Northwest Atlantic Fisheries Organization

Serial No. N6903 **NAFO SCR Doc. 19/001**

SCIENTIFIC COUNCIL MEETING – JANUARY 2019

Potential Operating Models, Harvest Control Rules and Performance Statistics for the NAFO 3M Cod MSE.

by

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

Instituto Español de Oceanografía, Vigo, Spain

Abstract

This document presents a proposal of possible Operating Models (OMs), Harvest Control Rules (HCR) and Performance Statistics (PS) to carry out the Management Strategies Evaluation (MSE) for the 3M cod of NAFO. This proposal will have to be reviewed by the NAFO SC to decide the first set of OMs to test with the possible HCRs in the 3M Cod MSE.

Introduction

The Management Strategies Evaluation (MSE) process to select a Management Procedure (MP) creates voluminous results in crossing candidate MPs with a large number of Operating Models (OMs). To reduce this volume and to aid focusing the MP selection process, the way forward set out in the new 3M Cod schedule approved by the August 2018 RBMS (NAFO, 2018a) meeting was to use candidates Harvest Control Rules (HCRs) to identify those OMs which have the greatest impact on performance (Reference set of OM to be approved by the NAFO Scientific Council (SC) in January 2019). Efficiency is then gained for the overall process by using this set of OMs only to explore the performance of the CMPs, and ultimately to report more detailed performance statists.

The SC discussed, in June 2018 (NAFO, 2018b), the general lines to develop the MSE of the Cod Div. 3M and agreed the following:

> The data used in the SC June 2018 Cod 3M assessments (over the time frame 1988-2017) will be used to conduct the MSE. If, during the MSE process, the age-length key from the Flemish Cap survey of 2017 becomes available, this should be included in the input data set.
>
> The base case reference OM will be the model assessment approved in the 2018 June SC meeting. The development of other operational models to be tested will take into account the following guidelines:

I. Possible OMs with alternate M priors and/or CVs
II. Possible OMs with different groups of qs if necessary.
III. Model scenarios with alternate assumptions on recruitment.
IV. Possible OMs considering auto-correlated, inter-correlated and/or density-dependent impacts on weights and maturities.

The period over which the simulations will be carried out will be 20 years. MSE performance statistics should reflect short, medium and long term objectives. The observation model to generate the future data should take into account the auto-correlation of the survey indices.

Reference points should be determined by each operating model independently and should be consistent with each other. The reference points should be Maximum Sustainable Yield (MSY) based if possible. If F30%SPR is used as a proxy for FMSY, a decision will be required on the appropriate data period to use in estimating F30%SPR (magnitude is sensitive to this given the significant changes in biological parameters for 3M cod).

Possible SC guidelines to develop HCRs. The SC recommends applying the same guidelines for the 3M cod expressed by WG-RBMS during the Greenland halibut MSE process. Consistent with these guidelines, a model free HCR should be considered. We should consider whether to use abundance or a biomass index in the rule.

The SC agreed that the base case reference OM is the model assessment approved in the 2018 June SC meeting. The Base Case SCAA model configuration is described by González-Troncoso *et al*. (2018). The aim of this document is to provide a list of candidate OMs, Harvest Control Rules (HCRs) and Performance Statistics/Criteria table taking into account the above guidelines approved by the SC and the main results of the 3M Cod Benchmark (NAFO, 2018c) carried out in April 2018.

Table 1 shows all the scenarios examined during the Benchmark and Figure 1 present the SSB results for the last year (2016) of all of these scenarios.

Initially, the following OMs are proposed for discussion in the SC.

Possible SCAA candidates OMs affecting the past (data conditioning)

I. Possible OMs with alternate M priors and/or CVs

Base Case: M is estimated by the model and the input is a prior with different M values for ages and constant in time. The prior values come from the M estimated in models that take into account the biological characteristics of the 3M Cod (Gonzalez-Costas and Gonzalez-Troncoso, 2018). The Base Case final M prior values by age and their variance were approved by the NAFO Scientific Council in June 2018 and they are the following medM[a]= c(1.26,0.65,0.44,0.35,0.30,0.27,0.24,0.24), cvM = 0.15

Possible OMs:
Mfix: M constant for years and ages M=0.19. This value of M come from the estimated M (constant by years and ages) estimated in the 2017 Bayesian XSA approved assessment (Gonzalez-Troncoso, 2017).

MGADGET: M variable by years and ages estimated in the GADGET model taking into account the predation. The natural mortality (M) estimated by GADGET by age and year (Table 2) was presented in the 2018 Benchmark (NAFO, 2018a).

MAnt: M variable by year and age estimated by the method proposed by Ávila de Melo and Alpoim (2018). Annex I present the formulation of this method to estimate M. Table 3 present the estimate M values by year (1988-2017) and age (1-8+).

MVec:. In this OM the M priors by age and their variance are different from the base case and equal to medM[a]= c(0.82, 0.57, 0.43, 0.37, 0.33, 0.31, 0.28, 0.28), cvM = 0.30. The reason to propose the different M priors is that in the Benchmark, the M vector was estimated as the mean of a group of biological methods (Figure 2). But in this OM, the M priors vector by age is estimated (Table 4) taking out the extreme values of the younger ages (Charnov, Gislason, Chen&Wata and the 2017 assessment) and doubling the Base Case cv.

OMs with alternate M priors and/or CVs to implement for January.

The Figure 3 and 3B presents the Base Case and the 4 OMs with alternate M priors and/or CVs results: Mfix (M=0.19), MGADGET (M matrix), MVec (M new vector) and MAnt (M steps). The technical team based on these results decided to implement the following OMs:

- Base case (M as in June 2018 assessment)
- M=0.19 fixed for ages and years (Mfix)
- M(y,a) from Gadget (MGADGET)
- M mix, fixed for a period and variable by year and ages by periods MAnt

It was decided not to implement the MVec OM because the results of it are very similar to those of the BC and do not bring anything new. It is thought that with the choice of OMs made the uncertainty of this parameter (M) is fairly well represented.

II. Possible OMs with different groups of qs.

Base Case: During the Benchmark, it was discussed what should be the best grouping for estimating qs. The final approved model (Base Case) estimates the survey qs by age groups for ages 1, 2, 3, 4+ but there were also reasons that supported other different groups. Two OMs are proposed with the alternative groupings of qs discussed during the benchmark.

Possible OMs:
OMGruq1: Survey qs age 1, 2, 3+. The reason to propose this OM is because the Base Case results shows that the q age 3 and q age 4+ are very similar and probably it would be better to estimate q3+.

OMGruq2: Based on the survey information available, our first attempt was to define these q groups by age: 1, 2, 3-6, 7-8+

OMs with different groups of qs to implement for January.

Figure 4 shows the estimated posterior q values for the Base Case and the possible OMs with different groups of qs results: OMGruq1 (q 3 groups) and OMGruq2 (q 4 groups) and Figure 5 presents the SSB, total biomass, recruitment and F results of these OMs. Base on the results, it seems clear that the OM with 3 groups of qs "OMGruq1" gives us the same results as the Base Case and it has been decided not to implement it as candidate OM. For the candidate OM with 4 groups of qs "OMGruq2" the decision based on the results it was not so clear. The results are slightly different from the Base Case but not much. It is proposed to decide if we develop this OM at the end of the development of all the other OMs agreed. If there is enough time, it can be developed.

III. Model scenarios with alternate assumptions on recruitment.

Base Case: The recruitment is independent of the SSB with a median medrec = 45000 and cvRec = 10

Possible OMs:
It seems complicated in the SCAA code to implement, for the past, the recruitment based on a stock recruitment relationship. In the base case, the results show not a clear R-SSB relationship (Figure 6) but it seems that when SSB is big the recruitment is quite low (Ricker). After some discussions, it was decided to condition the model only with the base case assumption. The implementation of a stock recruitment relationship will be investigated only in the projections.

IV. OM with different CVs for catches and survey information

Base Case: The coefficient of variation (CV) of the survey catchability at age can be estimated in the model. During the Benchmark there was a lot of discussion about whether CV values should be set or whether these values should be allowed to be estimated by the model. But when it is estimated, the estimated values are too large for a survey that covers the distribution of the resource rather well. So it was decided to set its value at 30% for all ages. The same problem was observed with the catch information by age (CaA), but in this case it was decided to set the CV of the CaA information at 20%.

Possible OMs:

OMCVfix: Some of the participants in the Benchmark felt that the CV of the survey should be lower than that of the CaA since it is expected that the survey information has better quality than the one of the commercial catches. So it was thought convenient to study the possibility of an OM with Survey CV 20% and CaA CV 30%.

OMCVEst: To see how sensitive the results are by letting the model estimate these CV, we studied the possibility of implementing an OM where the CV were estimated. In this case, the surveys CV qs were estimated by groups (1, 2, 3, 4+). In the catches a common CV for all ages was estimated.

OMs with different CVs for catches and survey information to implement for January.

Figure 7 presents the Base Case and the OMCVfix and the OMCVEst OMs results. Based on these results, it was decided not to keep the OMCVfix (OM with survey CV=20% and CV=30% for CAA) inasmuch as it gives similar results to Base Case. Moreover, as the base case has a larger survey CV (30%), if a HCR based on the survey index works under the Base Case it would very likely also work under this scenario.

Figure 8 shows the CVs estimated for the OMCVEst. The OMCVEst configuration estimates CVs of CAA (same prior and CV for all ages) and survey (CV groups for ages 1, 2, 3, 4+).

An OM of this type (estimated CV) has been deemed necessary because during the Benchmark this was a point with a big discussion and finally it was decided to fix the CV but after big discussions. Based on the results presented and to cover this uncertainty, it was decided to develop a new OM with the following configuration:

It was decided designed and implemented a new OM estimating the CVs but with different grouping of ages "CV 3 groups each": For EU indices the CV has 3 priors, for ages 1, 2, 3+ and for CaA the CV has 3 priors, for ages 2, 3-6, 7-8. These are the groups that have been considered more appropriate for catches and survey base on the catch information available. Figure 9 present the result of the Base Case, OMCVEst (in the plot variable) and the new one OM (in the plot CV 3 groups each). Figure 10 shows the prior and posterior of the CVs estimated in the new one OM (in the plot CV 3 groups each).

Possible SCAA candidates OMs affecting the projections

The discussion on OMs that affect the projections was made in a generic way. So the decisions made on the OMs for projections are presented together in the following paragraphs.

It is considered that the greatest sources of uncertainty for the projections are the variability the biological parameters and the recruitment observed in the past, as well as the correlation and/or density dependent impacts on these variables. Figure 11 shows the 1988-2016 values for the mean weights maturity and Figure 12 presents the normalized (by the mean and variance) mean weights and maturity at age and the Recruits per Spawner.

It is not clear yet what it will be the adopted as Base Case for the projection. We will have to see the results and see the plausibility of them to take the decision of the Base Case for the projections.

It was agreed to consider the following scenarios to simulate future biological parameters values: SW-at-age, CW-at-age, Mat-at-age, Natural Mortality (M), PR (partial recruitment, i.e. selection-at-age pattern of the fishery) and recruitment:

For recruitment, fit a segmented regression (SegReg) with breakpoint at Blim. In principle, Blim is considered to be OM iteration -specific (estimated by iteration). Gonzalez-Troncoso *et al.* (2019) propose different methods to estimate Blim by OM and iteration.

The fit of the SegReg is done iteration by iteration, i.e. if there are 1000 MCMC kept draws, we will have 1000 SegReg functions, one per iteration. For each iteration, the SegReg is fitted and corresponding residuals are as follows:

It is assumed that: log(Ry) = log(R0) + log(Zy) + Ey,

where

- Zy is a known covariate defined as Zy=min{1, SSB_{y-1}/Blim},
- R0 is the Rec value at the top of the SegReg (i.e. at the horizontal arm),
- Ey is a Normal(0, sigmaR^2) distribution.

Therefore, the Maximum Likelihood Extimation (MLE) of log(R0) is simply the mean of the observed values log(Ry/Zy) over the historic years.

The historic “residuals” are calculated as: resi_logRy = log(Ry/Zy) – MLE of log(R0)

To get an idea of the adjustment of the segmented regressions of the different OMs and iterations, Figure 13 presents the segmented regression fit performed with the medians, R / SSB of each OMs with the median of the Blim of all iterations fixed and the estimated value in the adjustment of the alpha parameter. This can give us an idea of the fit quality and the observed errors that would have iteration to iteration, which is how it has been fitted in reality.

In the projections, for each iteration separately, it will be:

- Use the fitted SegReg function
- Bootstrap historic years in various ways. For the bootstrapped historic year, take all biological parameters, M, the PR, and the recruitment residuals from that historic year. Note that it is the recruitment residuals, and not the actual historic recruitment, that gets bootstrapped.

The following ways to bootstrap historic years and that define the OMs of the projections were agreed:

ProjOM1: Bootstrap years are from the period 2012-2017. In principle, ProjOM1 does not include correlation between years. This OM reflects what would happen if the current situation is maintained throughout the period of the projections.

ProjOM2: As ProjOM1, but using the entire period for the Bootstrap (1989-2017). The year 1988 was eliminated because it has not a Stock/recruitment error. This OM would reflect what would happen if the conditions observed in the past are repeated in the future.

ProjOM3: As ProjOM2, but incorporating correlation between years, applying an idea similar to the random walk. The idea is to start making a Bootstrap of one of the observed years (1989-2017) for each iteration and for this year, take all the projection parameters (Catch and Stock mean weights at age, maturity at age, M, partial recruitment and recruitment residuals). The next year we could make a bootstrap with a time window of 5 years with the mean year of the period of the previously chosen year and so on. As example of the 5 years window the first year of the projection we make a bootstrap in one iteration and if the result is 2001, then we take all the projection parameters of this year and for this iteration. For the second year of the projection we make again a bootstrap in the period 1999-2003 and the result is 2003 then we take the parameter values of 2003 for the second year of the projection and for this iteration. The next year we make a bootstrap for the period 2001-2005 and the result is 2002, we take all the 2002 parameter values and so on. Here we take into account the correlation between parameters and the correlation between years.

ProjOM4: An OM using growth model incorporating density-dependence for the Cod 3M management plan simulations. In principle this growth model is valid to obtain the mean weights at age for the projections but it would be necessary to decide how are obtained the other parameters necessary for the projections: Maturity, PR, M. Initially this OM will only apply to the BC. The base to develop this possible Om will be the growth model proposed by Brunel T. (2019).

Possible Candidates HCR

Within the management strategy evaluation, the performance of a variety of candidate Management Procedures should be considered. The eventual selection amongst candidates will be based on the most robust results in terms of a set of agreed performance statistics.

The RBMS (NAFO 2018a) agreed that index-based rules were preferred, but the WG would consider model-based HCRs if required. Restrictions to maximum changes in the TAC in terms of percentages and absolute numbers should be considered either as part of the HCR or as part of a suite of performance statistics (there is an initial preference for the former because it provides a degree of certainty for the industry). These restrictions may differ depending on the direction of the change and/or status of the stock.

At this moment the TAC for 2018 and 2019 are approved, the first year in which the TAC should follow the HCR will be the TAC for 2020. It has been decided that initially all the HCRs developed for next January have as their starting point the level of TAC approved this year by the NAFO Commission which is 17500 tons. Other possible starting points to apply the HCRs should be discussed at the Scientific Council in January 2019.

It should be noted that the MSE will be done based on stock assessment data covering years up to 2017. So, the different projection OMs will already start to be applied from 2018 onwards.

After consulting the document "Model-free HCR literature review for NAFO Cod 3M" (Andres M. *et al.*, 2018), the following HCRs are proposed for discussion in the SC.

Model Free Trend HCR

The starting point is the Model Free Trend HCR approved for the Greenland halibut (NAFO, 2017b). This has the following formulation, considering *y* as the year of the assessment, *y + 1* would be the year for which the TAC is advised and *y-1* would be the year with available data to perform the assessment:

$$TAC_{y+1} = TAC_y \times \left(1 + \lambda \times slope\right)$$

And with the following values for its parameters: λ with Slope (+) =1 and λ with Slope (-) =2

In the Greenland halibut (GHL) case, the slope was calculated as the slope of the log index total biomass of different surveys over the last 5 years. And the final value was the average of the slopes of the different surveys.

In the case of cod 3M we only have one survey available (EU Flemish Cap), so it can only calculate one slope. In the previous 3M Cod MSE (Gonzalez-Costas et al., 2014) it was decided that the slope was calculated with log total biomass indices for the last 4 years. The main reason for choosing 4 years is the age composition of this cod stock. Most of the abundance and biomass in the whole survey series is concentrated in ages 4-7, although in the last years, abundance and biomass 8+ is increasing. Table 5 presents the survey abundance at age. We think that these decisions are still recommended to estimate the slope in the case of 3M cod.

The λ parameter in this HCR indicates the amount of variation of biomass (measured by the slope) that can be added or subtracted from the TACy of the current year to estimate the new TACy+1 for the following year. In the previous model-free HCRs used in NAFO, the value of this parameter was established independently of the dynamics and biology of the stocks. What is proposed in this paper is to relate the value of λ to the recruitment of a recent period that can give us information on the level of abundance that will be available in the year that is going to catch the TACy+1. The suggestion is that λ vary according to the survey recruitment observed in a recent period. We propose to use the arithmetic mean of the three most recent years of the absolute value of recruitment abundance in the survey (age 1) and compare it with the mean survey absolute recruitment abundance (age 1) observed in the entire survey series (1988-2017). But due to the big variation in this stock of the recruitment, it could be studied the use of the geometric mean in the future.

((Ry-1+Ry-2+ R y-3)/3)/(Mean R(1988-2017)) = Recruitment Ratio (RR)

The chosen average recruitment 3 years period is because this level give us an idea of the relative level of abundance that could be obtained in y+1 of ages 3-5 which are important ages in the catch composition in the historical series.

As a starting point to test this HCR in different OMs (one of the tasks for January), and until more calibration studies of this parameter are done, a first way of estimating λ could be the following. When the slope of the log total biomass survey index is positive and if RR is more than 1 the value of λ is 1. In the case of positive slope but RR less than 1, value of λ would be equal to RRvalue. In the case that the slope is negative, if the RR is greater than 1, the value of λ would be 1 and for RR less than 1 λ it would be equal to 2- RR. Table 6 shows the proposal for the starting λ values.

It has been decided to establish a minimum TAC of 1000 tons in the HCR. When the previous formulation gives us values lower than 1000, the TAC will be 1000 Tons.

Model Free Target HCR

As in the Model Free Trend HCR, the starting point is the Model Free Target HCR used for the GHL. That has the following formulation:

$$TAC_{y+1} = TAC_y * \left[1 + \gamma\left(J_y - 1\right)\right]$$

$$TAC_{y+1} = TAC_y + TAC_y * \gamma * J_y - TAC_y * \gamma$$

$$J_y = \frac{\left(J_{y-3} + J_{y-2} + J_{y-1}\right)}{3} \Big/ J_{target}$$

$$J_{target} = \alpha \frac{1}{10} \sum_{2008}^{2017} J_y$$

where *J(y)* is a ratio as follows: the numerator of *J(y)* is the average of the total survey biomass indices over the 3 most recent years and the denominator of *J(y)* is equal to alpha times a "target survey biomass", defined as the average of the total survey biomass indices over some pre-specified historical period. In this HCR the TACs increase or decrease depending on where the recent survey biomass is relative to the "alpha * target survey biomass" specified in the HCR.

It was decided as first step define the *Jtarget* period to estimate the target value would be from 2008 to 2017. In the 3M Cod case and based on the historical series of the total biomass index of the FC survey (Figure 14), this is the most recent period where biomass has been above Blim and with a fairly constant level of exploitation, although very low exploitation according to the benchmark-agreed stock assessment. As starting point, the α value to estimate *Jtarget* will be 1 and γ value similar to the λ parameter described in the Model Free Trend HCR. This γ parameter will be related with the arithmetic mean of the three most recent years of the absolute value of recruitment abundance in the survey (age 1) and compare it with the mean survey absolute recruitment abundance (age 1) observed in the entire survey series (1988-2017).

Recruitment Ratio (RR)=((Ry-1+Ry-2+ R y-3)/3)/(Mean R(1988-2017))

Table 7 presents the proposal staring values for these parameters of the Model Free Target HCR.

As in the Model Free Trend HCR, in the Model Free Target HCR case has been decided to establish a minimum TAC of 1000 tons in the HCR. When the previous formulation gives us values lower than 1000, the TAC will be 1000 Tons.

Short Cut Target HCR

This HCR is similar to the HCR used to manage the Icelandic Cod (ICES, 2010). The Icelandic Cod HCR is based in a trigger Biomass and has the following formulation:

$$TAC_{y+1} = \frac{min\left(\frac{SSBy}{MGT\ B_{trigger}}, 1\right) * 0.2 * B_{4+,Y} + TAC_y}{2}$$

Where $B_{4+,Y}$ is the biomass of cod Aged 4 and older in year *y* and MGT $B_{trigger}$ =220000 tonnes.

It was decided to try to develop a Short Cut HCR similar to the approved for Iceland Cod since it is the only one we have seen which essentially aims at a constant level of exploitation (with a proviso to reduce the exploitation level if the survey biomass falls below some pre-stablished threshold). As a target for January we will implement the other two model free HCRs but with the idea of later developing an HCR similar to the Icelandic one.

There was much discussion about whether the short cut method is capable of replicating the assessment errors and how to estimate them. It seems quite problematic and difficult to make such a replica for the future. In the beginning it could try to develop a similar HCR but instead of working with the assessment estimated biomasses it could try to work with the surveys indexes. Like that the HCR becomes a model free HCR. In order to apply this HCR with indices, it would be needed to define a value of the survey indices that are related to the Btrigger. Probably, it could be better to refer this value to a period of the past rather than to use an absolute value.

About the level of exploitation to test, it seems that 0.2 is a reasonable value to start with. It would also be necessary to decide about which biomass to apply that level of exploitation.

Model Base HCR

Taking into account that one of the general lines of the WG RBMS to develop HCRs is that they prefer the model free, looking at the tasks that must be presented for the January 2019 SC meeting and the tight 3M Cod MSE schedule, it would probably be more appropriate to consider the possibility of implementing or not this type of HCR at the SC January 2019 meeting.

Table 8 presents the list of possible scenarios resulting from the combination of the OMs and the HCRs described above. The Table also shows the prevision of when the results could be available to be examined by the SC. To test all these scenarios, it will try to, for each OM and iteration separately; all things that are "random stochastic variation" have the same values for all HCRs tested. This would most likely facilitate the evaluation of the different HCRs.

Proposals for full set of Management Objectives (MO)/Performances Statistics (PS)/Risks

Performance Statistics and Criteria agreed as required/desirable during the development of the Greenland halibut MSE in 2017 (NAFO, 2017a) 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.

For the 3M Cod, the required performance statistic, performance criterion and relevant management objectives were provisionally adapted by the NAFO RBMS (NAFO, 2018a) and are presented in Table 9. 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.

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 for the team in charge of the development of the 3M Cod MSE was to develop Proposals for full set of MO/PS/Risks. Some of the proposed Performance Statistics are related to the 3M Reference Points. Gonzalez-Troncoso, D. *et al.* (2019) presents different options on how to estimate the reference points for the

MSE of 3M Cod. The following sections presents the proposal for the MO/PS/Risks Table based on the RBMS 2018 agreements:

REQUIRED PERFORMANCE STATISTICS/CRITERIA

Performance statistic	Performance criterion	Relevant management objective
$P(B_{2037}<B_{MSY})$	$P \leq 0.5$	*Restore to within a prescribed period of time or maintain at $BMSY$* Long term

As was done in the GHL, this objective has been set to be achieved in the long term (2037), at the end of the term of the projections.

Performance statistic	Performance criterion	Relevant management objective
for y = 2023 to 2027; $count_y[P(F_y>F_{MSY})>0.3]$ for y = 2027 to 2037; $count_y[P(F_y>F_{MSY})>0.3]$	Count Count	Low risk of exceeding F*lim* (currently $FMSY$)

This objective has been set as required PS to be achieved in the medium and long term. In the proposal appears to measure every year but other ways to measure this PS is in the period ($count[\ P(Fy>FMSY)>0.3]$) or only for the final year of the different periods to give some flexibility to catch some years about Flim. El Performance Criterion more than count could be measure as a % of the total iterations.

Performance statistic	Performance criterion	Relevant management objective
$P(By<B_{lim})$	$P \leq 0.1$	Very low risk of going below an established threshold [e.g. *Blim* or *Blim* proxy].

It was decided to establish a Blim by OM and iteration.

DESIRABLE SECONDARY PERFORMANCE STATISTICS/CRITERIA

Performance statistic	Performance criterion	Relevant management objective
$P(B_{2027}<B_{MSY})$	$P \leq 0.5$	*Restore or maintain the Biomass in the medium term at $BMSY$*

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

Performance statistic	Performance criterion	Relevant management objective
for y = 2018 to 2022; $count_y[P(F_y>F_{MSY})>0.3]$	Count	Low risk of exceeding F*lim* short term (currently $FMSY$)

The idea is to put this PS as Desirable in the short-term and required in the medium long term. It would be necessary to decide how to measure this PS: by year, for the period or in the final year. Probably it is needed some plasticity in this PS due to the low recruitments observed in the last years and that the resulting TACs in the short term depend a lot on the starting point and the variability of the TAC between years that will be decided, so it is still better to measure this in the final year to give the resource a time to adapt to these variables.

Performance statistic	Performance criterion	Relevant management objective
$\sum_{y=2018}^{2022} C_y / 5$ $\sum_{y=2018}^{2027} C_y / 10$ $\sum_{y=2018}^{2037} C_y / 20$		Maximize yield in the short, medium and long term

No Comments on this point.

Performance statistic	Performance criterion	Relevant management objective
For each year (2018-2037) $Count_y\left(\frac{\lvert TAC_y - TAC_{y-1}\rvert}{TAC_{y-1}}\right) > 0.10$ $Count_y\left(\frac{\lvert TAC_y - TAC_{y-1}\rvert}{TAC_{y-1}}\right) > 0.15$ $Count_y\left(\frac{\lvert TAC_y - TAC_{y-1}\rvert}{TAC_{y-1}}\right) > 0.20$	Count Count Count	Keep inter annual TAC variation below “an established threshold”
$Average_{2018-2037} = \frac{1}{20}\sum_{y=2018}^{2037}\left(\frac{\lvert TAC_y - TAC_{y-1}\rvert}{TAC_{y-1}}\right)$		Minimize annual TAC variation in the long term

The idea is to measure in first step different variations of the TAC to later evaluate what could be a limit of reasonable variation to insert in the HCR. The RBMS (NAFO 2018a) agreed that restrictions to maximum changes in the TAC in terms of percentages and absolute numbers should be considered either as part of the HCR or as part of a suite of performance statistics (there is an initial preference for the former because it provides a degree of certainty for the industry).

If at the end a limit variation between TACs will be establish in the HCR, a PS that measures the average of variations between annual TACs for the entire period could be established.

Table 10 present the proposals for full set of Management Objectives (MO) and Performances Statistics (PS) for the 3M Cod MSE to be discussed in the 2019 January SC meeting.

Acknowledges

This research was partially funded by the European Union founds under the Framework Contract No EASME/EMFF/2016/008 - "provision of scientific advice for fisheries beyond EU waters”- Specific Contract No 03 (SI2.753135) “Support to a robust model assessment, benchmark and development of a Management Strategy Evaluation for cod in NAFO Division 3M”.

REFERENCES

Andrés M., Dorleta Garcia, Agurtzane Urtizberea, 2018. Model-free HCR: literature review for NAFO Cod 3M. Serial No. N6779 NAFO SCR Doc. 18-002.

Ávila de Melo, A. and R. Alpoim. 2018. On 3M cod natural mortality: a proposal for a separable approach over recent years (2005-2017). Serial No. N6847 NAFO SCR Doc. 18/051.

Brunel, T. 2019. Investigation of a growth model incorporating density-dependence for the Cod 3M management plan simulations. NAFO SCR Doc. 19/003

González-Costas, F., D. González-Troncoso, D. Miller, A. Urtizberea, A. Iriondo and D. García, 2014. Developing of a 3M cod MSE. NAFO SCR Doc. 14-044, Serial No. N6341.

Gonzalez-Costas F. and D. Gonzalez-Troncoso. 2018. Cod 3M Natural Mortality. Serial No. N6780 NAFO SCR Doc. 18-003.

González-Troncoso D., Carmen Fernández and Fernando González-Costas. 2018. Bayesian SCAA model for the 3M cod. Serial No. N6816 NAFO SCR Doc. 18/030.

González-Troncoso D., 2017. Assessment of the Cod Stock in NAFO Division 3M. Serial No. N6693 NAFO SCR Doc. 17/38.

González-Troncoso, D., González-Costas, F. and Fernández, C. 2019. Estimation of the reference points for the different OMs in the Cod 3M MSE. NAFO SCR Doc. 19/004.

ICES, 2010. Report of the Ad hoc Group on Iceland Cod HCR Evaluation (AGI-COD), 24-26 November 2009 ICES, Copenhagen, Denmark ICES CM 2009\ACOM:56.89 pp.

NAFO, 2017a. Report of the NAFO Joint Fisheries Commission-Scientific Council Working Group on Risk-Based Management Strategies (WG-RBMS) 25-27 April 2017 Falmouth, MA, USA. Serial No. N6705 NAFO/FC-SC Doc. 17-03.

NAFO, 2017b. Report of the NAFO Joint Commission-Scientific Council Working Group on Risk-Based Management Strategies (WG-RBMS) Meeting 15-17 September 2017 Montreal, Quebec, Canada. Serial No. N6768 NAFO/COM-SC Doc. 17-11.

NAFO,2018a. Report of the NAFO Joint Commission-Scientific Council Working Group on Risk-Based Management Strategies (WG-RBMS) Meeting13-15 August 2018 London, United Kingdom. Serial No. N6852 NAFO/COM-SC Doc. 18-02.

NAFO, 2018b. Report of the Scientific Council Meeting 01 -14 June 2018 Halifax, Nova Scotia. Serial No. N6849 NAFO SCS Doc. 18-19.

NAFO, 2018c. NAFO Scientific Council Flemish Cap (NAFO Div. 3M) Cod Stock Benchmark Assessment Meeting. Instituto Português do Mar e da Atmosfera (IPMA) 09–13 April 2018, Lisbon, Portugal. Serial No. N6841 NAFO SCS Doc. 18/18.

Table 1. Scenarios examined during the NAFO 3M Cod benchmark. In red appear the changes introduced in the estimation of the different parameters between one scenario and the next

Run	Base	S1.Ccond	qs	cv(caa)	cv(EU)	cv(rC)	S1.C	Gamma	cvs*	M	Y/Y-1	Ceros	medR	cvR	cvNyear1	DIC	Penalty
1	1	4	All different	All different	All different	All different	4	1,2	1	0.19	Y-1	Incl	15000	2	1	1376	94.3
2	1	0.75	All different	All different	All different	All different	4	1,2	1	0.19	Y-1	Incl	15000	2	1	1128	329.5
3	2	0.75	1,2,3-6,7-8	All different	All different	All different	4	1,2	2	0.19	Y-1	Incl	15000	2	2	1010	206.5
4	2	0.75	1, 2-8	All different	All different	All different	4	1,2	1	0.19	Y-1	Incl	15000	2	1	1085	284.6
5	3	0.75	1,2,3-6,7-8	1-8	1-8	All different	4	1,2	2	0.19	Y-1	Incl	15000	2	2	1580	138.8
6	3	0.75	1,2,3-6,7-8	1-8	1-8	1-8	4	1,2	2	0.19	Y-1	Incl	15000	2	2	1646	98.9
7	3	0.75	1,2,3-6,7-8	1-2,3-6,7-8	All different	All different	4	1,2	2	0.19	Y-1	Incl	15000	2	2	1029	235.5
8	3	0.75	1,2,3-6,7-8	All different	All different	All different	100	1,2	2	0.19	Y-1	Incl	15000	2	2	511	222.7
9	2	0.75	1,2,3-8	All different	All different	All different	4	1,2	2	0.19	Y-1	Incl	15000	2	2	1000	221.1
10	9	0.75	1,2,3-8	All different	All different	All different	4	1	2	0.19	Y-1	Incl	15000	2	2	1092	269.4
11	10	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	2	0.19	Y-1	Incl	15000	2	2	1037	189.7
12	11	0.75	1,2,3-8	1-2,3-6,7-8	All different	1,2-8 (-5)	4	1	2	0.19	Y-1	Incl	15000	2	2	1154	182.6
13	12	0.75	1,2,3-8	1-2,3-6,7-8	1,2,3-8	1,2-8 (-5)	4	1	2	0.19	Y-1	Incl	15000	2	2	1191	183.5
14	12	0.75	1,2,3-8	1-2,3-6,7-8	1,2-8	1,2-8 (-5)	4	1	2	0.19	Y-1	Incl	15000	2	2	1217	168.8
15	14	0.75	1,2,3-8	1-2,3-6,7-8	1,2-8	1,2-8 (-5)	4	1	4	0.19	Y-1	Incl	15000	4	4	1350	292.4
16	14	0.75	1,2,3-8	1-2,3-6,7-8	1,2-8	1,2-8 (-5)	4	1	16	0.19	Y-1	Incl	15000	16	16	1298	259.4
17	11	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	2	0.19	Y	Incl	15000	2	2	1119	233.7
18	11	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	4	0.19	Y-1	Incl	15000	4	4	1085	229.3
19	18	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	4	0.19	Y	Incl	15000	4	2	1135	276.3
20	15	0.75	1,2,3-8	1-2,3-6,7-8	1,2-8	1,2-8 (-5)	4	1	4	0.19	Y	Incl	15000	4	4	1272	246.0
21	19**	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	4	0.19	Y	Incl	15000	4	4	1449	176.0
22	19	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	4	Vector	Y	Incl	15000	4	4	1108	269.8
23	19	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	4	Matrix	Y	Incl	15000	4	4	1052	194.4
24	19	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	2,2	0.19	Y	Incl	15000	4	2	1131	250.7
25	19	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	2,2	0.19	Y	Incl	15000	4	4	1072	204.8
26	19	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	4,2	0.19	Y	Incl	15000	4	4	1157	276.5
27	19	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	4,4	0.19	Y	Incl	15000	4	4	1913	896.1
28	19	NA	1,2,3-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	1 prior	Y	Incl	15000	4	4	10501	170.1
29	28	NA	1,2,3-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	0.19	Y	Incl	15000	4	4	10481	125.8
30	19	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	4	1 prior	Y	Incl	15000	4	4	994	219.3
31	19	0.75	1,2,3-8	All different	All different	1,2-8 (-5)	4	1	4	8 priors	Y	Incl	15000	4	4	1022	229.3
32	28	NA	1,2,3-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	1 prior	Y	NA	15000	4	4	1612	127.0
33	32	NA	1,2,3-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors	Y	NA	15000	4	4	1639	148.8
34	28	NA	1,2,3-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors	Y	Incl	15000	4	4	9736	130.1
35	34	NA	1,2,3-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors, medM	Y	Incl	15000	4	4	9693	128.4
36	34	NA	1,2,3-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors, cvM	Y	Incl	15000	4	4	9693	161.8
37	33	NA	1,2,3,4-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors, cvM=0.15	Y	NA	15000	4	4	1596	121.7
38	37	NA	1,2,3,4-8	Fix (30%)	Fix (20%)	Fix (30%)	NA	1	4	8 priors, cvM=0.15	Y	NA	15000	4	4	2142	142.2
39	37	NA	1,2,3,4-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors, cvM=0.15	Y	NA	45000	4	4	1656	158.3
40	37	NA	1,2,3,4-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors, cvM=0.15	Y	NA	15000	10	4	1524	100.3
41	40	NA	1,2,3,4-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors, cvM=0.15	Y	NA	45000	10	4	1581	128.6
42	37	NA	1,2,3,4-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors, cvM=0.15	Y	NA	45000	10	10	1596	121.7
43*	42	NA	1,2,3,4-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	8 priors, cvM=0.15	Y	NA	45000	10	10	1596	121.7
44	37	NA	1,2,3,4-8	Fix (20%)	Fix (30%)	Fix (20%)	NA	1	4	0.19	Y	NA	15000	4	4	1596	121.7

Table 2. Total M (Mresid + Mpred) estimated with the model GadCap once Mresid is fixed as 0.35 for all ages and years.

age	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
1	0.766	1.125	0.91	0.455	0.479	0.406	0.41	0.471	0.392	0.373
2	0.397	0.842	0.656	0.41	0.374	0.389	0.395	0.419	0.385	0.362
3	0.358	0.388	0.581	0.367	0.355	0.355	0.36	0.357	0.362	0.358
4	0.352	0.356	0.368	0.361	0.352	0.351	0.351	0.351	0.351	0.353
5	0.35	0.351	0.353	0.351	0.351	0.35	0.35	0.35	0.35	0.35
6	0.35	0.35	0.351	0.35	0.35	0.35	0.35	0.35	0.35	0.35
7	NA	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
8	0.35	NA	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
9	0.35	0.35	NA	0.35	0.35	0.35	0.35	0.35	0.35	0.35
10	0.35	0.35	NA	NA	0.35	0.35	0.35	0.35	0.35	0.35
11	0.35	0.35	0.35	NA	NA	0.35	0.35	0.35	0.35	0.35
12	0.35	0.35	0.35	0.35	0.35	NA	0.35	0.35	0.35	0.35
age	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	0.362	0.367	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
2	0.359	0.363	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
3	0.351	0.353	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
4	0.351	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
5	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
6	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
7	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
8	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
9	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
10	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
11	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
12	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
age	2008	2009	2010	2011	2012	2013	2014	2015	2016	
1	0.35	0.35	0.876	0.822	0.581	0.592	1.441	1.425	0.809	
2	0.35	0.35	0.692	0.683	0.622	0.656	0.693	0.894	0.789	
3	0.35	0.35	0.412	0.457	0.506	0.497	0.517	0.48	0.527	
4	0.35	0.35	0.365	0.37	0.392	0.403	0.384	0.415	0.392	
5	0.35	0.35	0.352	0.354	0.356	0.363	0.361	0.364	0.373	
6	0.35	0.35	0.35	0.351	0.352	0.353	0.353	0.356	0.356	
7	0.35	0.35	0.35	0.35	0.35	0.351	0.351	0.352	0.352	
8	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
9	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
10	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
11	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	
12	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	

Table 3. Natural mortality by age and year estimated by the method proposed by by Ávila de Melo and Alpoim (2018).

Year/Age	1	2	3	4	5	6	7	8+
1988	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1989	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1990	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1991	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1992	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1993	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1994	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1995	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1996	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1997	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1998	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
1999	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
2000	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
2001	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
2002	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
2003	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
2004	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
2005	0.642	0.642	0.642	0.642	0.642	0.642	0.642	0.642
2006	1.764	1.781	0.543	0.339	0.217	0.194	0.196	0.208
2007	1.764	1.781	0.543	0.339	0.217	0.194	0.196	0.208
2008	0.767	0.362	0.188	0.150	0.149	0.141	0.121	0.148
2009	0.767	0.362	0.188	0.150	0.149	0.141	0.121	0.148
2010	0.797	0.362	0.352	0.286	0.189	0.182	0.187	0.162
2011	0.797	0.362	0.352	0.286	0.189	0.182	0.187	0.162
2012	1.823	1.194	2.126	1.067	0.613	0.633	0.635	0.540
2013	1.823	1.194	2.126	1.067	0.613	0.633	0.635	0.540
2014	0.895	0.422	0.440	0.302	0.153	0.159	0.170	0.185
2015	0.895	0.422	0.440	0.302	0.153	0.159	0.170	0.185
2016	0.813	0.350	0.522	0.192	0.185	0.180	0.169	0.219
2017	0.813	0.350	0.522	0.192	0.185	0.180	0.169	0.219

Table 4. Natural mortality priors by age (Mean priors MVec) used in the MVec OM and the different biological methods used to estimate this priors.

Method	A1	A2	A3	A4	A5	A6	A7
M (Gadget) (mean (1988-2016))	0.57	0.48	0.39	0.36	0.35	0.35	0.35
M(Peterson and Wroblewski)	0.7	0.48	0.37	0.32	0.29	0.26	0.23
M(Lorenzen General)	0.94	0.61	0.45	0.38	0.33	0.29	0.26
M(Lorenzen Fish)	1.08	0.69	0.5	0.42	0.36	0.32	0.27
Mean priors MVec	0.82	0.57	0.43	0.37	0.33	0.31	0.28

Table 5. EU Flemish Cap bottom trawl survey abundance at age and total (thousands) and total biomass (tons).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total Abundance	Total Biomass
1988	4868	79905	49496	13448	1457	211	225	72	0	0	0	0	0	0	0	0	149683	40839
1989	19604	10800	91303	54613	20424	1336	143	126	6	7	0	0	0	0	0	0	198363	114050
1990	2303	12348	5121	16952	15834	4492	340	146	77	25	0	0	0	0	0	0	57637	59362
1991	129032	26220	16903	2125	6757	1731	299	68	32	4	10	0	0	0	0	0	183181	40248
1992	71533	41923	5578	2385	385	1398	244	14	0	0	8	0	0	0	0	0	123468	26719
1993	4075	138357	31096	1099	1317	173	489	87	0	0	0	0	0	0	0	0	176693	60963
1994	3017	4130	27756	5097	130	67	7	111	0	5	0	0	0	0	0	0	40319	26463
1995	1425	11901	1338	3892	928	33	23	0	21	5	0	0	0	0	0	0	19567	9695
1996	36	3121	6659	892	2407	192	8	5	0	0	0	0	0	0	0	0	13320	9013
1997	37	150	3478	4803	391	952	21	0	0	0	0	4	0	0	0	0	9837	9966
1998	23	83	95	1256	1572	78	146	0	6	0	0	0	0	0	0	0	3259	4986
1999	5	84	116	117	717	444	19	5	0	0	0	0	0	0	0	0	1507	2854
2000	178	16	327	198	96	446	172	11	17	0	0	5	0	5	0	0	1470	3062
2001	473	1990	13	122	79	15	142	99	6	6	6	0	0	0	0	0	2951	2695
2002	0	1330	641	29	70	33	26	96	30	0	5	0	0	0	0	0	2261	2496
2003	684	54	628	134	22	42	7	8	39	24	0	0	0	0	0	0	1642	1593
2004	14	3380	25	600	168	5	10	3	5	15	0	0	0	0	0	0	4226	4071
2005	8069	16	1118	78	709	136		17	16	8	0	0	0	0	0	0	10166	5242
2006	19709	3886	62	1481	85	592	115	7	0	7	14	0	7	0	0	0	25965	12505
2007	3917	11620	5022	21	1138	58	425	74	13	20	0	0	0	0	0	0	22308	23886
2008	6096	16671	12433	4530	72	946	56	231	76	0	14	0	0	0	0	0	41124	43676
2009	5139	7479	16150	14310	4154	26	1091	0	335	0	0	14	0	0	0	0	48697	75228
2010	66370	27689	8654	7633	4911	1780	8	442	46	251	26	0	0	0	0	0	117810	69295
2011	347674	142999	16993	6309	7739	3089	1191	0	215	0	89	0	0	0	0	0	526300	106151
2012	103494	128087	10942	11721	4967	4781	1630	832	24	93	30	101	0	17	0	0	266720	113227
2013	5525	67521	32339	4776	4185	2782	1807	963	278	40	29	32	5	0	0	0	120280	72289
2014	7282	2372	48564	43168	17861	6842	3447	1931	1551	600	79	54	8	0	0	0	133760	159939
2015	1141	12952	7250	25614	14107	21854	3434	1426	762	366	194	14	21	21	0	7	89164	114807
2016	56	4485	14356	2230	14540	12375	4814	1157	522	303	145	28	20	0	0	0	55032	80583
2017	1714	484	9895	7051	12486	14741	8019	1784	554	318	146	26	7	0	0	14	57241	89414

Table 6. Proposal λ values for the Model Free Trend HCR.

Slope	Model Free λ
λ with Slope +	Min(1, RR)
λ with Slope -	2-Min(1, RR)

Table 7. Proposal initial parameters values for the Model Free Target HCR.

Index Biomass Target	Jy	α parameter	γ parameter
mean(2008-2017)	>1	1	Min(1, RR)
mean(2008-2017)	<1	1	2-Min(1, RR)

Table 8. List of scenarios resulting from the combination of the OMs and the HCRs proposed candidates.

HCR	OMs affecting the past	OMs affecting the projections	Priority
Model Free Trend	**Base Case**	**ProjOM1**	1
		ProjOM2	1
		ProjOM3	1
		ProjOM4	2
	MFix	**ProjOM1**	1
		ProjOM2	1
		ProjOM3	1
	MGADGET	**ProjOM1**	1
		ProjOM2	1
		ProjOM3	1
	MAnt	**ProjOM1**	1
		ProjOM2	1
		ProjOM3	1
	OMEst2	**ProjOM1**	1
		ProjOM2	1
		ProjOM3	1
	OMGruq2	**ProjOM1**	3
		ProjOM2	3
		ProjOM3	3
Model Free Target	**Base Case**	**ProjOM1**	1
		ProjOM2	1
		ProjOM3	1
		ProjOM4	3
	MFix	**ProjOM1**	1
		ProjOM2	1
		ProjOM3	1
	MGADGET	**ProjOM1**	1
		ProjOM2	1
		ProjOM3	1
	MAnt	**ProjOM1**	1
		ProjOM2	1
		ProjOM3	1
	OMEst2	**ProjOM1**	2
		ProjOM2	2
		ProjOM3	2
	OMGruq2	**ProjOM1**	3
		ProjOM2	3
		ProjOM3	3
Exploitation Ratio	**Base Case**	**ProjOM1**	3
		ProjOM2	3
		ProjOM3	3
		ProjOM4	3

	MFix	**ProjOM1**	3
		ProjOM2	3
		ProjOM3	3
	MGADGET	**ProjOM1**	3
		ProjOM2	3
		ProjOM3	3
	MAnt	**ProjOM1**	3
		ProjOM2	3
		ProjOM3	3
	OMEst2	**ProjOM1**	3
		ProjOM2	3
		ProjOM3	3
	OMGruq2	**ProjOM1**	3
		ProjOM2	3
		ProjOM3	3

Priority 1 it should be available for the January 2019 SC meeting.
Priority 2 it could be available for the January 2019 SC meeting.if all thing run well and we have time.
Priority 3 these scenarios only will be tested after the discussions of the NAFO SC January 2019.

Table 9. Performance Statistics and Criteria development for the 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"

Table 10. Proposed table for the 3M Cod MSE Performance Statistics and Criteria.

REQUIRED PERFORMANCE STATISTICS/CRITERIA		
Performance statistic	**Performance criterion**	**Relevant management objective**
$P(B_{2037}<B_{MSY})$	$P\leq 0.5$	*Restore to within a prescribed period of time or maintain at BMSY* Long term

for y = 2023 to 2027;
$count_y[P(F_y>F_{MSY})>0.3]$
 	
for y = 2027 to 2037;
$count_y[P(F_y>F_{MSY})>0.3]$
	Count
	
	Count
		Low risk of exceeding F*lim* (currently *FMSY*)

$P(By<B_{lim})$	$P \leq 0.1$	Very low risk of going below an established threshold [e.g. *Blim* or *Blim* proxy].
DESIRABLE SECONDARY PERFORMANCE STATISTICS/CRITERIA		
Performance statistic	**Performance criterion**	**Relevant management objective**
$P(B_{2027}<B_{MSY})$	$P\leq 0.5$	*Restore or maintain the Biomass in the medium term at BMSY*
for y = 2018 to 2022; $count_y[P(F_y>F_{MSY})>0.3]$	Count	Low risk of exceeding F*lim* short term (currently *FMSY*)
$\sum_{y=2018}^{2022} C_y/5$ $\sum_{y=2018}^{2027} C_y/10$ $\sum_{y=2018}^{2037} C_y/20$		Maximize yield in the short, medium and long term
For each year (2018-2037) $Count_y\left(\frac{\lvert TAC_y - TAC_{y-1}\rvert}{TAC_{y-1}}\right) > 0.10$ $Count_y\left(\frac{\lvert TAC_y - TAC_{y-1}\rvert}{TAC_{y-1}}\right) > 0.15$ $Count_y\left(\frac{\lvert TAC_y - TAC_{y-1}\rvert}{TAC_{y-1}}\right) > 0.20$ $Average_{2018-2037} = \frac{1}{20}\sum_{y=2018}^{2037}\left(\frac{\lvert TAC_y - TAC_{y-1}\rvert}{TAC_{y-1}}\right)$	Count Count Count	Keep inter annual TAC variation below "an established threshold" Minimize annual TAC variation in the long term

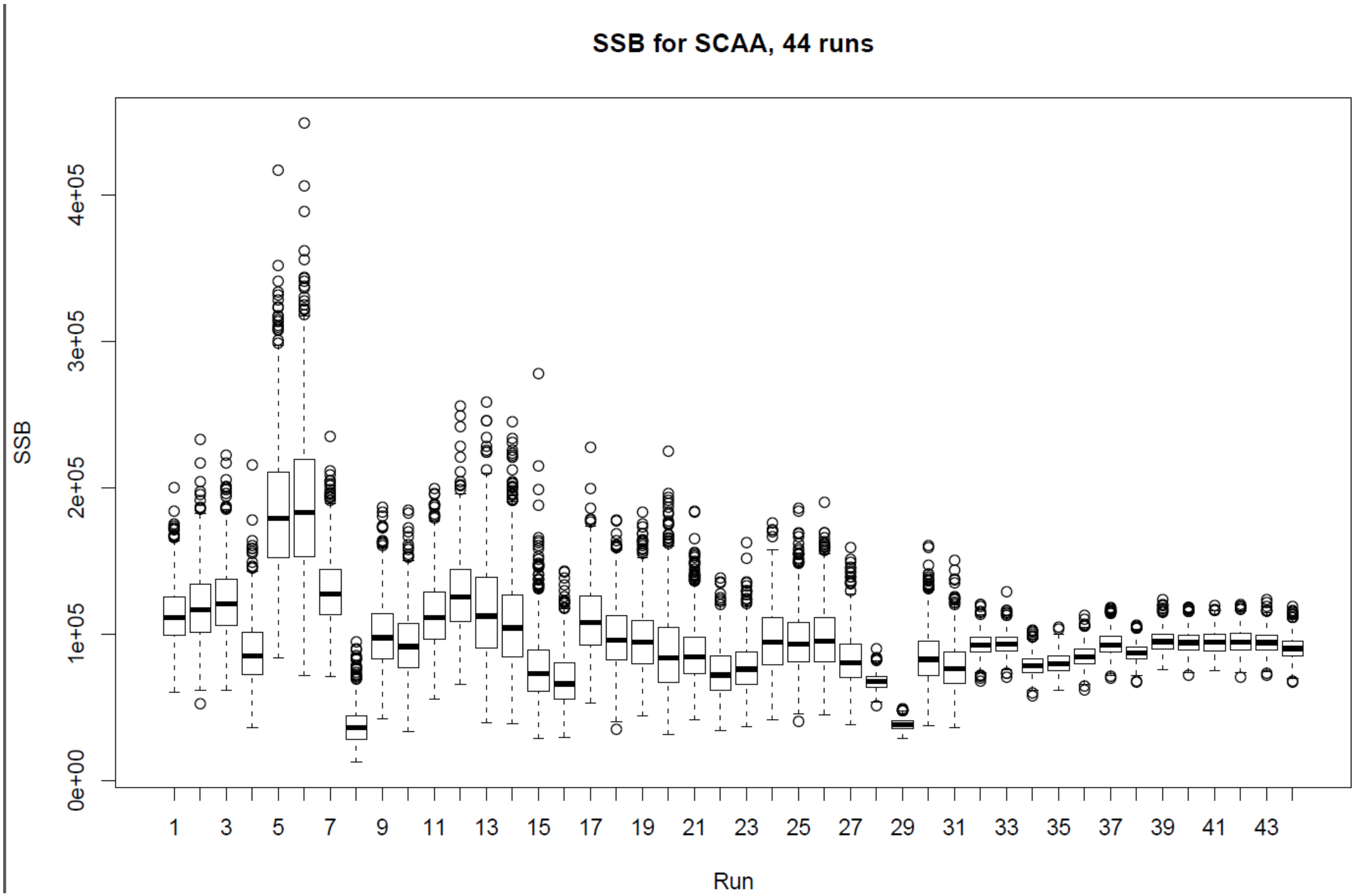

Fig. 1. SSB estimated in the last year (2016) for the different scenarios examined during the NAFO 3M Cod Benchmark.

Figures

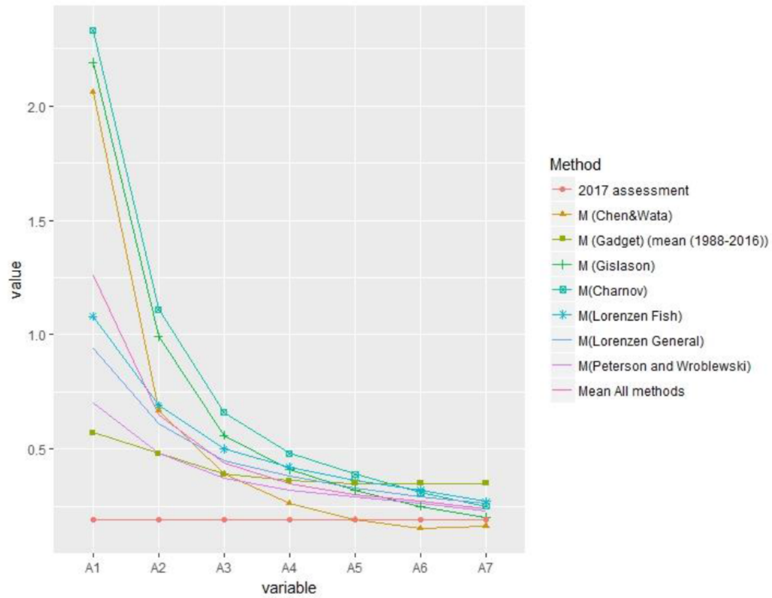

Fig. 2. Estimate M (Y axis) by age (X axis) for the different biological methods and the final prior values approved for the Base Case (Mean All methods).

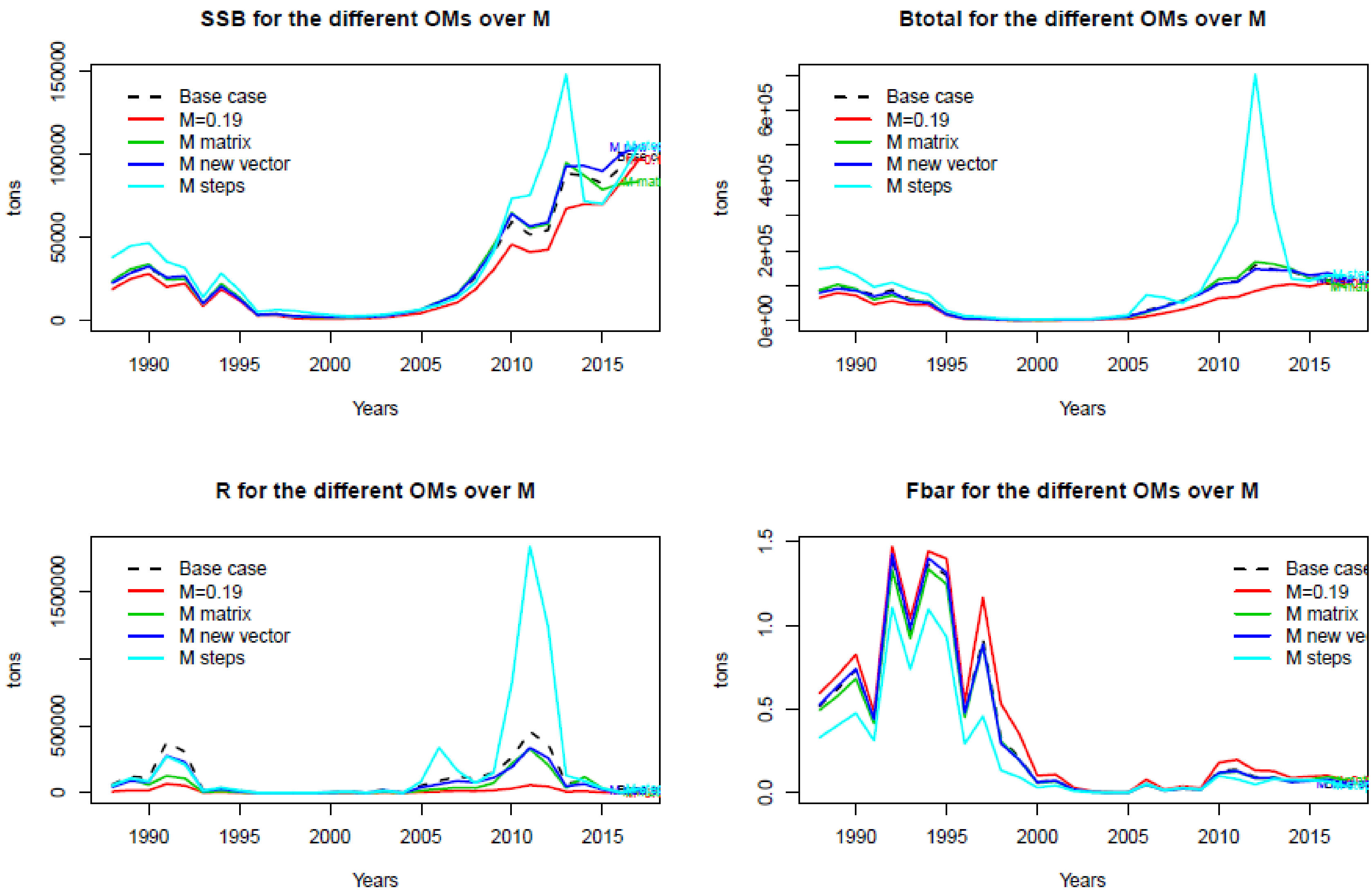

Fig. 3. SSB, Total Biomass, recruitment age 1 and Fbar (3-5) results in the period 1988-2017 for possible OMs with alternate M priors and/or CVs.

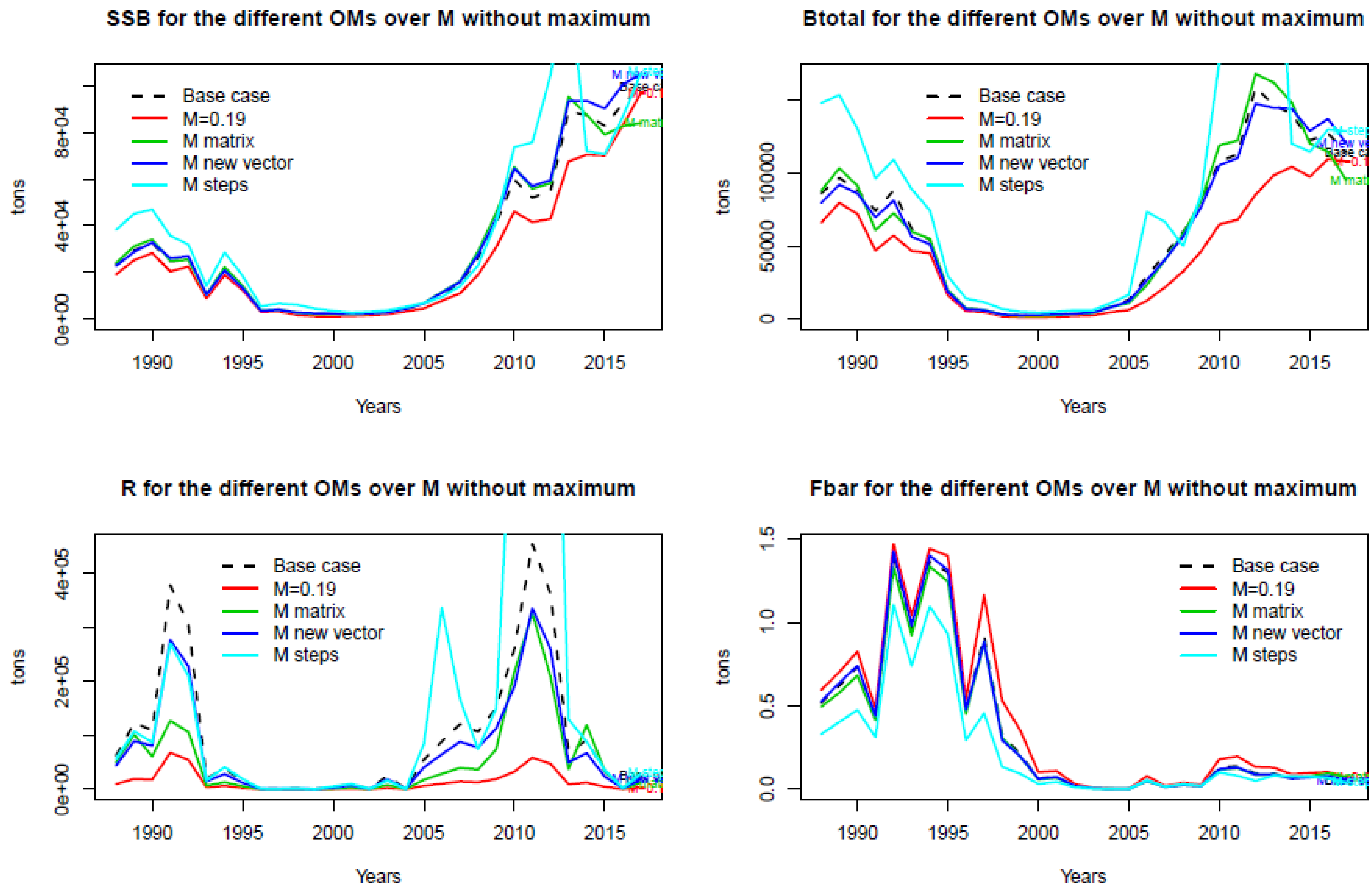

Fig. 3B. SSB, Total Biomass, recruitment age 1 and Fbar (3-5) results in the period 1988-2017 for possible OMs with alternate M priors and/or CVs without the maximum for OMSteps.

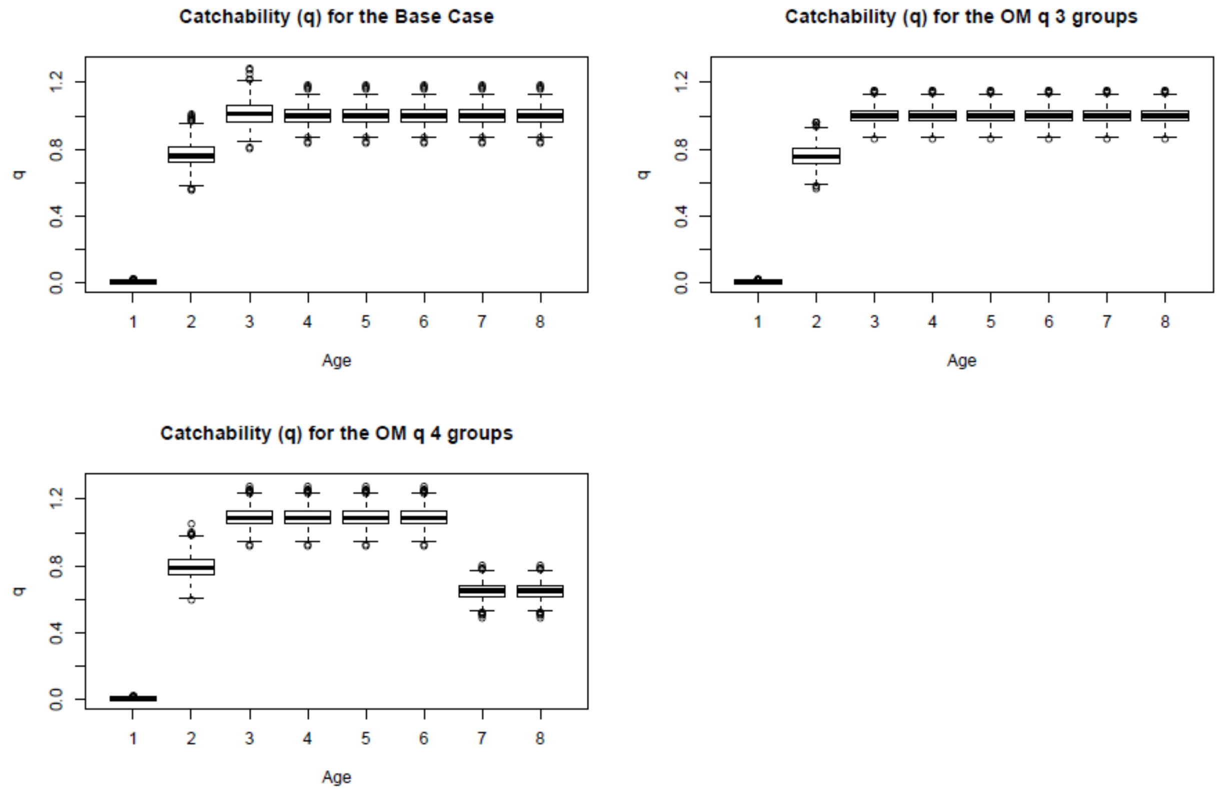

Fig. 4. Posterior values of the catchability of the survey (q) for: A. Base Case. B. OMq(3 groups). C: OMq(4 groups)

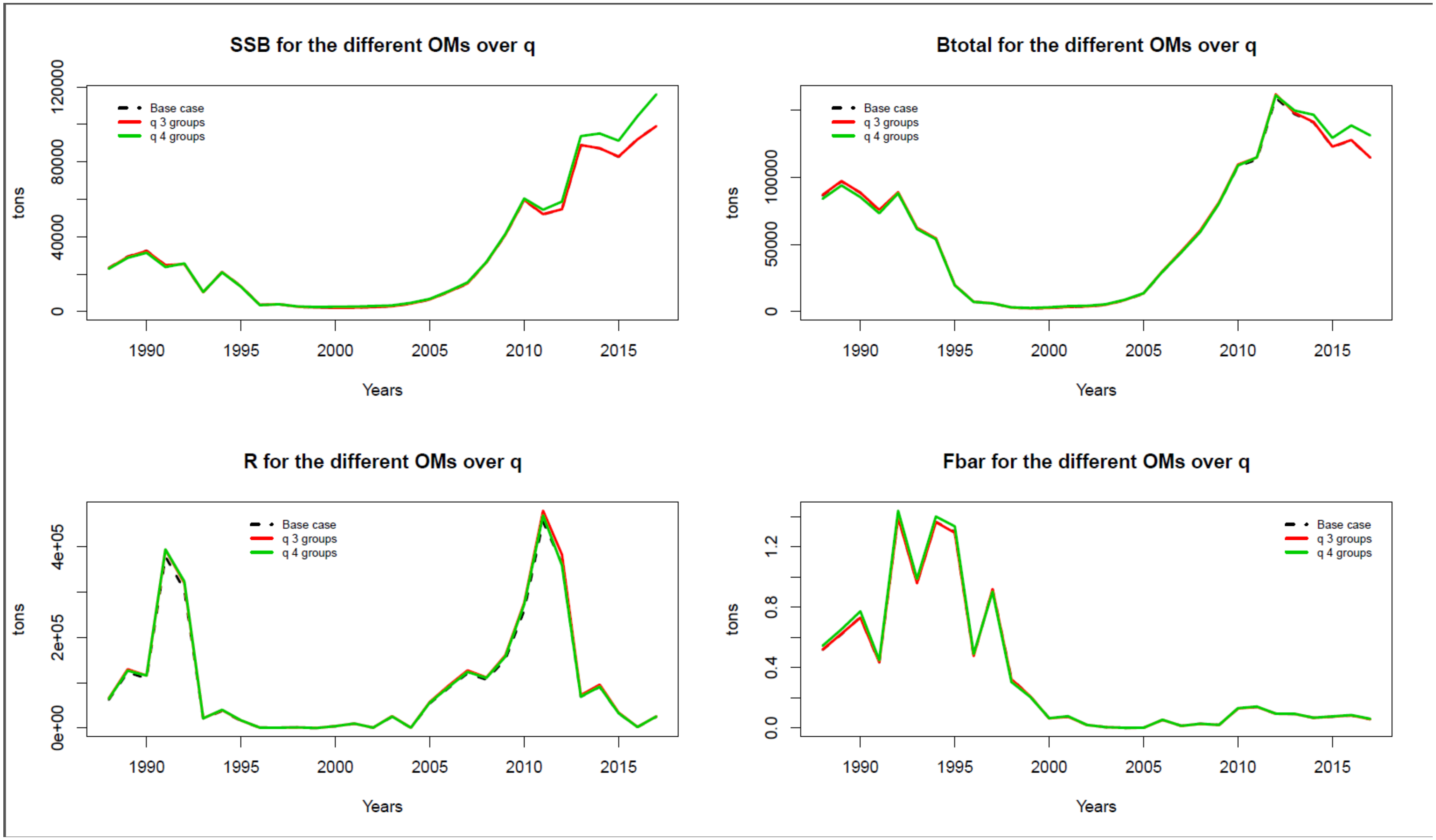

Fig. 5. SSB, Total Biomass, recruitment age 1 and Fbar (3-5) results in the period 1988-2017 for possible OMs with different groups of qs.

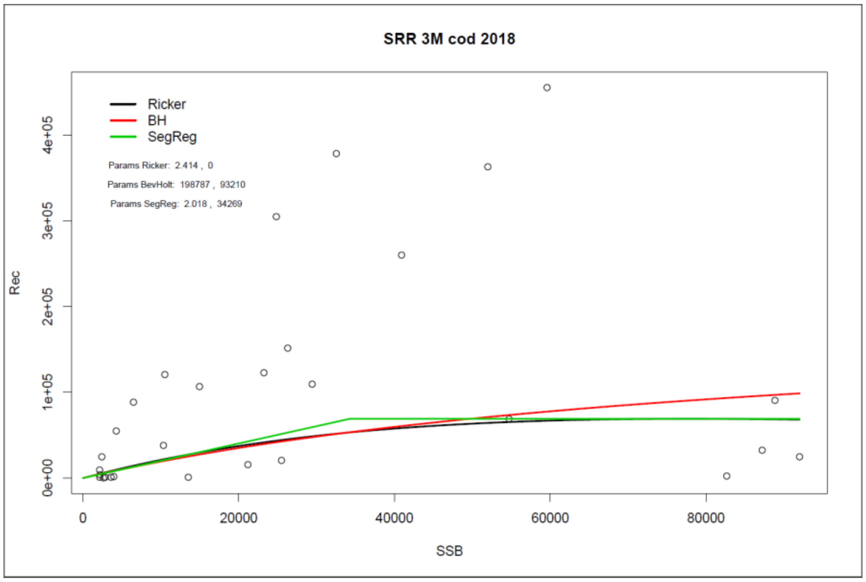

Fig. 6. Ricker, Beverton-Holt and Segmented regression Stock/Recruitment relationship fit to the Base Case 3M Cod median results.

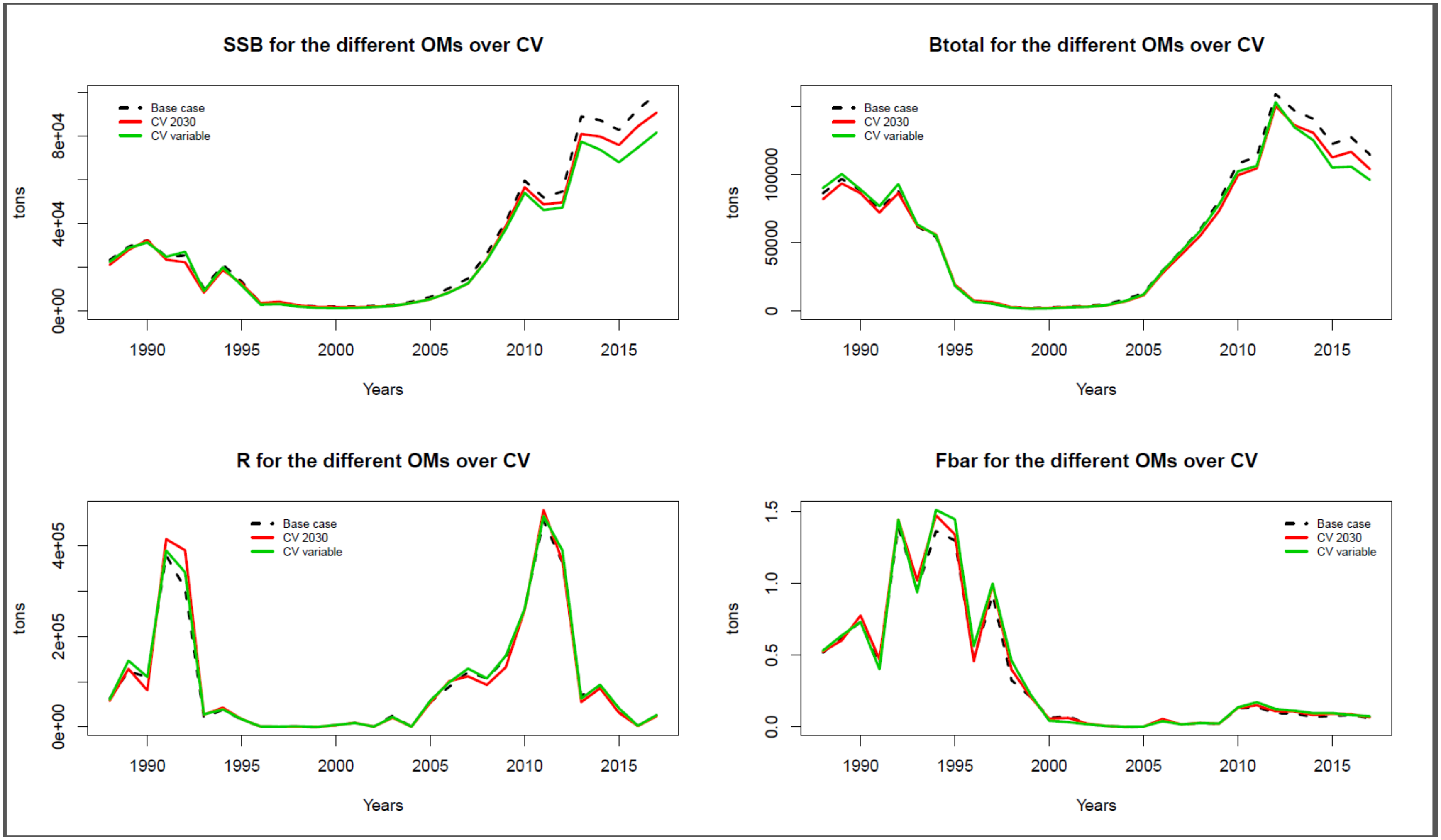

Fig. 7. SSB, Total Biomass, recruitment age 1 and Fbar (3-5) results in the period 1988-2017 for possible OMs with different CVs for catches and survey information.

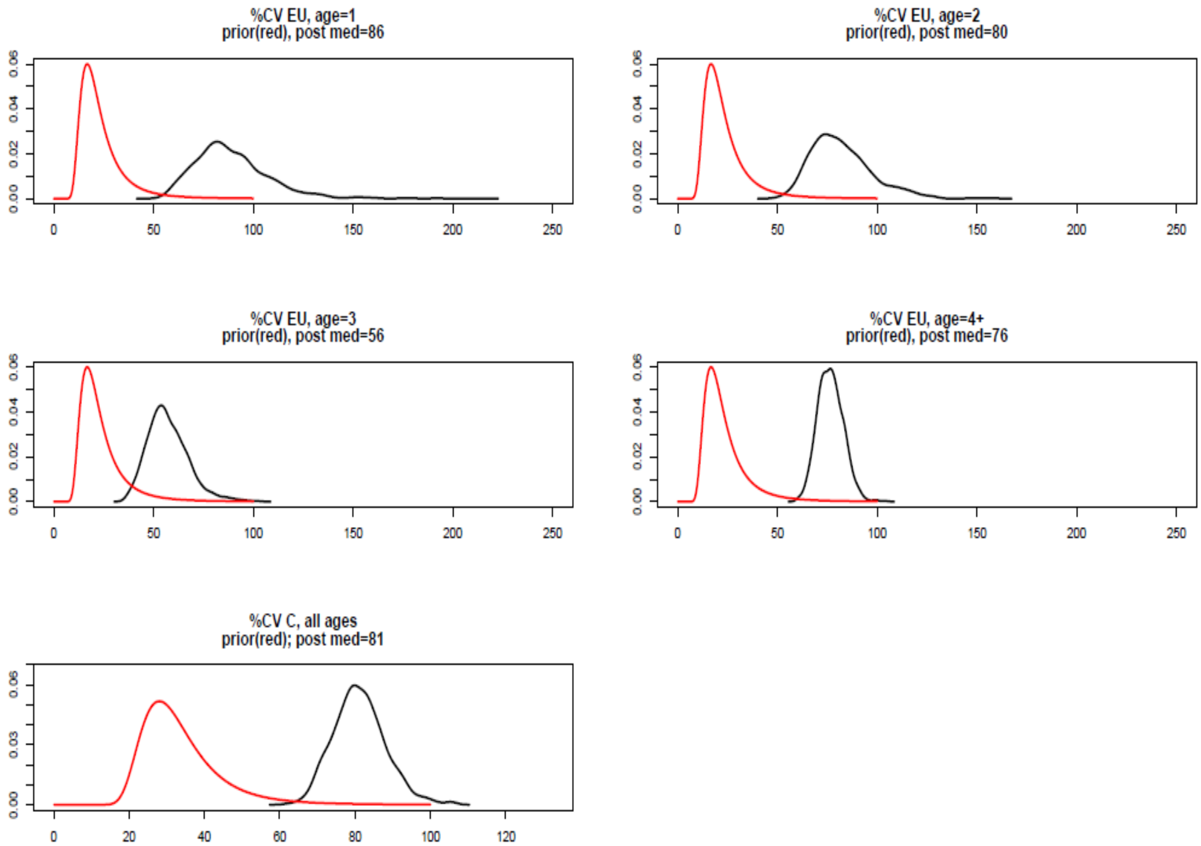

Fig. 8. Priors (red) and posterior (black) CVs. For the OMCVEst. The configuration of the OM that estimates CVs of CAA (same CV for all ages) and survey (CV groups for ages 1, 2, 3, 4+).

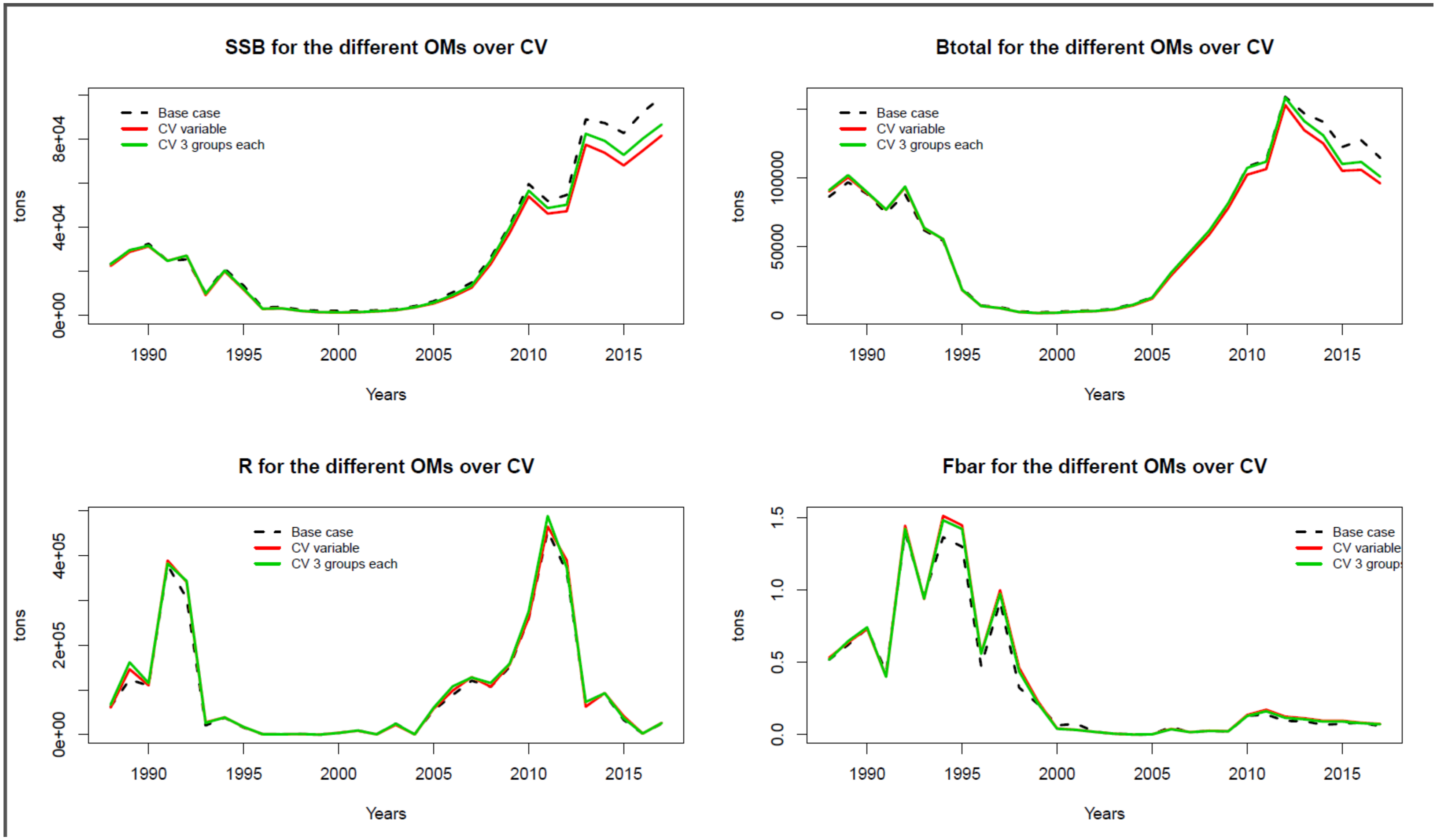

Fig. 9. SSB, Total Biomass, recruitment age 1 and Fbar (3-5) results in the period 1988-2017 for the OMs with different CVs for catches and survey information: Base Case, OMCVEst (in the plot variable) and the new one OM (in the plot CV 3 groups each).

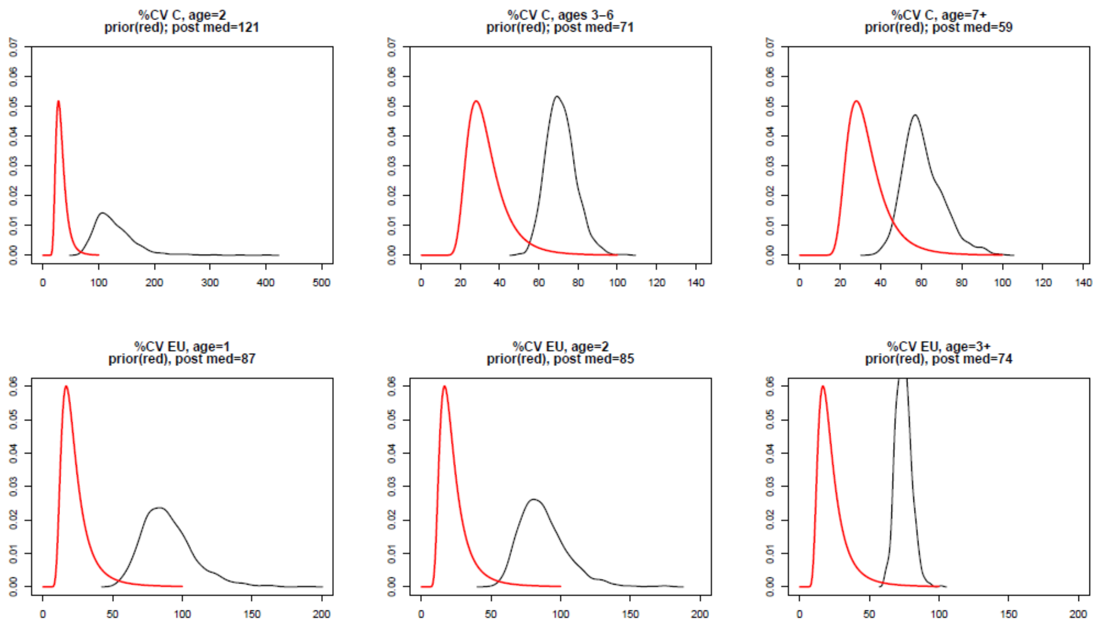

Fig. 10. Priors (red) and posterior (black) CVs. For the OMCVq 3 groups each.

Fig. 11. Catch, stock mean weights and Maturity, for the period 1988-2016 for 3M Cod

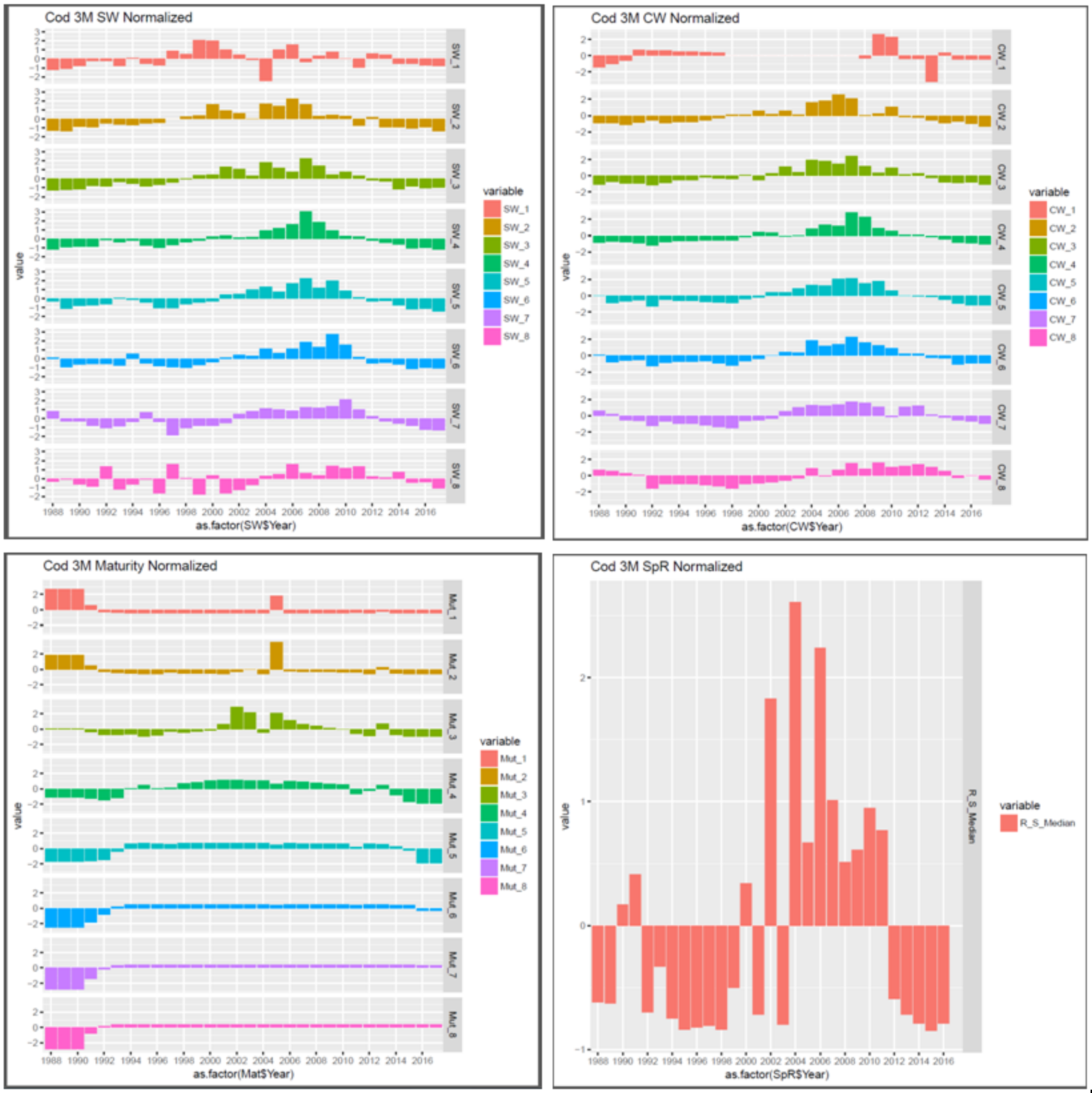

Fig. 12. Normalize (by the mean and its varianze) **s**tock, catches mean weights, maturity at age and Recruits per Spawner for the period 1988-2017 for 3M Cod

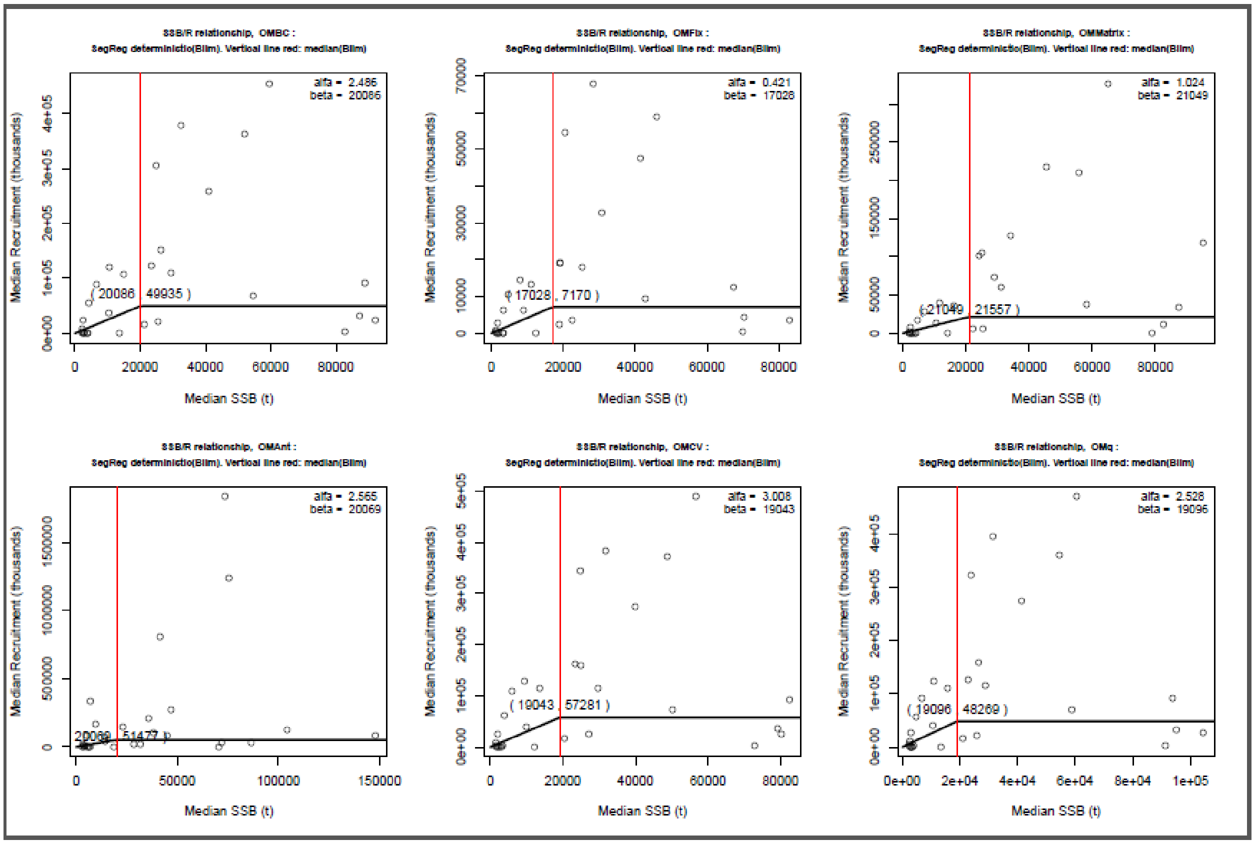

Fig. 13. Median R/SSB segmented regression fit for the different OMs. The β parameter have been fixed with the median Blim estimated by iteration with the Method1 (SCRxx).

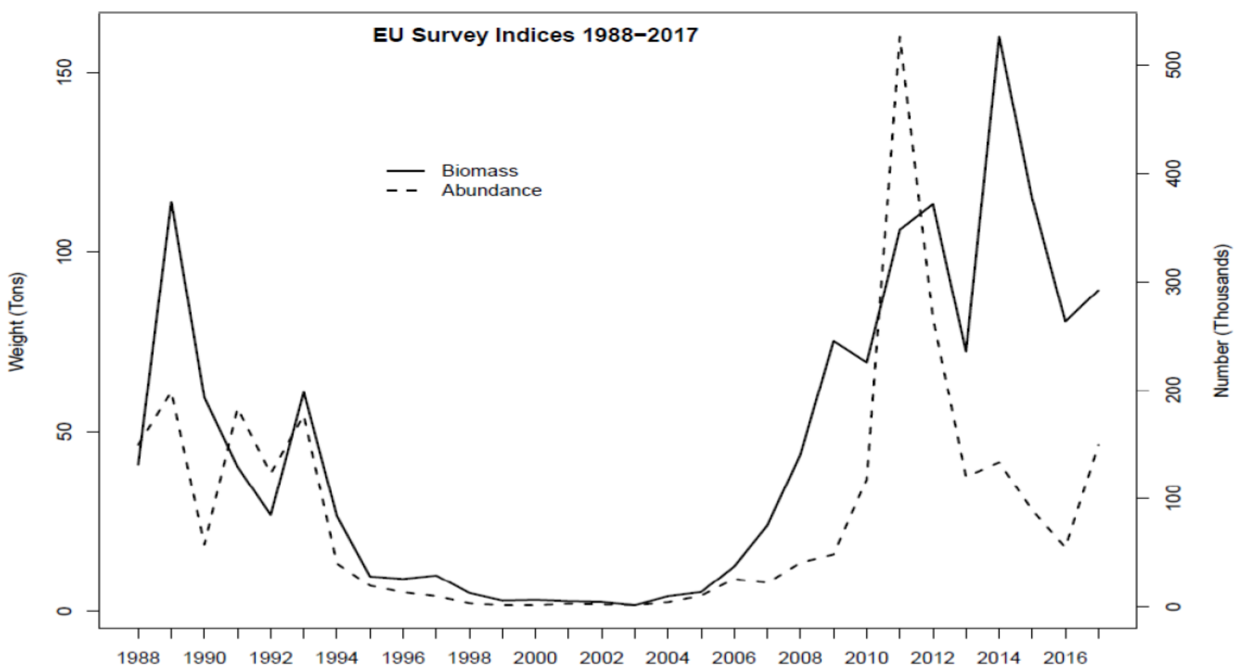

Fig. 14. Biomass and abundance from EU surveys.

Annex I

1. $M_{1-8}^{1988-2006} prior = 0.2$
2. $\mathbf{1st\ assement}$ $1988 - 2006 \rightarrow M_{1-8}^{1988-2006}\ posterior$
3. $\mathbf{2nd\ assessment}$ $1988 - 2008$, $\mathbf{first\ run}$, $2007 - 2008$ $M\ constant@age, with\ 1988 - 2006\ M_{1-8}^{1988-2006} fixed\ at\ posterior\ from\ 2.\ and\ M_{1-8}^{2007-2008} posterior\ from\ M_{1-8}^{1988-2006} as\ prior$
4. $2nd\ assessment\ 1988 - 2008$, $\mathbf{second\ run}$, $2007 - 2008\ M\ varying\ @age, with\ ages\ i\ from\ 1\ to\ 8,\quad M_i^{2007-2008} prior = M_{1-8}^{2007-2008} posterior * Mr_i$

   $$where\ \ Mr_i = relative\ natural\ mortality\ at\ age\ i\ averaging\ results\ for\ age\ i\ from\ cod\ growth\ based\ biological\ M@age\ models\ and\ from\ GadCap\ model.$$

   $$finally\ for\ ages\ 1\ to\ 8\quad from\quad M_i^{2007-2008} priors \rightarrow M_i^{2007-2008} posteriors.$$
5. $\mathbf{3rd\ assessment}$ $1988 - 2010$, $\mathbf{first\ run}$, $2009 - 2010\ M\ constant@age, with\ 1988 - 2006\ M_{1-8}^{1988-2006} fixed\ at\ posterior\ from\ 2,\ \ with\ 2007 - 2008\ M@age\ fixed\ \ at\ M_i^{2007-2008} posteriors\ from\ 4., and\ M_{1-8}^{2009-2010} posterior\ from\ M_{1-8}^{2007-2008} as\ prior$
6. $3rd\ assessment\ 1988 - 2010$, $\mathbf{second\ run}$, $2009 - 2010\ M\ varying\ @age, with\ \ ages\ i\ from\ 1\ to\ 8,\quad M_i^{2009-2010} prior = M_{1-8}^{2009-2010} posterior * Mr_i$

   $$finally\ for\ ages\ 1\ to\ 8\quad from\quad M_i^{2009-2010} priors \rightarrow M_i^{2009-2010} posteriors$$
7. $4\mathbf{th\ assessment}$ $1988 - 2012$, $\mathbf{first\ run}$, $2011 - 2012\ M\ constant@age, with\ 1988 - 2006\ M_{1-8}^{1988-2006} fixed\ at\ posterior\ from\ 2,\ \ with\ 2007 - 2010\ M@age\ fixed\ \ at\ M_i^{2007-2010} posteriors\ from\ 4. (2007 - 2008) and\ 6. (2009 - 2010), and\ M_{1-8}^{2011-2012} posterior\ from\ M_{1-8}^{2009-2010} as\ prior$

8. $\mathbf{4th\ assessment}$ $1988 - 2012$, $\mathbf{second\ run}$, $2011 - 2012\ M\ varying\ @age, with\ \ ages\ i\ from\ 1\ to\ 8,$

   $$M_i^{2011-2012} prior = M_{1-8}^{2011-2012} posterior * Mr_i$$

   $$finally\ for\ ages\ 1\ to\ 8\quad from\ \ M_i^{2011-2012} priors \rightarrow M_i^{2011-2012} posteriors$$
9. $\mathbf{5th\ assessment}$ $1988 - 2014$, $\mathbf{first\ run}$, $2013 - 2014\ M\ constant@age, with\ 1988 - 2006\ M_{1-8}^{1988-2006} fixed\ at\ posterior\ from\ 2,\ \ with\ 2007 - 2012\ M@age\ fixed\ \ at\ M_i^{2007-2012} posteriors\ from\ 4. (2007 - 2008), and\ 6. (2009 - 2010)\ and\ 8. (2011 - 2012), and\ M_{1-8}^{2013-2014} posterior\ from\ M_{1-8}^{2011-2012} as\ prior$
10. $5\mathbf{th\ assessment}$ $1988 - 2014$, $\mathbf{second\ run}$, $2013 - 2014\ M\ varying\ @age, with\ \ ages\ i\ from\ 1\ to\ 8,\quad M_i^{2013-2014} prior = M_{1-8}^{2013-2014} posterior * Mr_i$

    $$finally\ for\ ages\ 1\ to\ 8\quad from\ \ M_i^{2013-2014} priors \rightarrow M_i^{2013-2014} posteriors$$