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Establishment of reference points and harvest control rules in the Framework of the International Commission for the Conservation of Atlantic Tunas (ICCAT)

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Final Report

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Institut de recherche pour le développement	IRD	France
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Glossary of terms

Species and stocks

Code	Scientific name	Common name
ALB	*Thunnus alalunga*	Albacore
BFT	*Thunnus thynnus*	Bluefin tuna
SWO	*Xiphias gladius*	Swordfish
SKJ	*Katsuwonus pelamis*	Skipjack tuna
YFT	*Thunnus albacares*	Yellowfin tuna
BET	*Thunnus obesus*	Bigeye tuna
PBF	*Thunnus orientalis*	Pacific bluefin

Management bodies, organizations, research projects and others (in alphabetical order)

Accronym	*Full name*
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
ESC	Extended Scientific Committee
FAO	Food and Agriculture Organization
GBYP	Atlantic Wide Research Program for Bluefin Tuna
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
NAFO	Northwest Atlantic Fisheries Organization
PNA	Parties to the Nauru Agreement
RFMO	Regional Fisheries Management Organization
SCRS	Standing Committee for Research and Statistics
SPC	Secretariat of the Pacific Community
tRFMO	Tuna Regional Fisheries Management Organization
UN	United Nations
WCPFC	Western and Central Pacific Fisheries Commission
WGESA	Working Group on Ecosystem Science and Assessment

Technical terms (in alphabetical order)

Abbreviation	*Full name*
Blim, Flim	Limit Biomass and Fishing Mortality
Btar, Ftar	Target Biomass and Fishing Mortality
Bthresh, Bpa, Btrigg, Btrigg	Threshold Biomass
Fthresh, Fpa	Threshold Fishing Mortality
CAA	Catch at Age
CAS	Catch at Size
CMM	Conservation and Management Measures
CPUE	Catch Per Unit of Effort
FAD	Fish Aggregating Device
FMSY, BMSY	Biomass and Fishing Mortality that produce Maximum Sustainable Yield
HCR	Harvest Control Rule
K2SM	Kobe 2 Strategy Matrix
LRP	Limit Reference Point
MP	Management Procedure
MSE	Management Strategy Evaluation
MSY	Maximum Sustainable Yield
OEM	Observation Error Model
OM	Operating Model
PA	Precautionary Approach
RP	Reference Point
SA	Stock Assessment
SPR	Spawning Potential Ratio
SR	Stock-Recruitment
SSB	Spawning Stock Biomass
T1NC	Task 1 Nominal Catch
T2CE	Task 2 Catch and Effort
T2SZ	Task 2 Size
TAC	Total Allowable Catch
TRP	Target Reference Point
Y/R	Yield per Recruit

Abstract

The management objective of the International Commission for the Conservation of Atlantic Tunas (ICCAT) is to achieve high long-term yields with a high probability of stocks not being overfished, of no overfishing occurring and with a low probability of stocks being outside safe biological limits. Harvest Control Rules (HCRs) are a set of pre-agreed rules to determine annual Total Allowable Catches (TACs) and could be used as a management instrument to reach the goal of ICCAT. HCRs need to be agreed by policymakers and stakeholders, which is often difficult to achieve due to many uncertainties inherent to fisheries. To help managers designing appropriate HCRs, Management Strategy Evaluation (MSE) is often used. The MSE framework reproduces the different sources of uncertainty in the fisheries and biological system and allows making a comparative assessment of the performance of alternative HCRs in achieving the management objectives. In this study, an MSE for North Atlantic albacore was developed and simulations were performed to assess the impact of alternative HCRs. The study highlights some of the options leading to stable high long term yields while meeting conservation objectives. The grounds for an MSE framework for Atlantic bigeye is also presented, which may facilitate the decision making process over the use of Fish Aggregating Devices (FADs). The results produced have already contributed to the ongoing dialogue between scientists and policymakers in ICCAT and other tuna Regional Fisheries Management Organisations, and are expected to do so in the future.

Résumé

L'objectif de gestion de l'ICCAT est de maintenir des captures élevées à long terme avec une faible probabilité de surexploitation, de survenance de surpêche ou de dépassement des limites biologiques. L’outil de gestion retenu, les règles de contrôle de captures (RCC), sont des ensembles de règles à appliquer pour le calcul annuel des totaux admissibles de captures. Ces RCC doivent être convenues par les décideurs et les parties prenantes, ce qui est souvent difficile en raison des nombreuses incertitudes inhérentes aux pêcheries. Permettant de faciliter le processus d’adoption de ces règles, l’évaluation de stratégie de gestion (MSE) est un outil visant à comparer la performance de différentes RCC en terme réalisation des objectifs de gestions, dans un cadre apportant une représentation réaliste des diverses source de variabilité et d’incertitude du système halieutique considéré. Dans cette étude, nous avons développé une MSE pour le germon de l'Atlantique Nord et simulé l'impact de RCC alternatives, et mettons en évidence des scenarios de gestion assurant des captures élevées et stables à long terme tout en garantissant les objectifs de conservation. Nous avons également posé les bases d'un cadre MSE pour le patudo de l'Atlantique, ce qui facilitera les prises de décision sur l'utilisation des dispositifs de concentration de poissons. Les résultats obtenus ont déjà contribué à la poursuite du dialogue entre les scientifiques et les décideurs à l'ICCAT et dans d'autres ORGP, et devraient le faire dans l'avenir.

Executive Summary

Objective of the study

The objective of the study is to provide the European Commission with scientific advice for appropriate management frameworks, including harvest control rules, for the main stocks under ICCAT competence that are relevant for EU fisheries.

Tasks

Following tasks were completed:

1. Critically review the available information, the reference points currently used and their associated probabilities relevant to stock assessments of the following stocks under the purview of ICCAT: East-Atlantic bluefin (E-BFT), North-Atlantic swordfish (NA-SWO), North-Atlantic albacore (NA-ALB), Mediterranean swordfish (Med-SWO), Mediterranean albacore (Med-ALB) and Atlantic tropical tunas (bigeye (BET), yellowfin (YFT) and skipjack (SKJ)). Results of this task are included in section 1 of the report.

2. Establish an inventory of available information pertaining to the stocks indicated in Task 1 in relation with Limit Reference Points (LRP), Target Reference Points (TRP) and Harvest Control Rules (HCR). Results of this task are included in section 1 of the report.

3. Critically review the methodology and outputs of the past and current assessments, assess the pertinence of data and of the assessment models used including the identification of uncertainty sources. Results of this task are included in section 2 of the report.

4. Review the existing reference points and assess their robustness and the associated probabilities at least for two of the stocks indicated in task 1, following ICCAT`s recommendation (Draft Rec. Amending Rec. 13-18, Doc. No. PLE-118A/2014). This task focused on North Atlantic albacore by developing a full Management Strategy Evaluation (MSE) and on the Atlantic bigeye stock by presenting the first steps towards developing a full MSE that will be applicable to all three tropical tuna stocks (bigeye, yellowfin and skipjack).

5. In the light of the results of Task 4 discuss and propose different limit/target reference points and their robustness to different management scenarios and HCR for the stocks analysed. In particular suggest methodological approaches to fix LRP and their associated probabilities. Results of this task are included in sections 3 and 4 of the report and are the basis of the final conclusions of this project.

This work has been completed through desk-based research, two workshops and a dialogue with stakeholders. The work and responsibilities have been distributed to each partner of the consortium based on specific competencies and expertise in the assessment and management process of different ICCAT stocks, modelling capacities and involvement in the current process of designing Management Strategy Evaluation frameworks within ICCAT.

All partners have contributed to produce the current technical report and the coordinating partner, AZTI has compiled all outputs and information generated during the tasks to organize coherent outputs.

Achievements

The results produced during this project have contributed with documents and presentations to the following:

(i) ICCAT's Standing Working Group to enhance dialogue between Scientists and Managers (SWGSM, Bilbao, Spain, 22-24 June 2015)
(ii) ICCAT's albacore Working Group and the Standing Committee for Research and Statistics (Madrid, 21th September-2nd December 2015)
(iii) Indian Ocean Tuna Commission (IOTC) 4th meeting of the MSE Development Group of the Working Party of Methods (Ispra, Italy, 5-8 May 2015)
(iv) Western and Central Pacific Fisheries Commission (WCPFC) 4th Harvest Strategy Workshop (Bali, Indonesia, 30th November-1st December 2015)

In addition, the work developed in this project will contribute among others to the incoming:

(i) ICCAT's incoming Working Group in Stock Assessment Methods (WGSAM, Madrid February 2016)
(ii) IOTC MSE development group meeting (Tokyo, April 2016)
(iii) North Atlantic albacore (ICCAT) assessment (Madeira, Portugal May 2016)
(iv) IOTC's Management Procedure Dialogue (La Reunion, France May 2016)
(v) ICCAT's Atlantic yellowfin Stock Assessment (Pasaia, Spain, June 2016)
(vi) ICCAT Panel 2 intercessional meeting (Japan July 2016)

Résumé Exécutif

But du contrat spécifique

DG MARE a chargé un consortium dirigé par l'IEO (composé par les instituts AZTI, IEO, IRD, IMARES, IPMA et MRAG) pour mener à bien le contrat-cadre MARE (FWC) / 2012/21, 'Les avis scientifiques de la pêche en dehors des eaux de l'UE ». Ce projet concerne le 8ème contrat spécifique dans le cadre qui a pour objectif de fournir à la Commission européenne une proposition de cadres de gestion appropriés, y compris les règles de contrôle de capture, pour les principaux stocks relevant de la compétence de l'ICCAT qui sont pertinents pour les pêcheries de l'UE.

Tâches du contrat spécifique

À cette fin, les opérations suivantes ont été réalisées:

1. examen critique des informations disponibles, les points de référence actuellement utilisés et leur probabilités associées, pertinents pour l'évaluation des stocks suivants dans le cadre du mandat de l'ICCAT: thon rouge de l'Atlantique Est, espadon de l'Atlantique Nord, germon de l'Atlantique Nord, espadon de la Méditerranée, germon de la Méditerranée et thons tropicaux de l'Atlantique (thon obèse, albacore et listao). Cette tâche est incluse à l'annexe I et a été présenté à la DG MARE lors de la réunion d'information intermédiaire en Juin 2015.

2. Dresser un inventaire des informations disponibles concernant les actions indiquées dans la tâche 1 en relation avec les points de référence limite (PRL), points de référence cibles (PRC) et des règles de contrôle de capture (HCR). Cette tâche est incluse à l'annexe I et a été présentée à la DG MARE lors de la réunion d'information intermédiaire en Juin à 2015.

3. un examen critique de la méthodologie et les résultats des évaluations passées et actuelles, évaluer la pertinence des données et des modèles d'évaluation utilisés, y compris l'identification des sources d'incertitude. Cette tâche est incluse dans l'annexe II.

4. Passer en revue les points de référence existants et évaluer leur robustesse et les probabilités associées au moins pour deux des stocks indiqués dans la tâche 1, suivant recommandation de l'ICCAT (Projet de Rec. Modifiant Rec. 13-18, Doc. N ° PLE-118A / 2014). Une version préliminaire de cette tâche pour le germon de l'Atlantique Nord a été présentée à DGMARE lors de la réunion d'information intermédiaire en Juin 2015. Le rapport complet de cette tâche a été ajouté aux livrables 4.1 et 4.2 (annexe III) et présenté en Janvier 2016. En ce qui concerne le stock de thon obèse de l'Atlantique, l'annexe IV présente les premiers pas vers le développement d'une MSE complète qui sera applicable aux trois stocks de thons tropicaux (thon obèse, albacore et listao).

5. À la lumière des résultats de la tâche 4 discuter et proposer différents points de référence limite / cible et leur robustesse aux différents scénarios de gestion et HCR pour les stocks analysés. En particulier suggérer des approches méthodologiques pour fixer les LRP et leurs probabilités associées. Cette tâche est incluse à l'annexe V et sera la base des conclusions finales de ce projet.

Ce travail a été complété par des recherches documentaires, deux ateliers et un dialogue avec les parties prenantes. Le travail et les responsabilités ont été distribués à chaque associé en fonction des compétences et une expertise spécifique dans le processus d’évaluation et de gestion de différents stocks ICCAT, les capacités de modélisation et de la participation dans le processus actuel de la conception de cadres d'évaluation des stratégies de gestion (MSE) au sein de l'ICCAT.

Tous les partenaires ont contribué à produire les rapports techniques nécessaires et les résultats attendus, mais le partenaire de coordination, AZTI a compilé toutes les sorties et les informations générées pendant les tâches pour organiser des sorties cohérentes.

Réalisations

Les résultats obtenus au cours de ce projet ont contribué avec des documents et des présentations à ce qui suit:

i. Groupe de travail permanent de l'ICCAT visant à renforcer le dialogue entre les scientifiques et les gestionnaires (SWGSM, Bilbao, Espagne, 22-24 Juin 2015)
ii. Groupe de travail germon de l'ICCAT et le Comité permanent pour la recherche et les statistiques (Madrid, 21 Septembre- 2 Octobre 2015)
iii. Commission des thons de l'océan Indien (CTOI) 4e réunion du Groupe de développement MSE du Groupe de travail sur les méthodes (Ispra, Italie, 5 à 8 mai, 2015)
iv. Commission des pêches du Pacifique Ouest et Central (WCPFC) 4e Atelier sur les stratégies de capture (Bali, Indonésie, le 30 Novembre-1er Décembre 2015)

En outre, le travail développé dans ce projet contribuera entre autres aux réunions suivantes:

i. Groupe de travail à venir de l'ICCAT sur les méthodes d'évaluation des stocks (WGSAM, Madrid Février 2016)
ii. réunion du groupe de développement MSE de la CTOI (Tokyo, Avril 2016)
iii. évaluation du germon de l'Atlantique Nord (CICTA) (Madère, Portugal mai 2016)
iv. Procédure de gestion Dialogue CTOI (La Réunion, France Mai 2016)
v. l'évaluation du stock d’albacore de l'Atlantique de la CICTA (Pasaia, Espagne, Juin 2016)
vi. réunion intersessions du panel de la CICTA 2 (Japon Juillet 2016)

1. REVIEW OF REFERENCE POINTS (RP) IN ICCAT AND OTHER AREAS

The sustainability of fisheries is determined by the balance between the amount of biomass harvested and the capacity of fish stocks to respond to harvesting. The International Commission for the Conservation of Atlantic Tunas (ICCAT) is responsible for the conservation of tuna species in the Atlantic Ocean and adjacent seas and, on the basis of scientific evidence, makes recommendations with the aim of maintaining the populations of tuna at levels that will permit the maximum sustainable catch (ICCAT, 2007). Therefore, a foundational management objective of ICCAT is achieving the Maximum Sustainable Yield (MSY), an equilibrium point at which the capacity of the fish stocks to replace the removed biomass is maximised, and therefore, the long-term catch from fish stocks is maximised too (Schaefer, 1954).

In addition, two international agreements – the UN Fish Stocks Agreement (UN, 1995), and the FAO Code of Conduct for Responsible Fisheries (FAO, 1995)– provide the foundation of the Precautionary Approach (PA) to fisheries management, which in practical terms requires fisheries management bodies to determine the status of fish stocks relative to target reference points (TRP) and limit reference points (LRP), to predict outcomes of management alternatives (e.g. HCRs) for reaching the targets while avoiding the limits, and to characterise the uncertainty in both cases. PA to fishery management (Garcia, 1996) 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.

Despite not being included explicitly in its convention, in practice ICCAT has applied the principles of the PA, which requires that undesirable outcomes be anticipated and measures taken to reduce the probability of them occurring (De Bruyn et al., 2013). In addition, all five tuna Regional Fisheries Management Organisations (RFMOs) are in the process of incorporating the PA into their management approach, and most are developing and implementing TRPs, LRPs and HCRs for one or more stocks. To help provide consistency of advice across the RFMOs a common management advice framework has been developed to visualize the state of exploitation of fish stocks (De Bruyn et al., 2013) (i.e. the Kobe Framework). Kobe plots and the Kobe Strategy Matrix (K2SM) are the agreed way to report the probability of something happening (e.g. biomass-B falling below B_{MSY} or fishing mortality-F going over F_{MSY}) under alternative management scenarios (ISSF, 2013). In general, in ICCAT it is intended to recommend decisions that will maintain fish stocks at levels above that of B_{MSY} and fishing mortality at levels below F_{MSY} with high probability.

In general, LRPs are benchmarks that should not be exceeded with any substantial probability according to a given set of management objectives. They indicate the limit beyond which the state of a fishery and/or a resource is not considered desirable and remedial management action is required to allow the recovery of the stock. In the exceptional case when a stock is at very low abundance, LRPs can also be taken as an interim rebuilding target (ISSF, 2013). In contrast, a TRP is a benchmark that should be achieved on average according to a given set of management objectives. It corresponds to a state of a fishery and/or resource which is considered desirable (ISSF, 2013). The PA also recommends that LRPs and TRPs are used in combination with precautionary RPs (F_{pa}, B_{pa} or $B_{trigger}$) to determine what actions to be taken to avoid reaching the LRPs.

1.1 Candidate Reference Points: MSY, Depletion based and Spawning Potential per Recruit

Three categories of methods for Reference Points estimation, with varying data requirements and strengths and weaknesses are discussed (Preece et al., 2011), whose findings are summarized in this section: 1) MSY-based, 2) Spawning Per Recruit (SPR) based and 3) Depletion based. Despite their work being directed to discuss alternative LRPs, most of their indications are pertinent to the estimation of any RPs based upon MSY, depletion or spawning potential.

1) MSY is most often calculated by finding deterministic equilibrium dynamics of the stock using the selectivity values of the current fisheries. MSY based RPs are built into many of the legal frameworks of highly migratory fisheries (e.g. UNCLOS, 1982; UNFSA, 1995 and ICCAT foundational management objectives). Historically, MSY based RPs (F_{MSY}, B_{MSY}) have been used as a target, but these have been recognised for some time now as limit RPs for fishing mortality and biomass in some areas (Mace, 2001). MSY can be estimated for most of ICCAT stocks, as there are methods capable of providing estimates using catch data series only (Martell and Froese, 2012). However, estimates of MSY using more sophisticated models require selectivity, natural mortality, maturity and estimates of the spawner-recruit relationship.
   The strength of MSY (and MSY-based RPs) is that it covers productivity directly, maximising yields while maintaining the population level at a safe and productive level. The key weakness is the difficulty in robustly estimating it. This is because MSY based RPs are sensitive to uncertainties in the steepness of the stock-recruitment curve and fisheries selectivity at age. Several examples have shown that for various levels of steepness, there is a wide range of values for MSY, and therefore, also a wide range of values for the MSY-based reference points. Steepness is one of the parameters of stock-recruitment (SR) relationships and; it reflects the impact that a biomass reduction below a particular level has on recruitment. Note that steepness is a measure of the productivity of a stock, and can be interpreted as a measure of the resilience of the stock to fishing pressure. In tuna RFMOs, there is not enough information on steepness and therefore the SR relationship is weak. In ICES, in such situations, the recent trend in MSY estimation methods consists of considering different assumptions on the shape of the SR relationship in stochastic simulations. The available SR data is used to assess the likelihood of each relationship, which is then used jointly in long term stochastic simulations, using for each a weight proportion to its likelihood. This way the uncertainty in the steepness is incorporated into the estimation of MSY.
2) The spawning potential per recruit is the potential contribution of spawning stock biomass (SSB) over the lifetime of a single recruit. It can be calculated at any given fishing mortality level. A practical measure of the state of depletion of exploited stocks is the spawning potential ratio (SPR), which represents the ratio of the spawning potential per recruit for a given level of F, and the spawning potential per recruit in the pristine stock (SPR_0). The SPR is often used to estimate LRPs (Mace, 2001). Some authors recommend reductions of 35%-40% in SPR_0 as LRPs (Preece et

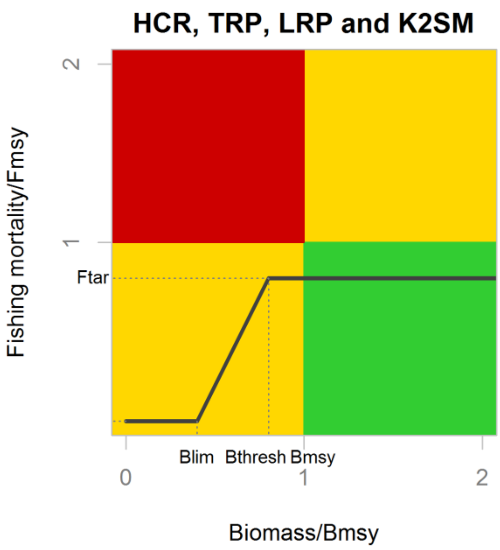
al., 2011). The information required to estimate this parameter includes natural mortality, maturity and selectivity, which are often available in ICCAT stock assessments.

3) Depletion based RPs are based on the depletion level of the total (or SSB) biomass and provide biomass based RPs (e.g. x% of SSB). Depletion estimates provide information on how much the SSB has been reduced since fishing began and therefore, how much SSB remains, and the estimated impact on historic, current and future recruitment and yield. Most common depletion based RPs are defined as % of the initial unfished biomass. An advantage of depletion based RPs is that they are relatively stable between assessments and, in many of the tuna stocks have provided the least variation in the range of results across a range of steepness values used (Kolody et al., 2010).

The above are characteristics of alternative RPs and the associated estimation problems. According to them, Preece et al (2011) recommend a three level hierarchical approach to setting LRPs. The first level uses F_{MSY} and B_{MSY} but only where reliable and precise estimates of steepness are available. The second uses F_{SPR} and 20% of SSB_0 assuming that steepness is not known well but the key biological estimates are reasonably well estimated. The third level does not provide an F-based LRP if the key variables are not well estimated or understood, but suggests that the SSB limit of 20% of SSB_0 be used (Preece et al., 2011). Finally, note that using a symmetric production function (logistic) for a fish stock, B_{MSY} will be located at 0.5 B_0 or unfished biomass, while 0.2 of B_0 will be 0.4 of B_{MSY}, which has been proposed as an interim LRP for North Atlantic albacore and swordfish stocks in ICCAT. Therefore, MSY-based RPs are combined with their recommended depletion levels for LRPs in ICCAT.

1.2 Limit and Target Reference Points and Harvest Control Rules in ICCAT

The foundational management objective of ICCAT is to maintain the populations of tuna at levels that will permit the MSY. Therefore, ICCAT has commonly used the MSY-based RPs of F_{MSY} and B_{MSY} as targets. However, the United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks (UN, 1995) subsequently defined the fishing mortality associated to MSY (F_{MSY}) as an upper limit. In the long term sense, B_{MSY} is the average biomass that results from fishing constantly at F_{MSY}. Given that there is considerable variability in the stock-recruitment relationship, that management operates on a stock perceived through a stock assessment model with associated uncertainties, and that management implementation may deviate from management targets, in practice, stock biomass will fluctuate above and below the B_{MSY} equilibrium level when fished at F_{MSY}, with p=50% of being above and below B_{MSY}. This is contrary to the objective of biomass falling below B_{MSY} with low probability (ICCAT, 2013a). Therefore, a target F should be lower than F_{MSY} and consequently the probability of biomass falling below B_{MSY} will be reduced, which is an objective. Therefore, some parties have stressed that F_{MSY} should be set as a limit that should not be exceeded (ICCAT, 2014a). According to the Recommendation 11-13 (ICCAT, 2013a), the implicit target for ICCAT is to maintain stocks in the green quadrant of the Kobe plot with high probability. Thus, the overall management intention is to maintain 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).



Harvest Control Rules are pre-agreed management decisions that determine how the fishing mortality used to compute the TAC should be set automatically in relation to the state of some indicator of stock status (ISSF, 2013). Figure 1 shows a Kobe plot on which a HCR is drawn. Here, when the stock level is above the precautionary threshold (B_{pa}), the fishing mortality applied to the stock will be below F_{MSY} (F_{tar}). When the stock falls below B_{pa} but above B_{lim}, the fishing mortality will be lower than F_{tar}. When the stock falls below B_{lim}, the remedial management action will be determined by F_{min}.

Figure 1. Model based Harvest Control Rule.

Harvest Control Rules can be empirical or model-based in management strategies. Model-based HCRs are attractive because they may be linked to the stock assessment results and generally have a greater capacity to "learn" about stocks' productivities (ISSF, 2013) and empirical based HCRs are generally applied in stocks with limited data availability. In ICCAT, both model based and empirical HCRs are being evaluated in species' working groups (ICCAT, 2014c). The model based HCRs have been explored in albacore, bluefin and swordfish stocks, while more empirical HCRs, for instance on size indicators, have been tested in the latest skipjack stock assessment.

In the report of the 2010 ICCAT Working Group on Stock Assessment methods (ICCAT, 2011a), formal definitions of target, limit and thresholds are provided:

1. A target is a management objective based on a level of biomass (B_{tar}) or a fishing mortality rate (F_{tar}) that should be achieved with high probability, on average. This generally means that the probability of exceeding the target reference point should be 50%. Targets should be set sufficiently far away from limits so that they result only in low probability that the limits will be exceeded.
2. A limit is a conservation reference point based on a level of biomass (B_{lim}) or a fishing mortality rate (F_{lim}) that should be avoided with high probability because it is believed that the stock may be in danger of recruitment overfishing or depensatory effects if the limit reference points are violated.
3. A threshold is a level of biomass ($B_{trigger}$, B_{thresh} or B_{pa}) or a fishing mortality rate (F_{thresh}) between the limit and target reference points that serves as a "red flag" and may trigger particular management actions designed to reduce fishing mortality.

As part of a HCR, buffer and limit reference points are intended to restrict harvesting so as to avoid highly undesirable states of the stock, such as the impairment of the recruitment, from which recovery could be irreversible or slowly reversible. LRPs can be set based on fishing mortality rates or related to biomass levels; in many cases, it is interpreted that the Commission is referring to biomass related to LRP (B_{lim}). A biomass related LRP is defined as a boundary (e.g. in terms of absolute or relative biomass levels, spawning potential ratios (SPR), etc., which, if crossed, would require the cessation (or setting it to a minimum, F_{min}) of harvesting until the stock has recovered to a level above the LRP). Additional HCRs can be put in place to avoid falling below the B_{LRP} with high probability (ICCAT, 2014c). The biomass limit should be lower than B_{MSY} by an amount that depends on recruitment variability and estimation error (ISSF, 2013; Restrepo and Powers, 1999).

To achieve management objectives, HCRs are sets of well-defined rules that can be used for determining annual catch limits or fishing mortality levels (Restrepo and Powers, 1999). The current procedure in ICCAT is different to that of a HCR: Currently, the Commission decides the actions to take considering various factors and choosing between actions of different strength, depending on the probability levels and timeframes for the achievement of management objectives (level of recovery, probability of stock being in the green zone etc). With HCRs, actions will be pre-agreed, automatic and can be as strong as suspending fishing or reducing fishing activities to a minimum (Miyahara, 2014). ICCAT recommendation 11-13 is a framework for a HCR but it has not yet been parameterized for any stock. In common practice using HCRs, in situations where there is little or no analysis of uncertainty, and particularly where F_{MSY} is determined assuming perfect knowledge, the estimate of F_{MSY} should be a minimum standard for a LRP, and consequently, the target F should be below F_{MSY} (Miyahara, 2014).

The following sections provide a more detailed overview of the reference points, including target and limit reference points, that have been implemented to date or are in the process of being developed by tuna RFMOs in the Atlantic (ICCAT), Pacific (IATTC and WCPFC), Indian Ocean (IOTC) and in the southern Ocean and adjacent waters (CCSBT), as well as in the International Council for the Exploration of the Sea (ICES) and Northwest Atlantic Fishery Organization (NAFO).

1.3 Current status of management strategies

The five tuna RFMOs have broad conservation objectives. ICCAT, IATTC and WCPFC mention explicitly MSY levels, while IOTC and CSBT do not. Of the five, only CCSBT has a formal management strategy (management procedure) in place, which is used to set TACs. The other four are at different stages in terms of formally adopting various elements of management strategies, which are summarized in the following table (Table 1), taken and updated from ISSF, Stock Assessment Workshop report (ISSF, 2013).

Table 1. Progress towards the implementation of HCRs in tuna RFMOs.

Element	IATTC	ICCAT	IOTC	WCPFC	CCSBT
Management Objectives (Convention and CMMs)	Population level that can produce MSY. Apply the Precautionary Approach.	Maintain population at level that can permit maximum sustainable catch.	Conservation and optimum utilization of stocks. Adoption of PA in 2012 (Res. 12-01). "Dialogue initiated" on identifying clear management objectives.	Maintain stocks at levels capable of producing MSY, as qualified by environmental, economic and SIDs considerations. Includes guidelines for RPs based on best science.	Ensure, through appropriate management, the conservation and optimum utilization of SBT. The 2011 Commission meeting requires TAC setting to also take PA into account.
Limit Reference Points	8% of the unfished biomass (8%SB_0)	None yet. ALB: Under development by SCRS (Rec. 11-04), Blim=0.4 B_{MSY} SWO: Under development by SCRS (Rec. 11-03) , Blim=0.4 B_{MSY}	Interim, non-binding limits: SKJ: 0.4B_{MSY}, 1.5FMSY BET: 0.5B_{MSY}, 1.3FMSY YFT, ALB and SWO: 0.4B_{MSY}, 1.4FMSY	BET, YFT, ALB: 20%$SB_{current, F=0}$ and F(x%SPR_0) SKJ: 20%$SB_{current, F=0}$ Currently investigating F-based LRPs for SC9 in 2013	Not defined yet. 20% SSB_0 is an interim rebuilding target, but would also become a limit at the end of the rebuilding program. The 2011 decision identifies the lowest observed stock size as the limit
Target Reference Points	FMSY and B_{MSY}	None in place yet Though the "green" quadrant of the Kobe plot is implied as a target region in Rec. 11-04 NALB: Ftar ≤ FMSY NSWO: Ftar ≤ FMSY Range of %$SSB_{current}$	Interim non-binding targets: SKJ, BET, YFT, ALB: B_{MSY}, FMSY	CMM-2012-01 indicates TRP ≤ FMSY for BET, SKJ, YFT 2013 MOW goal: developing TRPs. 2014, F≤FMSY by 2017 (bigeye) and 40%, 50% and 60% of $SB_{current,F=0}$, skipjack	"Interim rebuilding objective": 20% SSB_0 A long-term TRP will be considered once stock is rebuilt to 20%SSB_0.

Element	IATTC	ICCAT	IOTC	WCPFC	CCSBT
HCRs	None formal. Interim HCR recommended by IATTC secretariat staff.	Principles of Decision-making (Rec 11-13) provides HCR framework but parameters not defined ("high" or "low" probability, timeframes)	None formal. HCR development mentioned in the PA Resolution. “Informal” rule based on FMSY or B_{MSY} being exceeded Resolution 13/10 requests the SC to develop HCRs	None yet but SPC conducting PNA-requested review of alternative HCRs for SKJ. “Informal” rule based on FMSY when FMSY is exceeded In 2015 a workplan was defined.	Harvest rules via a TAC, that is the average catch value from two formulas designed to achieve the recovery target and tuned to juvenile surveys and CPUE. 0.7 probability of rebuilding to 20%SSB_0.
Management Strategies / Procedures	If fishing mortality exceeds the levels corresponding to MSY, it should be reduced to that level.	None formal. SCRS advice via Kobe framework (Res 11-14) and strategy matrices.	None formal. SC provides management advice based on stock assessment and recommends catch limits to the Commission.	None formal. SPC provide stock assessments and projections to the SC, and ISC provides them to the SC and Northern Committee	Adopted in 2011. Sets TAC in 3-year intervals. An interim plan to rebuild the stock to the limit level.
Management Strategy Evaluations (MSEs)	Further evaluation of the HCR will be used to adopt a final one.	Under SCRS development for BFT (Mediterranean), ALB (N. Atlantic) and SWO (N. Atlantic)	Under development SC for SKJ, ALB.	“Pseudo-MSE” (without feedback control) under development by SPC.	Completed for the measure adopted in 2013

1.3.1 Atlantic Ocean stocks

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

The biomass (B) and fishing mortality (F) levels, at which a fish stock is and has historically been exploited are estimated through stock assessments. The outputs of this process are estimations of F and B of the stocks of interest relative to those corresponding to a reference point. All stocks in ICCAT are evaluated against their MSY-based RPs (B_{MSY}, SSB_{MSY} and FMSY). However, the estimated MSY may change when changing gears’ selectivity and the productivity of the stock and in some cases proxies of MSY are used, for example: Y/R_{max} (F_{max} and B_{max}), and $Y/R_{0.1}$ ($F_{0.1}$ and $B_{0.1}$).

MSY is the cornerstone on which decision making process is built upon in ICCAT through a ‘*generic*’ HCR. Stock assessment output is expressed in terms of current stock status compared to MSY reference points (Figure 2). Based on this diagnostic Recommendation 11-13 specifies whether and which management action should be taken.

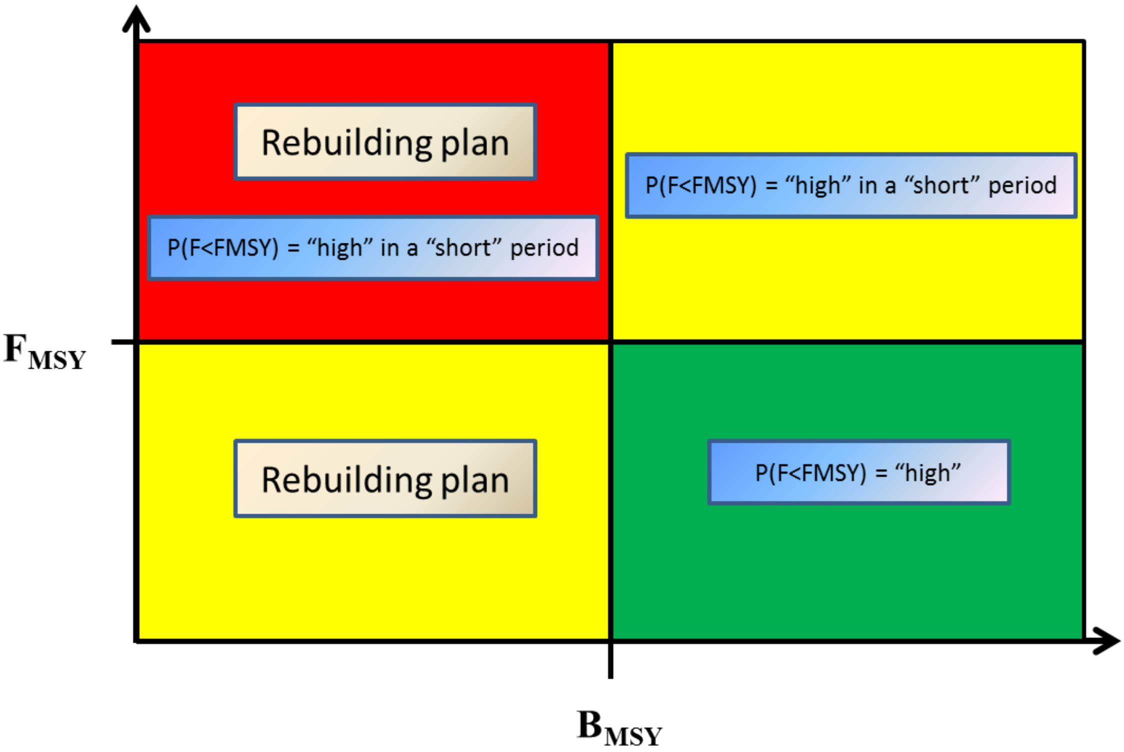


Figure 2. Schematic representation of the key elements of the Recommendation by ICCAT on the principles of decision making for ICCAT conservation and management measures (Rec 11-13) (ICCAT, 2013a).

According to this decision framework, in order to maintain stocks in the green quadrant of the Kobe diagram (not overexploited and not experiencing overexploitation), which is the management objective, ICCAT recommends that (ICCAT, 2013a):

a) For stocks that are not overfished and not subject to overfishing (i.e., stocks in the green quadrant of the Kobe plot, F<FMSY and $B>B_{MSY}$), management measures shall be designed to result in a high probability of maintaining the stock within this quadrant.

b) For stocks that are not overfished, but are subject to overfishing, (i.e., stocks in the upper right yellow quadrant of the Kobe plot, F>FMSY and $B>B_{MSY}$), the Commission shall immediately adopt management measures, taking into account, *inter alia*, the biology of the stock and SCRS advice, designed to result in a high probability of ending overfishing in as short a period as possible.

c) For stocks that are overfished and subject to overfishing (i.e., stocks in the red quadrant of the Kobe plot, F>FMSY and $B<B_{MSY}$), the Commission shall immediately adopt management measures, taking into account, *inter alia*, the biology of the stock and SCRS advice, designed to result in a high probability of ending overfishing in as short a period as possible. In addition, the Commission shall adopt a plan to rebuild these stocks taking into account, *inter alia*, the biology of the stock and SCRS advice.

d) For stocks that are overfished and not subject to overfishing (i.e. stocks in the lower left yellow quadrant of the Kobe plot, F<FMSY and $B<B_{MSY}$), the Commission shall adopt

management measures designed to rebuild these stocks in as short a period as possible, taking into account, inter alia, the biology of the stock and SCRS advice.

The implicit target of this recommendation is to maintain the stocks in the green area with high probability, which adds to the traditional objective of achieving the maximum sustainable catch. Within this framework, managers and stakeholders should provide guidance on terms such as the acceptable time lines and probability levels. For this, Management Strategy Evaluation (MSE) with simulation tests can be a valuable tool that will estimate different levels of probability of achieving management objectives and their timeframes through different management scenarios or HCRs. Through MSE, the validity of TRP and LRP, the plausibility of alternative hypotheses about population structure and dynamics, the capacity of alternative stock assessment approaches and the robustness of alternative HCR can be evaluated. MSE can facilitate the evaluation, selection and adoption of harvest strategies to meet management objectives.

1.3.1.2 Review of the use of reference points in ICCAT priority stocks

The current state of development of MSE in ICCAT is summarized in the table 2 and expanded below:

Table 2. Reference Points used in ICCAT stocks by the SCRS and progress towards MSE.

Stock	*Year of last SA*	*RPs used by SCRS*	*TRP*	*LRP*	*Progress towards RP, HCR and MSE*
NALB	2013	MSY/B_{MSY}/FMSY	Ftar ≤ FMSY	Blim=0.4BMSY (interim)	Developing LRP and HCRs using MSE. The Commission requested SCRS to identify LRPs (Recs 11-04 and 13-05).
MedALB	2011	MSY/B_{MSY}/FMSY	-	-	
EBFT	2014	MSY/B_{MSY}/FMSY F_{01}, BF_{01}	Range of %$SSB_{current}$		High priority placed by the Commission on the completion of the MSE work program
NSWO	2013	MSY/B_{MSY}/FMSY	Ftar ≤ FMSY	Blim=0.4BMSY (interim)	Developing LRP and HCRs using MSE. The Commission requested SCRS to identify LRPs (Rec 11-02).
MedSWO	2014	MSY/B_{MSY}/FMSY	-	-	
BET	2010	MSY/B_{MSY}/FMSY	-	-	
YFT	2011	MSY/B_{MSY}/FMSY	-	-	
SKJ	2014	MSY/B_{MSY}/FMSY	P-opt, P-mat, P-mega	Sustainability principles	Mandate to develop HCRs and tools for this in early stages

1) *North Atlantic albacore:* According to general ICCAT decision making framework over the past years, and consistent with ICCAT convention, MSY has been used as the RP in the latest assessments of this stock (ICCAT, 2013d).
Recommendation 11-04 requested the SCRS "*to develop a LRP for this stock. Future decisions on the management of this stock shall include a measure that would trigger a rebuilding plan, should the biomass decrease to a level approaching the defined LRP as established by the SCRS*."
In the latest assessment, in 2013, the stock status was characterized both with respect to B_{MSY} and FMSY, and the probability of currently being in the green area of the Kobe plot. In addition, future projections were produced to inform the Commission about the

estimated probability of being in the green quadrant in different timeframes for alternative levels of catch and fishing mortality. An LRP equivalent to 0.4 of B_{MSY} was proposed to the ICCAT Commission. Moreover, a suite of candidate HCRs were proposed as combinations of B_{lim} and other coordinates (B_{thresh}, F_{tar}). These HCRs were used to project stock statuses into the future and to facilitate the Commission's choice of probabilities and time frames, considering the uncertainty in stock status evaluations that could be quantified and assuming that the indicated strategy could be perfectly implemented. A suite of SCRS technical papers present the first steps for developing MSE frameworks using simulation testing for this stock (Kell et al., 2013a; Kell et al., 2013b; Kell et al., 2013c).

In 2013, the Commission adopted a new recommendation (Rec 13-05), "*As a matter of priority, the SCRS shall continue the development of a Limit Reference Point (LRP) and Harvest Control Rules (HCRs) for this stock with input from the Commission. Future decisions on the management of this stock should be in accordance with the LRP and HCRs*."

In ICCAT's albacore working group, a tentative interim biomass LRP (B_{lim} = 0.4 of B_{MSY}) was recommended for this stock. Moreover, the impact of a suite of candidate HCRs has been explored as a combination of B_{lim} and other coordinates ($B_{trigger}$, F_{tar}) in a series of technical and scientific papers (Kell et al., 2013a; Kell et al., 2013b; Kell et al., 2013c). Note that using a symmetric production function, B_{MSY} is located at 0.5 B_0, while 0.2 of B_0 will be 0.4 of B_{MSY}, which has been proposed as an interim LRP for this stock. However, others have also been tested through projections (Scott et al., 2013). Therefore, MSY-based RPs are combined with the recommended depletion levels for LRPs in Preece et al (2011).

2) *Mediterranean albacore:* Despite this being an important resource for several coastal countries, the Mediterranean albacore stock was assessed for the first time in 2011, including data up to year 2010 (ICCAT, 2011b). Due to the lack of fishery data the stock status of this species in the Mediterranean was assessed by using the natural mortality (M) as a proxy for F_{MSY}. Due to the preliminary nature of the Mediterranean albacore stock assessment and the state of knowledge, further discussion on RP and HCR have not been considered. Target and limit and reference points and harvest control rules have not yet been developed for this stock.

3) *East Atlantic bluefin tuna:* The stock status for this stock is presented against $B_{0.1}$ and $F_{0.1}$, which are proxies of MSY and also through the probability of being in the green area of the Kobe plot. Currently, this stock is undergoing a rebuilding plan with the objective of recovering the stock to B_{MSY} with a probability greater than 60% by 2023. According to the last SCRS scientific advice the goal of the recovery plan might already have been, or will soon, be reached.

ICCAT's Commission has placed high priority on the completion of an MSE workplan. For this, a specific modelling group ("GBYP Modelling and MSE Group") has been created which first met in December 2014 (ICCAT, 2014b) and which presented a work program for stock assessment and MSE for bluefin tuna. Within other objectives, this group will facilitate consultation and capacity building on RPs, harvest strategies and MSE for bluefin for the SCRS and Commission. For this, an MSE modelling platform will be developed.

For this stock, under ICCAT's Atlantic wide research program for Bluefin Tuna (GBYP), MSE is being conducted to develop novel assessment methods. However, there is no LRP proposed for this stock yet. The completion of the MSE for this stock is considered of high priority for the Commission.

4) *North Atlantic swordfish:* Similarly to other ICCAT stocks, MSY has been used as the reference point in the latest assessments of swordfish. In 2013, the stock status was characterized both with respect to B_{MSY} and F_{MSY}, and the probability of currently being in the green area of the Kobe plot. For swordfish and based on the research undergone in the albacore working group, an interim reference point of 0.4 of B_{MSY} was recommended, which is consistent with the robust limits recommended for a number of Pacific tuna stocks (Preece et al., 2011). A wider range of candidate target and limit reference points is to be evaluated for this stock through MSE testing.

5) Mediterranean swordfish: For this species, a series of reference points were calculated (MSY, F_{Crash}, $F_{0.1}$, F_{max} and $SPR_{30\%}$), with their associated fishing mortalities and biomass. However, the stock status is presented against MSY reference points (B_{MSY} and F_{MSY}). A series of management scenarios were projected but no formal LRP have been proposed or HCRs designed.

6) *Skipjack:* Traditional stock assessment models have been difficult to apply to skipjack because of their particular biological (continuous spawning, areal variation in growth, poor identification of cohorts) and fishery characteristics (difficulty to quantify the fishing effort). In addition, in a tropical tuna mixed fishery, maximizing catch from the most productive stock (skipjack) while keeping the stock in the green quadrant may not be achievable without overfishing of the least productive stocks (yellowfin and bigeye). Consequently, ICCAT-SCRS suggested to examine the consequences of the implementation of RP (or reference regions) and HCRs for skipjack on bigeye and yellowfin tuna stocks.
   In the latest skipjack stock assessment, a suite of indicators of performance of Atlantic skipjack tuna were estimated towards developing specifically built HCRs. In 2014, the ICCAT's dialogue between managers and scientists (ICCAT, 2014a) agreed to recommend the use of HCRs for this stock's management and to develop the required tools. As a first step, the size based information available in ICCAT was analysed and size-based indicators were built, with the aim of exploring potential pathways to develop size based HCRs. These and other HCRs are expected to contribute to the management of this stock but are currently in very early stages of development. Information on the method used can be found in the stock assessment report and a scientific paper (Cope and Punt, 2009; ICCAT, 2014d). According to the skipjack stock assessment report, other potential HCRs include multispecies methods that incorporate information from yellowfin and bigeye fisheries, which often accompany skipjack catch.

7) *Atlantic bigeye:* This stock is assessed against its MSY coordinates. In 2015 (ICCAT, 2010a), the stock status was characterized both with respect to B_{MSY} and F_{MSY}, and the probability of being in the different areas of the Kobe plot for a series of TAC levels. Future projections were produced to inform the Commission about the estimated probability of being in the green quadrant in different timeframes for alternative levels of catch and fishing mortality. The use of alternative RPs, HCRs or other components of MSE frameworks has not been explored for this stock. Target and limit and reference points and harvest control rules have not yet been developed for this stock.

8) *Atlantic yellowfin:* This stock is assessed against its MSY coordinates. In 2011 (ICCAT, 2011c), the stock status was characterized both with respect to B_{MSY} and FMSY, and the historical trajectory of the stock in the Kobe plot, including probabilistic estimates. The impact of alternative values of TAC was explored in relation to B_{MSY} and FMSY. Future projections were produced to inform the Commission about the estimated probability of being in the green quadrant in different timeframes for alternative levels of catch and fishing mortality. Target and limit and reference points and harvest control rules have not yet been developed for this stock.

1.3.2 Pacific Ocean stocks

1.3.2.1 Inter-American Tropical Tuna Commission (IATCC)

The Inter-American Tropical Tuna Commission (IATTC) is responsible for the conservation and management of tuna and other marine resources in the eastern Pacific Ocean. This Commission manages bigeye, yellowfin and skipjack tunas in the eastern Pacific Ocean, and also north and south Pacific albacore and Pacific bluefin in collaboration with WCPFC. Eastern Pacific Ocean stocks are assessed by the IATTC staffs, which makes recommendations to the IATTC.

The new Antigua Convention of the IATTC (formally adopted in 2010) refers to the application of the PA in Part II Article IV. A working group on reference points was established in the 2000s to suggest precautionary limits and targets for tuna stocks (IATTC, 2003), which have now been agreed and implemented by IATTC (Table 3). More recently, in 2014 the IATTC's Scientific Advisory Committee set out plans for the development of recommendations for reference points for blue, black and striped marlin, sailfish and swordfish (SAC-IATTC, 2014).

Limit reference points

In 2014 the IATTC agreed to the staff's recommendation that the LRP for bigeye, yellowfin and skipjack stocks should correspond to the equilibrium spawning biomass which produces a 50% reduction in recruitment from the unfished level, i.e. a spawning biomass that is approximately 8% of the unfished level (Table 3). The bigeye and yellowfin stocks are currently above this limit, and although no MSY-based reference points are available for skipjack, it is very likely that this stock is also above the limit. This is an example of a depletion-based reference point.

Target reference points

In 2014 the IATTC agreed to the staff's recommendation for bigeye, yellowfin and skipjack stocks target reference points should be FMSY and B_{MSY} (st control *rule can be adopted.*). The bigeye and yellowfin stocks are currently around this TRP, and although no MSY-based reference points are available for skipjack, it is very likely that this stock is also around this TRP.

Harvest control rule

In 2014 the IATTC agreed to the staff's recommended HCR that fishing mortality should be reduced to a level corresponding to MSY if it should exceed that level (st control *rule can be adopted.*).

Table 3. Reference points and harvest control rules for eastern Pacific Ocean tuna stocks managed by the IATTC

Species (stock)	*Limit RP*	*Target RP*	*HCR*
Bigeye (EPO)	8% of the unfished biomass (8%SB_0)*	F_{MSY}; B_{MSY}*	If fishing mortality exceeds the level corresponding to MSY, it should be reduced to that level*
Yellowfin (EPO)			
Skipjack (EPO)			

** Adopted in 2014 and currently applied on an interim basis; EPO = eastern Pacific Ocean*

In 2015 the IATTC staff recommends the following interim HCR:

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

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

3. If the probability that the spawning biomass (S) is below the limit reference point (S_{limit}) is greater than 10%, measures will be established that have a probability of at least 50% of rebuilding S to the target level (dynamic SMSY) or greater, and a probability of less than 10% that S will fall below S_{limit} within a period of two generations of the stock or five years, whichever is greater.

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

Further evaluation of this harvest control rule and alternatives will be conducted, so that a permanent harvest control rule can be adopted.

1.3.2.2 Western and Central Pacific Fisheries Commission (WCPFC)

In 2004, the WCPFC Convention entered into force, including provisions for the application of the PA. WCPFC specifies the guidelines for the estimation of RPs to be used when implementing the PA. In addition, it provides the principles for the application of the PA in fisheries management with special focus on the inclusion of uncertainty, the development of reference points and the monitoring of resource status in relation to these reference points. Those general principles of the PA are being taken into consideration, including the development of limit reference points for all three tropical tuna stocks managed by the WCPFC (Table 4).

Limit reference points

In 2012, the WCPFC adopted for bigeye, yellowfin and skipjack a LRP of 20% of the equilibrium spawning biomass that would be expected in the absence of fishing under current (most recent 10 years of the current assessment, excluding the last year) environmental and biological conditions.

The bigeye stock breached this limit in 2012, although yellowfin and skipjack stocks are estimated to be above this limit.

Target reference points

No TRPs have been defined for the long term for any WCPFC stocks. However, in 2014 an interim target of achieving $F \leq F_{MSY}$ by 2017 was implied for bigeye, and target reference points of 40%, 50% and 60% of unfished spawning stock biomass are currently being considered for skipjack (WCPFC, 2014a).

Harvest control rules

In relation to the development of HCRs, CMM-2014-01 calls for WCPFC to develop and implement a harvest strategy approach that includes TRP, LRP and HCRs for all stocks. The WCPFC is to establish a work plan for achieving this at its 2015 meeting. As part of this the WCPFC will establish stock-specific LRP and TRP; where these RP are already agreed they may be incorporated into the harvest strategy for that fishery. The WCPFC will also establish acceptable levels of risks associated with breaching LRP and shall decide a set of pre-agreed management actions with respect to these RP. CMM-2014-06 also states that evaluation of the likely performance of any HCR in achieving operation objectives should be undertaken by the Scientific Committee, most likely using simulation modelling (i.e. MSE).

Table 4. Reference points and harvest control rules for western and central Pacific Ocean tuna stocks managed by the WCPFC.

Species (stock)	*Limit RP*	*Target RP*	*HCR*
Bigeye (WCPO)	20% of the equilibrium spawning biomass that would be expected in the absence of fishing ($20\%SB_{current,\ F=0}$)	Not defined for the long term. Achieving $F \leq F_{MSY}$ by 2017 implied as an interim target (CMM-2014-01)	Not defined for any stock. CMM-2014-06 calls for the development of a harvest strategy approach that includes target/limit reference points, harvest control rules and other elements. At its 2015 meeting, the WCPFC is to establish a work plan for doing so
Yellowfin (WCPO)	20% of the equilibrium spawning biomass that would be expected in the absence of fishing ($20\%SB_{current,\ F=0}$)	Not defined	
Skipjack (WCPO)	20% of the equilibrium spawning biomass that would be expected in the absence of fishing ($20\%SB_{current,\ F=0}$)	Not defined. TRPs of 40%, 50% and 60% of unfished spawning stock biomass are being considered	

WCPO = western and central Pacific Ocean

1.3.2.3 Shared stocks in the Pacific Ocean: IATTC and WCPFC

The management of Pacific-wide stocks of north and south Pacific albacore and Pacific bluefin is shared by IATTC and WCPFC. The International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) evaluates north Pacific albacore and Pacific bluefin and the results are reviewed by the IATTC staff, the IATTC Scientific Advisory Committee and the WCPFC Science Committee, which make recommendations to either IATTC or WCPFC. The SPC evaluates South Pacific albacore and the results are reviewed by the WCPFC Science Committee, which makes recommendations to the WCPFC.

Limit reference points

Only south Pacific albacore has a LRP agreed as 20% of the equilibrium spawning biomass that would be expected in the absence of fishing under current environmental conditions (Table 5).

Target reference points

No target reference points have been agreed for any shared Pacific Ocean stocks, but south Pacific albacore is included in the WCPFC workplan (see the information regarding WCPFC CMM-2014-06 (WCPFC, 2014c)).

Harvest control rules

No harvest control rules have been agreed for any shared Pacific Ocean stocks, but south Pacific albacore is included in the WCPFC workplan (see the information regarding WCPFC CMM-2014-06[33]). Furthermore, CMM-2014-04 (WCPFC, 2014b) implements a multi-annual rebuilding plan commencing in 2015 to rebuild the Pacific bluefin spawning biomass to its median level (42,952 tonnes) by 2025 with at least 60% probability.

Table 5. Reference points and harvest control rules for Pacific-wide tuna stocks managed by the IATTC and the WCPFC.

Species (stock)	*Limit RP*	*Target RP*	*HCR*
Albacore (North PO)	Not defined	Not defined	Not defined
Albacore (South PO)	WCPFC: 20% of the equilibrium spawning biomass that would be expected in the absence of fishing (20%$SB_{current, F=0}$)	Not defined. CMM-2014-06 calls for WCPFC to develop and implement a harvest strategy approach that includes target/limit reference points, harvest control rules and other elements. At its 2015 meeting, the WCPFC is to establish a work plan for doing so.	
Bluefin (PO)	Not defined	Not defined	Not defined

PO = Pacific Ocean

1.3.3 Indian Ocean stocks

1.3.3.1 The Indian Ocean Tuna Commission (IOTC)

The Indian Ocean Tuna Commission (IOTC) manages stocks of bigeye, yellowfin, skipjack, albacore and swordfish in the eastern and western Indian Ocean. The stocks are assessed by the IOTC Scientific Committee, which makes recommendations to the IOTC.

The IOTC has not formally incorporated the PA into its Convention, which pre-dates the UN Fish Stocks Agreement. Indeed, the IOTC Agreement refers to the optimum utilisation of stocks. Nevertheless, the IOTC Scientific Committee generally interprets the objectives of the IOTC as keeping tuna stocks at sustainable levels while maximising catch, consistent with MSY, and in practice the concept of the PA is applied in many instances. The scientific advice for most stocks is given in relation to biological reference points, such SSB_{MSY} and F_{MSY}, and recently these have been adopted as TRP and interim LRPs (see Table 6).

In addition, the IOTC Scientific Committee has been requested to evaluate the performance of HCRs with respect to the species specific TRP and LRP adopted, no later than 10 years following adoption. In the latest IOTC Commission meeting in Busan, through resolution 15/10 which supersedes Resolution 13/10, it was adopted that (IOTC, 2015):

"Interim Target and Limit Reference Points (TRPs and LRPs)

1. *When assessing stock status and providing recommendations to the Commission, the IOTC Scientific Committee should, where possible, apply MSY-based TRP and LRP for tuna and tuna-like species, and in particular the interim reference points agreed by the Commission in 2013 for albacore, swordfish and tropical tunas (bigeye tuna, skipkjack tuna and yellowfin tuna)* (see table 7). "*

Table 6. Interim reference points and harvest control rules for Indian Ocean tuna stocks managed by the IOTC.

Species (stock)	*Limit RP*	*Target RP*	*HCR*
Bigeye (IO)	$0.5B_{MSY}$; $1.3F_{MSY}$*	F_{MSY}; B_{MSY}*	Not defined. Resolution 13/10 requests the SC to develop HCRs designed to maintain or restore stocks to the "green" quadrant of the Kobe plot
Yellowfin (IO)	$0.4B_{MSY}$; $1.4F_{MSY}$*		
Skipjack (IO)	$0.4B_{MSY}$; $1.5F_{MSY}$*		
Albacore (IO)	$0.4B_{MSY}$; $1.4F_{MSY}$*		
Swrodfish (IO)	$0.4B_{MSY}$; $1.4F_{MSY}$*		

** Reference points set out in Resolutions 13/10 and 15/10; IO = Indian Ocean*

"Alternate interim Target and Limit Reference Points

2. *Where the IOTC Scientific Committee considers that MSY-based RPs cannot be robustly estimated, biomass LRP will be set at a rate of B_0 (depletion based RP). Unless the IOTC Scientific Committee advises the Commission of more suitable LRP for a particular species, by default, the interim B_{lim} will be set at 0.2 B_0 and fishing mortality rate LRP at $F_{(0.2\ B_0)}$ (the value corresponding to this biomass LRP). These interim LRPs will be reviewed no later than 2018.*
3. *Where the IOTC Scientific Committee considers that MSY-based reference points cannot be robustly estimated, TRP based on the depletion proportion (i.e. reference points with respect to the ratio of current biomass to B_0, B_0 being the virgin biomass estimate) should be used as a basis for B_{tar} and F_{tar}, as follows:*
    a. *the interim biomass target reference point B_{tar} could be set at 40% of B_0, the virgin biomass;*
    b. *the interim fishing mortality rate target reference point F_{tar} could be set at a level consistent with the target biomass reference point, the fishing mortality rate corresponding then to the adopted 40% of B_0, the virgin biomass).*
4. *These target and limit reference points, referred to in paragraphs 1, 2 and 3, shall be further reviewed by the IOTC Scientific Committee according to the program of work and in accordance with paragraph 6. The results shall be presented to the Commission for adoption of species-specific reference points.*

5. *The IOTC Scientific Committee shall continue to provide advice on the status of stocks and on recommendations for management measures in relation to the reference points referred to in paragraphs 1, 2 and 3, where available, until the Commission adopts other reference points that achieve the IOTC's conservation and management objectives and are consistent with paragraph 6.*
6. *The IOTC Scientific Committee shall recommend to the Commission for its consideration options for harvest control rules for IOTC species in relation to agreed reference points and, in doing so, shall take into account:*
    a. *the provisions set forth in the UNFSA and in Article V of the IOTC Agreement;*
    b. *the following objectives and any other objective identified through the Science and Management Dialogue process designed in Resolution 14/03 (or any revision thereof) and agreed thereafter by the Commission:*
        i. *Maintain the biomass at or above levels required to produce MSY or its proxy and maintain the fishing mortality rate at or below F_{MSY} or its proxy;*
        ii. *Avoid the biomass being below B_{lim} and the fishing mortality rate being above F_{lim};*
    c. *the following guidelines:*
        i. *For a stock, for which the assessed status places it within the lower right (green) quadrant of the Kobe Plot, aim to maintain the stock with a high probability within this quadrant;*
        ii. *For a stock for which the assessed status places it within the upper right (orange) quadrant of the Kobe Plot, aim to end overfishing with a high probability in as short a period as possible;*
        iii. *For a stock, for which the assessed status places it within the lower left (yellow) quadrant of the Kobe plot, aim to rebuild these stocks in as short a period as possible;*
        iv. *For a stock for which the assessed status places it within the upper left quadrant (red), aim to end overfishing with a high probability and to rebuild the biomass of the stock in as short a period as possible."*

In addition, the IOTC Scientific Committee has been requested to evaluate the performance of any HCR with respect to the species specific TRP and LRP adopted for IOTC species, but not later than 10 years following their adoption, and the Commission will consider, as appropriate and consistent with the scientific advice these HCRs.

1.3.4 Southern Ocean and adjacent waters stocks

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

The Commission for the Conservation of Southern Bluefin Tuna (CCSBT) manages a single stock, southern bluefin tuna (*Thunnus maccoyii*, SBT), which is assessed by the Extended Scientific Committee (ESC).

Although the CCSBT has not formally embraced the Precautionary Approach in its Convention, in practice it has implemented parts of the concept through the development of the CCSBT

Management Procedure (MP). This procedure is effectively a HCR, with an interim management aim to rebuild the status of the stock to an interim building target reference point of 20% of the original spawning stock biomass by 2035. The MP is tuned to a 70% probability of achieving the interim rebuilding target. No LRP has been defined (Table 7).

MSE was formally used to develop and test alternative Harvest Control Rules and it is the framework used to evaluate the current MP in place.

The fishery is managed primarily through TACs, which are set using the MP. TACs are set for three-year periods to maintain the stock on the planned rebuilding trajectory, and the MP specifies the minimum and maximum changes in TAC depending on stock status relative to the rebuilding trajectory. For the period 2015-2017, the TAC is set to 14,647 tonnes.

Table 7. Reference points and harvest control rules for southern bluefin tuna managed by the CCSBT.

Species (stock)	*Limit RP*	*Target RP*	*HCR*
Southern bluefin (global)	Not defined	Not defined for the long-term. 20% of the unfished biomass (20%SB_0) is used as an interim target to be achieved with 70% probability by 2035	Harvest rules via a TAC; the average catch value from two formulas designed to achieve the recovery target and tuned to juvenile surveys and CPUE. 70% probability of rebuilding to 20%SSB_0

1.3.5 Use of RP in other areas: ICES and NAFO

The adoption of the Precautionary Approach has also led to the development and use of LRP and TRP in non-tuna RFMOs. This section provides a short summary of the PA frameworks developed by the International Council for the Exploration of the Sea (ICES) and by the Northwest Atlantic Fisheries Organization (NAFO):

1) *International Council for the Exploration of the Sea:* In its MSY framework for scientific advice (ICES, 2013), ICES combines the PA with the aim of achieving high, long term catches, i.e. uses MSY and PA principles as complementary: Populations need to be maintained within safe biological limits according to the PA to make MSY possible. However, within biological safe limits, an MSY approach is necessary to achieve MSY.

   With regards to the technicalities of ICES advice, the biomass LRP (B_{lim}) used in ICES frameworks corresponds to the biomass level at which the recruitment will be impaired, the point at which the recruitment starts to be driven by the SSB and not driven by environmental variability. For medium and long living species, ICES management plans are assumed to be precautionary if the *maximum* probability that SSB is below B_{lim} is less than 5%.

   The ICES approach uses both fishing mortality rates and biomass reference points in Harvest Control Rules. In general, F_{tar} should be lower than F_{pa}, (a precautionary buffer to avoid that *true* fishing mortality is at F_{lim} the rate associated with long term stock decline and ultimately crash) and MSY-$B_{trigger}$ should be equal to or higher than B_{pa} (Figure 3). This is appropriate since a precautionary approach is a necessary boundary to ensure sustainability, but not sufficient as a condition for achieving the maximum sustainable yield implied by the MSY framework. MSY-Btrigger is a biomass reference point that triggers a cautious response. The cautious response is to reduce fishing mortality to allow a stock to rebuild and fluctuate around a notional value of B_{MSY} (even though the notional value is not specified in the framework).

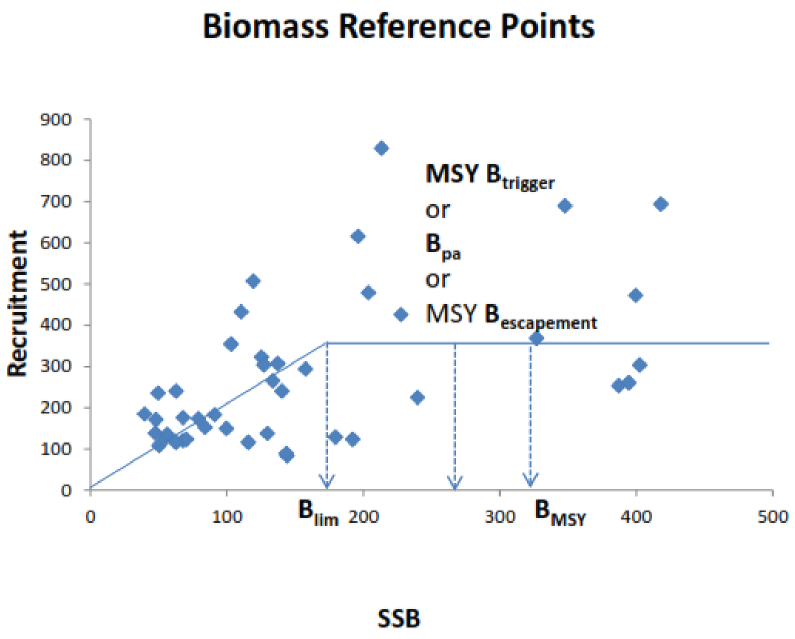


Figure 3. Biological Reference Points in ICES.

2) *Northwest Atlantic Fisheries Organization:* Upon the recommendation of the Scientific Council, the Fisheries Commission adopted in 2004 a Precautionary Approach Framework (PAF) (NAFO, 2004) to guide fisheries management decision making. The NAFO PAF does not define target reference points but it specifies both that Flim is to be no greater than FMSY and that Flim is to be exceeded with 'low probability'; assuring that FMSY will also be exceeded with low probability (Hvingel and Kingsley, 2014). The PAF is used for improved protection of the resources and to determine appropriate resource management measures in the absence of sufficient scientific data.

The NAFO PAF includes a set of management strategies and courses of action as well as reference point definitions. Fishing mortality reference points include Flim, a fishing mortality that should be exceeded with low probability (prob to be specified by managers, but it is proposed as 20%). Flim cannot be greater than FMSY. Fbuf is a rate, lower than Flim, which is required in the absence of analyses of the probability that current projected fishing mortality exceeds Flim. The more uncertain the stock assessment, the greater the buffer zone should be.

Biomass reference points also include limit and buffer RPs: Blim is defined as a biomass level, below which stock productivity is likely to be seriously impaired, that should have a very low probability of being violated. Very low probability is proposed to be defined as 5-10% but actually should be specified by managers. Similarly to Fbuf, Bbuf is the biomass level above Blim that is required in the absence of analyses of the probability that current or projected biomass is below B_{lim}. The more uncertain the stock assessment, the greater the buffer zone should be.

Biomass limit reference points have been identified for eight NAFO stocks. During its annual meeting of September 2010 the Scientific Council noted that few stocks have all the reference points necessary to fully delineate the NAFO Precautionary Approach framework (e.g. buffer reference points or target reference points), and further noted that most NAFO rebuilding actions for stocks below B_{lim} are related to bycatch control, which poses additional difficulties. Work is ongoing in this area.

NAFO includes a set of management strategies and management actions, which are comparable to ICCAT Recommendation 11-13, in that they do not specify time horizons or acceptable risk levels, which will be specified by managers. The management strategies are based on the PAF which includes five zones with regards to the stock status compared against biomass and fishing mortality reference points (Figure 4).

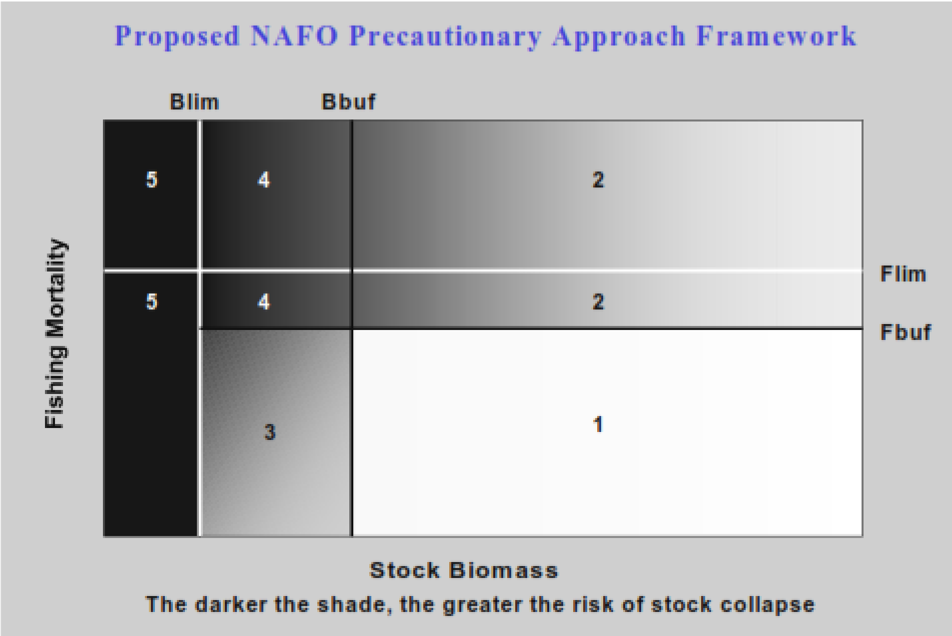


Figure 4. NAFO Precautionary Approach Framework.

Zone 1, Safe zone: Select and set fishing mortality from a range of F values that have a low probability of exceeding Flim in a situation where stock biomass (B) has a very low probability of being below Blim. In this area, target reference points are selected and set by managers based on criteria of their choosing (e.g. stable TACs; socio-economic considerations).

Zone 2, Overfishing zone: Reduce F below F_{buf}.

Zone 3, Cautionary F zone: The closer stock biomass (B) is to B_{lim}, the lower F should be below F_{buf} to ensure that there is a very low probability that biomass will decline below B_{lim} within the foreseeable future (5-10 years, but should be defined by managers).

Zone 4, Danger zone: Reduce F below F_{buf}. The closer stock biomass is to B_{lim} the lower F should be below F_{buf} to ensure that there is a very low probability that biomass will decline below B_{lim} within the foreseeable future.

Zone 5, Collapse zone: F should be set as close to zero as possible.

Table 8 shows the target and limit RPs and HCRs in used in ICES and NAFO.

Table 8. Target and Limit RPs and HCRs in used in ICES and NAFO.

RFMO	*Limit RP*	*Target RP*	*HCR*
ICES	-Biomass at which recruitment will be impaired (B_{lim}) -F_{MSY}	$F_{tar} \leq F_{MSY}$	Built using - $F_{tar} \leq F_{MSY}$ and ; - $B_{pa} \leq$ MSY Btrigger: The lower bound of SSB fluctuation around B_{MSY}. - p(SSB≤Blim) < 5%
NAFO	-$F_{buf} \leq F_{lim} \leq F_{MSY}$ -$B_{lim} < B_{buf}$	Flexible within zone 1 (Fig 4)	- Generic management actions (probabilities and timeframes suggested but actually decided by managers) - HCR for Greenland halibut agreed and implemented. - HCR for Cod 3M being developed and discussed.

2 REVIEW OF METHODS AND DATA AVAILABILITY IN ICCAT

ICCAT fisheries management is composed of data collection, stock assessment models and a decision making framework. In this chapter we discuss the methods and data available for stock assessment in ICCAT. We also classify ICCAT priority stocks according to the quality of data and models and the possibility to develop MSE based scientific advice.

2.1 Models and data availability

The biomass (B) and fishing mortality (F) levels at which a fish stock is and has historically been exploited are estimated through stock assessments. The outputs of this process are estimations of B and F relative to their corresponding reference points (RP). The models used for this aim in ICCAT range from relatively simple catch based methods to more sophisticated fully integrated models:

- Catch based models: Relatively simple methods to obtain plausible MSY estimates and other biological parameters from catch data, based on assumptions on resilience (corresponding to the intrinsic growth rate *r* in the surplus production model) and the plausible range of relative stock sizes at the beginning of the time series. The algorithm by Martell and Froese (2012) has been validated against analytical fish stock assessment estimates of MSY. Good agreement was found between stock assessment MSY estimates and the geometric mean of MSY values calculated from the plausible r-K pairs (Martell and Froese, 2012). A catch based approach relies on the assumption that catch reflects fish abundance and productivity. This principle is controversial, especially when management interventions change through the history of catch time-series. However, catch-based methods are widely used to assess data-poor fisheries and to produce large scale overviews of the state of fisheries (Merino et al., 2014).
- PROCEAN (PRoduction Catch-Effort ANalysis) (Maury, 2001) is a biomass dynamic model based on the generalized surplus production model of Pella and Tomlinson (Pella and Tomlinson, 1969) that allows for separating the different fishing fleets targeting a fish stock. In PROCEAN, a semi-implicit numerical scheme is used to integrate the ordinary differential equation of Pella and Tomlinson. The information required to run this model are catch series and fleet-specific abundance indices (catch per unit of effort, CPUE).
- ASPIC (A Stock Production Model Incorporating Covariates) is a non-equilibrium implementation of the well-known surplus production model of Schaefer (Pella and Tomlinson, 1969; Schaefer, 1954). ASPIC also fits the generalized stock production model of Pella and Tomlinson (1969). ASPIC can fit data from up to 10 data series of fishery-dependent or fishery-independent indices, and uses bootstrapping to construct approximate nonparametric confidence intervals and to correct for bias. In addition, ASPIC can fit the model by varying the relative importance placed on yield versus measures of effort or indices of abundance. The model has been extensively reviewed and tested in the context of various applications to tuna stocks via ICCAT by Prager (Prager, 1992; Prager, 1994).

Because of its limited data requirements, this model is easy to use and many national scientists are familiar with it. ASPIC is fast to run and facilitates simulation testing. Because of the limited data requirements, it allows the use of longer time series when data from earlier periods are usually poor. It only estimates few parameters but these are typically the ones needed to provide management advice and estimate RPs. ASPIC quickly produces diagnostics, bootstrap results, and projections. ASPIC often cannot resolve indices of abundance with conflicting trends (ICCAT, 2013b).

- BSP (Bayesian Surplus Production) (Babcock, 2003; McCallister and Babcock, 2003) is a lumped biomass model, which does not require the catches for separate fleets. In addition, it is possible to use available biological information about fish stocks to set up a Bayesian informative probability density function for the rate of population increase, which constrains the model to estimate parameter values that are biologically plausible. This can be useful when abundance index data are not very informative. This model has been used in ICCAT because it is not as data demanding as more sophisticated models. BSP requires catch and at least one CPUE index of abundance.
- Size Based models: Catch at size and age analyses can be used to estimate information on the state of the exploitation of fish stocks. For example, changes in total mortality and potential changes in selection patterns can be investigated through length and catch at age data. These methods have been used in ICCAT skipjack and bigeye stock assessments among others.
- Virtual Population Analysis (VPA) methods have been widely used by the SCRS for stock assessment purposes. Arguably fewer assumptions than biomass dynamic approaches. VPA can handle varying selectivity and, in general, projections can accommodate some of the management issues (size limits, etc). It can accommodate multiple CPUE indices with different selectivity. The method can only estimate uncertainty within the model through bootstrapping, assumed catch at age (CAA) is known without error and requires substantial support from the ICCAT to prepare the catch and size (CAS) and CAA matrices.
- Multifan-CL (Fournier et al., 1990) is a sophisticated computer program that implements a statistical, length-based, age-structured model for use in fisheries stock assessment. Multifan-CL provides a statistically-based, robust method of length-frequency analysis. Multifan-CL is now used routinely for tuna stock assessments by the Oceanic Fisheries Programme (OFP) of the Secretariat of the Pacific Community (SPC) in the Western and Central Pacific Ocean (WCPO). Beginning in 2001, the software gained additional users, with stock assessment applications to North Pacific blue shark, Pacific blue marlin, Pacific bluefin tuna, North Pacific swordfish, Indian Ocean yellowfin and Northwest Hawaiian lobster underway or planned. In ICCAT, Multifan-CL has been used to assess North Atlantic albacore and bigeye among others.
- Stock Synthesis (SS) (Mehtot and Wetzel, 2013) is a fully integrated age structured statistical model. The structure of Stock Synthesis allows for building simple to complex models depending upon the data available. As a result, the SS modelling framework is designed to allow the user to control the majority of the assumptions that go into the model. SS assumes that the observational data is a random and unbiased sample of the fishery and/or survey it is intended to represent. The overall model contains subcomponents which simulate the population dynamics of the stock and fisheries, derive the expected values for the various observed data, and quantify the magnitude of difference between observed and expected data. Stock Synthesis provides a statistical

framework for calibration of a population dynamic model using a diversity of fishery and survey data. SS is most flexible in its ability to utilize a wide diversity of age, size, and aggregate data from fisheries and surveys. It is designed to accommodate both age and size structure in the population and with multiple stock sub-areas. Selectivity can be cast as age specific only, size-specific in the observations only, or size-specific with the ability to capture the major effect of size-specific survivorship. While SS can accommodate a multitude of data types, at least a catch time series and an index of abundance are required. Conversely, a model can be built that incorporates multiple areas, seasons, sexes, growth and growth morphologies, as well as tagging data. Environmental data can also be used to modulate the parameters of the model. Size and age structure, size-at-age, ageing error and bias, and sex ratio can also be incorporated. The SS model output is commensurate with the complexity of the model configuration and observational data. All estimated parameters are output with standard deviations. Derived quantities include typical management benchmarks such as MSY, F_{MSY} and B_{MSY}, and SPR. Typical matrices of numbers-at-age, growth, age-length keys are also provided.

With regards to the data and statistics available for stock assessment, ICCAT Secretariat maintains information in various databases and catalogues which comprise:

- *Task I*: Nominal Catch information including annual catch by species, region, gear, flag and where possible, separated between EEZ and High Seas (T1NC).
- *Task II*: Catch and fishing effort statistics for each species by small area (1x1 degree squares for most gears, 5x5 degree squares for longlines), gear, flag, and month (T2CE). Purse seine catch and effort statistics of tropical fisheries are also available by operation model (FAD/Free School) between 1991 and 2013. Task II data also include actual size frequencies of samples measured for each species by small area, gear, flag and month (T2SZ). In some cases, detailed size samples are also extrapolated to match total catches in order to be used in stock assessments. This includes the CATDIS and catch-at-size datasets.
- *Tagging:* The Secretariat maintains an extensive database of conventional tagging data for Atlantic Tunas and tuna-like species. This database is currently undergoing a revision.
- *Other information:* In addition to Task I and Task II data, the SCRS also makes use of other types of information for its analyses of the stocks, depending on need, relevance, and availability. These include observer data and independent surveys.

2.2. Species-specific models and data used in Stock Assessment

In this section, the models used and data availability are reviewed, with specific comments on the main sources of uncertainty and how they are dealt with by the different models used. In brief, in ICCAT models ranging from the simplest catch based to the most sophisticated fully integrated models are used:

2.2.1 *North Atlantic albacore*

Data availability

Fishery statistics for this stock were reviewed in the data preparatory meeting for the 2013 assessment of this stock (ICCAT, 2013c). ICCAT Secretariat provided data on catch and effort (Task I and II) for a period between 1950 and 2011. The Secretariat also updated the CATDIS estimations (Task-I catch distribution by quarter and 5 by 5 degree squares of each major fishery-fleet/gear combinations) for the entire period 1950-2011. In order to prepare the input files for the use of the fully integrated Multifan-CL model, the available data was organized for twelve fisheries and different time periods.
The Task II catch and effort dataset (for 1950-2011) was presented for its use on CPUE analyses and model input.

Task II size data (T2SZ: size frequencies reported; CAS: catch at size reported) availability per stock, year, major gear and flag) are identified and catalogued. In order to be used by MultifanCL, all the size frequencies information was classified into 12 MFCL fisheries.

The albacore catch at size (CAS) catalogue is available for the period (1975-2011), which was used to build catch at age (CAA) data by applying age-length keys.

Catch per unit of effort (CPUE) series are available for Spanish baitboat and troll, the Irish mid-water pair trawl, Japanese longline, US longline and Chinese Taipei longline. All series were standardized and discussed by the NALB working group.

Tag data is available for this stock and it was used to build one MultifanCL scenario.

Models

The scientific recommendation in the form of TAC was provided by using projections of the biomass production model ASPIC in the 2013 stock assessment of albacore. In addition, other models were also tested including VPA and the fully integrated MultifanCL and SS3.

In general, the albacore working group noted that important uncertainties remain in the biology as well as fishery data. In particular, the group felt that some trends observed in T2SZ might not reflect trends in the population. Instead, they might be a reflection of variations of sampling practice over time. Similarly, some CPUE trends from different fleets showed somewhat conflicting trends, which might be due to changes in spatial distribution of the fleets that are not properly considered in the standardization process.

The existing uncertainty on fishery data are dealt with by setting alternative model runs with different CPUE time series with ASPIC. In addition, with MultifanCL alternative runs for different input parameters were tested.

2.2.2 *Mediterranean albacore*

Data availability

The Secretariat made available the most up-to-date information for this stock including Task I (Nominal catch, T1NC), Task II (catch and effort, T2CE and size frequencies T2SZ) and conventional tagging information. In general, Task I data are incomplete or have

partial gaps (for instance, EU-Spain 2003 and EU-Greece 1993-1995), with some important producers missing (Syria and Turkey). A high percentage of the catches is not ascribed to any specific gear (nearly 100% in the 1980s, about 40% in the 1990s and 30% in 2000 decade, mainly affecting EU-Greece and EU-Italy) (ICCAT, 2010b).
There is also a general lack of both Task II catch and effort data by fleet and gear, and Task II size frequencies. In addition, there is no correspondence between the gears reported in T1NC and T2CE.

The most important sources of uncertainty for this stock are a consequence of the incomplete historical series of catch and effort, and corresponding size composition of the catch. In addition, other uncertainties such as in the key life history traits and selectivity make the assessment of this stock problematic. In particular, growth characterization is uncertain (several studies reflect different size and age ranges and no study encompasses the full range of sizes captured in the Mediterranean); maturity at length or age, and natural mortality, which is assumed to be constant. Selectivity is also uncertain due to the lack of fishing gear allocation and to gear mixing problems.

Models

Given the current state of knowledge, the Mediterranean albacore has been assessed by means of relatively simple length-based models; specifically, length-converted catch curve analysis (LCC) and length based yield per recruit. In addition, a Bayesian surplus model was tentatively tested, whose results were rejected because of the lack of realism in the estimate of the population's intrinsic rate of increase parameter (r) (ICCAT, 2011b). Currently, there is a technical paper submitted to the SCRS with a catch based assessment model (Martell and Froese, 2012) applied to this stock with the aim of estimating MSY values.

2.2.3 East Atlantic bluefin tuna

Data availability

During the 2015 data preparatory meeting, the Secretariat provided the review of the most up to date bluefin tuna information T1NC statistics from 1950 to 2013, which incorporated information from the Atlantic Wide Research Programme for Bluefin Tuna (GBYP). With regards to T2CE data, this contains new datasets from the early years of the fishery (1950s, 1960s) from trap fisheries of Portugal, Spain and Morocco, as well as other data from the 1980s and 1990s from other gears. However, many of these datasets do not contain effort estimations and therefore, they are of no use for analyses based on CPUE indices. The Secretariat also presented the T2SZ data catalogue, which contains information reported by CPCs, GBYP size data, information from farm harvested specimen and size sampling using stereoscopic video cameras. Despite this information, the bluefin tuna working group is elaborating a plan to generate a new catch at size database using the latest length/weight relationships available.
The CPUE series used for the tuning of the eastern Atlantic stock VPA are the following: Norwegian purse seine for ages 10+, Spain-Morocco trap combined for ages 6+, Morocco only trap series for ages 6+, Japanese longline North East Atlantic for ages 4+, Japanese longline East Atlantic and Mediterranean for ages 6+, and the Spanish baitboat index.

Tagging data is available for this stock and a tagging group has been established to analyse and select the information currently available in ICCAT.

Models

Because the 2014 stock assessment was an update of the 2012 stock assessment, the group ran the same model, i.e. ADAPT VPA (as implemented in VPA-2box), with technical specifications as similar as possible and new updated data in 2014. In order to investigate the potential impact of the existing uncertainties, a suite of different specifications were investigated to test the sensitivity of the VPA to the choice of the CPUE series. Furthermore, a suite of different specifications were investigated to test the sensitivity of the VPA based on the continuity run, which have been explored in the past assessments including changes in fishing mortality ratios per age. In addition, the continuity run specifications were tried for two catch scenarios, i.e., the reported and inflated catch scenarios.

2.2.4 North Atlantic swordfish

Data availability

Fishery statistics for this stock were reviewed in the data preparatory meeting for the 2013 assessment of this stock. Directed surface longline fisheries from Canada, EU-Spain and the United States have operated since the late 1950s or early 1960s in the North Atlantic. The Secretariat provided data on nominal catch between 1950 and 2011 by fleet, gear and year and the swordfish working group noted the good coverage of these data. Task II catch and effort (T2CE) data per year, major gear and flag for 5 per 5 squares of geographical coverage are also catalogued by the Secretariat.

Task II size data from 1970 is included in ICCAT database, with most of the data reported after 1980.

Task II Catch at size (CAS) estimates from the Secretariat span from 1978 to 2011. These were made taking significant revisions into account. The CAS information uses data estimated by national scientists and size frequencies samples information. No catch at age (CAA) estimations are available for this stock.

Catch per unit of effort series are also available for swordfish including those from the Canadian, Chinese Taipei distant-water, Moroccan, Portuguese, Spanish, Japanese, United States longline fisheries. All CPUE series have been standardized by national scientists and results discussed by the working group which agreed on the series that would be used in the stock assessment (ICCAT, 2013b).

Despite available tagging for this stock, this was not used in stock assessment but the working group recommended its inclusion in future assessments.

Models

Three models were tested in the latest assessment of this stock: ASPIC, VPA and BSP.

The scientific recommendation in the form of TAC was provided by using projections of the biomass production model ASPIC in the 2013 stock assessment of swordfish. The NA albacore working group agrees that ASPIC does not allow for inclusion of uncertainty of the model inputs (e.g. CV of the CPUE series). Until now, this uncertainty has been dealt with by separate model runs. Another way to deal with the existing uncertainties is fixing some of the input parameters and running sensitivity tests.

VPA has been tested in previous SWO assessments but it has not been used to produce management advice because of the high uncertainty on CAA information. In the latest assessment it was recommended not to use this model in the upcoming evaluations (ICCAT, 2013b).

With regards to BSP, the model makes no assumptions about vulnerability at age. It uses available life history data to develop a prior distribution for *r*. BSP is a highly flexible approach to fit data. This model is a rigorous and theoretically consistent methodology to account for uncertainties in data and uncertainty between model forms. State-space production models were found to perform acceptably well in estimation of stock biomass and in management procedure evaluations for a recovering stock/ noisy data. As with any Bayesian method, training is required to run the software proficiently. As with other surplus production models, it may be biologically inaccurate and therefore might not reflect the true dynamics of the stock. BSP is in essence a surplus production model and as such, it has all the restrictions and advantages of other production models like ASPIC. BSP deals with uncertainty in estimated parameters, model variables, by showing posterior distributions, standard deviations, coefficients of variation and probability intervals. Bayes factors can be computed from the average importance ratio by run and can be used to weight output distributions from different runs to show the uncertainty in stock status and variables of interest resulting from uncertainty in model structure. The Group recommended the use of the BSP2 model in the upcoming assessment for both the North and South Atlantic SWO stocks, and to explore options to incorporate this model to the models already in use for the SCRS.

2.2.5 Mediterranean swordfish

Data availability

ICCAT Secretariat made available the most up-to-date information available for Mediterranean swordfish covering Task I (T1NC) and Task II (T2CE and T2SZ). No conventional tagging data has been made available since the 2010 stock assessment (ICCAT, 2014e). With regards to T1NC the MedSWO working group estimated these as complete. With regards to T2CE and T2SZ the working group noted significant absences of size information but also a general improvement from previous assessments. Task II data comprises information between 1975 and 2013.

CAS and CAA information is available for this stock, and the working group noted that these are representative of the fisheries. However, the group also noted that the age-slicing method used may be underestimating the proportion of younger fish.

Nine relative abundance indices were assembled to be considered for the assessment of this stock, spanning from 1987 to 2013.

Models

A number of assessment methods were used to provide an idea of the effect of model choice on the stock status determination and to attempt to use the widest possible range of available data. Two different production models (Bayesian and non-Bayesian), a size structured model, catch curve analysis and an age structured population model (XSA).

Two of these modelling approaches were used in the previous assessment (ASPIC and XSA). Like in the previous assessment, the age structured model (XSA) was chosen to develop the stock status advice and to develop projections.
As in the previous assessment, the Group weighed the limitations of all models, given the available data, and considered that the XSA provides a more reliable assessment of stock status than the others. A number of reasons were cited and informed the Group in reaching this conclusion:

- Catch at age data provides additional information to inform stock productivity in comparison to the production models that only use catch in biomass and relative abundance indices.
- Catch at age information used is an improvement from the one used in the last assessment as a consequence of completeness in the size frequency samples characterizing the catch at size for recent years.
- The lack of contrast in the relative abundance indices make production model results to be rather uncertain because stock productivity (estimates of r and K) is poorly defined by the data. This especially affects ASPIC results which do not have the additional information on stock productivity provided by the priors supplied to the BSP. It is also the result of the lack of relative abundance indices for the period when the stock is expected to have declined in abundance (1975-1985), as catch increased.

It should be noted that the approach of using the XSA results for stock status and projections is also consistent with previous assessments. Nevertheless, the XSA results have significant uncertainty, mainly due to the lack of a clear signal in the available data and the lack of abundance indices prior to 1987.

2.2.6 *Atlantic skipjack*

Data availability

No data preparatory meeting for this stock was held in advance of the latest assessment in 2014. However, the current status of Task I nominal catch (T1NC) statistics, Task II catch and effort (T2CE) and Task II size information (T2SZ) were reviewed by the Secretariat during the assessment. Data on by catch of this species was also made available. Task II data is available for the period between 1980 and 2012.
In addition, the CATDIS dataset (an estimation reflecting T1NC of the nine major ICCAT species stratified by quarter and 5 by 5 degree square grid for the period 1950-2012) and using the best Task II (T2CE) information was presented.

Catch at size estimations (CAS) for the period 1969 and 2013 for both the eastern and western stocks are available. An updated and reviewed CAS was accepted during the stock assessment.

Tagging information is also available for this species, mostly from the eastern stock.

The numerous changes that have occurred in this fishery since the early 1990s (such as the progressive use of Fishing Aggregation Devices, FAD and the expansion of the fishing area towards to west and north) have brought changes in catchability and in the fraction of the population exploited. This is a notable challenge for stock assessment and suggests that biomass production models may not be the most appropriate for the assessment of this stock.

In addition, there is a major difficulty to estimate the fishing effort applied to this stock because this species is not always targeted and besides, it is difficult to estimate fishing effort related to the use of FADs, including the quantification of the assistance provided by supply vessels.

In summary, although skipjack cannot be considered as a data poor stock, there are many uncertainties that impede the use of sophisticated stock assessment models. In particular, many uncertainties remain with regards to its particular biological and fishery characteristics: Skipjack presents continuous spawning (and as a consequence few if any cohorts are identifiable) and spatial variation in growth. At the same time about 90% of the purse seine catch (the major fishing gear in terms of catch for this species) is done under FADs whose fishing effort is difficult to quantify and to discriminate from free school conventional searching time effort (thus there is no reliable CPUE index for skipjack caught on FADs).

Models

The main model used to produce scientific recommendation was the catch based model by Martell and Froese. The start date for the models was 1950 for eastern skipjack and 1952 for western skipjack. It was assumed that the biomass in each of these years was very close to virgin conditions, since fishing prior to this period occurred on a relatively small-scale, and development of the large-scale baitboat and purse seine fisheries occurred after 1952 and 1950. ICCAT, based on tagging data and fishery dynamics, considers that there are two stocks of skipjack in the Atlantic: Eastern and Western stocks.

Catch based models do not capture changes on stock productivity due to selectivity changes. This potential bias was explored by running the model retrospectively, i.e. using data until 1990, 2000, 2003-2014. Results were consistent for the western stock but showed an increasing trend in the eastern stock.

Three additional models were tested for eastern skipjack, including a catch-only model (Martell and Froese 2012), and a Bayesian Surplus Production (BSP) model (McCallister and Babcock, 2003). Four alternative stock assessment models were analysed for western skipjack, and included, a mean length-based mortality estimator (Gedamke and Hoenig, 2006), a catch-only model (Martell and Froese 2012), a BSP model, and a Stock Production Model Incorporating Covariates (ASPIC) model.

2.2.7 Atlantic bigeye

Data availability

The Secretariat made available the data necessary for this stock assessment.

Fishery statistics for this stock were reviewed in the data preparatory meeting for the 2015 assessment. ICCAT Secretariat provided data on catch and effort (Task I and II) for a period between 1950 and 2014. The Task II catch and effort dataset (for 1950-2014) was presented for its use on CPUE analyses and model input.
Task II size data (T2SZ: size frequencies reported and CAS: catch at size; per year, major gear and flag) are identified and catalogued. In order to be used by SS3 and VPA, all the size frequency information was reviewed and potential problems with the age slicing were identified.

Catch per unit of effort (CPUE) series available include Chinese-Taipei, Japan, US and Uruguay longline indices split in early and late periods and Azores baitboat CPUE (only for SS3). All series were standardized and discussed by the working group.
The main uncertainties identified were some contradictory trends in CPUE series for stock assessment models and with regards to SS3 and VPA, the uncertain steepness parameter, growth function, mortality function and weight given to size information and abundance indices for the estimation of historical trends of biomass and fishing mortality.

Models

The results from three different runs of non-equilibrium production models (ASPIC) were used to provide the status of the resource, along with the results from the more sophisticated SS3 model runs. ASPIC runs were made using alternative individual series of CPUE indices. The integrated model SS3 was run with twelve different configurations to characterize uncertainty in model parameters (growth, steepness in recruitment and weighting of size data). Most of these different runs, however, give a similar view to ASPIC regarding the historical evolution of the relative trends in biomass and fishing mortality, except for the most recent years.

Other models tested include the age structured VPA and a catch at size and age analysis. With regards to the VPA, the initial model results, which were based on the specifications of the model used in 2010 and a series of changes and new runs were presented in the last stock assessment. The major differences in the biological input were a new natural mortality vector and a new growth curve. It was noted that the diagnostics didn’t recommend the use of this model for advice in 2015, specially a bias in the retrospective estimates. The retrospective bias is smaller with the new changes to the data and the specifications, but it is still considerable.

The catch at size and age analyses for the Atlantic bigeye were presented with an analysis of the length frequency data (i.e. catch-at-size, CAS). Two main methods were used, i.e. Powell-Wetherall plots to explore changes in Z based on length data and catch curve analysis using catch-at-age to evaluate changes in selection patterns.

2.2.8 Atlantic yellowfin

Data availability

ICCAT Secretariat made available updated versions of Task I catch statistics and Task II size information from ICCAT database. Task I catch data ranges from 1950 until 2011, the date of the last assessment. As in other multispecific surface tropical fisheries, it is difficult to assign fishing effort by species in Task II. In addition, the development of FAD fisheries has further complicated the estimation of effective fishing effort.
With regards to CAS and CAA estimations, a matrix for the period 1970-2010 is available.
In relation to CPUE series, a large number of them have been developed for this fishery, including those from surface and longline fisheries. However, these indices do not reflect changes in catchability due to fleets targeting yellowfin or other species and neither due to the use of FADs.

Models

The stock status and scientific advice was produced with the production model ASPIC and the age-structured VPA model. The alternative runs with these models were made with different combinations of CPUE indices reflecting the existing uncertainty on abundance trends. The estimates of current stock status (in terms of relative F and relative biomass) developed from the combined base runs of ASPIC and VPA were summarized for the management advice. Alternative models were also run with PROCEAN. In addition, the generalized functional relationship between the mean length in catch and total mortality rate by Gedamke and Hoenig (2006) was used to identify changes in the mortality rates of yellowfin (ICCAT, 2011c).

2.3 Classification of stocks with regards to data and models

It is difficult to classify a stock as data poor or data rich in absolute terms and therefore, we have ranked stocks with regards to the availability of information for stock assessment (Table 9). Mediterranean albacore and swordfish are the two stocks with the poorest databases, with nominal catch as their main source of information despite even this being incomplete for albacore due to historical and recent catch information. The information of task II is not complete and available for assessment. Even though some tagging information is available for Mediterranean albacore, this is not complete or incorporated into the assessment. In the second group in the data quality ranking are the tropical tunas (bigeye, yellowfin and skipjack). For the three of them nominal catch data and both T2CE, T2SZ and T2CAS are available. However, the main handicap for these species is the quality of the CPUE indices due to different causes: First, the use of FADs, including supply vessels, makes it difficult to quantify the fishing effort of purse seine fleets which have presumably produced a significant increase in fishing power and there are also issues with longline CPUE indices due to difficulties identifying the target species which has changed with time. In the third level, North Atlantic albacore and swordfish stocks' information includes complete series of Task I and II information. Although the information of CPUEs has some constrains as for tropical (for LL in the case of swordfish and Baitboat indices for Albacore), those are considered to be lesser as they are not associated to the FADs fishing which is very important in catch terms for the tropical species. There is also tagging information for these species but it is seldom used in stock assessments because it is insufficient to inform the estimation models. Eastern bluefin is the stock that is catalogued as the data richest. However, it is important to note that this information has not been available until recently and that the stock is still lacking some reliable information, especially of reliable standardized CPUE series. Bluefin tuna stock assessments are supported by ongoing tagging programs and fishery independent surveys such as aerial surveys in the Gulf of Lions.

In relation to models (Table 10), the fully integrated models MultifanCL and SS3 have been tested in four of the eight priority stocks selected, but it is only used for recommendation in bigeye (SS3). Production models have been tested in all but one stock, being the basis of scientific recommendation in four of them. Age/size based models have also been tried in seven stocks (including 4 VPA) and they have been used for recommendation in four assessments (2 in the case of VPA). Finally, a catch based model has been tested in two relatively data poor case studies and has been the basis of quota recommendation in the latest skipjack stock assessment.

Table 9. Summary of information available for stock assessment for ICCAT priority stocks (**√** = available and complete, **~** = incomplete or with absences and x = unavailable information).

Stock/Data	Task I	Task II			St. CPUE	Tagging	Others
	Catch	T2CE	T2SZ	T2CAS			Surveys
EBFT	√	√	√	√	~	√	√
NSWO	√	√	√	√	√	~	x
NALB	√	√	√	√	√	~	x
BET	√	√	√	√	~	~	x
YFT	√	√	√	√	~	~	x
SKJ	√	√	√	√	x	~	x
MedSWO	√	~	~	x	x	x	x
MedALB	~	~	~	x	x	x	x

Table 10. Summary of models used in the recent assessments of ICCAT priority stocks. Filled circle denotes the main method used for management recommendation and empty circles denote run models in the latest SA session, the previous one or available in SCRS Technical papers. M&F (2012) is Martell and Froese (2012), see reference list.

Stock/Model	CATCH	PRODUCTION MODELS			AGE/SIZE BASED			FULLY INTEGRATED	
	M & F (2012)	PROCEAN	ASPIC	BSP	Size based	VPA	XSA	MFCL	SS3
EBFT						●			
NSWO			●	○					○
NALB			●			○		○	○
BET		○	●	○	○	○		○	●
YFT		○	●		○	●			
SKJ	●		○	○	○				
MedSWO			○	○			●		○
MedALB	○			○	●				

2.4 Potential development of MSE for ICCAT stocks

During the first workshop of this project the possibilities of developing MSE frameworks for ICCAT priority stocks was discussed. A summary of those discussions is shown in Table 11. According to this, the model based MSE frameworks are likely to be possible for NALB, BET, YFT, NSWO and EBFT.

Table 11. Pros and cons for developing MSE in ICCAT priority stocks.

Stock	Pros	Cons
EBFT	High priority placed by ICCAT Commission on the completion of the MSE work program	Core group working with a plan already defined: 2018-2019
NSWO	ICCAT Commission requested SCRS to identify LRPs (Rec 11-02). Synergies with NALB. In the SCRS workplan. Data rich. SS3 already applied and candidate for Oms	Next update SA in 2017
NALB	ICCAT Commission requested SCRS to identify LRPs (Recs 11-04 and 13-05). Progress made and in the SCRS workplan.	
BET	Tropical species which allow to progress in collaboration with work is being done in IOTC/IATTC. Assessment in 2015 with SS3. Multispecific fishery. Interest in analysing the effect of FADs in a MSE as recommended by ICCAT FAD WG	No short term completion. Problems with PS CPUE
YFT	Tropical species which allow to progress in collaboration with work is being done in IOTC/IATTC. Multispecific and of interst for the FAD WG	No short term completion. Problems with PS CPUE
SKJ	Mandate to develop HCRs and tools for this in early stages (COM). Preliminary RPs explored using size based.	Complexity of fisheries, biology and absence of modelling approach
MedSWO	Sinergies with NSWO. Progress already	Very limited data
MedALB	Synergies with NALB	Lack of data and EU expertise

3 Evaluation of Reference Points and Harvest Control Rules for North Atlantic albacore

3.1 Introduction

In this chapter we explore the impact that the establishment of pre-agreed Harvest Control Rules (HCR) would have on the North Atlantic albacore stock and fishery. In order to do this a Management Strategy Evaluation framework is used. Throughout this chapter we describe the framework, including a description of the operating models and management procedures (Kell et al., 2013a; Kell et al., 2013b; Kell et al., 2013c). This framework is used to assess the robustness of HCRs to various sources of uncertainty.

In the 2013 stock assessment of North Atlantic albacore, the stock was diagnosed as being overfished but not undergoing overfishing. A drop in stock biomass between 1930 and 2000 was followed by an increasing trend. During the assessment, the albacore working group recommended to further develop the MSE framework to permit a better characterization of the uncertainty (ICCAT, 2013d) that could produce impacts on this stock's dynamics.

During the assessment, the north Atlantic albacore stock biomass was projected into the future under a suite of alternative HCR (as combinations of B_{lim}, B_{pa} and F_{target} values) evaluated every three years. Following Rec. 11-13, and with the spirit to facilitate the election of specific timeframes and probabilities by the Commission, results were summarized in terms of probabilities of being in the green zone at different timeframes for each of the HCR projected. Moreover, the short and long term yields expected to obtain under each of the HCR were added, and compared to values expected under fixed TAC projections.

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., 2014), i.e. different MPs. Here, MSE is used to identify which of a series of HCRs are used in combination with a simple stock assessment method would allow achieving a series of conservation and fisheries performance objectives. For this, we use an MSE framework following a series of guidelines and best practices, including the basic steps needed to be followed when conducting an MSE (Punt et al., 2014; Rademayer et al., 2007):

1. Identification of **management objectives**: Here, we assume that the management objectives are inherent to ICCAT fisheries, i.e. to maintain 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). We also include the objective of stability on fishing catch and effort.
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 will be included in this section. For this study we considered hypotheses on stock recruitment and catch rate series information.
    a. Three hypotheses on the future recruitment of this stock are considered:

   i. The future recruitment will be an average of the past recruitments.
   ii. Recruitment will be 20% higher than the historical average.
   iii. Recruitment will be 20% lower than the historical average.
 b. Two hypotheses on the observation of catch rates were considered:
   i. The abundance index for the SA represents the "true" trend of the fishery with a random error of 30%.
   ii. Hyperstability: The relation between fish abundance and CPUE index is non-linear (proportional), i.e. the abundance index declines less than the fish stock biomass.

3. **Constructing Operating Models (OM)**: These provide a mathematical representations 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. In this study, the OMs are the alternative Mutifan-CL model runs and specifications that were tried in the 2013 stock assessment (Kell et al., 2013c). These OMs are considered to be alternative representations of the "true" dynamics of this stock. The stock status diagnostic during the 2013 SA of this stock was made using the Base scenarios of these OMs.
4. **Defining Management Procedures (MP)**: A population-model-based framework within which the data obtained from the fishery are analysed and the current status, productivity and RPs of the fishery are estimated through a stock assessment model (Rademayer et al., 2007). The outputs of this are fed into a HCR that, in combination with RPs, provides recommendation for management action. In this study, the MP is composed by an observation model that feeds a surplus production model, MSY-based RPs and three alternative HCRs that represent different views towards fisheries management. The combination between the estimator (stock assessment model) and HCR provides the feedback between MP and OM, here assumed to occur every three years.
5. **Simulation** of the application of each of the HCRs and the surplus production model to manage the complex "true" dynamics represented by the OMs. In other words, if the "true" system was represented by the dynamics of the OMs, how efficient would be a fisheries management system (composed by a non-perfect observation scheme, a surplus production model and a set of HCRs) to achieve the management objectives of ICCAT.
6. **Summary and interpretation** of performance statistics: In this study, we use two conservation indicators (Sustainability and Safety) and three fisheries performance indicators (Catch, interannual variability of catch and interannual variability of effort). The candidate HCRs (and MP) providing the best trade-off between conservation and fisheries performance is selected as the most appropriate (Rademayer et al., 2007).

Each one of the components of a generic MSE framework and their use in this study are explained in detail throughout this document.

3.2 Methodology

3.2.1 Management objectives

Fisheries management needs to be supported by clear objectives to be expressed by policy makers through a specific decision-making process (ICCAT, 2014a). The overall management intention in ICCAT is to maintain 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). In the 5th session of IOTC's working group on methods, a series of management objectives and performance statistics are suggested for the evaluation of management procedures:

1) Stock status: maximise probability of maintaining stock in the green zone of the Kobe plot.
2) Safety: maximise the probability of the stock remaining above the biomass limit.
3) Catch: maximise catches across regions and gears.
4) Abundance: maximise catch rates to enhance fishery profitability.
5) Stability: maximise stability in catches to reduce commercial uncertainty.

These objectives can be used by ICCAT managers for guidance and their preferred objectives and indicators can be incorporated in the MSE framework developed in this study. However, as a first step, we have chosen a set of objectives and indicators to evaluate how MPs perform:

1) Stock:
    a. Sustainability: maximise probability of being in the green zone.
    b. Safety: maximise probability of the stock being above the BLRP.
2) Fisheries:
    a. Annual average catch after 30 years.
    b. Interannual variability of catch.
    c. Interannual variability of effort.

All the above can be re-designed or modified by other indicators at the request of managers.

3.2.2 Selection of hypotheses

a. *Recruitment:* Alternative hypotheses on the biological characteristics of this stock, including stock recruitment parameters and the existence of regime shifts can be explored within this framework. In our simulations we consider three alternative hypotheses for the future recruitment of this stock: Equal to the historical average, high (+20% than historical average) and low recruitment (-20% than historical average). We compared the impact of recruitment regime shifts on the Base Case Operating Model.

b. *Biological parameters:* The biological parameters used in this study are taken from the latest stock assessment of this species (ICCAT, 2013d) and are introduced in the framework in form of Operating Models (see below).

c. *Observation Error:* The Observation Error Model is part of the Management Procedure (see below). We adopt the approach of the Commission for the Conservation of Southern Bluefin Tuna (CCSBT) by including robustness trials for 2 factors corresponding to hypotheses about the CPUE series used as proxies for relative abundance. Namely i) the future CPUE from the fishery reflects fish biomass changes with a normally distributed error ii) a nonlinear relationship between CPUE and abundance so that proportional changes in actual abundance are greater than those observed in the CPUE. A recent study (Harley et al., 2001) showed that CPUE was likely to remain high while abundance declines (i.e., hyperstability), therefore as in the SBT case we assume hyperstable CPUE to biomass (CPUE proportional to 0.8 abundance). We analysed the impact of hyperstability on the Base Case Operating Model.

3.2.3 Operating Models

Operating Models are representations of the "true" dynamics of the system and may include a set of most plausible hypotheses or unlikely but not impossible situations (ISSF, 2013). In MSE frameworks the OMs are the system that has to be managed through MPs, i.e. the "true" system, that is observed, analysed and managed through data collection systems, stock assessment models and a decision making process. The capacity of alternative components of the MP to manage the system described by OMs is evaluated through MSE frameworks. The OMs in this study are set ups of the age structured model used in the assessment of this stock.

3.2.3.1 Models used in the latest Stock Assessment.

In the latest SA, one of the models used to provide stock status of North Atlantic albacore was Multifan-CL, a size structured model that was built using catch and standardized catch per unit of effort series. Their results were used to condition the OMs used in this MSE framework. The alternative Multifan-CL runs were alternative combinations of abundance indices used, hypotheses on fish growth parameters and the inclusion of tagging information. The conditioned OMs using the output from the 10 runs of Multifan-CL are shown in Table 12 and Figure 5.

Table 12. MFCL model runs and specifications in the 2013 North Atlantic albacore stock assessment.

Run	*Specifications*
Base	Model specifications provided in SCRS/2013/058
Alt1	Includes Chinese Taipei LL SF data and allows dome-shaped selectivity for this fleet
Alt2	Model starts in 1950
Alt3	All SF data down-weighted
Alt4	Japanese LL CPUE data no longer down-weighted
Alt5	Includes the Chen and Watanabe age-specific natural mortality vector (Santiago 2004)
Alt6	Excludes final 4 years of data (2008 – 2011)
Alt7	Includes equal weights for Japan and Chinese Taipei LL SF and CPUE data (similar to 2009 continuity run)
Alt8	Includes total catch in weight but effort calculated from CPUE in numbers (incorrect effort data calculation)
Tag	Includes tagging data for release events that occurred between 1988 and 1991

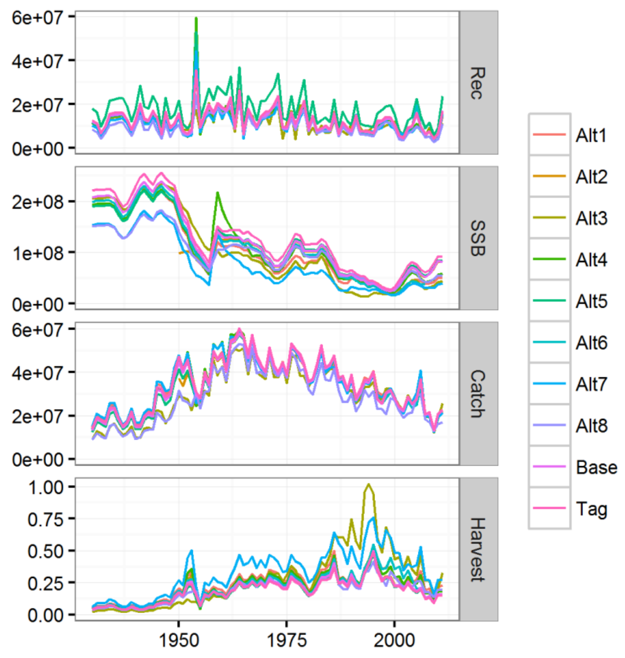


Figure 5. Operating Models for North Atlantic albacore: Recruits, Biomass (kg), Catch (kg) and Fishing mortality (F).

The 10 OMs have their production functions that can be used to estimate a series of potential RPs (Figure 6):

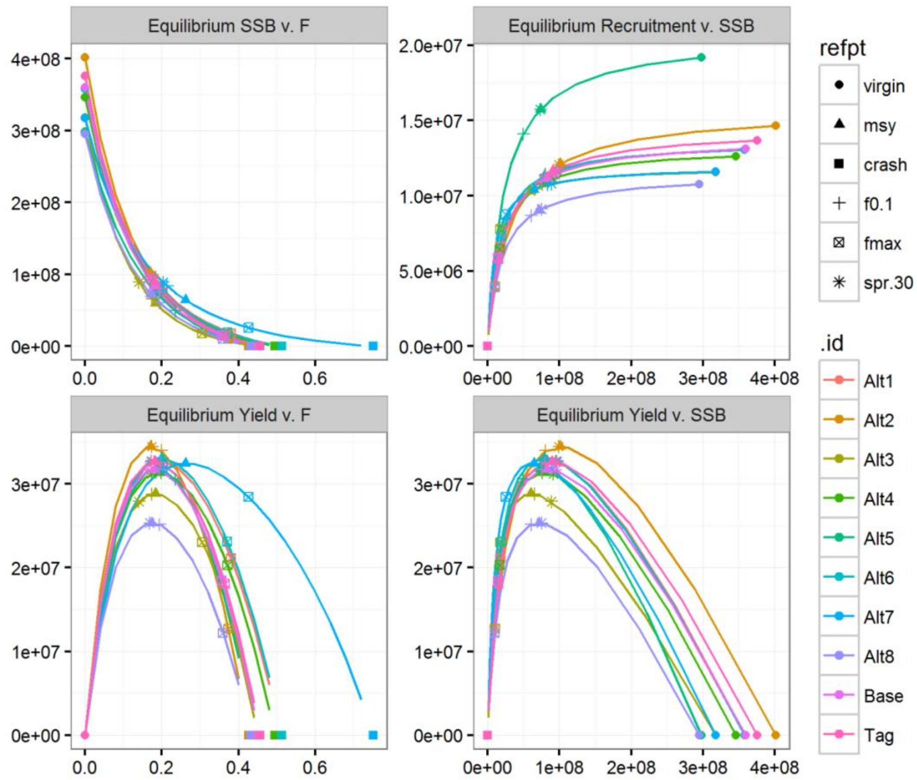


Figure 6. Equilibrium states of the OMs used for North Atlantic albacore and RPs. SSB is Spawning Stock Biomass (kg), Fishing mortality (F) and Recruitment.

3.2.3.2 Projections with perfect knowledge and control

In order to investigate the biological potential of the stock, simulation can be run assuming a perfect knowledge (i.e. no observation or assessment errors) and a perfect implementation of management advice (the realised catches correspond to the advice). The OM is used to project the stock into the future, imposing different levels of fishing mortality or catch. In the example below, we project forward the OM conditioned with the results of the Base case run of the Multifan-CL scenario in the 2013 stock assessment for different levels of F. For example, Figure 7 shows the Base case OM projected into the future with a constant F at FMSY.

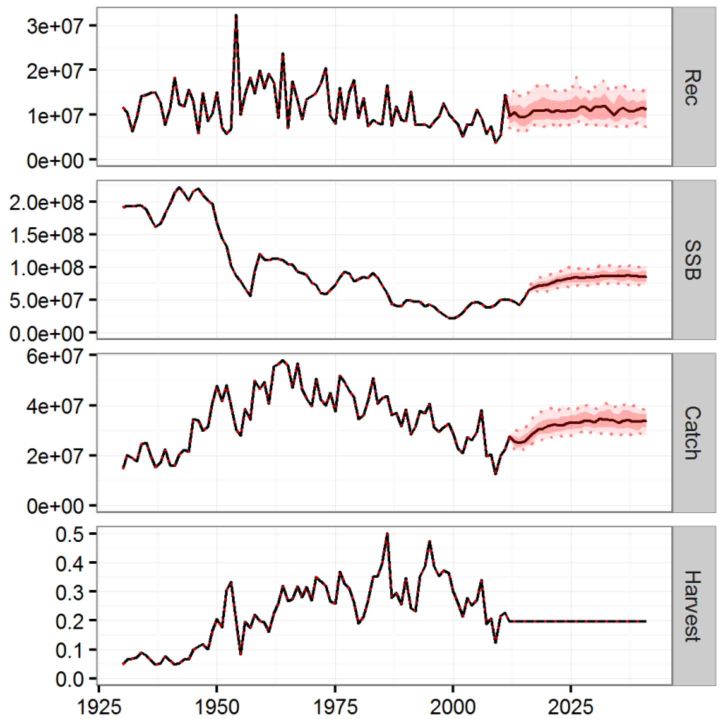


Figure 7. Projection of Base OM to 2040 using FMSY. Biomass and catch (th tonnes), and recruitment.

Figure 7 represents what would be the dynamics of this fishery if we had perfect knowledge and perfect control on the fishing mortality applied to the system. In this case, the "true" system would be fluctuating around the MSY RP, due to the recruitment variability considered (CV=0.3).

Pareto frontiers, or how well could this fishery perform if we had perfect knowledge and control

A Pareto frontier is a set of choices (or levels of F) in which it is impossible to improve the performance of one variable without worsening the other. If we had absolute control and knowledge of the system, we could not achieve better probability of being in the green zone for a given level of catch than that determined by the Pareto frontier. This figure is interesting because it shows the trade-off between conservation and exploitation management objectives in the hypothetical situation where we had perfect knowledge and control of the system. Figure 4 shows the Pareto frontiers between different probabilities of being the in the green zone for the Base OM projection with different levels of F, expressed as fractions of FMSY, and the average annual catch that would be fished by the end of the projection (in 2040). The trajectory shows the best we can achieve for a system that is described by the Base OM. Figure 8 shows that in the absence of fishing, with the variability considered in our OM, the probability of the stock being in the green zone is 1. As soon as we increase our F, the average annual catch also increases quickly but without reducing the probability of being in the green zone significantly. When the F is around 0.7-0.8, catch starts to reduce its increasing trend and at higher levels of F, the probability of being in the green zone decreases sharply. At FMSY, as expected, the probability of being in the green zone is 25%, the fishery would be fluctuating around the centre of the Kobe diagram, with 50% probability of B>BMSY and another 50% of being at F<FMSY. According to this, probabilities above 75% of the stock being kept in the green zone can be combined with levels of catch slightly lower than MSY.

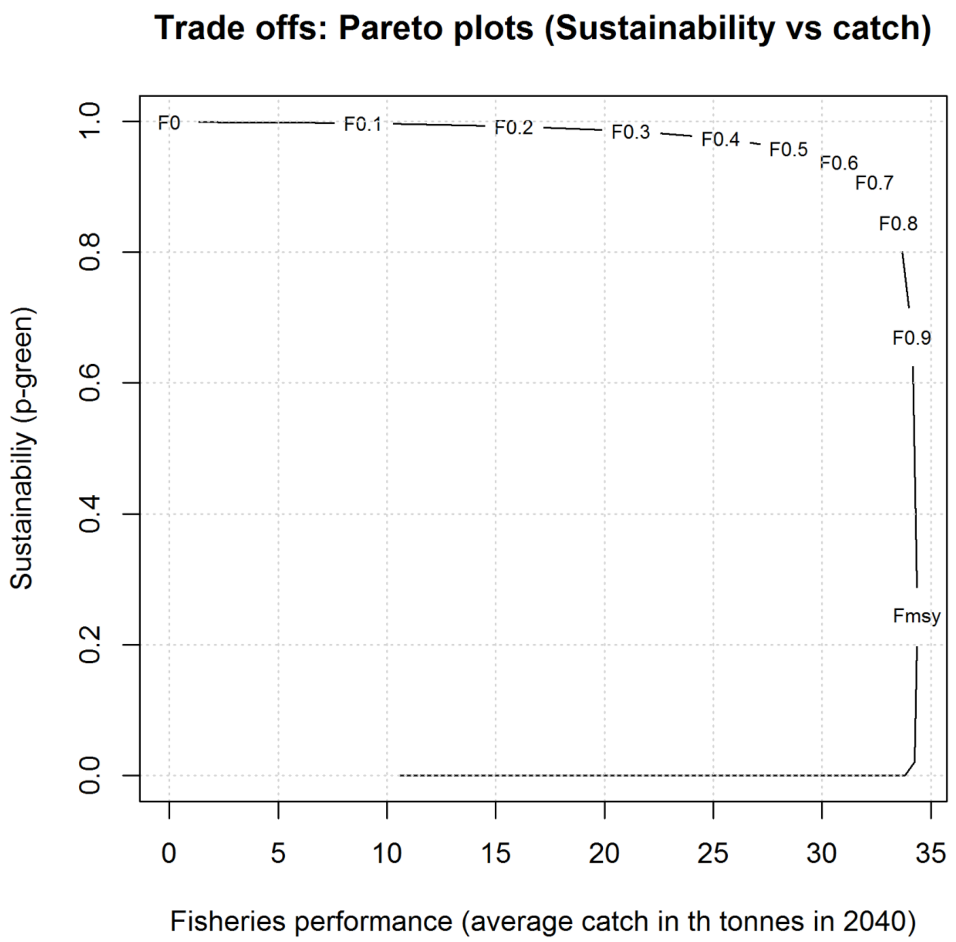


Figure 8. Pareto frontiers calculated by projecting one OM(Base) in a 30 year simulation. The trajectory drawn describes the best possible trade-off between two management objectives (p-Green and Catch) for a series of Ftargets, expressed as multipliers of FMSY, i.e. F0.2 is 0.2xFMSY.

Figure 9 shows the expected probability of the stock being within safe limits (B>BLRP) and average annual catch in 2030. As it is seen, the stock is within safe limits for fishing mortality levels equal or below FMSY with a 100% probability, with the recruitment variability used in this study.

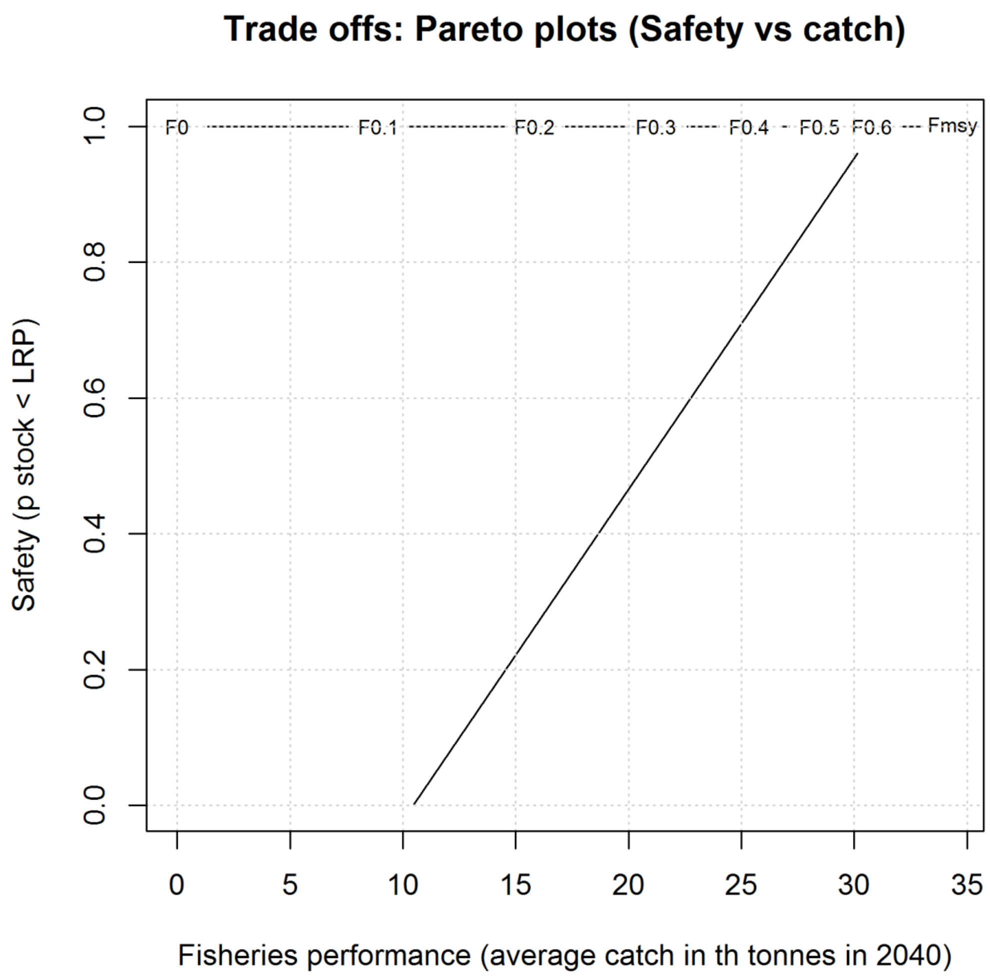


Figure 9. Pareto frontiers calculated by projecting one OM(Base) in a 30 year simulation. The trajectory drawn describes the best possible trade-off between management objectives (pB>BLRP and Catch) for a series of Ftargets expressed as multipliers of FMSY, i.e. F0.2 is 0.2xFMSY. BLRP is 0.4xBMSY.

However, it is important to stress that this is a projection, assuming perfect control and perfect knowledge of the system, which is far from what is expected from the understanding and management of any natural resource. These figures do not include any loop feedback between the MP. In the MSE developed in the following sections, we evaluate how a simpler stock assessment model, in combination with a series of HCRs could be effective in driving the system, the Base OM, to the desired situation of high catch and high probability of being in the green zone and low probability of being below BLRP.

3.2.4 Management Procedure

The Management Procedure represents the series of human actions undertaken to monitor the stock, assess its state, make management decisions and implement the management advice. In a MSE, these actions have to be implemented with a representation of their respective error associated. In other word, the Management Procedure component of the MSE describes how the true dynamics underlying fisheries exploitation are represented through stock assessment and controlled through fisheries management. A candidate MP is the framework within data from the fishery, the “true” fishery or OM, are obtained, analysed through a stock assessment model to estimate the current status of the fishery. Related outputs are then fed into a HCR to provide recommendation and management action (Rademayer et al., 2007). In this MSE framework, these four components are automatized, i.e., an observation model collects information from the OM (catch and CPUE), with an observation error (with and without hyperstability), these series feed a stock assessment model and output RPs and stock status, which in combination with HCRs produces recommended quotas, which are fed back to the OM. The three components are explained in detail in the following sections.

3.2.4.1 Observation model

Eight different indices of CPUE were used in this stock’s assessment. Generalized Additive Models (GAM) were used to standardize these and used to fit a surplus production model. A detailed analysis of these CPUE series is provided in two ICCAT technical papers (Merino et al., 2013a; Merino et al., 2013b). In this MSE framework, we assume two hypotheses for the observation error: (i) that the CPUE series that will fit the stock assessment model is proportional to the biomass of the OM multiplied by a log normal error, which was considered to be 0.3, i.e. $CPUE_{obs,t}$=stock(OM_t)*LN(1, 0.2) and (ii) a non-linear relation between CPUE and fish stock abundance (hyperstability).

3.2.4.2 Stock Assessment method

The SA model used in the MP of the MSE is a surplus production model. This model was not capable of estimating the significant peaks estimated by the Multifan-CL model at the beginning of the time series and therefore, we fitted the surplus production model to the biomass index of the OM since 1975. Figure 10 shows how the 10 OMs trajectories (black) are reproduced by the simpler surplus production model (red).

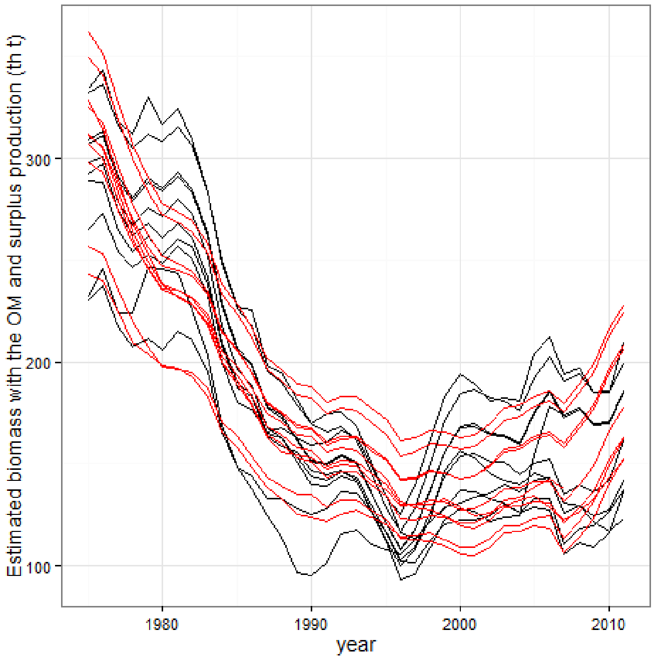


Figure 10. Fit of a surplus production model (red) to the runs of Multifan-CL of North Atlantic albacore stock assessment (black).

3.2.4.3 Harvest Control Rules

The analyses of HCRs for this study have been completed in two phases: First, three HCRs were evaluated (Figure 11). All three HCRs have the same Blim of 0.4 BMSY which is the interim LRP considered in the 2013 SA of this stock, which is consistent with robust limits recommended for a number of Pacific tuna stocks (Preece et al., 2011). The other decision thresholds of the HCRs considered in this study reflect alternative fisheries management performance trade-offs or tactical control options:

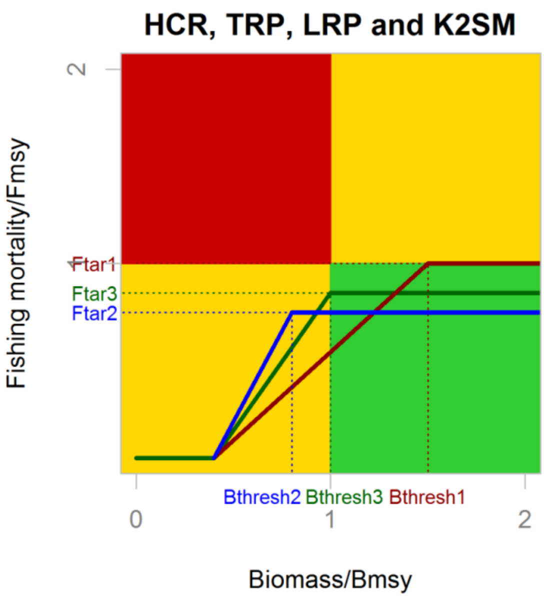


Figure 11. HCRs and their coordinates evaluated in this study.

HCR1: According to this, when stock status is assessed to be above $B_{thresh1}$=1.5 B_{MSY}, quotas will be set using a fishing mortality of F_{tar1}=F_{MSY}. However, when biomass falls below 1.5 B_{MSY}, i.e., still in the green quadrant, management action will be triggered and fishing mortality reduced progressively.

HCR2: In this, management action will only be triggered when biomass falls below $B_{thresh2}$=0.8 B_{MSY}, i.e. lower-left yellow quadrant, but, when the stock is assessed to be above 0.8 B_{MSY}, including in the right are of the green quadrant, the fishing mortality will still be precautionary, set at F_{tar2}=0.7 of F_{MSY}.

HCR3: This HCR is somehow an intermediate of HCR1 and HCR2. Management action will be triggered when biomass falls below B_{MSY}, and for levels above $B_{thresh3}$=B_{MSY} the fishing mortality will be below F_{MSY}, but not as precautionary as in HCR2, F_{tar3}= 0.85 FMSY.

In the second phase of the project, a full range of alternatives for HCRs were evaluated (Figure 8). Combinations of target Fishing mortality: F_{tar} [0.45, 0.55, 0.65, 0.75, 0.8, 0.85, 0.9, 0.95, 1, 1.05, 1.1, 1.15, 1.2, 1.25] x FMSY; threshold biomass: B_{thresh} [0.6, 0.8, 1, 1.2, 1.4] x B_{MSY}; Limit Biomass: B_{lim}=0.4 and F_{min}=0.1 (Figure 12).

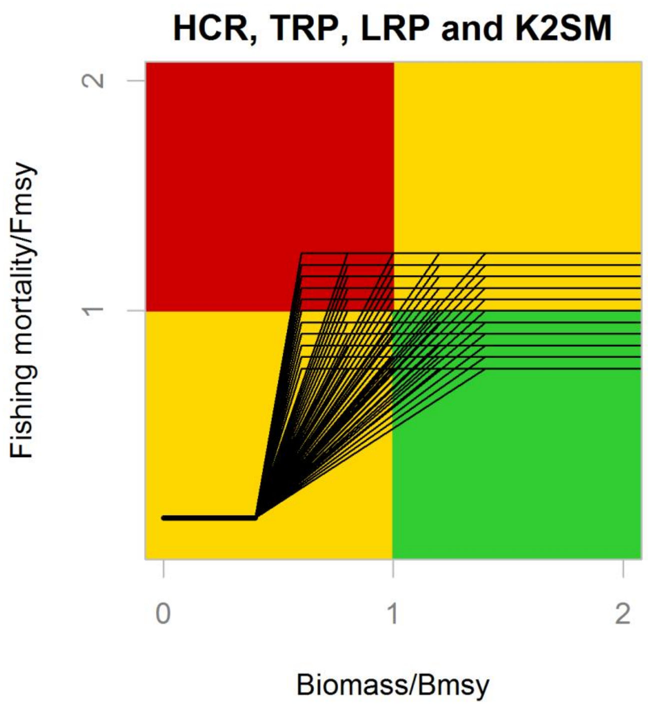


Figure 12. Full range of HCRs tested in this MSE.

With the simulation testing of the MSE framework we evaluate how these HCRs, applied in combination with a surplus production SA model could lead the “true” system, i.e. the OMs achieving management objectives of maintaining 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).

3.2.4.4 Simulations with HCRs as feedback control

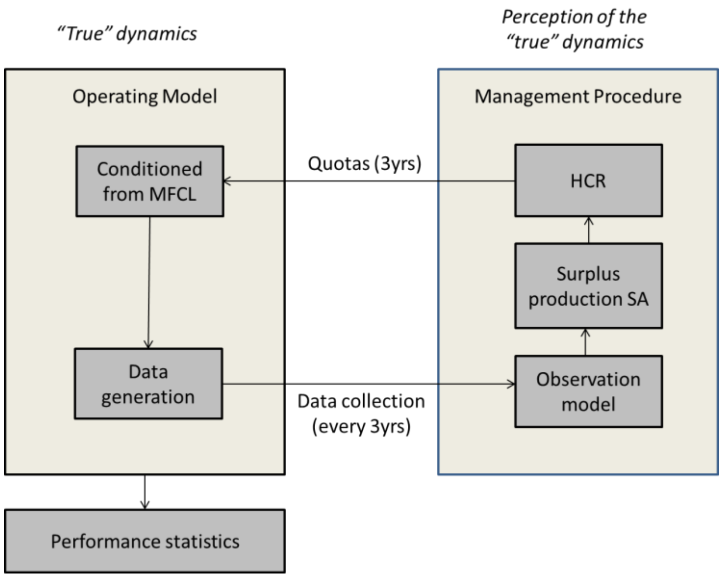


Figure 13. MSE framework and scheme of the simulation used in this study

The MSE framework used in the simulation is shown in Figure 8. The OM, in this case the Base OM generates data of stock biomass and catch, which are collected every three years and transformed into series of catch and CPUE with two hypotheses (lognormal error and hyperstability), which are analysed through a SA model, in this case a surplus production model. The outputs of this model are a series of RPs, and estimations of stock status. These are used in combination with a series of HCRs to deliver scientific recommendation in the form of three year quotas, which are sent to the OM, which is projected forward three years. Then, the OM generates data again which are sent back to the MP. At the same time, data from the OM are used to estimate conservation and fisheries performance statistics, which will be used to evaluate which of the three candidate HCRs can lead the OM towards achieving management objectives.

3.3 Results

3.3.1 Preliminary results

The results of the initial simulations compare only the performance of three HCRs, which can be seen in Figure 14 showing how the Base Case OM would evolve when driven by the MP used.

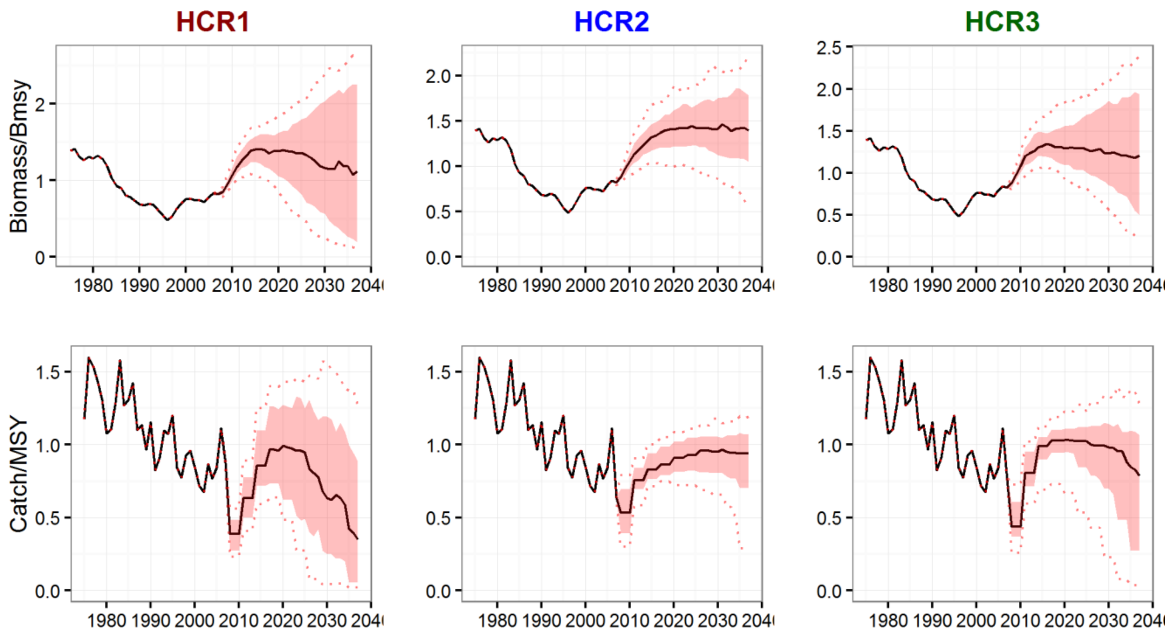


Figure 14. Impact on the Base OM of the three HCRs and the MP used. Figure shows relative biomass (B/BMSY) and Catch/CatchMSY.

Figure 14 shows in the first 10 years of the simulation (2010-2020), stock biomass will continue its current recovery to levels above its BMSY with all HCRs. However, as the simulation continues, it seems that HCR1 and HCR3 do not provide stability to the system and biomass fluctuates greatly at levels higher than twice BMSY but also at very low levels of biomass at the end of the simulation for some iterations (more than 30% below B_{MSY}). Fisheries catch reflects this tendency as well: In the first years, as the stock is recovering catch increases, but with higher F targets in HCR1 and HCR3 they increase faster. On average, in HCR1, the stock ends up the simulation at levels very close to BMSY but with a decreasing trend. HCR2 reaches some stability throughout the 30 years of simulation and HCR3, despite the stock being on average above BMSY, it also estimates stock status to be below BMSY with a significant probability and catch decreasing after approximately 2025.

Additionally, we plot the resulting Sustainability and Safety indicators against the average annual catch in 2040 using the framework shown previously in Figures 15 and 16:

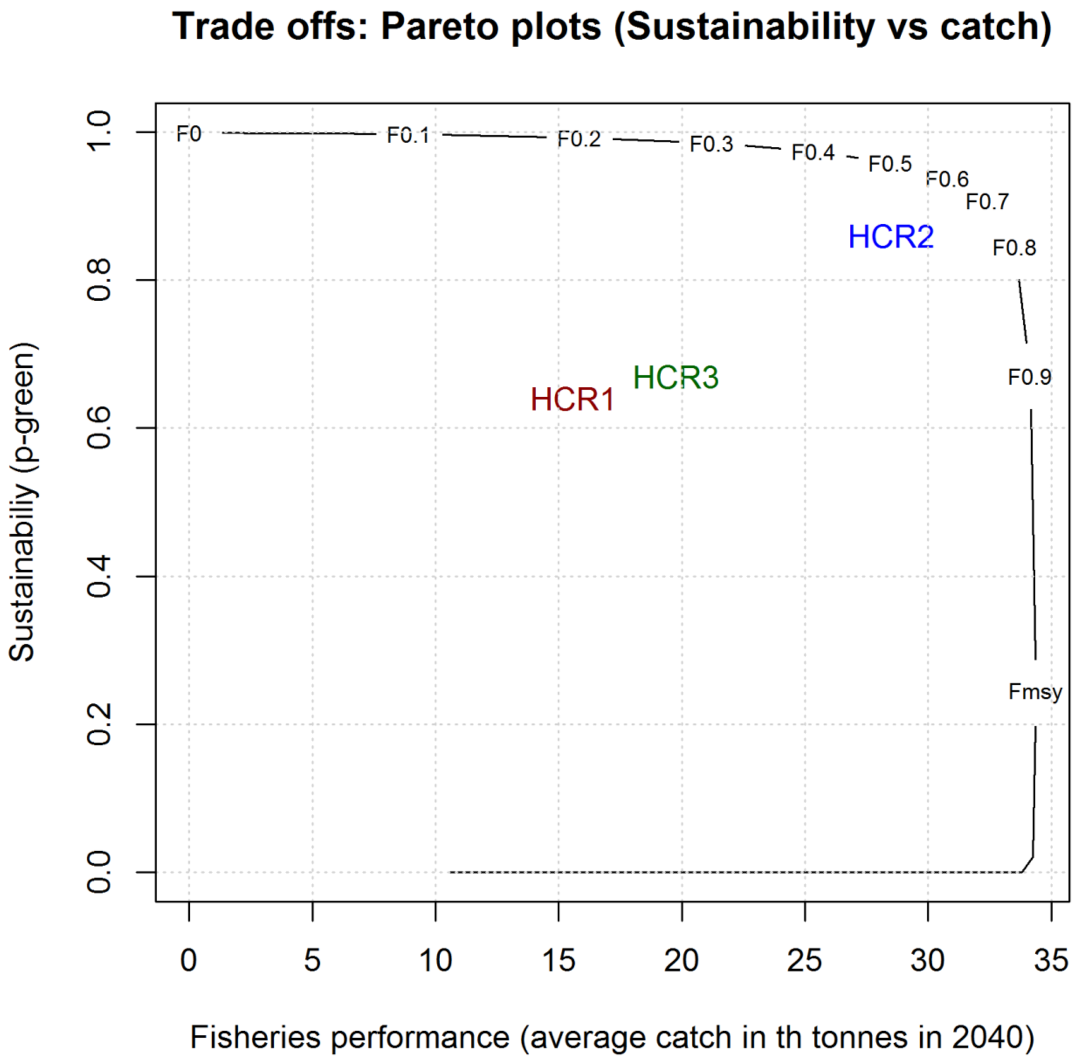


Figure 15. Performance of the three HCR assessed in relation to the Pareto frontiers (Sustainability and catch objectives) of this fishery.

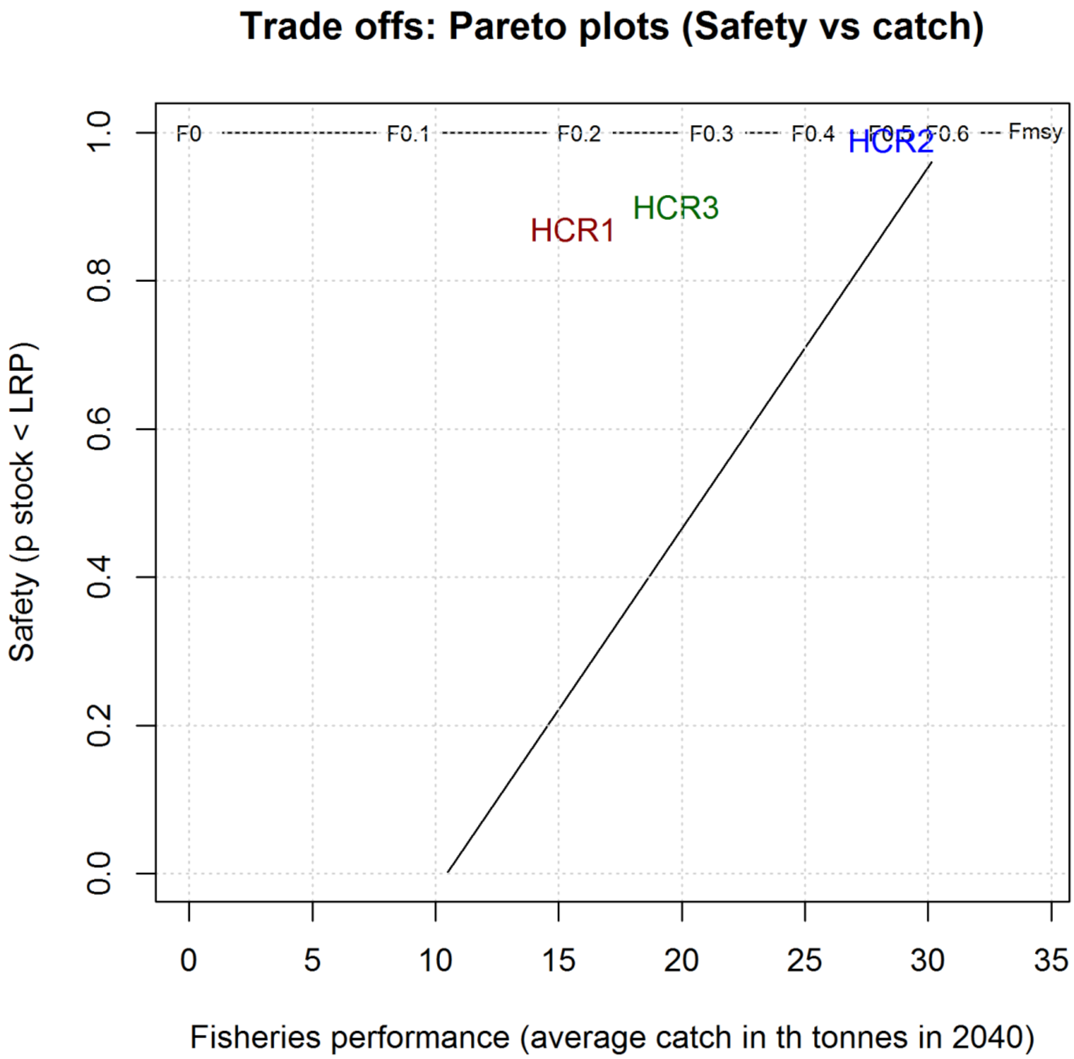


Figure 16. Performance of the three HCR assessed in relation to the Pareto frontiers (Safety and catch objectives) of this fishery.

Displaying the indicators for the three HCRs in the Pareto plots from the Base Case OM allow comparing how well this fishery could perform acknowledging that the data collection, SA and management are not a perfect process, in relation to how they would perform if we had perfect knowledge and control. The three HCRs would produce Sustainability levels of >50% of being in the green quadrant. However, HCR2 would achieve higher levels of catch at the end of the simulation in combination with higher p-green, which would be not very distant to what predicted by the perfect knowledge frontier for a projection with constant F0.7-F0.8 (x F_{MSY}). In relation to safety, again, all HCR achieve high levels of p(B>B_{LRP}), but HCR2 does better, with a probability of ~99% and catch not far from 95% of the estimated MSY in the OM.

Other performance indicators that can be explored are the Interannual variability (IAV) of catch and IAV of fishing effort. Figure 17 also confirms what is suggested in Figure 14, HCR1 provides more stability for the fishing industry in terms of catch and fishing effort.

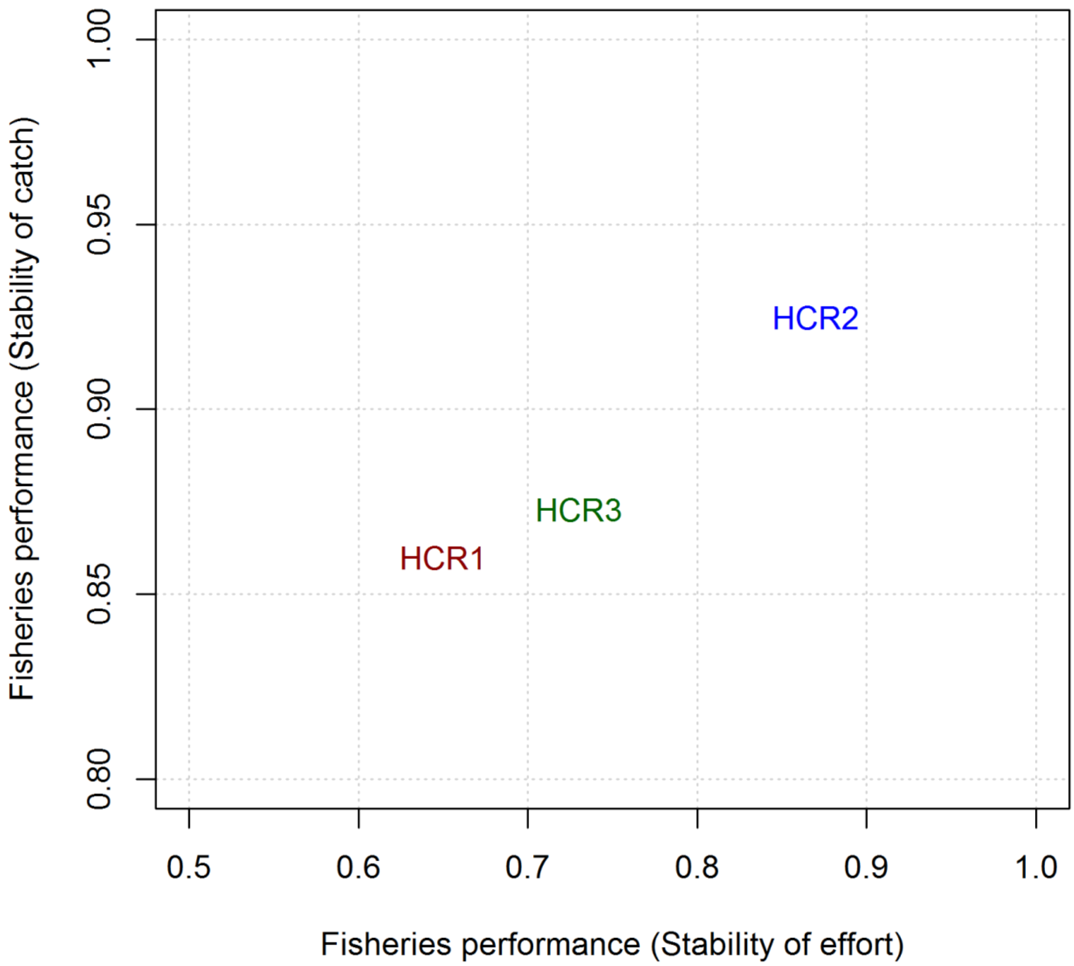


Figure 17 Performance of the three HCR assessed in relation to Stability measures (1-interannual variability of catch and effort).

A summary of the above and other performance indicators obtained in the simulation of the fishery are shown in Table 13.

Table 13. Performance indicators measured on the OM for three HCRs.

	B/Bmsy	F/Fmsy	red	yellow	green	ovFishd	ovFshng	pLRP	catch 2040	catch5	catch10	aavCatch	aavF
HCR1	1.36	0.65	0.26	0.10	0.64	0.28	0.34	0.87	15.61	19.85	10.39	0.12	0.15
HCR2	1.36	0.67	0.09	0.06	0.86	0.11	0.12	0.99	28.52	21.10	11.12	0.05	0.07
HCR2	1.30	0.74	0.25	0.09	0.67	0.26	0.32	0.90	19.77	18.96	10.13	0.09	0.13

Other performance indicators are related to catch only, with focus on short, medium and long term catch produced with each HCR and comparison with estimated MSY and latest assessment recommendation (Table 14).

Table 14. Catch performance indicators, short, medium and long-term catch produced using each of the HCRs tested. The units are thousands of tons.

	2013 SA		SHORT-MEDIUM			LONG TERM
	MSY(SA)	SA(2014-2016)	1-3 years	4-6 years	7-9 years	2020-2040
HCR1	31.68	28	20.60	29.65	33.20	24.32
HCR2	31.68	28	24.40	27.37	29.06	29.39
HCR3	31.68	28	25.60	31.49	32.19	26.18

It is interesting to see how on average, HCR1 and HCR2 achieve similar levels of relative biomass and harvest rates throughout the simulation (Table 13), but they perform significantly different when analysing the trade-offs between performance indicators (Figures 15-17). This is because the average of HCR1 is resulting from very high and very low levels of biomass while HCR2 is far more stable at levels above BMSY, with very low probability of being below BMSY.

An additional thing to see is how the MP is representing what is happening in the OM. Figure 18 shows the estimated stock trajectories (blue) that are compared with the "true" dynamics (red), seen in Figure 18.

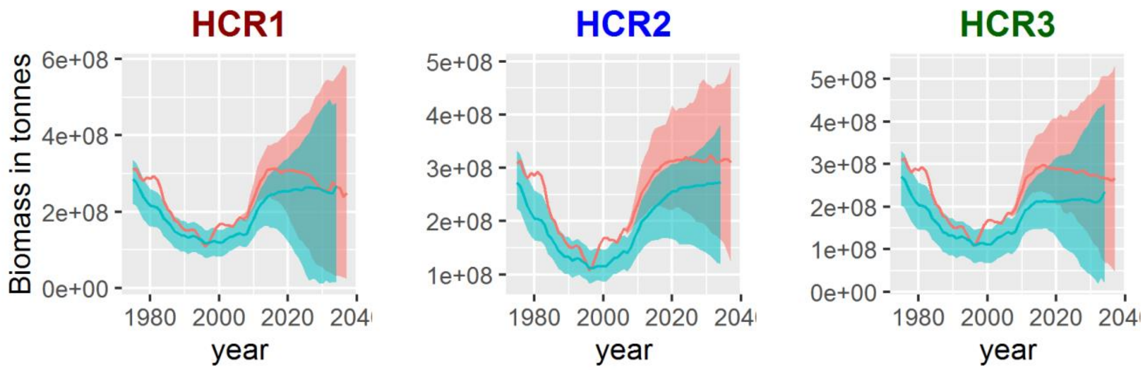


Figure 18. Estimated stock trajectory by the surplus production SA model and the "true" stock trajectory for the three HCR.

This figure shows that when simulation starts (2010), the MP estimates lower levels of biomass than the "true", but as the simulation continues, the average biomass trajectories of both OM and MP converge. This figure has to be analysed in further detail but suggests that in this case, the SA model learns and produces better estimates as the time series of biomass indices are longer. This is expected as the longer the time series, the better estimates of the "true" trajectory can be made with the stock assessment model.

3.3.2 Extended MSE results for North Atlantic albacore

In this section we expand the preliminary results presented previously with the addition of the complete series of Operating Models conditioned with the scenarios contemplated in the 2013 SA of this stock (Table 12 in section 3.2.3.1), three hypotheses on the future recruitment of North

Atlantic albacore and two hypotheses of the relationship between the CPUE series used in SAs and abundance.

The results plotted are intended to be compatible with ICCAT's Recommendation PA2-602B (2015) (ICCAT, 2015b). This recommendation indicates that "*the management objective for northern albacore is to maintain the stock in the green zone of the Kobe plot, with at least a 60% probability while maximizing long-term yield from the fishery (…)*". The recommendation also indicates the aim of "(…) *minimizing inter-annual fluctuations in TAC levels"*. Therefore, the results are displayed against the management objective of 60% of probability of being in the green zone (benchmark). The results displayed are the performance of a series of Management Procedures with regards to long term catch, probability of being in the green zone, safety (1-probability of falling below the LRP of B_{lim}=0.4xB_{MSY}) and the stability of fishing effort and catch. In addition, a full set of results including long, medium and short term catch, sustainability (p(green)) and Safety (1-p(red)) and variability of catch and effort for the simulations run are shown in the appendix.

Here we plot the resulting Sustainability and Safety indicators against the average annual catch in 2040 using the Pareto frontiers framework for 8 of the 10 OMs, conditioned with the scenarios run in the 2013 SA of NA albacore (Figures 19 and 20). In Figure 19 we indicate (dashed line) the probability benchmark of 60% for being in the green zone of the Kobe plot. In Figure 20 we show the probability of the stock not breaching the limit reference point against long term catch.

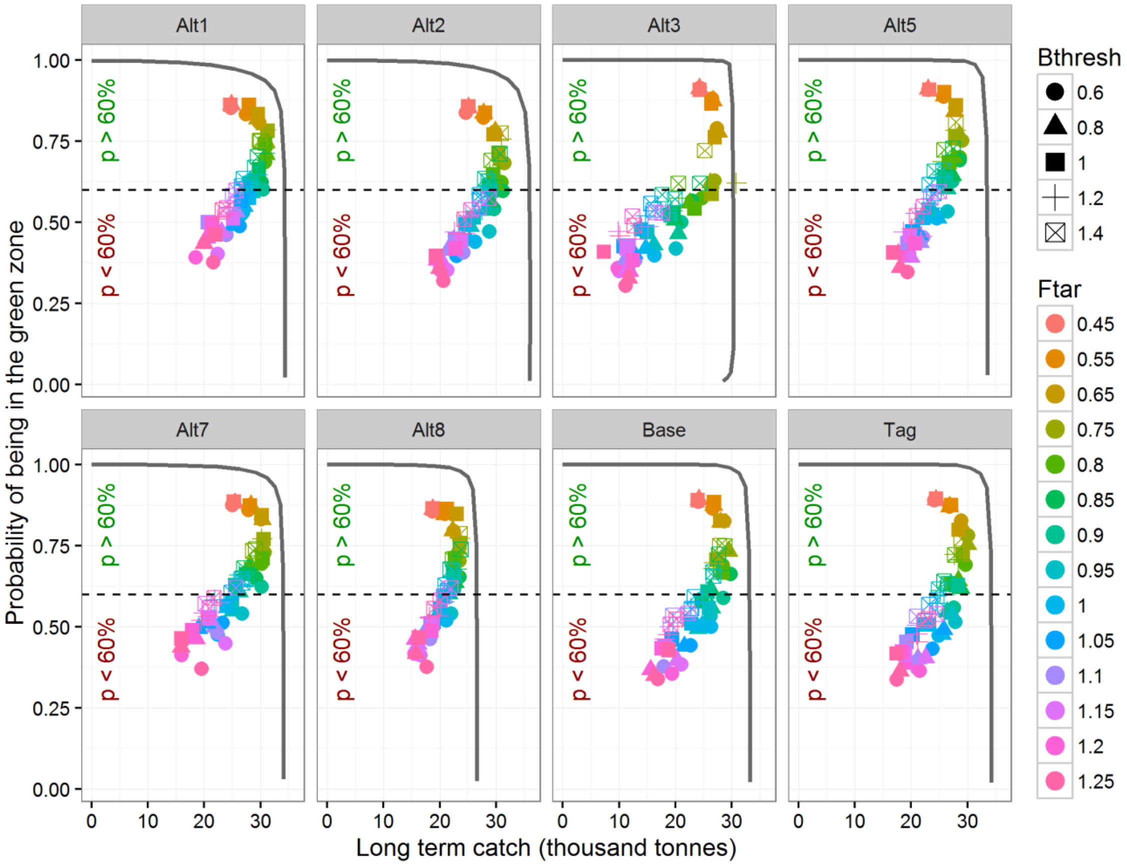


Figure 19. Long term catch and probability of being in the green zone (alternative model runs indicated in table 13 of section 3.2.3.1).

Figure 19 shows that for Ftar higher than 1, i.e. Ftar>FMSY, the management objective of achieving a p(green) of 60% of Recommendation PA2-602B (2015) would not be achieved in most scenarios. The largest long term catch would be achieved with levels of Ftar in a range of 0.65-0.9 for most Operating Models. With regards to Bthresh, the levels that would achieve higher p(green) and long term catch are ranged between 0.6 and 1.

Figure 20 shows that maintaining the stock at safety levels above 0.85 could be achieved with levels below Ftar<1.15.

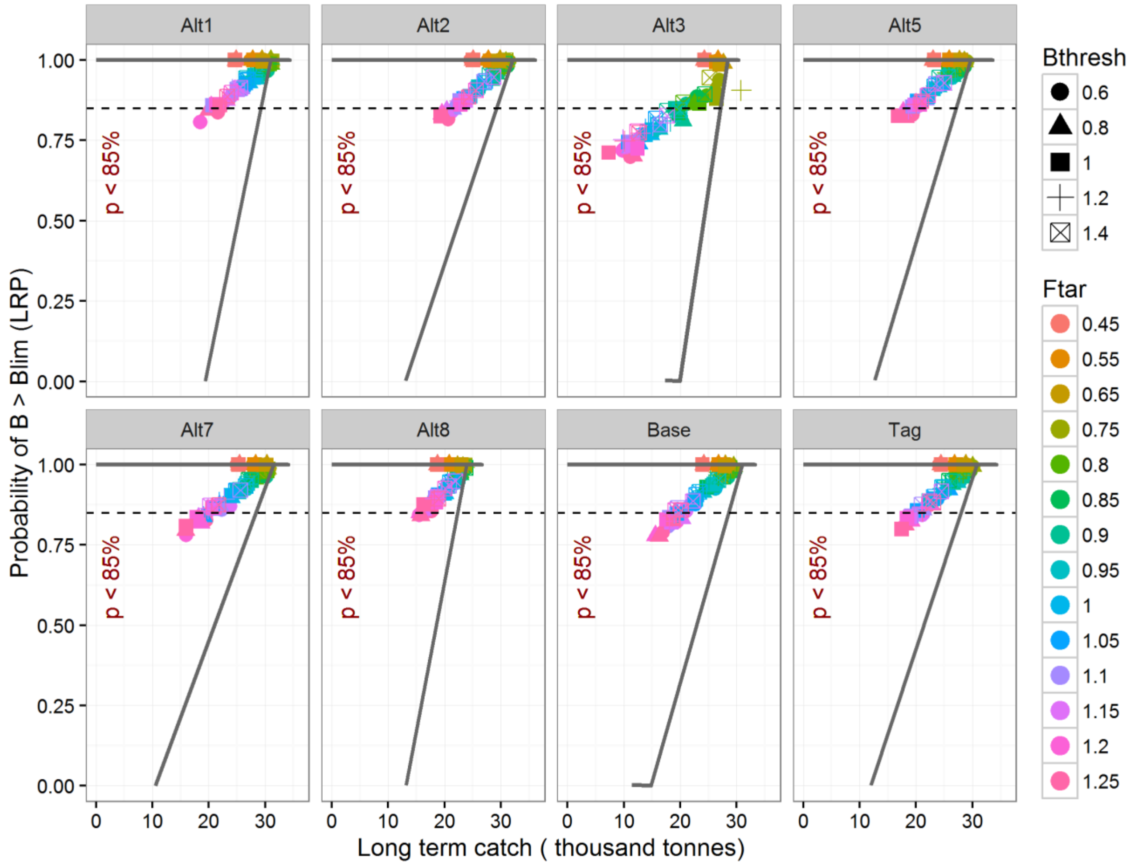


Figure 20. Long term catch and probability of being above the LRP.

Figure 21 shows that the highest stability levels are achieved with combinations of Ftar in a range of 0.65-0.8 and Bthresh of 0.6-0.8.

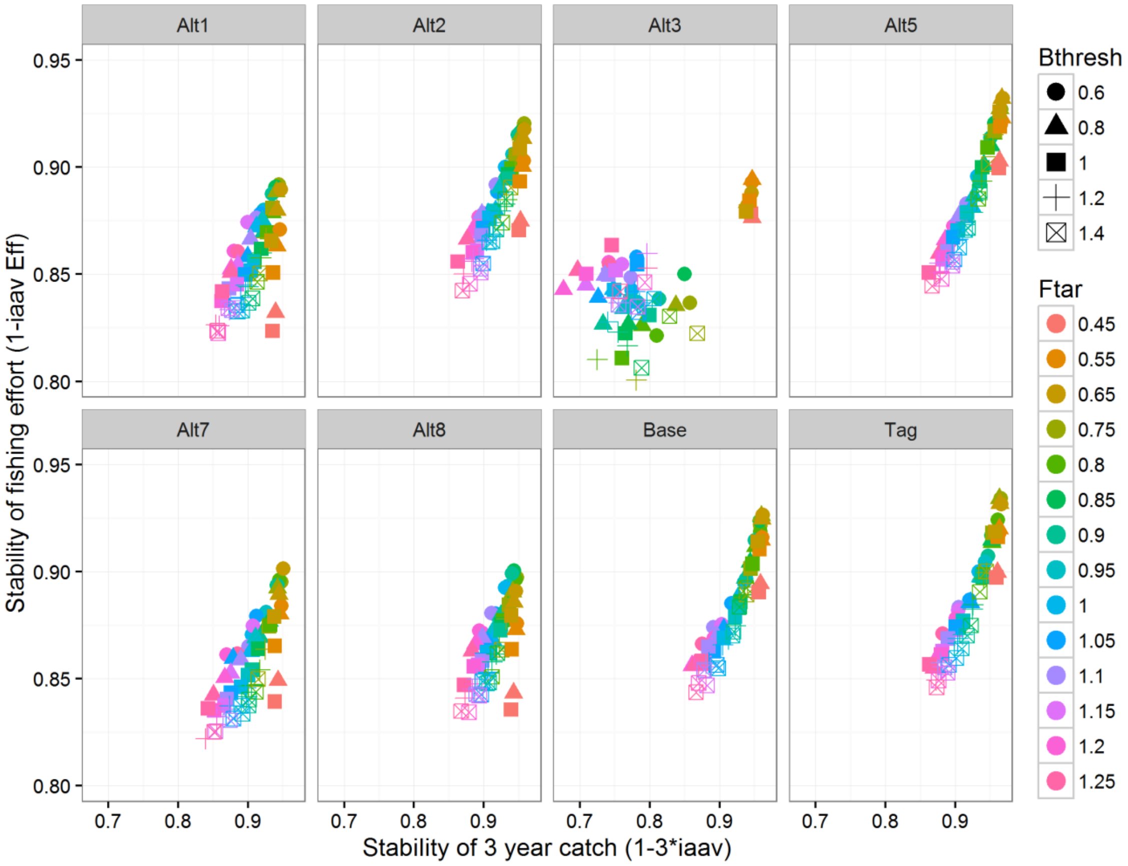


Figure 21. Stability of fishing effort and 3 year catch.

Figure 22 reproduces the previous results with the Operating Model conditioned with the accepted stock assessment in 2013 projected with alternative Observation Error Models (e.g. Hyperstability) and high and low recruitment scenarios (only for Base Case in Table 13). Assuming that the trends of the biomass dynamics of the fish stock are not perceived in the stock assessment process, the levels of precaution should be higher, i.e. Ftar would have to be below 0.9. In this scenario the higher catch and the management objective of p(green)>0.6 are achieved with Ftar of 0.55-0.65 with minor differences on the range of Bthresh 0.6-1. For the high recruitment the highest catch is achieved at Ftar of 1 and the Bthresh of 0.8. With regards to the low recruitment scenario, the highest catch would be achieved with threshold levels of 1.4 but only p(green) of 0.6 would be achieved at Ftar of 0.75.

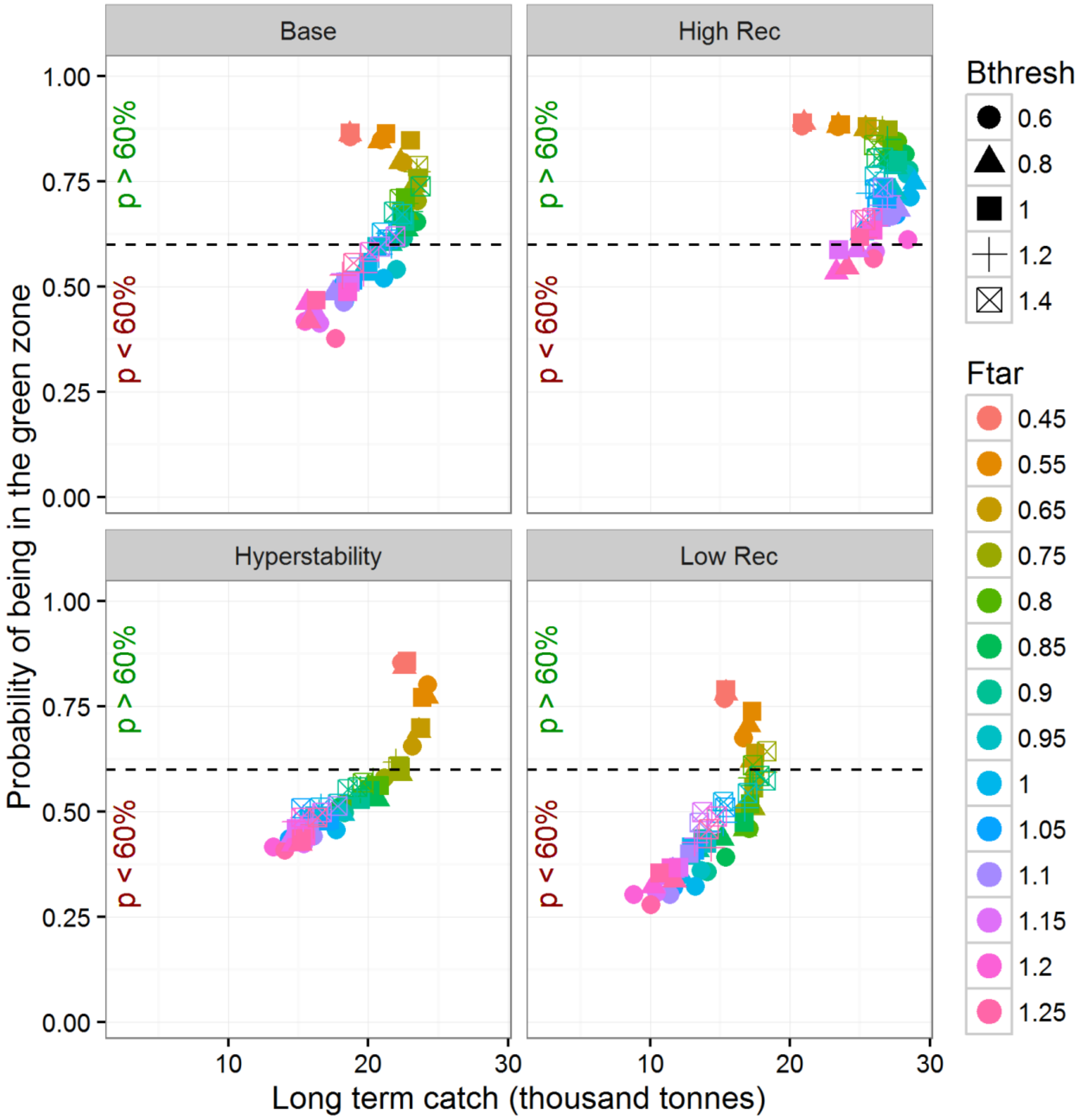


Figure 22. Long term catch and probability of being in the green zone for the Base Case, High Recruitment, Low Recruitment and Hyperstability scenarios.

Figure 23 also shows the differences in the performance of the HCRs have been tested with regards to safety. As seen in Figure 22, assuming the uncertainty on the observation of biomass trends and potential low recruitment scenarios would mean adopting higher levels of precaution, in this case Ftar<1 or Bthresh > 1. In the case of high recruitment, the stock would be at safe levels in all the HCRs tested (This result is obtained using the Base Case OM in Table 13).

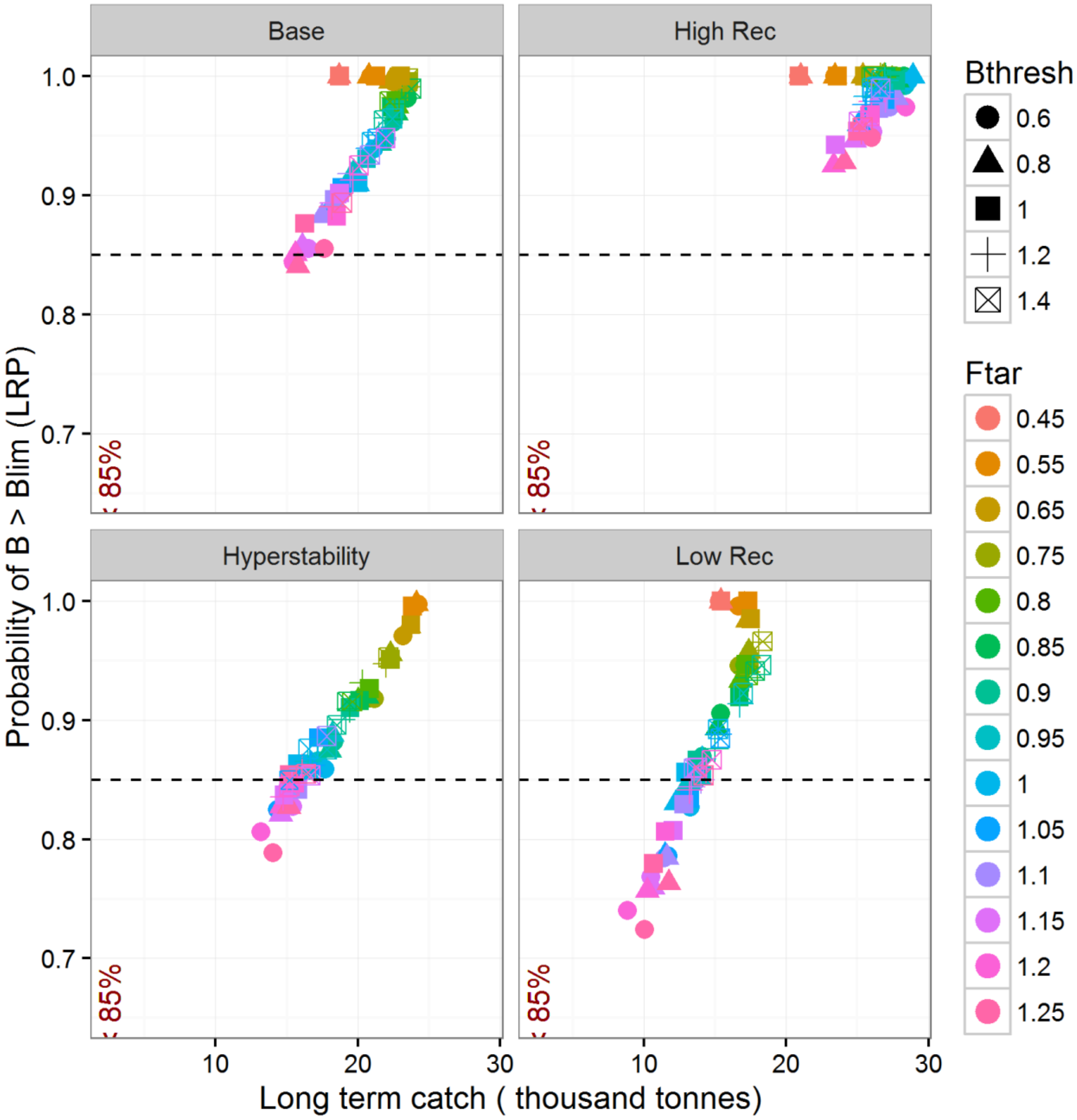


Figure 23. Long term catch and safety (B>Blim) for the Base Case, High Recruitment, Low Recruitment and Hyperstability scenarios.

Figure 24 shows that in the Hyperstability scenario, the highest levels of catch and effort stability are achieved for Ftar 0.55 and Bthresh of 0.6. For the high recruitment, Ftar could be around 0.8-0.9 and Bthresh between 0.6 and 0.8. The same Bthresh but lower Ftar would be necessary in the low recruitment scenario (This result is obtained using the Base Case OM in Table 13).

Summarizing the performance of all the OMs and scenarios we also show the probability of being in the green zone as a function of the Ftar of the HCRs.

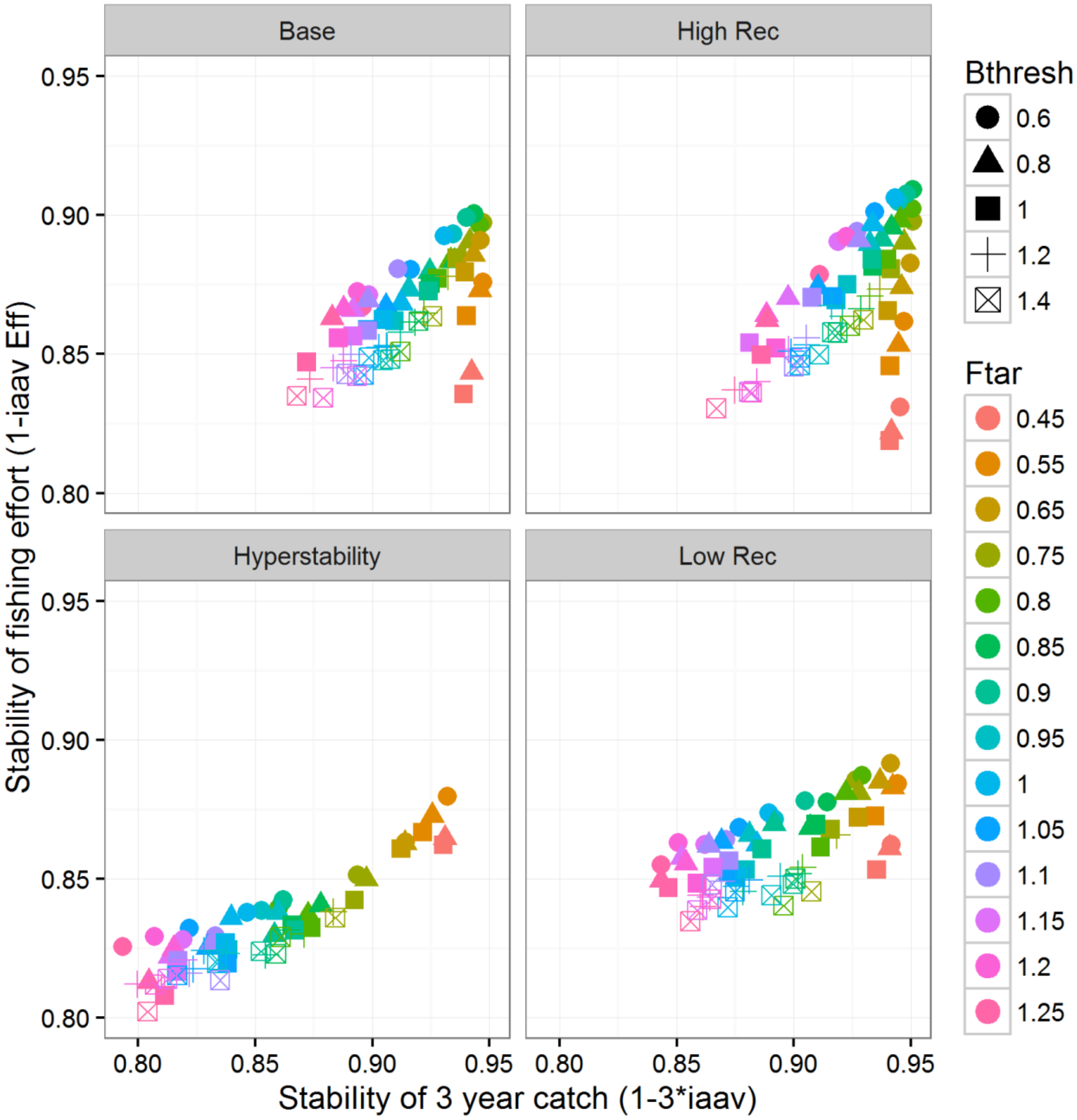


Figure 24. Catch and fishing effort stability for the Base Case, High Recruitment, Low Recruitment and Hyperstability scenarios.

Figure 25 shows the average long term catch for each Ftar using all the scenarios.

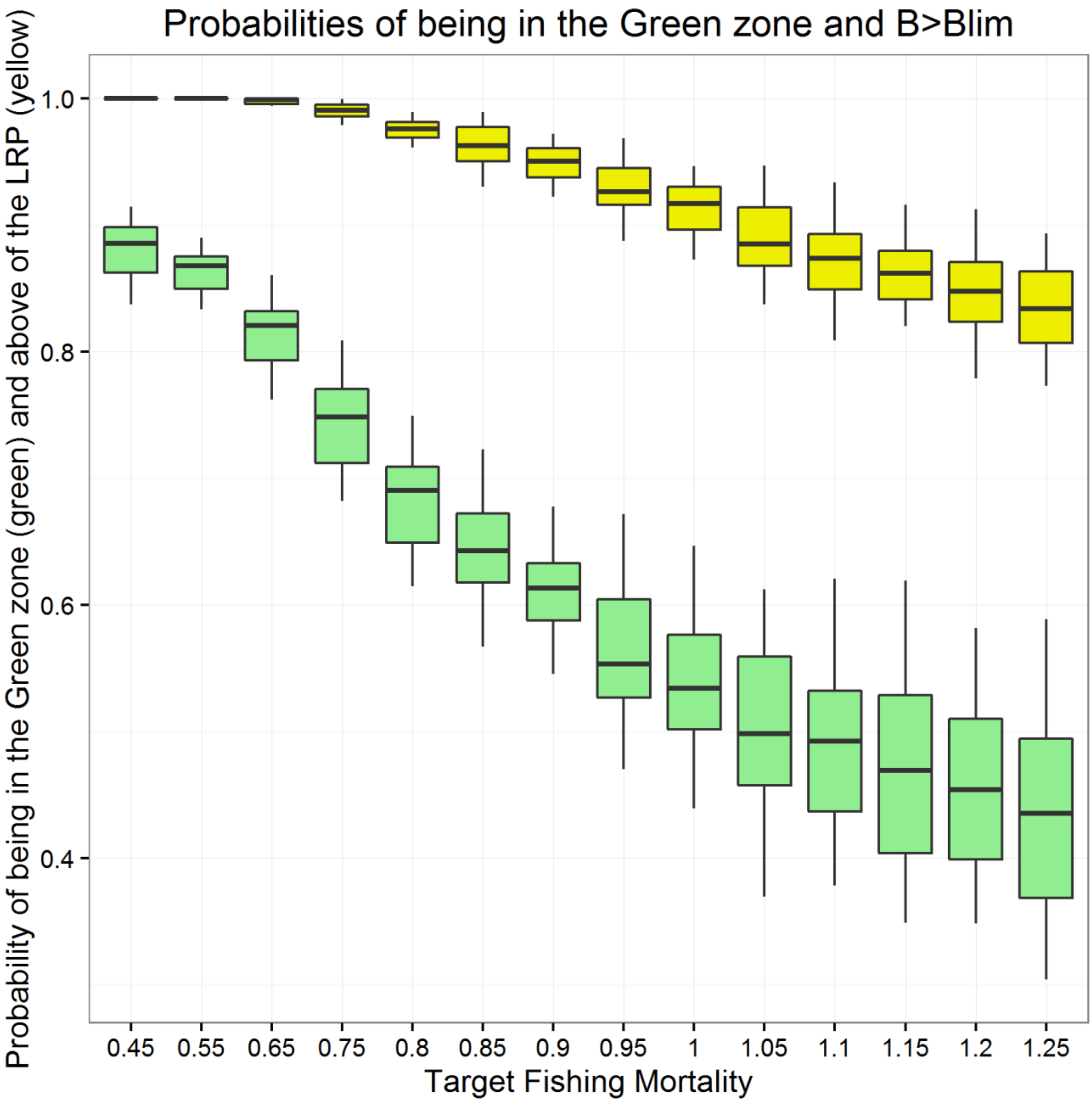


Figure 25. Sustainability and Safety for all scenarios as a function of Ftar.

The highest catch would be achieved with Ftar of 0.65-0.85 and still achieve high sustainability and safety levels in all scenarios (Figure 26).

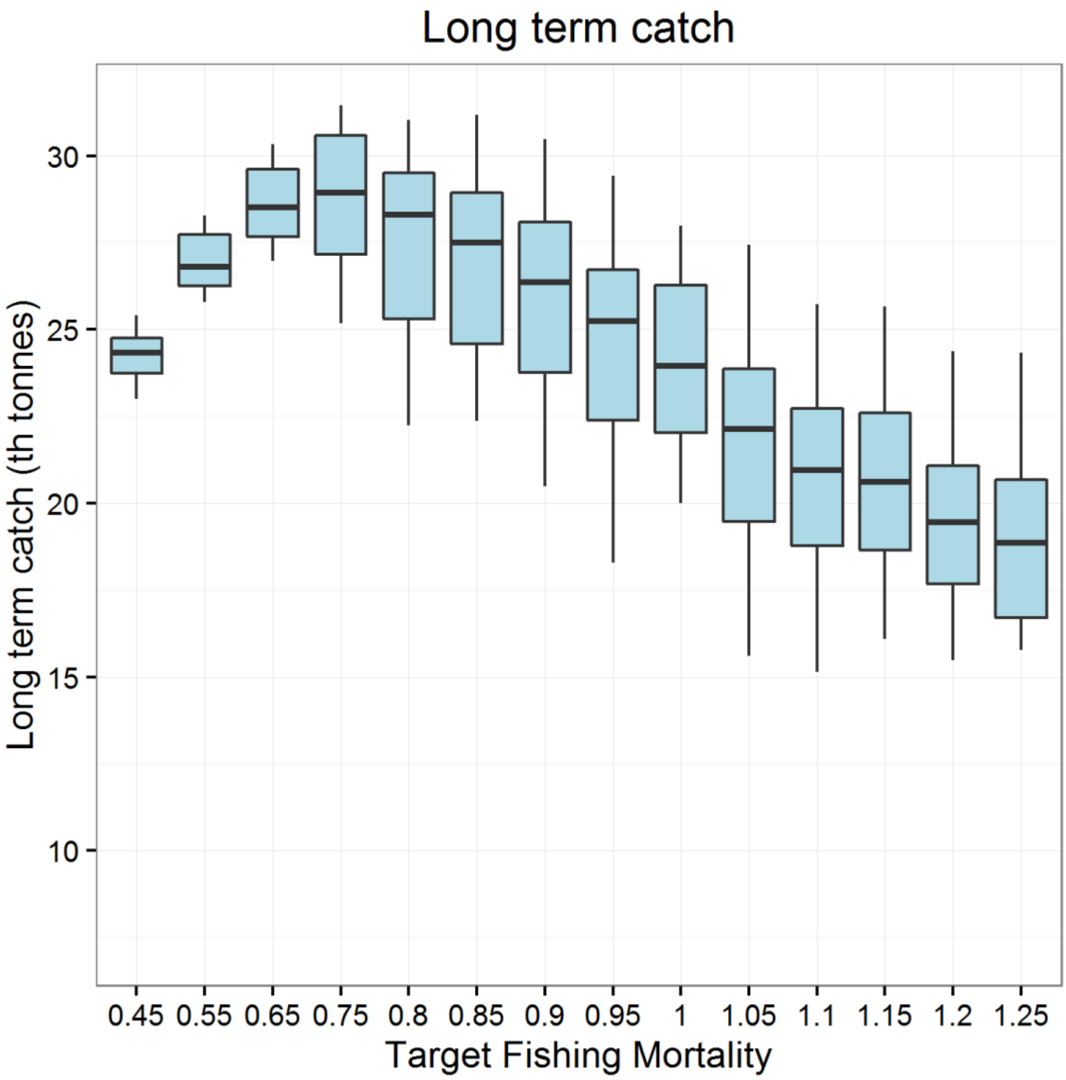


Figure 26. Long term catch for all scenarios as a function of Ftar.

3.4 Discussion

We have presented a Management Strategy Evaluation Framework and its results when assessing the potential impact of a series of HCR, hypotheses and scenarios in the North Atlantic albacore fishery.

Within this process, managers and stakeholders should provide guidance on terms such as acceptable time lines and probability levels. However, some figures shown in this study can facilitate this process. For example, the Pareto plots shown allow identifying the optimum and realistic levels of trade-off between two performance indicators, the probability of being in the green zone and the average annual catch after 30 years. As it is shown, in this fishery (or in this set up of the OM), it is impossible to increase the average catch for the levels of p-green shown in the Pareto frontiers. In addition, our simulations suggest that probabilities of being in the green area greater than 75% can be achievable without reducing the average annual catch more than 5% from the estimated MSY. Assessing on the probability levels that can be acceptable for the management of ICCAT stocks is one of the objectives of this project.

From the first assessment of three contrasting HCRs, it is suggested that HCR2, which includes significant levels of precaution despite the stock being assessed in the green quadrant of the Kobe plot, allows avoiding additional management action for levels above (B_{pa}=0.8 B_{MSY}) and additionally, not only does not produce lower levels of catch, but it reaches higher annual catch at the end of the simulation. In general, the same conclusion holds for all the HCRs tested (64 alternatives) in all simulations run (8 Operating Models x 3 recruitment scenarios x 2 Observation Error Models).

A number of management options appear to lead to maximum long term yields while at the same time resulting in p-green>60% and a p(B>B_{lim})>85%. These scenario correspond to F_{tar} in the range of 0.65 to 0.85 times F_{MSY} (except for the assessment model Alt3, where only F_{tar} < 0.75 ensure a p-green>80%). Among these scenarios, those corresponding to the lower range of the Ftarg (0.65) lead to a higher stability in both catches and fishing effort, especially when associated to lower B_{tresh} values. In these scenarios (lower F_{tar} associated to lower B_{thresh}) the stock is exploited at a lower F on average and stock size is therefore larger. Consequently, the stock spends more time above B_{thresh} (especially when B_{thresh} is smaller), which explains that the reduction of F happens less frequently, which in turn explains the higher stability. These conclusions are robust to the different scenarios of CPUE catchability and recruitment regimes tested.

We have also evaluated how the surplus production model can describe the complex system defined by the OM and still be useful to deliver adequate recommendation in combination with precautionary HCRs. It should be however noted that the catches obtained when applying the MP are substantially lower than the estimated potential of the stock (as assessed in simulations on the OM alone, e.g. Figure 19). This can be explained by the tendency of the stock assessment model to consistently underestimate the biomass of the stock (Figure 18). Therefore, even if the assessment leads to a proper estimate of F_{MSY}, the fishing mortality resulting from the HCR is applied to a perceived stock smaller than the real one, and therefore results in advising for catches which are lower than what the stock could withstand. In other words, the apparent bias in the stock assessment method results in a underexploitation of the stock.

There is a fundamental conflict between harvesting fish and conserving their biomass (Luehring et al., 2016; Quinn and Deriso, 1999). In the following paragraphs we discuss the capacity of HCRs and RPs to achieve the management objectives of high and stable catch combined with the 60% probability of being in the green quadrant of the Kobe plot as indicated by the recent ICCAT's Recommendations. In order to facilitate this decision we explore alternative ways to illustrate the trade-offs between management objectives with each HCR and discard the HCRs that do not fulfil the condition of p(Green)>60%. Here we examine the trade-offs between management objectives so that tuna fisheries managers can simultaneously evaluate a variety of regulations (Luehring et al., 2016).

Figure 27 shows the long term catch and probability of being in the green quadrant of all the HCRs evaluated using all the Operating Models and hypotheses that fulfil the condition of pGreen>0.6.

Within this figure, the Ftargets that achieve the highest long term yield range between 0.75-0.85 of FMSY.

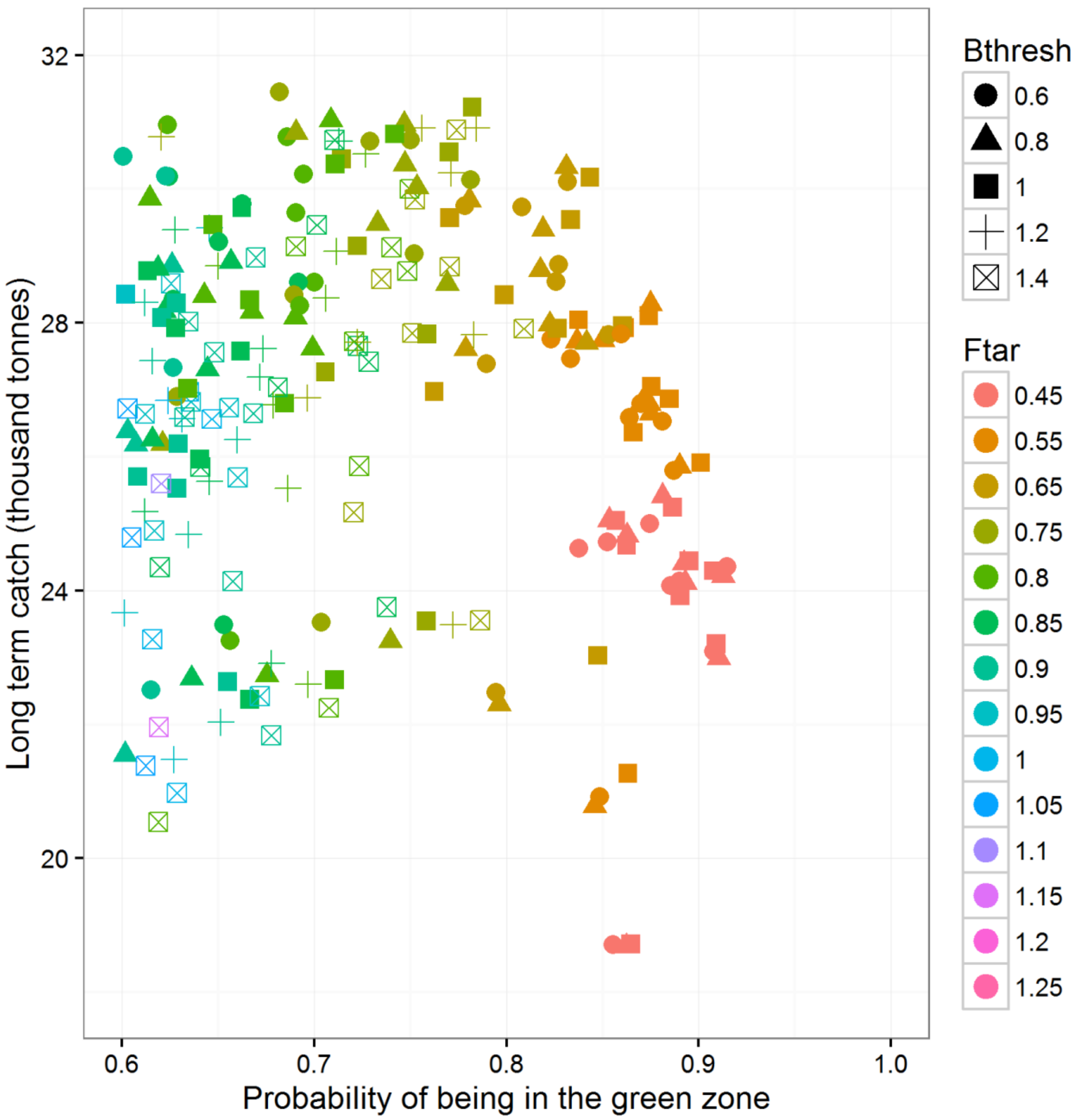


Figure 27. Probability of being in the green quadrant and long term catch for the HCRs that fulfil the constraint of pGreen>0.6. Dots are the performance for each HCR estimated with each OM.

This is also indicated in Figure 28, which shows the same results in a grid of Bthresh and Ftar. The points in this figure represent the estimated long term catch and pGreen with the alternative OMs for each combination of Ftar and Bthresh. Again, the highest catch is achieved with Ftargets of 0.75-0.85 of FMSY. With regards to the Bthresh, similar long term catch are estimated for a wide range of Bthresh for each Ftar.

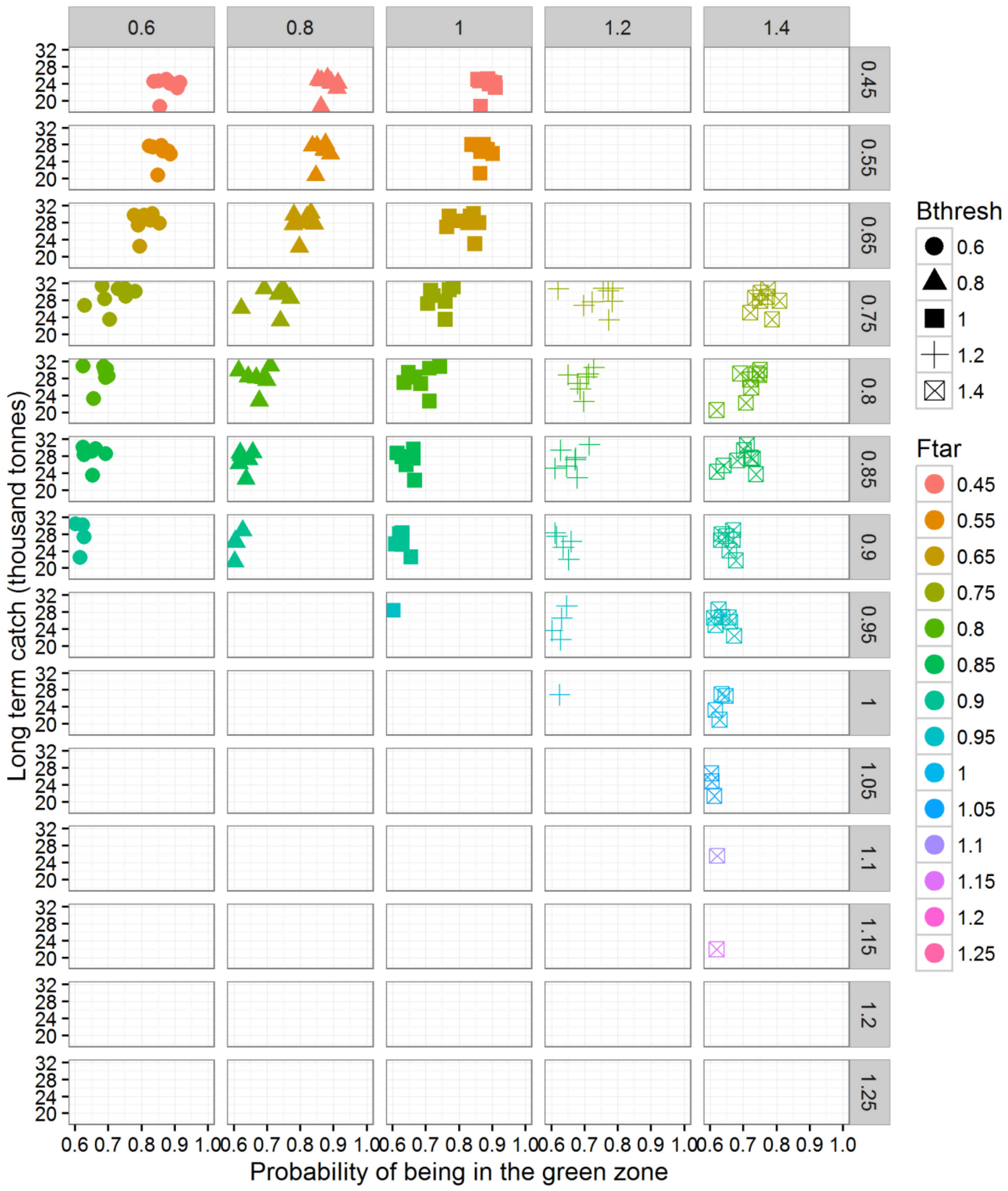


Figure 28. Probability of being in the green quadrant and long term catch for the HCRs that fulfil the constraint of pGreen>0.6. Dots are the performance for each HCR estimated with each OM.

In order to facilitate choosing the Bthresh value for the candidate HCRs, we plot the pGreen against the short term catch expected using the selected range of Ftar (0.75-0.85), again for HCRs that fulfil the pGreen>0.6. In Figure 29 we can see that higher short term catch values are achieved when the threshold reference point is located below 1, i.e. at values of 0.6 and 0.8.

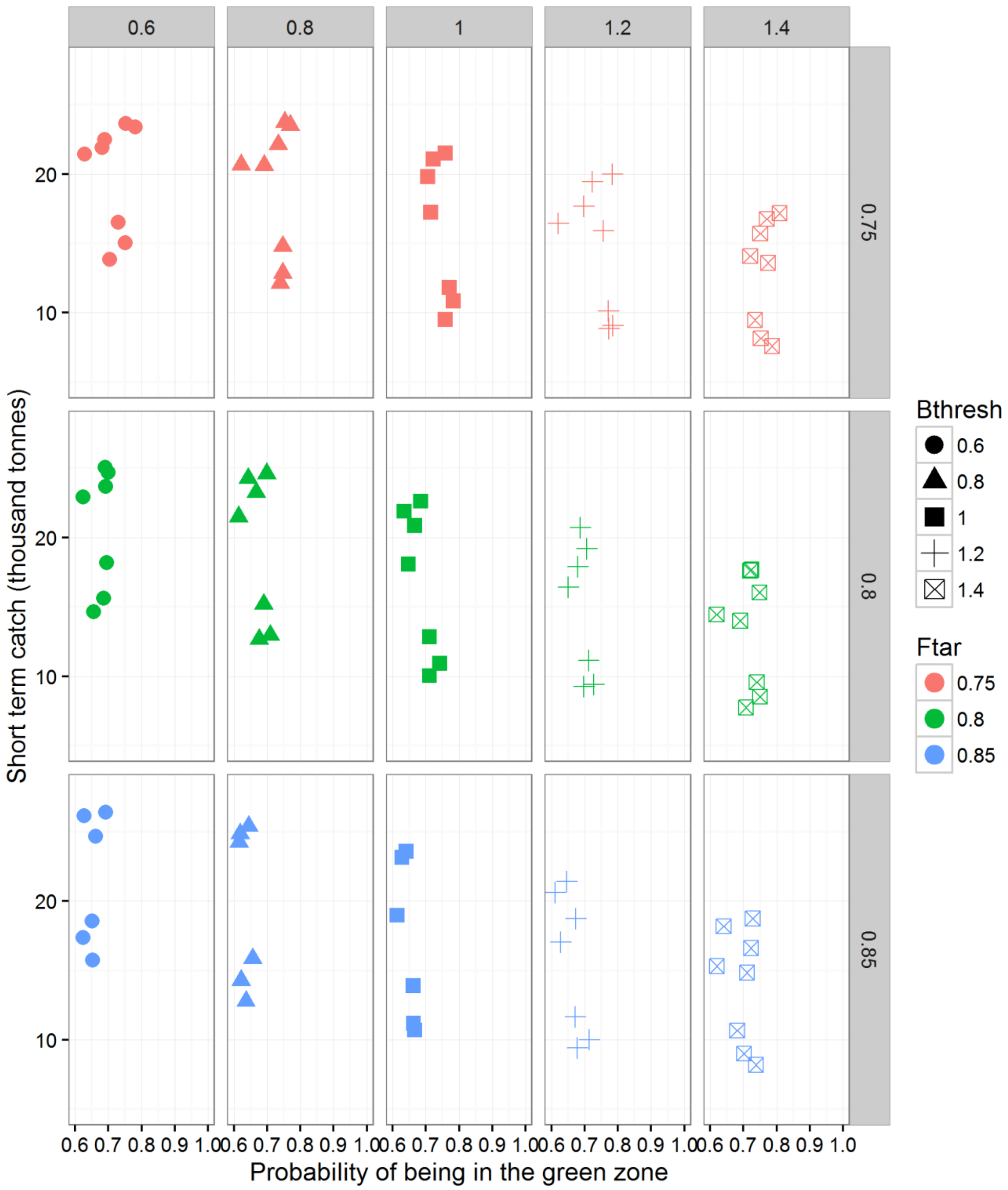


Figure 29. Short term catch and probability of being in the green quadrant for each Ftar and Bthesh combination. Dots are estimations using alternative OMs.

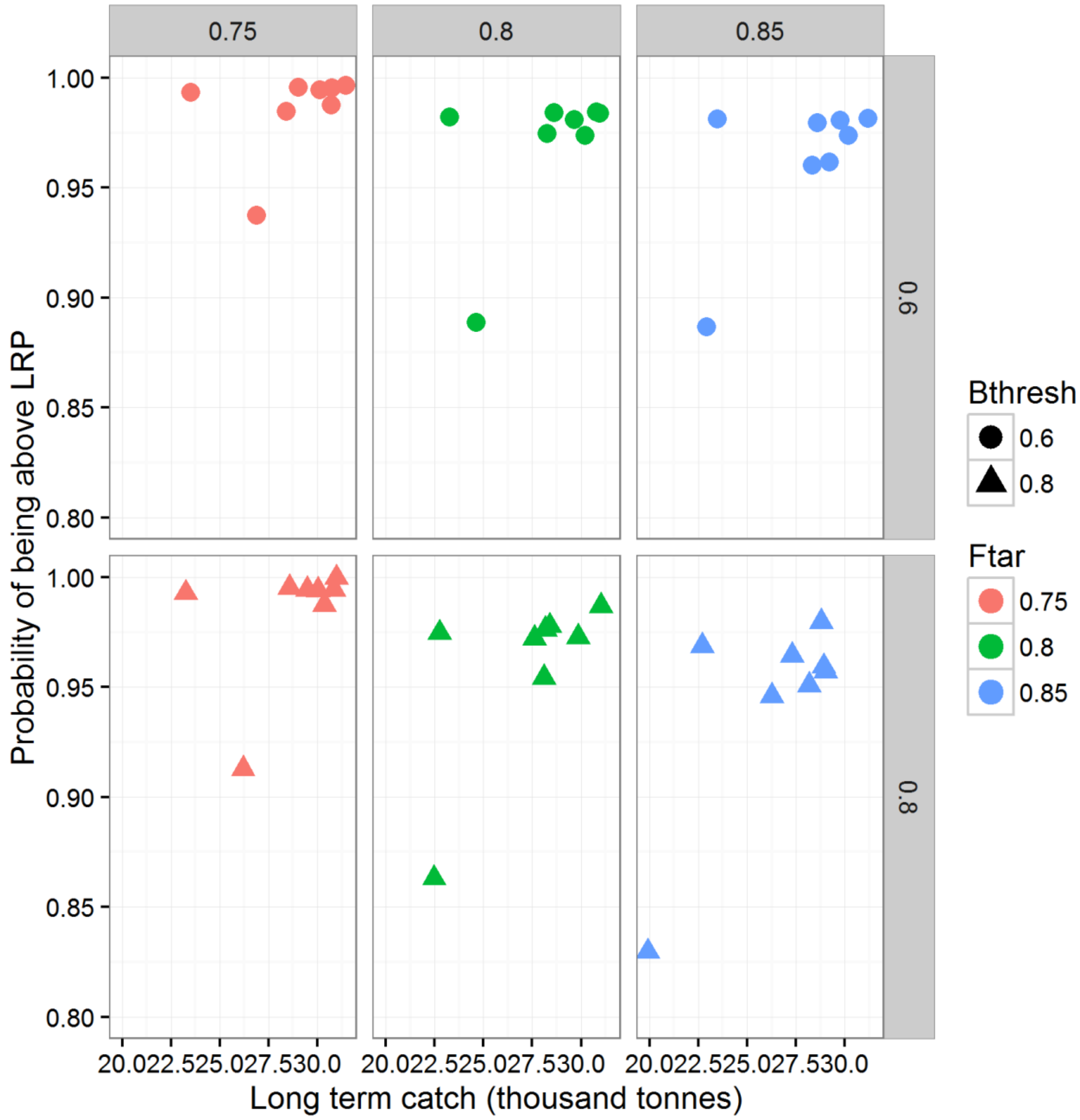


Figure 30. Probability of not falling below LRP and long term catch for the HCRs that fulfil the constraint of pGreen>0.6 for the candidate HCRs. Dots are the performance for each HCR estimated with each OM.

Therefore, we will focus in HCRs with Ftar ranging from 0.75-0.85 and Bthresh 0.6-0.8. From the selected, when plotting long term yield and safety (probability of not falling below the LRP), we obtain probabilities > 0.9 for Safety and high estimates for long term catch for most OMs and HCRs, with slightly higher values for the HCR with Ftar=0.75 and Bthresh 0.8. Note that at this point, with the ranges of Ftar and Bthresh the differences between HCRs are minimal (Figure 30).

We now plot the stability of catch and fishing effort achieved with these candidate HCRs (Figure 31):

With all six HCRs high and stable catch and efforts are achieved. As in Figure 30, only one OM is underperforming with all the six candidate HCRs.

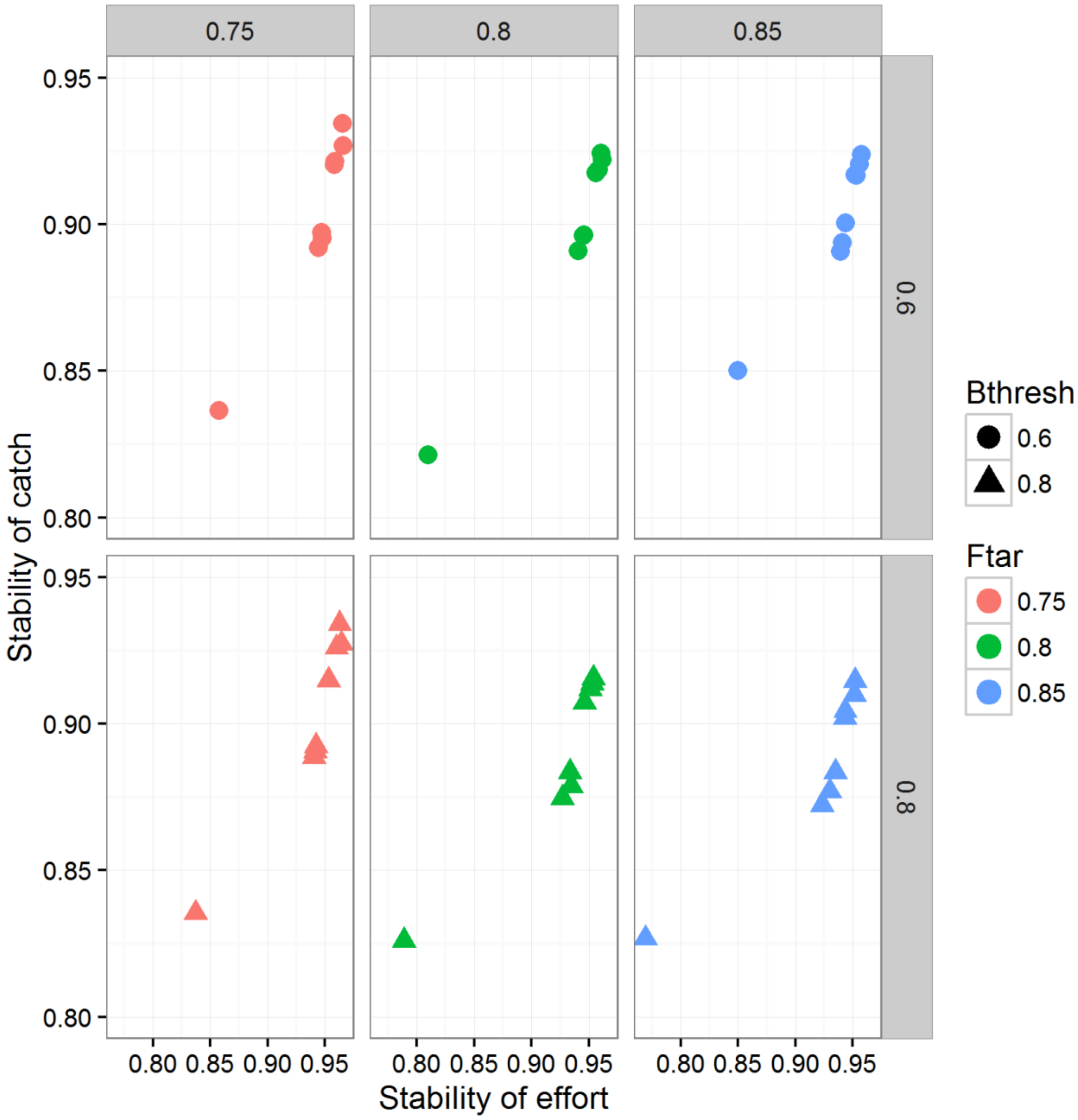


Figure 31. Stability of catch and stability of fishing effort for the candidate HCRs. Dots are the performance for each HCR estimated with each OM.

Radar charts allow displaying multivariate information in the form of a two-dimensional chart of many quantitative variables represented on axes. Figure 32 shows the performance of the six candidate HCRs according to seven management objectives displayed simultaneously and estimated using the base case OM. According to this, all candidate HCRs would perform similarly in all management performance metrics, with small differences (highest differences of 20% in short term catch and 13% in pGreen) between two HCRs of Ftar=0.85/Bthresh=0.6 and Ftar=0.75/Bthresh=0.8).

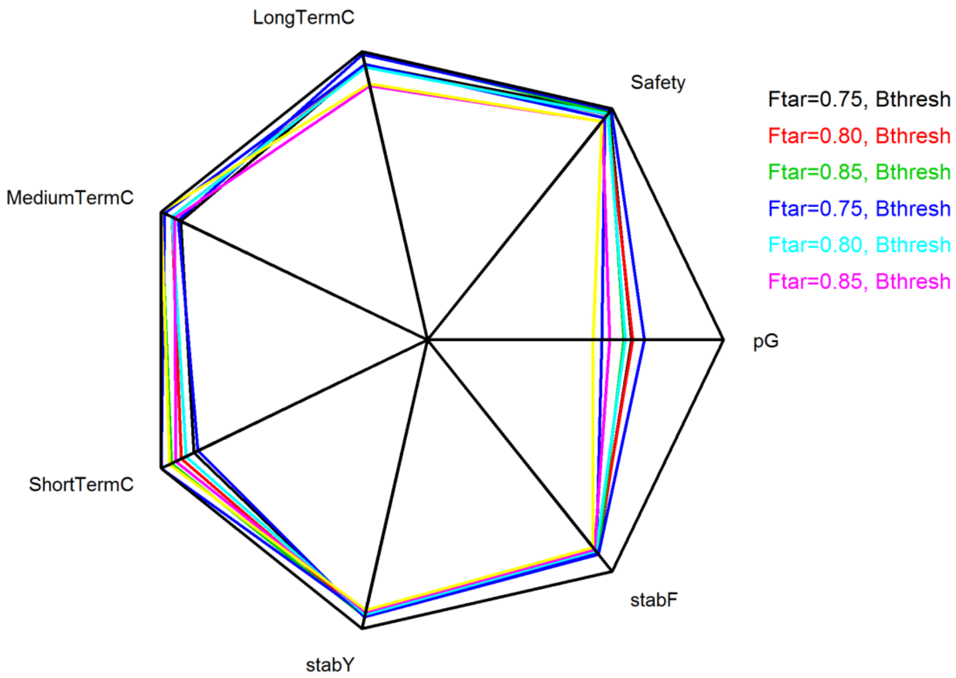
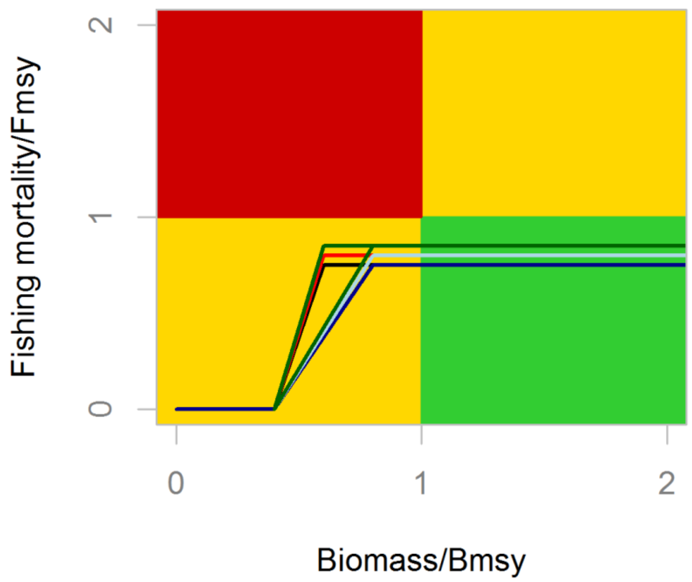


Figure 32. Multicriteria radar chart showing the performance of all the HCRs in relation to seven management objectives (short, medium and long term catch, Safety, pGreen (pG), sability in fishing effort and in catch (stabF, stabC)) estimated using the base case OM.

3.4.1 Candidate HCRs and RPs for North Atlantic albacore

According to the results shown in the previous section a selection of HCRs for the management of North Atlantic albacore can be made. The HCRs can be described by the principles "*more precaution and less action*". This means that targeting a fishing mortality below the corresponding to MSY (F_{MSY}) allows for refraining drastic management action when environmental or other factor reduces biomass below B_{MSY}. The performance of the six HCRs selected (Figure 32) is similar and alternative criteria may be added to select one among the six.



HCR	Blim	Bthresh	Ftar
1	0.4	0.6	0.75
2	0.4	0.6	0.8
3	0.4	0.6	0.85
4	0.4	0.8	0.75
5	0.4	0.8	0.8
6	0.4	0.8	0.85

Figure 33. Candidate HCRs and RPs resulting from the analyses of this project.

A summary table with the results HCRs evaluated for North Atlantic albacore is provided in the Annex I.

4 TOWARDS AN MSE FRAMEWORK FOR ATLANTIC BIGEYE

4.1 Introduction

Bigeye tuna is one of the three tropical tuna species targeted in the Atlantic. According to the most recent assessment of Atlantic bigeye, this stock is overexploited and undergoing overexploitation, despite catch being lower than TAC in the recent years. A possible reason for this is the overall increase of catch of small bigeye tuna by purse seine fleets. ICCAT has established several spatial closures to surface fishing gear in the Gulf of Guinea to reduce the mortality of the younger individuals (Recommendations 04-01, 08-01, 11-01 and 14-01). However, this moratorium has not been effective in rebuilding the stock by reducing the mortality of juvenile individuals due to the redistribution of fishing effort into adjacent areas. In 2015, ICCAT has recommended to reduce TAC to a level that would allow this stock's recovery with high probability and in as short period as possible (ICCAT, 2015a; ICCAT, 2015c). SCRS also indicates that the recently increased harvests of the purse seine fleets using Fish Aggregating Devices (FADs) could have had negative consequences for the productivity of this stock (reduced yield at MSY and increased SSB to produce MSY). Therefore, according to SCRS (ICCAT, 2015c), "*should the Commission wish to increase long-term sustainable yield, the Committee continues to recommend that effective measures be found to reduce FAD-related (…) fishing mortality of small bigeye tunas*". There is an ongoing debate on how to reduce the impact of FAD fishing not only in ICCAT but also in other tRFMOs. Accordingly, ICCAT adopted the new recommendation (Rec 15-01) reducing the TAC to 65,000 tons and establishing a new time/area closure (ICCAT, 2015a).

4.2 Methodology

In this section we lay the grounds to build a Management Strategy Evaluation framework for the Atlantic bigeye tuna fishery. MSE can contribute to estimate the potential impact of the harvest limitation of the purse seine fleets using FADs. For that, we propose a modelling platform: FLBEIA, which is a bio-economic impact assessment model based on the MSE approach (Garcia et al., 2013; Jardim E. et al., 2013). This model is written in R and requires the use of FLR libraries (www.flr-project.org). Figure 34 shows the structure of the MSE built with FLBEIA which includes Operational (OM) and Management Procedure Models (MP). The OM is composed by stock, fleet and OM covariates, and the MP is composed by the data collection, stock assessment and decision making components.

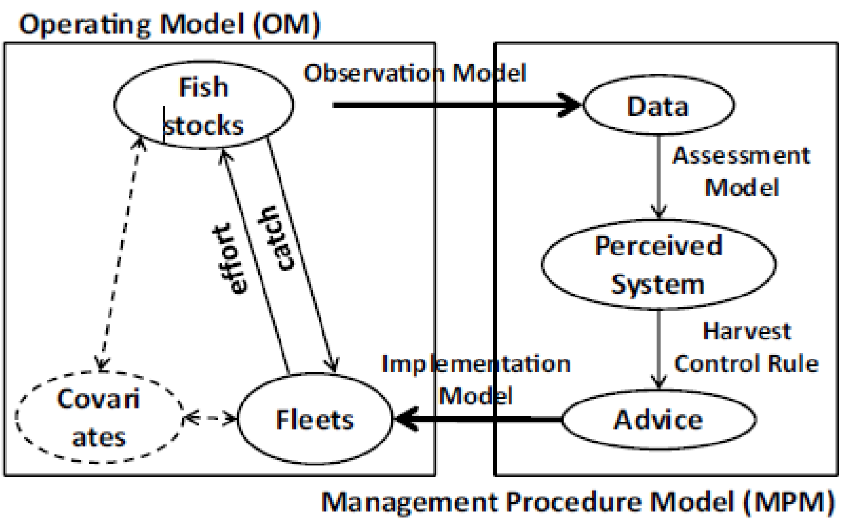


Figure 34. Conceptual representation of the main components modelled in FLBEIA (Garcia et al., 2013).

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 to management actions (Punt et al., 2014), i.e. different MPs. Here we plan to use the MSE framework to evaluate the impact of reducing the use of FADs by increasing the fishing effort with free school sets. In this chapter we attempt to show how the impact of transferring a fraction of the fishing effort of FAD-purse seiners into purse seiners targeting free schools can be evaluated. The simulations presented here are very preliminary and we only aim to describe the MSE framework and highlight its potential to contribute to discussions on the ongoing FAD management plans for the conservation of tropical tunas. For this, we use an MSE framework following a series of guidelines and best practices (Punt et al., 2014; Rademayer et al., 2007), including the basic steps needed to be followed when conducting an MSE.

4.2.1 Management objectives

The overall management objective 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. However, the last assessment of Atlantic bigeye suggests that it is overexploited. The assessment notes that even with the recent implementation of the spatial closure to surface fishing gears in order to reduce juveniles' mortality, the stock has not recovered to target levels. Therefore, ICCAT has recommended reducing the TAC to a level where the probability of the stock to recover as soon as possible is high, but SCRS also pointed out that a reduction in the use of FADs also could increase the likelihood of stock recovery.

4.2.2 Selection of hypotheses

We do not simulate a variety of hypotheses on the population and fishery dynamics of this stock but we only develop a Base Case for an MSE analysis with the latest stock assessment of Atlantic bigeye.

4.2.3 Operating Models

Operating Models are representations of the "true" dynamics of the system and may include a set of most plausible hypotheses or unlikely but not impossible situations. In MSE frameworks the OMs are the system that has to be managed through MPs, i.e. the "true" system, that is observed, analysed and managed through data collection systems, stock assessment models and a decision making process. The capacity of alternative components of the MP to manage the system described by OMs is evaluated through MSE frameworks. The OMs in this study are set ups of the age structured model used in the assessment of this stock.

In the latest SA, the stock status of Atlantic bigeye was provided using SS3, a size structured model and biodyn, a surplus production model that uses FLR libraries. In this MSE, the output of the SS3 model was used to estimate initial model conditions. Biological parameters such as maturity, weight and natural mortality at age were estimated as the average of the last three historical values. A deterministic segmented regression model was assumed as the stock-recruitment relationship and its parameters were calculated from the data series yielded by SS3.

4.2.4 Management Procedure

In the current set up, the model does not include any data observation model, assessment model or implementation. Therefore the simulations shown here assume that population data is known without error and management measures are also implemented without error. Should the bigeye MSE be further developed, a further development of an observation error model, a surplus production model comparable to the production model used in the 2015 SA and a detailed decision making framework will be completed.

4.3 First set-up of the bigeye simulation model and scenarios

The first set up of FLBEIA for the Atlantic bigeye case study is built using the output generated with SS3 in the 2015 stock assessment. The Cobb Douglas production model (Cobb C.W. and Douglas P.H., 1928) is used in order to estimate the catch production per fleet. Effort and elasticity parameters are assumed equal to one, so catches per fleet depend only on the fleet catchability and biomass. The fleets and their codes considered for this preliminary set up are also obtained from the 2015 SA (Table 15).

Table 15. Fleets considered in this simulation.

Fleet	Metiers	Description
PS_SPFR	PS_SPFR_FS	*Metier*: Spain and France Purse Seine Free School
	PS_SPFR_LS	*Metier*: Spain and France Purse Seine Log Set
PS_GH	PS_GH	Ghana Purse Seine
BB_PTSP	BB_PTSP	Portugal and Spain Bait Boat
BB_Other	BB_Other	Other Bait Boat
LL_JP	LL_JP	Japan Longline
LL_Other	LL_Other	Other Longline

Figure 35 shows the effort share of European purse seines in the current scenario (s1) and in the event of reducing the fishing effort of FAD fleets and increasing the effort of free schools proportionally (s2). We will simulate the impact of the latest TAC of 65,000 with the two scenarios. For that we project the OM into the future.

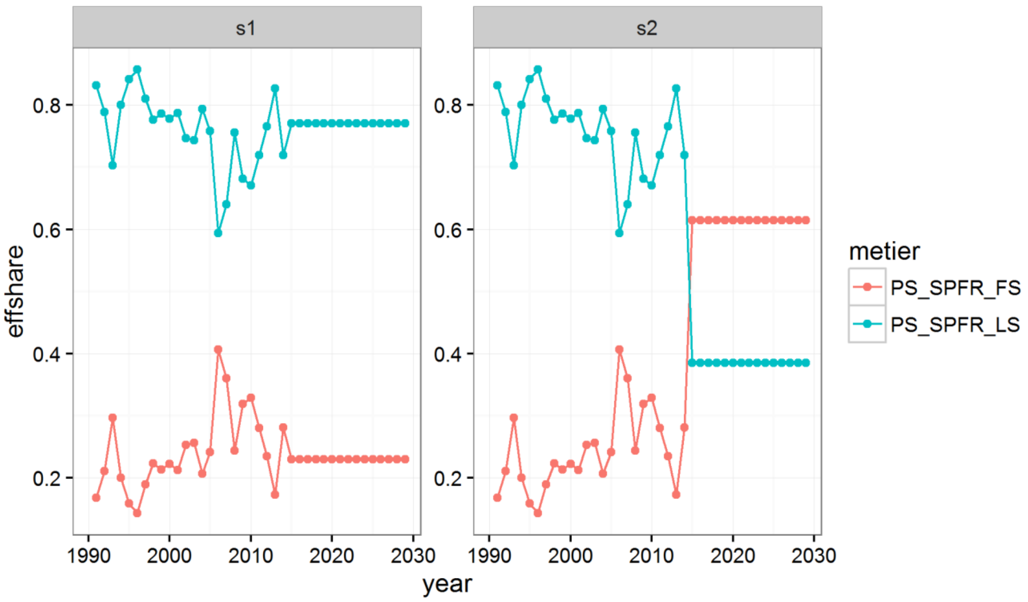


Figure 35. Effort share of European purse seine fleets: Free school (FS) and Log school or FADs (LS).

4.4 Preliminary simulation results

Figure 36 shows the age structured fishing mortality applied to Atlantic bigeye overall (Figure 36.a) and by the two European purse seine fleets (Figure 36.b) with the two effort share scenarios.

Figure 36 shows the change in the fishing mortality pattern originated by the redistribution of effort between FADs and FS. It is important to mention that the overall catch in both scenarios will be 65,000 tons, but the age distribution of catch is expected to differ between the two scenarios. In the current situation, the fishing effort applied over the individuals of age 0 and 1 is considerably higher than the one applied with scenarios 2. In contrast, the F applied over individuals from age 4 onwards increases with the proposed new effort distribution.

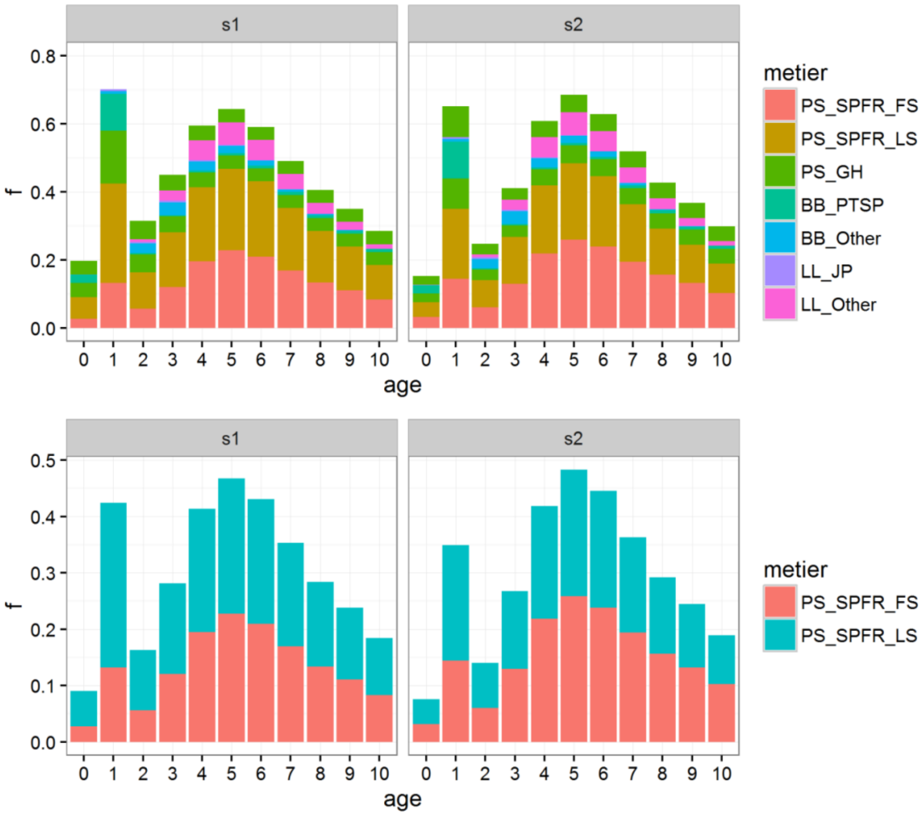


Figure 36. a) Upper: Age structured fishing effort applied over Atlantic bigeye according to the 2015 stock assessment. b) Below: Fishing mortality applied by the European purse seine fleets operating with FADs (PS_SPFR_LS) and with free schools (PS_SPFR_FS).

Figure 37 is a projection of the TAC recommended in 2015 (ICCAT, 2015a), i.e. 65,000 tons. The impact of transferring fishing effort into purse seine fleets is assessed. As seen, reducing the fishing mortality on the early ages of the population (sc2), can accelerate the recovery of Atlantic bigeye compared to maintaining the overall TAC limitation and a relatively stable catch per fleet. This is because the overall fishing mortality (f) is reduced by reducing the activity of FADs and increasing the free schools (Figure 36).

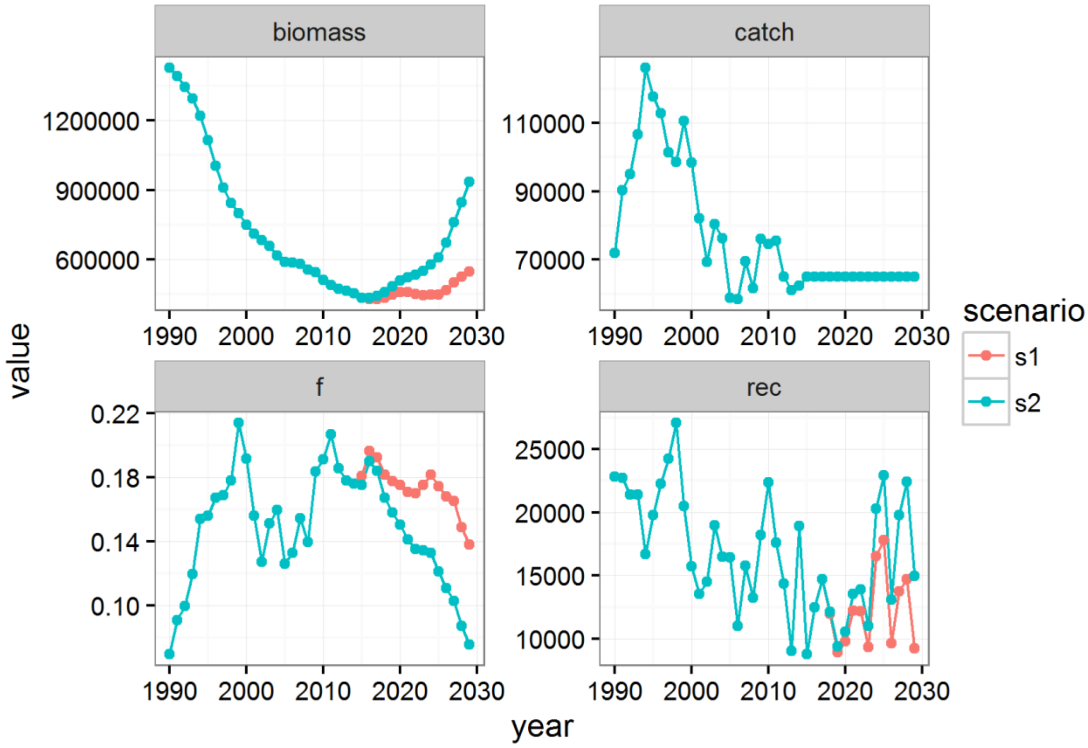


Figure 37. Summary of simulation results: biomass (tons), catch (tons), fishing mortality and recruits.

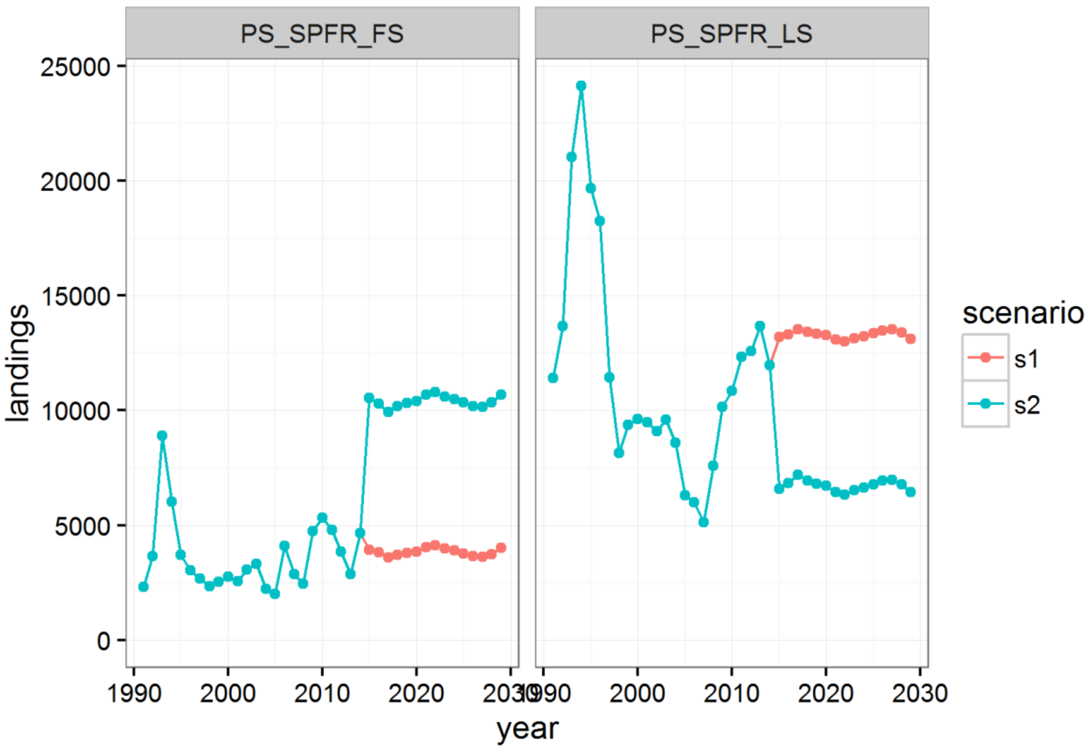


Figure 38. Estimated catch for European purse seines using FAD and Free Schools.

4.5 Further development of the Atlantic bigeye MSE using FLBEIA

The development of the MSE for the Atlantic bigeye tuna is at its very early stages. The shown trajectories are projections of the FLBEIA Operating Model conditioned with information from the 2015 SA. In the future, the full MSE of Atlantic bigeye will develop a separated OM-MP system, a simpler stock assessment model and an automatic decision making framework or HCR, whilst accepting observation (data), process (equations), implementation errors and biological and fisheries hypotheses. In addition, the bigeye MSE should eventually incorporate information of the other two tropical tuna species, in particular with regards to the impact of the activity of European purse seine fleets using FADs and redistributing their effort intro free schools. Tropical tunas (skipjack, yellowfin and bigeye) are often captured simultaneously, and therefore, any management measure to be implemented for the conservation of one stock will have implications for the other two, which needs to be assessed. Furthermore, purse seine fisheries introduce an important bycatch and collateral mortality issue, which should eventually also be evaluated in an MSE framework. The development of all these components will represent a major scientific challenge.

The simulations shown in this chapter allow introducing FLBEIA, an R library which provides a flexible and generic tool to conduct Bio-Economic Impact Assessment of fisheries management strategies. It has been built under a Management Strategy Evaluation framework which consists in simulating the fisheries system together with the management process. The fisheries system is simulated in the so called Operating Models which describe the true dynamics of the system and the management process is simulated in the Management Procedure which generates an observed system from the reality. The management advice is generated based on the observed system, instead of on the real one. The model is multistock, multifleet, seasonal and, uncertainty is introduced by means of montecarlo simulation. These features make this model appropriate for the level of detail required for this stock, as management action points mostly towards catch limits and the reduction of FADs impact, which requires a fleet level detail. In addition, it has a 'covariables' component that allows introducing variables of interest not present in biological and fleet components. For example, it could be used to introduce relevant ecosystem components in a simple way, such as discards, which are another salient aspect of the management of this fishery. FLBEIA represents a middle way between complicated whole ecosystem models and often simplistic bioeconomic fisheries models. The fishery system and management process are divided in low level interlinked processes, providing the library one or several models to describe each of the processes. The user chooses the models to be used in each specific model implementation and if the functions provided within FLBEIA do not fulfil the requirements for some of the components, the user can code the functions that adequately describe the dynamics of those processes and use the existing ones for the rest (Garcia et al., 2012).

Once the complete development of FLBEIA for bigeye tuna is achieved, this MSE framework can be used to contribute to answer the following questions:

- What are the consequences of the different harvest control rules on the sustainability of bigeye tuna in short term and long term? And in the sustainability of the other tropical tuna stocks? What are the consequences for the fleets? Do the trends in capture and profit of the fleets and *metiers* vary with time?

- What are the consequences of the reduction of FADs? Does the conclusion change depending on the harvest control rule used?
- How would the fleets behave if maximum profit is assumed?
- If the effort restriction depends only on bigeye tuna biomass, how does it affect the other two stocks? And what if the effort restriction depends on Yellowfin or skipjack tuna biomass?
- How does it affect the three stocks and fleets if the effort is assumed the minimum or maximum effort necessary to catch the quota of the three stocks?
- How does it affect the stocks if the effort is based on the maximum profit per fleet?

This chapter is a first step towards developing a powerful impact assessment tool, with which it is possible to provide robust scientific advice in relation to the incoming debate on the most appropriate actions to allow for a sustainable and efficient management of tropical tuna fisheries.

REFERENCE LIST

Babcock, E.A. Bayesian methods for accounting for data contradictions in stock assessment of Atlantic white marlin Col. Vol. Sci. Pap. ICCAT, 55(2): 541-558.; 2003

Cobb C.W.,Douglas P.H. A theory of production. American Economic Review. 18:139–165.; 1928

Cope, J.M.,Punt, E. Length based reference points for data-limited situations: Applications and restrictions. Marine and Coastal Fisheries Dynamics Management and Ecosystem Science. 1:169-186; 2009

De Bruyn, P.,Murua, H.,Aranda, M. The precautionary approach to fisheries management: How this is taken into account by tuna regional fisheries management organisations (RFMOs). Marine Policy. 38:397-406; 2013

FAO. Code of Conduct for Responsible Fisheries, Rome, FAO, 41 p.; 1995

Garcia, D.,Prellezo, R.,Sanchez, S.,Andres, M.,Santurtun, M. FLBEIA: A toolbox to conduct Bio-Economic Impact Assessment of fisheries management strategies. ICES CM 2012/ K: 01; 2012

Garcia, D.,Urtizberea, A.,Diez, G.,Gil, J.,Marchal, P. Bio-economic management strategy evaluation of deepwater stocks using the beia model. Aquatic Living Resources. 26:365-379.; 2013

Garcia, S. The precautionary approach to fisheries and its implications for fishery research, technology and management: an updated review. FAO Fisheries Technical Paper. 1996

Gedamke, T.,Hoenig, J.M. Estimating mortality from mean length data in nonequilibrium situations, with application to the assessment of goosefish. Transactions of the American Fisheries Society 135:476–487.; 2006

Harley, S.J.,Myers, R.A.,Dunn, A. Is catch-per-unit-effort proportional to abundance? . Canadian Journal of Fisheries and Aquatic Sciences. 58:1760–1772; 2001

Hvingel, C.,Kingsley, M.C.S. Limit reference Flim at Fmsy- a Flimsy point? On some possible revisions of the NAFO Precautionary Approach framework. Northwest Atlantic Fisheries Organization, NAFO SCR Doc 14/030, 5pp; 2014

ICCAT. International Commission for the Conservation of Atlantic Tunas. Basic Texts (5th revision). Madrid. 2007

ICCAT. Report of the 2010 ICCAT bigeye tuna stock assessment, Pasaia (Spain), 135pp.; 2010a

ICCAT. Report of the 2010 ICCAT Mediterranean albacore data preparatory meeting. SCRS/201016, Collect. Vol. Sci. Pap. ICCAT, 66(5): 1809-1856 (2011). 2010b

ICCAT. Report of the 2010 ICCAT Working Group on Stock Assessment Methods (Madrid, Spain - April 21 to 23, 2010). 2011a

ICCAT. Report of the 2011 ICCAT South Atlantic and Mediterranean albacore stock assessment sessions, Madrid (Spain), 70pp.; 2011b

ICCAT. Report of the 2011 ICCAT yellowfin tuna stock assessment session, San Sebastian (Spain), 113pp.; 2011c

ICCAT. Recommendation by ICCAT on the principles of decision making for ICCAT conservation and management measures. 2013a

ICCAT. Report of the 2013 Atlantic swordfish data preparatory meeting. SCRS/2013/15, Collect. Vol. Sci. Pap. ICCAT, 70(4): 1365-1483 (2014). 2013b

ICCAT. Report of the 2013 ICCAT North and South Atlantic albacore data preparatory meeting. SCRS/2013/13, Collect. Vol. Sci. Pap. ICCAT, 70(3): 717-829 (2014). 2013c

ICCAT. Report of the 2013 ICCAT North and South Atlantic albacore stock assessment meeting, Sukarrieta (Spain), 114pp.; 2013d

ICCAT. First meeting of the Standing Working Group to Enhance Dialogue Between Fisheries Scientists and Managers (SWGSM), Barcelona (Spain), 26-28 May.; 2014a

ICCAT. Report of the 1st meeting of the Core Modelling Group of BFT. 1-4 December 2014, Madrid (Spain). 2014b

ICCAT. Report of the 2014 Atlantic bluefin tuna stock assessment session, Madrid (Spain), 178pp.; 2014c

ICCAT. Report of the 2014 ICCAT East and West Atlantic skipjack stock assessment meeting, Dakar (Senegal), 97pp.; 2014d

ICCAT. Report of the 2014 ICCAT Mediterranean swordfish stock assessment meeting, Heraklion (Greece), 65pp.; 2014e

ICCAT. Recommendation by ICCAT on a multiannual conservation and management plan of tropical tunas. Rec 15-01; 2015a

ICCAT. Recommendation by ICCAT to establish Harvest Control Rules for the North Atlantic albacore stock. Rec 15-05; 2015b

ICCAT. Report of the 2015 ICCAT bigeye tuna stock assessment, Madrid (Spain), 60pp.; 2015c

ICES. General context of ICES advice. http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2013/2013/1.2_General_context_of_ICES_advice_2013_June.pdf. 2013

IOTC. Resolution 15/10 On target and limit reference points and a decision framework. Appendix XXV, Report of the 19th Session of the Indian Ocean Tuna Commission. 2015

ISSF. Report of the 2013 ISSF Stock Assessment Workshop: Harvest Control Rules and Reference Points for Tuna RFMOs. ISSF Technical Report 2013-03. International Seafood Sustainability Foundation, Washington, D.C., USA. 2013

Jardim E.,Urtizberea A.,Motova A.,Osio C.,Ulrich C.,Millar C.,Mosqueira I.,Poos J.J.,Virtanen J.,Hamon K.,Carvalho N.,Prellezo R.,S., H. Bioeconomic modelling applied to fisheries with R/FLR/FLBEIA. JRC Scientific and Policy Report EUR 25823 EN.; 2013

Kell, L.,Merino, G.,de Bruyn,Ortiz de Urbina, J.,Arrizabalaga, H.,Santiago, J.,Murua, H. An example of a Management Procedure based on a biomass dynamic stock assessment model. ICCAT, SCRS/2013/33 Technical Paper.; 2013a

Kell, L.,Merino, G.,de Bruyn,Ortiz de Urbina, J.,Arrizabalaga, H.,Santiago, J.,Murua, H. An example of a Management Strategy Evaluation of a Harvest Control Rule. ICCAT, SCRS/2013/35 Technical Paper.; 2013b

Kell, L.,Merino, G.,de Bruyn,Ortiz de Urbina, J.,Arrizabalaga, H.,Santiago, J.,Murua, H. An example of conditioning an Operating Model using Multifan-CL. ICCAT, SCRS/2013/34 Technical Paper.; 2013c

Kolody, D.,Herrera, M.,Million, J. Exploration of Indian Ocean bigeye tuna stock assessment sensitivities 1952-2008 using Stock Synthesis (updated to include 2009). 12th Session of the IOTC Working Party of Tropical Tuna. IOTC-2010-WPTT-04 (Rev1). 2010

Luehring, M.,Rose, J.D.,Hoening, J.M.,Treml, M.K. Visualizing trade-offs between yield and spawners per recruit as an aid to decision making. North American Journal of Fisheries Management. 36:1-10; 2016

Mace, P.M. A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. Fish and Fisheries. 2:2-32; 2001

Martell, S.,Froese, R. A simple method for estimating MSY from catch and resilience. Fish and Fisheries; 2012

Maury, O. PROCEAN: a production catch/effort analysis framework to estimate catchability trends and fishery dynamics in a Bayessian context. IOTC Proceedings, 4, 228-231; 2001

McCallister, M.K.,Babcock, E.A. Bayesian surplus production model with the Sampling Importance Resampling algorithm (BSP): a user's guide. Available from www.iccat.int. . 2003

Merino, G.,Barange, M.,Fernandes, J.A.,Mullon, C.,Cheung, W.,Trenkel, V.,Lam, V. Estimating the economic loss of recent North Atlantic fisheries management. Progress in Oceanography. 129:314-323; 2014

Merino, G.,De Bruyn, P.,Kell, L.,Arrizabalaga, H. A preliminary stock assessment for Northern albacore using the fully integrated stock assessment model, Multifan-CL. ICCAT, SCRS/2013/58 Technical Paper. 2013a

Merino, G.,De Bruyn, P.,Kell, L.,Scott, G. A preliminary stock assessment of the albacore tuna (Thunnus alalunga) stock in the Northern Atlantic Ocean using a non-equilibrium production model. ICCAT, SCRS/2013/56 Technical Paper. 2013b

Miyahara, M. Basic concept of Harvest Control Rules, Limit, Threshold and Target Reference Point. First meeting of the Standing Working Group to Enhance Dialogue Between Fisheries Scientists and Managers (SWGSM) of ICCAT, Barcelona (Spain), 26-28 May.; 2014. 2014

NAFO. NAFO Precautionary Approach Framework. NAFO/FC Doc. 04/18, Serial No. N5069. 5pp.; 2004

Pella, J.J.,Tomlinson, P.K. A generalized stock production model. Bulletin of the Inter-American Tropical Tuna Commission. 13:420-496; 1969

Prager, M.H. ASPIC: A Surplus-Production Model Incorporating Covariates. Coll. Vol. Sci. Pap., Int. Comm. Conserv. Atl. Tunas (ICCAT) 28: 218–229.; 1992

Prager, M.H. A suite of extensions to a nonequilibrium surplus-production model. U S Fishery Bulletin. 92:374-389; 1994

Preece, A.,Hillary, R.,Davies, C. Identification of candidate limit reference points for the key target species in the WCPFC. WCPFC-SC7-2011/MI-WP-03. 2011

Punt, A.,Butterworth, D.D.S.,de Moor, C.L.,De Olveira, A.A.,Haddon, M. Management strategy evaluation: best practices. Fish and Fisheries; 2014

Quinn, T.J.I.,Deriso, R.B. Quantitative fish dynamics. Oxford University Press, New York. 1999

Rademayer, R.A.,Plaganyi, E.E.,Butterworth, D.S. Tips and tricks in designing management procedures. ICES Journal of Marine Science. 64:618-625; 2007

Restrepo, V.R.,Powers, J.E. Precautionary control rules in US fisheries management: specification and performance. ICES Journal of Marine Science. 56:846-852; 1999

SAC-IATTC. Report of the fifth meeting of the Scientific Advisory Committee of the Inter-American Tropical Tuna Commission, La Jolla, California (USA), 12-16 May 2014.; 2014

Scott, G.,Merino, G.,Arrizabalaga, H.,Murua, H.,Santiago, J.,Restrepo, V.R. A framework for promoting dialogue on parameterizing a Harvest Control Rule with Limit and Target Reference Points for North Atlantic albacore. SCRS/2013/120.; 2013

Schaefer, M. Some aspects of the dynamics of populations important to the management of the commercial Marine fisheries. Bulletin of the Inter-American Tropical Tuna Commission. 1:27-56; 1954

UN. The United Nations Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. United Nations Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks, New York; 1995

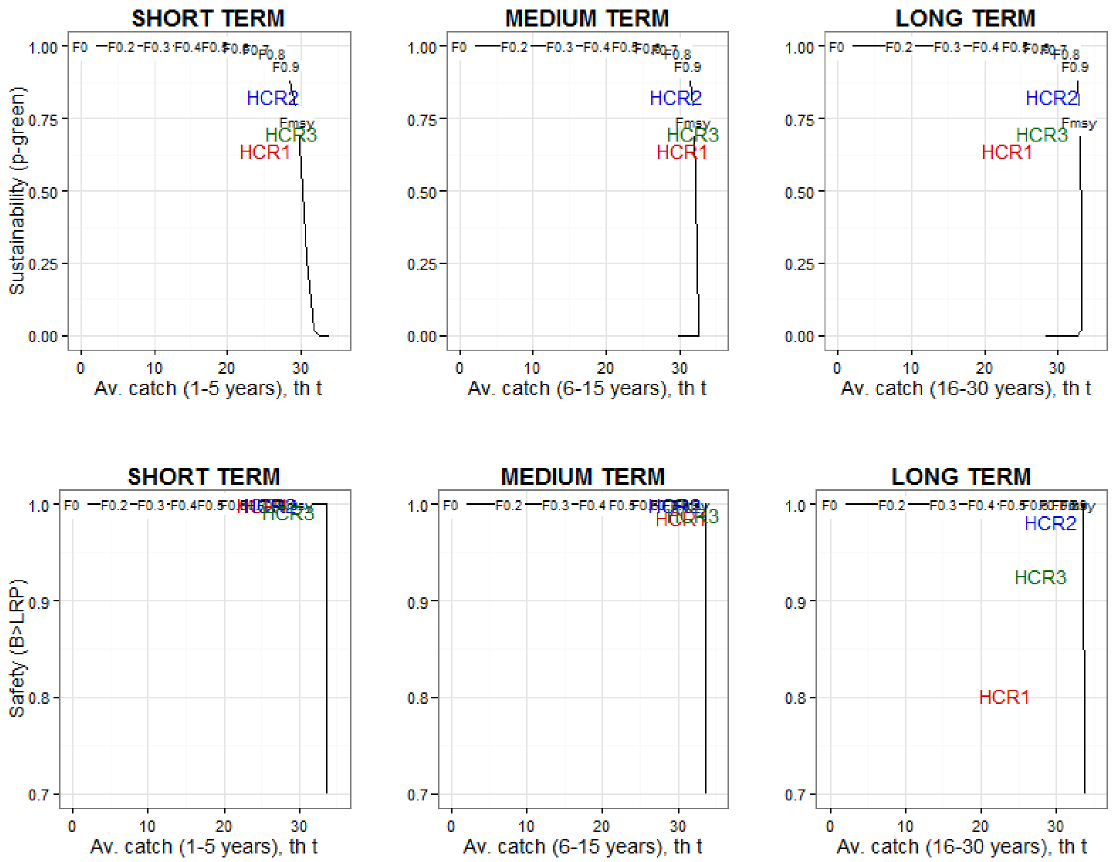
WCPFC. Conservation and Management Measure for bigeye, yellowfin and skipjack tuna in the western and central Pacific Ocean (2014-01). 2014a

WCPFC. Conservation and Management Measure for bigeye, yellowfin and skipjack tuna in the western and central Pacific Ocean (2014-04). 2014b

WCPFC. Conservation and Management Measure for bigeye, yellowfin and skipjack tuna in the western and central Pacific Ocean (2014-06). 2014c

ANNEX I. EXTENDED RESULTS FOR NORTH ATLANTIC ALBACORE HCR EVALUATION

1) Trade-off plots for short (1-5 years), medium (5-15 years) and long (16-30 years) term between catch, Sustainability (p-green) and Safety (p (B>LRP)).



2) Summary table of the results produced in this work: These include references to the Operating Model (OM), the scenario (Base, Hyperstability, Low Recruitment and High Recruitment), target fishing mortality (Ftar) relative to FMSY, threshold biomass (Bthresh) relative to BMSY, probability of being in the green zone (pGreen), probability of being at safe levels (Safety = 1-p(B<Blim)), long, medium and short term catch (CatchL, CatchS, CatchM) and variability of fishing effort (varF) and catch (varC).

OM	scen	Ftar	Bthresh	pGreen	Safety	CatchL	CatchS	CatchM	varF	varC
Alt1	Base	0.75	0.6	0.75	1	30.73	15.03	25.72	0.11	0.06
Alt1	Base	0.8	0.6	0.69	0.98	30.78	15.64	26.41	0.11	0.06
Alt1	Base	0.85	0.6	0.62	0.97	30.18	17.38	26.6	0.11	0.06
Alt1	Base	0.9	0.6	0.6	0.97	30.49	17.78	27.8	0.11	0.07
Alt1	Base	0.75	0.8	0.75	1	30.96	12.85	26.12	0.11	0.06
Alt1	Base	0.8	0.8	0.71	0.99	31.02	12.96	26.99	0.12	0.07
Alt1	Base	0.85	0.8	0.62	0.95	28.17	14.3	27.18	0.13	0.08
Alt1	Base	0.9	0.8	0.63	0.95	28.86	14.09	28.39	0.13	0.08
Alt1	Base	0.75	1	0.78	1	31.22	10.84	26.51	0.12	0.06

Alt1	Base	0.8	1	0.74	0.99	30.82	10.92	28.35	0.13	0.07
Alt1	Base	0.85	1	0.66	0.97	29.72	11.19	28.01	0.14	0.08
Alt1	Base	0.9	1	0.62	0.95	28.08	11.88	28.89	0.14	0.09
Alt1	Base	0.95	1	0.6	0.95	28.42	12.62	29.64	0.14	0.09
Alt1	Base	0.45	0.6	0.85	1	24.72	10.18	18.71	0	0.06
Alt1	Base	0.55	0.6	0.83	1	27.46	12.23	21.28	0.13	0.05
Alt1	Base	0.65	0.6	0.81	1	29.73	14.45	23.58	0.11	0.05
Alt1	Base	0.45	0.8	0.86	1	24.82	8.7	19.42	0.17	0.06
Alt1	Base	0.55	0.8	0.85	1	27.74	10.62	22.13	0.14	0.06
Alt1	Base	0.65	0.8	0.82	1	29.4	11.35	23.42	0.12	0.06
Alt1	Base	0.45	1	0.86	1	24.67	7.29	18.97	0.18	0.06
Alt1	Base	0.55	1	0.86	1	27.93	8.38	22.22	0.15	0.06
Alt1	Base	0.65	1	0.83	1	29.54	9.26	24.4	0.13	0.07
Alt2	Base	0.75	0.6	0.68	1	31.44	21.89	26.41	0.08	0.04
Alt2	Base	0.8	0.6	0.62	0.98	30.96	22.92	26.93	0.08	0.04
Alt2	Base	0.75	0.8	0.69	0.99	30.84	20.63	26.38	0.09	0.05
Alt2	Base	0.8	0.8	0.61	0.97	29.86	21.5	27.75	0.09	0.05
Alt2	Base	0.75	1	0.71	0.99	30.45	17.24	26.88	0.09	0.05
Alt2	Base	0.8	1	0.65	0.97	29.46	18.09	27.69	0.1	0.06
Alt2	Base	0.85	1	0.61	0.96	28.78	18.97	27.89	0.1	0.07
Alt2	Base	0.45	0.6	0.84	1	24.63	14.07	19.65	0	0.05
Alt2	Base	0.55	0.6	0.82	1	27.75	17.29	22.75	0.1	0.04
Alt2	Base	0.65	0.6	0.78	1	29.74	19.76	24.34	0.08	0.04
Alt2	Base	0.45	0.8	0.85	1	25.05	13.6	20.17	0.13	0.05
Alt2	Base	0.55	0.8	0.84	1	27.72	16.2	22.87	0.1	0.04
Alt2	Base	0.65	0.8	0.78	1	29.83	18.17	24.72	0.09	0.04
Alt2	Base	0.45	1	0.86	1	25.05	12.22	20.14	0.13	0.05
Alt2	Base	0.55	1	0.84	1	28.04	13.81	23.37	0.11	0.05
Alt2	Base	0.65	1	0.77	1	29.57	16.1	25.21	0.09	0.05
Alt3	Base	0.75	0.6	0.63	0.94	26.9	21.42	26.42	0.16	0.14
Alt3	Base	0.75	0.8	0.62	0.91	26.19	20.65	26.24	0.16	0.16
Alt3	Base	0.45	0.6	0.91	1	24.36	14.18	20.81	0	0.05
Alt3	Base	0.55	0.6	0.88	1	26.53	16.78	23.22	0.11	0.05
Alt3	Base	0.65	0.6	0.79	0.99	27.38	18.81	25.05	0.11	0.05
Alt3	Base	0.45	0.8	0.91	1	24.22	13.56	20.76	0.12	0.05
Alt3	Base	0.55	0.8	0.88	1	26.65	15.88	23.4	0.11	0.05
Alt3	Base	0.65	0.8	0.78	0.99	27.61	18.54	25.88	0.12	0.06
Alt3	Base	0.45	1	0.91	1	24.29	12.88	21.09	0.12	0.05
Alt3	Base	0.55	1	0.87	0.99	26.36	14.79	23.9	0.12	0.06
Alt3	Base	0.65	1	0.76	0.99	26.97	16.16	25.91	0.12	0.06
Alt5	Base	0.75	0.6	0.75	1	29.03	23.64	26.21	0.07	0.03
Alt5	Base	0.8	0.6	0.7	0.98	28.61	24.68	26.72	0.08	0.04
Alt5	Base	0.85	0.6	0.69	0.98	28.61	26.4	27.52	0.08	0.04
Alt5	Base	0.9	0.6	0.63	0.96	27.33	27.02	28.37	0.09	0.05
Alt5	Base	0.75	0.8	0.77	1	28.58	23.5	25.93	0.07	0.04
Alt5	Base	0.8	0.8	0.7	0.97	27.61	24.61	27.08	0.08	0.05
Alt5	Base	0.85	0.8	0.64	0.96	27.3	25.4	26.88	0.09	0.05
Alt5	Base	0.9	0.8	0.6	0.95	26.38	26.06	27.08	0.1	0.06
Alt5	Base	0.75	1	0.76	0.99	27.83	21.51	26.09	0.08	0.04
Alt5	Base	0.8	1	0.68	0.97	26.8	22.62	26.6	0.09	0.05
Alt5	Base	0.85	1	0.64	0.96	25.96	23.58	26.69	0.1	0.06
Alt5	Base	0.9	1	0.63	0.96	26.19	24.63	27.92	0.11	0.07
Alt5	Base	0.45	0.6	0.91	1	23.09	15.58	19.79	0	0.04
Alt5	Base	0.55	0.6	0.89	1	25.79	18.31	22.05	0.08	0.04
Alt5	Base	0.65	0.6	0.85	1	27.82	20.66	24.4	0.07	0.03
Alt5	Base	0.45	0.8	0.91	1	23	15.4	19.7	0.1	0.04
Alt5	Base	0.55	0.8	0.89	1	25.85	18.46	22.41	0.08	0.03

Alt5	Base	0.65	0.8	0.84	1	27.7	20.98	24.63	0.07	0.03
Alt5	Base	0.45	1	0.91	1	23.2	14.57	19.86	0.1	0.04
Alt5	Base	0.55	1	0.9	1	25.91	17.32	22.3	0.08	0.04
Alt5	Base	0.65	1	0.86	1	27.96	19.41	24.7	0.07	0.04
Alt7	Base	0.75	0.6	0.73	0.99	30.71	16.53	27.12	0.1	0.05
Alt7	Base	0.8	0.6	0.69	0.97	30.22	18.19	27.8	0.1	0.06
Alt7	Base	0.85	0.6	0.65	0.96	29.21	18.58	28.19	0.11	0.06
Alt7	Base	0.9	0.6	0.62	0.96	30.19	19.34	29.25	0.11	0.06
Alt7	Base	0.75	0.8	0.75	0.99	30.37	14.79	27.21	0.11	0.06
Alt7	Base	0.8	0.8	0.69	0.95	28.09	15.21	28.66	0.13	0.07
Alt7	Base	0.85	0.8	0.66	0.96	28.91	15.86	29.54	0.12	0.07
Alt7	Base	0.9	0.8	0.61	0.93	26.18	16.12	29.7	0.13	0.08
Alt7	Base	0.75	1	0.77	0.99	30.55	11.82	28.2	0.13	0.07
Alt7	Base	0.8	1	0.71	0.98	30.37	12.85	29.79	0.12	0.07
Alt7	Base	0.85	1	0.66	0.95	27.58	13.9	29.43	0.14	0.09
Alt7	Base	0.9	1	0.63	0.92	25.53	14.21	30.54	0.15	0.09
Alt7	Base	0.45	0.6	0.87	1	25	11.03	19.51	0	0.05
Alt7	Base	0.55	0.6	0.86	1	27.83	12.77	22.72	0.12	0.05
Alt7	Base	0.65	0.6	0.83	1	30.11	15.12	24.9	0.1	0.05
Alt7	Base	0.45	0.8	0.88	1	25.41	9.6	20.48	0.15	0.06
Alt7	Base	0.55	0.8	0.88	1	28.28	12.25	24	0.12	0.05
Alt7	Base	0.65	0.8	0.83	1	30.33	12.78	25.48	0.11	0.06
Alt7	Base	0.45	1	0.89	1	25.24	8	20.52	0.16	0.06
Alt7	Base	0.55	1	0.87	1	28.1	9.31	23.19	0.13	0.06
Alt7	Base	0.65	1	0.84	1	30.17	10.86	26.1	0.12	0.06
Base	Base	0.75	0.6	0.7	0.99	23.53	13.83	18.89	0.1	0.05
Base	Base	0.8	0.6	0.66	0.98	23.26	14.64	19.33	0.1	0.05
Base	Base	0.85	0.6	0.65	0.98	23.49	15.75	19.97	0.1	0.06
Base	Base	0.9	0.6	0.62	0.96	22.52	15.93	20.86	0.1	0.06
Base	Base	0.75	0.8	0.74	0.99	23.24	12.13	19.11	0.11	0.06
Base	Base	0.8	0.8	0.68	0.97	22.74	12.67	20.32	0.12	0.07
Base	Base	0.85	0.8	0.64	0.97	22.69	12.79	20.28	0.12	0.07
Base	Base	0.9	0.8	0.6	0.94	21.55	13.06	20.51	0.12	0.08
Base	Base	0.75	1	0.76	1	23.54	9.52	19.62	0.12	0.06
Base	Base	0.8	1	0.71	0.98	22.67	10.05	20.33	0.12	0.07
Base	Base	0.85	1	0.67	0.97	22.37	10.7	20.55	0.12	0.08
Base	Base	0.9	1	0.66	0.97	22.64	11.09	21.82	0.13	0.08
Base	Base	0.45	0.6	0.86	1	18.71	8.68	14.07	0	0.05
Base	Base	0.55	0.6	0.85	1	20.92	10.2	16.08	0.12	0.05
Base	Base	0.65	0.6	0.79	1	22.48	12.36	17.78	0.11	0.05
Base	Base	0.45	0.8	0.86	1	18.69	7.66	14.14	0.16	0.06
Base	Base	0.55	0.8	0.85	1	20.78	9.73	16.21	0.13	0.05
Base	Base	0.65	0.8	0.8	1	22.3	10.68	17.91	0.11	0.06
Base	Base	0.45	1	0.86	1	18.72	6.33	13.94	0.16	0.06
Base	Base	0.55	1	0.86	1	21.27	7.76	16.58	0.14	0.06
Base	Base	0.65	1	0.85	1	23.03	8.4	18.22	0.12	0.06
Alt8	Base	0.75	0.6	0.69	0.98	28.41	22.48	25.78	0.08	0.04
Alt8	Base	0.8	0.6	0.69	0.97	28.25	23.68	26.71	0.08	0.04
Alt8	Base	0.85	0.6	0.66	0.98	29.78	24.66	27.83	0.08	0.04
Alt8	Base	0.75	0.8	0.73	0.99	29.48	22.12	26.06	0.07	0.04
Alt8	Base	0.8	0.8	0.67	0.98	28.16	23.25	26.69	0.09	0.05
Alt8	Base	0.85	0.8	0.62	0.95	26.26	24.24	26.47	0.1	0.06
Alt8	Base	0.75	1	0.71	0.96	27.27	19.8	26.95	0.1	0.06
Alt8	Base	0.8	1	0.67	0.98	28.34	20.86	27.02	0.1	0.05
Alt8	Base	0.9	1	0.61	0.94	25.7	21.39	27.64	0.12	0.07
Alt8	Base	0.45	0.6	0.89	1	24.08	14.98	19.82	0	0.04
Alt8	Base	0.55	0.6	0.86	1	26.58	17.66	22.28	0.08	0.04

Alt8	Base	0.65	0.6	0.83	1	28.62	20.66	24.53	0.07	0.04
Alt8	Base	0.45	0.8	0.89	1	24.12	14.67	20.2	0.11	0.04
Alt8	Base	0.55	0.8	0.87	1	26.79	17.66	22.72	0.09	0.04
Alt8	Base	0.65	0.8	0.82	1	27.98	19.68	23.8	0.08	0.04
Alt8	Base	0.45	1	0.89	1	23.92	13.27	19.96	0.11	0.04
Alt8	Base	0.55	1	0.88	1	26.86	15.44	22.93	0.09	0.04
Alt8	Base	0.65	1	0.83	0.99	27.91	17.44	24.63	0.09	0.05
Tag	Base	0.75	0.6	0.78	0.99	30.14	23.37	26.66	0.07	0.03
Tag	Base	0.8	0.6	0.69	0.98	29.65	25.05	27.54	0.08	0.04
Tag	Base	0.85	0.6	0.63	0.96	28.35	26.15	27.41	0.08	0.05
Tag	Base	0.75	0.8	0.75	0.99	30.02	23.73	26.51	0.07	0.04
Tag	Base	0.8	0.8	0.64	0.98	28.41	24.27	26.52	0.09	0.05
Tag	Base	0.85	0.8	0.62	0.98	28.81	24.86	27.02	0.09	0.05
Tag	Base	0.75	1	0.72	1	29.15	21.07	25.95	0.08	0.05
Tag	Base	0.8	1	0.63	0.97	27.02	21.88	26.85	0.1	0.06
Tag	Base	0.85	1	0.63	0.97	27.92	23.14	28.03	0.1	0.06
Tag	Base	0.9	1	0.63	0.96	28.3	23.98	28.53	0.1	0.06
Tag	Base	0.45	0.6	0.89	1	24.14	15.3	19.92	0	0.04
Tag	Base	0.55	0.6	0.87	1	26.79	18.14	22.44	0.08	0.04
Tag	Base	0.65	0.6	0.83	1	28.87	21.26	24.66	0.07	0.03
Tag	Base	0.45	0.8	0.89	1	24.41	15.49	20.46	0.1	0.04
Tag	Base	0.55	0.8	0.87	1	26.8	18.05	22.59	0.08	0.04
Tag	Base	0.65	0.8	0.82	1	28.79	20.32	24.82	0.07	0.04
Tag	Base	0.45	1	0.9	1	24.44	14.38	20.54	0.1	0.04
Tag	Base	0.55	1	0.88	1	27.05	16.91	23.04	0.08	0.04
Tag	Base	0.65	1	0.8	1	28.42	18.48	24.85	0.08	0.04
Base	Hypers	0.75	1	0.61	0.95	22.29	7.71	25.73	0.16	0.11
Base	Hypers	0.55	0.6	0.8	1	24.26	9.11	21.39	0.12	0.07
Base	Hypers	0.65	0.6	0.66	0.97	23.17	9.84	22.48	0.14	0.09
Base	Hypers	0.55	0.8	0.77	1	24.13	7.38	21.26	0.13	0.07
Base	Hypers	0.65	0.8	0.69	0.98	23.6	8.25	23.35	0.14	0.09
Base	Hypers	0.55	1	0.77	1	23.86	6.48	21.64	0.13	0.08
Base	Hypers	0.65	1	0.7	0.98	23.74	7.33	23.5	0.14	0.09
Base	High Rec	0.45	0.6	0.88	1	20.86	9.17	15.86	0.17	0.05
Base	High Rec	0.55	0.6	0.88	1	23.44	10.98	18.54	0.14	0.05
Base	High Rec	0.65	0.6	0.87	1	25.53	12.83	20.29	0.12	0.05
Base	High Rec	0.45	0.8	0.89	1	21.01	8.02	16.14	0.18	0.06
Base	High Rec	0.55	0.8	0.88	1	23.44	9.6	18.4	0.15	0.06
Base	High Rec	0.65	0.8	0.87	1	25.38	10.95	20.26	0.13	0.05
Base	High Rec	0.45	1	0.89	1	20.9	7.25	16.25	0.18	0.06
Base	High Rec	0.55	1	0.88	1	23.61	8.27	18.88	0.15	0.06
Base	High Rec	0.65	1	0.88	1	25.51	9.14	20.76	0.13	0.06
Base	High Rec	0.75	0.6	0.85	1	26.86	14.03	21.74	0.1	0.05
Base	High Rec	0.8	0.6	0.84	1	27.71	14.78	22.28	0.1	0.05
Base	High Rec	0.85	0.6	0.82	1	28.27	15.7	23.32	0.09	0.05
Base	High Rec	0.9	0.6	0.78	1	28.53	16.35	23.75	0.09	0.05
Base	High Rec	0.95	0.6	0.77	0.99	28.38	16.66	24.07	0.1	0.06
Base	High Rec	1	0.6	0.71	1	28.6	17.4	24.84	0.09	0.06
Base	High Rec	1.05	0.6	0.67	0.98	27.62	18.47	25	0.1	0.07
Base	High Rec	1.1	0.6	0.67	0.97	27.3	18.27	25.51	0.11	0.07
Base	High Rec	1.2	0.6	0.61	0.97	28.44	19.78	26.09	0.11	0.08
Base	High Rec	0.75	0.8	0.86	1	26.92	12.37	22.2	0.11	0.05
Base	High Rec	0.8	0.8	0.84	1	27.43	13.67	23.13	0.1	0.05
Base	High Rec	0.85	0.8	0.82	1	27.8	13.63	24.17	0.1	0.06
Base	High Rec	0.9	0.8	0.78	0.99	27.54	14.23	24.06	0.11	0.06
Base	High Rec	0.95	0.8	0.72	0.99	27.49	14.43	24.82	0.11	0.07
Base	High Rec	1	0.8	0.75	1	28.89	14.91	25.26	0.1	0.07

Base	High Rec	1.05	0.8	0.63	0.96	25.12	15.62	25.01	0.13	0.09
Base	High Rec	1.1	0.8	0.68	0.98	27.74	16.17	25.92	0.11	0.07
Base	High Rec	0.75	1	0.87	1	27.01	10.31	22.57	0.12	0.06
Base	High Rec	0.8	1	0.83	1	27.4	11.04	23.43	0.12	0.06
Base	High Rec	0.85	1	0.8	1	27.05	11.18	23.61	0.12	0.07
Base	High Rec	0.9	1	0.8	1	27.73	11.89	24.82	0.12	0.07
Base	High Rec	0.95	1	0.74	0.99	26.87	12.17	25.17	0.12	0.08
Base	High Rec	1	1	0.71	0.98	26.58	12.2	25.73	0.13	0.08
Base	High Rec	1.05	1	0.71	0.98	26.93	13.3	26.52	0.13	0.08
Base	High Rec	1.1	1	0.66	0.97	26.52	13.55	26.03	0.13	0.09
Base	High Rec	1.2	1	0.63	0.97	25.94	13.71	26.81	0.15	0.11
Base	High Rec	1.25	1	0.62	0.95	25	14.46	27.19	0.15	0.11
Base	Low Rec	0.45	0.6	0.77	1	15.32	8.69	11.49	0.14	0.06
Base	Low Rec	0.55	0.6	0.68	1	16.66	10.4	12.93	0.12	0.06
Base	Low Rec	0.45	0.8	0.78	1	15.4	7.55	12.04	0.14	0.06
Base	Low Rec	0.55	0.8	0.71	1	17.02	9.21	13.58	0.12	0.06
Base	Low Rec	0.65	0.8	0.62	0.98	17.27	10.04	13.85	0.11	0.06
Base	Low Rec	0.45	1	0.79	1	15.41	6.24	11.54	0.15	0.06
Base	Low Rec	0.55	1	0.74	1	17.3	7.17	13.49	0.13	0.07
Base	Low Rec	0.65	1	0.64	0.99	17.51	8.08	14.49	0.13	0.07

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