WESTERN HORSE MACKEREL TECHNICAL FOCUS GROUP ON HARVEST CONTROL RULE EVALUATIONS 2020

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14/8/2020

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The Western horse mackerel technical Focus Group consisted of the following members:

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The group met during the period June 2019 – August 2020 to collate information, carry out analyses and report findings that are embedded in the current report.

Executive summary

This report has brought together many different topics that are related to the western horse mackerel stock in an attempt to develop a potential rebuilding plan for the stock. Even though western horse mackerel was not classified by ICES as in need of rebuilding in their latest advice (ICES, 2019a), the general perception within the fishing industries has been that the stock has been in a poor state but that there have been some positive signals in recent recruitment. Using the new recruitments to improve the stock status requires a careful management approach. The PELAC has been a proponent of developing management plans for all stocks in their remit. In this case, the PELAC has termed the approach a rebuilding plan because of the current stock status of the stock.

Substantial progress has been made over the past few years on horse mackerel stock ID (Farrell et al., 2020). The full genome sequencing of horse mackerel from samples taken all the way from the Skagerrak to the Mediterranean and North Africa, has yielded a suitable panel of SNP markers that can be used to differentiate between the different horse mackerel stocks. The strongest differentiation between populations was between the northern and southern populations, with the boundary being in the middle of Portugal. The North Sea population is clearly distinct from the Western population and it should be possible to tell the difference from mixed samples with a high probability (>93%). This would also allow screening of catches in 7d and 7e on the contribution of western and North Sea populations. The separation between the northern and southern populations could mean that the current division between western and southern horse mackerel is not adequate, as the northern part of 9a is currently included in the southern population. A similar split in the middle of Portugal has also been observed for boarfish (Farrell et al., 2016) and could indicate a biogeographical feature.

Length compositions of the catches are an important element of the assessment approach for western horse mackerel, because Stock Synthesis uses length composition in combination with age-length key to estimate the age compositions within the model. Part of a rebuilding plan for western horse mackerel could be to evaluate differences in length compositions in the catches in certain areas and to take specific measures to protect incoming recruitment. Therefore, we planned to carry out an analysis of length compositions by area and season. However, we found that such data is not currently available for all years. Length data for western horse mackerel is currently not included in the ICES InterCatch database. Instead, length data has been processed on a year by year basis in non-standardized Excel spreadsheets. A time series of length compositions by area and season can therefore only be derived by manually working through the spreadsheets and extracting the required information. This was not feasible as part of the project to develop and evaluate a rebuilding plan for western horse mackerel. We recommend to WGWIDE that the full time series of catch at length by country is recreated from the Excel spreadsheets and input into InterCatch to allow for future interrogations of the data and an underpinning of the input data to the stock assessment.

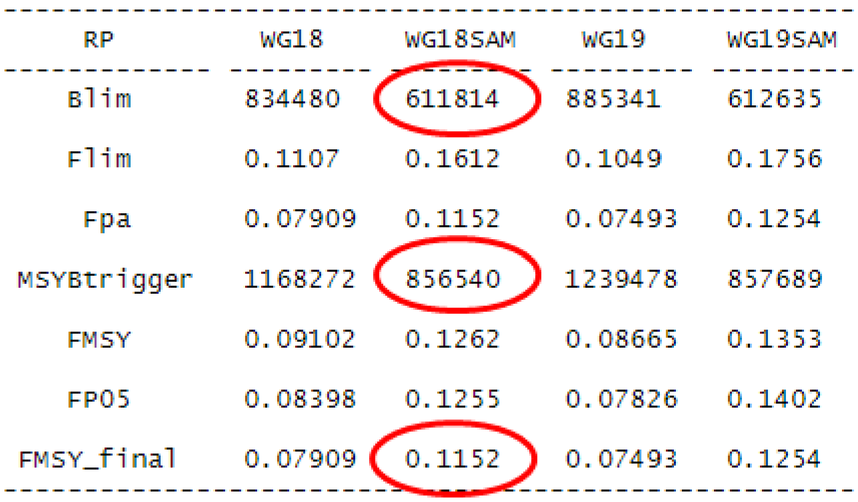
In order to understand how a stock would respond to recovery measures, it is useful to consider the age composition in the spawning stock which illustrates how recruitment in the previous years contributed to the present spawning stock. To this end, an SSB per recruit analysis has been carried out. As one should expect for a relatively long-lived species with low mortality, the spawning stock is currently rather old. At F =0.075, the mean age is about 9 years, 80% is older than 5 years and 20% older than 12 years. So, an improved recruitment will take some time to materialize as increased SSB.

The current stock assessment method for western horse mackerel is Stock Synthesis 3, as agreed in the WKWIDE benchmark of 2017 (ICES, 2017b). Reference point were also set at WKWIDE 2017 but have subsequently been updated in the IBPWHM 2019 (ICES, 2019b). In addition, an exploratory SAM assessment has been carried out as part of IBPWHM 2019. This was done in order to get a second view on stock trends but also to be able to run the SAM HCR forecast as part of the development of a potential rebuilding plan. The exploratory SAM assessment (https://www.stockassessment.org/setStock.php?stock=WHOM2018) was initiated with the same input data as was used for the Stock Synthesis assessment of WGWIDE 2018 (ICES, 2018) with the exception of the length frequency data, which was not used. The PELACUS survey data was therefore only used as an index of biomass within SAM. The process of fine-tuning the assessment lead to the binding of the observation variances for certain variables and to the application of a fixed selectivity pattern (correlation coefficient ϱ=1 in the F random process (https://github.com/martinpastoors/wgwide/blob/master/R/HOM%20optimization_SAM.R). A comparison of Fbar and SSB between the SS3 assessments of WG2018 and 2019 with the SAM assessment (WG18SAM, WG19SAM), shows that the general trends are the same but that there are some deviations in certain periods (e.g. the SSB in the late 1980s is estimated substantially higher in SAM compared to SS3). The Stock Synthesis results are in general a bit smoother compared to SAM.

In order to be able to use the SAM assessment as an alternative assessment in the rebuilding plan evaluation, we needed to estimate reference point for this assessment. In doing so, we aimed to follow the same procedure as during IBPWHM 2019 (ICES, 2019b). However, one of the elements of the reference point estimation, triggered a more in-depth study: the role of assessment uncertainty parameter Fcv and Fphi. There has been little standardization in how Fcv and Fphi have been calculated in different benchmarks where reference points were estimated. Fcv is expected to capture the assessment error in the advisory year and Fphi is the autocorrelation in assessment error in the advisory year (ICES, 2014a). We documented the method for generating the input data for the calculations and explored the sensitivity of Fcv and Fphi to the assessment that was used (both for western horse mackerel and for Atlantic mackerel). We found that there can be a high dependence of Fphi on the assessment that is used to compare against the Fset (the fishing mortalities that are back-calculated from the observed catches and the annual forecasts). When the assessment that is used has values that are all higher or lower than the Fset values, then Fphi will be close to zero. To our knowledge, this behaviour of Fphi was unknown so far. We also found that the number of years that is used for calculating Fcv and Fphi may have an impact on the values. In the recommendations from WKMSYREF3 it is stated that 10 years (or more) should be taken. A further study should be undertaken to assessment the impacts of using different time periods for estimating Fcv and Fphi.

During the IBPWHM 2019, reference points were estimated for western horse mackerel based on the 2018 WGWIDE assessment and using default values for Fcv and Fphi (0.212 and 0.423) and using a segmented regression through Blim (segregBlim). In order to calculate reference points for the exploratory SAM assessment and to explore the sensitivity to the assessment year, reference points were calculated on the basis of the 2018 or 2019 assessments for SS and SAM. The reference points for the SAM assessment are based on the 2018 assessment. Bpa and Blim are lower than the values for the SS assessment, while the Fmsy is higher. The calculated reference points were not sensitive to the assessmentyear that was used for the calculation for both the SS and SAM assessments.

Note that the calculated value for FMSY_final for the 2018 SS WGWIDE option (0.079) differs slightly from the value in IBPWHM 2019 (0.074). While a full explanation for this difference could not be arrived at, it is expected that this could have to do with the random seed and the instability of some of the calculations.



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-----------------------------------------------------------------
      RP          WG18      WG18SAM      WG19      WG19SAM
------------- ---------  ---------  ---------  ---------
     Blim        834480     611814      885341     612635

     Flim        0.1107     0.1612      0.1049     0.1756

      Fpa        0.07909    0.1152      0.07493    0.1254

  MSYBtrigger    1168272    856540      1239478    857689

     FMSY        0.09102    0.1262      0.08665    0.1353

     FP05        0.08398    0.1255      0.07826    0.1402

  FMSY_final     0.07909    0.1152      0.07493    0.1254
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HCR evaluations

The HCR analyses represent two different assessment methods (SS3 and SAM) and two different HCR evaluation tools (EqSim and SAM HCR). Both HCR evaluation tools are of the type 'short-cut' with appropriate conditioning of the uncertainties in the assessment based on historical CV and autocorrelation in line with the recommendations from WKMSYREF3 and WKMSYREF4 . The evaluations followed the guidelines from WKGMSE2 (ICES, 2019c) and WKREBUILD (ICES, 2020).

Three different types of harvest control rules were evaluated:

- Constant F strategy: fixed Ftarget independent of biomass level
- ICES Advice Rule: breakpoint at Btrigger and straight decline in F to zero below Btrigger.
- Double Breakpoint rule: breakpoint at Btrigger and straight decline in F to 20% of Ftarget at Blim. Below Blim continued fishing at F = 0.2 * Ftarget.

For each of the HCRs, a number of different target fishing mortalities were explored (0.0, 0.05, 0.075, 0.1, 0.125, 0.15). No evaluation of different Btrigger values was carried out, so that all evaluations used MSY Btrigger as the trigger point. All HCRs where evaluated with three variants:

- Without any additional constraints
- With a minimum TAC of 50 kT
- With a maximum 20% inter-annual variation (IAV) in TAC, but only when the stock is above Btrigger)

Two simulation tools were used: the EqSim simulator and the SAM HCR forecast. The EqSim simulator is a further worked up version of the SimpSIM approach that was used for the blue whiting MSE in 2016 (ICES, 2016). The code was further developed by Andrew Campbell and Martin Pastoors to improve standardization, documentation and visualization of results. EqSim makes use of an Operating Model (OM) and a Management Procedure (MP). The SAM HCR forecast is a simple stochastic forecast with HCR to evaluate management for fish stocks that need rebuilding in the short-term. The stochastic forecasts start from what we believe is the current level of the stock, i.e. the assessment estimates currently used for tactical management advice, with consideration of the uncertainty in these estimates. Rebuilding is evaluated forward for a specified number of years and for different target fishing mortality values.

The EqSim with SS3 results indicate that the constant F strategy is the least cautious rule and the double breakpoint rule is the most cautious rule. Under the F strategy rule with a Ftarget of 0.075, rebuilding to Bpa is only just being achieved (probability just above 50%) by 2025, while in the double breakpoint rule this is expected to be achieved in 2024 with substantially higher probabilities of remaining above Bpa. The first year of rebuilding to Bpa in the double breakpoint rule with target fishing mortalities up to 0.1 is the same as the first year of rebuilding under the zero fishing scenarios.

Similar results have been obtained with the EqSim with SAM evaluations although the levels of SSB are slightly higher and risk to Blim is slightly lower. According to these evaluations, rebuilding to Bpa could be obtained by 2022 in all scenarios.

The SAM HCR with SAM evaluations have only been carried out for the ICES Advice Rule scenario, as this was intended more as a contrasting study rather than a full analysis of HCR evaluation. Again, we find similar patterns in simulated stock trends, but SSB is estimated higher in the SAM evaluation than in the EqSim evaluations and risk to Blim stays below the 0.05 threshold in SAM HCR for all target fishing mortalities that have been explored.

Given that the EqSim with SS3 evaluation is closest to the ICES advisory practice, this was used as the basis for the preferred rebuilding plan by the PELAC. The PELAC preferred options are:

- Target fishing mortality at Fmsy = 0.074 (approximated by 0.075 in the simulations)
- Blim at ICES Blim (834 480 t)
- Btrigger at ICES MSY Btrigger (1 168 272 t)
- Double breakpoint rule with 20% constraint on IAV above Btrigger
- Minimum F when stock is below Blim at 20% of Fmsy = 0.015

The selected rebuilding plan has a 50% probability of rebuilding to Blim by 2021 (similar to zero catch option) and a 50% probability of rebuilding to Bpa/MSY Btrigger by 2024 (similar to the zero-catch option). Furthermore, the probability of being below Blim remains well below 5% for the duration of the simulation.

In this scenario, the average catch in the years 2021-2025 is expected to be lower than recent catches. However, after rebuilding, catches should be able to be maintained around 100 000 tonnes.

1 Introduction

1.1 Challenge

The Western Horse mackerel Focus Group of the Pelagic Advisory Council (PELAC) has been set up in 2015 already to a develop a PELAC proposal for a rebuilding plan or management plan for Western Horse mackerel. After several iterations (see below), the Focus Group initiated a technical working group to develop an operational evaluation tools for management plan evaluation and to evaluate potential Harvest Control Rules, so that PELAC could come to a recommended procedure. Such a recommended procedure, including the evaluation that was carried out, would need to be submitted for review to ICES to establish whether the evaluation procedure is in line with scientific standards and that the results of the HCR are in conformity with the precautionary approach and the MSY approach.

1.2 What happened before

An overview is presented of the attempt to develop a management plan for Western horse mackerel in the ICES area. After an initial egg-survey based management rule had been agreed and evaluated in 2008 (ICES, 2008), the management plan was called into question in 2011 which lead to the statement by ICES in 2013 that the plan was no longer precautionary (ICES, 2013a). In the years 2014-2015, CEFAS and the Marine Institute were commissioned by the Pelagic Regional Advisory Committee to evaluate potential new management plans (Campbell et al., 2015). The SAD assessment that was used to assess the stock in those years, and that underpinned the MSEs for Western horse mackerel, was so uncertain, that the results were that in the case of no-fishing, the stock was expected to increase, but the uncertainty in the stock was also increasing, to the effect that the probability of being below B_{lim} was larger than 5% for the next 40 years to come. Apparently, the framing of those MSEs could not resolve to a meaningful and acceptable management plan.

A second iteration occurred after the stock had been benchmarked in 2017 and was using the Stock synthesis model for the assessment (ICES, 2017). Using the methods described by Cox et al. (Cox and Kronlund, 2008), a proof-of-concept full-feedback MSE[1] was commissioned with Landmark Fisheries Research, Canada (Cox et al., 2018). The evaluations were directed at different fishing strategies, including strategies where fishing would continue when the biomass would be below B_{lim}. The results of the analysis demonstrated a clear recovery potential of the stock under different fishing scenarios, mostly dependent on the recruitment assumptions and the target fishing mortality. However, the starting conditions of the simulated populations did not include uncertainty, and therefore the behaviour of the MSE may have been estimated too positively.

For a final iteration of the management plan evaluation, it was anticipated to use the guidelines from WKGMSE2 (ICES, 2019c) and WKREBUILD (ICES, 2020) to plan for the next step in the development of the management plan. This work is embedded in the current report.

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[1] A full-feedback MSE means that the assessment (and forecast) are run within the Management Strategy Evaluation (MSE) framework for each year and for each iteration.

1.3 Approach

The approach during the Focus Group on Western Horse mackerel was to convene a number of physical meetings to identify the main issues and to plan regular updates. In June 2019, a technical subgroup was set up to further carry out the technical analyses that were required. This subgroup was closely affiliated with the ICES WKREBUILD workshop that was going to take place in February 2020.

The first technical subgroup meeting was held on 20-21 June 2019. After presenting the state of affairs during WKREBUILD 2020, a series of online meetings was held during May and June 2020 to finalize the evaluation tools and to carry out the studies and evaluations. Specific focus was paid to the following topics:

- Stock ID (through the genetic work coordinated by Edward Farrell, UCD)
- Analysis of length compositions of catches (Gwladys Lambert, Martin Pastoors)
- Analysis of SSB per recruit (Dankert Skagen)
- Stock assessment (with focus on exploratory SAM assessment; Vanessa Trijoulet and Martin Pastoors)
- Reference points and calculation of Fcv and Fphi (Martin Pastoors)
- Development of HCR evaluation tools
    - EqSim (Andrew Campbell, Martin Pastoors)
    - SAM HCR (Vanessa Trijoulet)
- Application of HCR tools to evaluate different potential rebuilding plan (Andrew Campbell, Vanessa Trijoulet, Martin Pastoors)
- Presentation of results to the PELAC western horse mackerel focus group (Martin Pastoors, Andrew Campbell)

2 Horse mackerel stock ID

Recently, a study has been completed on the population structure of the Atlantic horse mackerel (*Trachurus trachurus*) as revealed by whole-genome sequencing (Farrell et al., 2020). The executive summary of that report is repeated below:

"The Atlantic horse mackerel, Trachurus (Linnaeus, 1758) is a species of jack mackerel distributed in the East Atlantic, from Norway to west Africa and the Mediterranean Sea. It is a pelagic shoaling species found on the continental shelf and it is one of the most widely distributed species in shelf waters in the northeast Atlantic, where it is targeted in pelagic fisheries. In the northeast Atlantic region, the species is assessed and managed as three stocks: the Western, the North Sea and the Southern. Despite the commercial importance of the horse mackerel, the accuracy of alignment of these stock divisions with biological units is still uncertain.

The aims of this study were to identify informative genetic markers for the stock identification of horse mackerel and to estimate the extent of genetic differentiation among populations distributed across the distribution range of the species. For this we used modern sequencing techniques that allowed us to assess genetic variants in the entire genome. We discovered that while the populations differ in a small fraction of their DNA (< 1.5%), such genetic differences are significant as they likely represent natural selection and might be involved in local adaptation. We validated a small fraction of these highly differentiated genetic variants by a SNP assay and demonstrated that they can be used as informative molecular markers for the genetic identification of the main stock divisions of the Atlantic horse mackerel.

The results, based on the analysed samples, indicated that the North Sea horse mackerel are a separate and distinct population. The samples from the Western stock, west of Ireland and the *northern Spanish shelf, and the northern part of the Southern stock, northern Portugal, appear to form a genetically close group. There was significant genetic differentiation between the northern Portuguese samples and those collected in Southern Portuguese waters, with those in the south representing a separate population. The North African and Alboran Sea samples were distinct from each other and from all other samples.*

These results indicate that a further large-scale analysis of samples, with a greater temporal and spatial coverage, with the newly identified molecular markers is required to test and reassess the current stock delineations."

The main conclusions of the genetic work can be summarized as follows:

- A suitable panel of SNP markers can be identified to carry out routine population assignments of mixed samples.
- Main differentiation between populations is between northern and southern populations, with the boundary being in the middle of Portugal. Although more work needs to be done on this finding, this could imply that the current division between western and southern horse mackerel is not adequate, as the northern part of 9a is currently included in the southern population.
- The North Sea population is clearly distinct from the Western population and it should be possible to tell the difference from mixed samples with a high probability (>93%?). This allows screening of catches in 7d and 7e on the contribution of western and North Sea populations.

3 Length compositions of catches

A short study was initiated to analyse the length composition of catches by country, area, year and quarter. Length compositions could be informative on selectivity in different areas and fisheries and could therefore also be used to generate specific management measures as part of a rebuilding plan.

In the current SS assessment framework, length compositions are used as the key metric for catches in combination with age-length keys to generate age compositions dynamically. So, while it might be expected that the length information is readily available, this turned out to be not the case. The length data that is submitted by country, is not submitted in a standardized format and not included in the InterCatch database. Historical length data by country has been processed on an annual basis using ad hoc Excel spreadsheets and cannot be easily extracted. Therefore, no real progress has been made on this topic.

Recommendation:

- The Western Horse Mackerel Focus Group recommends to WGWIDE that the full time series of catch at length by country is recreated from the Excel spreadsheets and converted into InterCatch to allow for future interrogations of the data and an underpinning of the input data to the stock assessment.

4 Contribution of recruitment to SSB

Dankert W. Skagen, June 2020

For the understanding of how a stock responds to recovery measures, it is useful to consider the age composition in the spawning stock, to illustrate how recruitment in the previous years contribute to the present spawning stock. When we calculate SSB per recruit, we do this by calculating the sequence of numbers at age as they are reduced by mortality, starting with one recruit. Then we multiply numbers at each age with weight and maturity at that age to get biomass per recruit of the spawners at each age. The sum of these over all ages is the total SSB per recruit, which is normally what is presented, but the age profile of the SSB per recruit can also be interesting in itself. For example, when we consider a rebuilding strategy, it gives us an indication of how fast SSB can be expected to improve when recruitment improves. The age distribution in the spawning stock of course depends on the fishing mortality level, as does the total SSB per recruit.

The actual SSB at some age is the SSB per recruit at that age, multiplied with the number of recruits born in that cohort. Accordingly, the total SSB in any year is a weighted sum of previous recruitments. The products of cohort recruitment times SSB per recruit at age, summed over all ages. In an equilibrium where all weighting factors are constant, SSB is proportional to the mean recruitment, since it is the sum of SSB per recruit at age, raised by the recruitment.

This simple relation also gives us an easy direct means of calculating how the variation in recruitment carries over to variation in SSB. In probability theory, there is a very simple formula for variance of a weighted sum of independent components. Here the components are annual recruitment, with a presumably known variance, and the weightings are the SSB per recruit at age. Although this only covers the effect of one source of variation in SSB, the recruitment variation is a major source so a direct calculation of the variance, without elaborate bootstrap procedures, can be useful as a proxy in the early phase of management plan developments, and also for understanding the effect of variable recruitment.

Below is a set of age distributions in the SSB per recruit for Western horse mackerel (Figure 2). The data on weights, maturities, natural mortality and selection were those used as input to the short-term prediction by WGWIDE in 2019.

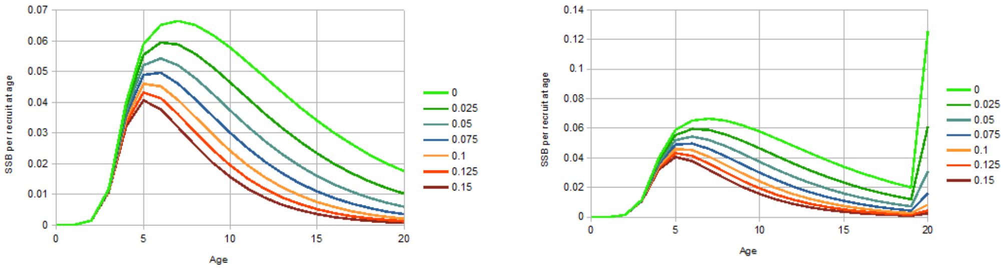


Figure 1 *SSB at age for a range of fishing mortalities (F1-10) With (right) and without (left) regarding age 20 as a plus group.*

Figure 3 shows SSB per recruit as function of F1-10, with the same input data, and in addition the 95 % confidence interval assuming a CV on recruitment of 0.6. which is slightly lower than the CV of the recruitments 1983 – 2018 according to the WGWIDE assessment in 2019, excluding the strong 2001 year class. In the same figure, the mean age in the SSB as function of the F1-10 is also shown.

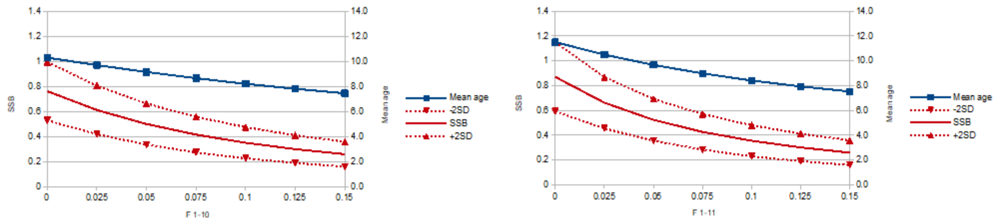


Figure 2 *Mean age (blue) and SSB (Mean ±2SD) for a range of fishing mortalities (1-10). Using only age up to 20 (left, without a plusgroup) and using all ages (right, with a plusgroup at 20). The SDs are the effect of recruitment variation, assuming a CV of 0.6*

As one should expect for a relatively long-lived species with low mortality, the spawning stock is rather old. At F =0.075, the mean age is about 9 years, 80% is older than 5 years and 20% older than 12 years. So, an improved recruitment will take some time to materialize as increased SSB. The results also indicate that with a low F, the plus group still does matter. Finally, the historical variation in recruitment translates into a confidence interval for long term equilibrium SSB that for F=0.075 ranges from approximately 700 to 1400 when the mean recruitment is 2500.

5 Stock assessment of Western horse mackerel

5.1 Stock synthesis assessment

WGWIDE 2019: The SS model with new length and age data from the commercial fleet, and the 2018 information from the 2 surveys available, is presented as the final assessment model. Stock numbers-at-age and fishing mortality-at-age are given in Tables 7.3.1.1 and 7.3.1.2, and a stock-summary is provided in Table 7.3.1.3 and illustrated in Figure 7.2.11.2. SSB peaked in 1988 following the very strong 1982 year class. Subsequently SSB slowly declined till 2003 and then recovered again following the moderate-to-strong year class of 2001 (a third of the size of the 1982 year class). Year classes following 2001 have been weak: 2010 2011, and 2013 recruitments in particular have been estimated as the lowest values in the time-series together with the 1983. The 2008 year class has been estimated to be fairly strong. Recruitment estimates for 2014-2018 are the highest observed since 2008 and are higher than the geometric mean estimated over the years 1983-2018. SSB in 2017 is estimated as the lowest in the time-series. Fishing mortality was increasing after 2007 as a result of increasing catches and decreasing biomass as the 2001 year class was reduced. Since 2012 F has then been decreasing, dropping to low values in 2015-2018 due to lower catches and a reduced proportion of the adult population in the exploited stock.

5.2 SAM assessment

IBPWHM 2019: Since the benchmark in 2017 (ICES, 2017b), the Western horse mackerel assessment has been carried out using the Stock Synthesis method. This method allows for the incorporation of length frequency information and the dynamic estimation of growth. The Stock Synthesis assessment of western horse mackerel utilizes the length distributions of the commercial catch and from the samples obtained during the PELACUS survey, while the other information is provided as biomass (total catch, egg survey) or age specific data (recruitment index). The SS assessments that have been carried out since the benchmark in 2017 have generally shown narrow confidence intervals, yet the annual revisions in estimated stock size and fishing mortality between subsequent assessments has been substantial. These retrospective revisions are not well understood. In addition, there has been some concern about the complex nature of the input data to the Stock Synthesis method and the ability to adequately quality control the input data and model performance.

As part of the Interbenchmark of Western horse mackerel, it was agreed to explore the possibility of an alternative assessment approach to Stock Synthesis. The intention was to test methods that are more familiar to members of the WGWIDE assessment group. It was decided to use the SAM model as the alternative approach because it is already being used for mackerel and blue whiting and because it will allow for an evaluation of harvest control rules in a similar manner as is currently being applied for Western Baltic Spring Spawning herring.

The exploratory SAM assessment (https://www.stockassessment.org/setStock.php?stock=WHOM2018) was initiated with the same input data as was used for the Stock Synthesis assessment of WGWIDE 2018 (ICES, 2018) with the exception of the length frequency data, which was not used. The PELACUS survey data was therefore only used as an index of biomass within SAM. When using the default SAM configuration, the assessment output displayed a strong retrospective pattern and very large uncertainty in both F and SSB. A process of fine-tuning the assessment lead to the binding of the observation variances for certain variables and the application of a fixed selectivity pattern (correlation coefficient ϱ=1 in the F random process, that was originally allowed to change by year (https://github.com/martinpastoors/wgwide/blob/master/R/HOM%20optimization_SAM.R). The only aged-structured observation available for this stock is for the commercial catch. As a result, the model has a tendency to over-fit these observations, notably for the older ages. This induced important variations in fishing selectivity over time that seemed inconsistent and led to very large retrospective patterns in both SSB and F. Fixing the fishing selectivity over time resulted in a significant improvement in these retrospective patterns for only a slightly larger AIC (1217.453 vs. 1212.974 with variable relative fishing mortality). The final exploratory assessment from this exercise was selected on the basis of the trade-off between a low AIC and reduced retrospective pattern.

A comparison of Fbar and SSB between the SS3 assessments of WG2018 and 2019 with the SAM assessment (WG18SAM, WG19SAM).

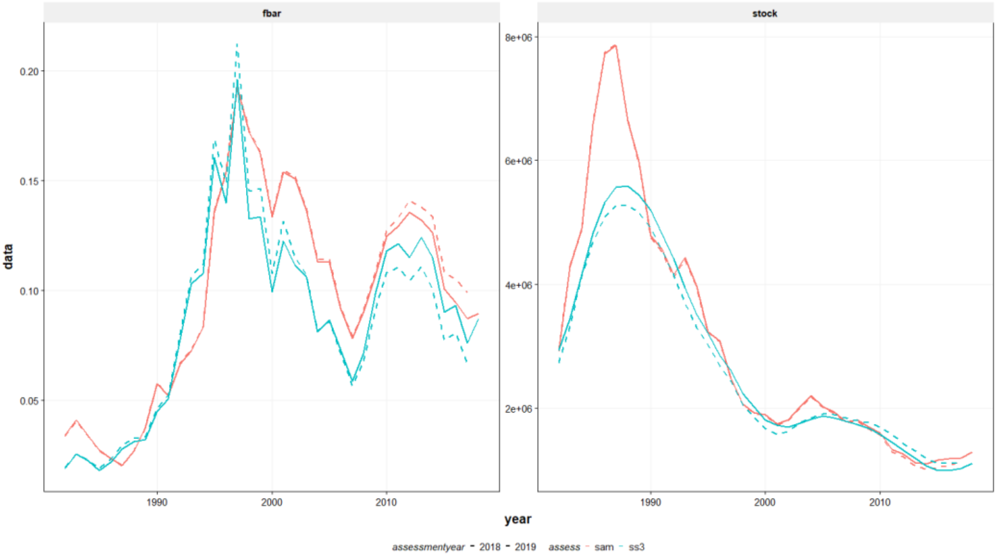


Figure 3 Time trends for Fbar and SSB for the SS3 (red) and SAM (blue) assessments for WG2018 and 2019.

6 Fcv and Fphi uncertainty parameters

The standard approach in ICES for estimating biological reference points is based on the EqSim software conditioned on the most recent assessment. Uncertainties in the assessment are included through two parameters: Fcv and Fphi, where Fcv is expected to capture the assessment error in the advisory year and Fphi is the autocorrelation in assessment error in the advisory year (ICES, 2014a). Methods for deriving Fcv and Fphi are loosely described in the WKMSYREF3 report (ICES, 2014a, p. 11):

> *"The estimated realised catch and F (Fyr) for the previous 10 years (or more) are taken from the most recent assessment. The annual ICES advice sheets issued in y-1 are consulted to estimate the F_{ya} that would have been advised to obtain the estimated catch. Where the appropriate catch is not available in the catch option table linear interpolation is used to estimate the F_{ya}. The deviation in year y d_y is calculated as $\log_e(F_{yr}/F_{ya})$, the standard deviation σ_m of the log deviations gives the marginal distribution. The conditional standard deviation σ_c is calculated as $\sigma_m \sqrt{(1-\varphi^2)}$, where φ is the autocorrelation of the AR(1) process. Then σ_c [and] φ are input parameters for Eqsim."*

The role of Fcv and Fphi in the process of estimating reference points is that they are used to calculate Fp05 which is used as the precautionary buffer on Fmsy, because Fp05 is the value whereby a (less than) 5% annual probability exists that SSB will be below Blim in the long term If the directly estimated Fmsy is larger than Fp05, then Fmsy needs to be reduced to Fp05.

When applying this approach to the western horse mackerel data, we found that there were important sensitivities in calculating the parameters Fcv and Fphi. This initial finding let us to carry out a broader review of the behaviour of Fcv and Fphi for a number of widely distributed pelagic stocks where reference points were recently estimated (western horse mackerel and Atlantic mackerel). The results will be summarized in a working document to ACOM in September 2020. While there has in general been ample attention during benchmark workshops to the estimation of reference point – albeit they are often carried out AFTER the benchmark instead of DURING the benchmark – we found that the documentation of the selection of data and the method to calculate the Fcv and Fphi has been mostly lacking. In most cases it is not clear how many years have been used, nor how the values for the interpolated fishing mortalities have been generated.

Western horse mackerel

Fset and SSBset were calculated from the historical assessment data. Realized catch by year was taken from the most recent advice document. Catch1fcy and Catch2fcy are the two catch options that bracket the actual realized catch in the forecast year and F1fcy and F2fcy are the associated fishing mortalities. Fset is the interpolated fishing mortality that matches the realized catch in a particular forecast.

In the case of horse mackerel, this procedure could not be followed for estimating the SSBset, because only one value of SSB in the forecast year is presented in the forecast tables.

tacyear	catchrealized	catch1fcy	catch2fcy	f1fcy	f2fcy	ssb1fcy	ssb2fcy	fset	ssbset
2011	193268	186433	201312	0.1048	0.1135	-	-	0.108797	1911900
2012	166579	155125	174007	0.0944	0.1064	-	-	0.101679	1879742
2013	165258	155633	170000	0.1638	0.18	-	-	0.174653	1568380
2014	136360	129640	144621	0.1541	0.1734	-	-	0.162757	749334
2015	98419	85820	99304	0.1053	0.1229	-	-	0.121745	601099
2016	98811	98544	99710	0.0997	0.1009	-	-	0.099975	718285
2017	82961	82526	84289	0.1105	0.113	-	-	0.111117	511789
2018	101682	99129	108515	0.081	0.089	-	-	0.083176	818082

The calculation of cv and phi for fishing mortality and SSB is shown below (figure 4). Fassess and SSBassess are taken from the WGWIDE 2019 assessment. The explanations below are only given for fishing mortality, but the same procedures apply to SSB.

The F deviation in year y d_y is calculated as ln(Fassess/Fset). The standard deviation σ_m (=lnSTD) of the log deviations gives the marginal distribution. The autocorrelation in the log deviations φ (=Fphi) is calculated by correlating the deviations 2011-2017 with the deviations 2012-2018 (this is the autocorrelation of the AR(1) process). The conditional standard deviation σ_c (=Fcv) is calculated as $\sigma_m \sqrt{(1-\varphi^2)}$.

In the case of western horse mackerel, Fcv is estimated at 0.2193 and Fphi at the very low value of 0.0212. This can be explained by the almost complete lack of overlap between Fassess and Fset because the most recent assessment estimates a substantially lower fishing mortality than was assumed in the forecasts. The F correlation plot below therefore shows a close to flat line. During IBPWHM 2019, reference points have been calculated using Fcv = 0.212 and Fphi = 0.423 (the default EqSim values) and thus substantially different from the calculated values.

Note that SSBcv and SSBphi have been calculated in the same way, but they are not currently used in the EqSim approach for estimating reference points.

A simulation study on the impact of different values of Fcv and Fphi on the Fmsy for western horse mackerel is shown below (figure 5). Fcv is on the horizontal axis, while the coloured lines indicate the values of Fphi. The five panels demonstrate the five steps in arriving at the final Fmsy.

- Estimate Fmsy without constraints
- Calculate Fpa (has been done previously).
- If Fmsy is larger than Fpa, set Fmsy_interim to Fpa
- Calculate Fp05 with Eqsim using Fcv, Fphi and Blim
- The final Fmsy is the minimum of Fp05 and Fmsy_interim.

The simulation study demonstrates that a larger Fcv leads to a lower Fp05 and also that a larger Fphi leads to the Fp05 being more sensitive to the impact of Fcv. Therefore, the estimated values of Fcv and Fphi can have an important impact on the Fmsy that is calculated in EqSim.

Horse mac Fishing mortality

Year	*Fassess*	Fset	*ln(Fass)*	ln(Fset)	Ln(Fassess/Fset
2009					
2010					
2011	0.1212	0.1088	*-2.1103*	-2.2183	0.1080
2012	0.1151	0.1017	*-2.1622*	-2.2859	0.1237
2013	0.1242	0.1747	*-2.0855*	-1.7450	-0.3405
2014	0.1151	0.1628	*-2.1622*	-1.8155	-0.3467
2015	0.0901	0.1217	*-2.4074*	-2.1058	-0.3016
2016	0.0930	0.1000	*-2.3755*	-2.3028	-0.0727
2017	0.0759	0.1111	*-2.5778*	-2.1972	-0.3807
2018	0.0871	0.0832	*-2.4409*	-2.4868	0.0459

lnSTD	*0.2194*
Fcv	***0.2193***
Fphi	***0.0212***

Horse mackerel SSB

Year	*SSBassess*	SSBset	*ln(SSBass)*	ln(SSBset)	Ln(SSBassess/SSBse
2009					
2010					
2011	1211620	1911900	*14.0075*	14.4636	-0.4561
2012	1164950	1879742	*13.9682*	14.4466	-0.4785
2013	1087630	1568380	*13.8995*	14.2656	-0.3660
2014	955525	749334	*13.7700*	13.5269	0.2431
2015	838866	601099	*13.6398*	13.3065	0.3333
2016	786772	718285	*13.5757*	13.4846	0.0911
2017	761613	511789	*13.5432*	13.1457	0.3975
2018	811685	818082	*13.6069*	13.6147	-0.0079

lnSTD	*0.3586*
SSBcv	***0.2927***
SSBphi	***0.5776***

Figure 4 Calculation of Fcv, Fphi, SSBcv and SSBphi for western horse mackerel

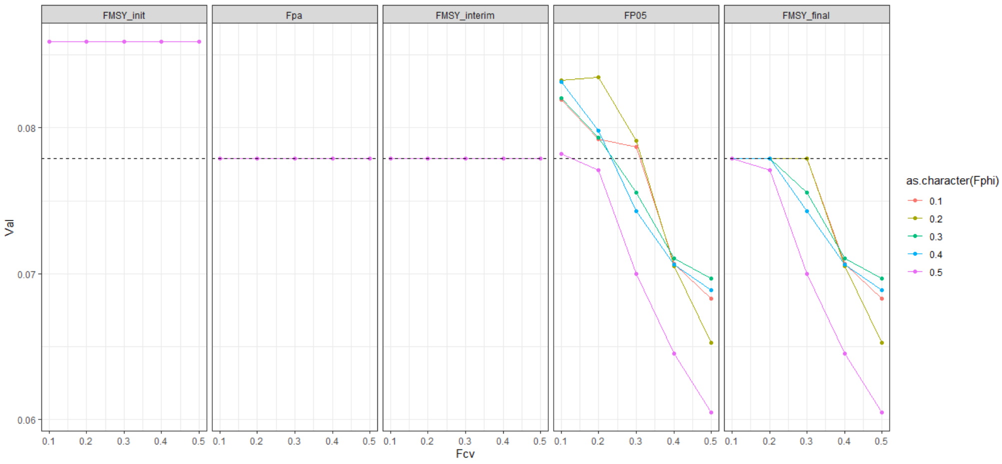


Figure 5 *Simulated values of the impact of Fcv and Fphi on the reference points for western horse mackerel.*

Atlantic mackerel

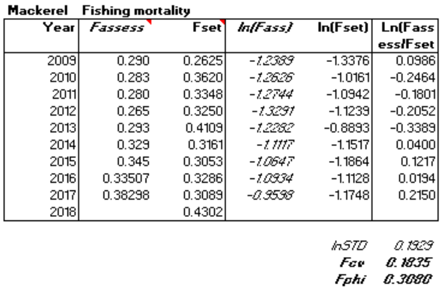
Following the same procedure as outlined above, we obtained the following values for Fset and SSBset for Atlantic mackerel.

tacyear	catchrealized	catch1fcy	catch2fcy	f1fcy	f2fcy	ssb1fcy	ssb2fcy	fset	ssbset
2009	737969	707000	831000	0.25	0.3	2891000	2842000	0.262488	2878762
2010	875515	726000	996000	0.29	0.42	2397000	2293000	0.361989	2339409
2011	946661	884093	959773	0.31	0.34	2697368	2668541	0.334802	2673535
2012	892353	742000	927000	0.26	0.34	2710000	2638000	0.325018	2651484
2013	931732	930000	1116000	0.41	0.51	2390000	2310000	0.410931	2389255
2014	1393000	1300000	1400000	0.291	0.318	4594000	4573000	0.31611	4574470
2015	1208990	1054000	1396000	0.26	0.36	4344000	4276000	0.305319	4313183
2016	1094066	960009	1235608	0.28	0.38	3766022	3712034	0.328642	3739761
2017	1155944	1067828	1281394	0.28	0.35	4398536	4358095	0.308882	4381850
2018	1026437	977765	1122906	0.405	0.48	3043254	3013235	0.430151	3033187

In the case of mackerel, we were particularly interested in the effect of the assessment year on the calculation of Fcv and Fphi because of the substantial change in perception between the 2018 and the 2019 assessments. Therefore, we calculated Fcv and Fphi for each assessment year separately.

Similar to the observations for Western horse mackerel, the impact of the final assessment year is noticeable here. Due to the revision of the assessment in 2019, there is almost no overlap between the fishing mortalities from the assessment and those derived from the historical forecasts. This impacts on the estimated Fphi (0.3080 using the 2018 assessment, 0.0076 using the 2019 assessment).

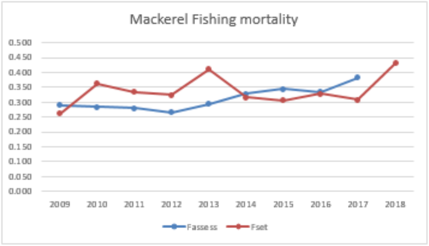
MACKEREL 2018



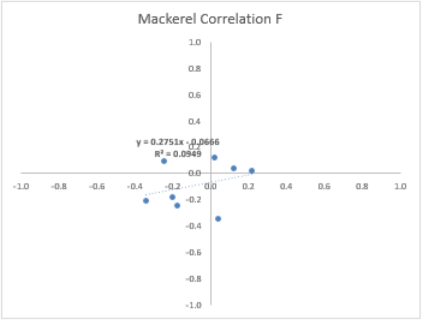
Mackerel **Fishing mortality**

Year	*Fassess*	Fset	*ln(Fass)*	ln(Fset)	Ln(Fassess/Fset
2009	0.290	0.2625	*-1.2383*	-1.3376	0.0986
2010	0.283	0.3620	*-1.2626*	-1.0161	-0.2464
2011	0.280	0.3348	*-1.2744*	-1.0942	-0.1801
2012	0.265	0.3250	*-1.3291*	-1.1239	-0.2052
2013	0.293	0.4109	*-1.2282*	-0.8893	-0.3389
2014	0.329	0.3161	*-1.1117*	-1.1517	0.0400
2015	0.345	0.3053	*-1.0647*	-1.1864	0.1217
2016	0.33507	0.3286	*-1.0934*	-1.1128	0.0194
2017	0.38298	0.3089	*-0.9598*	-1.1748	0.2150
2018		0.4302			

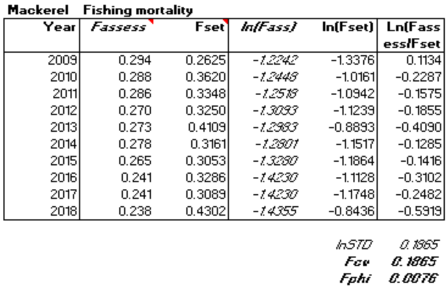
lnSTD *0.1929*
Fcv ***0.1835***
Fphi ***0.3080***



Mackerel Correlation F



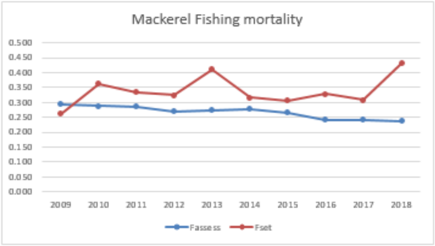
MACKEREL 2019



Mackerel **Fishing mortality**

Year	*Fassess*	Fset	*ln(Fass)*	ln(Fset)	Ln(Fassess/Fset
2009	0.294	0.2625	*-1.2242*	-1.3376	0.1134
2010	0.288	0.3620	*-1.2448*	-1.0161	-0.2287
2011	0.286	0.3348	*-1.2518*	-1.0942	-0.1575
2012	0.270	0.3250	*-1.3093*	-1.1239	-0.1855
2013	0.273	0.4109	*-1.2983*	-0.8893	-0.4090
2014	0.278	0.3161	*-1.2801*	-1.1517	-0.1285
2015	0.265	0.3053	*-1.3280*	-1.1864	-0.1416
2016	0.241	0.3286	*-1.4230*	-1.1128	-0.3102
2017	0.241	0.3089	*-1.4230*	-1.1748	-0.2482
2018	0.238	0.4302	*-1.4355*	-0.8436	-0.5919

lnSTD *0.1865*
Fcv ***0.1865***
Fphi ***0.0076***



Mackerel Correlation F

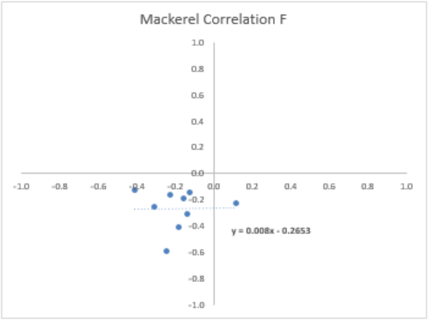


Figure 6 Comparison of Fcv and Fphi for Mackerel based on the assessments of 2018 and 2019.

Conclusions

While an elaborate procedure has been outlined to derive reference points for category 1 and 2 stocks in ICES (ICES, 2017a) based on the work of MSYREF workshops (ICES, 2013b; ICES, 2014a; ICES, 2014b; ICES, 2015), we conclude from our studies on western horse mackerel and Atlantic mackerel that insufficient attention has been given to the method of estimating forecast uncertainty and the impact of that uncertainty on the estimated reference points (notably Fmsy). Here we started with a method for documenting how the Fset is being derived from the historical data, so that at least the estimates of Fcv and Fphi are transparent and can be recreated.

We also note that there can be a high dependence of Fphi on the assessment that is used to compare against the Fset. When the assessment that is used has values that are all higher or lower than the Fset values, then Fphi will be close to zero. To our knowledge, this behaviour of Fphi was unknown so far.

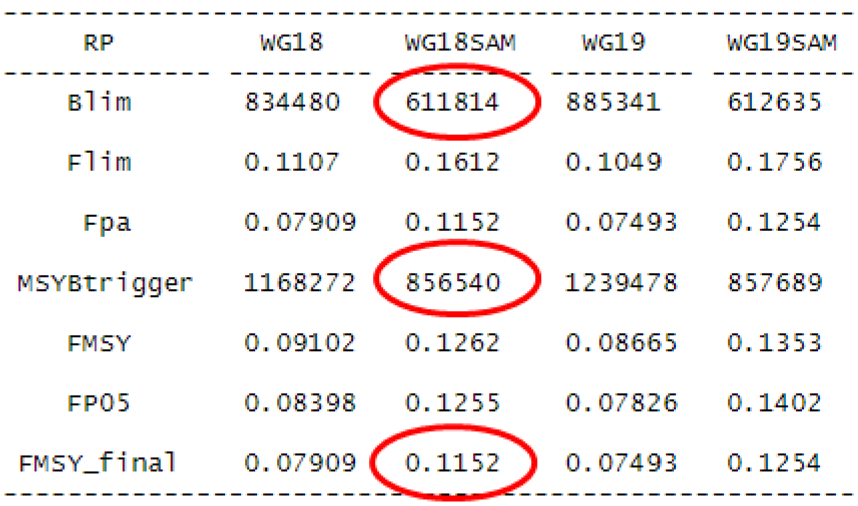
Finally, we note that the number of years that is used for calculating Fcv and Fphi may have an impact on the values. In the recommendations from WKMSYREF3 it is stated that 10 years (or more) should be taken. A further study should be undertaken to assessment the impacts of using different time periods for estimating Fcv and Fphi.

7 Estimation of reference points for SS and SAM assessments

During the IBPWHM 2019, reference points were estimated for western horse mackerel based on the 2018 WGWIDE assessment and using default values for Fcv and Fphi (0.212 and 0.423) and using a segmented regression through Blim (segregBlim). In order to calculate reference points for the exploratory SAM assessment and to explore the sensitivity to the assessment year, reference points were calculated on the basis of the 2018 or 2019 assessments for SS and SAM.

The reference points for the SAM assessment are based on the 2018 assessment. Bpa and Blim are lower than the values for the SS assessment, while the Fmsy is higher. These values will be used in the subsequent evaluations (section 8)

The changes due the assessment year were minor for both the SS and SAM assessments.



```
-----------------------------------------------------------
     RP           WG18      WG18SAM     WG19      WG19SAM
------------- ---------- ---------- ---------- ----------
    Blim        834480     611814     885341     612635

    Flim        0.1107     0.1612     0.1049     0.1756

     Fpa        0.07909    0.1152     0.07493    0.1254

 MSYBtrigger    1168272    856540     1239478    857689

    FMSY        0.09102    0.1262     0.08665    0.1353

    FP05        0.08398    0.1255     0.07826    0.1402

 FMSY_final     0.07909    0.1152     0.07493    0.1254
-----------------------------------------------------------
```

8 HCR evaluations

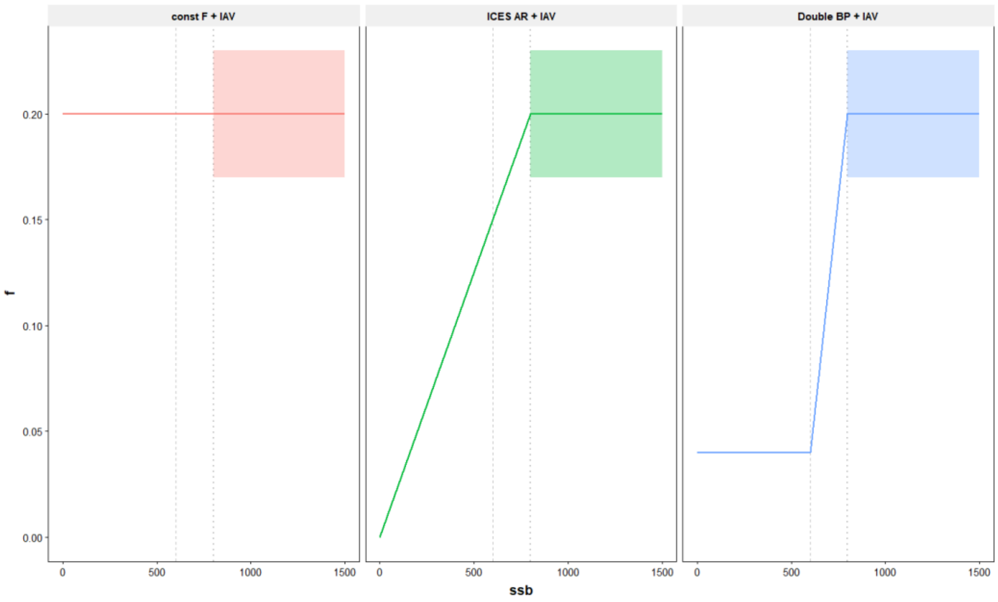
8.1 Type of HCRs evaluated

Three different types of harvest control rules were evaluated:

- Constant F strategy: fixed Ftarget independent of biomass level
- ICES Advice Rule: breakpoint at Btrigger and straight decline in F to zero below Btrigger.
- Double Breakpoint rule: breakpoint at Btrigger and straight decline in F to 20% of Ftarget at Blim. Below Blim continued fishing at F = 0.2 * Ftarget.

For each of the HCRs, a number of different target fishing mortalities were explored (0.0, 0.05, 0.075, 0.1, 0.125, 0.15). No evaluation of different Btrigger values was carried out, so that all evaluations used MSY Btrigger as the trigger point. All HCRs where evaluated with three variants:

- Without any additional constraints
- With a minimum TAC of 50 kT
- With a maximum 20% inter-annual variation (IAV) in TAC, but only when the stock is above Btrigger)



8.2 HCR evaluation tools

The base assessments ("Operating model") of the evaluations were either the WGWIDE 2019 SS3 assessment (ICES, 2019d) or the exploratory SAM assessment that was carried out as part of the IBPWHM 2019 (ICES, 2019b).

As input to the SS3 simulations, 1000 iterations were generated from respective assessments. For SS3 this was done by generating 10000 iterations and then resampling 1000 of them so as to end up with the same starting conditions as in the stock assessment itself.

The 1000 SAM iterations were generated by using the SAM simulate function, based on the IBPWHM 2019 exploratory SAM assessment; these were then converted to FLSAM objects which were again converted to 1000 FLStock objects[2]

The SRR model was the constrained segmented regression (SegRegBlim), similar to the IBPWHM 2019, while leaving out the exceptionally strong 1982 year class.

Two simulation tools were used: the EqSim simulator and the SAM HCR forecast

The EqSim simulator is a further worked up version of the SimpSIM approach that was used for the blue whiting MSE in 2016 (ICES, 2016). The code was further developed by Andrew Campbell and Martin Pastoors to improve standardization, documentation and visualization of results. Some key improvements where:

- the development of standardized codes for Operating Models (OM) a Management Procedures (MP), including new types of HCR elements.
- the development of standardized codes for statistical outputs and visualization thereof.

The SAM HCR forecast is a simple stochastic forecast with HCR to evaluate management for fish stocks that need rebuilding in the short-term. This method enables the investigation of several management strategies without the need of intensive computer power, while still accounting for different sources of uncertainty. The stochastic forecasts start from what we believe is the current level of the stock, i.e. the assessment estimates currently used for tactical management advice, with consideration of the uncertainty in these estimates. Rebuilding is evaluated forward for a specified number of years (here: 23 years) and for different target fishing mortality values (Ftarget)

The method was developed as an extension to the stockassessment R package for the SAM model (Nielsen and Berg, 2014; Berg and Nielsen, 2016) and applied to western horse mackerel[3].

We applied two different assessments to two different evaluation tools as follows:

	WGWIDE19 SS3	WGWIDE19 SAM
EqSim simulator	Yes	Yes
SAM HCR forecast	No	Yes

For each evaluation, we scanned over different F target values: 0, 0.05, 0.075, 0.10, 0.125, 0.15.

Each simulation was run over 23 year, split into the following periods:

---

[2] https://github.com/ices-eg/wk_WKREBUILD/blob/master/EqSimWHM/Scripts/HOM%20SAM%20simulator.r

Note: running the code required running it in batches of around 200 iterations due to unexplained errors arising when running for larger batches. This issue has not been solved, except by running it in multiple batches.

[3] https://github.com/vtrijoulet/SAM/tree/master2

- Current period (CU): 2018-2020
- Short term (ST): 2021-2025
- Medium term (MT): 2026-2030
- Long term (LT): 2031-2040

8.3 EqSim simulator tool

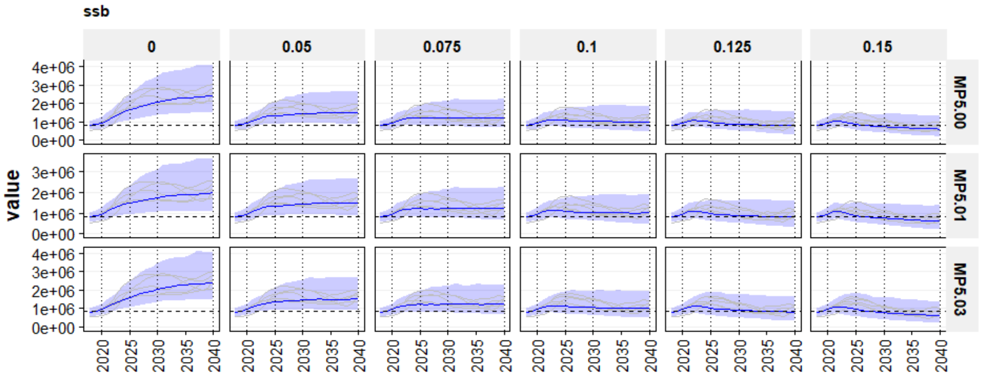
8.3.1 Eqsim applied to SS3 assessment

The SS3 assessment was run with OM2.2:

```
#WGWIDE2019 Update assessment, IBPWHM reference points, stochastic bio and selection
OM2.2 <- list("code" = "OM2.2",
            "desc" = "WGWIDE19",
            "IM" = NA,
            "SRR" = "SRR.WG19.SegReg_Blim.exterm", "RecAR" = TRUE, maxRecRes = c(3,-3),
            "BioYrs" = c(2008,2017), "BioConst" = FALSE,
            "SelYrs" = c(2008,2017), "SelConst" = FALSE,
            "Obs" = NA,
            refPts = list("Fpa" = 0.074, "Flim" = 0.103, "Fmsy" = 0.074, "Bpa" = 1168272,
                          "Blim" = 834480, "MSYBtrigger" = 1168272, "Bloss" = 761613),
            "pBlim" = 0.05)
```

8.3.1.1 Constant F strategy

- MP5.00 constant F;
- MP5.01 constant F with minimum TAC of 50kT;
- MP5.03 constant F with 20% IAV on TAC constraint above Btrigger.



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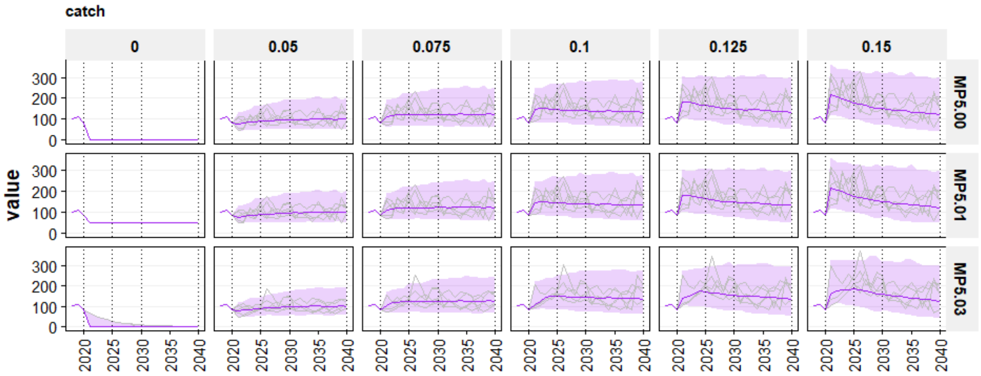
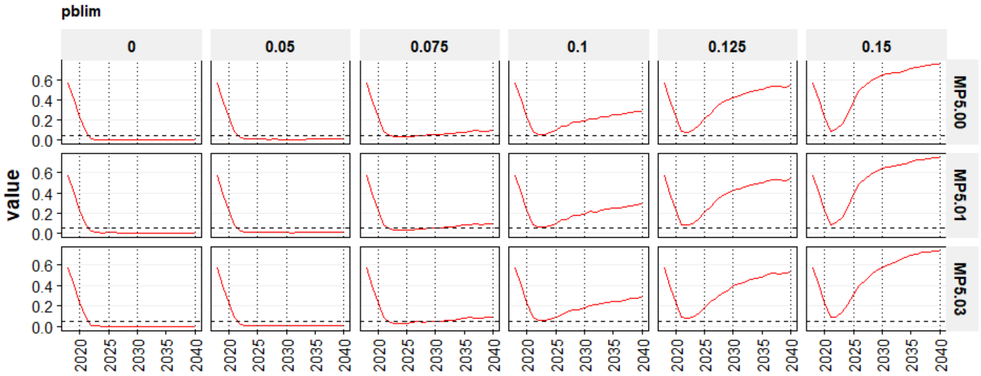
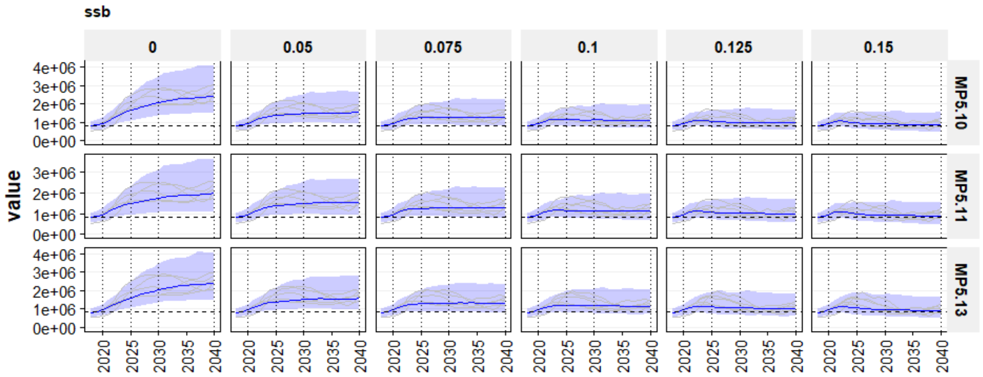


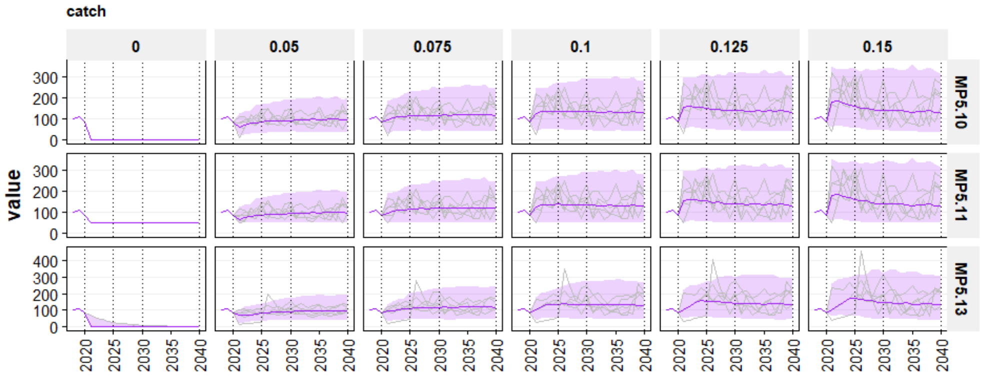


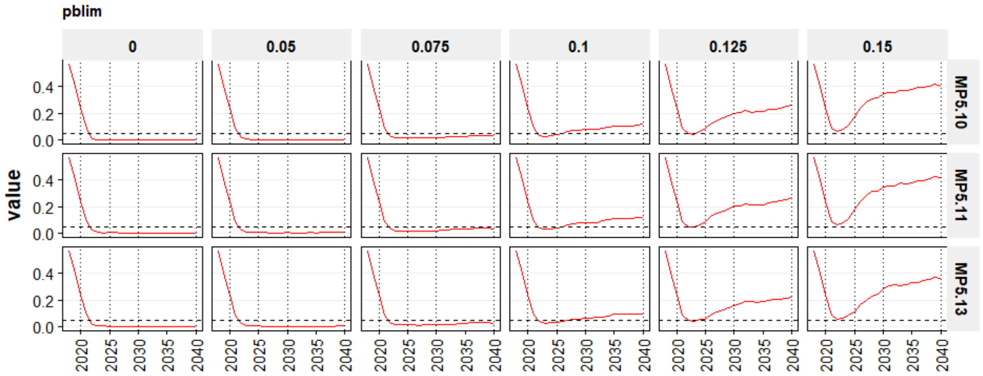
8.3.1.2 ICES Advice Rule

Scenarios 5.1, 5.11 and 5.13 (ICES advice rule variants)

- MP5.10 ICES AR
- MP5.11 ICES AR, min TAC = 50kt
- MP5.13 ICES AR, 20% IAV, only above Btrigger





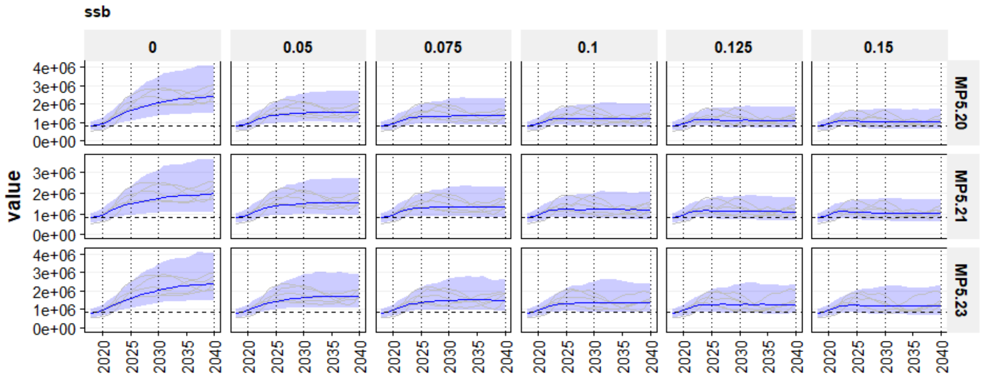


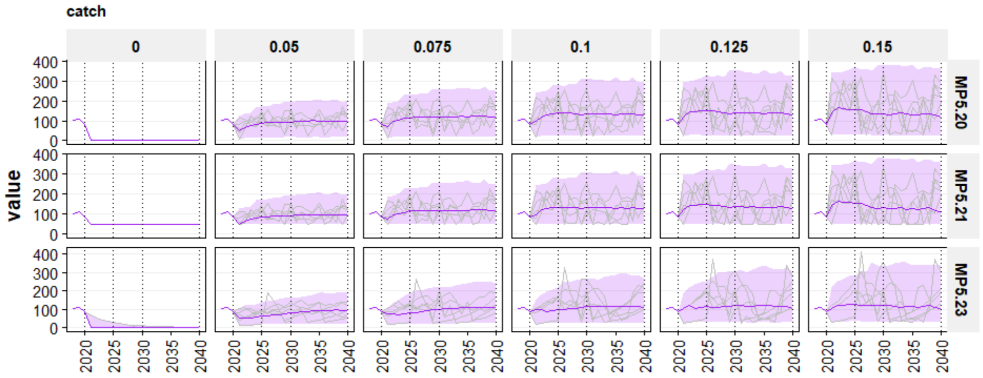
8.3.1.3 Double Breakpoint Rule

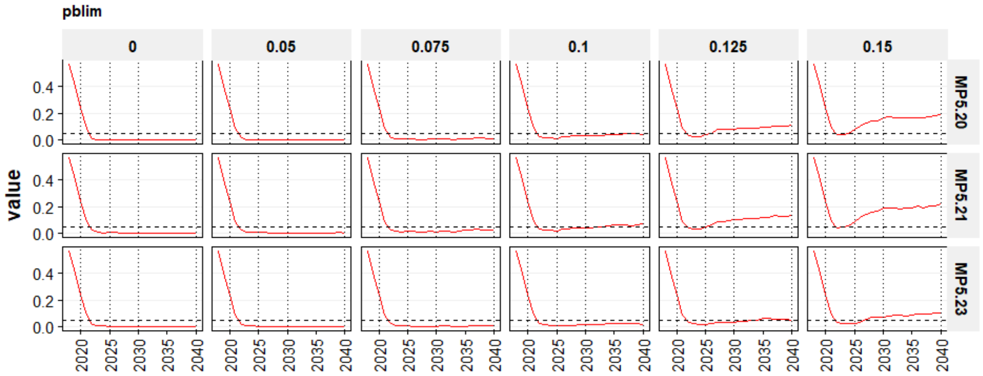
This HCR is similar to the blue whiting HCR that was evaluated in 2016 (ICES, 2016).

- MP5.20 Double BP
- MP5.11 Double BP with minimum TAC of 50kT
- MP5.13 Double BP with 20% IAV constraint above Btrigger.

Minimum F in the Double breakpoint rule is 20% of Ftarget.





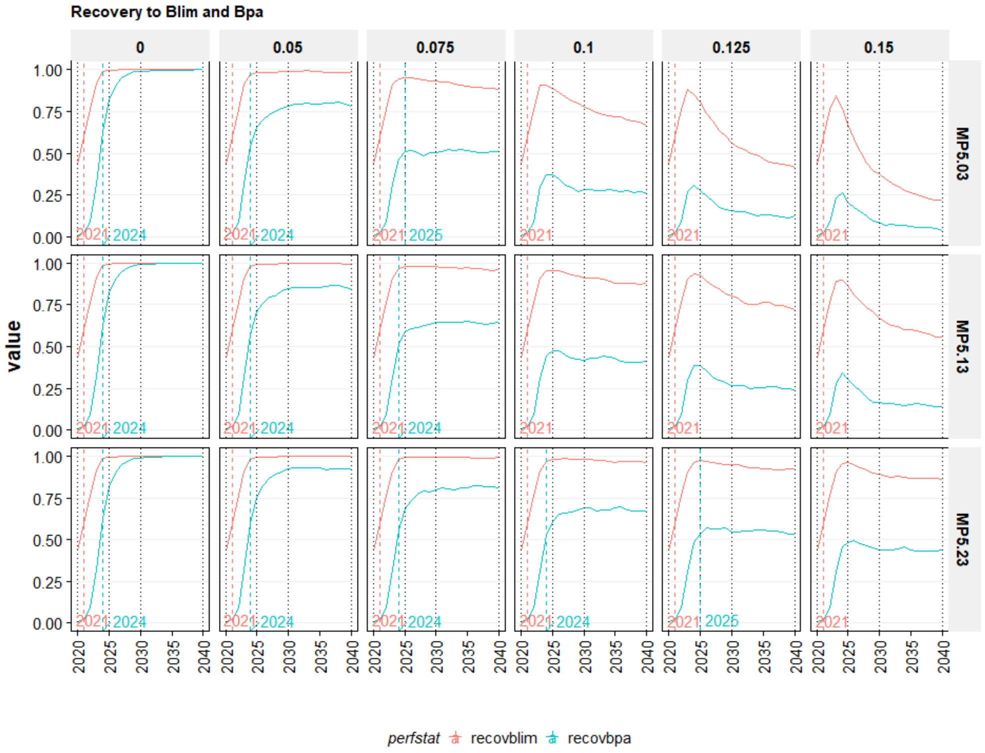


8.3.1.4 First year of achieving rebuilding with 20% IAV constraint scenarios

The first year of achieving rebuilding to Blim and Bpa was calculated as the first year where the probability of being above Blim or Bpa was larger than 50%. The analysis was carried out for the following scenarios:

- MP5.03 constant F with 20% IAV on TAC constraint above Btrigger.
- MP5.13 ICES AR, 20% IAV, only above Btrigger
- MP5.13 Double BP with 20% IAV constraint above Btrigger.

Results indicate that the constant F strategy is the least cautious rule and the double breakpoint rule is the most cautious rule. Under the F strategy rule with a Ftarget of 0.075, rebuilding to Bpa is expected to be achieved is only just being achieved (probability just above 50%) by 2025, while in the double breakpoint rule this is expected to be achieved in 2024 with substantially higher probabilities of remaining above Bpa. The first year of rebuilding to Bpa in the double breakpoint rule with target fishing mortalities up to 0.1 is the same as the first year of rebuilding under the zero fishing scenarios.



8.3.2 Eqsim applied to SAM assessment

The SS3 assessment was run with OM2.2:

```
#WGWIDE2019 SAM assessment, IBPWHM method for reference points, stochastic bio and selection
OM2.3 <- list("code" = "OM2.3",
              "desc" = "WGWIDE19_sam",
              "IM" = NA,
              "SRR" = "SRR.WG19.SegReg_Blim.exterm", "RecAR" = TRUE, maxRecRes = c(3,-3),
              "BioYrs" = c(2008,2017), "BioConst" = FALSE,
              "SelYrs" = c(2008,2017), "SelConst" = FALSE,
              "Obs" = NA,
              refPts = list("Fpa" = 0.115, "Flim" = 0.161, "Fmsy" = 0.115, "Bpa" = 856540,
                            "Blim" = 611814, "MSYBtrigger" = 856540, "Bloss" = 604476),
              "pBlim" = 0.05)
```

Note that the biomass reference points have been estimated separately for the SAM assessment, and are a bit lower than for the SS assessment (see section 7).

8.3.2.1 Constant F rule with SAM assessment

Results for the constant F rule are not presented because it was clear that this option would not be selected by the PELAC for the potential rebuilding plan.

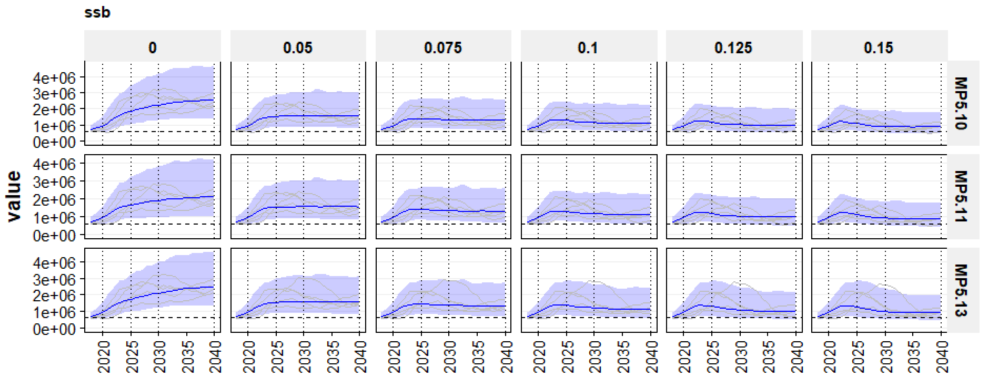
8.3.2.2 ICES Advice Rule with SAM assessment

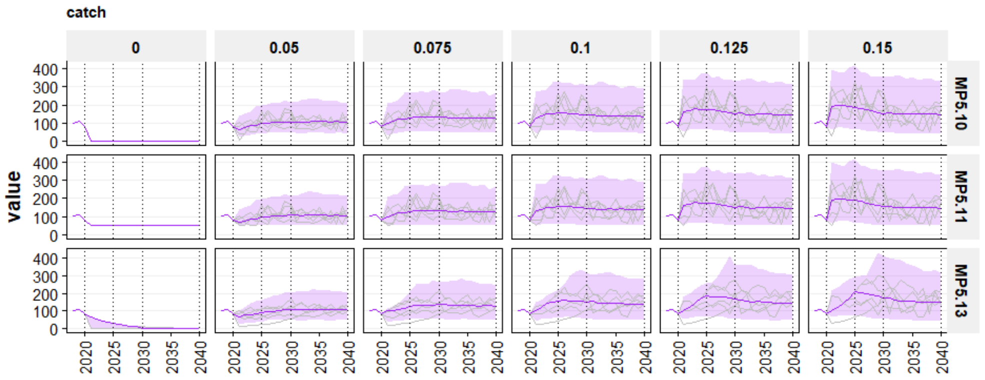
Scenarios 5.10, 5.11 and 5.13 (ICES advice rule variants)

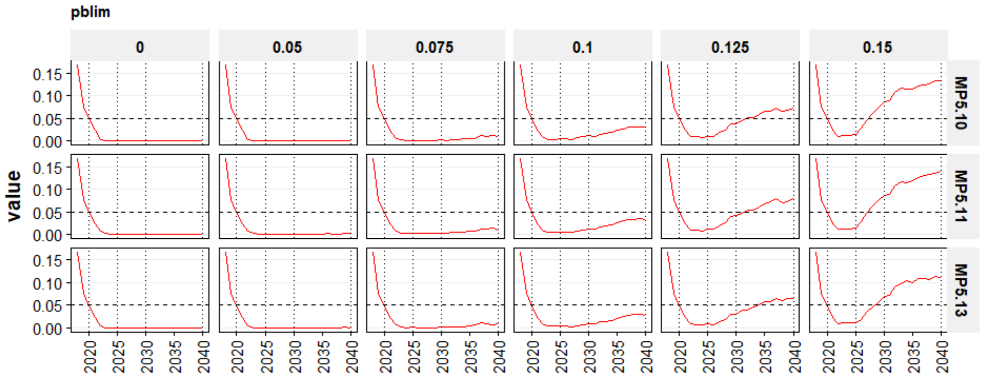
- MP5.10 ICES AR;

- MP5.11 ICES AR with minimum TAC of 50kT;
- MP5.13 ICES AR with 20% IAV constraint above Btrigger.

While the probability of being below Blim decreases in the beginning of the simulation period, for all F targets, the probability of being below Blim start to increase again after 2025 when target fishing mortalities are too high (e.g. > 0.075).







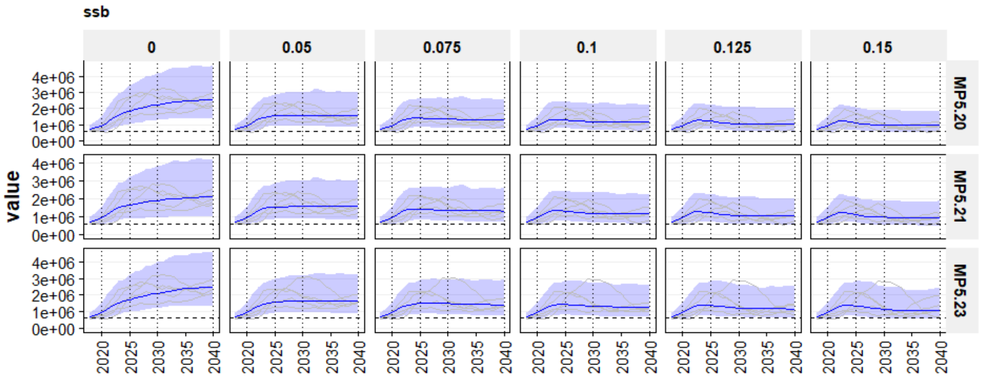
8.3.2.3 Double Breakpoint Rule with SAM assessment

This HCR is similar to the blue whiting HCR that was evaluated in 2016 (ICES, 2016).

- MP5.20 Double BP
- MP5.11 Double BP with minimum TAC of 50kT;

- MP5.13 Double BP with 20% IAV constraint above Btrigger. Minimum F in Double BP is 20% of Fmsy.

Generally, what we find is that the SAM assessment has a somewhat more optimistic view of the stock size in relation to the reference points. This means that the stock is estimated to be above Blim with a high probability in most of the scenarios. It also means that expected recovery to Bpa is in 2022 in all scenarios.



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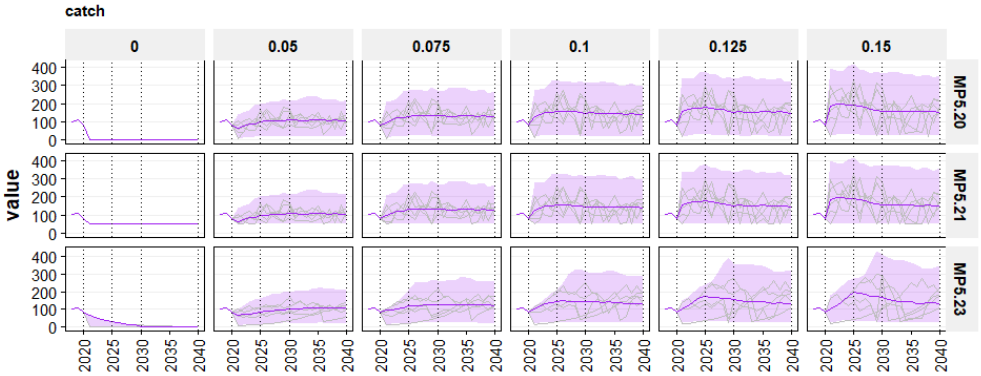
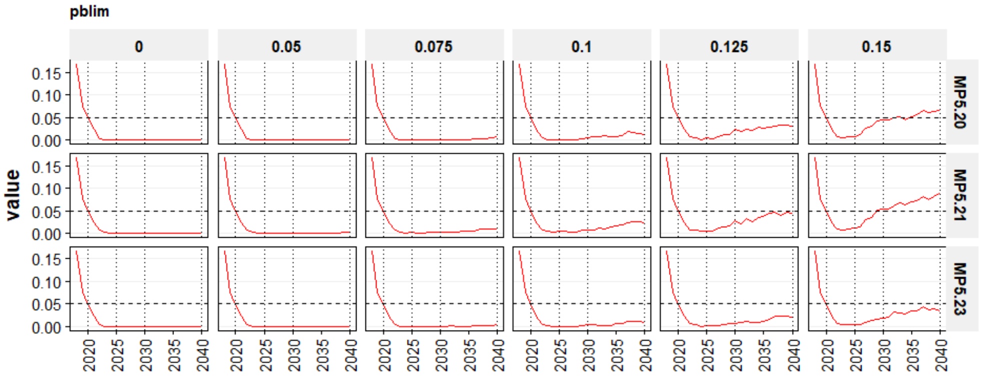
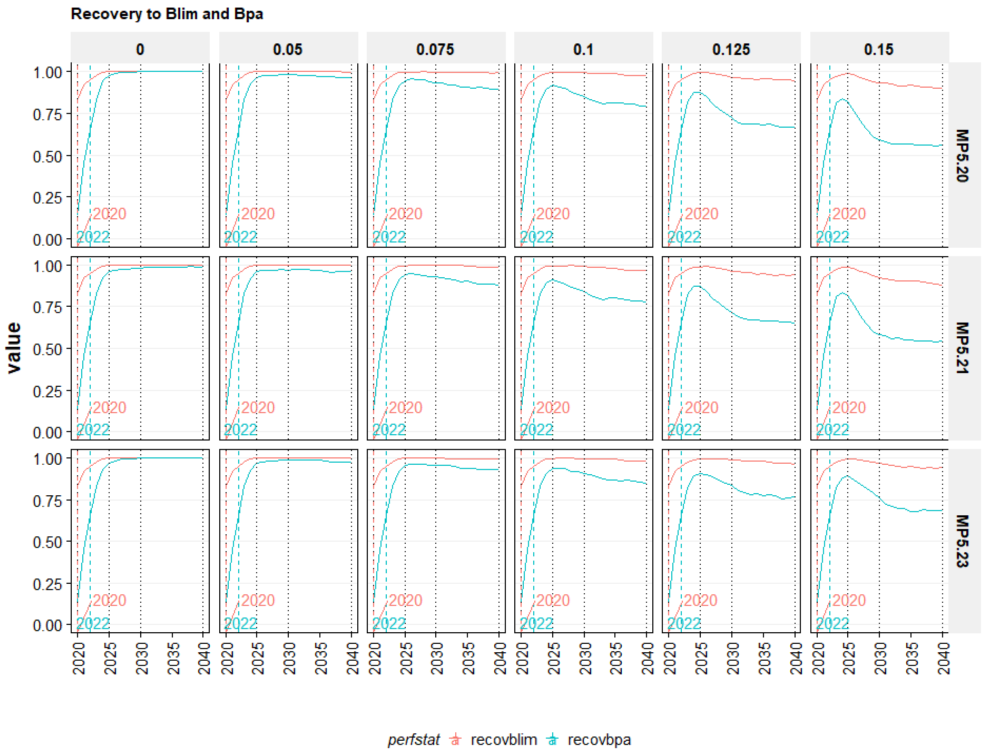






8.4 SAM HCR forecast tool

8.4.1 Description of the method

The SAM HCR was applied to the exploratory SAM assessment (IBPWHM 2019) that was also used for the EqSim with SAM analysis. The SAM HCR forecast can only be run on a SAM assessment[4].

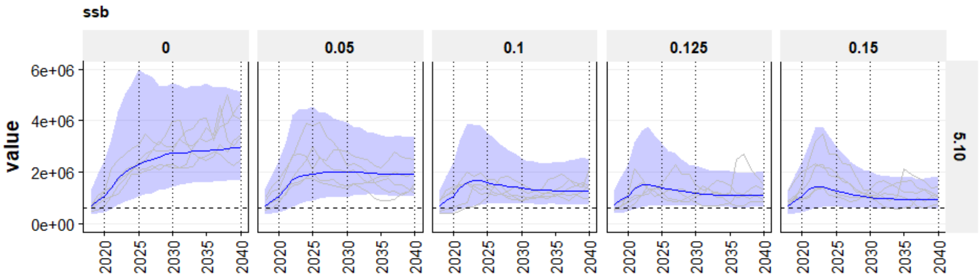
8.4.2 SAM HCR with ICES Advice Rule

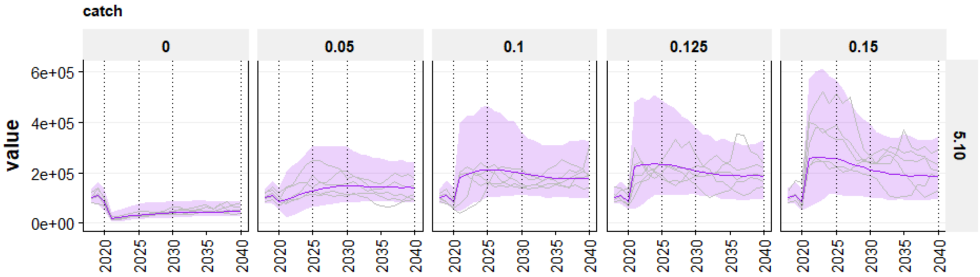
Here we only present the simple ICES AR scenario without any additional constraints as the main purpose is only to show the feasibility of using this simple method while generating similar results from more complicated methods.

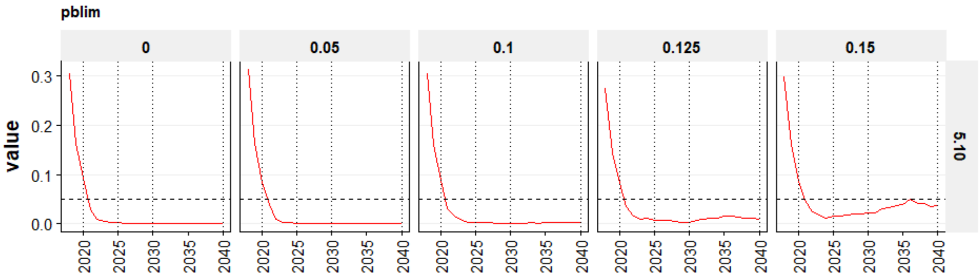
- MP5.10 ICES AR.

---

[4] Note that with the SAM HCR it was not possible to run the forecast with F = 0; therefore F = 0.01 has been run for the results denoted below with F = 0 .



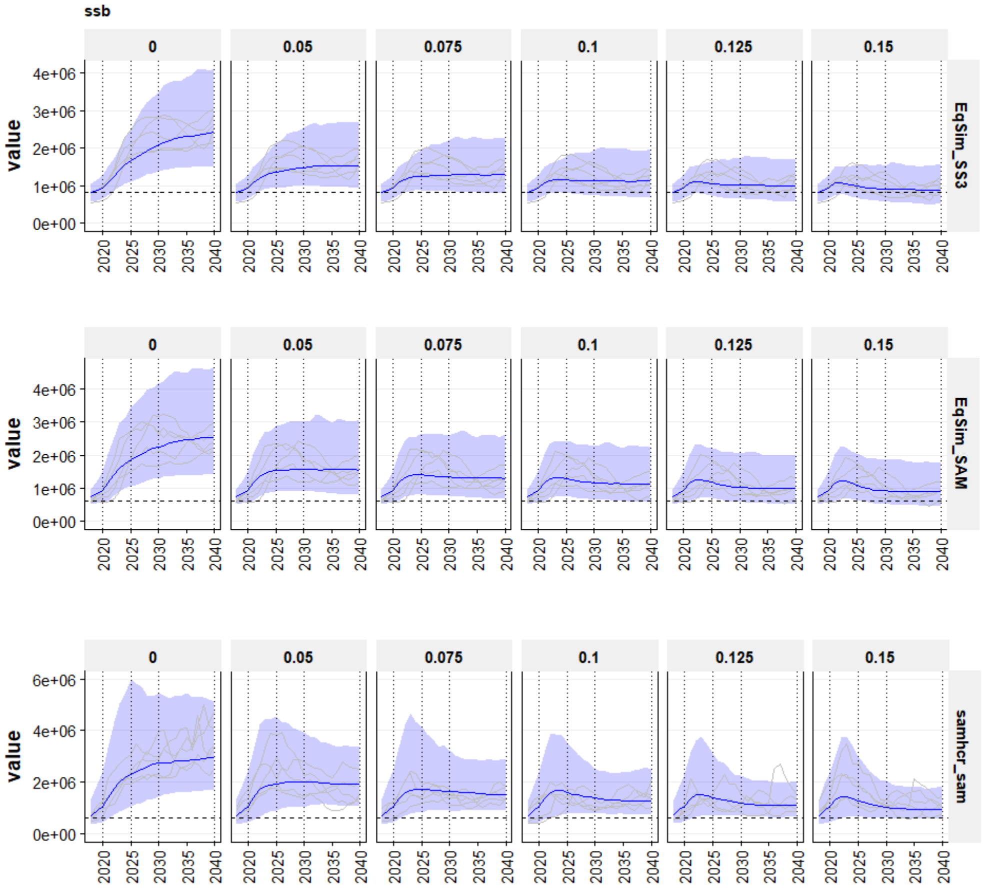


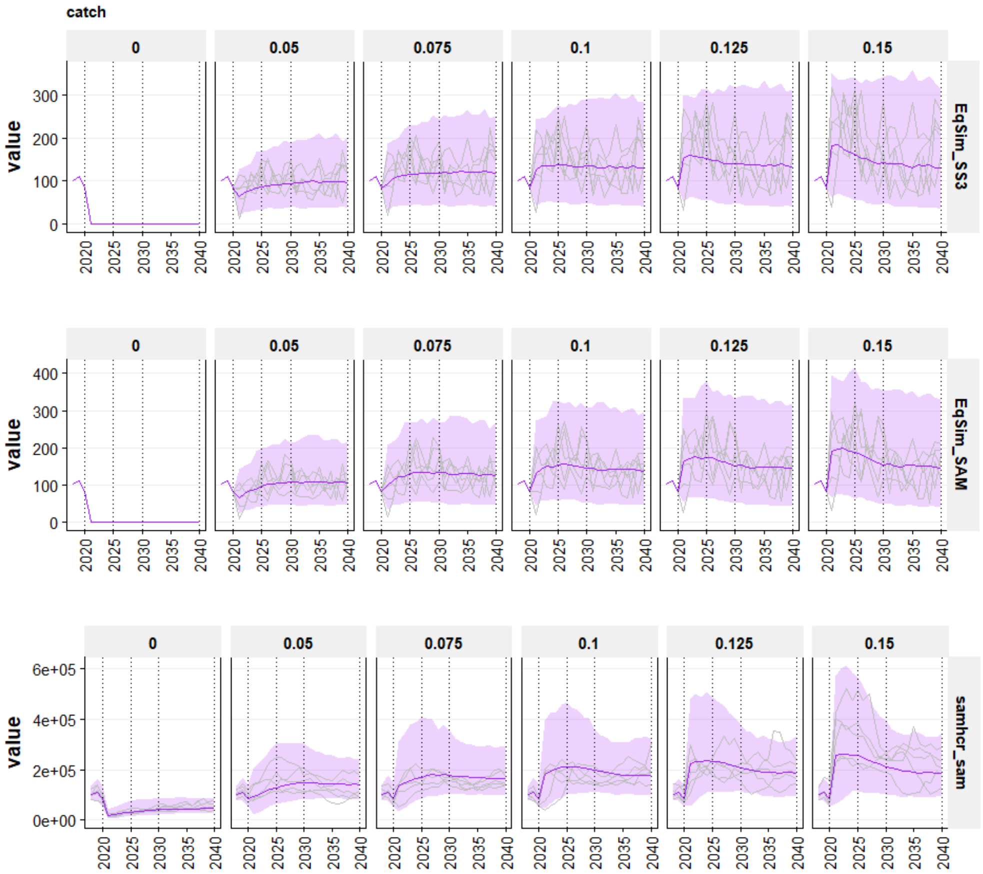


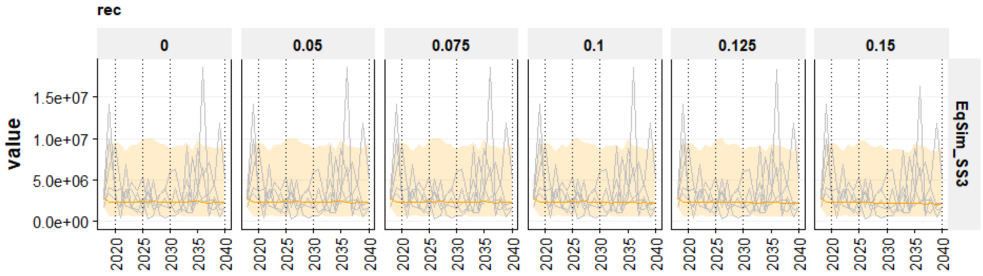
8.5 Comparison of results for different simulation tools and assessments

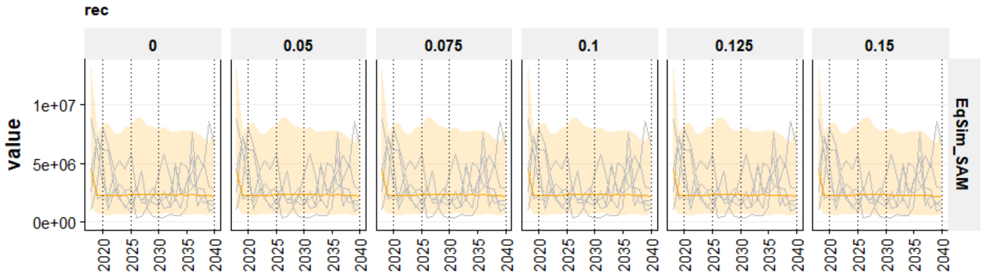
To compare the behaviour of evaluation tools (EqSim or SAM HCR) and assessment method (SAM or SS3), we compared the simple ICES AR scenarios for the three possible combinations:

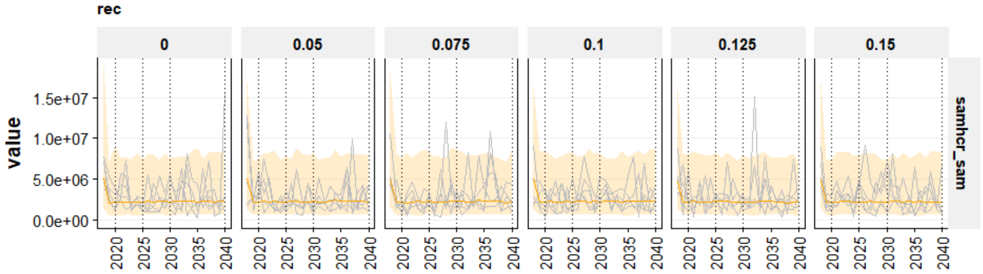
- EqSim – SAM – MP5.1 (ICES AR)
- EqSim – SS3 – MP5.1 (ICES AR)
- SAM HCR – SAM – MP5.1 (ICES AR)

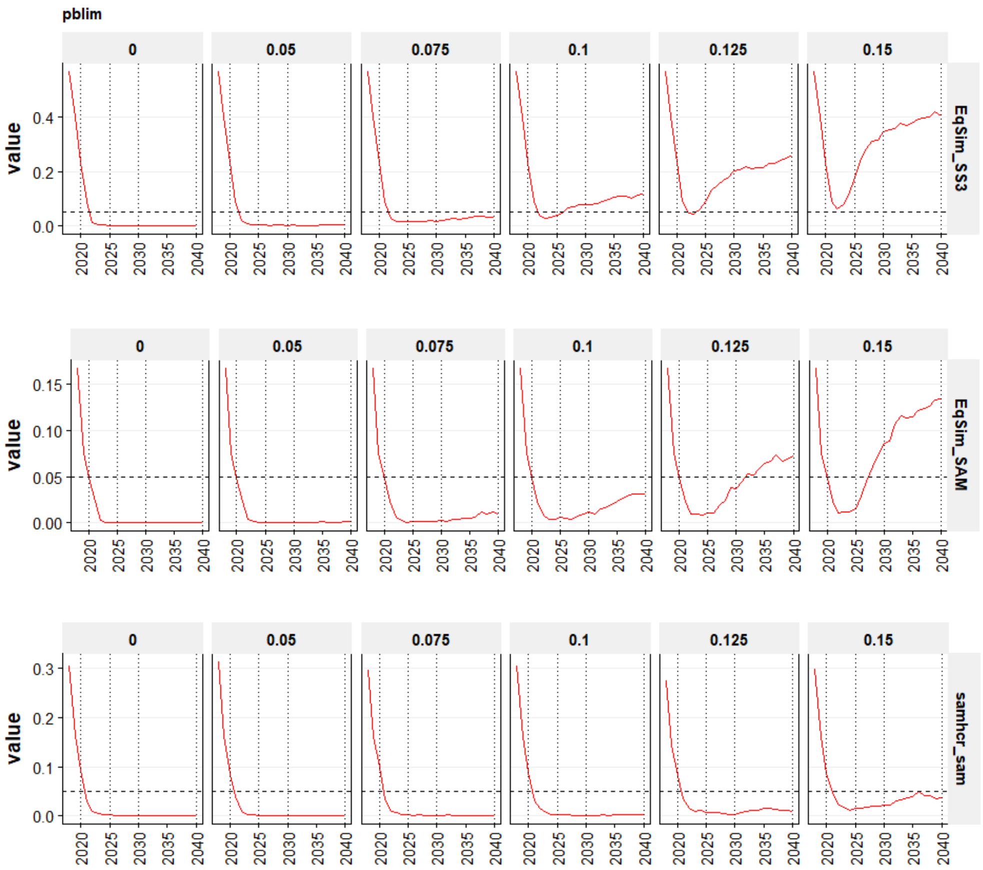

ssb
0
0.05
0.075
0.1
0.125
0.15
value
4e+06
3e+06
2e+06
1e+06
0e+00
EqSim_SS3
EqSim_SAM
6e+06
samhcr_sam
2020
2025
2030
2035
2040


catch
0
0.05
0.075
0.1
0.125
0.15
value
300
200
100
0
EqSim_SS3
400
300
200
100
0
EqSim_SAM
6e+05
4e+05
2e+05
0e+00
samhcr_sam
2020
2025
2030
2035
2040


rec
0
0.05
0.075
0.1
0.125
0.15
EqSim_SS3
value
1.5e+07
1.0e+07
5.0e+06
0.0e+00
2020
2025
2030
2035
2040


rec
0
0.05
0.075
0.1
0.125
0.15
EqSim_SAM
value
1e+07
5e+06
0e+00
2020
2025
2030
2035
2040


rec
0
0.05
0.075
0.1
0.125
0.15
samhcr_sam
value
1.5e+07
1.0e+07
5.0e+06
0.0e+00
2020
2025
2030
2035
2040



The probability of being below Blim broadly follows the same pattern across the three different evaluation method although the levels do differ between the evaluations. Because the SAM assessment estimates the most recent SSBs higher than year where Bloss was calculated, the probability of currently being below Blim is smaller. The patterns observed for the EqSim_SS and EqSim_SAM runs are qualitatively similar albeit at different levels. The SAMHCR_SAM run exhibits a slightly different pattern because the forecasted SSB is expected to remain above Blim with a high probability in all F scenarios. This may be due to the fact that the SAMHCR is operating as a forecast only and therefore lacks the feature that the management perception of the stock differs from the real stock, so that the implemented HCR in the simulation does not suffer from the mismatch between perception and reality.

9 Selection of preferred HCRs for Western Horse mackerel

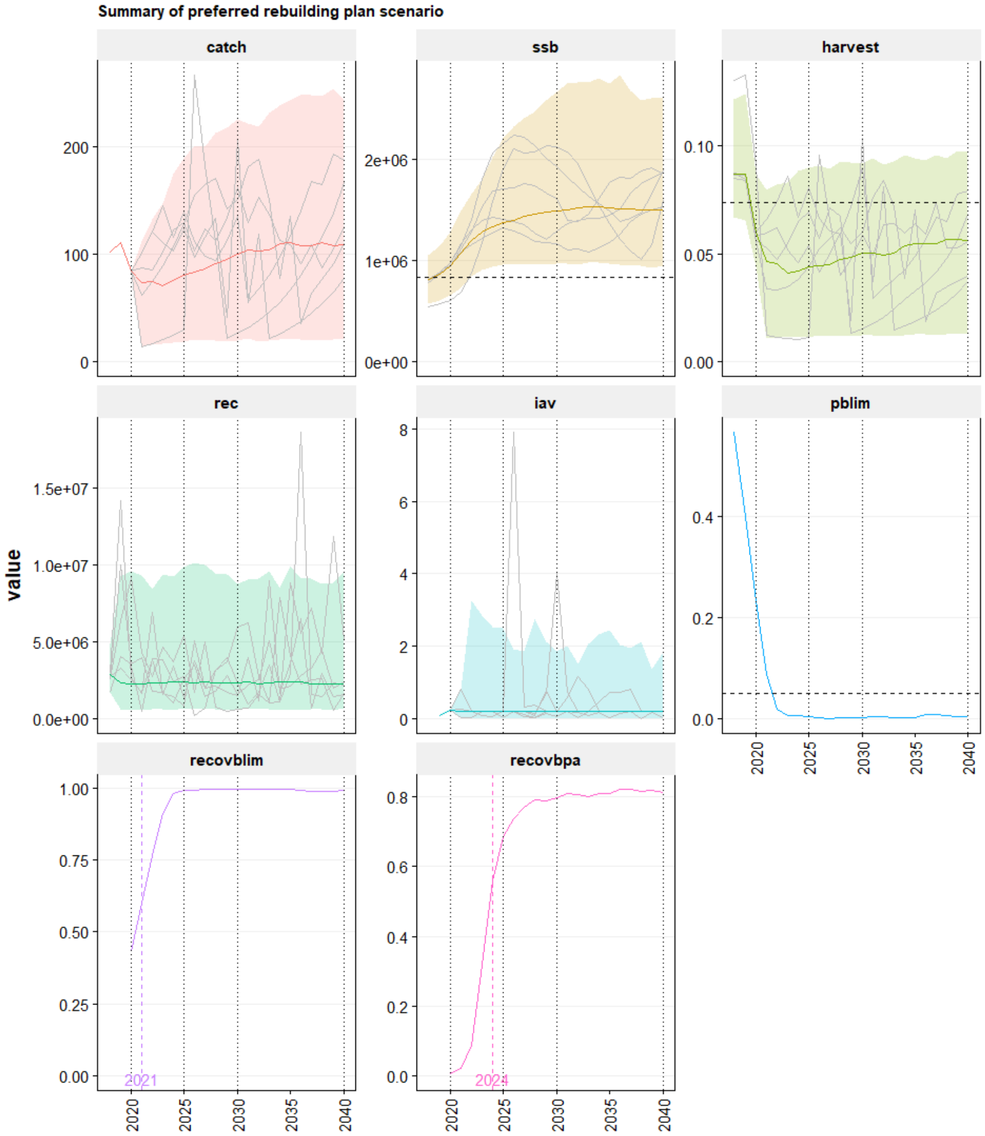
The PELAC selected the following preferred option for the Western horse mackerel rebuilding plan:

- Evaluation method: EqSim
- Assessment: Stock Synthesis (WGWIDE 2019), because this is the basis for the assessment and advice.
- Target fishing mortality at Fmsy = 0.074 (approximated by 0.075 in the simulations)
- Blim at ICES Blim (834 480 t)
- Btrigger at ICES MSY Btrigger (1 168 272 t)

- Double breakpoint rule with 20% constraint on IAV above Btrigger
- Minimum F when stock is below Blim at 20% of Fmsy = 0.015

The selected rebuilding plan has a 50% probability of rebuilding to Blim by 2021 (similar to zero catch option) and a 50% probability of rebuilding to Bpa/MSY Btrigger by 2024 (similar to the zero-catch option). Furthermore, the probability of being below Blim remains well below 5% for the duration of the simulation.

In this scenario, the average catch in the years 2021-2025 is expected to be lower than recent catches. However, after rebuilding, catches should be able to be maintained around 100 000 tonnes.



Summary of results of the preferred rebuilding plan

```
statistic  yearrange   period   median      range
---------- ----------- -------- ----------- ---------------------

catch      2018-2020   CU       102         84 - 110            * in kT
catch      2021-2025   ST       75          17 - 167
```

```
catch      2026-2030   MT       92          20 - 210
catch      2031-2040   LT       107         21 - 242

ssb        2018-2020   CU       872,454     608,164 - 1,210,564
ssb        2021-2025   ST       1,249,710   832,465 - 1,902,950
ssb        2026-2030   MT       1,451,882   966,840 - 2,506,102
ssb        2031-2040   LT       1,514,418   958,213 - 2,740,040

harvest    2018-2020   CU       0.080       0.048 - 0.118
harvest    2021-2025   ST       0.044       0.011 - 0.085
harvest    2026-2030   MT       0.047       0.012 - 0.092
harvest    2031-2040   LT       0.054       0.012 - 0.095

rec        2018-2020   CU       2,599,180   696,645 - 7,944,499
rec        2021-2025   ST       2,363,631   606,888 - 9,317,602
rec        2026-2030   MT       2,361,298   599,077 - 9,438,791
rec        2031-2040   LT       2,321,690   612,371 - 9,088,107

iav        2018-2020   CU       0.162       0.086 - 0.239
iav        2021-2025   ST       0.200       0.021 - 2.576
iav        2026-2030   MT       0.200       0.018 - 2.083
iav        2031-2040   LT       0.200       0.017 - 2.032

pblim      2018-2020   CU       0.401       0.243 - 0.560
pblim      2021-2025   ST       0.006       0.005 - 0.082
pblim      2026-2030   MT       0.002       0.001 - 0.003
pblim      2031-2040   LT       0.004       0.002 - 0.009
```

Table of settings used in the evaluation

```
class   desc                 value
------- -------------------- ------------------------------------
OM      code                 OM2.2
OM      desc                 WGWIDE19
OM      IM
OM      SRR                  SRR.WG19.SegReg_Blim.exterm
OM      RecAR                TRUE
OM      maxRecRes1           3
OM      maxRecRes2           -3
OM      BioYrs1              2008
OM      BioYrs2              2017
OM      BioConst             FALSE
OM      SelYrs1              2008
OM      SelYrs2              2017
OM      SelConst             FALSE
OM      Obs
OM      refPts.Fpa           0.074
OM      refPts.Flim          0.103
OM      refPts.Fmsy          0.074
OM      refPts.Bpa           1168272
OM      refPts.Blim          834480
OM      refPts.MSYBtrigger   1168272
OM      refPts.Bloss         761613
OM      pBlim                0.05


MP      code                 MP5.23
MP      desc                 Double BP HCR
MP      xlab                 Double BP IAVBtrig
MP      HCRName              DoubleBP
MP      F_target1            0
MP      F_target2            0.025
MP      F_target3            0.05
MP      F_target4            0.075
MP      F_target5            0.1
MP      F_target6            0.125
MP      F_target7            0.15
MP      B_trigger            MSYBtrigger
MP      minTAC
```

```
MP      maxTAC
MP      TAC_IAV1             0.2
MP      TAC_IAV2             0.2
MP      Obs.cvF              0.22
MP      Obs.phiF             0.03
MP      Obs.cvSSB            0.36
MP      Obs.phiSSB           0.51

OTHER   niters               1000
OTHER   nyr                  23
OTHER   CU                   2018-2020
OTHER   ST                   2021-2025
OTHER   MT                   2026-2030
OTHER   LT                   2031-2040
OTHER   flstock              WGWIDE19.RData
OTHER   flstock_sim          MSE_WGWIDE19_FLStocks_1k15PG.RData
```

10 Summary and conclusions

This report has brought together many different topics that are related to the western horse mackerel stock in an attempt to develop a potential rebuilding plan for the stock. Even though western horse mackerel was not classified by ICES as in need of rebuilding in their latest advice (ICES, 2019a), the general perception within the fishing industries has been that the stock has been in a poor state but that there have been some positive signals in recent recruitment. Using the new recruitments to improve the stock status requires a careful management approach. The PELAC has been a proponent of developing management plans for all stocks in their remit. In this case, the PELAC has termed the approach a rebuilding plan because of the current stock status of the stock.

Substantial progress has been made over the past few years on horse mackerel stock ID (Farrell et al., 2020). The full genome sequencing of horse mackerel from samples taken all the way from the Skagerrak to the Mediterranean and North Africa, has yielded a suitable panel of SNP markers that can be used to differentiate between the different horse mackerel stocks. The strongest differentiation between populations was between the northern and southern populations, with the boundary being in the middle of Portugal. The North Sea population is clearly distinct from the Western population and it should be possible to tell the difference from mixed samples with a high probability (>93%). This would also allow screening of catches in 7d and 7e on the contribution of western and North Sea populations. The separation between the northern and southern populations could mean that the current division between western and southern horse mackerel is not adequate, at the northern part of 9a is currently included in the southern population. A similar split in the middle of Portugal has also been observed for boarfish (Farrell et al., 2016) and could indicate a biogeographical feature.

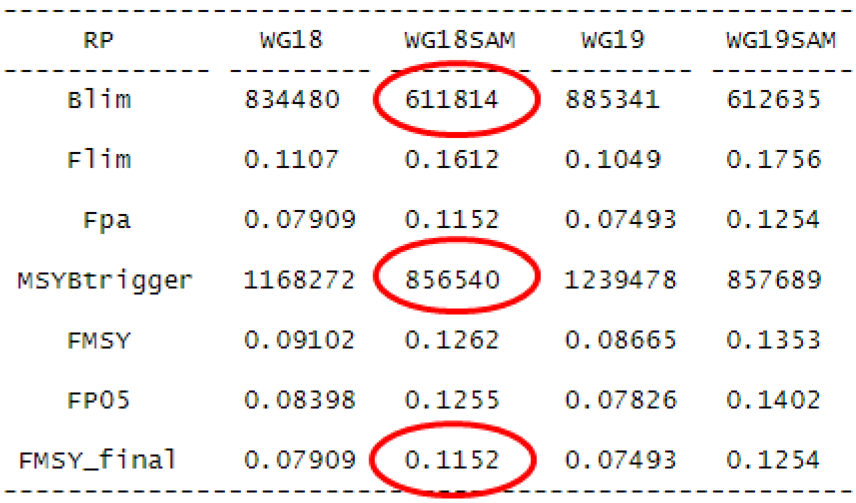
Length compositions of the catches are an important element of the assessment approach for western horse mackerel, because Stock Synthesis uses length composition in combination with age-length key to estimate the age compositions within the model. Part of a rebuilding plan for western horse mackerel could be to evaluate differences in length compositions in the catches in certain areas and to take specific measures to protect incoming recruitment. Therefore, we planned to carry out an analysis of length compositions by area and season. However, we found that such data is not currently available for all years. Length data for western horse mackerel is not included in the ICES InterCatch database. Instead, length data has been processed on a year by year basis in non-standardized Excel spreadsheets. A time series of length compositions by area and season can therefore only be derived by manually working through the spreadsheets and extracting the required information. This was not feasible as part of the project to develop and evaluate a rebuilding plan for western horse mackerel. We recommend to WGWIDE that the full time series of catch at length by country is recreated from the Excel spreadsheets and converted in a standardized database format to allow for future interrogations of the data and an underpinning of the input data to the stock assessment.

In order to understand how a stock would respond to recovery measures, it is useful to consider the age composition in the spawning stock which illustrates how recruitment in the previous years contributed to the present spawning stock. To this end, an SSB per recruit analysis has been carried out. As one should expect for a relatively long-lived species with low mortality, the spawning stock is currently rather old. At F =0.075, the mean age is about 9 years, 80% is older than 5 years and 20% older than 12 years. So, an improved recruitment will take some time to materialize as increased SSB. The results also indicate that with a low F, the plus group still does matter.

The current stock assessment method for western horse mackerel is Stock Synthesis 3, as agreed in the WKWIDE benchmark of 2017 (ICES, 2017b). Reference point were also set at WKWIDE 2017 but have subsequently been updated in the IBPWHM 2019 (ICES, 2019b). In addition, an exploratory SAM assessment has been carried out as part of IBPWHM 2019. This was done in order to get a second view on stock trends but also to be able to run the SAM HCR forecast as part of the development of a potential rebuilding plan. The exploratory SAM assessment (https://www.stockassessment.org/setStock.php?stock=WHOM2018) was initiated with the same input data as was used for the Stock Synthesis assessment of WGWIDE 2018 (ICES, 2018) with the exception of the length frequency data, which was not used. The PELACUS survey data was therefore only used as an index of biomass within SAM. The process of fine-tuning the assessment lead to the binding of the observation variances for certain variables and to the application of a fixed selectivity pattern (correlation coefficient ϱ=1 in the F random process (https://github.com/martinpastoors/wgwide/blob/master/R/HOM%20optimization_SAM.R). A comparison of Fbar and SSB between the SS3 assessments of WG2018 and 2019 with the SAM assessment (WG18SAM, WG19SAM), shows that the general trends are the same but that there are some deviations in certain periods (e.g. the SSB in the late 1980s is estimated substantially higher in SAM compared to SS3). The Stock Synthesis results are in general a bit smoother compared to SAM.

In order to be able to use the SAM assessment as an alternative assessment in the rebuilding plan evaluation, we needed to estimate reference point for this assessment. In doing so, we aimed to follow the same procedure as during IBPWHM 2019 (ICES, 2019b). However, one of the elements of the reference point estimation, triggered a more in-depth study: the role of assessment uncertainty parameter Fcv and Fphi. There has been little standardization in how Fcv and Fphi have been calculated in different benchmarks where reference points were estimated. Fcv is expected to capture the assessment error in the advisory year and Fphi is the autocorrelation in assessment error in the advisory year (ICES, 2014a). We documented the method for generating the input data for the calculations and explored the sensitivity of Fcv and Fphi to the assessment that was used (both for western horse mackerel and for Atlantic mackerel). We found that there can be a high dependence of Fphi on the assessment that is used to compare against the Fset. When the assessment that is used has values that are all higher or lower than the Fset values, then Fphi will be close to zero. To our knowledge, this behaviour of Fphi was unknown so far. We also found that the number of years that is used for calculating Fcv and Fphi may have an impact on the values. In the recommendations from WKMSYREF3 it is stated that 10 years (or more) should be taken. A further study should be undertaken to assessment the impacts of using different time periods for estimating Fcv and Fphi.

During the IBPWHM 2019, reference points were estimated for western horse mackerel based on the 2018 WGWIDE assessment and using default values for Fcv and Fphi (0.212 and 0.423) and using a segmented regression through Blim (segregBlim). In order to calculate reference points for the exploratory SAM assessment and to explore the sensitivity to the assessment year, reference points were calculated on the basis of the 2018 or 2019 assessments for SS and SAM. The reference points for the SAM assessment are based on the 2018 assessment. Bpa and Blim are lower than the values for the SS assessment, while the Fmsy is higher. The changes due the assessment year were minor for both the SS and SAM assessments.



```
-------------------------------------------------------
      RP          WG18     WG18SAM    WG19     WG19SAM
-------------  ---------  ---------  --------- ---------
     Blim       834480     611814     885341    612635

     Flim       0.1107     0.1612     0.1049    0.1756

      Fpa       0.07909    0.1152     0.07493   0.1254

  MSYBtrigger   1168272    856540     1239478   857689

     FMSY       0.09102    0.1262     0.08665   0.1353

     FP05       0.08398    0.1255     0.07826   0.1402

  FMSY_final    0.07909    0.1152     0.07493   0.1254
-------------------------------------------------------
```

HCR evaluations

The HCR analyses represent two different assessment methods (SS3 and SAM) and two different HCR evaluation tools (EqSim and SAM HCR). Both HCR evaluation tools are of the type ‘short-cut’ with appropriate conditioning of the uncertainties in the assessment based on historical CV and autocorrelation in line with the recommendations from WKMSYREF3 and WKMSYREF4 . The evaluations followed the guidelines from WKGMSE2 (ICES, 2019c) and WKREBUILD (ICES, 2020).

Three different types of harvest control rules were evaluated:

- Constant F strategy: fixed Ftarget independent of biomass level
- ICES Advice Rule: breakpoint at Btrigger and straight decline in F to zero below Btrigger.
- Double Breakpoint rule: breakpoint at Btrigger and straight decline in F to 20% of Ftarget at Blim. Below Blim continued fishing at F = 0.2 * Ftarget.

For each of the HCRs, a number of different target fishing mortalities were explored (0.0, 0.05, 0.075, 0.1, 0.125, 0.15). No evaluation of different Btrigger values was carried out, so that all evaluations used MSY Btrigger as the trigger point. All HCRs where evaluated with three variants:

- Without any additional constraints

- With a minimum TAC of 50 kT
- With a maximum 20% inter-annual variation (IAV) in TAC, but only when the stock is above Btrigger)

Two simulation tools were used: the EqSim simulator and the SAM HCR forecast. The EqSim simulator is a further worked up version of the SimpSIM approach that was used for the blue whiting MSE in 2016 (ICES, 2016). The code was further developed by Andrew Campbell and Martin Pastoors to improve standardization, documentation and visualization of results. EqSim makes use of an Operating Model (OM) and a Management Procedure (MP). The SAM HCR forecast is a simple stochastic forecast with HCR to evaluate management for fish stocks that need rebuilding in the short-term. The stochastic forecasts start from what we believe is the current level of the stock with appropriate uncertainty, i.e. the assessment estimates currently used for tactical management advice, with consideration of the uncertainty in these estimates. Rebuilding is evaluated forward for a specified number of years and for different target fishing mortality values.

The EqSim with SS3 results indicate that the constant F strategy is the least cautious rule and the double breakpoint rule is the most cautious rule. Under the F strategy rule with a Ftarget of 0.075, rebuilding to Bpa is expected to be achieved is only just being achieved (probability just above 50%) by 2025, while in the double breakpoint rule this is expected to be achieved in 2024 with substantially higher probabilities of remaining above Bpa. The first year of rebuilding to Bpa in the double breakpoint rule with target fishing mortalities up to 0.1 is the same as the first year of rebuilding under the zero fishing scenarios.

Similar results have been obtained with the EqSim with SAM evaluations although the levels of SSB are slightly higher and risk to Blim is slightly lower. According to these evaluations, rebuilding to Bpa could be obtained by 2022 in all scenarios.

The SAM HCR with SAM evaluations have only been carried out for the ICES Advice Rule scenario, as this was intended more as a contrasting study rather than a full analysis of HCR evaluation. Again, we find similar patterns in simulated stock trends, but SSB is estimated higher than in the EqSim with SAM evaluations and risk to Blim stays below Blim for all target fishing mortalities that have been explored.

Given that the EqSim with SS3 evaluation is closest to the ICES advisory practice, this was used as the basis for the preferred rebuilding plan by the PELAC. The PELAC preferred options are:

- Target fishing mortality at Fmsy = 0.074 (approximated by 0.075 in the simulations)
- Blim at ICES Blim (834 480 t)
- Btrigger at ICES MSY Btrigger (1 168 272 t)
- Double breakpoint rule with 20% constraint on IAV above Btrigger
- Minimum F when stock is below Blim at 20% of Fmsy = 0.015

The selected rebuilding plan has a 50% probability of rebuilding to Blim by 2021 (similar to zero catch option) and a 50% probability of rebuilding to Bpa/MSY Btrigger by 2024 (similar to the zero-catch option). Furthermore, the probability of being below Blim remains well below 5% for the duration of the simulation.

In this scenario, the average catch in the years 2021-2025 is expected to be lower than recent catches. However, after rebuilding, catches should be able to be maintained around 100 000 tonnes.

11 References

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