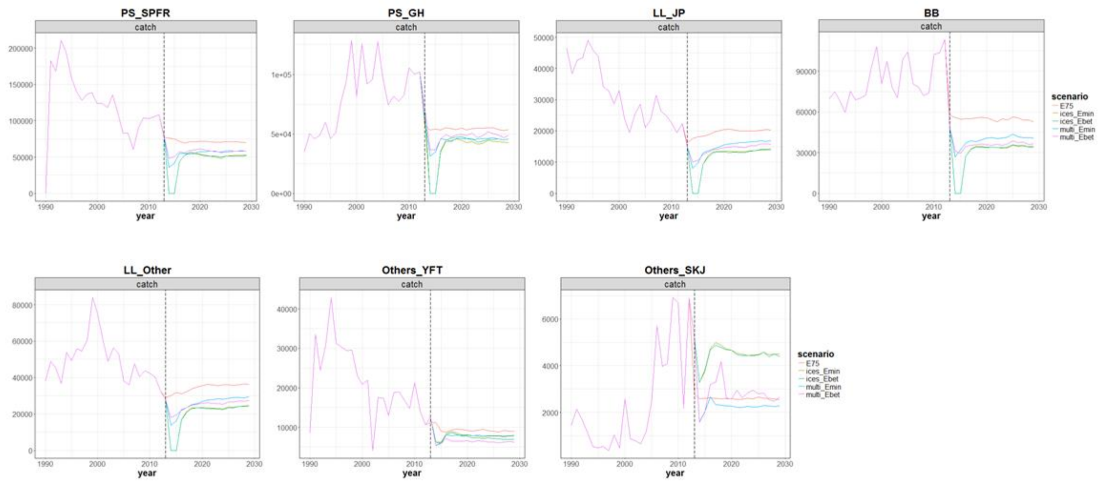

Figure 26: Historical and the estimated median values of total catches in the projection with the MSE model for each fleet.

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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