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Results of the 3M Cod MSE

by
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Abstract

The general objective of the 3M Cod MSE is to maintain the SSB of this species in the safe zone as defined by the NAFO precautionary approach framework and to assure the optimum utilization, rational management and conservation of the 3M cod stock. Based on this, five performance objectives were tested via five different Performance Statistics. Six different OMs and two HCRs with three different F_{target} were tested. The six OMs come from different assumptions over M and over the Stock-Recruitment relationship (SRR). The two HCRs are one model-based (based on the Bayesian XSA model approved by SC) and one model-free (based on the EU-FC survey). A 20% constraint of annual variation of TAC was set for both HCR. Based on this, a total of 24 scenarios were tested and results projected for the period 2014-2025. Differences in the results come mainly from the assumed stock recruitment relationship and in a much lesser extent of assumed M and the different F_{target} levels tested. The SSB have an increasing trend in all cases reaching a level well above B_{lim} at the end of the projected period. There are two main trends in yields, one for the scenarios with the model-based HCR and other for the scenarios with the model-free HCR. In the first case, landings decrease to 6 500 tons in 2020, and after that increase until 2025 reaching a value between 10 500 and 15 000 tons, depending on the SRR assumed. In the case of the model-free HCR, until 2023 the decrease is very small and then a quiet constant value between 5 000 and 11 000 tons is reached. None of the tested HCR reached the established performance objectives in the 2016-2023 period but most of the scenarios met the performance objectives after 2024. The main reasons for not achieving these objectives are the high initial F and catch levels and the 20% catch constraint. The necessary period to achieve the performance objectives would be longer if we had applied a more restrictive TAC constraint (15% or 10%). If the TAC constraint is not applied, lower landings are allowed in the short-term period (2016-2020), but after that the increase in TAC is higher than if the constraint is applied.

Methods

The 3M Cod MSE is developed in another document (González-Costas *et al.*, 2014) based on the proposals of the Fisheries Commission and Scientific Council Joint Working Group on Risk-Based Management Strategies (FC SC RBMS) reached in February 2014 (NAFO, 2014a) and in the comments made by the NAFO SC in the 2014 June meeting.

1. Management objectives

1. **Very low risk of breaching B_{lim}.** The probability of a spawning stock biomass under B_{lim} at 10% or lower.
2. **Low risk of overfishing**. For the model-free HCR only: The probability of F exceeding F_{msy} during the evaluation period should be kept at 30% or lower.
3. **Low risk of steep decline**. The probability of the decline of 25% or more of spawning stock biomass from year 0 to year 5 is kept at 10% or lower.
4. **Maximum averages catch over the period**. The average TAC over the period should be maximized.
5. **Limited annual catch variation.**

2. Performance measures

Based on the above objectives a group of Performance Statistics (PS) was developed for 3M cod (Table 1). These PS were presented by González-Costas *et al.* (2014) taking into account the performance objectives proposed in the FC SC RBMS of 2014 and the NAFO Scientific Council suggestions and comments.

3. Management Strategies

Two HCRs are tested under the MSE approach:

Option 1 (Model-based HCR): $TAC_y = \text{Total Biomass}_y \; F_{target} \; P\left(SSB_y > B_{lim}\right)$

being B_{lim} = 14 000 tons and F_{target} the probabilities of 20%, 35% and 50% of exceeding $F_{msy} = F_{30\%SPR}$.

Option 2 (Model-free HCR): $TAC_y = TAC_{y-1}\left(1 + \lambda \, slope_{3+}\right)$

Where: slope = $slope_{3+}$ is the slope of the log-linear regression lines fit of the EU Flemish Cap survey B_{3+} index from *y-5* to *y-2*.

λ = an adjustment variable:

$$\text{If SSB} < \text{maximum observed SSB} \Rightarrow \begin{cases} slope_{3+} < 0 \Rightarrow \lambda = 1.25 \\ slope_{3+} > 0 \Rightarrow \lambda = 1 \end{cases}$$

$$\text{If SSB} > \text{maximum observed SSB} \Rightarrow \begin{cases} slope_{3+} < 0 \Rightarrow \lambda = 1 \\ slope_{3+} > 0 \Rightarrow \lambda = 1.15 \end{cases}$$

Noting the desire for relative TAC stability, TAC should be constraint to a fixed percentage of annual change. The FC SC RBMS (NAFO, 2014a) established three different TAC constraint levels (10%, 15% and 20%). To reduce the high number of scenarios the Scientific Council (NAFO, 2014b) proposed to test only the 20% TAC constraint. It was decided to take into account the SC proposal and to use a 20% constraint level in this study for both HCRs.

4. The simulation algorithm

The simulation algorithm that was used in the 3M cod MSE is an R package to conduct Bio-Economic Impact assessments using FLR (FLBEIA) developed by Garcia *et al.* (2013).

The operating models (OMs)

In the 3M cod case we test a set of 6 operating models. These operating models are distinguished by: M values and stock-recruit function:

In the case of **natural mortality (M)**, we have two sets of operating models:

-with M constant estimated by the model for all ages and for all years,

-with M estimated by the model for three different ages ranges (1-2, 3-5, 6-8+) and for three different time periods (1972-1995, 1996-2008, 2009-last assessment year) (González–Troncoso and González-Costas, 2014).

In the case of the **Stock/Recruitment (S/R) relationship** we have three sets of operating models:

SR1: Recruitment independent of SSB: Bootstrapping recruitment values from 1972-2010. We eliminated the last 3 recruitments of the time series to do the bootstrap due to these recruitments have a high uncertainty and they are not well calculated by the model.

SR2: Segmented Regression with Beta=Approved B_{lim}: We fit a constrained segmented regression model (1972-2010) to have a beta parameter equal to the approved 3M cod B_{lim} (14 000 tons).

SR3: Segmented Regression fit with the assessment results (1972-2010).

In Table 2 we present the value of the parameters of the two fits of segmented regression (SR2 and SR3), as well as mean of the Recruitment for the projected years (2014-2025) for the three SRs. Figures 1 and 2 show the median fit of the two segmented regressions as well as the median recruitment over the historic years. We can see in Table 3 that the level of recruitment is quite different between the three SRs, being the median of the mean Recruitment by iteration for years 2014-2025 lowest in the case of the SR1 (19 582 for M fix and 20 910 for M variable), and the highest for SR3 (40 489 for M fix and 51 526 for M variable).

The WG RBMS proposed model based HCR included "F_{target} is defined as four different levels of F_{msy}, corresponding to probabilities of 20%, 30%, 40% and 50% of exceeding F_{msy}. If F_{msy} is not available, an appropriate proxy should be used". Scientific Council proposed three different probability levels to be tested: 20%, 35% and 50%. With this proposal we reduce 6 scenarios. The value of F_{target} in each case is the percentiles of the F_{msy}:

Percentile 20 F_{msy}	0.116
Percentile 35 F_{msy}	0.124
Percentile 50 F_{msy}	0.133

It was decided to take into account the SC recommendations and to use the probabilities of 20%, 35% and 50% of exceeding F_{msy} in this study. With this proposal and the 20% TAC constraint level the final number of scenarios presented in this document is 24 (Table 3).

The management procedure (MP)

For 3M cod the TAC for year *y* is set based on the assessment with data available up to year *y–2* based on the different Harvest Control Rules (HCRs) proposed by FC SC RBMS. The MP is applied every year up to the *y-2* final year of projections. We performed the HCRs for 10 years (2016-2025). During the 2014 SC it was decided to project until the year 2033, but the 2015 WG RBMS decided that it was a too long period to project and decided to use a projected period to 2025 (10 years projection), and to present the results for a mid-term period (2016-2020) and for long-term period (2016-2025). The last real population is in 2013 (last approved assessment, González-Troncoso *et al.*, 2014), but as the 2014 and 2015 TACs are set already, the first year of applying the HCR is 2016.

For the model-based HCR ($TAC_y = Total\,Biomass_y\, F_{target}\, P(SSB_y > B_{lim})$) we used as assessment process model the Bayesian XSA with 500 iterations (González–Troncoso *et al.*, 2014). The usual method of performing the short term projections with 3 years mean for the biological parameters inputs (PR, Mean weights, Maturity, etc) was used.

For the model-free HCR ($TAC_y = TAC_{y-1}(1+\lambda\, slope_{3+})$) the TAC for year *y* is set based on the EU Flemish Cap survey (Mandado, 2014) slope of the log-linear regression line fit to *y–2* till *y-5* period of the survey indices for 3+ biomass.

5. Results

5.1. Stock indicators (SSB, F and landings)

In all cases the results presented are the medians of the indicators.

Table 4 and Figures 4 and 5 present the SSB results for the 24 scenarios in the projected period (2016-2025), as well as the estimated valued for 2014 and 2015. It can be observed in the results (Figure 4) that the SSB trend in all the scenarios is quite similar but the level of the SSB is very different. At the end of the projected period there are three different main levels depending on the chosen stock recruitment function. The SR1 has around

150 000 tons, the SR2 around 250 000 and the SR3 350 000 tons for M fix and in the cases of M variable slightly lower for SR1 and slightly higher for SR2 and SR3. Figure 5 shows the SSB for the different scenarios of the M (M fix and M variable) operating models.

Table 5 and Figures 6 and 7 present the fishing mortality (F) for all the scenarios in the projected years. The F decreases in the medium term period (2016-2021) for all the scenarios and after (2022-2025) remains fairly constant and lower than the F_{msy} proxy. The decrease in F is in general faster in the first years for the scenarios with the model-based HCR than the scenarios with the model-free HCR. Figure 7 shows the F for the different scenarios of the M (M fix and M variable) operating models. These OMs have a very similar trend and values for F in all the scenarios of each OM with a decrease in the period 2016-2021 and a fairly constant F value lower than F_{target} in 2022-2025.

Table 6 and Figures 8 and 9 present the landings (yield) for all the scenarios in the projected years. There are two main trends in yields, one for the scenarios with the model-based HCR and other for the scenarios with the model-free HCR. Figure 9 shows the yield for the different scenarios of the M (M fix and M variable) operating models. In the cases of the model-based HCR all the scenarios present a similar decrease in landings until 2020, when these scenarios reach a yield around 6 500 tons, and after an increase trend till the end of the projected period. This increase trend depends on the SR functions assumed. The yield at the end of the period is around 10 500 tons for the SR1 scenarios, 13 000 tons for the SR2 and around 15 000 tons for the SR3 scenarios for M fix and a bit higher in the cases of the M variable. For the scenarios based on the model-free HCR the trend and level are quite different. Till 2023 all the scenarios have a general small decrease in the yield and after the 2023 level (around 5 000 t for SR1, 7 000 t for SR2 and 11 500 t for SR3) is quite constant until 2025 with a slight increase for SR1 and SR2 scenarios (reaching levels of around 6 000 t and 7000 t respectively) and a slight decrease for the SR3 scenario (reaching levels of 11 000 t).

The greatest impact on the stock indicators results comes from the assumption on the stock recruitment. It is clear that the level of F_{target} has little influence in the results, and the choice of M does not vary substantially the results of the stock indicators.

5.2. Performance Statistics (PS)

For deciding which of the HCR that we are analyzing is the best for the purposes of the MSE, a series of Performance Statistics were analyzed:

1. Very low risk of breaching B_{lim}: $P(SSB<B_{lim}) \leq 0.1$. The NAFO PA framework (NAFO, 2004) says that "there must be a very low probability that management actions result in projected biomass dropping below B_{lim} within the foreseeable future" and defined foreseeable future as "foreseeable future might be defined as 5-10 years, but the actual time horizon should be specified by managers". The NAFO SC in 2014 decided to measure this probability each year. During the 2015 WG RBMS it was recognized that this way to measure this PS was the most precautionary and it was decided to present 3 different options to measure the risk of this OM:

   a. Probability year by year
   b. Mean of the probability of each period (2020 and 2025)
   c. Probability at the end of each period (2020 and 2025)

The results are in Table 7 and Figures 10, 11 and 12. We can see that none of the OMs fulfills these PS1 (a, b and c) in the medium term (2016-2020). If we look at this PS year by year (PS1a, Figure 10), we can see that in the period 2016-2023 most of the scenarios have a value greater than the limit or they are very close to the limit of this PS. All scenarios reach the highest probability of breaching B_{lim} in the period 2019-2020, having in this period the M variable OM cases a lower probability of breaching B_{lim} than the M fix cases, and inside these the probability of breaching B_{lim} for OM based on different SR in increasing order are: SR3, SR2 and SR1. The SR1 model-free scenarios (19 and 22) have the worse behavior in these middle-years with a maximum probability of 0.37 and 0.36 respectively. However, from 2024 all the scenarios reach the condition except scenario 6 (model-based, SR2, M fix, F50) that slightly exceeding the limit.

If we look at the mean probability of each period (PS1b, Figure 11), none of the scenarios reach the accepted level of risk in the medium and long period. The probability is higher for all the scenarios in the medium period. The model free scenarios have a higher risk in general.

Looking at the probability at the end of each period (PS1c, Figure 12), none of the scenarios reach the accepted level of risk at the end of the medium term period (2020) but all the scenarios, except the scenario 6, reach it at the end of the long term period (2025).

2. Low risk of overfishing: $P(F>F_{msy}) \leq 0.3$. As for PS1, during the 2015 WG RBMS it was decided to present 3 different options to measure the risk of this OM:

a. Probability year by year
b. Mean of the probability of each period (2020 and 2025)
c. Probability at the end of each period (2020 and 2025)

The results are presented in Table 8 and Figures 13, 14 and 15. If we take into account the probability year by year (PS2a, Figure 13), this PS is achieved for all the OMs since year 2021. All the scenarios start the projection period with a very high probability (100%) and this probability drops to levels less than 30% in 2021 in all scenarios and remains low till the end of the projection period. This decline is faster in the model-based scenarios. In general, the model-free scenarios have a worse behavior than the model-based scenarios in the period 2016-2021.

If we look at the mean of the periods (PS2b, Figure 14), it is clear that in the first period (until 2020), the Ps is not reached for none of the scenarios. For the long term period (2016-2025), only six scenarios, almost all the model based SR3 scenarios, reach the approved level of risk.

At the end of the first period (2020, PS2c, Figure 15), almost all the scenarios with model-based attain the PS, while the model-free scenarios have a probability higher than 0.3 of being above F_{msy}. Instead of that, in 2025 all the scenarios get the PS, .

Although this PS was set only for the model-free scenarios, we present the results for the 24 scenarios in order to see the differences between them.

3. Low risk of steep decline: The probability of the decline of 25% or more of spawning stock biomass from year 0 to year y is kept at 10% or lower: $P(SSB_y/SSB_{2013} \leq 0.75) \leq 0.1$. In this case we check two periods: y=7 (medium term: year 2020) and y=10 (long term: year 2025). Moreover, we check if the lowest spawning stock biomass in the periods 2014-2020 and 2021-2025 achieves the condition too. The results are in Table 9 and Figure 16.

Although the first year of projection is 2016, the last "true" SSB known is in 2013, and for that we start to measure this PS in 2014. For that, we have a first period of 7 years instead of 5 years.

So, we have 4 different options in this PS:

3a. $P(SSB_{2020}/SSB_{2013} \leq 0.75) \leq 0.1$. This condition is not achieved by any of the OMs. The SR1 cases have a higher probability than the SR2 and the SR2 more than the SR3 scenarios. The scenarios based on the model-free HCR have a higher probability than the model-based scenarios.

3b. $P(SSB_{2025}/SSB_{2013} \leq 0.75) \leq 0.1$. This condition is achieved for almost all the scenarios. Note that the worst and the best cases are for the model-free cases: the worst for SR1 and SR2 and the best for SR3.

3c. $P(\min(SSB_{2014\text{-}2020})/SSB_{2013} \leq 0.75)\ ) \leq 0.1$. This condition is never achieved for any of the OMs. All the scenarios have high probability that the minimum SSB in the medium term period was 25% less than the 2013 SSB although the M fix scenarios have lower probability than the M variable cases.

3d. $P(\min(SSB_{2021\text{-}2025})/SSB_{2013} \leq 0.75)\ ) \leq 0.1$. This condition is never achieved for any of the OMS. All the scenarios have a probability more than 10% that the minimum biomass in this period was 25% less than the 2013 biomass. This probability is close to the 10% limit in the model-based scenarios and is higher in the model-free scenarios.

One more PS was calculated and is presented in Table 9: $P(\min(SSB_{2014-2025})/SSB_{2013} \leq 0.75)$, but as the SSB reaches the minimum between 2014 and 2020, this PS is redundant with the 3c PS.

4. Maximum average catch over the period: max(TAC). The results are presented in Table 10 and Figure 17. In the Table we present the median of the mean landings for the periods 2014-2025, 2014-2020 and 2021-2025, and in the Figure we present the median as well as the 95% confidence interval for the periods 2014-2020 and 2014-2025. As the 2014 and 2015 have been set, we decided to include it in the calculation of the mean TAC for the first period. In the medium term period (2014-2020), the mean TAC is much higher for the model-free OMs than for the model-based OMs with similar values within them (around 14 300 tons in the model-free scenarios and around 11 000 tons in the model-based scenarios). But when we take the complete projection period the differences are less, being around 10 500 t for the model-based and 11 500 t for the model-free. The highest TACs are set for the SR3 scenarios around 14 000 t and the minimum for the SR1 around 9 500 t.

5. Limited annual catch variation: Number of times the constraint of 20% (at the lower and at the higher boundaries) has been applied on average during the period. We present the number in percentage in Table 11 and Figure 18. We can see that in the majority of the cases the constraint is applied in a very high percentage of the iterations. In fact, if we look to the mean of the number of times that the constraint of 20% is applied (low or up), in the case of the model-based scenarios this percentage is around 64% and 50% in the model-free cases.

It can be observed that for the model-based scenarios in 2018 the low constraint ($TAC_y=0.8TAC_{y-1}$) was applied in the 80% of the cases and this % decreases till 2023 and after that remains very low (less than 20%). This general trend has small differences for M variable and M fix model-based scenarios.

The up constraint ($TAC_y=1.2TAC_{y-1}$) in the model-based scenarios has the opposite trend: starts in very low %, this percentage increases till 2023 (80%) and after that is more or less constant.

Considering the % that the constraint is applied (up and down) in the model-based scenarios, we can observe that is very high in all the projected period, being over or around 80% from 2018. For the model-free scenarios these trends are quite different. The number of times that the constraint of 20% (at the lower and at the higher boundaries) has been applied rather increases in the period 2016-2021 and after that slightly increases till 2025. These trends are quite similar for up and down but at different levels.

5.3. Results with and without constraint

In order to see how the use of the constraint influences in the results, we decided to run one scenario with no constraint to see the differences in the results. We decided to run the model-based, SR1, M fix and $F_{35\%}$ scenario with and without constraint. The main reason for choosing this scenario is that it is the most similar to SC 2014 3M Cod approved assessment.

The median results for the SSB, F and landings for the chosen scenario with and without constraint are in Figures 19, 20 and 21. In general, the SSB is higher for the case without constraint (Figure 19), although in the last year of projection (2025), the SSB is higher in the case with constraint. Until 2021 the F is lower in the case without constraint, and then it is higher (Figure 20). Landings are lower for the case without constraint until 2020, and then starts to increase doubling the value of the landings in the case with constraint in the last years of projections (2024 and 2025, Figure 21). It is clear that the catch constraint case in the medium term period (till 2020) does not allow the decrease of the high starting F to levels of F_{target} as fast as in the case without constraint and this has a small effect in the level of the SSB and catches. In 2020-2021, with similar level of F target in both cases, the recovery of the stock allows the catches to start to increase but after 2022 the increase is less in the case of the TAC constraint due to the constraint, leading in a F much lower than F_{msy}.

With regards to the results of the PSs, we present to illustrate the PS1a and PS2a as they are measured by year instead of by OM or period. For PS1a, the probability of being below B_{lim} is less in the without constraint case. This is due to the lower F and catches in the medium term period (till 2020) in the case without constraint that allows the stock to increase much than in the case with constraint. The risk set for this PS is reached before in the case without constraint (2021 instead of 2023). For PS2a, in the short-term period the probability of being below F_{lim} is less in the without constraint case, as the F drops quicker in this case and we achieve this PS in 2019 instead of 2021. But after 2022 the F starts to increase to levels very close or even above the established risk.

6. Discussion

The greatest impact on the stock indicators results comes from the assumption of the stock recruitment. The assumption of natural mortality (M) fix o variable has a little effect and the F_{target} uncertainty levels chosen (20%, 35% and 50%) have very little influence on the results of the stock indicators.

The median SSB in the medium term period (2016-2020) shows a small increase trend in the model-based cases and is more or less stable in the model-free scenarios (Figure 4). The relative stability of the SSB in all the scenarios with the increase in variability from the starting point is one of the reasons why most of the scenarios do not meet the PS1 in this period and reach the maximum risks at the end of the period. The model-based cases have PS1a values closer to the limit than the model-free scenarios. After 2020 the SSB starts to increase and consequently the PS1a values start to decrease in all the scenarios and reach a lower level than the proposed limit in 2024 for all cases, except the scenario 6 (model-based, SR2, M fix, F50) that slightly exceeding the limit till 2025.

The steep increase of the SSB from 2023 to 2024 for all the OMs is due to the weights-at-age in the stock that was randomly chosen for those years, as they are higher in 2024 than in 2023 (Figure 3). If we do not have into account the step in the SSB, the increase is more or less lineal. The great variability of biological parameters (mean weights, maturity ogives, etc) for this species is well known (Gonzalez-Costas and Gonzalez-Troncoso, 2014). The impact in the results (but no over the trends) of the biological parameters variability used for the projection period could be important. This study include only some variability, it was obtained the biological parameters in blocks of years to take into account the possible autocorrelation of the parameters but these blocks were the same for all the iterations. It was include only the uncertainty in the time periods but not between iterations.

The main reason for the stability of the SSB in the medium term period (2014-2020) is the F and catches levels. The starting point (2016) has a F and yield unsustainable in the long term and much higher than the F target levels (Figures 6 and 8) and due to the 20% TAC restriction applied down in these cases, the F_{target} level and its corresponding yield are reached at the end of this period. The necessary period to achieve the F_{target} level would be longer if we had applied a more restrictive TAC constrain (15% or 10%). The F_{target} level is reached before for the model-based cases than for the model-free. The F_{target} in the model-free is estimated based on the biomass trend and has not into account the high starting point F level, and due to the stability in the SSB in this period the yields are higher than in the model-based cases. In the second period (2021-2025) the SSB and the yields start to increase in all cases but the increase in yields are lower than the expected F_{target} yields due to the 20% TAC restriction applied up in these cases causing that the F levels in all scenarios are lower than the proposed F_{target}. In fact, it seems that we are testing an HCR of applying a constraint of 20% (up or low) more than a F_{target} model-based HCR or survey indices model-free HCR.

At the end of the projected period, the highest yield was attained in the SR3 cases followed by SR2 and SR1 cases. This is a consequence of the recruitment levels assumed for each of the S/R relationships. The level of recruitment is much higher for the SR3 cases, allowing biomass to increase more than for the SR1 and SR2 cases. This increase in biomass, mainly in the period from 2021, allows a higher level of catches for the SR3 cases than the SR2 and SR1 cases for similar levels of F.

The projection results show two periods with different behavior: 2016-2020 and 2021-2025. In the first period none of the tested HCR meets the performance objectives established. The main reasons for not achieving these objectives are the high initial F and catch levels and the 20% TAC constraint. The length of time to achieve the objectives is modulated by the TAC restriction that reduced gradually catches. Lower percentages of TAC variation would imply lengthening the period while higher percentages of TAC variation would imply shortening the period. In this period (2014-2020), the performance of the model-based HCR is better than the model-free HCR based on the established performance objectives. At the end of the second period (2025), almost all the scenarios of both HCR meet most of the established performance objectives and in this period the 20% TAC constraint is applied reducing the increase of the potential F_{target} catch levels.

If the constraint of the 20% is not used, the F decreases sharply in the short-term period (2016-2020), allowing the SSB to increase much quickly and the recovery of the stock earlier. Because of that, the TAC in the short-term period is lower if we don´t apply the constraint, but after 2020 starts to increase, reaching two times of the constraint case value in 2025. Although the risk is less than in the case with constraint, the case without constraint has not reach the level of risk established for the PS1a and PS2a in the 2016-2020 period but in the 2021-2025 period.

7. Conclusion

Differences in the results come mainly from the assumed stock recruitment relationship and in a much lesser extent of assumed natural mortality (M) and the different F_{target} levels tested. The impact in the results (but no over the trends) of the assumed variability of the biological parameters for the projection period could be important.

None of the tested HCR reached the established performance objectives in the 2016-2020 period but most of the scenarios met the performance objectives at the end of the 2021-2025 period. In the 2016-2020 period, the model-based HCR is closer to achieve the established performance objectives than the model-free HCR. The main reasons for not achieving these objectives are the high initial F and catch levels and the 20% catch constraint. The necessary period to achieve the performance objectives would be longer if we had applied a more restrictive TAC constraint (15% or 10%).

The results show that for both HCR it is very difficult to achieve the approved risk levels for different objectives maintaining the stability in catches tested (catch constraint).

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Disclaimer

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Table 1.- Management Objectives and the new Performance Statistics and Performance Targets proposed by the SC and FC SC RBMS for the 3M cod MSE.

Management Objectives	Performance Statistics (PS)	Performance Targets (PT)
Very low risk of breaching B_{lim}	$SSB_y / B_{\lim}$ SSB_y is the Spawning Stock Biomass in the year *y* of the projection period.	$P\left(SSB_y / B_{\lim} < 1\right) \leq 0.1$ y=1, ...,10 The probability of a spawning stock biomass under B_{lim} at 10% or lower.
Low risk of overfishing	**For the model-free HCR:** F_y / F_{msy} F_y is the Fishing Mortality in the year *y* of the projection period.	$P\left(F_y / F_{msy} > 1\right) \leq 0.3$ y=1,...,10 For the model-free HCR only: The probability of F exceeding F_{msy} during the evaluation period should be kept at 30% or lower.
Low risk of steep decline	SSB_5 / SSB_0 SSB_{10} / SSB_0 SSB_{lowest_5} / SSB_0 SSB_{lowest_10} / SSB_0 SSB_y is the Spawning Stock Biomass in the year *y* of the projection period. SSB_{lowest_y} is the lowest Spawning Stock Biomass level in the period year 1 to year *y* of the projection.	$P\left(SSB_5 / SSB_0 \leq 0.75\right) \leq 0.1$ $P\left(SSB_{10} / SSB_0 \leq 0.75\right) \leq 0.1$ $P\left(SSB_{lowest\_5} / SSB_0 \leq 0.75\right) \leq 0.1$ $P\left(SSB_{lowest\_10} / SSB_0 \leq 0.75\right) \leq 0.1$ The probability of the decline of 25% or more of spawning stock biomass from year 0 to year *y* is kept at 10% or lower.
Maximum average catch over the period	$\sum_{i=1}^{5} TAC_i / 5$ $\sum_{i=1}^{10} TAC_i / 10$	$\max\left(\sum_{i=1}^{5} TAC_i / 5\right)$ $\max\left(\sum_{i=1}^{10} TAC_i / 10\right)$ The average TAC over the period should be maximized.
Limited annual catch variation	$TAC_{assess\_y+1} / TAC_{assess\_y}$ TAC_{assess_y} is the TAC given by the assessment in year *y* before constraints.	$count\left(TAC_{assess\_y+1} / TAC_{assess\_y} \leq 1-x\right)$ $count\left(TAC_{assess\_y+1} / TAC_{assess\_y} \geq 1+x\right)$ x=0.1, 0.15, 0.2 y=1,...,5 y=1,...,10 This will be achieved through the constraint on the TAC variation.

Table 2.- Results of the fits for the different stock-recruitment relationships. Median of the parameters. R mean is the median of the mean of the Recruitment for all the projected years (2014-2025).

M fix	alfa	beta	Rmean
SR1			19582
SR2	0.680	14000	25022
SR3	0.547	32266	40489

M var	alfa	beta	Rmean
SR1			20910
SR2	0.796	14000	34403
SR3	0.633	33252	51526

Table 3.- Operating Models and Management procedures proposed in this study with their different scenarios.

OM		MP		Scenario
M value	S/R Function	HCR	F_{target}	
Constant	1	Model Based	20% F_{max}	1
			35% F_{max}	2
			50% F_{max}	3
	2	Model Based	20% F_{max}	4
			35% F_{max}	5
			50% F_{max}	6
	3	Model Based	20% F_{max}	7
			35% F_{max}	8
			50% F_{max}	9
Variable	1	Model Based	20% F_{max}	10
			35% F_{max}	11
			50% F_{max}	12
	2	Model Based	20% F_{max}	13
			35% F_{max}	14
			50% F_{max}	15
	3	Model Based	20% F_{max}	16
			35% F_{max}	17
			50% F_{max}	18
Constant	1	Model Free		19
	2	Model Free		20
	3	Model Free		21
Variable	1	Model Free		22
	2	Model Free		23
	3	Model Free		24

Table 4.- Median of the SSB (thousand tons) for the 24 OMs in the projection years: 2014-2025.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	min	max
2014	21.8	21.8	21.8	21.8	21.8	21.8	22.0	22.0	22.0	19.6	19.6	19.6	19.6	19.6	19.6	19.7	19.7	19.7	21.8	22.0	21.9	19.6	19.7	19.6	19.6	22.0
2015	26.5	26.5	26.5	26.5	26.5	26.5	26.8	26.8	26.8	24.4	24.4	24.4	24.5	24.5	24.5	24.5	24.5	24.5	26.5	26.7	26.7	24.4	24.5	24.4	24.4	26.8
2016	35.3	35.3	35.3	36.1	36.1	36.1	38.0	38.0	38.0	32.7	32.7	32.7	33.9	33.9	33.9	34.8	34.8	34.8	35.3	36.1	37.4	32.7	33.8	34.1	32.7	38.0
2017	52.9	51.8	49.9	58.4	56.8	54.9	63.8	62.1	60.7	51.7	51.7	51.7	55.9	55.8	55.6	61.0	60.7	60.1	48.8	51.5	55.9	45.4	53.8	54.5	45.4	63.8
2018	61.3	58.1	54.8	71.0	67.8	64.9	84.9	81.8	76.9	61.8	60.3	60.0	71.9	71.0	69.8	79.8	78.9	77.2	51.9	58.3	68.8	48.4	62.1	66.9	48.4	84.9
2019	50.6	46.7	42.0	61.9	57.7	53.0	77.4	73.3	68.9	50.0	49.2	47.7	65.3	64.0	62.1	73.5	71.9	68.8	34.5	41.4	54.0	34.5	49.0	53.3	34.5	77.4
2020	60.2	55.1	49.0	80.1	75.8	70.5	110.4	104.0	97.1	60.8	59.1	56.8	90.9	86.5	83.5	95.9	92.7	88.5	36.8	44.8	69.3	34.5	58.6	73.9	34.5	110.4
2021	59.2	54.3	49.7	83.7	78.8	73.2	128.5	120.0	114.6	59.9	56.7	54.6	93.4	91.0	88.6	114.4	112.4	107.3	34.3	44.8	78.7	31.8	66.0	89.3	31.8	128.5
2022	68.3	63.7	58.0	97.2	92.8	85.7	155.5	149.5	142.1	65.3	63.7	60.4	112.8	111.0	107.7	139.9	137.0	132.7	42.8	54.7	97.9	40.1	83.1	117.2	40.1	155.5
2023	77.6	72.6	68.8	107.3	100.0	95.6	172.1	165.2	157.7	69.6	67.3	64.6	126.6	122.9	122.1	162.7	159.2	157.3	52.9	62.6	116.6	50.1	90.4	138.3	50.1	172.1
2024	158.3	151.6	142.1	218.9	205.4	190.4	347.0	336.4	319.6	150.4	145.1	138.3	251.9	249.3	244.3	381.2	374.6	367.1	126.5	140.8	260.4	118.0	196.9	293.7	118.0	381.2
2025	165.0	157.3	150.1	226.6	217.7	206.6	377.0	354.6	344.9	154.9	151.0	145.9	262.4	254.8	248.4	387.9	379.8	371.5	138.8	145.1	287.1	125.3	221.7	321.0	125.3	387.9
min	21.8	21.8	21.8	21.8	21.8	21.8	22.0	22.0	22.0	19.6	19.6	19.6	19.6	19.6	19.6	19.7	19.7	19.7	21.8	22.0	21.9	19.6	19.7	19.6	19.6	
max	165.0	157.3	150.1	226.6	217.7	206.6	377.0	354.6	344.9	154.9	151.0	145.9	262.4	254.8	248.4	387.9	379.8	371.5	138.8	145.1	287.1	125.3	221.7	321.0		387.9

Table 5.- Median of the F for the 24 OMs in the projection years: 2014-2025.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	min	max
2014	0.395	0.395	0.395	0.395	0.395	0.395	0.395	0.395	0.395	0.441	0.441	0.441	0.441	0.441	0.441	0.441	0.441	0.441	0.395	0.395	0.395	0.441	0.441	0.441	0.395	0.441
2015	0.444	0.444	0.444	0.435	0.435	0.435	0.421	0.421	0.421	0.495	0.495	0.495	0.470	0.470	0.470	0.461	0.461	0.461	0.444	0.438	0.430	0.495	0.468	0.457	0.421	0.495
2016	0.269	0.294	0.313	0.253	0.274	0.296	0.235	0.252	0.276	0.253	0.256	0.259	0.243	0.247	0.249	0.225	0.227	0.236	0.341	0.319	0.304	0.341	0.303	0.303	0.225	0.341
2017	0.292	0.322	0.359	0.238	0.259	0.288	0.184	0.203	0.220	0.263	0.275	0.291	0.200	0.207	0.218	0.181	0.191	0.202	0.401	0.322	0.236	0.353	0.239	0.211	0.181	0.401
2018	0.181	0.204	0.236	0.149	0.169	0.189	0.125	0.141	0.157	0.172	0.182	0.188	0.136	0.143	0.151	0.119	0.125	0.134	0.292	0.268	0.191	0.275	0.207	0.179	0.119	0.292
2019	0.096	0.112	0.134	0.076	0.087	0.099	0.059	0.065	0.072	0.099	0.103	0.111	0.071	0.077	0.082	0.066	0.070	0.074	0.178	0.160	0.097	0.182	0.120	0.101	0.059	0.182
2020	0.057	0.066	0.078	0.046	0.052	0.059	0.035	0.039	0.043	0.062	0.066	0.072	0.047	0.051	0.054	0.040	0.043	0.047	0.117	0.104	0.061	0.104	0.075	0.055	0.035	0.117
2021	0.046	0.051	0.057	0.036	0.039	0.045	0.027	0.029	0.032	0.048	0.051	0.055	0.035	0.037	0.039	0.030	0.032	0.035	0.042	0.041	0.028	0.047	0.026	0.028	0.026	0.057
2022	0.048	0.051	0.056	0.038	0.041	0.045	0.030	0.032	0.035	0.052	0.056	0.060	0.036	0.038	0.041	0.030	0.032	0.034	0.037	0.035	0.026	0.038	0.021	0.025	0.021	0.060
2023	0.048	0.051	0.055	0.041	0.044	0.047	0.031	0.033	0.035	0.054	0.058	0.061	0.040	0.042	0.044	0.032	0.032	0.035	0.033	0.029	0.026	0.031	0.022	0.025	0.022	0.061
2024	0.037	0.039	0.041	0.032	0.033	0.036	0.024	0.025	0.027	0.041	0.043	0.045	0.032	0.034	0.035	0.023	0.025	0.025	0.026	0.023	0.020	0.025	0.018	0.018	0.018	0.045
2025	0.036	0.038	0.039	0.031	0.033	0.035	0.023	0.024	0.026	0.040	0.042	0.045	0.030	0.031	0.033	0.022	0.023	0.025	0.025	0.021	0.016	0.024	0.016	0.017	0.016	0.045
min	0.036	0.038	0.039	0.031	0.033	0.035	0.023	0.024	0.026	0.040	0.042	0.045	0.030	0.031	0.033	0.022	0.023	0.025	0.025	0.021	0.016	0.024	0.016	0.017	0.016	
max	0.444	0.444	0.444	0.435	0.435	0.435	0.421	0.421	0.421	0.495	0.495	0.495	0.470	0.470	0.470	0.461	0.461	0.461	0.444	0.438	0.430	0.495	0.468	0.457		0.495

Table 6.- Median of the Landings (thousand tons) for the 24 OMs in the projection years: 2014-2025.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	min	max
2014	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5	14.5
2015	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8	13.8
2016	12.5	13.3	14.2	12.5	13.4	14.2	12.6	13.3	14.2	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	11.0	16.6	16.6	16.6	16.6	16.6	16.6	11.0	16.6
2017	10.5	11.2	11.8	10.8	11.3	12.0	10.7	11.4	12.0	9.7	10.3	11.0	10.0	10.6	11.1	10.2	10.8	11.5	14.9	14.9	14.9	14.9	14.9	14.9	9.7	14.9
2018	8.4	8.9	9.4	8.6	9.0	9.5	8.7	9.1	9.6	7.8	8.3	8.8	8.0	8.5	8.9	8.3	8.7	9.3	14.6	14.6	14.6	14.3	14.6	14.6	7.8	14.6
2019	6.9	7.3	7.7	7.2	7.5	8.0	7.5	7.7	8.1	7.0	7.4	7.7	7.5	7.8	8.2	8.0	8.4	8.5	12.0	13.7	13.8	11.8	12.2	12.9	6.9	13.8
2020	5.7	6.0	6.3	6.3	6.4	6.6	6.8	7.1	7.2	6.1	6.3	6.6	6.7	6.8	7.0	6.8	7.1	7.4	13.0	14.0	14.0	9.3	14.0	14.0	5.7	14.0
2021	5.9	6.0	6.0	6.3	6.5	6.7	7.4	7.6	7.8	5.9	6.1	6.3	7.1	7.4	7.6	7.6	7.8	8.1	7.2	11.5	13.3	5.6	11.3	12.7	5.6	13.3
2022	6.3	6.2	6.2	7.3	7.6	7.7	8.6	8.9	9.1	6.5	6.7	6.8	8.2	8.6	8.8	8.9	9.2	9.7	5.0	9.4	12.8	5.0	6.8	13.5	5.0	13.5
2023	7.4	7.3	7.4	8.8	9.0	9.2	10.2	10.6	10.9	7.8	8.0	8.2	9.7	10.1	10.4	10.5	10.9	11.4	5.0	6.8	11.6	5.0	6.9	11.0	5.0	11.6
2024	8.9	8.7	8.9	10.5	10.8	11.0	12.2	12.7	13.0	9.4	9.5	9.7	11.6	12.0	12.4	12.6	13.1	13.6	6.0	6.6	11.9	5.8	7.1	11.5	5.8	13.6
2025	10.5	10.3	10.4	12.6	12.9	13.0	14.6	15.2	15.6	11.2	11.2	11.4	13.8	14.2	14.7	15.1	15.7	16.3	6.0	7.2	11.2	6.0	7.8	10.5	6.0	16.3
min	5.7	6.0	6.0	6.3	6.4	6.6	6.8	7.1	7.2	5.9	6.1	6.3	6.7	6.8	7.0	6.8	7.1	7.4	5.0	6.6	11.2	5.0	6.8	10.5	5.0	
max	14.5	14.5	14.5	14.5	14.5	14.5	14.6	15.2	15.6	14.5	14.5	14.5	14.5	14.5	14.7	15.1	15.7	16.3	16.6	16.6	16.6	16.6	16.6	16.6		16.6

Table 7.- Results for PS1: P(SSB_y<B_{lim}). In italics and bold, the values higher than 0.1.

PS1

PS1a: Probability of being below Blim year by year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2014	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	***0.13***	***0.13***	***0.13***	***0.12***	***0.12***	***0.12***	***0.12***	***0.12***	***0.12***	0.08	0.08	0.08	***0.13***	***0.12***	***0.13***
2015	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07	0.07	0.08	0.08	0.08
2016	***0.11***	***0.11***	***0.11***	0.09	0.09	0.09	0.09	0.09	0.09	***0.13***	***0.13***	***0.13***	***0.12***	***0.12***	***0.12***	0.09	0.09	0.09	***0.11***	0.10	0.10	***0.13***	0.10	0.10
2017	***0.12***	***0.13***	***0.14***	0.09	***0.11***	***0.11***	0.10	***0.11***	***0.12***	***0.13***	***0.13***	***0.13***	0.10	0.10	0.10	0.08	0.08	0.09	***0.14***	***0.13***	***0.13***	***0.16***	***0.12***	***0.11***
2018	***0.14***	***0.15***	***0.17***	***0.11***	***0.13***	***0.14***	***0.11***	***0.12***	***0.13***	***0.15***	***0.15***	***0.15***	***0.11***	***0.12***	***0.12***	0.10	***0.11***	***0.11***	***0.20***	***0.16***	***0.15***	***0.21***	***0.12***	***0.14***
2019	***0.22***	***0.25***	***0.29***	***0.18***	***0.21***	***0.24***	***0.15***	***0.16***	***0.18***	***0.23***	***0.25***	***0.27***	***0.17***	***0.18***	***0.19***	***0.15***	***0.16***	***0.17***	***0.37***	***0.29***	***0.24***	***0.33***	***0.25***	***0.20***
2020	***0.22***	***0.25***	***0.29***	***0.17***	***0.20***	***0.24***	***0.13***	***0.15***	***0.16***	***0.21***	***0.23***	***0.25***	***0.17***	***0.18***	***0.19***	***0.14***	***0.15***	***0.15***	***0.37***	***0.32***	***0.23***	***0.36***	***0.25***	***0.23***
2021	***0.17***	***0.21***	***0.23***	***0.15***	***0.18***	***0.21***	***0.12***	***0.13***	***0.14***	***0.19***	***0.21***	***0.22***	***0.14***	***0.15***	***0.16***	***0.11***	***0.12***	***0.12***	***0.34***	***0.29***	***0.19***	***0.32***	***0.23***	***0.19***
2022	***0.11***	***0.13***	***0.16***	***0.13***	***0.16***	***0.18***	0.10	***0.11***	***0.12***	***0.13***	***0.14***	***0.15***	***0.12***	***0.13***	***0.13***	0.09	0.10	0.10	***0.23***	***0.21***	***0.14***	***0.25***	***0.19***	***0.13***
2023	0.09	0.10	***0.13***	***0.11***	***0.14***	***0.15***	0.09	0.09	***0.11***	***0.11***	***0.11***	***0.12***	0.10	***0.11***	***0.12***	0.08	0.09	0.09	***0.18***	***0.18***	**0.10**	***0.18***	***0.14***	0.10
2024	0.04	0.05	0.06	0.07	0.10	***0.12***	0.08	0.08	0.09	0.06	0.06	0.06	0.07	0.07	0.08	0.07	0.08	0.08	0.09	0.08	0.04	0.09	0.06	0.04
2025	0.04	0.04	0.05	0.07	0.09	***0.12***	0.08	0.08	0.09	0.04	0.04	0.04	0.07	0.07	0.08	0.07	0.08	0.08	0.07	0.06	0.03	0.07	0.05	0.03
PS1b: Mean of the P(SSB<Blim)																								
2016-2020	***0.16***	***0.18***	***0.20***	***0.13***	***0.15***	***0.16***	***0.12***	***0.12***	***0.14***	***0.17***	***0.18***	***0.19***	***0.13***	***0.14***	***0.14***	***0.12***	***0.12***	***0.12***	***0.24***	***0.20***	***0.17***	***0.24***	***0.17***	***0.16***
2021-2025	0.09	***0.11***	***0.12***	***0.11***	***0.13***	***0.16***	0.09	0.10	***0.11***	0.10	***0.11***	***0.12***	0.10	***0.11***	***0.11***	0.09	0.09	0.10	***0.18***	***0.16***	0.10	***0.18***	***0.13***	0.10
2016-2025	***0.13***	***0.14***	***0.16***	***0.12***	***0.14***	***0.16***	0.10	***0.11***	***0.12***	***0.14***	***0.14***	***0.15***	***0.12***	***0.12***	***0.13***	0.10	***0.11***	***0.11***	***0.21***	***0.18***	***0.13***	***0.21***	***0.15***	***0.13***
PS1c: Probability of being below Blim at the end of each period																								
2020	***0.22***	***0.25***	***0.29***	***0.17***	***0.20***	***0.24***	***0.13***	***0.15***	***0.16***	***0.21***	***0.23***	***0.25***	***0.17***	***0.18***	***0.19***	***0.14***	***0.15***	***0.15***	***0.37***	***0.32***	***0.23***	***0.36***	***0.25***	***0.23***
2025	0.04	0.04	0.05	0.07	0.09	***0.12***	0.08	0.08	0.09	0.04	0.04	0.04	0.07	0.07	0.08	0.07	0.08	0.08	0.07	0.06	0.03	0.07	0.05	0.03

Table 8.- Results for PS2: $P(F_y>F_{msy})$. In italics and bold, the values higher than 0.3.

PS2

PS2a: Probability of being above Fmsy year by year

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2014	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***
2015	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***0.99***	***0.99***	***0.99***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***1.00***	***0.99***	***0.99***	***1.00***	***1.00***	***1.00***
2016	***0.91***	***0.92***	***0.94***	***0.87***	***0.89***	***0.92***	***0.82***	***0.85***	***0.87***	***0.88***	***0.88***	***0.88***	***0.81***	***0.81***	***0.82***	***0.79***	***0.79***	***0.80***	***0.88***	***0.86***	***0.83***	***0.85***	***0.83***	***0.82***
2017	***0.86***	***0.88***	***0.90***	***0.77***	***0.79***	***0.80***	***0.67***	***0.69***	***0.72***	***0.81***	***0.82***	***0.84***	***0.68***	***0.70***	***0.71***	***0.64***	***0.65***	***0.66***	***0.86***	***0.79***	***0.67***	***0.84***	***0.71***	***0.63***
2018	***0.65***	***0.70***	***0.74***	***0.57***	***0.61***	***0.64***	***0.46***	***0.52***	***0.57***	***0.60***	***0.63***	***0.65***	***0.51***	***0.52***	***0.54***	***0.44***	***0.46***	***0.51***	***0.74***	***0.71***	***0.60***	***0.71***	***0.61***	***0.56***
2019	***0.38***	***0.43***	***0.51***	***0.33***	***0.36***	***0.39***	0.23	0.27	0.30	***0.38***	***0.42***	***0.44***	0.30	***0.31***	***0.32***	0.24	0.26	0.29	***0.59***	***0.57***	***0.42***	***0.58***	***0.47***	***0.43***
2020	0.29	***0.32***	***0.37***	0.23	0.27	0.29	0.16	0.18	0.20	0.29	***0.31***	***0.34***	0.20	0.22	0.25	0.17	0.18	0.19	***0.47***	***0.44***	***0.33***	***0.45***	***0.39***	***0.33***
2021	0.17	0.22	0.26	0.16	0.20	0.22	0.12	0.13	0.15	0.18	0.19	0.22	0.15	0.16	0.17	0.12	0.13	0.14	0.28	0.26	0.18	0.29	0.21	0.16
2022	0.10	0.13	0.17	0.12	0.15	0.18	0.09	0.10	0.11	0.11	0.13	0.15	0.12	0.13	0.15	0.09	0.10	0.10	0.23	0.21	0.12	0.20	0.17	0.12
2023	0.07	0.10	0.12	0.10	0.13	0.16	0.09	0.09	0.10	0.10	0.12	0.14	0.10	0.12	0.13	0.08	0.09	0.09	0.18	0.18	0.07	0.17	0.12	0.07
2024	0.04	0.04	0.06	0.07	0.10	0.12	0.08	0.08	0.09	0.05	0.07	0.08	0.07	0.08	0.09	0.07	0.07	0.08	0.10	0.10	0.03	0.10	0.07	0.03
2025	0.04	0.05	0.05	0.06	0.09	0.11	0.07	0.08	0.09	0.06	0.07	0.08	0.07	0.08	0.09	0.07	0.07	0.08	0.08	0.08	0.02	0.09	0.06	0.02
PS2b: Mean of the P(F<Fmsy)																								
2016-2020	***0.62***	***0.65***	***0.69***	***0.55***	***0.58***	***0.61***	***0.47***	***0.50***	***0.53***	***0.59***	***0.61***	***0.63***	***0.50***	***0.51***	***0.53***	***0.45***	***0.47***	***0.49***	***0.71***	***0.67***	***0.57***	***0.69***	***0.60***	***0.55***
2021-2025	0.08	0.11	0.13	0.10	0.13	0.16	0.09	0.10	0.11	0.10	0.11	0.13	0.10	0.11	0.13	0.08	0.09	0.10	0.17	0.17	0.08	0.17	0.13	0.08
2016-2025	***0.35***	***0.38***	***0.41***	***0.33***	***0.36***	***0.38***	0.28	0.30	***0.32***	***0.35***	***0.36***	***0.38***	0.30	***0.31***	***0.33***	0.27	0.28	0.29	***0.44***	***0.42***	***0.33***	***0.43***	***0.37***	***0.32***
PS2c: Probability of being below Blim at the end of each periodin some moment of the period below Blim																								
2020	0.29	***0.32***	***0.37***	0.23	0.27	0.29	0.16	0.18	0.20	0.29	***0.31***	***0.34***	0.20	0.22	0.25	0.17	0.18	0.19	***0.47***	***0.44***	***0.33***	***0.45***	***0.39***	***0.33***
2025	0.04	0.05	0.05	0.06	0.09	0.11	0.07	0.08	0.09	0.06	0.07	0.08	0.07	0.08	0.09	0.07	0.07	0.08	0.08	0.08	0.02	0.09	0.06	0.02

Table 9.- Results for PS3: $P(SSB_y/SSB_{2013} \leq 0.75)$. In italics and bold, the values higher than 0.1.

PS3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
P(SSB2020/SSB2013<=0.75)	***0.29***	***0.32***	***0.35***	***0.23***	***0.26***	***0.28***	***0.17***	***0.19***	***0.21***	***0.30***	***0.31***	***0.33***	***0.22***	***0.23***	***0.24***	***0.18***	***0.19***	***0.20***	***0.44***	***0.37***	***0.29***	***0.43***	***0.31***	***0.28***
P(SSB2025/SSB2013<=0.75)	0.04	0.05	0.06	0.08	***0.11***	***0.13***	0.08	0.09	0.09	0.06	0.07	0.07	0.08	0.09	0.10	0.08	0.08	0.09	***0.12***	***0.11***	0.05	***0.12***	0.09	0.05
P(minSSB[2014:2020]/SSB2013)<=0.75)	***0.87***	***0.87***	***0.87***	***0.86***	***0.87***	***0.87***	***0.86***	***0.86***	***0.87***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.9***	***0.88***	***0.88***	***0.97***	***0.97***	***0.97***
P(minSSB[2021:2025]/SSB2013)<=0.75)	***0.26***	***0.3***	***0.34***	***0.23***	***0.25***	***0.27***	***0.15***	***0.16***	***0.18***	***0.3***	***0.31***	***0.33***	***0.19***	***0.2***	***0.21***	***0.15***	***0.16***	***0.17***	***0.49***	***0.41***	***0.27***	***0.48***	***0.32***	***0.26***
P(minSSB[2014:2025]/SSB2013)<=0.75)	***0.87***	***0.88***	***0.88***	***0.87***	***0.87***	***0.87***	***0.86***	***0.86***	***0.87***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.97***	***0.92***	***0.9***	***0.89***	***0.98***	***0.98***	***0.97***

Table 10.- Results for PS4: Mean of the TACs of different periods (median).

PS_4	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	max
Mean TAC_2014-2020	10.4	10.8	11.2	10.7	11.0	11.4	10.8	11.1	11.5	10.1	10.4	10.6	10.4	10.6	10.8	10.6	10.8	11.1	14.3	14.5	14.6	13.8	14.4	14.5	14.6
Mean TAC_2021-2025	7.8	7.7	7.8	9.1	9.4	9.5	10.7	11.0	11.3	8.1	8.3	8.5	10.1	10.4	10.7	11.0	11.4	11.9	5.4	7.0	12.7	5.4	6.9	12.4	12.7
Mean TAC_2014-2025	9.4	9.7	9.9	10.0	10.3	10.5	10.8	11.1	11.4	9.4	9.6	9.9	10.2	10.5	10.7	10.7	11.0	11.3	9.7	11.7	13.8	8.8	11.0	13.8	13.8

Table 11.- Results for PS5: Number of times the constraint of 20% (at the lower and at the higher boundaries) has been applied on average during the period.

PS_5

upp20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	90.6	90.8	90.4	86.8	86.8	87.2
2017	5.0	3.4	4.0	5.8	4.4	4.0	7.4	6.0	5.8	16.6	19.4	24.4	18.0	21.8	27.2	18.6	23.6	28.6	7.6	7.4	7.6	11.4	11.4	11.2
2018	0.2	0.0	0.0	0.0	0.0	0.0	0.4	0.6	0.6	1.0	1.6	1.6	2.2	2.4	3.4	2.8	3.2	3.8	2.0	2.4	2.0	3.4	3.6	4.0
2019	5.0	4.2	4.2	10.8	10.4	9.8	15.8	15.2	14.2	9.8	10.0	11.4	19.6	19.8	20.0	25.0	26.0	26.2	42.4	43.2	43.2	41.4	41.6	41.8
2020	5.4	4.6	4.6	13.8	12.8	12.0	21.8	20.8	21.0	10.8	9.2	10.0	24.0	23.2	24.8	31.2	30.8	29.8	41.0	39.8	41.0	41.2	44.8	43.8
2021	30.8	27.0	24.6	39.4	37.6	34.6	47.8	48.0	44.4	35.8	34.8	34.4	49.6	49.4	46.4	51.4	52.4	51.0	27.8	31.4	36.8	26.8	33.6	38.0
2022	51.6	49.6	45.2	58.4	55.2	54.6	72.2	68.2	67.6	55.2	55.6	53.8	64.6	64.6	63.8	70.2	70.6	71.2	35.8	41.0	46.6	38.8	44.0	44.6
2023	81.0	80.6	75.6	81.0	78.2	75.0	86.6	85.6	83.8	82.2	80.8	81.4	84.0	83.6	83.0	86.2	85.6	84.6	40.2	43.0	47.8	36.8	46.6	47.2
2024	84.2	81.8	79.8	85.2	81.8	78.8	87.2	85.8	84.8	82.2	82.2	81.0	85.6	83.8	82.8	87.0	87.2	86.2	44.2	38.6	48.8	41.4	38.4	45.2
2025	83.8	81.0	78.2	84.4	82.0	78.4	85.8	84.6	83.6	80.0	78.4	77.6	82.8	82.0	81.2	86.0	85.8	85.0	50.0	49.2	54.0	50.4	52.6	55.0
mean 2014-2020	2.2	1.7	1.8	4.3	3.9	3.7	6.5	6.1	6.0	5.5	5.7	6.8	9.1	9.6	10.8	11.1	11.9	12.6	26.2	26.2	26.3	26.3	26.9	26.9
mean 2021-2025	66.3	64.0	60.7	69.7	67.0	64.3	75.9	74.4	72.8	67.1	66.4	65.6	73.3	72.7	71.4	76.2	76.3	75.6	39.6	40.6	46.8	38.8	43.0	46.0
mean 2014-2025	28.9	27.7	26.4	31.6	30.2	29.0	35.4	34.6	33.9	31.1	31.0	31.3	35.9	35.9	36.1	38.2	38.8	38.9	31.8	32.2	34.9	31.5	33.6	34.8

low20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	3.0	0.2	0.0	3.2	0.2	0.0	2.4	0.2	0.0	85.8	78.0	66.0	85.6	77.0	66.8	85.8	79.2	66.8	9.4	9.2	9.6	13.2	13.2	12.8
2017	45.6	47.6	50.2	40.2	39.8	45.8	40.6	40.0	42.8	38.2	33.8	29.0	35.6	31.0	28.2	34.8	28.8	24.2	3.4	3.2	3.2	4.8	4.4	4.8
2018	88.8	87.4	89.6	86.8	84.0	86.6	81.8	81.2	81.0	86.2	83.8	84.2	81.8	77.8	76.6	77.2	76.8	76.8	5.4	4.0	4.8	7.8	6.4	6.0
2019	77.4	78.6	80.4	69.6	69.8	70.8	60.6	62.2	64.8	66.8	65.2	64.4	54.2	53.6	53.0	48.4	47.4	48.6	22.2	21.4	21.2	25.6	25.2	25.0
2020	67.6	70.6	74.6	57.8	59.2	64.2	46.6	48.4	53.8	63.6	65.2	66.4	49.8	52.6	51.4	47.6	48.8	47.2	27.6	29.8	26.6	30.2	28.8	28.2
2021	42.0	46.4	48.4	32.6	36.4	38.4	26.0	29.2	31.8	34.4	34.6	35.4	30.0	28.4	27.6	23.4	23.2	24.2	38.6	35.6	30.2	35.4	35.2	30.4
2022	23.8	27.6	31.4	21.8	24.2	26.4	14.8	16.2	16.4	23.8	25.0	25.8	18.6	19.6	19.4	13.6	14.6	15.4	22.8	20.8	22.6	21.6	21.2	19.2
2023	10.6	10.0	14.0	10.6	13.0	17.2	9.0	10.4	11.8	10.2	11.2	12.2	12.0	12.4	13.0	9.0	9.4	10.2	25.0	22.0	21.4	24.2	21.6	22.6
2024	9.2	10.2	13.0	10.4	12.4	15.0	10.2	10.4	11.4	9.6	10.2	11.8	10.6	10.8	12.0	9.0	9.4	9.2	26.2	28.8	29.0	25.4	29.8	26.4
2025	8.2	9.0	10.6	10.8	11.8	15.2	10.0	10.6	12.4	10.0	10.4	12.6	11.4	12.4	12.6	10.4	10.2	11.2	25.2	24.2	25.4	22.4	22.4	24.6
mean 2014-2020	40.3	40.6	42.1	36.8	36.1	38.2	33.1	33.1	34.6	48.7	46.6	44.3	43.9	41.7	39.4	42.0	40.1	37.7	9.7	9.7	9.3	11.7	11.1	11.0
mean 2021-2025	18.8	20.6	23.5	17.2	19.6	22.4	14.0	15.4	16.8	17.6	18.3	19.6	16.5	16.7	16.9	13.1	13.4	14.0	27.6	26.3	25.7	25.8	26.0	24.6
mean 2014-2025	31.4	32.3	34.4	28.7	29.2	31.6	25.2	25.7	27.2	35.7	34.8	34.0	32.5	31.3	30.1	29.9	29.0	27.8	17.2	16.6	16.2	17.6	17.4	16.7

20	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2014	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2015	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2016	3.0	0.2	0.0	3.2	0.2	0.2	2.4	0.2	0.4	85.8	78.0	66.0	85.6	77.0	66.8	85.8	79.2	66.8	100.0	100.0	100.0	100.0	100.0	100.0
2017	50.6	51.0	54.2	46.0	44.2	49.8	48.0	46.0	48.6	54.8	53.2	53.4	53.6	52.8	55.4	53.4	52.4	52.8	11.0	10.6	10.8	16.2	15.8	16.0
2018	89.0	87.4	89.6	86.8	84.0	86.6	82.2	81.8	81.6	87.2	85.4	85.8	84.0	80.2	80.0	80.0	80.0	80.6	7.4	6.4	6.8	11.2	10.0	10.0
2019	82.4	82.8	84.6	80.4	80.2	80.6	76.4	77.4	79.0	76.6	75.2	75.8	73.8	73.4	73.0	73.4	73.4	74.8	64.6	64.6	64.4	67.0	66.8	66.8
2020	73.0	75.2	79.2	71.6	72.0	76.2	68.4	69.2	74.8	74.4	74.4	76.4	73.8	75.8	76.2	78.8	79.6	77.0	68.6	69.6	67.6	71.4	73.6	72.0
2021	72.8	73.4	73.0	72.0	74.0	73.0	73.8	77.2	76.2	70.2	69.4	69.8	79.6	77.8	74.0	74.8	75.6	75.2	66.4	67.0	67.0	62.2	68.8	68.4
2022	75.4	77.2	76.6	80.2	79.4	81.0	87.0	84.4	84.0	79.0	80.6	79.6	83.2	84.2	83.2	83.8	85.2	86.6	58.6	61.8	69.2	60.4	65.2	63.8
2023	91.6	90.6	89.6	91.6	91.2	92.2	95.6	96.0	95.6	92.4	92.0	93.6	96.0	96.0	96.0	95.2	95.0	94.8	65.2	65.0	69.2	61.0	68.2	69.8
2024	93.4	92.0	92.8	95.6	94.2	93.8	97.4	96.2	96.2	91.8	92.4	92.8	96.2	94.6	94.8	96.0	96.6	95.4	70.4	67.4	77.8	66.8	68.2	71.6
2025	92.0	90.0	88.8	95.2	93.8	93.6	95.8	95.2	96.0	90.0	88.8	90.2	94.2	94.4	93.8	96.4	96.0	96.2	75.2	73.4	79.4	72.8	75.0	79.6
mean 2014-2020	42.6	42.4	43.9	41.1	40.1	41.9	39.6	39.2	40.6	54.1	52.3	51.1	53.0	51.3	50.2	53.1	52.1	50.3	35.9	35.9	35.7	38.0	38.0	37.8
mean 2021-2025	85.0	84.6	84.2	86.9	86.5	86.7	89.9	89.8	89.6	84.7	84.6	85.2	89.8	89.4	88.4	89.2	89.7	89.6	67.2	66.9	72.5	64.6	69.1	70.6
mean 2014-2025	60.3	60.0	60.7	60.2	59.4	60.6	60.6	60.3	61.0	66.9	65.8	65.3	68.3	67.2	66.1	68.1	67.8	66.7	49.0	48.8	51.0	49.1	51.0	51.5

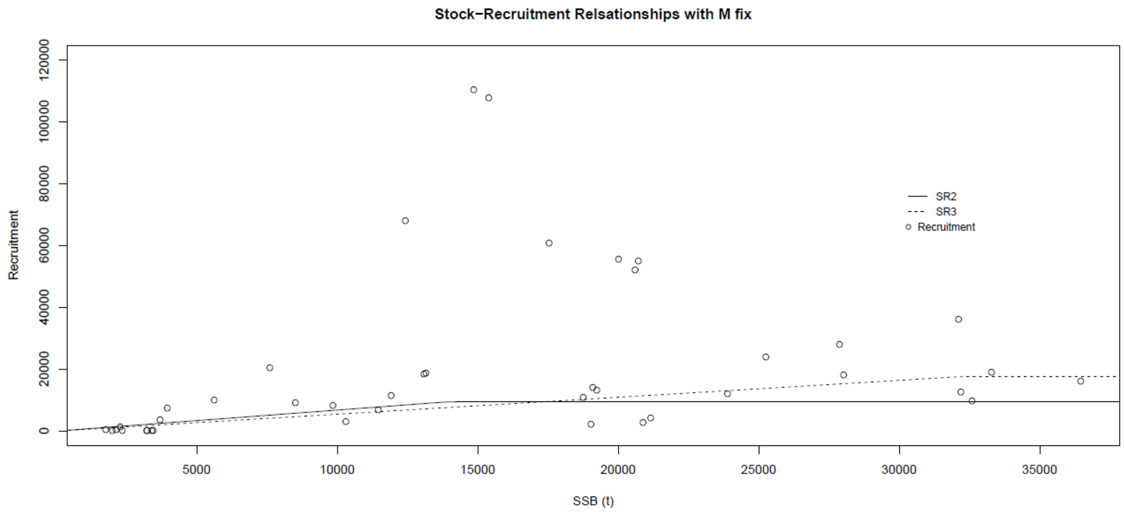

Figure 1.- Median Stock-Recruitment relationships (SR2 and SR3) and median Recruitment for M fix.

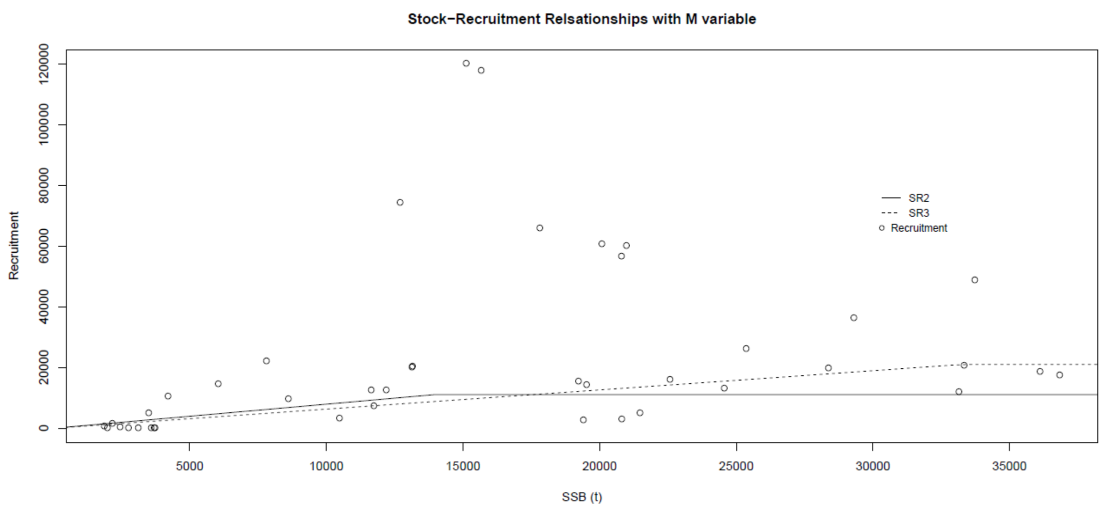

Figure 2.- Median Stock-Recruitment relationships (SR2 and SR3) and median recruitment for M variable.

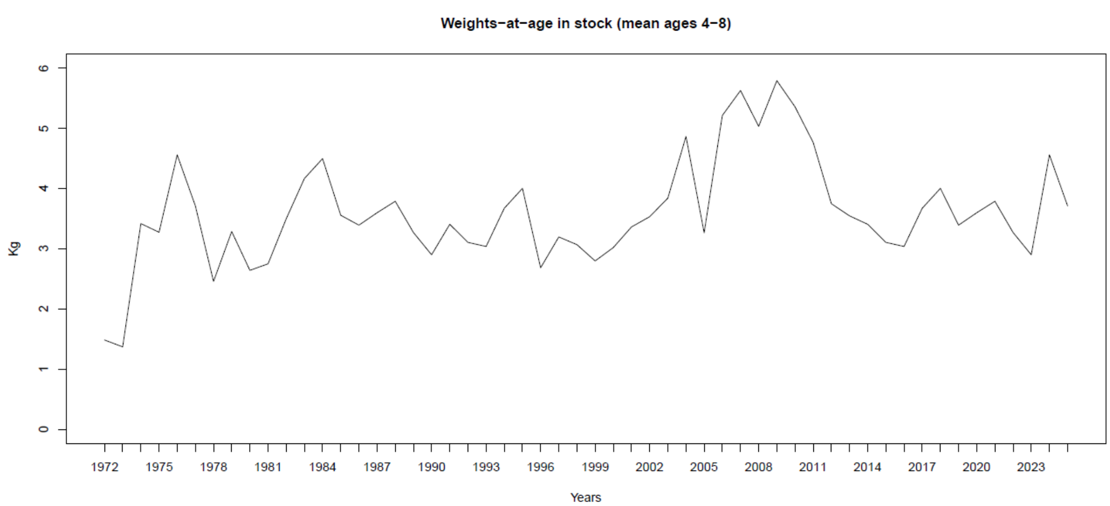

Figure 3.- Weight-at-age in stock. Mean of ages 4-8.

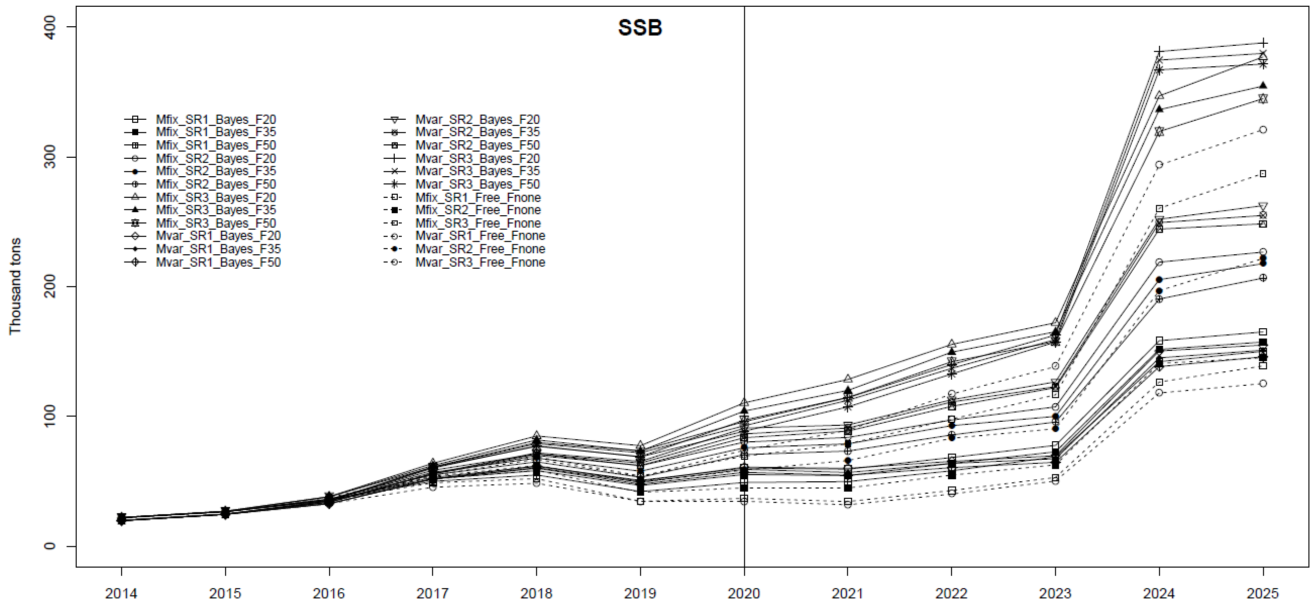

Figure 4.- Values of the median of SSB for all the tested scenarios.

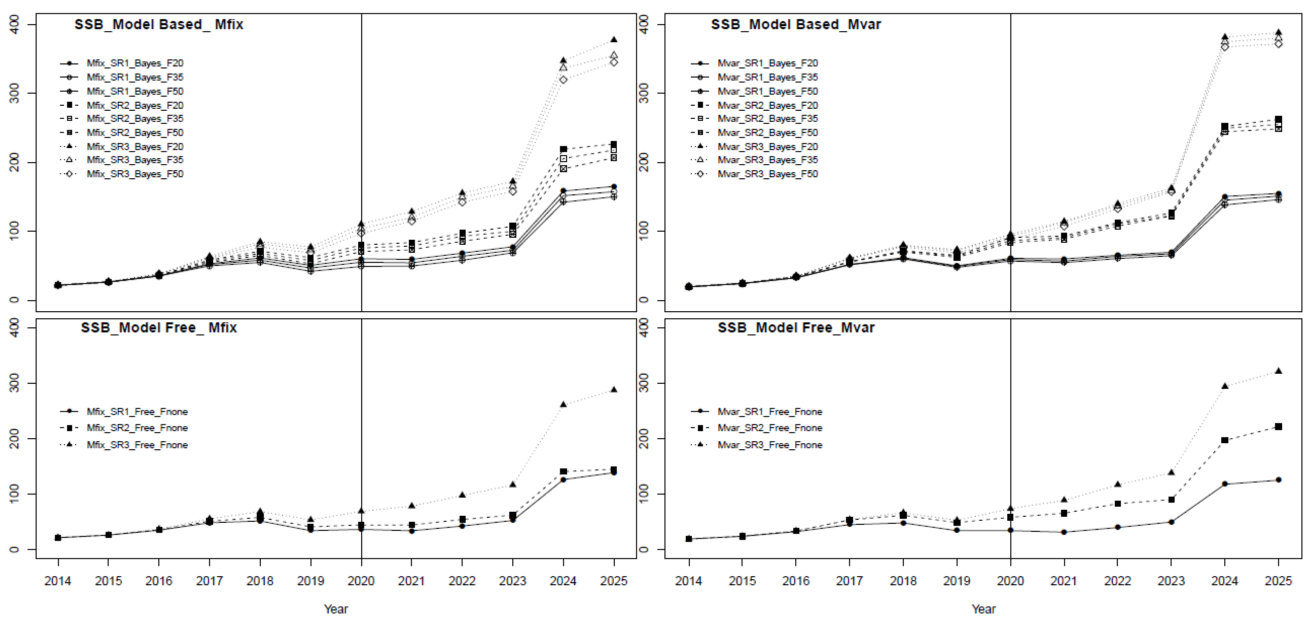

Figure 5.- Values of the median of SSB by Stock-Recruitment relationship for the different M scenarios.

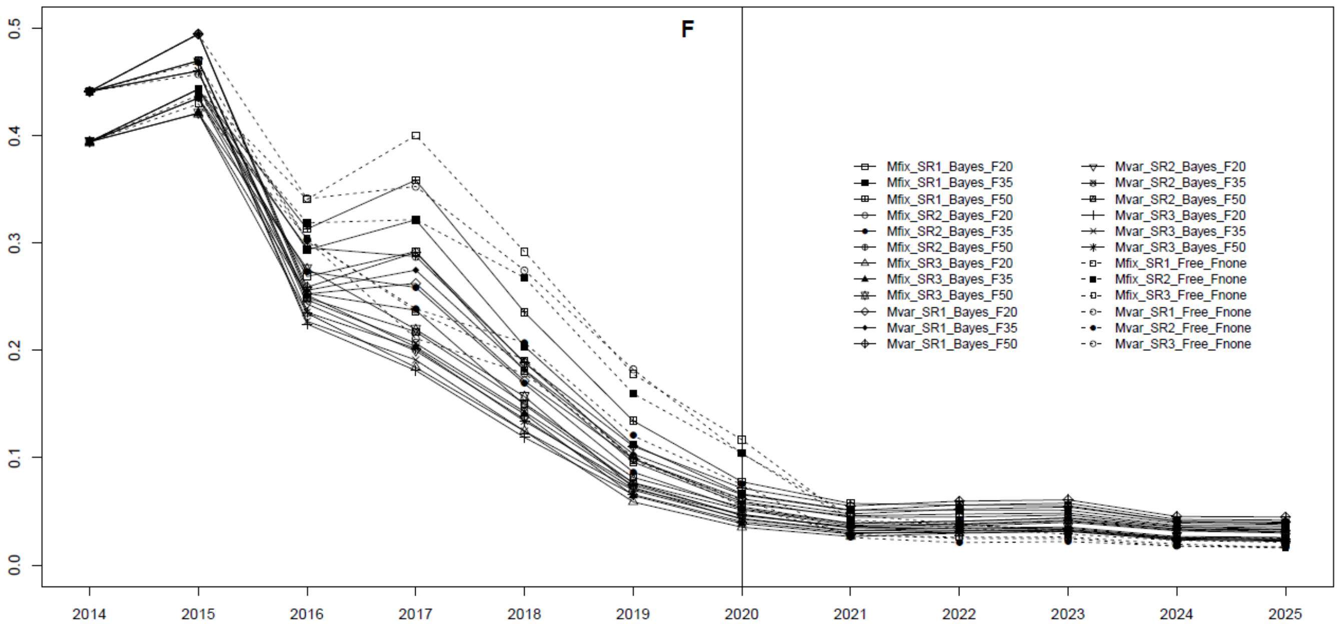

Figure 6.- Values of the median of F for all the tested scenarios.

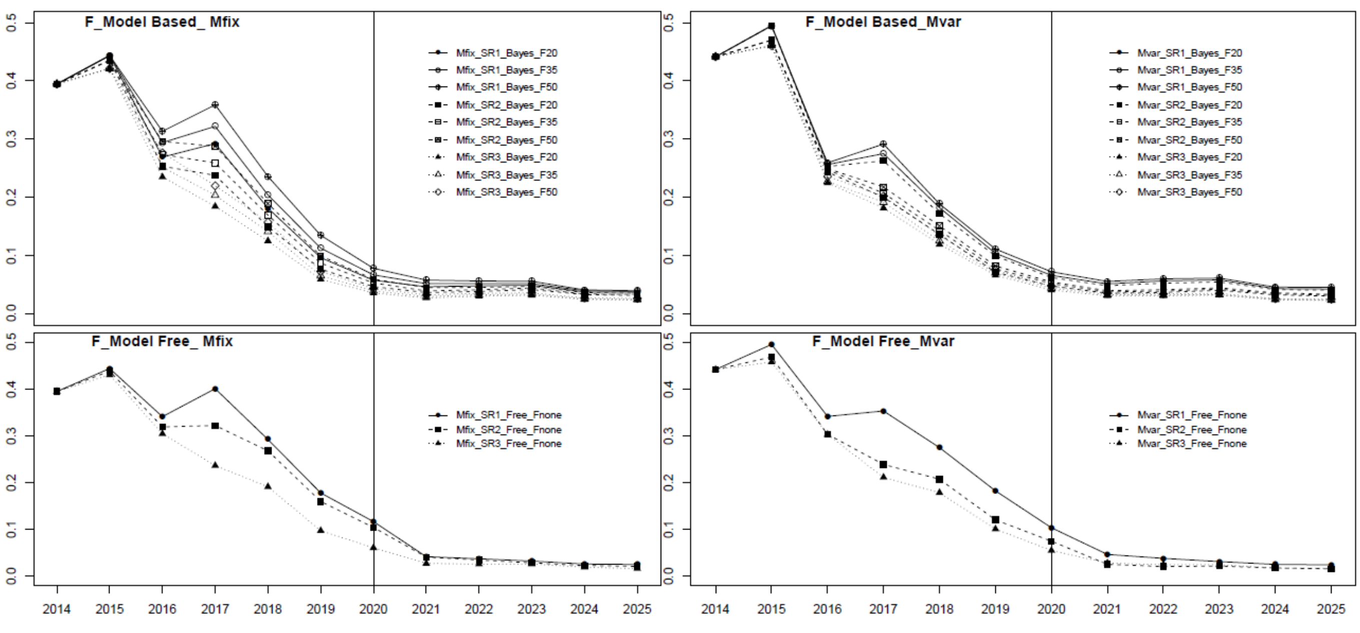

Figure 7.- Values of the median of F by Stock-Recruitment relationship for the different M scenarios.

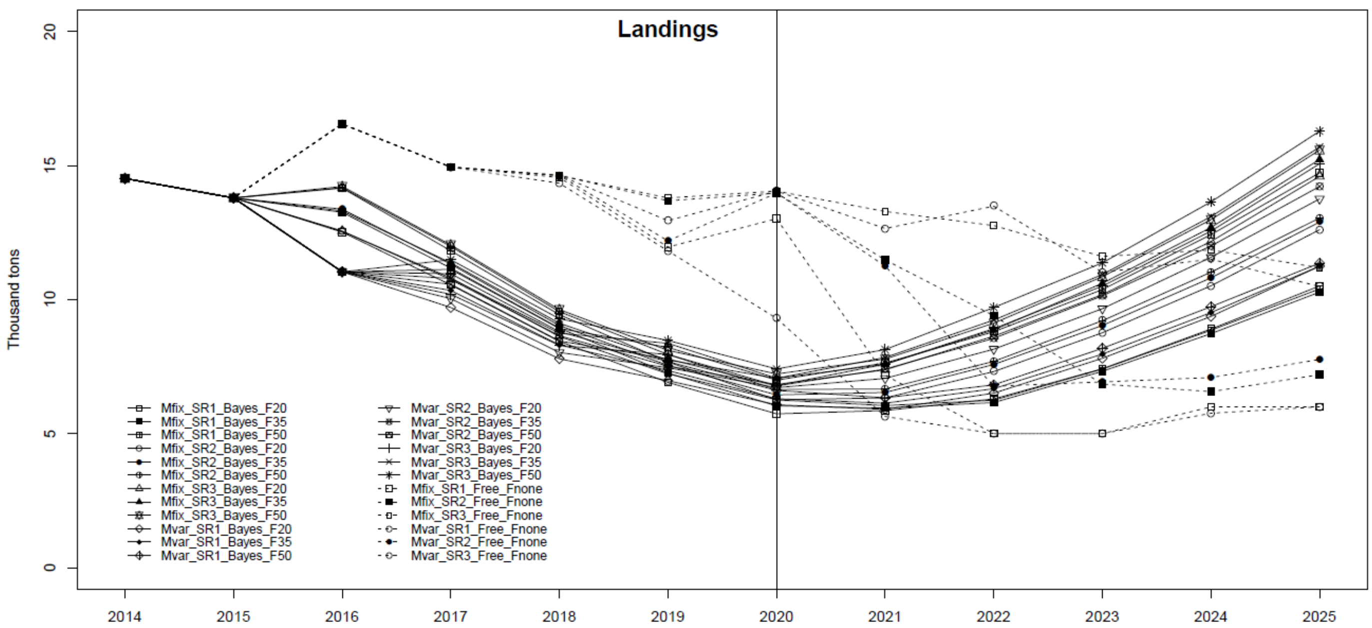

Figure 8.- Values of the median of Landings for all the tested scenarios.

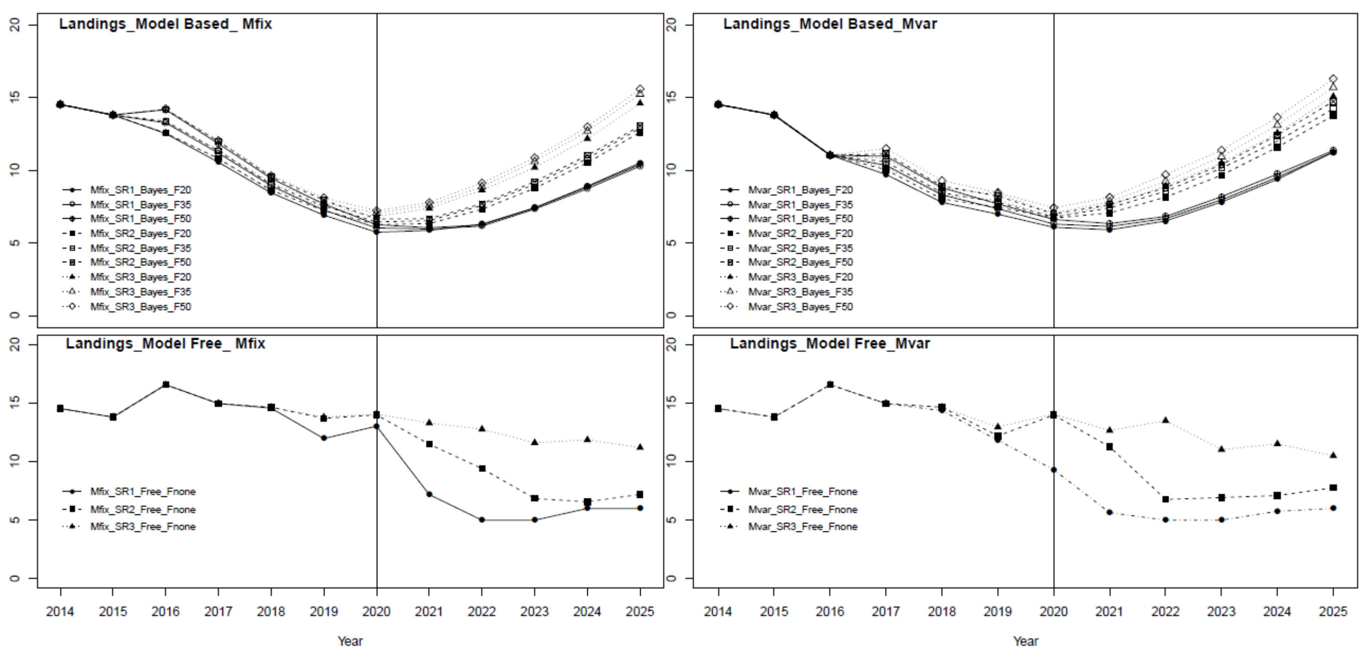

Figure 9.- Values of the median of Landings by Stock-Recruitment relationship for the different M scenarios.

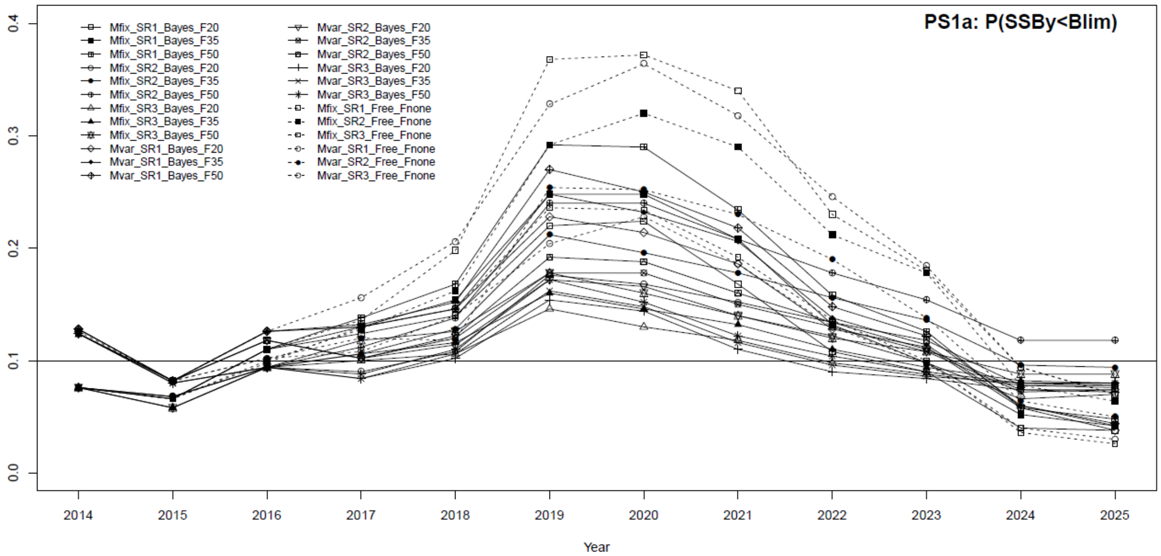

Figure 10.- Results of the PS1: P(SSB<B_{lim}) for all the tested scenarios. The horizontal line corresponds to a 10% of probability. PS1a: Probability year by year.

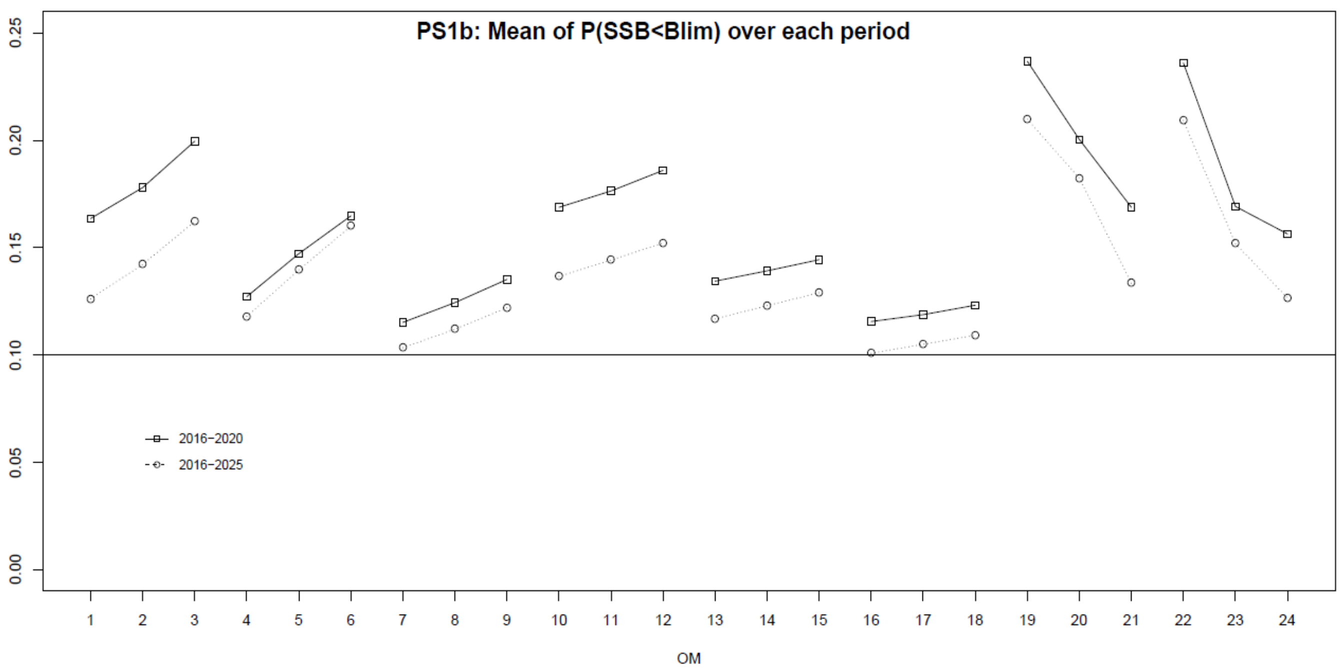

Figure 11.- Results of the PS1: P(SSB<B_{lim}) for all the tested scenarios. The horizontal line corresponds to a 10% of probability. PS1b: Mean probability over each period.

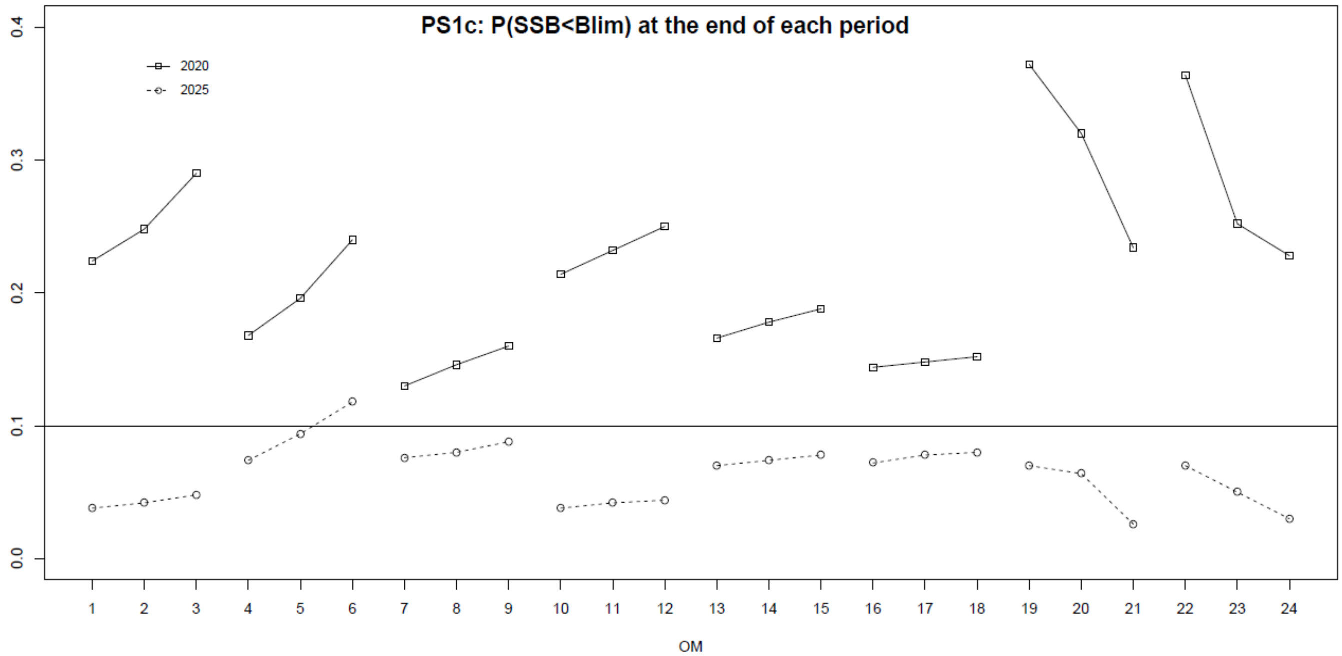

Figure 12.- Results of the PS1: P($SSB<B_{lim}$) for all the tested scenarios. The horizontal line corresponds to a 10% of probability. PS1c: Probability at the end of each period.

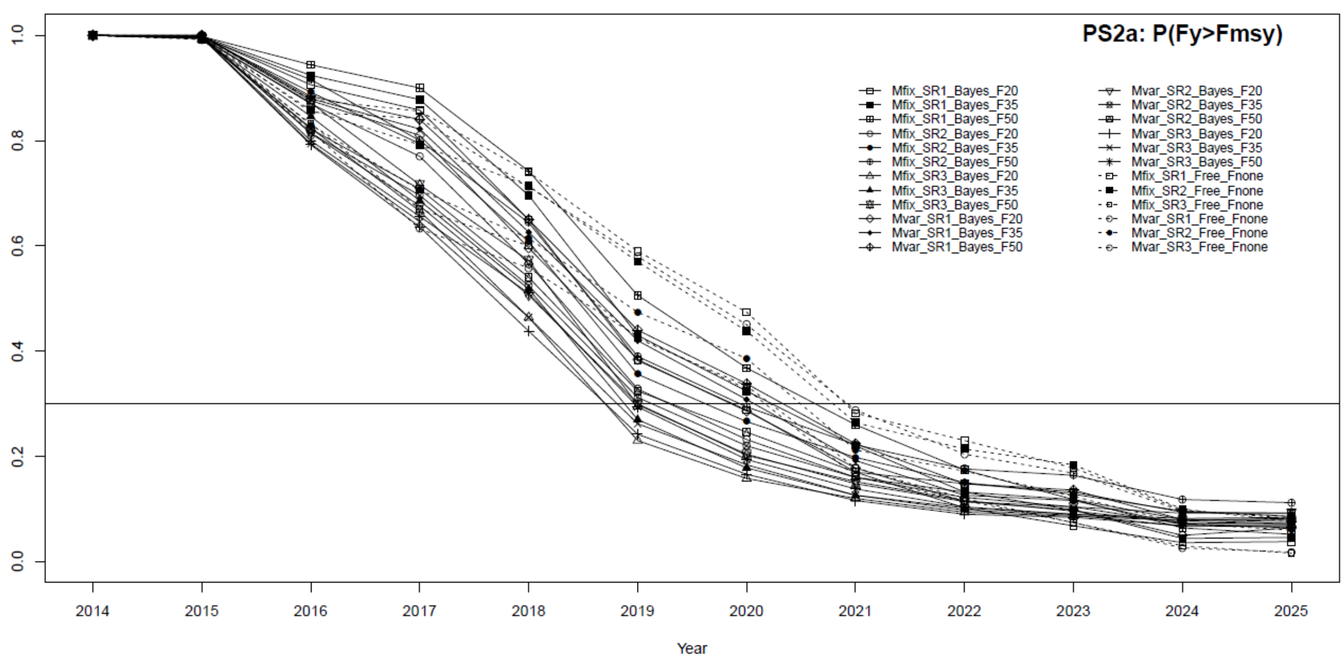

Figure 13.- Results of the PS2: P($F>F_{msy}$) for all the tested scenarios. The horizontal line corresponds to a 30% of probability. PS2a: Probability year by year.

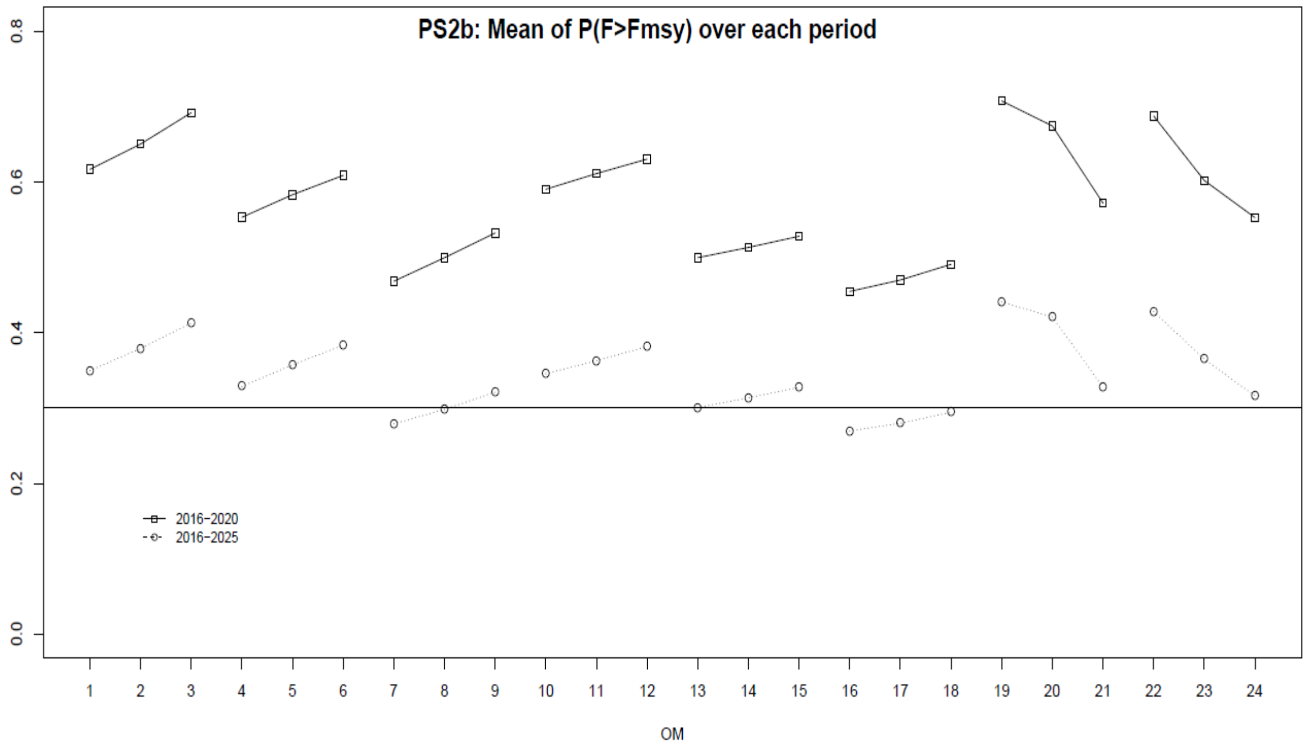

Figure 14.- Results of the PS2: P(F>F_{msy}) for all the tested scenarios. The horizontal line corresponds to a 30% of probability. PS2b: Mean probability over each period.

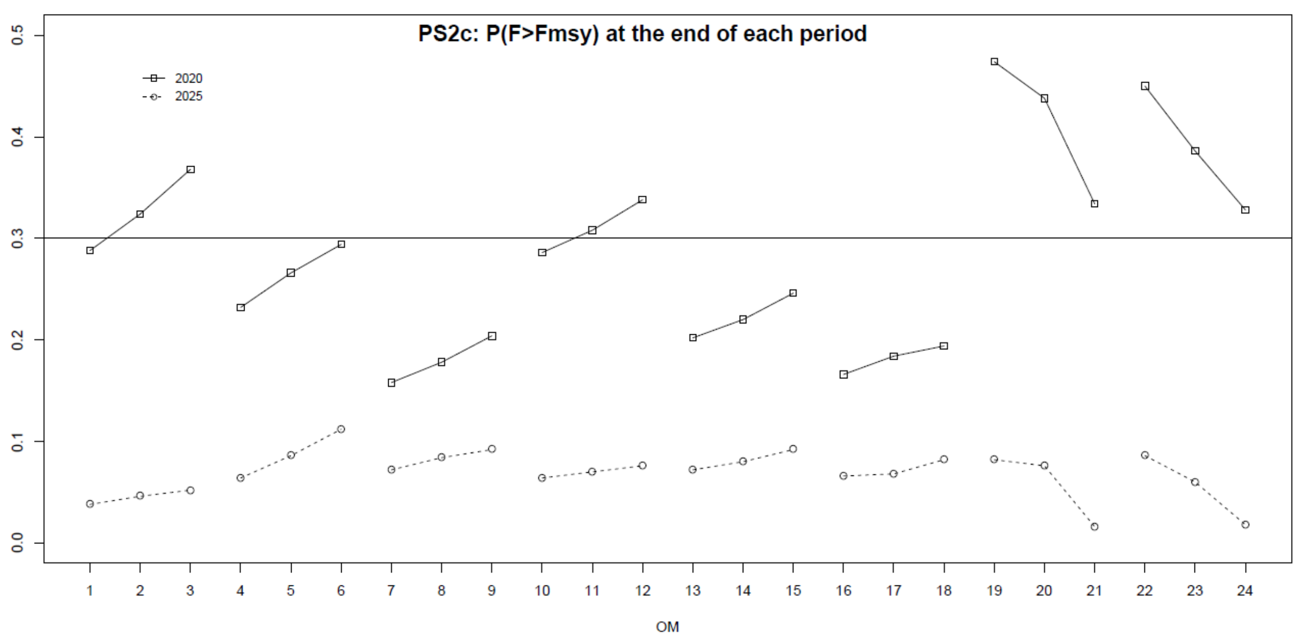

Figure 15.- Results of the PS2: P(F>F_{msy}) for all the tested scenarios. The horizontal line corresponds to a 30% of probability. PS2c: Probability at the end of each period.

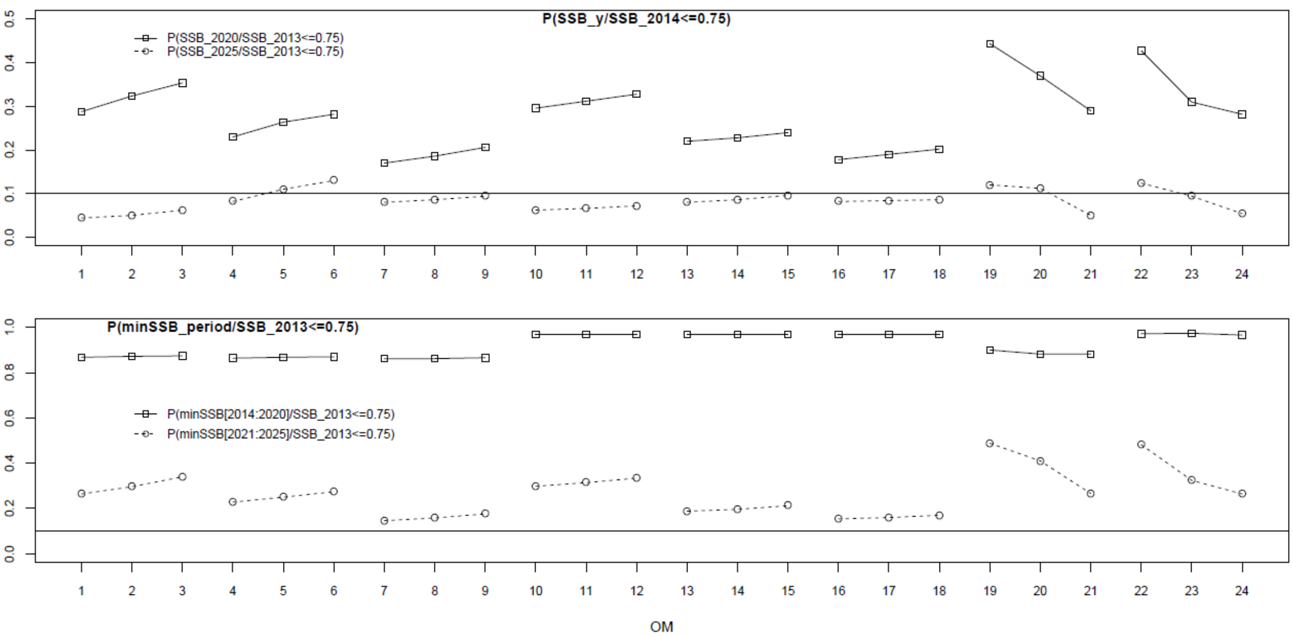

Figure 16.- Results of the PS3 for all the scenarios: $P(SSB_{2020}/SSB_{2013} \leq 0.75)$; $P(SSB_{2033}/SSB_{2013} \leq 0.75)$; $P(\min(SSB_{2014-2020})/SSB_{2013} \leq 0.75)$; $P(\min(SSB_{2021-2033})/SSB_{2013} \leq 0.75)$. The horizontal lines correspond to a 10% of probability.

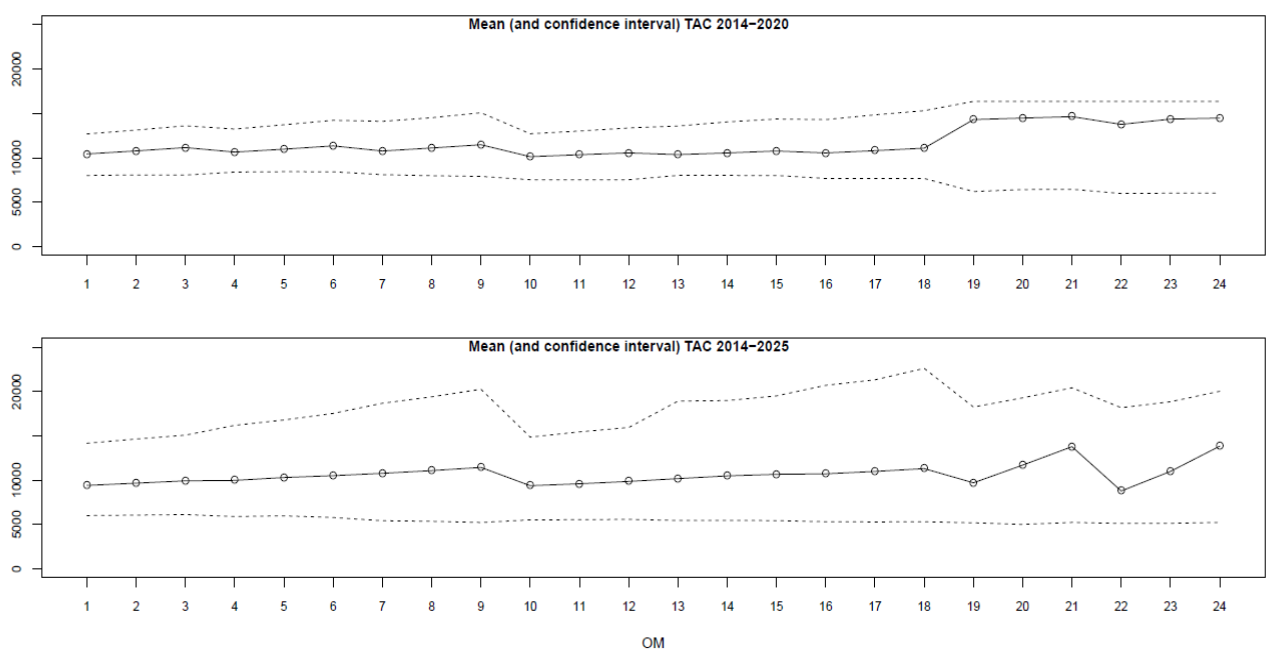

Figure 17.- Median (solid line) and 95% confidence interval (dot lines) of the mean of the TAC for all the cases in the 2014-2020 and 2014-2033 periods.

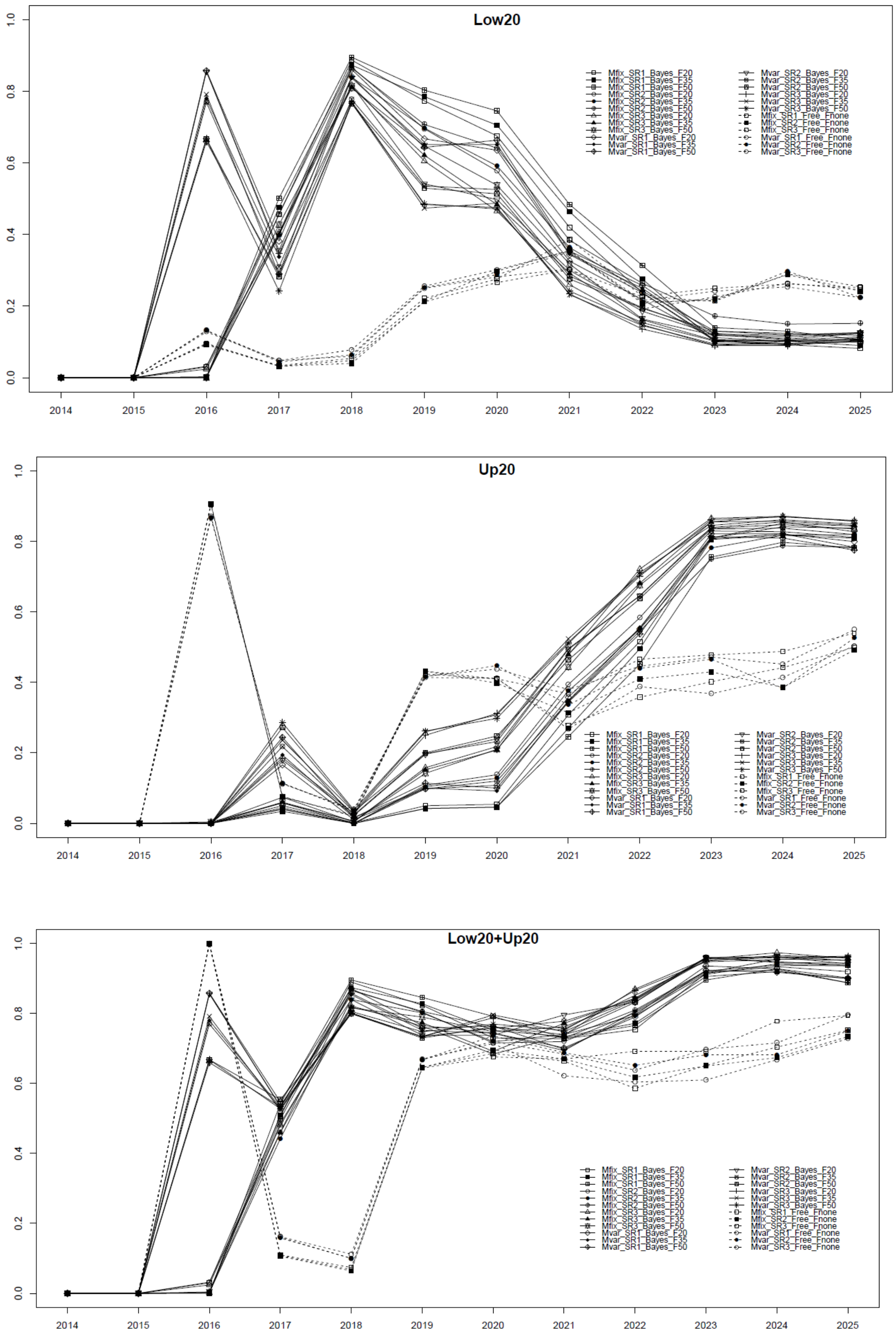

Figure 18.- Limited annual catch variation : number of times the constraint is applied (%).

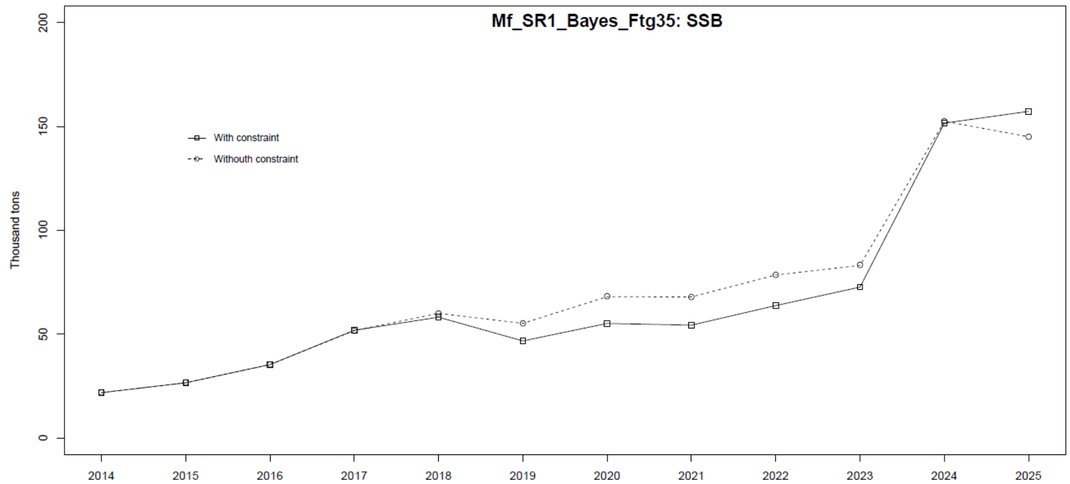

Figure 19.- SSB with and without constraint for scenario model based, SR1, M fix and $F_{35\%}$.

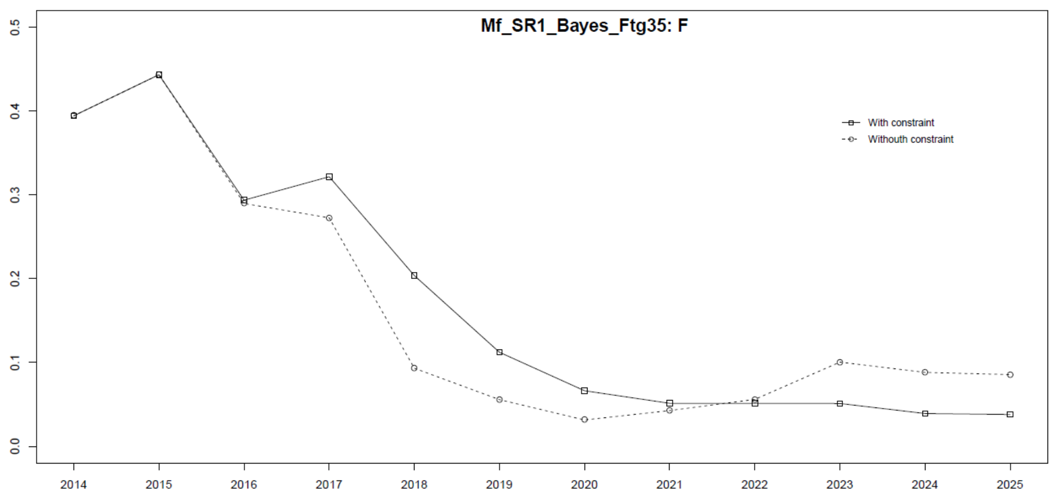

Figure 20.- F with and without constraint for scenario model based, SR1, M fix and $F_{35\%}$.

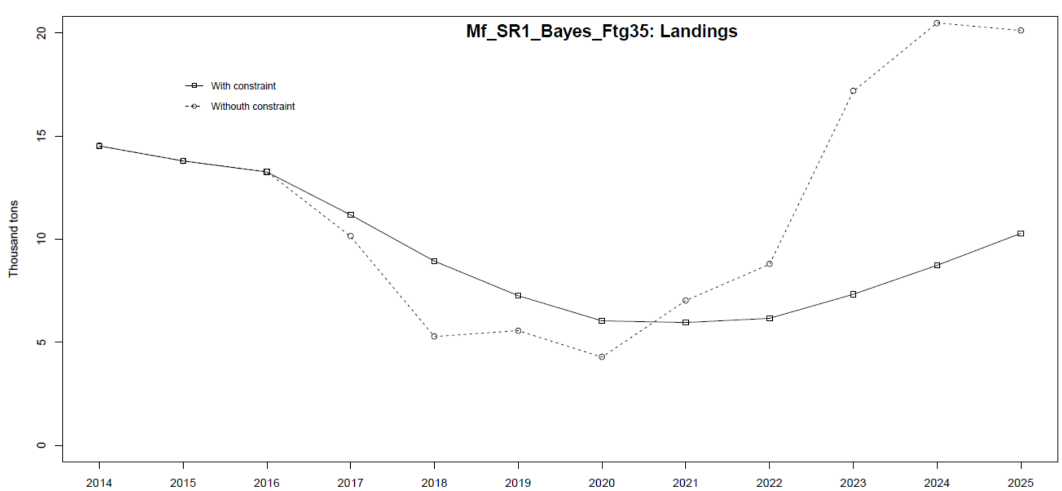

Figure 21.- Landings with and without constraint

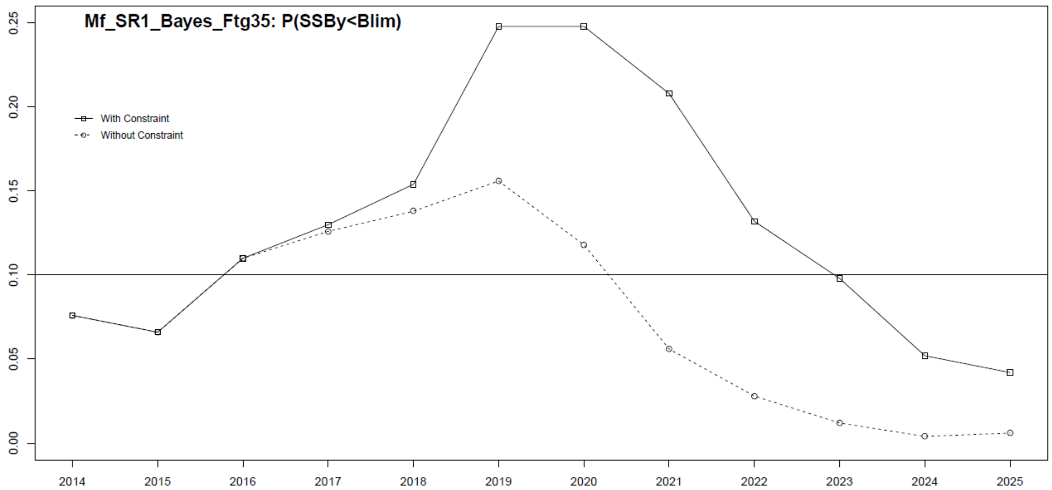

Figure 22.- PS1a with a without constraint for scenario model based, SR1, M fix and $F_{35\%}$.

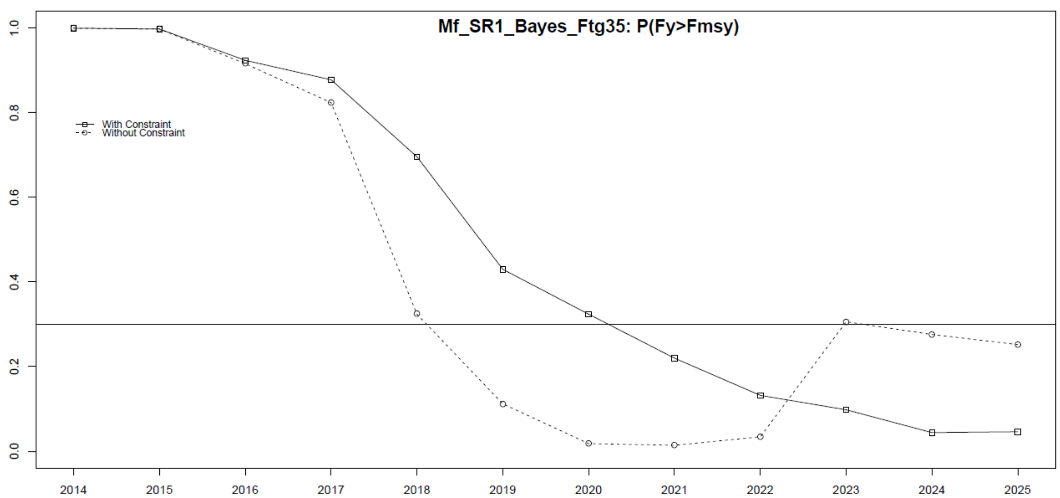

Figure 23.- PS2a with a without constraint for scenario model based, SR1, M fix and $F_{35\%}$.