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Northwest Atlantic Fisheries Organization

Report of the NAFO Joint Commission-Scientific Council Working Group on Risk-Based Management Strategies (WG-RBMS) Meeting

10-12 April 2019
Brussels, Belgium

NAFO
Dartmouth, Nova Scotia, Canada
2019

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1. Opening by the co-Chairs, Carmen Fernández (European Union) and Jacqueline Perry (Canada)

The meeting was opened at 09:00 hours on 10 April 2019 at the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG-MARE) in Brussels, Belgium. The co-Chairs, Carmen Fernández (European Union) and Jacqueline Perry (Canada), welcomed representatives from Canada, the European Union, Norway and the United States of America (Annex 1).

2. Appointment of Rapporteur

The NAFO Secretariat (Tom Blasdale, NAFO Scientific Council Coordinator) was appointed as rapporteur.

3. Adoption of Agenda

The agenda was adopted as circulated (Annex 2).

4. 3M Cod Management Strategy Evaluation (MSE)

a. Review objectives for the current meeting, taking into account the MSE timeline agreed by the Commission in September 2018.

Meeting participants considered the agreed MSE timeline, including the intersessional work to be conducted by the 3M cod MSE technical team, the tasks assigned to the Scientific Council (SC) Cod Management Strategy Evaluation meeting held 28-31 January 2019 and the objectives for the present WG-RBMS meeting. It was noted that generally all tasks had been completed according to the timeline so far.

b. Presentation of the single overall "*guiding and summary*" document for the 3M cod MSE process.

The need for an overall "*guiding and summary*" document was proposed in the SC January 2019 MSE meeting, where it was agreed to produce a single document which would include all the work done by both SC and WG-RBMS. This document should capture the main points of agreement and associated rationale and refer to other documents, as appropriate, for technical details. The aim of the "*guiding and summary*" document would be to enable future reviewers to follow through the complete MSE process from beginning to end. The completion of this type of document was identified as a gap in the Greenland halibut MSE process and recognized as an important step to include in future MSE work. Each meeting agenda of this MSE process should include an item to agree on the summary points for inclusion in this document. The Secretariat will lead its preparation.

The Secretariat will retain all code and the datasets used in the MSE and consider options for sharing the code externally though an online open source platform (e.g. GitHub). It was noted that in order for the code to be practical for external users, it will require some degree of annotation. The intention is not to produce a software package for external users but at a minimum to provide code in a form that can be easily understood. The Secretariat will develop a plan for storing and sharing the code and datasets, which should be provided by the 3M cod MSE technical team.

c. Presentation of main results from the 3M cod MSE Scientific Council meeting, January 2019.

The SC Chair (Brian Healey) presented the work of the January SC meeting (SCS Doc. 19-04), including the two HCR types discussed at the meeting (trend and target based) and the initial agreed set of candidate OMs.

A summary of the trial specifications (HCR settings and OM settings) agreed at the SC January 2019 MSE meeting, together with abbreviations that have been used in the standardized nomenclature, is presented in Table 1. The agreed OM settings resulted in a total of 28 OM variants. These are as follows: three (3) options for natural mortality in historical years, three (3) options for recruitment in future years and three (3) options for biological parameters in future years. When combined, this results in 27 OMs (3x3x3), all of which use flat-shaped survey selectivity. One extra OM allowing for dome-shaped survey selectivity is also included in Table 1, in principle to be examined as a robustness trial using Base-Case settings (see Table 1) for all /other variables. A full description of the OM settings can be found in the SC January 2019 MSE meeting report (SCS Doc. 19-04).

Table 1. Specifications of the scenarios. Base-Case OM in bold

	Variables	Scenarios		
HCR settings	HCR names	Model-Free Slope (MFS)	Model-Free Target (MFT)	
	α (tuning parameter in HCR)	1.0 (A10)	1.5 (A15)	
	Constraint on inter-annual TAC change	None (Cnone)	±20% (C20)	
	Starting Point*	TAC(2019)=17500 t (SP0)	TAC(2019)–25%=13125 t (SP25)	
OM settings	Natural Mortality (until year 2017)	**M vector (MV)**	M GADGET (MG)	M Steps (MS)
	Recruitment (2018 onwards)	**Bin Ricker (BR)**	Hockey Stick (HS)	Low Bin Ricker (LBR)
	Biological parameters (2018 onwards)	**Random walk (RW)**	3 Years Mean (3Y)	Density Dependent (DD)
	Groups q (age groups for survey catchability)	**Flat Shape (F)**	Dome Shape (D)	

* When the management strategy is applied for the first time (i.e. for year 2020 in the MSE simulation), the TAC obtained from the HCR is calculated starting from this value instead of starting from the adopted 2019 TAC.

d. Review of initial MSE results based on the initial set of operating models (OM) and candidate harvest control rules (HCR) agreed in the January SC meeting.

The preliminary HCRs considered at the SC January 2019 MSE meeting were extended for the present WG-RBMS meeting so as to include tuning parameters, and are as described below. The biomass and recruitment indices used in the HCRs are calculated from the EU survey.

<u>Model-Free Slope (MFS) HCR:</u>

$$TAC_{y+1} = TAC_y\left[1 + \lambda_y \cdot slope_y\right],\ \text{where}$$

$slope_y$ is the slope of a regression line fit to the four previous total biomass indices (indices in log-scale), and:

$$\lambda_y = \begin{cases} \min(\alpha, RR_y), & \text{if } slope_y \geq 0 \\ 2 - \min(\alpha, RR_y), & \text{if } slope_y < 0 \end{cases}, \quad \text{with } \alpha \in [1{,}1.5] \text{ used as a tuning parameter.}$$

<u>Model-Free Target (MFT) HCR:</u>

$$TAC_{y+1} = TAC_y\left[1 + \lambda_y \cdot (J_y - 1)\right], \qquad \text{where}$$

J_y is the ratio of recent (three-year) average of total biomass indices to a "*target*" biomass level, as follows:

$$J_y = \tfrac{1}{3} \cdot (I_{y-1} + I_{y-2} + I_{y-3})/I_{target},\ \text{with } I_{target} = (\tfrac{1}{10}) \cdot \textstyle\sum_{i=2008}^{2017} I_i, \quad \text{and}$$

$$\lambda_y = \begin{cases} \min(\alpha, RR_y), & \text{if } J_y \geq 1 \\ 2 - \min(\alpha, RR_y), & \text{if } J_y < 1 \end{cases}, \quad \text{with } \alpha \in [1{,}1.5] \text{ used as a tuning parameter.}$$

In both HCRs, RR_y is computed from the age-1 survey abundance indices, as the ratio of recent recruitment (geometric mean of three previous years) to the geometric mean level over the 1988-2017 years, i.e.

$$RR_y = \frac{\left(R_{y-1} \cdot R_{y-2} \cdot R_{y-3}\right)^{1/3}}{\left(\prod_{i=1988}^{2017} R_i\right)^{1/30}}.$$

The variable λ_y controls the degree to which the TAC changes in response to changes in stock biomass (slope HCR) or the distance between recent and "*target*" stock biomass (target HCR). The parameter α, which was equal to 1 in the HCR version seen at the SC January 2019 MSE meeting, can be used as a tuning parameter, i.e. a range of values can initially be considered for α with its final value selected after examining the outcomes of relevant performance statistics from the MSE simulations.

An exploration of some of the properties of the HCRs, prior to their testing via MSE, is included in Annex 3 of this report. The analysis examines the magnitude of possible interannual TAC changes that may result when these rules are applied, and offers insights that can inform appropriate HCR settings, in terms of HCR performance, before conducting involved MSE simulation work.

The HCRs developed for the WG-RBMS meeting also consider the possible inclusion of constraints in interannual TAC changes and starting values for the first year of application of the HCR (which, in the MSE simulations, corresponds to setting the TAC for 2020) different from the 2019 TAC (see Table 1).

As done in the work presented at the SC January 2019 MSE meeting, a minimum TAC of 1000 t was incorporated in the MSE simulations, to avoid being trapped in a 0-TAC situation. Hence, whenever the HCR resulted in a TAC less than 1000 t, it was assumed that the TAC would be 1000 t, and this was the value used in the HCR when calculating the TAC for the following year.

The MSE simulations conducted so far assumed that the catch taken is equal to the TAC, except in the following circumstances, which result in catch lower than the TAC:

- if the TAC obtained from the HCR is bigger than 90% of the ("*true*") stock biomass, then the catch taken is 90% of the stock biomass;
- if the TAC obtained from the HCR, or the catch obtained from the previous bullet point, corresponds to catch numbers larger than the population numbers for one or more of the ages, then the actual catch taken from such ages equals the population numbers of those ages.

Of all scenarios possible from Table 1 (combinations of 27 OM settings and 8 HCR settings for each of the 2 different HCRs, resulting in 432 scenarios, to which the robustness trial with the dome-shaped survey catchability OM is added), the 22 scenarios displayed in Table 2a had been run in advance of the WG-RBMS meeting and were available for examination at the meeting. In terms of OMs, these 22 scenarios are all based on MV and MG settings for natural mortality, BR and HS settings for recruitment, and RW and 3Y settings for future biological parameters, and were selected following the schedule agreed at the SC January 2019 MSE meeting and after further prioritisation emerging from subsequent discussion of the cod MSE technical team. Other scenarios, particularly those based on the OM settings MS, LBR and DD (right-most column of Table 1), will be run in the coming months.

During the present WG-RBMS meeting, 8 additional scenarios assuming no catch were run. The scenarios are described in Table 2b, where it should be noted that HCR settings, labelled "alfa", "Constraint" and "Starting Point" in the table, are irrelevant when F=0. The F=0 scenarios had been agreed at the SC January 2019 MSE meeting for presentation at the June SC meeting. Such evaluations provide expected results if there is no fishing, allowing decisions on HCRs to be informed of the relative impact of the corresponding removals. However, after seeing the initial MSE results, the WG-RBMS meeting decided it was important to run them and examine their results during the present meeting (see discussion below).

Table 2. Scenarios with MSE results available at the WG-RBMS meeting.

a) Table 2a: Scenarios for slope and target HCRs

	HCR				alfa		Constraint		Starting Point		M			Q		R			BP			RUN
	MFS	MFT	F0	Trigger	**A10**	A15	**Cnone**	C20	**SP0**	SP25	**MV**	**MG**	MS	**QF**	QD	**BR**	**HS**	LBR	**RW**	**3Y**	DD	Y/N
1. MFS_A10_Cnone_SP0_MV_QF_BR_RW	X				X		X		X		X			X		X			X			y
2. MFS_A10_Cnone_SP0_MV_QF_BR_3Y	X				X		X		X		X			X		X				X		y
3. MFS_A10_Cnone_SP0_MV_QF_HS_RW	X				X		X		X		X			X			X		X			y
4. MFS_A10_Cnone_SP0_MV_QF_HS_3Y	X				X		X		X		X			X			X			X		y
5. MFS_A10_Cnone_SP0_MG_QF_BR_RW	X				X		X		X			X		X		X			X			y
6. MFS_A10_Cnone_SP0_MG_QF_BR_3Y	X				X		X		X			X		X		X				X		y
7. MFS_A10_Cnone_SP0_MG_QF_HS_RW	X				X		X		X			X		X			X		X			y
8. MFS_A10_Cnone_SP0_MG_QF_HS_3Y	X				X		X		X			X		X			X			X		y
9. MFT_A10_Cnone_SP0_MV_QF_BR_RW		X			X		X		X		X			X		X			X			y
10. MFT_A10_Cnone_SP0_MV_QF_BR_3Y		X			X		X		X		X			X		X				X		y
11. MFT_A10_Cnone_SP0_MV_QF_HS_RW		X			X		X		X		X			X			X		X			y
12. MFT_A10_Cnone_SP0_MV_QF_HS_3Y		X			X		X		X		X			X			X			X		y
13. MFT_A10_Cnone_SP0_MG_QF_BR_RW		X			X		X		X			X		X		X			X			y
14. MFT_A10_Cnone_SP0_MG_QF_BR_3Y		X			X		X		X			X		X		X				X		y
15. MFT_A10_Cnone_SP0_MG_QF_HS_RW		X			X		X		X			X		X			X		X			y
16. MFT_A10_Cnone_SP0_MG_HS_3Y		X			X		X		X			X		X			X			X		y
17. MFS_A15_Cnone_SP0_MV_QF_BR_RW	X					X	X		X		X			X		X			X			y
18. MFS_A10_C20_SP0_MV_QF_BR_RW	X				X			X	X		X			X		X			X			y
19. MFS_A10_Cnone_SP25_MV_QF_BR_RW	X				X		X			X	X			X		X			X			y
20. MFT_A15_Cnone_SP0_MV_QF_BR_RW		X				X	X		X		X			X		X			X			y
21. MFT_A10_C20_SP0_MV_QF_BR_RW		X			X			X	X		X			X		X			X			y
22. MFT_A10_Cnone_SP25_MV_QF_BR_RW		X			X		X			X	X			X		X			X			y

b) Table 2b: Scenarios with F=0 (the HCR settings, labelled "alfa", "Constraint" and "Starting Point", are irrelevant when F=0)

	HCR				alfa		Constraint		Starting Point		M			Q		R			BP		
	MFS	**MFT**	F0	Trigger	**A10**	A15	**C100**	C20	**SP0**	SP25	**MV**	**MG**	MS	**QF**	QD	**BR**	**HS**	LBR	**RW**	**3Y**	DD
01. F0_A10_Cnone_SP0_MV_QF_BR_RW			X		X		X		X		X			X		X			X		
02. F0_A10_Cnone_SP0_MV_QF_BR_3Y			X		X		X		X		X			X		X				X	
03. F0_A10_Cnone_SP0_MV_QF_HS_RW			X		X		X		X		X			X			X		X		
04. F0_A10_Cnone_SP0_MV_QF_HS_3Y			X		X		X		X		X			X			X			X	
05. F0_A10_Cnone_SP0_MG_QF_BR_RW			X		X		X		X			X		X		X			X		
06. F0_A10_Cnone_SP0_MG_QF_BR_3Y			X		X		X		X			X		X		X				X	
07. F0_A10_Cnone_SP0_MG_QF_HS_RW			X		X		X		X			X		X			X		X		
08. F0_A10_Cnone_SP0_MG_QF_HS_3Y			X		X		X		X			X		X			X			X	

The MSE simulations were developed using the FLBEIA software (Garcia et al., 2017), which was presented during the SC January 2019 MSE meeting. FLBEIA is a software to perform bio-economic evaluation of fisheries management strategies and is based on R and FLR libraries. It has been applied to several case studies in single stock as well as mixed fisheries contexts, with different conservation or management objectives, and was also previously used for 3M cod. The model can be downloaded from github (https://github.com/flr/FLBEIA) and tutorials are available at the web site (http://www.flr-project.org/doc/index.html).

Inputs to the MSE and results for the 22 + 8 scenarios in Tables 2a and 2b are presented in detail in Annex 4.

When examining the MSE inputs, it was noted that simulating future recruitment residuals by sampling historical recruitment residuals within SSB bins implied biased residuals within the SSB bins (for example, with the BR recruitment OM setting, the bin corresponding to SSB values larger than SSB_{2007} but smaller than SSB_{2010} resulted in a large proportion of simulated recruitments being above the Ricker curve); additionally, the small numbers of historical years from which to sample in each SSB bin led to large variations in the simulated future recruitment values. None of this was unexpected, given that simulation of future recruitment was discussed at length in the SC January 2019 MSE meeting and the current implementation was agreed then as a way forward. Some possible alternatives for future recruitment simulation discussed during the WG-RBMS meeting included dividing the past into low and high productivity "*regimes*" and sampling from those two "*regimes*" separately, or incorporating time autocorrelation in the future recruitment simulation. The WG-RBMS meeting agreed that further consideration of recruitment simulation was relevant and that alternative methods of generating recruitment values should be considered in future MSE work and presented to SC if the decision in September 2019 is to continue with the 3M cod MSE (see discussion below).

Some observed features in the MSE results were as follows: the HCRs often resulted in very low future catches and F values, which indicates a need for further exploration of alternative HCR settings. The MSE results need to be further analysed and understood. It was also observed that future uncertainty ranges were very wide (see e.g. Figure 1 for the slope HCR, or Figure 2 for F=0). The meeting was concerned about this large uncertainty and about the fact that all of the OMs resulted in more than 10% probability of the stock being below B_{lim} in some future years when the slope or target HCRs are applied (see SSB/B_{lim} panel in Figure 1, and Figures 3 and 4 in Section 4.e).

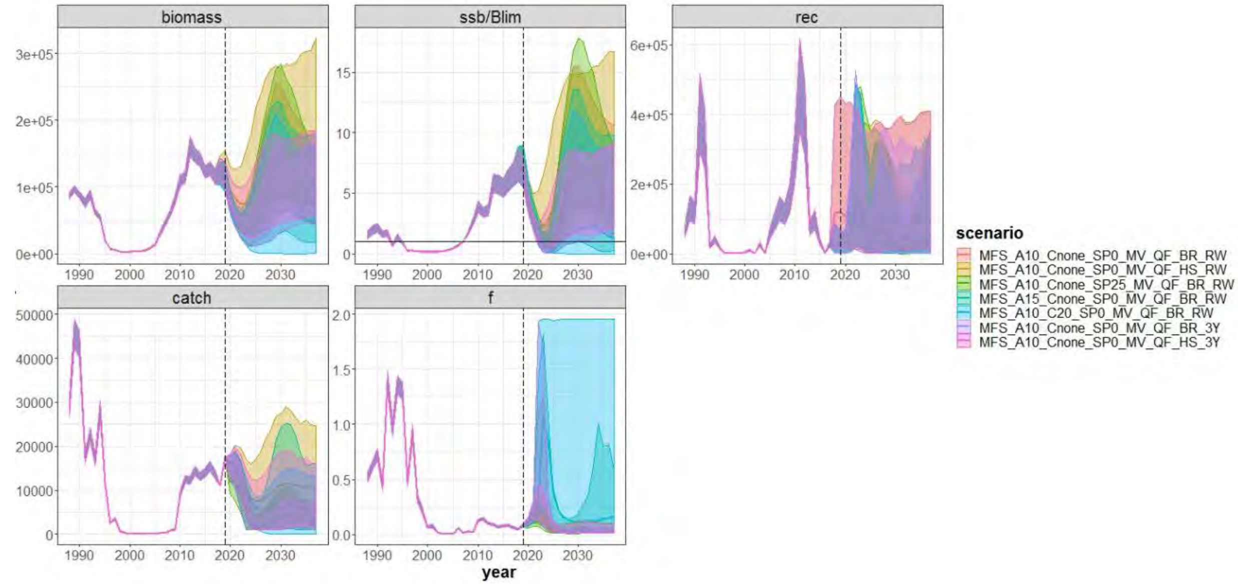


Figure 1. MSE results (10th to 90th percentile ranges) for the slope HCR (MFS), under alternative HCR and OM settings.

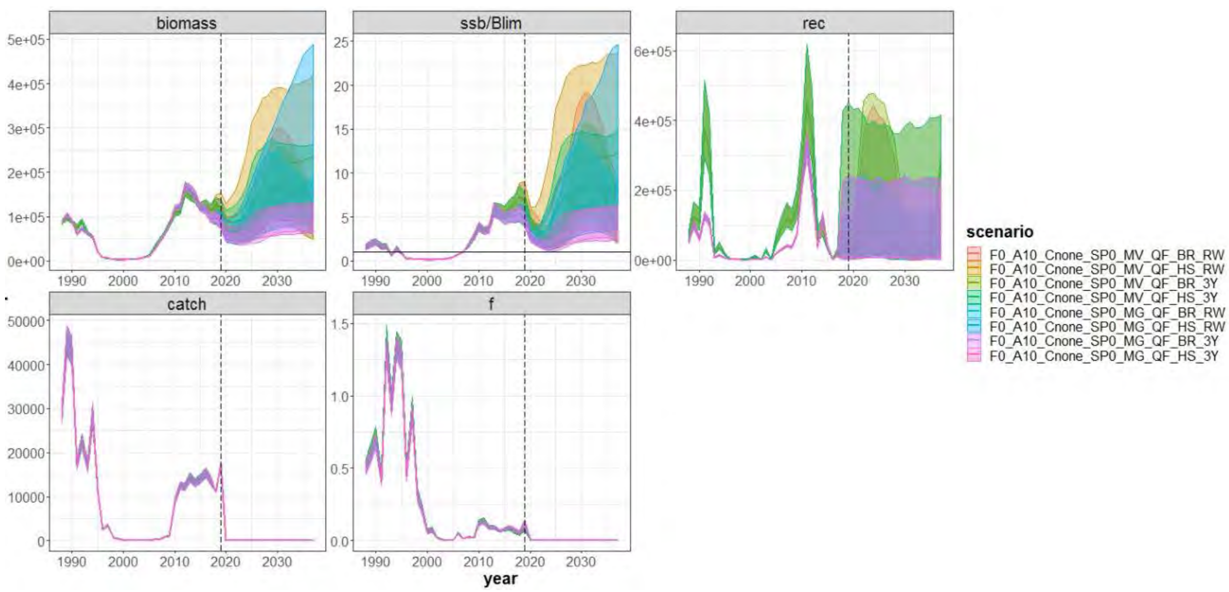


Figure 2. MSE results (10th to 90th percentile ranges) with F=0, under alternative OM settings.

e. Update and possibly finalization of Performance Statistics (PS) and associated risks levels.

The technical team of scientists working on the cod MSE presented an updated table of performance statistics and criteria for consideration and discussion at the WG-RBMS meeting (Table 3, with details provided in Annex 5).

With respect to the management objective "*Restore to within a prescribed period of time or maintain at* B_{MSY}", the following statement in the SC January 2019 MSE meeting report was noted: "*Due to issues related to* B_{MSY} *estimates, no* B_{MSY} *value has been proposed as an a priori performance statistic. If managers need* B_{MSY} *as a target to meet convention obligations, then we would be able to calculate a value retrospectively corresponding to the management strategy that would give highest long-term yield values in the projections and the associated* *biomass*.” Therefore no performance statistic involving B_{MSY} was included in the set of potential performance statistics presented by the technical team. It was proposed in the table that this level be achieved in the long term as required (2037) and that it is advisable to achieve it already in the medium term (2030). It was also noted in the table that it would be necessary to discuss which is the level of SSB that one wishes to reach in the future and how to estimate it.

As agreed during the SC January 2019 MSE meeting, the proportion of the cod stock biomass in the plus age group and the probability of stock collapse were included as potential performance statistics (see Table 3).

A “*Low risk of steep decline*” performance statistic, which was used in the Greenland halibut MSE, has not been considered for the 3M cod stock. The reason for not including it is that this cod stock changes very rapidly and steep stock decline, from its recent historical maximum, is expected in the near future regardless of any HCR that may be applied. One possibility might be to consider a statistic of this type, but evaluating it for the years after the current decline is expected to end (e.g. from about year 2025).

Following the presentation of the updated table, it was agreed to defer the discussion and finalization of the performance statistics in a subsequent working group meeting.

Table 3. Draft performance statistics/criteria

REQUIRED PERFORMANCE STATISTICS/CRITERIA			
Performance statistic	**Performance criterion**	**Relevant management objective**	**Notes**
PS1: for y = 2020 to 2037: $count_y[P(B_y<B_{lim})>0.1]$ i.e. count for how many years in the period the $P(B_y<B_{lim})$ is bigger than 0.1.	Count	Very low risk of going below an established threshold [e.g. *Blim* or *Blim* proxy].	It would be convenient to show a table with the value of $P(B_y<B_{lim})$ year by year to see its evolution over time.
PS2: for y = 2025 to 2029: $count_y[P(Fy>FMSY)>0.3]$ for y = 2030 to 2037; $count_y[P(Fy>FMSY)>0.3]$ i.e. count for how many years in the period the $P(Fy>FMSY)$ is bigger than 0.3.	Count	Low risk of exceeding F_{lim} (currently F_{lim}=$F_{30\%SPR}$)	It would be convenient to show a table with the value of $P(Fy>FMSY)$ year by year to see its evolution over time.
DESIRABLE SECONDARY PERFORMANCE STATISTICS/CRITERIA			
Performance statistic	**Performance criterion**	**Relevant management objective**	**Notes**
PS2: for y = 2020 to 2024: $count_y[P(Fy>FMSY)>0.3]$	Count	Low risk of exceeding F_{lim} in the short term (currently F_{MSY})	It would be convenient to show a table with the value of this PS year by year to see its evolution over time.
PS3: $\sum_{y=2020}^{2024} C_y/5$ $\sum_{y=2020}^{2029} C_y/10$ $\sum_{y=2020}^{2037} C_y/18$ i.e. average catch over the stated period of years.		Maximize yield in the short, medium and long term	It would be advisable to show this PS by making a graph with the median and the percentiles (10, 90) of the distribution of average catch in each of the 3 time-periods considered. The plot would include the different HCRs and OMs, for ease of comparison.
PS4: For each year (2020-2037), for the scenarios without constraint on inter-annual TAC change, calculate: $P\left[\left(\frac{\lvert TAC_y-TAC_{y-1}\rvert}{TAC_{y-1}}\right)>0.10\right]$ $P\left[\left(\frac{\lvert TAC_y-TAC_{y-1}\rvert}{TAC_{y-1}}\right)>0.15\right]$ $P\left[\left(\frac{\lvert TAC_y-TAC_{y-1}\rvert}{TAC_{y-1}}\right)>0.20\right]$ i.e. probability that the TAC changes by more than 10%, 15% or 20% (relative to the TAC of the previous year).	Probability	Keep inter annual TAC variation below "an established threshold"	Graph showing, for each of the 3 values (10%, 15%, 20%), the probability per year. This would give information on appropriate levels for the inclusion of a TAC constraint as part of the HCR.
The following PS is for all scenarios: $iter\_mean=\frac{1}{18}\sum_{y=2020}^{2037}\left(\frac{\lvert TAC_y-TAC_{y-1}\rvert}{TAC_{y-1}}\right)$ i.e. average inter-annual TAC change over the years 2020-2037.	Mean(iter_mean)	Minimize annual TAC variation in the long term	For each iteration in the MSE simulation, an average inter-annual TAC change over the period 2020-2037 is estimated. Then a mean (i.e. an average) is taken over the MSE iterations. This will allow us to compare different HCRs for a given OM

PS5: For each year (2020-2037): $\text{Median}\left(\frac{\text{Biomass}_{y,8+}}{\text{Biomass}_y}\right)$		Measure the proportion of stock biomass in the Plus Group	It would be convenient to show a table with the value of this PS year by year, to see its evolution over time.
PS6: *P*(SSBy<SSB$_{1997}$ for ALL years of the period 2032-2037)	Probability	Measure the number of crashed iterations.	

The results of initial testing of both HCR types (slope and target) against the performance statistic PS1 for all 22 scenarios in Table 2a are shown in Figures 3 (for the 11 scenarios involving the slope HCR) and 4 (for the 11 scenarios involving the target HCR). There is a higher than 10% probability of going below B$_{lim}$ in the short term with all 22 OMs under both HCR types. With the current HCR settings, the probability of being below B$_{lim}$ in the long term remains higher than 10% in many of the scenarios, although it was noted that the HCRs will be refined in future MSE work, which may change the results.

PS1 results for the zero catch scenarios (Figure 5) showed that the probability of the stock biomass falling below B$_{lim}$ was less than 10% for any of the OMs tested; however, the low recruitment OM (LBR setting in Table 1, not yet tested but expected in future work) will likely result in more than 10% probability of the stock biomass falling below B$_{lim}$.

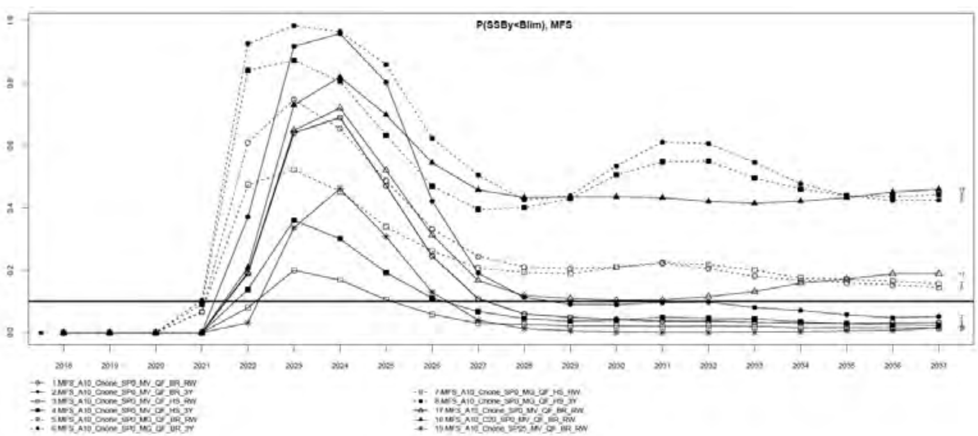


Figure 3. Yearly probabilities of the SSB being below B$_{lim}$, with the slope HCR. The horizontal line corresponds to 10% probability.

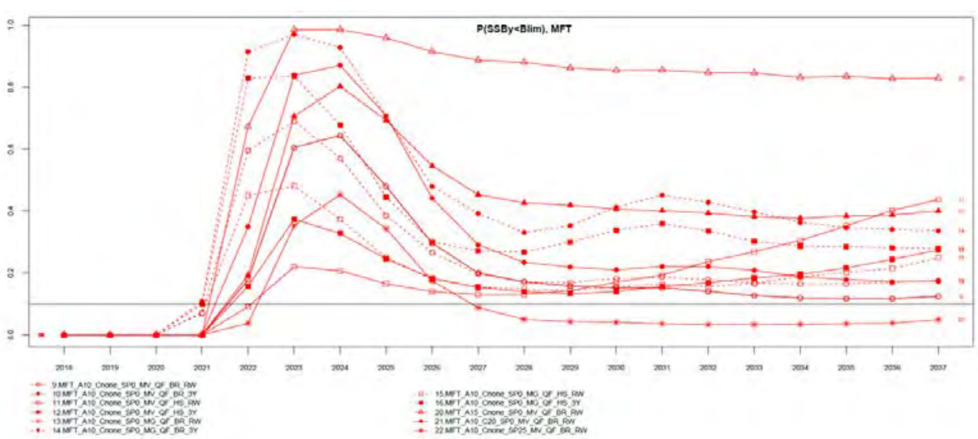


Figure 4. Yearly probabilities of the SSB being below B_{lim}, with the target HCR. The horizontal line corresponds to 10% probability.

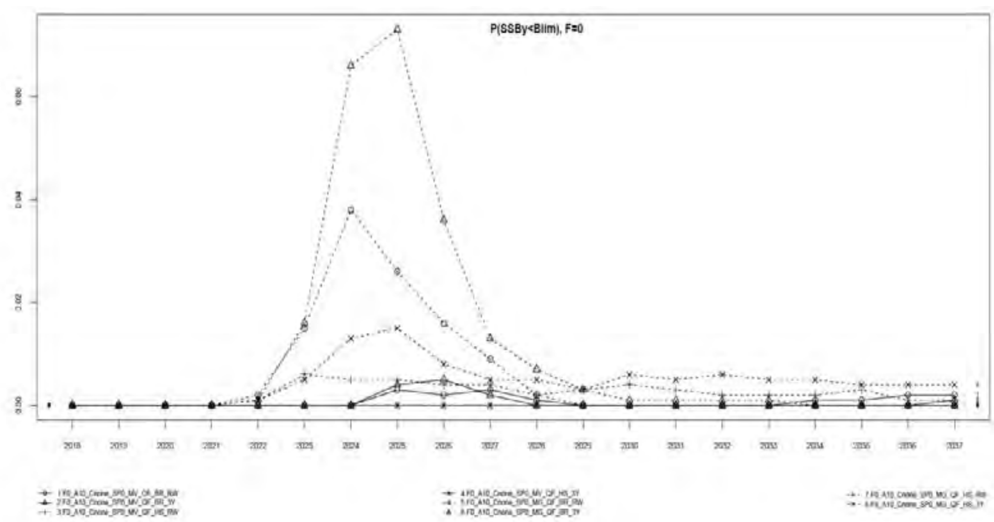


Figure 5. Yearly probabilities of the SSB being below B_{lim}, with F=0. Note that the vertical axis here goes up to approximately 0.08 whereas in Figures 3 and 4 it went up to 1. Here, all probabilities are smaller than 10%.

f. Identify where improvements in performance are most required to guide analysts in revising HCRs. In particular, identify desired features in terms of overall form of the HCR, potential ranges for maximum TAC change between years and starting TAC, indicating the order of priority.

Given the WG-RBMS decision to review in September the appropriateness of continuing with the 3M cod MSE work at this stage, which will in any case imply a delay relative to the timeline agreed last year for the cod MSE (see discussion in Section 4.g below), this agenda item was not addressed in the present WG-RBMS meeting.

g. Review the MSE timeline going forward from this meeting.

Initial testing of slope and target HCRs against the draft performance criteria showed that, in all scenarios, the probability of SSB dropping below B_{lim} was greater than 10% for at least one year (Figures 3 and 4). Only the F=0 scenario resulted in less than 10% probability of the stock falling below B_{lim} (Figure 5), although it is expected that the addition of a low recruitment OM (to be implemented in the coming months) will likely result in a greater than 10% probability of the stock biomass falling below B_{lim} even with F=0.

It was noted that in this stock biological parameters (weight and maturity at age) and recruitment have shown very high variability in the historical period. Projecting into the future without any obvious way of predicting how these variables will evolve in future years implies a very wide spectrum of possibilities for these variables in the future, which in turn results in very wide probability distributions (see e.g. Figures 1 and 2) and a high probability of failing the performance criteria.

Considering the initial set of MSE results against the draft performance criteria and the high variability and biological parameters of the stock, WG-RBMS discussed the likelihood that the MSE will produce results that will satisfy the performance criteria and therefore the merit in continuing the MSE work for this stock. The WG-RBMS also noted that given the stock dynamics and characteristics, it may not be a suitable candidate for a MSE approach.

It was agreed that the technical team will continue its work, including the development of the DD model and the low recruitment scenario. The WG-RBMS will meet prior to the NAFO Annual Meeting to consider the results and determine appropriate next steps in the MSE process including a revised timeline if the decision is to continue development of the MSE. In the interim, it was agreed that the SC at its June 2019 meeting will provide advice for the stock in 2020, if the technical team has new results for some of the approved scenarios available in time for the June SC meeting, those results could be reviewed by the SC in June along with those presented in this meeting.

WG-RBMS will meet prior to the NAFO annual meeting (Saturday, 21 Sept) to review the updated technical work, consider next steps including a revised timeline, if required, and formulate recommendations to the Commission.

h. Include main results and conclusions from the WG-RBMS meeting in the single overall "*guiding and summary*" document for the 3M cod MSE process.

This agenda item was covered in Section 4.b in terms of process. In line with that, once the present WG-RBMS meeting report is finalised, relevant parts of it will be extracted (by the NAFO Secretariat together with the WG-RBMS co-chairs) for inclusion in the "*guiding and summary*" MSE document. The parts to be extracted will consist of a very brief summary of the MSE scenarios and results presented at this meeting, followed by the conclusions from Sections 4.g and 6.

5. Other Business

No other business was considered at this meeting.

6. Recommendations to forward to the Commission and Scientific Council

There were no recommendations from this meeting but the overall conclusions were:

- Development of the MSE by the technical team should continue, with results of the candidate OMs approved in the 3M cod MSE meeting held in January 2019 to be presented to WG-RBMS in September 2019.
- WG-RBMS should meet in September 2019 to consider whether to proceed with the 3M cod MSE and, if the decision is to proceed, produce a revised timetable.
- Scientific Council at its June 2019 meeting should produce advice for 3M cod in 2020.

7. Date and Time of Next Meeting

The next meeting will be held on Saturday, 21 September 2019, in Bordeaux, France.

8. Adoption of Report

The report was adopted via correspondence.

9. Adjournment

The meeting was adjourned at 13:00 hours on 12 April 2019.

Literature cited

Garcia, D., S. Sánchez, et al. (2017). "*FLBEIA: A simulation model to conduct Bio-Economic evaluation of fisheries management strategies.*" SoftwareX 6: 141-147.

Annex 1. List of Participants

CO-CHAIRS

Fernandez Llana, Carmen. Instituto Español de Oceanografía (IEO). Avenida Príncipe de Asturias, 70 bis. 33212, Gijón, Spain
Tel: +34 985 308 672 – Email: carmen.fernandez@ieo.es

Perry, Jacqueline. Regional Director General, Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, 80 East White Hills, St. John's, NL A1C5X1 Canada
Tel: +1 709 772 4417 – Email: Jacqueline.perry@dfo-mpo.gc.ca

CANADA

Dwyer. Shelley. Regional Fisheries Management Officer, Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, 80 East White Hills, St John's, Newfoundland, A1C 5X1
Tel: +1 709 772-2080 – Email: Shelley.Dwyer@dfo-mpo.gc.ca

Fagan, Robert. Senior Resource Manager. Fisheries Management, Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, 80 East White Hills Road, St. John's, NL, A1C 5X1
Tel: +1 709 772 2920 – Email: Robert.Fagan@dfo-mpo.gc.ca

Healey, Brian. Science Advisor, Fisheries and Oceans Canada, Northwest Atlantic Fisheries Centre, 80 East White Hills, St. John's, NL A1C5X1
Tel: +1 709 772-8674 – Email: brian.healey@dfo-mpo.gc.ca

Milburn, Derrick. Senior Advisor, International Fisheries Management and Bilateral Relations, Fisheries and Oceans Canada, 200 Kent Street, Ottawa, ON K1A 0E6 Canada
Tel: +1 613 993 7967 – Email: Derrick.Milburn@dfo-mpo.gc.ca

Tibelius, Meghan. Second Secretary, Environment and Fisheries , Mission of Canada to the European Union, Government of Canada, Avenue des Arts 58, 1000 Brussels, Belgium
Tel: +32 (0)2 741 06 88 – Email: meghan.tibelius@international.gc.ca

EUROPEAN UNION (EU)

Alpoim, Ricardo. Instituto Portugues do Mar e da Atmosfera, Rua Alfredo Magalhães Ramalho, nº6, 1495-006 Lisboa, Portugal
Tel: +351 213 02 70 00 – Email: ralpoim@ipma.pt

Avila de Melo, Antonio. Instituto Portugues do Mar e da Atmosfera, Rua Alfredo Magalhães Ramalho, nº6, 1495-006 Lisboa, Portugal
Tel: +351 21 302 7000 – Email: amelo@ipma.pt

Biagi, Franco. European Commission, Law of the Sea and Regional Fisheries Organisations, DG-MARE B2, Rue Joseph II, 99, B-1049, Brussels, Belgium
Email: franco.biagi@ec.europa.eu

Blazkiewicz, Bernard. NAFO Desk Officer, European Commission, Law of the Sea and Regional Fisheries Organisations, DG-MARE B2, Rue Joseph II, 99, B-1049, Brussels, Belgium
Tel: +32-2-299.80.47 – Email: Bernard.BLAZKIEWICZ@ec.europa.eu

Caetano, Miguel. Instituto Português do Mar e da Atmosfera (IPMA), Division of Oceanography and Marine Environment, Rua Alfredo Magalhães Ramalho, 6, 1495-165 Algés, Portugal
Tel: +351 21 302 7070 – Email: mcaetano@ipma.pt

González-Costas, Fernando. Instituto Español de Oceanografía (IEO), Aptdo 1552, E-36280 Vigo, Spain
Tel: +34 986 49 22 39 – Email: fernando.gonzalez@ieo.es

González-Troncoso, Diana. Instituto Español de Oceanografía (IEO), Aptdo 1552, E-36280 Vigo, Spain
Tel: +34 986 49 21 11 – Email: diana.gonzalez@ieo.es

Granell, Ignacio. International Relations Officer, Regional Fisheries Management Organizations, European Commission, Rue Joseph II, 99, B-1049, Brussels, Belgium
Tel: +32 2 296 74 06 – Email: ignacio.granell@ec.europa.eu

Ribeiro Almendra Castro, Cristina. DG MARE, Rue Joseph II, 99, B-1049, Brussels, Belgium
Tel: +39 3668934792 – Email: cristina.ribeiro@ec.europa.eu

Sepúlveda Angulo, Pedro. Secretaría General de Pesca, Subdirección General de Acuerdos y Organizaciones Regionales de Pesca, Velazquez 144, 28006 Madrid, Spain
Tel: +34 913 476 137 – Email: psepulve@mapama.es

Teixeira, Isabel. Head of External Resources Division, Ministry of the Sea, Directorate General for Natural Resources, Safety and Maritime Services (DGRM), Avenida Brasilia, 1449-030 Lisbon, Portugal
Tel: +351 21 303 5825 – Email: iteixeira@dgrm.mm.gov.pt

Tuvi, Aare. Counsellor, Fishery Resources Department, Republic of Estonia, Ministry of the Environment, Narva mnt 7A, 15172, Tallinn, Estonia
Tel: + 372 6260 712 – Email: aare.tuvi@envir.ee

Urtizberea, Agurtzane. AZTI
Email: aurtizberea@azti.es

NORWAY

Hvingel, Carsten. Institute of Marine Research, Head of Research Group, P.O. Box 1870 Nordnes, 5817 Bergen, Norway
Tel: +47 95980565 – Email: carsten.hvingel@imr.no

UNITED STATES OF AMERICA

Kelly. Moira. Senior Fishery Program Specialist, Regional Recreational Fisheries Coordinator, Greater Atlantic Regional Fisheries Office, National Marine Fisheries Service, 55 Great Republic Drive, Gloucester, MA 01930 USA
Tel: +1 978-281-9218 – Email: moira.kelly@noaa.gov

Sosebee. Kathy. Science Advisor, Northeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration (NOAA) USA
Tel: +1 508 495 2372 – Email: katherine.sosebee@noaa.gov

Warner-Kramer, Deirdre. Acting Deputy Director, Bureau of Oceans, International Environmental and Scientific Affairs, Office of Marine Conservation (OES/OMC), Department of State, Washington, DC 20520 USA
Tel +1 202 647 2883 – Email: warner-kramerdm@fan.gov

NAFO SECRETARIAT

2 Morris Drive, Suite 100, Dartmouth, Nova Scotia, Canada – Tel: +1 902 468-5590
Tom Blasdale. Science Coordinator. Email: tblasdale@nafo.int
Lisa LeFort. Senior Executive Assistant. Email: llefort@nafo.int

Annex 2. Agenda

1. Opening by the co-Chairs, Carmen Fernández (European Union) and Jacqueline Perry (Canada)
2. Appointment of Rapporteur
3. Adoption of Agenda
4. 3M Cod Management Strategy Evaluation (MSE)
    a. Review objectives for the current meeting, taking into account the MSE timeline agreed by the Commission in September 2018.
    b. Presentation of the single overall "*guiding and summary*" document for the 3M cod MSE process.
    c. Presentation of main results from the 3M cod MSE meeting held in January 2019.
    d. Review of initial MSE results based on the initial set of operating models (OM) and candidate harvest control rules (HCR) agreed in the January SC meeting.
    e. Update and possibly finalization of Performance Statistics (PS) and associated risks levels.
    f. Identify where improvements in performance are most required to guide analysts in revising HCRs. In particular, identify desired features in terms of overall form of the HCR, potential ranges for maximum TAC change between years and starting TAC, indicating the order of priority.
    g. Review the MSE timeline going forward from this meeting. Ability to achieve deliverables: (i) between April-June, (ii) at the June SC meeting, (iii) after the June SC meeting. Time and format of next WG-RBMS meeting.
    h. Include main results and conclusions from the WG-RBMS meeting in the single overall "*guiding and summary*" document for the 3M cod MSE process.
5. Other Business
6. Recommendations to forward to the Commission and/or Scientific Council
7. Date and Time of Next Meeting
8. Adoption of Report
9. Adjournment

Annex 3. Examination of proposed Harvest Control Rules for 3M Cod

Brian Healey
Fisheries and Oceans Canada
Northwest Atlantic Fisheries Centre
80 East White Hills Road, St. John's, Newfoundland and Labrador, Canada
brian.healey@dfo-mpo.gc.ca

I. Introduction

This report details a simple exploration of the formulation of the HCRs proposed for 3M cod. The intent is to understand how the computation of the TAC in the HCR responds to various parameters simply based on the mathematical description of the rule itself. The advantage of this approach is that in relying on simply the equations for the proposed rules, it is completely independent of the very complex and detailed process required for a Management Strategy Evaluation. This simple understanding can prove helpful for changing rule formulations and/or tuning the parameters used within the rules.

II. Harvest Control Rules

In the proposed Harvest Control Rules for 3M cod, the computed TAC for year y+1 is a function of three quantities:

i) the TAC in year y,
ii) the relative change in the stock size, and,
iii) one or more scaling parameters which controls the responsiveness of the rule to changes in stock size.

For the current MSE, two different rules are being considered. The difference between these rules is the metric is used in the HCR to represent the change in stock size. The full specification of each rule follows.

Model-Free Slope HCR

The first rule alters future TACs based upon recent trends in the survey biomass:

$$TAC_{y+1} = TAC_y\left[1 + \lambda_y \cdot slope_y\right],\ \text{where}$$

$slope_y$ is the slope of a regression line fit to the four previous biomass indices (log-scale), with

$$\lambda_y = \begin{cases} \min(\alpha, RR_y), & slope_y \geq 0 \\ 2 - \min(\alpha, RR_y), & slope_y < 0 \end{cases}, \qquad \text{for } \alpha \in [1,1.5],\ \text{and,}$$

$$RR_y = \frac{\left(R_{y-1} \cdot R_{y-2} \cdot R_{y-3}\right)^{1/3}}{\left(\prod_{i=1988}^{i=2017} R_i\right)^{1/30}}$$

RR_y is the ratio of recent recruitment (three-year geometric mean) to the geometric mean level of recruitment, computed from the age 1 estimates of abundance in the EU Flemish Cap survey. Additionally, the parameter λ_y controls the responsiveness of TAC change to changes in stock size as measured by the slope.

Model-Free Target HCR

The first rule alters future TACs based upon how far current status is from a pre-set target biomass. In the proposed rule, the target biomass level is the average survey biomass over 2008-2017.

The rule is computed as follows:

$$TAC_{y+1} = TAC_y\left[1 + \lambda_y \cdot \left(J_y - 1\right)\right], \qquad \text{where}$$

J_y is the ratio of recent (three-year) average of survey biomass to the target biomass level, i.e.,

$$J_y = \frac{1}{3} \cdot \left(I_{y-1} + I_{y-2} + I_{y-3}\right)/I_{target}\ \text{,with}$$

$$I_{target} = 1/10 \cdot \sum_{y=2008}^{2017} I_y,$$

$$\lambda_y = \begin{cases} \min(\alpha, RR_y), \ J_y \ \geq 1 \\ 2 - \min(\alpha, RR_y), \ J_y < 1 \end{cases}, \text{ for } \alpha \in [1{,}1.5], \text{ and,}$$

$$RR_y = \frac{\left(R_{y-1} \cdot R_{y-2} \cdot R_{y-3}\right)^{1/3}}{\left(\prod_{i=1988}^{i=2017} R_i\right)^{1/30}}.$$

As with the Slope HCR, RR_y is the ratio of recent recruitment (three-year geometric mean) to the geometric mean level of recruitment (geometric mean; recruitment from survey). The parameter λ_y controls the responsiveness of TAC to changes in stock size measured by the current fraction of the target level.

III. 3M Cod data affecting HCR Calculations

Recruitment Ratio (RR)

Each of the rules detailed above includes an adjustment based on the "*Recruitment Ratio*". In order to understand how this will impact TACs generated within the simulations, it is useful to examine the RR's calculated from the existing survey recruitment observations. Figure 1 illustrates the values of RR_y over 1990-2017. As the HCRs have a "*constraint*" on how large of an RR_y value affects the HCR (see α parameter in equations above), the right panel of Figure 1 has RR_y values of that are less than or equal to 1.5.

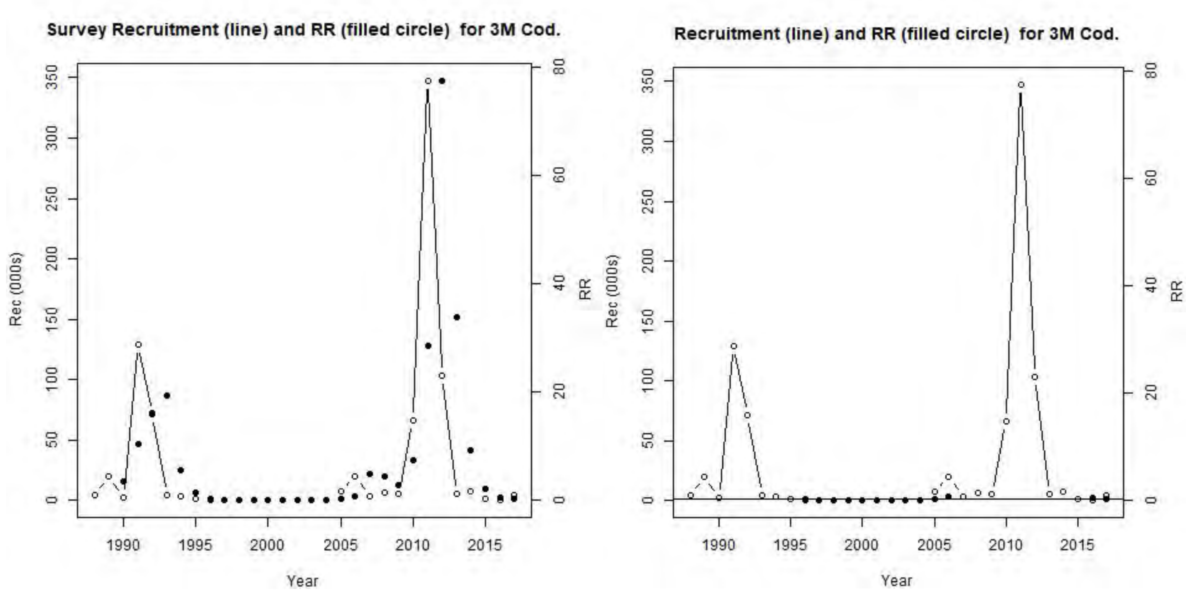


Figure 1. Left: Survey abundance at age 1 and Recruitment Ratio. Right: Survey abundance at age 1 and Recruitment Ratio values less than 1.5. Horizontal reference line in lower panel is the geometric mean recruitment.

Table 1. Summary statistics for RR.

Minimum	0.01
25th Percentile	0.07
Median	1.79
Mean	8.21
75th Percentile	7.88
Maximum	77.47

With the exception of two periods of large RR values corresponding to large recruitment events, the time-series shows that recruitment was much lower than average in most years and that the distribution of values is heavily skewed (Table 1).

Slope of recent survey values

For the slope-based HCR, the metric that reflects changes in stock size is the slope of the survey biomass index on the logarithmic scale. This slope is computed for the most recent four years. Figure 2 illustrates how this has varied based on the survey biomass time series from 1988-2017.

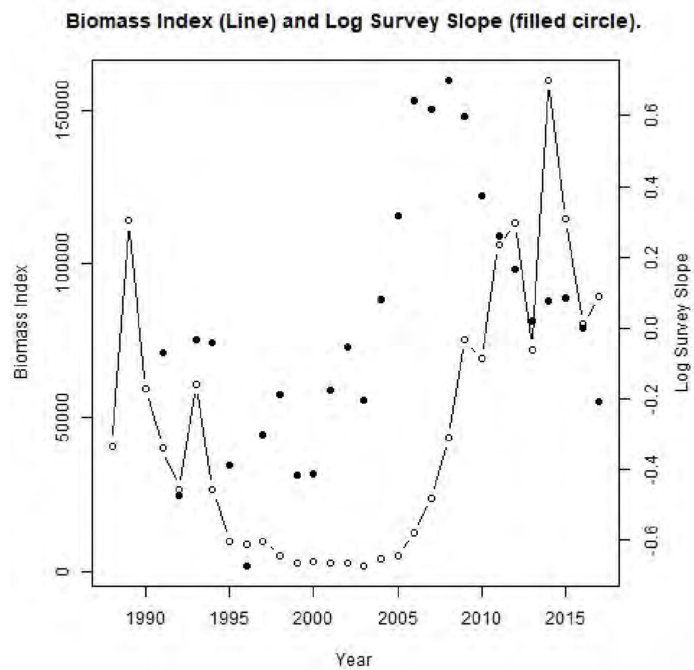


Figure 2. Survey Biomass Index and 4-year survey slope (regression on log biomass index).

Survey slopes are negative for the first half of the time series, followed by considerable increase when stock size improved dramatically in the early-mid 2000s. In the most recent years the trend has remained positive but the values are declining. The distribution of values is relatively symmetric (Table 2).

Table 2. Summary statistics for Slope.

Minimum	-0.67
25th Percentile	-0.21
Median	-0.03
Mean	0.01
75th Percentile	0.21
Maximum	0.7

Target: Survey biomass relative to Target Level

For the target-based HCR, the metric that reflects changes in stock size is ratio of current biomass for the most recent three years, to some reference or target level of biomass (J_y in the equations above). In this application, the target level is the average biomass over 2008-2017, inclusive. Figure 4 illustrates how this has varied based on the survey biomass time series of 1988-2017.

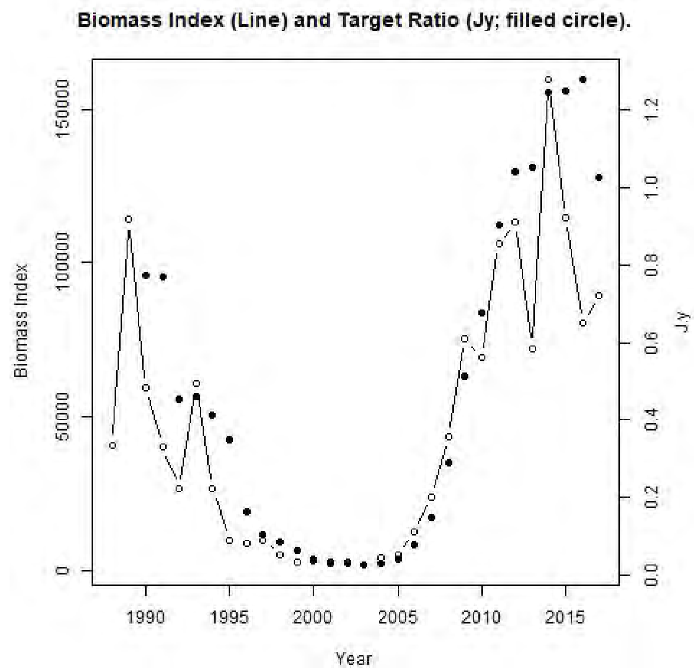


Figure 3. Survey Biomass index and J_y metric ('current' biomass relative to target level).

The target biomass metric, J_y, is below 1 (i.e. current below target level) in all but the final six years. During the collapsed period, the stock was at just 5-10% of this target level. The summary statistics for the target biomass metric J_y is shown in Table 3.

Table 3. Summary statistics for Target Biomass metric J_y.

Minimum	0.02
25th Percentile	0.08
Median	0.38
Mean	0.48
75th Percentile	0.81
Maximum	1.28

IV. HCR Rule Results – Previous observations

Next we explore the range of outcomes under each of the HCRs given the historic or observed ranges of the input parameters (i.e. each of RR_y, $slope_y$ and J_y). For the purposes of illustration, the parameter α is fixed at 1 in all subsequent calculations. For both the slope and the target rules, one can take the annual values of RR_y, $slope_y$ and J_y and compute what the inter-annual percentage change in the TAC would be under each rule. For the slope rule, which uses the four prior biomass index values, this can be computed over 1992-2018 and for the target rule – which uses a three year average to inform 'current' status - computed over 1991-2018.

These results suggest that a re-parameterization of both rules is necessary. The HCRs as structured are overly sensitive to the input parameters, with extreme inter-annual change. Figures 4 and 5 show the annual percent adjustment to TAC that would be applied annually. In addition to being very large, the values are predominantly negative. In some cases, the adjustments exceed a decrease of more than 100%, which implies a negative TAC. It is worth noting that the years for which negative values are generated include years outside the period corresponding to the closure of directed fishing following stock collapse.

Table 4. Summary statistics for percent change in TAC under the slope rule.

Minimum	-114%
25th Percentile	-38%
Median	-3%
Mean	-9%
75th Percentile	12%
Maximum	70%

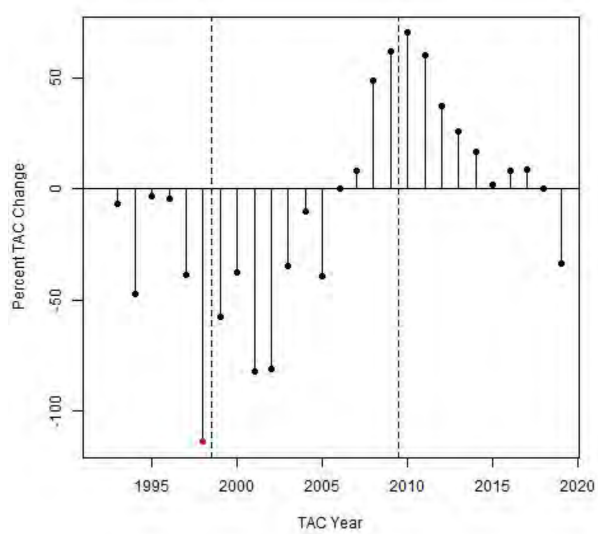


Figure 4. Annual percent change in TAC using the historic values of RR_y and $slope_y$. Point highlighted in red indicates year in which TAC generated by the HCR would be negative. Dashed lines mark the beginning and end of the moratorium on directed fishing.

Table 5. Summary statistics for percent change in TAC under the target rule.

Minimum	-192%
25th Percentile	-175%
Median	-62%
Mean	-85%
75th Percentile	19%
Maximum	25%

Under the observed conditions, the Target HCR as parameterized would only have yielded TAC increases in the most recent six years. For many of the years there is a greater than 100% reduction (i.e. negative TAC), and the magnitude of these negative values is excessive.

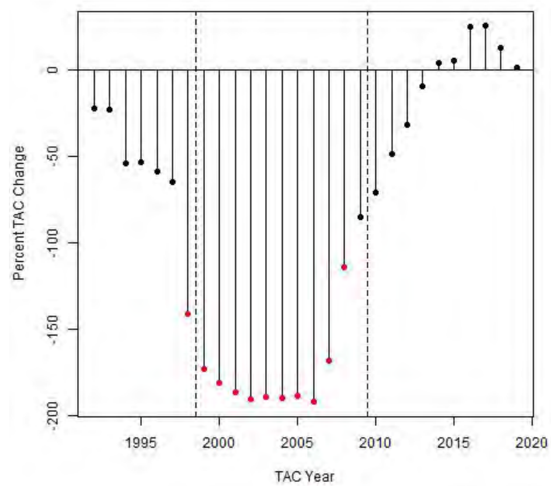


Figure 5. Annual percent change in TAC using the historic values of RR_y and J_y. Points highlighted in red indicate years in which TAC generated by the HCR would be negative. Dashed lines mark the beginning and end of the moratorium on directed fishing.

One suggested adjustment to mitigate this issue for both rules would be to add an additional parameter to each HCR to provide an 'appropriate' response to the slope and target metrics within each rule. This This is consistent with discussions during the SC January 2019 MSE meeting (NAFO, 2019) and could be accomplished via:

$$TAC_{y+1} = TAC_y\left[1 + \beta \cdot \lambda_y \cdot slope_y\right] \text{ and } TAC_{y+1} = TAC_y\left[1 + \beta \cdot \lambda_y \cdot (J_y - 1)\right].$$

For the Target rule, an adjustment to target level (i.e. target could be redefined as x% of the 2008-2017 average) and/or the time period over which the target is defined could also be considered to produce a more 'stable' rule that seems appropriate.

V. HCR Rule Results – Wider view

Next we explore the HCR results computed across the entire observed range of RR_y and $slope_y$ for the slope rule, and of RR_y and J_y for the target rule. Specifically, across all possible combinations of these input parameters, compute what the inter-annual percentage change in the TAC generated from the HCRs would be. This yields the results illustrated below through the use of contour plots. The annual values of RR_y, $slope_y$ and J_y calculated from the existing survey time series are plotted (as points) within these contours for context. As in the previous section, the wide range of potential one-year TAC changes confirms that modifications of the rules within this MSE are required.

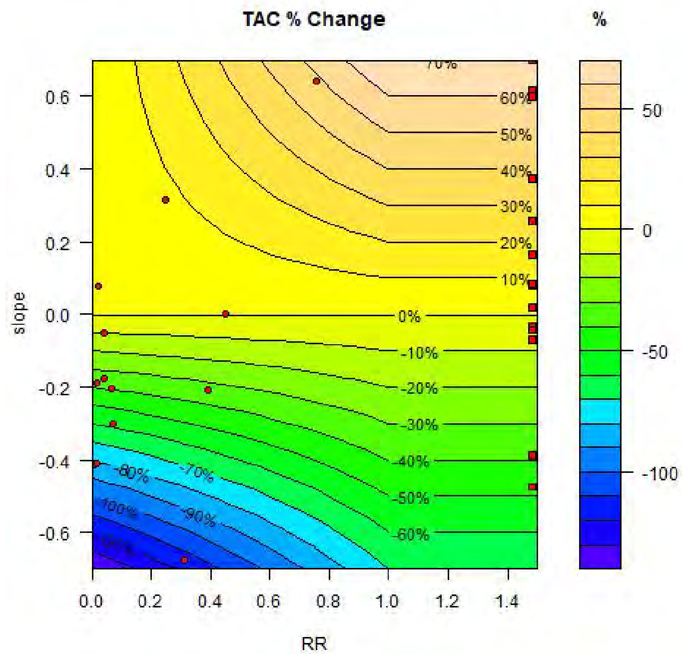


Figure 6. Slope-rule HCR results for values of RR_y and $slope_y$ across the range of historic observations. Lines show contours of TAC change (relative percent difference between $TAC_{y+1}$and TAC_y). Points correspond to values obtained over 1993-2019. Values shown as squares correspond to (RR_y, $slope_y$) pairs for which RR>1.5, and are plotted at RR=1.5 for illustrative purposes.

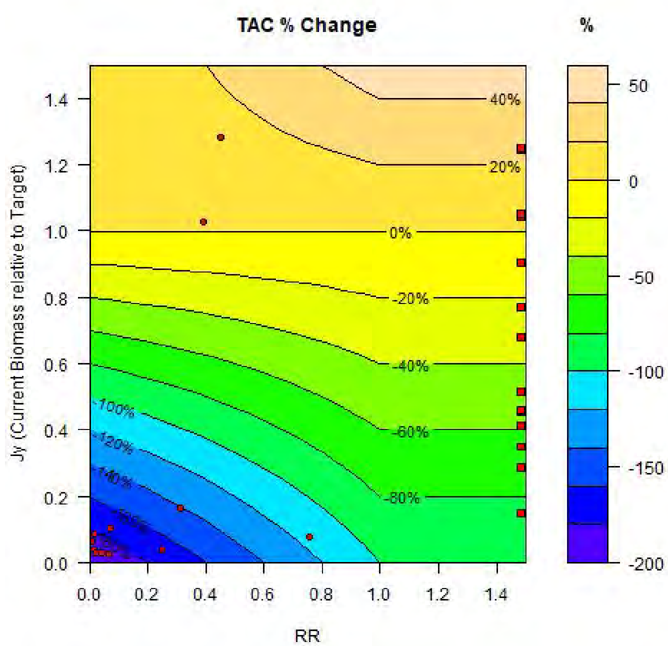


Figure 7. Target-rule HCR results for values of RR_y and $J_y$across the range of historic observations. Lines show contours of TAC change (relative percent difference between $TAC_{y+1}$and TAC_y). Points correspond to values obtained over 1992-2019. Values shown as squares correspond to (RR_y, J_y) pairs for which RR>1.5, and are plotted at RR=1.5 for illustrative purposes.

Annex 4. MSE: Inputs and Outputs

Agurtzane Urtizberea[1], Diana González-Troncoso[2], Fernando González-Costas[2] and Carmen Fernández[2]

[1]AZTI
[2]Instituto Español de Oceanografía (IEO)

Introduction

FLBEIA is the software used to develop the model with the MSE framework (Garcia *et al.*, 2017). FLBEIA is a software to perform bio-economic evaluation of fisheries management strategies and is developed based on R and FLR libraries. It has been applied to several case studies in single stock as well as mixed fisheries contexts, with different scientific or management objectives, and was also previously used for 3M cod. The model can be downloaded from github (https://github.com/flr/FLBEIA) and tutorials are available in the next web site http://www.flr-project.org/doc/index.html)

The initial set of candidate OMs and HCRs to be run in the 3M cod MSE were discussed and agreed in the NAFO SC January 2019 meeting. The report of that meeting (NAFO SCS Doc. 19/04) includes the following table about the specifications of the different scenarios:

	Variables	Scenarios		
HCR settings	HCR names	Model-Free Slope (MFS)	Model-Free Target (MFT)	
	alpha	1.0 (A10)	1.5 (A15)	
	Constraint on inter-annual TAC change	None (Cnone)	±20% (C20)	
	Starting Point*	TAC(2019)=17500 t (SP0)	TAC(2019)–25%=13125 t (SP25)	
OM settings	Natural Mortality (until year 2017)	**M vector (MV)**	M GADGET (MG)	M Steps (MS)
	Recruitment (2018 onwards)	**Bin Ricker (BR)**	Hockey Stick (HS)	Low Bin Ricker (LBR)
	Biological parameters (2018 onwards)	**Random walk (RW)**	3 Years Mean (3Y)	Denso Dependent (DD)
	Groups q	**Flat Shape (F)**	Dome Shape (D)	

* When the management strategy is applied for the first time (i.e. for year 2020 in the MSE simulation), the TAC obtained from the HCR is calculated starting from this value instead of starting from the TAC in the previous year.

Harvest Control Rules (HCRs) tested

The first formulations of the HCRs were proposed to the SC in January 2019 (SCR 19/01). After the comments and recommendations made by SC to them (SCS 19/04) the final version of the HCRs that have been applied to the different scenarios presented in this document have the following formulation:

$$TAC_{y+1}=TAC_y\,(1+\delta\, fy)$$

Where *fy* is some function of survey biomass in previous years (with the actual function being different for the slope and the target HCRs). Note that HCRs with larger values of δ imply larger interannual changes in TAC; by contrast, if δ=0 then the TAC is constant.

HCR with tuning parameter α:

If *fy>=0, then* $\delta = \delta_{up} = \min\{\alpha, RRy\} \leq \alpha$, $\alpha \in [1, 1.5]$

If *fy<0, then* $\delta = \delta_{down} = 2 - \min\{\alpha, RRy\} \in [2-\alpha, 2]$, $\alpha \in [1, 1.5]$

$RRy = \frac{GeoMeanRec\ (y-1, y-2, y-3)}{GeoMeanRec\ (1988-2017)}$, calculated using the age-1 survey abundance indices.

Slope HCR

In this case, *fy* is the slope of a regression line fit to the four previous biomass indices (log-scale):

$$TAC_{y+1} = TAC_y\ (1+\ \delta\ slope_y)$$

Target HCR

In this case, *fy* is calculated from the mean of the survey biomass of the three previous years divided by the mean survey biomass index for the period 2008-2017:

$$TAC_{y+1} = TAC_y\ (1+\ \delta\ (Jy-1))$$

where $J_y = \frac{(I_{y-3}+I_{y-2}+I_{y-1})/_3}{I_{target}}$ and $I_{target} = \sum_{y=2008}^{2017} \frac{I_y}{10}$.

Harvest Control Rules (HCRs) parameters values presented

For both HCRs (slope and target):

-α =1.0 (A10)

-α =1.5 (A15)

- without reduction in the starting point, TAC 2019, 17500 t (SP0)

- 25% of reduction in the starting point, 13125 t (SP25)

- Interaannual variability of the TAC constrained of 20% (C20)

A minimum TAC of 1000 t was incorporated in the MSE simulations, to avoid being trapped in a 0-TAC situation. Hence, whenever the HCR resulted in a TAC less than 1000 t, it was assumed that the TAC would be 1000 t, and this was the value used in the HCR when calculating the TAC for the following year.

Apart from that, it was agreed that scenarios with zero catch (F=0) should be included in the MSE as a robustness test, to see how the OMs would perform under no fishery and to allow managers to evaluate the differential impact of multiple HCRs.

Scenarios run

Among all the possible approved scenarios, it was agreed to define the following as priorities for presenting their results in the RBMS of April 2019: The base-case OM (MV, BR and RW combination), together with the MG, HS and 3Y alternative OM settings, for both MFS and MFT HCRs with alfa=1, no constraint on interannual TAC change and using the 2019 TAC as starting point when first applying the HCR. Additionally, for the base-case OM, 3 more scenarios for each of the two HCRs, namely, a scenario with alfa=1.5 (A15), another one with a constraint of 20% on the TAC interannual change (C20), and a third one with a different Starting Point (SP25) were run for testing. A total of 22 scenarios were run and they are described in Table 1.

Furthermore, eight of these scenarios were run with F=0 and they are described in Table 2.

MSE inputs for future years (starting from 2018):

Biological parameters (mean weights in the stock, mean weights in the catch and Natural mortality): Several approaches were proposed to the SC in January 2019 (SCR 19/01) to generate these parameters in the projection period. After the comments and recommendations made by the SC (SCS 19/04), it was decided to use an approach inspired on a "random walk" type of idea (RW) and the 3-year mean of 2015-2017 (3Y). Figure 1a shows the generated values for these parameters in the projection period (2018-2037) with the RW approach and Figure 1b with the 3Y approach.

Selectivity: It was decided to use, in all the scenarios, the mean of the years 2015-2017 due to the changes in the gears used in the fishery in recent years, with an increasing presence of longliners supposed to continue in the next years (Figure 2).

Recruitment: During the SC January 2019 MSE meeting (SCS 19/04) it was decided to use two different methods for generating future recruitment, a bin-Ricker (BR) approach with four different SSB bins for sampling recruitment residuals depending on the SSB value in the future, and a Hockey-Stick (HS) with two SSB bins separated at B_{lim}. Ricker and Hockey-Stick fits for the two OMs presented here (OMV and OMG) are shown in Figure 3. It was noted that simulating future recruitment residuals by sampling historical recruitment residuals within SSB bins implied biased residuals within the SSB bins (for example, with the BR recruitment setting, the bin corresponding to SSB values larger than SSB_{2007} but smaller than SSB_{2010}, resulted in a large proportion of simulated recruitments being above the Ricker curve); additionally, the small numbers of historical years from which to sample in each SSB bin led to big jumps up and down in the simulated future recruitment values.

Results

Figures 4-8 display MSE results. In all these figures, panel a) shows the median and panel b) the 10^{th} and 90^{th} percentiles.

Figure 4 corresponds to the scenarios with F=0. The biomass and SSB trends in the short term (2020-2025) are similar in almost all the scenarios analyzed with a fairly pronounced drop in biomass, mainly due to the poor recruitments that have been observed between 2014 and 2017. In the medium term, the trajectory of the biomass is different depending on how the biological parameters and future recruitments are simulated. If they are simulated with the 3Y approach and assuming a Hockey-Stick, the trajectory in the medium term has an increasing trend in almost all this period, while in the RW scenario assuming a Bin-Ricker the biomass grows in the medium term between 2025 and 2030, to fall again until 2037. The 10^{th} percentile shows (Figure 4b) that the SSB is not far from B_{lim} in a large part of the analyzed scenarios even with no catches in the projection period. One of the approved management objectives for this stock is that the probability that the SSB falls below B_{lim} must be equal to or less than 10%. Therefore, most of the scenarios analyzed with F=0 are very close to this risk in the short term (2020-2025), as shown in Figure 4b.

The scenarios analyzed with the slope HCR (MFS) and M vector (MV) are presented in Figure 5, whereas Figure 6 shows the results of the scenarios analyzed for the same HCR (MFS) but with M GADGET (MG). In Figure 5 it can be seen that the trajectories of the biomass are very similar to those observed in the scenarios with F=0, which means that the catches have little influence on the trend of these biomass. The results in Figure 6 show different trends in the biomass, with a decrease in the period 2020-2025 and a subsequent increase in the period 2025-2037, much higher in the scenarios with the biological parameters generated through the RW approach than with the 3Y approach.

The catches resulting from applying the slope HCR in the MV scenarios are greater than in the MG scenarios. In all scenarios, these catches are quite lower than the level of catches observed for the period 2011-2017. The resulting level of F for the MV scenarios increases in the short term with respect to that observed in the period

2011-2017 and then falls to levels considerably lower than those observed in this period. In the MG scenarios the level of F falls from the beginning and then remains at fairly small values.

In all the scenarios analyzed, in the short term (2020-2025) the risk of the biomass falling below B_{lim} is greater than the established 10%.

Figures 7 and 8 present the same scenarios as Figures 5 and 6 but for the target HCR (MFT). The trajectories of the biomass and F are similar to those described for the scenarios with the slope HCR. The catches and F of the scenarios with the target HCR are lower than those observed with the slope HCR, and this may be due to the fact that the established target biomass could be high and would have to be revised in subsequent analyses.

As is the case in the scenarios with the slope HCR, in all the scenarios analyzed with the target HCR in the short term (2020-2025) the risk of the biomass falling below the B_{lim} is greater than the established 10%. This happens in spite of the low catches and F of the scenarios where the target HCR is applied.

Discussion

The MSE results show that there is some risk that in the short / medium term the biomass will fall below B_{lim} even in the scenarios with F=0. This is mainly due to the low recruitments observed in the 2014-2017 period. This will make it very difficult to find a robust HCR that meets the management objectives already established in the agreed workplan. In particular, the objective that the biomass should not fall annually below B_{lim} with a risk higher than 10% will be very difficult to reach.

It is very likely that the current status of the stock of 3M cod as well as the great variability of the biological parameters and possible future recruitments will make it nearly impossible to find a robust HCR in the established period (September 2019) that meets the proposed management objectives.

Once all the MSE results of the scenarios agreed in the January 2019 SC meeting are available, we will have a clearer idea of the possible difficulties faced, which will allow us to review the new calendar possible for the 3M cod MSE.

References

García, D., S. Sánchez, et al. (2017). "FLBEIA: A simulation model to conduct Bio-Economic evaluation of fisheries management strategies." SoftwareX 6: 141-147.

González-Costas, F., D. González-Troncoso, C. Fernández, A. Urtizberea, R. Alpoim, A. Avila de Melo, J. De Oliveira, P. Apostolaki, T. Brunel, D. García, 2019. Potential Operating Models, Harvest Control Rules and Performance Statistics for the NAFO 3M Cod MSE. NAFO SCR Doc. 19/001. Serial No. N6903

NAFO, 2019. Cod Stock Management Strategy Evaluation (MSE). NAFO SCS Doc. 19/04, Serial No. N6911.

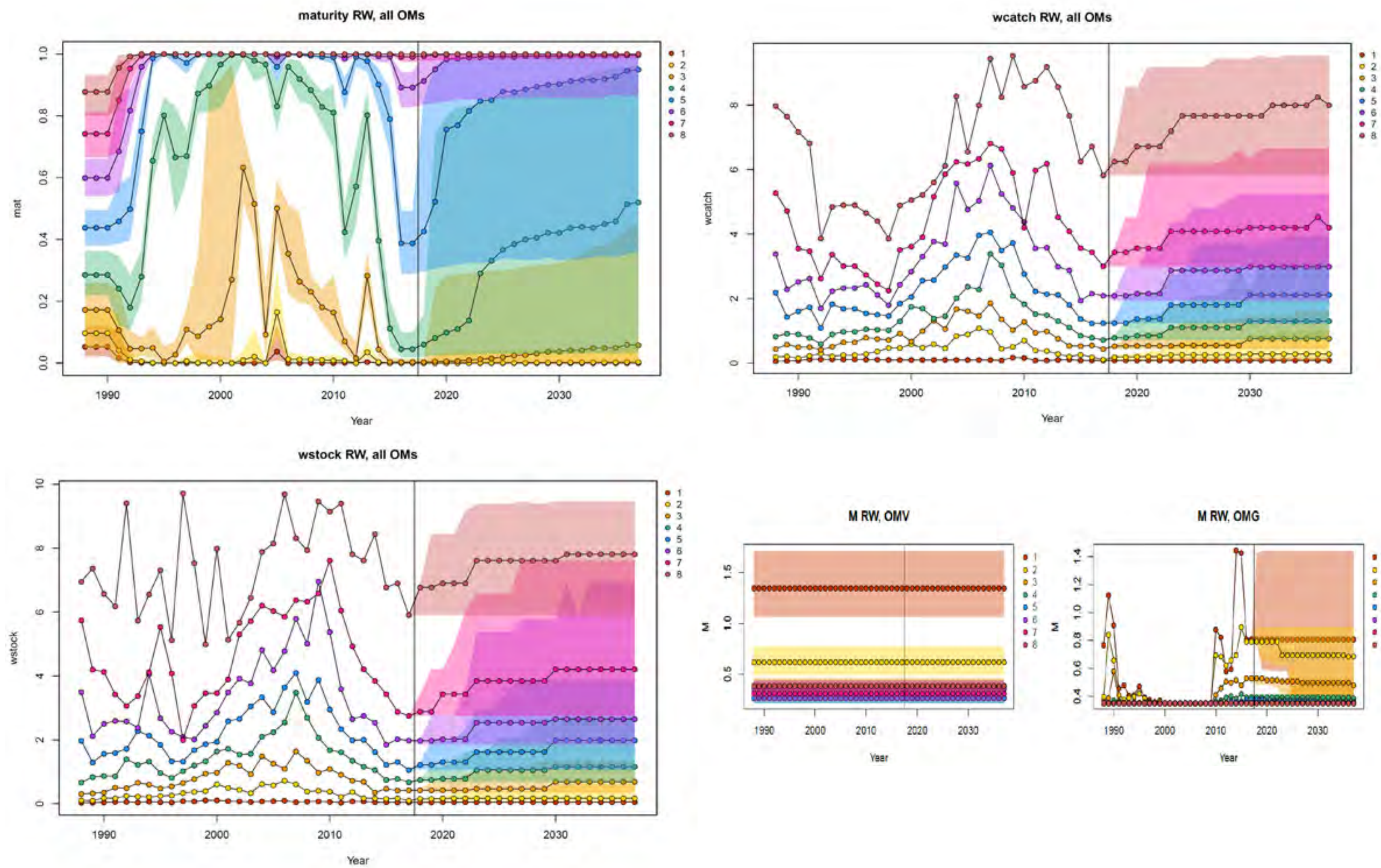
Table 1. List of scenarios run for the HCRs MFS and MFT

	HCR				alfa		Constraint		Starting Point		M			Q		R			BP			RUN
	MFS	MFT	F0	Trigger	**A10**	A15	**Cnone**	C20	**SP0**	SP25	**MV**	**MG**	MS	**QF**	QD	**BR**	**HS**	LBR	**RW**	**3Y**	DD	Y/N
1. MFS_A10_Cnone_SP0_MV_QF_BR_RW	X				X		X		X		X			X		X			X			y
2. MFS_A10_Cnone_SP0_MV_QF_BR_3Y	X				X		X		X		X			X		X				X		y
3. MFS_A10_Cnone_SP0_MV_ QF_HS_RW	X				X		X		X		X			X			X		X			y
4. MFS_A10_Cnone_SP0_MV_ QF_HS_3Y	X				X		X		X		X			X			X			X		y
5. MFS_A10_Cnone_SP0_MG_ QF_BR_RW	X				X		X		X			X		X		X			X			y
6. MFS_A10_Cnone_SP0_MG_ QF_BR_3Y	X				X		X		X			X		X		X				X		y
7. MFS_A10_Cnone_SP0_MG_ QF_HS_RW	X				X		X		X			X		X			X		X			y
8. MFS_A10_Cnone_SP0_MG_ QF_HS_3Y	X				X		X		X			X		X			X			X		y
9. MFT_A10_Cnone_SP0_MV_QF_BR_RW		X			X		X		X		X			X		X			X			y
10. MFT_A10_Cnone_SP0_MV_ QF_BR_3Y		X			X		X		X		X			X		X				X		y
11. MFT_A10_Cnone_SP0_MV_ QF_HS_RW		X			X		X		X		X			X			X		X			y
12. MFT_A10_Cnone_SP0_MV_ QF_HS_3Y		X			X		X		X		X			X			X			X		y
13. MFT_A10_Cnone_SP0_MG_ QF_BR_RW		X			X		X		X			X		X		X			X			y
14. MFT_A10_Cnone_SP0_MG_ QF_BR_3Y		X			X		X		X			X		X		X				X		y
15. MFT_A10_Cnone_SP0_MG_ QF_HS_RW		X			X		X		X			X		X			X		X			y
16. MFT_A10_Cnone_SP0_MG_HS_3Y		X			X		X		X			X		X			X			X		y
17. MFS_A15_Cnone_SP0_MV_ QF_BR_RW	X					X	X		X		X			X		X			X			y
18. MFS_A10_C20_SP0_MV_ QF_BR_RW	X				X			X	X		X			X		X			X			y
19. MFS_A10_Cnone_SP25_MV_ QF_BR_RW	X				X		X			X	X			X		X			X			y
20. MFT_A15_Cnone_SP0_MV_ QF_BR_RW		X				X	X		X		X			X		X			X			y
21. MFT_A10_C20_SP0_MV_ QF_BR_RW		X			X			X	X		X			X		X			X			y
22. MFT_A10_Cnone_SP25_MV_ QF_BR_RW		X			X		X			X	X			X		X			X			y

Table 2. List of scenarios run with F=0

	HCR				alfa		Constraint		Starting Point		M			Q		R			BP		
	MFS	**MFT**	F0	Trigger	**A10**	A15	**C100**	C20	**SP0**	SP25	**MV**	**MG**	MS	**QF**	QD	**BR**	**HS**	LBR	**RW**	**3Y**	DD
01. F0_A10_Cnone_SP0_MV_QF_BR_RW			X		X		X		X		X			X		X			X		
02. F0_A10_Cnone_SP0_MV_QF_BR_3Y			X		X		X		X		X			X		X				X	
03. F0_A10_Cnone_SP0_MV_QF_HS_RW			X		X		X		X		X			X			X		X		
04. F0_A10_Cnone_SP0_MV_QF_HS_3Y			X		X		X		X		X			X			X			X	
05. F0_A10_Cnone_SP0_MG_QF_BR_RW			X		X		X		X			X		X		X			X		
06. F0_A10_Cnone_SP0_MG_QF_BR_3Y			X		X		X		X			X		X		X				X	
07. F0_A10_Cnone_SP0_MG_QF_HS_RW			X		X		X		X			X		X			X		X		
08. F0_A10_Cnone_SP0_MG_QF_HS_3Y			X		X		X		X			X		X			X			X	

a) RW scenario



b) 3Y scenario

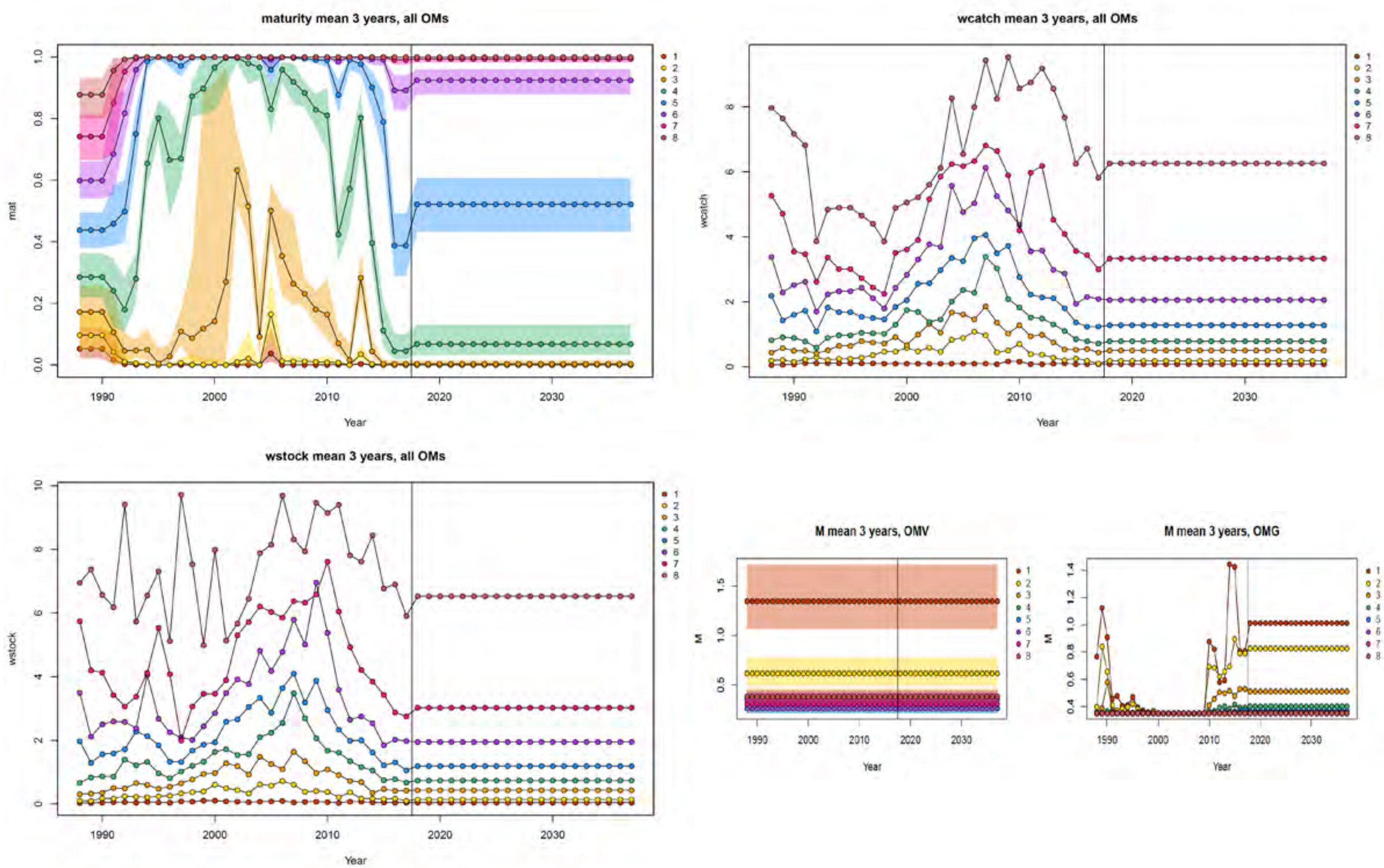


Figure 1. Biological parameters "observed" in the past and range of simulated future values. In the graphs, each colour represents one age. a): "Random Walk" (RW) scenario. b): "3 Years Mean" (3Y) scenario.

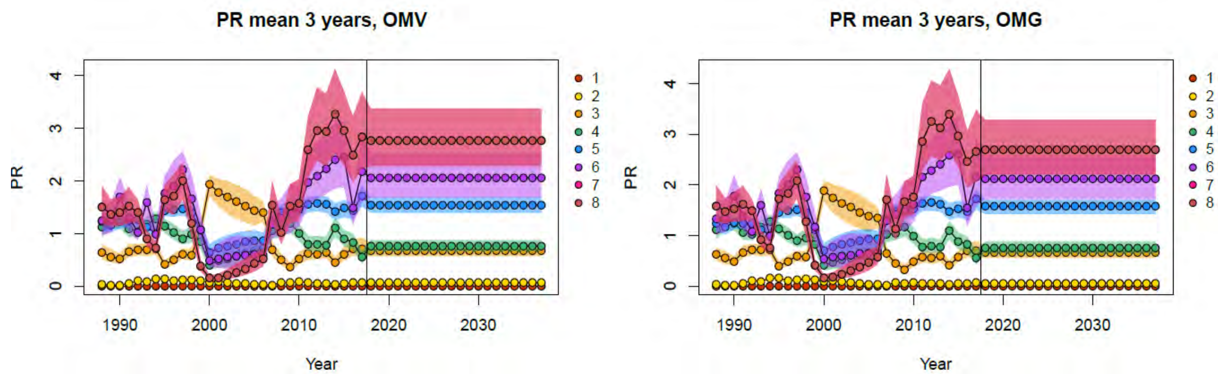


Figure 2. Selectivity for the future. In the graphs, each colour represents one age.

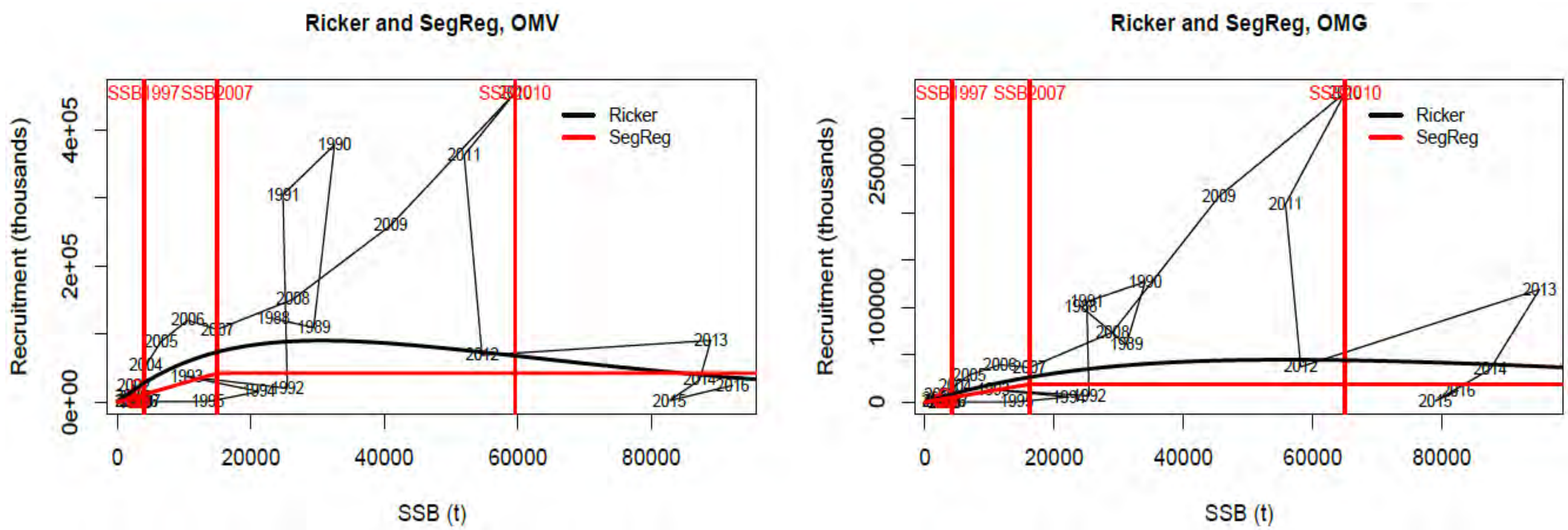
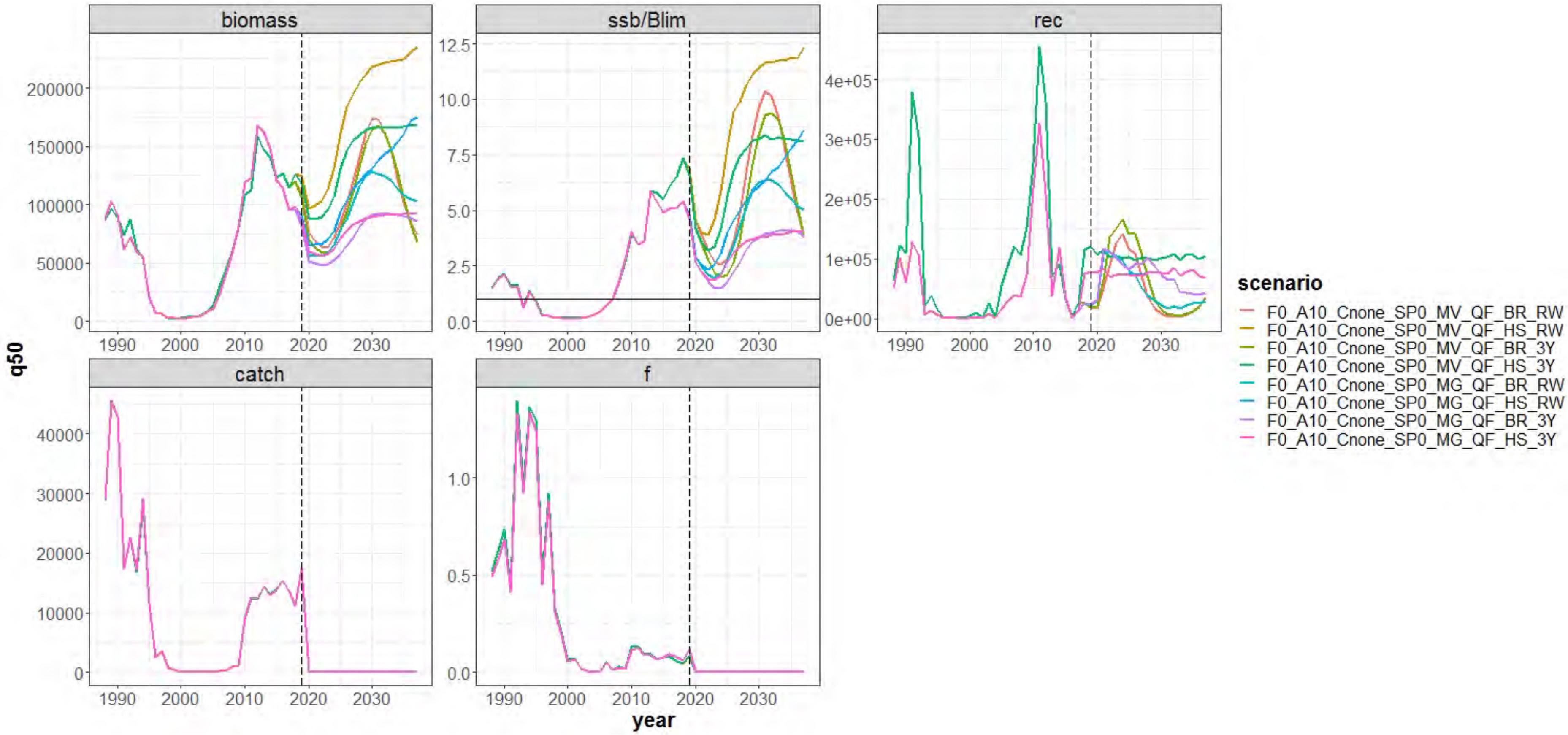


Figure 3. Stock-recruitment fits to (SSB, Recruitment) historical estimates from OMV and OMG: Ricker was fitted to pairs with SSB above SSB_{1997} and Hockey Stick was fitted to all historical estimates. The vertical lines mark the SSB values used to define the bins for future recruitment simulation in the BR setting.

a)


biomass
ssb/Blim
rec
catch
f
q50
year
scenario
F0_A10_Cnone_SP0_MV_QF_BR_RW
F0_A10_Cnone_SP0_MV_QF_HS_RW
F0_A10_Cnone_SP0_MV_QF_BR_3Y
F0_A10_Cnone_SP0_MV_QF_HS_3Y
F0_A10_Cnone_SP0_MG_QF_BR_RW
F0_A10_Cnone_SP0_MG_QF_HS_RW
F0_A10_Cnone_SP0_MG_QF_BR_3Y
F0_A10_Cnone_SP0_MG_QF_HS_3Y

b)

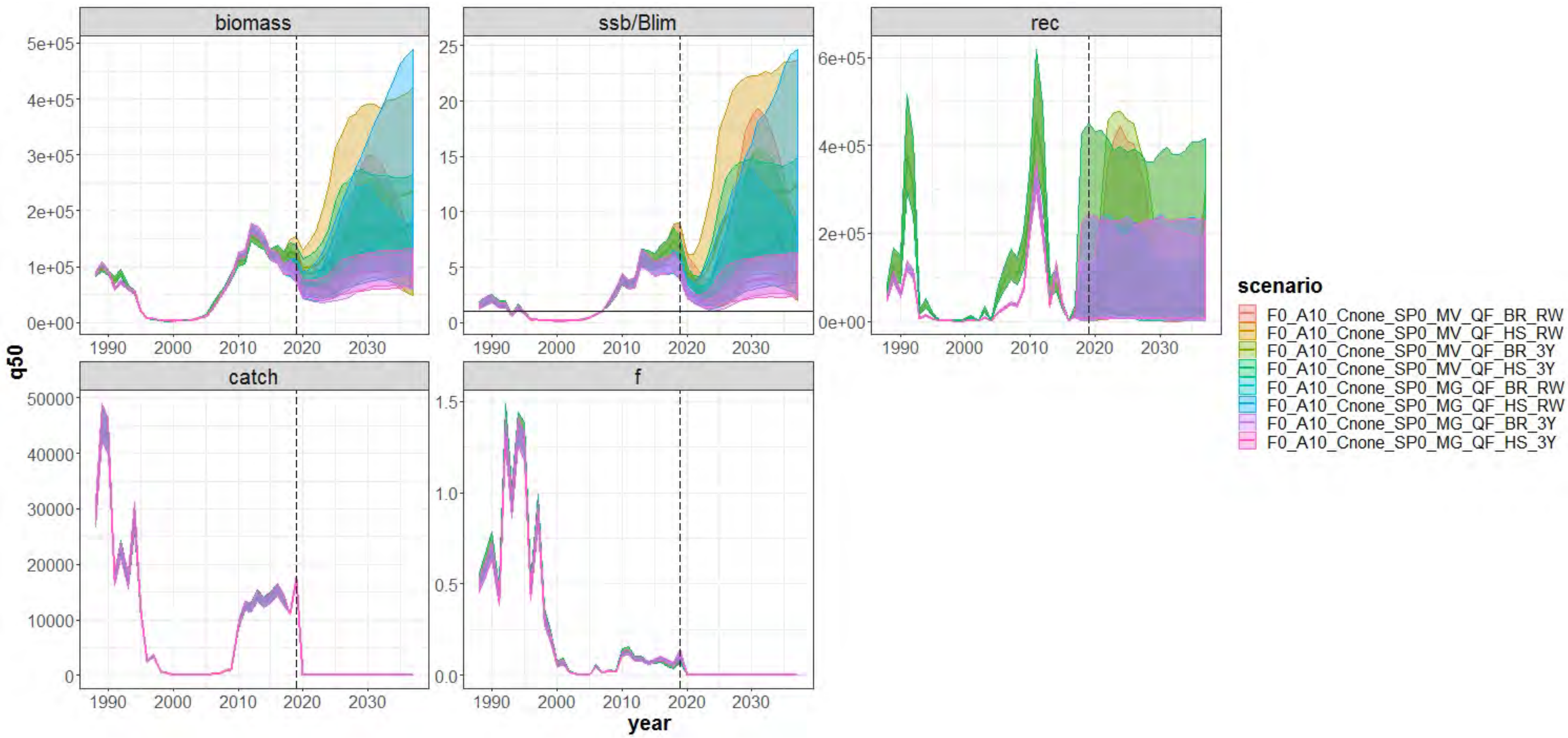
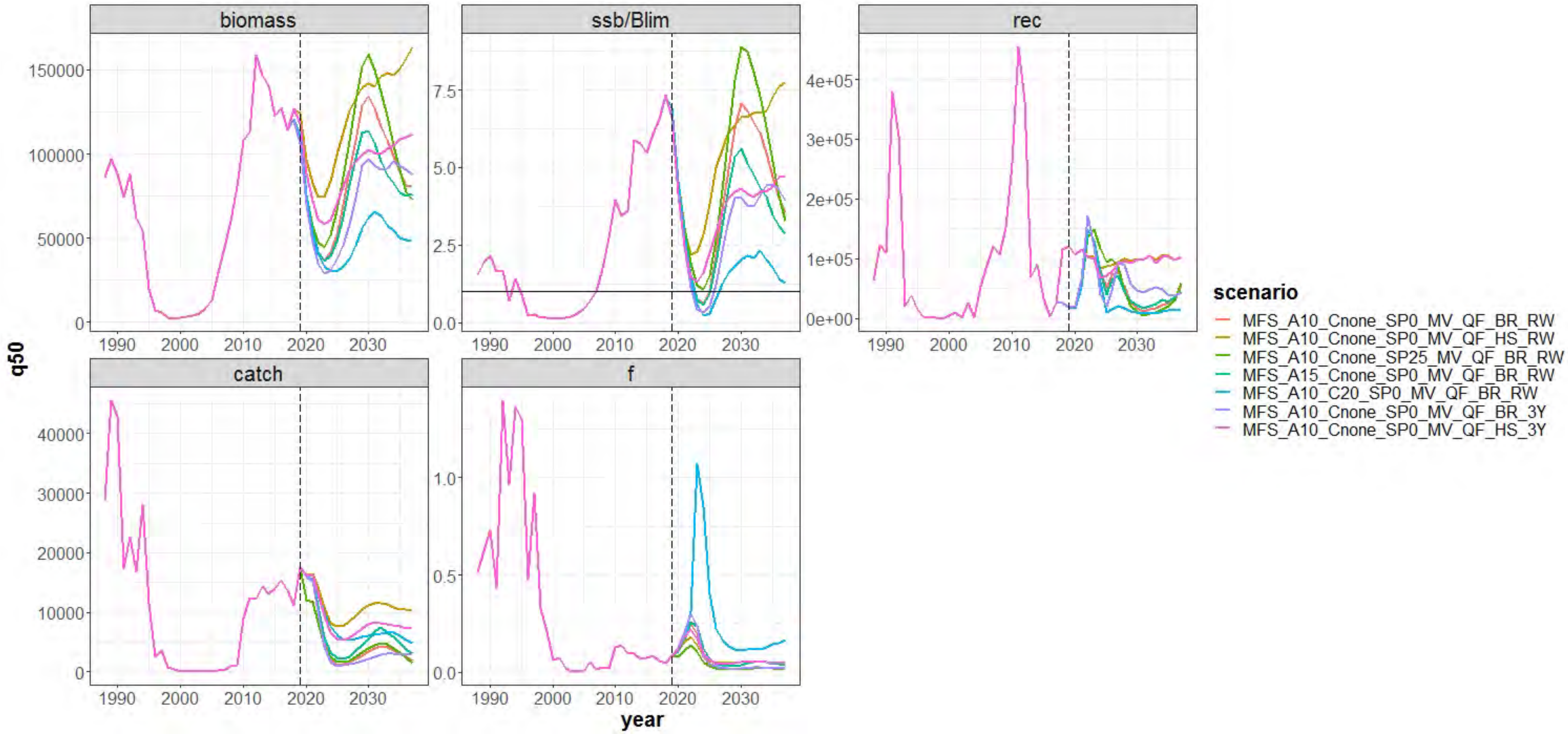


Figure 4. Results of the MSE simulations with F=0. a) Median. b) 80% CI (10th-90th percentiles)

a)


biomass
ssb/Blim
rec
catch
f
q50
year
150000
100000
50000
0
7.5
5.0
2.5
0.0
4e+05
3e+05
2e+05
1e+05
0e+00
40000
30000
20000
10000
1.0
0.5
1990
2000
2010
2020
2030
scenario
MFS_A10_Cnone_SP0_MV_QF_BR_RW
MFS_A10_Cnone_SP0_MV_QF_HS_RW
MFS_A10_Cnone_SP25_MV_QF_BR_RW
MFS_A15_Cnone_SP0_MV_QF_BR_RW
MFS_A10_C20_SP0_MV_QF_BR_RW
MFS_A10_Cnone_SP0_MV_QF_BR_3Y
MFS_A10_Cnone_SP0_MV_QF_HS_3Y

b)

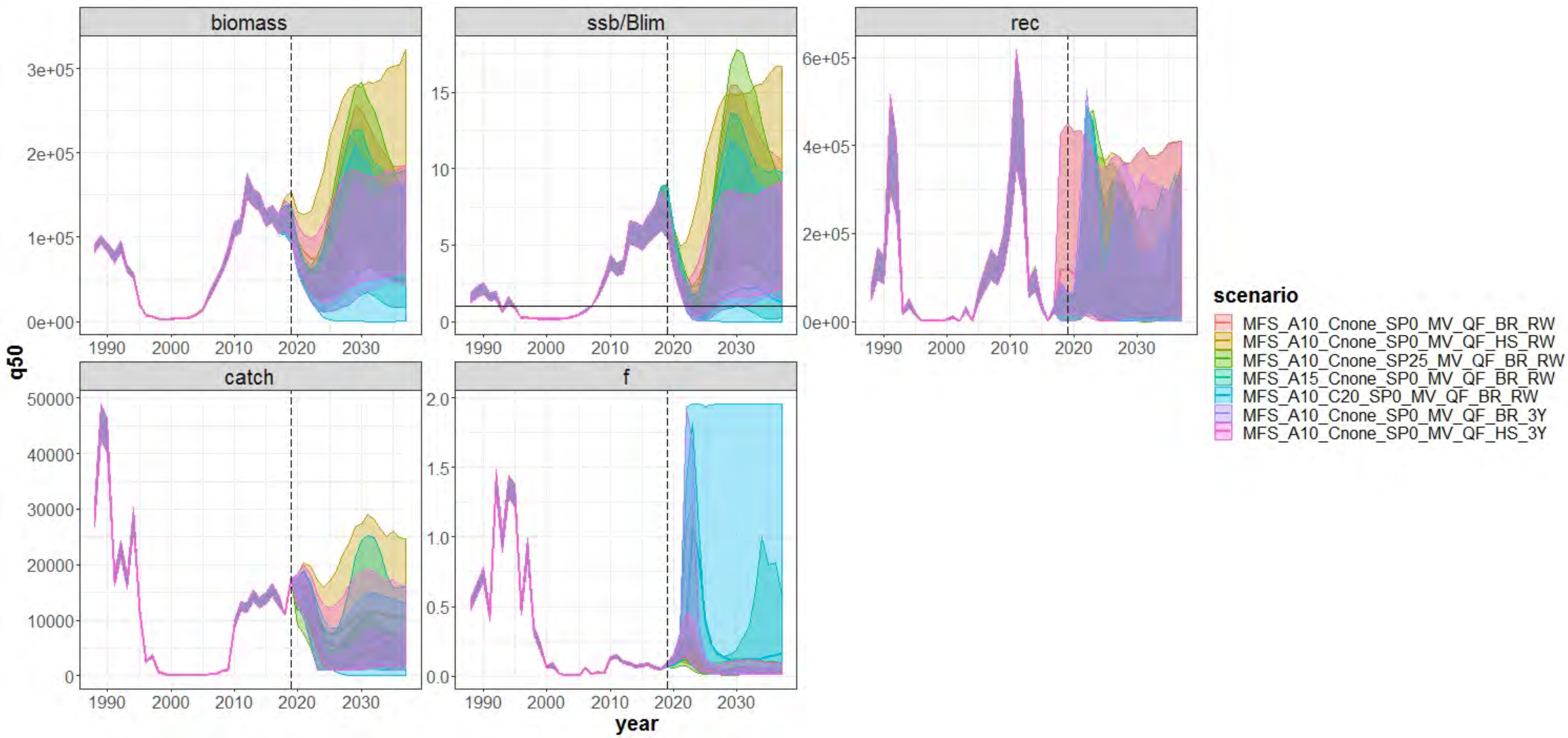
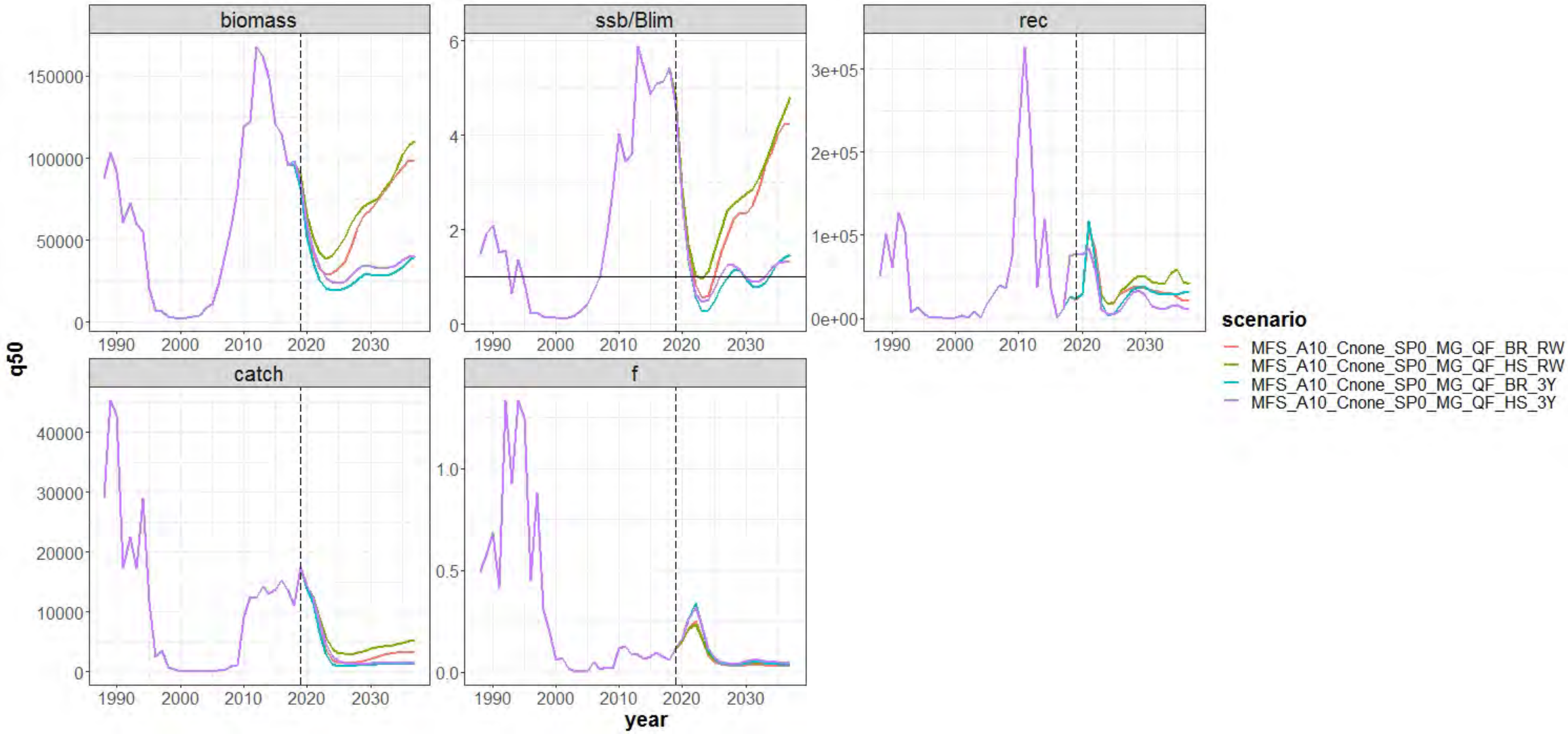


Figure 5. Results of the MSE simulations with the HCR MFS and OMV. a) Median. b) 80% CI (10th-90th percentiles)

a)


biomass
ssb/Blim
rec
catch
f
q50
year
scenario
MFS_A10_Cnone_SP0_MG_QF_BR_RW
MFS_A10_Cnone_SP0_MG_QF_HS_RW
MFS_A10_Cnone_SP0_MG_QF_BR_3Y
MFS_A10_Cnone_SP0_MG_QF_HS_3Y

b)

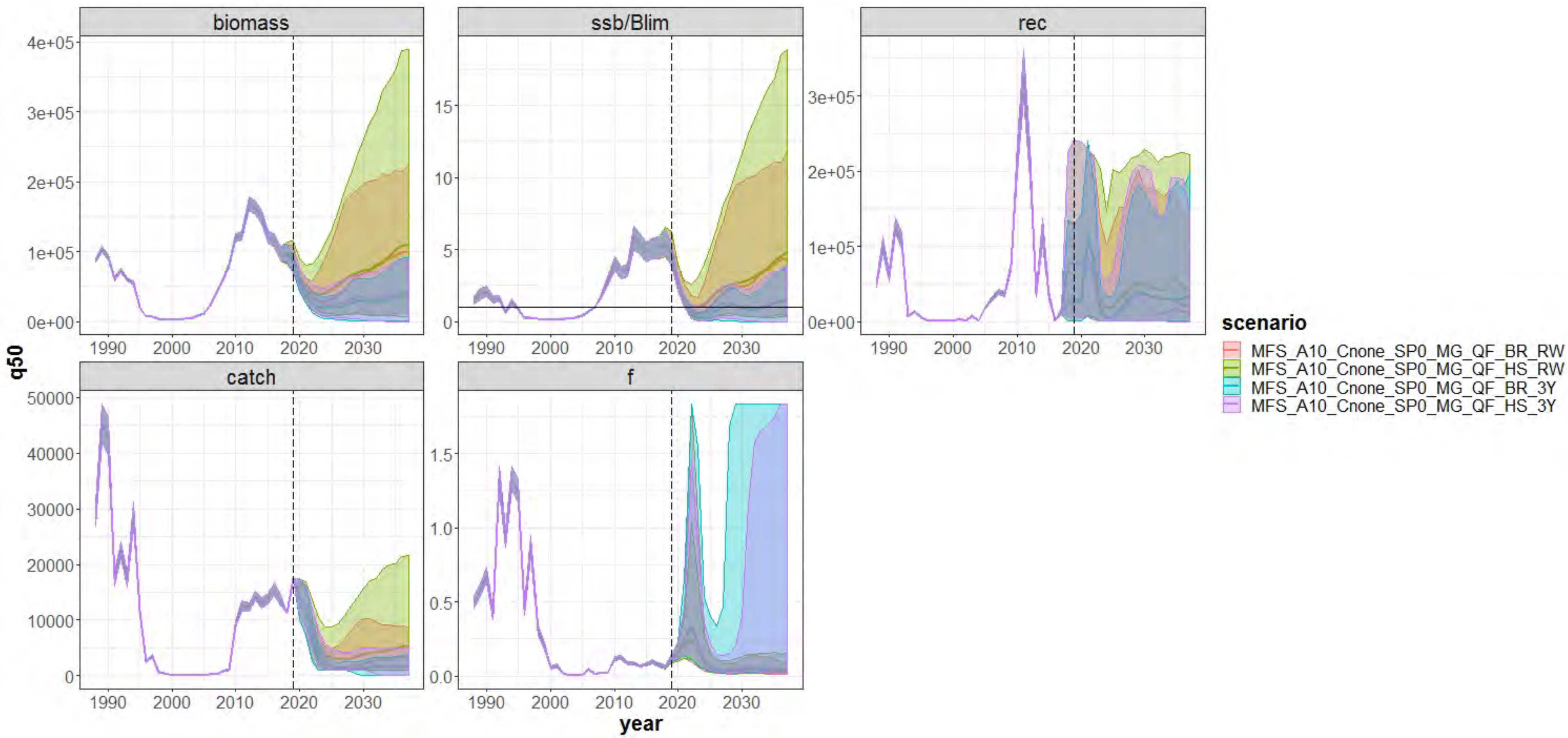
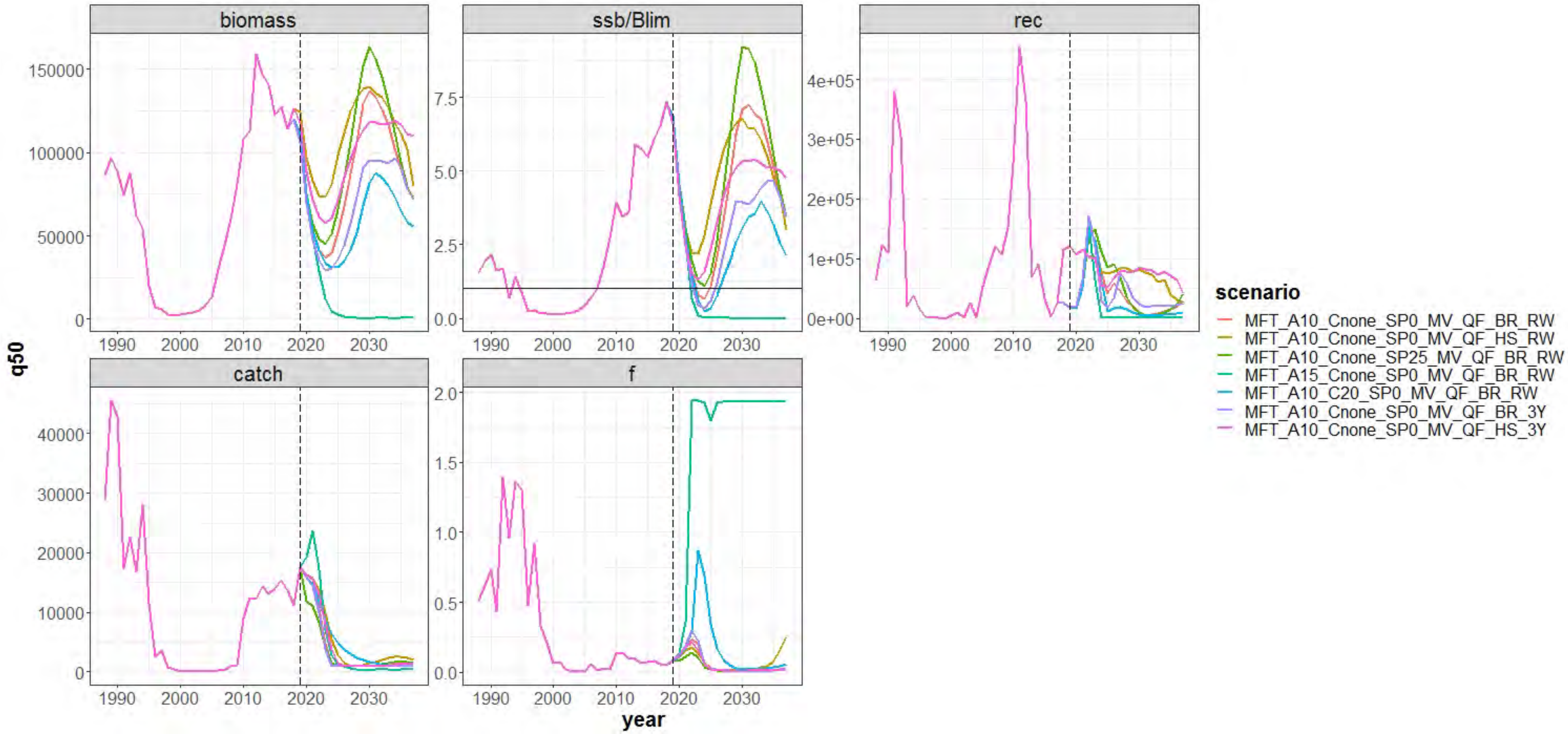


Figure 6. Results of the simulations with the HCR MFS and OMG. a) Median. b) 80% CI (10th-90th percentiles)

a)


biomass
ssb/Blim
rec
catch
f
q50
year
scenario
MFT_A10_Cnone_SP0_MV_QF_BR_RW
MFT_A10_Cnone_SP0_MV_QF_HS_RW
MFT_A10_Cnone_SP25_MV_QF_BR_RW
MFT_A15_Cnone_SP0_MV_QF_BR_RW
MFT_A10_C20_SP0_MV_QF_BR_RW
MFT_A10_Cnone_SP0_MV_QF_BR_3Y
MFT_A10_Cnone_SP0_MV_QF_HS_3Y

b)

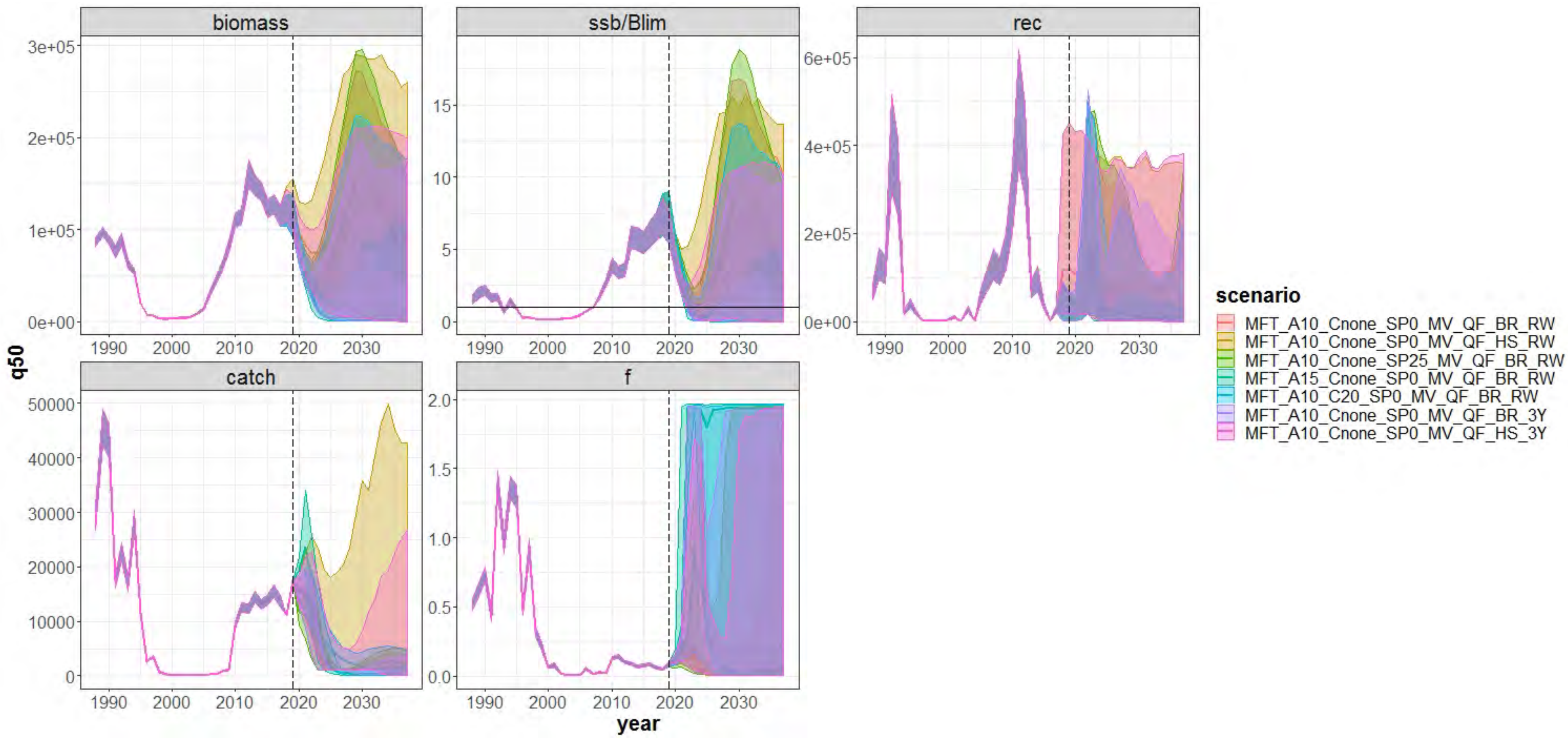
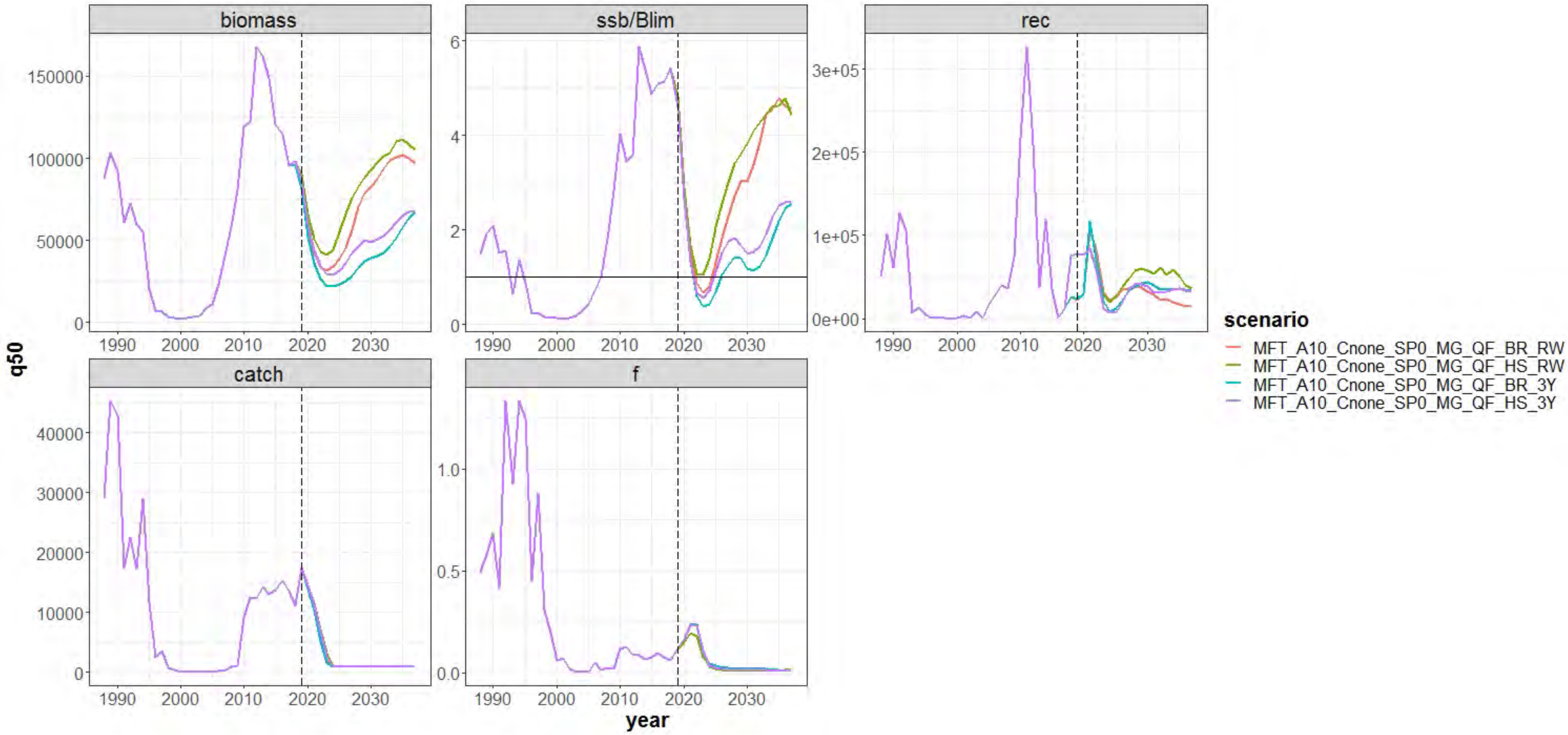


Figure 7. Results of the simulations with the HCR MFT and OMV. a) Median. b) 80% CI (10th-90th percentiles)

a)


biomass
ssb/Blim
rec
catch
f
q50
year
scenario
MFT_A10_Cnone_SP0_MG_QF_BR_RW
MFT_A10_Cnone_SP0_MG_QF_HS_RW
MFT_A10_Cnone_SP0_MG_QF_BR_3Y
MFT_A10_Cnone_SP0_MG_QF_HS_3Y

b)

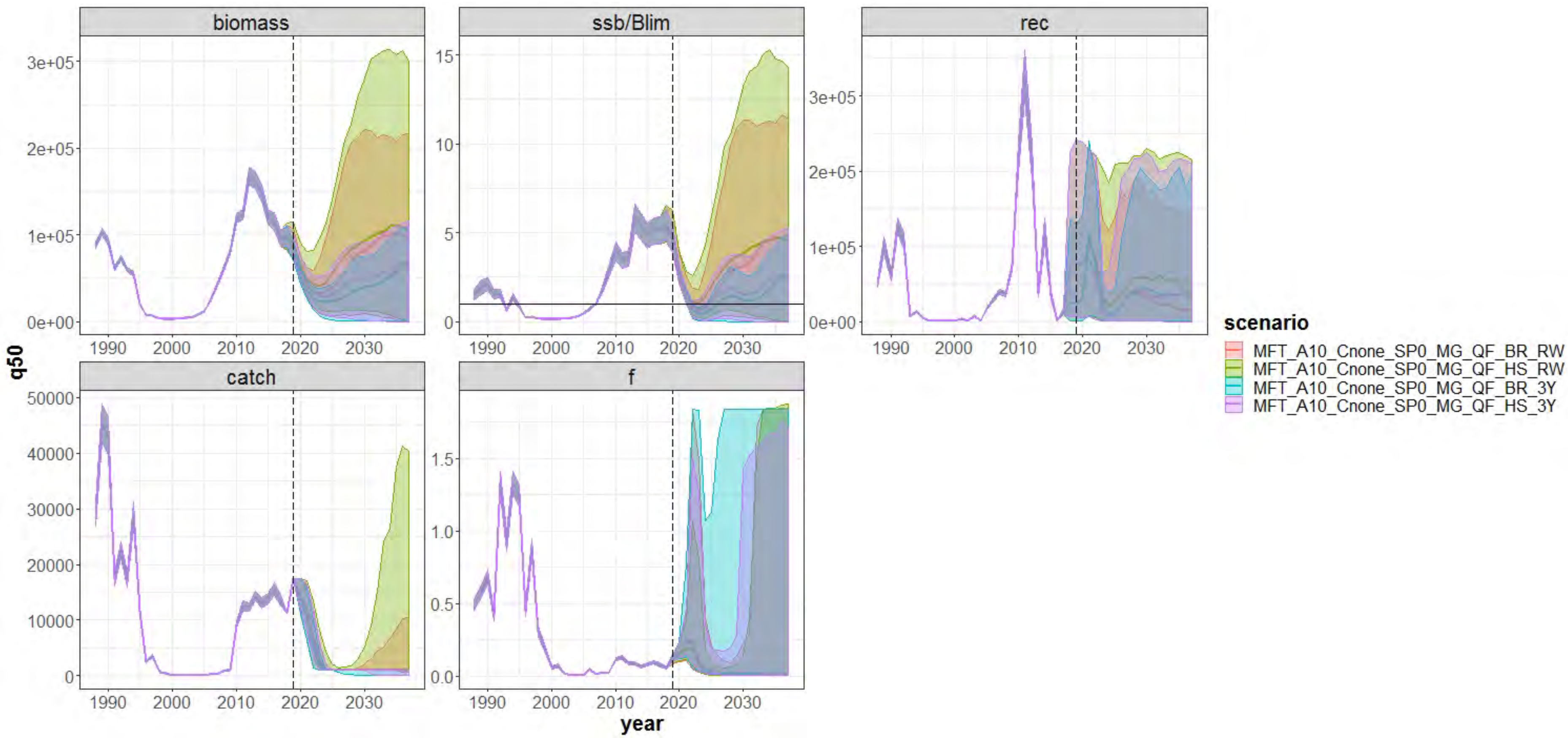


Figure 8. Results of the simulations with the HCR MFT and OMG. a) Median. b) 80% CI (10th-90th percentiles)

Annex 5. Performance Statistics: definitions and results

Diana González-Troncoso[1], Fernando González-Costas[1], Carmen Fernández[1] and Agurtzane Urtizberea[2]

[1]Instituto Español de Oceanografía (IEO)
[2]AZTI

Introduction

The discussion of the Management Objectives (MO) and the Performance Statistics (PS) for the Management Strategy Evaluation (MSE) of the NAFO 3M cod began at the WG-RBMS meeting in August 2018. The report of that meeting (NAFO/COM-SC Doc. 18-02) included the following paragraphs about this subject:

b. Development of Management Objectives, Performance Statistics and associated Risk Thresholds for Cod in Div. 3M

Performance Statistics and Criteria agreed as required/desirable during the development of the Greenland halibut MSE in 2017 (FC-SC Doc. 17-03, Table 2) were taken as a starting point for the development of equivalent objectives for the 3M Cod MSE. The WG-RBMS agreed that the Greenland halibut MSE elements were not being endorsed as a template. However, it was accepted they could inform the 3M Cod process recognizing there may be specific considerations for the management of each species and therefore may be considered individually.

The required performance statistic, performance criterion and relevant management objectives were provisionally adapted. They are included in Table 1 below. There was no agreement on the content highlighted in grey and it was recognized that further discussion on these aspects is required before they serve as the basis of any evaluation. These details have been left in the table for illustrative purpose only.

Table 1. Performance Statistics and Criteria development for 3M Cod MSE.

This table was adapted from one developed during the Greenland halibut MSE. Content highlighted in grey has not been agreed to apply to 3M Cod but has been left in for illustrative purposes.

REQUIRED PERFORMANCE STATISTICS/CRITERIA		
Performance statistic	**Performance criterion**	**Relevant management objective**
$P(B_{20YY} < B_{MSY})$	$P \leq 0.5$	Restore to within a prescribed period of time or maintain at B_{MSY}
To be determined	Count	Low risk of exceeding F_{lim} (currently F_{MSY})
To be determined	$P \leq 0.1$ Count	Very low risk of going below an established threshold [e.g. B_{lim} or B_{lim} proxy].
DESIRABLE SECONDARY PERFORMANCE STATISTICS/CRITERIA		
Performance statistic	**Performance criterion**	**Relevant management objective**
$P(B_{2022} < B_{2018})$	$P \leq \alpha$ Where: $\alpha = 0.10$ if $B_{2018} < 0.3B_{MSY}$: 0.25 if $0.3 B_{MSY} < B_{2018}$	The risk of failure to meet the B_{msy} target and interim biomass targets within a prescribed period of time should be kept moderately low
C_{2019} C_{2020} $\sum_{y=2018}^{2022} C_y / 5$ $\sum_{y=2018}^{2027} C_y/10$ $\sum_{y=2018}^{2037} C_y/20$		Maximize yield in the short, medium and long term
For each year, y $P\left(\frac{\lvert C_y - C_{y-1}\rvert}{C_{y-1}} > 0.15\right)$ $AAV_{2018-2022} = \frac{1}{5}\sum_{y=2018}^{2022}\frac{\lvert C_y - C_{y-1}\rvert}{C_{y-1}}$ and $AAV_{2018-2037} = \frac{1}{20}\sum_{y=2018}^{2037}\frac{\lvert C_y - C_{y-1}\rvert}{C_{y-1}}$	P≤0.15	Keep inter annual TAC variation below "an established threshold"

It was agreed that short medium and long-term objectives will be evaluated over 5, 10 and 20-year periods but that this may vary to some extent depending on the specific statistic.

One of the tasks assigned to the analysts team in charge of developing the 3M cod MSE was to develop a proposal for a full set of MO/PS/Risks table. The following sections present the proposal for such a table based on the WG-RBMS 2018 agreements. The results of these PSs applied to the scenarios presented during the April 2019 RBMS meeting (COM-SC RBMS-WP 19-01) are also included in the sections below. The first year for measuring the PSs was taken as the year 2020, which is the first year that the TAC is calculated with the HCR.

The MSE simulations conducted so far assumed that the catch taken is equal to the TAC, except in the following circumstances, which result in catch lower than the TAC:

- if the TAC obtained from the HCR is bigger than 90% of the ("true") stock biomass, then the catch taken is 90% of the stock biomass;
- if the TAC obtained from the HCR, or the catch obtained from the previous bullet point, corresponds to catch numbers larger than the population numbers for one or more of the ages, then the actual catch taken from such ages equals the population numbers of those ages.

Specifications of the PSs

REQUIRED PERFORMANCE STATISTICS/CRITERIA
Even considering the following PS as required and necessary, probably they do not all have the same priority. A possible priorization could be the following:

Performance statistic	Performance criterion	Relevant management objective	Notes
for y = 2020 to 2037; $count_y[P(B_y<B_{lim})>0.1]$ i.e. count for how many years in the period 2020-2037 the $P(B_y<B_{lim})$ is bigger than 0.1.	Count	Very low risk of going below an established threshold [e.g. B_{lim} or B_{lim} proxy]. Currently B_{lim}=SSB_{2007}.	It would be convenient to show a table with the value of $P(B_y<B_{lim})$ year by year to see its evolution over time.

The Scientific Council (SC) agreed in their January 2019 meeting to establish B_{lim} as the SSB_{2007} level, by OM and iteration.

Performance statistic	Performance criterion	Relevant management objective	Notes

for y = 2025 to 2029;
 	
$count_y[P(F_y>F_{MSY})>0.3]$
 	
i.e. count for how many years in the period 2025-2029 the $P(F_y>F_{MSY})$ is bigger than 0.3.
 	
for y = 2030 to 2037;
 	
$count_y[P(F_y>F_{MSY})>0.3]$
 	
i.e. count for how many years in the period 2030-2037 the $P(F_y>F_{MSY})$ is bigger than 0.3.
	Count
	
	Count
		Low risk of exceeding F_{lim} (currently F_{lim}=$F_{30\%SPR}$)	It would be convenient to show a table with the value of $P(F_y>F_{MSY})$ year by year to see its evolution over time.

It was agreed in the January 2019 SC meeting that F_{lim}=$F_{30\%SPR}$ estimated with the 3 most recent years mean of the inputs (running mean), would be used as proxy for F_{MSY}. Within each OM, this will give an F_{lim} value for each projected year and each iteration. The objective of this PS is to set a low probability of exceeding F_{lim} as a requirement in the medium (2025-2029) and long (2030-2037) terms.

Performance statistic	**Performance criterion**	**Relevant management objective**	**Notes**
	P≤0.5	*Restore to within a prescribed period of time or maintain at B_{MSY}* Long term	*Initially, and as agreed by the SC, a PS is not proposed to measure this objective. It would be necessary to discuss which is the level of SSB that one wishes to reach in the future and how to estimate it.* *It would be proposed that this level be achieved in the long term as required (2037) and that it is advisable to achieve it already in the medium term (2030).*

The January 2019 SC meeting (NAFO SCS Doc. 19/04) agreed that "Due to issues related to B_{MSY} estimates, no B_{MSY} value has been proposed as an a priori performance statistic. If managers need B_{MSY} as a target to meet convention obligations, then we would be able to calculate a value retrospectively corresponding to the management strategy that would give highest long term yield values in the projections and the associated biomass".

DESIRABLE SECONDARY PERFORMANCE STATISTICS/CRITERIA

Performance statistic	**Performance criterion**	**Relevant management objective**	**Notes**
	P≤0.5	*Restore or maintain the Biomass in the medium term at B_{MSY}*	*Initially, and as agreed by the SC, a PS is not proposed to measure this objective. It would be necessary to discuss which is the level of SSB that one wishes to reach in the future and how to estimate it.* *It would be proposed that this level be achieved in the long term as required (2037) and that it is advisable to achieve it already in the medium term (2030).*

The idea is to put this Management Objective as *Desirable* in the medium-term and *required* in the long term, in line with how it was done for GHL.

Performance statistic	Performance criterion	Relevant management objective	Notes
for y = 2020 to 2024; $count_y[P(F_y>F_{MSY})>0.3]$ i.e. count for how many years in the period 2020-2024 the $P(F_y>F_{MSY})$ is bigger than 0.3.	Count	Low risk of exceeding F_{lim} in the short term (currently F_{MSY})	It would be convenient to show a table with the value of this PS year by year to see its evolution over time.

The idea is to put this PS as *Desirable* in the short-term and *required* in the medium and long terms.

Performance statistic	Performance criterion	Relevant management objective	Notes
$\sum_{y=2020}^{2024} C_y/5$ $\sum_{y=2020}^{2029} C_y/10$ $\sum_{y=2020}^{2037} C_y/18$ i.e. average catch over the stated period of years.		Maximize yield in the short, medium and long term.	It would be advisable to show this PS by making a graph with the median and the percentiles (10, 90) of the distribution of average catch in each of the 3 time-periods considered. The plot would include the different HCRs and OMs, for ease of comparison.

Performance statistic	Performance criterion	Relevant management objective	Notes
For each year (2020-2037), for the scenarios without constraint on inter-annual TAC change, calculate: $P\left[\left(\frac{\lvert \mathrm{TAC_y}-\mathrm{TAC_{y-1}}\rvert}{\mathrm{TAC_{y-1}}}\right)>0.10\right]$ $P\left[\left(\frac{\lvert \mathrm{TAC_y}-\mathrm{TAC_{y-1}}\rvert}{\mathrm{TAC_{y-1}}}\right)>0.15\right]$ $P\left[\left(\frac{\lvert \mathrm{TAC_y}-\mathrm{TAC_{y-1}}\rvert}{\mathrm{TAC_{y-1}}}\right)>0.20\right]$	Probability Probability Probability	Keep inter annual TAC variation below “an established threshold”	Graph showing, for each of the 3 values (10%, 15%, 20%), the probability per year. This would give information on appropriate levels for the inclusion of a TAC constraint as part of the HCR.

i.e. probability that the TAC changes by more than 10%, 15% or 20% (relative to the TAC of the previous year). The following PS is for all scenarios: $iter\_mean = \frac{1}{18}\sum_{y=2020}^{2037}\left(\frac{\lvert \mathrm{TAC_y} - \mathrm{TAC_{y-1}} \rvert}{TAC_{y-1}}\right)$ i.e. average inter-annual TAC change over the years 2020-2037.	Mean(iter_mean)	Minimize annual TAC variation in the long term	For each iteration in the MSE simulation, an average inter-annual TAC change over the period 2020-2037 is estimated. Then a mean (i.e. an average) is taken over the MSE iterations. This will allow us to compare different HCRs for a given OM.

The idea is, first, to examine inter-annual TAC change with different values in the HCR without constraint with the first PS to obtain information on what could be an appropriate level to insert as a constraint in the HCR. The second PS measures the average inter-annual TAC change over the entire period.

The next two PSs were recommended by the SC in the 2019 January meeting (NAFO SCS Doc. 19/04).

Performance statistic	**Performance criterion**	**Relevant management objective**	**Notes**
For each year (2020-2037) $\text{Median}\left(\frac{\mathrm{Biomass_{y,8+}}}{\mathrm{Biomass_y}}\right)$		Measure the proportion of stock biomass in the Plus Group	It would be convenient to show a table with the value of this PS year by year, to see its evolution over time.

This PS would be calculated each year of the projection.

Performance statistic	**Performance criterion**	**Relevant management objective**	**Notes**
$P(SSB_y<SSB_{1997}$ for ALL years of the period 2032-2037)	Probability	Measure the number of crashed iterations.	

"Crash" was defined as the stock biomass being below the SSB_{1997} value, for ALL years of the period 2032-2037.

Complete proposal for the PERFORMANCE STATISTICS/CRITERIA Table.

REQUIRED PERFORMANCE STATISTICS/CRITERIA			
Performance statistic	**Performance criterion**	**Relevant management objective**	**Notes**
PS1: for y = 2020 to 2037; $count_y[P(B_y<B_{lim})>0.1]$ i.e. count for how many years in the period 2020-2037 the $P(B_y<B_{lim})$ is bigger than 0.1.	Count	Very low risk of going below an established threshold [e.g. B_{lim} or B_{lim} proxy].	It would be convenient to show a table with the value of $P(B_y<B_{lim})$ year by year to see its evolution over time.

PS2:
for y = 2025 to 2029;
$count_y[P(F_y>F_{MSY})>0.3]$
 	
i.e. count for how many years in the period 2025-2029 the $P(F_y>F_{MSY})$ is bigger than 0.3.
 	
for y = 2030 to 2037;
$count_y[P(F_y>F_{MSY})>0.3]$
 	
i.e. count for how many years in the period 2030-2037 the $P(F_y>F_{MSY})$ is bigger than 0.3.
	Count
	
	Count
		Low risk of exceeding F_{lim} (currently $F_{lim}=F_{30\%SPR}$)	It would be convenient to show a table with the value of $P(F_y>F_{MSY})$ year by year to see its evolution over time.

	$P\leq0.5$	*Restore to within a prescribed period of time or maintain at B_{MSY}* Long term	*Initially, and as agreed by the SC, a PS is not proposed to measure this objective. It would be necessary to discuss which is the level of SSB that one wishes to reach in the future and how to estimate it.* *It would be proposed that this level be achieved in the long term as required (2037) and that it is advisable to achieve it already in the medium term (2030).*

DESIRABLE SECONDARY PERFORMANCE STATISTICS/CRITERIA			
Performance statistic	**Performance criterion**	**Relevant management objective**	**Notes**
	$P\leq0.5$	*Restore or maintain the Biomass in the medium term at B_{MSY}*	*Initially, and as agreed by the SC, a PS is not proposed to measure this objective. It would be necessary to discuss which is the level of SSB that one wishes to reach in the future and how to estimate it.* *It would be proposed that this level be achieved in the long term as required (2037) and that it is advisable to achieve it already in the medium term (2030).*
PS2: for y = 2020 to 2024; $count_y[P(F_y>F_{MSY})>0.3]$ i.e. count for how many years in the period 2020-2024 the $P(F_y>F_{MSY})$ is bigger than 0.3.	Count	Low risk of exceeding F_{lim} in the short term (currently F_{MSY})	It would be convenient to show a table with the value of this PS year by year to see its evolution over time.
PS3: $\sum_{y=2020}^{2024} C_y/5$ $\sum_{y=2020}^{2029} C_y/10$ $\sum_{y=2020}^{2037} C_y/18$ i.e. average catch over the stated period of years.		Maximize yield in the short, medium and long term.	It would be advisable to show this PS by making a graph with the median and the percentiles (10, 90) of the distribution of average catch in each of the 3 time-periods considered. The plot would include the different HCRs and OMs, for ease of comparison.

PS4: For each year (2020-2037), for the scenarios without constraint on inter-annual TAC change, calculate: $P\left[\left(\frac{\lvert \mathrm{TAC_y}-\mathrm{TAC_{y-1}}\rvert}{\mathrm{TAC_{y-1}}}\right) > 0.10\right]$ $P\left[\left(\frac{\lvert \mathrm{TAC_y}-\mathrm{TAC_{y-1}}\rvert}{\mathrm{TAC_{y-1}}}\right) > 0.15\right]$ $P\left[\left(\frac{\lvert \mathrm{TAC_y}-\mathrm{TAC_{y-1}}\rvert}{\mathrm{TAC_{y-1}}}\right) > 0.20\right]$ i.e. probability that the TAC changes by more than 10%, 15% or 20% (relative to the TAC of the previous year). The following PS is for all scenarios: $iter\_mean = \frac{1}{18}\sum_{y=2020}^{2037}\left(\frac{\lvert \mathrm{TAC_y}-\mathrm{TAC_{y-1}}\rvert}{TAC_{y-1}}\right)$ i.e. average inter-annual TAC change over the years 2020-2037.	Probability Probability Probability Mean(iter_mean)	Keep inter annual TAC variation below “an established threshold” Minimize annual TAC variation in the long term	Graph showing, for each of the 3 values (10%, 15%, 20%), the probability per year. This would give information on appropriate levels for the inclusion of a TAC constraint as part of the HCR. For each iteration in the MSE simulation, an average inter-annual TAC change over the period 2020-2037 is estimated. Then a mean (i.e. an average) is taken over the MSE iterations. This will allow us to compare different HCRs for a given OM
PS5: For each year (2020-2037); $\mathrm{Median}\left(\frac{\mathrm{Biomass_{y,8+}}}{\mathrm{Biomass_y}}\right)$		Measure the proportion of stock biomass in the Plus Group	It would be convenient to show a table with the value of this PS year by year, to see its evolution over time.
PS6: P(SSBy<SSB_{1997} for ALL years of the period 2032-2037)	Probability	Measure the number of crashed iterations.	

Results

The list of OMs and the slope and target HCR settings applied, for which MSE results are available, is presented in Table 1 of COM-SC RBMS-WP 19-01, resulting in 22 scenarios. The present document shows (in Tables 1-6 and Figures 1-6) the results of applying the proposed PSs to the 22 scenarios. *Note: PS 5 is not implemented yet*.

Several additional scenarios with F=0 were also run (see Table 2 of COM-SC RBMS-WP 19-01). Results of the proposed PSs for these scenarios are shown in Tables 7-12 of the present document. *Note: PS 5 is not implemented yet*.

Table 1, Figure 1 (top and middle) and Figure 2 (top) show the results of PS1 (P(SSB<B_{lim})) by year for the 22 scenarios with the Slope or Target HCRs. We can see that in the medium term (2022-2025) none of the scenarios reach the proposed objective of having a risk equal or less than 10% of SSB<B_{lim}. Many scenarios reach values close to a probability of 1 of SSB being below B_{lim} in some of those years, which is due to the drop in biomass in the first years due to the poor recruitments between 2014 and 2017. The more positive scenarios are the ones with Hockey Stick recruitment, and the one in which the Starting Point is lower, but they still have a risk of more than 10%.

In the medium term, the value of the PS1 varies depending on the scenario. Most of the scenarios do not reach the objective in any of the projected years. The two scenarios tested with starting point equal to the 75% of the 2019 TAC (SP25 scenarios) reach the objective of less than 10% risk of SSB<B_{lim} from 2027 till 2037. This objective was also reached in the medium/long term in the scenarios with MFS_A10_Cnone_SP0_MV, with a slope HCR.

With regards to PS2 (P(F>F_{lim})) (Table 2, Figures 3 and 4), the figure is similar to that for the PS1; none of the presented scenarios have less than the proposed risk of 30% in the short term (2022-2025). The better behavior in this case is the one with a lower starting point, allowing the SSB to recover slightly. In the medium term, almost all the scenarios reach the objective, except five scenarios with different configurations.

PS3, that is the average annual catch over different periods, is presented in Table 3 and Figure 5. There are differences if we choose to maximize the catches in the short, medium and long term. In general, the Slope HCR gives catches higher than the Target HCR. Overall, these catches are quite lower than the level of catches observed during 2011-2017.

The average interannual TAC change (PS4) is presented in Table 4 and Figure 6. The lower change is in scenarios 14 and 16, combining the Target HCR, the M GADGET (MG) and three years mean (3Y). The highest interannual TAC change is when we choose a Hockey-Stick (HS) with a Random Walk (RW). Overall, the change is of about 20%.

PS5 (Table 5 and Figure 7 top), which measures the proportion of stock biomass in the plus group (8+), has not been implemented yet.

The proportion of crashed iterations, defined as the stock biomass being below the SSB_{1997} value, for all years of the period 2032-2037 (PS6), is presented in Table 6 and Figure 8 (top). With regards to this PS, the best behavior is with the Slope HCR and the OM vector, with the starting point in the 2019 TAC and α equal to 1. The scenario that crashes more times is, as in the PS4, when we change in the Target HCR the value of α from 1 to 1.5.

For the F=0 scenarios, the results are quite different and all the scenarios result in a risk less than 10% of SSB<B_{lim} (Table 7 and Figures 1 (bottom) and 2 (bottom)). Although the probability that the stock biomass drops below B_{lim} is higher between years 2023 and 2027, especially for the OMs with MG and BR, it is less than 10%. PS2, PS3 and PS4 do not apply in the F=0 scenarios as these PSs measure F or catches, which are always 0 in these scenarios. PS5 (Table 8 and Figure 7 bottom) has not been implemented yet. The number of crashed iterations in the period 2032-2037 (PS6, Table 9 and Figure 8 bottom) is 0 for all the F=0 scenarios.

Discussion

The results show that there is some risk that in the short /medium term the biomass will fall below B_{lim}. This is mainly due to the low recruitments observed in the 2014-2017 period. This is going to make it very difficult to find a robust HCR that meets the management objectives already established in the agreed work plan. Mainly the objective that the biomass does not fall annually below B_{lim} with a risk higher than 10% will be very difficult to reach in the scenarios with catches.

It is very likely that the current status of the 3M cod stock as well as the great variability of the biological parameters and the complexity of simulating possible future recruitments make it difficult to test and find a robust HCR in the established period (September 2019) that meets the proposed management objectives.

Once all the results of the scenarios agreed in January 2019 are available, we will have a clearer idea of the possible difficulties we face to find an HCR robust to the uncertainties observed in this stock, which will allow us to decide and review the possible new 3M cod MSE calendar.

References

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NAFO, 2019. Cod Stock Management Strategy Evaluation (MSE). NAFO SCS Doc. 19/04, Serial No. N6911.

Urtizberea, A., D. González-Troncoso, F. González-Costas and C. Fernández, 2019. 3M cod MSE: Results of the Scenarios. COM-SC RBMS-WP 19/01.

Table 1. **PS1:** P(SSB<B_{lm}) by year. In red, the cases in which P(SSB<B_{lim})>0.1. The final column counts the number of years of the 2020-2037 period in which P(SSB<B_{lim})>0.1.

Year/OM	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Number
1.MFS_A10_Cnone_SP0_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.19	0.64	0.69	0.47	0.25	0.11	0.06	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.03	6
2.MFS_A10_Cnone_SP0_MV_QF_BR_3Y	0.00	0.00	0.00	0.00	0.37	0.92	0.96	0.80	0.42	0.19	0.11	0.09	0.09	0.10	0.10	0.08	0.07	0.06	0.05	0.05	7
3.MFS_A10_Cnone_SP0_MV_QF_HS_RW	0.00	0.00	0.00	0.00	0.08	0.20	0.17	0.11	0.06	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	3
4.MFS_A10_Cnone_SP0_MV_QF_HS_3Y	0.00	0.00	0.00	0.00	0.14	0.36	0.30	0.19	0.11	0.07	0.05	0.04	0.04	0.05	0.05	0.04	0.04	0.03	0.03	0.02	5
5.MFS_A10_Cnone_SP0_MG_QF_BR_RW	0.00	0.00	0.00	0.07	0.61	0.75	0.65	0.49	0.33	0.25	0.21	0.21	0.21	0.22	0.21	0.18	0.17	0.16	0.15	0.15	16
6.MFS_A10_Cnone_SP0_MG_QF_BR_3Y	0.00	0.00	0.00	0.10	0.93	0.99	0.97	0.86	0.62	0.51	0.43	0.44	0.54	0.61	0.61	0.55	0.48	0.44	0.42	0.43	17
7.MFS_A10_Cnone_SP0_MG_QF_HS_RW	0.00	0.00	0.00	0.07	0.48	0.52	0.45	0.34	0.26	0.21	0.19	0.19	0.21	0.23	0.22	0.20	0.18	0.17	0.17	0.16	16
8.MFS_A10_Cnone_SP0_MG_QF_HS_3Y	0.00	0.00	0.00	0.09	0.84	0.87	0.81	0.63	0.47	0.40	0.40	0.43	0.51	0.55	0.55	0.50	0.46	0.44	0.44	0.44	16
9.MFT_A10_Cnone_SP0_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.18	0.61	0.64	0.48	0.30	0.20	0.17	0.16	0.15	0.15	0.14	0.13	0.12	0.12	0.12	0.12	16
10.MFT_A10_Cnone_SP0_MV_QF_BR_3Y	0.00	0.00	0.00	0.00	0.35	0.84	0.87	0.71	0.44	0.29	0.23	0.22	0.21	0.22	0.22	0.21	0.19	0.18	0.17	0.17	16
11.MFT_A10_Cnone_SP0_MV_QF_HS_RW	0.00	0.00	0.00	0.00	0.09	0.22	0.21	0.17	0.14	0.13	0.13	0.14	0.17	0.19	0.24	0.27	0.31	0.35	0.40	0.44	15
12.MFT_A10_Cnone_SP0_MV_QF_HS_3Y	0.00	0.00	0.00	0.00	0.16	0.37	0.33	0.25	0.18	0.15	0.14	0.13	0.14	0.16	0.17	0.18	0.20	0.22	0.24	0.27	16
13.MFT_A10_Cnone_SP0_MG_QF_BR_RW	0.00	0.00	0.00	0.07	0.60	0.69	0.57	0.39	0.27	0.20	0.17	0.17	0.18	0.19	0.18	0.17	0.17	0.17	0.17	0.18	16
14.MFT_A10_Cnone_SP0_MG_QF_BR_3Y	0.00	0.00	0.00	0.11	0.91	0.97	0.93	0.71	0.48	0.39	0.33	0.35	0.41	0.45	0.43	0.40	0.36	0.35	0.34	0.34	17
15.MFT_A10_Cnone_SP0_MG_QF_HS_RW	0.00	0.00	0.00	0.07	0.45	0.48	0.37	0.25	0.18	0.16	0.15	0.14	0.16	0.16	0.16	0.17	0.19	0.20	0.21	0.25	16
16.MFT_A10_Cnone_SP0_MG_QF_HS_3Y	0.00	0.00	0.00	0.10	0.83	0.84	0.68	0.45	0.30	0.27	0.27	0.30	0.34	0.36	0.34	0.30	0.29	0.29	0.28	0.28	16
17.MFS_A15_Cnone_SP0_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.19	0.65	0.72	0.52	0.31	0.17	0.12	0.11	0.10	0.11	0.12	0.13	0.16	0.17	0.19	0.19	16
18.MFS_A10_C20_SP0_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.21	0.73	0.82	0.70	0.55	0.46	0.43	0.44	0.44	0.43	0.42	0.42	0.42	0.43	0.45	0.46	16
19.MFS_A10_Cnone_SP25_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.03	0.34	0.46	0.31	0.13	0.04	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	4
20.MFT_A15_Cnone_SP0_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.67	0.99	0.99	0.96	0.92	0.89	0.88	0.86	0.85	0.86	0.85	0.85	0.83	0.84	0.83	0.83	16
21.MFT_A10_C20_SP0_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.19	0.71	0.80	0.69	0.55	0.45	0.43	0.42	0.41	0.40	0.39	0.38	0.38	0.38	0.39	0.40	16
22.MFT_A10_Cnone_SP25_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.04	0.35	0.45	0.34	0.17	0.09	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.04	0.05	4

Table 2. **PS2:** P(F>F_{lim}) by year. In red, the cases in which P(F>F_{lim})>0.3. The final columns count the number of years in which P(F>F_{lim})>0.3 for different periods.

Year/OM	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Number 2020-2037	Number 2025-2029	Number 2030-2037	Number 2020-2024
1.MFS_A10_Cnone_SP0_MV_QF_BR_RW	0.00	0.00	0.07	0.54	0.72	0.53	0.23	0.05	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	3	0	0	3
2.MFS_A10_Cnone_SP0_MV_QF_BR_3Y	0.00	0.00	0.09	0.79	0.87	0.68	0.27	0.08	0.05	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.03	0.03	0.03	0.04	3	0	0	3
3.MFS_A10_Cnone_SP0_MV_QF_HS_RW	0.00	0.00	0.05	0.46	0.56	0.39	0.14	0.04	0.01	0.01	0.02	0.02	0.03	0.04	0.03	0.02	0.02	0.02	0.02	0.02	3	0	0	3
4.MFS_A10_Cnone_SP0_MV_QF_HS_3Y	0.00	0.00	0.07	0.74	0.81	0.59	0.21	0.03	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.04	0.03	0.02	0.02	0.02	3	0	0	3
5.MFS_A10_Cnone_SP0_MG_QF_BR_RW	0.00	0.06	0.43	0.67	0.70	0.49	0.21	0.10	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	4	0	0	4
6.MFS_A10_Cnone_SP0_MG_QF_BR_3Y	0.00	0.06	0.61	0.87	0.84	0.68	0.34	0.18	0.15	0.14	0.15	0.16	0.18	0.20	0.21	0.21	0.21	0.22	0.22	0.23	5	0	0	5
7.MFS_A10_Cnone_SP0_MG_QF_HS_RW	0.00	0.06	0.44	0.69	0.70	0.48	0.21	0.10	0.07	0.06	0.06	0.07	0.08	0.09	0.09	0.10	0.09	0.10	0.10	0.10	4	0	0	4
8.MFS_A10_Cnone_SP0_MG_QF_HS_3Y	0.00	0.06	0.64	0.90	0.90	0.75	0.34	0.15	0.10	0.10	0.10	0.11	0.14	0.16	0.19	0.20	0.21	0.22	0.23	0.26	5	0	0	5
9.MFT_A10_Cnone_SP0_MV_QF_BR_RW	0.00	0.00	0.07	0.48	0.63	0.52	0.32	0.17	0.13	0.11	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11	0.11	0.11	4	0	0	4
10.MFT_A10_Cnone_SP0_MV_QF_BR_3Y	0.00	0.00	0.09	0.69	0.73	0.57	0.34	0.21	0.18	0.16	0.15	0.15	0.15	0.16	0.16	0.15	0.16	0.16	0.16	0.16	4	0	0	4
11.MFT_A10_Cnone_SP0_MV_QF_HS_RW	0.00	0.00	0.06	0.44	0.54	0.39	0.23	0.16	0.13	0.14	0.16	0.19	0.22	0.27	0.29	0.35	0.39	0.44	0.48	0.51	8	0	5	3
12.MFT_A10_Cnone_SP0_MV_QF_HS_3Y	0.00	0.00	0.08	0.64	0.68	0.49	0.25	0.15	0.12	0.12	0.12	0.13	0.14	0.16	0.18	0.22	0.25	0.27	0.31	0.35	5	0	2	3
13.MFT_A10_Cnone_SP0_MG_QF_BR_RW	0.00	0.06	0.44	0.62	0.52	0.28	0.14	0.10	0.10	0.09	0.09	0.10	0.10	0.10	0.11	0.11	0.12	0.14	0.15	0.17	3	0	0	3
14.MFT_A10_Cnone_SP0_MG_QF_BR_3Y	0.00	0.06	0.65	0.82	0.65	0.40	0.20	0.17	0.14	0.14	0.14	0.15	0.17	0.18	0.19	0.19	0.19	0.19	0.20	0.20	4	0	0	4
15.MFT_A10_Cnone_SP0_MG_QF_HS_RW	0.00	0.06	0.45	0.64	0.52	0.26	0.10	0.08	0.07	0.07	0.07	0.08	0.09	0.11	0.13	0.16	0.19	0.22	0.26	0.29	3	0	0	3
16.MFT_A10_Cnone_SP0_MG_QF_HS_3Y	0.00	0.06	0.67	0.87	0.69	0.38	0.14	0.11	0.10	0.10	0.11	0.11	0.12	0.14	0.14	0.15	0.16	0.17	0.17	0.17	4	0	0	4
17.MFS_A15_Cnone_SP0_MV_QF_BR_RW	0.00	0.00	0.07	0.55	0.74	0.59	0.38	0.20	0.12	0.09	0.08	0.08	0.10	0.13	0.16	0.18	0.17	0.17	0.16	0.16	4	0	0	4
18.MFS_A10_C20_SP0_MV_QF_BR_RW	0.00	0.00	0.07	0.61	0.86	0.93	0.85	0.69	0.54	0.47	0.45	0.44	0.44	0.42	0.42	0.42	0.44	0.44	0.45	0.46	17	5	8	4
19.MFS_A10_Cnone_SP25_MV_QF_BR_RW	0.00	0.00	0.00	0.17	0.35	0.22	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1	0	0	1
20.MFT_A15_Cnone_SP0_MV_QF_BR_RW	0.00	0.00	0.34	0.94	1.00	0.99	0.97	0.91	0.85	0.82	0.80	0.80	0.80	0.80	0.81	0.81	0.80	0.80	0.80	0.80	18	5	8	5
21.MFT_A10_C20_SP0_MV_QF_BR_RW	0.00	0.00	0.08	0.55	0.83	0.87	0.79	0.63	0.49	0.43	0.40	0.38	0.38	0.37	0.37	0.37	0.37	0.37	0.38	0.38	17	5	8	4
22.MFT_A10_Cnone_SP25_MV_QF_BR_RW	0.00	0.00	0.00	0.17	0.38	0.34	0.17	0.06	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	2	0	0	2

Table 3. **PS3**: Average annual catch over different periods. Median, 10th and 90th percentiles.

Year/OM	10% 2020-2037	50% 2020-2037	90% 2020-2037	10% 2020-2024	50% 2020-2024	90% 2020-2024	10% 2020-2029	50% 2020-2029	90% 2020-2029
1.MFS_A10_Cnone_SP0_MV_QF_BR_RW	3708	5031	8120	7381	9910	12577	4757	6071	8575
2.MFS_A10_Cnone_SP0_MV_QF_BR_3Y	3428	4432	6790	7160	9494	11543	4489	5608	7127
3.MFS_A10_Cnone_SP0_MV_QF_HS_RW	5498	11642	20851	9812	13186	17215	6770	11006	18499
4.MFS_A10_Cnone_SP0_MV_QF_HS_3Y	4455	9024	15050	9345	12319	15631	6060	9199	14409
5.MFS_A10_Cnone_SP0_MG_QF_BR_RW	2639	4230	8210	5282	7882	10786	3441	5002	8275
6.MFS_A10_Cnone_SP0_MG_QF_BR_3Y	2254	3026	4319	5139	7458	9533	3164	4371	5582
7.MFS_A10_Cnone_SP0_MG_QF_HS_RW	2959	5683	14311	6512	9168	12428	4182	6219	11094
8.MFS_A10_Cnone_SP0_MG_QF_HS_3Y	2532	3593	6089	6252	8623	11036	3815	5248	7248
9.MFT_A10_Cnone_SP0_MV_QF_BR_RW	2599	3724	5323	5701	9641	14349	3430	5383	7739
10.MFT_A10_Cnone_SP0_MV_QF_BR_3Y	2471	3442	4407	5565	9227	13010	3304	5102	6943
11.MFT_A10_Cnone_SP0_MV_QF_HS_RW	3687	10112	25989	7477	12536	21378	4499	8011	24722
12.MFT_A10_Cnone_SP0_MV_QF_HS_3Y	3140	5128	16479	7368	11543	18014	4249	6523	11730
13.MFT_A10_Cnone_SP0_MG_QF_BR_RW	2040	2841	6147	4450	6653	10491	2737	3860	5826
14.MFT_A10_Cnone_SP0_MG_QF_BR_3Y	1920	2443	3157	4349	6519	9475	2675	3712	5129
15.MFT_A10_Cnone_SP0_MG_QF_HS_RW	2295	3321	24946	5219	7603	11813	3166	4374	6908
16.MFT_A10_Cnone_SP0_MG_QF_HS_3Y	2137	2685	3518	5215	7332	10477	3108	4121	5654
17.MFS_A15_Cnone_SP0_MV_QF_BR_RW	3979	7030	14309	7551	10259	13604	4968	6853	12101
18.MFS_A10_C20_SP0_MV_QF_BR_RW	3601	7928	12060	9956	12179	14814	6237	8789	11799
19.MFS_A10_Cnone_SP25_MV_QF_BR_RW	3382	4642	7115	5764	7766	9834	3919	5134	7319
20.MFT_A15_Cnone_SP0_MV_QF_BR_RW	3402	4500	6876	11221	14434	19504	5867	7621	10757
21.MFT_A10_C20_SP0_MV_QF_BR_RW	3651	4746	7223	9412	11594	16110	6248	7185	10125
22.MFT_A10_Cnone_SP25_MV_QF_BR_RW	2204	3317	4832	4363	7538	11666	2752	4341	6477

Table 4. **PS4:** Probability that the interannual TAC change exceeds 10% (top), 15% (middle) or 20% (bottom). The right-most column of the top table is the average interannual TAC change over the 2020-2037 period (the values in the column should be multiplied by 100 to express this change as a percentage).

Case	10																		
Year/OM	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Mean
1.MFS_A10_Cnone_SP0_MV_QF_BR_RW	0.48	0.32	0.81	0.94	0.85	0.57	0.46	0.66	0.67	0.67	0.64	0.62	0.58	0.56	0.58	0.56	0.53	0.49	0.22
2.MFS_A10_Cnone_SP0_MV_QF_BR_3Y	0.48	0.34	0.91	0.97	0.83	0.52	0.39	0.52	0.47	0.52	0.60	0.68	0.62	0.58	0.59	0.56	0.56	0.54	0.20
3.MFS_A10_Cnone_SP0_MV_QF_HS_RW	0.44	0.36	0.62	0.77	0.75	0.66	0.62	0.65	0.66	0.63	0.62	0.64	0.63	0.61	0.63	0.62	0.63	0.62	0.18
4.MFS_A10_Cnone_SP0_MV_QF_HS_3Y	0.44	0.33	0.70	0.84	0.81	0.67	0.56	0.56	0.57	0.58	0.57	0.60	0.55	0.57	0.58	0.56	0.59	0.56	0.16
5.MFS_A10_Cnone_SP0_MG_QF_BR_RW	0.73	0.64	0.94	0.92	0.79	0.52	0.46	0.45	0.47	0.52	0.55	0.57	0.57	0.54	0.57	0.59	0.53	0.54	0.20
6.MFS_A10_Cnone_SP0_MG_QF_BR_3Y	0.73	0.71	0.98	0.95	0.79	0.45	0.28	0.20	0.20	0.27	0.35	0.43	0.39	0.35	0.38	0.34	0.35	0.38	0.16
7.MFS_A10_Cnone_SP0_MG_QF_HS_RW	0.71	0.57	0.87	0.86	0.81	0.62	0.52	0.49	0.48	0.52	0.54	0.53	0.55	0.56	0.54	0.52	0.51	0.53	0.18
8.MFS_A10_Cnone_SP0_MG_QF_HS_3Y	0.71	0.63	0.95	0.94	0.87	0.63	0.40	0.31	0.27	0.30	0.35	0.41	0.37	0.38	0.37	0.32	0.30	0.33	0.15
9.MFT_A10_Cnone_SP0_MV_QF_BR_RW	0.51	0.53	0.74	0.95	0.87	0.56	0.17	0.06	0.11	0.18	0.23	0.25	0.24	0.20	0.17	0.17	0.23	0.26	0.16
10.MFT_A10_Cnone_SP0_MV_QF_BR_3Y	0.51	0.54	0.79	0.98	0.83	0.49	0.04	0.01	0.02	0.06	0.12	0.17	0.19	0.17	0.15	0.18	0.19	0.22	0.14
11.MFT_A10_Cnone_SP0_MV_QF_HS_RW	0.49	0.55	0.71	0.85	0.91	0.84	0.64	0.48	0.44	0.47	0.53	0.58	0.60	0.62	0.62	0.61	0.60	0.57	0.37
12.MFT_A10_Cnone_SP0_MV_QF_HS_3Y	0.49	0.55	0.73	0.91	0.96	0.86	0.56	0.31	0.24	0.27	0.33	0.40	0.42	0.47	0.49	0.51	0.50	0.48	0.24
13.MFT_A10_Cnone_SP0_MG_QF_BR_RW	0.75	0.81	0.96	0.93	0.72	0.27	0.07	0.06	0.10	0.14	0.15	0.19	0.22	0.22	0.25	0.30	0.33	0.34	0.18
14.MFT_A10_Cnone_SP0_MG_QF_BR_3Y	0.76	0.86	0.98	0.92	0.66	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.11
15.MFT_A10_Cnone_SP0_MG_QF_HS_RW	0.74	0.80	0.93	0.98	0.89	0.48	0.19	0.13	0.15	0.19	0.25	0.29	0.32	0.36	0.40	0.43	0.45	0.47	0.31
16.MFT_A10_Cnone_SP0_MG_QF_HS_3Y	0.73	0.83	0.97	0.99	0.87	0.32	0.04	0.01	0.00	0.01	0.01	0.01	0.02	0.02	0.02	0.04	0.05	0.05	0.11
17.MFS_A15_Cnone_SP0_MV_QF_BR_RW	0.48	0.32	0.76	0.91	0.82	0.55	0.52	0.66	0.64	0.64	0.62	0.61	0.59	0.59	0.59	0.58	0.54	0.53	0.24
18.MFS_A10_C20_SP0_MV_QF_BR_RW	0.48	0.32	0.81	0.96	0.97	0.92	0.82	0.79	0.77	0.75	0.73	0.71	0.69	0.63	0.62	0.59	0.60	0.57	0.14
19.MFS_A10_Cnone_SP25_MV_QF_BR_RW	1.00	0.32	0.79	0.92	0.86	0.62	0.53	0.71	0.81	0.77	0.70	0.61	0.58	0.52	0.54	0.57	0.55	0.48	0.23
20.MFT_A15_Cnone_SP0_MV_QF_BR_RW	0.53	0.74	0.52	0.69	0.98	0.88	0.64	0.28	0.06	0.04	0.04	0.05	0.06	0.07	0.08	0.09	0.09	0.09	0.16
21.MFT_A10_C20_SP0_MV_QF_BR_RW	0.51	0.53	0.74	0.96	1.00	1.00	0.99	0.98	0.96	0.93	0.89	0.85	0.78	0.62	0.50	0.40	0.33	0.29	0.15
22.MFT_A10_Cnone_SP25_MV_QF_BR_RW	1.00	0.53	0.74	0.93	0.85	0.56	0.21	0.08	0.14	0.23	0.31	0.33	0.31	0.24	0.19	0.19	0.25	0.30	0.17

Case	15																	
Year/OM	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
1.MFS_A10_Cnone_SP0_MV_QF_BR_RW	0.37	0.20	0.73	0.91	0.82	0.51	0.37	0.55	0.60	0.58	0.53	0.50	0.49	0.46	0.50	0.49	0.45	0.41
2.MFS_A10_Cnone_SP0_MV_QF_BR_3Y	0.37	0.20	0.83	0.95	0.81	0.47	0.30	0.43	0.41	0.42	0.46	0.56	0.50	0.44	0.47	0.44	0.43	0.43
3.MFS_A10_Cnone_SP0_MV_QF_HS_RW	0.30	0.18	0.43	0.67	0.64	0.54	0.49	0.53	0.53	0.49	0.48	0.49	0.49	0.45	0.47	0.46	0.46	0.47
4.MFS_A10_Cnone_SP0_MV_QF_HS_3Y	0.30	0.14	0.53	0.75	0.71	0.54	0.41	0.41	0.43	0.44	0.44	0.45	0.41	0.42	0.43	0.41	0.42	0.39
5.MFS_A10_Cnone_SP0_MG_QF_BR_RW	0.63	0.47	0.88	0.88	0.75	0.43	0.35	0.36	0.37	0.40	0.43	0.46	0.44	0.41	0.45	0.46	0.42	0.41
6.MFS_A10_Cnone_SP0_MG_QF_BR_3Y	0.62	0.54	0.95	0.92	0.75	0.39	0.19	0.14	0.13	0.15	0.25	0.30	0.26	0.22	0.24	0.21	0.24	0.26
7.MFS_A10_Cnone_SP0_MG_QF_HS_RW	0.57	0.37	0.78	0.80	0.73	0.52	0.42	0.39	0.38	0.42	0.42	0.41	0.42	0.42	0.42	0.39	0.38	0.41
8.MFS_A10_Cnone_SP0_MG_QF_HS_3Y	0.57	0.43	0.90	0.89	0.82	0.55	0.32	0.21	0.19	0.19	0.24	0.27	0.26	0.26	0.26	0.22	0.21	0.22
9.MFT_A10_Cnone_SP0_MV_QF_BR_RW	0.39	0.39	0.66	0.93	0.86	0.55	0.15	0.05	0.09	0.16	0.21	0.20	0.19	0.16	0.13	0.13	0.18	0.21
10.MFT_A10_Cnone_SP0_MV_QF_BR_3Y	0.39	0.41	0.72	0.97	0.82	0.46	0.04	0.01	0.01	0.05	0.11	0.15	0.15	0.14	0.11	0.13	0.14	0.17
11.MFT_A10_Cnone_SP0_MV_QF_HS_RW	0.34	0.39	0.57	0.76	0.86	0.80	0.58	0.43	0.39	0.44	0.49	0.55	0.57	0.58	0.59	0.58	0.57	0.53
12.MFT_A10_Cnone_SP0_MV_QF_HS_3Y	0.34	0.39	0.59	0.85	0.93	0.84	0.52	0.28	0.21	0.24	0.28	0.35	0.39	0.42	0.44	0.47	0.45	0.45
13.MFT_A10_Cnone_SP0_MG_QF_BR_RW	0.65	0.72	0.93	0.92	0.71	0.24	0.06	0.05	0.09	0.12	0.14	0.16	0.18	0.18	0.22	0.26	0.28	0.30
14.MFT_A10_Cnone_SP0_MG_QF_BR_3Y	0.64	0.76	0.97	0.91	0.65	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
15.MFT_A10_Cnone_SP0_MG_QF_HS_RW	0.59	0.65	0.89	0.97	0.87	0.46	0.16	0.12	0.13	0.18	0.22	0.27	0.29	0.34	0.37	0.40	0.42	0.44
16.MFT_A10_Cnone_SP0_MG_QF_HS_3Y	0.59	0.70	0.94	0.99	0.87	0.30	0.04	0.01	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.03	0.03	0.04
17.MFS_A15_Cnone_SP0_MV_QF_BR_RW	0.37	0.19	0.65	0.85	0.75	0.45	0.41	0.58	0.57	0.57	0.54	0.53	0.51	0.50	0.52	0.50	0.47	0.45
18.MFS_A10_C20_SP0_MV_QF_BR_RW	0.37	0.20	0.73	0.94	0.96	0.88	0.75	0.71	0.71	0.69	0.66	0.62	0.61	0.55	0.55	0.52	0.52	0.49
19.MFS_A10_Cnone_SP25_MV_QF_BR_RW	1.00	0.20	0.69	0.87	0.81	0.54	0.41	0.61	0.72	0.69	0.61	0.51	0.46	0.41	0.46	0.48	0.48	0.42
20.MFT_A15_Cnone_SP0_MV_QF_BR_RW	0.31	0.62	0.40	0.58	0.96	0.87	0.64	0.28	0.05	0.03	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.08
21.MFT_A10_C20_SP0_MV_QF_BR_RW	0.39	0.39	0.67	0.94	1.00	1.00	0.99	0.97	0.94	0.91	0.86	0.80	0.74	0.55	0.43	0.35	0.27	0.25
22.MFT_A10_Cnone_SP25_MV_QF_BR_RW	0.99	0.39	0.65	0.90	0.83	0.55	0.20	0.07	0.11	0.20	0.27	0.29	0.26	0.19	0.15	0.15	0.20	0.25

Case	20																	
Year/OM	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
1.MFS_A10_Cnone_SP0_MV_QF_BR_RW	0.26	0.10	0.62	0.87	0.79	0.45	0.27	0.48	0.53	0.52	0.43	0.41	0.40	0.37	0.40	0.41	0.39	0.34
2.MFS_A10_Cnone_SP0_MV_QF_BR_3Y	0.26	0.11	0.73	0.93	0.78	0.42	0.23	0.35	0.33	0.33	0.37	0.44	0.39	0.34	0.37	0.33	0.33	0.31
3.MFS_A10_Cnone_SP0_MV_QF_HS_RW	0.20	0.09	0.28	0.54	0.54	0.43	0.36	0.41	0.41	0.39	0.35	0.36	0.37	0.33	0.35	0.33	0.32	0.34
4.MFS_A10_Cnone_SP0_MV_QF_HS_3Y	0.18	0.06	0.36	0.65	0.62	0.43	0.29	0.30	0.33	0.31	0.31	0.30	0.29	0.27	0.31	0.29	0.31	0.27
5.MFS_A10_Cnone_SP0_MG_QF_BR_RW	0.51	0.33	0.81	0.82	0.70	0.35	0.26	0.29	0.30	0.32	0.34	0.35	0.34	0.33	0.34	0.35	0.32	0.32
6.MFS_A10_Cnone_SP0_MG_QF_BR_3Y	0.51	0.38	0.91	0.89	0.72	0.34	0.14	0.09	0.09	0.09	0.17	0.19	0.17	0.14	0.13	0.12	0.17	0.16
7.MFS_A10_Cnone_SP0_MG_QF_HS_RW	0.45	0.22	0.67	0.72	0.65	0.42	0.32	0.31	0.31	0.32	0.32	0.32	0.31	0.31	0.32	0.30	0.29	0.28
8.MFS_A10_Cnone_SP0_MG_QF_HS_3Y	0.43	0.26	0.80	0.83	0.77	0.48	0.24	0.14	0.12	0.11	0.17	0.18	0.16	0.16	0.18	0.14	0.13	0.14
9.MFT_A10_Cnone_SP0_MV_QF_BR_RW	0.28	0.29	0.58	0.89	0.85	0.52	0.13	0.04	0.08	0.14	0.18	0.17	0.16	0.13	0.10	0.10	0.15	0.17
10.MFT_A10_Cnone_SP0_MV_QF_BR_3Y	0.28	0.31	0.65	0.96	0.81	0.45	0.03	0.01	0.01	0.04	0.09	0.13	0.13	0.10	0.09	0.10	0.13	0.14
11.MFT_A10_Cnone_SP0_MV_QF_HS_RW	0.21	0.25	0.43	0.67	0.80	0.76	0.53	0.37	0.36	0.40	0.46	0.51	0.55	0.55	0.55	0.55	0.53	0.50
12.MFT_A10_Cnone_SP0_MV_QF_HS_3Y	0.20	0.23	0.48	0.79	0.89	0.80	0.47	0.24	0.18	0.21	0.26	0.32	0.35	0.39	0.41	0.43	0.42	0.42
13.MFT_A10_Cnone_SP0_MG_QF_BR_RW	0.52	0.59	0.90	0.91	0.69	0.22	0.05	0.04	0.08	0.11	0.13	0.14	0.16	0.16	0.19	0.23	0.24	0.25
14.MFT_A10_Cnone_SP0_MG_QF_BR_3Y	0.52	0.63	0.94	0.91	0.63	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
15.MFT_A10_Cnone_SP0_MG_QF_HS_RW	0.45	0.50	0.84	0.94	0.86	0.43	0.14	0.10	0.12	0.16	0.20	0.24	0.27	0.31	0.35	0.37	0.39	0.42
16.MFT_A10_Cnone_SP0_MG_QF_HS_3Y	0.43	0.54	0.90	0.99	0.85	0.28	0.03	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.02	0.03
17.MFS_A15_Cnone_SP0_MV_QF_BR_RW	0.26	0.11	0.54	0.78	0.66	0.34	0.35	0.52	0.53	0.51	0.47	0.45	0.45	0.43	0.45	0.43	0.40	0.37
18.MFS_A10_C20_SP0_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19.MFS_A10_Cnone_SP25_MV_QF_BR_RW	0.99	0.10	0.58	0.82	0.77	0.46	0.30	0.53	0.63	0.61	0.51	0.40	0.37	0.33	0.37	0.43	0.41	0.36
20.MFT_A15_Cnone_SP0_MV_QF_BR_RW	0.17	0.54	0.30	0.47	0.91	0.87	0.63	0.27	0.05	0.03	0.03	0.04	0.04	0.06	0.07	0.07	0.08	0.07
21.MFT_A10_C20_SP0_MV_QF_BR_RW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22.MFT_A10_Cnone_SP25_MV_QF_BR_RW	0.97	0.29	0.56	0.87	0.82	0.53	0.18	0.05	0.10	0.18	0.24	0.23	0.22	0.15	0.12	0.11	0.16	0.20

Table 5. [not yet available]

PS5: Proportion of stock biomass in the plus group:

Table 6. **PS6:** Proportion of crashed iterations (out of 1000 iterations) in the period 2032-2037. The values in the table should be divided by 10 to convert to percentage of crashed iterations.

OM	Number
1.MFS_A10_Cnone_SP0_MV_QF_BR_RW	0.015
2.MFS_A10_Cnone_SP0_MV_QF_BR_3Y	0.033
3.MFS_A10_Cnone_SP0_MV_QF_HS_RW	0.005
4.MFS_A10_Cnone_SP0_MV_QF_HS_3Y	0.012
5.MFS_A10_Cnone_SP0_MG_QF_BR_RW	0.088
6.MFS_A10_Cnone_SP0_MG_QF_BR_3Y	0.214
7.MFS_A10_Cnone_SP0_MG_QF_HS_RW	0.086
8.MFS_A10_Cnone_SP0_MG_QF_HS_3Y	0.204
9.MFT_A10_Cnone_SP0_MV_QF_BR_RW	0.107
10.MFT_A10_Cnone_SP0_MV_QF_BR_3Y	0.153
11.MFT_A10_Cnone_SP0_MV_QF_HS_RW	0.167
12.MFT_A10_Cnone_SP0_MV_QF_HS_3Y	0.136
13.MFT_A10_Cnone_SP0_MG_QF_BR_RW	0.099
14.MFT_A10_Cnone_SP0_MG_QF_BR_3Y	0.196
15.MFT_A10_Cnone_SP0_MG_QF_HS_RW	0.088
16.MFT_A10_Cnone_SP0_MG_QF_HS_3Y	0.151
17.MFS_A15_Cnone_SP0_MV_QF_BR_RW	0.058
18.MFS_A10_C20_SP0_MV_QF_BR_RW	0.375
19.MFS_A10_Cnone_SP25_MV_QF_BR_RW	0.000
20.MFT_A15_Cnone_SP0_MV_QF_BR_RW	0.782
21.MFT_A10_C20_SP0_MV_QF_BR_RW	0.364
22.MFT_A10_Cnone_SP25_MV_QF_BR_RW	0.028

Table 7. **HCR: F=0**: PS1: P(SSB<B_{lim}) by year. In red, the cases in which P(SSB<B_{lim})>0.1. The right-most column is the number of years in which P(SSB<B_{lim})>0.1.

Year/OM	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	Number
1.F0_A10_Cnone_SP0_MV_QF_BR_RW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.002	0.003	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0
2.F0_A10_Cnone_SP0_MV_QF_BR_3Y	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.005	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0
3.F0_A10_Cnone_SP0_MV_QF_HS_RW	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0
4.F0_A10_Cnone_SP0_MV_QF_HS_3Y	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0
5.F0_A10_Cnone_SP0_MG_QF_BR_RW	0.000	0.000	0.000	0.000	0.002	0.015	0.038	0.026	0.016	0.009	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0
6.F0_A10_Cnone_SP0_MG_QF_BR_3Y	0.000	0.000	0.000	0.000	0.001	0.016	0.066	0.073	0.036	0.013	0.007	0.003	0.001	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0
7.F0_A10_Cnone_SP0_MG_QF_HS_RW	0.000	0.000	0.000	0.000	0.001	0.006	0.005	0.005	0.004	0.004	0.002	0.003	0.004	0.003	0.002	0.002	0.002	0.003	0.001	0.001	0
8.F0_A10_Cnone_SP0_MG_QF_HS_3Y	0.000	0.000	0.000	0.000	0.001	0.005	0.013	0.015	0.008	0.005	0.005	0.003	0.006	0.005	0.006	0.005	0.005	0.004	0.004	0.004	0

Table 8. [not yet available]

HCR: F=0: PS5: Proportion of SSB in the plus group:

Table 9. **HCR: F=0**: PS6: Crashed iterations in the period 2032-2037

OM	Number
01.F0_A10_Cnone_SP0_MV_QF_BR_RWS	0
02.F0_A10_Cnone_SP0_MV_QF_BR_3Y	0
03.F0_A10_Cnone_SP0_MV_QF_HS_RW	0
04.F0_A10_Cnone_SP0_MV_QF_HS_3Y	0
05.F0_A10_Cnone_SP0_MG_QF_BR_RW	0
06.F0_A10_Cnone_SP0_MG_QF_BR_3Y	0
07.F0_A10_Cnone_SP0_MG_QF_HS_RW	0
08.F0_A10_Cnone_SP0_MG_QF_HS_3Y	0

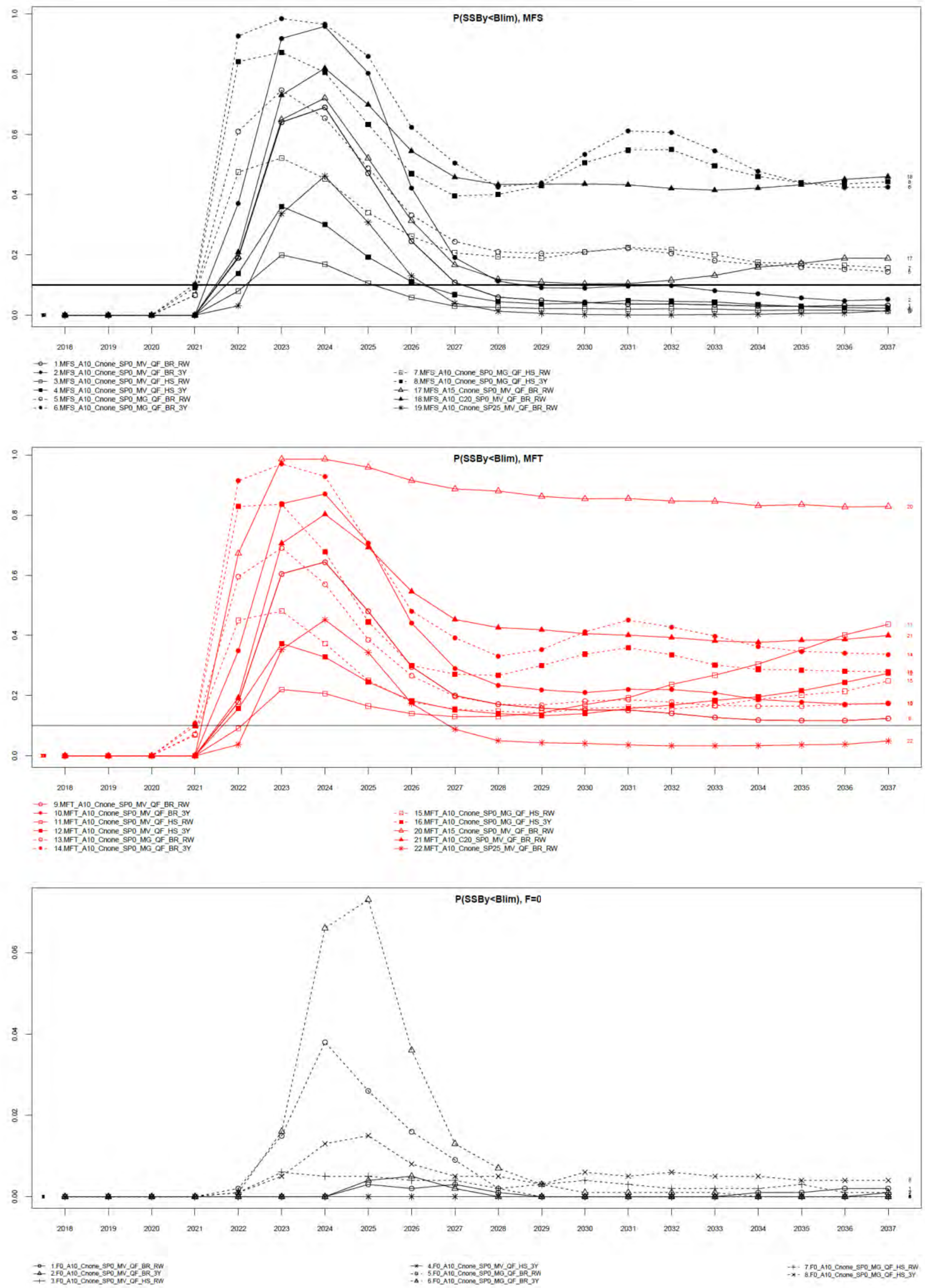

Figure 1. Results of PS1 for MFS HCR (top), MFT HCR (middle) and F=0 (bottom). The horizontal line indicates the 10% level. Note that in the bottom plot, 10% is outside the y-**axis** range.

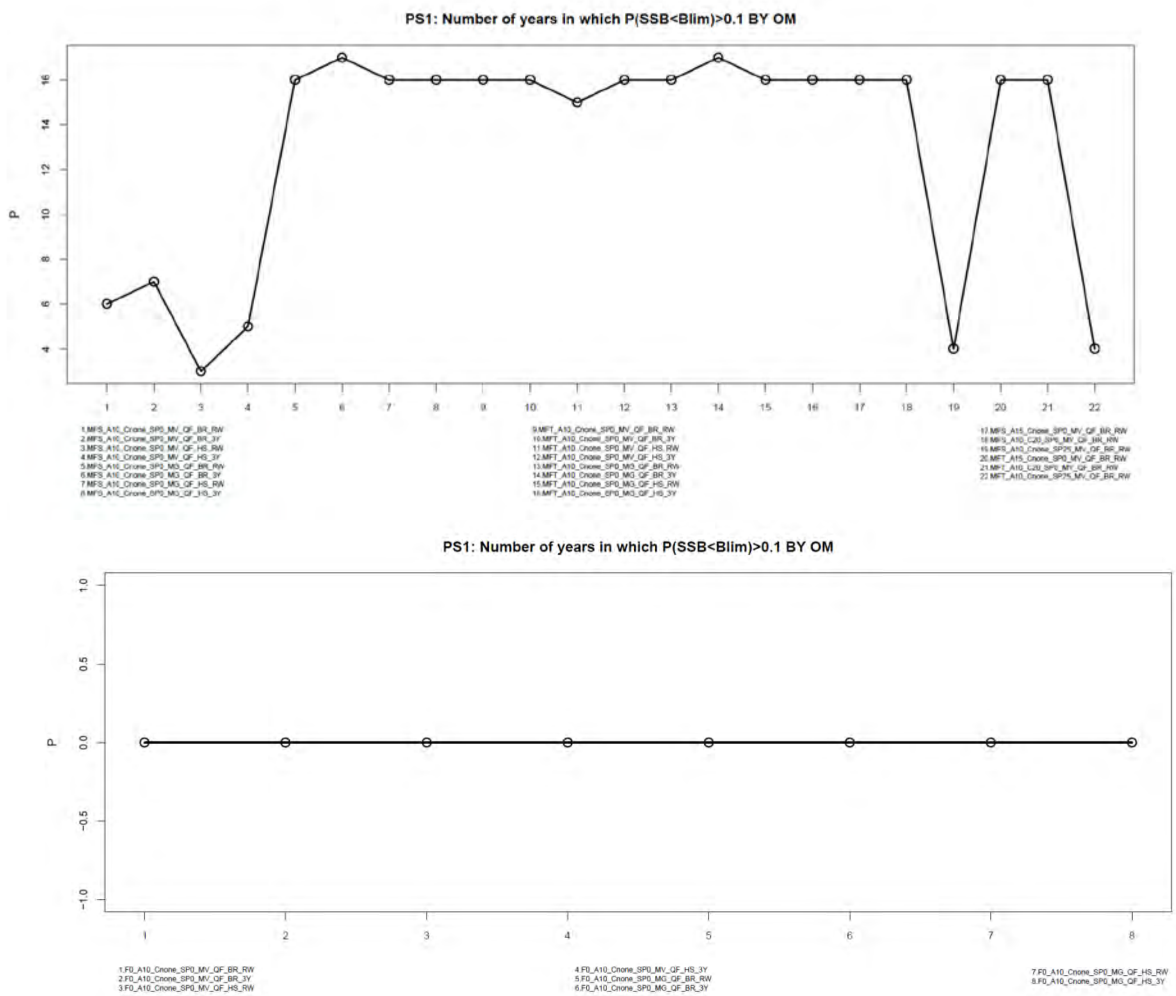

Figure 2. **PS1:** Number of years of the 2020-2037 period in which P(SSB<B_{lim})>0.1, for MFS and MFT HCRs (top) and F=0 (bottom).

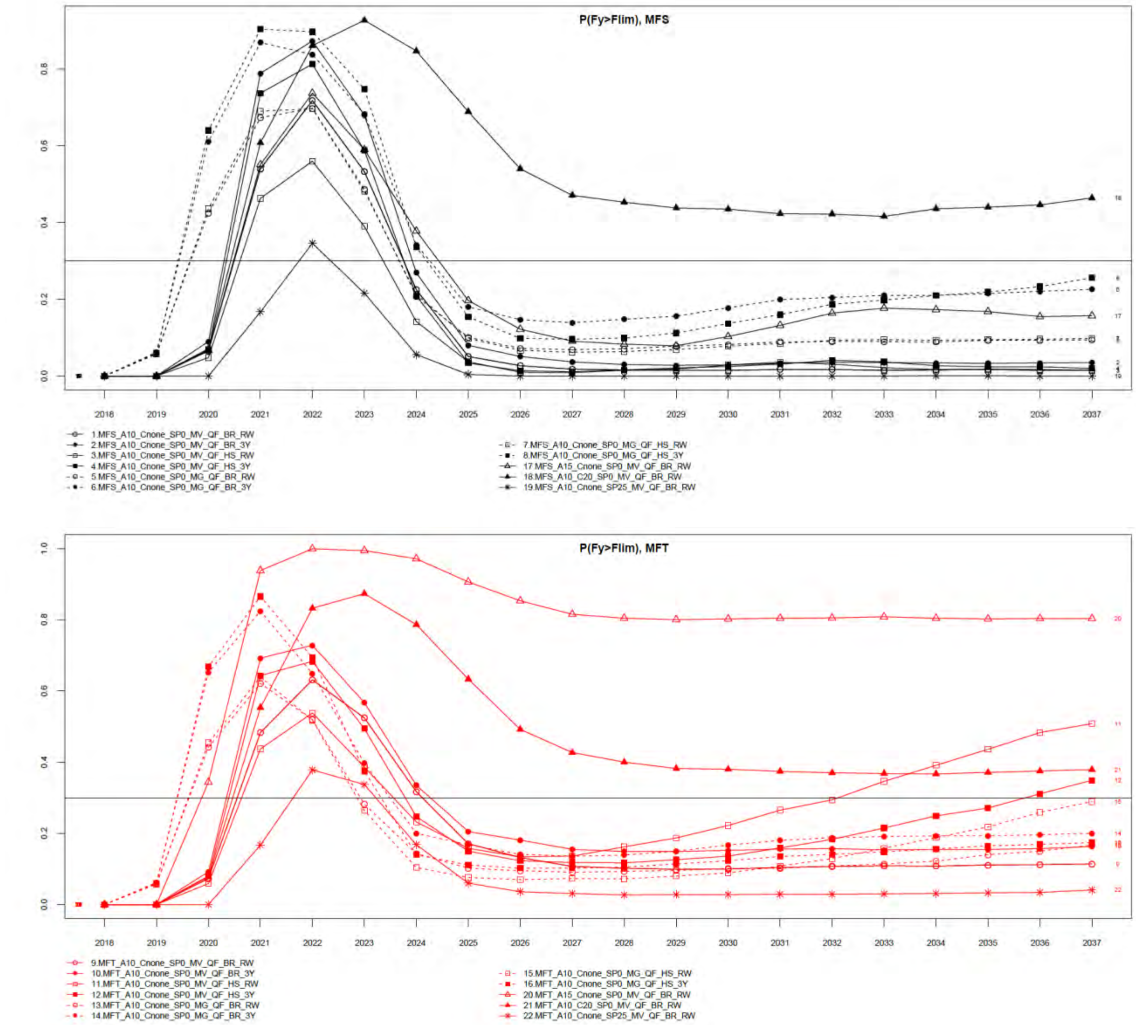

Figure 3. Results of PS2 for MFS (top) and MFT (bottom). The vertical line indicates the 30%.

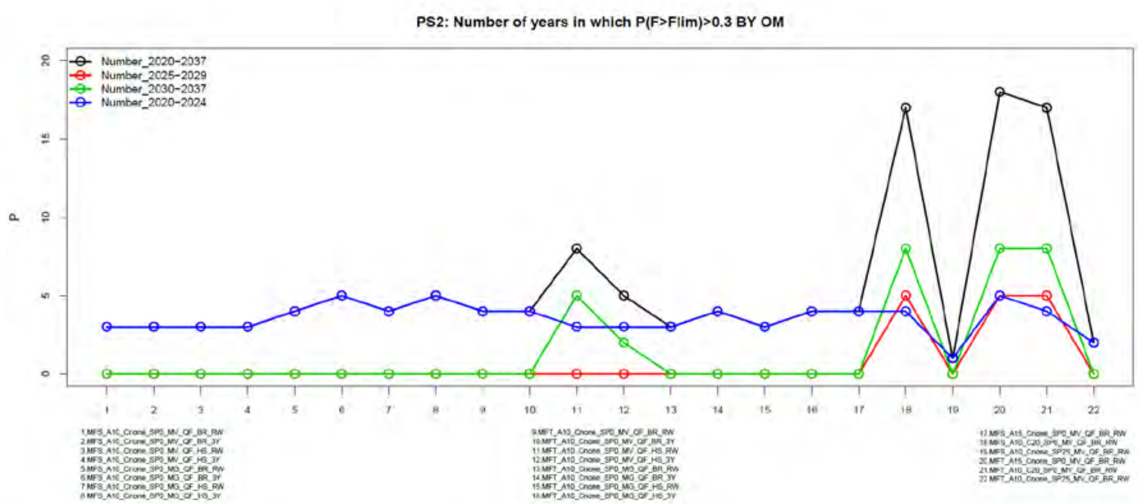

Figure 4. **PS2:** Number of years in which P(>F_{lim})>0.3. Results for MFS and MFT.

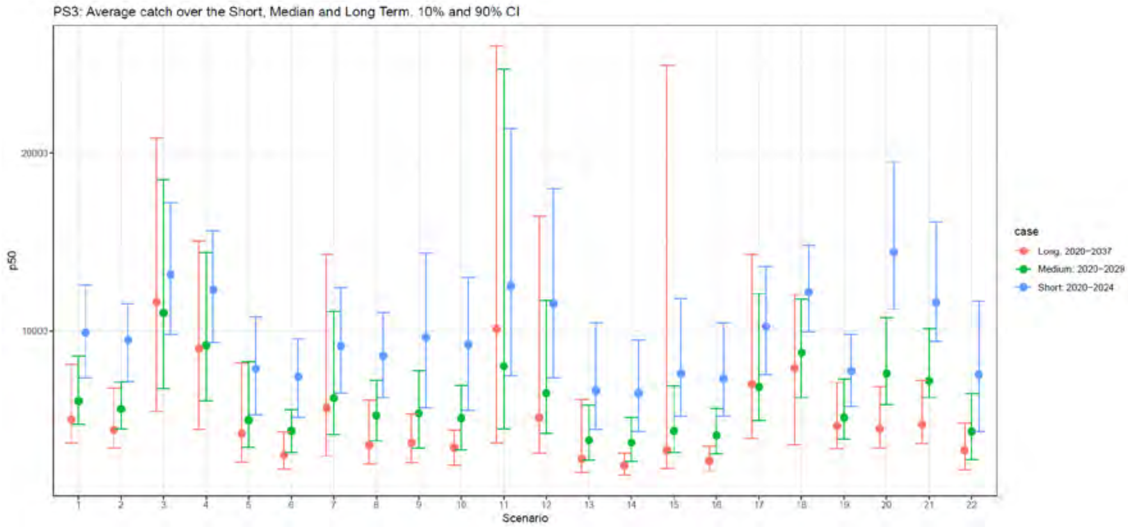

Figure 5. Average catch over the short, medium and long terms for MFS and MFT for the 22 scenarios. Scenario numbers are as in Figure 4 (top).

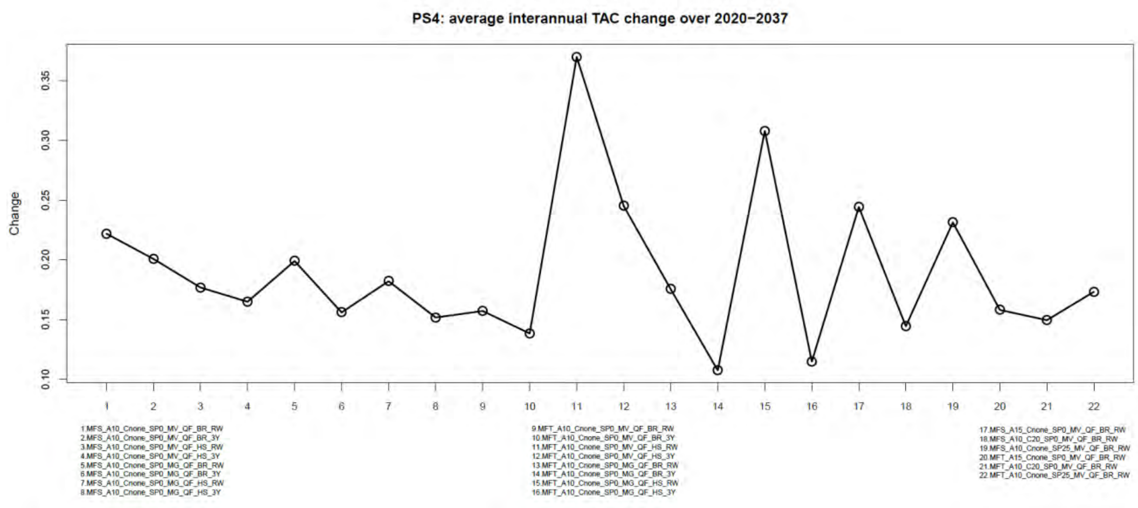

Figure 6. **PS4: Average** interannual TAC change over 2020-2037 for MFS and MFT.

Figure 7. [not yet available]

PS5: Proportion of stock biomass in the plus group (8+). Results for MFS and MFT (top) and F=0 (bottom).

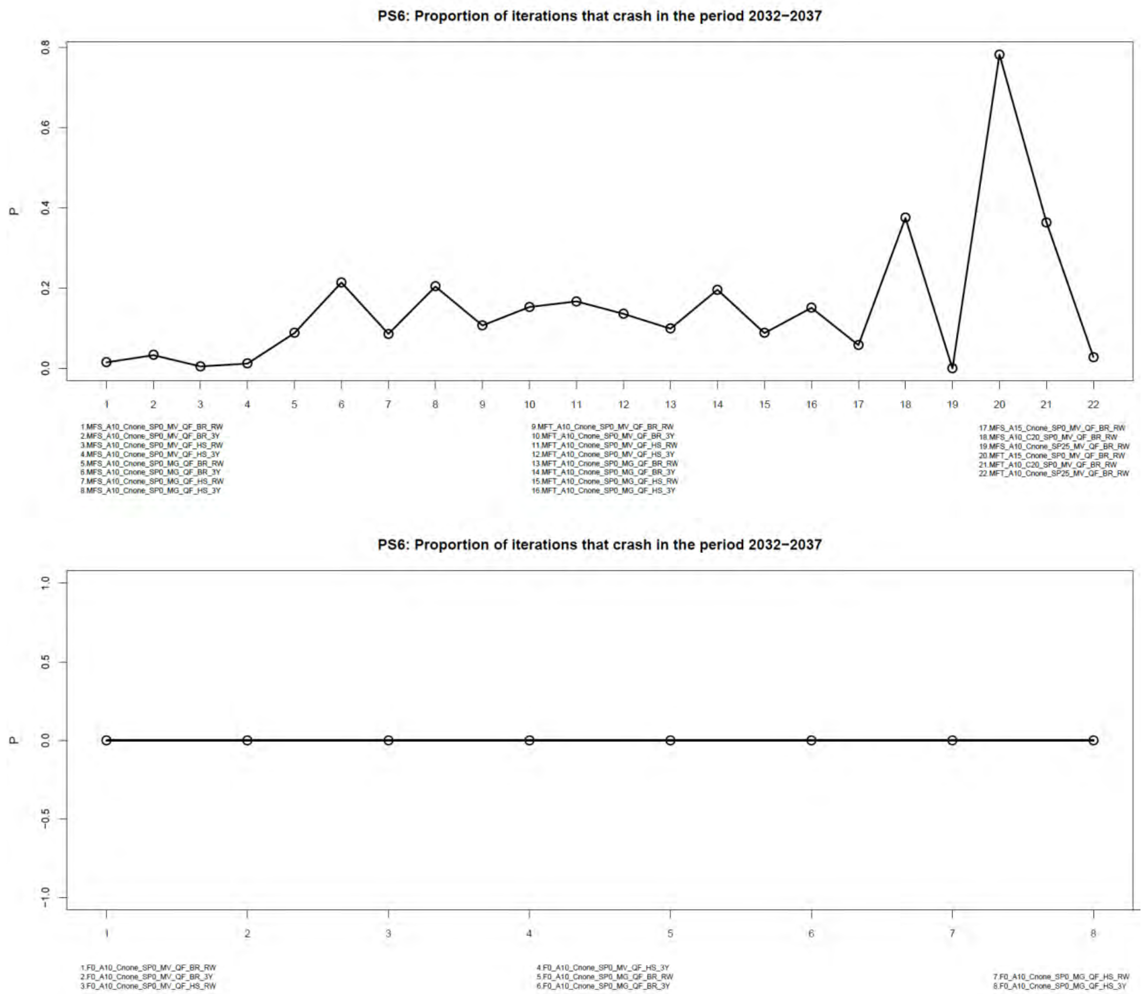

Figure 8. **PS6:** Number of iterations (out of 1000 iterations) that crash in the period 2032-3027 by scenario. Results for MFS and MFT (top) and F=0 (bottom).