UPDATED CONSOLIDATED REPORT FOR NORTH ATLANTIC ALBACORE MANAGEMENT STRATEGY EVALUATION

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SUMMARY

The North Atlantic albacore Management Strategy Evaluation (MSE) provided the scientific support for the adoption of an interim harvest control rule by ICCAT in 2017. The process included the technical development of simulation models and an iterative consultation. The first has been carried out by experts from ICCAT Secretariat and by scientists of its Contracting Parties and the second has been the result of the dialogue between scientists and managers under ICCAT's Panel 2 and the Standing Working Group on Dialogue Between Fisheries Scientists and Managers (SWGDSM). In this document we compile the most important information of the working documents that describe the North Atlantic albacore MSE in a consolidated report in a way that contains all the information needed to: understand how the MSE framework was built; how it has been peer-reviewed and updated and; what are the 2020 updates. This document is intended to be a reference document that can be updated in the future, if necessary, as the north Atlantic albacore MSE evolves. The "living" document will be stored in the ICCAT website for consultation.

RÉSUMÉ

L'évaluation de la stratégie de gestion (MSE) du germon de l'Atlantique Nord a fourni le soutien scientifique à l'adoption d'une règle de contrôle des captures en 2017. Le processus comprenait le développement de modèles de simulation et une consultation. La première a été réalisée par des experts du secrétariat de la CICTA et par des scientifiques de ses parties contractantes, et la seconde est le résultat du dialogue entre les scientifiques et les gestionnaires dans Panel 2 de la CICTA et SWGDSM. Dans ce document, nous rassemblons les informations plus importantes des documents qui décrivent l'ESM du germon dans un rapport consolidé de manière à contenir toutes les informations nécessaires pour: comprendre comment l'ESM a été construit; comment il a été examiné et mis à jour et; quelles sont les mises à jour de 2020. Ce document est conçu comme un document de référence qui pourra être mis à jour à l'avenir, au fur et à mesure de l'évolution de l'ESM du germon de l'Atlantique Nord. Le document "vivant" sera stocké sur le site web de la CICTA pour consultation.

RESUMEN

La Evaluación de Estrategias de Ordenación (MSE) del bonito del Atlántico Norte ofreció apoyo científico para la adopción de una regla de control de captura en 2017. El proceso incluyó el desarrollo técnico de modelos de simulación y un proceso consultivo. El primero fue llevado a cabo por expertos de la Secretaría de ICCAT y científicos de las Partes Contratantes y el segundo ha resultado del dialogo entre científicos y gestores bajo el Panel 2 de ICCAT y el SWGDSM. En este documento compilamos la información más relevante de los documentos de trabajo que describen el MSE del bonito del Atlántico norte en un informe consolidado de manera que contenga toda la información necesaria para: comprender como se construyó el marco MSE; cómo ha sido revisado y actualizado; cuales son las novedades de 2020. Este documento intenta ser una referencia que pueda ser actualizada en el futuro y, de ser necesario, a medida que el MSE evoluciona. El documento "vivo" será almacenado en la web de ICCAT para poder ser consultado.

KEYWORDS

North Atlantic albacore, Management Strategy Evaluation, Harvest Control Rules, Operating Models, Management Procedures

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1. Introduction

In 2017, ICCAT adopted the "*Recommendation by ICCAT on a Harvest Control Rule for North Atlantic albacore (…)*". This recommendation follows one of the main goals of SCRS Science Strategic Plan (2015-2020) and represents the first step of a change in ICCAT's management paradigm from the decision framework established in Rec 11-13 towards the adoption of operational management objectives (including specific probabilities and timeframes), reference points, harvest control rules (HCR) and ultimately Management Procedures (MP) for Atlantic tuna stocks.

The North Atlantic albacore MSE provided the scientific support for the adoption of Rec 17-04. This was done by developing a numerical framework specifically tailored for North Atlantic albacore and by evaluating a range of model-based HCRs. The main features of the North Atlantic albacore MSE that are compiled here were previously described in three SCRS documents (Merino et al., 2017b; Merino et al., 2017a; Merino et al., 2017c). However, the initial developments of the MSE can be traced back in earlier documents too (Kell et al., 2013c; Kell et al., 2013a; Kell et al., 2013b; Kell et al., 2013d; Kell et al., 2016a; Kell et al., 2016b; Kell et al., 2016c; Kell et al., 2016d; Merino et al., 2016). This consolidated report also contains references to the independent review to this MSE (Scully, 2018) and two updates made in 2018 and 2019 (Merino et al., 2018).

Likewise other similar frameworks, the North Atlantic albacore MSE contains two main components: (i) the Operating Model (OM), which represents a number of potential "true dynamics" of the fishery and, (ii) the Management Procedure (MP), composed by data generated in the OM, a stock status estimator and a decision framework or HCR. OM and MP are linked through an Observation Error Model (OEM) that generates data with error from the OM and, by the catch limits that are set in the MP and that are directly used in the OM for forward simulation. The components of the MSE are described in detail in this document.

The North Atlantic albacore MSE has adapted to the specific requests of ICCAT's Panel 2 and the SWGSM in producing outputs and constraining the number of candidate HCRs. The MSE has also been adapted to the independent review carried out in 2018 (Scully, 2018; Merino et al., 2019b). In this document we describe the current state of the numerical framework and do not review all the results that have been produced throughout the iterative process of technical development and stakeholder consultation. Throughout the document we do show the updated results of the evaluation of the HCR adopted and the alternatives requested by the Commission through Recommendation 17-04.

This document is one the agreed deliverables of the "short-term contract for improvement of the North Atlantic albacore Management Strategy Evaluation (MSE) framework" between ICCAT and AZTI.

2. The MSE framework

2.1 General strategy of North Atlantic albacore MSE

MSE is used to evaluate the impacts of uncertainties inherent to fisheries (Punt et al., 2014). Conducting an MSE requires following a series of basic steps that were followed for albacore. Here we advance the general steps followed in the MSE.

Step 1. Identification of management objectives and performance statistics

The conceptual objective of ICCAT is to maintain populations at levels that can permit the maximum sustainable yield (or above). For north Atlantic albacore this is converted into operational objectives relative to stock status, safety, catch and stability through ICCAT's recommendation 16-06: "*The management objective is to maintain the stock in the green quadrant of the Kobe plot with at least 60% of probability and a low probability of being outside biological limits, while maximizing long-term yield and average catch, and minimizing the inter-annual fluctuations in TAC levels*". Therefore, there is only one management objective that contains a minimum standard (60% probability of being in the green quadrant).

The performance statistics used to evaluate MPs are directly taken from Recommendation 16-06 (Annex 2). In particular, in the North Atlantic MSE we evaluated HCRs using the following 15 performance indicators (ICCAT, 2016a; ICCAT, 2016b):

Stock Status

- Minimum spawner biomass relative to $B_{MSY.}$
- Mean spawner biomass relative to B_{MSY}.
- Mean fishing mortality relative to F_{MSY}.
- Probability of being in the Kobe green quadrant (threshold 60%).
- Probability of being in the Kobe red quadrant.

Safety

- Probability that spawner biomass is above B_{LIM} (0.4xB_{MSY}).
- Probability of B_{LIM}<B<B_{THRESH}.

Yield

- Mean catch – short term (Mean over 1-3 years)
- Mean catch – medium term (Mean over 5-10 ye
- Mean catch – long term (Mean over 15-30 years)

Stability

- Mean absolute proportional change in catch
- Variance in catch
- Probability of shutdown
- Probability of TAC change over a certain level (10%)
- Maximum amount of TAC change between management periods

Before the 2017 SCRS meeting, the SWGSM requested summary tables of results for each HCR for one indicator of each group of metrics (underlined above): Probability of being in the green quadrant, probability of being between the B_{LIM} and B_{THRESH}, long term catch and mean proportional change in catch. These are shown in the albacore section of the SCRS reports of 2017 and 2018 in tables (ALB-Table 2) and spider plots (SCRS 2017 Figure ALB-12 and SCRS 2018 Figure 11 and Figure 13).

Step 2. Selection of hypotheses of system dynamics

Management Strategy Evaluation (MSE) requires characterizing the main sources of uncertainty inherent to fisheries. The unknowns that challenge the interpretation of fish stock assessments include gaps on biological processes and fishery dynamics. The first are often dealt with hypotheses on input biological parameters to stock assessment models; and the second with hypotheses over the available datasets. In this MSE we characterize uncertainty using alternative model runs of the stock assessment model used in the 2013 assessment of the stock (Multifan-CL). In 2013, the uncertainties explored included 10 scenarios with options for the available data series and a natural mortality scenario. For the MSE we expanded this initial set of scenarios with hypotheses on biological parameters (natural mortality and steepness) and fishery dynamics.

Step 3. Constructing OMs

Operating Models are representations of the “true” dynamics of the system and may include a set of the most plausible hypotheses or unlikely but not impossible situations (ISSF, 2013). In MSE frameworks the OMs represent the system that has to be managed through MPs, i.e. the “true” system that is observed, analyzed and managed through data collection systems, stock assessment and harvest control rules.

The outputs of the Multifan-CL scenarios were used to condition 132 OMs. The OMs were conditioned using libraries from the FLR-project (www.flr-project.org). The conditioned OMs are FLR objects composed by a single fishery and include parameters (selectivity, growth, natural mortality, stock-recruitment and maturity), time series of catch and biomass (in total and by age) and harvest time series, among other information. The technical details of how OMs have been conditioned is described in the appropriate sections of this document.

Step 4. Defining MPs

Management Procedures represent how the true dynamics underlying fisheries exploitation are represented through stock assessment and driven by fisheries management. A population-model-based framework within which the data obtained from the fishery are analyzed 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 plugged into a decision framework or HCR that, in combination with RPs, provides recommendation for a management action. In this study, the observation error model (OEM) generates simulated abundance indices for fitting a biomass dynamic model, to estimate stock status and MSY-based RPs. These are used in combination with HCRs to determine TAC every three years. The MP proposed here aims at simulating the current processes of data collection and stock assessment of North Atlantic albacore, plus a range of alternatives for Harvest Control Rules. The three components of the MP are described in detail in the following sections of this document.

Step 5. Simulation with feedback

The Operating Models and the Management Procedures have been linked through specifically tailored R functions and libraries from the FLR project (www.flr-project.org). The OMs produce series of biomass, catch, fishing mortality, recruitment and other fishery trends, which are measured every three years to generate series of catch and abundance indices through an Observation Error Model. These are then used to fit the surplus production stock assessment model. The outputs of this model include estimates of relative biomass and fishing mortality, of RPs (B_{MSY}, F_{MSY}, MSY) and model parameters. These are used in combination with HCRs to set catch limits, which are then used to project forward the OMs for another three years. This process is simulated every three years for the duration of simulation, 30 years in the current version, which corresponds to two generations of North Atlantic albacore. The interest is on the outcome of the OMs and therefore, biomass, catch and harvest series of the OMs are used to produce performance statistics for interpretation by managers and scientists.

Step 6. Summary and interpretation of performance statistics

The evaluation of HCRs is completed with the summary and interpretation of the performance of the OMs. Four group of indicators relative to stock status, safety, yield and stability are used (see *Step 1*). A summary of the performance of HCRs is also provided. In general, HCRs performance is summarized using median values across OMs but we other figures that illustrate the variability of performance across OMs are also included (Scully, 2018; Merino et al., 2019a).

2.2 North Atlantic albacore MSE

The MSE developed for North Atlantic albacore is composed by a grid of OMs and an MP which contains an Observation Error Model, a biomass dynamic model for simulating the stock assessment process and a decision framework (Figure 1). The OMs produce data series of biomass, catch and fishing mortality, which are measured every three years to generate series of catch and abundance indices through an Observation Error Model. These are then used to fit a surplus production stock assessment model. The outputs of this model include trends of relative biomass and fishing mortality, of RPs (B_{MSY}, F_{MSY}, MSY) and model parameters. These are used in combination with HCRs to set catch limits (TAC), which are then used to project forward the OMs for another three years. The performance statistics are measured from the OMs after the projection.

2.2.1 Operating Models

MSE is used to evaluate the impacts of the uncertainties to fisheries performance (Punt et al., 2014). For this, MSE requires characterizing the main sources of uncertainty inherent to fisheries. Therefore, it is necessary to (a) identify a range of uncertainties related to biology, the environment, the fishery and the management system, to which a management strategy should be robust; (b) developing a set or grid of models which provide mathematical representation of the plausible dynamics of the fishery system (OM); and (c) fitting or conditioning the OMs and quantifying the impact of the uncertainties considered.

The OMs are used to characterize uncertainty on the North Atlantic albacore fishery. For this, we used data and hypotheses from the 2013 stock assessment that was carried out using Multifan-CL, a computer program that implements a statistical, size-based, age-structured model for use in fisheries stock assessment (Kleiber et al., 2012). The program is 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) and both the Indian Ocean Tuna Commission (IOTC) and ICCAT have used this model for stock assessment. The model is fit to time series of catch and size composition data from either one or many fishing fleets.

Reference set

The hypotheses considered in the 2013 stock assessment of North Atlantic albacore include a *Base case* and runs with a series of changes to include/exclude sources of data and one run with one alternative natural mortality vector. In total, 10 scenarios were used in 2013 to characterize uncertainty. For the MSE, we started from the set of 10 scenarios from 2013 and added hypotheses on biological parameters (natural mortality (3 options) and steepness (4 options)) and fishery dynamics (increase in catchability, 1%). In total, 132 scenarios of Multifan-CL were selected to condition the Reference set of OM (Table 1).

The outputs of the Multifan-CL runs are used to condition 132 OMs. The results of the stock assessments are contained in the *files 07.par* and *plot-07.par* for each scenario. The OMs are conditioned using libraries from the FLR-project (www.flr-project.org). In particular, the function *readMFCL* is applied to the two results files and it creates FLR objects of the type *FLStock*. This object contains the features and parameters of the stock as estimated from Multifan-CL. In the MSE, the new object is composed by a single fishery and includes parameters (selectivity, growth, natural mortality, stock-recruitment and maturity), time series of catch and biomass (in total and by age) and harvest time series. The *FLStock object*¸ which is the OM has been projected forward using catch information until 2014.

The Reference set of 132 OMs represent a range of potential stock and fishery dynamics, including reference points, equilibrium curves and stock status at the beginning of the simulation. Figure 2 shows how each of the factors of the uncertainty grid modifies the equilibria of the *Base case* used in 2013.

Figure 3 shows the impact of each of the factors of the uncertainty grid on the initial set of scenarios considered in 2013.

Figures 2 and 3 show that natural mortality, steepness and dynamic catchability do not produce major changes on stocks productivity (MSY) but they do produce notable changes on equilibrium recruitment curves and in the estimated unfished biomass. The changes are larger for the natural mortality scenarios than for steepness or catchability scenarios. Figure 1 also shows that the dynamic catchability does not produce significant changes on reference points and equilibrium curves. Figure 2 shows that the larger changes are produced by the scenarios designed in 2013. For example, MSY can vary 36% (from a lowest of 25 th tons (*Alt8*) to a higher of 34 th tons (*Alt2*)). Across the grid of OMs MSY can vary from 24 th tons to 40 th tons (66%).

Figure 4 and 5 show the impact of the different factors considered in the Reference set of OMs in the reference points and current state (2015) of the North Atlantic albacore stock. This figure shows that steepness produces higher variability on B_{MSY} and F_{MSY} than the other factors. B_{MSY} ranges from 150 th tons to approximately 380 th tons. The F_{MSY} ranges from 0.15 to 0.34 across the set of OMs. With regards to the stock status at the begging of the forward simulations (year 2015) it is seen that natural mortality produces the larger changes in the estimated values but steepness has a notable impact too. The lowest stock status is estimated for M02 and steepness values of 0.7. The largest stock status is estimated when using M04 and steepness of 0.9. At the beginning of the MSE simulations stocks biomass ranges from levels below $0.25xB_{MSY}$ to $1.7xB_{MSY}$. With regards to the relative fishing mortality in 2015, this ranges from $0.2xF_{MSY}$ and $3.4xF_{MSY}$. Figure 5 shows that the increasing catchability scenarios estimate a lower relative biomass and larger fishing mortality in 2015.

The impact of natural mortality, steepness and catchability scenarios on the overall selectivity of the single fleet considered in the OMs is illustrated in Figure 5. This figure shows that the factors included in the uncertainty grid do not have a major impact on the overall selectivity of the North Atlantic fishery.

Figures 2 to 6 illustrate the range of uncertainty on stock dynamics characterized with the 132 scenarios included in the Reference set of OMs. They describe stocks with productivities larger than the recent catches observed for North Atlantic albacore and different RPs and temporal trends of biomass and fishing mortality.

Robustness case

In the independent review to the North Atlantic MSE (Scully, 2018) it was recommended to generate negative catchability scenarios as Robustness cases. The albacore WG discussed the possibility that catchability has decreased as North Atlantic albacore is caught primarily by artisanal/pole and line/trolling vessels, and their searching efficiency may be directly linked to the number of vessels, which has decreased notably in recent times. We generated decreasing catchability scenarios by modifying the input files of the Multifan-CL scenarios in a similar manner as done for the 12 increasing catchability scenarios but with a negative trend of -1% since 1980. We run the 12 decreasing catchability Multifan-CL scenarios and conditioned the Robustness OMs.

2.2.2 Management Procedures

In general, MPs are composed by (i) fishery and fishery-independent data generated with error, (ii) stock assessment models or indicators of stock status and (iii) a decision framework or harvest control rules (HCR). The MP developed for North Atlantic albacore mirrors the data and methods used in the 2016 stock assessment and model-based HCRs as requested by ICCAT Commission. All components of the MP used in the North Atlantic albacore MSE are explained in this section.

2.2.2.1 Observation Error Model (OEM)

In MSE, the Operating Model is used to simulate resource dynamics in order to evaluate the performance of a Management Procedure. Where the MP is the combination of pre-defined data, together with an algorithm to which such data are input to provide a value for a management control measure. To link the OM and the MP it is necessary to develop a OEM to generate fishery-dependent or fishery-independent resource monitoring data. The OEM reflects the uncertainties, between the actual dynamics of the resource and perceptions arising from observations and assumptions by modelling the differences between the measured value of a resource index and the actual value in the OM (Kell and Mosqueira, 2016). In Merino et al (2017a) options for an OEM are explored by combining OMs biomass trends, catch per unit of effort series, fleet specific and overall selectivity patterns and analyses of the indices used in the latest stock assessment of North Atlantic albacore, including their residuals of fit. A procedure to simulate CPUE from the OM and compare the properties of the simulated to those used in the assessment is proposed. The option adopted for this MSE simulates fleet specific CPUE indices using each fleet's selectivity pattern, catch and effort. The method to generate four abundance indices from the OM for Spanish baitboat, China Taipei longline, Japanese longline and a combined index to simulate Venezuelan and US longline is the following:

$$Index_f = \frac{\sum_a^{max} Catch_{a,f}\ x\ Selectivity_{a,f}}{fbar}\ x\ \varepsilon\ ;\ f = fleet; a = age; fbar = fishing\ mortality$$

A CV of 20% is used to estimate each fleets' CPUE with error for each iteration of the projections (see example in Figure 7).

2.2.2.2 Stock status estimator

The CPUE indices generated are used with theh total catch series to fit the biomass dynamic model *mpb* (Kell, 2016), which was used in the 2016 stock assessment of North Atlantic albacore (ICCAT, 2016c). The fits are made using the same specifications and modelling choices as in 2016, i.e. CPUE series from the years specified in Table 2 and the same starting values and fixed parameters used in 2016 (Table 3). Every three years, the OEM generates CPUE indices with error and one catch series which are used to estimate stock status and reference points.

The model *mpb* has been used in a number of ICCAT stocks and it has been validated against other biomass production models (Kell et al., 2016b).

The stock status estimator uses data until years (t-1) of the simulated assessment year and uses the estimated Bcurr as B(t) to calculate TAC using the HCR for the following management period.

2.2.2.3. Harvest Control Rules

The North Atlantic albacore MSE was specifically designed to evaluate model-based HCR. These describe how harvest is automatically controlled by management in relation to the estimated biomass relative to B_{MSY} (Figure 8). The user of the MSE can specify the control parameters of the HCR which are the target fishing mortality (F_{tar}), a precautionary threshold (B_{thresh}), a limit reference point (B_{lim}), and a minimum fishing mortality that will be applied when biomass falls below B_{LIM} (F_{min}). When the stock falls below B_{thresh} but above B_{lim}, the fishing mortality will be reduced linearly from F_{tar} to F_{min}.

In addition, in the spirit of avoiding the adverse effects of potentially inaccurate stock assessments, HCRs can include additional constraints. For example, maximum and minimum TAC can be set and also a maximum % of TAC change be adopted.

2.3 Updated evaluation of the HCR adopted and alternatives requested in Recommendation 17-04

In 2017, ICCAT adopted Recommendation 17-04 which establishes interim reference points and a harvest control rule (HCR) to set 3-year constant annual total allowable catch (TAC) for the North Atlantic albacore stock (Figure 9).

This HCR is defined by four coordinates:

(i) B_{THRESH}=B_{MSY}, biomass below which the fishing mortality will start to be reduced linearly.
(ii) BLIM=0.4xBMSY, biomass below which the TAC will be set to a minimum.
(iii) FTAR=0.8xFMSY, target fishing mortality, the fishing mortality at which the stock will be exploited when its biomass is estimated to be above the threshold (BTHRESH).
(iv) F_{MIN}=0.1xF_{MSY}. The fishing mortality that will be used to estimate the TAC when the stock is assessed to be below the limit reference point (B_{LIM}).

In order to set 3-year TAC, the HCR requires the estimation of three quantities from stock assessment:

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

(ii) B_{CURR}, the estimate of current biomass with respect to B_{MSY}.

(iii) F_{MSY},The estimate of fishing mortality at MSY

The TAC will be set as follows:

(a) if the current biomass (B_{CURR}) is estimated to be at, or above, the threshold biomass (i.e., $B_{CURR} \geq B_{MSY}$), then the catch limit shall be set at TAC = F_{TAR} * $B_{CURR.}$

(b) if the current biomass (B_{CURR}) is estimated to be below the threshold biomass (i.e., $B_{CURR} < B_{MSY}$) but greater than B_{LIM} (i.e., $B_{CURR} > 0.4*B_{MSY}$), then the catch limit shall be set at TAC = F_{NEXT} * B_{CURR} , where F_{NEXT} can be calculated from the HCR.

(c) if the current biomass (B_{CURR}) is estimated to be at, or below, the B_{LIM} (i.e., $B_{CURR} \leq 0.4*B_{MSY}$), then the catch limit shall be set at TAC = F_{MIN} * B_{CURR} with a view to ensure a level of catch for scientific monitoring.

(d) the catch limit resulting from the above calculations will be below the maximum catch limit (Cmax=50,000 tons) and shall not increase or decrease by more than 20% from the previous catch limit except when $B_{CURR} < B_{THRESH}$ or unless otherwise required pursuant to an agreed management response when exceptional circumstances are determined to have occurred by the SCRS.

With this, ICCAT established a 3-year constant annual TAC of 33,600 tons for the period 2018-2020.

Also, in its final provisions, Recommendation 17-04 requested additional MSE simulations to evaluate alternatives to the adopted HCR during 2018-2020. Specifically, Rec 17-04 requests exploring management procedures that:

1) Include carry overs,
2) Include a lower TAC limit,
3) Apply the restriction of 20% (see d) above) when B_{CURR}>B_{LIM} and B_{CURR}<B_{THRESH}.
4) Apply the restriction of 20% maximum reduction and 25% maximum increase of TAC when B_{CURR}<B_{THRESH} and B_{CURR}>B_{LIM}.

For this, in Merino et al (2018) six scenarios were developed:

a. *Scenario 1 (Rec 17-04):* Here we have evaluate the HCR with the MSE framework updated in 2019.

b. *Scenario 2 (20% when B>Blim):* The HCR adopted in 2017 establishes that the 20% TAC change limitation will only be applied when the stock is estimated at levels above the B_{THRESH}=B_{MSY}. In this scenario we use a stability clause that establishes that the 20% limitation is applied also when the stock is assessed to be at levels above the B_{LIM}=0.4xB_{MSY}.

c. *Scenario 3 (Cmin=15kt):* In this scenario we evaluate the impact of using a minimum catch limit of 15,000 tons.

d. *Scenario 4 (20% down-25% up):* In this scenario, the stability clause imposes a 20% of maximum TAC reduction and 25% maximum increase when B_{CURR}>B_{LIM}. We also evaluate the performance of this scenario when the 20% down and 25% up limit is applied when the B_{MSY} > B_{CURR}>B_{LIM}

e. Scenario 5 (Carry Over): For this scenario, we simulate the historical Catch and TAC differences for this fishery using a normal distribution (Figure 10). The North Atlantic albacore fishery has been managed using TAC since 2001. In most cases, the catch has been notably lower than the catch limit (light blue) and in three years between 2001-2016 catch has exceeded TAC (orange). We have used the historical average difference between catch and TAC (81.12%) and its standard deviation (16.8%) to generate catch from the simulated TAC (green). Overall, the OMs are projected using catch lower than the 3-year TACs established by the HCR.

f. *Scenario 6 (Implementation error or "Bank and borrowing"):* This scenario is based on a previous study for saithe in the ICES area (De Oliveira, 2013). For this scenario we simulate an extreme case where catch is alternatively 20% higher ("*borrowing*") and 20% lower ("*banking*") than TAC. For example, if the TAC for the period 2018-2024 is 30,000 tons, the catch will be TAC_{t}=30,000-(20%), TAC_{t+1}=30,000+(20%), TAC_{t+2}=30,000-(20%) etc. This will be applied for each iteration and will start alternatively by banking or borrowing.

In 2018 these scenarios were evaluated after the MSE was updated with catch from 2018-2020 as set by Rec 17-04 (33,600 tons). In 2019, a minor modification was made to the MSE code so that the model identified absurd fits to data (e.g. Figure 11) and TAC would be kept at levels of the previous management period. Also in 2019, an error was found in the code of *Scenario 4*: This scenario was built under the condition that the stability clause imposes a 20% of maximum TAC reduction and 25% maximum increase when B_{CURR}>B_{LIM} but Rec 17-04 requested that the stability clause was applied when when B_{MSY}>B_{CURR}>B_{LIM}. For clarity, both options have been included in this analysis.

Figure 12 and **Table 4 s**how a summary of the performance of the HCR adopted in Rec 17-04 and the alternatives requested by ICCAT. HCRs performance is averaged across models using medians.

Full results of the performance of the selected HCRs with regards to all indicators of stock status, safety, catch and stability are shown in the following figures and table:

Also, a summary of the performance indicators is shown for Robustness test (Scully, 2018) for the adopted HCR and negative catchability OMs (**Figure 17**).

2.4 Tabulation exceptional circumstances' indicators

ICCAT requested that SCRS develops ways to identify exceptional circumstances that have not been considered in the North Atlantic albacore MSE. The albacore wg and the Working Group on Stock Assessment Methods (WGSAM) identified a number of indicators that could be used for that purpose including *System state* indicators (stock biomass, fishing mortality, growth, maturity and natural mortality) and indicators that could impede the application of the HCR (CPUE and catch data). The SCRS has also been requested to tabulate the range of values of these indicators seen in the MSE simulations. Growth, maturity and natural mortality parameters do not change throughout the MSE simulations and are describe in the OM section. The others, catch, cpue, biomass and fishing mortality do change across the simulations and across scenarios. **Figure 18** shows boxplots with time series of biomass, fishing mortality, catch and CPUE as estimated across all OMs of the Reference Set in the evaluation of the HCR specified in Rec 17-04.

Additionally, following comments on the 2020 stock assessment meeting for North and Southern albacore, the relative biomass and fishing mortality levels estimated in the MSE simulations are shown in **Figures 19-22**. The figures are B/Bmsy and F/Fmsy in the grid of OMs (green) and in the MPs (blue) and correspond to the period 1950-2040. Also, **Figure 23** shows the CPUE values observed for the four fleets considered in the MSE.

Also, noting that growth, maturity and natural mortality are part of the *System state* indicators for evaluating exceptional circumstances, we note that the values used for natural mortality can be consulted in Table 1, that the maturity vector used in all OMs is (Mat=0 for age <5; Mat=0.5 for age=5 and, Mat=1 for age>5) and that the growth curve used is that from the 2013 stock assessment (Santiago and Arrizabalaga, 2005, **Figure 24**).

2.5 Update in 2020

In 2020 two advances have been made to the North Atlantic albacore MSE: First, following the definitions of exceptional circumstances being developed for this stock, the impact of one or more indices not being updated for the 2020 stock assessment is evaluated. Second, the fits of the available indices to the Operating Models and the implicit Management Procedure are evaluated.

2.5.1 Simulation of the effects of one or more indices not being updated for the stock assessment

The North Atlantic albacore is re-run with one or more indices not being updated since 2014. It is important to note that the index for the period before 2014 is available in the MSE and thus, it would simulate the use of the same indices used in the 2016 stock assessment with one or more not being updated since 2014. The code of the MSE is exactly the same code used after the improvements made in 2019. Table 6 shows the results of the new evaluations and the evaluation of the adopted HCR made in 2019 for comparison. Results suggest that the lack of update of one or more index would not impede achieving the management objective of keeping the stock above B_{MSY} with at least 60% probability. However, the results estimate a significantly lower performance (20-32%) in long term catch if only one index is updated. Also, with only one updated index the probability of being in the green quadrant would be reduced between 7 and 15%, still achieving values larger than 60% pGreen.

Overall, these results suggest that in the exceptional circumstance that one or more index is not available for stock assessments, the HCR would still achieve management objectives.

2.5.2 Fits of OMs to the available indices

The OMs used in the North Atlantic albacore MSE were developed from 10 initial scenarios developed with Multifan-CL. The 132 OMs (see section *Operating Models*). These fits of the 132 Multifan-CL, from which the OMs were conditioned were not analyzed in detail and here, we show figures that help evaluating the fits to each and every scenario. We present two kinds of figures: 1) histograms for residuals are shown with density distributions for the twelve CPUE indices available in the 2013 stock assessment, with the indices used in the MSE framed in orange. The density distributions correspond to the distribution generated with the mean and standard deviations of the residuals (blue), distribution generated using mean 0 and the standard deviation of the residuals (green), and the mean and standard deviations used in the MSE to generate indices with variability from the biomass of the OMs (red). 2) We show the observed and fitted value for the indices used in 2013. Therefore, we have produced 132 x 2 figures, which are all sent in an Appendix.

Overall, there are no differences in fits of the OMs with regards to different natural mortality, steepness or dynamic catchability but there are some differences between the original model scenarios developed in 2013. Specifically, adding size frequency data for Chinese Taipei worsens the fit of this CPUE, and its deviates exceed the variability considered in the MSE (scenarios *Alt 7*, see **Figure 25**). Also, in general, the Spanish baitboat data shows residuals with a wider variability then the values considered in the MSE. For the latest, it seems that a small number of extreme values is widening the confidence interval of the residual values (**Figure 26**).

3. Acknowledgments

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Table 1. Hypotheses and scenarios considered in the North Atlantic albacore MSE. The 10 Multifan-CL scenarios in the upper left panel (in gray) are the scenarios considered in the 2013 stock assessment. These are combined with three natural mortality options (explicit values shown in **Table1(addendum)**) and four options for steepness. Also, the Base model is used with increasing catchability. In total, the Reference set of OM of the North Atlantic albacore is conditioned from 132 scenarios.

OM-Reference Set	*Natural mortality*	*Steepness prior*
Base: Model specifications provided in SCRS/2013/058 (Merino et al., 2013) **Alt1:** Includes China Taipei longline size frequency data and allows dome-shaped selectivity for this fleet. **Alt2:** Model starts in 1950 **Alt3:** All size frequency data down-weighted **Alt4:** Japanese longline CPUE data no longer down-weighted **Alt5:** Includes the Chen and Watanabe age-specific natural mortality vector (Santiago and Arrizabalaga, 2005a) **Alt6:** Excludes final 4 years of data (2008-2011) **Alt7:** Includes equal weights for Japan and Chinese Taipei longline size frequency data and catch per unit of effort data **Alt8:** Includes total catch in weight but effort calculated from CPUE in numbers **Tag:** Includes tagging data for release events that occurred between 1988 and 1991	• 0.2 • 0.3 • 0.4	• 0.75 (sd=0.15) • 0.7 (sd=0.05) • 0.8 (sd=0.05) • 0.9 (sd=0.05)
Base: Model specifications provided in SCRS/2013/058 (Merino et al., 2013) with dynamic catchability (+1%)		

Table 1(addendum). Natural mortality values used in the Operating Models of North Atlantic albacore.

Age class	*Original (2013) Scenarios*					
	Base, Alt1, Alt2, Alt3, Alt4, Alt6, Alt7, Alt8, Tag			*Alt5*		
	Natural Mortality scenarios					
	M0.2	*M0.3*	*M0.4*	*M0.2*	*M0.3*	*M0.4*
1	0.2	0.3	0.4	0.3605949	0.5410000	0.7213001
2	0.2	0.3	0.4	0.2772044	0.4160000	0.5546600
3	0.2	0.3	0.4	0.2341016	0.3510000	0.4679939
4	0.2	0.3	0.4	0.2074220	0.3110000	0.4146585
5	0.2	0.3	0.4	0.1900000	0.2850000	0.3799939
6	0.2	0.3	0.4	0.1899489	0.2890000	0.3853513
7	0.2	0.3	0.4	0.1926269	0.3140000	0.4186584
8	0.2	0.3	0.4	0.2092972	0.3420000	0.4559829
9	0.2	0.3	0.4	0.2280934	0.3770000	0.5026808
10	0.2	0.3	0.4	0.2513271	0.4200002	0.5600104
11	0.2	0.3	0.4	0.2799904	0.4730000	0.6306527
12	0.2	0.3	0.4	0.3153728	0.5430000	0.7239739
13	0.2	0.3	0.4	0.3620402	0.5430000	0.7239739
14	0.2	0.3	0.4	0.3620402	0.5430000	0.7239739
15	0.2	0.3	0.4	0.3620402	0.5430000	0.7239739

Table 2. CPUE series used in the 2016 stock assessment and their starting years. Where t is the year of the MP iteration (when the TAC is set for years t+1, t+2 and t+3).

Index	*First year*	*Last year*
Chinese Taipei LL late	1999	t-2
Japan bycatch LL	1988	t-2
Spanish Baitboat	1981	t-2
US LL	1987	t-2
Venezuelan LL	1991	t-2

Table 3. Specifications of the biomass dynamic used for the 2020 stock assessment and also used in the MSE.

Software	Model	Catch series	Starting values
mpb	Fox (biomass dynamic)	Start: 1930 Final year: t-2	Biomass at t=0 (fixed): 1 x *K* Variance treatment of the CPUE indices: model weighted

Table 4. Summary performance statistics for the HCR adopted in Rec 17-04 and alternatives.

HCR	**Stock status**	**Safety**	**Catch**	**Stability**
	pGr%	**pBint%**	**Y3 (kt)**	**MAP (%)**
Adopted	78.34	13.08	29.65	8.43
20% above LRP	65.54	15.52	28.83	7.04
Cmin	66.56	15.02	30.96	8.36
20down_25up_aboveLRP	64.86	15	30.09	7.78
20down_25up_aboveLRP_belowBTHR	69.3	14.76	29.79	7.35
Carry overs	89.88	7.12	28.09	29.36
Implementation error	66.4	17.1	30.05	36.56

Table 5. Full results of the evaluation of the HCRs.

	Stock Status					Safety		Catch			Stability					
HCR	**Bmin**	**Bmean**	**Fmean**	**pG(%)**	**pR(%)**	**pBlim(%)**	**pBint(%)**	**Yshort**	**Ymid**	**Ylong**	**MAP**	**sd**	**var**	**pshut**	**p(δTAC+10%)**	**p(δTAC-10%)**
Adopted	0,35	1,47	0,57	78,34	5,56	99,9	13,08	29,14	23,21	29,65	8,43	7,64	58,42	0,84	13,27	10,91
20% above LRP	0,26	1,21	0,70	65,54	10,76	99,54	15,52	31,17	27,89	28,83	7,04	5,39	29,04	0	11,03	11,67
Cmin	0,20	1,26	0,73	66,56	11,34	99,16	15,02	29,83	26,63	30,96	8,36	7,46	55,61	0	12,50	12,29
20%-25% B>Blim	0,23	1,24	0,74	64,86	12,48	99,46	15	31,05	28,07	30,07	7,78	5,72	32,76	0	11,33	12,25
20%-25% Bmsy>B>Blim	0,23	1,22	0,73	69,3	11,52	99,66	14,76	30,82	27,78	29,75	7,35	5,46	29,85	0	11,04	12,08
Carry overs	0,41	1,88	0,47	89,88	2	100	7,12	22,56	25,08	28,05	29,36	8,40	70,51	0,36	43,83	32,48
Implementation error	0,21	1,32	0,60	66,4	10,96	98,98	17,1	30,31	26,16	30,06	36,56	10,92	119,33	1,86	48,33	48,90

Table 6. Evaluation of the HCRs with one or more indices not being updated since 2014.

	Stock Status					Safety		Catch			Stability					
HCR	Bmin	Bmean	Fmean	pG(%)	pR(%)	pBlim(%)	pBin(%)	Yshort	Ymid	Ylong	MAP	sd	var	pshut	p(δTAC+10%)	p(δTAC-10%)
Adopted	0.35	1.47	0.57	78.34	5.56	99.9	13.08	29.14	23.21	29.65	8.43	7.64	58.42	0.84	13.27	10.91
Except Spain BB	0.31	1.43	0.56	76.26	6.78	99.82	13.88	29.75	23.6	29.99	8.65	7.58	57.51	1.02	12.83	10.73
Except Japan LL	0.34	1.46	0.58	75.32	6.06	99.88	13.16	29.5	23.7	29.21	8.3	7.71	59.44	1.14	12.98	10.79
Except Taiwan LL	0.4	1.53	0.55	80.48	4.82	99.96	12.68	27.99	22.64	28.81	8.4	7.67	58.83	1.32	12.98	10.96
Except Other LL	0.38	1.49	0.55	80.14	5.3	99.96	12.54	28.62	22.3	28.47	8.71	7.89	62.28	0.96	13.38	11.03
Spain BB- Jp LL	0.44	1.57	0.53	82.14	4.54	100	12.3	26.67	21.66	28.47	8.44	7.61	57.96	1.2	13.63	10.36
Spain BB- Chi Tai LL	0.43	1.55	0.55	81.46	4.98	100	13.64	27.94	21.02	27.98	8.57	7.8	60.77	1.68	13.83	10.83
Spain BB - US-Ven LL	0.43	1.52	0.51	79.46	4.96	100	13.68	27.8	21.54	28.84	8.44	7.7	59.31	1.68	13.04	11.08
Jp LL - Chi Tai LL	0.31	1.45	0.58	78.04	6.16	99.74	12.72	30.37	23.41	28.39	8.28	7.4	54.82	0.96	12.85	11.02
Jp LL - US-Ven LL	0.31	1.43	0.55	76.46	7.26	99.82	13.68	28.7	22.95	29.24	8.68	7.84	61.49	1.56	13	11.13
Chi Tai LL - US-Ven LL	0.28	1.4	0.6	73.9	7.74	99.66	14.2	30.27	25.57	29.52	8.6	7.6	57.8	1.56	12.67	11.08
Only Spain BB	0.3	1.38	0.52	72.72	6.8	99.44	17.96	27.45	19.31	23.61	9.7	8.18	66.85	3.24	12.67	10.71
Only Japan LL	0.27	1.38	0.46	68.06	9.72	99.24	19.74	30.6	23.01	22.79	10.11	8.31	69.1	2.94	12.46	12.29
Only Taiwan LL	0.22	1.33	0.43	71	9.02	98.72	19.34	28.06	19.57	21.47	10.33	8.64	74.72	4.32	12.8	12.9
Only Ven-US LL	0.24	1.37	0.45	67.04	8.92	99.48	18.44	26.35	21.58	20.08	9.96	8.55	73.17	4.5	12.46	12.9

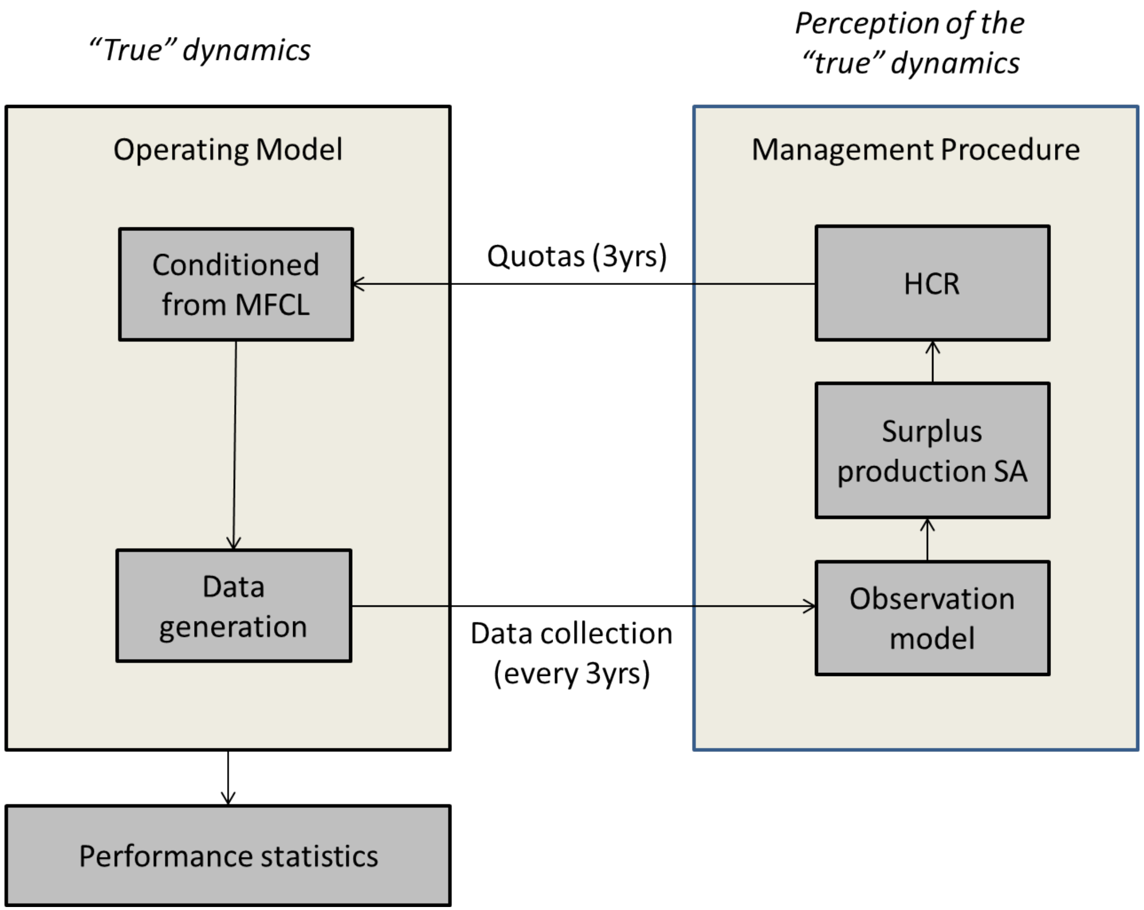

Figure 1. Conceptual description of North Atlantic albacore MSE. The OMs represent the "true dynamics" of the fishery system and the MP represent the "perceive dynamics".

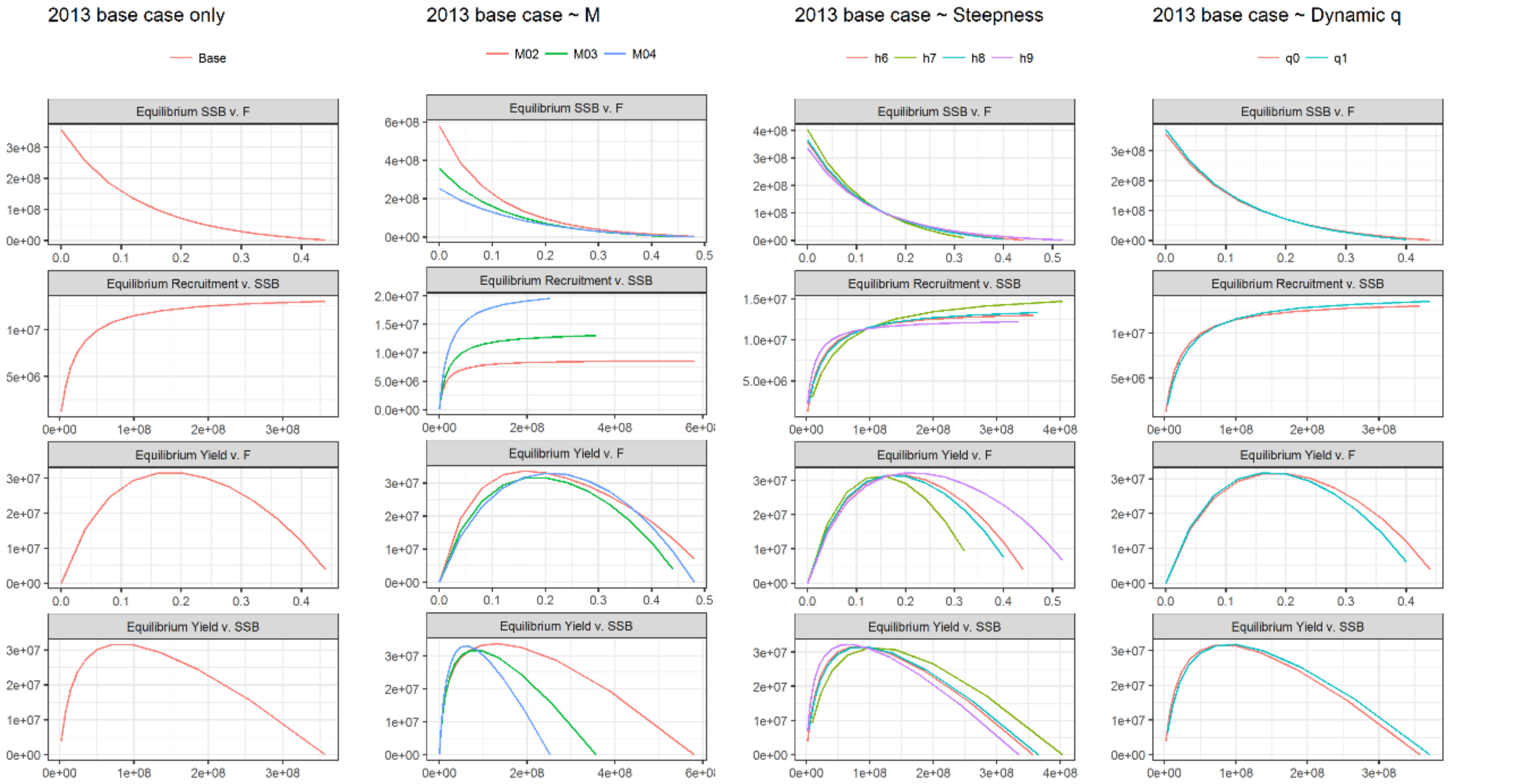

Figure 2. Impact of natural mortality, steepness and dynamic catchability on the Base case scenario. Values for steepness are: h6 (prior 0.75, sd=0.15), h7 (prior=0.7, sd=0.05), h8 (prior=0.8, sd=0.05) and h9 (prior=0.9, sd=0.05). Values for natural mortality are: M02=0.2, M03=0.3 and M04=0.4. The value for the catchability dynamic effect (q1) is a 1% increase since 1980.

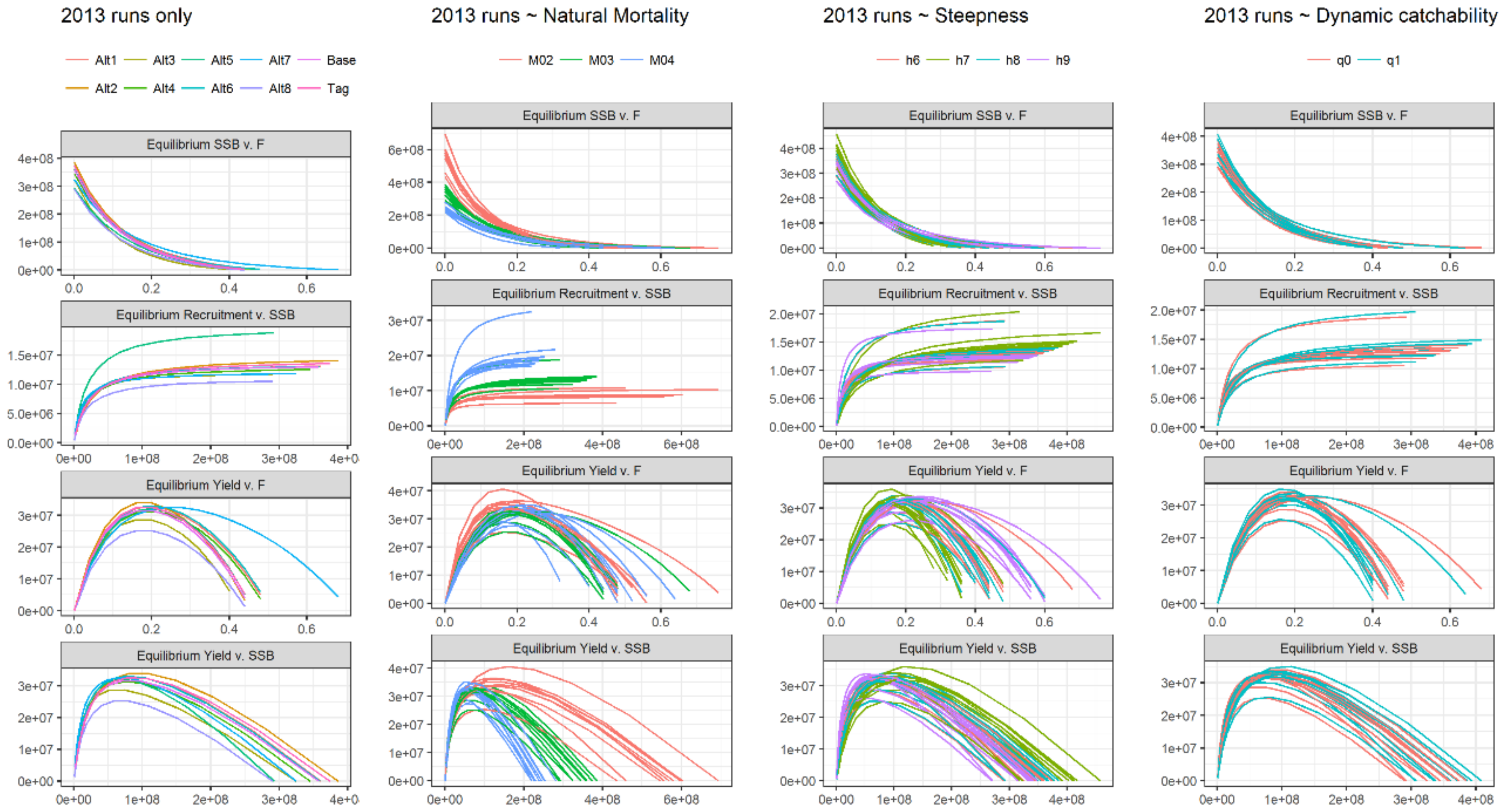

Figure 3. Impact of natural mortality, steepness and dynamic catchability on the set of scenarios considered in the 2013 stock assessment. Values for steepness are: h6 (prior 0.75, sd=0.15), h7 (prior=0.7, sd=0.05), h8 (prior=0.8, sd=0.05) and h9 (prior=0.9, sd=0.05). Values for natural mortality are: M02=0.2, M03=0.3 and M04=0.4. Note that for the scenarios derived from the 2013 *Alt5* scenario, the natural mortality is a vector and not a single value for all ages. For the scenarios derived from *Alt5* M03 is the Chen and Watanabe age-specific natural mortality vector (Santiago and Arrizabalaga, 2005b) and M02 and M04 are the same vector scaled 33.3% up and down. The value for the catchability dynamic effect (q1) is a 1% increase since 1980.

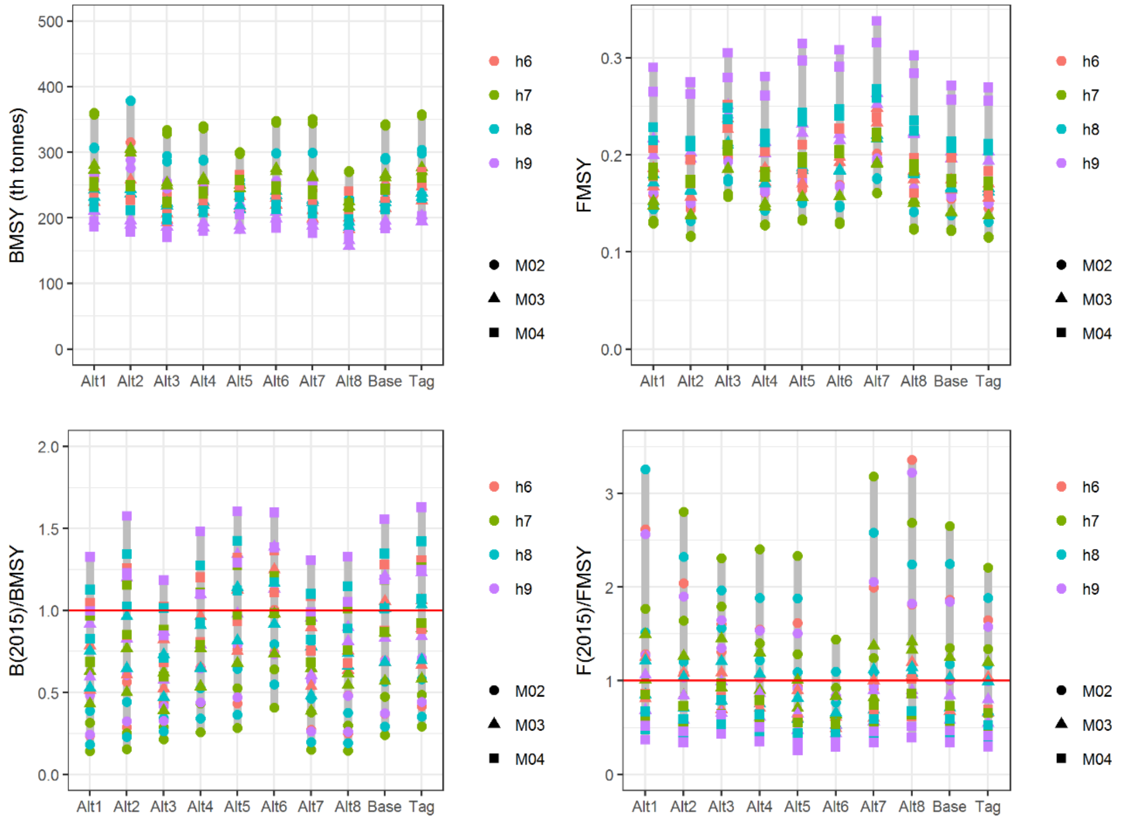

Figure 4. Impact of steepness (h) and natural mortality (M) on the reference points and current state of North Atlantic albacore stock. Values for steepness are: h6 (prior 0.75, sd=0.15), h7 (prior=0.7, sd=0.05), h8 (prior=0.8, sd=0.05) and h9 (prior=0.9, sd=0.05). Values for natural mortality are: M02=0.2, M03=0.3 and M04=0.4. Note that for the scenarios derived from the 2013 *Alt5* scenario, the natural mortality is a vector and not a single value for all ages. For the scenarios derived from *Alt5* M03 is the Chen and Watanabe age-specific natural mortality vector (Santiago and Arrizabalaga, 2005b) and M02 and M04 are the same vector scaled 33.3% up and down. The value for the catchability dynamic effect (q1) is a 1% increase since 1980.

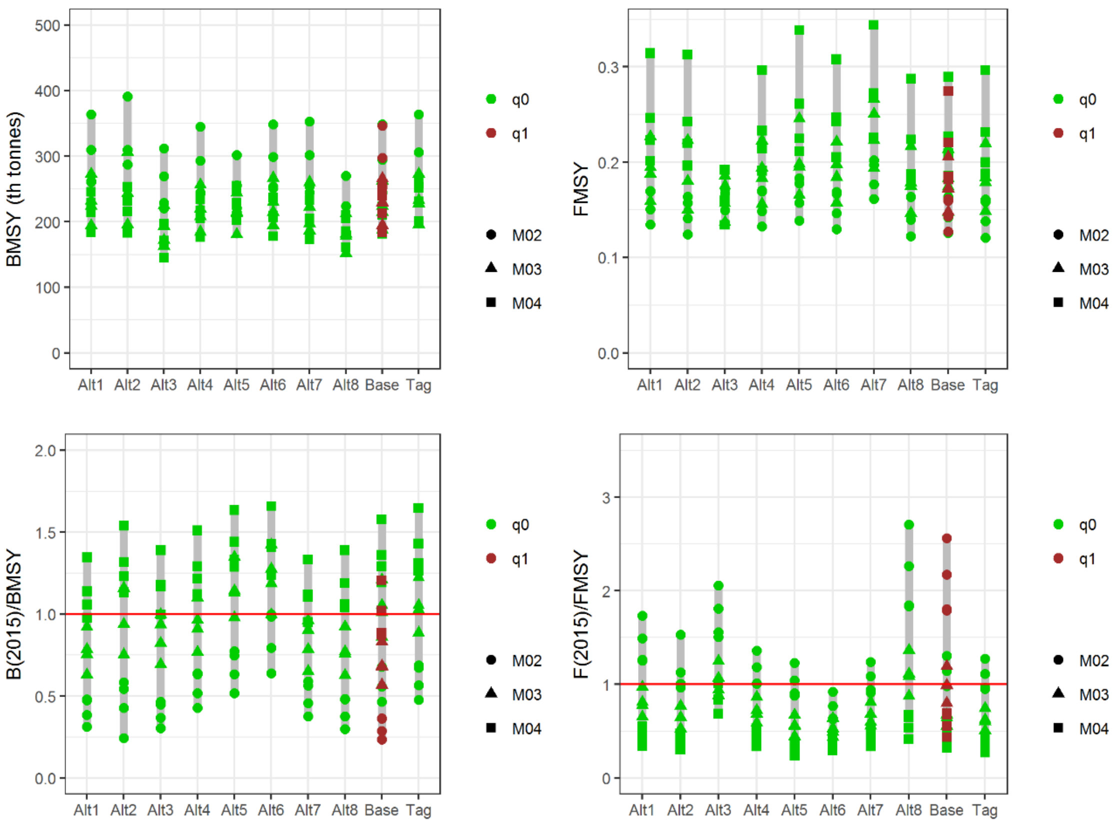

Figure 5. Impact of steepness (h) and natural mortality (M) on the reference points and current state of North Atlantic albacore stock. The value for the catchability dynamic effect (q1) is a 1% increase since 1980. Values for natural mortality are: M02=0.2, M03=0.3 and M04=0.4. Note that for the scenarios derived from the 2013 *Alt5* scenario, the natural mortality is a vector and not a single value for all ages. For the scenarios derived from *Alt5* M03 is the Chen and Watanabe age-specific natural mortality vector (Santiago and Arrizabalaga, 2005b) and M02 and M04 are the same vector scaled 33.3% up and down.

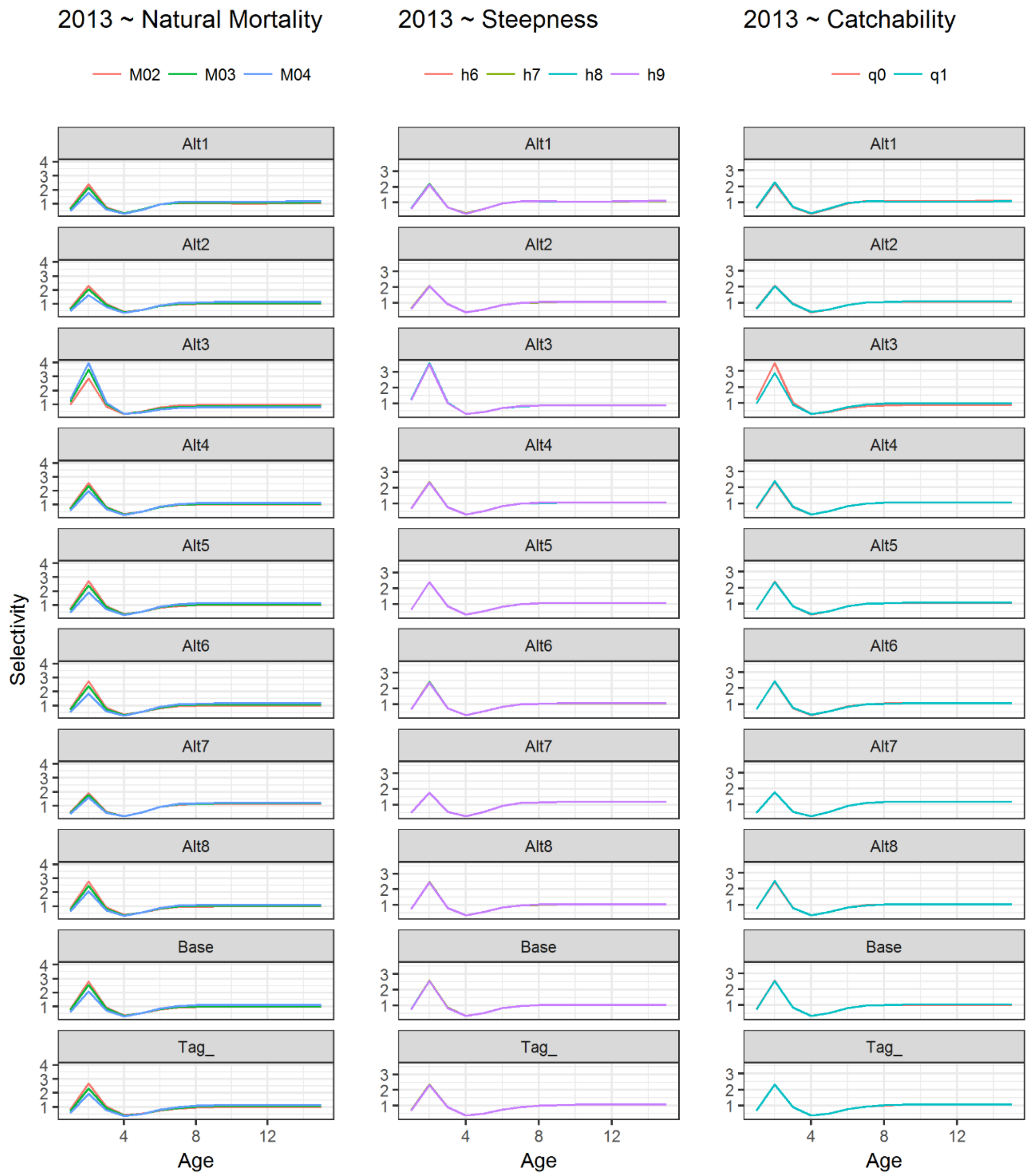

Figure 6. Impact of natural mortality, steepness and dynamic catchability on the overall estimated selectivity of the North Atlantic albacore fishery (*Base case*). Values for steepness are: h6 (prior 0.75, sd=0.15), h7 (prior=0.7, sd=0.05), h8 (prior=0.8, sd=0.05) and h9 (prior=0.9, sd=0.05). Values for natural mortality are: M02=0.2, M03=0.3 and M04=0.4. The value for the catchability dynamic effect (q1) is a 1% increase since 1980.

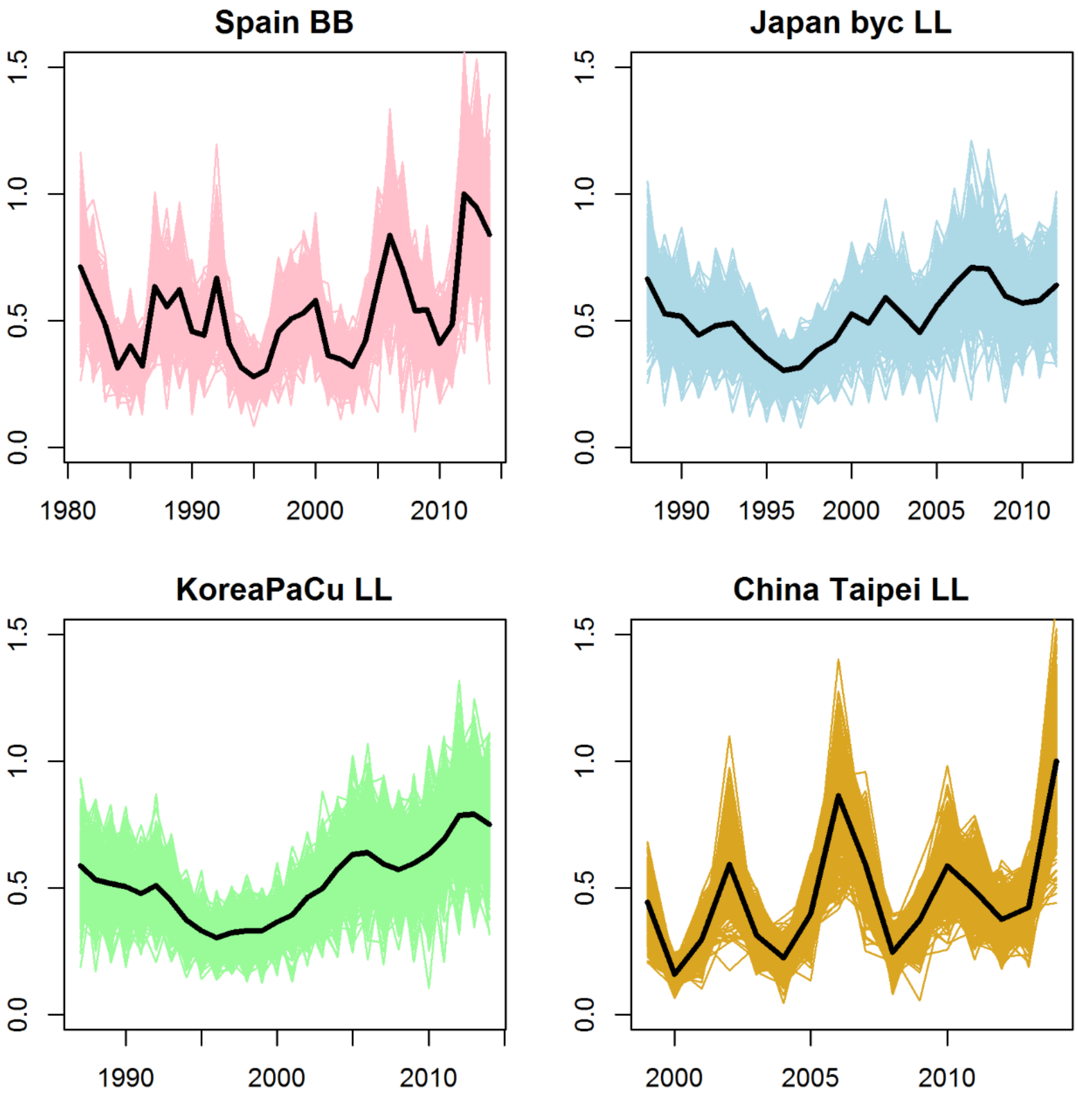

Figure 7. CPUE generated from the OM conditioned from the 2013 Base case. A CV of 20% is applied to each CPUE. In black the median trajectory and in colors 100 CPUE generated with error.

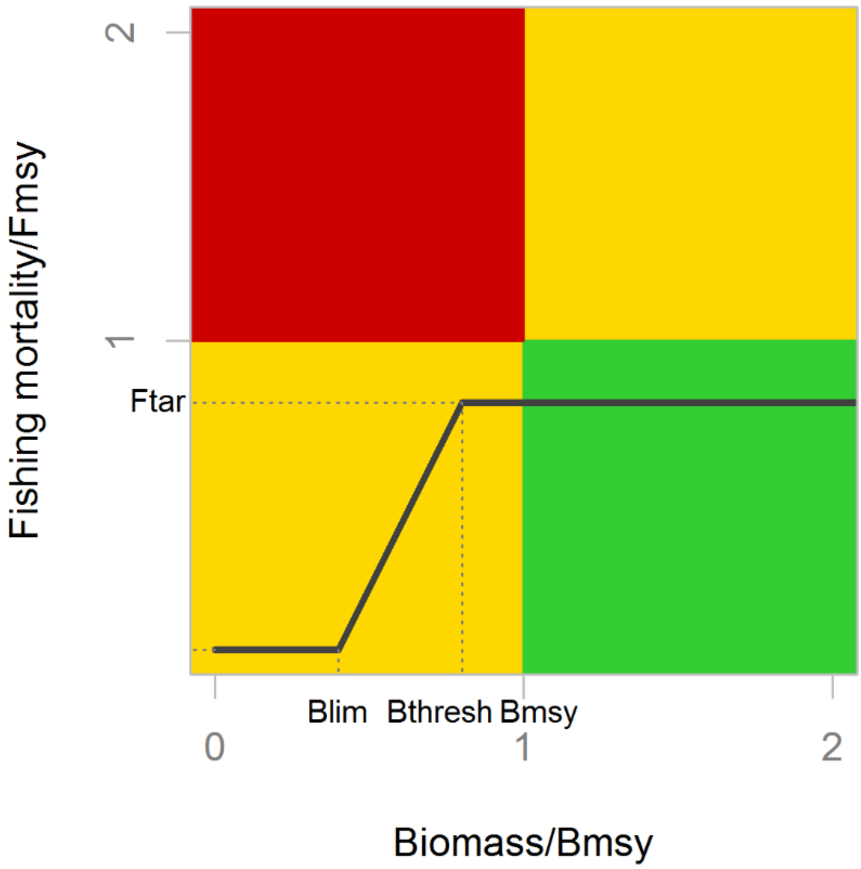

Figure 8. Linear model based HCR.

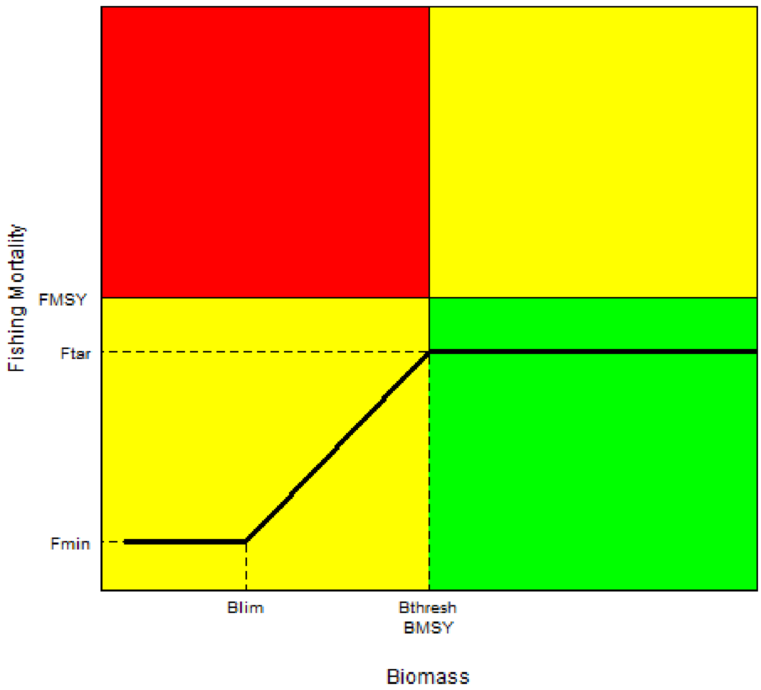

Figure 9. HCR adopted by ICCAT in 2017 (Rec 17-04).

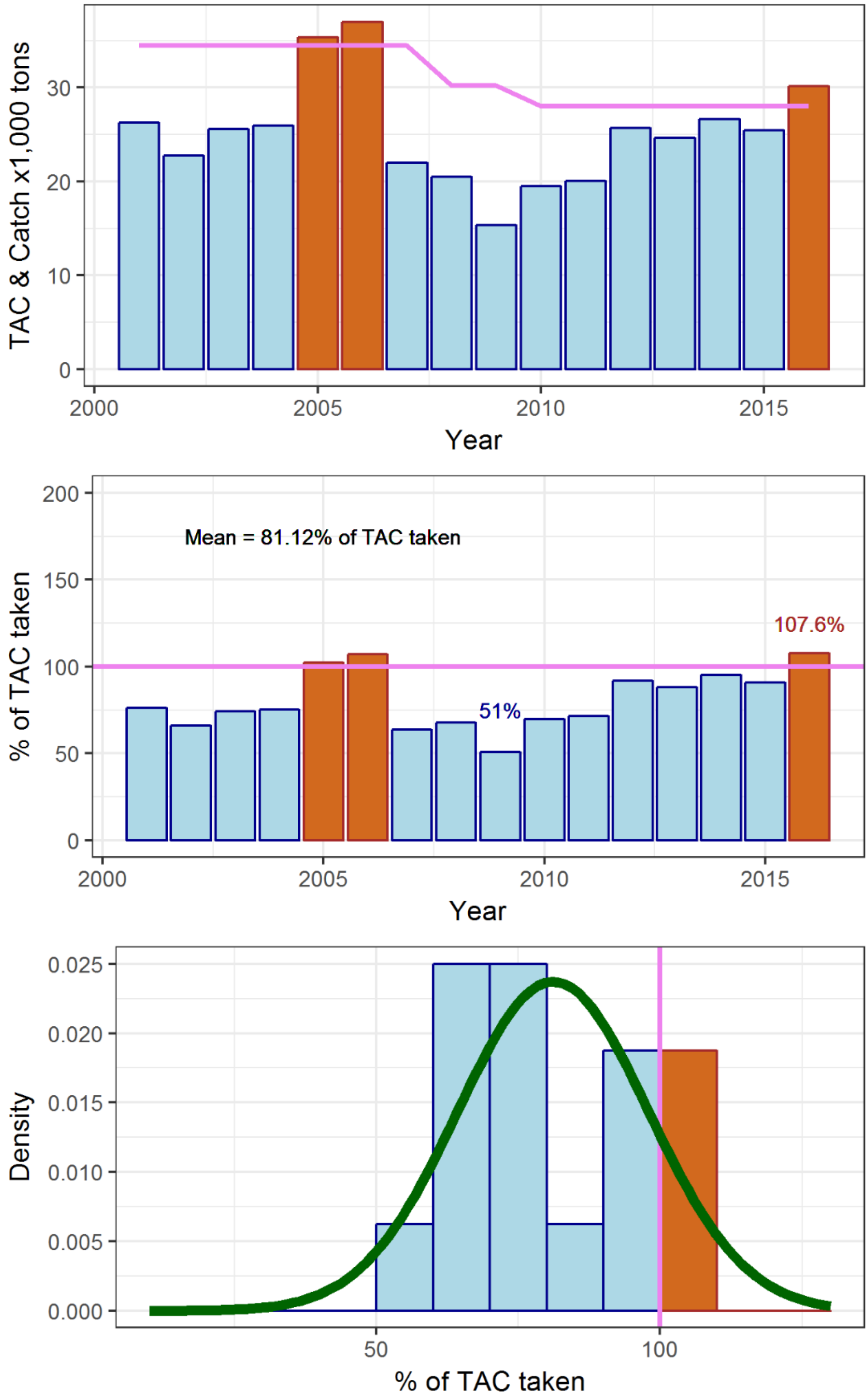

Figure 10. Historic differences between catch and TAC (in blue when TAC has not been reached and in brown when TAC has been exceeded). The bottom figure shows the probabilistic distribution used to generate the carry over scenario.

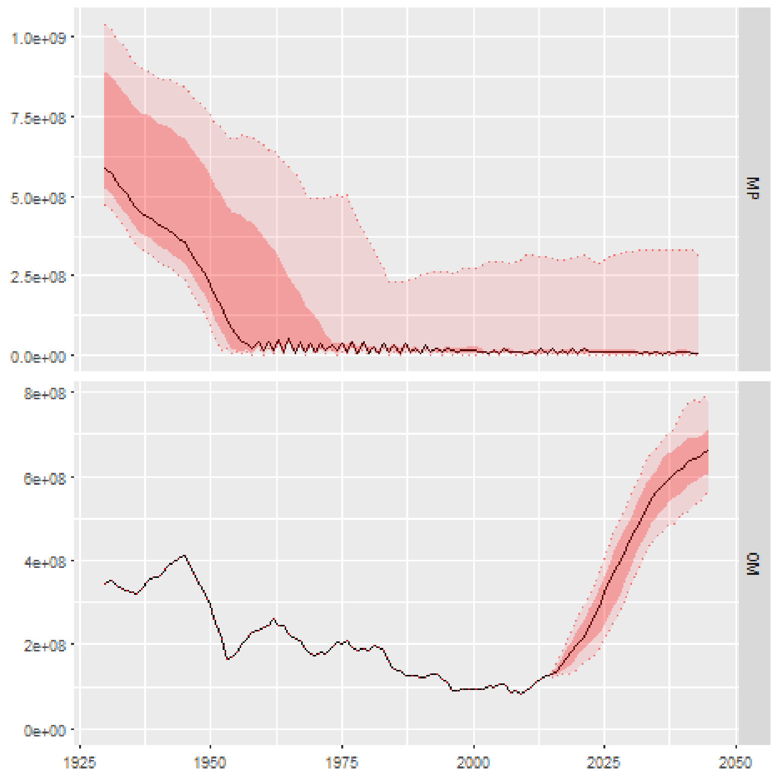

Figure 11. Example of MP producing absurd fits to data from the OM. In previous versions the MP would interpret this as the stock being at extremely low levels and would reduce TAC to a minimum. In the 2019 MSE, fits like this are identified as absurd and will maintain previous management periods' TAC.

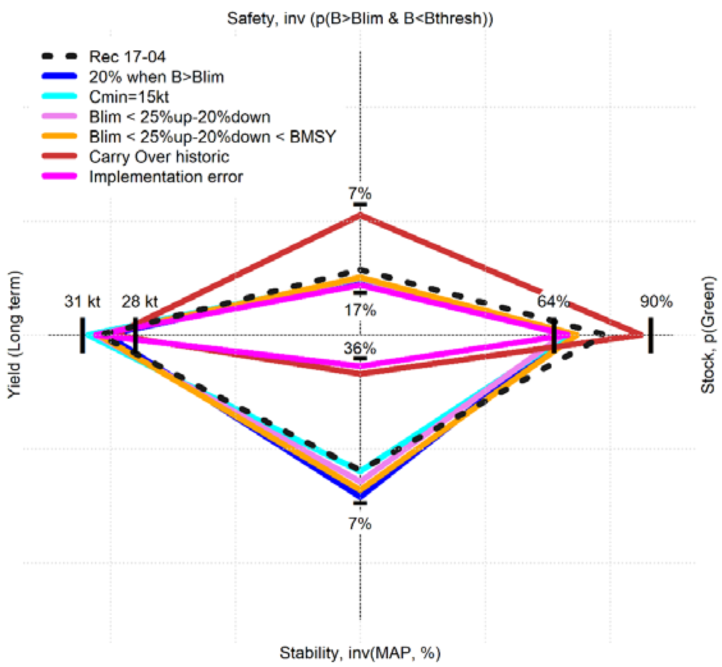

Figure 12. Summary performance statistics of the HCR adopted in Rec 17-04 and the requested alternatives.

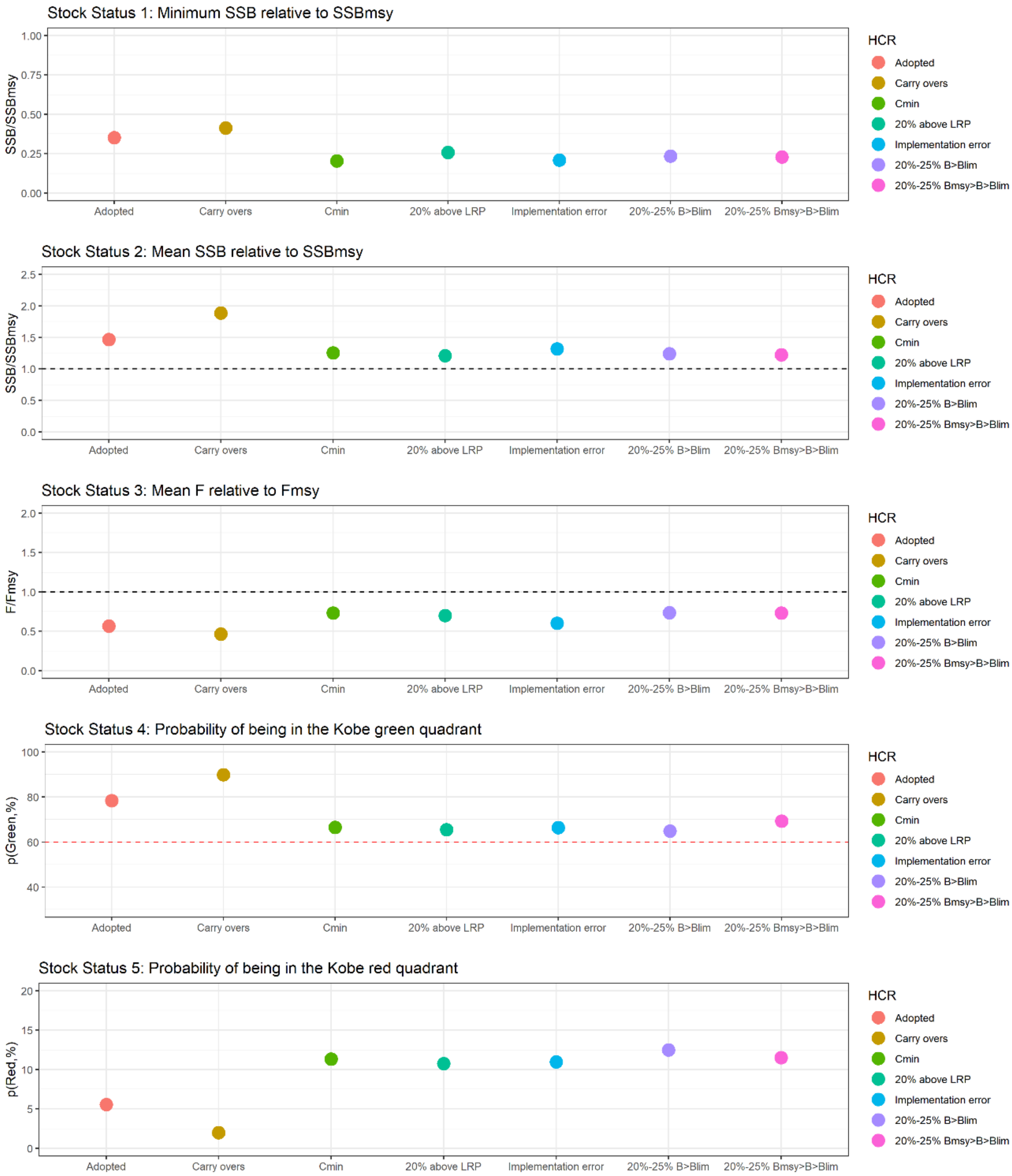

Figure 13. Stock status indicators for the evaluated HCRs.

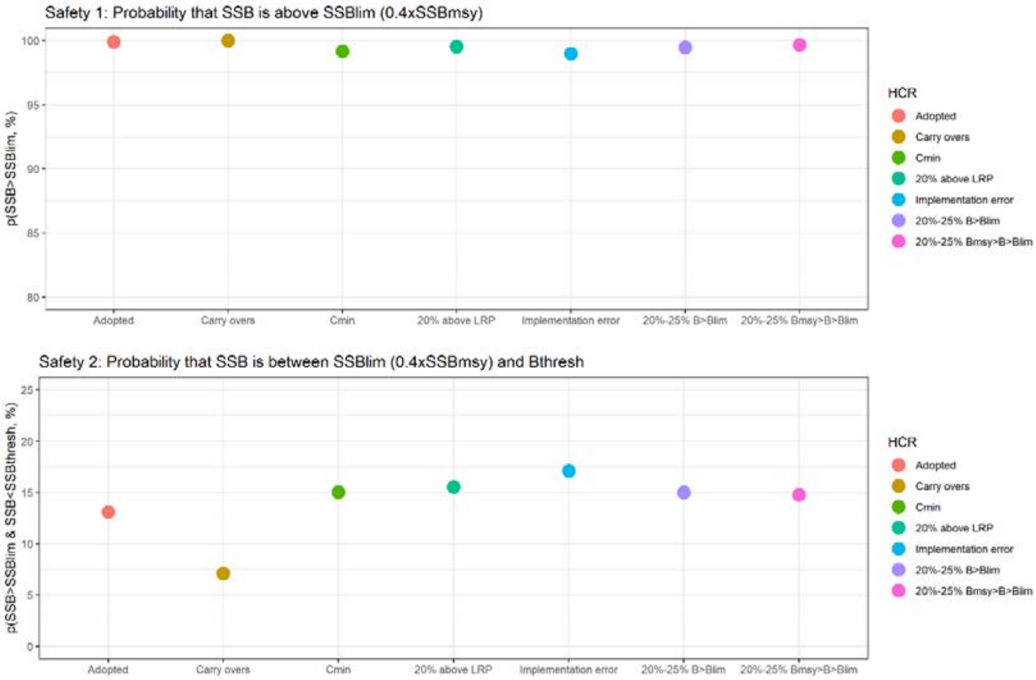

Figure 14. Safety indicators for the evaluated HCRs.

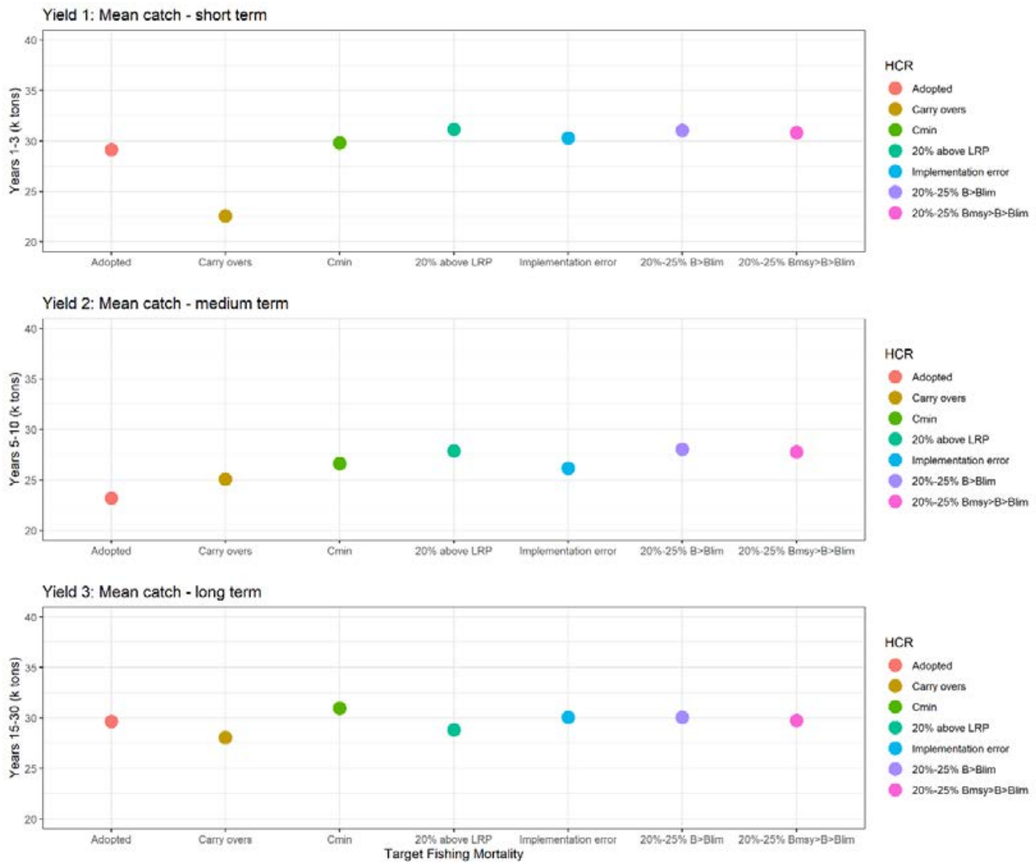

Figure 15. Catch indicators for the evaluated HCRs.

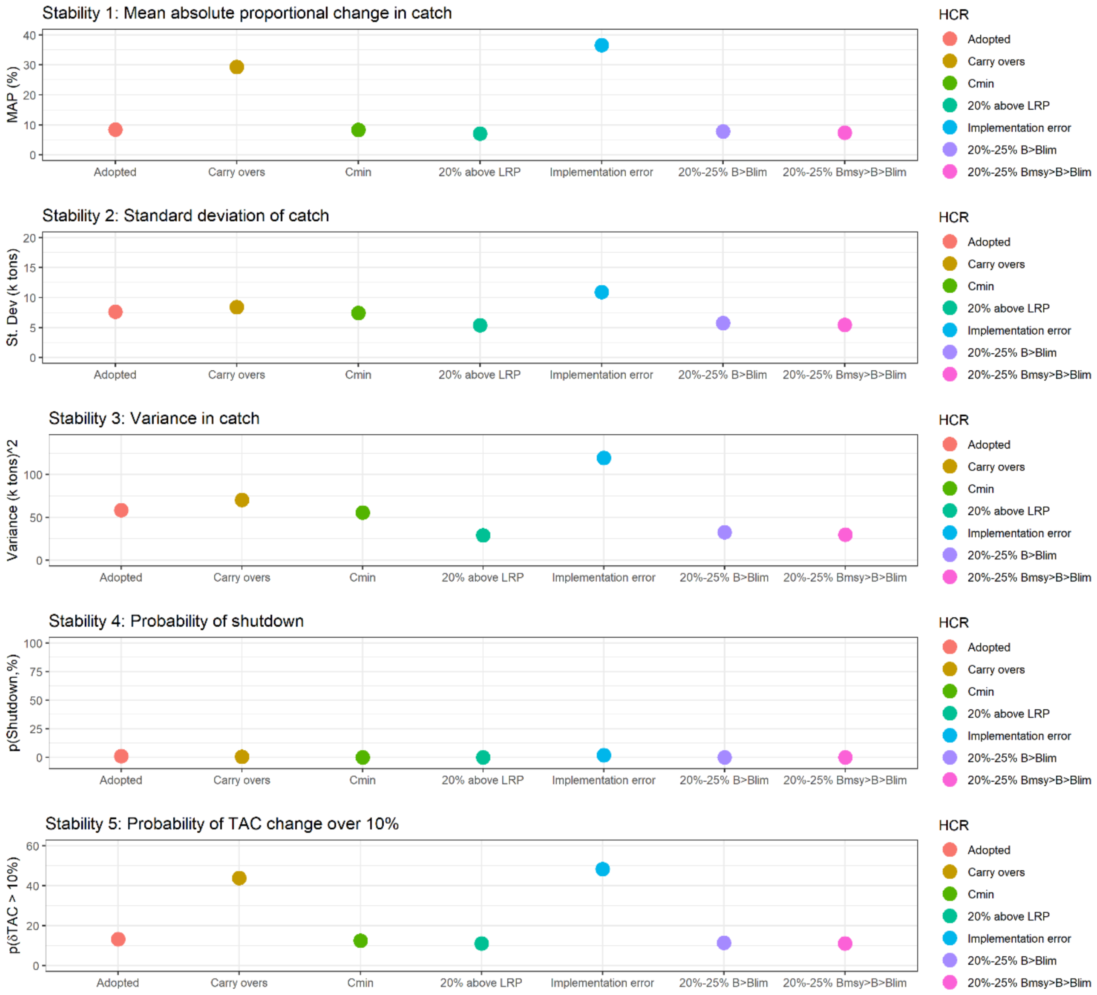

Figure 16. Stability indicators for the evaluated HCRs.

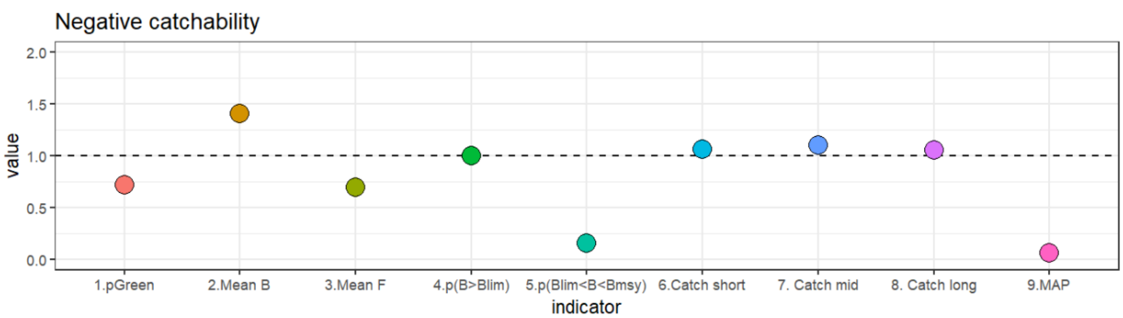

Figure 17. Performance of the adopted HCR for negative catchabiltiy OMs.

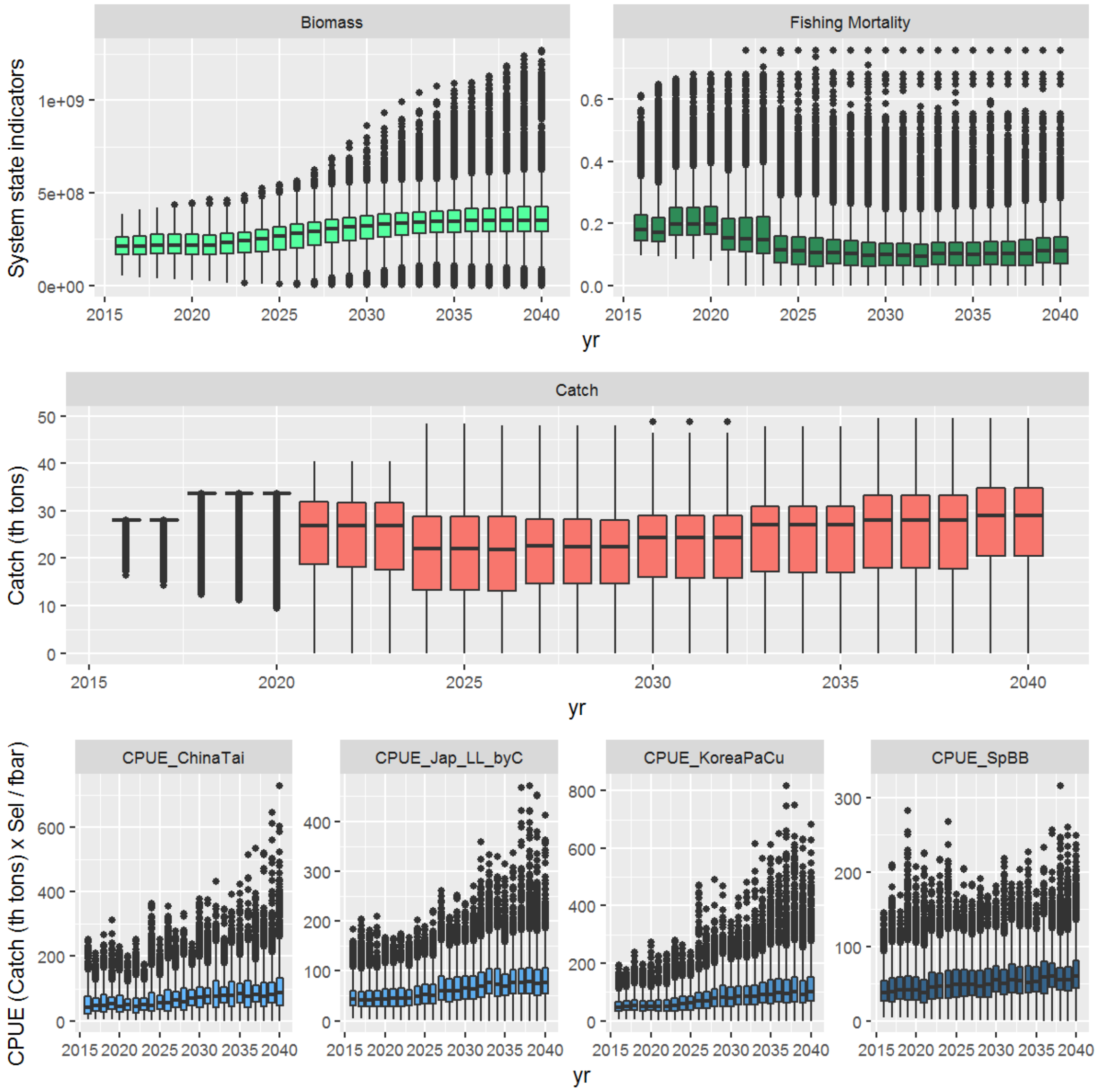

Figure 18. Values of indicators estimated per year across the Reference Set of OMs when evaluating the HCR adopted in Rec 17-04. Boxplots contain (25-75% quantiles), whisks contain (5-95% quantiles), points are outlier points.

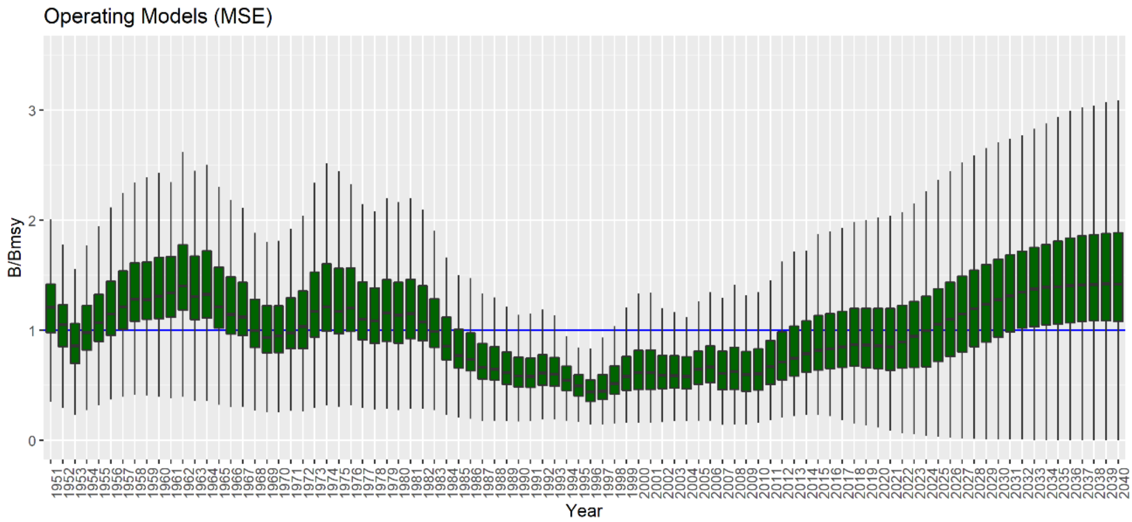

Figure 19. Relative biomass levels estimated in the OMs of the North Atlantic albacore MSE. Boxplots contain (25-75% quantiles), whisks contain (5-95% quantiles).

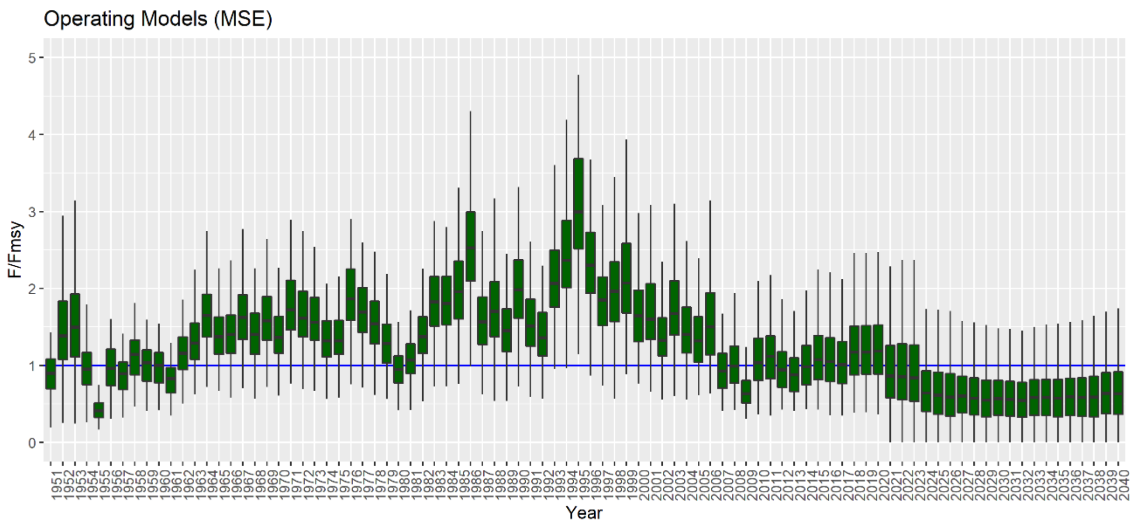

Figure 20. Relative fishing mortality estimated in the OMs of the North Atlantic albacore MSE. Boxplots contain (25-75% quantiles), whisks contain (5-95% quantiles).

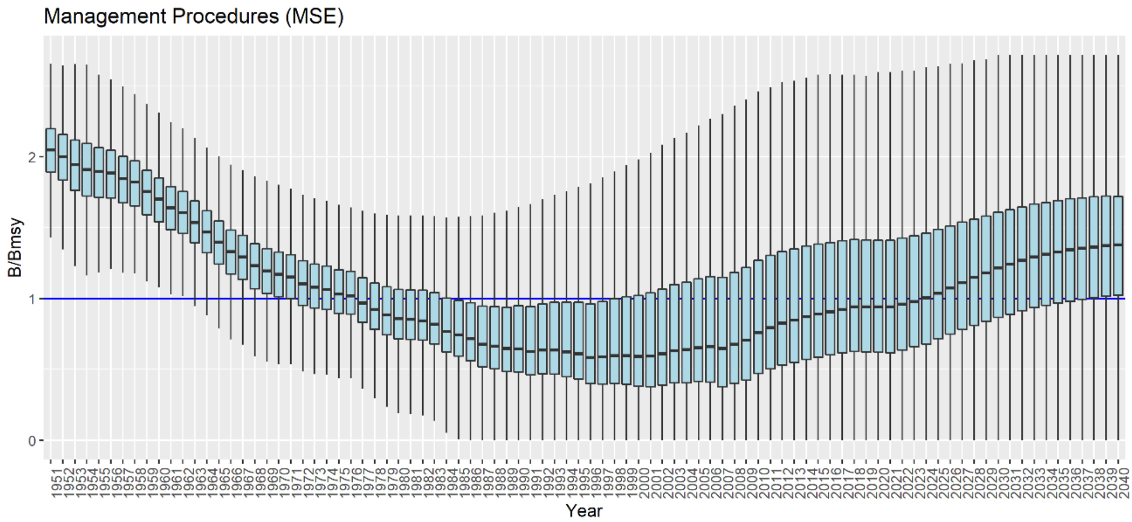

Figure 21. Relative biomass levels estimated in the adopted MP of the North Atlantic albacore MSE. Boxplots contain (25-75% quantiles), whisks contain (5-95% quantiles).

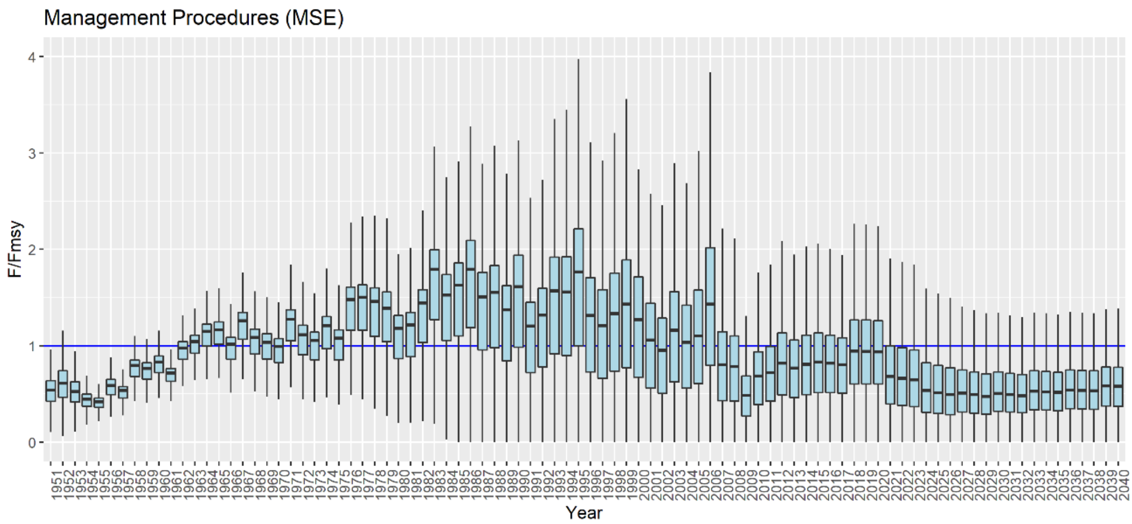

Figure 22. Relative fishing mortality estimated in the adopted MP of the North Atlantic albacore MSE. Boxplots contain (25-75% quantiles), whisks contain (5-95% quantiles).

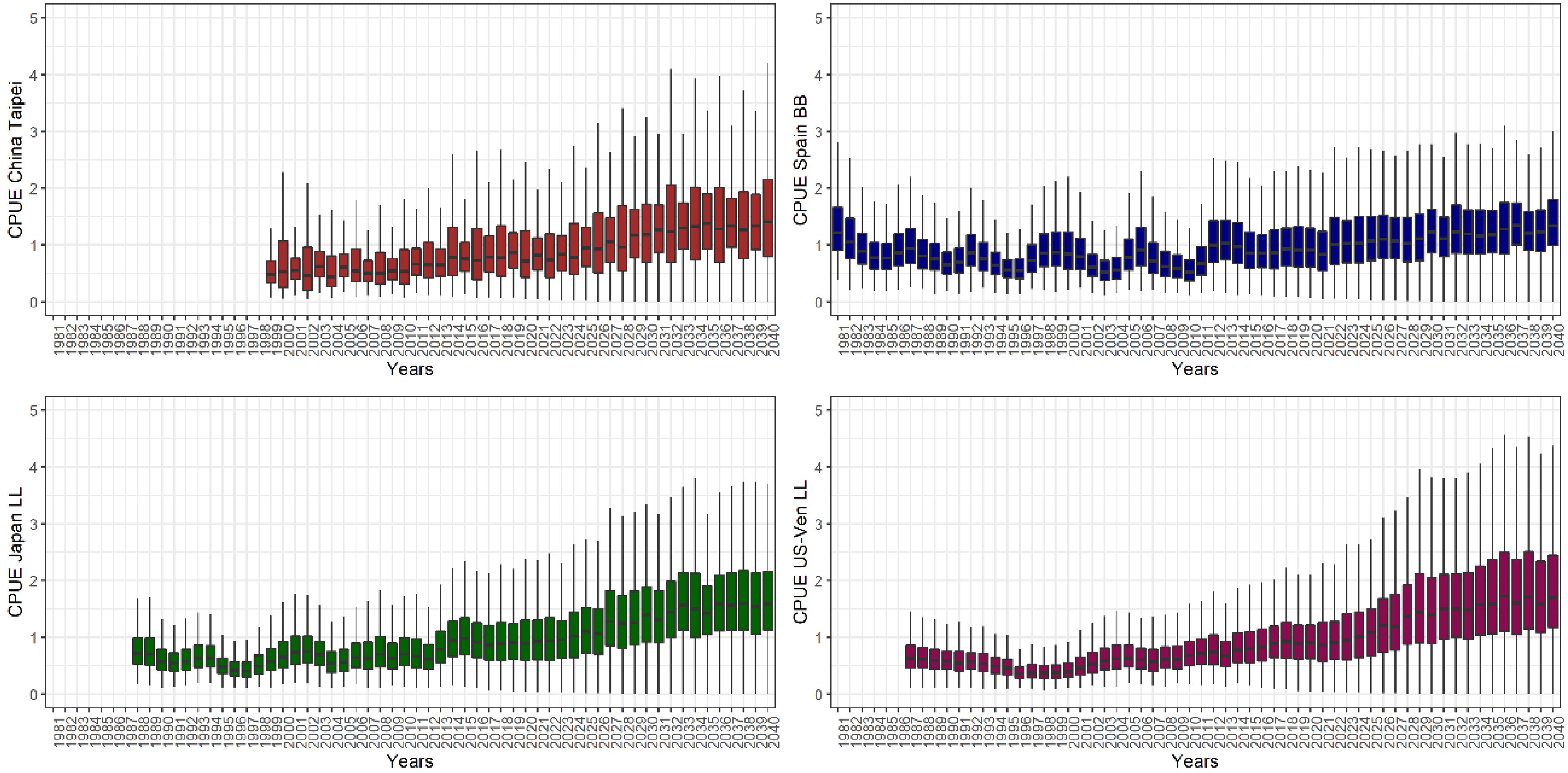

Figure 23. CPUEs simulated in the MSE for the entire period of the simulation.

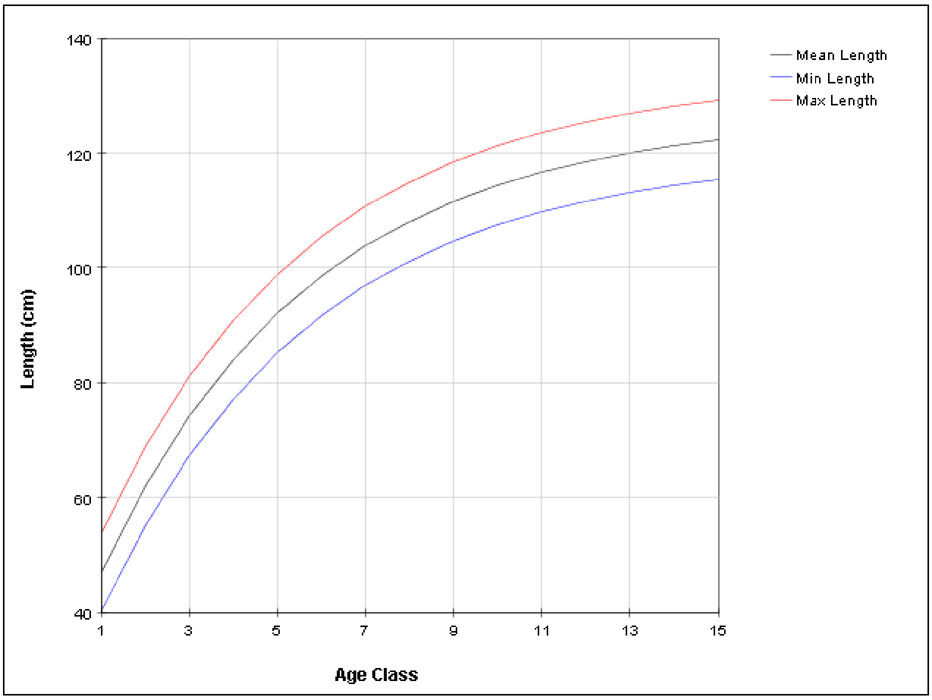

Figure 24. Growth curve used in the MULTIFAN-CL base model, taken from the 2013 stock assessment report.

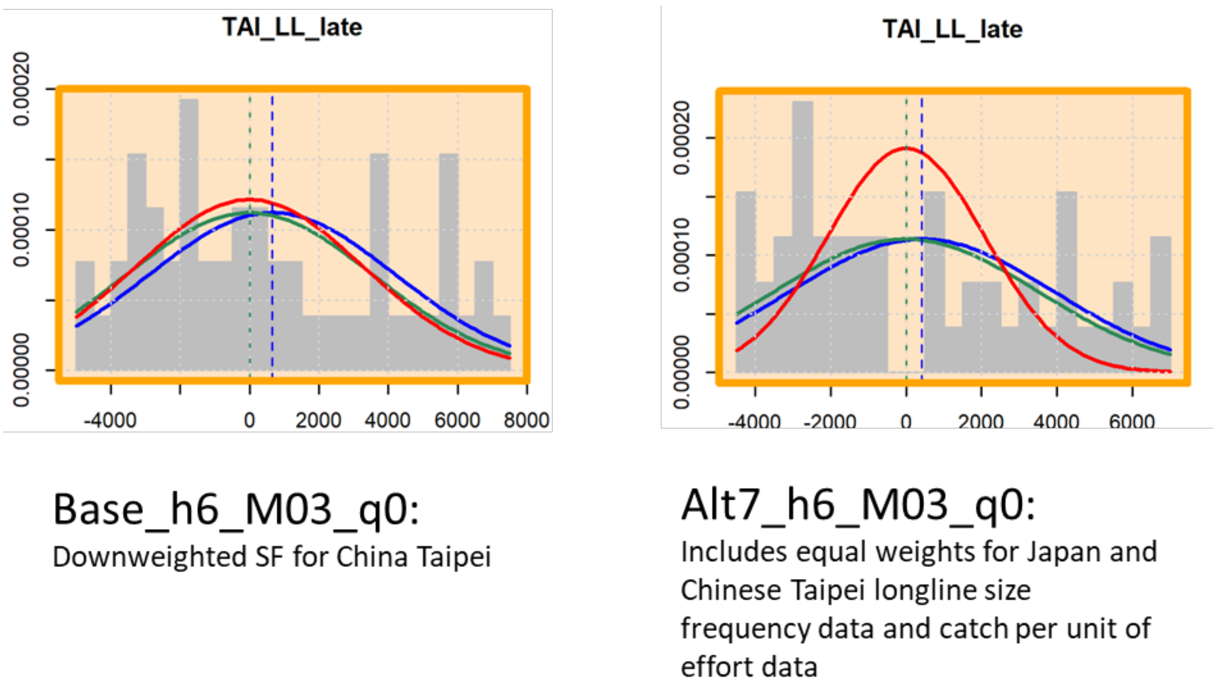

Figure 25. Histogram of residuals for the Chinese Taipei longline (late) index in the Base scenario and scenarios that include size frequency data and CPUE for this fleet.

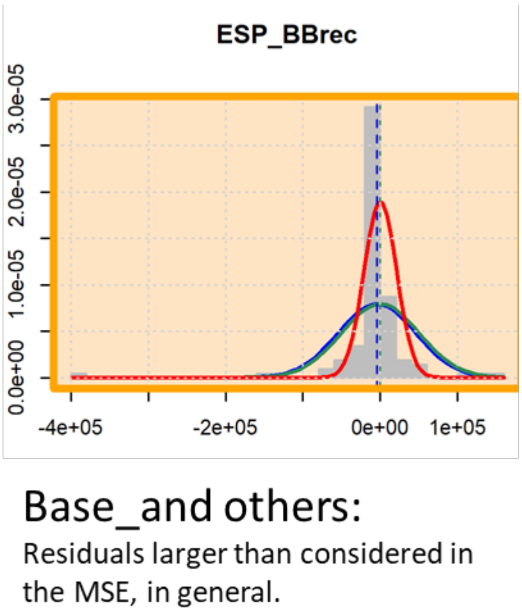

Figure 26. Histograms that show that the residuals for the Spanish baitboat CPUE may be larger than considered in the MSE.