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NAFO Scientific Council Flemish Cap (NAFO Div. 3M) Cod Stock Management Strategy Evaluation (MSE).

North East Atlantic Fisheries Commission (NEAFC) headquarters

London, UK, 28-31 January 2019

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Scientific Council Flemish Cap (NAFO Div. 3M) Cod Stock
Management Strategy Evaluation (MSE) Meeting Participants

Back row: António Avila de Melo, Brian Healey, Daniel Howell, Ricardo Alpoim, Fernando González Costas, Jim Ianelli, Tom Blasdale

Front row: Dayna Bell MacCallum, Joanne Morgan, Cristina Ribeiro, Diana González-Troncoso, Carmen Fernández, Agurtzane Urtizberea, Luis Ridao

Missing from Photo: Katherine Sosebee

NAFO Scientific Council Flemish Cap (NAFO Div. 3M) Cod Stock

Management Strategy Evaluation (MSE).

London, UK. 28-31 January 2019

Chair: Brian Healey Rapporteur: Tom Blasdale

1. Opening of the meeting

The Scientific Council met in London, UK between 28 and 31 January 2019 to discuss 3M cod Management Strategy Evaluation (MSE). The meeting was attended by representatives from Canada, the EU, the Faroes and the USA (by WebEx). In addition, two expert external reviewers also participated in the meeting. The full participants list is included as Appendix III. The meeting was chaired by the SC Chair, Brian Healey (CAN).

The agenda was adopted with the following amendments: additional agenda items were added for documentation of results and estimation of reference points for operating models. The SC coordinator was appointed as rapporteur.

2. Documentation of results and decisions of the MSE.

The chair stressed the importance of having full documentation of the entire MSE process in a form that would allow future reviewers to follow through the complete process from beginning to end. Ideally this should take the form of a single document which would include all the work done by both SC and WG-RBMS. This was not fully achieved in the Greenland halibut MSE process and we will learn from that experience.

It was agreed the SC Chair will liaise with WG-RBMS co-chairs to ensure that a single overall "guiding and summary" document is produced for the whole 3M cod MSE process. The NAFO Secretariat should prepare the structure of the document and the main results and conclusions of all meetings contributing to the cod MSE process should be included in it (if possible also with the rationale as to why the conclusions were reached). This document would refer to SCR documents or other documents, as relevant, for details. The document itself would not include much detail, but it should permit an "outsider" to follow all key points of the cod MSE process and to find all relevant information.

The possibility of storing relevant code on an online service such as GitHub in order to allow access for reviewers was also discussed. At a minimum, it was agreed that all required elements to reproduce the work (input data, code for simulations, etc.) would be retained by the Secretariat.

3. Models currently under consideration for generating operating models (OMs)

The 2018 3M cod benchmark meeting (SCS Doc. 18/18) agreed to move forward with the Bayesian SCAA model as the base case for the June 2018 stock assessment (pending a few technical checks that were conducted in time for the June 2018 SC meeting). This, in itself, did not necessarily preclude further consideration of the Bayesian XSA model for potential use within the MSE context, particularly if an OM was proposed that would require use of this model. However, this has not been the case and therefore all modelling work conducted since then, including during this meeting, has been on the basis of the Bayesian SCAA model

4. Review and further refinements of initial set of OMs.

SCR Doc. 19-001 describes in detail the initial set of Operating Models (OMs), Harvest Control Rules (HCR) and Performance Statistics (PS) for the NAFO 3M Cod MSE developed in advance of this meeting. The initial HCRs and PS have not been informed by input from fisheries managers or industry participants, but were constructed using the experience of the Greenland halibut MSE, and for selected PS, in an attempt to be consistent with the objectives of the NAFO convention.

Preliminary trials were run using six OM variants and two candidate HCRs (trend and target based). The results were shown in presentations and are available on the SC Share Point.

a) Natural Mortality (M).

OMs with different M priors/values and/or CVs were considered. Detailed descriptions can be found in SCS Doc. 19-001. The alternative M scenarios considered were as follows:

Base Case: M is estimated by the model and the input is a prior with different M values for different ages and constant in time. The prior median values are taken as the means of M values estimated in a number of models that take into account the biological characteristics of the 3M Cod (SCR Doc. 18-03). The Base Case M prior median values by age and their CV were approved by the NAFO Scientific Council in June 2018 and they are as follows: medM[a]= c(1.26,0.65,0.44,0.35,0.30,0.27,0.24,0.24), cvM = 0.15 (i.e. 15%).

Fixed M (Mfix): under this approach, M is constant for years and ages at M=0.19 (input, without any prior distribution). This value of M came from the posterior median M (constant by years and ages) estimated in the 2017 Bayesian XSA approved assessment (SCR Doc. 17-038). It was agreed that this approach will not be taken forward in future work as SC does not consider this fixed value of M to be realistic.

Matrix based M (MGADGET): this scenario uses M values variable by year and age estimated in the GADGET model taking into account predation (the M values are treated as inputs, without any prior distribution). The natural mortality M estimated by GADGET by age and year was presented in the 2018 Benchmark report (SCS Doc. 18-018).

A separable approach to M estimation (MAnt or Msteps): M variable by year and age estimated by the method proposed by Ávila de Melo and Alpoim (2018). The formulation of this method to estimate M is presented in SCR Doc. 19-002. In this document, several formulations of this approach were presented, varying the way the steps are constructed and the year of the first step. In the last scenario (named Steps3_c), the CV of the catch-ate-age is estimated via a prior.

SC had concerns with this approach, particularly in relation to the fact that the M is high for age 1 when the recruitment is good, but it is still high in the subsequent years, when the recruitment falls. Further investigations of the last configuration tried in the SCR (Steps3_c) showed that the rationality of this model is good, with the M at young ages being higher in the years with higher recruitment (2011-2014), and the M of ages 3+ being lower and quite constant across the years (Figure 1). For this reason, this configuration was chosen to be one of the OMs of the MSE.

As an alternative, it was suggested to have a new M scenario which takes the M matrix from the GADGET model in which the predation M varies but the residual M matrix remains constant across years and ages. In this scenario the residual M would be estimated by the Bayesian model rather than fixed, as in the benchmark. This alternative was not implemented during the meeting and at the end it was discarded in favor of the last Msteps.

A new vector based M (MVec): In this scenario, the M prior medians by age and their CV 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 for this different set of M priors is to remove the extreme values of the younger ages observed in some of the models contributing to the mean values used in the base case (estimated using the methods of Charnov *et al* (2012), Chen & Watanabe (1989), Gislason *et al* (2010) and the 2017 assessment (SCS Doc. 17-016)) and to double the base case CV. The results under this scenario were very similar to the base case and SC decided that this approach will not be taken forward in future work.

The results of conditioning these OMs using the historical data are presented in Figure 2 (in the figure, the M steps OM is the one named OMSteps_3 in SCR Doc 19-002).

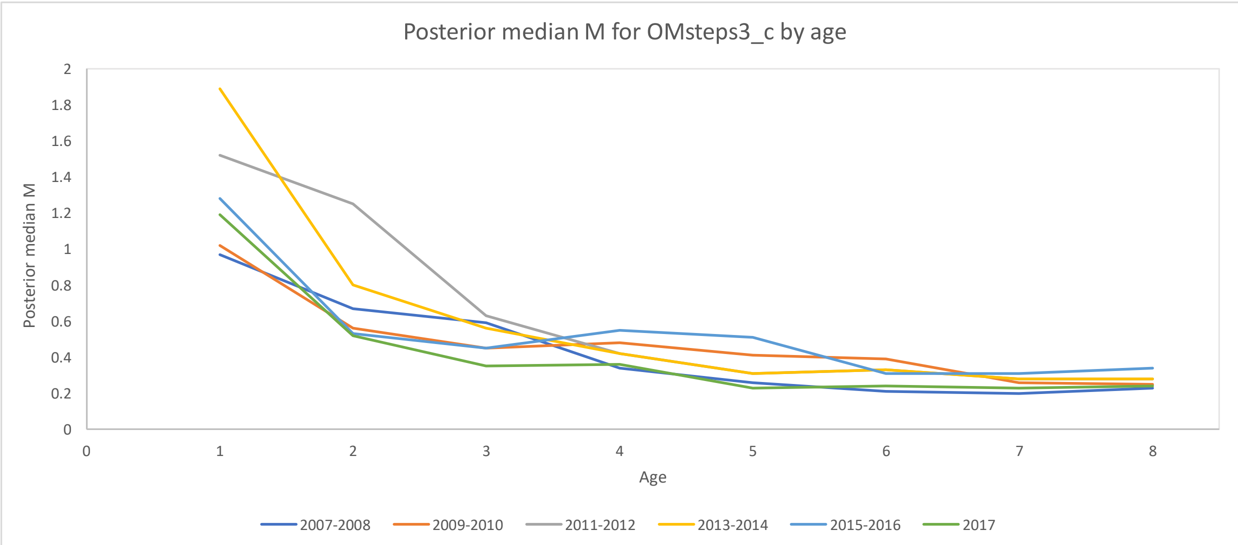

Figure 1. Posterior median M in the configuration applied in OMSteps3_c (SCR Doc 19-002)

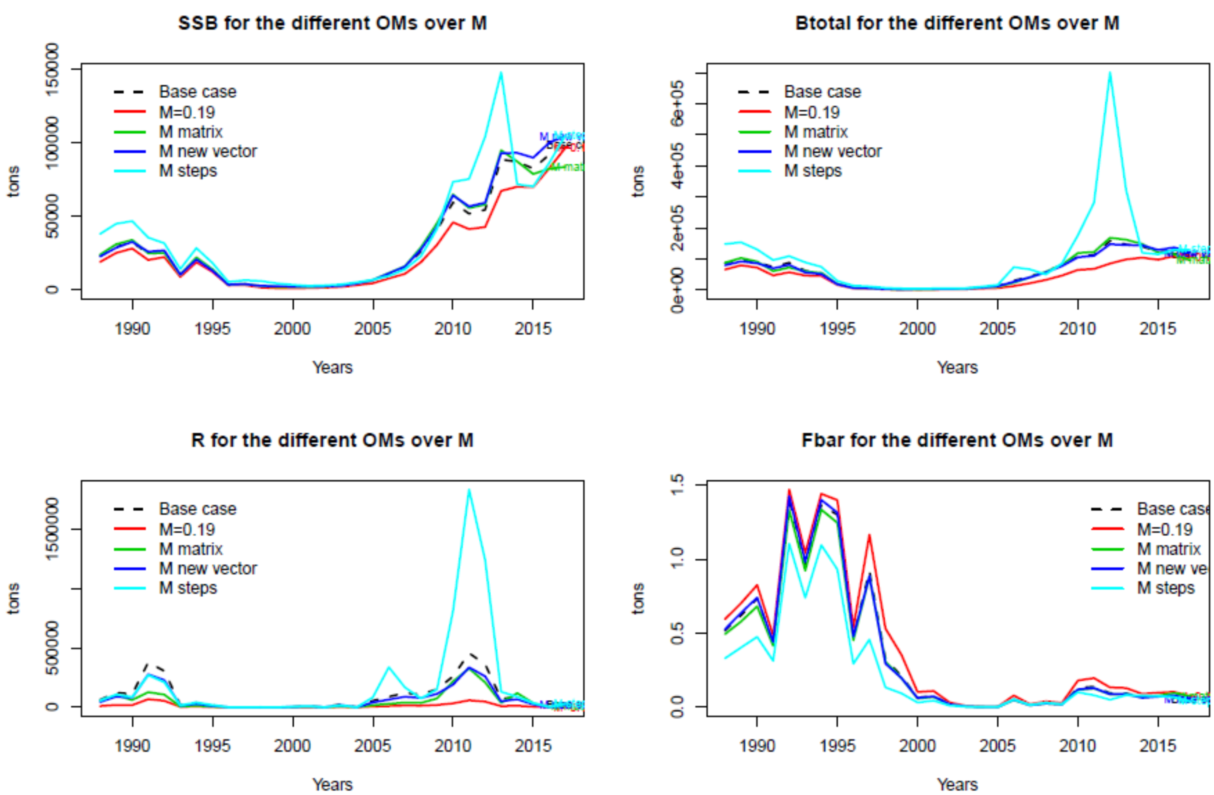

Figure 2. OM outputs under different M settings

It was agreed that the following M priors and/or CVs will be used in OM variants going forward:

- **Base Case:** M is estimated by the model and the input is a prior with different M values for ages and constant in time. medM[a]= c(1.26,0.65,0.44,0.35,0.30,0.27,0.24,0.24), cvM = 0.15.
- **Matrix M**: M variable by years and ages estimated in the GADGET model taking into account the predation.
- **Msteps**: this is the last version of the separable approach to M estimation (OMSteps_3c).

b) Catchability (q)

Three variant catchability scenarios were considered:

a. **Base Case:** The final approved model from the benchmark (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 were examined with the alternative groupings of qs discussed during the benchmark:

b. **OMGruq1**: Survey qs estimated for ages 1, 2, and common for ages 3+. The reason to consider this OM is because the Base Case results show that the q at age 3 and q at age 4+ are very similar and probably it would be better to estimate q3+.
c. **OMGruq2**: Based on the survey information available, q groups were defined for the ages: 1, 2, 3-6 (grouped), 7-8+ (also grouped together).

Figure 3 shows the estimated posterior q values for the OMs with different groups of qs. It is evident that the OM with 3 groups of qs "OMGruq1" gives the same results as the Base Case and it has been decided not to implement this as candidate OM. For the scenario with 4 groups of qs "OMGruq2" the decision was not so clear: the results are only slightly different from the Base Case. The four group scenario will therefore be included in the MSE as a robustness trial. This scenario will use the base case settings for all other variables; in principle, it will only be tested on the slope HCR.

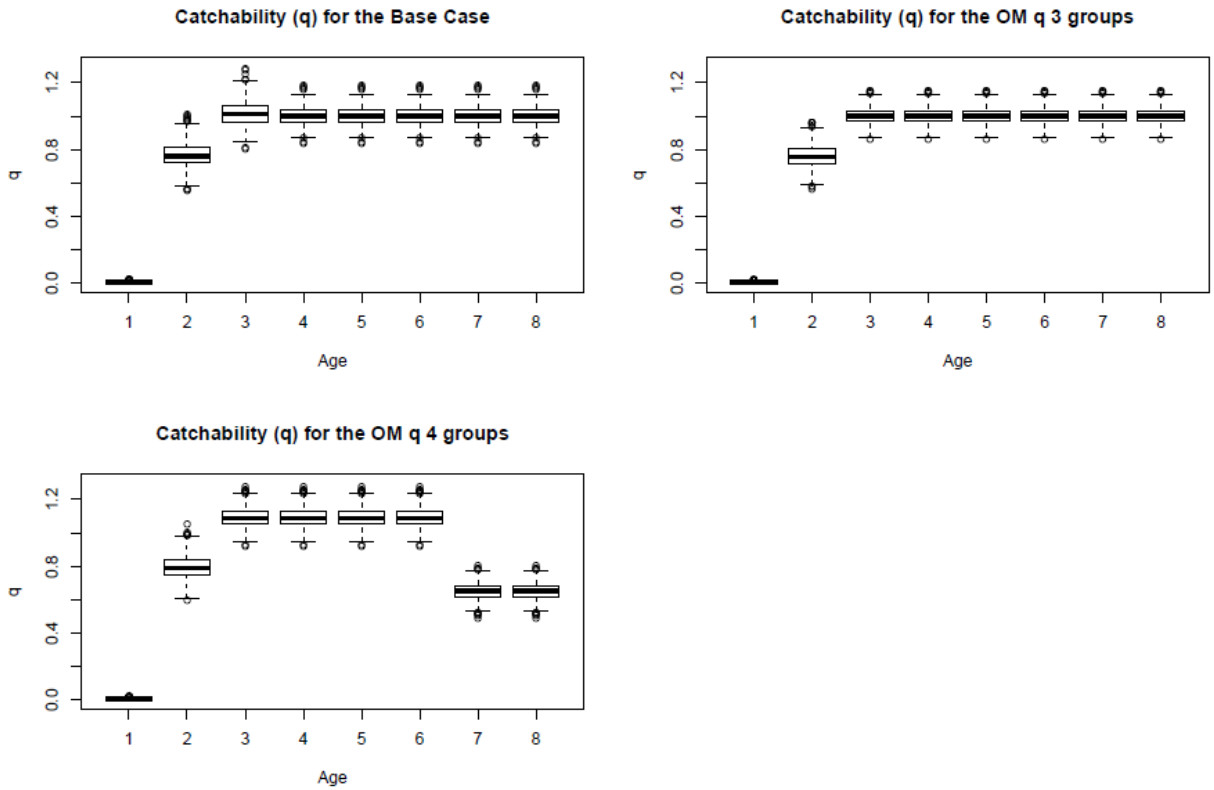

Figure 3. Posterior values of the catchability of the survey (q) for: a) Base Case. b) OMGruq1 (3 groups). c) OMGruq2 (4 groups)

c) Catch

Catches in recent years are considered to be potentially less reliable as they depend on CDAG estimates rather than scientific estimates. In the Greenland halibut MSE, catches were considered to be accurate in the OM but one of the projection scenarios included a 10% TAC overrun. In the case of 3M cod, a sensitivity test was run by conditioning the OM assuming that past catch estimates were under-estimated; this was done setting a 20% over-catch in years from 2013 onward. Figure 4 shows that the results of the base case and the new scenario are very similar, so this new scenario was discarded.

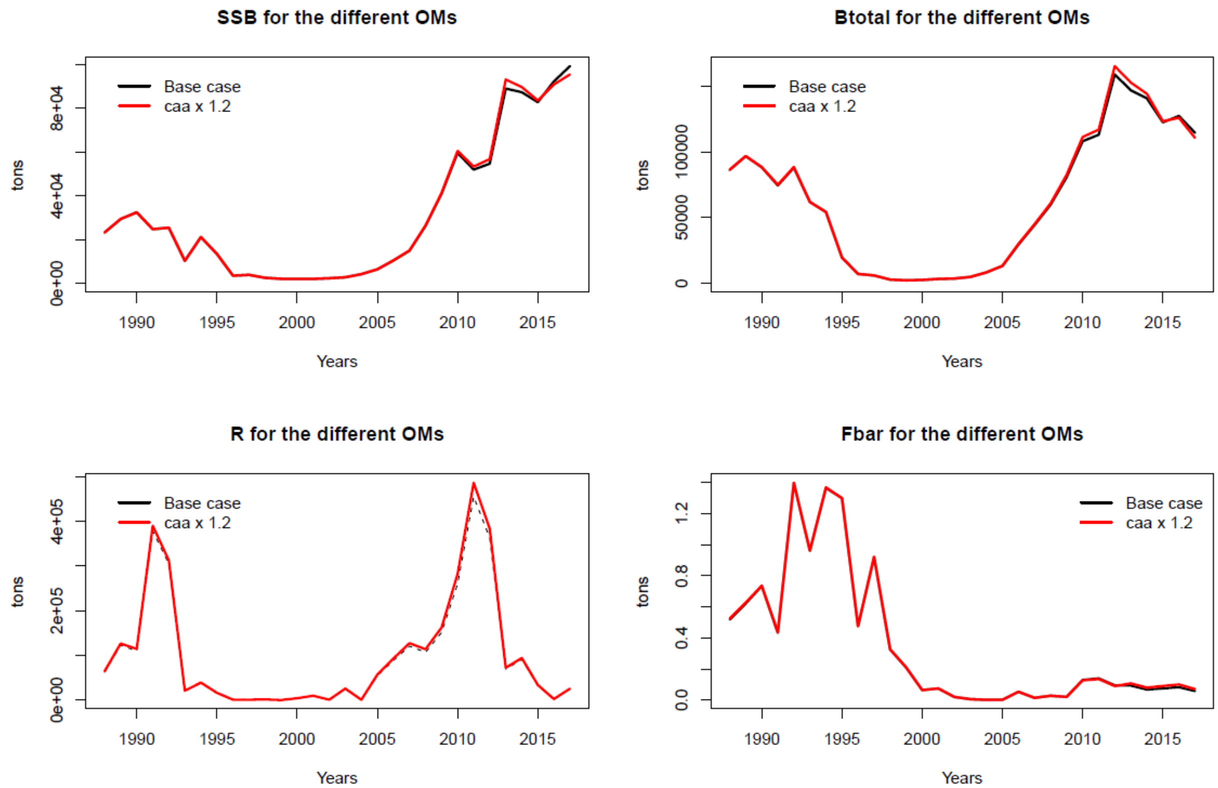

Figure 4. Results of the base case versus the base case with a 20% over-catch

d) Stock recruit relationship in projections:

A number of possible stock recruit relationships were considered during the meeting, including a segmented regression with a break point at B_{lim}, a Ricker curve either fitted to the entire time series or excluding years with very low recruitment values, and geometric means of r4ecruitment within a number of separate SSB bins (with break points at fixed values of SSB, specified quantiles, or corresponding to SSB in specific years). For all the fitted relationships, the fits were poor with particularly large positive residuals in the mid range of SSB (see Figure 5).

Due to the nature of the Ricker curve, it is considered unlikely to generate prolonged periods of low recruitment such as have been observed in the past. In addition, when fitting a Ricker stock recruit relationship to the entire data series, the resulting fit was quite similar to the segmented regression and would likely not add an additional OM to the MSE. To address these concerns it was agreed to truncate the Ricker curve at the SSB_{1997} line (considering that points below the line were not used in the fitting) and use re-sampled values of R below that point.

It was agreed that the segmented regression with a breakpoint at $B_{lim}=SSB_{2007}$ (see discussion of reference points below) and the Ricker curve fitted excluding values of SSB less than SSB_{1997} will be used going forward.

Residuals will be re-sampled from historic recruitment, however, given the magnitude of some residuals there was concern that re-sampling over the entire series would result in predicted values that were unrealistic when compared to historic values, and that potentially very high recruitment values could be drawn even at very low SSB. As an alternative, it was suggested to slice the distribution into several SSB bins, and to re-sample residuals from within those bins (selecting in each future year the bin in which SSB lies in that year). The advantage of this approach is that it would confine the largest SSB residuals within the SSB range that they were observed. Based upon visual examination of the stock-recruit plot, suggested cut-offs were 20000 t and 60000 t, with the possibility of another to take account of the lowest values of SSB (ca. 5000t). Because each OM and iteration would produce different values of SSB, it was considered more appropriate to use SSB corresponding to specific years. Therefore, the years selected as cut-offs for the SSB bins in the Ricker scenario were 1997, 2007 and 2010. In the segmented regression scenario, the year suggested as cut-off was only SSB_{2007}, so resampling the residuals from the period in which SSB was below B_{lim} and from the period in which SSB was below B_{lim}, depending on the future value of the SSB.

The possibility that variation in recruitment per spawner is driven by environmental factors was considered. Numerical values for bottom temperature and composite environmental index were not available during the meeting and so a visual comparison of recruitment and recruitment per SSB was made with the bottom temperature figures produced by STACFEN in 2018. There is some evidence that cold periods may be associated with poor recruitment, however the recruitment peak of 1990 also occurred in cold conditions. It was concluded that the short time series, during which only two recruitment peaks occurred, was insufficient to draw robust conclusions regarding environmental drivers of recruitment.

The recruitment settings to be used in trials going forward were agreed as:

Method 1 (Base case):

Ricker curve fitted to (SSB_y, R_{y+1}) pairs from historical years, such that $SSB_y > SSB_{(1997)}$ only

If, in a future year, $SSB > SSB_{1997}$, use the Ricker curve with re-sampled residuals from within the specified bins, i.e. $SSB \in (SSB_{1997}, SSB_{2007\_})$, $SSB \in (SSB_{2007}, SSB_{2010})$ and the SSB range above SSB_{2010}.

If, in a future year, $SSB \leq SSB_{1997,}$ re-sample from the historical values of recruitment for $SSB \leq SSB_{1997}$.

Method 2:

Segmented regression with break at B_{lim} ($=SSB_{2007}$)

if $SSB > SSB_{lim}$ resample residuals from historical years with $SSB > B_{lim}$

if SSB ≤ Blim, resample residuals from historical years with $SSB \leq B_{lim}$

It was also agreed to develop an additional low recruitment scenario for the next SC June meeting. This scenario should simulate the situation observed in the past of having a series of consecutive years with very low recruitment (the first 7-8 years of the projections) independent of the magnitude of SSB. For the remaining years of the projection, method 1 (Ricker + bins) will be used. After seeing these result in June, it will be possible to decide whether additional scenarios with low recruitment + segmented regression will be required.

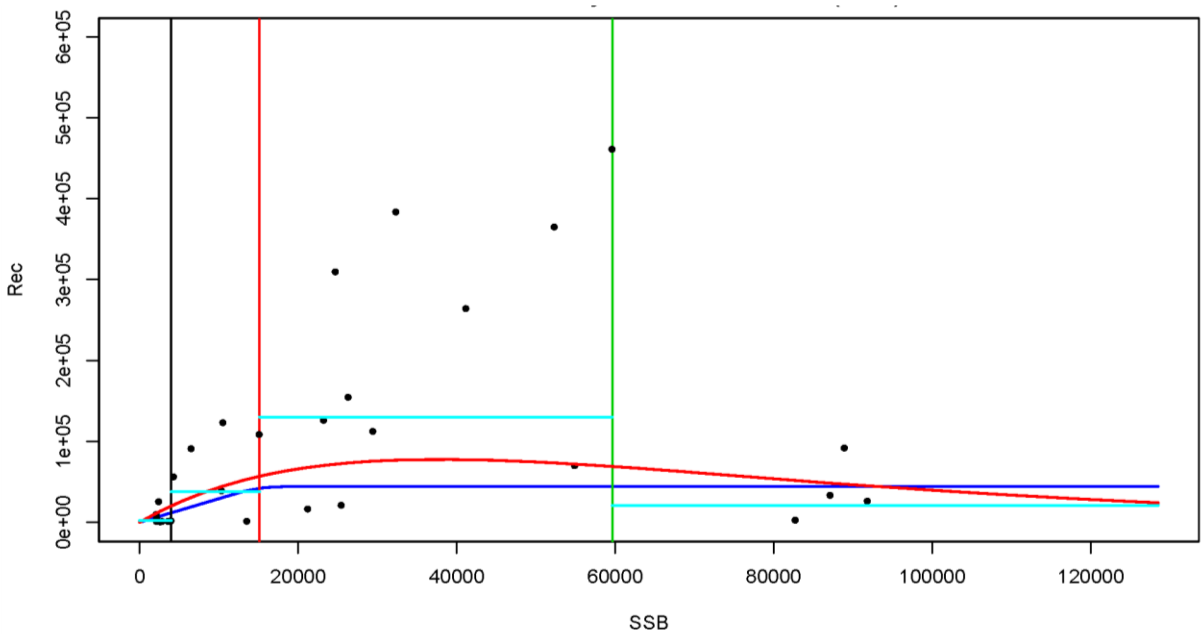

Figure 5. Historical SSB/recruit pairs (posterior medians) for the base case OM, with the SSB divided into bins with cut-offs at SSB_{1997} (black line), SSB_{2007} (red) and SSB_{2010} (green). A segmented regression with a break point at SSB_{2007} and a Ricker curve fitted to years with SSB > SSB_{1997} are shown by the dark blue and red fitted lines respectively. The sky blue lines represent the geometric mean of historical recruitment within each SSB bin.

e) Survey indices in the projections

Three methods were presented for the estimation of the errors in the survey indices to be used as inputs to the Management Procedure (MP) (SCR 19/005); two were based on the total biomass and one on numbers-at-age. In all cases, the aim is to estimate the error (ε) in a regression of real survey indices against corresponding estimated index values in the historical period.

Method 1:

This method is based on total biomass. Three cases were considered using respectively the whole data series, only those years with SSB<B_{lim}, and only those with SSB≥B_{lim}. The actual survey biomass index by year and a corresponding estimated index derived from the OM numbers at age, survey catchability at age and weight at age by year are compared over the historical period using the regression:

$$ln(Iw_y) \sim 0 + 1 * ln(IwEst_y) + \varepsilon$$

where:

Iw_y is the "real" biomass of the survey by year estimated by the swept area method,

$IwEst_y$ is the total biomass of the survey by year from the numbers-at-age, obtained from the OM numbers at age, catchability-at-age and mean weight-at-age in the survey,

$\varepsilon \sim N(0, \sigma)$, and with σ estimated using the following years:

y = case one: 1988-2017 (whole series)

case two: 1995-2006 (SSB<B_{lim})

case three: 1988-1994, 2007-2017 (SSB≥B_{lim})

Method 2:

This is a numbers-at-age based method and thus relies of the availability of reliable age length keys (ALK). It corresponds directly to the observation equations used for the survey index-at-age in the Bayesian SCAA model agreed at the 2018 benchmark:

$$lnI_a^y \sim N\left(lnIEst_a^y,\ CV = 0.3\right)\left(lnIEst_a^y,\ \sigma CV = \sqrt{ln(1+CV^2)}0.3\right)$$

with $CV = 0.3$,

lnI_a^y is the observed numbers-at-age by year in the survey

$lnIEst_a^y$ is numbers-at-age by year in the survey generated from the results of the OM

$y = 1988 - 2017$ and

$a = 1 - 8 +$

Method 3:

This method also uses total biomass, but in this case the estimated index is calculated from the total population biomass estimate from the OM (B_y) combined with a single survey catchability (q) independent of age:

$$ln(Iw_y) \sim ln()q) \ + 1 * ln(B_y) + \varepsilon$$

$\varepsilon \sim N(0,\sigma)$

where σ is estimated based on years y = 1988 - 2017

Autocorrelation of the regressions was analyzed (SCS Doc. 19-05), and it was concluded that there was high autocorrelation in all cases except for method 1 case 3 (using only years where SSB≥B_{lim}), with the highest autocorrelation in the case where only years in which SSB<B_{lim} were fitted. Given the problems of age reading for this stock, it is considered that methods that do not use ages are more appropriate. Additionally, the results of methods 1 and 2 were very similar.

It was therefore decided to move forward based on method 1, fitting only the years in which the SSB ≥ B_{lim}.

f) Recruitment index and CV

The (initial) MPs considered so far for cod also used an index of abundance at age 1. To produce this index in the future it was agreed to use the Method 2 explained above, with CV=30%below Blim. Having looked at regression of ln(R) vs ln(Rest), it was agreed to run an additional robustness trial with CV=50%

g) Biological parameters in projections

In SCR Doc. 19-001, three different methods were considered to generate biological parameters for use in projections including two bootstraps, i.e. resampling of values from past years (these two options differ in the time period over which the re-sampling takes place) and one similar to a "random walk" procedure. An additional idea considered was to use a growth model to develop density dependent weights and maturity parameters.

The methods presented at this meeting were:

a. 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.
b. ProjOM2: As ProjOM1, but using the entire period for the bootstrap (1989-2017). This OM would reflect what would happen if the conditions observed in the past are randomly repeated in the future.

c. ProjOM3: As ProjOM2, but incorporating correlation between years, applying an idea similar to a "random walk". The idea is to start the projection period by randomly resampling one of the observed years (1989-2017), for each iteration of the MSE, and take all the projection parameters from that year. The next projection year we could make a bootstrap with a time window of 5 years centered around the year previously resampled. In the last year (2017) or in the first year (1989), only a window of 3 years (mean ± 2 years) is taken, and in the previous (2016) or next years (1990), a window of 4 years around the mean is taken. The potential biases that may arise by oversampling the years at the very beginning and very end of the time period using this approach were discussed and will be monitored during subsequent work.

Projections were run in all cases using 1000 iterations in the MSE. It was observed in the results presented that the bootstrapping methods produced very large inter-annual variation in parameters. Some of the problems could be avoided by sampling change between consecutive years (delta) rather than actual past values, however this can result in too extreme values.

In the random walk method, it was observed that maturity at age values in the projection increase for some ages over time. Random walk is initiated from a random year in the past and the subsequent years are samples from a 5 year window around that (2 before, 2 after). All the biological parameters are taken from the same year (as in the bootstrap methods). There seems to be a very big jump in the value from the last year of the historic to the first of the projection: this may be related to the fact that the most recent values are very low compared to the rest of the series. It was, therefore, agreed by the meeting that the first year of the projections can only be drawn from the last three years of the historical period (2015-2017) in order to begin the simulations with recent conditions. It was noted that this method could result in over-sampling of the most recent years, although to a lesser extent than the first bootstrap made (ProjOM1).

In general, it appears that the short bootstrapping period method has more issues that the long period and that the random walk is preferable to either.

SC considered work carried out by Thomas Brunel to develop a growth model incorporating density-dependence (SCR Doc. 19-03). The model used is the classical von Bertalanffy equation, modified so that growth is reduced when stock size increases. The correlation between growth and temperature was also analyzed. This empirical model was able to reproduce the trends in the observed historical weight-at-age data. Most of the changes in growth operate on individuals during the first 2 years of their lives, and less variability occurs during the growth of the subsequent years. Growth during the first years (length at age 1) was inversely related to the size of the cohort (log(R)). Growth during second year (but also later ages also less significantly) correlated best with total stock biomass.

This framework was proposed to simulate future weights at age for 3M cod in which changes in growth are driven by changes in stock size, thereby reproducing a density-dependent growth mechanism. It was agreed that this will be further developed as a potential additional OM variant. The OM to be designed would use this model to estimate the mean weights at age in the future catches and stock, but it would be necessary to decide how the values at age of the other necessary parameters such as -maturity, M, etc are obtained. It was noted that both maturity and M are likely to be density dependent.

This will be further developed and evaluated as an additional OM variant in MSE at the June SC meeting.

It was agreed that OM runs going forward will use the following methods to generate biological parameters:

- Random walk starting 2017
- average values of last 3 years for all biological parameter (maturity, weight, selectivity, M).
- continue development of density dependent OM (for June).

h) Fishery Selectivity / Partial Recruitment

For the fishery PR pattern, it was agreed to use the average of the last 3 years (independently for each iteration of the MSE) for all the OMs that are developed, since it is considered that the recent fleets composition as well as the fishing gears is the most realistic for the projection period. It was also noted that there had been substantial selectivity changes over the past decade and there was no reasonable approach to defensibly project such variations in the simulations.

5. Other operating models to be developed prior to June SC meeting

In addition to the low recruitment scenario (see Section 4.d), no other OMs are currently under consideration, however SC does not rule out the possibility that other OMs may be developed for consideration by the June 2019 SC meeting.

6. Estimation of reference points for operating models

Assuming that the reference points will be interpreted as a characteristic of the "real" population and not as a characteristic of a "real" population together with a stock assessment (i.e. not as control parameters to be used within the definition of the HCR), it would be more appropriate to estimate the reference points for each OM and iteration as this is what represents a potential "real" population in the MSE.

B_{lim}

Estimation of B_{lim} from the Base Case OM in June SC 2018 was by visual examination of the stock recruit historical pairs, to identify an SSB level below which only low recruitments are observed (SCR Doc. 18-042). This resulted in a B_{lim} value of 20 000t.

Because absolute levels of SSB and R will differ according to the OM used, it was agreed that B_{lim} in the MSE should be computed separately for each OM. During the present meeting, two methods of determining B_{lim} were considered, one based on visual identification of SSB levels below which good recruitment has not been observed, and the second based on identifying an SSB level from which recovery could occur in one generation given favourable conditions (SCR Doc. 19/004).

In method 1, B_{lim} was estimated visually, as previously, for each candidate OM (Figure 6). In all cases the resulting estimate fell between the SSBs of 1994 and 2007. In order to generalize this approach to the simulations, an automated method of estimating B_{lim} based on linear combination of the median values of SSB_{1994} and SSB_{2007} across multiple OM iterations was tried. This yielded results very similar to the visual assessment approach (SCR Doc. 19-04). However, there were concerns that visual assessment of reference points may be strongly influenced by the few extreme high recruitment values observed in some past years and that, as a result, a number of years with relatively high recruitment contributing to the recovery of the stock in the 1990s would be considered to be below B_{lim}.

Method 2 is based on an approach presented in the Report of the NAFO Study Group on Limit Reference Points (SCS Doc. 04-12) and defines B_{lim} as *the SSB from which the stock could recover to the "safe zone" in one generation under good productivity conditions*. SSBs for the period 2005-2007 seem to meet this condition in all of the proposed OMs, allowing for recovery of the stock after many years of collapse, and so the average SSB over this period was used. Values estimated by this method are considerably lower than those estimated with the B_{lim} Method1.

After discussion, the meeting finally agreed to use SSB_{2007} as B_{lim}, as this is the highest SSB value of the three years (2005-2007) in which good recruitment leading to stock recovery was observed in the past. The highest value, rather than the mean of the three, was chosen to give a degree of security.

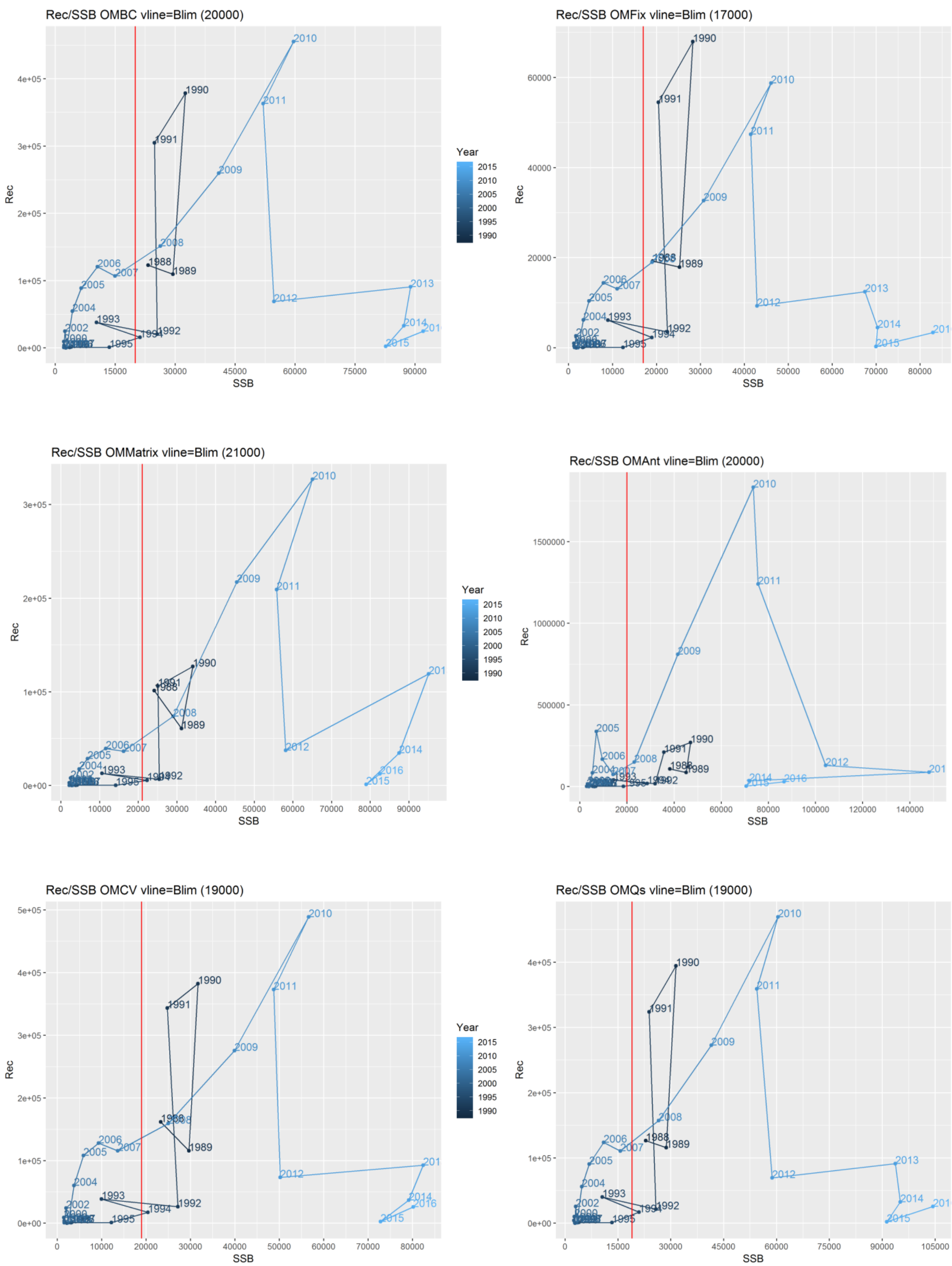

Figure 6. Medians of the recruitments and SSB of the different candidate OMs (conditioned to the data). The vertical red line is the proposed value for B_{lim} by OM.

F_{MSY}

SC agreed during its June 2018 meeting that the method for estimation of F_{MSY} in cod 3M would be to use $F_{30\%SpR}$ as a proxy. Results presented in this meeting indicated that $F_{30\%SpR}$ is a fairly robust F_{MSY} proxy for this stock. For the MSE, it was agreed that this was an appropriate proxy, and that it should be calculated separately for each OM and iteration. One issue with this is that the value of $F_{30\%SpR}$ will be very sensitive to the selection of biological parameters and the great variability observed in the past for this stock is likely to be problematical.

To solve this problem, it was proposed that a dynamic $F_{30\%SpR}$ could be estimated using the average of biological parameters of the most recent three years as inputs values. This means that for each OM and iteration each projected year we would estimate one F_{MSY} with the inputs of the mobile three years mean.

It was therefore agreed that $F_{30\%SpR}$ computed dynamically within the projections going forward will be used as a proxy for F_{MSY}

B_{MSY}

Due to issues related to B_{MSY} estimates, no B_{MSY} value has been proposed as an *a priori* performance statistic. If managers need B_{MSY} as a target to meet convention obligations, then we would be able to calculate a value retrospectively corresponding to the management strategy that would give highest long term yield values in the projections and the associated biomass.

7. Development of performance statistics

Table 1 is an initial table developed during the 2018 WG-RBMS meeting (SC-COM Doc. 18-02, Table 1). According to the agreed workplan for the 3M Cod MSE, the Technical Team should develop proposals for a full set of MO/PS/Risks, which should then be updated, and possibly finalized, by the WG-RBMS meeting in April 2019. Some proposals were included in SCR Doc. 19-001, but the SC meeting did not have time to fully consider them. The Technical Team will further develop this work for presentation and discussion at the WG-RBMS meeting in April 2019.

It was suggested that two additional performance statistics could be included in the new proposal, one for measuring the probability of the stock collapsing (it was left up to the Technical Team to make a proposal as to how this may be defined), and another one for the proportion of the stock biomass in the plus group. It was agreed that these statistics should be tracked during ongoing testing work by the analysts and would be presented for discussion at WG-RBMS. Further, the importance of having sufficient conservation-based PS was highlighted by the meeting and should be considered by WG-RBMS.

It was also noted that the probability of something happening over a period of years, e.g. $P(SSB_y<B_{lim})$, depends on how these probabilities are measured over the period of years. As there was no time to consider this issue during the SC meeting, it was deferred to WG-RBMS.

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.

Table 1. Performance Statistics and Criteria development for 3M Cod MSE by WG-RBMS, 2018. 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**
$P(B_{20\mathbf{YY}} < B_{MSY})$	$P \leq 0.5$	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; α = 0.10 if $B_{2018} < 0.3B_{\mathrm{MSY}}$; 0.25 if 0.3 $B_{\mathrm{MSY}} < B_{2018}$	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”

8. Guidance for development of Candidate HCRs

It was agreed by the 2018 WG-RBMS meeting (SC-COM Doc. 18-02) that index-based rules were preferred, but that SC could continue to consider model-based HCRs. The analysts working on the 3M Cod MSE noted that there is a substantial increase in complexity required for performing MSE on model-based HCRs using an age-structured stock assessment model (such as the model agreed at the 2018 benchmark) and that it would not be possible for them to evaluate HCRs of this type under the current timeline for the MSE.

Restrictions to maximum changes in the TAC between consecutive years, in terms of percentages and/or absolute numbers, should be considered for potential inclusion as part of the HCR. Such restrictions were not included in the HCRs presented at this meeting (see below), but will be considered in future work. It was noted that given the expectation for short-term decline in this stock (based on the June 2018 SC advice) that it will be necessary to consider the interaction of the starting TAC and any potential constraints on inter-annual change.

Initially, all the HCRs developed for this meeting have as their starting point the level of TAC approved for 2019, which is 17500 tons. Other possible starting points to apply the HCRs will be explored during ongoing MSE trials.

For the coming RBMS meeting, the SC chair will aim to develop a graphical representation of each of the rules which will allow the WG to visualize potential changes in TAC that would result from application of the rules under different parameterizations (review the percentage change in TAC from the HCR calculation across a range of input parameters/stock size change independent of any 3M cod dynamics).

Several HCRs were initially developed by the analysts (details given in SCR Doc. 19-001) and presented at the SC meeting. A summary is provided here.

a) Model free slope based

The Model Free Slope-based HCR is similar to that included in the approved Management Strategy for Greenland halibut (NAFO, 2017b). Unlike the Greenland halibut HCR, in the HCR examined so far for cod the λ parameter is determined by the recruitment ratio (RR), which is the ratio between the recent 3-year average recruitment and the long-term average; the slope is calculated from the log total biomass indices for the last 4 years.

For technical reasons, in order to avoid the HCR becoming trapped in a 0 TAC, the Technical Team included a minimum TAC of 1 000 tons in the HCR; this means that when the application of the HCR gives a value less than 1 000 tons, the TAC is set at 1 000 tons. Setting a minimum TAC may not be necessary if the HCR includes a constraint whereby the TAC can not change by more than a certain percentage between consecutive years, although this would depend on the actual details of how/when exactly the restriction on TAC change was implemented.

The HCR formulation presented at the meeting is:

$$TAC_{y+1} = TAC_y \times (1 + \lambda_y \times slope_y), \text{ where}$$

$slope_y$ is calculated from the log(total survey biomass) for years y-1, ... , y-4, and λ is defined depending on the sign of the slope, as follows:

Sign of slope	Value of λ
positive	min(1, RR)
negative	2-min(1, RR)

with RR defined as:

$$RR = \frac{(R_{y-1} + R_{y-2} + R_{y-3})/3}{mean\ R_{1988-2017}}$$

It was agreed during the meeting that an extra parameter should be added to this HCR to act as a “tuning” parameter to allow direct control over how the rule will respond to changes in slope. That is, add a new parameter α, as follows:

$$TAC_{y+1} = TAC_y \times (1 + \alpha\lambda_y \times slope_y).$$

b) Model Free Target HCR

The Model Free Target HCR is also similar to that included in the approved Management Strategy for GHL. As in the Greenland halibut case, the term J_y is taken to be the average of the total survey biomass indices over the 3 most recent years divided by a “target survey biomass”, defined as proportional to the average of the total survey biomass indices over some pre-specified historical period. For cod, as a first step, it was decided to define I_{target} as equal to the average of the survey biomass indices for the years 2008-2017. This is the most recent period during which biomass has been above B_{lim} and with a fairly constant level of exploitation, although very low exploitation according to the benchmark-agreed stock assessment.

For the same reasons described for the Model Free Trend HCR, in this case the Technical Team also included a minimum TAC of 1 000 tons in the HCR.

The HCR presented at the meeting has the following formulation:

$$TAC_{y+1} = TAC_y \times (1 + \lambda_y(J_y - 1))$$

where

$$J_y = \frac{(I_{y-1} + I_{y-2} + I_{y-3})/3}{I_{target}}$$

with

$$I_{target} = \alpha \frac{1}{10} \sum_{y=2008}^{2017} I_y$$

with $\alpha = 1$.

The value of γ was set depending on whether J_y is bigger or smaller than 1, as follows:

J_y	λ parameter
≥ 1	Min(1, RR)
<1	2-Min(1, RR)

with RR defined as for the Model Free Trend HCR.

As for the Model Free Trend HCR, it was agreed during the meeting a “tuning” parameter should be considered in this HCR. Whereas α, in the J_{target} definition, might be used as a tuning parameter, other options are possible.

c) Target Harvest Rate HCR

This HCR is similar to the HCRs used for several Icelandic stocks. For example, the Icelandic cod HCR 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 $MGT\ B_{trigger}$ =220 000 tons.

This HCR has not yet been implemented in trials for the 3M cod MSE, but it is of interest as it is the only HCR that aims for a constant level of exploitation (with safeguards when the stock biomass estimates fall below some pre-determined value). It was agreed to consider the possibility of implementing an HCR similar to this one but based directly on survey biomass indices instead of the biomass estimates from a stock assessment. The SC considers that a harvest rate of 0.2 would be a good starting point to test. This HCR will be run in the MSE only if time permits.

d) Model Based HCR

Taking into account that one of the general lines of the WG-RBMS to develop HCRs is that they prefer model free HCRs and looking at the very tight 3M Cod MSE schedule, the SC considers model-based HCR to be the last priority for this MSE.

e) Zero catch scenario

It is proposed that a scenario with zero catch should be included in the MSE as a robustness test, to see how the OMs would perform under no fishery and to allow managers to evaluate the differential impact of multiple HCRs.

9. Specification of MSE trials going forward

Table 2 contains the variables, both HCR and OMs, with which will be included in on going MSE trials and the names of the different scenarios that arise from the combination of both that technical team propose. For example the name of the scenario Model-Free Slope with an alpha value=1.0, without TAC constrain, with a starting point =17500t. applied to an OM with M vector, q flat shape (four groups), recruitment Bin Ricker and with the biological parameters random walk will be the following “. MFS_A10_Cnone_SP0_MV_QF_BR_RW “.

Table 3 shows the full list of combinations of variable that will be run as OM scenarios in MSE trials going forward, together with the standardized OM nomenclature that will be adopted. All these scenarios will be run for the slope and target HCR with different parameters values except for those in red, which will be run as “robustness trials” with slope HCR only.

Table 2. Specifications of the scenarios. In bold, the base case OM.

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

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

Table 3. Priority scenarios for the 3M cod MSE for the April RBMS meeting. The Scenario in bold is the base cases. Scenarios in blue (low recruitment) will be developed for the June 2019 SC meeting, while all other combinations will be run before the April 2019 WG-RBMS meeting. The scenario in red is a "robustness trial" to be run with slope HCR only

	M			Q		R			BP			RUN
	MV	**MG**	MS	**QF**	QD	**BR**	**HS**	LBR	**RW**	**3Y**	DD	Y/N
1. MV_QF_BR_RW	**X**			**X**		**X**			**X**			
2. MG_ QF_BR_RW		X		X		X			X			
3. MS_QF_BR_RW			X	X		X			X			
4. MV_QF_BR_3Y	X			X		X				X		
5. MG_ QF_BR_3Y		X		X		X				X		
6. MS_QF_BR_3Y			X	X		X				X		
7. MV_QF_BR_DD	X			X		X					X	
8. MG_ QF_BR_DD		X		X		X					X	
9. MS_QF_BR_DD			X	X		X					X	
10. MV_QF_HS_RW	X			X			X		X			
11. MG_ QF_HS_RW		X		X			X		X			
12. MS_QF_HS_RW			X	X			X		X			
13. MV_QF_HS_3Y	X			X			X			X		
14. MG_ QF_HS_3Y		X		X			X			X		
15. MS_QF_HS_3Y			X	X			X			X		
16. MV_QF_HS_DD	X			X			X				X	
17. MG_ QF_HS_DD		X		X			X				X	
18. MS_QF_HS_DD			X	X			X				X	
19. MV_QF_LBR_RW	X			X				X	X			
20. MG_ QF_LBR_RW		X		X				X	X			
21. MS_QF_LBR_RW			X	X				X	X			
22. MV_QF_LBR_3Y	X			X				X		X		
23. MG_ QF_LBR_3Y		X		X				X		X		
24. MS_QF_LBR_3Y			X	X				X		X		
25. MV_QF_LBR_DD	X			X				X			X	
26. MG_ QF_LBR_DD		X		X				X			X	
27. MS_QF_LBR_DD			X	X				X			X	
28. MV_QD_BR_RW	X				X	X			X			

10. External Reviewer perspectives.

The external reviewers' reports are included as Appendix IV

11. Closing

The meeting Chair thanked all the participants for their contributions to the meeting. The volume of work provided by the technical team to allow a discussion of specific issues and points relating to the MSE rather than having abstract discussions was vital to the success of the meeting. The participation and contributions of highly-qualified external reviewers was noted as a particular strength of this meeting, and the Chair thanked the reviewers for their contributions. In addition, gratitude was expressed to NEAFC for hosting the meeting and to the Secretariat for their support prior to and during the meeting.

The Chair wished all participants a pleasant return journey and the meeting was closed at 15:00 on Friday January 31st .

12. References

Charnov, E.L., Gislason, H. and Pope, J.G., 2012. Evolutionary assembly rules for fish life histories. Fish andFisheries. doi:10.1111/j.1467-2979.2012.00467.x.

Chen, S., and Watanabe, S., 1989. Age Dependence of Natural Mortality Coefficient in Fish Population Dynamics. Nippon Suisan Gakkaishi 55:205-208.

Gislason, H., Daan, N., Rice, J.C., Pope, J.G., 2010. Size, growth, temperature and the natural mortality of marine fish. Fish and Fisheries. 2010;11:149–158. doi: 10.1111/j.1467-2979.2009.00350.x.

APPENDIX I- PROVISIONAL AGENDA

Provisional Agenda- 3M Cod MSE

London, UK – 28-31 January 2018

Scientific Council Chair: Brian Healey

Vice-Chair of Scientific Council & STACREC Chair: Carmen Fernandez

1. Opening - Introductions, meeting arrangements
2. Appointment of rapporteur
3. Adoption of agenda
4. Documentation of results and decisions of the MSE.
5. Background, Terms of Reference (Chair)
6. Introductory presentations
    a. MSE timeline, including required outcomes from SC.
    b. Outcomes of the 2018 3M cod benchmark
7. Models currently under consideration for generating operating models (OMs):
    a. Bayesian SCAA
    b. Bayesian XSA?
8. Review OMs and approve initial set of OMs, and/or suggest further refinements.
9. Estimation of reference points for operating models
10. Other operating models to be developed prior to June SC meeting
11. Develop advice for RBMS regarding quantification of objectives/performance criteria and constraints
12. Give guidance for development of Candidate Management Strategies and/or HCRs (if required)
13. Specify MP "trials", including operating model variants to be fit, projection specifications, observation models for future generated data, and performance statistics (initial quantification of objectives)
14. External Reviewer perspectives.
15. Conclusions
16. Report timelines
17. Adjournment

APPENDIX II: LIST OF DOCUMENTATION

SCR Documents

Document	Serial Number	Author (s)	Title
SCR Doc. 19-001	N6903	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	Potential Operating Models, Harvest Control Rules and Performance Statistics for the NAFO 3M Cod MSE.
SCR Doc. 19-002	N6904	Diana González-Troncoso and Antonio Ávila de Melo	3M cod MSE: Different OMs based on M calculated in steps (in prep.)
SCR Doc. 19-003	N6905	Thomas Brunel	Investigation of a growth model incorporating density-dependence for the Cod 3M management plan simulations.
SCR Doc. 19-004	N6906	González-Troncoso, D., González-Costas, F. and Fernández, C.	Estimation of the reference points for the different OMs in the Cod 3M MSE.
SCR Doc. 19-005	N6907	Carmen Fernández, Diana González-Troncoso, Fernando González-Costas, Thomas Brunel, Jose de Oliveria, Agurtzane Urtizberea and Panayiota Apostolaki	3M cod MSE: Survey indices in the projection years (in prep)
SCR Doc. 19-006	N6908		Specifications of the OMs and the projections for the 3M cod MSE (in prep.)

SCS Documents

Document	Serial Number	Author (s)	Title
SCS Doc. 19/04	N6911	NAFO	Report of the NAFO Scientific Council Flemish Cap (NAFO Div. 3M) Cod Stock Management Strategy Evaluation (MSE).

APPENDIX III: PARTICIPANT LIST

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APPENDIX IV: REVIEWERS' REPORTS

Dr. Daniel Howell

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Review of the *NAFO Scientific Council Flemish Cap (NAFO Div. 3M) Cod Stock Management Strategy Evaluation (MSE)* meeting, 28–31 January 2019 in London, United Kingdom

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Introduction

The overall impression of the history of this stock is of a fairly short time series with a large amount of stock dynamics, including both a period of extended recruitment failure followed by a short-lived period of high recruitment. Associated with this have been changes with in both weight and maturity at age. Consequently, simulating this into the future is going to be difficult, and it is unlikely that there will be any one clear ideal approach.

It should noted that the meeting process involved extensive participation from the reviewers in a collaborative approach. Consequently, the main text of the final report already includes the concerns of the reviewers, and this review will therefore attempt to highlight key issues and comment on the overall process.

The meeting was charged with the following tasks.

- Review OMs and approve initial set of OMs, including the acceptability of their conditioning, and/or suggest further refinements
- Approve Projection Specifications
- Comments on initial set of HCR (if required)

It is the judgement of this reviewer that the meeting achieved these goals. There was a review of the initial set of OMs and their conditioning, which resulted in several changes from the initial proposals. The overall specifications for the projections seem appropriate, with the proviso that this should continue to evolve as the work continues. A limited set of comments on the set of HCRs was given, although there was limited time and again these will need to be refined during the ongoing work.

Recruitment

The recruitment pattern is extremely difficult to simulate with any degree of certainty. The combination of a single period of poor extended extremely poor recruitment followed by a shorter period of extremely high recruitment presents a major difficulty in modelling. This is compounded by having only a single example of each extreme in the tuning series, makes it very difficult to assign a probability of occurrence to either the recruitment failure or the recruitment peak. The meeting attempted to produce a recruitment function for the simulations that could reproduce the historical patterns. Given the difficult historical data, this reviewer considers that the proposed recruitment function is a reasonable approach. It would be advantageous to have some sensitivity tests around this function to see how sensitive the MSE results are to the specification of the recruitment function

Natural Mortality

There is evidence for two different variations in natural mortality arising from ecosystem/multispecies effects. One is to do with cannibalism, where a high SSB can impose a large mortality on the recruits. The other is presumably to do with food limitation, where very large yearclasses have experienced higher mortalities at young ages. Both of these need to be considered in the simulations, as excluding either could lead to unrealistically high stock simulations. The revised method of estimating M-at-age in two-year blocks gives both of these. It may be that two years is an un-necessarily fine timestep, analysis at this meeting suggest that simply splitting between the highest stock sizes and the other years may be sufficient. This approach is regression-based and does not include process-based effects. The Gadget based approach does have explicitly process-based cannibalism, but does not account for food limitation. The proposed approach of using both as potential OMs is a good one. However, this reviewer would stress that the time varying (2-year) estimate is the only proposed method for estimating M that accounts for this variability.

It seems reasonable that the scenario of M=0.19 for all ages has been dropped. This seems an unrealistic pattern by age, one would expect higher mortalities for the youngest fish.

HCRs and OMs

The structure of the simulations seems adequate to test out the proposed HCRs. Even where the HCR is slope-based, it is possible to compute the Bmsy and msy yield by post processing the results.

This reviewer would be highly concerned if there is a minimum catch imposed on the HCRs. At present a 1000 tonne minimum catch is imposed in order to avoid the difficulties in a slope-based HCR once a zero catch is reached. Such a minimum ctach is high enough to wipe out the stock during a prolonged recruitment failure. Historically when the stock collapsed catches were reduced to a much lower level (well under 100 tonnes per year), so a more realistic minimum catch level should be used.

The risk criteria for the HCRs are not yet fully defined. For example, what is actually meant by a specific probability of dropping below Blim. These do not need to be specified in this report, but they do need to be specified before the final MSE runs are made.

The proposal of the meeting for 27 candidate OMs seems reasonable, but involves a significant amount of work. Given the tight timescale, the amount of work may be unreasonable. It may well be that some of the combinations are not realistic. This will be revealed by the diagnostic run of the model with F=0, which may allow some of these combinations to be removed. Further, if several of the OM combinations turn out to be very similar to each other, then the set of OMs can be reduced further. It is possible that further reductions in work time are required, if this is the case then some of the scenarios could be reduced the status of a robustness test. Since this would be a single variant of the base case, the number of simulations required would be reduced. I would not recommend that the variable mortality scenario be downgraded in this way, as this may turn out to be a significant driver for this stock.

Communication

Communicating the results and configuration of the MSE is always a challenge in MSE work, but will be more difficult in this case, given the variable history of this stock and the short timespan available for the work. It is important that work on communicating with managers and other stakeholders not be rushed in order to focus on the technical modelling work.

It is important for the group to explain not just the choices that were made, but also the implications of those choices. To give an example, consider the choice to estimate selectivity for simulations from the average of the last three years. Given that the overall fleet is a composite of different gear types, this is implicitly assuming that there will be no significant change in the distribution of catches by gear over the simulation period (along with no major changes in technical regulations). This is not a weakness, such choices are an inherent part of producing a constrained set of simulations to test. However, it is important to make these features of the runs clear when the results are communicated.

Multispecies modelling

Cannibalism on the young cod is a function of the amount of cannibalistic larger cod and the amount of other food for those cod to eat. Fully modeling this would require a full multispecies OM. This is technically possible, and the Gadget multispecies model has been connected in the FLR/A4A MSE system. Similar code would link the model into the FLBEIA system. There is not time in the current work to examine this, but it should be noted as a possibility for future MSEs in this region.

Summary and Conclusions

This reviewer would accept the outcomes of the work at the meeting as the basis for a valid MSE exercise. Not all of the details have yet been finalized, but the framework presented in the report is a viable basis to build upon. I would stress, however, the need to be flexible as results from the simulations become available.

Consequently, the possibility should remain open for the strategy presented to be adapted as more work is done.

The recruitment pattern remains a concern, and it does not seem likely that any modelling approach will be able to estimate the actual likelihood of an extended recruitment failure reoccurring. Consequently any communication of the HCRs and simulation results should include the addition that a prolonged recruitment period observed in the real fishery may require a closure of the fishery regardless of the performance of the HCRs at higher stock sizes.

Finally, it should be noted that conducting a high quality MSE exercise is a scientifically demanding task, which requires significant commitment in personnel and time. This reviewer notes that, given the technical challenges associated with this stock, the timescale for conducting this MSE seems rather challenging, and any unforeseen delays could impact on the timing of delivery. It is therefore possible that the timespan for delivery of the MSE results may need to be adapted, or that the set of OMs may need to be reduced. Even if this current exercise is completed on time, then it is strongly recommended that a longer timespan should be allocated to future MSE work. Such a more realistic timescale would improve both the quality of the work and the likelihood of being able to complete the work on time.

Jim Ianelli

Alaska Fisheries Science Center, USA.

Review of the NAFO Scientific Council Flemish Cap (NAFO Div. 3M) Cod Stock Management Strategy Evaluation (MSE) meeting, 28–31 January 2019 in London, United Kingdom

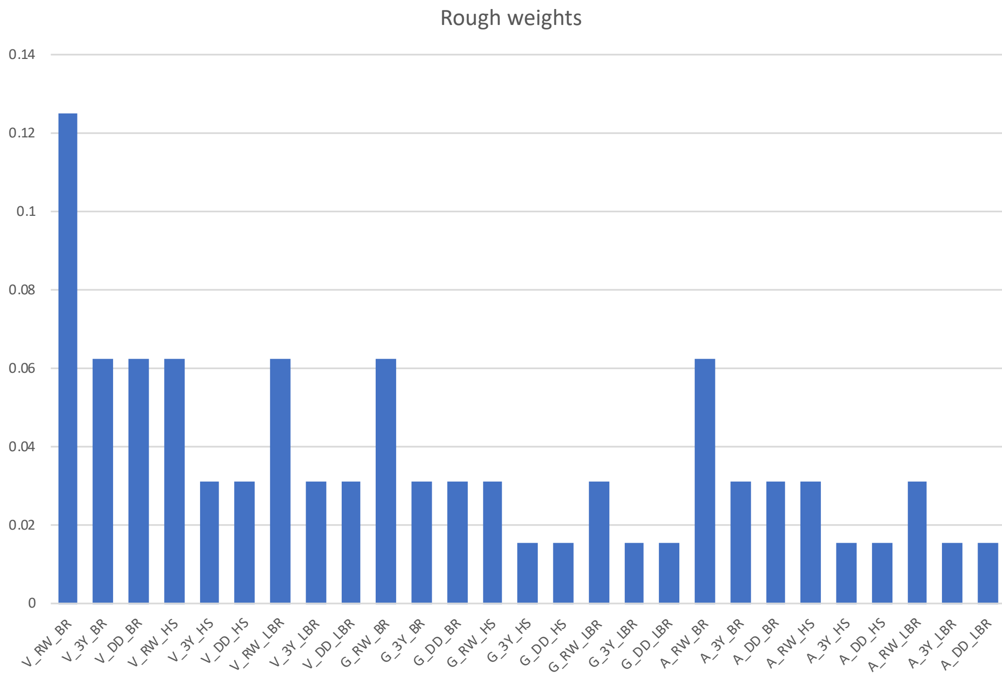
Developing operating models (OM) models provide opportunity for including plausible biological and ecological features for simulating the types of data than can be used for testing strategic and tactical management approaches. In fisheries science meshing rigorous quantitative statistical models with plausible ecological and biological attributes to form rational conservation and management measures is an important and key activity. The work presented at this meeting relied extensively on the model conditioned during the benchmark and one purpose of this workshop was to help refine operating model considerations. In general, the entire schedule for this development is highly compressed with many moving parts and plans for completing a large number of tasks in a short period. The cost for this may be a lack of opportunity interactions among managers and experts. In my view, a good process for an MSE will clearly consider multiple objectives, characterize uncertainty given available data and understanding of biology, involve stakeholders appropriately, and selection of candidate management procedures be based on agreed performance metrics and tradeoffs. Noting that the schedule is very ambitious, the capabilities of the experts and the work completed to date is of high quality. Nonetheless, I offer the following recommendations / comments on specific topics:

1) **Biological age-specific schedules.** To the extent practical, use some biological functional form in place of bootstrap/random walk scheme for projecting patterns in the future mean weights-at-age within the OM. The approach shown by the Brunel paper, and the one I demonstrated with a spreadsheet supplied during the week (which used a cohort-specific impact), seems preferable since it provides a plausible mechanism (density dependence). As shown in the presentation provided at benchmark and again during this week, the historical changes in mean body mass at age have a significant impact on changes in spawning biomass (more than changes in maturity at age too). This has repercussions for future rebuilding plans and reference point calculations.
2) **Natural mortality.** Drop fixed M=0.19 for all ages and years. The rationale for including was for historical reasons that no longer apply for OM consideration. As there were no statistical nor biological reasons proposed for including this model configuration, it should be dropped. Also, the complicated approach of "Antonio" could be simplified (e.g., random walk approach demonstrated) and/or merged with an age- and time- varying approach. Reducing the number of OMs to consider without losing the biological plausibility and uncertainty would be an advantage going forward.
3) **Partial recruitment.** Selecting partial recruitment (fishery selectivity) for future catch scenarios should be wary of assumptions. For example, using the past PR without considering the age composition it's applied to may lead to errors in specified fishery mortality. E.g., in years where a strong year class is apparent, the fishery might focus on that year-class due to better CPUE (or avoid it depending) which can affect the relative selection.
4) **Software**. Whereas there is already significant investment in the application, I think it would be advantageous to abandon the WinBugs implementation. To me, this software seems outdated and slow for developing such a complicated set of OMs and testing. The group noted that runs needed to happen on a cluster of compute nodes back at their science centers. For such a short time series, only one sex and one fishery, even with estimating hundreds of parameters (e.g., time-varying processes such as natural mortality) should be possible and was demonstrated. It was also unclear how FLBEIA was used but it certainly looked interesting (were performance statistics based on any economic outputs?).
5) **Stock-recruit relationship**. Rather than dealing with the difficult problem of how to model recruitment failure, I think concerns about future recruitment failures should be a part of the control rule or meta-analysis. That is, apply a stock-recruit relationship (and auto-correlation / variability) that conforms more closely to other cod stocks and apply a hard performance statistic (e.g., probability that the stock drops below 2007 level) to tune candidate management procedures. A metarule or exceptional circumstances could be specified if there is clear evidence of a recruitment failure outside of the range tested.

6) **Blim and reference points.** A significant time during the week aspects of reference points were discussed. Given a wide range of issues, and the fact that some long-term "brute force" simulations to evaluate B_{MSY} given some different stock-recruit relationship assumptions.
7) **Reference set versus robustness tests.** Management procedures should be "tuned" to satisfy a set of objectives (e.g., ensuring that the probability of spawning biomass dropping below a specified value is "low") using the reference OM (or set of OMs). Candidate MPs can then be subjected to robustness tests so that tradeoffs can evaluated and find which of the MPs perform the best (and are robust to plausible—but typically unlikely—OM scenarios). Keeping this distinction will be important in subsequent meetings and developments. As this overall MSE development is on an accelerated schedule and efficiency in OM selections is important, categorizing a reference set as a primary next step is important so that MPs can be designed (and after that, tested against robustness set of OMs).
8) **Harvest control rules.** The increase in effort to "catch" the fish should be a consideration. I.e., just specify TAC and assuming catch will attain that TAC without considering the level of effort needed to take that might be unrealistic. Percentage change in TAC should be included/tested.
9) **Transparency/documentation.** Some common repository for NAFO member scientists would help with transparency and will be important for designing candidate management procedures. This can help with coordinating development (e.g., using git version control (https://git-scm.com/) and some accessible repository).
10) **Exceptional circumstances.** The situation where such an event might occur was discussed in the context of specifying a management procedure down the road. For this stock in particular, the role of this may help simplify OM specifications (e.g., as suggested by how the stock-recruit relationship could be simulated). Some types of exceptional circumstances for consideration might include
    a) Observations in monitoring series outside the range tested in the OM;
    b) New knowledge;
    c) New stock assessment changes range of uncertainty;
    d) Missing data; and
    e) Clear exceptional circumstances (e.g. recruitment failure).

A table and suggested naming convention for OMs based on what was there at the end of the workshop is provided below, followed by a figure showing how the relative weights might be applied (assuming that the first case of each category gets 50% of the weight and the other two get 25% each—just as an example).

	Cases (abbreviation)	Cum. N	Cum. N	Weighting
Natural mortality	Vector (V), Gadget (G), Antonio (A)	3	3	?
Biological schedules	Random Walk (RW), 3-yr (3Y), Dens Dep (DD)	3	9	?
Recruitment	Bin_Ricker (BR), Hockey Stick (HS), Low_BR (LBR)	3	27	?


Rough weights
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
V_RW_BR
V_3Y_BR
V_DD_BR
V_RW_HS
V_3Y_HS
V_DD_HS
V_RW_LBR
V_3Y_LBR
V_DD_LBR
G_RW_BR
G_3Y_BR
G_DD_BR
G_RW_HS
G_3Y_HS
G_DD_HS
G_RW_LBR
G_3Y_LBR
G_DD_LBR
A_RW_BR
A_3Y_BR
A_DD_BR
A_RW_HS
A_3Y_HS
A_DD_HS
A_RW_LBR
A_3Y_LBR
A_DD_LBR

APPENDIX V. SUMMARY OF KEY MEETING OUTCOMES

It was agreed to liaise with WG-RBMS co-chairs to ensure a single overall "guiding and summary" document is produced for the whole 3M cod MSE process. The NAFO Secretariat should prepare the structure of the document and all meetings contributing to the cod MSE process should include in it the main results and conclusions from their meeting (if possible also with the rationale as to why the conclusions were reached). This document would refer to SCR documents or other documents, as relevant, for details. The document itself would not include much detail, but it should permit an "outsider" to follow all key points of the cod MSE process and to find all relevant information.

SUMMARY OF AGREED SETTINGS FOR OMs:

Natural Mortality for past years, i.e. until 2017 (SCR 19/001)

The following M priors and/or CVs will be used in OM variants:

- **Base Case**: M is a vector with different values per age but constant over time. M is estimated by the model using a log-Normal prior distribution with the following median and CV: medM[a] = c(1.26,0.65,0.44,0.35,0.30,0.27,0.24,0.24), cvM = 0.15
- ~~**Fixed M:** constant for years and ages M=0.19.~~ [Dropped from consideration in OMs as it is not considered realistic.]
- **GADGET:** M variable by years and ages, estimated in the GADCAP GADGET model taking into account the predation.
- **Msteps:** final version (SCR 19/002, OMsteps_3c).

Survey catchability, for past and future years (SCR 19/001)

Agreed q scenarios:

- base case (Estimates the survey qs by age groups for ages 1, 2, 3, 4+)
- 4 groups by age (1, 2, 3-6, 7-8+). This scenario for q is only for a robustness test which will use base case settings for all other variables; in principle, it will only be tested on the slope HCR.

Biological parameters for future years, i.e. 2018 onwards (mean weights at age in stock and catch, natural mortality and maturity) (SCR 19/001)

- Base Case: Random walk starting from 2017 and sampling from 2 years before or after (2 years before only for last year)
- Mean of the last 3 years, i.e. 2015-2017 (maturity, weights and natural mortality)
- Continue development of density dependent (for June) (SCR 19/003)

Selectivity for future years, i.e. 2018 onwards

- average of the last 3 years, i.e. 2015-2017, for all OMs (independently for each iteration)

Stock recruit relationship for future years, i.e. 2018 onwards (SCR 19/001)

Method 1 (Base case):

Ricker curve fitted to (SSB_y, R_{y+1}) pairs estimated for past years, i.e. until R_{2017}, for which $SSB_y > SSB_{1997}$

Consider the SSB in a future year, SSB_{yfut}:

- if $SSB_{yfut} > SSB_{1997}$, use the fitted Ricker curve with re-sampled historical values of **residuals** from years with SSB within the following bins: (SSB_{1997}, B_{lim}]; (B_{lim} , SSB_{2010}]; and SSB > SSB_{2010} – note that B_{lim} was set by the meeting at SSB_{2007}.
- if $SSB_{yfut} \leq SSB_{1997}$, re-sample from the historical values of **recruitment** from years with SSB ≤ SSB_{1997}.

Method 2:

Segmented regression with break at $B_{lim} = SSB_{lim}$ fitted to all (SSB_y, R_{y+1}) pairs estimated for past years, i.e. until R_{2017}.

Consider the SSB in a future year, SSB_{yfut}:

- if $SSB_{yfut} > B_{lim}$ resample residuals from historical years with SSB > B_{lim}
- if $SSB_{yfut} \leq B_{lim}$, resample residuals from historical years with SSB ≤ B_{lim}

Additionally, a Low recruitment scenario (low recruitment over an extended period of years) should be developed for June.

Candidate HCRs (SCR 19/001)

- Model free slope
- Model free target
- F=0 (this is not an HCR, just a way to increase understanding of OM behaviour)
- trigger/20%, i.e. a constant harvest rate of 20%, or some other value, which is reduced gradually when the stock biomass index falls below a trigger value (as a possibility if time permits)

It was agreed that some tuning parameter(s) should be introduced in the HCRs … then, it would be checked e.g. the value of the tuning parameter(s) that gives highest LT average yield, and examine trade-offs between different PS…

Generation of "observed" indices in projections, for application in HCRs (SCR 19/005)

- For the Biomass index, it was agreed to use method 1, case 3 (which estimates σ from past years, excluding the years where the SSB was below B_{lim}: Table 5, Med_3 and Figures 7-9):

  $ln(Iw_y) \sim 0 + 1 * ln(IwEst_y) + \varepsilon$, where $\varepsilon \sim N(0, \sigma)$.

- For the recruitment index (age 1), it was agreed to use Method 2 with a fixed CV of 30% (Figure 15) in the base case and with an additional robustness trial having CV = 50%

Agreements on reference points (SCR 19/004)

- Reference points will be estimated for each OM and iteration.
- $F_{30\%SPR}$ computed dynamically within the projections going forward (using in each year the average of the three most recent years) will be used as a proxy for F_{MSY}=F_{lim} – this is the same procedure applied by the NAFO SC in June 2018.
- It was **agreed** that we will use SSB_{2007} as B_{lim}; this is the highest value of the three years (2005-2007) that gave recovery in the past.
- Due to issues related to B_{MSY} estimates, no B_{MSY} value has been proposed as an *a priori* performance statistic. If managers need B_{MSY} as a target to meet convention obligations, then we would be able to calculate a value retrospectively corresponding to the management strategy that would give highest long term yield values in the projections and the associated biomass.

Proposals for full set of Management Objectives (MO)/Performances Statistics (PS)/Risks (SCR 19/001)

In addition to the PS presented in the above mentioned document, it was agreed to track the following two measures for presentation at WGRBMS for their consideration as potential secondary PS:

- The annual fraction of stock biomass in the plus group
- The probability of stock collapse (the meeting did not define this exactly, it was left up to the Technical Team to provide a proposal).

It was also noted that the probability of something happening over a period of years, e.g. P(SSB_y<B_{lim}), depends on how these probabilities are measured over the period of years. The meeting agreed to this but, as there was no time to consider it in detail here, it was left for discussion and resolution at WGRBMS.

Priority work for the upcoming WGRBMS meeting (in April 2019):

The meeting agreed that a main task now was to develop the OMs.

But given that the 3M cod MSE plan agreed in 2018 includes the following tasks for the upcoming WGRBMS meeting:

- Review initial MSE results
- Update and possibly finalize PS and associated risk levels
- Indicate where improvements in performance are most required to guide analysts in revising HCRs

it was noted that the Technical Team should also have some results ready for the WGRBMS, even if only preliminary, so as to be able to have a useful conversation with managers at the meeting.