WORKSHOP ON GUIDELINES AND METHODS FOR THE DESIGN AND EVALUATION OF REBUILDING PLANS FOR CATEGORY 1-2 STOCKS (WKREBUILD2)

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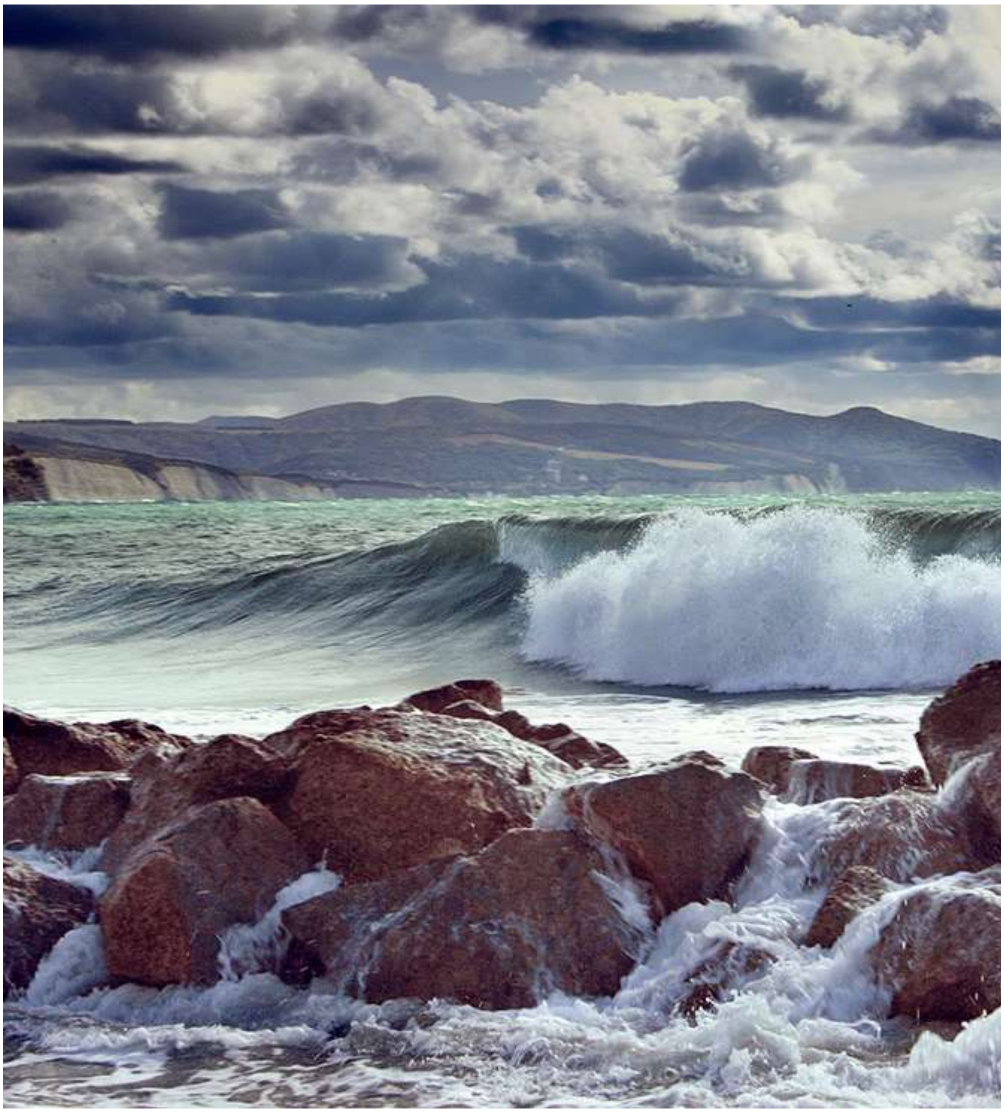

ICES INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA
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International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Editors

Dorleta Garcia • Martin Pastoors

Authors

Christoffer Moesgaard Albertsen • Elena Balestri • Valerio Bartolino • Andrew Campbell • Massimiliano Cardinale • Santiago Cerviño • Harriet Cole • Kenny Coull • David Curtis • Johanna Fall • Niall Fallon • Edward Farrell • Dorleta Garcia • Hans Gerritsen • Nicolas Goñi • Karen Green • Stefanie Haase • Niels Hintzen • Kristiina Hommik • Daniel Howell • Ruth Kelly • Alexander Kempf • Kristján Kristinsson • Polina Levontin • Iago Mosqueira • Richard Nash • Rosana Ourens • Martin Pastoors • Inés Rodríguez • Claus Reedtz Sparrevohn • Noa Steiner • Marc Taylor • Mary Thiess • Vanessa Trijoulet • Luís Vicente • Maria Ching Villanueva • Ashley Wilson • Henning Winker

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i Executive summary

A first workshop on guidelines and methods for the design and evaluation of rebuilding plans for category 1-2 stocks, WKREBUILD, took place in 2020. WKREBUILD generated a guidance on best practices for evaluation of rebuilding plans against potential criteria of acceptability. However, it did not propose specific rebuilding plans or harvest control rules (HCRs). Instead, the workshop recommended that a follow-up workshop be organized for testing the guidelines with actual test cases, with the aim of defining more specific criteria and guidelines. Thus, the main objective of WKREBUILD2 was to propose performance indicators and thresholds for the implementation and acceptability of rebuilding plans and a framework for the integration of rebuilding advice rules within the ICES advice framework.

To facilitate the evaluation of rebuilding plans a simulation tool was developed. The tool is based on FLR libraries and the application to specific cases is facilitated through a template consistent with TAF (Transparent Assessment Framework) and ensures an easy integration of the analysis into the ICES TAF system. The tool was tested in three specific case studies, Celtic Sea Whiting, Western Horse Mackerel and Western Baltic Herring. The application to the case studies served to validate the tool and to provide the science base to propose operational performance thresholds and criteria for the evaluation and implementation of rebuilding strategies in ICES.

WKREBUILD2 proposes to use B_{PA} as the entry point to the rebuilding phase and MSY $B_{trigger}$ as the exit point. Once a stock is estimated to be below B_{PA} in the last assessment year, stock specific rebuilding strategies should be tested by means of simulations, preferably using the WKREBUILD2 simulation tool as the performance of HCRs are dependent on depletion rate and life history. The harvest control rule that fulfils the rebuilding criteria could then be selected to provide headline catch advice. Two criteria to be simultaneously fulfilled are proposed for the selection of the HCR: 1) the time of recovery (i.e., time to rebuild the stock) should not exceed twice the time required to recover the stock in the absence of fishing; 2) cumulative catches are maximised over a common rebuilding period. A stock is considered to be rebuilt when it has been above MSY $B_{trigger}$ for at least three consecutive years.

Future work should be focused on defining suitable MSY $B_{trigger}$ reference points that are linked to a target biomass level as for example B_{MSY} and not to B_{PA}, replacing the three consecutive year criteria by a time criteria based on the biological characteristics of the stock as for example generation time or time to sexual maturity, revising the proposed guidelines based on the implementation of rebuilding strategies in practice and considering augmenting the rebuilding criteria with indicators of the demographic structure of the stock. The acceptable time to recovery (twice the time needed in the absence of fishing) could be shortened and the maximum cumulative catch criteria could be replaced according to management objectives agreed by relevant management parties. Recommendations for the improvement and further development of the simulation tool were made and they are already being implemented.

ii Expert group information

Expert group name	Workshop on guidelines and methods for the design and evaluation of rebuilding plans for category 1-2 stocks (WKREBUILD2)
Expert group cycle	Annual
Year cycle started	2023
Reporting year in cycle	1/1
Chairs	Martin Pastoors, Netherlands
	Dorleta Garcia, Spain
Meeting venue and dates	6-10 November 2023, Copenhagen, Denmark (40 participants)

1 Introduction

1.1 Background

The Workshop on guidelines and methods for the design and evaluation of rebuilding plans for category 1-2 stocks (WKREBUILD2) is the second workshop on the topic of rebuilding plans, following up from WKREBUILD, that was held in 2020(ICES, 2020d), and that had generated a guidance table summarizing the best practices for evaluation of rebuilding plans against the potential criteria of acceptability. The guidance table included elements such as estimation of reference points, time-frames for rebuilding, rebuilding targets, handling uncertainties and bias, probability of achieving rebuilding targets and visualizing results. The WKREBUILD in 2020 recommended a follow-up workshop to be organized for testing the guidelines with actual test cases, with the aim of defining more specific criteria and guidelines, i.e. learning by doing (ICES, 2020d). This is how the WKREBUILD2 has been initiated. A simulation tool to test rebuilding strategies following the guidelines of WKREBUILD was implemented in advance and three case studies were selected to test the tool and the guidelines within the WKREBUILD2.

Rebuilding plans are management tools and ICES can recommend its implementation when a stock is perceived to be in a poor state. Furthermore, advice requesters can ask ICES to evaluate the performance of such plans before they are implemented. However, for situations where ICES considers necessary to provide a robust advice on fishing opportunities that ensures rebuilding of the stock, ICES should implement a default mechanism to provide advice following similar guidelines to those presented here. In the context of this workshop and this report, we assume that rebuilding plans are initiated by advice requesters, that ICES should have objective criteria to recommend implementation of rebuilding plans and a robust default procedure to provide rebuilding advice.

1.2 Terms of reference

The workshop on guidelines and methods for the design and evaluation of rebuilding plans for category 1-2 stocks (WKREBUILD2) met from 6 to 10 November 2023 at ICES headquarters, to:

a) Define a framework for scientific advice for developing rebuilding plan elements as part of overall management strategies, that could be widely applied to ICES stocks.

b) Develop guidelines for the evaluation of rebuilding plan elements that consider the precautionary approach, the species' life-history (incl. longevity), changes in productivity and rebuilding potential.

c) Propose the performance indicators and thresholds to be used for the acceptability of rebuilding plan elements including rebuilding target, probability of rebuilding and rebuilding time relative to rebuilding time in the absence of fishing.

d) Test the rebuilding plan evaluation guidelines on a limited number of test cases using a newly developed and dedicated evaluation tool

e) Identify any additional requirements for an evaluation tool that would allow the evaluation of rebuilding plans elements proposed in ToR (a) in the context of assessment working groups.

The ToRs are addressed in dedicated sections of the report with inputs based on presentations of the participants (summarized in section 1.4) and additional work carried out during the workshop. Sections 2-6 thus cover ToRs a-e. Section 7 addresses the need to review the ICES MSY Advice Rule (AR) that is currently being used as the basis for ICES advice in the absence of an accepted and precautionary management strategy.

1.3 Relevant ICES expert groups

Several ICES expert group reports, relevant to WKREBUILD2, have been reviewed during the workshop: WKGMSE1,2,3 (ICES, 2013; ICES, 2019b; ICES, 2020a), WKREF1,2 (ICES, 2022c; d), WKWHMRP (ICES, 2021f), WKLIFEX (ICES, 2020b), WKDLSSLS3 (ICES, 2021h), WKRPCHANGE (ICES, 2021g), WKMSEDEV (ICES, 2023e, report in progress), WKNCCHCR (ICES, 2022e) and the DFO Science Guidelines to Support Development of Rebuilding Plans for Canadian Fish Stocks (DFO, 2021). The review resulted in a table (see Annex 3) that was used to update the Guidelines for evaluation of rebuilding plans (section 3).

1.4 Contributions presented to WKREBUILD2

The following papers/presentations were contributed to the WKREBUILD2:

- Consequences of ignoring the possibility of depensatory recruitment for rebuilding times (Christoffer Moesgaard Albertsen, Vanessa Trijoulet, Tommi Perälä) – ToR b
- Iceland Slope Beaked Redfish (*Sebastes Mentella*) (Kristjan Kristinsson) – ToR a
- Recruitment Hindcasting – Dorleta Garcia– ToR d
- What does a shift in productivity mean for stock rebuilding? The case of Western Baltic Spring Spawning Herring Stefanie Haase and Christopher Zimmermann (Thünen Institute of Baltic Sea Fisheries) – ToR b
- Western Horse Mackerel Rebuilding Plan Evaluation 2021 (Andrew Campbell, Martin Pastoors) – ToR d
- Fishing gently as a means of rebuilding in the absence of biomass rebuilding targets (Joanna, Daniel) – ToR c
- Testing the rebuilding of western Baltic herring while considering stock mixing and current management (Vanessa Trijoulet, Christoffer Moesgaard Albertsen, et al.) – ToR c
- Influence of depletion rate and life histories on harvest control rules for stock rebuilding (Max Cardinale and Valerio Bartolino) – ToR a

Consequences of ignoring the possibility of depensatory recruitment for rebuilding times (Christoffer Moesgaard Albertsen, Vanessa Trijoulet, Tommi Perälä)

Often, recruitment is modelled using compensatory models such as the Beverton-Holt, segmented regression/hockey stick or constant median. This is the case for ICES reference points. Compensatory models assume that productivity increases as stock sizes decreases. However, when this is not the case, rebuilding potential from low stock sizes may be affected.

To investigate the effect of assuming compensatory recruitment in the presence of depensation, a simulation study was conducted. For each of 77 ICES stock assessments, a total of 20 recruitment models were fitted using a penalized maximum likelihood errors-in-variables approach, accounting for uncertainty in both recruitment and stock size. The recruitment models included the compensatory Beverton-Holt, Ricker, Deriso, and smoothed hockey stick models. Further, each of them were combined with four depensatory modifications. For each stock, the best fitting recruitment family was determined by the resulting AIC and, within this family, the compensatory model was compared with the best fitting depensatory modification in terms of rebuilding time and probability of stochastic collapse. Further, three depensatory thresholds were calculated: (i) the biomass of maximum productivity, S_{MP}, (ii) the biomass where the recruitment function changes from convex to concave, S_0, and (iii) the biomass where the reproductive rate changes from negative to positive, stock-recruitment response (S_{RR}).

To evaluate rebuilding potential, stocks were projected for 200 years without fishing in a simulation study and results were aggregated to fisheries guilds in a meta-analysis. Across stocks, S_{MP} was at 30% of the compensatory B_{MSY}, S_0 was at 20% of B_{MSY}, and S_{RR} was found at very low biomass. All three thresholds were higher for the pelagic than for benthic and demersal stocks.

To compare rebuilding time, the biomass starting point leading to a median rebuilding time of 10 years was extracted from the simulations. Across stocks, this point was at 5% of B_{MSY} for compensatory fits and at approximately 18% of B_{MSY} for depensatory fits. For pelagic stocks, the increase was from 12 to 32% of B_{MSY}. In the simulations, compensatory models would always rebuild in the absence fishing. However, for depensatory models, there was a 5% probability of stochastic collapse at 25% of B_{MSY} across stocks. Again, the risk was higher for pelagic stocks, where there was a 5% probability of collapse at 45% of B_{MSY}. For demersal stocks, the point was at 15% of B_{MSY}, while there was almost no risk for benthic stocks.

The simulations indicate that recruitment assumptions should be evaluated with additional care when biomass is below 30% of the compensatory B_{MSY}, or 45% for pelagic stocks, including the possibility of depensation. In particular, ignoring depensation in recruitment, if present, will result in overoptimistic rebuilding projections and risk assessments from low biomass.

Iceland Slope Beaked Redfish (*Sebastes mentalla*) (Kristjan Kristinsson) – ToR a

Icelandic slope beaked redfish (*Sebastes mentella*) in Va and XIV (Icelandic Waters Ecoregion) was benchmarked in February 2023 during the WKBNORTH and was moved from Category 3 to Category 1 (ICES, 2023a). Based on the assessment result the advice for 2024 was 0 t. The reason was that the SSB was estimated to be below B_{lim} and has been so for the past 20 years. For more than a decade the recruitment has been very low and, in the foreseeable future the stock, is expected to continue to decline even without fishing.

A rebuilding plan has not been evaluated or developed nor has it been tested with the current tool provided during the meeting. Rebuilding (time for the stock be above B_{lim} and/or MSY $B_{trigger}$) is likely to take a long time (>10 years) as beaked redfish is a long-lived and late-maturing (age at 50% maturity ~10-14 years).

Current action in the conservation of the stock is to minimize by-catch in the Greenland halibut and Greater silver smelt fisheries.

Golden redfish (*S. norvegicus*) is a related species found in the same ecoregion. Although the SSB is estimated to be large and well above MSY $B_{trigger}$ it has shown a similar pattern in recruitment, that is, little recruitment in the past decade. Under the current HCR, the stock is expected to decrease and reach MSY $B_{trigger}$ in the next few years. The discussion during the meeting was whether the gap between B_{lim} and MSY $B_{trigger}$ was too narrow and whether MSY $B_{trigger}$ should be set higher to minimize the probability of the SSB going below B_{lim}.

Recruitment Hindcasting (Dorleta Garcia)

Evaluations of recovery plans depend greatly on the probabilities in both the short- and long-term. The accuracy of these forecasted probabilities, especially in the first years of the recovery plan, are directly related to how well the uncertainty is represented in the initial year of the analysis. Hence, it is important to characterize the uncertainty in the initial conditions properly. The initial conditions for the simulations used to calculate or evaluate reference points in ICES are usually based on the output of the last assessment model. For Bayesian assessment model, the uncertainty arises naturally in the replicates of model estimates. However, in the most used likelihood-based models the uncertainty comes in the form of a variance-covariance matrix of the parameter estimates. In this case, it is not possible to obtain replicates directly and it is necessary to sample the variance-covariance matrix to obtain a sample of model parameters and then reconstruct the historical population abundance and exploitation levels for each set of model parameters. The problem with these models is that sometimes the uncertainty is sometimes very low. Furthermore, there are still cases in which the assessment models do not provide any measure of uncertainty.

In the development of the tool to test rebuilding strategies, we developed a method based on a hindcast introducing uncertainty in recruitment, the recruitment hindcast, that can be broadly used to incorporate uncertainty. The method consists on the following steps:

1. Define the uncertainty to be introduced around the historical recruitment estimates, for example a log-normal with parameters 0 and σ.
2. Define a year in the past, hy, to start projecting the population forward.
3. Generate recruitment replicates since year yf to last data year (dy), using the point estimate from the assessment model and adding the uncertainty defined in (1).
4. Project forward the population until year 'yd' using the recruitments in (3), the classical exponential equation and constraint the exploitation to the historical catches or the estimated fishing mortality. In the case of catches, if the model estimates them then it the estimated catches should be used and the observed ones otherwise.

To ensure that the starting point of the random initial population is the same as the starting point estimated by the assessment model, it is important that the mean/median of the random initial population equals the assessment point estimates. The method was tested on the horse mackerel and other stocks assessed with the stock synthesis (SS; Methot Jr. and Wetzel, 2013) framework and it has worked correctly, with the median values similar to the assessment point estimates.

However, there were problems to replicate the SAM-based assessments. The problem was that SAM (Nielsen and Berg, 2014) introduces a process error in the survival equation. As SAM does not return the age- and year-dependent process errors a procedure was conducted to replicate SAM introducing the process error. The procedure worked well in a deterministic way but not when uncertainty was introduced. The problem was two-fold:

1. The sum of medians is not equal to the median of sums and then even if the numbers-at-age were the same, the SSB was not the same.
2. The median of the recruitment deviations, as the sample was limited, was not exactly equal to 1.

(1) makes it impossible to obtain the same results in median as in the assessment model for the recruitment hindcast approach. However, a possible solution is to compare the mean instead of the median. As the sum of means is equal to the mean of sums, the problem in (1) then does not exist in this case. But then, it needs to be ensured that the recruitment deviations have a mean equal to 1 and this can be obtained by standardizing the deviations after generating them, or changing the μ parameter to obtain a lognormal distribution with a mean equal to 1 in the case of the lognormal distribution, i.e $\mu = -\sigma^2/2$.

What does a shift in productivity mean for stock rebuilding? The case of Western Baltic Spring Spawning Herring (Stefanie Haase and Christopher Zimmermann - Thünen Institute of Baltic Sea Fisheries)

A decrease in the stock's productivity might lead to unrealistic rebuilding targets when applying the standard ICES procedure. Western Baltic Spring Spawning Herring (WBSSH) was used as a case study to show that even with very low fishing pressure, altered environmental condition might make rebuilding of a stock very unlikely if recruitment is impaired not only due to a small spawning stock size.

The stock size of WBSSH has been decreasing due to a combination of low recruitment and high fishing mortality. The stock has been below B_{lim} since 2007 and rebuilding is necessary. Since the early 2000s, recruitment of WBSSH is impaired (ICES, 2023a). The productivity of the Rügen spawning component has decreased, as shown in several scientific studies, due to a combination of climate change and eutrophication (see Polte et al., 2021, Moyano et al., 2023). Reasons for this are a reduction of suitable spawning beds mainly caused by eutrophication (Kanstinger et al., 2018), and warming of winters leading to a mismatch of prey availability and larvae searching for food (Polte et al., 2021). Although the productivity of the stock has roughly halved, it should be possible to use the stock sustainably. Rebuilding plans should consider a change in the stock's productivity and should also consider a re-evaluation of the reference points if new scientific evidence is presented.

The presentation formed the baseline for a discussion on:

1) When do we acknowledge a regime shift or change in productivity? How much evidence is considered sufficient to trigger the definition of new rebuilding targets and/or reference points?
2) What does a regime shift or change in productivity mean for rebuilding a stock?
3) How can a change in productivity be acknowledged within the ICES process?

Western Horse Mackerel Rebuilding Plan Evaluation 2021 (Andrew Campbell, Martin Pastoors)

The assessment model for Western Horse Mackerel was benchmarked in 2017 with the SS3 model (Methot Jr. and Wetzel, 2013) replacing the previous bespoke (Separate ADAPT; SAD) assessment framework (ICES, 2017). The SS3 model provided the flexibility to incorporate additional fishery-independent information (e.g., a survey-based recruitment index and an acoustic survey). Following the benchmark, the stock was estimated to be above, but close to, B_{lim} with no indication of an increase in recruitment. Moreover, the new assessment continued to be characterised by retrospective revisions as seen with the SAD assessment. A further revision to the reference points was made by an inter-benchmark in 2019 (ICES, 2019a). The Pelagic Advisory Council established a focus group in 2019 for the purposes of the development of a rebuilding plan for Western Horse Mackerel given the increased probability that the stock would decline below B_{lim} in the near future.

Throughout 2019 and 2020, a rebuilding plan evaluation was conducted. The basis for the evaluation was an adaption of the *EqSim* codebase used by ICES in the estimation of reference points, similar to the approach adopted in the evaluation of the long-term management strategy for Blue Whiting. The *EqSim* codebase was expanded to allow evaluation of a number of candidate HCRs, in terms of their ability to allow stock recovery. Additional functionality was incorporated into base *EqSim* to allow appropriate initial conditioning of the simulations, alternative HCR designs, specification of TAC change constraints (min/max change, minimum TAC) and calculation of appropriate statistical outputs.

The HCRs considered during the evaluation included constant F strategies, an ICES-type rule and a double breakpoint rule whereby a low level of fishing could continue when below B_{lim}, regardless of stock size. The HCR selected by the Pelagic AC corresponded to the double breakpoint design with a target fishing mortality equivalent to F_{MSY} when above MSY $B_{trigger}$ (B_{PA}) and a linear reduction to a fishing mortality equivalent to 20% of F_{MSY} at (and maintained below) B_{lim}. TAC changes are constrained to +/- 20% when the stock is above MSY $B_{trigger}$. In the absence of definitive guidelines, stocks were considered to be in a recovered state when the SSB was above B_{PA} for 3 consecutive years with a probability of greater than 0.5.

In 2020, the evaluation and proposed harvest rule was submitted to ICES by the European Commission for review. ICES established the WKWHMRP with 2 external reviewers to carry out the review (ICES, 2021f). An initial review of the plan requested additional information on several aspects of the evaluation. The focus group reconvened and carried out additional work including: additional documentation in the simulation platform, parameterisation, results and metrics; exploration to the sensitivity to the assessment used for simulation conditioning; exploration of the sensitivity to recent recruitment estimates; sensitivity to the assessment error parameterisation and the sensitivity to the reference points used in the calculation of simulation performance metrics. An additional working document was supplied to the WKWHMRP which concluded that all ToRs were adequately covered and that the minimum requirements for simulation testing the HCRs, as developed by WKGMSE process, were met. The WKWHMRP further concluded that proposed rebuilding plan offered the potential for the stock to rebuild within the planned target timeframe, given the proposed rebuilding metric although the timeframe would be impacted should the recent recruitment prove to be overly optimistic. The ICES advice was published following the conclusion of WKWHMRP (ICES, 2021f).

In 2021, the annual WGWIDE update to the stock assessment indicated that the stock size was close to, but just above, B_{lim} (ICES, 2021e). ICES therefore published a catch advice for 2022 on the basis of the MSY approach, whilst providing a catch option consistent with the recovery plan. In 2022, the stock was assessed as being below B_{lim} and the MSY-based advice was given for zero-catch (ICES, 2022f). Although an advice based on the recovery plan was again included in the catch options for 2023, the plan was not accepted by all parties involved in the fishery and therefore, it was not used as a basis for the headline catch advice. A similar scenario arose in 2023 and currently the precise status of the rebuilding plan remains unclear.

Fishing gently as a means of rebuilding in the absence of biomass rebuilding targets (Johanna, Daniel)

ICES currently advises zero fishing and development of a rebuilding plan if the median SSB of a stock is estimated below B_{lim} at the beginning of the advice year and the forecast based on the ICES AR does not allow the stock to reach above B_{lim} at the end of the forecast year. The choice of B_{lim} – and the stock-recruit relationship assumed – are therefore, central to the rebuilding concept. However, it can often be difficult to estimate B_{lim} with any degree of precision, and therefore, difficult to ascertain the stock status with any degree of confidence. In this presentation, we contribute input to ToR a) by demonstrating a management strategy where reducing F_{target} from F_{MSY} to $F_{0.1}$ may ensure rebuilding despite high uncertainty in stock status.

The WKNCCHCR workshop (ICES 2022d) was initiated in response to a request from the Norwegian managers to reevaluate the B_{lim} reference point, evaluate a set of HCRs, and, if required, a rebuilding plan for northern Norwegian coastal cod (cod.27.1-2coastN). The stock was first assessed as a category 1 stock in 2021, after a larger category 3 coastal cod stock had been split in two at the 2021 WKBARFAR benchmark (ICES 2021a). In summary, plausible B_{lim} values for this stock varied between the lowest and highest SSB observed (and several points in between), in turn affecting our perception of the stock as above critical levels or in need of rebuilding. Reference points for F varied by a factor of 1.5 and the advice based on the ICES AR by a factor of 2 because of the uncertainty in whether the stock was above or below B_{lim}. Additional data sources, such as an extended catch series back in time, indicated that recruitment had not been impaired to the point of near collapse, but it was unclear to what extent, if any, it was currently impaired. The workshop concluded that with current knowledge, no reliable B_{lim} estimate could be produced for this stock and, therefore, none of the HCRs based on the ICES AR could be considered precautionary. An alternative HCR with constant F_{target} at $F_{0.1}$ was recommended by the WK. Simulations demonstrated that if F_{target} is set at a sufficiently safe distance from F_{max} (here: $F_{0.1}$), a precautionary advice can be produced even in the absence of biomass limit and trigger points (and thus, without traditional status determination). In addition, given that $F_{0.1}$ is expected to drive the stock towards B_{MSY}, fishing at this level may also work as a rebuilding plan in cases where it is unclear whether the stock has impaired reproductive capacity. The constant $F_{0.1}$ HCR was approved as the basis for ICES advice for this stock and adopted by managers. The resulting fishery has recently been MSC (re-)certified on the basis that the management plan fulfils the precautionary criteria. This stock is currently the only category 1 stock in ICES without the B_{lim} reference point.

We suggest that reducing F to a more precautionary fraction of F_{max} than the current F_{MSY} approach could act as a fallback option for the HCR that includes a rebuilding element in cases where critical biomass levels cannot be definitively estimated. This would allow moderate fishing to continue, allow the stock to rebuild if necessary, until such time as a more precise determination can be made. More generally, we would argue that a larger buffer between F_{max} and F_{target} would reduce the risk for stocks to fall to levels requiring a rebuilding plan, and strongly recommend that next WKNEWREF considers adopting a lower standard F_{target}.

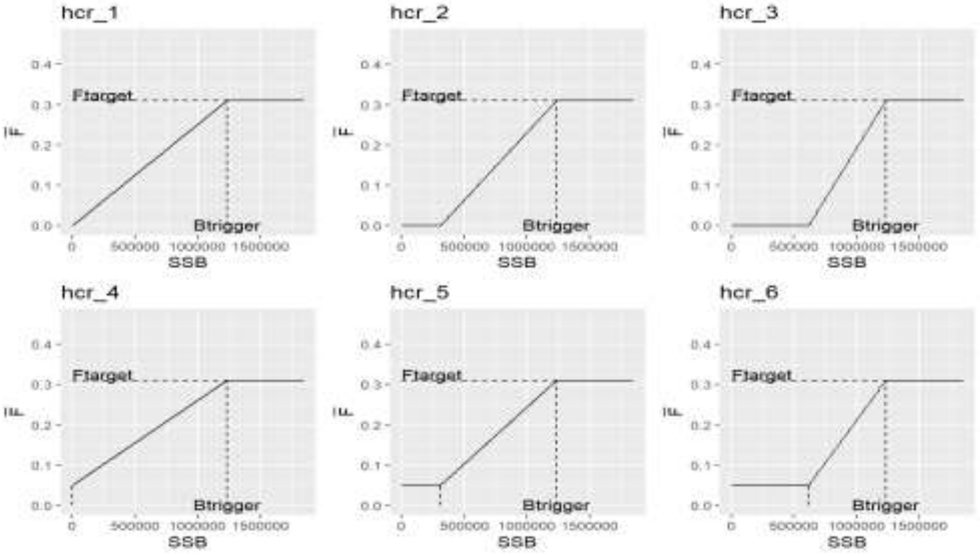
Testing the rebuilding of western Baltic herring while considering stock mixing and current management (Vanessa Trijoulet, Christoffer Moesgaard Albertsen, et al.)

Western Baltic spring-spawners (WBSS) herring was last benchmarked in 2018, where it was estimated to be below B_{lim} (ICES, 2018). A zero-catch advice has been given ever since. While catches have decreased since the zero-catch advice, rebuilding of the WBSS herring is made difficult due to the mixing with North Sea autumn-spawners (NSAS) herring (currently above MSY $B_{trigger}$) and quota setting, notably for the human consumption fleet in Division 3.a, where quotas also depend on the NSAS herring catch advice.

To account for these uncertainties in the WBSS herring rebuilding, a multi-stock, multi-fleet SAM was developed including a stochastic forecast as shortcut to MSE. Assessments are independent for WBSS and NSAS herring stocks but the forecasts are combined through a management loop that takes into account the current quota setting. The assessments were fitted assuming the stock-recruitment relationship (SRR) considered at the last benchmark for both stocks so that reference points are consistent. The forecast was run for 30 years and 1 000 iterations. Advice catch is estimated following the ICES AR, and realized catch is estimated from the advised catch using current quota setting. Uncertainties considered include the uncertainty in the current perception of the stocks, in recruitment, in the model parameters (resampled at each iteration), process errors estimated by SAM (Nielsen and Berg, 2014), and implementation error in realized catch per fleet. The forecast is run for different scenarios of recruitment (SRR and low recruitment), and for different management options including different transfer of quota from 3.a to the North Sea. The diagnostics relevant to the WKREBUILD2 ToR c are extracted.

The results show that WBSS herring is unlikely to rebuild if recruitment stays low no matter the management scenario and the biomass target, but rebuilding is possible above MSY $B_{trigger}$ with more than 50% probability if recruitment increases with SSB. The probability of the stock falling below B_{lim} at the end of the forecast is rarely < 5%. The minimum and maximum average rebuilding probabilities in the last 5 years across management options are as follows: 62-90% with low recruitment when the biomass target is B_{lim}, and 96-99% when it is MSY $B_{trigger}$, and 4-23% when recruitment follows a SRR with B_{lim} as target, and 5-30% with MSY $B_{trigger}$ as target. The median scaler between rebuilding time in each scenario and rebuilding time when there is no fishing were estimated between 1.00 - 2.00 for low recruitment when the biomass target is B_{lim}, and 2.00 - 2.16 when it is MSY $B_{trigger}$, and 1.00 - 1.33 when recruitment follows the SRR with B_{lim} as target, and 1.00 - 1.40 with MSY $B_{trigger}$.

Influence of depletion rate and life histories on harvest control rules for stock rebuilding (Max Cardinale, Valerio Bartolino)



Simulations were run to evaluate the influence of depletion rate and life-histories on HCRs for stock rebuilding. Model simulations assumed that future biology and selectivity in the simulations set is the average of the last three assessment years. Stock and recruitment were fitted as Beverton & Holt, B_{lim} was set at 15% B_0 and $B_{trigger}$ set at 30% B_0 to allow the comparison in recovery between stocks and initial depletion conditions. Six different life-histories were tested derived from cod, herring, monkfish, plaice, sardine and Northern shrimp stocks. Three fractions of depletion as starting point of the simulations were tested. Those correspond to 0.02, 0.05 and 0.10 of B_0. A total of six different HCRs were tested. HCRs were selected using the overarching ICES criteria (PA and maximise catches) and additional criteria (50% probability of reaching 0.8 B_{MSY}).

Results showed that there is no single HCR that fits all conditions. "Best" HCR is dependent on depletion rate and life-history. The two long living stocks (cod and monkfish) when highly depleted (0.02) they share HCR1. With an increasing level of depletion there is a general change from HCR4 (or HCR5) to HCR2 (or HCR1). There are several stock and depletion level combinations where the recovery to $B>B_{lim}$ (with $P>=0.95$) has the same time length for all the HCR. In most/all of those cases, the HCR that maximise the catch is HCR4 and that one maximizing the stock size is HCR3 (evident also from the HCR shape). Difference between HCR3 and HCR4 is in the range of 8–23% in SSB.

species	`0.02`	`0.05`	`0.1`
cod.27.6a	hcr_1	hcr_2	hcr_5
her.27.3a47d	hcr_2	hcr_2	hcr_4
mon.27.78abd	hcr_1	hcr_4	hcr_4
pil.27.8c9a	hcr_4	hcr_4	hcr_4
ple.27.420	hcr_4	hcr_2	hcr_4
pra.27.3a4a	hcr_2	hcr_2	hcr_4

The overarching criteria are the key to the selection of the "best" HCR. Thus, within an advisory process, it is crucial that they are established a priori to avoid cherry picking. When catch is preferred to stock size as the selection criteria, the time delay to reach 0.8 B_{MSY} is generally at 0-1 year but in few cases, it can arrive to 5 years (i.e., western Baltic herring). R scripts for the analyses are available at https://github.com/ices-taf/2023_generic_sims_rebuild.

2 Framework for scientific advice for developing rebuilding plan elements as part of overall management strategies (ToR a)

The current ICES advisory framework distinguishes two general situations.

1. When an agreed and implemented management plan is available that has been tested by ICES to be precautionary and is agreed by all the management parties, ICES provides advice based on such plan.
2. When no agreed or implemented management plan is available or when the plan has been tested as not being in accordance with the precautionary approach, the ICES advice is based on the ICES AR in combination with the established biological reference points (i.e. B_{lim}, MSY $B_{trigger}$, F_{MSY}, F_{p05})

The AR was introduced by ICES in 2010 (ICES, 2010) to provide advice consistent with MSY for category 1 long-lived stocks. The AR is not completely clear about the actions to be taken if a stock falls below B_{lim}. In 2021, ACOM agreed to provide positive advice, when the SSB is below B_{lim}, only if there exists a fishing mortality level for which forecasted SSB level at the end of advice year is above B_{lim} with a 50% probability. Furthermore, ICES regularly recommends to implement rebuilding plans in combination with zero-catch advice, especially when stocks are estimated to be below B_{lim} and there is no possibility of rebuilding above B_{lim} within the time frame of a short-term forecast (2 years; intermediate year + TAC year). However, the consistency of the rule with the precautionary approach and the ability to promote robust rebuilding of stocks above B_{lim} has never been tested.

While there has been ample attention in ICES to the guidelines and methods for carrying out Management Strategy Evaluations (MSEs) that are applicable to test long-term management strategies (WKGMSE2; ICES, 2019b), there are no agreed methods or guidelines on evaluating rebuilding plans. There are also no alternative options in the current ICES AR that ensures recovery once a stock is estimated to be below B_{lim} apart from advising catch levels that bring the stock back to B_{lim} with a 50% probability within the time frame of the short-term forecast or to provide a zero-catch advice.

ICES has recently advised zero catch for several herring stocks (Celtic Sea herring, western Baltic spring-spawning herring, herring in 6.a and 7.b-c), for western horse mackerel and for Celtic Sea whiting among others. In several cases, this advice was combined with a recommendation to develop a rebuilding plan. This poses a challenge for ICES given the requirement to evaluate such rebuilding plans and their potential to achieve a form of rebuilding that is consistent with the precautionary approach. The ICES WKMSE2 guidelines (ICES, 2019b) touched on the issue of rebuilding plans but did not address the technical and advisory implications. The specific feature of the evaluation of rebuilding plans (or different options for the ICES advice rule when the stocks fall below MSY $B_{trigger}$ or B_{lim}) is that they tend to focus on the short-term perspectives, and thereby, the starting conditions, while MSEs tend to focus on the longer-term performance.

To assess the current situation, we can take the results from the most recent stock assessment. However, the uncertainty cannot always be taken directly from the assessment, as the different assessment methods have very different ways of estimating (parametric) uncertainty and may underestimate the uncertainty in the end of the assessment period. In these cases, WKREBUILD2 suggests to carry out a recruitment hindcast, which consists of the following steps: 1) Define the uncertainty around the historical recruitment estimates, 2) define a year in the past to start projecting the population forward, 3) generate recruitment replicates using the point estimates from the assessment model and adding the uncertainty, 4) project the populations forward while constraining the exploitation to the historical catches or the estimated fishing mortalities.

In the application of the tool to the case studies, four HCRs were tested (Figure 2):

1. The ICES AR with continuous decrease in advice fishing mortality until SSB = 0.
2. An AR where the advice fishing mortality decreases linearly up to B_{lim} below where catch advice is 0.
3. The ICES AR with zero-catch advice below B_{lim}.
4. An AR with advice fishing mortality equal to $0.2*F_{MSY}$ below B_{lim}.

This does not mean that these four HCRs are considered better options than other possible HCRs in the frame of those presented in Figure 1. Given the limited time to analyse results, these four HCRs were considered to provide enough contrast to test the tool and provide recommendations for future testing of rebuilding plans and advice.

In order to test different options, it is mandatory to define appropriate metrics that allow the assessment of the rebuilding potential of proposed plans/advice rules and whether suggested plans/advice rules reach B_{target} (SSB indicating a successful rebuilding, MSY $B_{trigger}$ as proposed here) within a suitable/precautionary time frame with a certain probability. An appropriate tool is needed that is able to test the performance of such plans/advice rules within MSE-type simulations considering relevant sources of uncertainties and bias (e.g., uncertainty around stock recruitment relationships, implementation bias). Such a tool should be easy to use for stock assessors and coordinators in a time-efficient way during working groups and benchmark workshops.

In this context, WKREBUILD2 focused on testing the WKREBUILD toolset (see section 5.1) by trialling the application of the tool to three case studies (sections 5.3-5.55.4) and a first set of potential performance metrics (section 4.1). It should be realized that the three case studies cannot be a basis for updating the generic properties of the ICES AR. They can merely highlight issues that may have to be considered when assessing the performance of rebuilding plans and AR. To reformulate the ICES AR, in a generic way and at low biomass levels, a more comprehensive and extensive simulation study would need to be carried out, similar to the study by Cardinale & Bartolino (section 1.4).

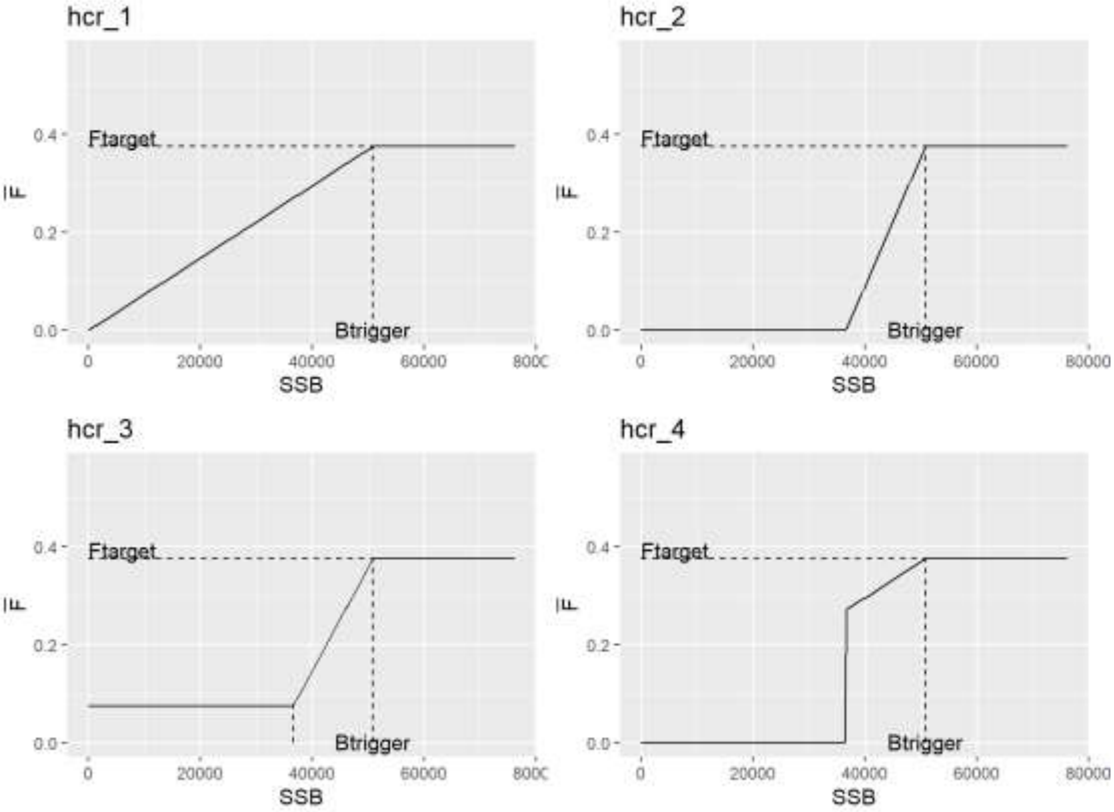


Figure 2. HCRs tested in the 3 case studies using the simulation tool.

3 Guidelines for the evaluation of rebuilding plan elements (ToR b)

Case studies and simulations presented at the workshop provided new elements to consolidate and partly revisit the initial recommendations/guidelines formulated by WKREBUILD in 2020 (ICES, 2020d).

The ICES framework currently lacks specific reference points to determine the entry and exit points for stock rebuilding which are essential for the evaluation of rebuilding plans. Although the group acknowledged that adding these two additional points in the advice framework may be better from a theoretical perspective, it was agreed that operationally, it is better not to define additional reference points as the current ones are already challenging in terms of calculations and the management framework could become even more complicated. Thus, it was agreed that:

- *The entry point should be B_{PA}.* If SSB is above B_{PA}, the stock is considered to have full reproductive capacity, having accounted for estimation uncertainty. If the estimated SSB is above B_{PA}, its definition ensures that the true SSB has less than 5% probability of being below B_{lim}, i.e. the 95th percentile of the distribution of the estimated SSB is equal to B_{lim}, when the estimated SSB is equal to the true one. B_{PA} is usually defined as $B_{PA} = B_{lim} \times \exp(1.645 \times \sigma)$ where σ is the standard deviation of ln(SSB) at the start of the year following the terminal year of the assessment.

  If SSB is below B_{PA}, the group considered that additional measures should be taken to avoid the stock to fall below B_{lim}. Thus, below B_{PA}, ICES should provide rebuilding catch advice which should come from the HCR that was identified using the pre-agreed criteria and should recommend the implementation of a rebuilding management plan.

- *The exit point should be MSY $B_{trigger}$.* MSY $B_{trigger}$ is a lower bound to the SSB when the stock is fished at F_{MSY}. To exit the rebuilding phase the stock should be above MSY $B_{trigger}$ for at least 3 consecutive years. The group discussed to link somehow the number of years above MSY $B_{trigger}$ to the lifespan of the stock. However, there was no scientific basis to define it. In practice MSY $B_{trigger}$ is usually set at B_{PA}. In the future, however, MSY $B_{trigger}$ should be connected to a target biomass and it should be above B_{PA} and aims to safe biomass levels. A fraction of B_{MSY} should probably be preferred but it remains unclear which specific fraction should be elected as rebuilding target. Simulations carried out in the case of herring that B_{lim} and MSY $B_{trigger}$ are too close together. In the definition of reference points, some simulations around these points would be required to ensure they are fit for purpose.

For the evaluation of rebuilding plans, it is of utmost importance that reference points are robust to the current and expected productivity of the stock during the rebuilding period. For this reason, particular attention is needed towards understanding the recent periods of low productivity which may have contributed to low stock size, and which are likely to characterise and influence the rebuilding period. The effect of depensation in recruitment, where productivity of the stocks does not increase at low biomass levels, was analysed in one on the presentations (see section 1). As expected, with depensation rebuilding was lower and risk for the stock higher. A critical point was detected at 30% of the compensatory B_{MSY} for demersal stocks and 45% for pelagics, where possibility of depensation should be considered.

Transition out of a rebuilding plan should meet biomass rebuilding targets and at the same time be robust to uncertainties in the estimation of the stock status or the ephemeras effect of an individual good year class. In addition to achieving a few consecutive years above the rebuilding target (e.g., WKWHMRP adopted three consecutive years above MSY B_{trigger} with 50% probability [ICES, 2021f]), evaluation of a rebuilt demographic structure would reduce the risk of stocks falling back shortly after exiting a rebuilding phase. A suite of age- and size-based indicators like ABI_{MSY} (Griffiths *et al.*, 2023) are currently being evaluated in ICES for their possible integration in the advisory process (WKD3C3THRESHOLD and WKSIMULD3) and their role could be particularly relevant in relation to the evaluation of stock rebuilding. These indicators could provide the science-base for the definition of the number of years needed above MSY B_{trigger} based on life-history traits and the definition should be revisited in light of the findings of these working groups.

Stocks below limit reference levels have a higher risk to see their productivity and resilience further compromised as they persist in a poor state. For this reason, rebuilding strategies should trigger promptly when required. Also, to be effective and precautionary, they should be able to rebuild a stock in a relatively short and pre-defined time-frame. Time windows for rebuilding are highly influenced by socio-economic considerations but a rebuilding plan needs to be evaluated in relation to the precautionary criteria which necessarily reduce the risks for the stock, hence, reduce the time of recovery. For the case studies tested at WKREBUILD2, in most of the scenarios $T_{REBUILD}/T_{MIN}$ was 2 or less independent of the biomass target was used, where T_{rebuild} is the time needed for rebuilding for a specific HCR and T_{MIN} is the time needed for rebuilding in the absence of fishing. Therefore, WKREBUILD2 suggests that time-frames for recovery should not be longer than twice the time needed for recovery in the absence of fishing ($T_{MAX}/T_{MIN} <= 2$), as also used in other jurisdictions.

The simulations should be run for a pre-agreed time period, until 2040 in this case, and the capacity of the management strategies to rebuild the stock should be analysed within this time frame. In this case, 2040 was chosen as a time frame of around 15 years was considered long enough for the considered stocks to recover However, the time period for the simulations should be predefined in each case based on the biology of the stock (long-lived stocks will need longer time periods). In the future, more efforts should be devoted to establishing an appropriate time window depending on biology.

The evaluation of HCRs in the three test cases have provided several lessons on conditioning:

Uncertainty in the initial conditions

Introducing uncertainty in the initial conditions of the stocks is crucial when looking at the performance of management strategies in the short term, as is the case of rebuilding plans.

Some assessment models include options to provide random initial populations, but in some cases the uncertainty is too narrow, or it is not provided. In WKREBUILD2, a generic method to introduce uncertainty was presented and used in the whiting case study (see section 5.3). The method consisted of doing a hindcast using the estimated recruitment as mean or median but introducing uncertainty around the point estimate, although uncertainty could be introduced in other variables too. When doing the hindcasting, it is important that the generated population, in mean or median, matches the stock assessment estimates, so both populations are similar in the first year of the simulation. When doing the hindcast projection, either the catch or fishing mortality-at-age needs to be constrained to the values estimated by the model. In statistical catch-at-age models like SAM (Nielsen and Berg, 2014), it is important to use the estimated catches and not the observed one, to ensure that the simulated population matches the SAM estimates. SAM was difficult to replicate because it introduces process error in the classical survival equation.

With a correction factor, it was possible to account for this and the code will be available, in the same github site as the rebuild template, to be applied in other cases.

Recruitment modelling

Many of the stocks that are close to B_{lim} have suffered from lower productivity in recent years, especially low recruitment. Two recruitment scenarios were tested for each of the case studies, a scenario where recruitment was simulated using the same configuration as in the calculation of reference points and an alternative scenario where recent low productivity was simulated using different approaches in each case study. The conditioning of recruitment based on short-time series of recent recruitments poses some challenges as the time-series could be too short and could have a lack of contrast to obtain a reliable fit of a stock-recruitment relationship. Different approaches were proposed during the workshop based on a segmented regression relationship:

- Using a mean recruitment above the breakpoint equals to the observed mean in the most recent low productivity period and:
    - the same *breakpoint* as in the calculation of reference points and calculating the slope based on the breakpoint and mean recruitment, or
    - the same *slope* as in the calculation of reference points and calculating the breakpoint based on the slope and mean recruitment.
- Fitting a segmented regression stock recruitment relationship to the stock-recruitment pairs in the low productivity period

Defining the low productivity period can be challenging and have significant impact on the performance of rebuilding plans. Thus, the period should be selected carefully based on the time-series analysis (i.e., conducting a regime shift analysis or alternative analysis wherever possible) and the robustness of the results to the selected period should be analysed.

Another problem is the difficulty of moving from low to higher productivity within the simulation as it is not generally understood why stocks suffer from low productivity (see section 5.5 for explanations in the case of the western Baltic herring stock). In the simulations carried out, the stocks were kept in the same productivity scenario in the whole projection while in the case of low productivity scenario, this led to an impossibility of recovering above MSY Bt_{rigger} in most of the cases. On the contrary, when the productivity was based on the whole time-series the chance of recovery was much higher.

Probability dependent on conditioning of uncertainty

The accuracy of performance indicators based on probabilities depend on how well the uncertainty in the initial and future conditions is introduced in the system. This is especially important in the tails of the probability distributions which are more difficult to estimate and are more sensitive to choices and assumptions. For example, when we look at the common criteria of probability of SSB being below B_{lim} lower than 5% indicator, $p(SSB \leq B_{lim}) \leq 5\%$, the criteria will be more difficult to reach if the procedure used to condition uncertainty leads to wide intervals. To overcome this problem, the working group proposed to consider, if possible, central tendency statistics, such as mean or median, instead of quantiles in the tails. For example, to replace $p(SSB<B_{lim}) < 5\%$ criteria by $p(SSB < MSY\ B_{trigger}) \geq 50\%$.

B_{lim} and MSY $B_{trigger}$ too close together

In the Western Baltic Herring case study, it was detected that B_{lim} and MSY $B_{trigger}$ are so close that the SSB jumped from above MSY $B_{trigger}$ to below B_{lim} in one year. Thus, the special measures (reduced advice for F) below MSY $B_{trigger}$ were (almost) never applied and the buffer zone between them was ineffective. Although the role of MSY $B_{trigger}$ in the ICES AR is to protect the stock against falling below B_{lim}, its calculation is based on the parametric uncertainty of the assessment model and it is never tested that is fit for purpose. When reference points are calculated, it should be ensured that MSY $B_{trigger}$ allows for stock recovery when the SSB falls below it. In the western Baltic herring case, the one-year time lag between advice and management was found determinant in the ineffectiveness of MSY $B_{trigger}$. With a one-year time lag the situation could have been different. Hence, the one-year time lag should be considered when the robustness of MSY $B_{trigger}$ is simulation tested.

Selection or combination of scenarios to compute performance statistics

In the three case studies analysed by the group, the scenario with reduced productivity was considered the most plausible scenario. Although the performance was analysed for the two scenarios, if these analyses were to be used to select an HCR for stock recovery, the performance statistics in the reduced productivity scenario should be considered exclusively. In cases where scenarios were considered equally plausible, or it was possible to assign a weight associated to their plausibility, the performance statistic could be calculated using a weighted mean of the statistic along scenarios.

Table 3.1. Proposed guidelines for the evaluation of rebuilding plans for ICES category 1 and 2 stocks, updated from WKREBUILD (ICES, 2020d).

Rebuilding targets	Defining rebuilding biomass and fishing targets is critical to the evaluation of rebuilding plans and should be clearly defined at the beginning of the evaluation. The rebuilding target should aim for a safe biomass level and the use of MSY $B_{trigger}$ is proposed. However, ICES should redefine MSY $B_{trigger}$, avoiding to define it as B_{PA}, and linking it to some target biomass reference points, such as a fraction of B_{MSY}, the biomass level at F_{MSY}.
Reference points	In the context of rebuilding plans, reference points must be robust to the contemporary productivity of the stock at low SSB and environmental conditions. Regular updates of reference points ensure they are consistent with recent developments in the stock and the ecosystem. Robustness of the reference points to detected productivity changes should be ensured, e.g., testing the AR with low recruitment while maintaining reference points unchanged. Evaluation of rebuilding targets that may differ from current reference points may be necessary for depleted stocks when those were estimated including periods of high productivity and optimistic stock-recruitment relationships.

Time frame leading into a rebuilding plan	When a stock is estimated to be below B_{PA} in the last assessment year, ICES should: • Recommend the implementation of a rebuilding plan. • Carry out a simulation study to identify the HCR that allows to recover the stock in a time frame not longer than $2*T_{MIN}$. T_{MIN} is defined as the time taken for the stock to rebuild with zero fishing above the pre-specified biomass threshold with a predefined probability. If among the HCRs tested, there are several HCRs that allow the stock to recover in $2*T_{MIN}$ time, the HCR that produces the highest cumulative yield should be selected. If there was no HCR that allow for stock recovery in $2*T_{TIM}$ time, the advice should be zero and the analysis should be repeated when the perception of the stock improves. T_{MAX}, defined as the maximum acceptable amount of time for rebuilding the stock, is usually specified by managers/requesters and could be expressed as $x* T_{MIN}$ with $x > 1$. WKREBUILD2 recommends, in absence of clear guidance on required rebuilding time by the advice requester, to set T_{MAX} as $2*T_{MIN}$. $x=2$ is often used in other jurisdictions and is supported by the results in the analysed case studies.
Time frame leading out from a rebuilding plan	The exit strategy should be embedded in the rebuilding plan. Leading out from the rebuilding plan too early or too late should be avoided. The exit strategy should preferably contain elements on how to ensure a "smooth" transition between the rebuilding phase and the post-rebuilding phase (i.e., ICES AR or a (long term management plan) to reduce the risk of inversion of positive trends. The exit from a rebuilding plan should be robust to uncertainty in the estimation of the stock status to reduce the risk of falling back to a rebuilding phase soon after the exit. Robustness to uncertainty could include setting a certain probability of SSB being above rebuilding reference points, being above rebuilding targets for a number of consecutive years, for example i_{mat} number of years [where i_{mat} equals to the age at 50% maturity], a consistent positive trend in SSB, evidences of a strong year class confirmed by independent observations (i.e., survey and commercial fishery) and through time, a rebuilt demographic structure as could be informed by age based indicators. WKREBUILD2 proposes that, based on the current ICES reference point and advice framework, the stock should exit the rebuilding plan when the probability of being above MSY $B_{trigger}$ is higher than 50% for at least 3 consecutive years. However, the definition of MSY $B_{trigger}$ should be linked to some biomass target and the use of B_{PA} as MSY $B_{trigger}$ should be avoided. The optimum number of consecutive years should be further investigated, linking the number of years to the biology of the stock.
Time period for the calculation of performance statistics	The time period used to calculate the performance statistics represents the time window between the first simulation year and T_{MAX} which is used to assess the level of rebuilding achieved, and the yield produced by alternative rebuilding strategies. In some cases, T_{MIN} could be close to the time period for the calculation of performance statistics, or rebuilding may not be achieved at all during that period (for example horse mackerel in this report, section 5.6). In such cases, the catch advice should be zero and rebuilding strategies should be re-evaluated when the forecast for the stock improves.
Checking the progress of the rebuilding plan	Re-evaluation of the rebuilding plan is necessary if the stock trajectory is outside the range of expected performance relative to timelines of the rebuilding plan or if exceptional circumstances arise such as unexpected data or a new understanding of the stock. The new rebuilding plan evaluation will need to adapt to the new data or findings. A re-evaluation of the rebuilding targets or objectives may also be necessary. Re-evaluation of rebuilding plan could be agreed with requesters (e.g. after X years), and formalizing the frequency (e.g. annually) for evaluating exceptional circumstances protocol.

Probability of achieving rebuilding	The default probability for rebuilding the SSB in the final year of the evaluation above the rebuilding target (e.g MSY $B_{trigger}$) is at least 50% for a number of consecutive years (3 years proposed here or number of years related to the biology of the stock). However, for certain stocks a different probability or target could be more relevant, for example in the case of short-lived stocks with high recruitment variability that are estimated to be below B_{lim} with a probability larger than 5% even if unfished.
Harvest rules in rebuilding phase	Several HCRs should be evaluated during a rebuilding plan evaluation. The HCRs in Figure 1 were discussed during WKREBUILD2 as they can provide a more precautionary advice than the ICES AR, and they can be integrated in a continuous way with the current ICES AR. The performance of the HCRs tested should be compared against the zero-catch scenario and the ICES advice rule.
Evaluation tools	A single-stock and single fleet annual simulation tool is available in ICES (https://github.com/ices-tools-prod/WKREBUILD_toolset) that allows to test a wide range of HCRs under a wide-range of assumptions about system dynamics. The tool follows the MSE approach and has been built in R using FLR libraries (Kell et al., 2007). However, other tools could be used if they better describe the conditions of the stocks under analysis.
Uncertainty considerations	Alternative operating models should be evaluated to account for stock specific uncertainties. Typical uncertainties to consider in the rebuilding plan context are uncertainties in stock productivity (e.g. recruitment, especially low recruitment regimes and/or depensation), in the assessment model (e.g. stock perception, bias such as retrospective patterns), the short-term forecast (e.g. wrong assumptions in the intermediate year), observation error (in closed-loop MSE) and implementation error. The selection and treatment of alternative operating models and additional uncertainties should be done carefully as they could affect the forecasted probabilities of rebuilding.
Special considerations	Rebuilding plans may be framed taking into account mixed stocks, mixed fisheries, and socio-economic objectives. The WKREBUILD2 toolset does not currently allow this.
Use of ICES guidelines for rebuilding plan evaluations	The guidelines are intended to guide the decisions based on best practice throughout the evaluation. Following or deviating from the guidelines should be appropriately motivated.

See also Annex 3 with summary of guidelines from other ICES expert groups.

4 Performance indicators and thresholds to be used for the acceptability of rebuilding plan elements (ToR c)

4.1 Performance indicators

Performance indicators are intended to measure the performance of different rebuilding strategies in achieving rebuilding. The following performance indicators have currently been included in the WKREBUILD toolbox:

- Probability that spawner biomass is above B_{lim} (PB_{lim})
- Probability that spawner biomass is above MSY $B_{trigger}$ ($PB_{trigger}$)
- Mean catch per year (mean(C))
- CV of catch per year (cv(C))
- Mean catch over a certain number of years (mean(C))
- Cumulative catch over a certain number of years
- Average annual variability in catch (AAV(C))
- Percentage inter-annual change in catch (IAC(C))
- ICES Risk 2, probability that spawner biomass is below Blim once (once(P(SB<B[limit])).
- First year in which $P(SB/SB_{lim}) >= 0.95$, optionally with a certain number of years.
- First year in which $P(SB/MSY\ B_{trigger}) >= 0.50$, optionally with a certain number of years.
- Ratio of rebuilding time ($T_{REBUILD}$) over rebuilding time with zero fishing (T_{MIN}): $T_{REBUILD}/T_{MIN}$.

A series of workshops is being carried out in ICES, specifically WKD3C3SCOPE (ICES, 2023g), WKD3C3THRESHOLDS and WKSIMULD3, to identify operational indicators for D3C3 MSFD indicator that measures the age and size distribution of individuals in the populations of commercially-exploited species. The outcome of this series of workshops could provide valuable information to define indicators to assess the age or length structure of the populations. These indicators could be used together with the probability of being above the target biomass level (e.g., MSY $B_{trigger}$) to define when a stock is considered to have rebuilt instead of using a fixed number of years (e.g., three) independent of the biology of the stock.

4.2 Thresholds

The incorporation of rebuilding plans/strategies to the ICES advice framework requires the definition of thresholds and performance statistics to:

1. Define when a stock requires rebuilding (i.e., when a stock enters a rebuilding phase).
2. Define when a stock is considered to have rebuilt (i.e., when a stock exits the rebuilding phase).
3. Select the best plan among candidates rebuilding plans.

For (1), WKREBUILD2 proposes that a stock requires rebuilding when the SSB estimated in the final year of the assessment drops below B_{PA} (with 50% probability). Alternatively, an additional reference point could be defined which should be located between B_{lim} and MSY $B_{trigger}$. However, WKREBUILD2 considered B_{PA} an adequate threshold for the purpose of rebuilding the stock and avoid it to fall below B_{lim}, and had the advantage of being already part of the ICES reference point framework so there is no need to make it more complex. From that moment onwards, ICES should provide advice according to the selected rebuilding advice rule and no longer based on the MSY advice rule or long-term management plans. Furthermore, ICES could recommend the definition and implementation of rebuilding management plans to relevant management parties. If the existing HCRs agreed by advice requesters have been evaluated by ICES to be able to achieve stock rebuilding from current biomass levels, then ICES could continue to provide catch advice on the basis of the existing HCR.

For (2), ICES will advise a stock to be rebuilt and provide advice based on the MSY advice rule if the stock has been above MSY $B_{trigger}$ in at least the most recent three years in the assessment. The definition of MSY $B_{trigger}$ as B_{PA} should be avoided and should be linked to a biomass target such as B_{MSY}. Furthermore, the three years criteria should be replaced by a time period depending on the biology of the stock as for example i_{mat} where i_{mat} equals to the age at 50% maturity or generation time. However, further research is needed on this topic to develop the science base for the selection of an adequate threshold. The outcomes of the WKD3C3SCOPE (ICES, 2023g) are already available while those from the WKD3C3THRESHOLDS and WKSIMULD3 workshops which will be available soon, could be a good starting point.

To select the rebuilding strategy itself, interpreted here as a specific HCR design, WKREBUILD2 proposes to identify stock specific rules by means of simulation.

For the selection of the stock specific rebuilding strategy, two performance indicators should be considered:

a) the time it takes to rebuild,
b) the cumulative catch it generates over a common rebuilding period (i.e., from the year the stock enters the rebuilding phase to the year the stock exits the rebuilding phase in HCR with the longest rebuilding period).

The threshold for (a) is to be set at $2*T_{MIN}$, with T_{MIN} defined as the time taken for the stock to rebuild above MSY $B_{trigger}$ for three consecutive years with zero fishing. $2*T_{MIN}$ is set as T_{MAX}, defined as the maximum amount of time for rebuilding the stock. Candidates rebuilding strategies for which rebuilding time is longer than T_{MAX} should be discarded and cannot be considered as basis for advice.

When more than one rebuilding strategy fulfills (a), the rebuilding strategy that leads to the highest cumulative catch over the entire rebuilding period of the HCR with the longest rebuilding time (b) should be selected. The WKREBUILD tool could be used to explore rebuilding strategies. The assumptions used in the simulations should be consistent with those used when the reference points were calculated. However, the current conditions should be considered (e.g. changes in stock productivity) and the robustness of the rebuilding strategies to alternative plausible hypotheses about stock and fleet dynamics should be tested. Simulations need to be in line with best practices on management strategy evaluation and be in line with the recommendations as given under ToR b (section 3).

5 Test of rebuilding plan evaluation guidelines using the WKREBUILD toolset (ToR d)

5.1 Description of WKREBUILD toolset

Based on the recommendation of WKREBUILD (ICES, 2020d), a new simulation toolset was implemented that can be generically applied to a wide-range of stocks under most common assumptions about stock and exploitation dynamics. The simulation toolset has been developed in R using FLR libraries (Kell et al. 2007). A template to run the whole process, from model conditioning to analysis of the results, have been developed to facilitate the implementation of the tool in new case studies. The template is fully compatible with the TAF framework (https://www.ices.dk/data/assessment-tools/Pages/transparent-assessment-framework.aspx). The tool is available in a public Github repository (https://github.com/ices-tools-prod/WKREBUILD_toolset) and it includes a tutorial to help with new implementations (https://github.com/ices-tools-prod/WKREBUILD_toolset/blob/main/tutorial.html).

The WKREBUILD2 follows the MSE approach (Punt et al., 2016) where the simulation is divided in two main components: (1) the operating model (OM), which represents the real world and is formed in this case by a single stock and a single fleet, and (2) the management procedure (MP) where the whole management process is simulated. The implementations of the previous toolset in WKREBUILD2 toolset now uses the shortcut approach in the MP, so without carrying out a stock assessment within the loop.

The OM runs in annual time steps and the stock is structured by age. Every year the recruitment is simulated with a predefined stock recruitment model which can incorporate parametric uncertainty and natural variability around the model. The survival of existing year classes is simulated using the classical exponential survival equation. All the biological parameters can include uncertainty and can vary along time. The exploitation is carried out by a single fleet using the Baranov catch equation. The selection pattern, the discard ratio, and the weight in the landings and discards can vary along time and include uncertainty. The exploitation is constrained by the catch advice (TAC) generated in the MP by the HCR and it can include implementation error.

The MP runs annually with a one-year time lag in management, so the catch advice for year ‘y’ is generated with the perceived population up to year ‘y-2’. To generate the catch advice the population up to year ‘y-2’ is carried forward until year ‘y’ doing a short-term forecast with the usual assumptions about recruitment and exploitation level. The catch advice is generated using an HCR. A versatile HCR has been implemented that can simulate all the HCRs shown in Figures 1 and 2.

The toolset included several functions to summarize the results and calculate the relevant performance statistics described in section 4. In the scripts code based on ggplot2 R library (Wickham, 2016) is used to present the results graphically.

The whole process is divided in five scripts, ‘data.R’, ‘model.R’, ‘output.R’, ‘report.R’ and ‘report.Rmd’ which are consistent with the TAF approach and allow to implement the whole work following TAF directrices easily. The scripts are organized as follows:

- ‘data.R’: Conditioning of the OM is carried out.
- ‘model.R’: Conditioning of the MP and simulations.
- ‘output.R’: Summary of the results and calculation of the performance statistics.
- ‘report.R’: Generation of the graphs and tables to be included in the report.

- ‘report.Rmd’: Rmarkdown to present the conditioning of the model, the results in general and the performance statistics.

A detailed description of the code in each script can be found in the tutorial,(https://github.com/ices-tools-prod/WKREBUILD_toolset/blob/main/tutorial.html.

Selection of test cases

Three test cases were selected for WKREBUILD2 where recently a zero-catch advice has been given based on the status of the stock:

- Celtic Sea whiting (whg.27.7b-ce-k)
- Western horse mackerel (hom.27.2a4a5b6a7a-ce-k8)
- Western Baltic Spring-Spawners herring (her.27.20-24)

These test cases were selected based on the utilization of different assessment methods, SAM (Nielsen and Berg, 2014) or SS3 (Methot Jr., and Wetzel, 2013), different areas (Baltic, Celtic Sea, widely distributed) and different fleet structures (single fleet, multi fleet). For each of the test cases, a TAF github repository has been set-up where the WKREBUILD2 toolset has been developed and deployed.

5.2 Description of HCRs

The HCRs described in section 2 and Figure 2, were tested in the three case studies and their performance was compared to the scenario with no fishing (F=0). The ICES AR was tested with two different settings, a linear decrease in fishing mortality until SSB = 0 (HCR_1) and zero advice for any SSB below B_{lim} (HCR_2). In a third HCR fishing mortality was reduced linearly from MSY $B_{trigger}$ up to B_{lim} below which advice was equal to zero (HCR_2). Finally, in the last HCR the advice fishing mortality below MSY $B_{trigger}$ decreased linearly up to B_{lim} where the value was equal to 0.2*F_{MSY} and below B_{lim} fishing mortality was kept constant and equal to 0.2*F_{MSY}.

Description of scenarios tested

Most of the stocks which SSB is close to B_{lim} are subjected to low recruitment levels and it was agreed that recruitment success was the main factor impacting stock recovery in the short term. Hence, two different scenarios were tested which depended on how the recruitment was simulated.

- Base case scenario: The same conditioning as in the calculation of reference points was used in terms of recruitment and the rest of model components.
- Low recruitment scenario: The same options as in the base case scenario were used except for recruitment. A new recruitment model was used based on the recruitments in the most recent period. First, the period to be considered was selected, which determined the mean recruitment in the projection. Then, the way to condition the slope and the breakpoint was decided (see section 3 for the options considered). The time period and the way slope and breakpoint were determined depended on the stock.

5.3 Celtic Sea whiting

About the stock

The Celtic Sea whiting stock is assessed with a single-fleet, single-area SAM model. The model from WGCSE (ICES, 2023d) was used. It can be accessed on www.stockassessment.org under the name 'whg.7b-ce-k_WGCSE22_RevRec_2023'.

The stock was benchmarked in 2020 (ICES, 2020a) and an inter-benchmark took place in 2021 (ICES 2021c) after an error was discovered in the input data. The final MSY $B_{trigger}$ reference point was considerably higher (at 50 818 t) than before the benchmark (35 000 t) while the estimated biomass levels had not changed much as the result of the new assessment. The result was that the stock was now perceived to be below MSY $B_{trigger}$. In 2021 (ICES, 2021d) and 2022 (ICES, 2022b), a non-zero advice could be given but the advice in 2023 was for a zero-catch in 2024 (ICES, 2023c).

Implementation of the advice

The stock area covers ICES division 7bc,ek; the TAC area covers 7b-k. Area 7d is assessed as part of the North Sea stock and the advice for this area is added in to establish a TAC. In recent years, the 7d component has become a significant part of the overall advice. Until 2000, the TAC and catches were well in excess of the advice. In recent years, the TAC has been set in line with the advice but not all countries catch their full quota, resulting in catches that were lower than the TAC. This year is the first year that a zero-catch advice has been given. For other demersal stocks, a zero-catch advice has resulted in a low bycatch TAC in addition to technical measures to avoid a 'choke' situation.

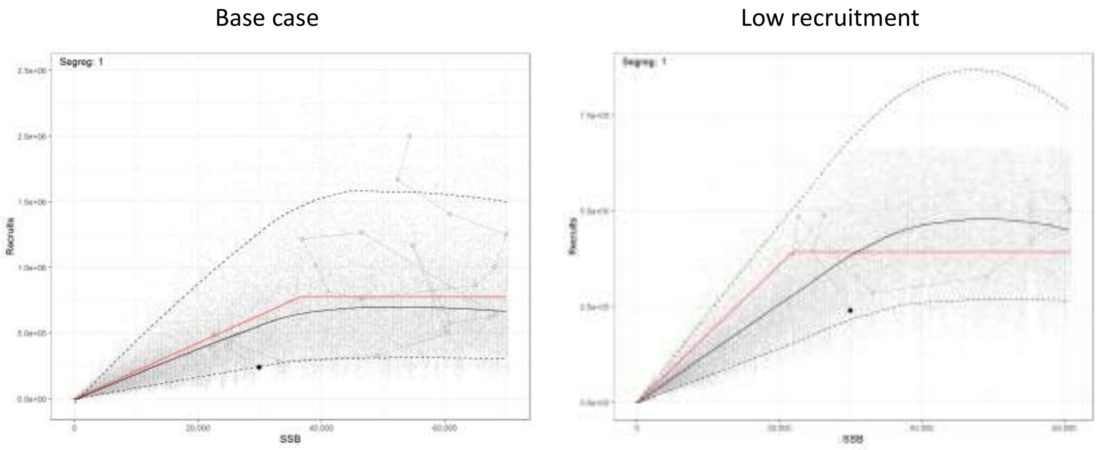
The current rebuilding scenarios do not try to simulate any implementation error and will assume zero catch when the HCR results in F=0.

Stock-recruitment assumptions

A number of rebuild scenarios were investigated, the main two are listed in Table 5.5.1.

1) The base case followed the conditions that were used for the estimation of the reference points (ICES 2021c); in particular the stock-recruit and assessment error.
2) The second scenario was for a low recruitment assumption. Recruitment has been low since 2014. It is unclear whether this is due to impaired recruitment at low stock levels or other factors. This low recruitment scenario was implementing by fitting as stock-recruit relationship to the S-R pairs from 2014 onwards only.

At the last benchmark, B_{lim} was taken to be the lowest biomass from which the stock had recovered (the SSB in 2008). Because the stock has a relatively narrow range of observed biomass, B_{lim} is around half of the highest observed biomass (Figure 5.3.1).


Base case

Low recruitment

Figure 5.3.1. Celtic Sea whiting. Stock recruitment fits in the base case (left), where the regimented regression breakpoint was fixed at the lowest biomass from which the stock had recovered (SSB 2008; 36 571 t); this is also the B_{lim} reference point. The low recruitment scenario only uses SR pairs from 2014 onwards and the segreg breakpoint was fixed at the lowest observed biomass (SSB 2021; 20 107 t).

Rebuild scenarios

The runs presented below apply the following settings: F_{cv}=0.212, F_{phi}=0.423, SSB_{cv}=0 (the same default values used in *EqSim* in the calculation of reference points), no implementation error or simulated fleet behaviours. The uncertainty in the initial conditions of the stock was simulated through hindcasting after adding recruitment deviations conditioned on the sigmaR estimate from bootstrapping the stock-recruitment relationship. The function to simulate recruitment deviations (`FLCore::flnormar1`) applies a bias correction but despite this, the deviations did not centre exactly on one. Therefore, they were standardised to one (in the historical part of the OM only). Annex 4 provides some more detail on the base case OM and rebuild scenario.

The forecast trajectories are presented in Figure 5.3.2, and Figure 5.3.3, for the baseline and low recruitment runs, respectively. In the base case, rebuilding at F=0 is relatively fast but all of the HCRs result in an equilibrium stock that is only just above MSY $B_{trigger}$. In the low-recruitment run, all HCRs result in a stock that settles between B_{lim} and MSY $B_{trigger}$.

In the base case, relative quick rebuilding to B_{lim} with >95% probability and MSY $B_{trigger}$ with >50% probability is possible for all HCRs (Figure 5.3.4). However, in the low recruitment scenario, only F=0 results in reaching B_{lim} with >95% probability and MSY $B_{trigger}$ with >50% probability (Figure 5.3.5). In both scenarios, hrc_1 results in the longest recovery time. This is the rule where F declines linearly to the origin below MSY B_{trigg}er. In the low-recruitment scenario, hrc_2 and hcr_4 both result in some oscillation, where F is apparently ramped up too rapidly when the stock is increasing, resulting in a subsequent decrease in biomass.

Given that rebuilding time is also of interest for the evaluation of rebuilding strategies, Table 5.3.2 shows the median rebuilding time for the different HCRs and for different recruitment and target assumptions as a scaler to TMIN (rebuilding time when F=0). In this case, rebuilding was defined as being above the target with a 95% or 50% probability for 3 consecutive years. TRECOVERY/TMIN is either ≤ 2 or no recovery takes place, depending on the assumption. Rebuilding with 95% probability is only possible under the baseline recruitment assumption. The low recruitment assumption only achieved rebuilding if it was defined as 50% above B_{lim}.

Conclusions

The scripts to run and evaluate rebuilding scenarios worked well for this stock with no major issues. One of the most challenging parts was to account for uncertainty in the historic part of the stock. This can be done by simulating input data and refitting the assessment model (this was the approach used for Western Baltic Spring Spawning herring). The alternative (which was used here) is to simulate recruitment deviations and propagating these through the population using M, F and catch (hindcasting). In a SAM model (Nielsen and Berg, 2014) this means that the process error needs to be accounted for. The two approaches resulted in a similar error in this case study. There is a concern that in some models the estimated uncertainty is an under-estimate and those cases, hindcasting might be preferable.

In the case of whiting, the biomass reference points are relatively high, compared to the observed SSB. This is a consequence of the narrow range of biomass observed over the assessment period. None of the HCRs resulted in a biomass that was above MSY $B_{trigger}$ with a high probability. With such a short stock assessment time-series, it is difficult to determine whether the stock is suffering from impaired recruitment due to low stock size or whether a more robust basis for establishing biomass reference points is required. It should be noted that while the current biomass is near the lowest observed, it is more than 40% of the highest observed SSB.

As with nearly all rebuilding simulations, the assumptions of future recruitment are critical. In the base case, recruitment increased quite fast because of the assumed slope of the stock-recruit relationship. This may not be realistic and is likely over-optimistic. Without an understanding of the drivers of recruitment, an assumption of low recruitment or future recruitment that is similar to recently observed recruitment is likely to be more realistic.

The rebuild scripts for this case study are available on:

https://github.com/ices-taf/2023_whg.27.7b-ce-k_rebuild

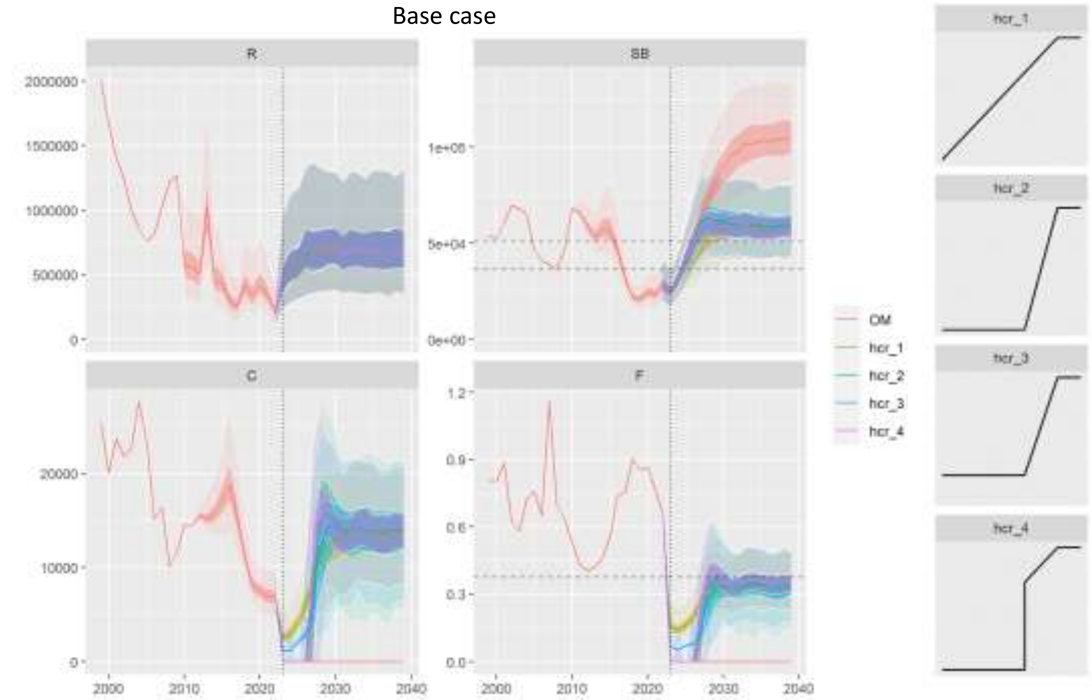


Figure 5.3.2. Celtic Sea whiting. Trajectories in the base case recruitment scenario. The OM trajectory corresponds to F=0 in the forecasted years. The vertical dotted line marks the last assessment year. The dashed horizontal lines illustrate the MSY $B_{trigger}$, B_{lim}, and F_{MSY} reference points. The harvest control rules are illustrated on the left side.

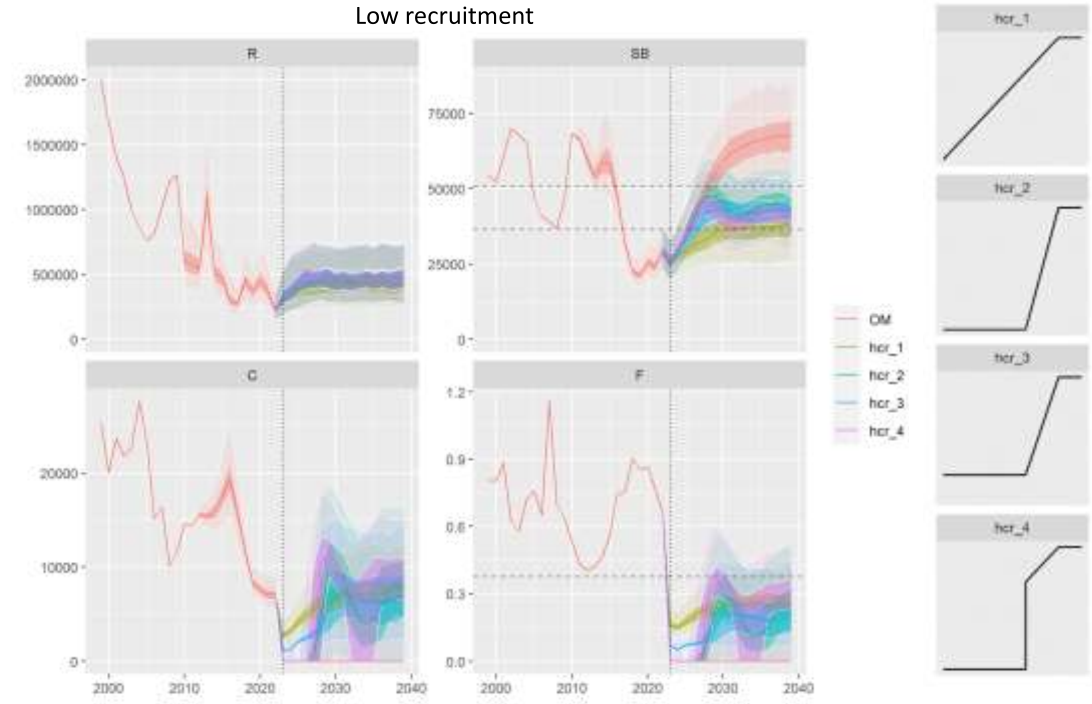
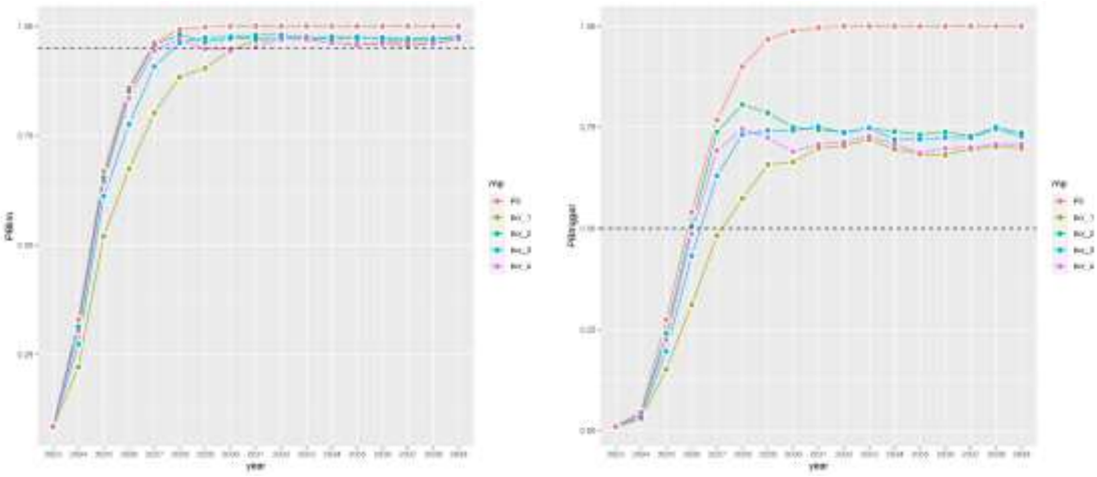


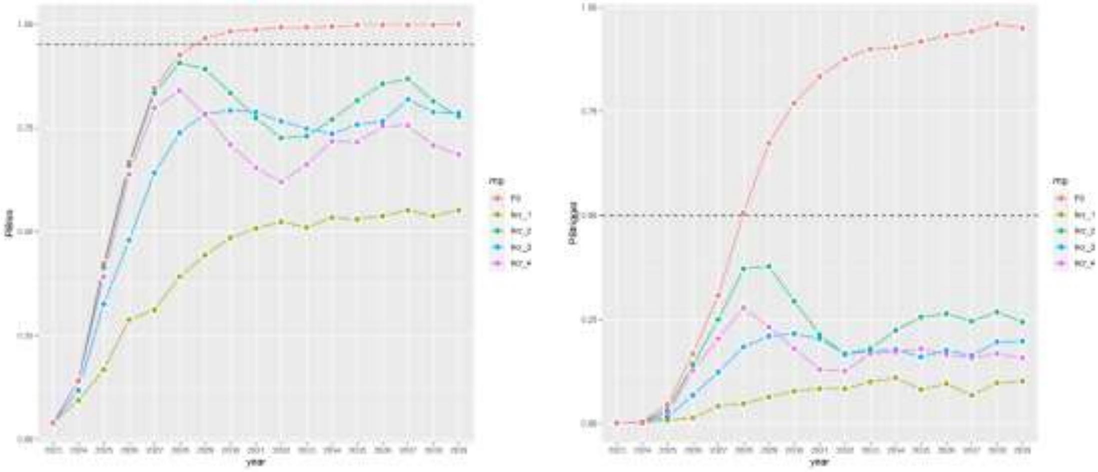
Figure 5.3.3. Celtic Sea whiting. Trajectories in the low recruitment scenario. The OM trajectory corresponds to F=0 in the forecasted years. The vertical dotted line marks the last assessment year. The dashed horizontal lines illustrate the MSY $B_{trigger}$, B_{lim}, and F_{MSY} reference points. The harvest control rules are illustrated on the left side.



a) Base case – prob B_{lim}

b) Base case – prob $B_{trigger}$

Figure 5.3.4. Celtic Sea whiting. Probabilities to get above B_{lim} (a), and MSY $B_{trigger}$ (b) in the forecast years, in the base case recruitment run.

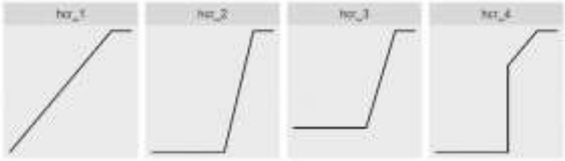


a) Low recruitment – prob B_{lim}

b) Low recruitment – prob $B_{trigger}$

Figure 5.3.5. Celtic Sea whiting. Probabilities to get above B_{lim} (a), and MSY $B_{trigger}$ (b) in the forecast years, in the low recruitment run.

Table 5.3.1. Celtic Sea whiting. Summary of the conditions in the two main scenarios (base case and low recruitment). The only difference in the low-recruitment scenario is the length of the stock-recruit time-series and the fixed breakpoint of the segmented regression.

Scenario	Description		Component	Process	Model used	years used for estimation/ source of the information
Base Case	The conditions in this scenario, except the conditioning of the initial population, are the same used in the calculation of the reference points in 2021 (ICES, 2021c)	Operating model	Initial population	model	SAM	whg.7b-ce-k_WGCSE22_RevRec_2023'
				uncertainty	hindcast	with process error correction
			Stock recruitment	functional form	segreg	1999-2022, breakpoint fixed at SSB2008
				parametric uncertainty	bootstrap	
				process error	Lognormal AR1	sigmaR=0.49; rho=-0.047
			Biological parameters	Natural mortality	fixed	
				Maturity	sample	last 10 years (but is time-invariant in input data)
				Weight at age	sample	last 10 years
			Selection pattern		sample	last 10 years
			Discards		fixed	last 3 years
			Fleet Behaviour		none	
		Management procedure	Short cut approach	SSB deviations	$SSB_{cv}=0$	
				F deviations	$F_{cv}=0.212$, $F_{phi}=0.423$	
			Harvest Control Rules		hcr_1-4	
			Implementation error		None	

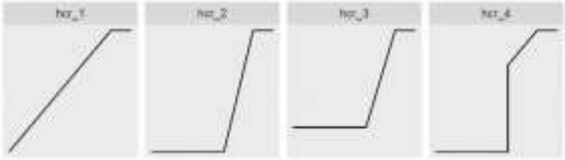
Scenario	Description		Component	Process	Model used	years used for estimation/ source of the information
Low recruitment scenario	The conditions in this scenario, are the same as in the base case expect for the recruitment (ICES, 2021c)	Operating model	Initial population	model	SAM	whg.7b-ce-k_WGCSE22_RevRec_2023'
				uncertainty	hindcast	with process error correction
			Stock recruitment	functional form	segreg	2014-2022, breakpoint at Bloss
				parametric uncertainty	bootstrap	
				process error	Lognormal AR1	sigmaR=0.35; rho=-0.12
			Biological parameters	Natural mortality	fixed	
				Maturity	sample	last 10 years (but is time-invariant in input data)
				Weight at age	sample	last 10 years
			Selection pattern		sample	last 10 years
			Discards		fixed	last 3 years
			Fleet Behaviour		none	
		Management procedure	Short cut approach	SSB deviations	$SSB_{cv}=0$	
				F deviations	$F_{cv}=0.212$, $F_{phi}=0.423$	
			Harvest Control Rules		hcr 1-4	
			Implementation error		None	

Table 5.3.2 Time of rebuilding compared to rebuilding time when F=0 (T_{MIN}) as a scaler (T/T_{MIN}) for different recruitment, biomass target, and probability to rebuild. Rebuilding is assumed when the stock is above a target for at least across 3 consecutive years. NA means the rebuilding to the target for the given probability was not reached.

HCR	Recruitment assumption	Biomass target	Probability to be above target	Scaler compared to T_{MIN}
hcr_1	baseline	B_{lim}	0.95	1.5
hcr_2	baseline	B_{lim}	0.95	1
hcr_3	baseline	B_{lim}	0.95	1.166666667
hcr_4	baseline	B_{lim}	0.95	1
hcr_1	baseline	MSY $B_{trigger}$	0.95	NA
hcr_2	baseline	MSY $B_{trigger}$	0.95	NA
hcr_3	baseline	MSY $B_{trigger}$	0.95	NA
hcr_4	baseline	MSY $B_{trigger}$	0.95	NA
hcr_1	baseline	B_{lim}	0.5	1
hcr_2	baseline	B_{lim}	0.5	1
hcr_3	baseline	B_{lim}	0.5	1
hcr_4	baseline	B_{lim}	0.5	1
hcr_1	baseline	MSY $B_{trigger}$	0.5	1.4
hcr_2	baseline	MSY $B_{trigger}$	0.5	1
hcr_3	baseline	MSY $B_{trigger}$	0.5	1.2
hcr_4	baseline	MSY $B_{trigger}$	0.5	1.2
hcr_1	LowRec	B_{lim}	0.95	NA
hcr_2	LowRec	B_{lim}	0.95	NA
hcr_3	LowRec	B_{lim}	0.95	NA
hcr_4	LowRec	B_{lim}	0.95	NA
hcr_1	LowRec	MSY $B_{trigger}$	0.95	NA
hcr_2	LowRec	MSY $B_{trigger}$	0.95	NA
hcr_3	LowRec	MSY $B_{trigger}$	0.95	NA
hcr_4	LowRec	MSY $B_{trigger}$	0.95	NA
hcr_1	LowRec	B_{lim}	0.5	2
hcr_2	LowRec	B_{lim}	0.5	1
hcr_3	LowRec	B_{lim}	0.5	1.2
hcr_4	LowRec	B_{lim}	0.5	1
hcr_1	LowRec	MSY $B_{trigger}$	0.5	NA
hcr_2	LowRec	MSY $B_{trigger}$	0.5	NA
hcr_3	LowRec	MSY $B_{trigger}$	0.5	NA
hcr_4	LowRec	MSY $B_{trigger}$	0.5	NA

5.4 Western horse mackerel

Western horse mackerel (WHM) is a highly migratory stock with a wide distribution, encompassing ICES subarea 8, and Divisions 2a, 4a (only in quarters 3 and 4), 5b, 6a, 7a-c,e-k. The stock is annually assessed by the ICES working group WGWIDE using a length- and age- based model in SS3 (Merthot Jr. and Wetzel, 2013). The short-term forecast is deterministic and is carried out in FLR. Recent assessments show a consistent downward revision of SSB and an upward revision in F (ICES 2023b), and the stock is being benchmarked in 2024 to explore these retrospective patterns and improve the model.

The spawning stock biomass has been estimated to be below B_{lim} in the last two years, leading to a zero-catch advice for 2023 and 2024, with impossibility of rebuilding the stock above B_{lim} within the timeframe of the short-term forecast even with F=0. Fishing mortality is currently above F_{MSY} but below F_{PA} and F_{lim}, and the recruitment has been generally low since 2001 (ICES, 2023b). The outputs of the 2023 assessment were used for the simulations in this workshop.

The evaluation tool was tested on WHM assuming two different recruitment scenarios (Table 5.4.1): (i) a baseline stock-recruitment relationship (SRR) that resembles the one used at the last inter-benchmark for estimation of MSY referent points (ICES, 2019a), and (ii) a low recruitment scenario. In both cases, a segmented regression with the breakpoint at B_{lim} (834 480 t) was fitted to the SSB - recruitment pairs for the period 1995-2021. For scenario (ii) only pairs where recruitment was below the 50th percentile (2016 840) were used to fit the model (Figure 5.4.1).

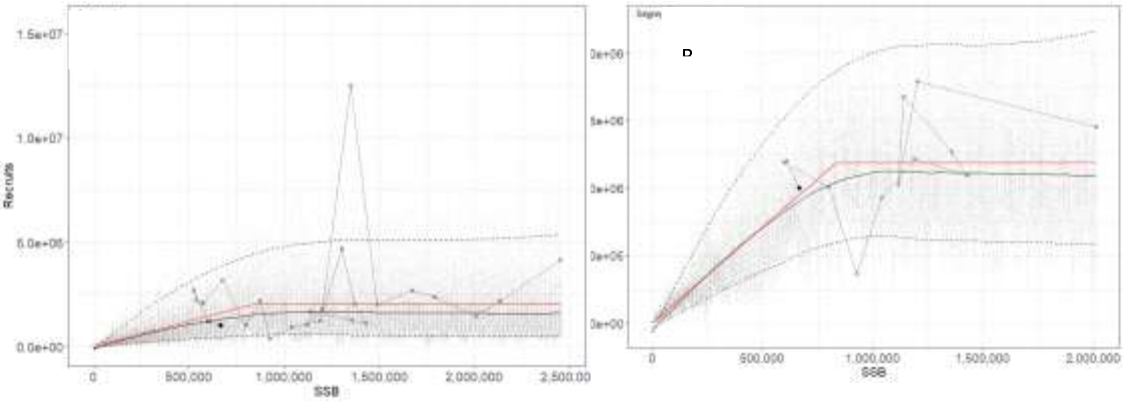


Figure 5.4.1. Western horse mackerel. Stock recruitment relationships estimated for the base case (A) and the low recruitment scenario (B).

The uncertainty in the initial conditions (2010–2022) was incorporated into the model using the hindcast method explained in section 1.4. Lognormal deviances were also propagated into the simulated period using the sigmaR and rho values from the SRR. It must be noted that these parameters were smaller in the low recruitment scenario, and consequently the uncertainty was also smaller (Figures 5.4.2, 5.4.3). Some noise has been also included in F and SSB using the function 'shortcut-devs' and the parameters F_{cv}=0.212, F_{phi}=0.423, SSB_{cv}=0.1 (Table 5.4.1). Implementation error has not been considered in the simulation. The harvest control rules described in section 5.3 were tested.

Table 5.4.5.4.15.4. Western horse mackerel. Summary of the conditions in the two main scenarios (base case and low recruitment).

Scenario	Description		Component	Process	Model used	years used for estimation/ source of the information
Base Case	The conditions in this scenario, except conditioning of the initial population, are the same used in the calculation of reference points in 2019 (ICES, 2019a)	Operating model	Initial population	model	2023 assessment model (SS3)	WGWIDE (ICES, 2023f)
				uncertainty	Hindcast	with process error correction
			Stock recruitment	functional form	Segmented regression	1995-2021. Breakpoint fixed at B_{lim}
				parametric uncertainty	Bootstrap	500 iterations
				process error	Lognormal AR1	sigmaR=0.655, rho=-0.0392
			Biological parameters	Natural mortality	fixed across all ages	0.15
				Maturity	constant over time	age logistic
				Weight at age	constant over time	
			Selection pattern		Average of last three years	2020-2022
			Discards		none	
			Fleet Behaviour		none	
		Management procedure	Short cut approach	SSB deviations	SSB_{cv}=0.1	
				F deviations	F_{cv}=0.212,F_{phi}=0.423	
			Harvest Control Rules		HCR 1-4, F=0	Section 5.3
			Implementation error		none	

Scenario	Description		Component	Process	Model used	years used for estimation/ source of the information
Low recruitment scenario	The conditions in this scenario, are the same as in the base case expect for the recruitment	Operating model	Initial population	model	2023 assessment model (SS3)	WGWIDE (ICES, 2023f)
				uncertainty	Hindcast	with process error correction
			Stock recruitment	functional form	Segmented regression	1995-2021, using only SR pairs where R was within the 50th percentile. Breakpoint fixed at B_{lim}
				parametric uncertainty	Bootstrap	500 iterations
				process error	Lognormal AR1	sigmaR=0.402, rho=-0.101
			Biological parameters	Natural mortality	fixed across all ages	0.15
				Maturity	constant over time	age logistic
				Weight at age	constant over time	
			Selection pattern		Average of last three years	2020-2022
			Discards		none	
			Fleet Behaviour		none	
		Management procedure	Short cut approach	SSB deviations	SSBcv=0.1	
				F deviations	F_{cv}=0.212,F_{phi}=0.423	
			Harvest Control Rules		HCR 1-4, F=0	Section 5.3
			Implementation error		none	

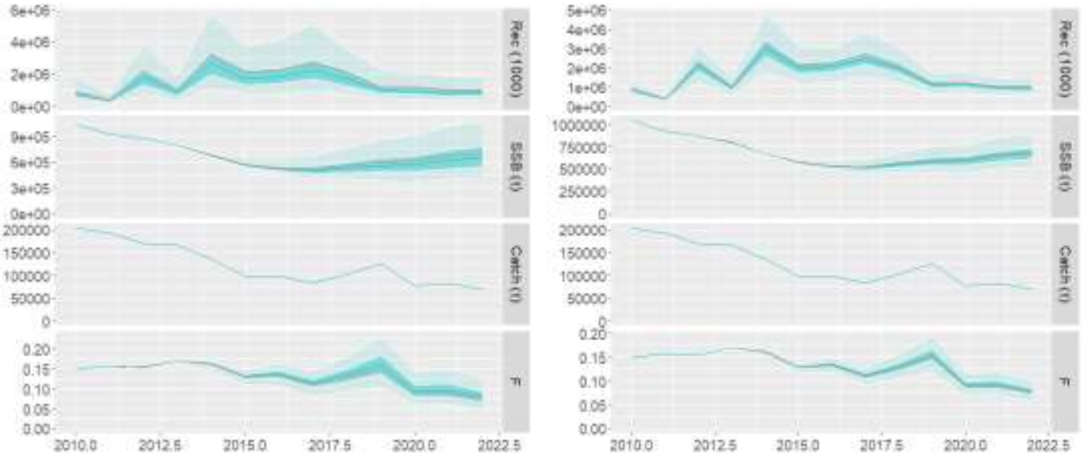


Figure 5.4.2. Western horse mackerel. Uncertainty and median recruitment, SSB, catch and F values for the period 2010–2022 obtained with the hindcast method (in blue) and the estimates from the assessment (in pink) for the base case (A) and the low recruitment scenario (B).

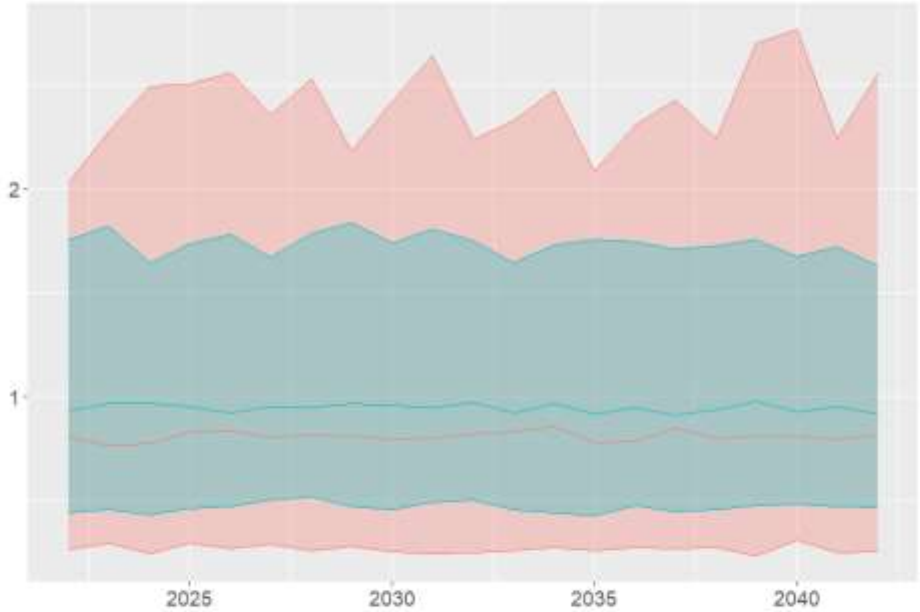


Figure 5.4.3. Western horse mackerel. Median and confidence intervals of the deviances propagated for the period 2022–2042 in the base case (pink) and low recruitment (blue) scenarios.

The forecast trajectories are presented in Figures 5.4.4, and 5.4.5 for the baseline and low recruitment runs, respectively. In both scenarios, the biomass increased significantly faster when there was no fishing. Within the fishing options, HCR_2, which is the HCR being currently used, led to the highest biomass, whereas the application of the HCR_1 produced a decrease in biomass in the low recruitment scenario.

The probability of rebuilding the stock in the time frame used here and with the tested HCR is low. In the baseline run (Figure 5.4.6), rebuilding to B_{lim} with >50% probability is possible for all HCRs but the chances of rebuilding to MSY $B_{trigger}$ are significantly lower (<50% in all cases except F=0). In the low recruitment run, the 95% probability of being above B_{lim} is not reached in the simulated period, even with F=0 (Figure 5.4.7). In those cases where B_{lim} is reached with a probability higher than 50% and for 3 consecutive years, the time to rebuild is up to 2 times the time needed to rebuild under a catch 0 scenario (Table 5.4.2). MSY Btrigger and Blim with a probability higher than 50% are not reached for 3 consecutive years with any of the HCR tested here.

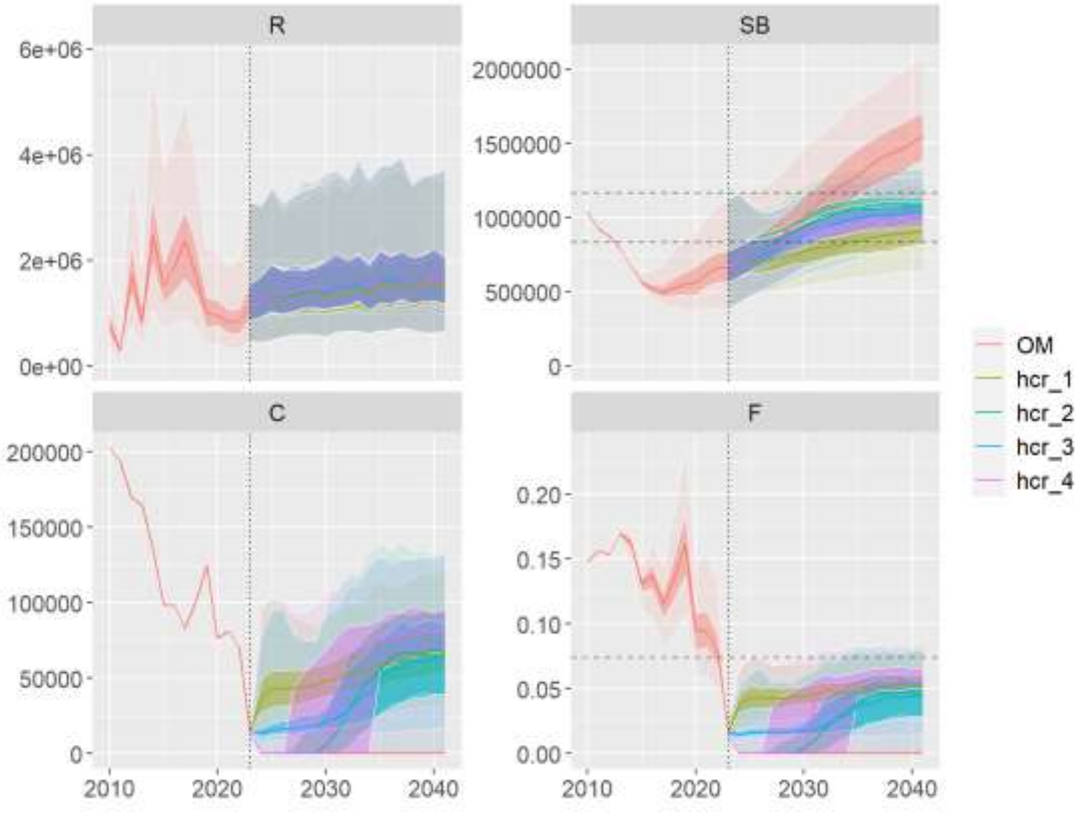


Figure 5.4.4. Western horse mackerel. Trajectories in the baseline recruitment case. The OM trajectory corresponds to F=0 in the forecasted years. The vertical dotted line marks the last assessment year. The dashed horizontal lines illustrate the MSY $B_{trigger}$, B_{lim}, and F_{MSY} reference points.

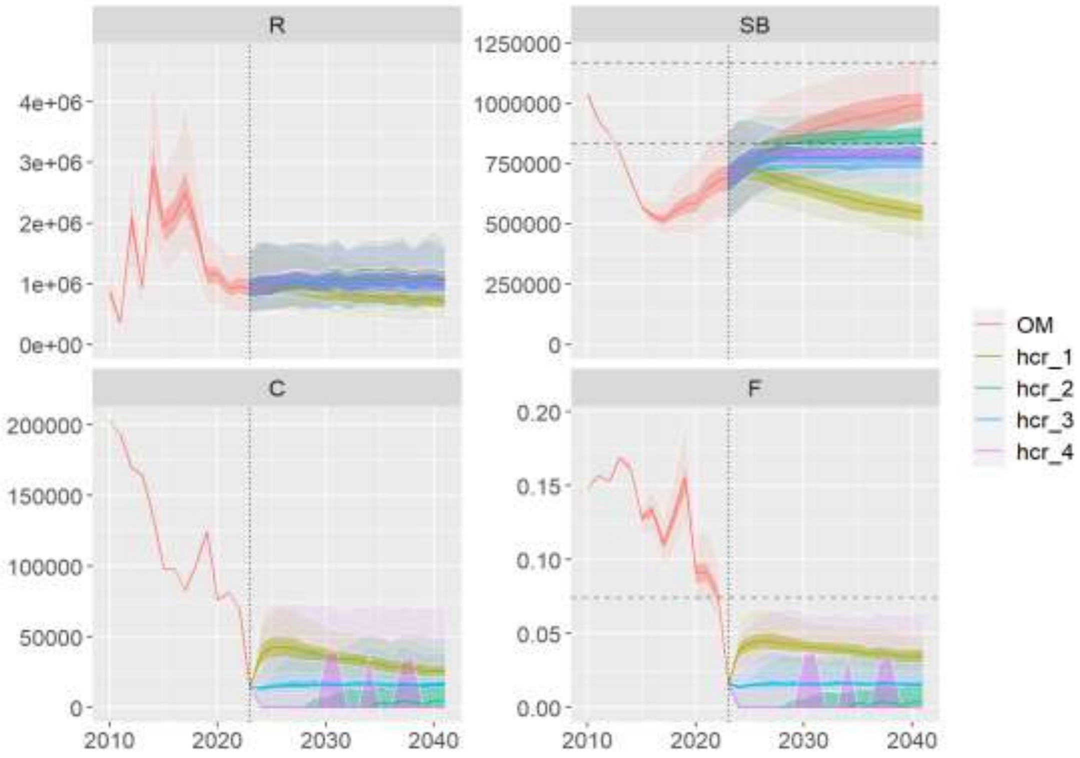


Figure 5.4.5. Western horse mackerel. Trajectories in the low recruitment scenario. The OM trajectory corresponds to F=0 in the forecasted years. The vertical dotted line marks the last assessment year. The dashed horizontal lines illustrate the MSY $B_{trigger}$, B_{lim}, and F_{MSY} reference points.

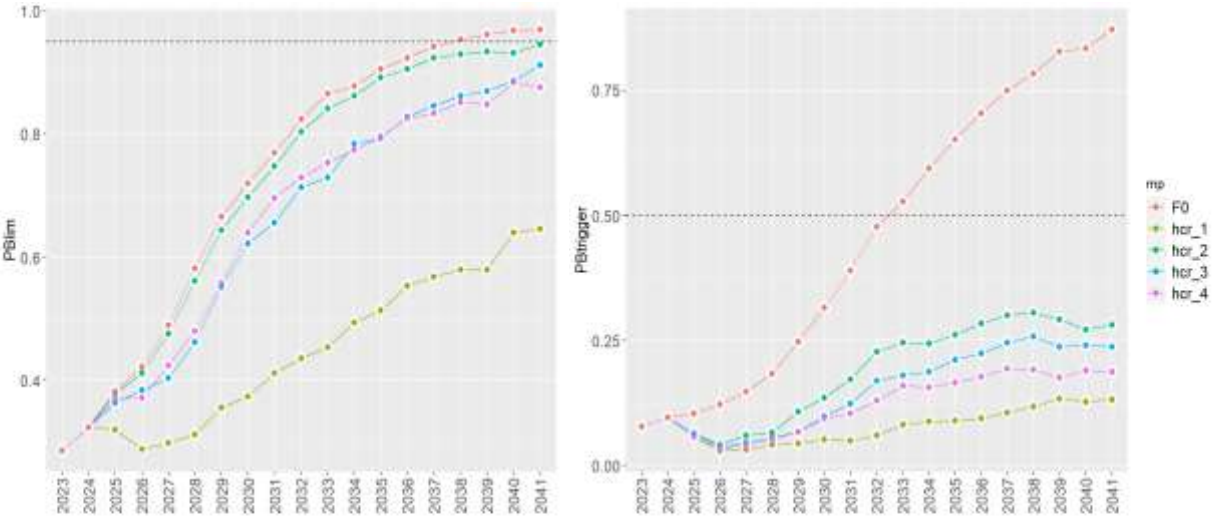


Figure 5.4.6 Western horse mackerel. Probabilities to get above B_{lim} (A), and MSY $B_{trigger}$ (B) in the forecast years, in the base case recruitment run. The dashed lines highlight the probability of 0.95 in (A) and 0.5 in (B)

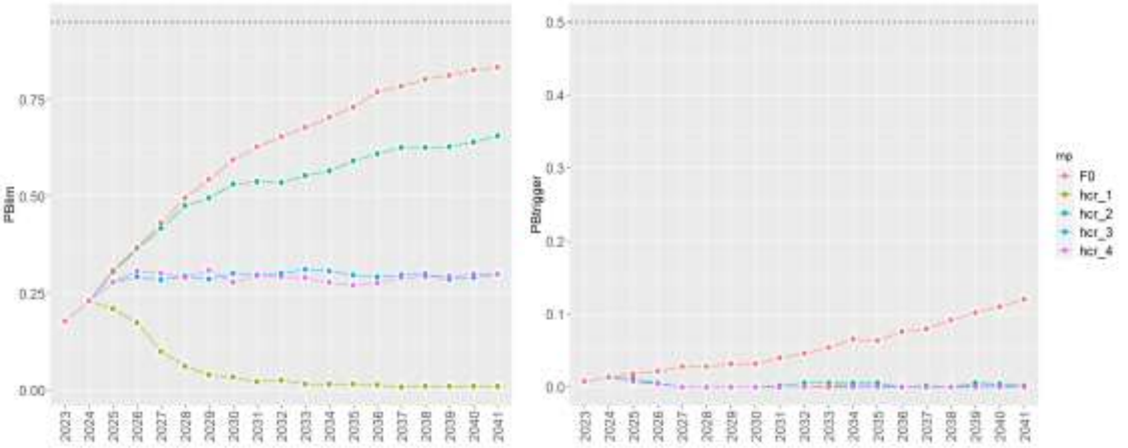


Figure 5.4.7. Western horse mackerel. Probabilities to get above B_{lim} (A), and MSY $B_{trigger}$ (B) in the forecast years, in the low case recruitment run. The dashed lines highlight the probability of 0.95 in (A) and 0.5 in (B).

Table 5.4.5.4.2.5.4 Western horse mackerel. Time of rebuilding compared to rebuilding time when F=0 (T_{MIN}) as a scaler (T/T_{MIN}) for different recruitment, biomass target, and probability to rebuild. Rebuilding is assumed when for at least across 3 consecutive years. NA means the rebuilding to the target for the given probability was not reached.

mp	Scenario	target	prob	scaler
hcr_1	Baseline	B_{lim}	0.95	NA
hcr_2	Baseline	B_{lim}	0.95	NA
hcr_3	Baseline	B_{lim}	0.95	NA
hcr_4	Baseline	B_{lim}	0.95	NA
hcr_1	Baseline	MSY $B_{trigger}$	0.95	NA
hcr_2	Baseline	MSY $B_{trigger}$	0.95	NA
hcr_3	Baseline	MSY $B_{trigger}$	0.95	NA
hcr_4	Baseline	MSY $B_{trigger}$	0.95	NA
hcr_1	Baseline	B_{lim}	0.5	2
hcr_2	Baseline	B_{lim}	0.5	1
hcr_3	Baseline	B_{lim}	0.5	1.143
hcr_4	Baseline	B_{lim}	0.5	1.143
hcr_1	Baseline	MSY $B_{trigger}$	0.5	NA
hcr_2	Baseline	MSY $B_{trigger}$	0.5	NA
hcr_3	Baseline	MSY $B_{trigger}$	0.5	NA
hcr_4	Baseline	MSY $B_{trigger}$	0.5	NA
hcr_1	Low recruitment	B_{lim}	0.95	NA
hcr_2	Low recruitment	B_{lim}	0.95	NA
hcr_3	Low recruitment	B_{lim}	0.95	NA
hcr_4	Low recruitment	B_{lim}	0.95	NA
hcr_1	Low recruitment	MSY $B_{trigger}$	0.95	NA
hcr_2	Low recruitment	MSY $B_{trigger}$	0.95	NA
hcr_3	Low recruitment	MSY $B_{trigger}$	0.95	NA
hcr_4	Low recruitment	MSY $B_{trigger}$	0.95	NA

mp	Scenario	target	prob	scaler
hcr_1	Low recruitment	B_{lim}	0.5	NA
hcr_2	Low recruitment	B_{lim}	0.5	1.125
hcr_3	Low recruitment	B_{lim}	0.5	NA
hcr_4	Low recruitment	B_{lim}	0.5	NA
hcr_1	Low recruitment	MSY $B_{trigger}$	0.5	NA
hcr_2	Low recruitment	MSY $B_{trigger}$	0.5	NA
hcr_3	Low recruitment	MSY $B_{trigger}$	0.5	NA
hcr_4	Low recruitment	MSY $B_{trigger}$	0.5	NA

Conclusions

The forecasted trajectories for WHM are concerning. In the base case scenario, the stock is unlikely to be rebuilt above B_{lim} (probabilities >95%) before 2038. The low recruitment scenario, which is in line with the recruitment levels in recent years, showed even more grim outcomes, where B_{lim} is not reached (>95% probabilities) within the simulated time frame. Guidelines are needed to provide advice under these exceptional circumstances where rebuilding is not possible until higher recruitment episodes feed into the population. This is especially relevant for stocks that are part of mixed fisheries and a zero-catch advice is difficult to implement.

Unlike the simulations presented here, the evaluation of the rebuilding plan previously developed for WHM (section 1.4, ICES 2021e) found that the stock was able to rebuild above MSY $B_{trigger}$ with a probability higher than 50% in 7 years. This arises the question of whether the implementation of the rebuilding plan at that time, when the biomass was still above Blim, would have avoided the current situation.

Regarding the methodology, the tool developed to evaluate rebuilding plans worked well. Although it is already quite versatile, new settings have been suggested during the workshop to accommodate a wider range of management scenarios and operating models. In this regard, additional harvest control rules based on a fixed and low F have been recently added to the tool but there was not time to test them during the workshop. These HCRs might be an option to rebuild WHM considering the stock is only achieving MSY $B_{trigger}$ (>50% probabilities) with F=0 in the current evaluation (assuming base recruitment scenario).

It must be also noted that the uncertainty in both recruitment scenarios is different because it is derived from the SRR, and the uncertainty affects the probability of rebuilding. These variations in uncertainty between scenarios need to be considered when interpreting outputs.

The rebuild scripts for this case study are available on:

[ices-taf/2023_hom.27.2a4a5b6a7a-ce-k8_rebuild (github.com)]()

5.4.1 Comparison with 2021 Rebuilding Plan Evaluation

Simulations using the WKREBUILD toolset were also carried out on the basis of the conditioning used during the 2021 rebuilding plan evaluation (§1.4), for which the following settings pertained:

- OM conditioned on the WGWIDE 2019 (ICES, 2019c) update assessment
- Segmented–regression stock recruit model, constrained at B_{lim}, fit to data pairs from 1995-2017
- Catch constraints applied in 2019 (110 381 t) and 2020 (83 954 t)
- 2021 is the first management year
- Double breakpoint harvest rule with a fixed F_{target} (0.075) when SSB is above MSY $B_{trigger}$ with a linear decline to 20% of F_{target} at B_{lim}. Below B_{lim} the target fishing mortality remains at 20% of F_{target}.
- A 20% limitation on the inter-annual variation in TAC, applied only when SSB is above MSY $B_{trigger}$ (an unconstrained HCR was also tested).
- The short-cut assessment uncertainty was parameterised with $F_{cv} = 0.22$, $F_{phi} = 0.02$ and $SSB_{cv} = 0.29$.

Notable differences between the current (WKREBUILD toolset) approach and the 2021 evaluation (using an adaptation of *EqSim*) include:

- Initial uncertainty incorporated via 1 000 stock replicates constructed from the variance-covariance matrix of parameter estimates. The hind-cast method (§1.4, 5.6) is used to incorporate uncertainty for the toolset-based evaluation (from 2006)
- Stock-recruitment model conditioned on SSB-Recruitment estimates from the (more optimistic) 2019 assessment (ICES, 2019c) and modelled using the *EqSim* functionality.
- No management lags are incorporated in the 2021 evaluation whereas the WKREBUILD2 simulations include a (more realistic) data and management lag.

The fit to the recruitment time-series from the 2019 assessment (ICES, 2019c) is shown in Figure 5.4.8 (a). In comparison with the fit from the most recent assessment (b), the 2019 data leads to higher average recruitment.

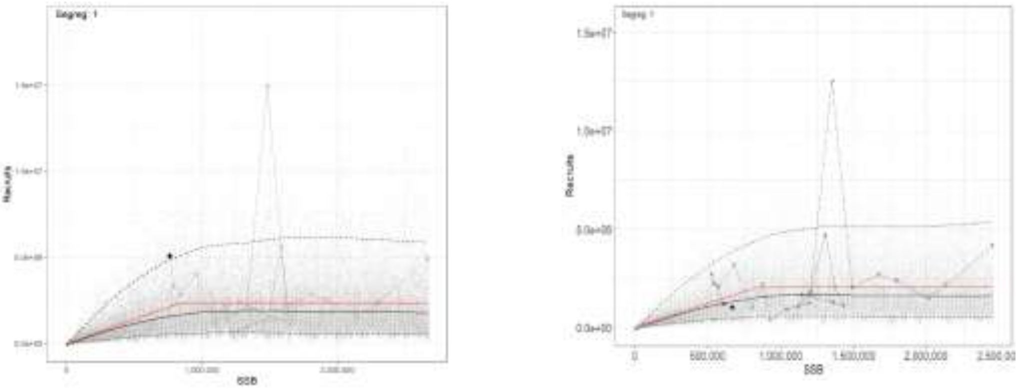

(a) (b)

Figure 5.4.8. Segmented regression stock recruit model estimated from (a) 2019 SSB-Recr pairs 1995-2017 (b) 2023 SSB-Recr pairs 1995–2021.

Stock projections under the no-fishing, double break-point and constrained double break-point management procedures are shown in Figure 5.4.9.

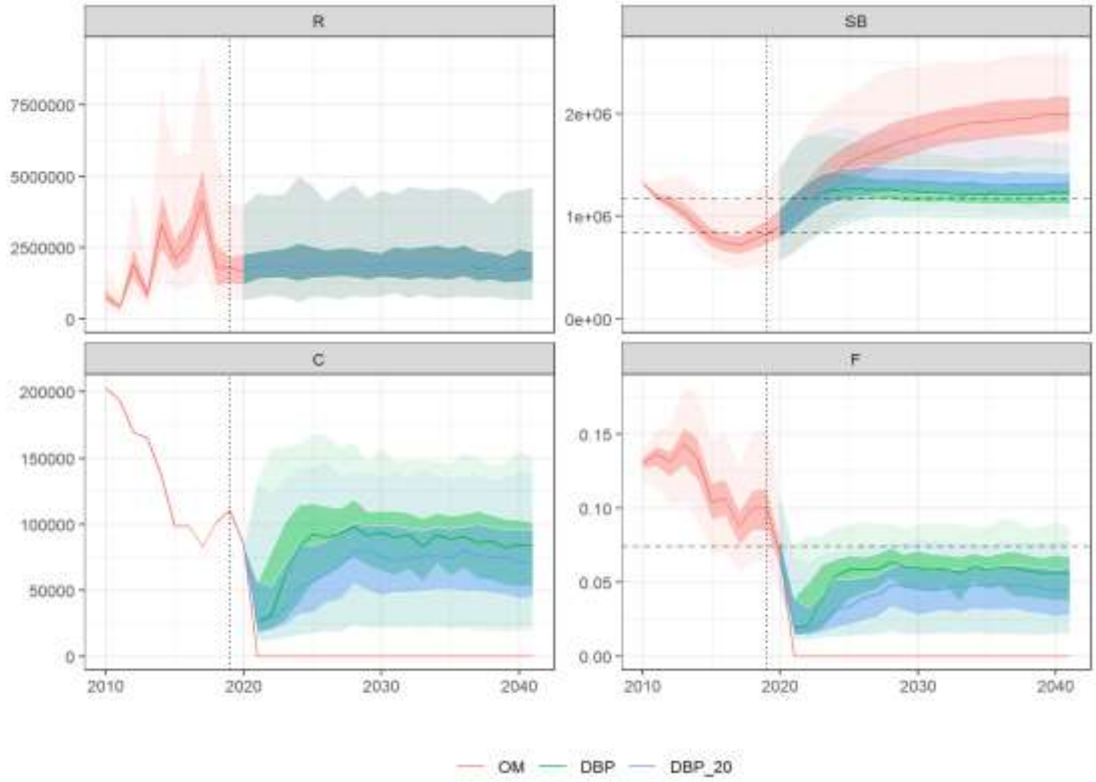


Figure 5.4.9. Stock trajectories under OM (F_{target} = 0 during projection period), DBP (double break point) and DBP_20 (double breakpoint with TAC change constrained to 20% when SSB is above MSY $B_{trigger}$).

In the first management year (2021), the target fishing mortality is derived from the SSB in 2019 (marked by the vertical dashed line) for which there is approximately a 50% probability of being below B_{lim} (ICES, 2019c). As a result, the target fishing mortality for 2021 represents a significant reduction on that for 2020 leading to median catch in 2021 of approximately 25kt. This relatively low catch which is maintained into 2022 when combined with the increased recruitment seen in the years leading up to the projection period, reinforces the increasing trend in SSB since 2017. The growth in SSB in the near term for all 3 scenarios is reflected in the risk the B_{lim} and MSY $B_{trigger}$ as shown in Figure 5.4.10.

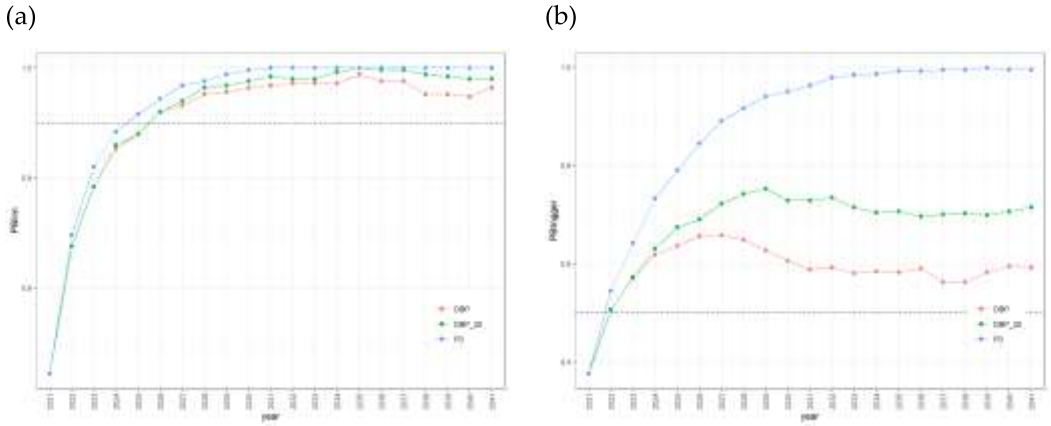


Figure 5.4.10. Probability of SSB greater than (a) B_{lim} (threshold 95%) and (b) MSY $B_{trigger}$ (threshold 50%) over the projection period.

Based on the 2019 assessment conditioning, simulations indicate that the double break point rule is capable of recovering the stock above B_{lim} relatively rapidly. The probability of exceeding MSY $B_{trigger}$ is greater than 50% for all scenarios although substantially lower for the non-zero HCRs with the unconstrained rule associated with the highest risks.

The WKREBUILD toolset results are compared to those from the 2021 *EqSim*-based evaluation in Figure 5.4.11.

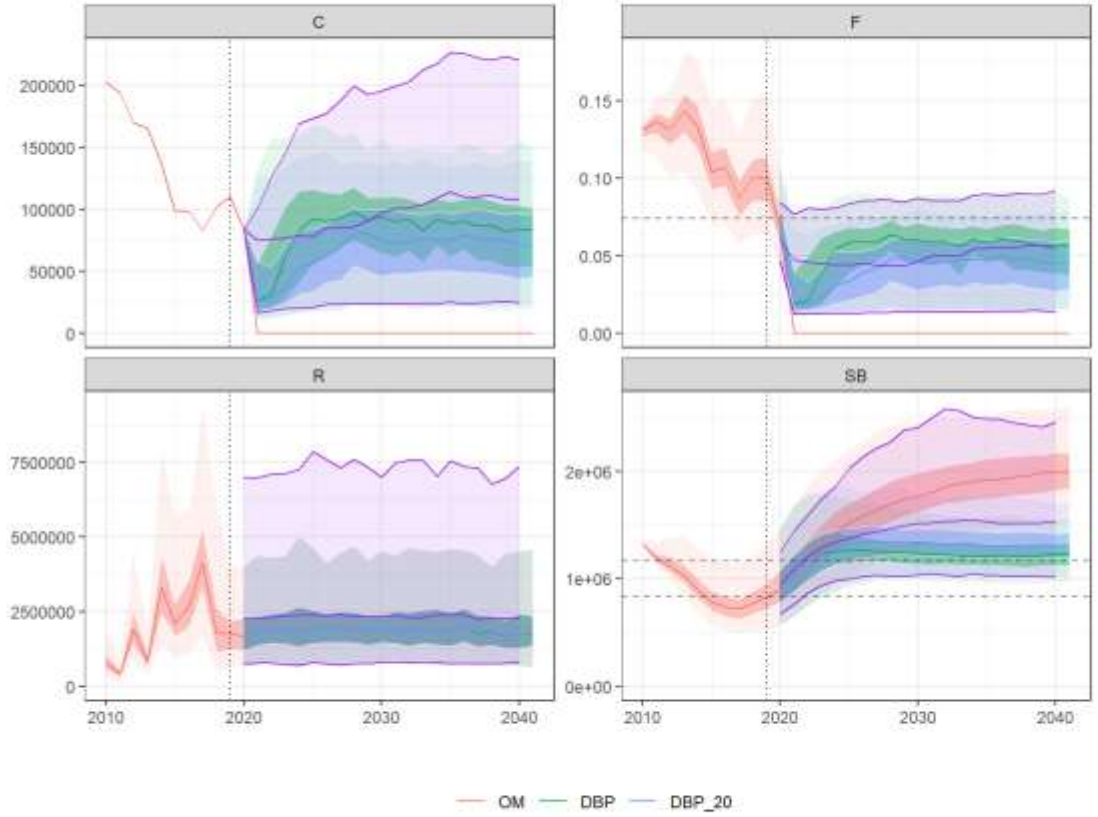


Figure5.4.11. WKREBUILD stock trajectories overlaid with 2021 evaluation output of a double breakpoint with 20% TAC change limitation (purple).

Although both approaches indicate that the HCR can lead to stock recovery there are some notable differences in the results.

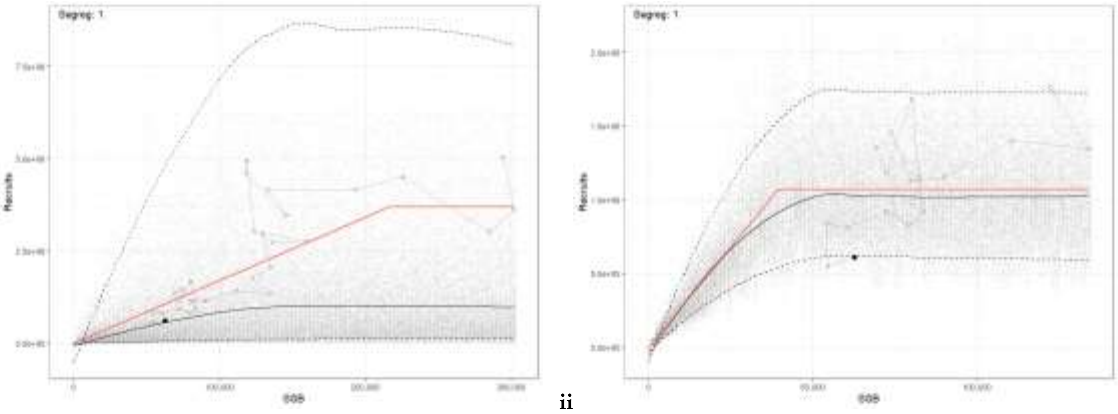
Uncertainty in recruitment (and consequently SSB, catch and F) is greater in the 2021 evaluation, using the *EqSim* stock-recruitment modelling approach. Additionally, the 2021 evaluation did not incorporate a management lag and, as a result the initial reduction in catch for 2021 is much reduced over that in the WKREBUILD toolset evaluation (as it is based on a higher SSB). The resultant trajectories in catch and fishing mortality differ significantly in the near term, although all indicate an increasing SSB trend, favourable for rebuilding. In the longer term, the 2021 evaluation indicates a higher steady state SSB and yield.

5.5 Western Baltic Spring-spawning herring

Western Baltic Spring Spawners (WBSS) herring was last benchmarked in 2018 and the stock has been estimated below B_{lim} (ICES, 2018) ever since leading to a zero-catch advice since 2019 with impossibility to rebuilding the stock above B_{lim} within the timeframe of the short-term forecast even with F=0. The stock is currently estimated in multi-fleet SAM and the forecast for advice is a multi-fleet deterministic forecast (Nielsen et al., 2021). The assessment from 2022 was used as basis for the evaluation (ICES, 2022a).

The evaluation tool was tested on WBSS herring assuming two different recruitment scenarios: (i) a baseline stock-recruitment relationship (SRR) that most resembles the one used at the last benchmark for estimation of MSY referent points (segmented regression with breakpoint at

SSB=217 000 t), and (ii) low recruitment option where a segmented regression was fitted to the SSB and recruitment pairs in the years 2005–2021.



i ii

Figure 5.5.8. Western Baltic Spring-spawning herring. Baseline recruitment assumption (i), and low recruitment assumption (ii).

The runs presented below assume the following settings: F_{cv}=0.212, F_{phi}=0.423, SSB_{cv}=0 (the default settings in *EqSim*), no implementation error, and the uncertainty in the perception of the stock was simulated from the covariance matrix in SAM (see **Error! Reference source not found.** for the full settings).

The forecast trajectories are presented in Figure 5.5.8, and Figure 5.5.9, for the baseline and low recruitment runs, respectively. Rebuilding is uncertain no matter the recruitment assumption. In the baseline run, rebuilding to B_{lim} with >50% probability is possible for all HCRs but rebuilding to MSY $B_{trigger}$ decreases the probabilities, notably for hcr_1 (Figure 5.5.11). In the low recruitment run, HCRs 2-4 show undesired oscillations in SSB which are caused by the lag between assessment and management and the fact that B_{lim} and MSY $B_{trigger}$ are too close (Figure 5.5.10). This behaviour is also seen in Figure 5.5.12 where the probabilities oscillate between high and low values across the forecast years.

Table 5.5.1 Western Baltic Spring-spawning herring. Summary of the conditions in the two main scenarios (base case and low recruitment).

Scenario	Description		Component	Process	Model used	years used for estimation/ source of the informatiom
Base Case	The conditions in this scenario, except conditioning of the initial population, are the same used in the calculation of reference points in 2021 (ICES, 2021)	Operating model	Initial population	model	2022 SAM assessment	ICES HAWG 2022
				uncertainty	covariance matrix from SAM	
			Stock recruitment	functional form	Segmented regression	1991-2021 with breakpoint fixed at 217,000 t (similar as benchmark)
				parametric uncertainty	Bootstrap	
				process error	Lognormal AR1	sigmaR=1.300949; rho=-0.035544
			Biological parameters	Natural mortality	fixed	as in assessment
				Maturity	mean	last 5 years
				Weight at age	mean	last 5 years
			Selection pattern		mean	last 5 years
			Discards		NA	
			Fleet Behaviour		none	
		Management procedure	Short cut approach	SSB deviations	SSBcv=0	
				F deviations	Fcv=0.212, Fphi=0.423	
			Harvest Control Rules		hcr1-4 as described in report	
			Implementation error		none	
Low recruitment scenario	The conditions in this scenario, are the same as in the base case expect for the recruitment	Operating model	Initial population	model	2022 SAM assessment	ICES HAWG 2022
				uncertainty	covariance matrix from SAM	
			Stock recruitment	functional form	Segmented regression	2005-2021
				parametric uncertainty	Bootstrap	
				process error	Lognormal AR1	sigmaR=0.30918; rho=-0.08376
			Biological parameters	Natural mortality	fixed	as in assessment
				Maturity	mean	last 5 years
				Weight at age	mean	last 5 years
			Selection pattern		mean	last 5 years
			Discards		NA	
			Fleet Behaviour		none	
		Management procedure	Short cut approach	SSB deviations	SSBcv=0	
				F deviations	Fcv=0.212, Fphi=0.423	
			Harvest Control Rules		hcr1-4 as described in report	
			Implementation error		none	

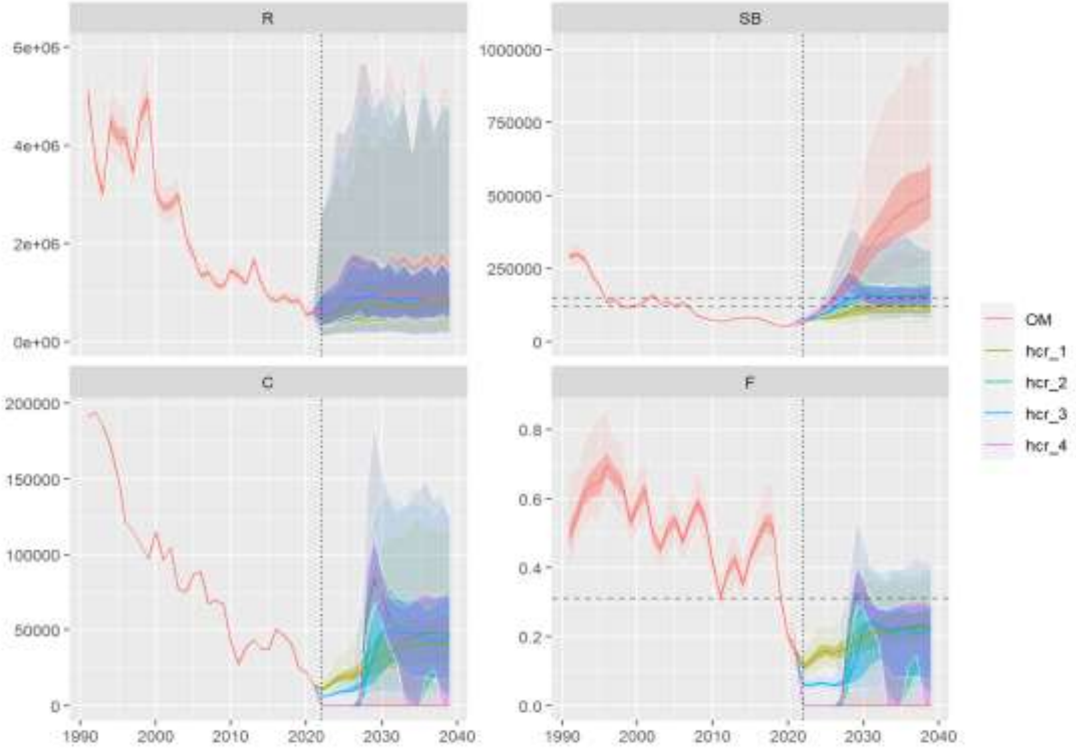


Figure 5.5.9. Western Baltic Spring-spawning herring. Trajectories in the baseline recruitment case. The OM trajectory corresponds to F=0 in the forecasted years. The vertical dotted line marks the last assessment year. The dashed horizontal lines illustrate the MSY $B_{trigger}$, B_{lim}, and F_{MSY} reference points.

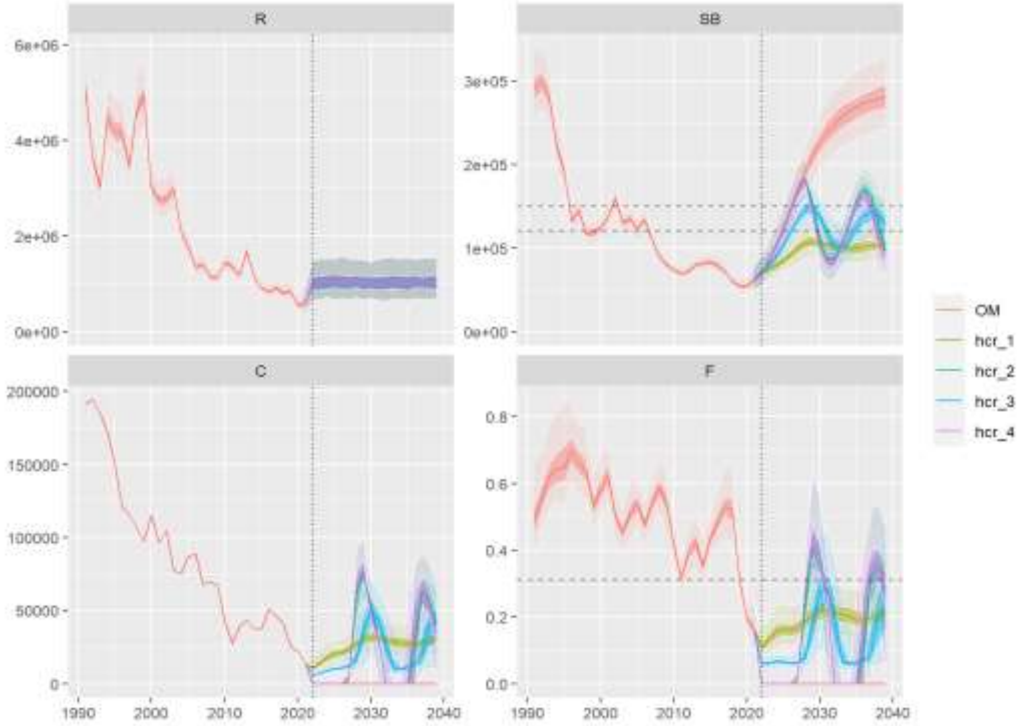
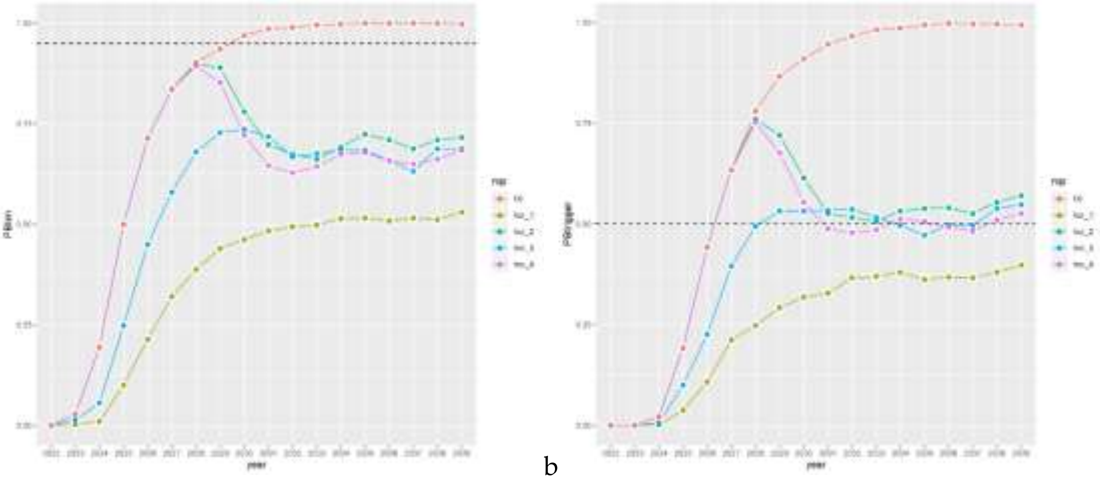
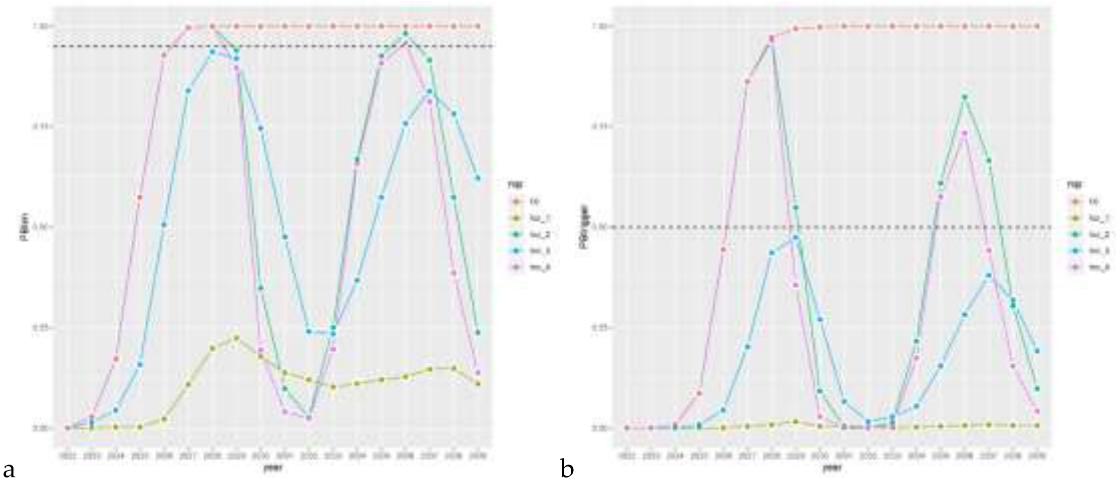


Figure 5.5.10. Western Baltic Spring-spawning herring. Trajectories in the low recruitment case. The OM trajectory corresponds to F=0 in the forecasted years. The vertical dotted line marks the last assessment year. The dashed horizontal lines illustrate the MSY $B_{trigger}$, B_{lim}, and F_{MSY} reference points.



a b

Figure 5.5.11. Western Baltic Spring-spawning herring. Probabilities to get above B_{lim} (a), and MSY $B_{trigger}$ (b) in the forecast years, in the baseline recruitment run.



a b

Figure 5.5.12. Western Baltic Spring-spawning herring. Probabilities to get above B_{lim} (a), and MSY $B_{trigger}$ (b) in the forecast years, in the low recruitment run.

Given that rebuilding time is also of interest for the evaluation of rebuilding strategies,

Table 5.5.25.5 extracts the rebuilding time for the different HCRs and for different recruitment and target assumptions as a scaler to TMIN (rebuilding time when F=0). The scaler to TMIN varies between 1 and 2.8 depending on the assumption. Rebuilding with 95% probability for 3 consecutive years is only possible in two cases, however we know from Figure 5.5.12 that the rebuilding does not last due to the oscillations for these HCRs.

Table 5.5.25.5. Western Baltic Spring-spawning herring. Time of rebuilding compared to rebuilding time when F=0 (T_{MIN}) as a scaler (T/T_{MIN}) for different recruitment, biomass target, and probability to rebuild. Rebuilding is assumed when for at least across 3 consecutive years. NA means the rebuilding to the target for the given probability was not reached.

HCR	Recruitment assumption	Biomass target	Probability to be above target	Scaler compared to T_{MIN}
hcr_1	baseline	B_{lim}	0.95	NA
hcr_2	baseline	B_{lim}	0.95	NA
hcr_3	baseline	B_{lim}	0.95	NA
hcr_4	baseline	B_{lim}	0.95	NA
hcr_1	baseline	MSY $B_{trigger}$	0.95	NA
hcr_2	baseline	MSY $B_{trigger}$	0.95	NA
hcr_3	baseline	MSY $B_{trigger}$	0.95	NA
hcr_4	baseline	MSY $B_{trigger}$	0.95	NA
hcr_1	lowR	B_{lim}	0.95	NA
hcr_2	lowR	B_{lim}	0.95	2
hcr_3	lowR	B_{lim}	0.95	NA
hcr_4	lowR	B_{lim}	0.95	2
hcr_1	lowR	MSY $B_{trigger}$	0.95	NA
hcr_2	lowR	MSY $B_{trigger}$	0.95	NA
hcr_3	lowR	MSY $B_{trigger}$	0.95	NA
hcr_4	lowR	MSY $B_{trigger}$	0.95	NA
hcr_1	baseline	B_{lim}	0.5	2.8
hcr_2	baseline	B_{lim}	0.5	1
hcr_3	baseline	B_{lim}	0.5	1.4
hcr_4	baseline	B_{lim}	0.5	1
hcr_1	baseline	MSY $B_{trigger}$	0.5	NA
hcr_2	baseline	MSY $B_{trigger}$	0.5	1
hcr_3	baseline	MSY $B_{trigger}$	0.5	1.285714
hcr_4	baseline	MSY $B_{trigger}$	0.5	1
hcr_1	lowR	B_{lim}	0.5	NA
hcr_2	lowR	B_{lim}	0.5	1
hcr_3	lowR	B_{lim}	0.5	1.2
hcr_4	lowR	B_{lim}	0.5	1
hcr_1	lowR	MSY $B_{trigger}$	0.5	NA
hcr_2	lowR	MSY $B_{trigger}$	0.5	1
hcr_3	lowR	MSY $B_{trigger}$	0.5	NA
hcr_4	lowR	MSY $B_{trigger}$	0.5	1.857143

Some limitations were encountered when testing the evaluation tool on WBSS herring as follows:

- When the HCR results in consecutive years of F=0, fishing selectivity can be affected with an impossibility to come back to a positive F when the HCR advises in a positive catch. This was solved in the runs presented here by using a low F (1e-8) rather than 0 when defining the HCRs. Some developments are needed to make the model deals with this problem internally.
- The recruitment deviations are estimated from the SRR used in the different runs. As a result, probabilities to rebuilding above a biomass target will be dependent on the recruitment uncertainty considered. For instance, for WBSS herring, the low recruitment run with F=0 rebuilds above B_{lim} with >95% probability quicklier than the baseline run due to lower uncertainty in recruitment coming from less variable pairs in the shorter time series.
- The hindcast option (to account for uncertainty in the perception of the stock) might induce different historical OMs trajectories per scenario because recruitment uncertainty comes from the SRR deviations. This is why the results presented here use SAM uncertainty in the historical part instead.

5.6 Exploration of the role of F_{cv}, F_{phi} and SSB_{cv}

5.6.1 Sensitivity to F_{cv}, F_{phi} and SSB_{cv}

During discussions at WKREBUILD2, a gap in knowledge was identified regarding the effect of SSB and $\overline{F}$ deviance parameters (F_{CV}, F_{PHI}, and SSB_{CV}) assumed for the shortcut assessment model. In order to address this, a set of simulations with alternative implementations of shortcut deviances were run using the Western horse mackerel base case operating model with HCR1 (ICES AR “in practise”, i.e., with scaled F_{MSY} advice below B_{lim}). Shortcut assessment deviances (Table 5.8.1) were generated using the following parameter sets: the WKREBUILD toolset default deviance parameters; parameter values calculated with historical forecast values from 2013–2022 using the method which was outlined in WKWHMRP (ICES 2021f); calculated SSB_{CV} and F_{CV} multiplied by two; all deviance parameters set to zero; all deviance parameters set to 0.6 (i.e. a high deviance scenario). Stock projections and tracking objects were then inspected to assess the effect of each parameterisation on simulation outputs.

Table 5.8.1. Deviance parameter values used for each of the shortcut deviance scenarios tested.

Scenario	F_{CV}	F_{PHI}	SSB_{CV}
CV = 0	0	0	0
Default	0.212	0.423	0.1
Calculated	0.183	0.493	0.266
2 x Calculated	0.365	0.985	0.531
CV = 0.6	0.6	0.6	0.6

Broadly, the simulations behaved similarly, with variability in the distributions of simulated values generally increasing with increases in parameter values. Simulated SSB values are the same for first two years of scenario, with differences in deviance parameters borne out in the distributions of simulated values thereafter (e.g. Figure 5.8.1). Distributions of simulated SSB follow an increasing trend in all cases, with median simulated SSB exceeding (and staying above) B_{lim} by 2034 in all cases. Median simulated SSB did not exceed MSY $B_{trigger}$ in any of the scenarios tested.

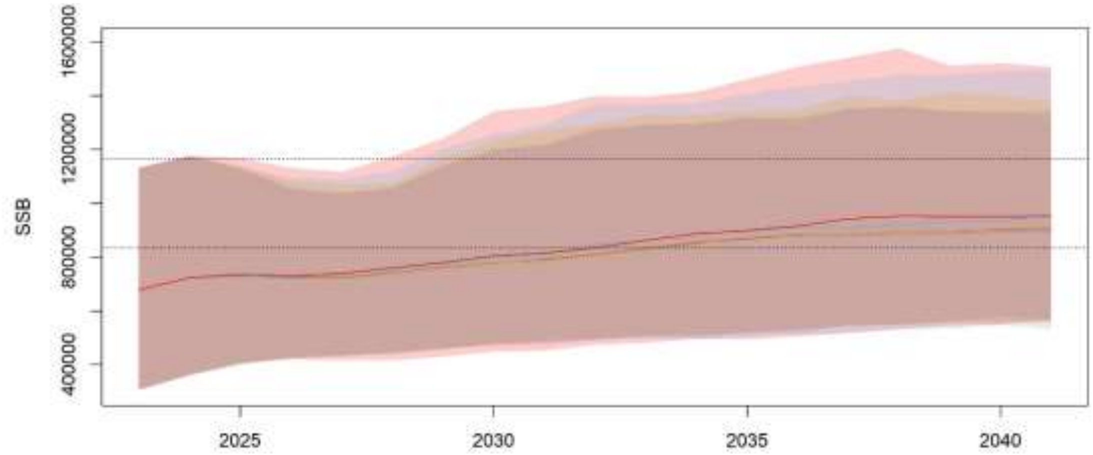


Figure 5.8.1. Forecast SSB for Western horse mackerel generated with shortcut deviances calculated with: all parameters set to zero (*pink*), WKREBUILD toolset default parameter values (*grey*), calculated values (*orange*), calculated SSB_{CV} and F_{CV} multiplied by two (*blue*), and all deviance parameters set to 0.6 (*red*). Polygons/bands represent the 0.05 to 0.95 quantile region. B_{lim} and $MSY_{Btrigger}$ reference points are included as dotted *black* lines (lower and upper, respectively).

The impacts of alternative deviance parameter values are more readily apparent in median projected $\overline{F}$ values, and their associated distributions, across the simulated time-series (Figure 5.8.2). The properties of the distributions of projected $\overline{F}$ values indicate a general decrease in median $\overline{F}$ with increasing deviances. In contrast, median values of SSB were similar across deviance scenarios, and interquartile ranges of SSB were similar for the zero deviance, default, and calculated deviance parameter scenarios. The spread in distribution of SSB values was noticeably higher for the high deviance scenarios as simulations progressed.

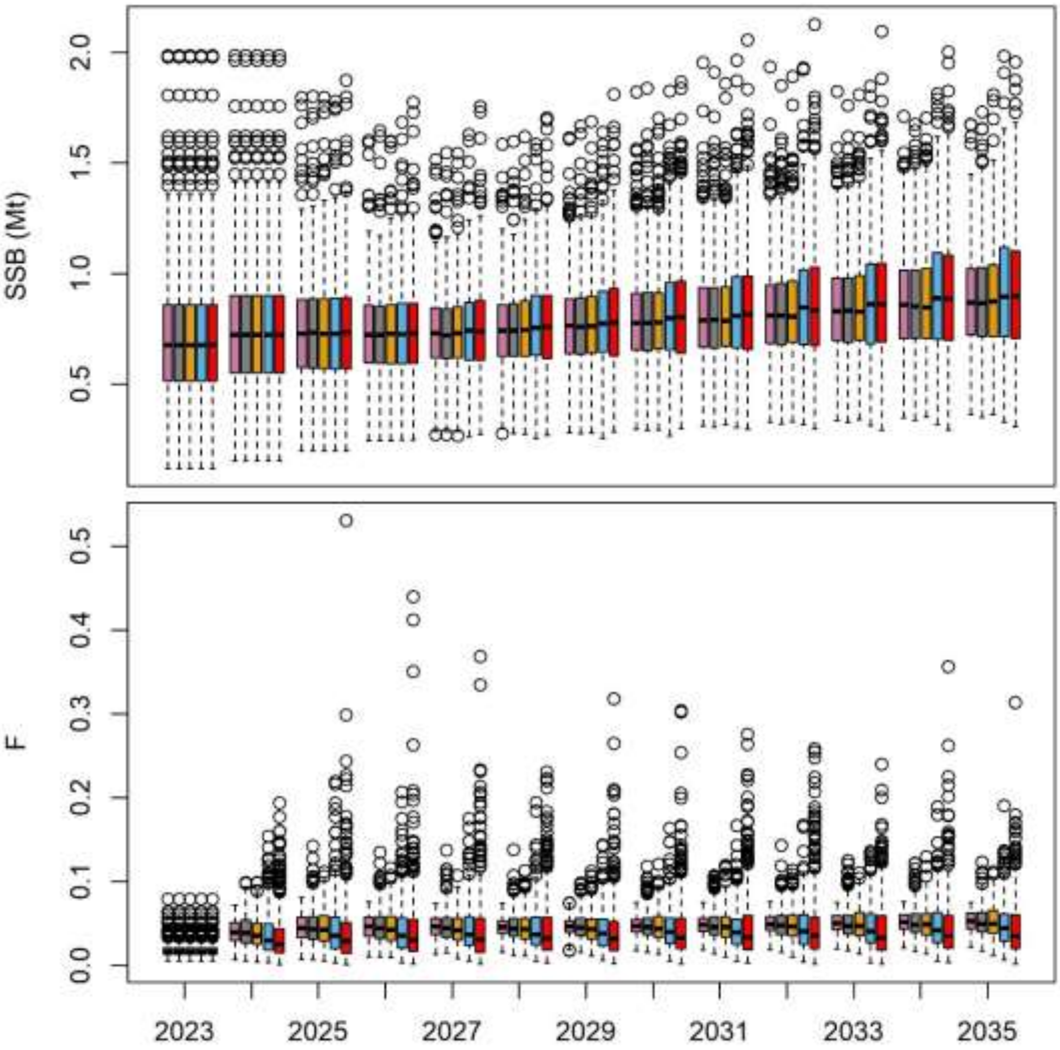


Figure 5.8.2. Forecast SSB and $\overline{F}$ for Western horse mackerel generated with shortcut deviances calculated with: all parameters set to zero (*pink*), default parameter values (*grey*), calculated parameter values (*orange*), calculated SSB_{CV} and F_{CV} multiplied by two (*blue*), and all deviance parameters set to 0.6 (*red*).

As expected, when deviance parameter values are set to zero, simulations followed the HCR perfectly (Figure 5.8.3) as the SSB input to the harvest rule corresponded to that of the OM (true) population and the resulting target fishing mortality was not subject to uncertainty. With non-zero deviances, variability in SSB (actual and perceived) increased in accordance with increases in deviance parameter values. $\overline{F}$ as applied to the stock in the management plan is well correlated with the $\overline{F}$ as defined by the HCR, with variability in values of applied $\overline{F}$ increasing according to increases in deviance parameter values. Correlation between $\overline{F}$ as defined by the HCR and applied $\overline{F}$ decreased with increasing deviance parameters, for a given value of F_{PHI}, due to the increasing variability.

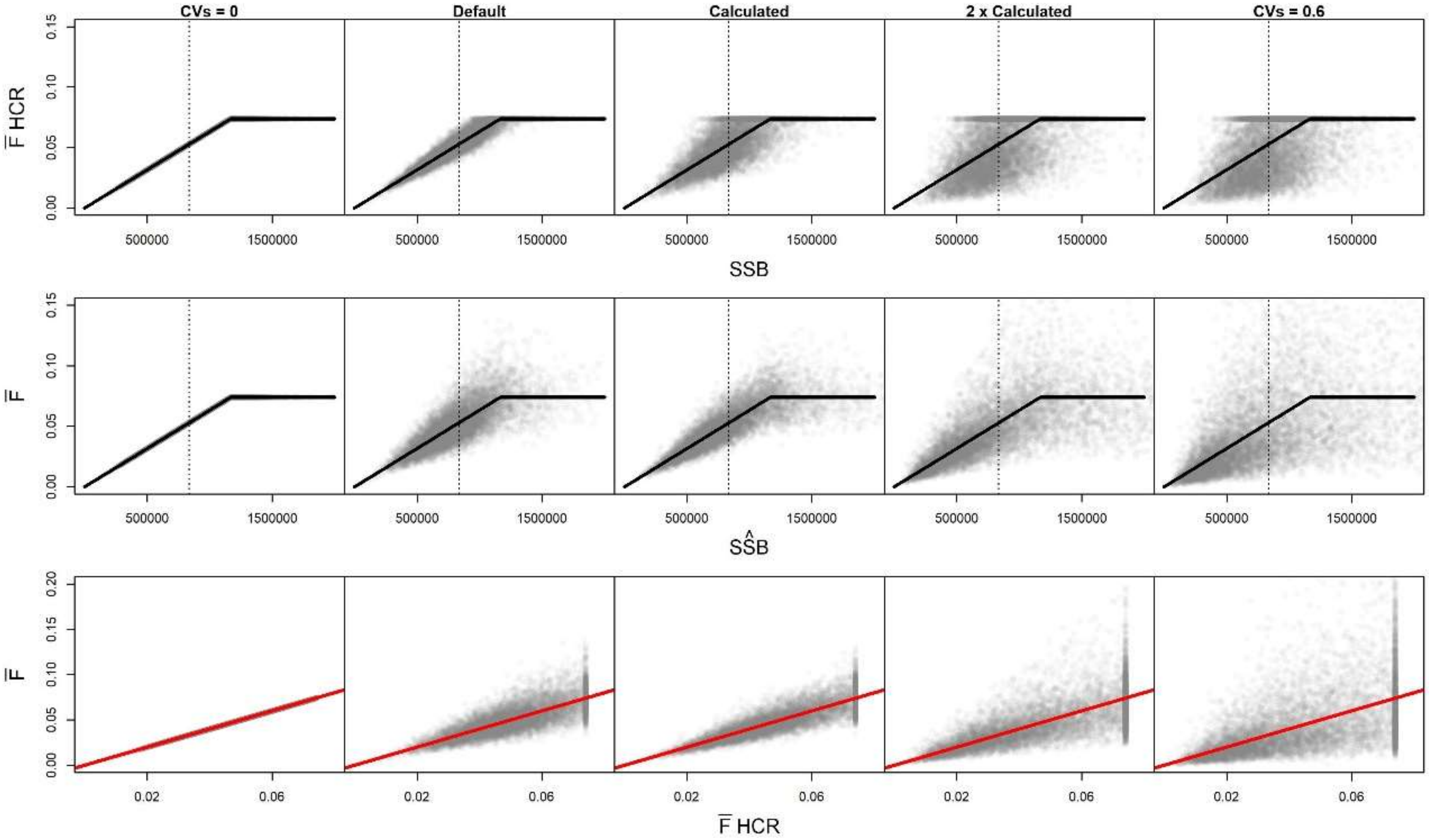


Figure 5.8.3. Scatterplot of tracking output from the five shortcut deviance scenarios tested on the Western horse mackerel base case operating model: $\overline{F}$ as defined by the HCR based on the SSB from the operating model (top row) with the HCR (black lines); $\overline{F}$ as applied to the stock in the management plan as a function of estimated/perceived SSB (middle row) with the HCR; and $\overline{F}$ as applied to the stock as a function of $\overline{F}$ as defined by the HCR.

Standard WKREBUILD2 performance statistics were calculated and plotted for the scenarios tested. Average annual variability in catch increased in magnitude and spread with increases in deviance parameters (Figure 5.8.4). Mean catch decreased for the two high deviance scenarios, as the distributional properties of the $\overline{F}$ applied to the stock resulted in lower median values than for the other three scenarios. Recovery (P (SSB > B_{lim}) > 95%) was not achieved in any scenario, as they each have a relatively low mean probability of SSB exceeding B_{lim} by the end of the simulation period (Figure 5.8.5). Probability of dropping below B_{lim} once during the simulation period was similar across scenarios (Figure 5.8.4). Although recovery (as defined above) was not achieved in these scenarios, it does not appear that our perception of stock recovery would be significantly affected the range of deviance parameters tested even if the threshold for recovery was at a lower level than defined here by B_{lim}.

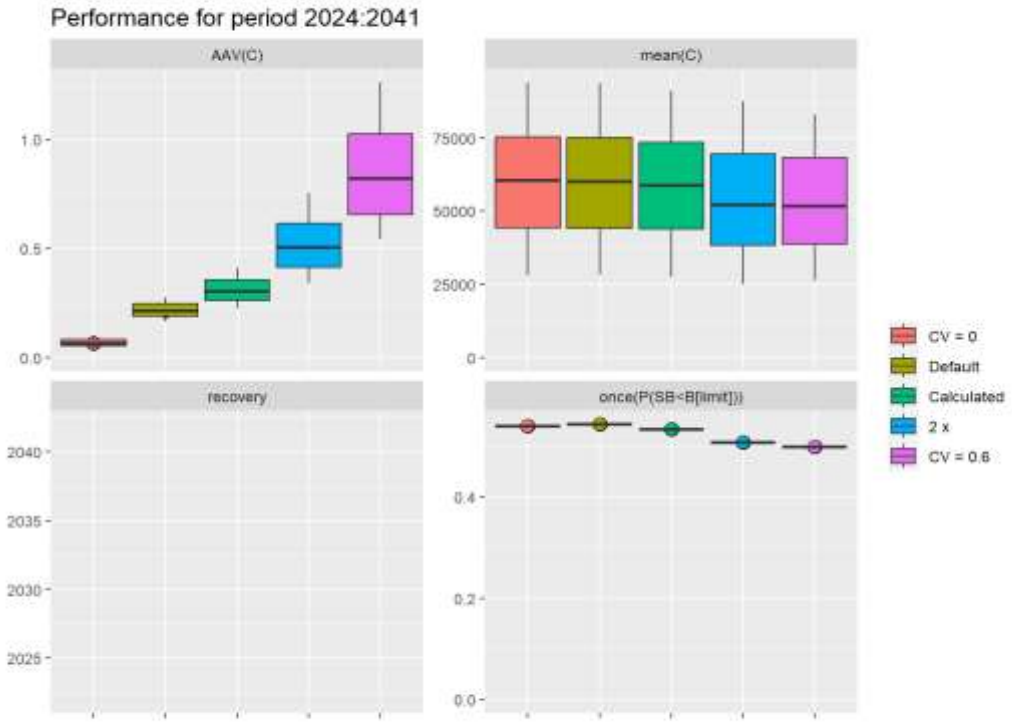


Figure 5.8.4. Default WKREBUILD toolset performance statistics (Clockwise from top left: Average annual variability in catch, mean catch, probability that SSB drops below B_{lim} once during the simulation period, year in which stock recovery is achieved) for Western horse mackerel simulations generated using shortcut deviances calculated with: all parameters set to zero (*red*), default parameter values (*olive*), calculated parameter values (*green*), calculated SSB_{CV} and F_{CV} multiplied by two (*blue*), and all deviance parameters set to 0.6 (*pink*).

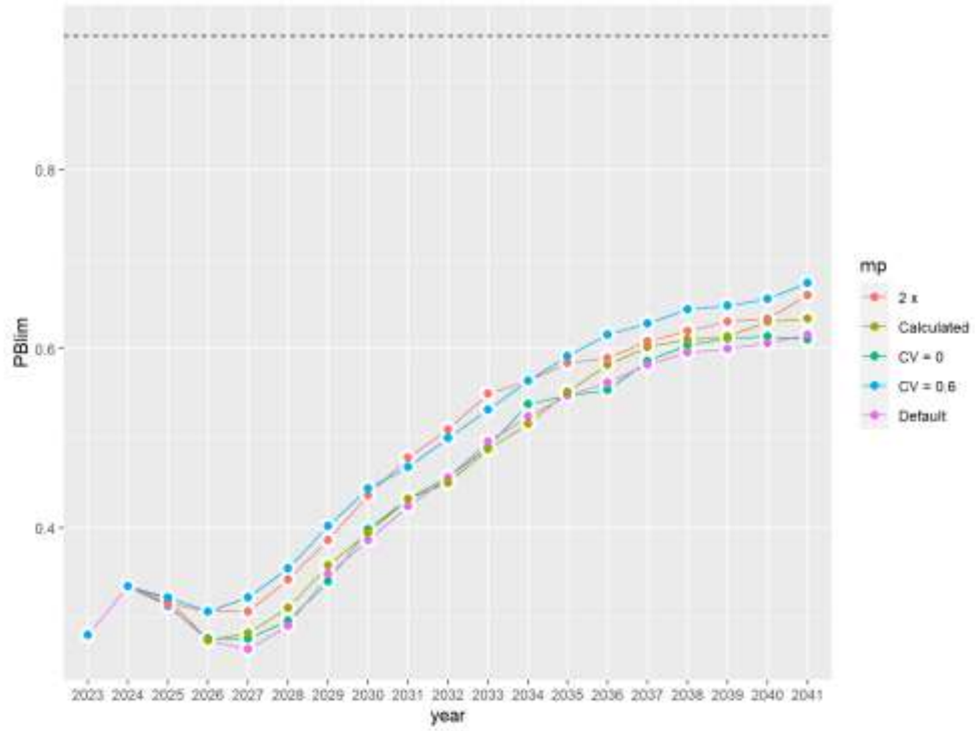


Figure 5.8.5. Mean *P* (SSB > B_{lim}) over the simulation period for deviance scenarios tested.

5.6.2 Estimation of F_{cv}, F_{phi}, SSB_{cv} and SSB_{phi}

Estimation of F_{cv}, F_{phi}, SSB_{cv} and SSB_{phi} has been carried out using the method outlines in WKMSYREF4 (ICES, 2015) for the three test-cases stocks. Table 5.8.1 contains the data used to calculate the CV's and phi's, interpolating between the actual catch values in the forecast tables of the different years. Table 5.8.2 and Figure 5.8.1 show the actual CV's and phi's calculated from different assessment year, in principle going back 10 years in each case, if such data was available. Results demonstrate that CV's are relatively stable around 0.25–0.30 but that phi (i.e. autocorrelation) can be strongly deviating, depending on the starting year and length of the time series.

Table 5.8.1. Realized catch and estimated Fset and SSBset.

her.27.20-24

year	catchrealized	catch1fcy	catch2fcy	f1fcy	f2fcy	ssb1cty	ssb2cty	fset	ssbset
2011	28000	26500	37200	0.17	0.25	113700	105400	0.1812	112536
2012	39000	37100	42700	0.21	0.25	142000	137000	0.2236	140304
2013	44000	50600	0	0.24	0	181000	230000	0.2087	187391
2014	37000	39321	41602	0.28	0.3	129175	127016	0.2596	131372
2015	37000	39184	46264	0.23	0.277	157236	150528	0.2155	159305
2016	51000	50527	52115	0.28	0.29	160381	158853	0.283	159926
2017	46340	43071	47206	0.38	0.42	93833	90000	0.4116	90803
2018	41041	37118	41178	0.31	0.35	84275	80704	0.3487	80824
2019	25420	19289	26849	0.15	0.22	96445	95790	0.2068	95914
2020	22130	17609	23157	0.176	0.238	74889	74407	0.2265	74496
2021	14180	12393	14410	0.144	0.17	65786	65603	0.167	65624
2022	6251	6142	9073	0.039	0.064	90852	88093	0.03993	90749

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year	catchrealized	catch1fcy	catch2fcy	f1fcy	f2fcy	ssb1cty	ssb2cty	fset	ssbset
2011	193698	185000	213000	0.1	0.12	1690000	1660000	0.1062	1680681
2012	169858	156000	183000	0.1	0.11	1489000	1466000	0.1051	1477195
2013	165258	156000	170000	0.16	0.18	1167000	1151000	0.1732	1156419
2014	136360	110546	137524	0.13	0.16	554000	531000	0.1587	531992
2015	98419	0	99304	0	0.12	576528	480681	0.1189	481535
2016	98811	84408	99304	0.08	0.1	605358	566789	0.09934	568065
2017	82961	69186	93031	0.092	0.126	490225	464906	0.1116	475598
2018	101682	99129	102253	0.081	0.084	911587	908915	0.08345	909403
2019	124947	92028	145237	0.067	0.108	1033814	987878	0.09237	1005395
2020	76422	0	83954	0	0.06	1159081	1083932	0.05462	1090674
2021	81557	81376	98167	0.061	0.074	1037631	1022274	0.06114	1037465
2022	70144	36423	71138	0.029	0.058	974909	942827	0.05717	943746

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year	catchrealized	catch1fcy	catch2fcy	f1fcy	f2fcy	ssb1cty	ssb2cty	fset	ssbset
2013	12400	0	12800	0	0.25	53700	58900	0.2422	58738
2014	12800	0	14618	0	0.33	62023	46331	0.289	48283
2015	19638	17663	18501	0.3	0.32	77959	77208	0.3471	76189
2016	23460	17926	19076	0.3	0.32	67196	66187	0.3962	62341
2017	15168	9020	15344	0.16	0.28	63258	57746	0.2767	57899
2018	11146	10064	13348	0.24	0.33	54705	51873	0.2697	53772
2019	7558	0	10468	0	0.32	58900	49610	0.231	52193
2020	7197	6481	8104	0.35	0.45	33720	32365	0.3941	33122
2021	7377	6729	7232	0.375	0.409	32216	31793	0.4188	31671
2022	7577	6883	7803	0.375	0.492	35338	33115	0.4633	33661

Table 5.8.2. CV and phi estimates (for F and SSB).

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```
 assessmentyear   n    firstyear   lastyear   sdDevLnF    Fphi      Fcv     sdDevLnSSB   SSBphi    SSBcv
---------------- ---- ----------- ---------- ---------- --------- -------- ------------ --------- --------
      2018        6      2012        2017      0.2784    0.4956    0.2418     0.2745     0.03997   0.2743
      2019        7      2012        2018      0.2238    0.4168    0.2035     0.2661     0.3846    0.2457
      2020        8      2012        2019      0.1761    0.02003   0.1761     0.2105     0.1817    0.207
      2021        9      2012        2020      0.2536    0.2167    0.2476     0.2123      0.179    0.2089
      2022        10     2012        2021      0.2999    0.4654    0.2654     0.2395     0.2905    0.2291
      2023        10     2013        2022      0.343     0.4612    0.3044     0.2466     0.3782    0.2283
```

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 assessmentyear   n    firstyear   lastyear   sdDevLnF     Fphi       Fcv     sdDevLnSSB   SSBphi   SSBcv
---------------- ---- ----------- ---------- ---------- ----------- -------- ------------ -------- --------
      2018        6      2012        2017      0.2292     0.3712     0.2129     0.4085     0.733    0.2779
      2019        7      2012        2018      0.2122    -0.006939   0.2122     0.3741     0.4676   0.3307
      2020        8      2012        2019      0.2093     0.1374     0.2073     0.3545     0.5093   0.3051
      2021        9      2012        2020      0.1983     0.2149     0.1937     0.3352     0.5422   0.2817
      2022        10     2012        2021      0.2009     0.3296     0.1896     0.3208     0.5666   0.2643
      2023        10     2013        2022      0.2035      0.342     0.1912     0.307      0.5312   0.2601
```

```
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 assessmentyear   n   firstyear   lastyear   sdDevLnF    Fphi      Fcv     sdDevLnSSB   SSBphi   SSBcv
---------------- --- ----------- ---------- ---------- -------- --------- ------------ -------- --------
      2018        4     2014        2017      0.313     0.9895   0.04514     0.2709     0.7921   0.1653
      2019        5     2014        2018      0.4272    0.8315   0.2374       0.44      0.9283   0.1636
      2020        6     2014        2019      0.1991    0.3482   0.1866      0.3028     0.6129   0.2393
      2021        7     2014        2020      0.3129    0.2366   0.3041      0.3326     0.4768   0.2923
      2022        8     2014        2021      0.342     0.5763   0.2795      0.3552     0.5327   0.3006
      2023        9     2014        2022      0.3284    0.6649   0.2452      0.3465     0.5586   0.2874
```

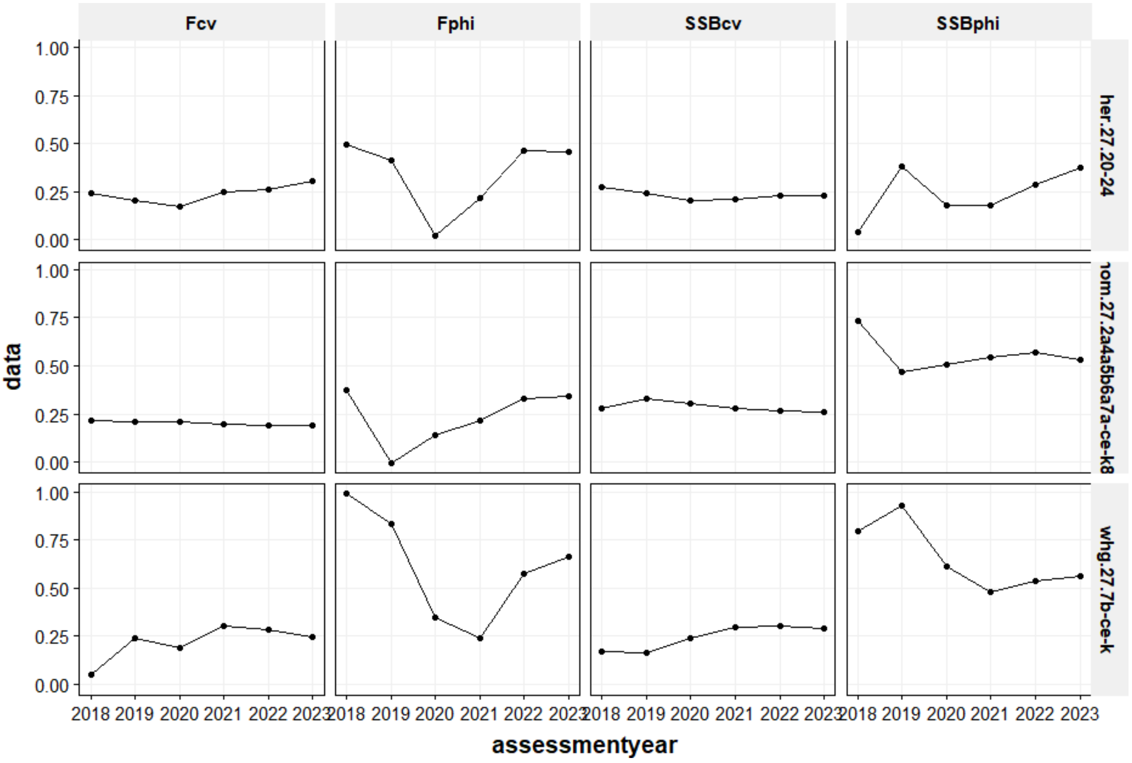

Figure 5.6.13 F_{cv}, F_{phi}, SSB_{cv} and SSB_{phi} for the three test-cases stocks taking different assessment years as starting points for the calculations.

Conclusions on test cases and WKREBUILD2 toolset

The developed simulation tool was satisfactorily applied to the three test cases studies and several improvements were suggested as a result. The template is fully compatible with TAF and facilitates the implementation of TAF in the evaluation of rebuilding plans. One thing that could be improved is the way case specific data and options are introduced to make it more visible to avoid possible bugs in the code and facilitate quality checking. In terms of model conditioning, the uncertainty in recruitment is a key uncertainty and consistency across scenarios and periods (historical and projection) needs to be ensured. The results were sensitive to the values used in the management procedure to emulate assessment error, the same used in *EqSim* for the calculation of reference points. As the variance was more impacted than the median, among the statistics analyses, annual average variability in catch and probability of being above Blim were the most impacted. The values corresponding to the stock assessment of the three stocks were calculated, the CV of F and SSB were around 0.25 in the whole analysed period, close to the default value of 0.21. The values for F_{phi} were more variable, with whiting values being higher than the default (0.423), lower for horse mackerel and similar to the default for western Baltic

herring.

The results depend on the case study. In the three cases studies, persistent low recruitment has been observed in the most recent historical period and a scenario was implemented to reproduce this low recruitment in the forecast. The performance of the rebuilding strategies was highly dependent on the recruitment assumption. For western Baltic herring and horse mackerel, even under the baseline scenario, the probability of rebuilding above the current reference points was low with any of the tested harvest control rules. The ICES AR with a linear decrease in F up to SSB = 0 was the HCR with the worse rebuilding potential. The other three HCRs result in similar results in the case of western Baltic herring and whiting, but in the case of horse mackerel HCR_2, the HCR with zero catch advice below or at B_{lim} and linear decrease in advice fishing mortality from MSY $B_{trigger}$ to zero advice at B_{lim}, resulted in significantly better performance.

Under low recruitment scenario the rebuilding of the stock above current reference points was not possible even with zero fishing in the case of horse mackerel and was only possible with zero fishing for withing and western Baltic herring. Under low recruitment the distance between B_{lim} and MSY $B_{trigger}$ in the case of western Baltic Herring demonstrated to be too narrow. With the two-year time lag between assessment and management the HCRs jumped from advice above MSY $B_{trigger}$ to zero catch advice in two years, without intermediate steps in most of the iterations. This highlights the importance of defining MSY $B_{trigger}$ based on the dynamics of the joint ecological-management system avoiding the default approach of using the parametric uncertainty in the estimation of SSB as the basis.

For wester Baltic herring in the base case scenario, the biomass for the 4 HCRs tested fluctuated around MSY $B_{trigger}$ in the long term and for Horse Mackerel MSY $B_{trigger}$ was not even reached in median. This suggests that the reference points are not well defined for these stocks, either because F_{MSY} is too high or MSY $B_{trigger}$ is too high. In both cases there is room between F=0 scenario and the current F_{MSY} level to define more sustainable fishing mortality targets

When two scenarios of plausible future conditions for the stock are simulated, the results need to be summarized to arrive to a conclusion. The two scenarios simulated here are extreme scenarios and define the area in which the stock will potentially move in the future. Combining both scenarios in a single scenario assigning some weight to each of the scenarios could be an option but could hide important information provided by the two scenarios individually. Furthermore, there is no objective way of assigning weights. Both scenarios should be analysed in relation to the performance of the system under no fishing and the recovery criteria for the acceptability of rebuilding plans should be reconsider depending on what happens under no fishing.

When the uncertainty in the initial conditions and future recruitments is high, defining rebuilding criteria based on the tails of the distribution ($p(SSB < B_{lim}) < 95\%$) could be problematic as it could be difficult to achieve and criteria based on central tendency statistics (median or mean for example) would be preferred. Furthermore, if the uncertainty is not conditioned similarly in for all the stocks the risk could not be equivalent among them.

6 Additional requirements for the evaluation tool (ToR e)

During the testing of the WKREBUILD2 toolset, a number of issues have come up that should be addressed in future versions:

1. Keep settings and options in a separate r-script so that all sections of the code can refer to it. Explore how the tool could be better split into input data/parameters and the actual model formulas (so that user is mostly focussed on input data and parameters)
2. Generate version information on packages, data files and settings and include all those in an output table.
3. Include a verify function that will check the consistency of the objects to be used for the simulations.
4. Include the rebuilding criterion of achieving a certain biomass target for a certain number of years and with a certain probability.
5. Include a recruitment depensation module for stock-recruitment relationships.
6. Include and explore biomass-based HCRs: Such HCRs could be an alternative to F-based HCRs during the rebuilding phase. Rules like the SSB has to increase by x% with y% probability per year (with x% a function of how far away the current SSB is from the target SSB and the maximum time allowed for the rebuilding (T_{MAX})) that can circumvent the need to prescribe F to be applied in the coming years. Target F becomes a consequence of the biomass rule and is determined each year based on short-term forecasts. Therefore, any new information (e.g., incoming recruitment) could be taken into account to calculate F/catch that ensures an increase by x% with y% probability in the next TAC year. Also, in the ICES AR it may be beneficial to allow at least no further decline in SSB with y% probability if the stock is estimated to be below MSY $B_{trigger}$.
7. Develop a standard set of HCRs to be tested in any specific application of the tool.
8. Allow definition of alternative HCRs.
9. Include the possibility of tuning the HCR with the highest non-zero catch/F to achieve rebuilding within a specified time-frame window (e.g. $T_{REBUILD}/T_{MIN} <= 2$).
10. Need to implement performance indicators that consider the size/age structure of the population. There are some ongoing working groups in ICES (WKD3C3SCOPE (ICES, 2023g), WKD3C3THRESHOLDS and WKSIMULD3) dealing with this issue. Proposed indicators, if any, should be considered from their potential incorporation in the tool (e.g., ABI).
11. Agree on a short name for the tool.

7 Review of ICES advice rule (AR)

The current ICES advice on fishing opportunities is based on the ICES MSY AR if no agreed management plan has been tested and implemented. The objective of the AR is to provide advice based on F_{MSY} target when the stock is above MSY $B_{trigger}$. Below MSY $B_{trigger}$ the fishing mortality used to provide advice is reduced. Below B_{lim}, non-zero catch advice is only provided if there exists a fishing mortality higher than 0 that is able to bring the stock above B_{lim} at the end of the advice year with a probability equal or higher than 50%.

The performance of the AR is currently only tested in the long term when estimating reference points, but the potential of the AR to recover stocks at low biomass levels has not been broadly tested. When the stock is between MSY $B_{trigger}$ and B_{lim}, the ICES AR may result in a catch advice that leads to a decrease in the biomass level. When the stock is below B_{lim}, the AR specifies that at least a probability of 50% of being above B_{lim} should be achieved. However, in the absence of favourable conditions the stock could remain around B_{lim} indefinitely. Thus, the re-formulation of the ICES AR below $B_{trigger}$ is needed to ensure that it promotes a strong recovery of stocks above B_{lim}.

WKREBUILD2 proposed to provide advice based on an alternative HCR when the stock is below B_{PA}. The advice should be based on a rebuilding AR as soon as the median SSB of a stock is estimated to be below this reference level in the final year of the assessment model.

Before the implementation of the rebuilding AR, its performance should be tested. The WKREBUILD2 tool could be used to explore rebuilding plan elements. The evaluation could be done in a case-by-case basis or generically to cover a broad range of case studies. In the first case, once the stock is estimated to be below the operational reference point, different rebuilding plan elements (HCRs) should be tested under different stock dynamics scenarios following the guidelines in section 3. In the second case, a massive simulation study should be conducted to identify an HCR shape that works correctly under different stock life history characteristics, stock depletion and stock productivity levels. To ensure the HCR works in a broad range of cases it should be more cautious, but it will guarantee quicker implementation. On the contrary, the case-by-case testing will allow to tailor the rebuilding advice rule to the precise conditions of the stock which will result in a more robust rebuilding advice.

WKREBUILD2 supports the definition of stock specific rebuilding strategies. Once the stock is detected to be below B_{PA} in the final assessment year, a simulation study should be carried out to identify the HCR that fulfills the criteria defined in section 4. The simulation should preferably be carried out using the WKREBUILD2 simulation tool.

Figure 7.1 shows some alternative HCRs to the current ICES AR that could be used when stocks are below MSY $B_{trigger}$. It is not intended to be prescriptive or restrictive on those configurations. In all cases they would need to be tested with the WKREBUILD2 tool to assess their potential capacity to rebuild stocks. Furthermore, HCRs different to those presented in Figure 1 could be tested. The assumption is that MSY $B_{trigger}$ would be estimated in such a way that it is larger than B_{PA} and possibly derived as a proportion of a target biomass, instead of a multiplier on B_{lim}. All of the HCRs could be integrated within the current ICES framework to provide advice on fishing opportunities (ICES MSY AR and reference points). An explanation for each set of HCRs is given below:

A. HCRs with linear decrease in recommended fishing mortality up to the SSB point where the HCR intersects the F = 0 axis below which the advice is zero. In the case of very steep decrease in fishing mortality below MSY $B_{trigger}$, the HCR could result in zero-catch advice from some point between B_{lim} and MSY $B_{trigger}$.

B. HCRs with linear decrease in recommended fishing mortality up to B_{lim} and a constant fishing mortality below B_{lim} ensuring continuity of the HCR shape at B_{lim}. The aim of this HCR is to ensure recovery while maintaining a low level of catch to allow for bycatch in non-directed fisheries, for example.
C. HCRs similar to those in (B) but between MSY $B_{trigger}$ and B_{PA} the ICES advice rule is used.
D. HCRs where below B_{lim} catch advice is always zero.

In practice, as the entry point to the recovery phase is B_{PA}, the rebuilding advice HCR in the [B_{PA}, MSY $B_{trigger}$] range would only come into effect once it is in the rebuilding phase when the stock recovers above B_{PA}. But in this way, it is ensured that the advice fishing mortality is more precautionary than the advice with the ICES AR until the stock has rebuilt above MSY $B_{trigger}$.

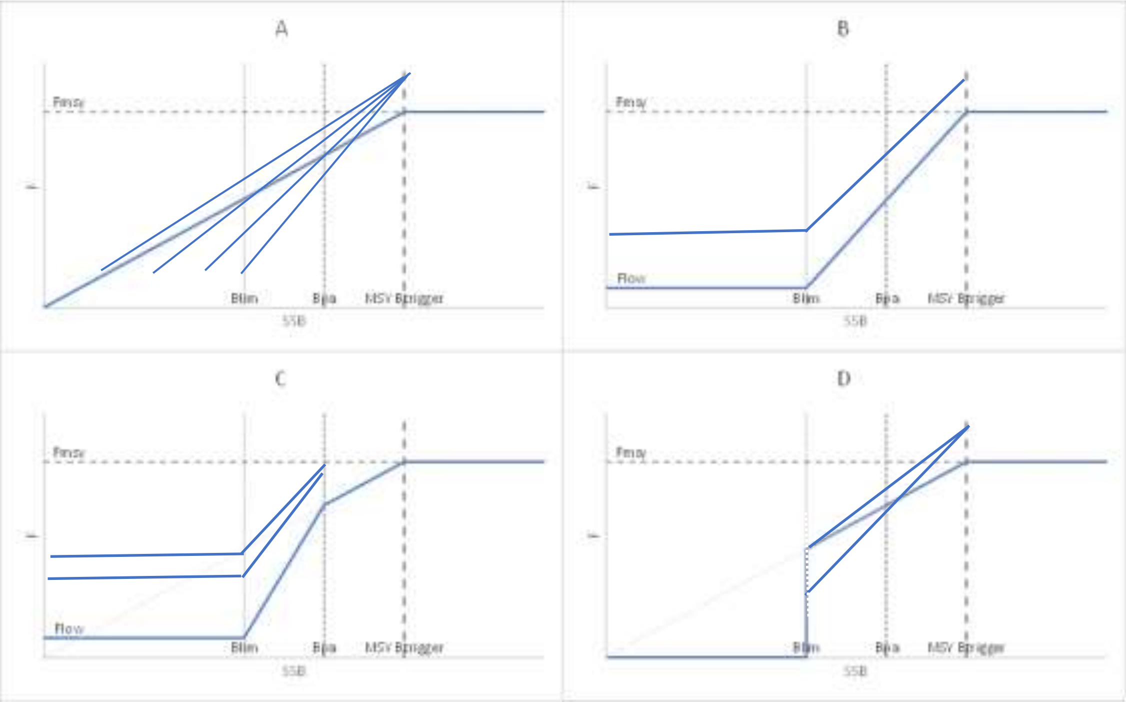

Figure 7.1. Possible harvest control rules shapes to be considered when the stock is below MSY $B_{trigger}$.

8 Conclusions

WKREBUILD2 reviewed the work on reference points, MSE and tool development that has taken place since the first WKREBUILD in 2020 (ICES, 2020b). The guidelines for evaluation of rebuilding plans and proposed thresholds and criteria are based on this revision and further discussions during the workshop. The guidelines should be followed by ICES in future evaluations of rebuilding plans.

Furthermore, the WKREBUILD toolset developed by Iago Mosqueira/FLR was tested in practice on three case studies: Celtic Sea whiting, Western horse mackerel and Western Baltic spring spawners herring. The tests demonstrated that the tool can generate realistic and plausible patterns in stock development and exploitation levels, based on assessment outputs with uncertainty and under different productivity assumptions. Further development is required to streamline the method such that users would have minimal coding requirements and all relevant options could be embedded in parameter settings. The tool is distributed as a TAF template which facilitates a full compatibility of rebuilding plan evaluations with TAF.

Evaluation of rebuilding plans is highly dependent on the conditioning of starting conditions, including the level of uncertainty. During WKREBUILD2 uncertainties in starting conditions were generated with a hindcast methodology or simulated from the assessment model covariance matrix.

Four different types of HCRs were tested during WKREBUILD2 (Figure 2.2).

In the test cases, two major productivity assumptions/stock recruitment curves were used: 1) same assumption as during estimation of reference points, 2) using low recruitment only. We found that in one case (western horse mackerel), the low recruitment scenario did not lead to a rebuilding, above MSY $B_{trigger}$ with a probability >= 50%, even in the absence of fishing. In other cases, rebuilding ($p(SSB > B_{trigger}) >= 50\%$) was achieved with a zero-catch scenario and some scenarios could be generated with non-zero catches that would still achieve rebuilding within an appropriate timeframe. The simulations in WKREBUILD2 showed that B_{lim} and MSY $B_{trigger}$ are too close to each other, specifically in the case of western Baltic herring, which suggest that the definition of MSY $B_{trigger}$ should be based on its capacity to act as a buffer to B_{lim} instead of on the uncertainty with which it is estimated within the stock assessment. WKREBUILD2 proposes to use B_{PA} as a threshold to define the entry into the rebuilding phase and MSY $B_{trigger}$ the exit. In the future, MSY $B_{trigger}$ should be linked to some biomass target (e.g., B_{MSY}) and defining it as B_{PA} should be avoided.

Currently, stock-recruitment scenarios do not include depensation. A simulation study presented to WKREBUILD2 suggested that depensation of productivity may be expected at low stock size and needs to be included in the evaluation of rebuilding plans. During the workshop, the simulation framework was extended to include a depensatory recruitment model. The implemented model was a sigmoid Beverton-Holt, which includes a depensation parameter as an exponent of SSB (Myers et al., 1995). The model was parameterized such that the depensation parameter does not change the interpretation of other model parameters.

The indicator for rebuilding that has been tested during the workshop is the probability of being above a biomass target, i.e., B_{lim} and MSY $B_{trigger}$. The indicator for achieving rebuilding could be framed such that the stock is above the target for a consecutive number of years (e.g., three, or equivalent to the age where 50% of the stock is mature). WKREBUILD2 proposes to use a three consecutive years period in the absence of a threshold based on the biology of the stock with a solid scientific basis. However, further work should be carried out to define a stock-specific threshold. WKREBUILD2 concluded that rebuilding is better described by achieving a biomass target with at least 50% probability, instead of the probabilities in the tails of the distributions (i.e. 95%) because this is also useable in the context of normal stock assessments, as it (1) is easier to estimate accurately, (2) is less dependent on how well uncertainty is characterized and (3) is better to ensure risk equivalence among stocks.

The ICES MSY AR is currently the basis for the ICES advice in case that there is no management strategy implemented that has been evaluated, which is consistent with the precautionary approach. The AR is framed in the SSB-fishing mortality space and has a slope down from (MSY $B_{trigger}/F_{MSY}$) to (0,0). When the SSB is below B_{lim} and the stock cannot move back to B_{lim}, in the forecast with a non-zero catch, then ICES recommends a zero catch. WKREBUILD2 proposes to replace the ICES AR by stock-specific rebuilding strategy when the SSB is below B_{PA}. The rebuilding strategy should be identified by means of simulation once the stock is estimated to be below B_{PA}. Candidate rebuilding strategies should be able to rebuild the stock in less than twice the rebuilding time in the absence of fishing. If more than one strategy fulfils the rebuilding time constraint, the rule with the highest cumulative catches in a predefined period should be selected. If a rebuilding strategy is proposed by a management party, it should fulfil the same time constraint but the catch criteria could be modified based on other objectives.

WKREBUILD2 discussed evaluations of rebuilding strategies (harvest control rules) in two contexts:

1. When advice requesters request ICES to evaluate specific rebuilding plans to assess whether they can be used as the basis for advice (hence, is in agreement with the ICES guidelines on rebuilding plans)
2. To update the current ICES AR, it is necessary to include more stringent management recommendations when stocks are assessed to be below B_{PA}.

The current ICES AR could be re-formulated in a generic way, so there is a single shape that fits all the stocks in category 1 and 2, or the re-formulation could be stock-specific. In the first case, a massive simulation work would be required to ensure that the new AR works under a wide-range of life-history characteristics, and the depletion level of the stocks. In the case of stock specific re-formulation, it would take place when a stock is detected to be below the biomass reference point. The shape of the rule would not be pre-defined and the selection would be based on pre-defined criteria and thresholds. The generic option, after a big simulation work, would be simpler and quicker to implement in specific cases. However, it would require a more precautionary approach to ensure recovery under a wide-range of conditions which would lead to a loss in stock yield in some cases. The stock-specific option would require defining a process where the evaluation of rebuilding strategies and the most adequate AR is selected based on the pre-defined criteria once the stock is identified to be below the biomass threshold defined beforehand (B_{PA}). WKREBUILD2 supports the definition of stock-specific rebuilding strategies.

9 Recommendations

Further develop and test the new WKREBUILD2 toolset (e.g., on different stocks) including the recommendations in section 6.

ICES needs to define a process for the provision of rebuilding advice once the stock is identified to be below B_{PA}, when to carry out the simulations (e.g. during the assessment working group), who reviews the analysis and when, the format of the advice sheet and the possible delayed of the advice.

Define MSY B_{trigge}r based on a biomass target and avoid defining it as B_{PA}. Furthermore, when defining B_{PA}, test that it is fit for purpose and together with the ICES AR avoids the stock to fall below B_{lim}.

Based on the outcome of the D3C3 MSFD indicator related workshop series (WKD3C3SCOPE (ICES, 2023g), WKD3C3THRESHOLDS and WKSIMULD3), investigate possible use of an indicator of stock age/length structure that together with SSB being above MSY $B_{trigger}$ determines stock rebuilding. Alternatively, define the number of years that the stock needs to be above MSY $B_{trigger}$ to consider it for rebuilding based on the biology of the stock.

The robustness of the reference points and AR to different assumptions, notably their robustness to low recruitment regime, should be tested when the reference points are calculated every 3–5 years.

10 References

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Annex 1: List of participants

Name	Institute	Country (of institute)	Email
Alexander Kempf	Thünen-Institute of Sea Fisheries	Germany	alexander.kempf@thuenen.de
Andrew Campbell	Marine Institute	Ireland	andrew.campbell@marine.ie
Ashley Wilson	Pew Charitable Trusts London Office	International	awilson@pewtrusts.org
Christoffer Moesgaard Albertsen	DTU Aqua, National Institute of Aquatic Resources	Denmark	cmoe@aqua.dtu.dk
Claus Reedtz Sparrevohn	Danish Pelagic Producers' Organisation	Denmark	crs@pelagisk.dk
Daniel Howell	Institute of Marine Research	Norway	daniel.howell@hi.no
David Curtis	Unaffiliated	United Kingdom	david.curtis@octave-im.com
David Miller	ICES - International Council for the Exploration of the Sea	International	david.miller@ices.dk
Dorleta Garcia	ICES - International Council for the Exploration of the Sea	International	Dorleta.Garcia@ices.dk
Edward Farrell	Killybegs Fishermen's Organisation Ltd.	Ireland	edward@kfo.ie
Elena Balestri	Scottish Fishermen's Federation	United Kingdom	e.balestri@sff.co.uk
Hans Gerritsen	Marine Institute	Ireland	hans.gerritsen@marine.ie
Harriet Cole	Marine Scotland Science	United Kingdom	Harriet.Cole@gov.scot
Henning Winker	FAO - The Food and Agriculture Organization of the United Nations	Iinternational	henning.winker@fao.org
Iago Mosqueira	Wageningen University & Research	Netherlands	iago.mosqueira@wur.nl
Inés Rodríguez	ACERGA	Spain	asoc.acerga@gmail.com
Johanna Fall	Institute of Marine Research	Norway	johanna.fall@hi.no
Karen Green	NOAA Fisheries	United States	karen.e.greene@noaa.gov
Kenny Coull	Scottish White Fish Producers Association Limited	United Kingdom	kenny@swfpa.com
Kristiina Hommik	University of Tartu	Estonia	kristiina.hommik@ut.ee
Kristján Kristinsson	Marine and Freshwater Research Institute	Iceland	kristjan.kristinsson@hafogvatn.is
Luís Vicente	Associação dos Armadores das Pescas Industriais	Portugal	adapi.pescas@mail.telepac.pt
Marc Taylor	Thünen-Institute of Sea Fisheries	Germany	marc.taylor@thuenen.de
Maria Ching Villanueva	Ifremer - National Institute for Ocean Science	France	Ching.Villanueva@ifremer.fr
Martin Pastoors	Martin Pastoors F&F	Netherlands	martinpastoors@mpff.nl
Mary Thiess	Fisheries and Oceans Canada	Canada	mary.thiess@dfo-mpo.gc.ca
Massimiliano Cardinale	SLU Department of Aquatic Resources	Sweden	massimiliano.cardinale@slu.se
Niall Fallon	Marine Institute	Ireland	Niall.Fallon@Marine.ie
Nicolas Goñi	Natural Resources Institute	Finland	nicolas.goni@luke.fi

Name	Institute	Country (of institute)	Email
Niels Hintzen	Pelagic Freezer-Trawler Association	Netherlands	nhintzen@pelagicfish.eu
Noa Steiner	Christian-Albrechts-University of Kiel	Germany	nsteiner@ae.uni-kiel.de
Polina Levontin	Imperial College London	United Kingdom	polina.levontin02@imperial.ac.uk
Richard Nash	CEFAS - Centre for Environment, Fisheries and Aquaculture Science	United Kingdom	richard.nash@cefas.gov.uk
Rosana Ourens	CEFAS - Centre for Environment, Fisheries and Aquaculture Science	United Kingdom	rosana.ourens@cefas.gov.uk
Ruth Kelly	Agri-food and Biosciences Institute	United Kingdom	ruth.kelly@afbini.gov.uk
Santiago Cerviño	Spanish Institute of Oceanography	Spain	santiago.cervino@ieo.csic.es
Sarah Millar	ICES - International Council for the Exploration of the Sea	International	sarah-louise.millar@ices.dk
Stefanie Haase	Thünen-Institute of Baltic Sea Fisheries	Germany	stefanie.haase@thuenen.de
Valerio Bartolino	SLU Department of Aquatic Resources	Sweden	valerio.bartolino@slu.se
Vanessa Trijoulet	DTU Aqua, National Institute of Aquatic Resources	Denmark	vtri@aqua.dtu.dk

Annex 2: Resolutions

WKREBUILD2 – Workshop on guidelines and methods for the design and evaluation of rebuilding plans for category 1-2 stocks

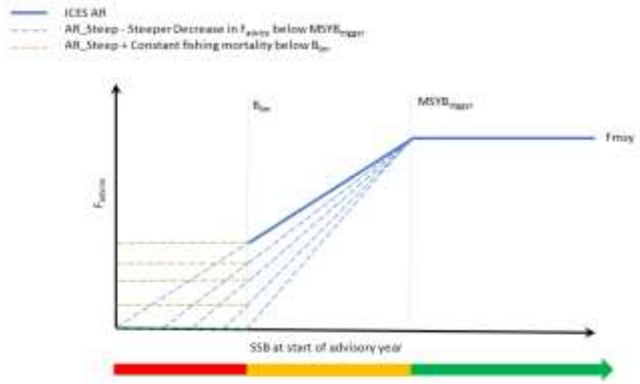
A **Workshop on guidelines and methods for the design and evaluation of rebuilding plans for category 1-2 stocks (WKREBUILD2)**, chaired by Martin Pastoors (Netherlands) and Dorleta Garcia (Spain) will meet in ICES HQ, Copenhagen, Denmark 6–10 November 2023 to:

a) Define a framework for scientific advice for developing rebuilding plan elements as part of overall management strategies, that could be widely applied to ICES stocks.
b) Develop guidelines for the evaluation of rebuilding plan elements that consider the precautionary approach, the species life history (incl. longevity), changes in productivity and rebuilding potential.
c) Propose the performance indicators and thresholds to be used for the acceptability of rebuilding plan elements including rebuilding target, probability of rebuilding and rebuilding time relative to rebuilding time in the absence of fishing.
d) Test the rebuilding plan evaluation guidelines on a limited number of test cases using a newly developed and dedicated evaluation tool
e) Identify any additional requirements for a evaluation tool that would allow the evaluation of rebuilding plans elements proposed in ToR (a) in the context of assessment working groups.
f)

WKREBUILD will report by 1 December 2023 for the attention of FRSG and ACOM.

Supporting Information

Priority	High. ICES regularly recommends rebuilding plans in combination with zero TACs for the next year, This occurs when stocks are estimated to be below B_{lim} and there is no perceived possibility of rebuilding above B_{lim} within the timeframe of a short-term forecast. Furthermore, the performance of ICES category 1 advice rule below $B_{trigger}$ and especially below B_{lim} has been questioned. WKREBUILD2 should build on the findings of the first workshop on guidelines and methods for the evaluation of rebuilding plans (WKREBUILD) and taking into account the general guidelines on management strategy evaluations (e.g. WKGMSE3). In 2020, WKREBUILD analyzed guidelines and methods for the evaluation of rebuilding plans. The workshop generated a guidance table summarizing the best practices for evaluation of rebuilding plans against the potential criteria of acceptability. However, it did not propose specific rebuilding plans of harvest control rules. Instead, the workshop recommended that a follow-up workshop (WKREBUILD2) be organized for testing the guidelines with actual test cases, with the aim of defining more specific criteria and guidelines. A simulation tool is being developed and will be ready to be used during WKREBUILD2. The framework proposed for rebuilding plans should be transferable between the current and proposed new advice frameworks. In terms of the definition of rebuilding plans, independently of specific values, the main difference between the current and the new advice framework is B_{safe}.

	The current ICES advice rule specifies the recommended management action when the stock is estimated to be above B_{lim}. When the stock is estimated to be below B_{lim} and unable to recover to B_{lim} within the period of the short term forecast, ICES recommends a zero catch and the development of a rebuilding plan.  WKREBUILD2 should explore how rebuilding plan elements could be included into the ICES advice rule. This can be done through specific (and different) actions when the stock is between between B_{lim} and MSY $B_{Trigger}$ and when the stock is below B_{lim}. This should involve different shapes of HCRs that take into account recommended management actions at different biomass levels and under different conditions (uncertainty in the assessment, distance between references points, lifespan of the species, role of the stock in the fishery (target/bycatch) etc.) The rebuilding plan elements should be aimed at restoring the stock biomass above B_{lim} and ensuring a non-decreasing trend in stock biomass between B_{lim} and $B_{trigger}$. As the plan will need to be evaluated in a short time frame for specific cases, developing a standardized tool is required. It could be similar to eqSim but with initial population equal to the last population estimate and focused on assessing impacts in the short to medium term. The tool should report on the rebuilding probability metrics in absolute terms and in comparison with zero fishing mortality scenario.
Scientific justification	ICES is regularly recommending the development of rebuilding plans so guidance on how to evaluate these plans is required.
Resource requirements	One meeting room at ICES HQ with at least one breakout room.
Participants	Scientists with experience and interest in rebuilding plans and tools for short-term evaluations of potential effects of rebuilding plans.
Secretariat facilities	Secretariat administrative and scientific support.
Financial	No extra funding requested.
Linkages to advisory committees	The results of this work will feed in directly in the ICES advisory process.
Linkages to other committees or groups	HAWG, WKGMSE2, WGBIE, WGWIDE, WGBFAS, WGCSE, WGNSSK, NWWG, AFWG, WGHANSA

Annex 3: Table with review of ICES expert groups

	WKGMSE 1	WKGMSE 2	WKGMSE 3	WKWHMRP	WKREF1	WKREF2	WKLIFEX	WKDLSSDS	WKRPCHANGE	WKMSEDEV	WKNCCHCR	DFO CANADA
Rebuilding targets				MSY Btrigger	If a recovery plan sets a recovery target, this target should be checked, every 3-5 years		Data-Limited MSY proxies (various)				biomass level to F0.1 (i.e., driving the stock towards BMSY	High prob. of being above LRP, low prob. of falling below LRP in the short - medium term.
Reference points	Evaluation of the historic use of precautionary criteria		Framework for calculating reference points from simulation models used in MSEs	Taken from the most recent stock assessment	Results from a hindcast reinforced the need to re-estimate reference points regularly at benchmark assessments.	Highlighted the need to revise reference points. WKNEWREF is scheduled for Feb 2024.	Data-Limited MSY proxies (various) Itrigger <5% prob. below Blim (1.4Iloss or 0.5BMSY)	Estimate .35 fractile for SPiCT assessments. Estimate Bescape and Fcap, estimate a biomass safeguard using MSE	Regular revision of Reference Points is important		Initially from benchmark, however ended in Blim reevaluation as uncertainty was too high.	LRP, upper stock reference (USR), and target reference point (TRP) as well as a limit fishing mortality rate
Time frame leading to a rebuilding plan				hovering at/above Blim							below the uncertain Blim.	At or below the LRP with a greater than 50% probability, or if stock falls below the LRP with >50% prob. at zero catch
Time frame leading out from a rebuilding plan	The probability of rebuilding the stock to a certain level within a given time frame			Achieving three consecutive years above MSY Btrigger with 50% probability							Transition to Fmsy approach once a wider range of stock-recruit pairs have been observed	
Time frame for the evaluation of a rebuilding plan				Maximum of 10 years for reaching rebuilding target			short, medium, or long-term (user defined).				Btrigger/Bpa-based target, max 7 years (Tmin + 1 generation) for reaching rebuilding target.	
Checking the progress of the rebuilding plan							review performance of HCRs					Advice on frequency of evaluation, monitoring needed for

	WKGMSE 1	WKGMSE 2	WKGMSE 3	WKWHMRP	WKREF1	WKREF2	WKLIFEX	WKDLSSDS	WKRPCHANGE	WKMSEDEV	WKNCCHCR	DFO CANADA
							at regular periods					evaluation, and advice on adapting the rebuilding strategy
Probability of achieving rebuilding				Rebuilding: at least three consecutive years with >50% probability of being above Blim or Bpa			Probability-based performance metrics for ICES PA and MSY Approach.			Using constant variance in recruitment could lead to too optimistic rebuilding		Not specified; should be high probability that the stock is above the LRP when the target is achieved and a low probability of the stock falling below the LRP in the short to medium term.
Harvest rules in rebuilding phase	Celtic Sea herring rebuilding plan evaluation described	When biomass < Blim, the HCR should be better explored; high risk of impaired recruitment		Double breakpoint on SSB. If SSB < Blim, Flow = 0.2 * Ftarget; If Blim<SSB<Bpa: linear slope between Flow and Ftarget; If SSB > Bpa: F = Ftarget			1 SpiCT: MSY harvest control rule 2 Empirical 2.1 *“rfb rule”.* 2.2 *“chr rule”.* 2.3 *“rb rule”.* 3 WKDLSSLS	3 – *3.1 SPICT for short-lived stocks* *3.2 Constant HR* *3.3 1-over-2 rule*			Ftarget = F0.1 valid for all stock sizes above the minimum SSB observed in time series.	
Evaluation tools	FLR, FPRESS, FLBEIA, IAM	FLR, HCS, FPRESS, FLBEIA, IAM, DLMtool	Discussion on pros and cons of the full and shortcut methods.	FLR, FPRESS, FLBEIA, IAM			Simulation/ management strategy evaluation (MSE) is recommended.	The use of MSE is recommended	Recruitment models need to be conditioned on as long a data set as possible.	Scoping exercise to include relevant processes. Multi-species OMs	EqSim	
Uncertainty considerations				Advice uncertainty is larger than model parametric uncertainty. Historic advice error derived with WKMSYREF3 method			Assumes unbiased independent randomly distributed noise	Ensure appropriate starting condition of the simulation from recent exploitation. uncertainty cap of +/- 80% is recommended		Using constant variance in recruitment could lead to overestimate of prob. of good recruitment.	Standard EQSim settings	Simulation-testing of management options, against a range of plausible hypotheses for uncertain stock and fishery dynamics.
Special considerations	Guidelines for simulation table included in the report	Limited attention to rebuilding plans. Rebuilding plans do not pass the precautionary standard		Rebuilding plan was proposed by PELAC. Evaluation carried out by experts associated with PELAC. Reviewed by ICES.		Allee effect should be considered in low stock situations	Revisit definition of Blim (should consider life-history traits)	Do not use an interim year assumption, use within-year advice	Scoping exercise to identify which processes need to be included			

Annex 4: Celtic Sea whiting base case rebuilding scenario

This document outlines some additional details on the Celtic Sea whiting operating model and base case rebuilding scenario.

Operating Model (OM)

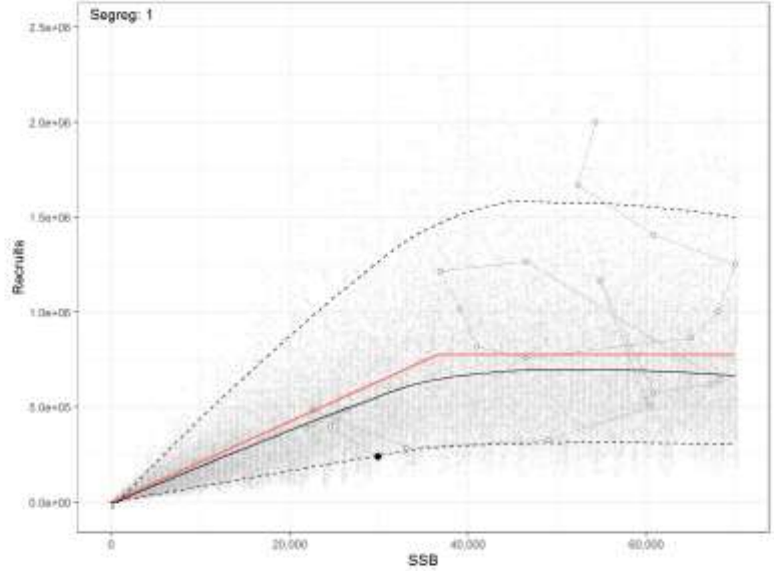
The operating model was based on the latest SAM assessment (WGCSE; ICES, 2023d)

```
SAMfit <- stockassessment::fitfromweb('whg.7b-ce-k_WGCSE22_RevRec_2023')
stock <- SAM2FLStock(SAMfit,catch_estimate = T)
```

The reference points were those used in the latest advice

```
refpts <- FLPar(Btrigger = 50818, Fmsy = 0.375, Blim = 36571, Bpa = 50818,
                Flim = 0.64, Fpa = 0.375, lFmsy = 0.315, uFmsy = 0.375,
                F05 = 0.375, F05noAR = NA)
```

A segmented regression stock-recruit model was fitted to the full dataset and with B_{lim} as a fixed breakpoint. Considering the retrospective bias and uncertainty around the last recruitment value, it would have been better to omit the 2022 SR pair. SR parameters with uncertainty were estimated from 500 bootstrap iterations.

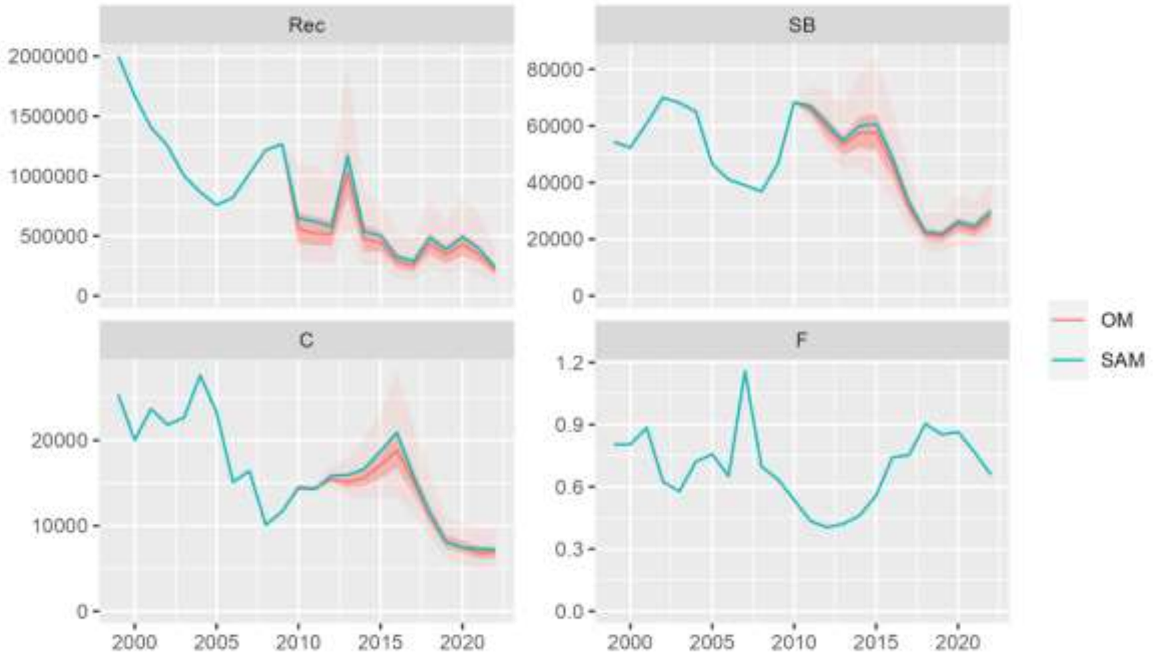


```
An object of class "FLPar"
iters:  500

params
              a              b              m                rho              sigmaR
 21.242(2.1304)  36571(0.0000)  3.0000(0.0000)  -4.7071e-02(0.2092)  4.9463e-01(0.0624)
units:  NA
```

Recruitment deviances were generated for 500 iterations with lognormal auto-correlated (order 1) errors for the years 2010-2022. These deviances were standardised to 1 to ensure consistency with the assessment results; the mean recruitment now matched the assessment (although the median recruitment did not; see plot below).

Stock numbers and catch numbers were then generated using hindcasting with F_{bar} fixed at the observed values (and accounting for SAM's process error).



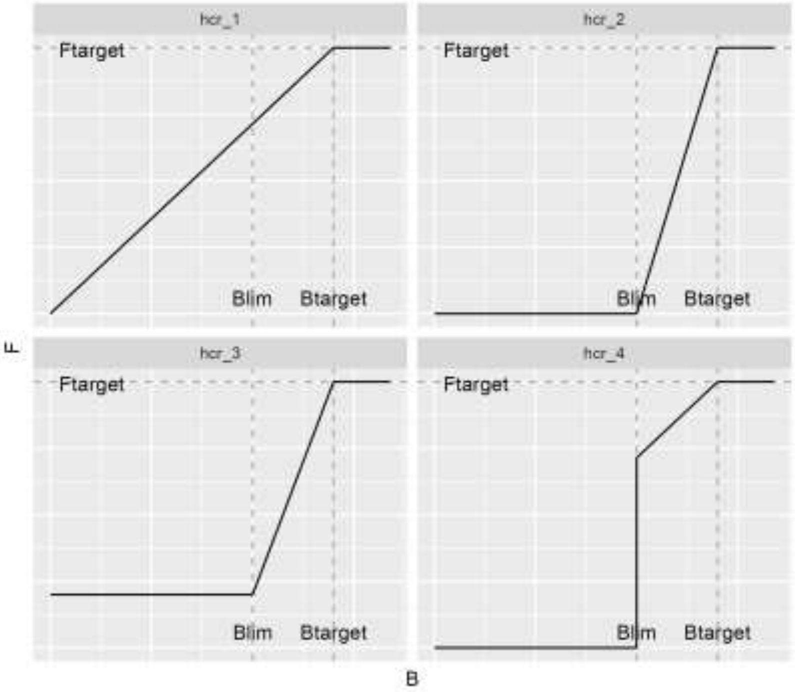
The OM was extended to 2040, future recruitment deviances were calculated in the same way as those in the hindcast but without standardising to one. No additional error was added to the catch or any other observations. No implementation error was applied.

Evaluation of HCRs

A shortcut estimation method was applied, using the same settings as used in the estimation of the reference points:

```
sdevs <- shortcut_devs(om, Fcv=0.212, Fphi=0.423, SSBcv=0)
```

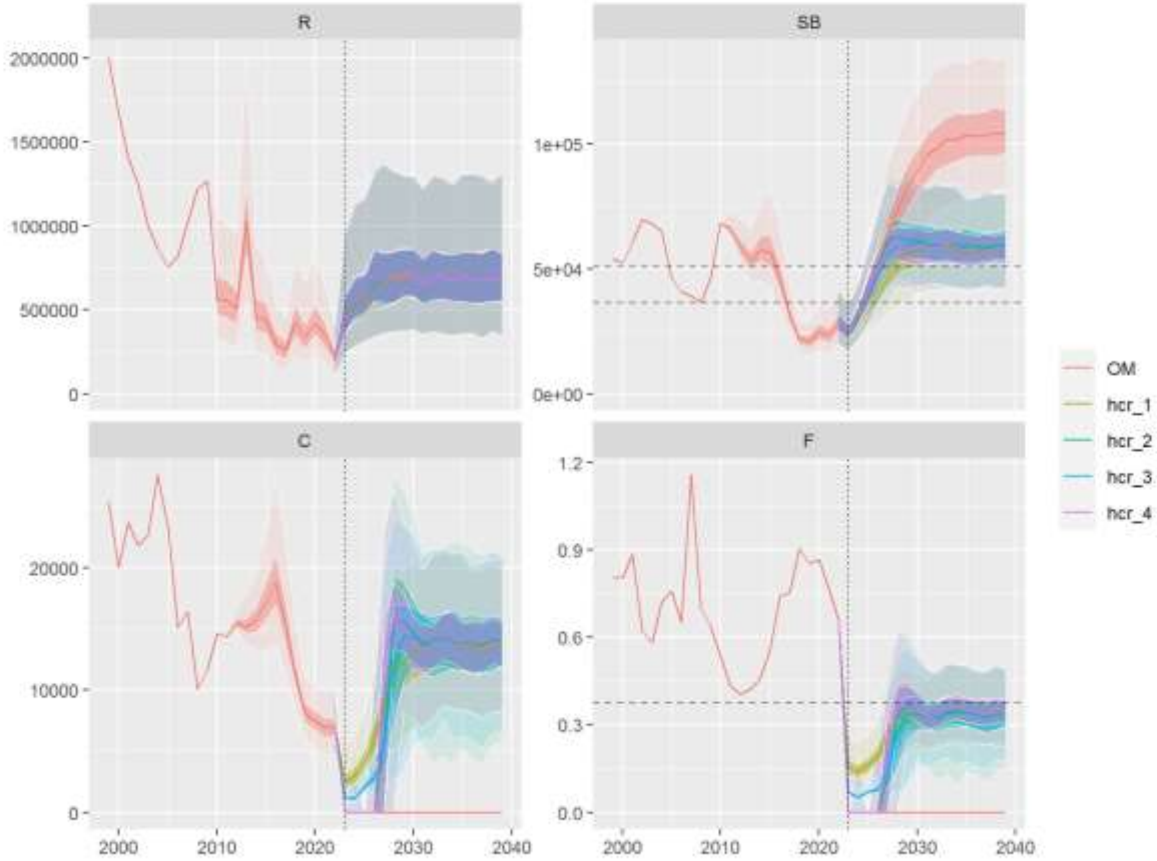
Four harvest control rules were explored in addition to a scenario with no fishing.



The implementation system converts the HCR catch into a TAC with a 2-year lag with an intermediate year assumption of F being equal to F in the last observed year.

No fleet behaviour deviances from the TAC are simulated.

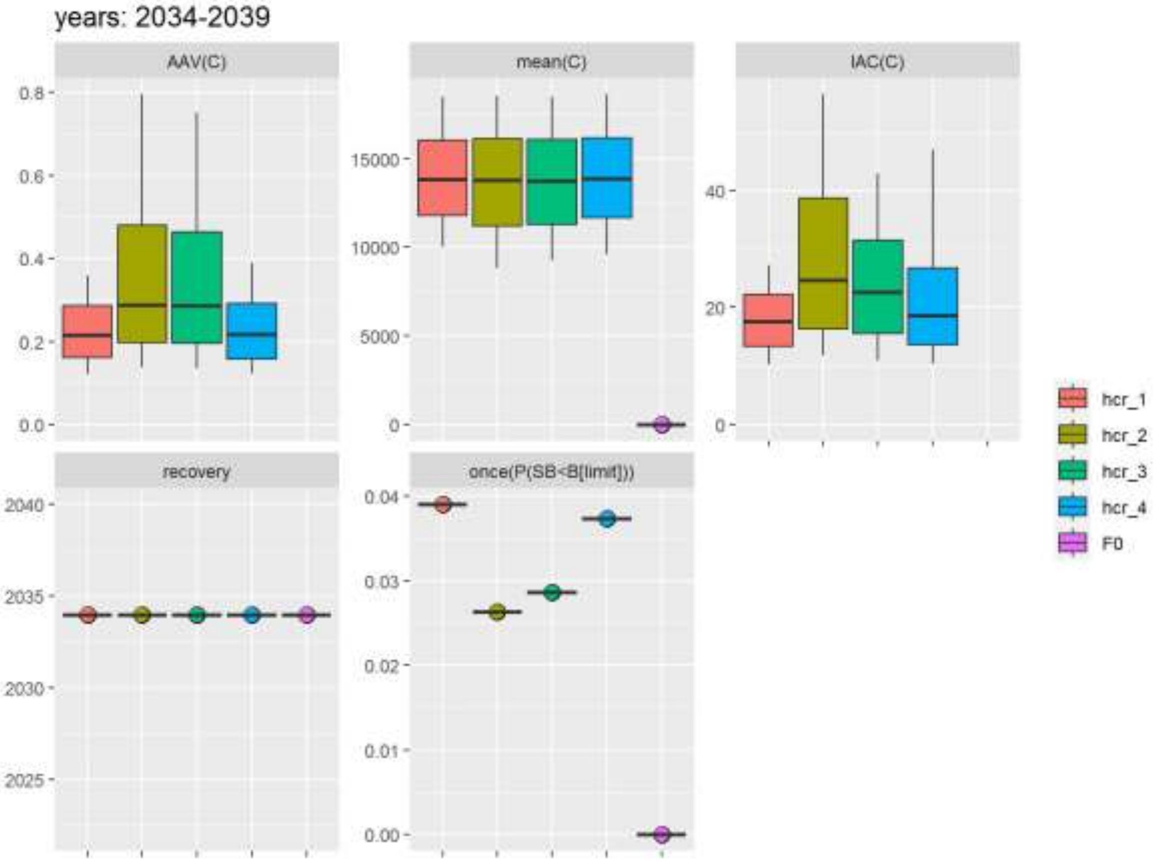
The plot below shows the 5 management plan simulations (no fishing plus 4 HCRs). The dashed horizontal lines indicate the B_{trgger}, B_{lim} and F_{MSY} reference points.



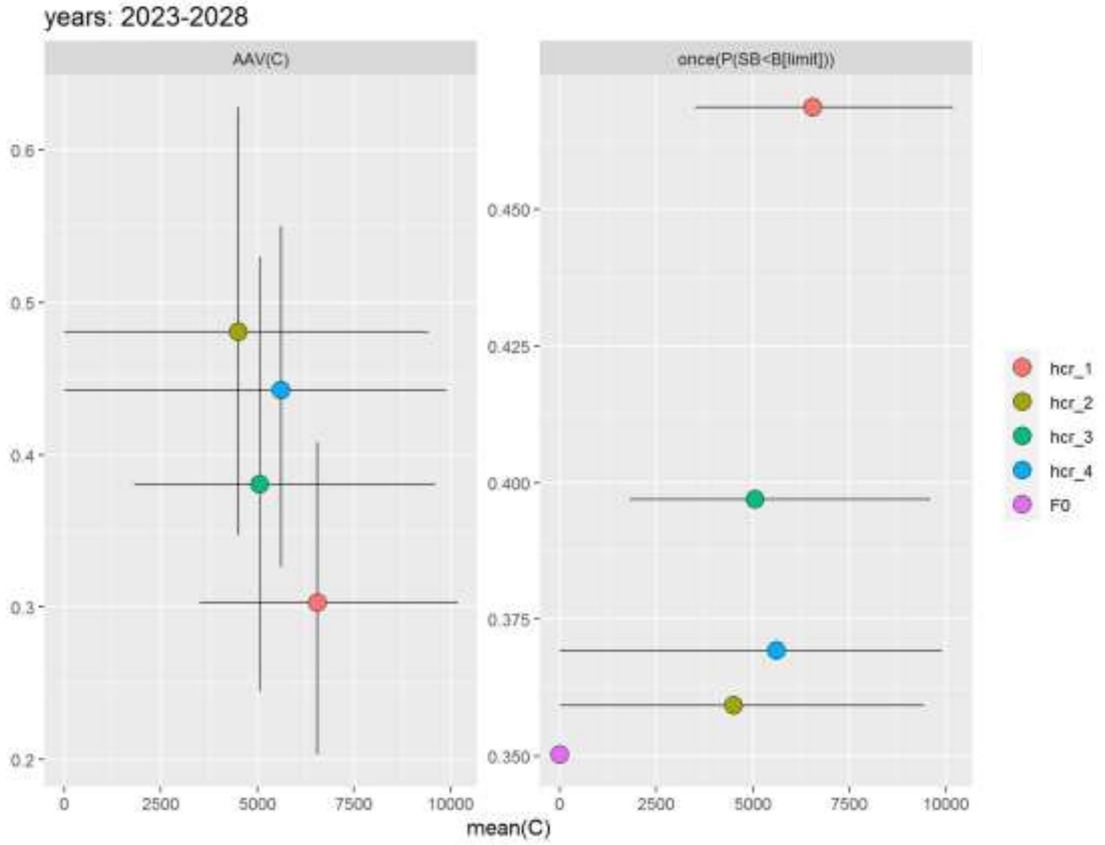
Performance

Some performance statistics are shown in the plot below:

- AAV(C) is Average Annual Variability in Catch;
- mean(C) is mean catch;
- IAC(C) is the percentage Inter-Annual Change in Catch;
- recovery is the first year where $B>B_{lim}$ with 95% probability;
- once(P(SB<B[limit])) is ICES Risk 2, probability that B is below B_{lim} once.



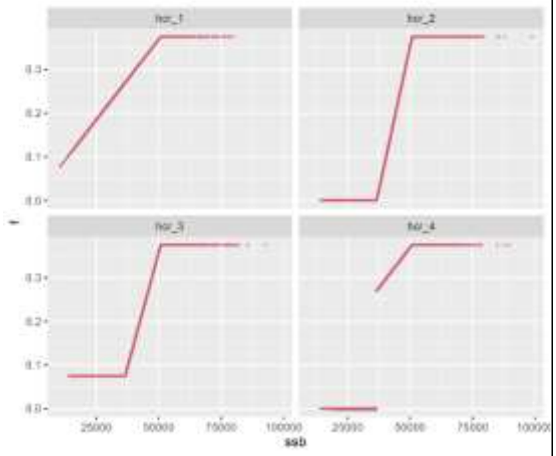
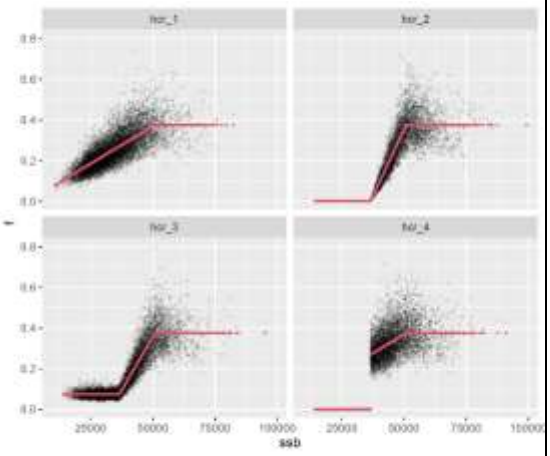
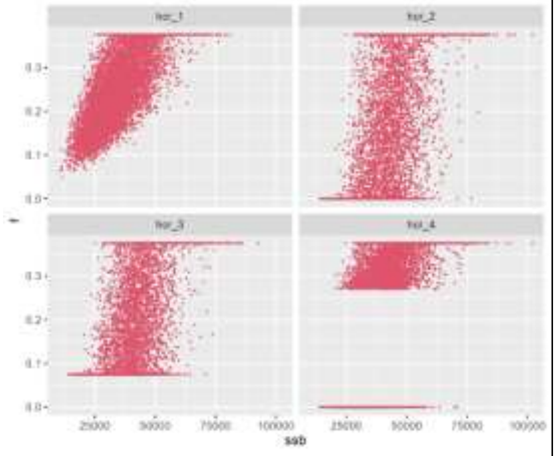
Trade-off of mean catch versus AAV(C) and risk of B<Blim are shown below.



Impact of error assumptions on the implementation of the HCRs

Below are plots of the harvest control rules in red and the F that was actually applied after the shortcut assessment error was applied – all years and all iterations. The black points plot the observed SSB (SB.obs) against the F that is implemented (fbar.isys), while the red points are the observed SSB with a lag of 2 years, against the F that is given by the HCR (fbar.hcr).

A number of different scenarios were explored. With no error in the shortcut assessment, the HCR is implemented exactly (a). With error only on F, there is a difference between the implemented F (black) and the F given by the HCR, i.e. noise along the y-axis (b). With error only on SSB, the deviances are applied before passing them to the HCR, therefore the implemented F is the same as that given by the HCR but with noise along the x-axis (SSB). Finally, when an Implementation Error Model (IEM) is applied, this is done after the decision-making process has taken place. The catch advice coming out of the isys module (the STF) is passed through IEM before being applied to the OM in the forward projection (d).

a) $F_{cv}=0$; $SSB_{cv}=0$; no IEM – black and red points overlap perfect implementation of the HCR, as expected  	b) $F^{cv}=0.212$; $SSB_{cv}=0$; no IEM – all the noise is along the y-axis, as expected 
c) $F_{cv}=0$; $SSB_{cv}=0.243$; no IEM – all the noise is along the x axis, as expected, but the red points are on top of the black points.  	d) $F_{cv}=0$; $SSB_{cv}=0$; IEM with 10% random noise. Black points in this case are the F in the OM.