WORKSHOP ON THE IBERIAN SARDINE MANAGEMENT AND RECOVERY PLAN (WKSARMP)

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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

Manuela Azevedo

Authors

Leire Citores • Laura Wise • Leire Ibaibarriaga • Andrés Uriarte • Alexandra Silva • Susana Garrido • Hugo Mendes • Isabel Riveiro

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Contents

i Executive summary

The **Workshop on the Iberian Sardine Management and Recovery Plan**, chaired by Manuela Azevedo (Portugal), met in Lisbon, Portugal, 1–5 April 2019 to evaluate if the management and recovery strategies jointly proposed by the Portuguese and Spanish administration meet the client´s objective and are precautionary according to ICES precautionary criterion. The request also asked for the re-examination of the Biological Reference Points (BRPs) for the Iberian sardine stock. The working group decided to keep the current BRPs, B_{lim} of 337.4 thousand tonnes and F_{MSY} of 0.12year^{-1}, corresponding to the scenario of medium stock productivity, because the updated estimates as well as the estimates from the analysis of the effect on the BRPs of the assessment retrospective showed that both were within confidence bounds (95%) of the current adopted reference points. The working group also estimated BRPs considering the recent low stock productivity to be in the period 2006–2017 as specified in the request. B_{lim_low} was estimated to be 196.3 thousand tonnes and F_{MSY_low} was estimated to be 0.032year^{-1}, corresponding to the scenario of low stock productivity. The estimated BRPs were used to set the biomass and fishing mortality reference levels of the catch rules and also, following the ICES guidelines for the evaluation of management plans, the basis to compute performance statistics of the management strategy evaluation under each operating model.

The special request proposed two catch rules each with three reference levels for fishing mortality (no fishing, low F and target F) and three reference levels for the biomass of age 1 and older individuals, B1+ (low biomass, 80%B_{lim} and B_{lim}). Both catch rules were simulation tested considering management under a medium productivity of the stock: HCR1 (F_{low}=0.10, F_{tgt}=0.12, B_{low}=112.9 th t, 80%B_{lim}=270.0 th t) and HCR2 (F_{low}=0.085, F_{tgt}=0.12, B_{low}=112.9 th t, B_{lim}=337.4 th t). The catch rules consider a fishing closure in case B1+ is forecast to be below or equal to B_{low} and a fishing mortality at F_{tgt}=0.12 in case B1+ is forecast to be above 270.0 thousand tonnes for HCR1 and above 337.4 thousand tonnes for HCR2. HCR1 considers a step decrease in F from F_{tgt}=0.12 to F_{low}=0.10 in case B1+ is forecast to be below or equal to 270.0 thousand tonnes and above 112.9 thousand tonnes as long as it leads to an inter-annual increase in B1+ of 5%, otherwise F is reduced until the 5% increase in B1+ is achieved or set to F=0 if the condition is not met. HCR2 considers a linear decrease in F from F_{tgt}=0.12 to F_{low}=0.085 in case B1+ is forecast to be below or equal to 337.4 thousand tonnes and above 112.9 thousand tonnes.

Alternative catch rules, also corresponding to a medium productivity of the stock but with lower fishing reference points, HCR5 (F_{low}=0.083 and F_{tgt}=0.10) and HCR6 (F_{low}=0.071 and F_{tgt}=0.10) were simulation tested. Given the uncertainty on the true scenario of recruitment productivity, two other catch rules were defined according to a permanent low productivity scenario, HCR3 (F_{low}=0.027, F_{tgt}=0.032, B_{low}=112.9 th t, 80%B_{lim_low}=157.1 th t) and HCR4 (F_{low}=0.023, F_{tgt}=0.032, B_{low}=112.9 th t, B_{lim_low}=196.3 th t). Finally, a no fishing rule, HCR7, was also considered.

The performance of the catch rules was analysed with full-feedback MSE implemented in FLBEIA using R-FLR packages, generating 1000 independent populations, each projected for thirty years. Simulation testing of the catch rules was carried out for four scenarios of true productivity, medium (B_{lim} of 337.4 th t), low (B_{lim_low} of 196.3 th t) and two scenarios with a persistent (low–medium) or non-persistent (mix) transition between the low and medium productivity dependent on the level of B1+.

Given the current condition of the stock (under B_{lim}=337.4 th t), the evaluation of the proposed MRP needs to consider a recovery phase and a long-term perspective. Compliance of the HCRs with the client recovery objective to restore the stock to 80%B_{lim} by 2023 with at least 90% probability and the ICES precautionary criterion of 5% in the long-term is dependent on the true stock productivity.

Under the assumption of permanent future medium productivity, the proposed HCRs do not comply with the client recovery objective (to 80%B_{lim}=270.0 tht) but recovery of the stock would be achieved between 2025 (HCR1) and 2028 (HCR2). However, if the true future productivity of the stock is low the recovery target (to 80%B_{lim_low}=157.1 th t) will be reached with 90% probability earlier, between 2022 (HCR1) and 2026 (HCR2). Compliance with the ICES precautionary criterion will only be achieved if the actual true productivity of the stock corresponds effectively to the medium productivity regime as it results in a 5% (HCR1) and 6% (HCR2) probability of B1+ < B_{lim} in the long-term. Performance of catch rules HCR5 and HCR6, which reduce F_{tgt} to 0.10, is slightly improved in relation to the recovery objective of the MRP, particularly when applying HCR6, and both rules comply with the ICES precautionary criterion as it results in 4% probability of B1+ < B_{lim} in the long-term in the situation that true productivity in future is medium and is correctly perceived. Both conditions, recovery and precautionary, are not met with these rules iftrue productivity in future is low. Catch rules HCR3 and HCR4, defined accordingly to the assumption of a permanent low productivity regime, have the capacity of recovering the stock by 2023 (to 80%B_{lim_low}=157.1 th t), whatever the true productivity regime and are considered precautionary as it results in 1% probability of B1+ < B_{lim_low} in the long term, thus preventing further depletion of the stock. Long-term equilibrium conditions were not achieved for any of the HCRs when simulation testing was performed assuming true low–medium or mix productivity scenarios since by the end of the projection period there was not a dominance of any of the two productivity regimes.

In the situation of no fishing (HCR7) the recovery objective of the MRP would be achieved by 2025 when true medium stock productivity is correctly perceived (i.e. to 80%B_{lim}=270.0 th t) and by 2021 in the case of the true low productivity scenario (i.e. to 80%B_{lim_low}=157.1 th t). Compared with the recovery time of the other HCRs, under the same conditions (i.e. true and perceived of medium productivity), the recovery is much faster than with HCR1 or HCR2, is the same as with HCR5 and is only two years sooner than with HCR6. In relation to HCR3 and HCR4, when true low productivity is wrongly perceived as medium, the stock recovery with HCR7 would be achieved only one year sooner.

For all scenarios, advice based on catch rules HCR1, HCR3 and HCR5 would lead to frequent fishery closures, particularly in the short term (28–35%) which is not the case when advice is based on catch rules HCR2, HCR4 and HCR6given very low probability of fishery closure (0 to 1%). Median catches estimated with HCR1 and HCR2 are similar both in the first ten years, 32 and 27 thousand tonnes, and in the last ten years, 51 thousand tonnes. Catch rules HCR5 and HCR6 have slightly lower median catch compared to HCR1 and HCR2, being less than 6 tonnes. The probability of fishery closure with HCR3 and HCR4 is very low (0 to 2%) but estimated catches are much lower than for the other rules, of 6 and 17 thousand tonnes in the first ten years and in the last ten years, respectively, for both catch rules under true medium and true low productivity.

ii Expert group information

Expert group name	Workshop on the Iberian Sardine Management and Recovery Plan (WKSARMP)
Expert group cycle	NA
Year cycle started	2019
Reporting year in cycle	1/1
Chair(s)	Manuela Azevedo, Portugal
Reviewers	Martin Dorn, US and Sonia Sánchez, Spain
Meeting venue and dates	1–5 April 2019, Lisbon, Portugal (18 participants)

1 Introduction

1.1 Terms of reference

The **Workshop on the Iberian Sardine Management and Recovery Plan**, chaired by Manuela Azevedo (Portugal) and attended by the invited external experts Martin Dorn (US) and Sonia Sánchez (Spain), will work by correspondence from November 2018 to March 2019 and meet in Lisbon, Portugal on the 1–5 April 2019 to:

1. Re-examine and update (if necessary) reference points according to ICES guidelines taking into account two alternative scenarios of recruitment: the recent low productivity (2006–2017) and the historical productivity (1993–2017);
2. Develop the tools to be used in the analyses (e.g. integration of Stock Synthesis into FLBEIA);
3. Agree on the setup of the Operating Model and scenarios to be tested;
4. Ensure that the minimum requirements for conducting MSE, as developed by WKGMSE2 (The second Workshop on guidelines for management strategy evaluations, February 2019), are met for the harvest rules analysed;
5. Conclude on whether the proposed harvest control rule (or rules) meet the objectives defined in the request;
6. Conclude in relation to ICES guidelines on whether the proposed management strategies (see Annex 1) are precautionary or not.

WKSARMP will report by 24 April 2019 for the attention of ACOM.

1.2 Interpretation of the request

ICES received a Special Request from Portugal-Spain to evaluate a management and recovery plan for the Iberian sardine (Annex 1). The request also asks for the re-examination of Biological Reference Points (BRPs) for the Iberian sardine stock accounting for i) the possibility that the low productivity of the stock in the recent past (since 2006) might continue in the future and, ii) the retrospective bias in the stock assessment estimates of recruitment, biomass of fish age 1 and older and fishing mortality.

The objective of the management and recovery plan (MRP) is the recovery of the Iberian sardine stock by 2023. Recovery is defined as ensuring, with a probability ≥ 90%, that the biomass of fish age 1 and older (B1+) is equal or above 80% of B_{lim} by 2023. In case this objective is not achieved by 2023, the request asks for the computation of the least time frame required to achieve the objective using the same risk.

To achieve the recovery objective two Harvest Control Rules (HCRs), hereafter designated by HCR1 and HCR2, are proposed (Figure 1):

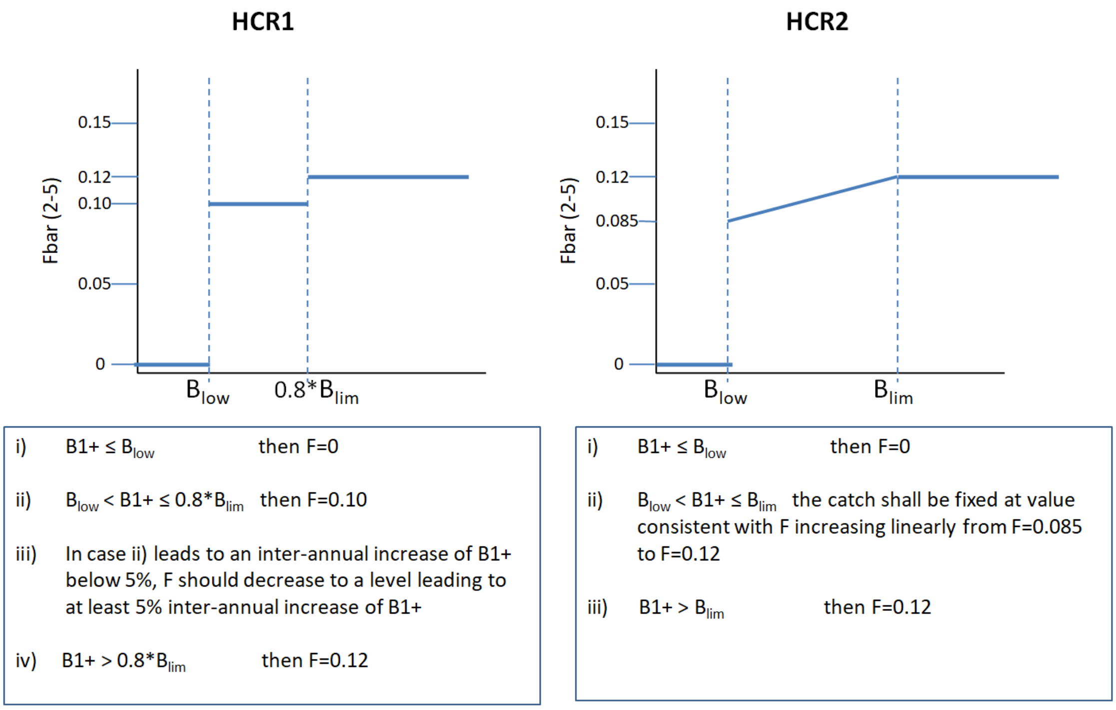


Figure 1. Harvest Control Rules of the management and recovery plan for the Iberian sardine stock.

The HCRs have three reference levels for the fishing mortality (no fishing, F=0, low F, hereafter designated by F_{low} and a target F, hereafter designated by F_{tgt}) and three reference levels for B1+ (a low biomass, B_{low}, the recovery objective of 80%$B_{lim}$and the limit biomass, B_{lim}). The reference level 'B_{low}' is defined in the request as the B1+ estimated for 2015 in the 2018 stock assessment (ICES, 2018), of 112 943 tonnes. The reference level B_{lim} is not defined in the request and the group considered that B_{lim} should be set accordingly to the re-examination analysis of the BRPs and the productivity regime scenario adopted in each simulation testing performed for the evaluation of the MRP (Sections 2 and 3). Both HCRs consider a fishing closure (F=0) in case B1+ is forecast to be below or equal to B_{low} and a fishing mortality at F_{tgt}=0.12 in case B1+ is forecast to be above 0.8*B_{lim} for HCR1 and above $B_{lim}$for HCR2. In case B1+ is forecast to be below or equal to 0.8*B_{lim} and above B_{low}, HCR1 considers a step decrease in F from fishing mortality at F_{tgt}=0.12 to F_{low}=0.10 as long as it leads to an inter-annual increase in B1+ above 5% in each year. Otherwise, F should be reduced until a 5% increase in B1+ is achieved or, in case a 5% increase in B1+ is not achievable by reducing F, F is set to zero. HCR2 considers a linear decrease in F from F_{tgt}=0.12 to F_{low}=0.085 in case B1+ is forecast to be below or equal to B_{lim} and above B_{low}.

The request further asks to assume catches in 2018 to be 12 028 tonnes, as agreed by Spain and Portugal. However, at the time of the WKSARMP meeting preliminary estimates of the 2018 catches were made available by the Portuguese Administration and by the Spanish Secretary-General for Fisheries. The preliminary value for the catches in 2018 of 14 060 tonnes was therefore adopted for the analysis.

1.3 Conduct of the meeting

The list of participants is presented in Annex A.

Intersession work and discussions took place ahead of the meeting by IPMA, IEO and AZTI participants and the external experts, including the revision of BRPs and technical aspects related to the simulations to be carried out. This work was presented during the first day of the workshop. Some participants worked by correspondence during the meeting and participated in plenary discussions via WebEx. The chair made available to all participants the ICES code of conduct (CoC) for Expert Group Meetings and at the start of the WKSARMP meeting all participants declared they would abide by the CoC.

The management strategy evaluation of the proposed Management and Recovery Plan (MRP) of the Iberian sardine was performed with full-feedback MSE that was run in the high-performance computer cluster of AZTI during the first days of the meeting for three scenarios of 'true' productivity and operating model settings agreed and using a limited number (200) of iterations. The analysis of the preliminary results of the simulation testing of the proposed HCRs led the group to decide on exploring alternative HCRs as well as considering a fourth productivity scenario. Each HCR simulation testing run using 1000 iterations took several hours, despite running in parallel using more than 180 computation nodes. Therefore, final results were available close to the end of the meeting (April 5) for the proposed HCRs and their alternatives but only for some of the productivity scenarios. The Chair supported and agreed on running the MSE for the remaining scenarios and alternative HCRs after the meeting since the analysis of the results and the conclusions would be objectively (i.e. not prone to subjective interpretations) based on the performance statistics adopted by the WG. Final runs were available on April 8.

1.4 External review

The external reviewers participated in the meetings, via WebEx, to discuss the work carried out intersessionally, provided feedback and guidance on the further specification of simulation work and attended the WKSARMP meeting in Lisbon, fully participating in subgroups work and on the plenary discussions. The report of the external reviewers will be presented to ICES no later than 24th April 2019 and appended as Annex 2 to this report.

2 Biological Reference Points

To answer the request, Biological Reference Points (BRPs) for this stock were re-examined to account for:

i. the possibility that the low productivity of this stock in the recent past (since 2006) might continue in the future;

ii. the retrospective bias in the assessment estimates.

The re-examination was based on the most recent assessment data (ICES, 2018) and detailed analysis is presented in Wise, L. (2019) (WD2019, Annex 3).

Current adopted reference points for this stock (Table 2.1) were estimated during WKPELA 2017 (ICES, 2017a) using assessment results for the period 1993–2015, and accepted in the same year.

Table 2.1. Summary of current Iberian sardine stock reference points.

BRP	VALUE	TECHNICAL BASIS
B_{lim}	337 448 t	B_{lim} = Hockey-stick change point
B_{pa}	446 331 t	$B_{pa} = B_{lim} * exp(1.645 * \sigma), \sigma = 0.17$
MSY$B_{trigger}$	446 331 t	$B_{trigger} = B_{pa}$
F_{lim}	0.25	Stochastic long-term simulations (50% probability $B1+< B_{lim}$)
F_{pa}	0.19	$F_{pa} = F_{lim} * exp(-1.645 * \sigma), \sigma = 0.17$ If $F_{pa} < F_{MSY}$ then $F_{MSY} = F_{pa}$
$F_{p0.5}$	0.12	Stochastic long-term simulations with ICES MSY AR ≤ 5 probability $B1+<$ $Blim$); Constraint to F_{MSY} if $F_{p0.5} < F_{MSY}$
F_{MSY}	0.20	Median F_{target} which maximizes yield without $B_{trigger}$
Adopted F_{MSY}	0.12	If $F_{p0.5} < F_{MSY}$ then $F_{MSY} = F_{p0.5}$

2.1 Methodology

The methodology used followed the framework proposed in ICES (2017b) guidelines for fisheries management reference points (the same procedure as in WKPELA 2017 (ICES, 2017a)). All statistical analyses were carried out in R environment (R version 3.4.1).The sardine latest stock information (ICES, 2018) was converted to an FLStock object using the “FLCore” package (version 2.6.9). Simulations analyses were conducted with the package “MSY” (version 0.1.18; https://github.com/ices-tools-prod/MSY) using the EqSim routines (ICES, 2016), a stochastic equilibrium reference point software that provides MSY reference points based on the equilibrium distribution of stochastic projections. Data and model settings to estimate BRPs are shown in Table 2.2.

Two periods were simulated as to reproduce two different stock productivity periods: 1993–2017, representing a medium stock productivity regime and 2006–2017 representing a low stock productivity regime (see Section 3).Three S–R relationships (Ricker, Beverton–Holt and Hockey-stick) were fit to both sets of data. The automatic weighting method implemented in EqSim

(ICES, 2016) was used to weight the combination of the three S–R models fitted from bootstrap samples of the B1+ and recruit pairs.

To account for the retrospective bias in the assessment (overestimation of B1+ and underestimation of F_{bar}), biological reference points were estimated from five analytical retrospective assessments. Initially BRPs were estimated using only the S–R data pairs from 1993 to 2013 (short retrospective analysis) in order to use a common period between retrospectives and then BRPs were also estimated using all S–R data pairs from 1993 up to the year prior to the last year of the retrospective (full retrospective analysis).In the later case, this means, for example, that for the retrospective series of 2018 we used the S–R data pairs to estimate the BRPs from 1993 up to 2017 while in the retrospective series of 2017 we used the S–R data pairs from 1993 up to 2016.

Table 2.2 Model and data selection settings.

DATA AND PARAMETERS	SETTING	COMMENTS
Stock data	1993–2017; 2006–2017	The period 1993–2017 broadly corresponds to the period where survey information is available. The stock shows a wide dynamic range of B1+ and evidences that recruitment is impaired. Sardine productivity has declined over time; productivity in 2006–2017 has been generally lower than in the earlier period.
Exclusion of extreme values	No	
Trimming of R values	No	
Mean weights and proportion mature; natural mortality	2012–2017	6 yr. period was chosen. Knife-edge maturity ogive with 100% mature at age 1+. Biomass 1+ is the stock index. Natural mortality is age-dependent and time-invariant.
Exploitation pattern	2012–2017	6 yr. period. Corresponds to a constant selectivity period.
Assessment error of fishing mortality	0.233	Taken from WKMSWREF4 (ICES, 2016) of estimates of five stocks in WKMSYREF3 (ICES, 2015)[1]
Autocorrelation of fishing mortality in assessment error	0.423	Taken from WKMSWREF4 (ICES, 2016) of estimates of five stocks in WKMSYREF3 (ICES, 2015)[1]

1 – At the moment these errors are not estimated for this stock. Also, in the previous estimation of reference points these were the values adopted.

2.2 Results

2.2.1 Productivity scenarios

For the mean productivity period (1993–2017),stock–recruitment models showed comparable maximum likelihood estimates but the Hockey-stick achieved a better fit by far (weights estimated to be 86%, 4% and 10% for the Hockey-stick, Ricker and Beverton–Holt). As in WKPELA 2017, the Hockey-stick was adopted for the calculation of reference points (Figure 2.1).

For the low productivity period (2006–2017), the weighted combination of the three S–R models showed a better fit of the Ricker model (weights were 51%, 37% and 13% for the Ricker, Beverton–Holt and the Hockey-stick, respectively). Since the Ricker dominates the S–R combination but with only 51% in weight,the group agreed to consider reference points estimated with a Hockey-stick model (Figure 2.2). The potential candidate B_{lim} was estimated as the change point of the Hockey-stick model fitted to the data.

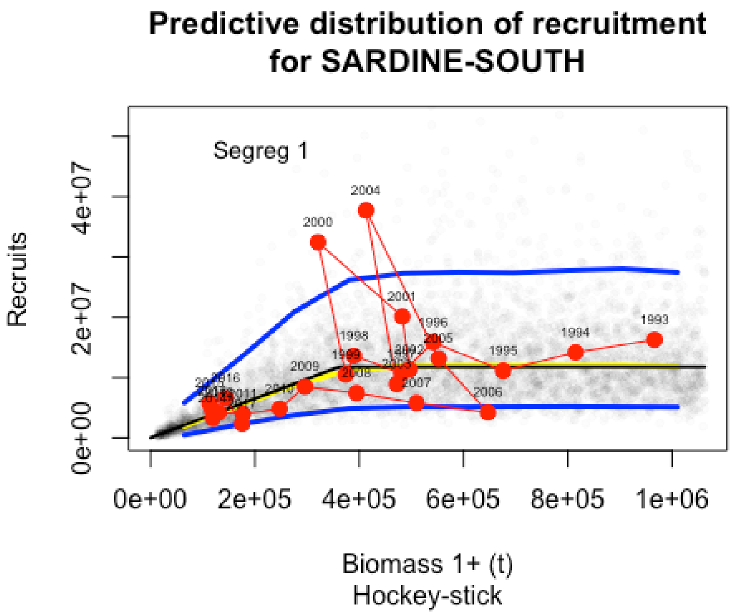


Figure 2.1. Fitted Hockey-stick (black) for the period 1993–2017. The median recruitment based on the weighted distribution of the model (yellow) is shown. Red lines are the historic sequence of recruitment.

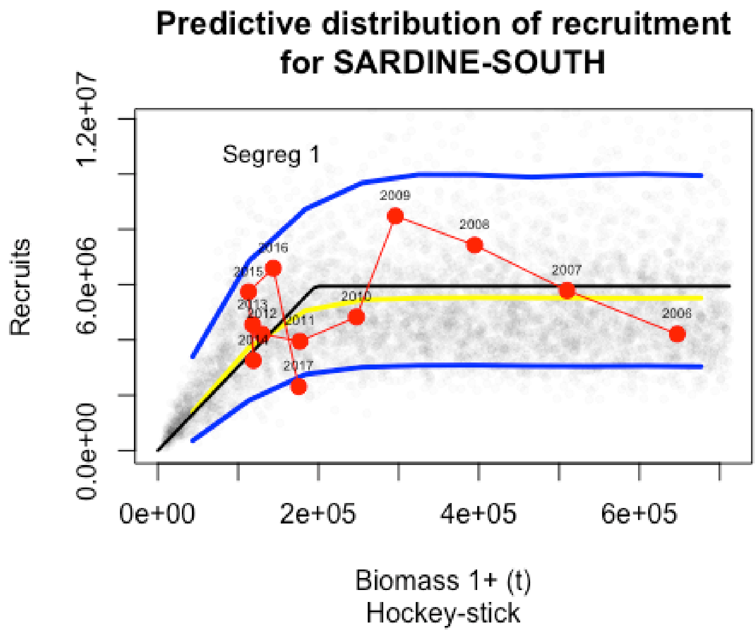


Figure 2.2. Fitted Hockey-stick (black) for the period 2006–2017. The median recruitment based on the weighted distributions of the model (yellow) is shown. Red lines are the historic sequence of recruitment.

For the time period 1993–2017 (medium productivity)the potential candidate for B_{lim} would be 7.2% higher but within the 95% confidence interval of the current B_{lim} (296 057, 514 150 tonnes) (Tables 2.3 and2.4). The reference point that shows a higher percentage difference when compared with the current reference points is the potential candidate for F_{MSY}, $F_{p0.5}$ (18% lower).

For the timeperiod 2006–2017 (low productivity), the potential candidate for B_{lim} is 196 334 tonnes (46% lower than the current B_{lim}). The candidate F_{MSY} would be equal to $F_{p0.5}$ and would be 67% below the current F_{MSY}.

Table 2.3 Estimated reference points. Current reference points (1993–2015, WKPELA 2017, benchmark assessment) and estimated reference points for the medium productivity (1993–2017, WGHANSA 2018 assessment) and for the low productivity scenario (2006–2017, WGHANSA 2018 assessment). The Hockey-stick model was used in all cases.

	Current	1993–2017	2006–2017
B_{lim}	337448	361639	196334
B_{pa}	574066	465137	252523
F_{lim}	0.250	0.232	0.156
F_{pa}	0.189	0.176	0.118
F_{MSY}*	0.204	0.198	0.224
$F_{p0.5\_Btrig}$	0.119	0.098	0.032

***current adopted F_{MSY}= $F_{p0.5\_Btrig}$=0.12.**

Table 2.4. Difference (percentage) between reference points estimated for each productivity scenario (medium: 1993–2017; low: 2006–2017) and the current reference points.

	1993–2017	2006–2017
B_{lim}	7.2	-45.7
B_{pa}	-19.0	-45.7
F_{lim}	-7.2	-32.8
F_{pa}	-6.9	-33.0
F_{MSY}	-2.9	13.1
$F_{p0.5\_Btrig}$	-17.6	-67.3

2.2.2 Retrospective errors

The Hockey-stick relationship was used for the estimation of reference points, since it had better results than the Ricker and Beverton–Holt in all retrospectives (weights above 66%). Table 2.5presents the differences between the BRPs estimated in the short and in the full retrospective years. B_{lim} increases while all other reference points decrease from 2014 to 2018 in both approaches (Table 2.5). Increases in $B_{lim}$are small from year to year ranging from 3% to 1.4% in the short retrospective analysis and from 0.2 to 11.5% in the full retrospective analysis. All estimated candidates for B_{lim} are within the 95% confidence interval of the current adoptedB_{lim} (Figure 2.3).

Table 2.5. Difference (in percentage) between B_{lim} of the two retrospective analyses.

Retrospective year	B_{lim}in the short retro	Change (%)	B_{lim}in the full retro	Change (%)
2014	321996	0.00	321996	0.00
2015	320258	-0.54	324918	0.91
2016	331876	3.63	323697	-0.38
2017	339935	2.43	324347	0.20
2018	344700	1.40	361639	11.50

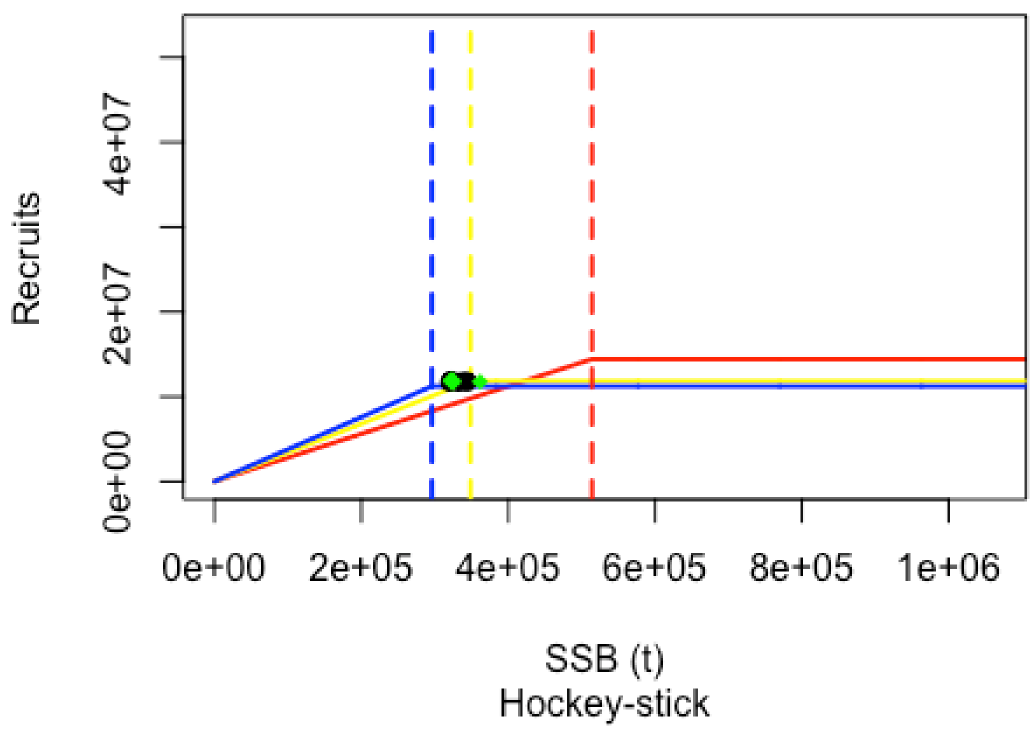


Figure 2.3.Blue, yellow and red dashed vertical lines represent the 2.5, 50 and 97.5 percentiles of parameter b of a Hockey-stick curve from 1000 bootstrap resamples of S–R pairs from the time-series 1993–2017. Black dots represent the

values estimated for B_{lim} within the short retrospective analysis. Green diamond shapes represent the values estimated for B_{lim} within the full retrospective analysis.

2.3 Conclusions

The updated estimate of B_{lim} and all B_{lim} estimated from retrospective runs were within the 95% confidence interval of the current B_{lim} therefore the WG decided to keep the current B_{lim}=337 448 tonnes.

Following the new ICES guidelines for the evaluation of management strategies, when calculating performance statistics in management strategy evaluations, each Operating Model should have their own BRPs. So, for the analysis of the proposed MRP, the group decided to adopt:

- B_{lim}=196 334 tonnes, hereafter designated as B_{lim_low}, estimated with data for the time-period 2006–2017 from WGHANSA 2018 assessment, for scenarios of low productivity;
- B_{lim} = 337 448 tonnes, estimated with data for time period 1993–2015 from the WKPELA 2017 assessment, for scenarios of medium productivity.

3 Productivity Scenarios

The major indicator of stock productivity for pelagic species is the average level of recruitment. The assessment of the Iberian sardine stock (ICES subdivisions 8c and 9a) reveals a rather variable recruitment, but with a general decreasing tendency, disrupted by occasional high peak recruitment years (Figure 3.1).

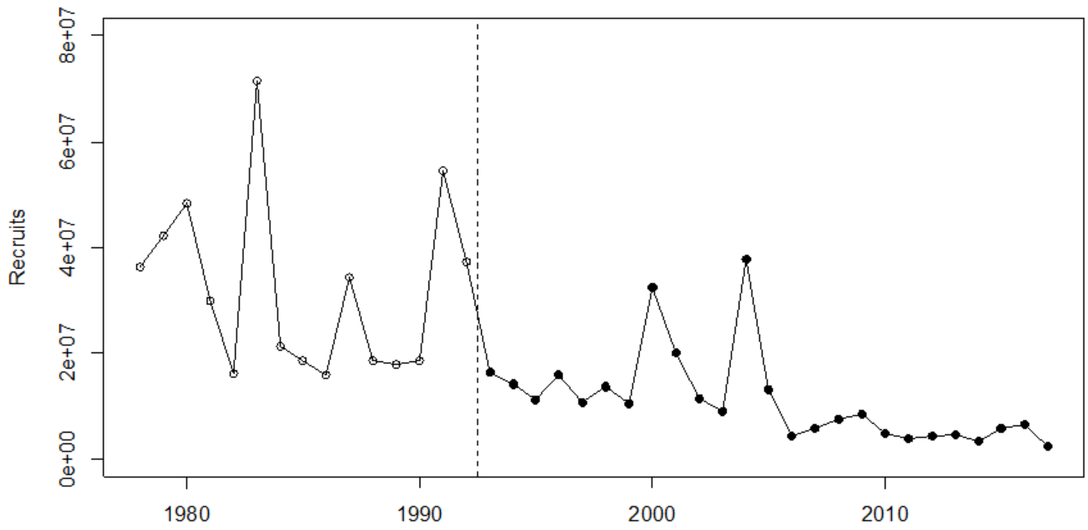


Figure 3.1. Series of recruits from the latest assessment of the Iberian sardine stock (ICES, 2018). Open circles from 1978 to 1992 and bullet points from 1993 to 2017. The breakpoint in 1993 was identified in WKPELA 2013 (ICES, 2014). Reference point calculations were based on a S–R model fitted only to the period from 1993 onwards.

Since 2006, no high recruitment has been observed and the stock went to low historical biomass levels in recent years. If this is the result of a general decline or a shift of productivity regime of this sardine population is a matter of concern, given that the evaluation of management strategies depends on the future productivity of the stock.

In this section, the indications on potential changes in sardine productivity are examined and four potential scenarios of recent and future productivity are defined and discussed on their relevance and implications for the analysis of the performance of the Harvest Control Rules (see Section 3.4).

3.1 Regime shift analysis

Regime shifts are large, abrupt, persistent changes in the structure and function of ecosystems, from one decadal-scale period of a persistent state to another decadal-scale period of a persistent state (King, 2005). In the framework of the assessment, the criteria to identify a regime-shift in a population or stock are: 1) observed changes in a productivity indicator, such as a period when fishing pressure has declined but the biomass has not recovered or a period when the stock recruitment relationship changes, 2) changes in the input data of the assessment model, e.g. those related to data quality or stock definition, 3) changes in model assumptions, e.g. fishery selectivity, recruitment, natural mortality etc. and, 4) an exploratory hypothesis, for example, environmental studies pointing to changes in the ecosystem (Klaer *et al.*, 2015).

To investigate changes in the recruitment strength of the Iberian sardine stock over time, we applied the change point analysis algorithm (CPA) from Rodionov and Overland (2005) to the recruitment time-series from 1978 to 2017 (ICES, WGHANSA 2018). The method consists on applying sequential t tests to detect statistically significant deviations from the mean value of a subset of sequential values in a time-series. The CPA based on a probability for false positives of0.1, a Huber parameter equal to 1 and a cutoff length of 10, which are the default values, detected a breakpoint in 1993. In the first period, the average recruitment was 32 084 567 individuals and in the second period the average recruitment was 11 091 677 individuals. When the cutoff length was set to 20 years, the CPA resulted in two breakpoints: in 1993 and 2010. The mean was equal to 32 084 567 in the first period, 14 226 846 in the second period and 4 429 443 in the third and last period. These results allow us to establish the transition probability from a high to a low regime. However, the transition from a low to a high regime has not been observed yet, and it is uncertain which will be the duration of the current regime. Therefore, based on these results, it is not possible to set a S-R scenario with regime shifts as in A'mar *etal.* (2009).

3.2 Environmental and biological factors with potential effect on stock productivity

Biological responses to climatic regime shifts fall into several categories: change in the production/species dominance of a marine system, change in the ''governing rules" (for example multiple stock/recruit curves) or spatial displacement of populations (Overland *et al.*, 2008). Small pelagic fish populations respond rapidly to those changes, and fluctuations in biomass and abundance are well documented in different regions of the world, as a result of a mixture of climate-driven mechanisms, such as primary productivity and prey availability, mediated by changes in water temperature.

The Atlanto-Iberian pelagic ecosystem where the Iberian sardine stock inhabits has changed significantly in recent years. Water temperature increased in Western Iberia coast ranging from 0.02 to 0.03°C yr^{-1} since 1985 (Relvas *et al.*, 2009). Time-series analysis from 1950 to 2010 showed that sea surface temperature (SST) increased 0.1°C per decade in the western coast of Iberia and 0.2°C per decade in the Southern coast (Baptista *et al.*, 2018). Off the southwestern coast, four breakpoints (1994, 1998, 2003 and 2008) were found in the SST time-series from 1988 to 2013, the most abrupt ones in 1995 and 2008 (Costa Goela *et al.*, 2016).

The observed warming of the recent decade in this area can have a major impact on the survival of sardine early life stages. Several works have found a relationship between environmental factors and sardine abundance/recruitment/catches in the Atlanto-Iberian ecosystem (e.g. Borges *et al.*, 2003;Solari *et al.*, 2010; Santos *et al.*, 2012; Leitão *et al.*, 2014; Gamito *et al.*, 2015; Teixeira *et al.*, 2016;Cabrero *et al.*, 2017). Most of these studies found significant relationships of total sardine landings with several environmental factors, mainly SST followed by wind strength and the North Atlantic Oscillation (NAO). Through laboratory experiments it was shown that sardine eggs and larvae have a narrow range of temperature tolerance for survival and development (Bernal *et al.*, 2008; Garrido *et al.*, 2015) as seen for other sardine species and in contrast with other small pelagics such as anchovies (Takasuka *et al.*, 2008). Analysis of recruitment strength in the three sardine recruitment hotspots off the Iberia (Bay of Biscay, Northwestern Portugal and Gulf of Cadiz) showed that food availability and temperature (satellite-derived chlorophyll a -Chla- and SST, respectively) were able to discriminate between good and bad recruitment years, and generally high recruitments were associated with lower temperatures off Western and Southern Iberia (Garrido *et al*., 2017).

Decade-scale regimes of sardine and anchovy species have been documented in several upwelling ecosystems such as the Northwestern, Northeastern and Southeastern Pacific and the Southeastern Atlantic (Schwartzlose *et al*., 1999) and generally, the two groups fluctuate out of phase with each other. In the ICES subdivisions 8.c and 9.a, sardine has always been the dominant species of the pair, as observed in acoustic surveys (from 1996) and landings (from 1943), but this has changed dramatically in recent years. Anchovy biomass has increased significantly and is now occupying the area traditionally known as the major sardine recruitment hotspot off the Iberia, the northwestern coast of Portugal. Before 2007, anchovy was only detected sporadically on the western coast by acoustic surveys and landings were residual. From 2007 onwards, anchovy started to be regularly present with an increasing trend off western Iberia, reaching the historical maximum biomass during 2018 with 65 097 tonnes in the western area. The high level of biomass of this species in the northwestern Iberia may indicate a change of the prevailing oceanographic conditions that are favoring this species over sardines and on the other side, may pose a difficulty for the recovery of the sardine stock, given their niche overlap as pelagic plancktivorous fish. Nevertheless, anchovy is a short-lived species that depends on the consistency of strong year classes to sustain the high levels of biomass. Therefore it is difficult to predict the length of time that this increased abundance is going to last.

On the other hand, chub mackerel (*Scomber colias*) has been moving northwards, reaching the sardine northwestern recruitment area on occasions. It has been observed an alternation of good recruitment years for both species in this area (Martins *et al*., 2013). It was also shown that chub mackerel is the pelagic fish species that is potentially the major trophic competitor of sardines given that it has a very similar diet, at least during the juvenile phase when both species cohabit in mixed shoals (Garrido *et al*., 2017). Chub mackerel is also a major predator of sardine eggs, therefore acting not only as competitor but also as an important predator (Garrido *et al*., 2017) and its displacement northward and increased abundance in the area may be a consequence of an environmental shift that will persist in the future with potential to negatively affect sardine productivity.

3.3 Productivity scenarios

For the assessment of the performance of the first Iberian sardine stock management plan proposed by ICES (2013), an approach for the definition of the reference points proposed by Silva *et al*. (2013) was followed, which adopted the period 1993–2010 as representative of the recent productivity of the stock. In the updated series of recruitments until 2017, a break in 1993 of the productivity of the stock has been confirmed by the application of the sequential algorithm of Rodionov and Overland (2005) to identify regime shifts (Section 3.1).

The scatterplot of stock and recruitment estimates (Figure 3.2) shows that recruitment levels since 2006 are always lower than previous recruitment strength levels for the same level of stock biomass. Therefore and as pointed out in the special request to ICES, a potential reduction of productivity might be happening since 2006.

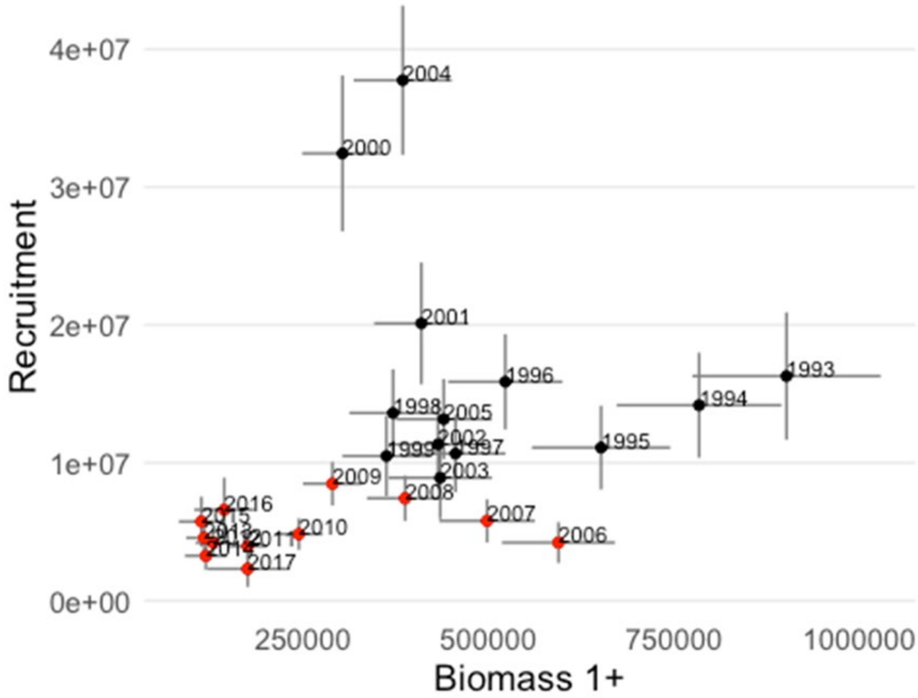


Figure 3.2.Stock–recruitment pairs for the Iberian sardine stock (1993–2017). Horizontal bars represent the 95% confidence interval of B1+ estimates and vertical bars represent the 95% confidence interval of recruitment estimates. Points in color red correspond to the recent low recruitment series 2006–2017.

The fitting of a Hockey-stick stock–recruitment relationship (Figure 3.3) shows that, with the exception of the 2000, 2004 and 2006 recruitments, all the other recruitments of recent years fall within the 95% confidence intervals of the fitted model. Despite the fact that many of these values fall below the mean expected values, recruitmentin the most recent years is around (above and below) mean expected recruitments for their respective low biomass levels. This leads us to conclude that the continuity of a regime shift that started in 1993 cannot be discarded to hold at the present time.

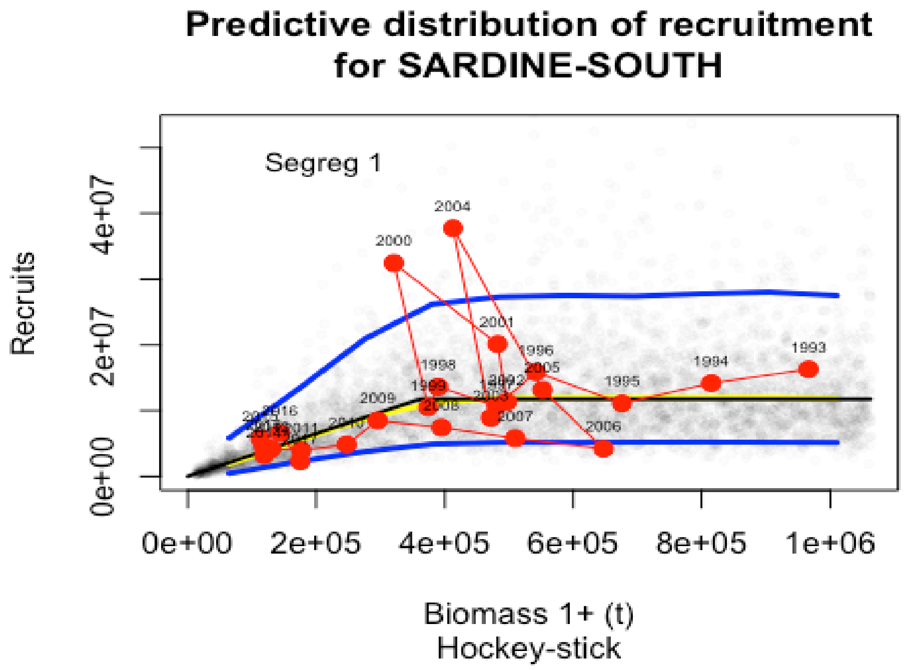


Figure 3.3. Fitted Hockey-stick (black) for the period 1993–2017. The median recruitment is based on a weighted distribution of three models (Ricker, Beverton–Holt and Hockey-stick according to their likelihoods) and is shown in yellow (see Annex 3). Red lines are the historic sequence of recruitment.

Given that 1) regime shift(s) might have occurred based on the stock–recruitment relationship and environmental indicators but 2) low recruitments observed in the last decade can also be the result ofthe stock biomass being below B_{lim},the working group proposed the following four plausible scenarios of productivity, with their respective Hockey-stick S–R relationships:

Sc. 1: "Medium" productivity: corresponds to the series of stock recruits from 1993–2017, which correspond with the productivity assumed to infer the reference points used since 2013 for this population (ICES, 2013). In support of this scenario are the former (Silva, 2013) and current regime shift analysis (Section 3.1 above) that indicate a break in 1993 and the fact that the actual residuals are within 95% confidence intervals of the fitted Hockey-stick model (Hockey-stick fit is represented in Figure 3.3 and the parameters associated to this scenario of productivity are shown in Table 3.1). However, this proposal has some reliability issues due to the fact that many recruitments since 2006 are below the expected mean for the fitted Hockey-stick model. Low recruitments observed since 2010 can be a consequence of stock biomass being below B_{lim}, for which the occurrence of high recruitments is impaired by definition. In addition, the confidence intervals of the Hockey-stick model fit imply that, in the context of MSE, the simulated recruitments, in the range of low biomasses (between 180 and 310 tonnes below B_{lim}), will be on average substantially higher than historical (recent) recruitments at the same biomass range. This implies an increase in the biomass that is faster and larger than that suggested by recent recruitment levels.

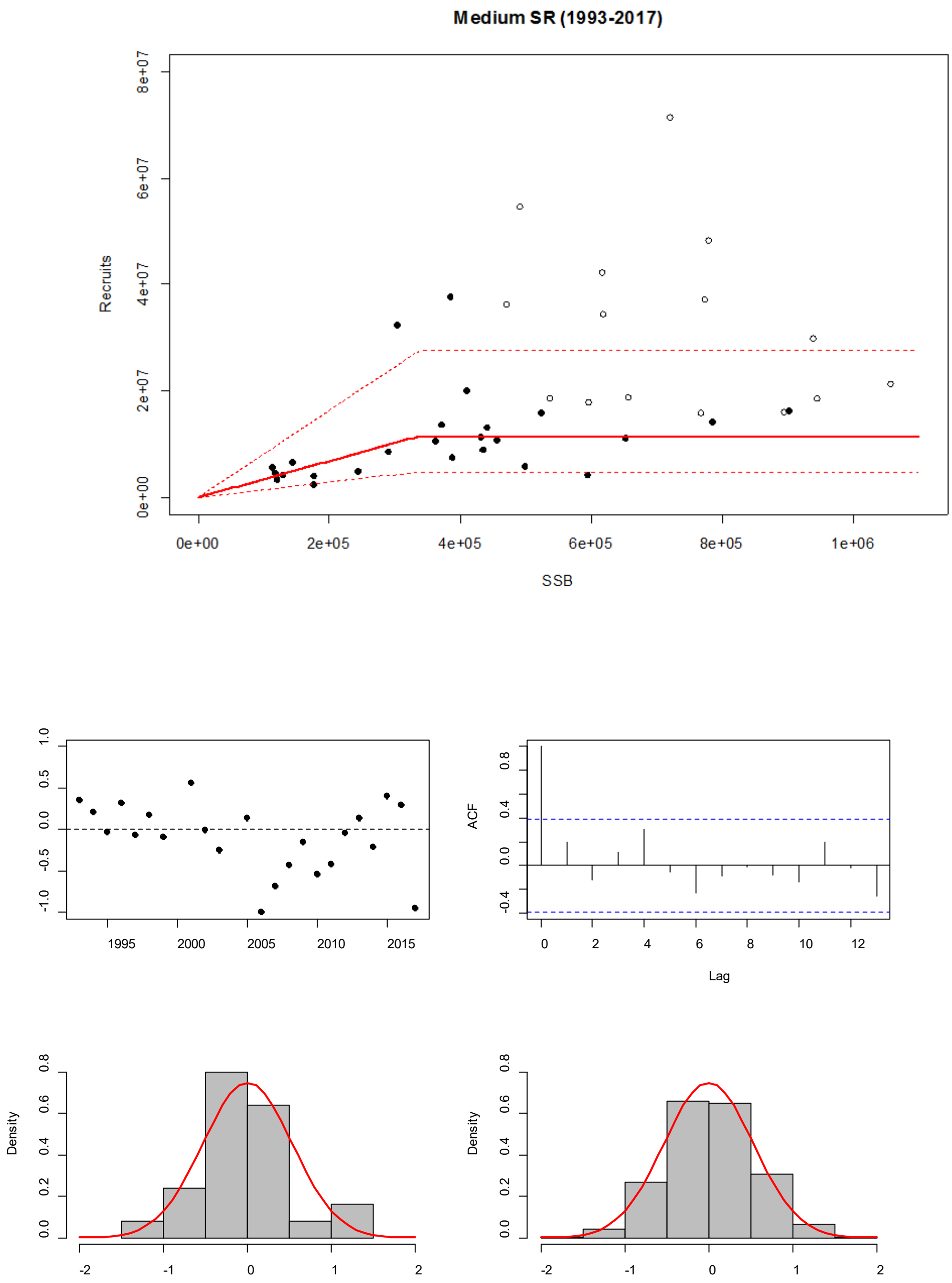


Figure 3.3. Fitted (red solid line) and 90% confidence intervals (dashed lines) for Hockey-stick for the period 1993–2017 (top panel). Plots of residuals (in log scale) along time and autocorrelation function (middle panel) and density distribution of the residuals and density distribution of an approximated normal distribution to the residuals (bottom panel).

Sc. 2: "Low" productivity: In order to address ToR (a) of the special request, an alternative scenario, corresponding to the series of stock–recruitment pairs 2006–2017, was considered. The Hockey-stick fit is in Figure 3.4 and the parameters associated to this scenario of low productivity are in Table 3.1. In support of this scenario is the fact that since 2006 there is a continuous poor level of recruitments (Figure 3.1 and 3.2), most of them below the expected levels of recruitment of the Hockey-stick fitted to the medium productivity scenario. However, the selection of 2006 as a starting point of a change in the scenario of productivity is not statistically justified, and the actual duration of the scenario is uncertain, although, as seen in several ecosystems where small pelagic inhabit, it is unlikely that a low productivity scenario persists for several decades, if there is no overfishing. Moreover, the short series of years since 2006 (12 years) and the compatibility of those observations with the medium productivity fitted Hockey-stick model are indications to take care with this proposal.

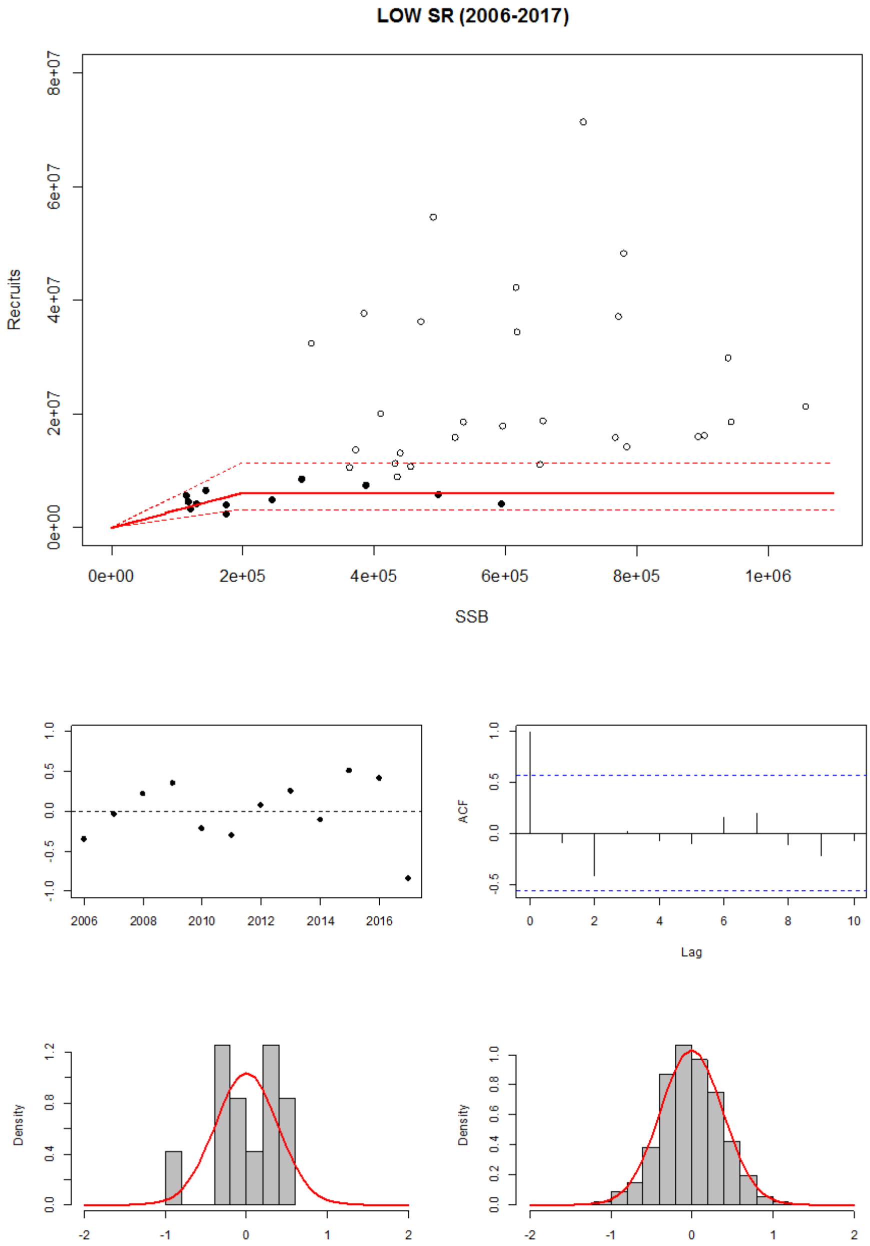


Figure 3.4. Fitted (red solid line) and 90% confidence intervals (dashed lines) for Hockey-stick for the period 2006–2017 (upper panel). Plots of residuals (in log scale) along time and autocorrelation function (middle panel) and density-distribution of the residuals and density-distribution of an approximated normal distribution to the residuals (bottom panel).

Sc. 3: "Low-to-Medium" productivity: Corresponds to a sequential application of the two former scenarios(first low and thenmedium),including their corresponding uncertainties, with identification of the year of transition when the biomass exceeds B_{lim}. This scenario incorporates the concern of a continuity of poor level of recruitmentfor the next years, until the population recovers above the B_{lim}as defined in the medium productivity scenario, of 337 448 tonnes. Once recovered above B_{lim}, it is presumed that the medium productivity will applyonwards for the rest of the simulation. Here, two Hockey-stick models exist, first the "low" productivity recruitment model, applicable over the recovery phase until the year B_{lim} is exceeded (Figure 3.5) and then the "medium", applied for the rest of the simulated years (Figure 3.3), even if the population occasionally fallsbelow B_{lim}. See the parameters in Table 3.1.

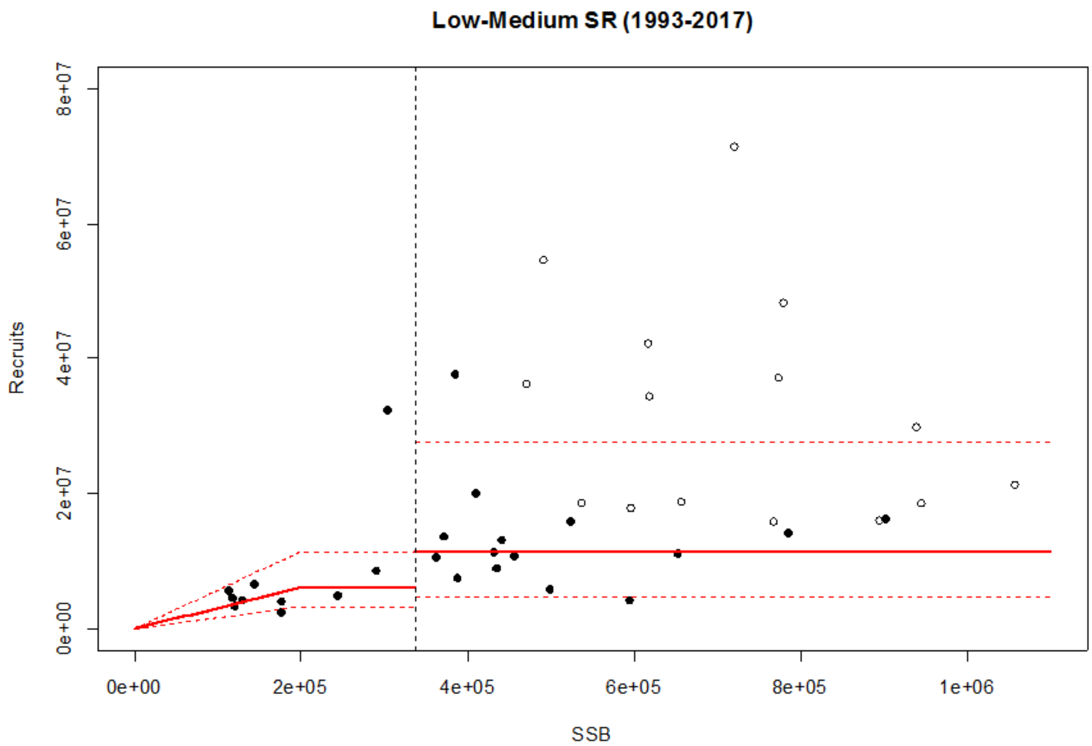


Figure 3.5. Combined Hockey-stick models for the Low–Medium productivity scenario and for the recovery phase of the Low-To-Medium recruitment productivity scenario.

Sc. 4: "Mix (Low–medium)" productivity: This is a variant of the former scenario, corresponding to a combination of the two first scenarios of recruitment productivity (including their corresponding uncertainties), but in this case,after a recovery above B_{lim}, if the biomass falls again below B_{lim}, then the "Low" recruitment scenario would prevail again. Therefore, the actual Mix model is the one in Figure 3.5, whereby recruitments of biomass above B_{lim} lay around the expected recruitments for the Medium productivity scenario but the recruitments for biomass below B_{lim} will always correspond to the "Low" productivity regime. This incorporates the concern that, for populations below B_{lim} (of 337 448 tonnes), the actual dynamics of recruitment could be the "Low" recruitment productivity scenario. See the actual Hockey-stick model for this scenario of Mix productivity in Figure 3.5 (and parameters in Table 3.1 below).

Table 3.1. Scenarios of productivity and fitted parameters for the Hockey-stick S–R relationships.

Scenario	Productivity	S–R model and parameters
Sc1	'Medium': whole simulation period (2019:ny)	Hockey-stick; 1993–2017, fitting conditional to b=337 448 tonnes results in a=33.9
Sc2	'Low': whole simulation period (2019:ny)	Hockey-stick; 2006–2017; a=30.4, b=196 334 tonnes
Sc3	'Low–medium': Start with 'low' in 2019	
	If $B1+_{y-1}$<B_{lim}(337 448 tonnes) then R='Low';	Hockey-stick; 2006–2017; a=30.4, b=196 334 tonnes
	When$B1+_{y-1}$≥B_{lim} (337 448 tonnes) then R='Medium' and stays in the Medium productivity regardless of future decrease in $B1+_{y-1}$	Hockey-stick; 1993–2017; a=33.9, b=337 448 tonnes
Sc4	Mix 'Low–medium': Start with 'low' in 2019	
	If $B1+_{y-1}$<B_{lim} (337 448 tonnes) then R='Low';	Hockey-stick; 2006–2017; a=30.4, b=196 334 tonnes
	If $B1+_{y-1}$≥B_{lim}(337 448 tonnes) then R ='Medium' but may reverse to 'Low' productivity if $B1+_{y-1}$<B_{lim} (337 448 tonnes)	Hockey-stick; 1993–2017; a=33.9, b=337 448 tonnes

An intermediate 5thscenario for the 'Low'/poor recruitment scenario for the operating model (OM) was proposed (Uriarte and Ibaibarriaga, WD2019, Annex 4): the stock productivity would be governed by a Ricker S–R fitted to the period 1978–2017 but excluding the high R (R >30 million individuals) (Figure 3.6), eight strong yearclasses which occurred in years: 1978–1980, 1983, 1991–1992, 2000, 2004) since:

Ricker S–R fit quite well all the recruits in the recent period (2006–2017) as well as any other "Normal" recruits in the entire series of biomass and, at the same time, it does not prevent the stock to increase as the biomass increases (because it is a continuous increasing curve contrary to the Hockey-stick approach of the Low productivity scenario).

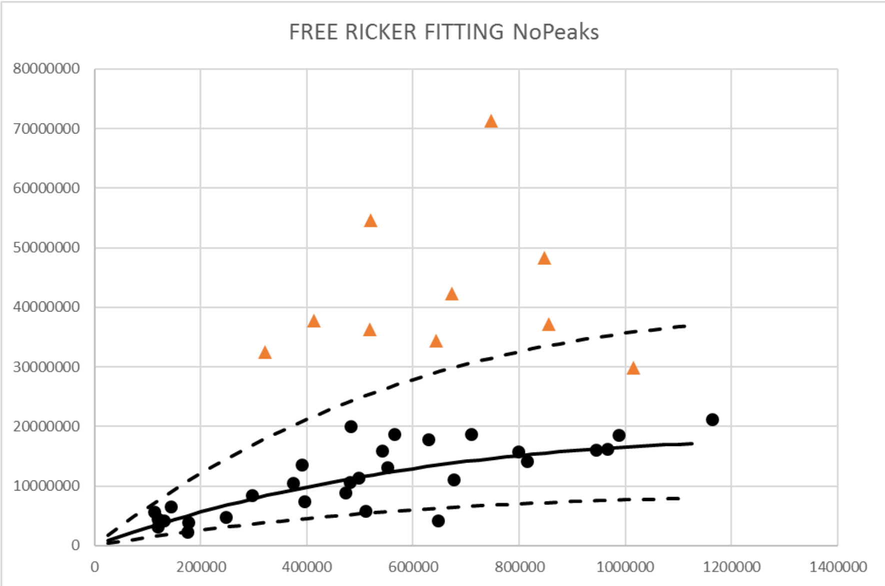


Figure 3.6. Ricker stock–recruitment model fitted to the "Normal" Level of recruitment (R below 30 million fish).

However, the WG considered that this approach was not standard, given that the discrimination between "Normal" and "High" recruitments is a bit arbitrary and because it is unclear what B_{lim} would be associated to the new scenario. Therefore, the WG decided to discard this idea.

3.4 Discussion on the scenarios and the uncertainty of future productivity of the stock

When fish populations suffer a shift in the productivity regime that is unrelated to stock size, a change in the management strategy might be appropriate. If the Harvest Control Rules are based on the Medium productivity regime, a shift to the Low productivity will result in an increased risk of overfishing. On the other hand, if the Harvest Control Rules are based on the Low productivity regime, it might be overly cautious in periods of high productivity (King and McFarlane, 2006; Vert-pre *et al*., 2013).

Table 3.2 summarizes arguments in favour and against the adoption of different scenarios of productivity.

Table 3.2. Pros and cons arguments for each of the productivity scenarios considered.

Productivity scenarios	Arguments pro	Arguments against
Medium	Former (Silva, 2003) and current regime shift analysis (section 3.1 above) point to a change in the productivity regime in 1993. All (except one) of the recent recruitment residuals since 2006 are within 95% confidence intervals of the fitted Hockey-stick model. Even though many of them fall below the mean expected values, the recruits of the most recent years are placed around (above and below) mean expected recruits for their respective low biomass levels.	Simulated recruitments in a range of low biomasses (below B_{lim}) are substantially higher than historical recruitments at the same biomass range. This leads to an increase in biomass faster and larger than seen, e.g. in the early 2000s following two strong year-classes. If this scenario is implemented there is a risk of overfishing if the true scenario is the Low, the Low–medium or the Mix.
Low	Since 2006, there is a continuous poor level of recruitments, most falling below the expected levels of recruitment of the Hockey-stick fitted to the Medium productivity scenario.	It is a short time-series(20062017) and since 2010, the SSB_{y-1} is below B_{lim}, so the observed low recruitments are expected and compatible with the Medium productivity H-S relationship. The selection of 2006 as the starting point of the Low scenario of productivity is not statistically supported. The possibility of new good recruitment (Medium productivity) in the next years cannot be discarded.
Low–medium	The Low–medium scenario presumes poor productivity until biomass approaches B_{lim}, allowing then the stock to produce good recruitments again according to the Medium productivity, as seen in the past. Only low recruitments have been seen in the last 12 years (since 2006). Low recruitment can be a combination of environmental conditions and low biomass levels. Among the environmental drivers, increased SST in the area seems to be detrimental to recruitment success and global warming may continue to negatively affect recruitment levels. The increased abundance of a eurythermal species in recent years (anchovy) is consistent with the shift to low productivity in 2006 and may contribute to hamper or delay sardine recover. This cast doubts on the applicability of the Medium productivity scenario in the near future. The major difference with the Medium productivity scenario is that the chance of occurrence of recruitments above the expected mean is sharply reduced. The approach is precautionary compared to the Medium productivity scenario which allows high variability around expected R.	The possibility of new good recruitment in the next years (short-term) cannot be discarded according to the series of S–R observations. In fact, since 2006all residuals (except one) are within 95% confidence intervals of the fitted Hockey-stick model for the Medium productivity scenario. If the duration of the next Medium productivity regime is unusually short for some reason but it is assumed to be Medium for a longer period, there is an increasing risk of overfishing.

Productivity scenarios	Arguments pro	Arguments against
Mix	The Mix scenario assumes Low productivity until biomass approaches B_{lim}, allowing then the stock to produce good recruitments again according to the Medium productivity, as seen in the past. However, the stock productivity may reverse back to Low when biomass is lower than B_{lim}. Arguments in favour equal to the former Low–medium scenario. If in the future the duration of the Medium productivity regime is unusually short for some reason this scenario is precautionary.	The possibility of new good recruitment in the next years (short-term) cannot be discarded according to the series of S–R observations. In fact, since 2006all residuals (except one) are within 95% confidence intervals of the fitted Hockey-stick model for the Medium productivity scenario. Moreover, it is unlikely that there is a regime-shift of productivity as soon as one year of low recruitment (below B_{lim}) occurs, so this scenario can be overly cautious when regulating the possibilities of catch if it considers a continuing Low productivity regime when in fact it is Medium.

3.5 Conclusions

With respect to the selection of a scenario of reference to answer the request and acknowledgement of uncertainty on the future productivity of the stock, the working group concluded that:

a) There is not sufficient evidence from the available series of parental biomass and recruitment estimates, to indicate that the Medium productivity scenario does not apply to the current situation of the sardine stock. However, the succession of poor recruitment levels in recent years suggest that a poorer scenario of productivity affecting recruitment cannot be discarded either.

b) There are several indications from the literature suggesting that environmental covariates (mainly increasing SST, but there are others) in the context of global warming may be detrimental for sardine productivity in this region. Observations on temperature increase are reported for this area. In addition, from an ecological perspective, the outburst of anchovy biomass and partially of chub mackerel in the western region of the Iberian Peninsula, are indicators of a potential change in the structure of the pelagic ecosystem. These indications from environmental variables and the relative abundance of the species in the pelagic habitat suggest that some regime shift may have occurred. The duration of this change in the future is uncertain.

c) For these reasons, the WG decided to acknowledge that:
    1. The current and future state of nature of sardine productivity is unknown, and the four scenarios outlined above (Medium, Low, Low–medium and Mix) should be considered as likely states of productivity for the sardine stock.
    2. The probability of presently facing a poor regime of sardine productivity of unknown duration cannot be discarded.

The implications of the former conclusions are:

- Considering that the true productivity of the stock is unknown, the Harvest Control Rules based on the current BRPs, which correspond to a Medium productivity of the stock, should be tested for the robustness of their performance to different states of nature of the sardine productivity (Medium, Low, Low–medium and Mix). The WG also tested the performance of parallel HCR1 and HCR2based on lower fishing mortality reference levels;
- Considering that the actual productivity of sardine can be Low for a potentially large period of time, the WG explored the performance of parallel HCR1 and HCR2 formulated in terms of the BRPs corresponding to the Low productivity scenario (B_{lim_low}= 196 334 tonnes), to test for their performance and particularly to assess if the modified rules would be capable of preventing the stock to decline below this new B_{lim}, corresponding to the low productivity scenario (risk 3) with 95% probability or more.

4 Management Strategy Evaluation

4.1 Introduction

The management strategy evaluation (MSE) of the proposed Management and Recovery Plan (MRP) was undertaken using FLBEIA (García *et al.*, 2017). FLBEIA is a simulation toolbox to conduct bioeconomic impact assessments of fisheries management strategies following a MSE framework. The model is divided into two main blocks, the operating model (OM) and the management procedure model (MP) as shown in Figure 4.1. The OM is the mathematical representation of the best knowledge of the natural and fishery systems('true' stock, fleets and any other covariate affecting the system). The MP includes the stock assessment ('perceived' stock), the short-term forecast and advice for fisheries management following the application of the management strategy (Harvest Control Rules or Decision Rules), and the management process to implement the scientific advice. Two other important components are the observation error, which represents the process of collecting information for stock assessment, and the implementation error that incorporates the way the actors implement regulations and perceive the management objectives.

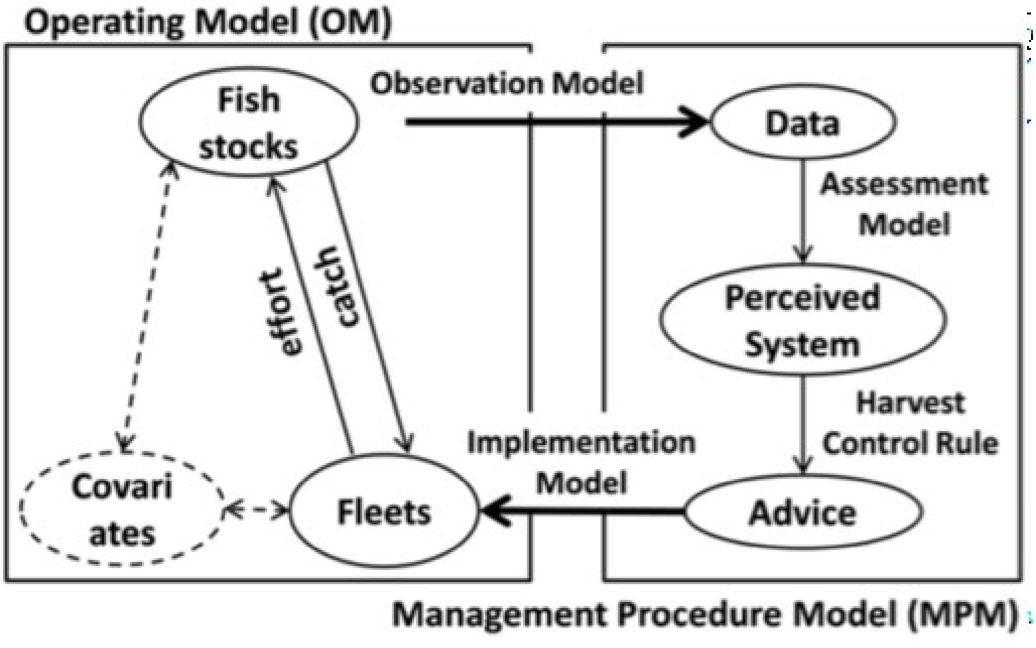


Figure 4.1.Diagram of the implemented full-feedback Management Strategy Evaluation (adapted from García et al., 2018).

4.2 Operating Model

The OM is the part of the model that simulates the real dynamics of the natural and fishery systems with the best available scientific knowledge. It is divided into three components, the biological, the fleets and the covariates. It runs in seasonal time-steps and projects the components in each time-step. First, it updates the biological component, then the fleet component and finally the covariates component. The operating model for the MSE to evaluate a MRP for the Iberian sardine was based on the last stock assessment (ICES, WGHANSA, 2018) conducted using Stock Synthesis (SS3, Methot and Wetzel, 2013). The population was considered age structured (from ages 0 to 6+) and exploited by a unique fleet (composed by one métier) and was moved forward in annual time-steps.

4.2.1 Initial population size

The estimates of abundance in numbers-at-age (ages 0-6+) for the start of the projection period were created as a product of the estimate of numbers in the previous year (2017) of the last assessment (ICES, 2018)and a lognormal distribution with μ=0 and σ=$\sqrt{\mathbf{log}(\boldsymbol{cv}^{\mathbf{2}}+\mathbf{1})}$ where *cv* is the coefficient of variation of the log-numbers-at-age of the population estimate of the SS3 assessment in year 2018 (Table 4.1).

Table 4.1. Numbers-at-ages 0–6+ (in millions) in 2017 from last assessment (ICES, 2018) and coefficient of variance (cv) used for generating the initial 1000 populations.

Age	0	1	2	3	4	5	6+
Number	2308	2395	1018	298	213	94	102
Cv	0.29	0.19	0.20	0.22	0.21	0.26	0.26

4.2.2 Biological characteristics

Assumptions on future natural mortality and proportion of mature individuals at-age are detailed in Table 4.2. Natural mortality is age-dependent (higher for younger ages) and time-invariant (same values as in the stock assessment). The proportion of mature individuals at-age follows a knife-edge ogive and all individuals of age 1+ are considered mature. As a result, spawning–stock biomass (SSB) and biomass 1+ (B1+) are equal during the projection period.

Assumptions about future mean weight-at-age of Iberian sardine follow the guidance of the short-term forecast described in the stock annex agreed on the last stock benchmark review (ICES, 2017). Weight-at-age in the stock are calculated as the arithmetic mean value of the last six years of the assessment (2012–2017) while weight-at-age in the catch are calculated as the arithmetic mean value of the last three years of the assessment (2015–2017).No variability was considered for these variables, as there is no indication of significant trends in historical weight-at-age.

Table 4.2. Natural mortality, proportion of mature individuals, mean weight-at-age in the stock and in the catch-at-age for ages 0–6+, used in the simulations.

Variable	Age						
	0	**1**	**2**	**3**	**4**	**5**	**6+**
Natural Mortality (year^{-1})	0.98	0.61	0.47	0.40	0.36	0.35	0.32
Maturity (prop)	0	1	1	1	1	1	1
Weight in the stock (kg)	0	0.031	0.049	0.064	0.067	0.075	0.079
Weight in the catch (kg)	0.022	0.045	0.064	0.075	0.085	0.089	0.097

Recruits (numbers-at-age 0) are estimated from the spawning–stock biomass following a functional relationship:

$$N_{a,t} = f(SSB_t)\exp(\varepsilon_t)$$

The relationships used in the simulations to generate recruits depend on the productivity regime assumed for the true state of nature in each scenario (Table 3.1). Recruitment variability (ε_t) was introduced by generating random draws from a lognormal distribution with μ=0 and σ as estimated in the fitting of the stock–recruitment model.

4.2.3 Fleet dynamics-selectivity and catchability

Four submodels describe the fleet dynamics in FLBEIA: the effort model, the catch model, the price model and the capital model. The effort model simulates the fishing tactic of the fishermen in the short term. It gives the effort exerted by each fleet and its distribution along métiers. In this case, the effort is allocated to the unique fleet and its unique métier along the projection period. In addition, no economic data were available and price and capital models were not considered.

The catch model is given by the Cobb-Douglas production function (Cobb and Douglas, 1928; Clark, 1990) that relates the actual catch with the effort and the stock size as follows:

$$C_t = q.E_t^{\alpha}.B_t^{\beta} \ ,$$

where $\boldsymbol{C_t}$ denotes total catch, $\boldsymbol{B_t}$ is the total biomass and $\boldsymbol{E_t}$ represents the effort in year $\boldsymbol{t}$. The model parameters are the catchability q and the elasticity parameters α and β that are associated to effort and biomass. In this case $\alpha=\beta=1$ and effort was assumed to be equal 1 during the historic period. Therefore, catchability-at-age for the historic period was estimated as the ratio between catch and biomass (in weight) at-age in the middle of the year (Table 4.3). Catchability-at-age during the projection period was set as the average from the last six years of the assessment (2012–2017). These values mimic the dome shape pattern estimated in the assessment with ages from 3 to 5 bound and a decline at the 6+ group.

Table 4.3. Catchability-at-age estimated and assumed for the projection period.

Age	0	1	2	3	4	5	6+
Catchability	0.052	0.152	0.234	0.256	0.255	0.255	0.211

4.2.4 Observation model

The link between the OM and the MP is done through the observation model that generates the observed data. Two types of data were generated, the catches and the abundance indices. These variables were subject to observation error and the error is divided into two components, the ageing error component and a multiplicative error. In FLBEIA, errors are introduced as input data therefore they can be conditioned using any distribution, bootstrap or other analysis.In the sardine MSE simulation testing no ageing error was considered and abundance indices used as input to each assessment cycle were generated from the "true" population with lognormal distributed errors. For the DEPM survey the estimated catchability value in the last assessment was used (q =1.1337) and a lognormal distribution with μ=0 and σ=$\sqrt{\log(cv^2+1)}$ where $cv$is the coefficient of variance of the parameter assumed fixed, and equal to 0.25, from the SS3 assessment. Catchability-at-age ($q_{a,t}$) of the acoustic survey was estimated as the mean of $\frac{Nas_{a,1996:2017}}{Npop_{a,1996:2017}}$, where

N_{as} is the number-at-age observed in the acoustic survey and N_{pop} is the number-at-age estimated by the assessment. Number-at-age for the acoustic survey were then estimated as the product of catchability-at-age by the number-at-age in the 'true' stock and error was introduced as a lognormal distribution with μ=log $\frac{Nas_{a,1996:2017}}{Npop_{a,1996:2017}}$ and σ equal to the standard deviation of log $\frac{Nas_{a,1996:2017}}{Npop_{a,1996:2017}}$ (Table 4.4).

Table 4.4. Mean catchability and standard deviation (sd) for the acoustic number-at-age.

Age	0	1	2	3	4	5	6+
Catchability (log scale)	0	0.034	-0.067	-0.035	0.181	0.355	-0.166
sd	0	0.484	0.518	0.440	0.513	0.628	0.716

Observation error was also introduced in the numbers-at-age in the catch as a multiplicative error by means of a lognormal distribution with μ and σ of the logarithmic residuals in the catch (Table 4.5).

Table 4.5. Mean observation error and standard deviation (sd) for the catch-at-age.

Age	0	1	2	3	4	5	6+
Mean (log scale)	-0.095	-0.029	-0.065	-0.002	0.109	0.215	-0.101
sd	0.532	0.226	0.109	0.205	0.382	0.378	0.227

These observations are then used as input to the stock assessment model.

4.3 Management procedure

4.3.1 Stock assessment

In a full-feedback MSE, an assessment model with the same settings that will be used when implementing the management strategy in reality should be applied within the MSE simulation.

The model used to assess the sardine is Stock Synthesis 3 (SS3), version 3.24f (Methot, 2012). SS3 is a generalized age and length-based model. A description and discussion of the model can be found in Methot and Wetzel (2013).

The sardine assessment is an age-based assessment assuming a single area, a single fishery, a yearly season and genders combined. Input data include catch (in biomass), age composition of the catch, total abundance (in numbers) and age composition from an annual acoustic survey and spawning–stock biomass (SSB) from a triennial DEPM survey. Considering the current assessment calendar (annual assessment WG in November) in year (y), the assessment includes fishery data up to year y-1and acoustic data up to year y.

The reference assessment used was the one from the last assessment year (ICES, 2018), with the following settings:

- Natural mortality specific input values as listed in Table 4.2.

- Growth is not modelled explicitly. Weights-at-age and maturity-at-age in the beginning of the year are input values that were assumed to be equal to the true values.
- Fishing mortality is applied as the hybrid method. This method does a Pope's approximation to provide initial values for iterative adjustment of the continuous F values to closely approximate the observed catch.
- Total catch biomass by year is assumed to be accurate and precise. The F values are tuned to match this catch.
- Both the acoustic survey and the DEPM survey are assumed to be relative indices of abundance. The corresponding catchability coefficients are considered to be mean unbiased.
- In the acoustic surveys, selectivity is assumed to be 1 at all ages (1 to 6+).
- In the fishery, age selectivity is such that the parameter for each age is estimated as a random walk from the previous age. However, this applies only to ages 1, 2, 3 and 6+ in the fishery. Selectivity at ages 3 to 5 years in the fishery are bound, meaning that parameters for ages 4 and 5 are not estimated but assumed to be equal to the parameter estimated for age 3. Selectivity-at-age 0 is not estimated and is used as the reference age against which subsequent changes occur. The initial values for the fishery survey selectivity mimic dome-shaped patterns with a decline at the 6+ group. However, the range of initial values is wide and almost any pattern can be estimated.
- The fishery selectivity is allowed to vary over time in the assessment period. Three periods are considered: 1978–1987, 1988–2005 and 2006–2016. Selectivity-at-age is estimated for each period and assumed to be fixed over time. The transition between periods is done as a random walk.

The model estimates population biomass in the beginning of the last assessment year (interim year). There are data from the acoustic survey but not from the fishery (catch and age composition) for the interim year. Data used for the interim year are the following: stock weights-at-age, catch biomass and catch weights-at-age are equal to those assumed for short-term predictions. The fishery age composition in the interim year is assumed to be equal to that in the previous year. The fishery age composition is included in the calculation of expected values but excluded from the objective function. Recruitment in the interim year is derived from the stock–recruitment relationship.

The model estimates spawning–stock biomass (SSB) and summary biomass (B1+, biomass of age 1 and older) at the beginning of the year. The reference age range for output fishing mortality is 2–5.

To include the SS3 stock assessment model within the MSE simulations running in FLBEIA, a function named 'ss32flbeia' originally developed to mimic the stock assessment of the Bay of Biscay sardine has been adapted for the Iberian sardine case study during WKSARMP (Citores, L. WD2019, Annex5). This function was used to update values for every assessment cycle. The 'ss32flbeia' function allows running assessments using SS3within FLBEIA.

The function needs the stock and indices objects as well as a folder with the reference assessment in SS3 (the one used to the conditioning of the OM for MSE). Within the FLBEIA MSE process, for each projection year, the function works as follows:

- Copies the reference assessment folder (containing all files needed to run ss3);
- Reads the ss3.dat, wtatage and .ctl files;
- Reads the catch and the indices values from the FLR objects;
- Sets 10^{-5} value for catches $<10^{-5}$;
- Eliminates catch-at-age for years where catch $<10^{-5}$;

- Creates new .dat,wtatage and .ctl files based on the reference .dat, wtatage and .ctl files with new catch and indices values from FLR objects;
- Runs ss3.exe executable;
- Reads ss3 output files using the r4ss package;
- Updates stock@harvest and stock@stock.n slots with SS3 output;
- Saves convergence indicator, recruitment, F_{bar}, SSB, catchabilities and selectivities from SS3 runs in the covars component of the OM and,
- Deletes the copied folder after running each realization.

Iberian Sardine case study: convergence issues

Specific model configurations were described above, but they include constant selectivity for ages 1+ for the acoustic survey and three distinct periods for fishery selectivity in which selectivity for ages 3, 4 and 5 are assumed to be equal. The rest of fishery selectivity-at-age parameters are a random walk from the previous age. Initial trials that mimicked the stock assessment with these reference settings resulted in convergence problems (Citores, L WD2019, Annex 5). During the projection period in some years the SS3 assessment resulted in extremely high SSB values in comparison with the values obtained in the previous assessments (Figure 4.2), meaning that all the assessment was rescaled.

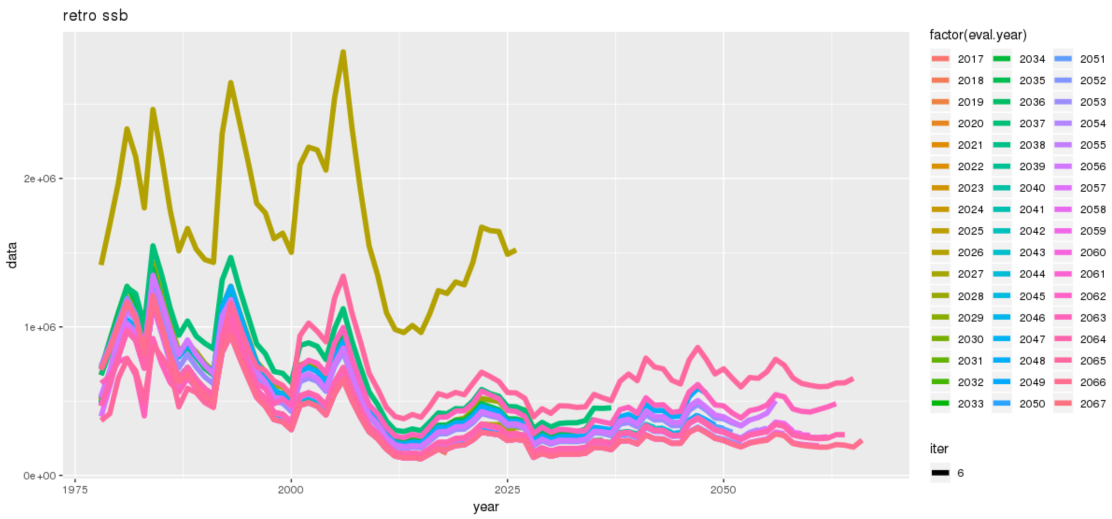


Figure 4.2. Estimated SSB values along the whole time period (from 1978 until the last projection year 2067) for each assessment year (eval.year).

These types of realizations were identified using the gradient change at SS3 and the ratio of the change of SSB from one assessment year to the next as indicators of convergence. Runs that did not converge showed a very low selectivity for the plus group (6+) in blocks 2 and 3 (Figure 4.3) in comparison with the values obtained in the reference assessment. Originally, the parameter to estimate selectivity in the last age was bounded by (-4, 4) and for many of the iterations within FLBEIA the stock assessment with SS3 could not converge. In an attempt to solve this, the bounds for the fishery selectivity for the last age group were changed to (-0.2, 0.2) so that 80% of iterations converged.

Finally, in order to have the number of desired iterations converged for the MSE, a condition was added when running FLBEIA iterations. The final gradient change from SS3 outputs is saved and it checks if this value is <0.001 for every assessment year. If this condition is not fulfilled the simulation seed in R is changed and the FLBEIA process is run again until the condition is held.

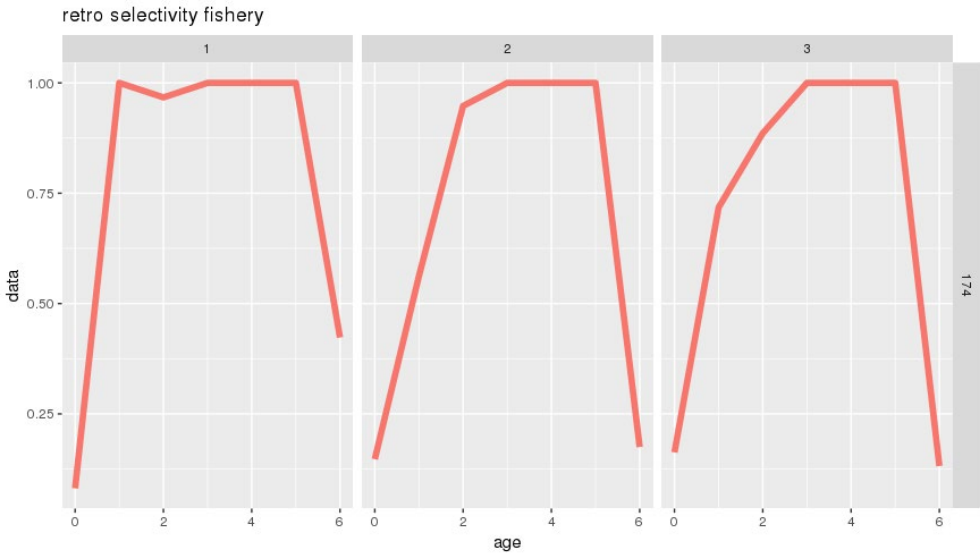


Figure4.3. Estimated fishery selectivity-at-age for each of the three time blocks defined in ss3. Selectivity for the last age in blocks 2 and 3 is very low which was detected in the run that did not converge, and this plot is a particular case.

Fitting the 6+ group has been problematic over the years. If estimated separately from the oldest true ages, both survey and fishery selectivity of the 6+ group indicate that less old fish are observed/caught than expected according to the mortality model. Possible explanations have been discussed in WGs, such as emigration of old individuals from the survey/fishing areas and higher natural mortality due to senescence. The issue was addressed at benchmarks since 2006 (ICES, 2006; 2012; 2017), in some cases together with temporal variation in selectivity and model over-parameterization. The WGs recognized the influence of small changes of selectivity assumptions, both in terms of model fit and on the scale of the assessment. It has been acknowledged that current model assumptions, such as freely estimated selectivity-at-age 6+ and block changes in selectivity over time, have improved the assessment. It has also been acknowledged in the benchmarks, that a better understanding of the biological basis for time- and age-varying selectivity is needed and that further analysis of the impact of this assumption on the assessment is required.

4.3.2 Short-term forecast

Regarding the short-term forecast the same procedure as described in the stock annex with small deviations was used. For the case of the sardine, the initial stock size corresponds to the assessment estimates for ages 1–6+ at the final year of the assessment. The maturity ogive corresponds to a knife-edge ogive. Input values for the proportion of F and M before spawning are zero, which corresponds to the beginning of the year when the SSB is estimated by the model. Weights-at-age in the stock are calculated as the arithmetic mean value of the last six years of the assessment but in this case were calculated as the arithmetic mean value of the last three years of the assessment. Weights-at-age in the catch are calculated as the arithmetic mean value of the last three years of the assessment. The exploitation pattern is equal to the last year of the assessment. For the intermediate year assumptions, predictions were carried out assuming no implementation error and therefore they were made with a catch constraint for the assessment year equal to the TAC advised for that year. Recruitment in the interim year and forecast year was set equal to the geometric mean of the last five years.

4.3.3 Decision Rule

The forecast B1+ at spawning time of year t+1 is used to apply the TAC setting procedures according to the MRP. Simulation testing was performed for the two harvest control rules proposed in the MRP (Section 1.2) and to alternative catch rules as described in the next section (Section 4.4).

4.3.4 Implementation error

The present MSE is run without implementation error, i.e. assuming perfect implementation of the Total Allowable Catch (TAC) advice, which may include zero catch.

4.4 Simulations

The FLBEIA MSE simulation carried out to analyse the performance of the proposed MRP is based on 1000 populations (*iters*), each projected from 2019 to 2048. Therefore, the full-feedback MSE performed simulations for *nt*= 30 future years resulting in 30 000 assessment cycles for each scenario. For comparison, the same MSE simulations were carried out for the case in which no observation and assessment errors were included. Given the computational burden, all the simulations were carried out in the computation cluster located in AZTI. Simulations were carried out using the FLR packages FLCore (version 2.6.12), FLBEIA(version 1.15.4) and FLash (version 2.5.11; used for short-term projections). The results were examined using the package FLBEIAshiny (1.0.0).

4.4.1 Scenarios and harvest control rules

No base scenario was defined. Instead, several scenarios with different OMs (i.e. productivity regimes) and different MPs (i.e. advice assumptions on the Biological Reference Points or 'perceived' BRPs) were run (Table 4.6). HCR1 and HCR2 (Figure 4.5) consider that we are in a Medium productivity regime and therefore the BRPs are the same as the current adopted (ICES, 2018). To consider the possibility that we could be in a Low productivity regime (Section 3.3) simulation testing was performed for two additional catch rules, HCR3 and HCR4, with reference levels (B_{lim}, F_{low} and F_{tgt}) based on the BRP's estimated for that regime (Figure 4.6). Moreover, other two HCRs were considered, designated HCR5 and HCR6, by scaling the F_{tgt} in HCR1 and HCR2 to 0.10 instead of 0.12 and all other F reference points accordingly (Figure 4.7). In total 12 scenarios (Table 4.6, sc1 to sc12) were run in full feedback MSE with 1000 iterations, variability in the initial population and with observation error. Finally, a no fishing rule (HCR7) was also run (Table 4.6, sc13 to sc16).

It was found that full-feedback MSE runs show some bias in the assessment (Citores, L. WD2019, Annex 6).To further explore the performance of the HCRs tested and compare scenarios 1 to 12 that have bias in the assessment, all scenarios were also run without assessment and without observation error.

Table 4.6. Simulations scenarios run with full-feedback MSE.

Scenario code	Operating Model (BRPs)	Advice (BRPs)	HCRs
SC1	Medium B_{lim}=337 thtF_{MSY}=0.12	Medium B_{lim}=337 th t F_{MSY}=0.12	HCR1: F_{low}=0.10, F_{tgt}=0.12 B_{lim}=337 th t, B_{low}=113 th t
			HCR2: F_{low}= 0.085, F_{tgt}=0.12 B_{lim}=337 th t, B_{low}=113 th t
SC2	Low B_{lim}=196 thtF_{MSY}=0.03		HCR1: F_{low}=0.10, F_{tgt}=0.12 B_{lim}=337 th t, B_{low}=113 th t
			HCR2: F_{low}= 0.085, F_{tgt}=0.12 B_{lim}=337 th t, B_{low}=113 th t
SC3	Low–medium		HCR1: F_{low}=0.10, F_{tgt}=0.12 B_{lim}=337 th t, B_{low}=113 th t
			HCR2: F_{low}= 0.085, F_{tgt}=0.12 B_{lim}=337 th t, B_{low}=113 th t
SC4	Mix		HCR1: F_{low}=0.10, F_{tgt}=0.12 B_{lim}=337 th t, B_{low}=113 th t
			HCR2: F_{low}= 0.085, F_{tgt}=0.12 B_{lim}=337 th t, B_{low}=113 th t
SC5	Medium B_{lim}=337 thtF_{MSY}=0.12	Low B_{lim}=196 th t F_{MSY}=0.03	HCR3: F_{low}=0.027, F_{tgt}=0.032 B_{lim}=196 th t, B_{low}=113 th t
			HCR4: F_{low}=0.023, F_{tgt}=0.032 B_{lim}=196 th t, B_{low}=113 th t

Scenario code	Operating Model (BRPs)	Advice (BRPs)	HCRs
SC6	Low B_{lim}=196 thtF$_{MSY}$=0.03		HCR3: F_{low}=0.027, F_{tgt}=0.032 B_{lim}=196 th t, B_{low}=113 th t
			HCR4: F_{low}=0.023, F_{tgt}=0.032 B_{lim}=196 th t, B_{low}=113 th t
SC7	Low–medium		HCR3: F_{low}=0.027, F_{tgt}=0.032 B_{lim}=196 th t, B_{low}=113 th t
			HCR4: F_{low}=0.023, F_{tgt}=0.032 B_{lim}=196 th t, B_{low}=113 th t
SC8	Mix		HCR3: F_{low}=0.027, F_{tgt}=0.032 B_{lim}=196 th t, B_{low}=113 th t
			HCR4: Flow=0.023, Ftgt=0.032 Blim=196 th t, Blow=113 th t
SC9	Medium B_{lim}=337 thtF$_{MSY}$=0.12	Medium B_{lim}=337 th t F_{MSY}=0.12	HCR5: F_{low}=0.083, F_{tgt}=0.10 B_{lim}=337 th t, B_{low}=113 th t
			HCR6: F_{low}=0.071, F_{tgt}=0.10 B_{lim}=337 th t, B_{low}=113 th t
SC10	Low B_{lim}=196 thtF$_{MSY}$=0.03		HCR5: F_{low}=0.083, F_{tgt}=0.10 B_{lim}=337 th t, B_{low}=113 th t
			HCR6: F_{low}=0.071, F_{tgt}=0.10 B_{lim}=337 th t, B_{low}=113 th t

Scenario code	Operating Model (BRPs)	Advice (BRPs)	HCRs
SC11	Low–medium		HCR5: F_{low}=0.083, F_{tgt}=0.10 B_{lim}=337 th t, B_{low}=113 th t
			HCR6: F_{low}=0.071, F_{tgt}=0.10 B_{lim}=337 th t, B_{low}=113 th t
SC12	Mix		HCR5: F_{low}=0.083, F_{tgt}=0.10 B_{lim}=337 th t, B_{low}=113 th t
			HCR6: F_{low}=0.071, F_{tgt}=0.10 B_{lim}=337 th t, B_{low}=113 th t
SC13	Medium	Medium B_{lim}=337 th t No fishing	HCR7: TAC=0
SC14	Low		HCR7: TAC=0
SC15	Low–medium		HCR7: TAC=0
SC16	Mix		HCR7: TAC=0

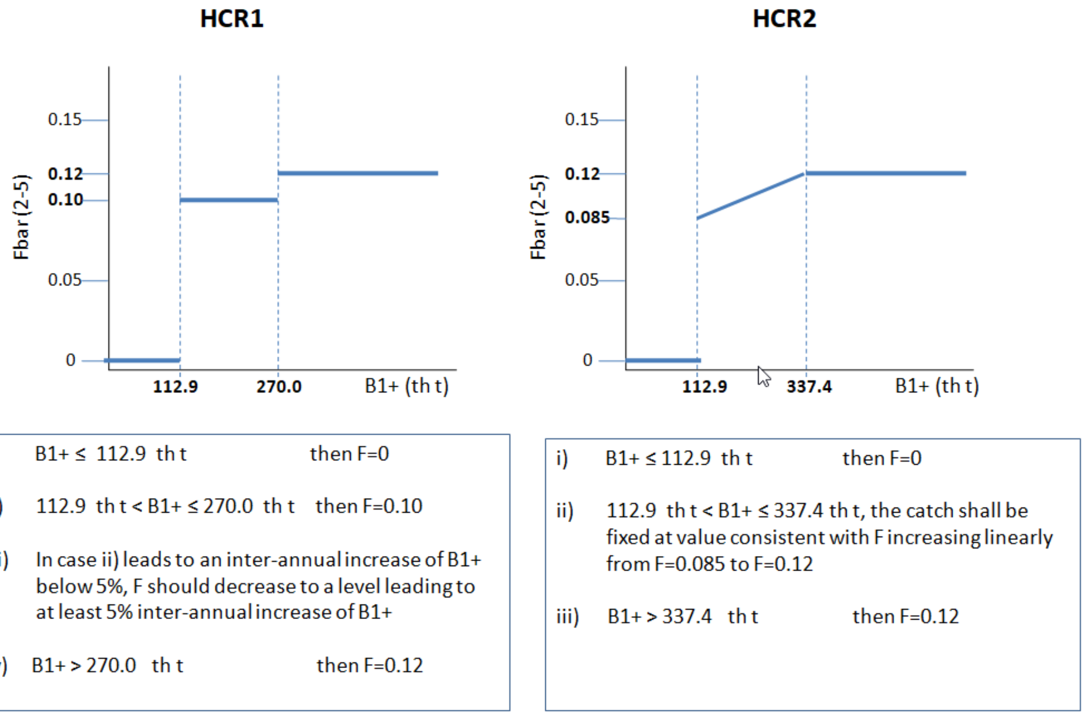


Figure 4.5. Harvest Control Rules HCR1 and HCR2 with fishing mortality and biomass of fish age 1 and older (B1+) reference levels.

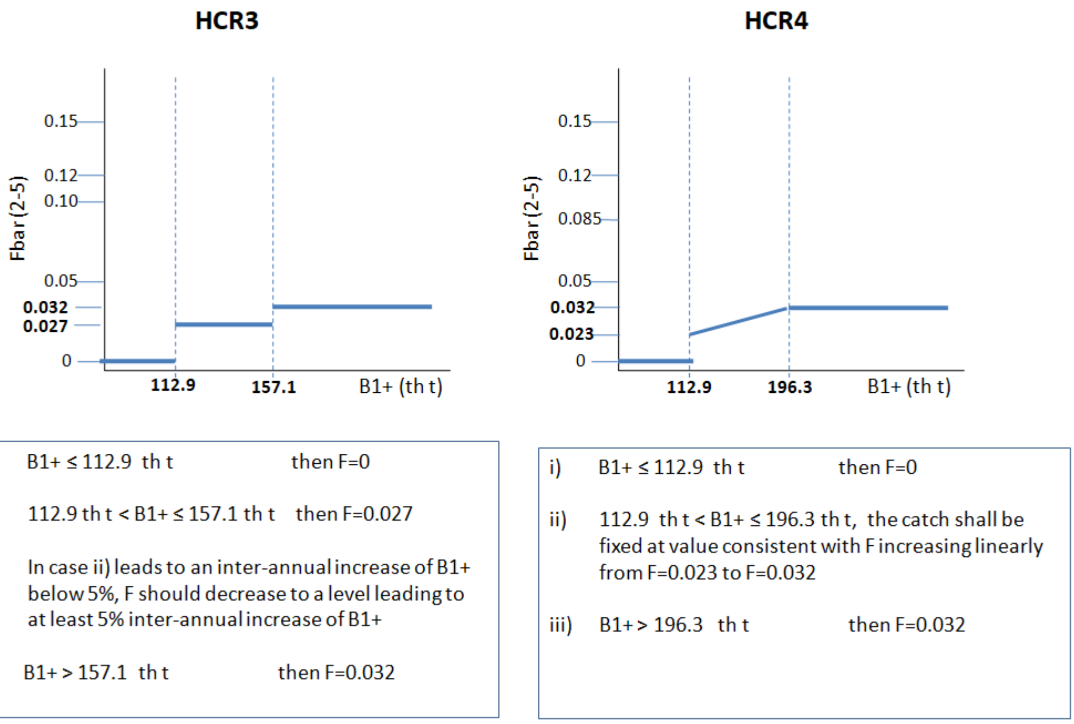
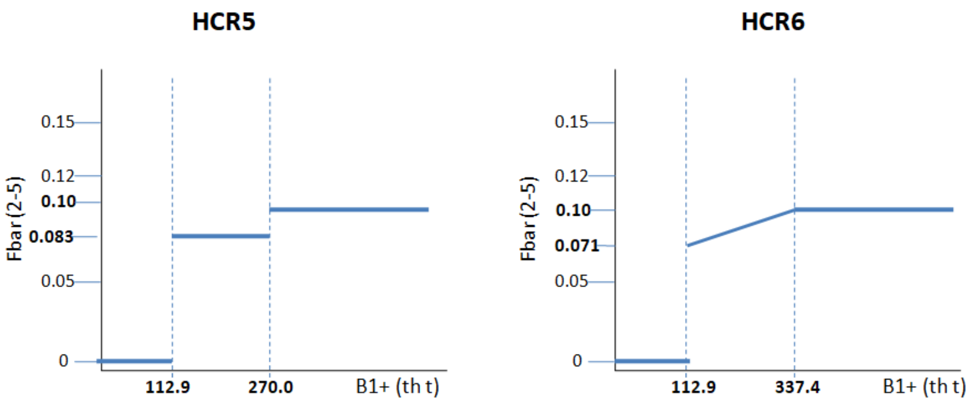


Figure 4.6. Harvest Control Rules HCR3 and HCR4 with fishing mortality and biomass of fish age 1 and older (B1+) reference levels.



i) B1+ ≤ 112.9 th t then F=0

ii) 112.9 th t < B1+ ≤ 270.0 th t then F=0.083

iii) In case ii) leads to an inter-annual increase of B1+ below 5%, F should decrease to a level leading to at least 5% inter-annual increase of B1+

iv) B1+ > 270.0 th t then F=0.10

i) B1+ ≤ 112.9 th t then F=0

ii) 112.9 th t < B1+ ≤ 337.4 th t , the catch shall be fixed at value consistent with F increasing linearly from F=0.071 to F=0.10

iii) B1+ > 337.4 th t then F=0.10

Figure 4.7. Harvest Control Rules HCR5 and HCR6 with fishing mortality and biomass of fish age 1 and older (B1+) reference levels.

4.5 Performance statistics

Table 4.7summarizes the performance statistics used during the MRP decision analysis. They include the median average biomass of fish age 1 and older (B1+), fishing mortality and catch. The interannual variation (IAV) of the catch (absolute values) was also estimated(average across years and then across iterations) as well as the probability of the fishery being closed (i.e. TAC equal to zero).

Following the special request, additional statistics were computed to evaluate if the main objective of the MRP (P(B1+≥0.80*B_{lim}) with at least 90% probability) was achieved by 2023. If this objective was not achieved by 2023, the year in which this objective would be achieved was estimated.

The probability of B1+ falling below B_{lim} was also computed. Currently ICES uses the risk3 ≤0.05 criterion as the basis for defining a multiannual plan as precautionary, although with exceptions made in cases requiring an initial recovery phase, or where a short-lived stock's natural variability (without fishing) exceeds the 5% threshold value (ICES, 2019). Risk type 3 is defined as the maximum probability that B1+ is below B_{lim}, where the maximum (of the annual probabilities) is taken over *nt* years. Finally, the year in which B1+ would be above or equal to B_{lim} with 95% probability was computed.

All these metrics were estimated for three time periods: an initial time period starting in the first projection year 2019 and ending in 2023, the year the clients would like to achieve the main objective of the MRP; a short timeperiod considered to be 2019 to 2028 (i.e. the first ten years of the projection period) and another one that corresponds to the last ten years of the projection period (2039 to 2048) which corresponds to the period after recovery and when the 'true' stock as reached equilibrium.

Table 4.7.Statistics used to summarize the performance of the MRP.

	Indicator	Time frame
Yield	Median catch	2019:2023;2019:2028;2039:2048
	IAV =$Mean\lvert Catch_{t-1} - Catch_t\rvert$	2019:2023;2019:2028;2039:2048
Fishing Mortality	Median F_{bar}, 5th and 95th percentiles	2019:2023;2019:2028;2039:2048
B1+	Median B1+, 5th and 95th percentiles	2019:2023;2019:2028;2039:2048
Probability of closure	P(TAC = 0)	2019:2023;2019:2028;2039:2048
Management objectives	$P(B1+_{2023} \geq 0.8B_{lim})$	In year 2023
	Year in which $P(B1+_{y} \geq 0.8B_{lim})$≥90%	NA
Precautionary considerations	Year in which $P(B1+ \geq B_{lim}) \quad > 95\%$	NA
	$P(B1+ < B_{lim})$	2019: 2048
	$Risk\ 3 = max(P(B1+ < B_{lim}))$	2039:2048

Given the current poor condition of the stock, the evaluation of the proposed MRP needs to consider a recovery phase and a long-term perspective. In the special request, the recovery time is specified to be by 2023. To consider also ICES guidelines in relation to considerations for a precautionary recovery plan, the generation time of the Iberian sardine stock should take into account that the stock recovery depends on the it´s life-history strategy (longevity, growth and fecundity rates as well as natural mortality). The mean generation time (the average time it takes for a mature female to be replaced by an offspring with the same reproductive capacity, it depends on fecundity and survivorship of each age group in the absence of fishing) of the Iberian sardine stock was estimated with Charlesworth (1994) and Punt (2012) approaches and using current adopted natural mortality-at-age, mean weight-at-age and maturity-at-age (Table 4.1) and considering a maximum age of 11 years. Generation time of the Iberian sardine stock was estimated to be around four years (Punt, 2012) or five years (Charlesworth, 1994). Number of years to fulfil the management objectives and the precautionary considerations for a recovery phase were compared to the generation time.

4.6 Software

FLBEIA is a generic tool to conduct Bio-Economic Impact Assessment of fisheries management strategies in a management strategy evaluation framework (Garcia *et al*., 2017). FLBEIA can be categorized as a ‘Models of Intermediate Complexity for Ecosystem assessments’ or MICE (Plagányi *et al*., 2014) focused on fishing activity in a multistock and multifleet context. It has been built using R-FLR packages (Kell *et al*., 2007) and can automatically beneficiate from new developments in those packages.

The stocks can be age or biomass structured. Trophic interactions have never been modelled in FLBEIA, but it could be done. There is also a development version where Gadget (Begley and

Howell, 2004) can be used as operating model. The activity of the fleet is divided in métiers and four processes are modelled. The short-term dynamics (total effort and its distribution along métiers), long-term dynamics (entry-exit of new vessels in the fishery), price formation and catch production. The covariates can be used to store any variable not included in the stocks and fleet components.

The link between the OM and the MP is done through the observation model that generates de observed data. Two types of data can be generated, the stocks and the abundance indices. Any observable variable can be subject to observation error, and the error is divided into two components, the aging error component and a multiplicative error. As the errors are introduced as input data, they can be conditioned using any distribution, bootstrap or other analysis. The perceived population is generated using an assessment model. There is the possibility of using the 'short-cut' approach or any assessment model available in R/FLR. What is needed, is a wrapper that generates the input and output of the model in the right shape. Wrappers are already available for SPiCT, XSA, sca in Fla4a and FLSAM. The management advice is generated using a harvest control rule. Two types are available, model-free HCRs and model-based ones. The model-free HCRs use the abundance indices generated by the observation model and do not require to apply any assessment model. In turn, the model-based HCRs use the output of the short-cut approach of an assessment model to generate the advice.

The adaptive management advice based on catch can be accompanied by technical measures like changes in selectivity, implicitly simulated spatio-temporal closures or effort restrictions for example.

The stochasticity is introduced using Montecarlo approximation and the iterations run in parallel. The results can be analysed and presented using the Shiny application available in the FLBEIAShiny package (https://github.com/flr/FLBEIAshiny).

The model is constructed in a modular way. The fishery system is discomposed in processes (recruitment, catch production, population growth…) and several models are provided to simulate each of them. Alternatively, new models can be coded and call from the function with no extra coding.

The model documentation is extensive. There is a research paper describing the model (Garcia *et al*., 2017). A manual that describes in detail all the models available is provided within the R library. And there is a set of dedicated tutorials in the FLR website http://www.flr-project.org/. The source code can be downloaded from GitHub (https://github.com/flr/FLBEIA) and the compiled package from the FLR website (http://www.flr-project.org/). There is a support mailing list flbeia@azti.es.

4.7 Summary of the methodology

A summary of the methodology used in the evaluation of the MRP for the Iberian sardine stock is presented in Table 4.6, following the ICES guidelines on MSE (ICES, 2019).

Table 4.6. Summary of the methodology used in the evaluation of the MRP for the Iberian sardine stock.

Background	
Motive/initiative/background	ICES received a Special Request from Portugal-Spain to evaluate a management and recovery plan (MRP) for the Iberian sardine under two Harvest Control Rules (HCR). The request also asks for the re-examination of Biological Reference Points (BRPs) for the stock. Scientists of IPMA, AZTI and IEO and external experts carried out the performance analysis during the WKSARMP workshop and several meetings via WebEx. Participants from the Portuguese purse seine producer's organization and NGO´s also contributed in the discussions of the MRP performance analysis. The Iberian sardine stock had a management plan from 2014 to 2016. The plan was re-evaluated in 2017 and found to be not precautionary (ICES, 2017) The stock biomass is well below Blim and fishing mortality is above F_{MSY}. The depletion of the population has made explicit the need for a recovery plan. The fishermen of Portugal and Spain have expressed their own points of view about the crisis of the sardine fishery.
Main objectives	The main objective of the MRP is the recovery of the stock, with a probability ≥90% that the stock–spawning biomass (B1+) is equal or above 80% of Blim by 2023.
Formal framework	The performance of the MRP is analysed during the WKSARMP workshop with scientists from several institutions
Evaluation work	The WKSARMP performance analysis is evaluated by ICES ACOM.
Method	
Software	MSE framework implemented in FLBEIA (García *et al*., 2017) using R-FLR packages (Kell *et al*., 2007).
Name, brief outline	The performance of the two proposed HCRs, as well as alternative HCRs, were analysed with a full-feedback MSE under several scenarios with different OMs and different MPs (i.e. advice assumptions on the BRP or 'perceived' BRP's). Age-structured operating model based on the last stock assessment and assessment model (Stock Synthesis) with catches-at-age and annual acoustic survey (PELAGO and PELACUS) and triennial DEPM survey as input. Assessment is performed in each simulation loop and the abundance indices are generated from the "true population" with lognormal distributed errors to simulate observation error. Observation error was also introduced in the numbers-at-age in the catch as a multiplicative lognormal error. The MSE was run without implementation error.
Reference or documentation	Documentation for the FLBEIA available in García *et al*., 2017 and for the stock assessment model in Methot and Wetzel, 2013.Code used for the simulation testing available in GitHub (https://github.com/ssanchezAZTI/FLBEIA_mseIBpil).
Type of stock	Medium–short life span (6+), pelagic, high socio-economic importance at the regional level.
Knowledge base	ICES category 1 stock.
Type of regulation	Annual catch limits and seasonal closures regulated by Portugal and Spain.

Operating model (Biology and Fishery Model)	Function, source of data	Stochastic? – how (distribution, source of variability)
Base case	Given that regime shifts might have occurred based on the stock–recruitment relationship and environmental indicators, WKSARMP concluded that the performance analysis of the MRP should be based on a combination of OMs and reference points consistent with the OMs. Given the high uncertainty on the future productivity of the stock and the duration of regime shifts, the group did not propose a base case. Instead presented the arguments in favour and against the adoption of each scenario and their implications for stock recovery (Section 3.4).	
Recruitment	Hockey-stick model according to four scenarios of productivity: (low, medium productivity and two scenarios with a persistent or non-persistent transition between the low and medium productivity dependent on the biomass level).	Modelled as stochastic, variability introduced from a lognormal distribution with μ=0 and σ as the estimated in each productivity fit of the stock–recruitment model. The low productivity regime uses data pairs from historical years of 2006–2017, and the medium and transition low–medium regimes uses data pairs from 1993–2017.
Growth	Stock weight-at-age as the arithmetic mean of the last six years of the assessment (2012–2017). Catch weight-at-age as the arithmetic mean value of the last three years of the assessment (2015–2017).	Stochasticity not included as no significant trends are found in historical weight-at-age. Age-dependent and time-invariant
Maturity	Knife-edge, with 0 for age 0 and assumed to fully mature at-age 1+; as in last assessment (WGHANSA, 2018)	No evidences to support added stochasticity in maturity. The knife-edge ogive is time-invariant resulting in SSB=B1+ during the projection period.
Natural mortality	As in last assessment (WGHANSA, 2018)	No evidence that support including variability in the natural mortality pattern. Natural mortality is age-dependent and time-invariant.
Fishery selectivity	Age-dependent and set as the average from the last six years of the assessment (2012–2017).	No. These values mimic the recent dome-shaped pattern estimated in the last assessment with ages from 3 to 5 bound and a decline at the 6+ group.
Initial stock numbers	The estimates of abundance (ages 0–6+) in 2017 from the last assessment (WGHANSA, 2018)	Variability in the initial populations implemented with a lognormal distribution error with **μ=0 and σ=**$\sqrt{\log(cv^2+1)}$) with coefficient of variation (cv) derived from the estimated log-numbers-at-age for the year 2018.
Technical interactions	Majority of sardine catches and landings are made by the purse-seine fleet in clean and single species hauls. No significant technical interactions are expected with other gears.	N/A

Biological interactions	Asynchronous dynamics of sardines and the pair anchovy and chub mackerel in the area are documented. Conditions that favour these two species were reported to be opposite to those favouring sardines, but a direct causality was not shown yet, with the available data. Therefore, it is not clear yet if they are a consequence of a modification of the ecosystem or the result of a direct impact of these species on sardine distribution and abundance. For the purposes of the MSE, these biological interactions were believed not to be significant drivers of Iberian sardine stock development.	N/A
Decision basis	Catch in the advice year, t, based on B1+ at the beginning of year t	N/A
Number of populations	1000	N/A
Projection time	2019 to 2048; 30 years	N/A
Observation and implementation models		
With assessment		
Input data	Catches, annual acoustic survey (PELAGO and PELACUS) and triennial DEPM survey	Catch: errors lognormally distributed with μ and σ from the logarithmic residuals in the observed catch-at-age Surveys: error coefficients lognormally distributed to simulate observation error, where: i) Acoustic survey: $\mu = \log \frac{Nas_{a,1996:2017}}{Npop_{a,1996:2017}}$ and $\sigma =$ $sd(\log\log \frac{Nas_{a,1996:2017}}{Npop_{a,1996:2017}})$ ii) DEPM survey: $\mu=0$ and $\sigma=\sqrt{\log(0.25^2 + 1)}$
Comparison with ordinary assessment?	Yes	Full feedback MSE runs show similar bias when compared to the current assessment in scenarios assuming medium (“normal”) productivity. In other scenarios (mainly low productivity), this bias tends to aggravate and diverge from the level observed in the assessment.
Deviations from WG practice?	Yes	The SS3 bounds settings for the fishery selectivity-at-age 6+ were changed to minimize convergence issues in the projection years.

Harvest rule	
Harvest rule design	HCR1: i) B1+ ≤ Blow then F=0 ii) Blow< B1+ ≤ 0.8*Blim then F=0.10 iii) In case ii) leads to an inter-annual increase of B1+ below 5%, F should decrease to a level leading to at least 5% inter-annual increase of B1+ iv) B1+ > 0.8*Blim then F=0.12 HCR2: i) B1+ ≤ Blow then F=0 ii) Blow< B1+ ≤ Blim the catch fixed at value consistent with F increasing linearly from F=0.085 to F=0.12 iii) B1+ >Blim then F=0.12 Blow = 112 943 tonnes, is the biomass of fish of age 1 and older estimated for 2015 in the 2018 stock assessment (ICES, 2018).
Stabilizers	No stabilizers
Duration of decisions	TAC annually
Revision clause	After five years or before if any of the following situations are identified: i) If the performance of the stock assessment deteriorates substantially relative to what was assumed in the MSE; ii) If the observed conditions of the stock and/or fishery depart considerably from what was assumed in the MSE.

Presentation of results	
Interest parameters	$P(B1+ \geq 0.8B_{lim})$ ≥90% by 2023(MRP main objective) First year that ($\left(B1+ \geq 0.8B_{lim}\right)$ with≥90% probability Computed in the short-term (2019:2023), first ten years (medium-term) (2019:2028), and long-term (2029:2048): P(B1+ <B_lim) Probability of fishery closure, average number of years with fishery closure Median catch and IAV; MedianFbar, 5th and 95th percentiles; Median B1+, 5th and 95th percentiles First year that (B1+ ≥B_lim) with≥95% probability
Risk type and time interval	Prob3 = maximum probability that B1+ is below Blim, where the maximum of the annual probabilities is taken over the long-term period.
Precautionary risk level	Prob3 <= 5% in the long-term

5 Results and Discussion

Simulation testing of the performance of proposed MRP and alternative Harvest Control Rules was carried out with fullfeedback MSE for twelve scenarios (combinations of assumed 'true' state of nature, 'perceived' state of nature and HCRs; Table 4.6). All scenarios were also run without observation error and no assessment.

5.1 MSE testing of catch rules HCR1 and HCR2

The simulation testing of the catch rules proposed in the special request, namely HCR1 and HCR2 (Figure 4.5), was performed assuming four productivity scenarios for the 'true' stock, corresponding to Medium, Low, Low–medium and Mix productivity, and considering that the 'perceived' stock was of Medium productivity (Table 4.6: sc1, sc2, sc3 and sc4).

5.1.1 Simulated recruitment, spawning–stock biomass (B1+), fishing mortality and catch

The trajectories of the key parameters R, B1+, F_{bar} and catch under sc1 to sc4 (Medium, Low, Low–medium and Mix productivity in the 'true' stock and 'perceived' Medium productivity), are shown in Figures 5.1–5.4.

Medium true stock productivity leads to an increase of median R to around 11 million individuals and an increase of median B1+ to around 500 thousand tonnes in the medium and longterm. The lower confidence limit of B1+ is close to the corresponding B_{lim} = 337.4 thousand tonnes in the longterm (Figure 5.1). If the true stock has Low productivity, median R will also increase, but to maximum values around 6 million individuals, and the median B1+ increases to around 250 thousand tonnes (Figure 5.2). The lower confidence limit of B1+ is below the corresponding B_{lim} = 196.3 thousand tonnes in the long term. For Low–Medium and Mix productivity scenarios, the long-term median R and B1+ are closer to those of the Low productivity than to those of the Medium productivity, although the confidence intervals are much wider (Figures 5.3–5.4).

For corresponding scenarios, the trajectory of median B1+ is similar for HCR1 and HCR2 although HCR1 always leads to slightly higher B1+ at medium and long-term than those of HCR2, because it implies a higher frequency of fishery closures. Frequent fishery closures in HCR1 are observed at the beginning of the simulation period (while B1+ is below 80% B_{lim}) whenever the target of a 5% inter-annual increase of B1+ is not achievable for any fishing mortality. A similar situation applies to the trajectories of median R. The main difference between the two rules is the trajectory of median F_{bar} and therefore of the predicted median catches; HCR1 predicts a sharp decrease of the catches with several years of closure of the fishery in the first 5–6 years, followed by a sharp increase of F_{bar} and catches in the next 2–3 years. In the medium and long-term, HCR1 leads to lower overall catches with higher fishing mortality and a higher probability of fishery closure over the whole simulation period (Figures 5.1–5.4).

In the scenarios for which the true stock productivity is Medium and it is perceived as Medium as well (therefore the stock is managed according to a Medium productivity), all parameters increase in the medium-term and stabilize in the long-term (Figure 5.1). If the stock productivity is wrongly perceived the trajectories do not stabilize. In the scenarios for which the Low productivity is perceived as Medium, after the initial increasing phase, B1+ shows a decreasing trend while median F_{bar} and catches show an increasing trend (Figure 5.2).

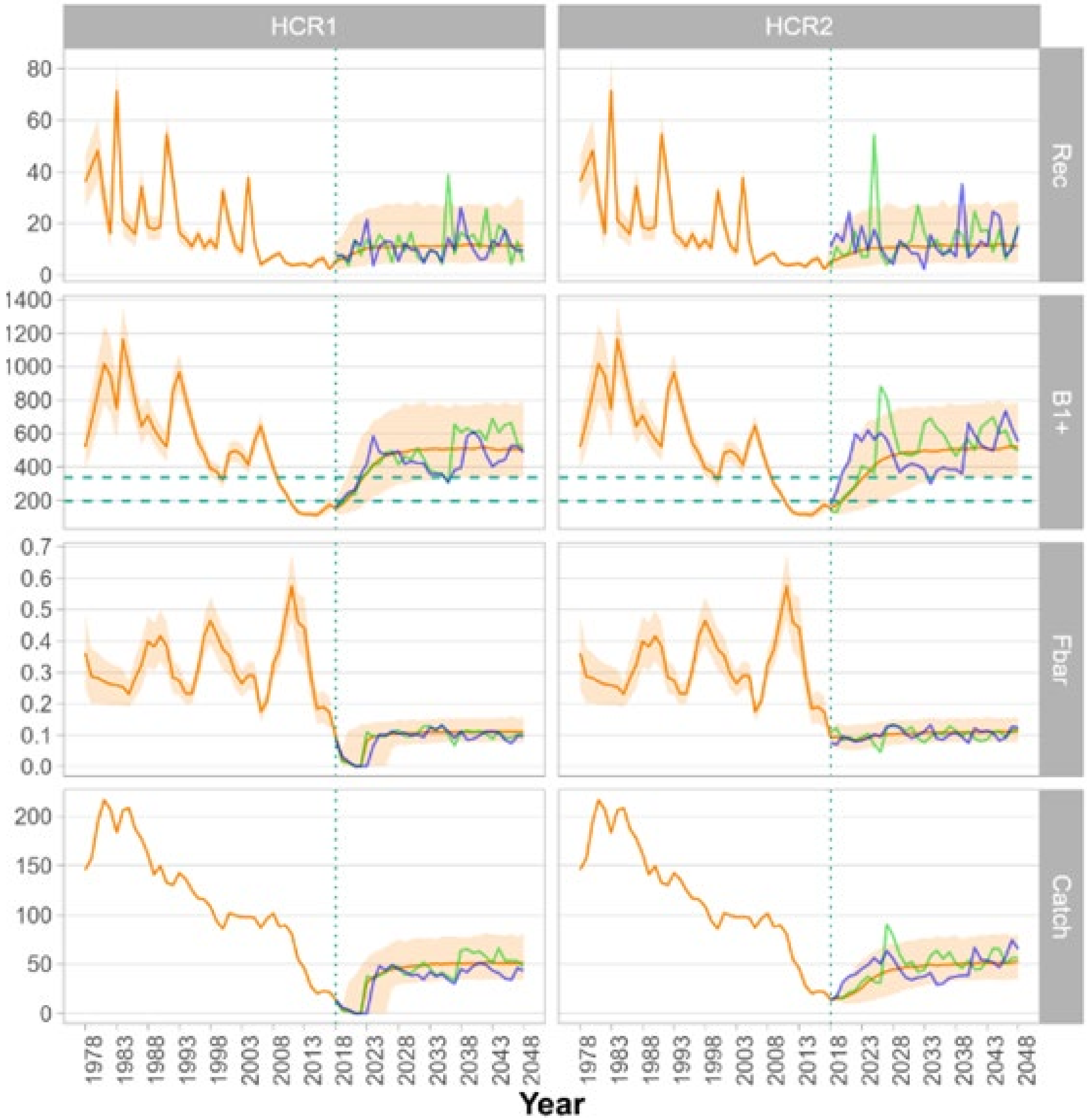


Figure 5.1. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2\text{-}5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR1 and HCR2 under 'true' stock of Medium productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

Figure 5.2. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2\text{-}5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR1 and HCR2 under 'true' stock of Low productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

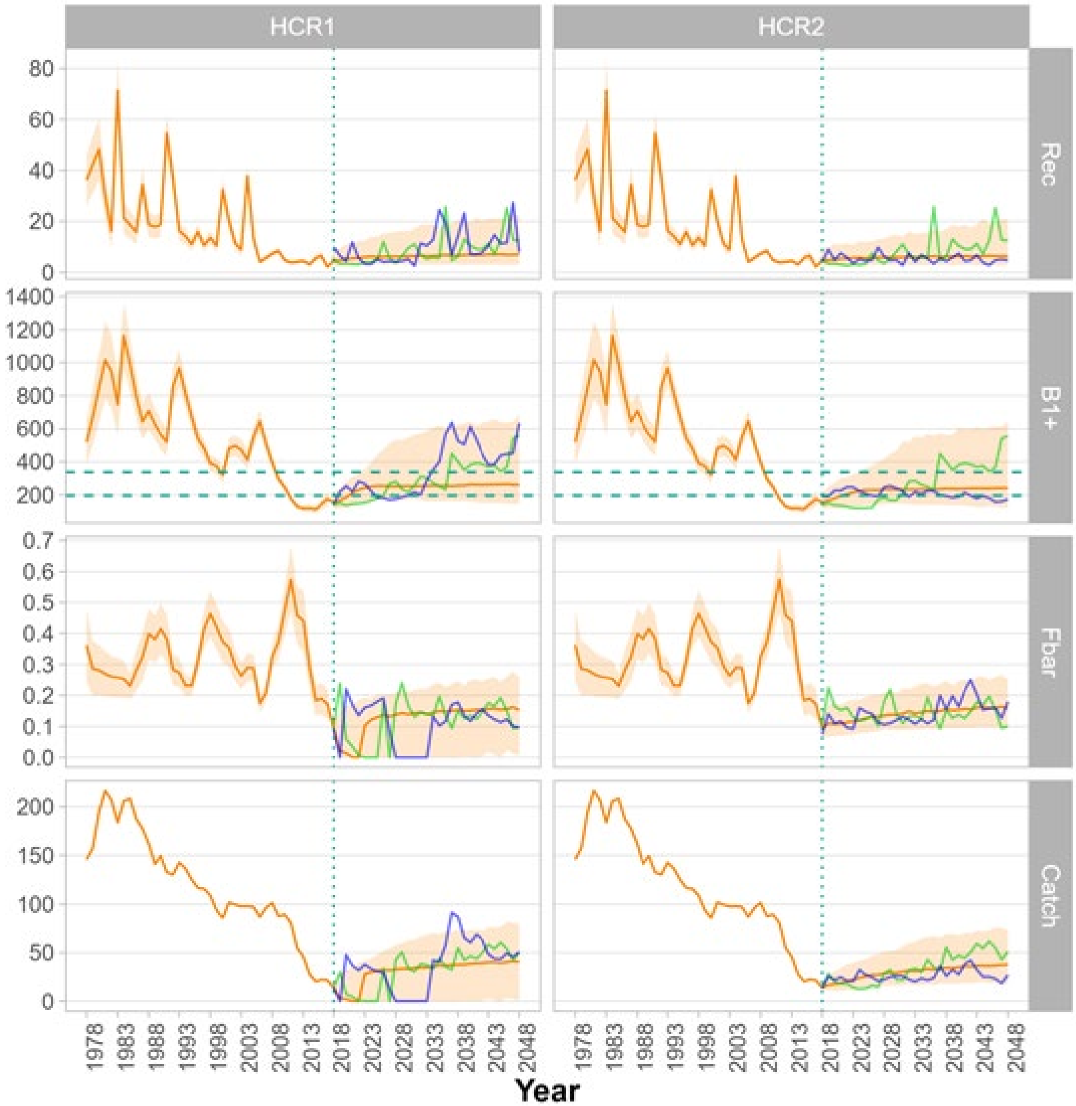


Figure 5.3. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality (F_{bar2-5}, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR1 and HCR2 under 'true' stock of Low–medium productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

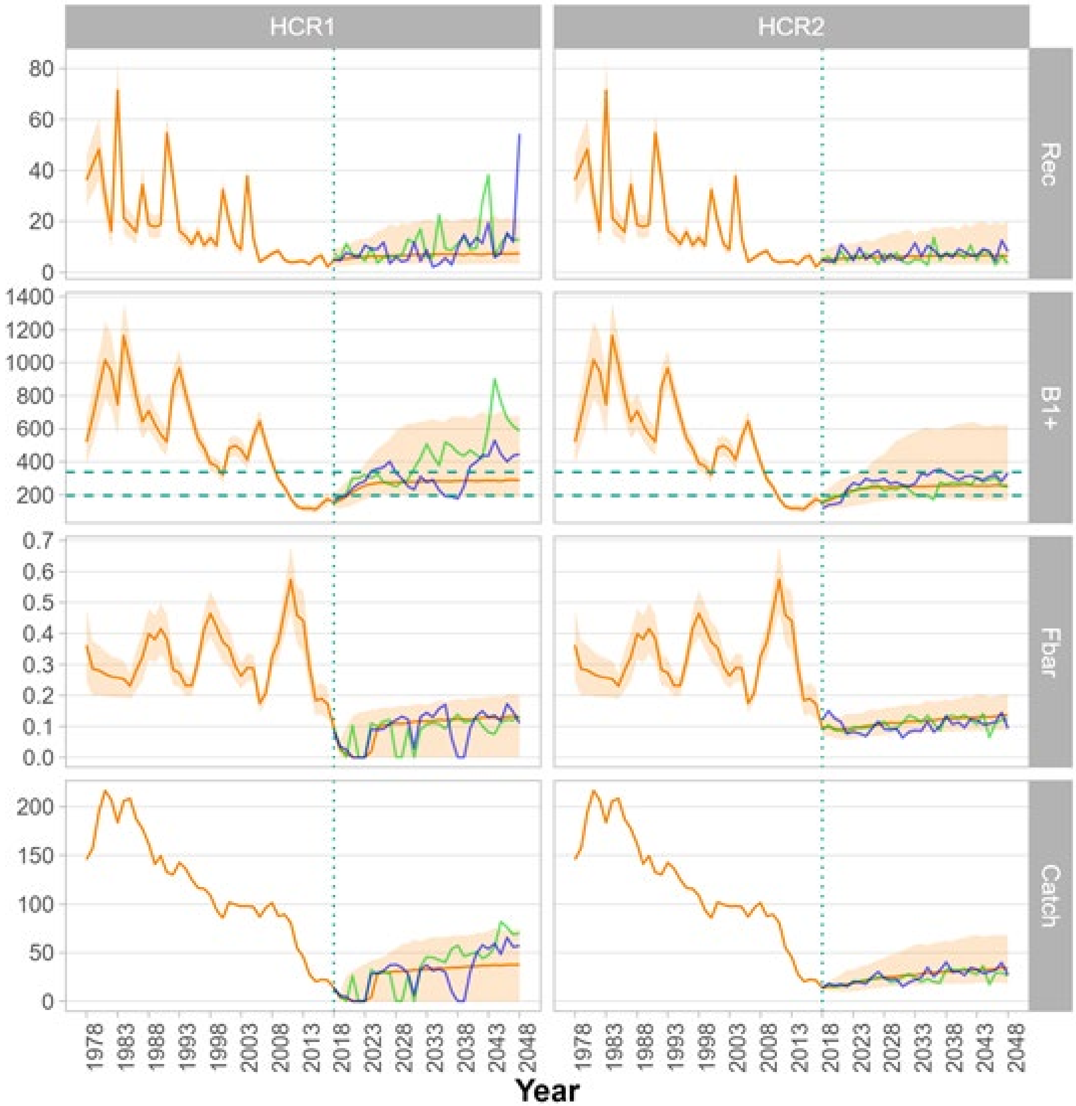


Figure 5.4. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality (F_{bar2-5}, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR1 and HCR2 under 'true' stock of Mix productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

5.1.2 Performance statistics

During the first five years of the projection period (2019–2023, initial period) the estimated median biomass of fish age 1 and older(B1+) varied between 190 and 251 thousand tonnes, depending on the assumed productivity for the 'true' stock and the HCR applied (Table 5.1). For each scenario, the median B1+ is estimated to be higher when applying HCR1 (251 thousand tonnes for the Medium productivity scenario, 213 thousand tonnes for the Mix and 206–207 thousand tonnes for the Low and Low–medium scenarios) than when applying HCR2 (232 thousand tonnes for the Medium, 195 thousand tones for the Mix and 190 thousand tonnes for both Low and Low–medium scenarios). As shown in Table 5.1,the probability of a fishery closure in the initial period with HCR1 is estimated between 28% and 40%, which ranges, on average, between one (Medium scenario) and two years (Low, Low–medium and Mix scenarios) for this initial period (Figure 5.9). With HCR2, the probability of a fishery closure is 0, except in the Mix scenario. The estimated median catch among productivity scenarios was lower when applying HCR1 (1 to 3 thousand tonnes) than when applying HCR2 (16 to 19 thousand tonnes) with an interannual variability between 6 and 9 thousand tonnes for HCR1 and between 3 and 5 thousand tonnes for HCR2 (Table 5.1).

In the long term, i.e. for the last ten years of the projected period (2039–2048, last period) the median B1+ is estimated as the highest for the Medium scenario, with values similar between the two catch rules (508 and 510 thousand tonnes for the HCR1 and HCR2, respectively). Under the Low, Low–medium and Mix scenarios, the estimated B1+ ranges between 220 thousand tonnes (HCR2 applied to the Low scenario) and 256 thousand tonnes (HCR2 applied to the Mix scenario). There is still a probability of fishery closure with HCR1 in the Low (7%), in the Low–medium (4%) and in the Mix (6%) scenario. The median catch in the longterm is similar for both rules, being estimated for both catch rules as 51, 32–34, 36–40 and 33–37 thousand tonnes under the Medium, Low, Low–mediumand Mix scenario, respectively.

The probability that B1+ is equal or above 80%B_{lim}(157.1 thousand t for the Low scenario and 270 thousand t for the other scenarios) by 2023 with the HCR1, is around 79%, 95%, 29% and 38% for the Medium, Low, Low–medium and the Mix scenario, respectively. For the HCR2 the probability is around 67%, 85%, 19% and 21% for the Medium, Low, Low–medium and the Mix scenario, respectively (Table 5.1, Figure 5.6). Assuming Medium productivity for the 'true' stock, the estimated average number of years of the projected period required to ensure, with a probability of at least 90% that B1+≥0.8*B_{lim}, are seven years for HCR1 (from 2019 to 2025) and ten years for HCR2 (from 2019 to 2028) (Table 5.1), and when assuming a Low productivity, the average number of years is four for HCR1 (2019–2022) and eight for HCR2 (2019–2026). Note that these probabilities are calculated in relation to the B_{lim} of each true productivity scenario, 196.3 thousand tonnes in the Low and 377.4 thousand tonnes in the other scenarios. This condition is not met for both HCRs in the Low–medium and Mix scenarios since the median B1+ is estimated to be well below 80%B_{lim}during the thirty years of the projection period (Table 5.1).

It is estimated that the average number of years of the projected period required to ensure, with a probability of 95%, that B1+≥B_{lim} are seventeen for HCR1 and twenty-two for HCR2 under Medium scenario. The ICES precautionary criterion, computed as the risk3 in the long term (2039–2048), is 5% for HCR1 and 6% for HCR2 under the Medium productivity scenario. For scenarios Low, Low–medium and Mix, risk3 largely exceeds 5% for both catch rules, ranging between 31–34% for the Low scenario, 68–78% for the Low–medium and 63–75% for the Mix scenario (Table 5.1).The scenario Medium is the only one where B1+ stabilizes in the last ten years of the simulation period, therefore it is considered appropriate to use the probability computed for risk3. In fact, as shown in Figure 5.7, the probability profile of all the other scenarios is still decreasing

(Low scenario) or increasing (Low–medium and Mix scenarios) in the last ten years of the simulation, clearly indicating that the stationary phase has not been reached. In fact, in the case of the Low–medium and Mix scenarios the proportion of population that have changed regime during the 30 years of the projection period is between 35% and 43% for HCR1 and between 26% and 33% for HCR2.

Performance statistics were also computed in relation to a low biomass reference level (B_{lim_low}=196.3 thousand t) for the true Medium productivity and in relation to a higher biomass reference level (B_{lim}=337.4 thousand t) for the true Low productivity scenario (Table 5.1, unshaded cells). Under the Medium scenario the MRP recovery objective would be reached for both HCRs (2021 with HCR1 and 2023 with HCR2). Also, risk3 would be 0% for both rules since between 2024 (HCR1) and 2027 (HCR2) the probability of B1+ being above B_{lim_low} is 95%. On the contrary and as expected, under the Low productivity scenario neither the MRP objective (17% for HCR2 and 30% for HCR1) or the ICES precautionary criterion would be fulfilled (98% risk3).

Table 5.1. Summary of the performance statistics for HCR1 and HCR2 assuming the 'perceived' stock to be Medium productivity and the 'true' stock to be of Medium, Low, Low–medium and Mix productivity. Shaded cells show the metric values corresponding to the reference B_{lim} of the 'true' stock (B_{lim}=337.4 thousand tonnes for Medium, Low–medium and Mix scenarios and B_{lim_low}=196.3 thousand tonnes for the Low scenario).

			Medium							
			Medium		Low		Low-Medium		Mix	
			HCR1	HCR2	HCR1	HCR2	HCR1	HCR2	HCR1	HCR2
	Metrics	Period	SC1		SC2		SC3		SC4	
Indicators	Spawning Biomass: B1+ (median, th tonnes)	2019-2023	251	232	207	190	206	190	213	195
		2019-2028	362	325	231	211	232	211	247	222
		2039-2048	508	510	228	220	262	240	286	256
	F (median, year-1)	2019-2023	0.017	0.088	0.013	0.112	0.013	0.111	0.003	0.093
		2019-2028	0.084	0.094	0.104	0.121	0.097	0.119	0.019	0.098
		2039-2048	0.110	0.110	0.167	0.165	0.154	0.158	0.128	0.130
	Catch (median, th tonnes)	2019-2023	3	18	2	19	2	19	1	16
		2019-2028	32	27	28	23	28	23	3	19
		2039-2048	51	51	34	32	40	36	37	33
	IAV1 Catch (absolute, th tonnes)	2019-2023	9	5	9	4	9	4	6	3
		2019-2028	10	6	10	4	10	4	9	4
		2039-2048	8	8	9	5	9	7	10	6
	Probability of closure (%)	2019-2023	28	0	40	0	31	0	37	1
		2019-2028	17	0	29	0	23	0	31	1
		2039-2048	0	0	7	0	4	0	6	0
Special Request	Prob(B1+ ≥ 80%Blim) in 2023 (%)	2023	**79**	**67**	30	17	**29**	**19**	**38**	**21**
	Prob(B1+ ≥ 80%Blim_low) in 2023 (%)	2023	98	93	**95**	**85**	95	85	98	88
	first year P(B1+ ≥ 80%Blim) ≥90%	2019-2048	**2025**	**2028**	NA	NA	**NA**	**NA**	**NA**	**NA**
	first year P(B1+ ≥ 80%Blim_low) ≥90%	2019-2048	2021	2023	**2022**	**2026**	2022	2026	2022	2024
ICES criterion	first year P(B1+ ≥ Blim) > 95%	2019-2048	**2035**	**2040**	NA	NA	**NA**	**NA**	**NA**	**NA**
	first year P(B1+ ≥ Blim_low) > 95%	2019-2048	2024	2027	**NA**	**NA**	NA	NA	2025	NA
	Risk3 for Blim (%)	2039-2048	**5**	**6**	98	98	**68**	**78**	**63**	**75**
	Risk3 for Blim_low(%)	2039-2048	0	0	**31**	**34**	21	26	9	16

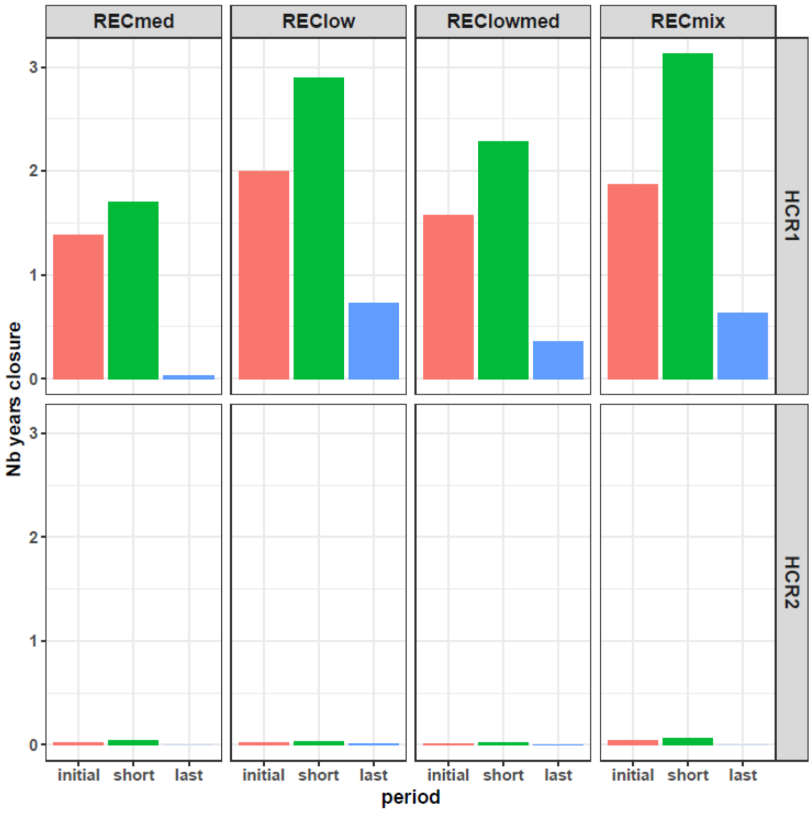


Figure 5.5. Average number of years with a fishery closure for catch rules HCR1 and HCR2 by period (initial: 2019–2023, short: 2019–2028, last: 2039–2048) for each assumed productivity of the 'true' stock.

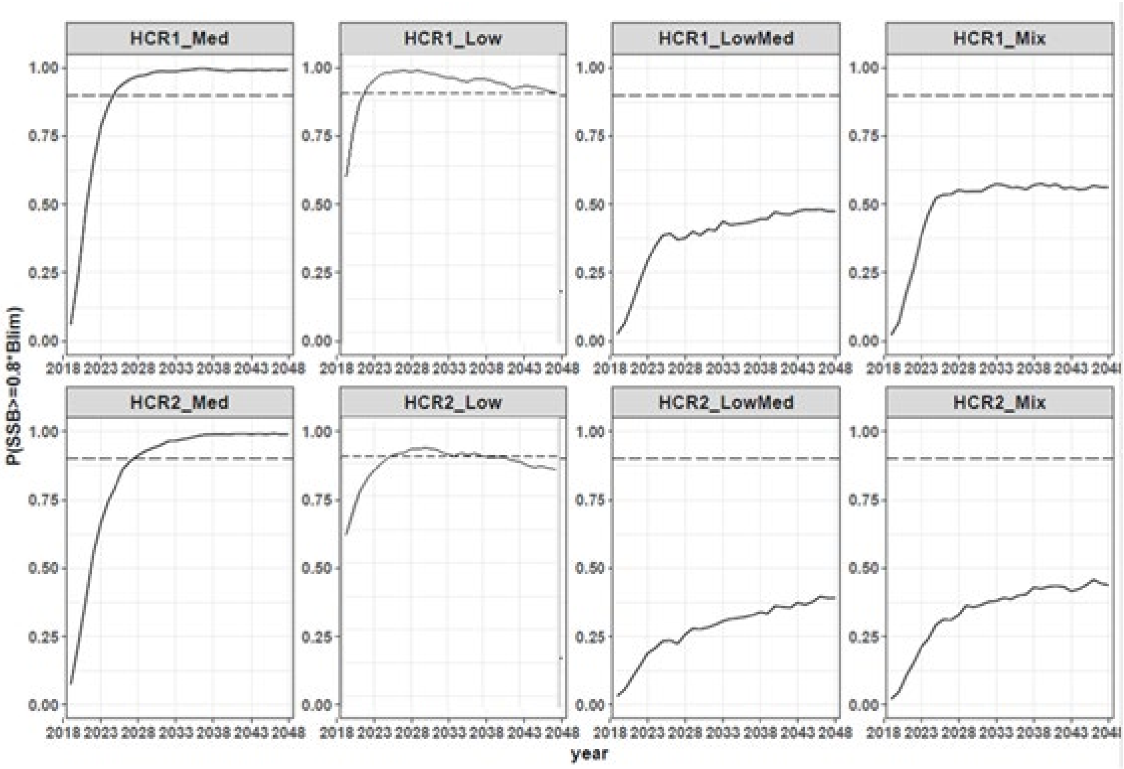


Figure 5.6. Probability profile of P(B1+≥80%B_{lim}) for catch rules HCR1 and HCR2 when 'true' stock is Medium, Low–medium, Mix (B_{lim}=337.4 thousand tonnes) and Low (B_{lim_low}=196.3 thousand tonnes) productivity and 'perceived' stock is Medium productivity, from 2018 to 2048. Horizontal dashed lines represent 90% probability.

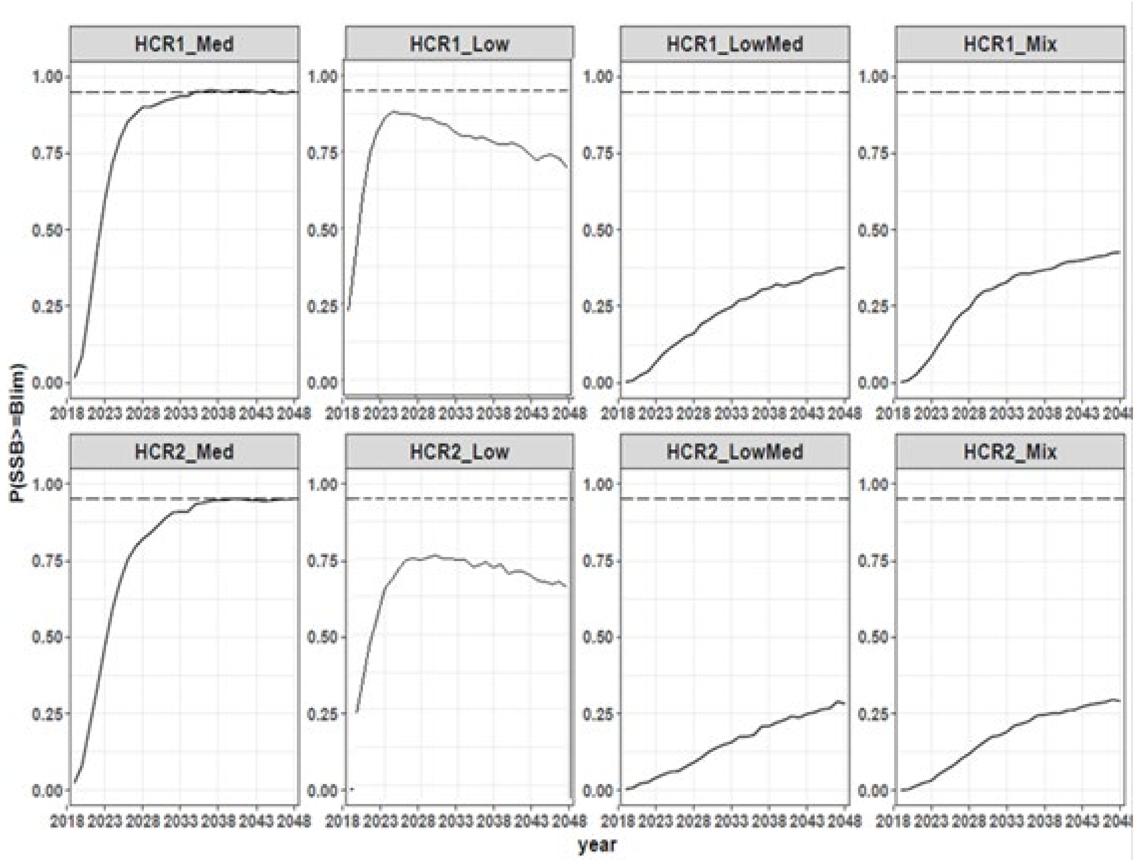


Figure 5.7. Probability profile of P(B1+≥B_{lim}) for catch rules HCR1 and HCR2 when 'true' stock is Medium, Low–medium, Mix (B_{lim}=337.4 thousand tonnes) and Low (B_{lim_low}=196.3 thousand tonnes) productivity and 'perceived' stock is of Medium productivity, from 2018 to 2048. Horizontal dashed lines represent 95% probability.

5.1.3 Comparison with runs without assessment

In the scenario where the true stock has Medium productivity and when testing HCR1 and HCR2 (sc1), in the simulations runs with assessment and observation errorB1+ is estimated above the B1+ estimates in the runs without assessment and observation error, along the whole projection period (Figure 5.8).Values are higher in the beginning of the projection period, especially for HCR1. This pattern is consistent with the overestimation of B1+ in the assessment (WGHANSA, 2018) though of lower magnitude. However, for scenarios where the true stock has Low (sc2), Low–medium (sc3) and Mix (sc4) productivity, B1+ is generally estimated below with the exception of the first years of the projection period. Differences are aggravated with time and are higher for HCR1 and when the true stock has Low–medium productivity (more than -0.4 relative change). The opposite behaviour is observed for F_{bar}, i.e. in the simulations runs with assessment and observation error F_{bar} estimates are lower than in the simulations runs without assessment and observation error in scenario 1 and higher in scenarios 2, 3 and 4.One possible reason for the observed pattern for the Low, Low–medium and Mix scenarios is that the assessment method (SS3) is currently adjusted for a Medium productivity scenario (WGHANSA, 2018) and as such may need adaptations when running under other productivity scenarios.

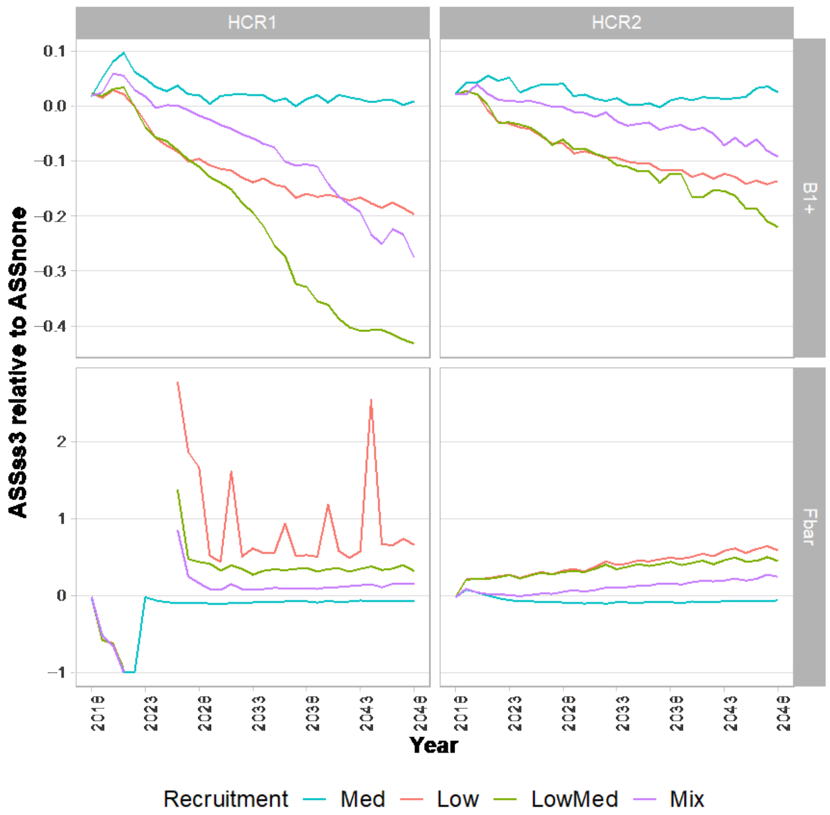


Figure 5.8. HCR1 (left panels) and HCR2 (right panels): relative change of estimates of B1+ (upper panels) and $F_{bar2\text{-}5}$ (lower panels) of runs with assessment and observation error in relation to runs without assessment and no observation error for scenarios assuming Medium, Low, Low–medium and Mix productivity for the 'true' stock, from 2018 to 2048.

5.1.4 Conclusions

In a scenario for which the true stock has Medium productivity and is managed consistently with that productivity, both HCR1 and HCR2 allow B1+ to increase and stabilize with a probability of being above B_{lim}=337.4 thousand tonnes in the long term of 95% for HCR1 and close to 95% for HCR2. When applying HCR1, fishery closures are very frequent, particularly in the short and mediumterm. An optimistic perception of the stock productivity, e.g. manage the stock according to Medium productivity when the true productivity is Low, there is a limited chance of B1+ being above B_{lim_low}=196.3 thousand tonnes in the long term (risk3 is 31–34%).

The simulation testing of HCR1 and HCR2 shows that population equilibrium in the last ten years of the simulation period is only reached under the scenario Medium and as such, it is not reliable to infer on risk3 for the other productivity scenarios. The analysis of the performance statistics considering a low biomass reference level (B_{lim_low}=196.3 thousand t) for the true Medium scenario indicate a high probability of stock recovery by 2023, between 93% (HCR2) and 98% (HCR1) and 0% risk3 while considering a higher biomass reference level (B_{lim}=337.4 thousand t) for the true Low scenario, neither the recovery objective or the ICES precautionary criterion (98% risk3) would be fulfilled.

5.2 MSE testing of catch rules HCR5 and HCR6

HCR5 and HCR6 are comparable to HCR1 and HCR2 but apply lower levels of F_{bar} (Figure 4.7, Table 5.2). The simulation testing of HCR5 and HCR6 was performed assuming also four productivity scenarios for the 'true' stock (Medium, Low, Low–medium and Mix productivity)and considering that the 'perceived' stock is of Medium productivity (Table 4.6: sc9 to sc12).

5.2.1 Simulated recruitment, spawning–stock biomass (B1+), fishing mortality and catch

The trajectories of the key parameters R, B1+, F_{bar} and catch under Medium, Low, Low–medium and Mix productivity in the 'true' stock and 'perceived' Medium productivity are shown in Figures 5.9–5.12.

HCR5 and HCR6 lead to slightly higher median R and B1+ compared to HCR1 and HCR2 but the trajectories of all key parameters are similar between the two sets of rules.

The application of lower fishing mortality in HCR5 (F_{low}=0.083, F_{tgt}=0.10) and HCR6 (F_{low}=0.071, F_{tgt}=0.10) compared to HCR1 and HCR2 allows the biomass to increase to above B_{lim}=337.4 thousand tonnes in the longterm, with >95% probability with both catch rules, in scenarios for which the Medium productivity is correctly perceived (Figures 5.9). This situation does not occur if the true stock productivity is Low–medium and Mix (Figures 5.11 and 5.12). In scenarios of Low productivity, the median B1+ increases above B_{lim}=196.3 thousand tonnes in the shortterm (Figure 5.10).

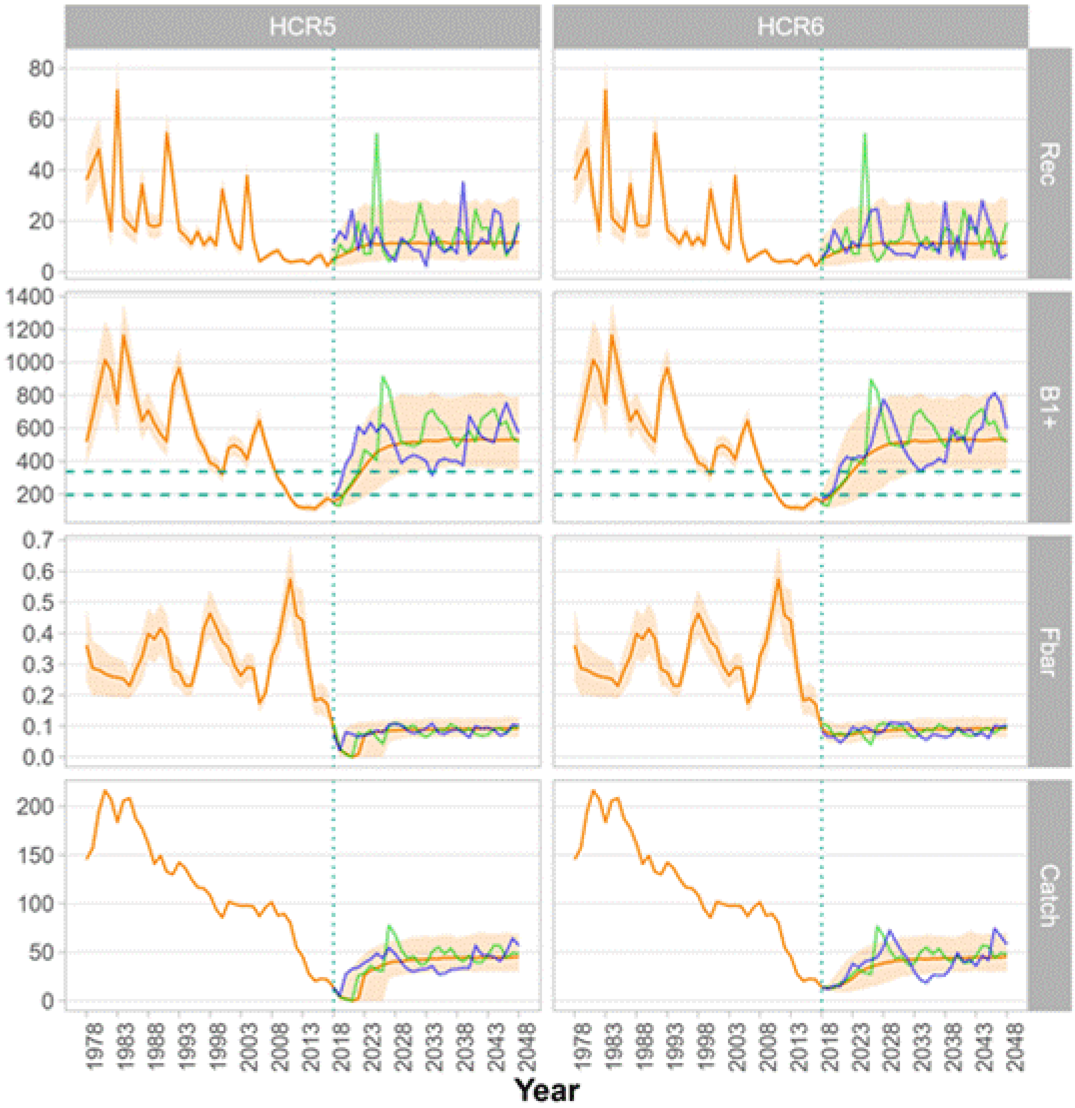


Figure 5.9. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2\text{-}5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR5 and HCR6 under 'true' stock of Medium productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

Figure 5.10. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2–5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR5 and HCR6 under 'true' stock of Low productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

Figure 5.11. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2–5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR5 and HCR6 under 'true' stock of Low–medium productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

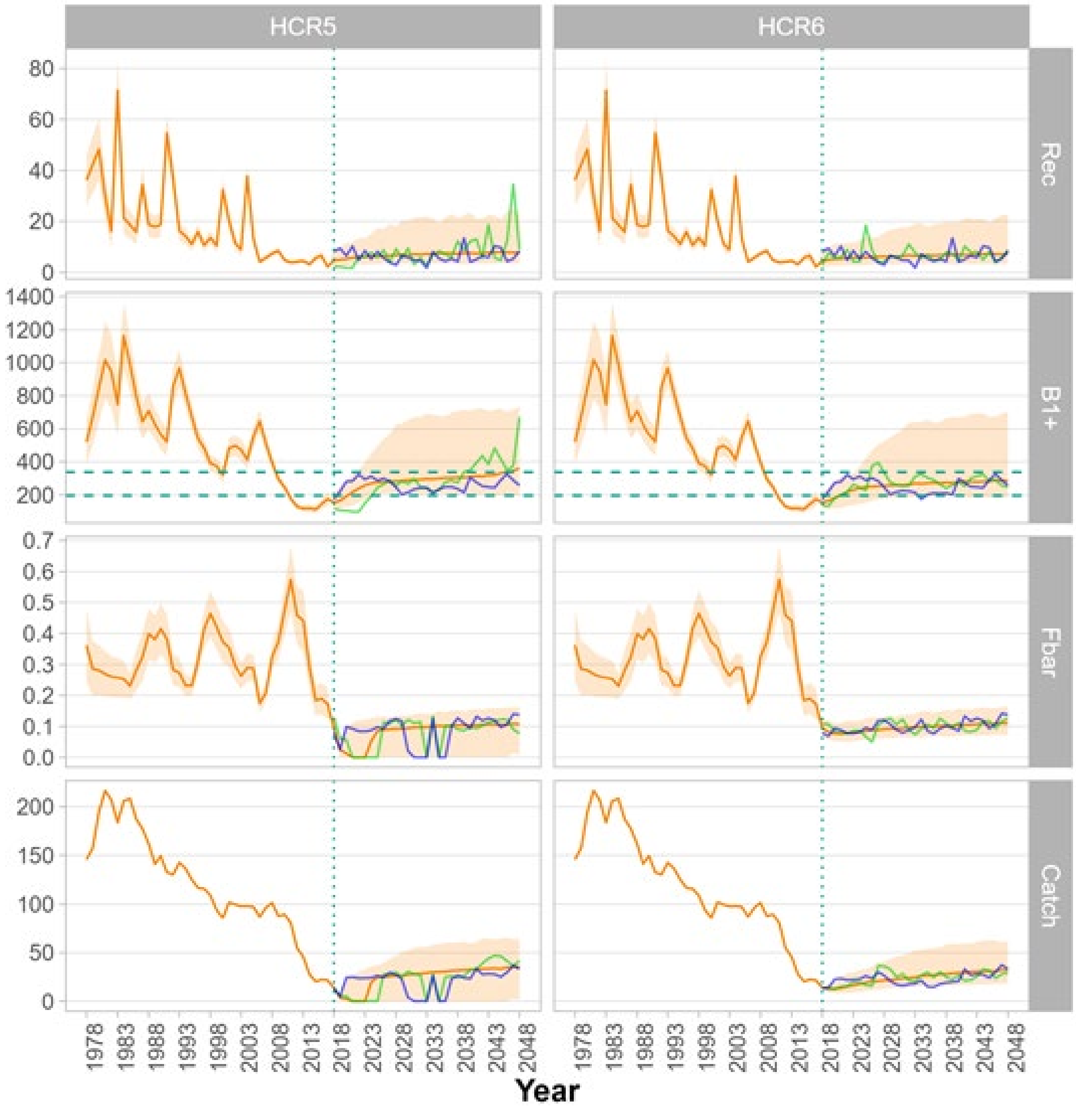


Figure 5.12. Recruitment (Rec, million individuals), biomass of fish age 1 and older(B1+, thousand tonnes), fishing mortality ($F_{bar2–5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR5 and HCR6 under 'true' stock of Mix productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

5.2.2 Performance statistics

The estimated median biomass of fish age 1 and older(B1+) varied during the initial period (2019–2023) between208–249 thousand tonnes and between 194–234 thousand tonnes for the HCR5 and HCR6, respectively (Table 5.2). The median catch, when applying HCR5, was estimated as ranging between 1–3 thousand tonnes, and ranging between 14–16 thousand tonnes when applying HCR6. The inter-annual variability of catches was higher for HCR5 than for HCR6, particularly for the initial period (between 6–8 and 3–4 thousand t for the HCR5 and HCR6, respectively). The probability of fishery closure with HCR5 is high, ranging between 32–46% among scenarios, being lower than 1% with HCR6 (Table 5.2, Figure 5.13).

In the last period of the simulation, the median B1+ is estimated to increase to around 529–530 thousand tonnes for both catch rules under the Medium scenario, and to be below 288 thousand tonnes for the other productivity scenarios. The catch is estimated to be 45 thousand tonnes for the Medium scenario and to be below 36 thousand tonnes for the Low, Low–medium and Mix scenarios. There is still a probability of fishery closure when applying HCR5 of 3% under Low–medium scenario and of 6% for both Low and Mix scenarios (Table 5.2, Figure 5.13).

The probability that B1+ is equal or above 80%B_{lim} (157.1 thousand t for the Low scenario and 270.0 thousand t for the other scenarios) by 2023 is for HCR5 78%, 95%, 32% and 40% for the Medium, Low, Low–medium and the Mix scenarios, respectively. Regarding HCR2, the values are lower, being 69%, 88%, 21% and 24% for the Medium, Low, Low–medium and the Mix scenarios, respectively (Table 5.2). This means that in any of the productivity regime scenarios and for both rules, the MRP objective is reached by 2023. The estimated average number of years of the projected period required to ensure, with a probability of 90%, that B1+≥0.8*B_{lim} is seven years (from 2019 to 2025) and nine years (from 2019 to 2027) when applying HCR5 and HCR6, respectively, under the Medium scenario and between four (2019–2022) and six (2019–2024) under Low stock productivity. The recovery objective is never met for both catch rules under the Low–medium and Mix scenarios (Table 5.2).

The first year when B1+ is above or equal to $B_{lim,}$ with 95% probability, is 2031 (i.e. in 13 years' time, HCR5) and 2034 (in 16 years' time, HCR6) under the Medium scenario. In fact, under the Medium scenario the probability that B1+ is below B_{lim} in the longterm is 4% for both HCR5 and HCR6, thus complying with the ICES precautionary criterion (Table 5.2). This criterion is not fulfilled for any of the catch rules under the other productivity scenarios since risk3 is between 19% (HCR5, Low) and 71% (HCR6, Low–medium).

As for HCR1 and HCR2, the Medium scenario is the only one for which B1+ stabilizes in the last ten years of the simulation period, therefore the probability computed for risk3 are considered appropriate to make precautionary considerations. Figure 5.14 shows that, with the exception of the scenario Medium, the probability profile of all other scenarios is still decreasing (Low scenario) or increasing (Low–medium and Mix scenarios) in the end of the simulation period indicating that equilibrium conditions were not achieved. The proportion of population that have changed regime in each scenario during the 30 years of the projection period is slightly higher for both catch rules in the Low–medium scenario compared to the Mix scenario, of 43–50% for HCR5 and of 36–40% for HCR6.

The analysis of the performance statistics considering B_{lim_low} (196.3 thousand t) for the true Medium productivity and B_{lim} (337.4 thousand t) for the true Low productivity scenario (Table 5.2, unshaded cells) show that under the Medium scenario the MRP recovery objective would be reached before 2023 for both catch rules (2021 with HCR5 and 2022 with HCR6) and risk3 would be 0%. In the case of the Low scenario neither the MRP objective (31% with HCR5 and 20% with HCR6) nor the ICES precautionary criterion (97% risk3) would be fulfilled.

Table 5.2. Summary of performance statistics for HCR5 and HCR6 assuming the 'perceived' stock to be of Medium productivity and the 'true' stock to be of Medium, Low, Low–medium and Mix productivity. Shaded cells show the metric values corresponding to the reference B_{lim} of the 'true' stock (B_{lim}=337.4 thousand t for Medium, Low–medium and Mix scenarios and B_{lim_low}=196.3 thousand t for the Low scenario).

			Medium							
			Medium		Low		Low-Medium		Mix	
			HCR5	HCR6	HCR5	HCR6	HCR5	HCR6	HCR5	HCR6
	Metrics	**Period**	**SC9**		**SC10**		**SC11**		**SC12**	
Indicators	**Spawning Biomass: B1+** (median, th tonnes)	2019-2023	249	234	208	194	208	194	214	197
		2019-2028	368	340	236	218	238	218	251	227
		2039-2048	530	529	239	236	288	263	322	281
	F (median)	2019-2023	0.017	0.074	0.015	0.093	0.014	0.092	0.005	0.079
		2019-2028	0.070	0.079	0.094	0.100	0.089	0.099	0.022	0.083
		2039-2048	0.092	0.092	0.140	0.138	0.127	0.129	0.106	0.107
	Catch (median, th tonnes)	2019-2023	3	16	3	16	2	16	1	14
		2019-2028	27	24	24	20	24	20	4	17
		2039-2048	45	45	30	30	36	34	34	31
	IAV1 Catch (absolute, th tonnes)	2019-2023	8	4	7	3	7	3	6	3
		2019-2028	8	5	8	4	8	4	8	3
		2039-2048	7	7	7	4	7	6	7	5
	Probability of closure (%)	2019-2023	35	1	38	0	32	0	46	1
		2019-2028	22	0	28	0	22	0	38	1
		2039-2048	0	0	6	0	3	0	6	0
Special Request	**Prob(B1+ ≥ 80%Blim) in 2023 (%)**	2023	**78**	**69**	31	20	**32**	**21**	**40**	**24**
	Prob(B1+ ≥ 80%Blim_low) in 2023 (%)	2023	98	94	**95**	**88**	96	88	98	90
	first year P(B1+ ≥ 80%Blim) ≥90%	2019-2048	**2025**	**2027**	NA	NA	**NA**	**NA**	**NA**	**NA**
	first year P(B1+ ≥ 80%Blim_low) ≥90%	2019-2048	2021	2022	**2022**	**2024**	2022	2024	2022	2024
ICES criterion	**first year P(B1+ ≥ Blim) > 95%**	2019-2048	**2031**	**2034**	NA	NA	**NA**	**NA**	**NA**	**NA**
	first year P(B1+ ≥ Blim_low) > 95%	2019-2048	2024	2026	**NA**	**NA**	NA	NA	2025	NA
	Risk3 for Blim (%)	2039-2048	**4**	**4**	97	97	**62**	**71**	**56**	**68**
	Risk3 for Blim_low(%)	2039-2048	0	0	**19**	**22**	12	16	6	8

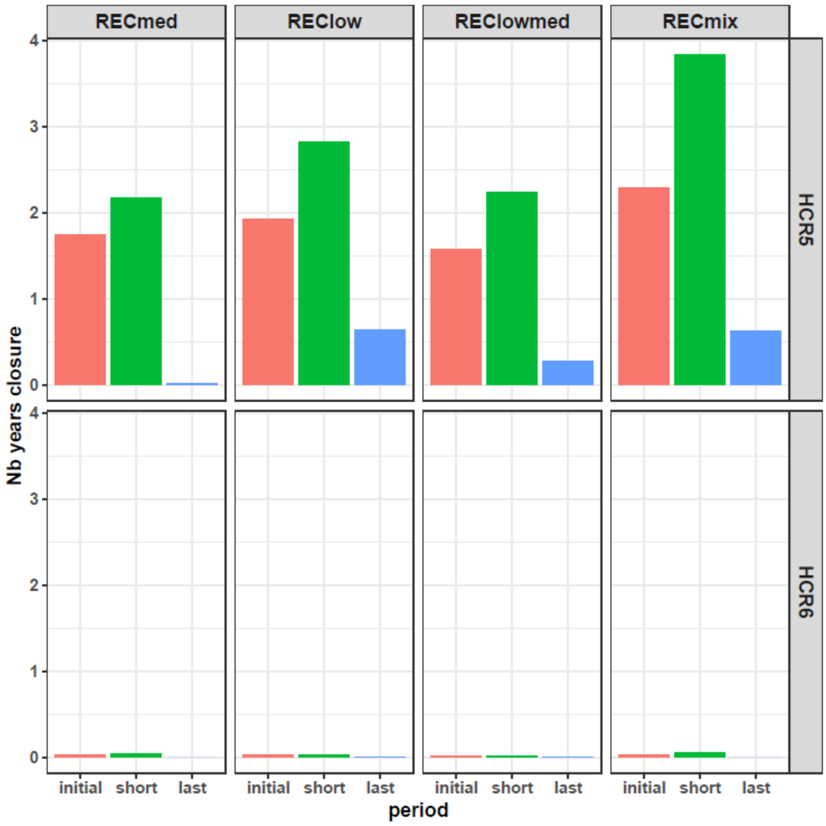


Figure 5.13. Average number of years with fishery closure for catch rules HCR5 and HCR6 by period (initial: 2019–2023, short: 2019–2028, last: 2039–2048) and assumed productivity for the 'true' stock.

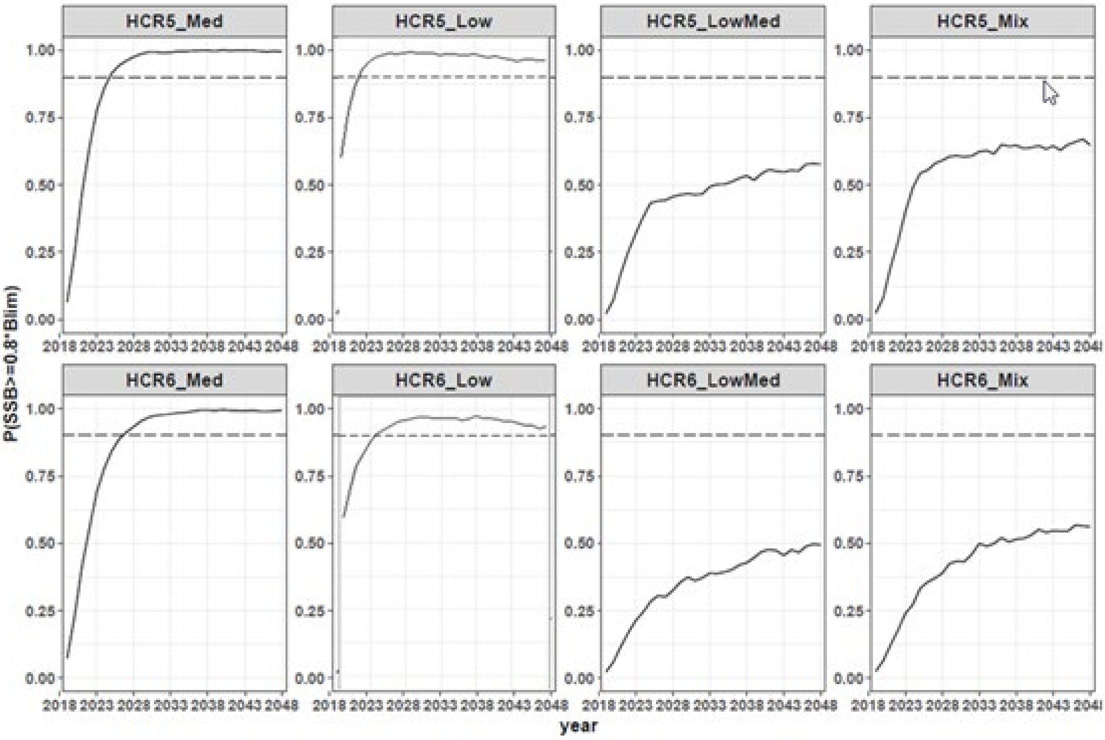


Figure 5.14. Probability profile of P(B1+≥80%B_{lim}) for catch rules HCR5 and HCR6 when 'true' stock is of Medium, Low–medium, Mix (B_{lim}=337.4 thousand t) and Low (B_{lim_low}=196.3 thousand t) productivity and 'perceived' stock is of Medium productivity, from 2018 to 2048. Horizontal dashed lines represent 90% probability.

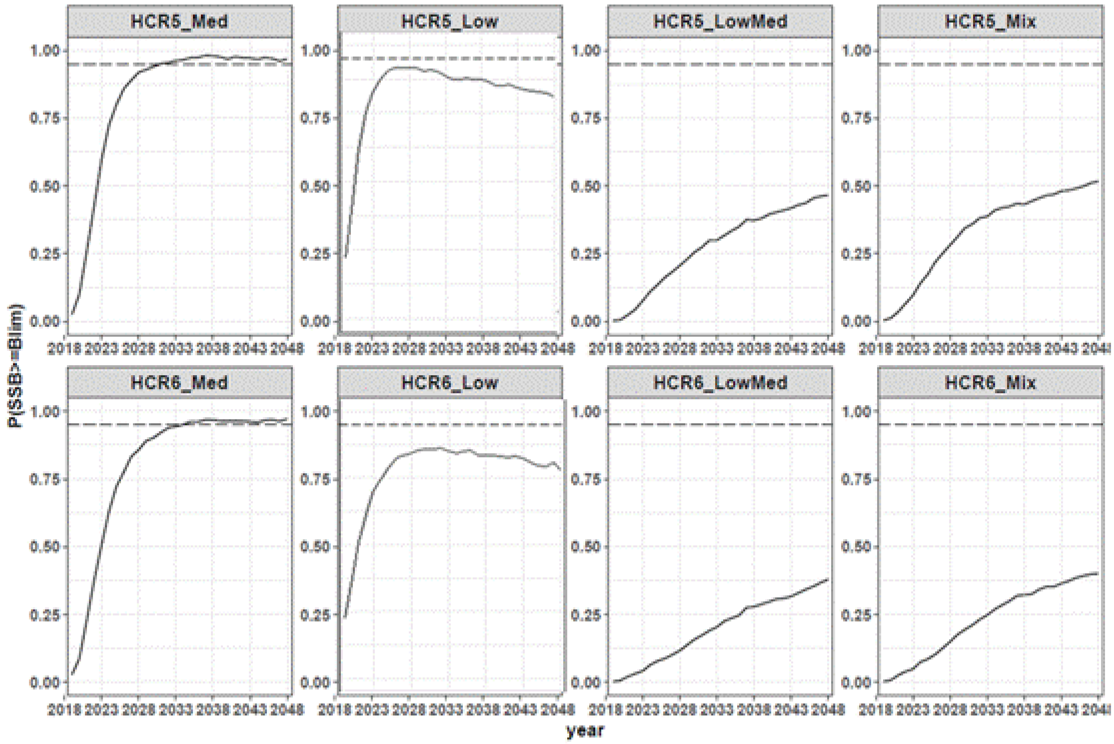


Figure 5.15. Probability profile of P(B1+≥B_{lim}) for catch rules HCR5 and HCR6 when 'true' stock is of Medium, Low–medium, Mix (B_{lim}=337.4 thousand t) and Low (B_{lim_low}=196.3 thousand t) productivity and 'perceived' stock is of Medium productivity, from 2018 to 2048. Horizontal dashed lines represent 95% probability.

5.2.3 Comparison with runs without assessment

The analysis for HCR5 and HCR6on the relative change of B1+ and $F_{bar}$of runs with assessment and observation error in relation to runs without assessment and no observation error along the whole projection period (Figure 5.16) show the same patterns as when testing HCR1 and HCR2: overestimation of B1+ along the period for true Medium productivity scenario (sc9) and an underestimation trend for scenarios true Low (sc10), Low–medium (sc11) and Mix (sc12) productivity scenarios. The opposite behaviour is in general observed for F_{bar}, since F_{bar} estimates are lower than in the simulations runs without assessment and no observation error in scenario 9 and higher in scenarios 10, 11 and 12. Again, this behaviour is very similar when testing HCR1 and HCR2 with the exception that in the first years of the simulation period and for HCR5, F_{bar} estimates in simulations runs with assessment and observation error are above the estimates of runs without assessment and observation error.

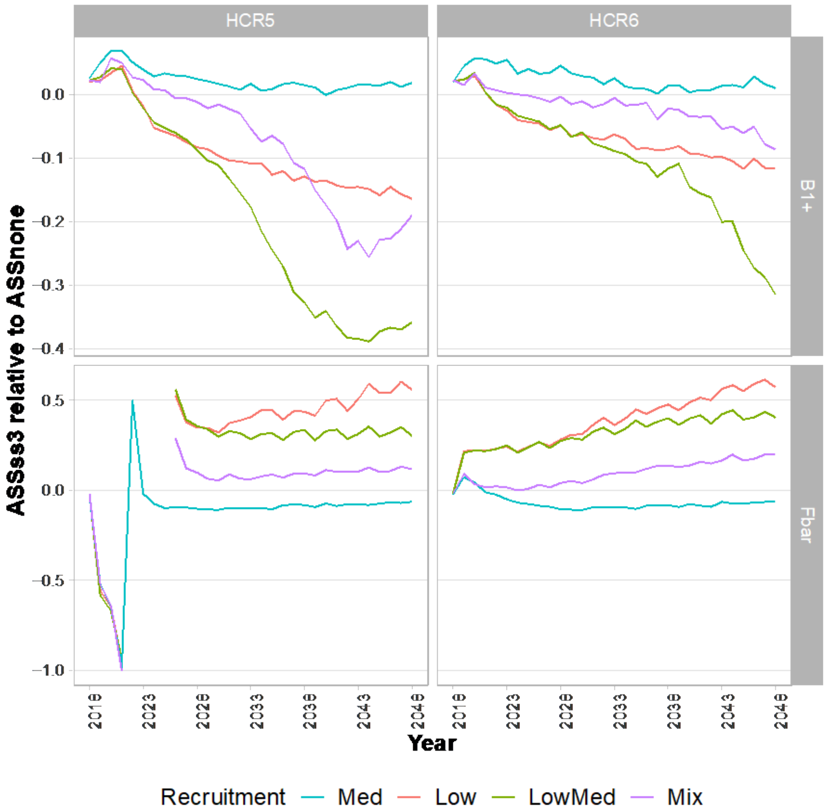


Figure 5.16. HCR5 (left panels) and HCR6 (right panels): relative change of estimates of B1+ (upper panels) and F_{bar2-5} (lower panels) of runs with assessment and observation error in relation to runs without assessment and no observation error for scenarios assuming Medium, Low, Low–medium and Mix productivity for the 'true' stock, from 2018 to 2048.

5.2.4 Conclusions

The trajectories of key parameters when HCR5 and HCR6 are applied are similar to those applying HCR1 and HCR2 for corresponding scenarios. In a scenario for which the true stock has Medium productivity and is managed consistently with that productivity, both catch rules will lead the stock to above B_{lim}=337.4 thousand tonnes in the longterm with a probability higher than 95%. In the shortterm, this condition is met by 2031 for HCR5 and by 2034 for HCR6. This does not apply to scenarios for which the true productivity is not perceived correctly. HCR5 and HCR6 do not fulfil the recovery criterion specified in the special request, though the objective would be achieved by 2025 for HCR5 and by 2027 for HCR6.

The analysis of the performance statistics considering a low biomass reference level (B_{lim_low}=196.3 thousand t) for the true Medium scenario indicate a high probability of stock recovery by 2023 and 0% risk3 for both catch rules while considering a higher biomass reference level (B_{lim}=337.4 thousand t) for the true Low scenario, neither the recovery objective or the ICES precautionary criterion would be fulfilled.

5.3 MSE testing of catch rules HCR3 and HCR4

The simulation testing of the catch rules HCR3 and HCR4 was also performed assuming four scenarios for the 'true' stock (Medium, Low, Low–medium and Mix productivity) but considering that the 'perceived' stock was of Low productivity (Table 4.6: sc5 to sc8).

5.3.1 Simulated recruitment, spawning–stock biomass (B1+), fishing mortality and catch

The trajectories of the key parameters R, B1+, F_{bar} and catch under sc5 to sc8, Medium, Low, Low–medium and Mix productivity in the 'true' stock and 'perceived' Low productivity, are shown in Figures 5.17–5.20.

As for previous scenarios, the key parameters have comparable median trajectories for the two HCRs tested. In the case of true Low productivity scenario HCR3, the variant of HCR1, leads to fishery closures, although only in the short term, and with lower frequency than the previous HCR variants.

F_{low} and F_{tgt} values of HCR3 and HCR4 are 73% lower than those of HCR1 and HCR2, and F levels of the latter rules are comparable with recent historical F_{bar} levels. The application of HCR3 and HCR4 lead to an abrupt decrease of median F_{bar} and, therefore of catches, in 2019, the first year the rules are applied.

When Medium and Low true productivity are perceived as Low productivity, median B1+ increases and stabilizes well above the corresponding B_{lim} values, 337.4 thousand tonnes (Medium) and 196.3 thousand tonnes (Low), with more than 95% probability (Figures 5.17 and 5.18). Median catches are estimated to be below 10.0 thousand tonnes in case the perception is correct and below 20.0 thousand tonnes, in case the perception is of Medium productivity, for most of the whole simulation period.

In scenarios of Low–medium and Mix true productivity, the median B1+ trajectory has a slow initial increase for 15–16 years followed by a period of faster increase, continuing with an increasing trend in the last years of the simulation period (Figures 5.19 and 5.20). For both scenarios, B1+ is forecast to increase to above B_{lim}= 337.4 thousand tonnes in the medium term but with a probability lower than 95%. After the initial drop, median F_{bar} stabilises rapidly around the target Fs of the catch rules while catches show a continuous increase until the end of the simulation as the biomass also increases.

Figure 5.17. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality (F_{bar2-5}, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR3 and HCR4 under 'true' stock of Medium productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

Figure 5.18. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2–5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR3 and HCR4 under 'true' stock of Low productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

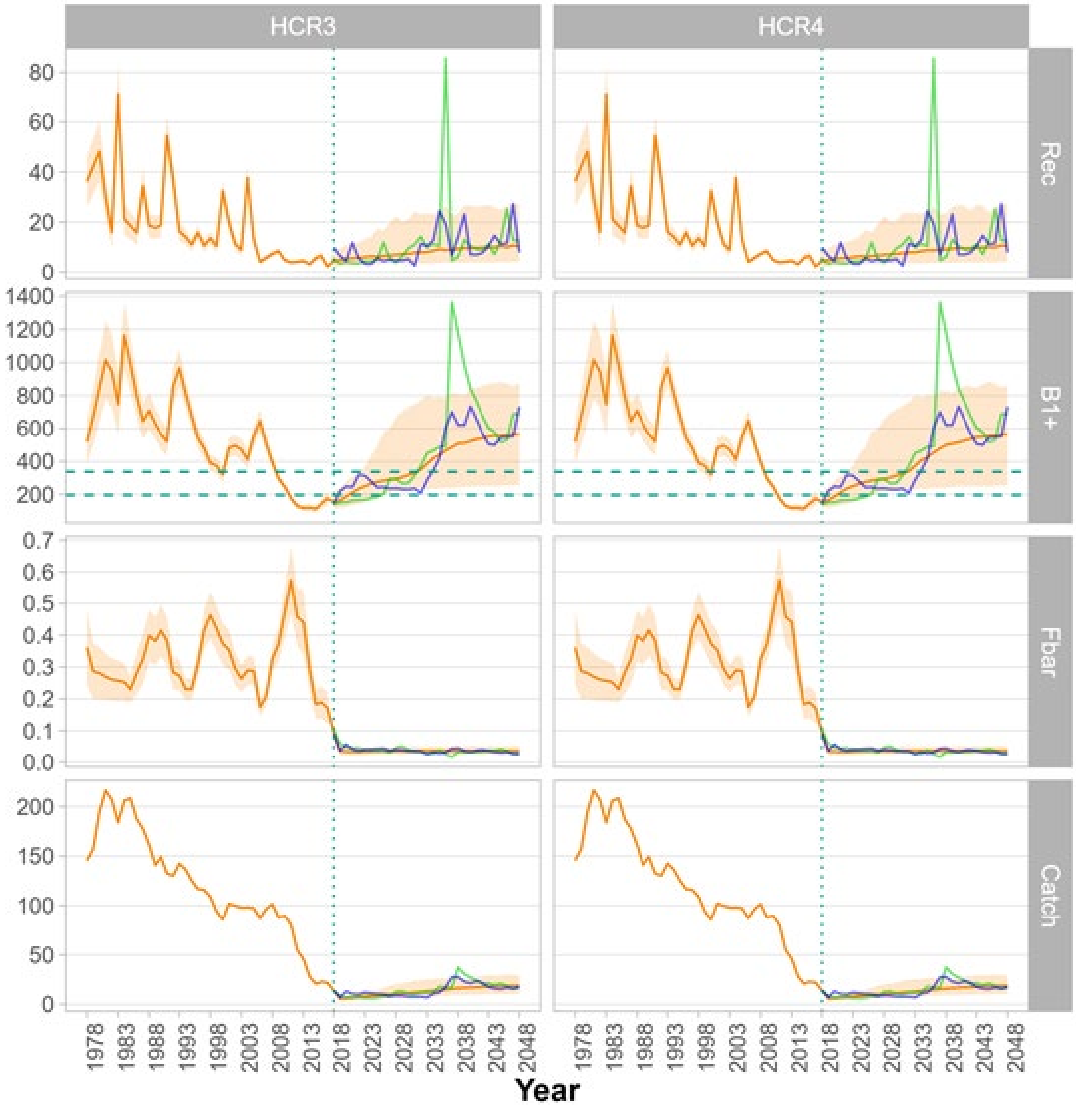


Figure 5.19. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2–5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR3 and HCR4 under 'true' stock of Low–medium productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

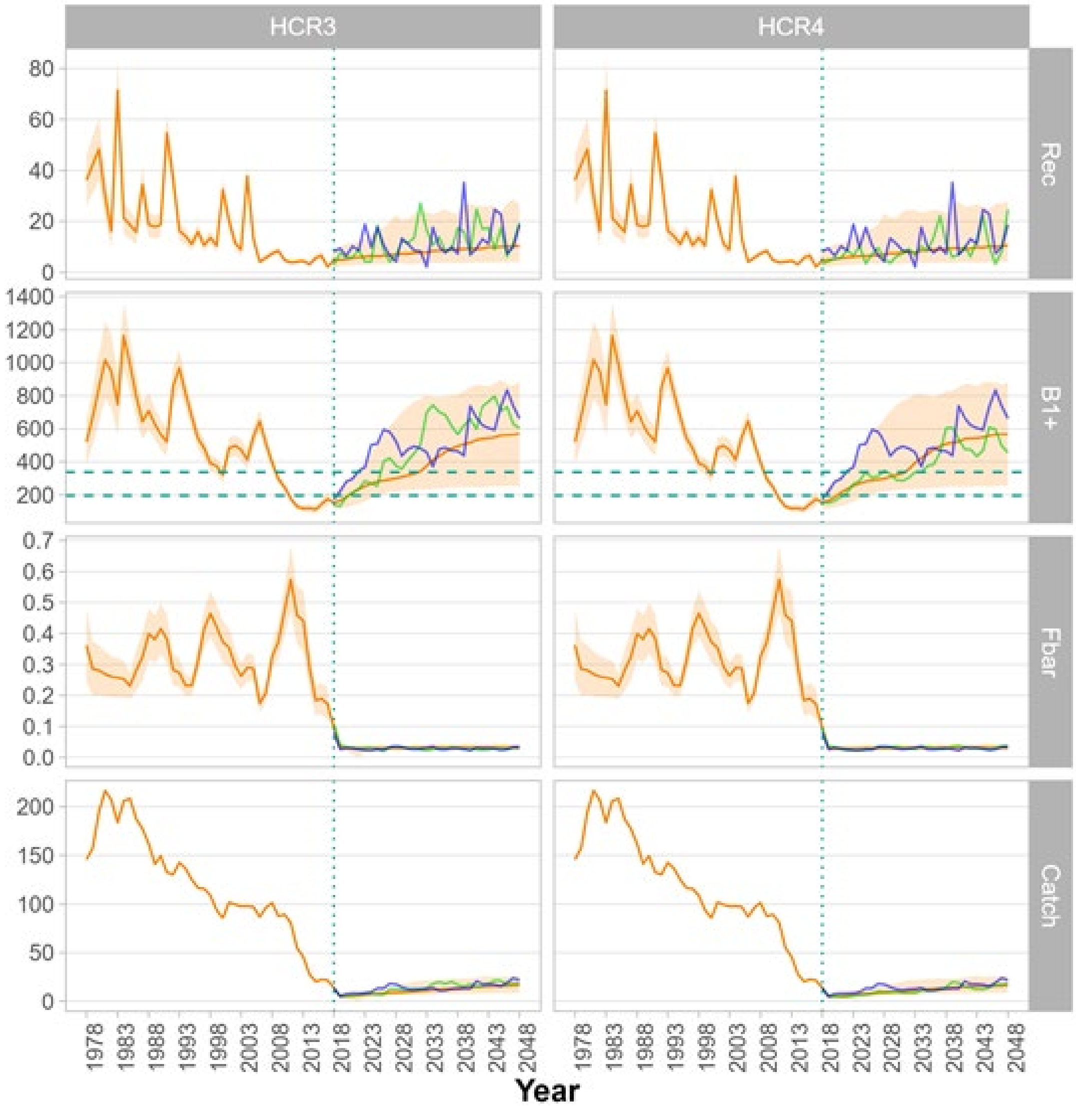


Figure 5.20. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2–5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR3 and HCR4 under 'true' stock of Mix productivity and 'perceived' stock of Medium productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196.3 thousand t) and of Medium productivity (337.4 thousand t). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

5.3.2 Performance statistics

For the period 2019–2023, median B1+ is estimated between 207 and 209 thousand tonnes for both catch rules under Low, Low–medium and Mix productivity scenarios. It is, however, higher for the Medium scenario, being 244 thousand tonnes for HCR3 and 248 thousand tonnes for HCR4. For this period, the mean catch is estimated between 6 and 7 thousand tonnes, considering all scenarios, with an inter-annual variability of around 1–2 thousand tonnes (Table 5.3).

In the longterm (last period) the median B1+ is estimated to increase to 615–619 thousand tonnes under the Medium scenario, to 544–548 thousand tonnes under the Low–medium and Mix scenarios and to 295–296 thousand tonnes under the Low scenario (Table 5.3). The median catch is estimated to increase for both catch rules to 12, 16, 17 and 18 thousand tonnes under scenarios of Low, Mix, Low–medium and Medium productivity, respectively.

The probability of fishery closure is very low for both catch rules, being below 3% in the initial period and zero in the longterm.

Both catch rules show a high probability of achieving the recovery objective of the special request for the Low scenario (95%), since the condition is met in 2022. In the situation for which the stock productivity is perceived to be Medium, the probability is below 90% (76–77%) and the condition would be met only in 2025. The objective is also not achieved for any of the catch rules under the Low–medium and Mix scenarios by 2023being met by 2041 (Low–medium) and by 2042 (Mix) (Table 5.3, Figure 5.21).

The first year whenB1+ is above or equal to $B_{lim,}$ with 95% probability, is 2026 (HCR3) and 2027 (HCR4) under the Low and 2028 (HCR3) and 2029 (HCR4) under the Medium scenarios, i.e. in a timeframe of eight to 11 years. In fact, risk3 when applying HCR3 and HCR4 is 0% for the Medium and 1% for the Low scenarios. The Low–medium and Mix scenarios do not comply with the ICES precautionary criterion, since risk3 is estimated to be above 27% (Table 5.3). However, as shown in Figure 5.22 the probability profile is still increasing in the last ten years of the simulation period, although getting close to the 95% probability. This is due to the fact that the proportion of population that have changed regime in each scenario during the 30 years of the projection period is much higher for both scenarios when managed with HCR3 and HCR4 (86% in the Low–mediumregime and 75–75% in the Mix regime) than for these productivity scenarios when populations are managed by any of the other tested rules.

The analysis of the performance statistics considering B_{lim_low} (196.3 thousand t) for the true Medium productivity and B_{lim} (337.4 thousand t) for the true Low productivity scenarios (Table 5.3, unshaded cells) indicate a high probability (98%) of fulfilling the MRP recovery objective as well as the ICES precautionary criterion for both catch rules under the Medium productivity scenario. Under the Low scenario, the probability of stock recovery is well below the 90% specified in the request (35–36% for both catch rules) and risk3 is very high (81%).

Table 5.3. Summary of performance statistics for HCR3 and HCR4 assuming the 'perceived' stock to be of Low productivity and the 'true' stock to be of Medium, Low, Low–medium and Mix productivity. Shaded cells show the metric values corresponding to the reference B_{lim} of the 'true' stock (B_{lim}=337.4 thousand t for Medium, Low–medium and Mix scenarios and B_{lim_low}=196.3 thousand t for the Low scenario).

			Low							
			Medium		Low		Low-Medium		Mix	
			HCR3	HCR4	HCR3	HCR4	HCR3	HCR4	HCR3	HCR4
	Metrics	Period	SC5		SC6		SC7		SC8	
Indicators	Spawning Biomass: B1+ (median, th tonnes)	2019-2023	244	248	207	207	207	207	208	209
		2019-2028	379	386	248	248	248	248	252	252
		2039-2048	615	619	295	296	547	544	545	548
	F (median)	2019-2023	0.027	0.027	0.034	0.034	0.034	0.034	0.030	0.029
		2019-2028	0.027	0.027	0.035	0.035	0.035	0.035	0.030	0.030
		2039-2048	0.029	0.029	0.042	0.042	0.036	0.036	0.032	0.032
	Catch (median, th tonnes)	2019-2023	6	6	7	7	7	7	6	6
		2019-2028	9	9	8	8	8	8	7	7
		2039-2048	17	17	12	12	18	18	16	16
	IAV1 Catch (absolute, th tonnes)	2019-2023	2	1	1	1	1	1	1	1
		2019-2028	2	2	1	1	1	1	1	1
		2039-2048	2	2	1	1	2	2	2	2
	Probability of closure (%)	2019-2023	2	0	2	0	2	0	3	0
		2019-2028	1	0	1	0	1	0	2	0
		2039-2048	0	0	0	0	0	0	0	0
Special Request	Prob(B1+ ≥ 80%Blim) in 2023 (%)	2023	**76**	**77**	35	36	**35**	**35**	**38**	**40**
	Prob(B1+ ≥ 80%Blim_low) in 2023 (%)	2023	98	98	**95**	**95**	95	95	96	96
	first year P(B1+ ≥ 80%Blim) ≥90%	2019-2048	**2025**	**2025**	NA	NA	**2041**	**2041**	**2042**	**2042**
	first year P(B1+ ≥ 80%Blim_low) ≥90%	2019-2048	2021	2021	**2022**	**2022**	2022	2022	2022	2022
ICES criterion	first year P(B1+ ≥ Blim) > 95%	2019-2048	**2028**	**2029**	NA	NA	**NA**	**NA**	**NA**	**NA**
	first year P(B1+ ≥ Blim_low) > 95%	2019-2048	2024	2024	**2026**	**2027**	2026	2026	2026	2026
	Risk3 for Blim (%)	2039-2048	**0**	**0**	81	81	**27**	**29**	**31**	**29**
	Risk3 for Blim_low(%)	2039-2048	0	0	**1**	**1**	0	0	0	0

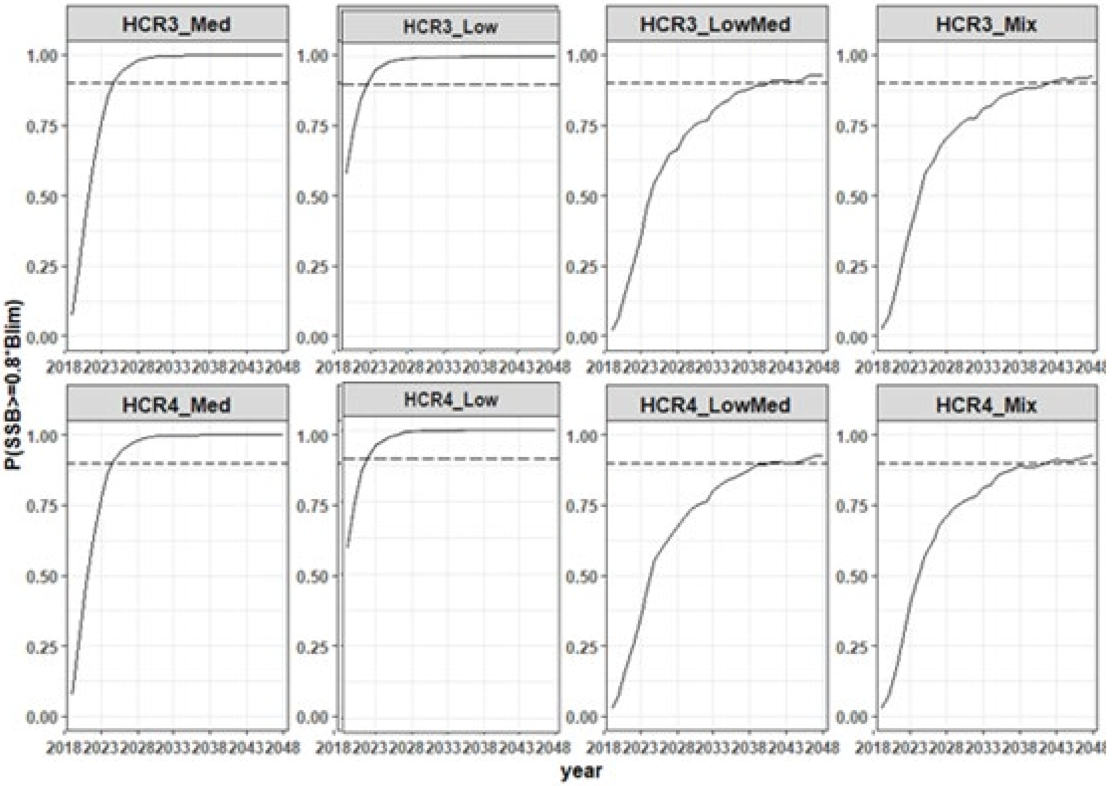


Figure 5.21. Probability profile of P(B1+≥80%Blim) for catch rules HCR3 and HCR4 when 'true' stock is of Medium, Low–medium, Mix (B_{lim}=337.4 thousand tonnes) and Low (B_{lim_low}=196.3 thousand tonnes) productivity and 'perceived' stock is of Low productivity, from 2018 to 2048. Horizontal dashed lines represent 90% probability.

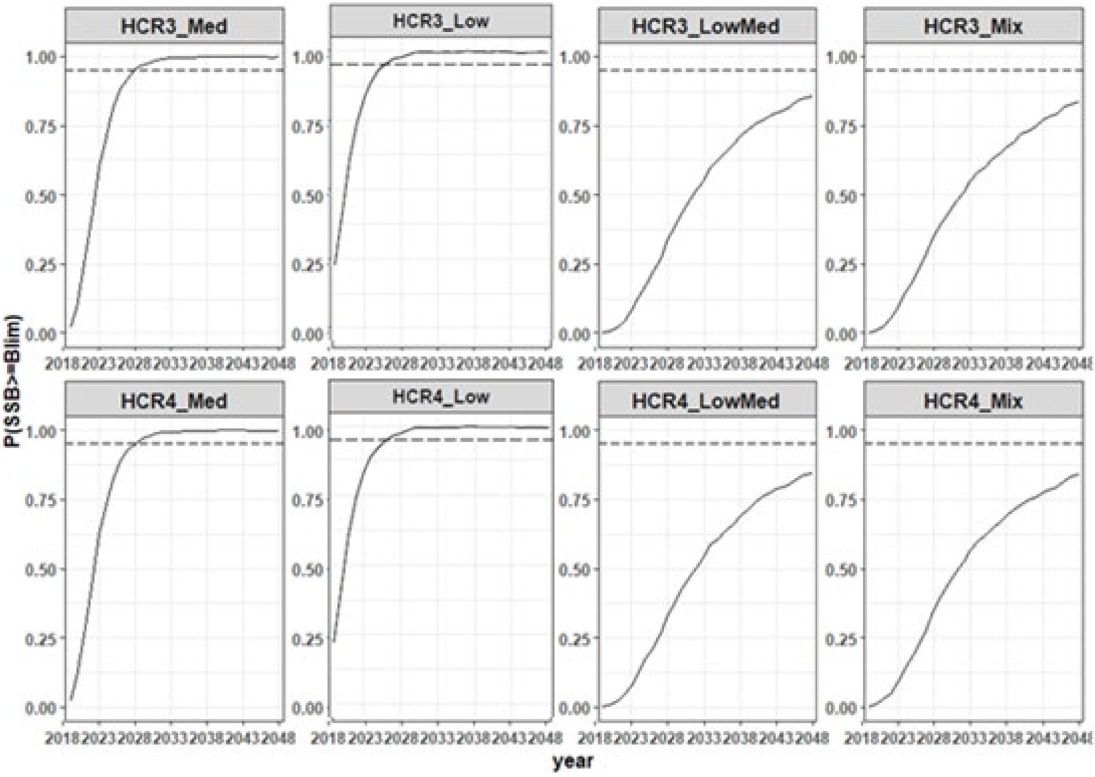


Figure 5.22. Probability profile of P(B1+≥B_{lim}) for catch rules HCR3 and HCR4 when 'true' stock is of Medium, Low–medium, Mix (B_{lim}=337.4 thousand tonnes) and Low (B_{lim_low}=196.3 thousand tonnes) productivity and 'perceived' stock is of Low productivity, from 2018 to 2048. Horizontal dashed lines represent 95% probability.

5.3.3 Comparison with runs without assessment

When testing HCR3 and HCR4 for scenarios 5, 6, 7 and 8, in the simulations runs with assessment and observation error B1+ is estimated above the B1+ estimates in the runs without assessment and no observation error in the beginning of the projection period and then are estimated below with the exceptions for scenario 5 where the true stock has Medium productivity and estimates are almost always above (Figure 5.23).Relative changes in B1+ are smaller when testing these two rules when compared with testing HCR1, HCR2, HCR5 and HCR6. For F_{bar} and in all scenarios, estimates are initially estimated above and then tend to stabilise at different values for each scenario of productivity. While in the Medium productivity F_{bar} is estimated to be 0.1 below the runs without assessment and observation error, in the Low–medium productivity estimates are around 0.15 above and in the Mix productivity are similar to the runs without assessment and no observation error. However, the Low productivity scenario shows a trend upwards, i.e. estimates are even higher with time.

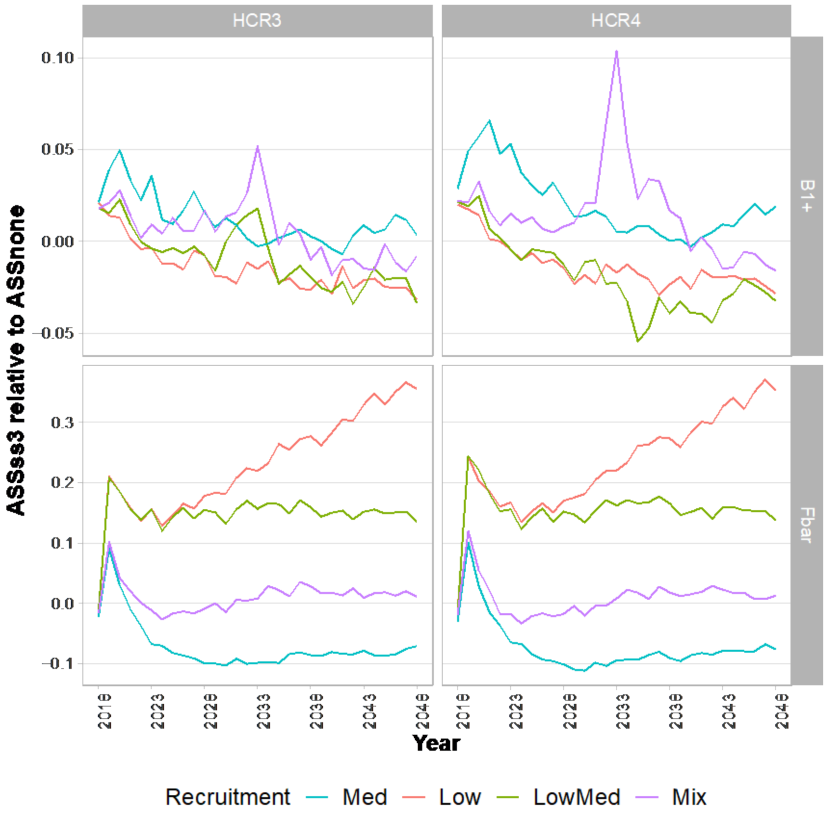


Figure 5.23. HCR3 (left panels) and HCR4 (right panels): relative change of estimates of B1+ (upper panels) and F_{bar2-5} (lower panels) of runs with assessment and observation error in relation to runs without assessment and no observation error for scenarios assuming Medium, Low, Low–medium and Mix productivity for the 'true' stock, from 2018 to 2048.

5.3.4 Conclusions

For all scenarios, the application of HCR3 and HCR4 leads to an abrupt decrease of median F_{bar} and therefore of the catches in 2019, because fishing mortality levels allowed by these rules are very low, compared to recent historical F_{bar}. When the true stock productivity is Medium or Low and is perceived as Low, these rules lead to median B1+ values above the reference B_{lim} of the corresponding true productivities with >95% probability by 2028–2029 for Medium scenario and by 2022 for the Low scenario. As expected, the $B_{lim}$is achieved faster if the true productivity is Medium than if it is Low. If the true productivity is Low–medium and Mix, B1+ does not increase above B_{lim}=337.4 thousand tonnes with >95% probability. The stock recovery to 80%B_{lim} by 2023 with 90% probability (special request) is only fulfilled when both the perceived and the true productivity is Low. In this case, a higher than 90% probability would be achieved by 2022, for both rules. In the situation for which the perceived stock is Medium but the true stock is Low, the condition would be achieved also for both rules but by 2025.

The analysis of the performance statistics considering a low biomass reference level (B_{lim_low}=196.3 thousand t) for the true Medium scenario indicate a high probability of stock recovery by 2023 and 0% risk3. On the contrary, considering a higher biomass reference level (B_{lim}=337.4 thousand t) for the true Low scenario, neither the recovery objective or the ICES precautionary criterion would be fulfilled.

5.4 Simulated productivity scenarios under no fishing

Table 5.4 presents summary statistics for the simulations performed for no fishing (HCR7, Table 4.6: sc13 to sc16). It is noted that in this case it is the same as if observation and assessment error were included because the TAC=0 does not change during the simulation period.

For the period 2019–2023, the median biomass of fish age 1 and older (B1+) is similar among scenarios, between 211 and 244 thousand tones, which is slightly higher compared to HCR3 and HCR4. In the longterm (last period) the median B1+ is estimated to increase to 640–668 thousand tonnes under the Medium, Low–medium and Mix scenarios but to only 329 thousand tonnes for the Low scenario (Table 5.4).

The probability that B1+ is above or equal to 80%B_{lim} in 2023 is 98% for the scenario assuming ‘true’ state of nature to be of Low productivity and of 78%in case the case of ‘true’ Medium productivity but below 50% for the other scenarios of ‘true’ stock. In fact, the 90% probability of B1+ to be above or equal to 80%B_{lim} would be achieved by 2021 for the Low scenario and by 2025 for the Medium scenario. On the contrary, under Low–medium and Mix scenarios this condition would be met later in time (2031).

Compliance with ICES precautionary criterion, risk3<0.05 will be achieved in the longterm (during the last ten years of the simulation) for HCR7 if the true productivity is Medium but not for the Low, Low–medium or Mix productivity scenarios, even though in the two latter scenarios the risk3 will be about 8% and 10%. Considering the reference biomass B_{lim_low} (196.3 thousand t) HCR7 (no fishing) will assure risk3 below 5% for all productivity scenarios, given that in all cases of productivity the risk of being below B_{lim_low} approaches 0 in the long term (in fact, in all cases such compliance will be achieved by 2024 or 2025).

Table 5.4. Summary of performance statistics for HCR7 (no fishing) for the simulations under ‘perceived’ Medium productivity and ‘true’ stock of Medium, Low, Low–medium and Mix productivity. Shaded cells show the metric values corresponding to the reference B_{lim} of the productivity assumed for the ‘true’ stock (B_{lim}=337.4 thousand t for the Medium, Low–medium and Mix scenarios and B_{lim_low}=196.3 thousand t for the Low scenario).

			Medium			
			Medium	Low	Low-Medium	Mix
			HCR7	HCR7	HCR7	HCR7
	Metric	Period	sc13	sc14	sc15	sc16
Indicators	**Spawning Biomass: B1+** (median, th tonnes)	2019-2023	244	211	212	211
		2019-2028	393	264	264	264
		2039-2048	668	329	643	640
	Catch (median, th tonnes)	2019-2023	0	0	0	0
		2019-2028	0	0	0	0
		2039-2048	0	0	0	0
	IAV1 Catch (absolute, th tonnes)	2019-2023	0	0	0	0
		2019-2028	0	0	0	0
		2039-2048	0	0	0	0
	Probability of closure (%)	2019-2023	100	100	100	100
		2019-2028	100	100	100	100
		2039-2048	100	100	100	100
Special Request	**Prob(B1+ ≥ 80%Blim) in 2023 (%)**	2023	**78**	46	**46**	**46**
	Prob(B1+ ≥ 80%Blim_low) in 2023 (%)	2023	98	**98**	98	98
	first year P(B1+ ≥ 80%Blim) ≥90%	2019-2048	**2025**	2035	**2031**	**2031**
	first year P(B1+ ≥ 80%Blim_low) ≥90%	2019-2048	2021	**2021**	2021	2021
ICES criterion	**first year P(B1+ ≥ Blim) > 95%**	2019-2048	**2028**	NA	**2043**	**2044**
	first year P(B1+ ≥ Blim_low) > 95%	2019-2048	2024	**2025**	2024	2025
	Risk3 for Blim (%)	2039-2048	**0**	59	**8**	**10**
	Risk3 for Blim_low(%)	2039-2048	0	**0**	0	0

6 Conclusions

To answer the special request in relation to the Biological Reference Points (BRPs), the WG decided to keep the current B_{lim} = 337 448 tonnes (based on data from the 2016 assessment for the period 1993–2015). The updated estimate of B_{lim} using data from the most recent assessment (1993–2017), as well as the estimate from the analysis of the effect of the assessment retrospective on B_{lim}, were both within the 95% confidence interval of the current B_{lim}.

The WG estimated BRPs considering the recent low stock productivity to be in the period 2006–2017, as specified in the request. B_{lim_low} was estimated to be 196 334 tonnes, and F_{MSY_low} was estimated to be 0.032 year^{-1}.

The estimated B_{lim} were used to set the B1+ reference levels of the simulation tested HCRs.Also, according to the new ICES guidelines for the evaluation of management strategies, when calculating performance statistics in management strategy evaluations, each Operating Model should have their own BRPs (ICES, 2019). Therefore, performance statistics of the tested HCRs were computed by adopting B_{lim_low}=196 334 tonnes for scenarios of 'true' Low productivity, and by adopting B_{lim}=337 448 tonnes for scenarios of 'true' Medium, Low–medium and Mix productivity.

The objective of the management and recovery plan (MRP) is the recovery of the Iberian sardine stock by 2023. Recovery is defined as ensuring, with a probability ≥90%, that B1+ is equal or above 80% of B_{lim}. In case this objective is not achieved by 2023, the request asks for the computation of the least amount of time frame required to achieve the objective, while using the same risk. The ICES precautionary criterion in terms of risk3 was also evaluated.

The catch rules proposed in the MRP, defined accordingly to a Medium productivity scenario, HCR1 (80%B_{lim}=270.0 thousand t, F_{low}=0.10 and F_{tgt}=0.12) and HCR2 (B_{lim}=337.4 thusand t, F_{low}=0.085 and F_{tgt}=0.12) have a close compliance with the recovery objective of the MRP. The capacity of recovering to above 80%B_{lim} will depend upon the actual true productivity of the stock. None of the rules will be able to restore B1+ above 80%$B_{lim}$with at least 90% probability in 2023 or before for any true productivity regime. However, this objective will be achieved by 2025 for HCR1 and by 2028 for HCR2 if the true stock productivity is Medium and is correctly perceived. For the other potential true stock productivity regimes, the application of these rules will not ensure such a recovery in the 30 years of the projection period. Considering a recovery to above B_{lim} with at least 95% probability, it would take 17 years (more than three generation times) with HCR1 and 22 years (more than four generation times) with HCR2 if the true productivity of the stock is Medium.

Catch rules HCR5 (80%B_{lim}=270.0 thousand t, F_{low}=0.083 and F_{tgt}=0.10) and HCR6 (B_{lim}=337.4 thousand t, F_{low}=0.071 and F_{tgt}=0.10) have a similar compliance to HCR1 and HCR2 in relation to the recovery objective of the MRP but, in addition, comply with the ICES precautionary criterion (risk3 <5%). The application of these rules leads to a stock recovery above 80%B_{lim} (270.0 thousand t) with at least 90% probability by 2025 for HCR5 and by 2027 for HCR6, assuming that the true stock productivity is Medium and is correctly perceived. Considering a recovery to above B_{lim} with at least 95% probability, it would take 13 years with HCR5 and 16 years with HCR6, which represents between two and three generation times.

Given the uncertainty on the true productivity scenario, catch rules HCR3 (80%B_{lim_low}=157.1 thousand t, F_{low}=0.027 and F_{tgt}=0.032) and HCR4 (B_{lim_low}=196.3 thousand t, F_{low}=0.023 and F_{tgt}=0.032) were defined assuming for the stock a permanent Low productivity. These rules comply with both the recovery objective of the MRP and the ICES precautionary criterion (risk3 <5%)

when the true stock productivity is correctly perceived. Both catch rules leads to a stock recovery above 80% of B_{lim_low} (157.1 thousand t) with at least 90% probability by 2022. The recovery of the stock to above B_{lim_low}(196.3 thousand t) with at least 95% probability would take 8–9 years(less than two generation times) with both catch rules.Risk3 is 1%. In case that the true stock productivity is Medium, hence B_{lim}=337.4 thousand t, the recovery to above 80%B_{lim} (270.0 thousand t) is achieved by 2025 for both rules, the stock would take 10–11 years to recover to above B_{lim} with at least 95% probability and risk3 is 0% is the long term.

For HCR1, HCR2, HCR5 and HCR6, where advice is based on assuming a permanent Medium productivity in the future, it is noted that values for risk3 are not reliable when the true stock productivity is Low, Low–medium or Mix, because the trajectories of B1+ do not stabilize (probability profile decreasing for Low and increasing for Low–medium and Mix scenarios) in the end of the simulation period. The decreasing trend of the probability profiles for the Low scenario suggests that risk3 would be higher than 19% if the simulation period was extended until equilibrium is achieved. For HCR3 and HCR4, defined assuming a permanent Low productivity during the 30 projected years, population equilibrium is also not reached when the true productivity is Low–medium and Mix.

The performance statistics were also computed considering a low biomass reference level (B_{lim_low} of 196.3 thousand t) for the true Medium productivity and a higher biomass reference level (B_{lim}=337.4 thousand t) for the true Low productivity scenarios. Under the Medium scenario, both the MRP recovery objective and the ICES precautionary criterion would be fulfilled for all simulation tested HCRs since all HCRs would ensure an increase of B1+ to above 196.3 thousand tonnes in the short or mediumterm. As expected, under the Low scenario the probability of achieving the MRP objective is low (between 17% and 36%) and risk3 is high (between 81% and 98%) since none of the catch rules would ensure an increase of B1+ to above 337.4 thousand tonnes.

Advice based on catch rules HCR1, HCR3 and HCR5 would lead to more frequent fishery closures, particularly in the short term, than advice based on catch rules HCR2, HCR4 and HCR6, for all scenarios. Median catches and IAV estimated with HCR1 and HCR2 are similar both in the first ten years (32 and 27 thousand tonnes) and in last ten years (51 thousand tonnes) of the simulation period. The main difference between these rules is that with HCR2 the probability of fishery closure is 0% while with HCR1 it is 17% in the first ten years. Catch rules HCR5 and HCR6 have slightly lower median catch and IAV, although of a similar order of magnitude, compared to HCR1 and HCR2. With HCR6 the probability of fishery closure is 0–1%.Catches estimated with HCR3 and HCR4 are much lower than for the other rules, of 6 and 17 thousand tonnes in the first ten years and in the last ten years, respectively, for both catch rules under perceived Medium and Low productivity. The probability of fishery closure is very low (0–2%).

In a situation of no fishing (HCR7) during the whole projected period, the recovery objective of the MRP would be achieved by 2025 when true Medium productivity is correctly perceived (to 80%B_{lim}=270.0 thousand t) and by 2021 when true Low productivity (to 80%B_{lim}=157.1 thousand t) is wrongly perceived as Medium. Comparing with the recovery time of the other HCRs, under the same conditions (i.e. true and perceived of Medium productivity), the recovery is much faster than with HCR1 or HCR2, is the same than with HCR5 and is only two years sooner than with HCR6. In relation to HCR3 and HCR4, when true Low productivity is wrongly perceived as Medium, the stock recovery with HCR7 would be achieved only one year sooner. Considering a recovery to above B_{lim} with at least 95% probability, it would take ten years in the situation of no fishing for the true Medium (B_{lim}=337.4 thousand t), which represents three years less than with HCR5 and six years less than with HCR6, and seven years for the true Low productivity (B_{lim_low}=196.3 thousand t), condition that is not reached with HCR5 and HCR6.

The catch rule HCR6 is the one that represents a better trade-off between the MRP objective of stock recovery, the ICES precautionary criterion and catch levels and maintenance of fishing activity. It is noted however, that this rule is not precautionary according to ICES criterion in case the future stock productivity remains low.

7 References

A'mar Z. T., Quinn T., Punt A. E. and Dorn, M. W. 2009. The impact of regime shifts on the performance of management strategies for the Gulf of Alaska walleye pollock (*Theragra chalcogramma*) fishery. Canadian Journal of Fisheries and Aquatic Sciences, 66: 2222–2242.

Baptista V., Laginha Silva P., Relvas P., Teodósio M.A., Leitão F. 2018. Sea surface temperature variability along the Portuguese coast since 1950. International Journal of Climatology 38 (3): 1145–1160.

Bernal M., Ibaibarriaga L., Lago de Lanzós A., Lonergan M. *et al*. 2008. Using multinomial models to analyse data from sardine egg incubation experiments; a review of advances in fish egg incubation analysis techniques. ICES J Mar Sci 65:51–59.

Borges M.F., Santos A.M.P., Crato N., Mendes H. and Mota B. 2003. Sardine regime shiftsoff Portugal: a time-series analysis of catches and wind conditions. Sci. Mar. 67, 235–244.

Clark C.W. 1990. Mathematical Bioeconomics: The Optimal Management of Renewable Resources. John Wiley and Sons.

Cobb C.W. and Douglas P.H. 1928. A theory of production.American Economic Reviews, 18:139–165.

Costa-Goela P., Cordeiro C., Danchenko S., Icely J., Cristina S. and Newton A. 2016. Time-series analysis of data for sea surface temperature and upwelling components from the southwest coast of Portugal. Journal of Marine Systems163: 12–22.

García D., Sánchez S., Prellezo R., Urtizberea A. and Andrés M. 2017. FLBEIA: A simulation model to conduct Bio-Economic evaluation of fisheries management strategies, SoftwareX, Volume 6, Pages 141–147. https://doi.org/10.1016/j.softx.2017.06.001.

García D., Prellezo R., Sánchez S., Andrés M., Urtizberea A. and Carmona I. 2018. Technical manual for FLBEIA an R package to conduct Bio-Economic Impact assessments using FLR (version 1.15). October 2018.

Gamito R., Teixeira C.M., Costa M.J. and Cabral H.N. 2015. Are regional fisheries'catches changing with climate? Fish. Res. 161, 207–216.

Garrido S., Silva A., Pastor J., Dominguez R., Silva A.V. and Santos A.M. 2015. Trophic ecology of pelagic fish species off the Iberian coast: diet overlap, cannibalism and intraguild predation. Mar Ecol Prog Ser 539: 271−285.

Garrido S., Silva A., Marques V., Figueiredo I., Bryère P., Mangin A. and Santos A.M.P. 2017. Temperature and food-mediated variability of European Atlantic sardine recruitment. Progress in Oceanography 159: 267–275.

ICES. 2006. Report of the Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy, Galway, Ireland, 5–14 September 2006 (ICES CM 2006/ACFM: 36).

ICES. 2012. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA 2012), 13–17 February 2012, Copenhagen, Denmark. ICES CM 2012/ACOM: 47. 572 pp.

ICES. 2013. Report of the Workshop to Evaluate the Management Plan for Iberian Sardine (WKSardineMP), 4–7 June 2013, Lisbon, Portugal. ICES CM 2013/ACOM:62.

ICES. 2014. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA), 17–21 February 2014, Copenhagen, Denmark. ICES CM 2014/ACOM: 43. 341pp.

ICES. 2015. Report of the Joint ICES-MYFISH Workshop to consider the basis for F_{MSY} ranges for all stocks (WKMSYREF3), 17–21 November 2014, Charlottenlund, Denmark. ICES CM 2014/ACOM:64. 156 pp.

ICES. 2016. Report of the Workshop to consider F_{MSY} ranges for stocks in ICES categories 1 and 2 in western waters (WKMSYREF4), 13–16 October 2015, Brest, France. ICES CM 1025/ACOM:58. 187 pp.

ICES. 2017a. Report of the Benchmark Workshop on Pelagic Stocks, 6–10 February 2017, Lisbon, Portugal. ICES CM 2017/ACOM:35. 278 pp.

ICES. 2017b. ICES fisheries management reference points for category 1 and 2 stocks. ICES Advice, Book 12, Section 12.4.3.1.

ICES. 2018. Report of the Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA), 26–30 June 2018, Lisbon, Portugal. ICES CM 2018/ACOM:17. 605 pp.

ICES. 2019. Report of the second Workshop on guidelines for Management Strategy Evaluations (WKGMSE2), 4–8 February 2019, JRC, ISPRA, Italy. ICES CM 2019/FRSG27. XXX pp.

Kell L. T., Mosqueira I., Grosjean P., Fromentin J.M., Garcia D., Hillary R., Jardim E., *et al*. 2007. FLR: an open-source framework for the evaluation and development of management strategies. ICES J. Mar. Sci., 64: 640–646.doi: 10.1093/icesjms/fsm012.

King J.R. (Ed.). 2005. Report of the study group on fisheries and ecosystem responses to recent regime shifts. PICES Scientific Report 28, 162 pp.

Klaer N.L., O´Boyle R., Deroba J.J. and Wayte S.E. 2015. How much evidence is required for acceptance of productivity regime shifts in fish stock assessments: Are we letting managers off the hook? Fisheries Research 168. DOI: 10.1016/j.fishres.2015.03.021.

Leitão F., Alms V. and Erzini K. 2014. A multi-model approach to evaluate the role ofenvironmental variability and fishing pressure in sardine fisheries. J. Mar. Syst. 139, 128–138.

Martins M.M., Skagen D., Marques V., Zwolinski J. and Silva A. 2013. Changes in the abundance and spatial distribution of the Atlantic chub mackerel (*Scomber colias*) inthe pelagic ecosystem and fisheries off Portugal. Sci. Mar. 77, 551–563.

Overland J., Rodionov S., Minobe S., Bond N. 2008. North Pacific regime shifts: Definitions, issues and recent transitions. Progress in Oceanography 77, 92–102.

Plagányi É. E., Punt A. E., Hillary R., Morello E. B., Thébaud O., Hutton T., Pillans R.D., *et al*. 2014. Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. Fish and Fisheries, 15: 1–22.

Punt, A.E. 2012. SSC default rebuilding analysis – technical specifications and User Manual, version 3.12e.University of Washington, Seattle, 28 pp.

Relvas P., Luis J. and Santos A.M.P. 2009. The importance of the mesoscale in the decadal changes observed in the Northern Canary upwelling system. Geophys. Res. Lett. 36,L22601. http://dx.doi.org/10.1029/2009GL040504.

Rodionov S.N. 2004: A sequential algorithm for testing climate regime shifts. Geophys. Res. Lett., 31, L09204, doi:10.1029/2004GL019448.

Rodionov S. and Overland J.E. 2005. Application of a sequential regime shift detection method to the Bering Sea ecosystem. ICES J. Mar. Sci. 62(3): 328–332.doi:10.1016/j.icesjms.2005.01.013.

Santos M.B., Gonzalez-Quirós R., Riveiro I., Cabanas J.M., Porteiro C. and Pierce G.J. 2012. Cycles, trends, and residual variation in the Iberian sardine (*Sardina pilchardus*)recruitment series and their relationship with the environment. ICES J. Mar. Sci. 69(5), 739–750.

Silva A., Uriarte A., Riveiro I., Santos B., Azevedo M., Murta A., Carrera P., Ibaibarriaga L., and Skagen D. 2013. Reference points for the Iberian sardine stock (ICES areas 8c and 9a). Working Document to ICES-ACOM (5 June 2013) and to WGHANSA. In Report of the Working Group on Southern Horse Mackerel, Anchovy, and Sardine (WGHANSA), 21–26 June 2013, Bilbao, Spain. ICES CM 2013/ACOM:16.

Schwartzlose R.A., Alheit J., Bakun A., Baumgartner T.R.,Cloete R., Crawford R.J.M.,Fletcher W.J. *et al*. 1999. Worldwide large-scale fluctuations of sardine and anchovy populations. S. Afr. J. Mar. Sci. 21, 289–347.

Solari A.P., Santamaría M.T.G., Borges M.F., Santos A.M.P., Mendes H., Balguerías E., Díaz Cordero J.A., Castro J.J. and Bas C. 2010. On the dynamics of *Sardina pilchardus*:orbits ofstability and environmental forcing. ICES J. Mar. Sci. 46, 16–23.

Teixeira C.M., Gamito R., Leitão F., Murta A.G., Cabral H.N., Erzini, K. and Costa M.J. 2016. Environmental influence on commercial fishery landings of small pelagic fishing Portugal. Reg. Environ. Change 16 (3SI), 709–716.

Vert-pre K.A., Amoroso R.O., Jensen O. and Hilborn R. 2013. Frequency and Intensity of Productivity Regime Shifts in Marine Fish Stocks PNAS 110 (5): 1779–1784.

Recommendation to ACOM

Management Strategy Evaluation (MSE) of management and recovery plans undertaken with full-feedback MSE requires thoroughly discussions to agree on the settings for the conditioning of the OMs as well as coding work. Moreover, simulation testing runs are computationally demanding (usually take several hours for one scenario, despite running the simulations in parallel using several nodes). Although work has been carried out by correspondence beforehand of WKSARMP, it was not possible to run all simulation testing during the meeting because much time was dedicated to refine and agree on MSE conditioning, running limited number of simulations to check simulation performance and discuss preliminary results. From this experience, the WG recommends to ACOM to consider, for ICES meetings aimed at evaluating management plans with full-feedback MSE, the adoption of a process similar to the ICES benchmarks. The WG recommends a first physical meeting to agree on the MSE conditioning and a second physical meeting to analyse the simulation testing results and report writing. The time between physical meetings, which should consider also meetings by correspondence (e.g. WebEx meetings), would be dedicated to code the MSE and run the simulations.

Annex 1: The Request

O'REÇÂO-GE'?AL DE
SEGUPANÇA E stnv.ços MARíT1

To

Anne Christine Brusendorff

General Secretary ICES

H. C. Andersens

Boulevard 44-46, DK 1553

Copenhagen V,

Denmark

Cc: Helen Clark
DGMARE

Clarifications regarding the special request to evaluate the management and recovery plan for the Iberian sardine.

ICES has asked by a letter of 28th June to Spain and Portugal that the Harvest Control Rule (HCR) should:

- Define the maximum value for the I-ICR catch/fishing mortality rate as a function of the biomass.
- Define all biomass points that trigger changes in the value of catch/fishing mortality rate and how these catch/fishing mortality rates would change.
- In case a minimum catch/fishing mortality rate is wanted, it should be clarified if this is to be applied just for the starting year or if this is a constraint to the Harvest Control Rule; in the latter case, the plan should also state above which biomass level does the constraint applies.

As it has been requested by ICES please find attached a copy of the Working Document from Instituto Português do Mar e da Atmosfera (IPMA) mentioned in the management and recovery plan submitted.

To clarify the Iberian sardine Harvest Control Rule proposed in the Management Plan we inform that:

Objective:

Assure that the stock biomass will be equal or above 80% of B_{lim} with a probability 90% by the year 2023,

(If this objective is not achieved in the specified number of years (n = 5), please evaluate what would be the least time frame possible to achieve this objective with the same risk).

<u>Harvest Control Rule (HCR)</u>:

i. In the case B1+ is estimated to be below or equal to B_{low} (B_{low} — lowest biomass estimated for the year 2015 in the 2018 assessment (ICES, 2018)), the catch shall be zero which is consistent with a fishing mortality (F) equal to zero.
If B1+ ≤ B_{low} then F = 0

ii. In the case B1+ is estimated to be less than or equal to 80% of B_{lim} and larger than B_{low}, the catch shall be fixed at a value that is consistent with a fishing mortality (F) equal to 0.10.
If B_{low}< B1+ ≤ 80% B_{lim} then F = 0.10

iii. Where the clause in paragraph ii would lead to an interannual increase in B1+ inferior to 5%, F should decrease to a level that would led to at least a 5% inter-annual increase of B1+.

iv. In the case B1+ is estimated to be above 80% of B_{lim}, the catch shall be fixed at a value that is consistent with a fishing mortality (F) equal to 0.12.
If B1+ > 80%B_{lim} then F= 0.12

In the context of the management and recovery plan submitted, we ask ICES to consider also, instead of ii) and iii): in the case B1+ is estimated to be less or equal to B_{lim} and larger than B_{low}, the catch shall be fixed at a value that is consistent with F increasing linearly from F = 0.085 to F=0.12 (F_{MSY}).

We also ask ICES to evaluate if it is necessary to re-estimate reference points for this stock to account for:

a) The possibility that the low productivity of this stock in the recent past (since 2006) might continue in the future.

b) Possible retrospective bias in the assessment estimates.

And to test 2 alternatives:

i. Start from the population (numbers-at-age) estimated in the beginning of the interim year of the last assessment (ICES, 2018) and

ii. Start from the population projected one year ahead, to the beginning of year for which the catch is to be set.

In both cases assume the 2018 catch to be 12028 t, as agreed by Spain and Portugal.

Portuguese and Spanish scientists can be contacted in order to solve any doubt about these proposals.

Yours sincerely,

Assinado de forma digital por
JOSÉ CARLOS DIAS SIMÃO
Dados: 2018.09.27 17:50:23
+01'00'

José Carlos Simão

Director General for

Natural Resources Safety and Maritime Services PORTUGAL

IsabÅ Artime Garcia

Director General for Fisheries

SPAIN

Annex 2: Reviewers report

External reviewer report for a workshop on the management and recovery plan for Iberian sardine (WKSARMP, 1–5 April 2019)

Martin Dorn and Sonia Sánchez acted as the external experts for a workshop held 1–5 April 2019 on the management and recovery plan for Iberian sardine (WKSARMP). They participated in the WebEx preparatory meetings and attended to the final workshop. Terms of reference for the workshop included a re-evaluation of reference points, and the development of management strategy evaluation (MSE) of proposed harvest control rules to recover the Iberian sardine, which is currently at low abundance due to overfishing and an extended period of low recruitment. Workshop participants should be commended for their efforts to implement a full feedback MSE using stock synthesis and FLBEIA, which may be a tool with wider applicability both within ICES and elsewhere. In our view, the group provided adequate technical basis to respond to the request, and the report of the workshop is suitable for providing management advice. The uncertainty in the most plausible future scenario of recruitment complicates decision-making, but this accurately characterises the state of scientific knowledge, and is not a defect of the analysis. Below we provide comments on the re-evaluation of reference points and the MSE for Iberian sardine, and conclude with general comments. This report reflects solely the views of the external experts.

Comments on re-evaluation of reference points

The working group identified two productivity regimes in the recent history of the Iberian sardine stock, a medium productivity regime for the year 1993–2017 and the low productivity regime for years 2006–2017. This decision is supported by a change point analysis and an evaluation of ecosystem and environmental changes in sardine habitat, and is consistent with previous characterisations of Iberian sardine productivity. The stock–recruit analysis to estimate reference points for these productivity periods was carefully done and followed standard procedures. The time-series of recruitment and spawning biomass for the low productivity period is very short, and reference points, particularly B_{lim}, the point at which recruitment is impaired, should be considered very uncertain.

The benchmark assessment for Iberian sardine displays a relatively strong retrospective pattern, in which each additional year of data results in the stock being estimated at lower abundance. A decision was made to keep B_{lim} from the benchmark assessment for the medium productivity regime rather than updating this estimate with a value from new analyses. The working group supported this decision by noting that all of the newer estimates were within the 95% CI of the original value. We supported this approach, and note that the largest change in B_{lim} was an increase that occurred when the 2018 data were added. It is likely because recent low recruitment, despite being highly uncertain, had high leverage of the sloping portion of the segmented regression. For this reason, it would be difficult to support a revised estimate of B_{lim}.

The next benchmark assessment for Iberian sardine would be the logical place to re-estimate biological reference points. MSE sensitivity runs suggested that one potential source of the retrospective bias is the assumption of a stationary stock–recruit relationship in the stock synthesis model. This assumption could be relaxed by allowing for time blocks of stock–recruit parameters like Rzero, and we recommend that this be evaluated in the next benchmark assessment.

Comments on Management Strategy Evaluation

The management strategy evaluation generally followed the WKGMSE2 guidelines. The elements of uncertainty included in the MSE include uncertainty in catch-at-age, survey catchability, survey numbers-at-age, and initial numbers-at-age. Some elements of uncertainty were not modelled, such as weight-at-age and maturity-at-age, but these have been relativity stable historically, and are not likely to be major sources of uncertainty. A summary table is included as requested by ICES that includes technical details, and these details are also described in the report text (e.g. assumptions made, scenarios tested, summary statistics used to test the performance of the HCRs…). However, the summary table provided does not follow precisely the same format as the ICES guidelines.

The working group did not identify a base case scenario, due to the uncertainty in the future productivity of the stock. Four alternative scenarios were considered in the MSE, a medium productivity scenario, a low productivity scenario, and two scenarios with different assumptions about how the stock would transition between low and medium scenarios. The group presented detailed arguments for and against each of the alternative productivity scenarios tested. We considered this approach a very thorough and appropriate evaluation of possible scenarios, though decision-making process for providing management advice is made more complicated with this approach.

Although the MSE implementation was considered appropriate, a number of improvements should be considered for future MSE evaluations. These include: i) use of MCMC draws from stock synthesis to condition the operating model; ii) evaluate the incremental addition of uncertainty by comparing the results with the runs without error; iii) adding uncertainty in all the biological parameters, not only in the initial numbers-at-age; and iv) implementing a short-cut approach for faster computation. The short-cut approach should be compared to the full feedback MSE to understand respective advantages and limitations.

The time required to prepare the code to implement an MSE and the high computation load for running the iterations prevented MSE results from being available in time to be discussed within the workshop. Therefore, it would be advisable to have the MSE conditioned in advance of the final meeting to allow final runs to be available at the meeting to discuss the results and conclusions. MSE requires extensive computation, and it is unreasonable to expect that adequate model runs can be completed during the duration of a week-long workshop.

General comments

The harvest control rules in the request were very specific, as were the performance standards. While this simplifies the analysis, it was not obvious to the working group what additional analyses would be desirable if the harvest control rules did not meet the performance standard, or the ICES guidelines for a precautionary approach, as turned out to be the case. Although the group were able identify an alternative set of harvest control rules with satisfactory performance, this is not the best approach. The situation could have been avoided if the harvest control rules had been specified in a more flexible way to allow tuning to ensure performance standards can be met. Harvest control rule tuning is normally an important part of the MSE process.

More sophisticated tools to incorporate uncertainty in the stock assessment and harvest strategy evaluation (including observation error, process error, and model error) could lead to a progressive reduction in target harvest rates in order to meet the ICES precautionary standard. It may be worthwhile to study this issue by tabulating across ICES assessments the elements of uncertainty that are incorporated and the size of the precautionary buffer. It would also be of interest to compare precautionary buffers derived from uncertainties in stock assessment, and those that come from management strategy evaluations.

There is some evidence (though not presently overwhelming) that the current low productivity of Iberian sardine is partially caused by climate change (i.e. a warming ocean), and may not be reversible. This situation is likely to be encountered more frequently, as the climate shifts further away from historical means. Whether this should lead to changes in biological reference points is a difficult issue for fisheries management, and guidance is needed for suitable approaches. The working group provided analyses that considered as alternative states of nature both a low and a medium productivity regime and the reference points associated with each regime, which we considered a good approach for dealing with the present uncertainties with the Iberian sardine stock. Other approaches may be needed in the future.

Annex 3: Laura Wise, WD BRPs

Introduction

ICES received a Special Request from Portugal and Spain to evaluate a multiannual management and recovery plan for the Iberian sardine (2018–2023). The request also includes the re-examination of biological reference points (BRP) for this stock to account for:

i. the possibility that the low productivity of this stock in the recent past (since 2006) might continue in the future;
ii. possible retrospective bias in the assessment estimates.

Current reference points

Reference points for this stock (Table 1) were estimated during WKPELA 2017 (ICES, 2017a) and accepted in the same year.

Table 1. Summary of current Iberian sardine stock reference points.

BRP	VALUE	TECHNICAL BASIS
B_{lim}	337 448 t	B_{lim} = Hockey-stick change point
B_{pa}	446 331 t	$B_{pa} = B_{lim} * exp(1.645 * \sigma), \sigma = 0.17$
MSY$B_{trigger}$	446 331 t	$B_{trigger} = B_{pa}$
F_{lim}	0.25	Stochastic long-term simulations (50% probability $B1+< B_{lim}$)
F_{pa}	0.19	$F_{pa} = F_{lim} * exp(-1.645 * \sigma), \sigma = 0.17$ If $F_{pa} < F_{MSY}$ then $F_{MSY} = F_{pa}$
$F_{p0.5}$	0.12	Stochastic long-term simulations with ICES MSY AR ≤ 5 probability $B1+< Blim$); Constraint to F_{MSY} if $F_{p0.5} < F_{MSY}$
F_{MSY}	0.20	Median F_{target} which maximizes yield without $B_{trigger}$
Adopted F_{MSY}	0.12	If $F_{p0.5} < F_{MSY}$ then $F_{MSY} = F_{p0.5}$

Source data

The re-examination of BRP for this stock was based on the most recent assessment data (Figure 1, ICES, 2018) and stock–recruitment (S–R) plots (Figure 2).

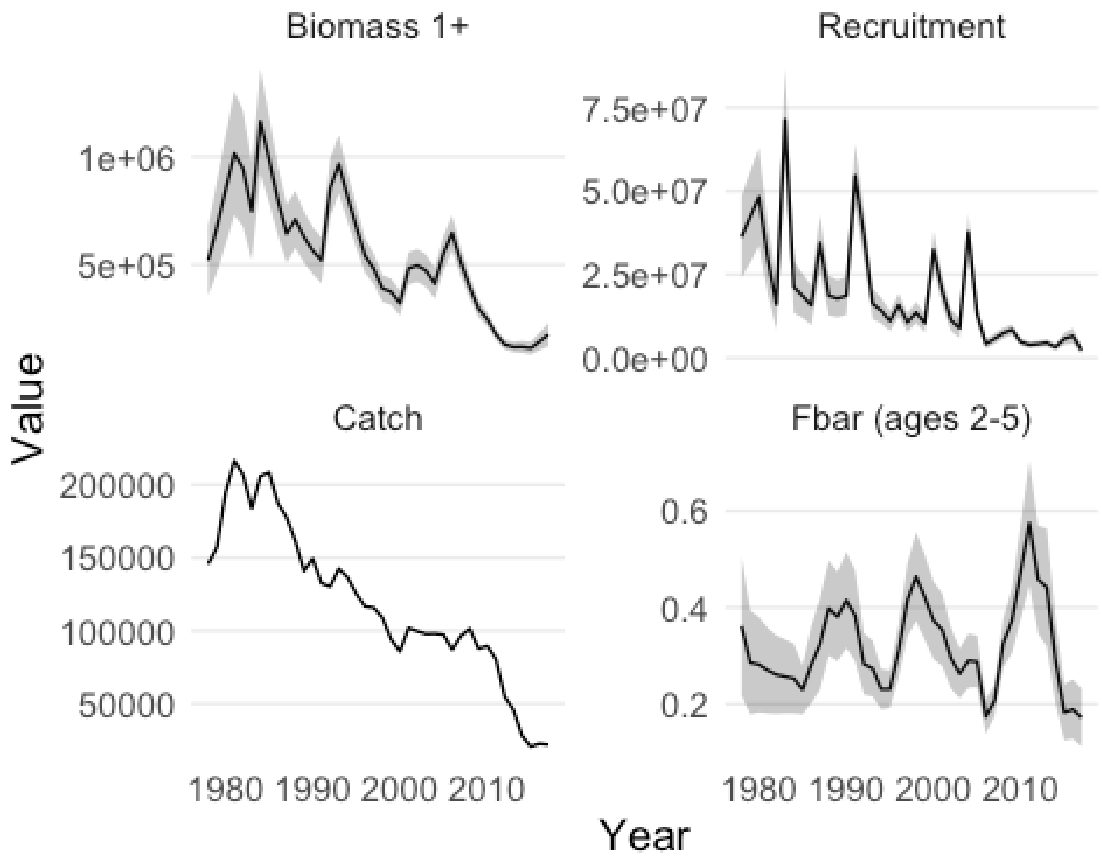


Figure 1. Sardine in divisions 8.c and 9.a. Stock summary from WGHANSA 2018 assessment used as the basis for the re-evaluation of reference points. Upper panel: Biomass 1+ (t), left, Recruitment (thousand individuals), right. Lower panel: Catch (t), left and Fishing Mortality (reference ages 2–5) (year $^{-1}$), right. Shades represent the 95% confidence interval of the estimates.

Stock–recruitment data pairs

Figure 2 shows the stock–recruitment pairs estimates for the Iberian sardine and their estimated 95% confidence interval (time-series 1993–2017).

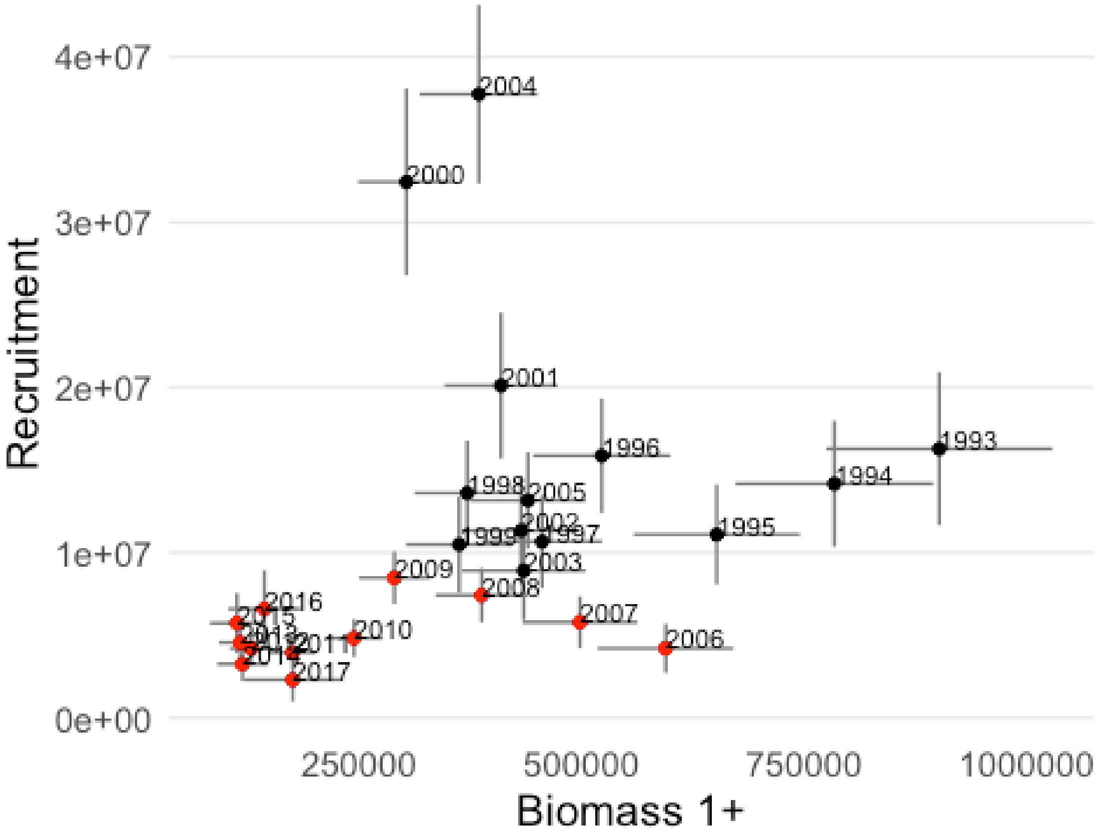


Figure 2.Stock–recruitment pairs for the Iberian sardine stock (1993–2017). Horizontal bars represent the 95% confidence interval of Biomass 1+ estimates and vertical bars represent the 95% confidence interval of Recruitment estimates. Points in colour red evidence the recent low recruitment period 2006–2017.

Methods used

The methodology used followed the framework proposed in ICES (2017b) guidelines for fisheries management reference points (the same procedure as in WKPELA 2017 (ICES, 2017a)). All statistical analyses were carried out in R environment (R version 3.4.1). The sardine latest stock information (ICES, 2018) was converted to an FLStock object using the "FLCore" package (version 2.6.9). Simulations analyses were conducted with the package "MSY" (version 0.1.18) using the EqSim routines (ICES, 2016), a stochastic equilibrium reference point software that provides MSY reference points based on the equilibrium distribution of stochastic projections. First, stock–recruitment functions were fitted to the stock–recruitment pairs and then reference points were estimated. Limit and precautionary reference points for Biomass of fish age 1 and older ($B1+$) and fishing mortality (F), namely B_{lim}, B_{pa}, F_{lim} and F_{pa}, were defined. Finally, F_{MSY} and $F_{p0.5}$ were estimated.

Settings

Simulations were performed with stochasticity in population biology parameters using the observed historical stock variation from the last six years (2012–2017). Stock weight-at-age is calculated from DEPM surveys, which are carried out on a triennial basis. For years in between DEPM surveys, weight-at-age is linearly interpolated from adjacent surveys. A period of six years was chosen to include two survey estimates. This procedure is similar to the one adopted for the short-term forecast (ICES, 2018).

In relation to stock productivity two regimes were considered (1993–2017 and 2006–2017). Following the analysis performed in ICES (2013a) a productivity break was identified in 1992–1993 in the time-series. The period 1993–2017 assumes this break for the stock productivity in the historical series and is a plausible scenario for future stock dynamics. To account for the question raised by the clients that there is the possibility that a lower productivity of the stock in the recent past might continue in the future, another period was considered, 2006–2017. Also, there are no indications of an increase in recruitment in the near future, which has been low during last years, promoted by a regime change in environmental conditions in the main recruitment areas in the stock (Cabrera *et al*., 2018). Therefore, two period were simulated as to reproduce two different stock productivity periods: the former represents a mean stock productivity regime while the later represents a low stock productivity regime (Table 2).

During WKPELA (2017) it was already acknowledged that recruitments since 2006 are well below the average of the period 1993–2015 and recommended a close monitoring of the stock productivity and a re-evaluation of reference points in case there were signs that the current very low productivity continued in the future which is the case of 2016 and 2017 (recruitment in 2017 is in fact the lowest estimated in the historical series of this stock).

Table 2. Model and data selection settings.

DATA AND PARAMETERS	SETTING	COMMENTS
Stock data	1993–2017; 2006–2017	The period 1993–2017 broadly corresponds to the period where survey information is available. The stock shows a wide dynamic range of B1+ and evidences that recruitment is impaired. Sardine productivity has declined over time; productivity in 2006–2017 has been generally lower than in the earlier period.
Exclusion of extreme values	No	
Trimming of R values	No	
Mean weights and proportion mature; natural mortality	2012–2017	6 yr. period was chosen. Knife-edge maturity ogive with 100% mature at-age 1+. Biomass 1+ is the stock index. Natural mortality is age-dependent and time-invariant.
Exploitation pattern	2012–2017	6 yr. period. Corresponds to a constant selectivity period.
Assessment error of fishing mortality	0.233	Taken from WKMSWREF4 (ICES, 2016) of estimates of five stocks in WKMSYREF3 (ICES, 2015)[1]
Autocorrelation of fishing mortality in assessment error	0.423	Taken from WKMSWREF4 (ICES, 2016) of estimates of five stocks in WKMSYREF3 (ICES, 2015)[1]

[1] **At the moment, these errors are not estimated for this stock. Also, in the previous estimation of reference points these were the values adopted.**

Recruitment series showed a 4-year lag autocorrelation in the period 1993–2017 and no autocorrelation in the shorter period (2006–2017) (Figure 3). No scenarios were run with autocorrelation in recruitment.

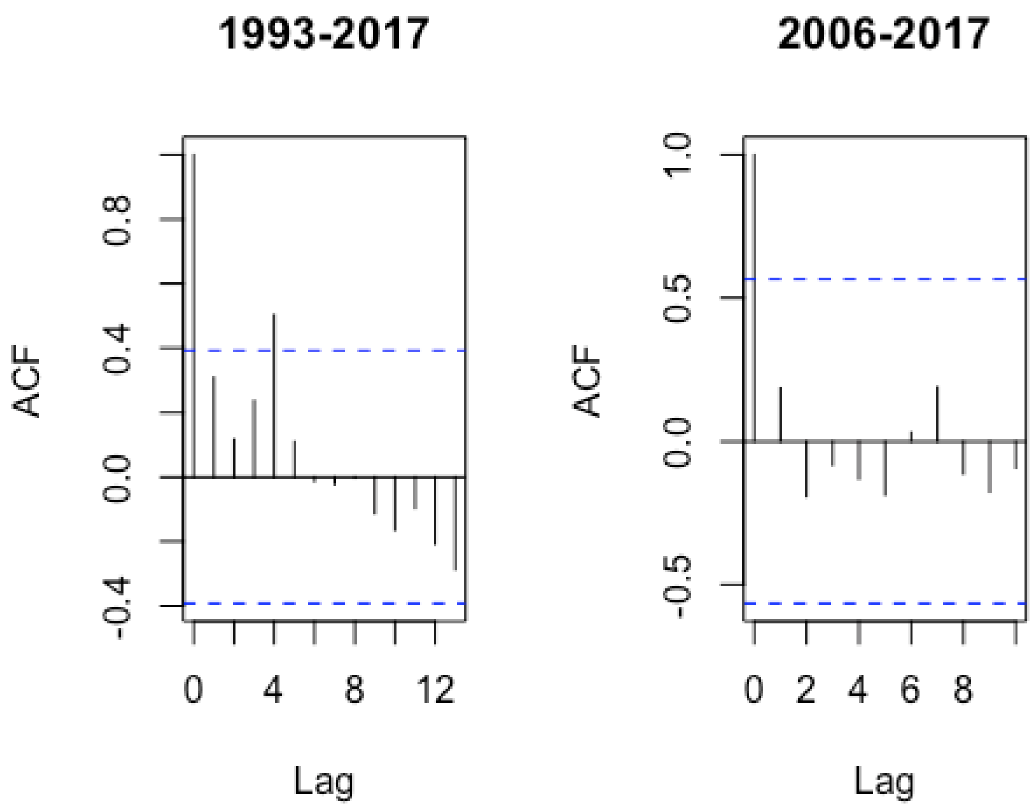


Figure 3. Estimates of autocorrelation in recruitment of the 1993–2017 time-series (left panel) and of the 2006–2017 time-series (right panel).

Results

Stock–recruitment relationship

Time-series 1993–2017

Three S–R relations (Ricker, Beverton–Holt and Hockey-stick) were fit to both sets of data. For the longer period (1993–2017), models showed comparable maximum likelihood estimates (Table 3) but the Hockey-stick achieved a better fit. The automatic weighting method implemented in EqSim (ICES, 2016) was used to weight the combination of the three S–R models fitted from bootstrap samples of the B1+ and recruit pairs (Figure 4). Again, the Hockey-stick had better results than the Ricker and Beverton–Holt with weights estimated to be 86%, 4% and 10%. Since the Hockey-stick dominates the S–R combination by far (86% weight) and that this was the same model used to estimate BRP currently in use, the Hockey-stick S–R (Figure 5) was adopted for the calculation of reference points.

B_{lim} and B_{pa}

In order to analyse an F_{MSY} candidate in relation to precautionary limits, i.e. $prob(SSB < B_{lim})$, a B_{lim} needs to be defined. Following ICES (2017b) guidelines, the S–R data of this stock are consistent with a Type 2 pattern given the wide dynamic range of B1+ and evidence that recruitment is impaired. In this case, B_{lim} is equal to the change point of a Hockey-stick model fitted to S–R data (Figure 5). The B_{lim} candidate calculated as the change point of the Hockey-stick model was 361 639 t. This estimate of B_{lim} is within the 95% confidence interval (Figure 6) of the currently in use B_{lim} (296 057, 514 150). B_{pa} was derived as $B_{pa} = Blim * exp(1.645 * \sigma)$, with $\sigma = 0.153$, the coefficient of variation of $B1+_{2017}$ from the last stock assessment (ICES, 2018).

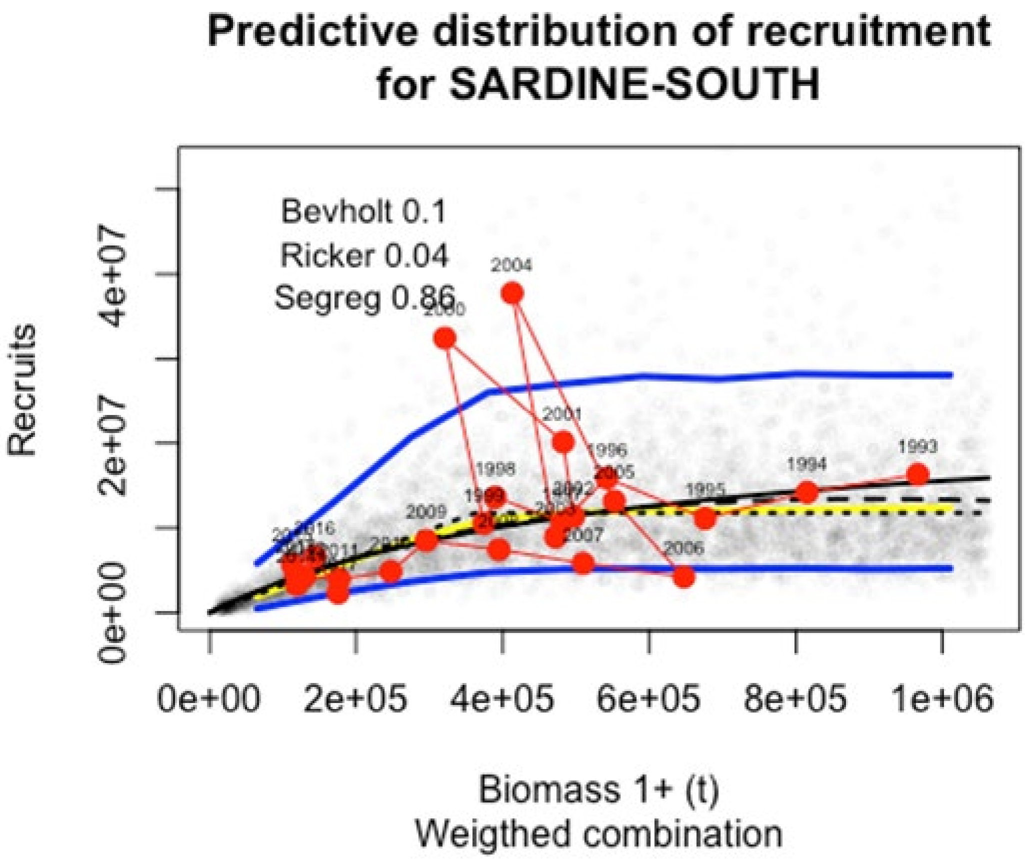


Figure 4. Fitted Hockey-stick (black dashed), Ricker (black), Beverton–Holt (black dotted) with 90% intervals (blue) for the period 1993–2017. The median recruitment based on the weighted distributions of each model (yellow) and the weighting/contribution of each model are shown. Red lines are the historic sequence of recruitment.

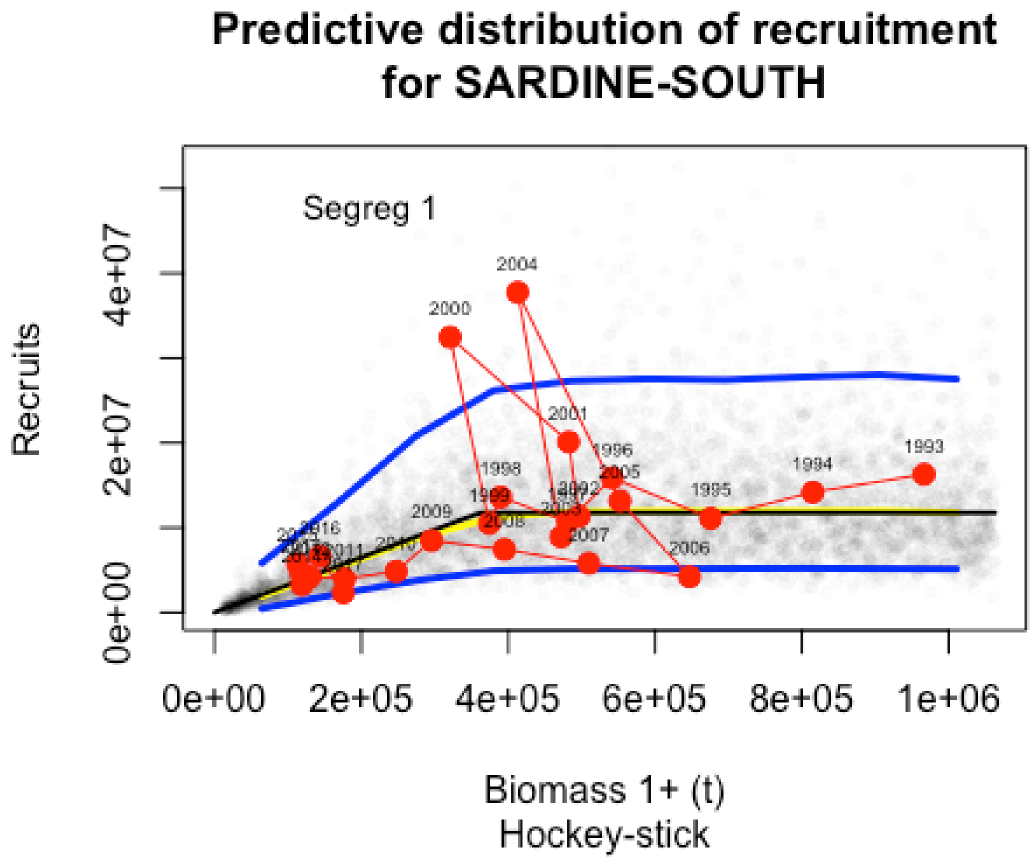


Figure 5. Fitted Hockey-stick (black) for the period 1993–2017. The median recruitment based on the weighted distribution the model (yellow) is shown. Red lines are the historic sequence of recruitment.

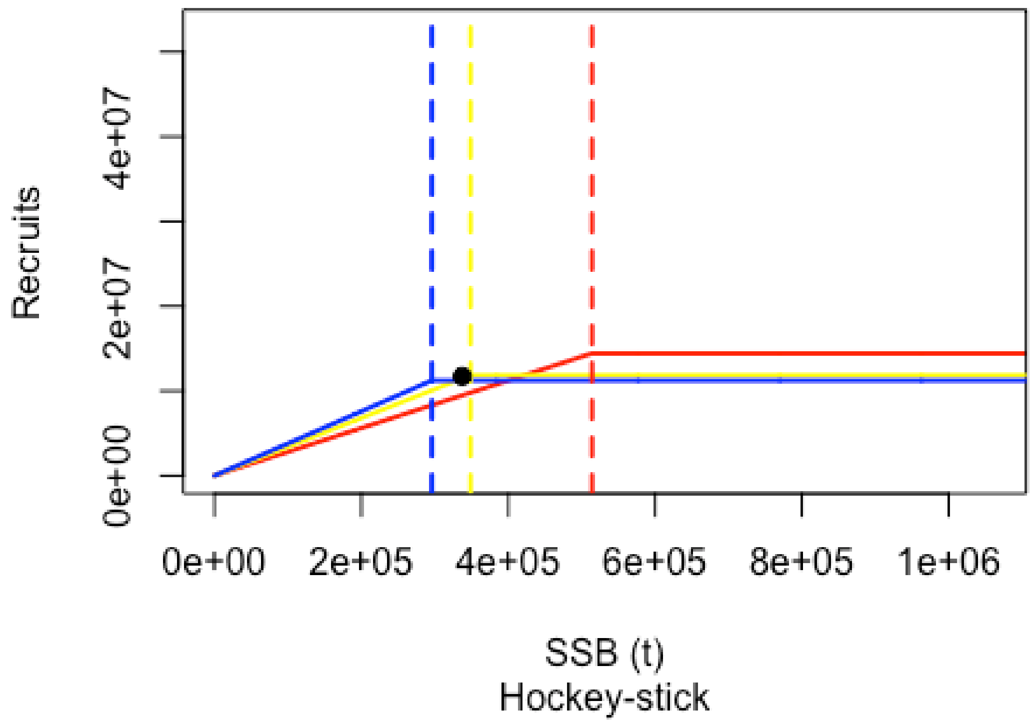


Figure 6.Blue, yellow and red dashed vertical lines represent the 2.5, 50 and 97.5 quantiles of parameter b of a Hockey-stick curve from 1000 bootstrap resamples of S–R pairs from the time-series 1993–2017. Blue, yellow and red lines represent the Hockey-stick model fitted to the S–R pairs when parameter b is fixed at 2.5, 50 and 97.5 quantiles. The black dot represents the current adopted B_{lim}.

Time-series 2006–2017

For the shorter period (2006–2017), models showed comparable maximum likelihood estimates (Table 3) but the Ricker achieved a better fit. The automatic weighting method implemented in EqSim (ICES, 2016) was used to weight the combination of the three S–R models fitted from bootstrap samples of the B1+ and recruit pairs (Figure 7). Again, the Ricker had better results than the Beverton–Holt and the Hockey-stick with weights estimated to be 51%, 37% and 13%. Residuals plots of the different fits to the S–R pairs for this period are shown in the Annex section (Section 9). Since the Ricker dominates the S–R combination but with only 51% in weight, reference points were estimated with (a) the Hockey-stick S–R relation (Figure 8) and with (b) the Ricker S–R relation (Figure 9).

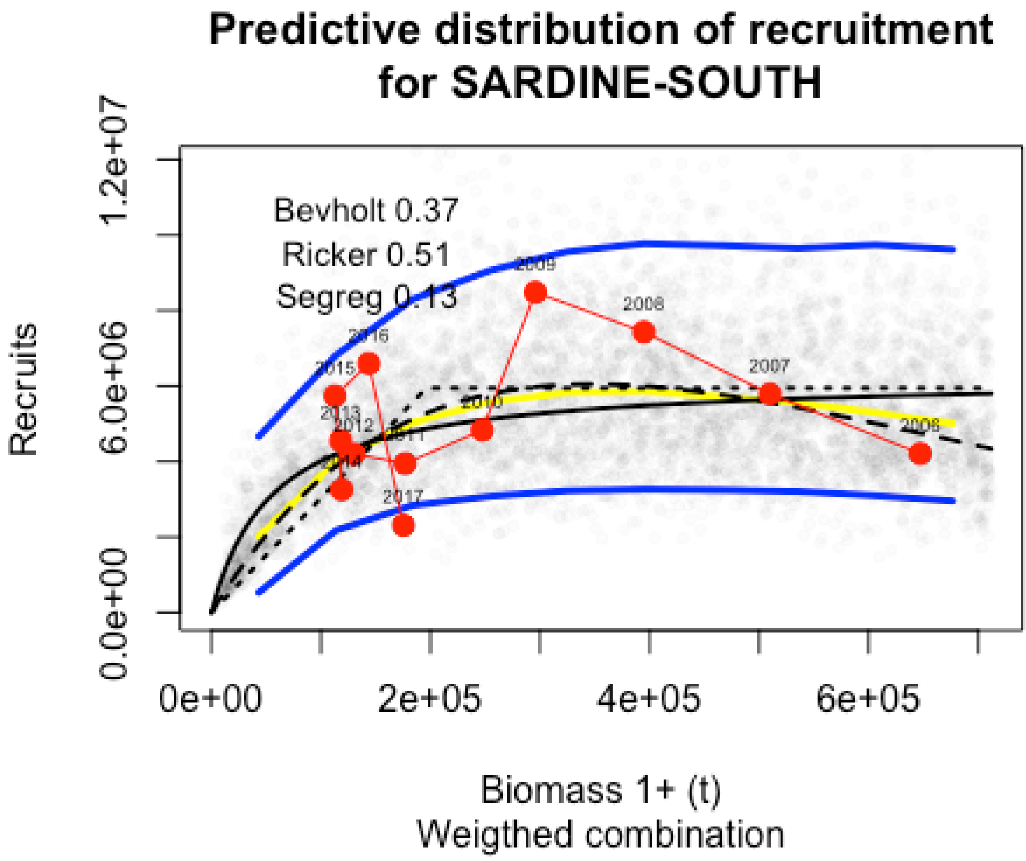


Figure 7. Fitted Hockey-stick (black dashed), Ricker (black), Beverton–Holt (black dotted) with 90% intervals (blue) for the period 2006–2017. The median recruitment based on the weighted distributions of each model (yellow) and the weighting/contribution of each model are shown. Red lines are the historic sequence of recruitment.

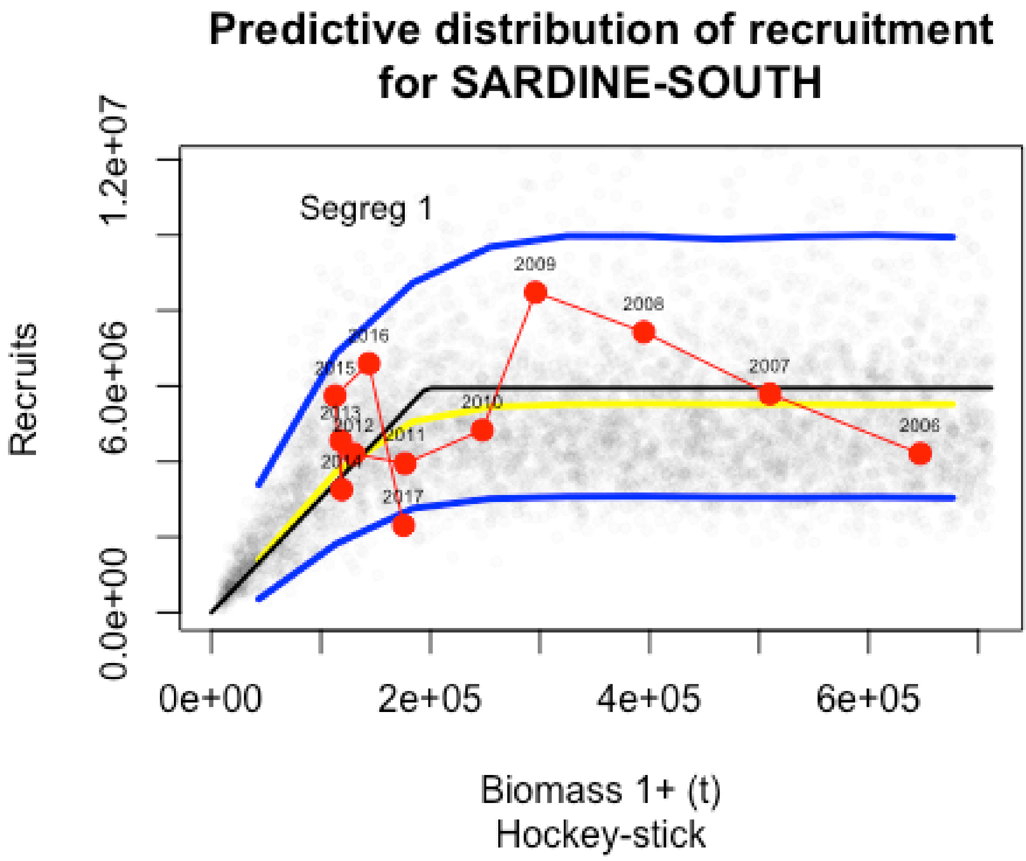


Figure 8. Fitted Hockey-stick (black) for the period 2006–2017. The median recruitment based on the weighted distributions of the model (yellow) is shown. Red lines are the historic sequence of recruitment.

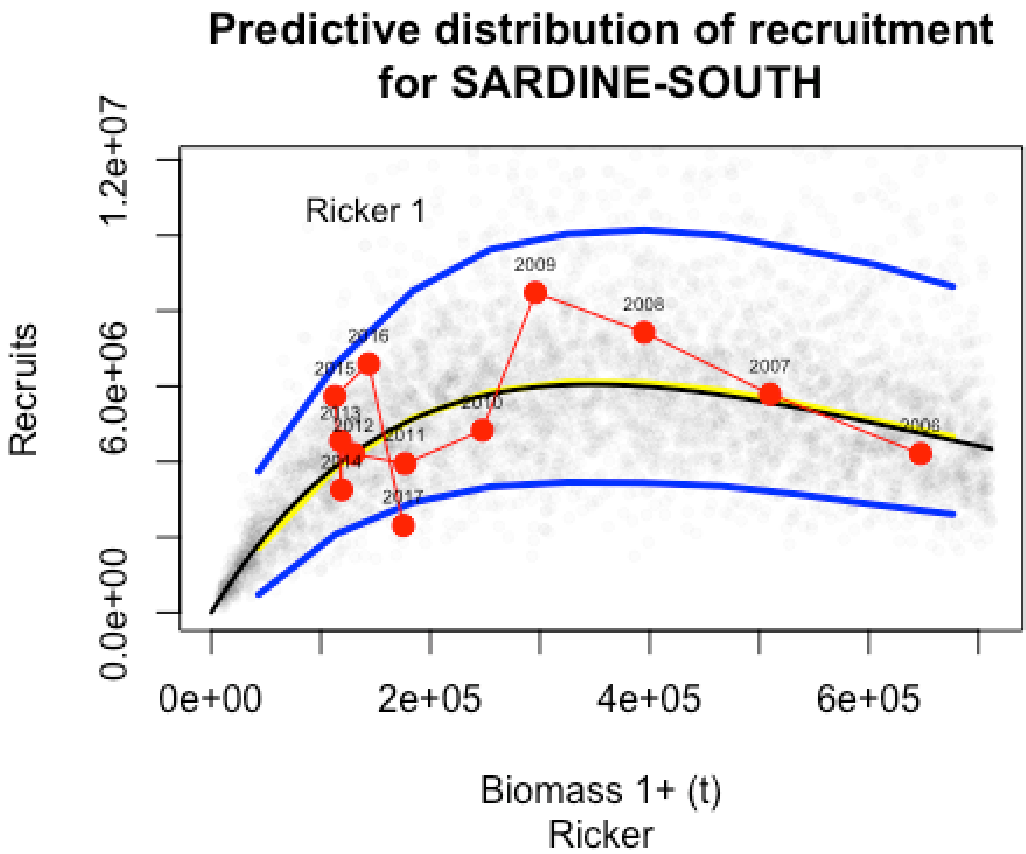


Figure 9. Fitted Ricker (black) for the period 2006–2017. The median recruitment based on the weighted distributions of the model (yellow) is shown. Red lines are the historic sequence of recruitment.

B_{lim} and B_{pa}

For the timeperiod 2006–2017 it is rather difficult to decide what type of stock the S–R data pairs indicate. Therefore, several scenarios were run. In one scenario we used the (a) Hockey-stick S–R relation and considered that B_{lim} = change point of the Hockey-stick. Other scenarios run were (b) with the Ricker S–R relation where (b.1) B_{lim} = change point of the Hockey-stick model and (b.ii) B_{lim} = Biomass 1+ that produces $R_{max}/2$. For all scenarios, B_{pa} was derived as $B_{pa} = B_{lim} * exp(1.645 * \sigma)$, with $\sigma = 0.153$, the coefficient of variation of $B1+_{2017}$ from the last stock assessment (ICES, 2018).

Table 3. Parameters estimates (a, b) from deterministic fit and 2.5 and 97.5 quantiles from 1000 bootstrap resamples of S–R pairs for period 1993–2017 and 2006–2017.

Model	Time-series	a	b	Conf. Int. param b	AIC
Bev–Holt	1993–2017	43.6	$1.8*10^{6}$	-	-12.421
Bev–Holt	2006–2017	111.9	179 000	-	-14.836
Ricker	1993–2017	40.6	$1.1*10^{-6}$	-	-12.767
Ricker	2006–2017	47.3	$2.9*10^{-6}$	$1.63*10^{-6}$-$3.5*10^{-6}$	-15.410
Segreg	1993–2017	32.5	361 639	299 149–541 822	-14.632
Segreg	2006–2017	30.3	196 334	98 389–296 557	-12.039

Table 4. Scenarios run in Eqsim to estimate reference points.

SCENARIO	TIME-SERIES	S-R relationship	B_{lim}
ts9317Seg	1993–2017	Hockey-stick	Change point of Hockey-stick
ts0617Seg	2006–2017	Hockey-stick	Change point of Hockey-stick
ts0617RicSeg	2006–2017	Ricker	Change point of Hockey-stick
ts0617RicRec	2006–2017	Ricker	Biomass that produces $R_{max}/2$

The estimated BRP for all scenarios are shown in Table 5.

Table 5. Estimated reference points for each scenario.

	Current	ts9317Seg	ts0617Seg	ts0617RicSeg	ts0617RicRec
Blim	337 448	361 639	196 334	196 334	80 604
Bpa	574 066	465 137	252 523	252 523	103 671
Flim	0.250	0.232	0.156	0.173	0.415
Fpa	0.189	0.176	0.118	0.130	0.314
FMSY*	0.204	0.198	0.224	0.260	0.260
Fp0.5_Btrig	0.119	0.098	0.032	0.061	0.238

***current adopted F_{MSY}= $F_{p0.5\_Btrig}$=0.12**

And the percentual difference between reference points estimated for each scenario and the current reference points are presented in Table 6.

Table 6. Percentual difference between reference points estimated for each scenario and the current reference points.

	ts9317Seg	ts0617Seg	ts0617RicSeg	ts0617RicRec
Blim	7.2	-45.7	-45.7	-77.7
Bpa	-19.0	-45.7	-45.7	-77.7
Flim	-7.2	-32.8	-25.4	78.9
Fpa	-6.9	-33.0	-26.1	78.4
FMSY	-2.9	13.1	31.3	31.3
Fp0.5_Btrig	-17.6	-67.3	-37.8	142.9

The run for the timeperiod 1993–2017 shows that using the latest information available on the stock (ICES, 2018) the potential candidate for B_{lim} would be 7.2% higher but within the 95% confidence interval of the current B_{lim} (296 057, 514 150). The reference point that shows a higher percentual difference when compared with the current reference points is the potential candidate for $F_{p0.5}$ (18% lower) that conditions what would be the adopted F_{msy}. This is also what happens with the current F_{msy} since $F_{msy} > F_{p0.5}$in both runs.

Regarding the different runs for the time-series 2006–2017, comparisons were made against the productivity scenario 1993:2017 (ts9317Seg). If the potential candidate for B_{lim} was to be the change point of the Hockey-stick model adjusted to the S–R data pairs from 2006 to 2017 (ts0617Seg), it would be B_{lim} = 196 334 which would be 46% lower than the estimated B_{lim} for the time-series 1993–2017 (ts9317Seg). In both scenarios where B_{lim} = 196 334, the adopted F_{msy} would be equal to $F_{p0.5}$ and would be 67% (ts0617Seg) or 38% (ts0617RicSeg) below the estimated F_{msy} for the time-series 1993:2017. If, on the other hand, the possible candidate for B_{lim} would be the $B1+$ that produces half of R_{max} of the Ricker curve model, B_{lim} = 80 604, 78% lower than the estimated B_{lim} for the time-series 1993–2017. However, the adopted F_{msy} would be equal to $F_{p0.5}$ and would be 143% higher than the candidate in the time-series 1993–2017.

Retrospective bias

To account for possible retrospective bias in the assessment estimates, biological reference points were estimated from five analytical retrospective assessments. The time-series used was 1993 to 2013 so that for all retrospective there would be the same number of pairs of S–R data (Figure 10). In this period (1993–2013), the "Mohns Rho" is 0.015 for *B1+*, 0.055 for Recruitment and 0.011 for F_{bar}. Then, we used the time-series 1993 up to previous year of each retrospective (full retrospective analysis) that differ in the number of S–R data pairs.

For both cases, the automatic weighting method implemented in EqSim (ICES, 2016) was used to weight the combination of three S–R models fitted from bootstrap samples of the B1+ and recruit pairs. The Hockey-stick had better results than the Ricker and Beverton–Holt in all retrospectives with weights estimated to be above 66% or higher. Therefore, and since this was the adopted procedure for the current estimated reference points, the Hockey-stick was used for the estimation of reference points. B_{lim} was estimated as the change point of the Hockey-stick model fitted to the data. For the estimation of B_{pa} and F_{pa}, $\sigma = 0.153$ and $\sigma = 0.170$ respectively, were used so that σ would be equal for all BRP estimations. See Table 7 to see the differences between the BRP estimated in the short retrospective years and Table 8 to see the differences between the BRP estimated in the full retrospective years.

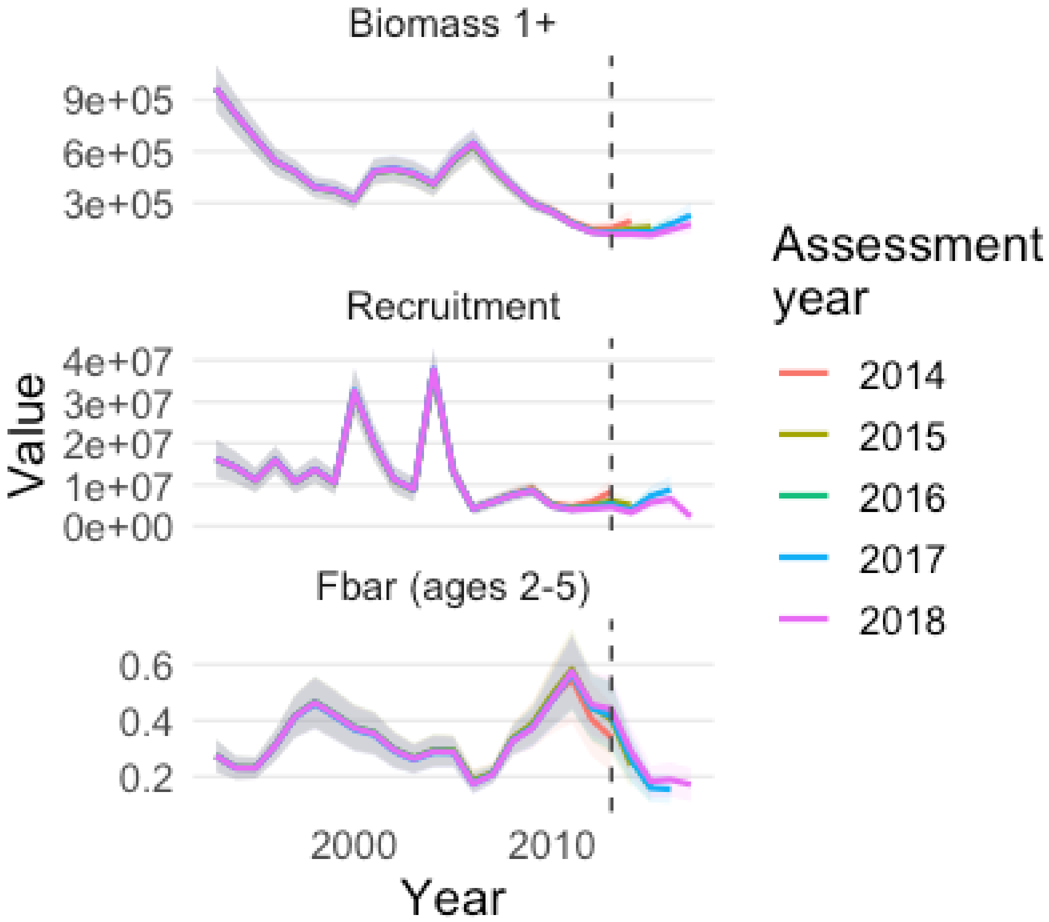


Figure 10. Retrospective plots of Biomass 1+ (t), upper panel, Recruitment (thousand individuals), middle panel and Fishing Mortality (reference ages 2–5) (year $^{-1}$), lower panel. Shades represent the 95% confidence interval of the estimates. Dashed vertical line represents the cut at the year 2013 made within the short retrospective analysis.

Table 7. Estimated reference points in the short retrospective analysis.

	2014	2015	2016	2017	2018
Blim	321 996	320 258	331 876	339 935	344 700
Bpa	414 148	411 912	426 856	437 221	443 350
Flim	0.312	0.290	0.258	0.246	0.232
Fpa	0.236	0.219	0.195	0.186	0.176
FMSY	0.272	0.242	0.220	0.202	0.192
Fp0.5_Btrig	0.138	0.130	0.112	0.107	0.097

Table 8. Estimated reference points in the full retrospective analysis.

	2014	2015	2016	2017	2018
Blim	321 996	324 918	323 697	324 347	361 639
Bpa	414 148	417 906	416 336	417 172	465 137
Flim	0.312	0.276	0.268	0.292	0.232
Fpa	0.236	0.208	0.203	0.220	0.176
FMSY	0.272	0.234	0.230	0.244	0.198
Fp0.5_Btrig	0.138	0.125	0.130	0.141	0.098

Table 9. Difference (in percentage) between B_{lim} of the two retrospective analysis.

Retrospective year	B_{lim} in the short retro	Change (%)	B_{lim} in the full retro	Change (%)
2014	321 996	0.00	321 996	0.00
2015	320 258	-0.54	324 918	0.91
2016	331 876	3.63	323 697	-0.38
2017	339 935	2.43	324 347	0.20
2018	344 700	1.40	361 639	11.50

For the retrospective analysis, results show that B_{lim} increases from 2014 to 2018. Increases are small from year to year (see Table 9) ranging from 3% to 1.4% in the short retrospective analysis and from 0.2 to 11.5% in the full retrospective analysis. All estimated B_{lim} are within the 95% confidence interval of the current adopted B_{lim} (Figure 11). The opposite behaviour is observed for all other reference points, i.e. reference points decrease from 2014 to 2018.

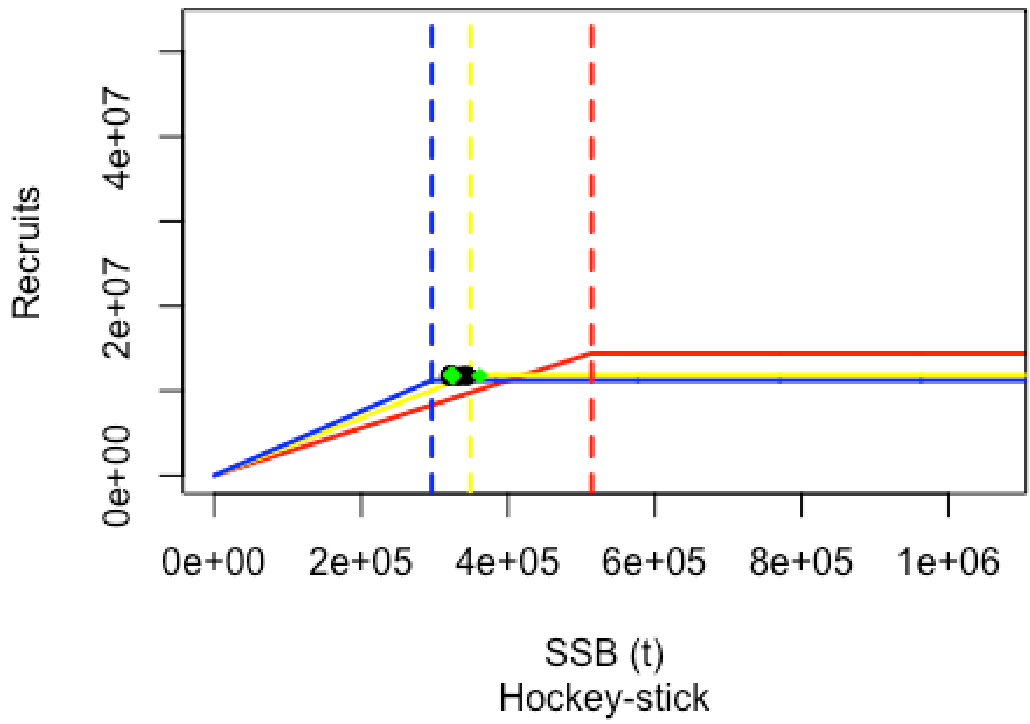


Figure 11. - Blue, yellow and red dashed vertical lines represent the 2.5, 50 and 97.5 quantiles of parameter b of a Hockey-stick curve from 1000 bootstrap resamples of S–R pairs from the time-series 1993–2017. - Blue, yellow and red lines represent the Hockey-stick model fitted to the S–R pairs when parameter b is fixed at 2.5, 50 and 97.5 quantiles. Black dots represent the values estimated for B_{lim} within the short retrospective analysis. Green diamond shapes represent the values estimated for B_{lim} within the full retrospective analysis.

Biological parameters

In this section we describe the biological parameters used in the assessment and that were revised in the last benchmark (ICES, 2017a). The assumptions made for these biological parameters in the short-term prediction are also described.

Maturity

Since the last benchmark in 2017 (ICES, 2017a), maturity ogive of the stock comes from DEPM surveys:

- For years with no DEPM survey a linear interpolation of the data between two consecutive surveys was carried out to obtain the estimates of maturity-at-age.
- For the period 1978–1998 (years before starting DEPM series), constant proportions of maturity-at-age were assumed, based on the average of the estimates obtained from the six DEPM surveys of the 1999–2014 period, thus including both years of strong year classes and years of low recruitment.
- For the years after the last DEPM survey, the estimates of the last DEPM survey are assumed.

According to the stock annex, the maturity ogive to use in the short-term predictions corresponds to the arithmetic mean of the last six years of the assessment (2012–2017).

Natural maturity

Natural mortality are age-specific input values fixed over time as listed in Table 10.

Table 10. Natural mortality input values by age (ICES, 2017a).

Age	M
0	0.98
1	0.61
2	0.47
3	0.40
4	0.36
5	0.35
6	0.30

Weight-at-age

Catch mean weights-at-age were revised for part of the historical series in WKPELA2017 (ICES, 2017a). The mean weights-at-age from 1978 to 1990 were not revised, and are assumed to be fixed at the mean values of the period 1991–1995. The mean weights-at-age for 1991 to 2017 are calculated using quarter and area disaggregated data reported to the assessment WGs every year by Spain and Portugal. The method adopted to calculate catch mean weights-at-age is the following: mean weights-at-age by quarter and area are aggregated to the quarter and then to the year using the corresponding catch numbers-at-age as weighting factors.

Mean weights-at-age in the stock comes from DEPM surveys (ICES, 2017a):

- For years with no DEPM survey, a linear interpolation of the data from two consecutive surveys was carried out to obtain the estimates of mean weight-at-age.
- For the period 1978–1998 (before DEPM series started) it was decided to consider the two closest DEPM surveys, and assume for that period the average between 1999 and 2002 estimates.
- For years after the last DEPM survey, the estimates of the last DEPM survey are assumed.

Figure 12 shows the mean weights-at-age in the catch and in the stock used in the assessment. In the last assessment (2018) stock weights weren’t updated after the 2017 DEPM survey so stock weights are the same from 2014 till 2017.

For the short-term prediction, weights-at-age in the stock are calculated as the arithmetic mean value of the last six years of the assessment while weights-at-age in the catch are calculated as the arithmetic mean value of the last three years of the assessment.

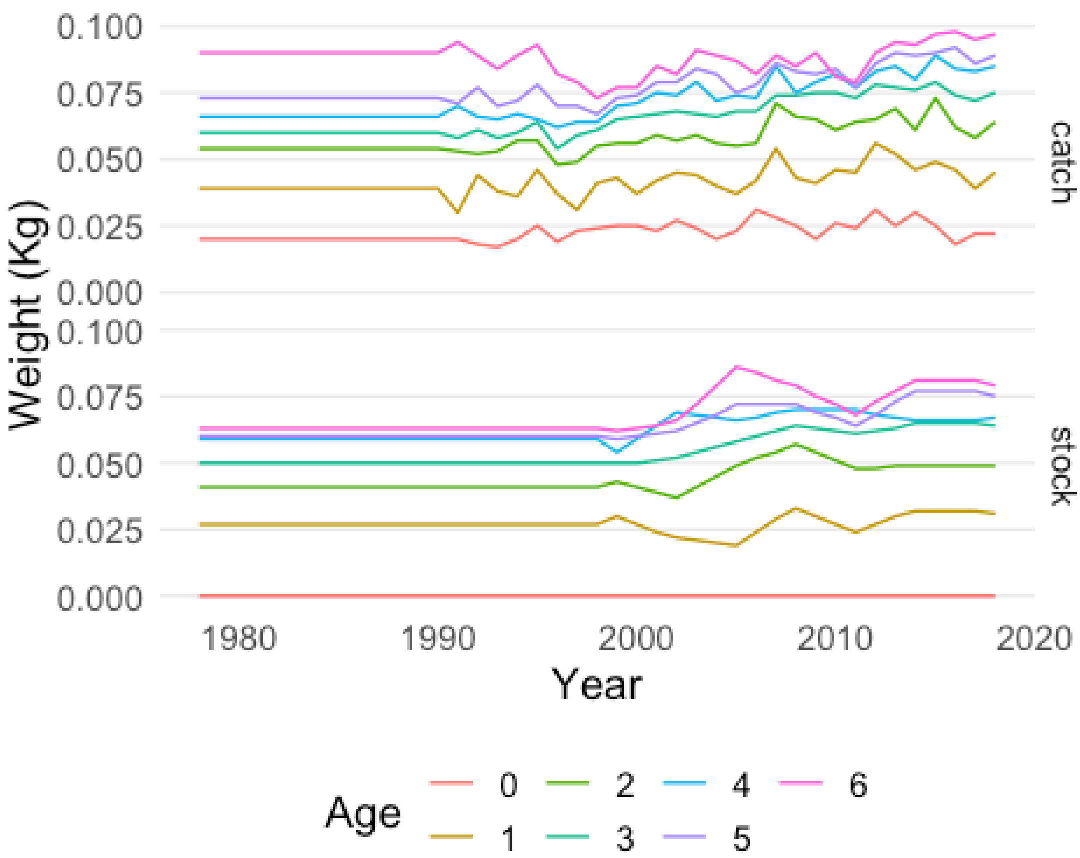


Figure 12. Catch (upper panel) and stock (lower panel) weights by age used in the assessment.

References

[1] ICES. 2017a. Report of the Benchmark Workshop on Pelagic Stocks, 6–10 February 2017, Lisbon, Portugal. ICES CM 2017/ACOM:35. 278 pp.

[2] ICES. 2017b. ICES fisheries management reference points for category 1 and 2 stocks. ICES Advice, Book 12, Section 12.4.3.1.

[3] ICES. 2016. Report of the Workshop to consider F_{MSY} ranges for stocks in ICES categories 1 and 2 in western waters (WKMSYREF4), 13–16 October 2015, Brest, France. ICES CM 1025/ACOM:58. 187 pp.

[4] ICES. 2018. Report of the Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA), 26–30 June 2018, Lisbon, Portugal. ICES CM 2018/ACOM:17. 605 pp.

[5] ICES. 2015. Report of the Joint ICES-MYFISH Workshop to consider the basis for F_{MSY} ranges for all stocks (WKMSYREF3), 17–21 November 2014, Charlottenlund, Denmark. ICES CM 2014/ACOM:64. 156 pp.

Annex I

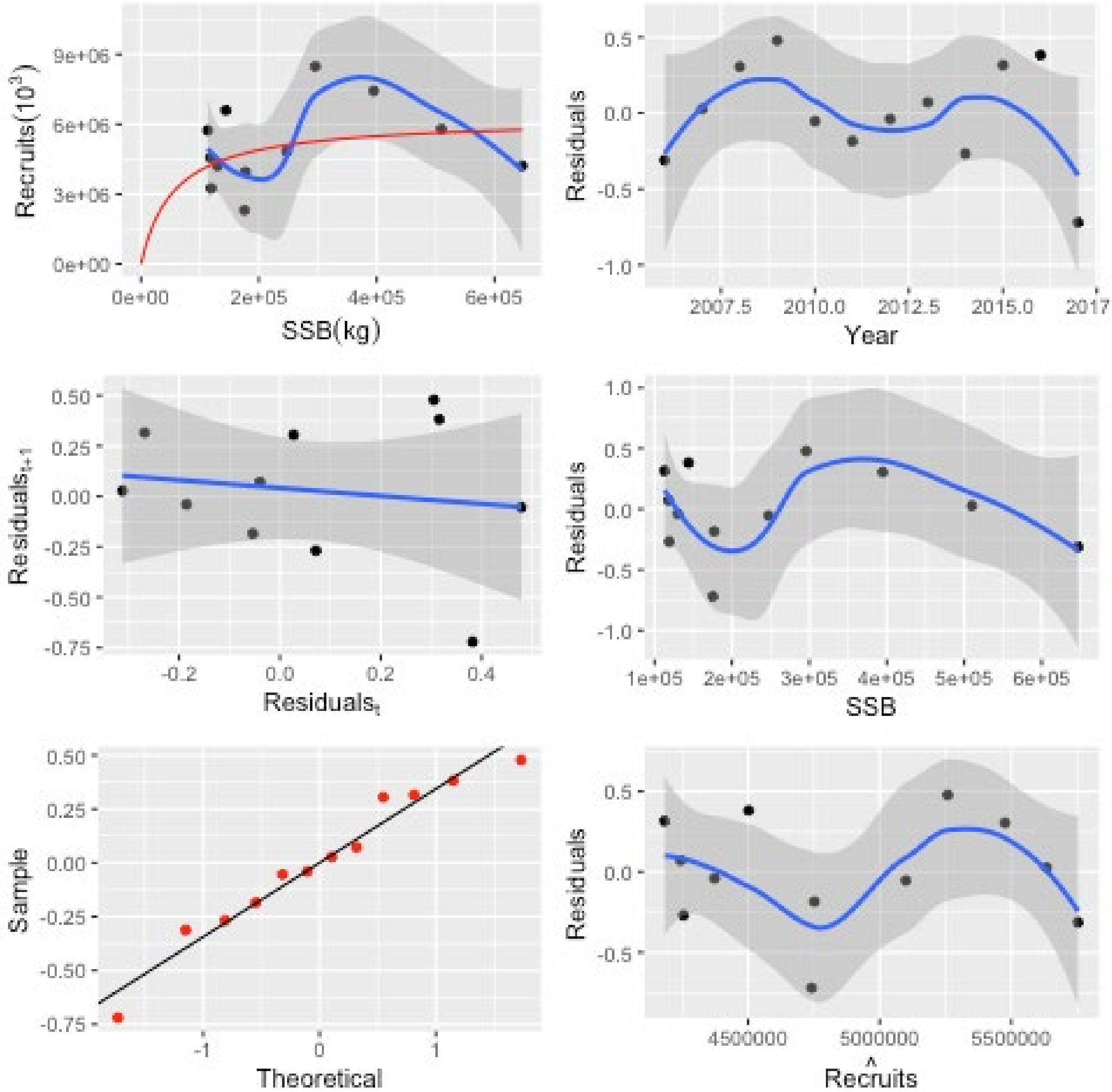


Figure 13. Beverton–Holt Residuals Plot (2006–2017).

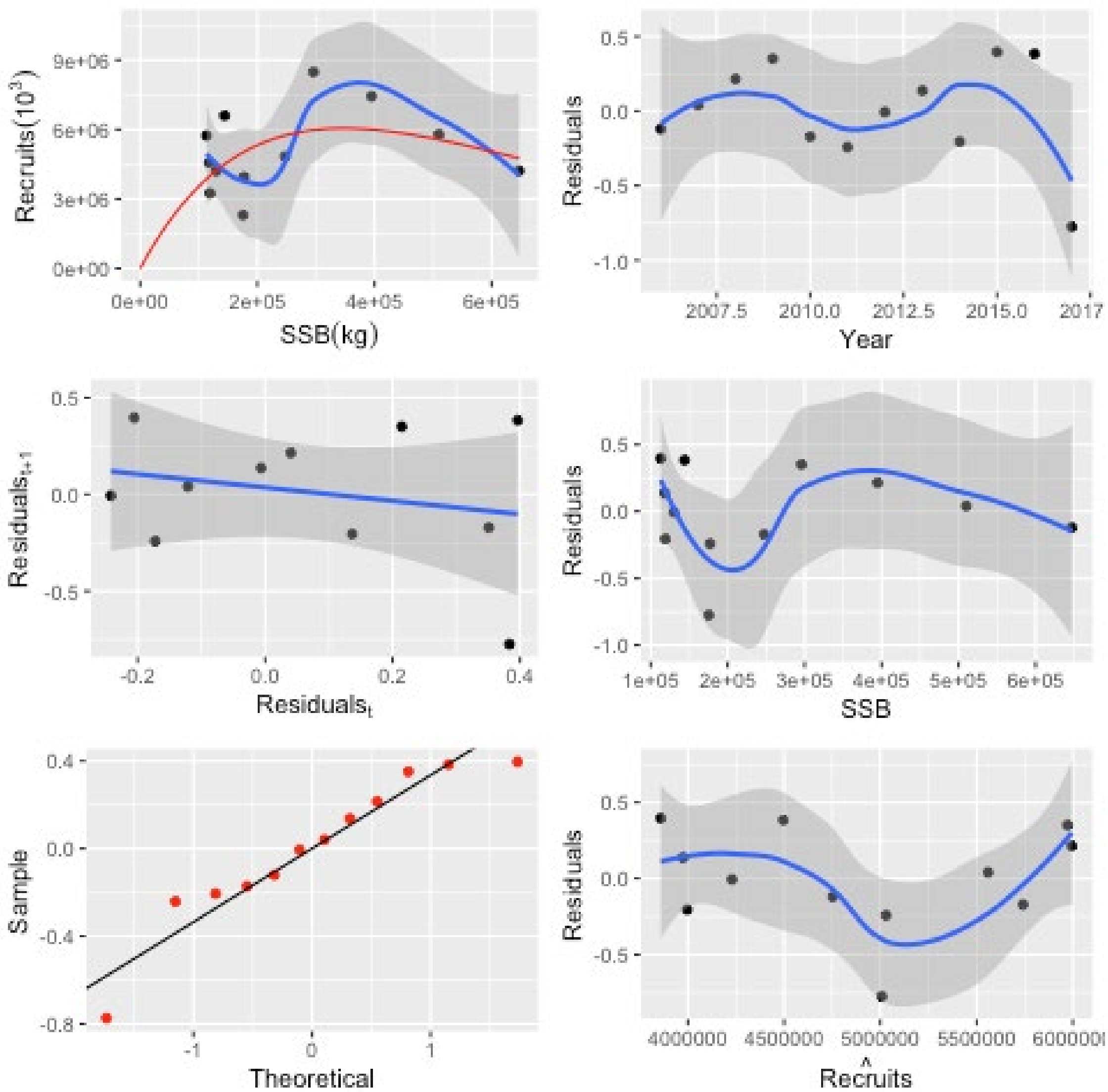


Figure 14. Ricker Residuals Plot (2006–2017).

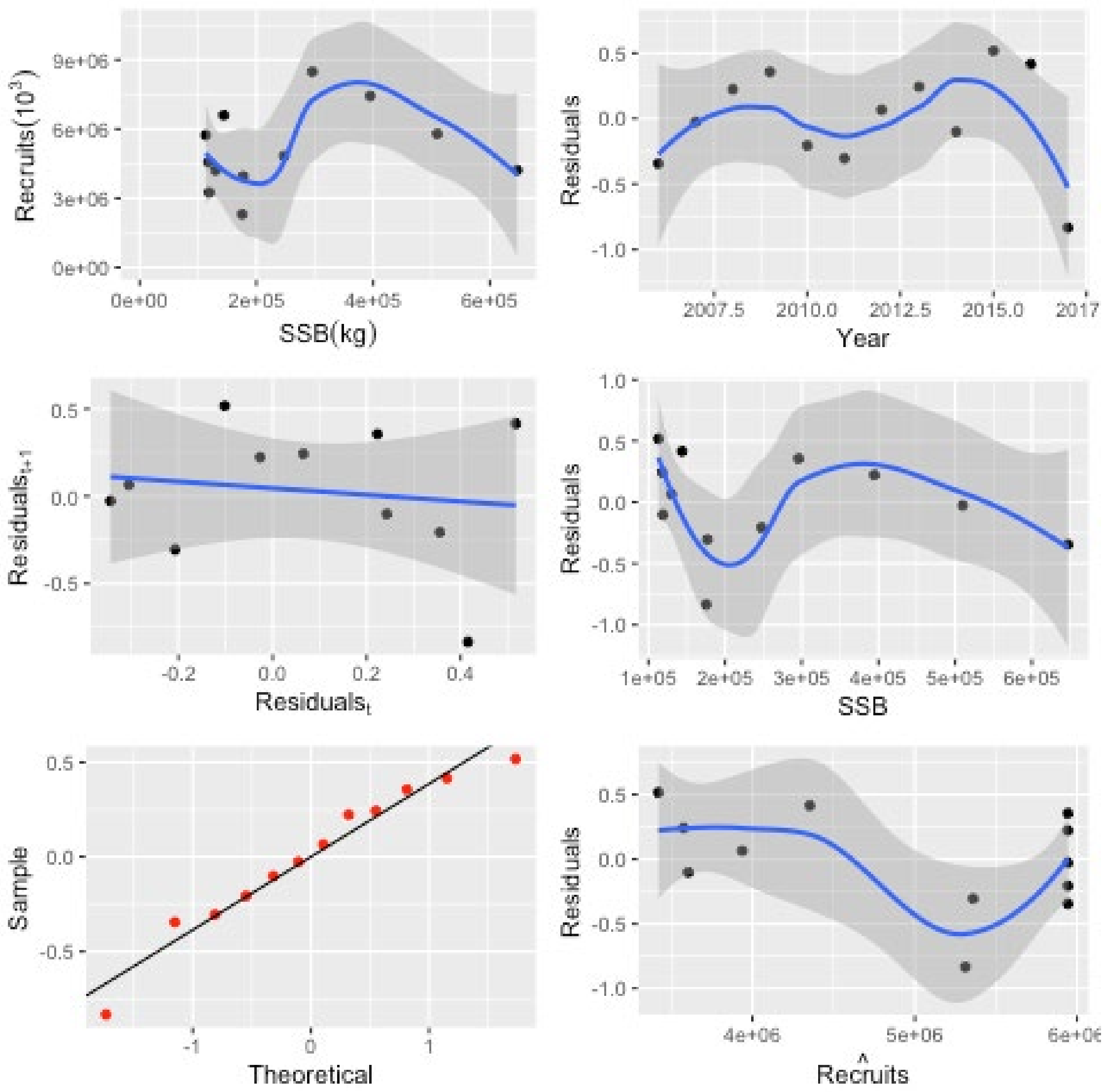


Figure 15. Hockey-stick Residuals Plot (2006–2017).

This document was created with knitr (2018-12-20 15:16:41) with the following setup:

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## Platform: x86_64-apple-darwin15.6.0 (64-bit)
## Running under: OS X El Capitan 10.11.6
##
## Matrix products: default
## BLAS: /System/Library/Frameworks/Accelerate.framework/Versions/A/Frameworks/vecLib.framework/Versi
ons/A/libBLAS.dylib
## LAPACK: /Library/Frameworks/R.framework/Versions/3.4/Resources/lib/libRlapack.dylib
##
## attached base packages:
## [1] stats     graphics  grDevices utils     datasets  methods   base
##
## other attached packages:
## [1] tibble_1.4.2    bindrcpp_0.2.2  dplyr_0.7.7     ggplotFL_2.6.0
## [5] ggplot2_3.1.0   FLCore_2.6.9    lattice_0.20-35 MSY_0.1.18
## [9] lubridate_1.6.0
##
## loaded via a namespace (and not attached):
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##  [5] pillar_1.1.0     plyr_1.8.4       tools_3.4.1      digest_0.6.18
##  [9] evaluate_0.10.1  gtable_0.2.0     pkgconfig_2.0.1  rlang_0.3.0.1
## [13] Matrix_1.2-10    rstudioapi_0.7   xfun_0.4         gridExtra_2.3
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## [25] R6_2.3.0         rmarkdown_1.9    bookdown_0.7     reshape2_1.4.3
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```

Annex 4: Andres Uriarte and Leire Ibaibarriaga, WD BRPs

Uriarte A. and Ibairriaga L. 2019. Scenarios of stock productivity for Iberian sardine stock. WD presented to the ICES Workshop on the Iberian Sardine Management and Recovery Plan. IPMA-Lisbon, 1–5 April 2019.

Summary

It is acknowledged that since 2006 recruitments are below the average for the period 1993–2017, and the question is how can we define a poor recruitment scenario? What is the scenario of poor recruitment we should consider as an alternative productivity framework where the HCRs (the one proposed or any alternative) should be tested on their performance?

In this WD it is suggested to consider the poor recruitment scenario as the one where low biomass levels (below B_{lim}) prevent the occurrence of high recruitments. And in such framework, the WD propose a Ricker curve fitting which seems to provide a good fitting to the entire series of "normal" recruitments occurring at all ranges of biomass, from the poor recent biomass levels (since 2006) to the highest biomass levels in the series, just leaving aside high recruitment levels (here defined as those above 30 000 000 individuals). The main advantage versus the Hockey-Stick S–R model fitted so far for the poor productivity scenario over the period 2006–2017 is that:

a) the new Ricker proposal fit quite well all the recruits in that recent period as well as any other "Normal" recruits in the entire series of biomass ;

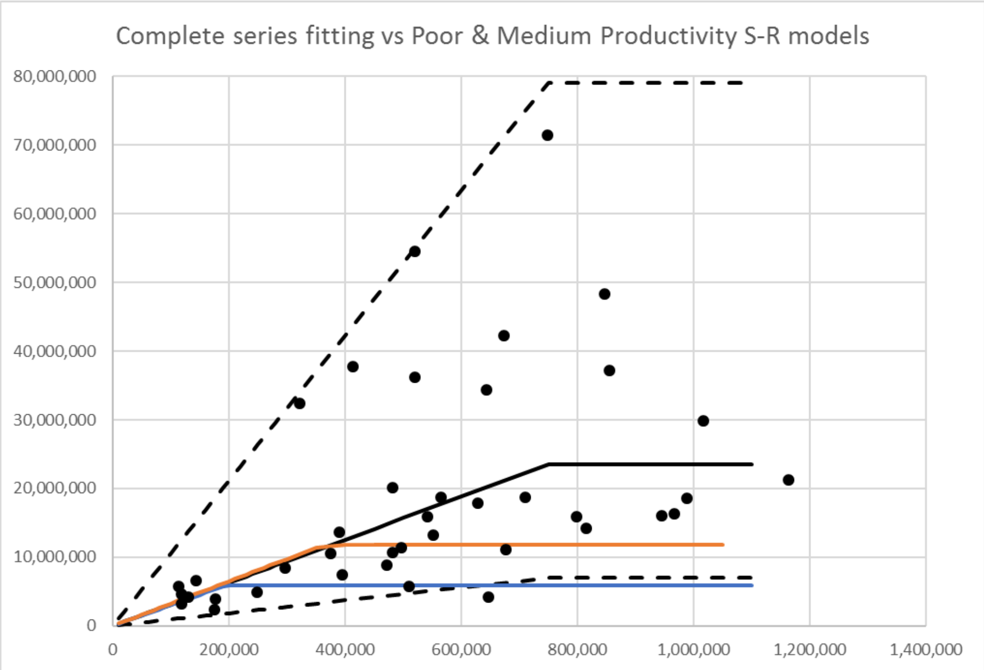
b) at the same time, it does not prevent the stock to increase as the Biomass increases (because it is a continuous increasing curve contrary to the hockey-stick just fitted to the most recent period since 2006).

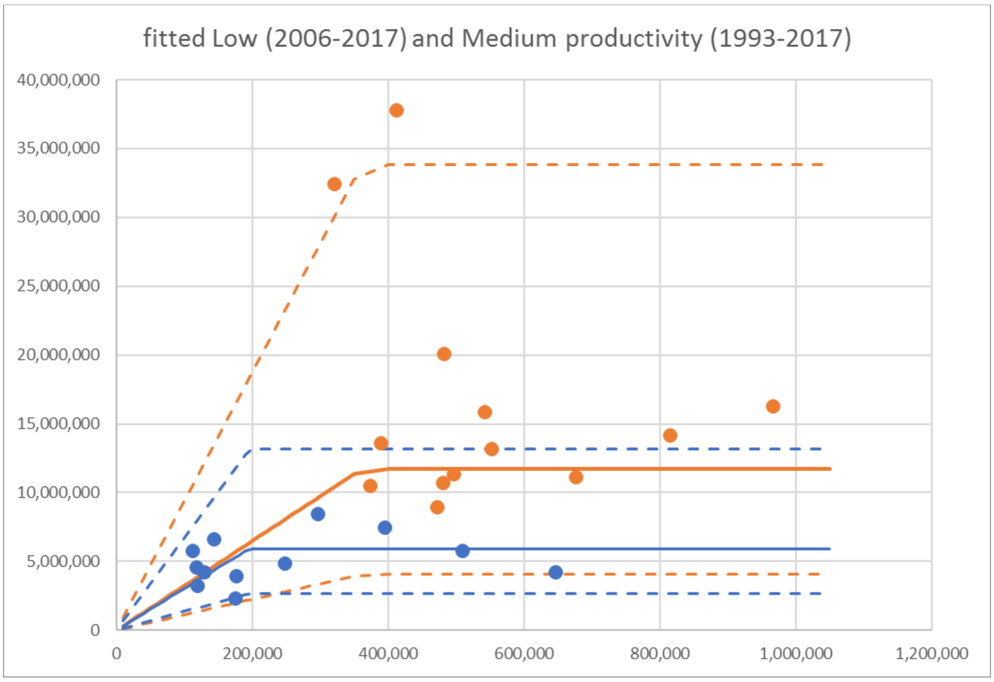
Therefore, the later Ricker model would allow testing any harvest strategy for their robustness to rebuild the stock to the official B_{lim} even in the absence of High recruitments, i.e. for the poor scenario of recruitment levels as defined above (by the underlined sentence of the former paragraph).

So the WD pretended to trigger discussion on whether this new approach to define the poor recruitment scenario is good enough to be worth pursuing. If Yes, we should discuss whether it can replace, or should be tested in addition to, the poor recruitment scenario which was defined as the H-S fitting to the recent series of S–R since 2006.

Content

1. So far hockey-stick models present high sensitivity to the actual range of years included in the fitting, mainly in terms of the threshold biomass level (B_{lim}?), i.e. the biomass where recruitment level moves from being linearly dependent on Biomass to a mean constant recruitment level independent of biomass. See the figures below.





The three fitted models are rather consistent in terms of slope but point to different inflection point (B_{lim}) levels:

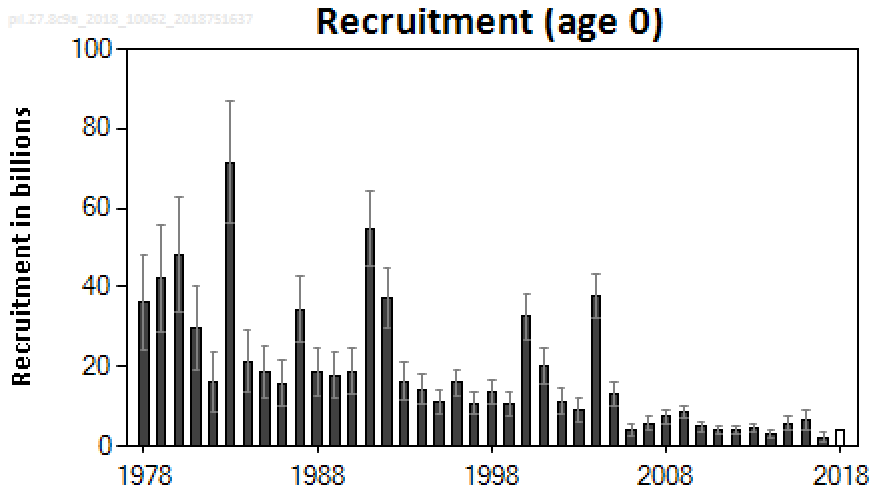
	Productivity Scenarios		
FITTING	**Low Prod.**	**MediumProd.**	**LongTermProd.**
Year Range	**2006-2017**	**1993-2017**	**1978-2017**
Upper MeanRecr.	**5,948,920**	**11,754,395**	**23,469,274**
Param a Slope	**30.30**	**32.53**	**31.39**
Param b Blim	**196,334.00**	**361,369.00**	**747,620.00**
Sigma 2	0.1641	0.2907	0.3840
LogSigma	0.4051	0.5392	0.6197

To incorporate the big recruitment levels log sigma are rather big but this makes that for biomasses 150 000 t and 300 000 t no recruitment above expectation is seen (well seen above in the figure for the medium productivity fitted model 1993–2017). And this is the range where management procedures has to operate to restore the population to high levels above B_{lim}. Current official B_{lim} is 337 448 t. In the figure above, the two highest recruitment are slightly above the 95% confidence intervals and well distant above from the rest of observations.

The controversy is that in the context of ICES MSY AR we need to define a threshold biomass (might be B_{pa}) which for stock category 1 depends on the B_{lim} level (in the form of F_{MSY}<= F_(Risk0.05toB_{lim}).

2. IN the benchmarking WKPELA it was agreed to select the fitting of the hockey-Stick S–R model to the period 1993–2017 as the model defining current productivity of the stock concerning recruitment levels (Medium productivity scenario). A problem with this fitting is that the actual variability (sigma around the fitting) can hardly explain by chance the highest peaks in the series, or it does it at the expenses of allowing a high variability around the fitted model, with some gaps between the two peaks and the fitted line (this was mentioned above regarding the second figure in the previous page).
3. Given the persistence of poor recruitments levels in the most recent years, it is suspected that we might actually be facing a poorer recruitment scenario, as defined by the fitting in the period 2006–2017 (Low productivity scenario) (blue lines in the first figures). A problem with such fitting is that the ceiling recruitment level will most probably prevent any sufficient recovery of the stock to the official B_{lim} level (see the ICES, 2017report on the management plan for sardine[1]).
4. Finally, a third intermediary scenario is being searched capable of mixing both medium and low productivity regimes by means of defining a rule allowing moving from the poor to the medium level productivity scenario (either by fixing the transition at a fixed biomass level or by selecting a probability transition model according to time).
5. Alternative way of looking at the problem: Several times in the past, we have looked at the complete series of Stock and Recruitment values as a series of occasional high peaks, happening around every 4–5 years, followed by valleys while in recent years the peaks are not occurring and hence a succession of low recruitment levels are being repeated. This might be interpreted as if below the current B_{lim} the chances of generating peaks has vanished. Alternatively this all may play around an unknown very positive environmental events not occurring in recent years, which as soon re-occurring again would allow producing high peaks in future as to restore the stock to healthier levels. But as the later possibility is uncertain and out of managers control, we can take the former interpretation to define an operative poor scenario model, whereby for Biomass below official B_{lim} the chances of having high recruitment vanish.

[1] ICES. 2017. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA), 6–10 February 2017, Lisbon, Portugal. ICES CM 2017/ACOM:35. 294 pp.



6. Modelling the poor recruitment scenario: By looking at the past series as occasional high peaks followed by normal recruitment levels whereby for Biomass below official B_{lim}, the chances of having high recruitment vanish, we can make the following fitting of the series:

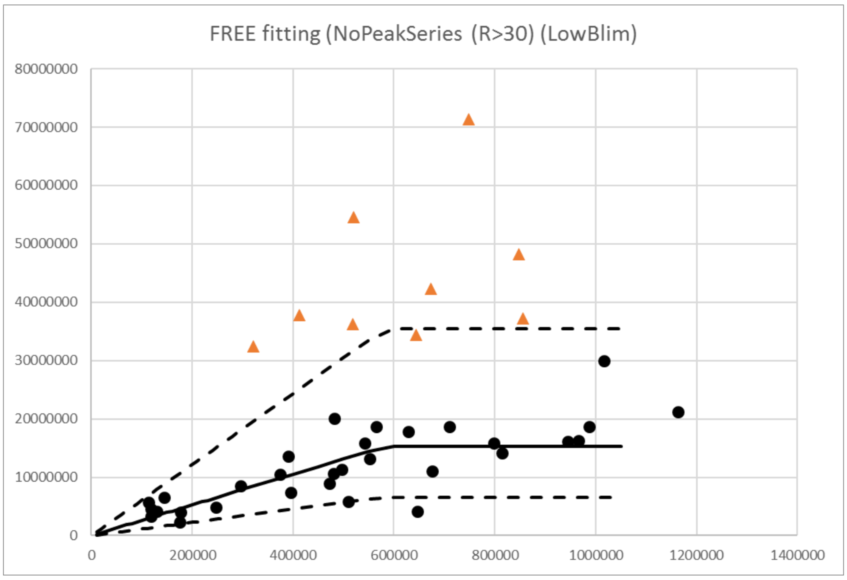
   a) Fitting to the S–R series to normal recruitment values, whereby normal recruitment values are those R<30*10^6

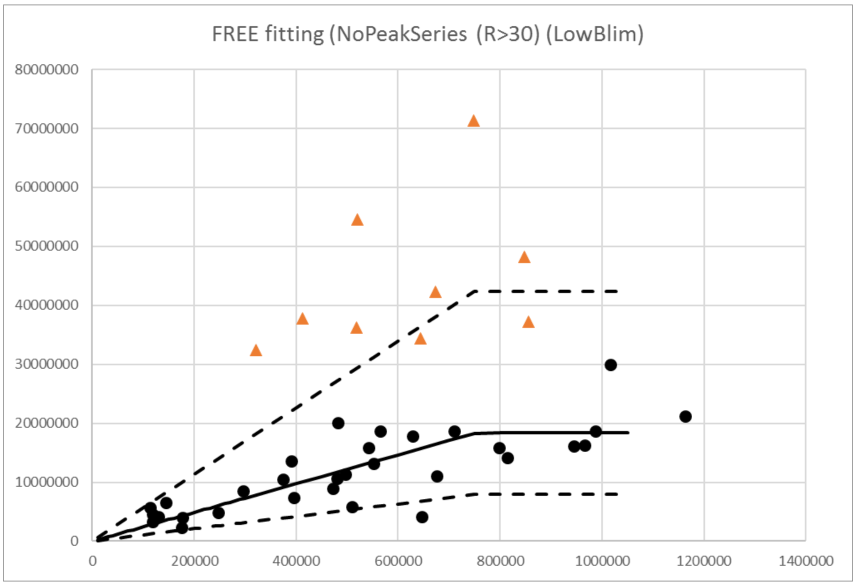
There might be several competing recruitment models: two (or more) hockey-stick levels and a Ricker recruitment model. The two hockey-stick models have almost identical residual sigma but result in contrasting inflection points (B_{lim}?). The Ricker has the smallest residual sigma and lets aside (above the confidence intervals) all high recruitment levels, making a clearer distinction between the normal and high recruitment levels. Confidence intervals seem visually suitable as well.

FITTING	**Hock_Stick1**	**Hock_Stick2**		**Ricker fitting**
Year Range *	**1978-2017**	**1978-2017**		**1978-2017**
MeanRecruit	**15,312,180**	**18,336,251**		
Param a Slope	**26.30**	**24.41**	**a-Slope at origin**	**30,901.19**
Param b Blim	**582,157.32**	**751,120.26**	**b- param**	**0.0005545**
Sigma 2	0.1835	0.1830	Sigma 2	0.1592
LogSigma	0.4284	0.4278	**LogSigma**	0.3989

This Ricker fitting can be used to formulate an alternative poor recruitment model scenario (though this is debatable and any of the above ones could be used as well).

See figures below: Rhombs are recruits values not used in the fitting.


FREE fitting (NoPeakSeries (R>30) (LowBlim)
80000000
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
0
200000
400000
600000
800000
1000000
1200000
1400000


FREE fitting (NoPeakSeries (R>30) (LowBlim)
80000000
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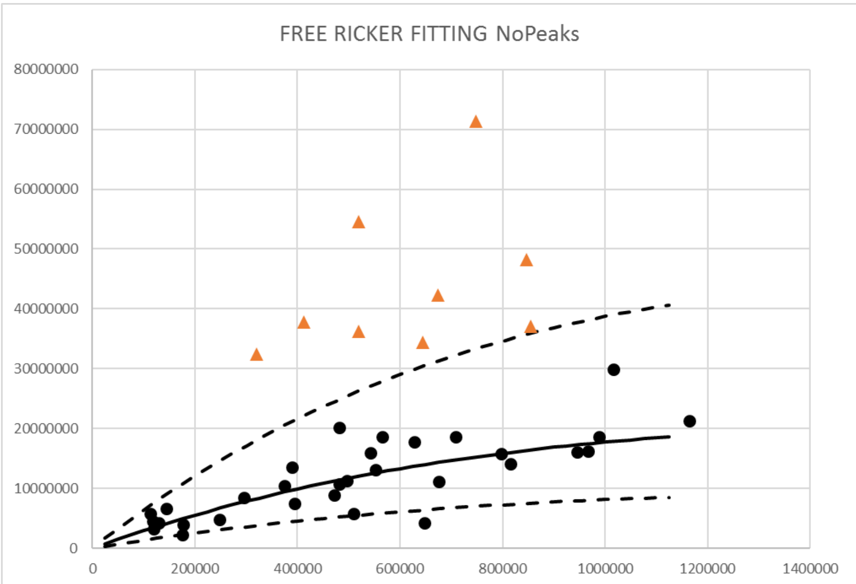
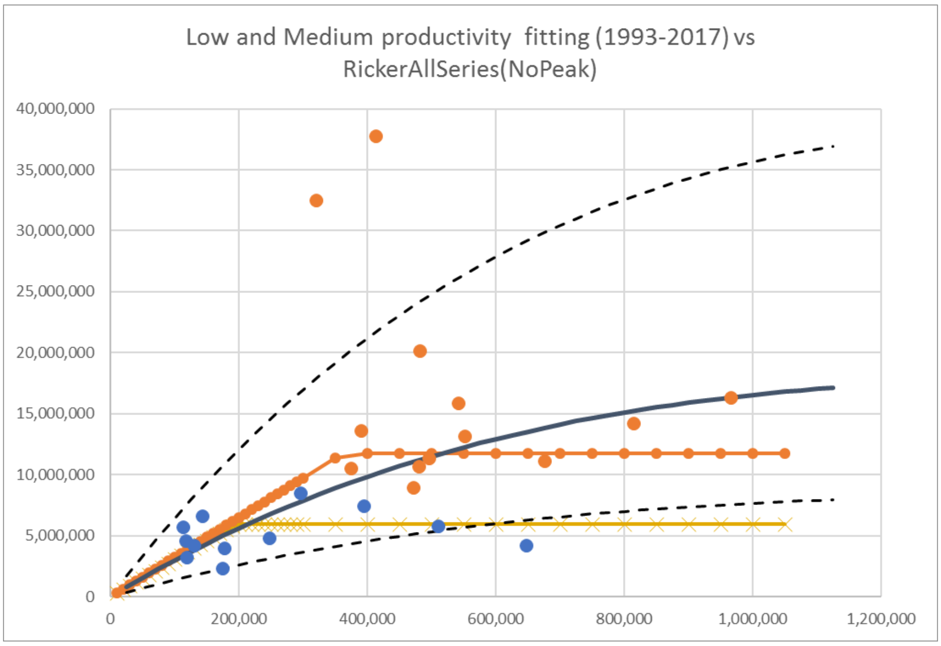
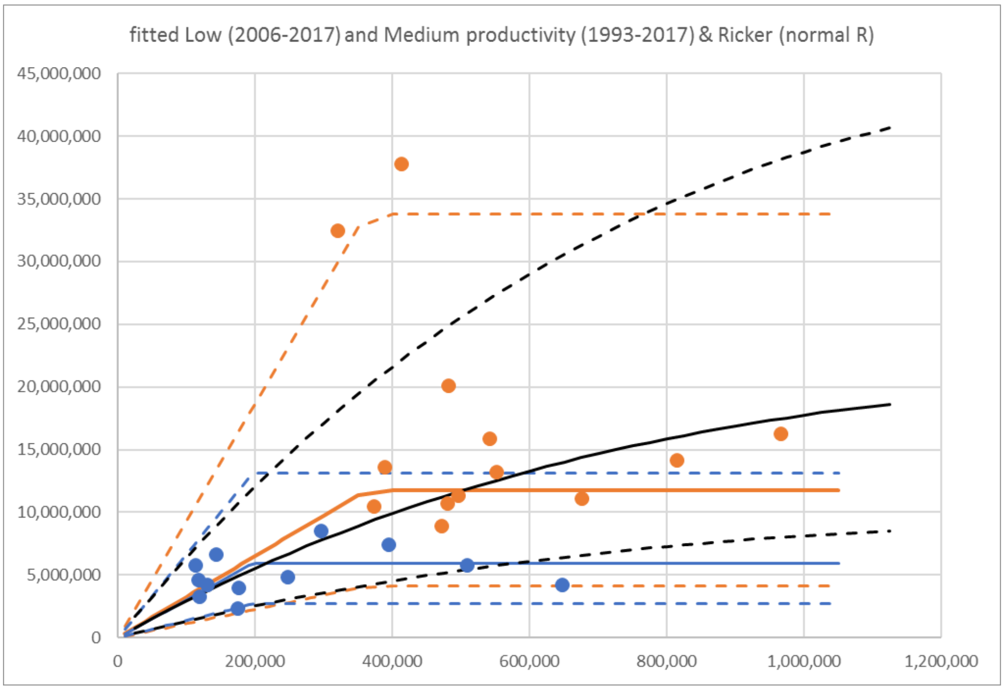
1200000
1400000


FREE RICKER FITTING NoPeaks
80000000
70000000
60000000
50000000
40000000
30000000
20000000
10000000
0
0
200000
400000
600000
800000
1000000
1200000
1400000

7. Advantage: This model may overcome the former proposal of poor scenario because it is very similar to the previous poor recruitment scenario while still allowing a gradual increase of recruitment levels as stock increases. Confidence intervals (from the sigma estimate in the fitting) along the Ricker curve seems to duly encapsulate the observed variability of normal recruitment levels around the fitted model all along biomass levels, and particularly for the low biomass levels where management should rebuild the stock. This sigma is far smaller than the ones found for the hockey-stick medium level of productivity. This model is put for consideration as an alternative model to the low productivity scenario where the current proposal of a MP can be framed (and may be the only required for the poor recruitment scenario).

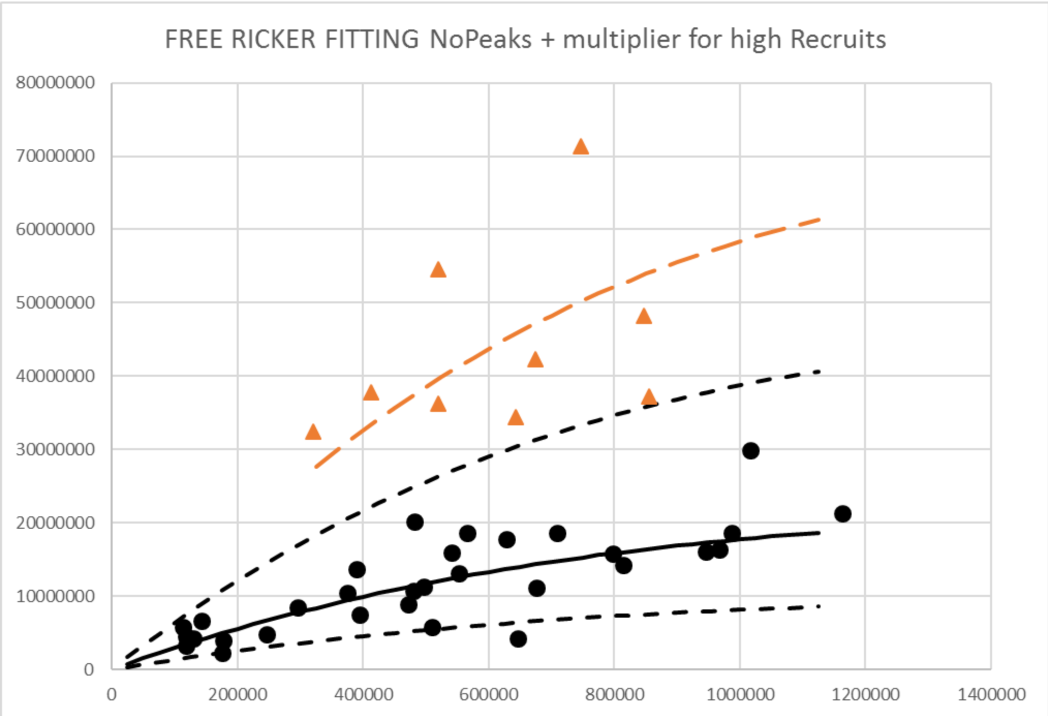


This should serve to test in a poor recruitment scenario (of no high peak recruitments) if the proposed and/or any alternative management strategies can recover the stock. Recovery would be achieved once reached the current B_{lim} level around 338 000 t, when reverting to a medium to high productivity scenario might be expected.



8. <u>Discussion</u>: High peaks can also be modelled, conditioned to the former modelling of the normal level of recruitments.

In the example below this is made for the Ricker model:



The multiplier for the High recruitments is around 3.29, so high recruitments are around 3.3 times normal recruitment levels. In log scale this is an additive deviance of 1.1909, which for the sigma of the fitting around normal recruitment values (sigma= 0.3989) supposes a stardised residual of 2.99 sigmas. This would happen by chance with a p=0.002.

The fitting is as follows:

NormalR=exp(Ln(Biom)+LN(Alpha/1000)-Biom*Beta/1000 +logError(f(Sigma)) for normal recruitments at all biomass ranges (with Sigma = 0.399)

And Rhigh=exp(Ln(Biom)+LN(Alpha/1000)-Biom*Beta/1000 +logError(f(SigmaHighR)+HighRAdditiveComponent) for High recruitments occurring with a likelihood of 0.29 at biomass above 300 (or 320′ t) (with HighRAdditiveComponent= 1.19091838 and SigmaHighR= 0.2563)

According to the ANOVA:

	SSQR	Counts	params	**Sigma^2**	**Sigma**
Total SSQR	5.14092	40	3	0.13894	0.37275
Total SSQR PeakLevel	0.52541	9	1	0.06568	0.25627
NotPeak Level	4.61551	31	2	0.15916	0.39894

Above B_{lim} high Recruitment values occur with a probability around 0.29. This has been used above to set relative probabilities above B_{lim} of the Normal and High recruitments or it could be used to define a transition probability vector.

Some probability values for different range of biomasses follow below to think about them:

Min SSB	0	300000	600000	900000	600000
Max SSB	300000	600000	900000	1200000	1200000
N Years	9	15	11	5	16
N_ExtraRecs	0	4	5	0	5
ob(ExtraRec)	0.00	0.27	0.45	0.00	0.31
Min SSB	300000		300000	650000	
Max SSB	1200000		650000	1200000	
N Years	31		18	13	
N_ExtraRecs	9		5	4	
ob(ExtraRec)	0.29		0.28	0.31	
Min SSB	0				
Max SSB	1200000				
N Years	40				
N_ExtraRecs	9				
ob(ExtraRec)	0.23				

Annex 5: Leire Citores, WD Ss32flbeia function code and convergence issues

Citores L. 2019. Ss32flbeia function and analysis of convergence issues. WD presented to the ICES Workshop on the Iberian Sardine Management and Recovery Plan. IPMA-Lisbon, 1–5 April 2019.

General description of ss32flbeia function

The ss32flbeia function allows running assessments using Stock Synthesis (Methot and Wetzel, 2013) within FLBEIA (Garcia *et al*., 2017). FLBEIA is a simulation toolbox to conduct bioeconomic impact assessments of fisheries management strategies following a management strategy evaluation (MSE) framework.

The function was originally developed to mimic the stock assessment of the Bay of Biscay sardine and it has been adapted for the Iberian sardine case study during the Workshop on the Iberian Sardine Management and Recovery Plan (WKSARMP).

The function needs the stock and indices objects as well as a folder with the reference assessment in ss3 (usually the one used to the conditioning of the operating model for MSE). Within the FLBEIA MSE process, for each projection year, the function works as follows:

- Copies the reference assessment folder (containing all files needed to run ss3);
- Reads the ss3 .dat, wtatage and .ctl files;
- Reads the catch and the indices values from the FLR objects;
- Sets 10^-5 value for catches <10^-5;
- Eliminates catch-at-age for years where catch <10-5;
- Creates new .dat,wtatage and .ctl files based on the reference .dat, wtatage and .ctl files with new catch and indices values from FLR objects;
- Runs ss3.exe executable;
- Reads ss3 output files using the r4ss package;
- Updates stock@harvest and stock@stock.n slots with ss3 output;
- Saves convergence indicator, rec, fbar, ssb, catchabilies and selectivities from ss3 runs in covars;
- Deletes the copied folder after running each realization.

Iberian Sardine case study: convergence issues

For the Iberian Sardine case study, the stock assessment model is age-structured, with a single area, a single fishery and annual time-steps. Input data consist on total catch in mass, age composition of the catch, total abundance (in numbers) and age composition from the annual acoustic survey and total spawning–stock biomass from a triennial DEPM survey. Specific model configurations are described in detail in the stock annex, but they include constant selectivity for ages 1+ for the acoustic survey and three distinct periods for fishery selectivity in which selectivity for ages 3, 4 and 5 are assumed to be equal. The rest of fishery selectivity-at-age parameters are a random walk from the previous age. Initial trials that mimicked the stock assessment with these reference settings resulted in convergence problems. During the projection period in some years, the ss3 assessment resulted in extremely high SSB values in comparison with the values obtained in the previous assessments (i.e. Figure 1), meaning that all the assessment was rescaled. This type of realisations were identified using the gradient change at ss3 and the ratio of the change of SSB from one assessment year to the next as indicators of convergence. Runs that did not converge showed a very low selectivity for the plus group (6+) in blocks 2 and 3 (Figure 2) in comparison with the values obtained in the reference assessment. The parameter to estimate selectivity in the last age, had originally very wide bounds (-4, 4), and for many of the iterations within FLBEIA the stock assessment with ss3 could not converge. In an attempt to solve this, the bounds for the fishery selectivity for the last age group were changed to smaller ones (-0.2-0.2) so that the 80% of the iterations converged.

Finally, in order to have the number of desired iterations converged for the MSE, a condition was added when running each FLBEIA iteration. The final gradient change from ss3 outputs is saved, and it checks if this value is <0.001 for every assessment year. If this condition is not fulfilled the simulation seed in R is changed and the FLBEIA process is run again until the condition is held.

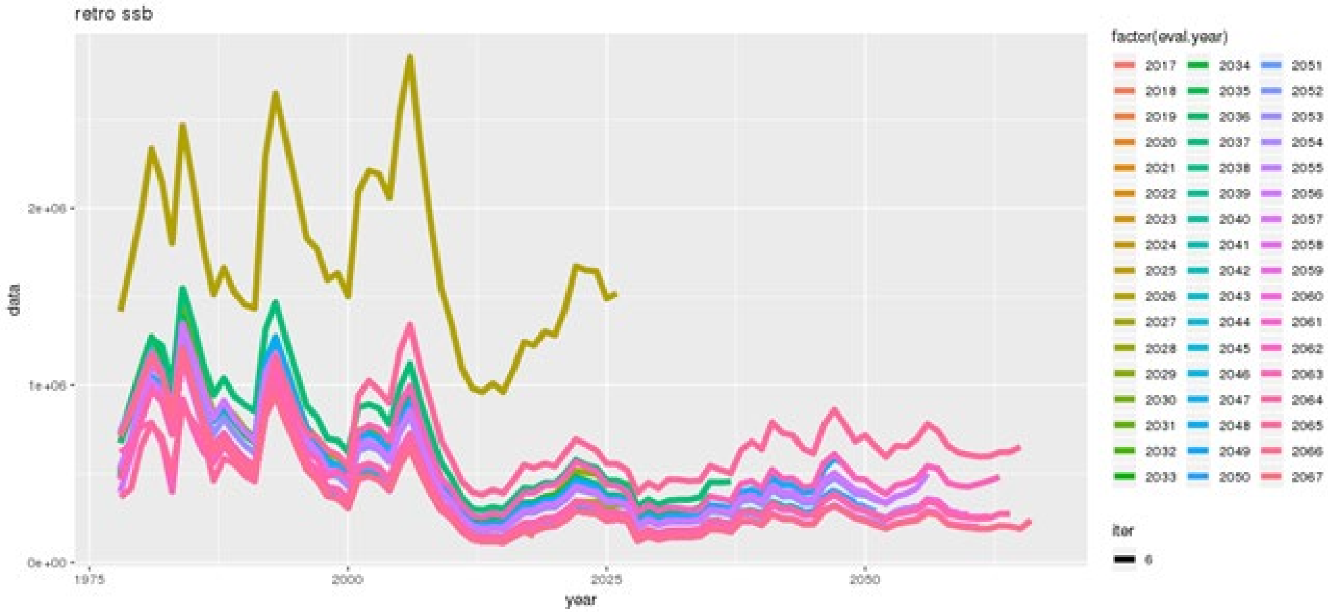


Figure 1. Estimated SSB values along the whole time period (from 1978 until the last projection year 2067) for each assessment year (eval.year)

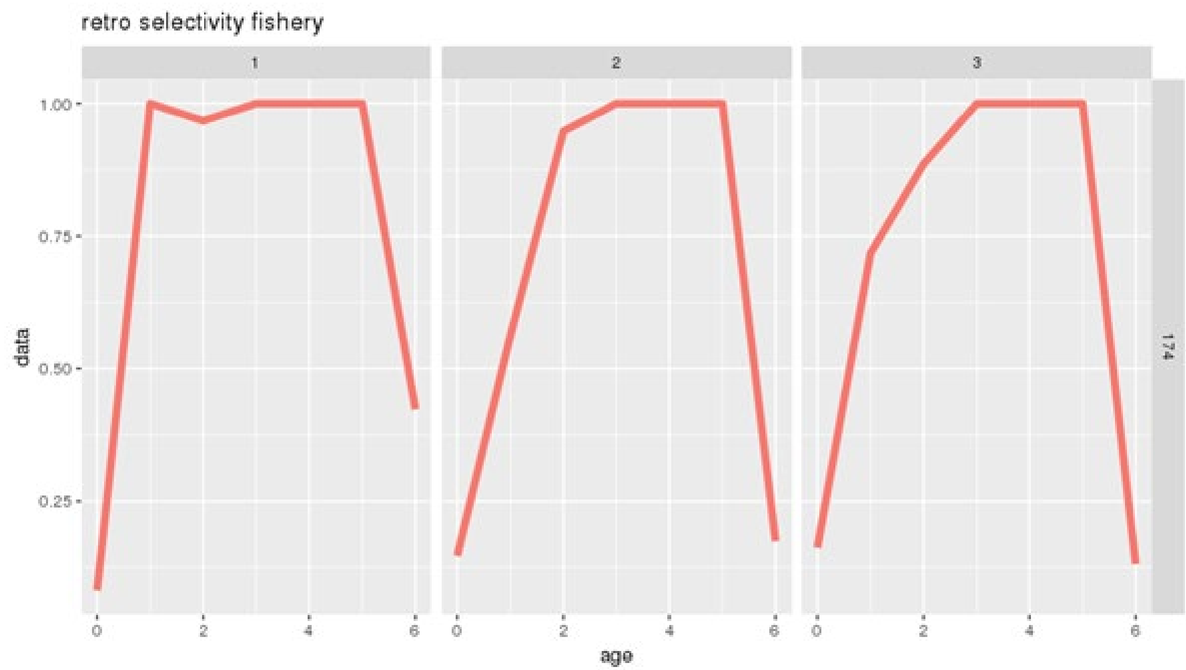


Figure 2. Estimates fishery selectivity-at-age for each of the time block defined in ss3. Selectivity for the last age in blocks 2 and 3 is very low, this was detected in the run that did not converge, this plot is a particular case.

Annex 6: Leire Citores, WD bias in the assessment

Citores L. 2019. Bias in the assessment of Iberian sardine stock with full-feedback MSE. WD presented to the ICES Workshop on the Iberian Sardine Management and Recovery Plan. IPMA-Lisbon, 1–5 April 2019.

It was found that full feedback MSE runs show some bias in the assessment (Figures A6.2–A6.3). While in the Medium productivity regime this issue seems to reflect the retrospective pattern within the assessment of the Iberian sardine (overestimation of B1+, Mohn's rho of 0.39, and underestimation of F_{bar}, Mohn's rho of -0.17) in the other productivity regimes considered this issue tends to aggravate. It was assessed that these biases are kept when running simulations without observations errors in the inputs for the assessment (A6.1 and A6.4–A6.5). There is still uncertainty on the origin of this bias but possible causes should be further explored in future within the WGHANSA. Allowing for the update of all model parameters within the SS3 assessment in each loop of the MSE and with the current default parameterization seem to increase bias for all HCR with productivity regimes different from the Medium productivity for which SS3 is currently adjusted.

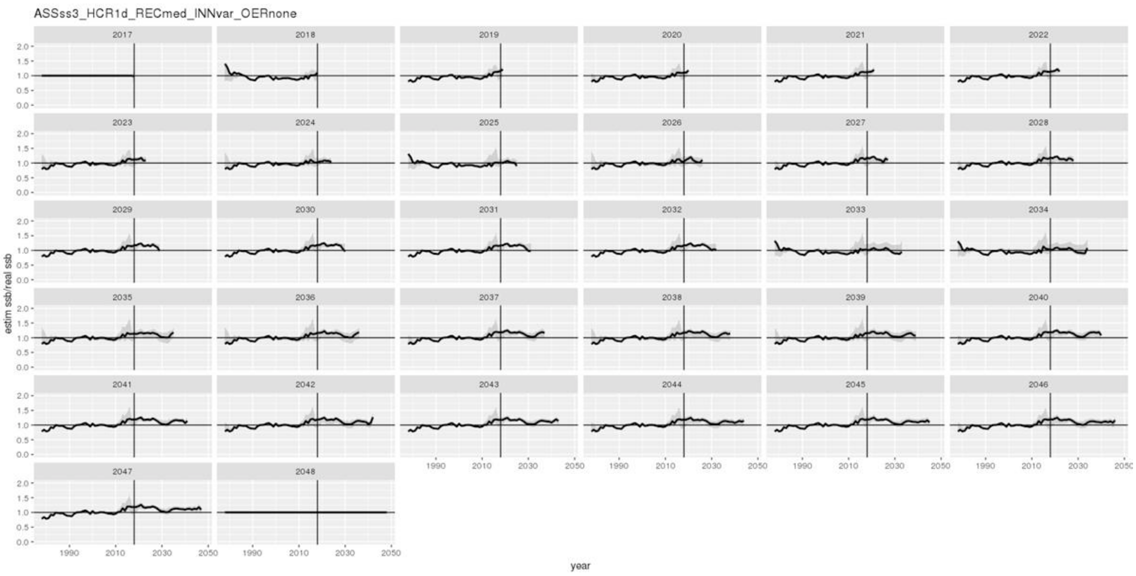


Figure A6.4. Example of assessment bias for the simulations performed for sc1 ('true' Medium productivity that is correctly 'perceived' as Medium, HCR1) without observation error (OERnone). Values on the y-axis are the estimated B1+ (in the Management Procedure model) divided by the 'true' B1+ (in the Operating Model).

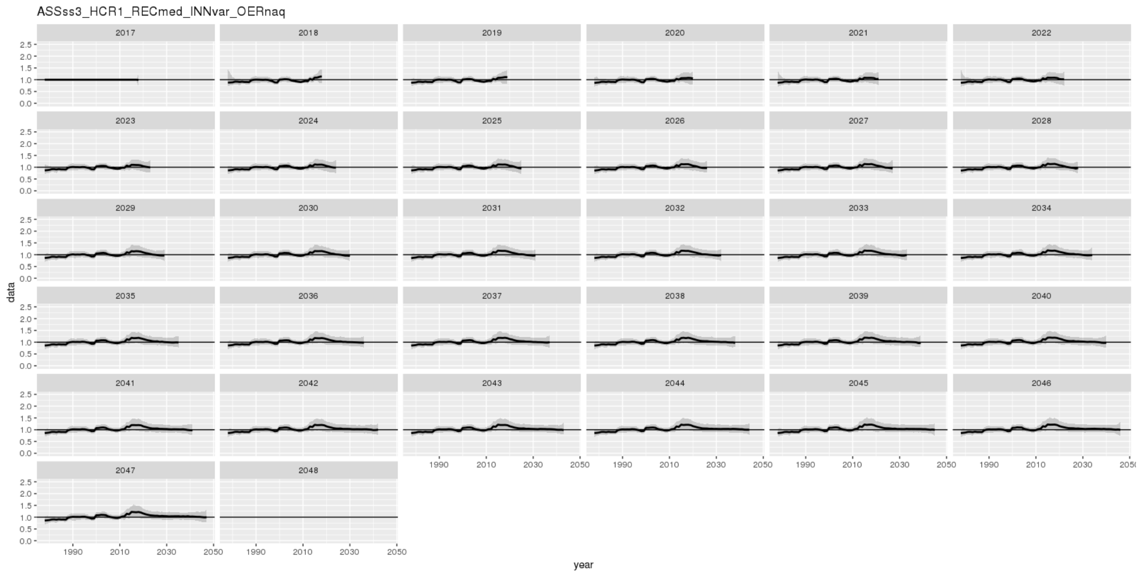


Figure A6.2. Example of assessment bias for the simulations performed for sc1 ('true' Medium productivity that is correctly 'perceived' as Medium, HCR1) with observation error (OERnaq). Values on the y-axis are the estimated B1+ (in the Management Procedure model) divided by the 'true' B1+ (in the Operating Model).

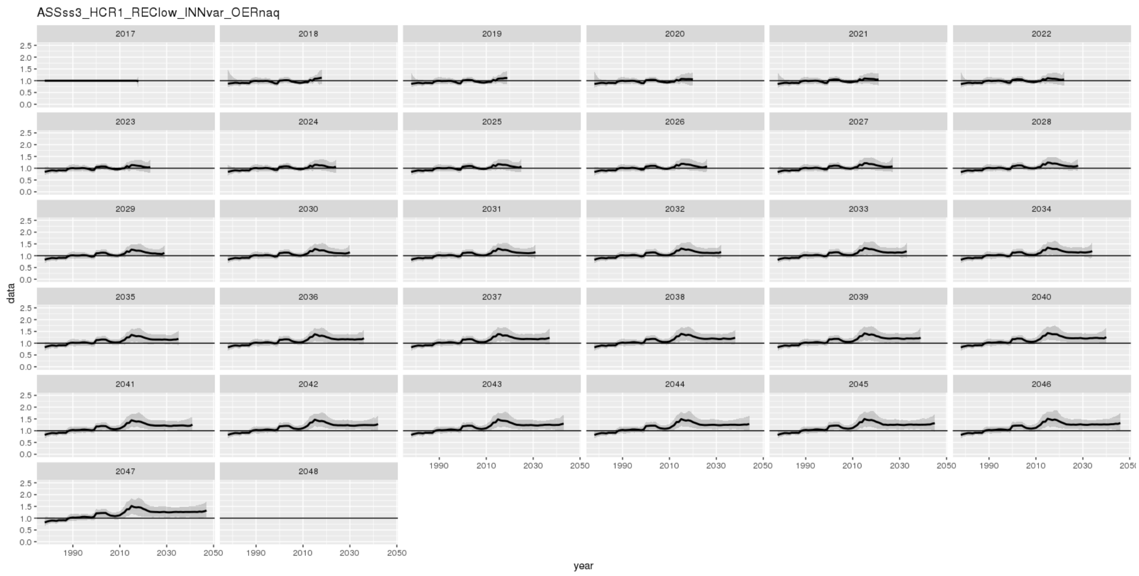


Figure A6.3. Example of assessment bias for the simulations performed for sc2 ('true' Low productivity that is wrongly 'perceived' as Medium, HCR1) with observation error (OERnaq). Values on the y-axis are the estimated B1+ (in the Management Procedure model) divided by the 'true' B1+ (in the Operating Model).

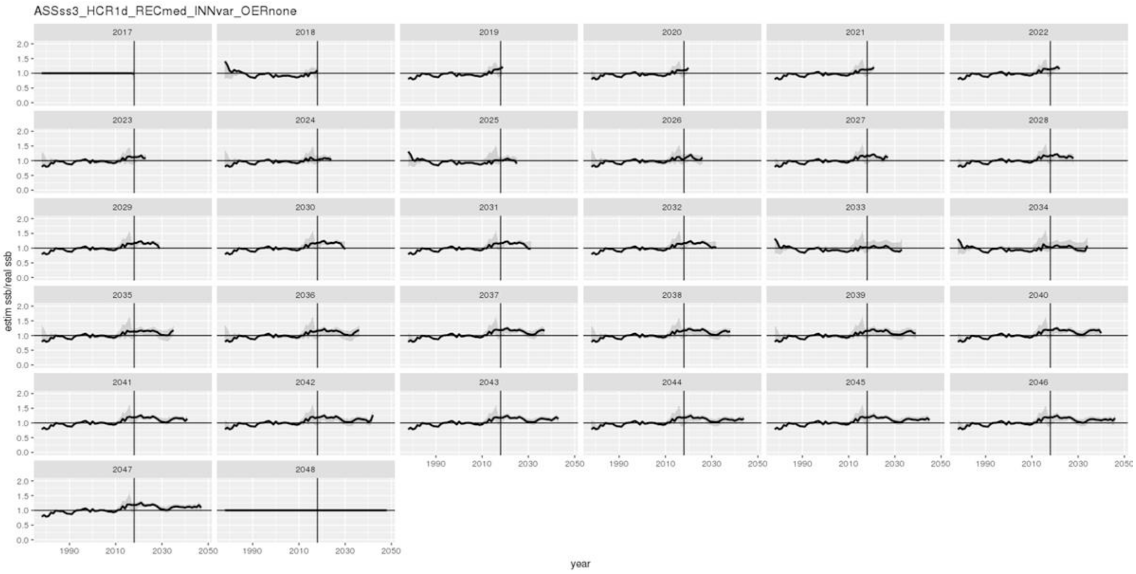


Figure A6.4. Example of assessment bias for the simulations performed for sc1 ('true' Medium productivity that is correctly 'perceived' as Medium, HCR1) without observation error (OERnone). Values on the y-axis are the estimated B1+ (in the Management Procedure model) divided by the 'true' B1+ (in the Operating Model).

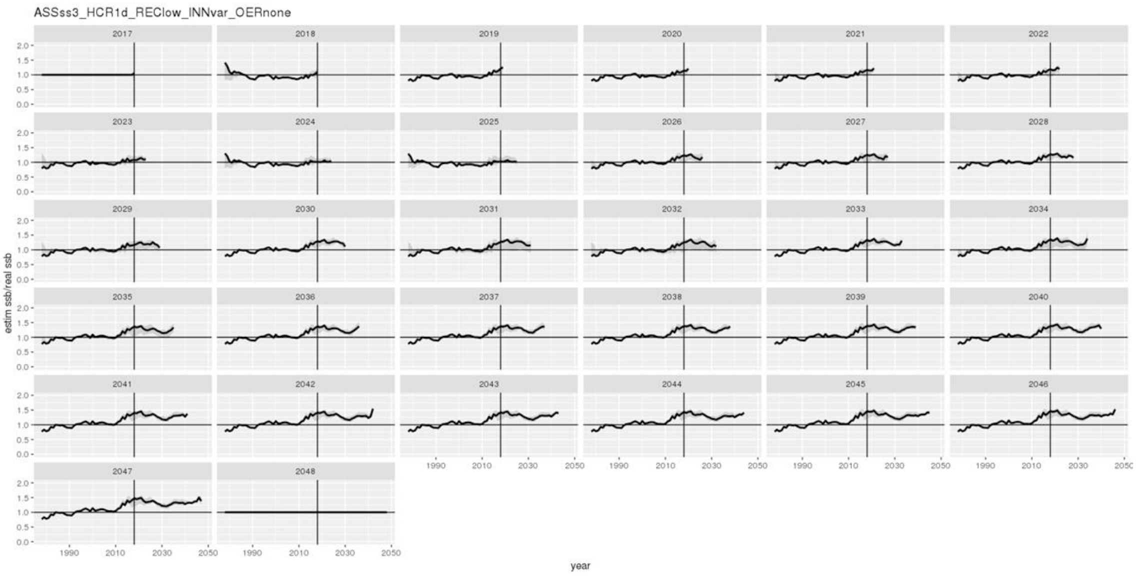


Figure A6.5. Example of assessment bias for the simulations performed for sc2 ('true' Low productivity that is wrongly 'perceived' as Medium productivity, HCR1) without observation error (OERnone). Values on the y-axis are the estimated B1+ (in the Management Procedure model) divided by the 'true' B1+ (in the Operating Model).

Annex 7: List of participants

Name	Organisation	Country	E-mail
Jorge Abrantes	South Western Waters Advisory Council National Association of Purse Seiners Producer´s Organization	Portugal	abrantesj56@gmail.com
Manuela Azevedo Chair	Portuguese Institute for the Sea and the Atmosphere (IPMA)	Portugal	mazevedo@ipma.pt
Nicolas Blanc	Platform of Portuguese NGOs on Fisheries (PONG-Pesca)	Portugal	nblanc@sciaena.org
Gonçalo Carvalho	Marine Conservation and Cooperation Association	Portugal	carvalho.gf@gmail.com
Leire Citores	AZTI Tecnalia AZTI Sukarrieta	Spain	lcitores@azti.es
Martin Dorn Reviewer	Alaska Fisheries Science Center NOAA Fisheries	US	martin.dorn@noaa.gov
Susana Garrido	Portuguese Institute for the Sea and the Atmosphere (IPMA)	Portugal	susana.garrido@ipma.pt
Leire Ibaibarriaga	AZTI Tecnalia AZTI Sukarrieta	Spain	libaibarriaga@azti.es
Javier Lopez	Oceana	Spain	jlopez@oceana.org
Hugo Mendes	Portuguese Institute for the Sea and the Atmosphere (IPMA)	Portugal	hmendes@ipma.pt
David Miller	International Council for the Exploration of the Sea	Denmark	David.miller@ices.dk
ChloéPocheau	South Western Waters Advisory Council	France	cpocheau@cc-sud.eu
Isabel Riveiro	Instituto Español de Oceanografía (IEO) Centro Oceanográfico de Vigo	Spain	isabel.riveiro@ieo.es
Sonia Sánchez Reviewer	AZTI Tecnalia AZTI Pasaia	Spain	ssanchez@azti.es
Alexandra (Xana) Silva	Portuguese Institute for the Sea and the Atmosphere (IPMA)	Portugal	asilva@ipma.pt
Andrés Uriarte	AZTI Tecnalia AZTI Sukarrieta	Spain	auriarte@azti.es
Laura Wise	Portuguese Institute for the Sea and the Atmosphere (IPMA)	Portugal	lwise@ipma.pt
Renato Nunes Rosa	Nova School of Business and Economics	Portugal	renato.rosa@novasbe.pt

Annex 8: Working Document to the Workshop on the Iberian Sardine Management and Recovery Plan (WKSARMP)

Laura Wise, Hugo Mendes, Alexandra Silva, Leire Ilbaibarriaga, Andrés Uriarte, Isabel Riveiro, Manuela Azevedo

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Please note that this annex was modified following ADGANSA (3–4 December 2019). ADGANSA considered that HCR10 (giving a 5.1% probability of the spawning–stock biomass being below B_{lim}) could not be considered precautionary. As a consequence HCR12 was selected.

Executive Summary

Following the work of WKSARMP April´s meeting seven additional harvest control rules considering a permanent low productivity regime were tested seeking the highest F_{tgt} that has a maximum risk3 of 5% in the long-term and that will give higher median catches in the short and long term than with the previous simulated tested, and evaluated as precautionary, harvest catch rule HCR4. Simulations were performed using the approach and methodology adopted in WKSARMP April´s meeting.The harvest control rule HCR8, with F_{low}=0.060 and F_{tgt}=0.08 (F_{tgt} in the request of the Portuguese and Spanish Administrations) as well as HCR9, with F_{low}=0.047 and F_{tgt}=0.065, are not precautionary since risk3 is 13.4% and 6.1%, respectively. However, the harvest control rule HCR12, with F_{low}=0.046 and F_{tgt}=0.064, complies with the ICES precautionary criterion since the maximum risk3 in the long term is 5.0%. The median spawning–stock biomass (B1+) is estimated to recover above B_{lim_low} in 2031 with 95% probability. HCR12 results in median annual catches of 12 805 tonnes in the initial period (2019-2023) and 21 367 tonnes in the long-term (2039-2048), with a small interannual change, between 2 039 tonnes and 2 678 tonnes. The probability of fishery closure is 0% in all periods.

1 Introduction

The Workshop on the Iberian Sardine Management and Recovery Plan - WKSARMP reported in April 2019 for the attention of ACOM and on the 29th May the ICES advice was published (ICES, 2019a; Appendix A). ICES considers that the Iberian sardine stock has been in a state of low productivity since 2006 and therefore recalculated the value of B_{lim} to be 196 334 tonnes and F_{MSY} to be 0.032. ICES advised that the harvest control rules HCR3 and HCR4, similar to those in the Portuguese and Spanish request to evaluate a management and recovery plan for the Iberian sardine stock (Divisions 8.c and 9.a) but with trigger points and biological reference points that reflect a persistent low productivity, fulfil the recovery objective in the request by 2022, and are consistent with the ICES precautionary approach with no more than 5% probability of the spawning–stock biomass (biomass of fish age 1 and older, B1+) falling below B_{lim}. These harvest rules result in annual catches of around 7000 and 18 000 tonnes in the first ten years and in the last ten years, respectively (Section 5.3).

In September 2019, ICES received an additional Special Request from the Portuguese and Spanish Administration to follow up the work done during WKSARMP to evaluate alternative catch rules to HCR4 (Appendix B). The new request asks ICES to consider F_{tgt} between 0.08 and 0.09

or, in case the catch rules with these higher F_{tgt} do not comply with the 5% precautionary criterion, to seek the highest F_{tgt} (i.e., an F_{tgt} higher than the HCR4 F_{tgt}, of 0.032) that has a maximum risk3 of 5% in the long-term and that will give higher median catches in the short and long-term than with HCR4 (AppendixB).

The evaluation of alternative catch rules (HCR8 to HCR14) was performed applying the approach and methodology used during WKSARMP April´s meeting (Section 4.4) and already reviewed by ICES (Annex 2).

2 Simulations

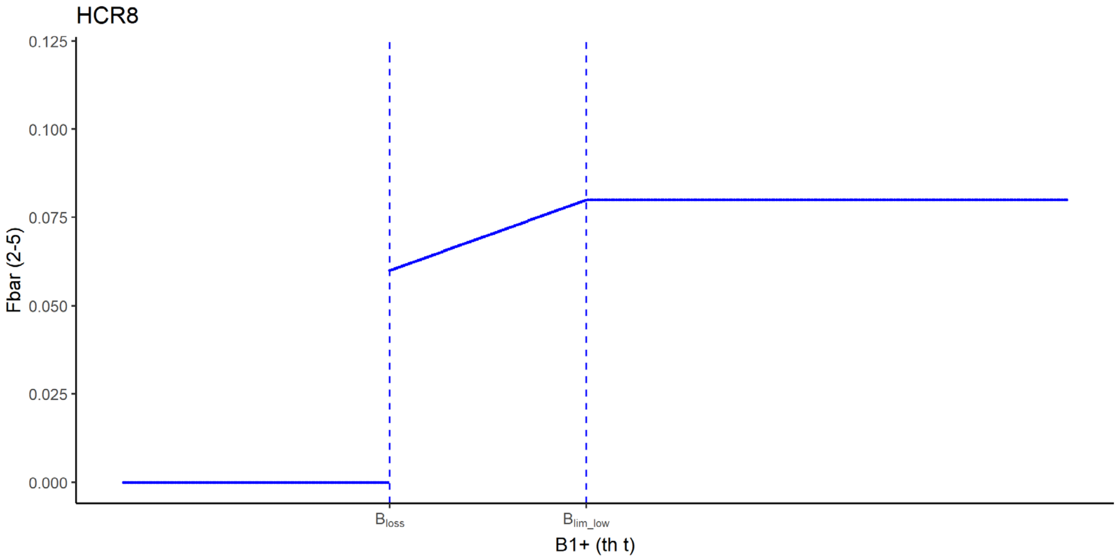
The FLBEIA MSE simulation carried out to analyse the performance of the additional HCR is based on 1000 populations (iters), each projected from 2019 to 2048 (Section 4.4). Therefore, the full-feedback MSE performed simulations for nt=30 future years resulting in 30000 assessment cycles for each rule. For comparison, the same MSE simulations were carried out for the case in which no observation and assessment errors were included. All simulations were carried out in the computation cluster located in IPMA. Simulations were carried out using the FLR packages FLCore (version 2.6.12), FLBEIA (version 1.15.4) and FLash (version 2.5.11; used for short-term projections). The results were examined using the package FLBEIAshiny (1.0.0).The operating model for the MSE to evaluate a Management Recovery Plan for the Iberian sardine was based on the last stock assessment (ICES, WGHANSA 2018) conducted using Stock Synthesis (SS3, Methot and Wetzel, 2013).

2.1 Scenarios and harvest control rules

All additional catch rules (HCRs, Appendix C) were evaluated considering a permanent low productivity regime for the Iberian sardine (scenario 17; 'sc17'). In this scenario the Operating Model (i.e. productivity regime) is the Low productivity regime and the Management Procedure uses the corresponding and recently adopted B_{lim} (B_{lim_low}) (ICES, 2019a; Appendix A), while the F_{tgt} and F_{low} are scaled. Several harvest control rules were tested until one was found to be precautionary in the long-term (the last ten years of the simulation period) with 95% probability while producing the highest catch. This was an iterative process where one tested one harvest control rule at a time, inspected the performance statistics of that harvest control rule and if it was found not to be precautionary the F_{tgt} and F_{low} would be scaled down and a new harvest control rule would be tested. Table 2.1 and Figures 2.1 to 2.3 show three harvest control rules that differ in the reference levels F_{low} and F_{tgt}. The three HCRs, designated HCR8, HCR9 and HCR12, where determined by scaling the F_{tgt} in HCR4 (Section 4, Figure 4.6; 0.032) to 0.080, 0.065 and 0.064 and the corresponding F_{low} accordingly. All catch rules were run in full feedback MSE with 1000 iterations, variability in the initial population and with observation error. Since it was previously found that full-feedback MSE runs show some bias in the assessment (Annex 6), all catch rules were also run without assessment and without observation error.

Table2.1. Simulation scenarios run with full-feedback MSE.

Scenario code	Operating Model (BRPs)	Advice (BRPs)	HCRs
SC17	Low B_{lim}=196.3 th t F_{msy}=0.032	Low B_{lim}=196. 3 th t F_{msy}=0.032	HCR8: F_{low}=0.060, F_{tgt}=0.080 B_{lim}=196.3 th t, B_{low}=112.9 th t
			HCR9: F_{low}=0.047, F_{tgt}=0.065 B_{lim}=196.3 th t, B_{low}=112.9 th t
			HCR12: F_{low}=0.046, F_{tgt}=0.064 B_{lim}=196.3 th t, B_{low}=112.9 th t

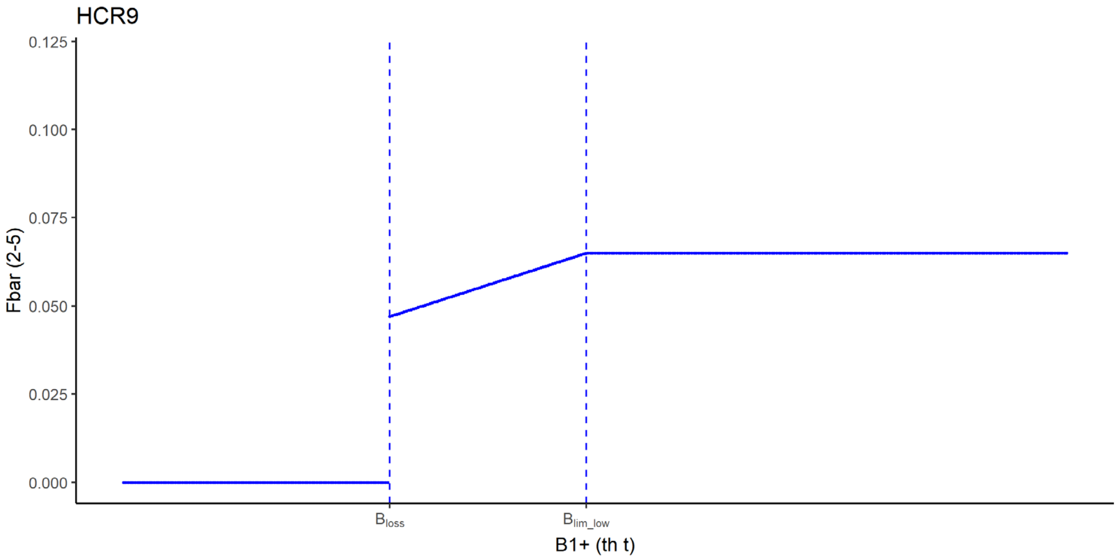


i) $B1^{+} \leq 112.9$ th t then F=0

ii) $112.9 < B1^{+} \leq 196.3$ th t, then the catch shall be fixed at value consistent with F increasing linearly from F=0.06 to F=0.08

iii) $B1^{+} > 196.3$ th t then F=0.08

Figure 2.1. Harvest Control Rule HCR8 with fishing mortality and biomass of fish age 1 and older (B1+) reference levels.

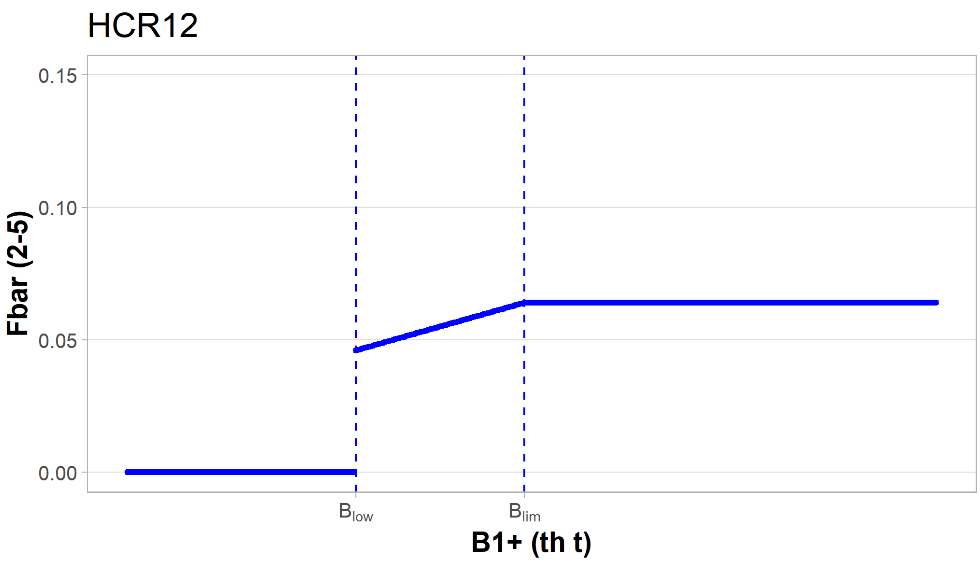


i) $B1^+ \leq 112.9$ th t then F=0

ii) $112.9 < B1^+ \leq 196.3$ th t, then the catch shall be fixed at value consistent with F increasing linearly from F=0.047 to F=0.065

iii) $B1^+ > 196.3$ th t then F=0.065

Figure 2.2. Harvest Control Rule HCR9 with fishing mortality and biomass of fish age 1 and older (B1+) reference levels.



i) B1+ ≤ 113.9 th t then F=0

ii) 113.9 th t < B1+ ≤ 196.3 th t, the catch shall be fixed at a value consistent with F increasing linearly from F=0.046 to F=0.064

iii) B1+ > 196.3 th t then F=0.064

Figure 2.3. Harvest Control Rule HCR12 with fishing mortality and biomass of fish age 1 and older (B1+) reference levels.

2.2 Performance statistics

Performance statistics include the median average biomass of fish age 1 and older (B1+), fishing mortality and catch. The interannual variation (IAV) of the catch (absolute values) was also estimated (average across years and then across iterations) as well as the probability of the fishery being closed (i.e. TAC equal to zero). The probability of B1+ falling below B_{lim_low} was also computed. Currently ICES uses the risk3 ≤0.05 criterion as the basis for defining a multiannual plan as precautionary, although with exceptions in cases requiring an initial recovery phase, or where a short-lived stock's natural variability (without fishing) exceeds the 5% threshold value (ICES, 2019b). Risk type 3 is defined as the maximum probability that B1+ is below B_{lim_low}, where the maximum (of the annual probabilities) is taken over nt years. Finally, the year in which B1+ would be above or equal to B_{lim_low} with 95% probability was computed. All these metrics were estimated for three time periods: an initial time period starting in the first projection year 2019 and ending in 2023; a short time period from 2019 to 2028 (i.e. the first ten years of the projection period) and in the long- term (i.e. the last ten years of the projection period; 2039 to 2048) which corresponds to the period after recovery and when the 'true' stock has reached equilibrium.

Table2.2. Statistics used to summarize the performance of the HCRs.

	Indicator	Time frame
Yield	Median catch	2019:2023;2019:2028;2039:2048
	IAV = $Mean\ \lvert Catch_{t-1} - Catch_t \rvert$	2019:2023;2019:2028;2039:2048
Fishing Mortality	Median $F_{bar2\text{-}5}$, 5th and 95th percentiles	2019:2023;2019:2028;2039:2048
B1+	Median B1+, 5th and 95th percentiles	2019:2023;2019:2028;2039:2048
Probability of closure	P(TAC = 0)	2019:2023;2019:2028;2039:2048
Precautionary considerations	Year in which $P(B1+ \geq B_{lim}) > 95$	NA
	$P(B1+ < B_{lim})$	2019: 2048
	$Risk\ 3 = max(P(B1+ < B_{lim}))$	2039:2048

3 Results and Discussion

The simulation of the catch rules was performed assuming one scenario for the 'true' stock (Low productivity) and considering that the 'perceived' stock was of Low productivity. Detailed results from the simulation testing are presented in this section for HCR8, HCR9 and HCR12 (Table 2.1: sc17) while summary results for the seven tested HCRs are presented in Appendix C.

3.1 MSE testing of catch rule HCR8, HCR9 and HCR12

3.1.1 Simulated recruitment, spawning–stock biomass (B1+), fishing mortality and catch

The trajectories of the key parameters R, B1+, $F_{bar2\text{-}5}$ and catch under 'sc17', Low productivity in the 'true' stock and 'perceived' Low productivity, are shown in Figures 3.1–3.3.

The key parameters have comparable median trajectories for the three HCRs tested. None of the catch rules tested leads to fishery closures and all show small interannual changes in catches (2–3 thousand tonnes IAV) (Table 3.1).

F_{low} and F_{tgt} values of HCR8 are 2.5 times higher than those of HCR4 but lower than recent historical $F_{bar2\text{-}5}$ levels ($F_{bar2\text{-}5[2015\text{-}2017]}$ = 0.18). The application of HCR8 leads to a decrease of median $F_{bar2\text{-}5}$ and, therefore of catches, in 2019, the first year the rules are applied.

Median B1+ increases above the corresponding B_{lim_low} value, 196 334 tonnes, but never with more than 95% probability (Figure 3.1). Median catches are estimated to be 15 569 tonnes in the initial period (2019–2023) and 25 422 tonnes tonnes in the long term (2039–2048).

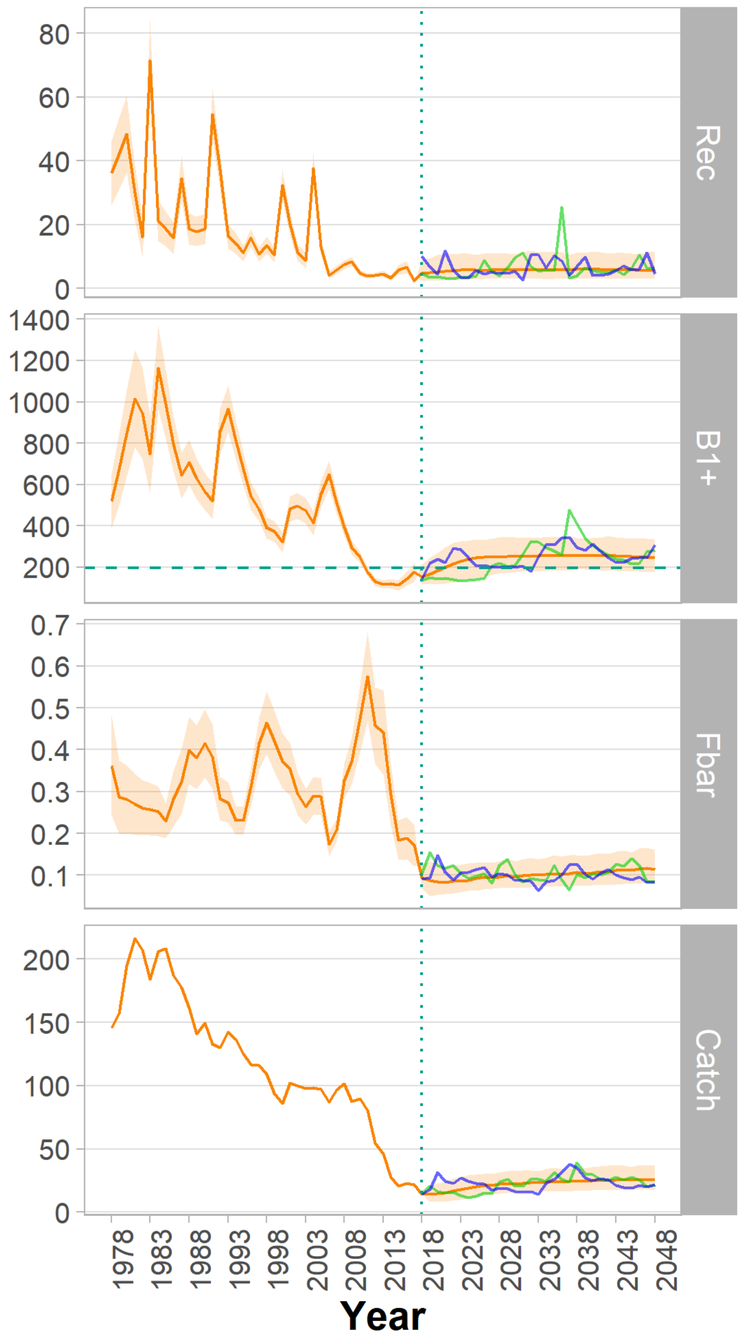


Figure 3.1. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2\text{-}5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR8 under 'true' stock of Low productivity and 'perceived' stock ofLow productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196 334tonnes). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

F_{low} and F_{tgt} values of HCR9 and HCR12 are two times higher than those of HCR4but lower than recent historical $F_{bar2\text{-}5}$ levels. The application of HCR9 and HCR12 leads to very similar trajectories of key parameters R, B1+ and $F_{bar2–5}$ given that the differences between F_{low} and F_{tgt} of these two catch rules are very small. Both catch rules lead to a decrease of median $F_{bar2–5}$ in relation to HCR8 and, therefore of catches, in 2019, the first year the rules are applied.

Median B1+ increases above the corresponding B_{lim_low} (196 334 tonnes) with more than 95% probability in the case of the harvest catch rule HCR12 (Figure 3.3). Median catches are estimated to be 12 805 tonnes in the initial period (2019–2023) and 21 367 tonnes in the long term (2039–2048).

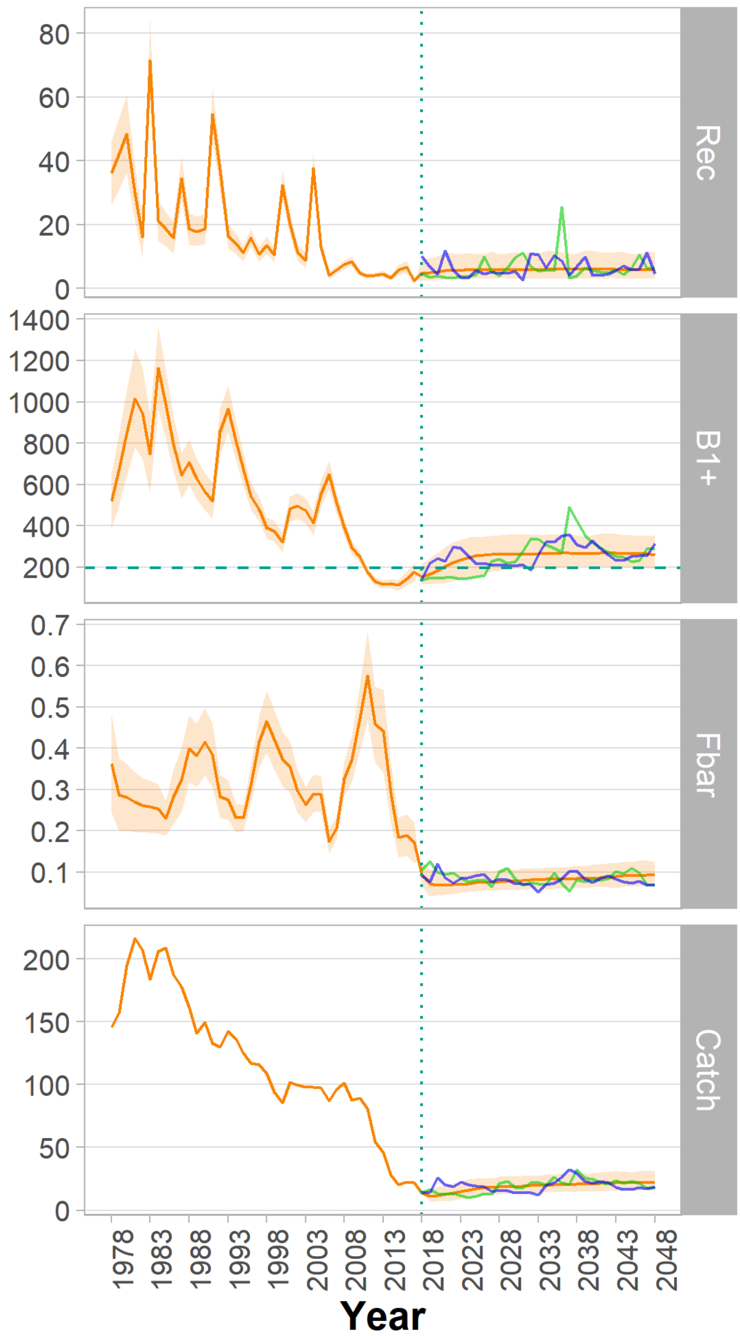


Figure 3.2. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2–5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR9 under 'true' stock of Low productivity and 'perceived' stock of Low productivity. Shaded area represents 90% confidence intervals. Horizontal dashed line in B1+ show B_{lim} of Low productivity (196 334 tonnes). Vertical

long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

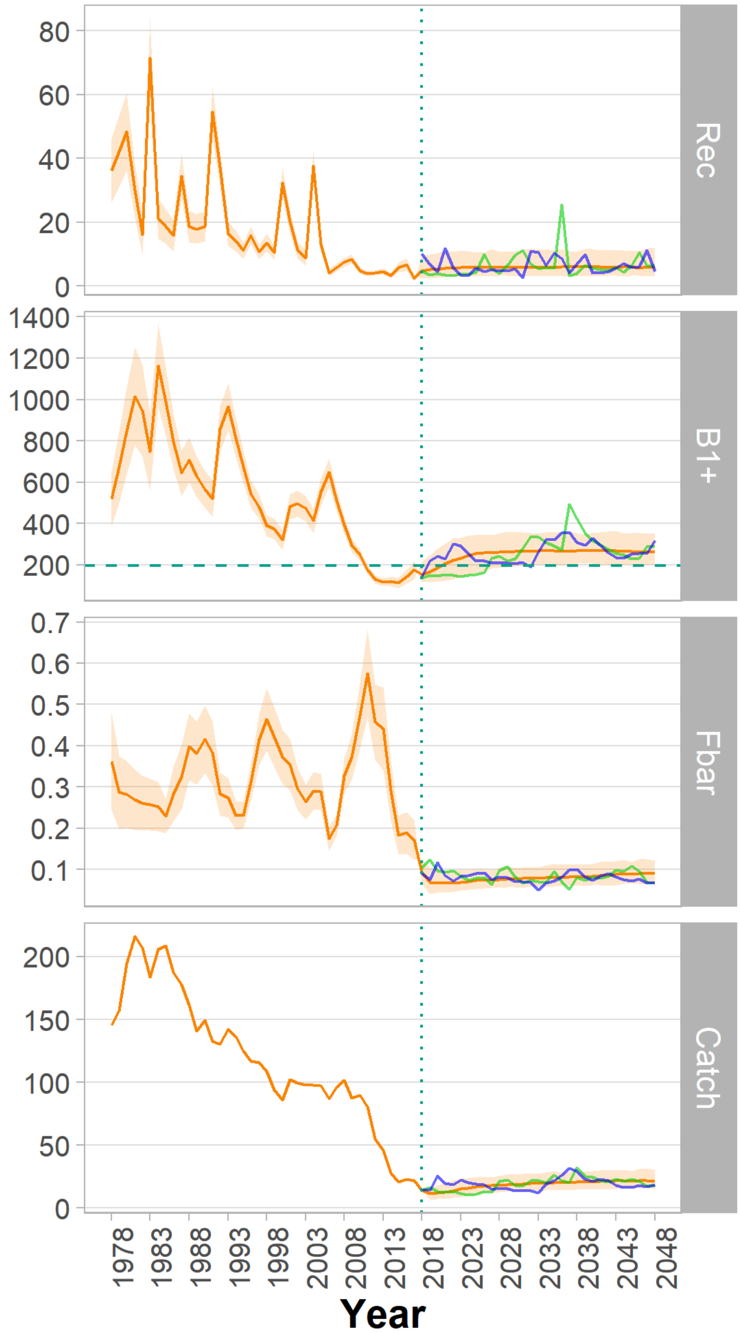


Figure 3.3. Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{bar2–5}$, year^{-1}) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for HCR12 under 'true' stock of Low productivity and 'perceived' stock of Low productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} of Low productivity (196 334 tonnes). Vertical long dashed lines separate the historical from the projected period. The blue and green lines show the results from two simulated iterations selected randomly.

3.1.2 Performance statistics

For the period 2019–2023 and with persistent low recruitment, the median spawning–stock biomass (B1+) is estimated between 197 and 201–202 thousand tonnes for catch rules HCR8 and HCR9/HCR12, respectively. For this period, the median catch is estimated between 13 and 16 thousand tonnes with an interannual variability of around 2–3 thousand tonnes (Table 3.1).

In the long term, the median B1+ is estimated to increase to 253–266 thousand tonnes (Table 3.1), depending if we are considering HCR8 or HCR9/HCR12. The median catch is estimated to increase to 25, 22 and 21 thousand tonnes under HCR8, HCR9 and HCR12, respectively.

The probability of fishery closure is 0% in all periods and catch rules considered.

The first year when B1+ is above or equal to $B_{lim\_low,}$ with 95% probability, is 2032 (HCR9) and 2031 (HCR12), i.e. in a time-frame of 14 to 13 years. The catch rule HCR8 does not comply with the ICES precautionary criterion, since risk3 is estimated to be 13.4% (Table 3.1 and Figure 3.4). Therefore, simulation testing of catch rules with F_{tgt} between 0.08 and 0.09, as requested, was not carried out as these catch rules would not be precautionary. Catch rule HCR9 is also not precautionary since risk3 is 6.1%. However, catch rule HCR12 was found to be precautionary since risk3 was estimated at 5.0%.

Table 3.1. Summary of performance statistics for HCR8, HCR9 and HCR12 assuming the 'perceived' stock to be of Low productivity and the 'true' stock to be of Low productivity. The values presented for Risk3 were rounded following ICES rounding rules (values rounded to two significant figures when the first non-zero digit is 2 or larger; values rounded to three significant figures when the first non-zero digit is 1).

			HCR8	HCR9	HCR12
	Metrics	Period	sc17		
Indicators	**Spawning Biomass: B1+** (median, tonnes)	2019-2023	196956	200575	202422
		2019-2028	224612	231347	232265
		2039-2048	252576	265811	266330
	F (median)	2019-2023	0.085	0.069	0.068
		2019-2028	0.089	0.072	0.071
		2039-2048	0.111	0.089	0.087
	Catch (median, tonnes)	2019-2023	15569	12847	12805
		2019-2028	18188	15289	15170
		2039-2048	25422	21664	21367
	IAV1 Catch (absolute, tonnes)	2019-2023	2521	2042	2039
		2019-2028	2684	2175	2141
		2039-2048	3317	2688	2678
	Probability of closure (%)	2019-2023	0	0	0
		2019-2028	0	0	0
		2039-2048	0	0	0
	first year P(B1+ ≥ Blim) > 95%	2019-2048	NA	2032	2031
ICES criterion	**Risk3 for Blim(%)**	2039-2048	13.4	6.1	5.0

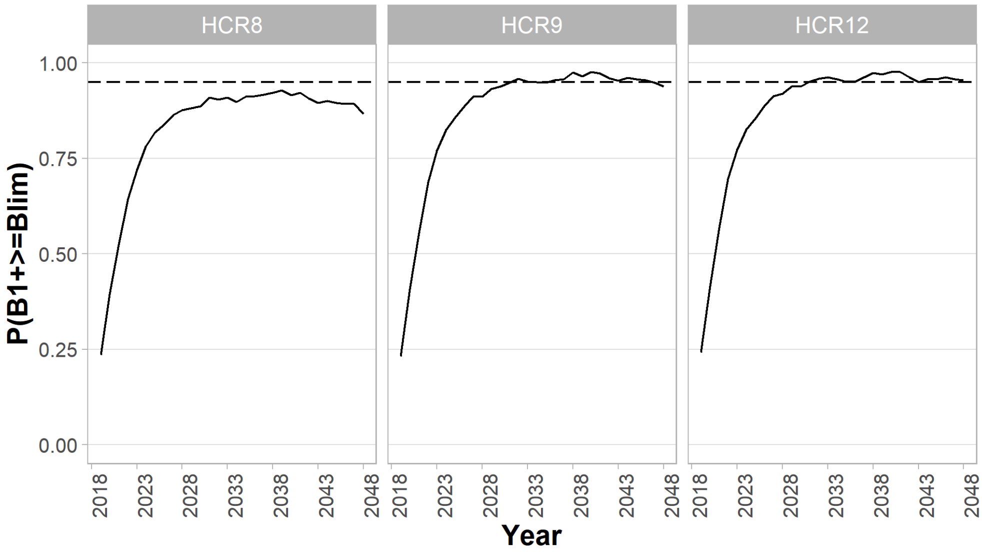


Figure 3.4. Probability profile of P(B1+≥B_{lim_low}) for catch rules HCR8, HCR9 and HCR12 when 'true' stock is of Low (B_{lim_low}=196 334 tonnes) productivity and 'perceived' stock is of Low productivity, from 2018 to 2048. Horizontal dashed lines represent 95% probability.

3.1.3 Comparison with runs without assessment

The analysis for HCR8, HCR9 and HCR12 on the relative change of B1+ and $F_{bar2\text{-}5}$ of runs with assessment and observation error in relation to runs without assessment and no observation error along the whole projection period (Figure 3.5) show the same patterns as when testing HCR4: underestimation trend of B1+ along the period for true Low ('sc17') productivity scenarios. The opposite behaviour is in general observed for $F_{bar2\text{–}5}$, since modelled true $F_{bar2\text{–}5}$ estimates are lower in scenario 17 than estimated under assessment and observation errors. The behaviour between rules is very similar and the differences in the relative change of parameter estimates are very small. This imply that the testing framework of the rules, under assessment and observation errors, is risk averse.

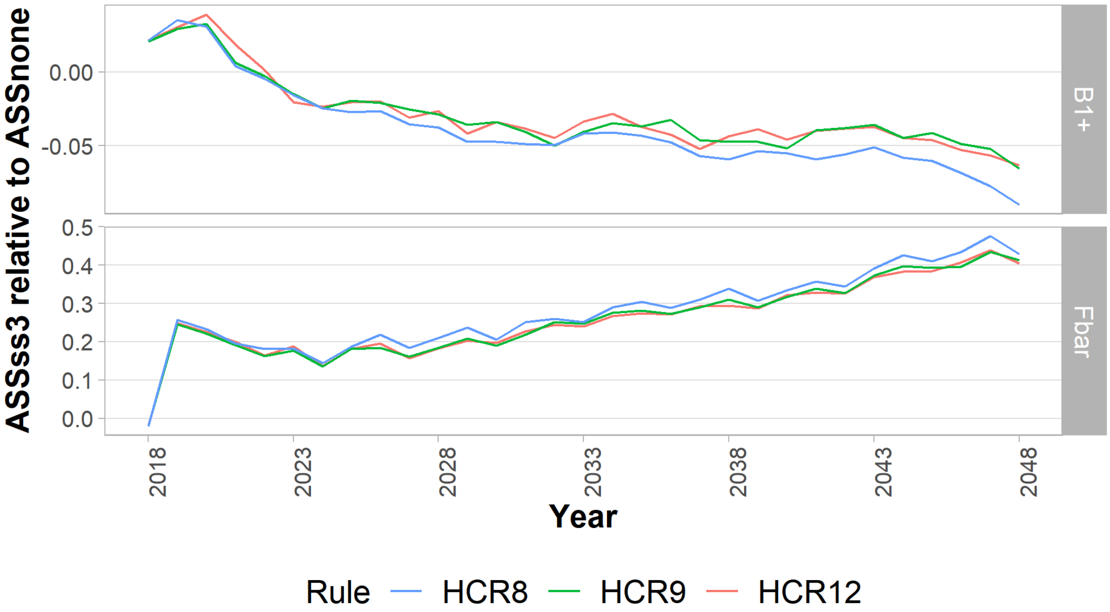


Figure 3.5. HCR8, HCR9 and HCR12: relative change of estimates of B1+ (upper panel) and $F_{bar2–5}$ (lower panel) of runs with assessment and observation error in relation to runs without assessment and no observation error for scenario assuming Low productivity for the 'true' stock, from 2019 to 2048.

4 Conclusions

The application of all catch rules leads to a decrease of median $F_{bar2–5}$ and therefore of the catches because fishing mortality levels allowed by these rules are lower when compared to recent historical $F_{bar2–5}$. The HCR9 and HCR12 rules lead to median B1+ values above the reference B_{lim_low} of the corresponding productivity with ≥95% probability by 2032–2031. As expected, the B_{lim_low} is achieved faster when F_{low} and F_{tgt} are lower, even if the difference is small. However, with catch rule HCR9 the probability of B1+ being above B_{lim_low} with 95% probability is not met in the last ten years (2039–2048) of the projection period. With HCR8 B1+ never increases above B_{lim_low}=196 334 tonnes with≥95% probability.

Harvest control rule HCR12 is considered precautionary as it resulted in 5% probability of B1+ ≤ B_{lim_low} in the long term while resulting in the highest catch among the precautionary HCRs evaluated (Appendix C).

HCR12 results in median catches in the period 2019–2023 (12 805 tonnes) higher than the median catches estimated with HCR4 in the long term (around 12 000 tonnes). This implies that median B1+ with HCR12 is expected to be lower than those with HCR4 (Section 5, Table 5.3) in all periods considered (between 3% and 10%) and that recovery of B1+ to or above B_{lim_low} with 95% probability occurs four years later.

5 References

ICES. 2018. Report of the Working Group on Southern Horse Mackerel, Anchovy and Sardine (WGHANSA), 26–30 June 2018, Lisbon, Portugal. ICES CM 2018/ACOM:17. 605 pp.

ICES. 2019a. Request from Portugal and Spain to evaluate a management and recovery plan for the Iberian sardine stock (divisions 8.c and 9.a). In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, sr.2019.10,https://doi.org/10.17895/ices.advice.5275

ICES. 2019b. Workshop on Guidelines for Management Strategy Evaluations (WKGMSE2). ICES Scientific Reports. 1:33. 162 pp. http://doi.org/10.17895/ices.pub.5331

Appendix A (ICES Special Request Advice)

Request from Portugal and Spain to evaluate a management and recovery plan for the Iberian sardine stock (divisions 8.c and 9.a)

Advice summary

ICES considers that the Iberian sardine stock has been in a state of low productivity since 2006 and ICES has therefore recalculated the values of B_{lim} to 196 300 tonnes and F_{MSY} to 0.032.

ICES advises that harvest control rules HCR3 and HCR4, that are similar to those in the request but with trigger points, and with biological reference points that reflect a persistent low productivity, fulfil the recovery objective in the request by 2022, and are consistent with the ICES precautionary approach with no more than 5% probability of the spawning–stock biomass (SSB) falling below B_{lim}. These harvest rules result in annual catches of around 7000 tonnes.

Neither of the harvest control rules (HCRs) proposed in the request (HCR1 and HCR2) comply with the ICES precautionary criterion. The HCR with step changes in fishing mortality between trigger points and an imposed 5% interannual increase in the spawning biomass, meets the objective in the request by 2022, with a 40% probability of fishery closure in the first five years.

Request

To clarify the Iberian sardine Harvest Control Rule proposed in the Management Plan we inform that:

Objective:
Assure that the stock biomass will be equal or above 80% of Blim with a probability 90% by the year 2023, (If this objective is not achieved in the specified number of years (n = 5), please evaluate what would be the least time frame possible to achieve this objective with the same risk).

Harvest Control Rule (HCR):

i. *In the case B1+ is estimated to be below or equal to B_{low} (B_{low} - lowest biomass estimated for the year 2015 in the 2018 assessment (ICES, 2018a)), the catch shall be zero which is consistent with a fishing mortality (F) equal to zero.*
   If $B1+ \leq B_{low}$ then $F = 0$
ii. *In the case B1+ is estimated to be less than or equal to 80% of B_{lim} and larger than B_{low}, the catch shall be fixed at a value that is consistent with a fishing mortality (F) equal to 0.10.*
   If $B_{low} < B1+ \leq 80\% \; B_{lim}$ then $F = 0.10$
iii. *Where the clause in paragraph ii would lead to an inter-annual increase in B1+ inferior to 5%, F should decrease to a level that would lead to at least a 5% inter-annual increase of B1+.*
iv. *In the case B1+ is estimated to be above 80% of Blim, the catch shall be fixed at a value that is consistent with a fishing mortality (F) equal to 0.12.*
   If $B1+ > 80\% B_{lim}$ then $F= 0.12$

In the context of the management and recovery plan submitted, we ask ICES to consider also, instead of ii) and iii): in the case B1+ is estimated to be less or equal to B_{lim} and larger than B_{low}, the catch shall be fixed at a value that is consistent with F increasing linearly from F = 0.085 to F=0.12 (F_{MSY}).

We also ask ICES to evaluate if it is necessary to re-estimate reference points for this stock to account for:

a) *The possibility that the low productivity of this stock in the recent past (since 2006) might continue in the future.*
b) *Possible retrospective bias in the assessment estimates.*

And to test 2 alternatives:

i. *Start from the population (numbers-at-age) estimated in the beginning of the interim year of the last assessment (ICES, 2018a) and*
ii. *Start from the population projected one year ahead, to the beginning of year for which the catch is to be set*

In both cases assume the 2018 catch to be 12.028 t, as agreed by Spain and Portugal.

Elaboration on the advice

ICES considers that the Iberian sardine stock is in a state of low productivity which has resulted in low recruitment for the last decade. This is likely caused by a combination of fisheries and environmental changes. Taking the low productivity state into account, ICES has recalculated the values of the biological reference points (BRPs).

Evaluation of reference points

The re-evaluation of the BRPs was based on data from the period 2006–2017 which is considered representative of this low productivity state. The updated BRPs are B_{lim} = 196 300 tonnes and F_{MSY} = 0.032; these values are significantly different from the previous ones (Table 1). The harvest control rules in the request have a target F of 0.12, which is considerably higher than the estimated F_{MSY} in the current state of low productivity (0.032). ICES did explore harvest control rules HR1 and HR2, using the previous BRPs, but these estimates do not reflect the current stock dynamics in the stock's state of low productivity. The updated BRPs, assuming a state of low productivity, were used to set the biomass and fishing mortality reference levels for the two other harvest control rules (HR3 and HR4) considered in this advice. For all harvest control rules, the value of B_{low} (lower trigger point) was set at 112 900 tonnes, corresponding to the biomass estimate for 2015 from the 2018 assessment (ICES 2018a) as specified in the request.

ICES is not able to predict the persistence of the current state of low productivity and therefore recommends that the state of productivity for this stock is monitored regularly to determine if the BRPs and the resulting harvest control rules associated with low productivity remain valid.

Table 1 Estimated reference points. Previous reference points (based on data from 1993–2015; ICES, 2017) and updated reference points based on the state of low productivity (2006–2017; ICES, 2019a). The hockey-stick model was used in both cases.

Reference point	Previous	Updated
B_{lim} (tonnes)	337448	196334
B_{pa} (tonnes)	574066	252523
F_{lim}	0.250	0.156
F_{pa}	0.189	0.118
F_{MSY}*	0.12	0.032

* The F that maximizes long-term yield under the constraint that the long-term probability of SSB < B_{lim} is ≤ 5% when applying the ICES MSY advice rule (ICES, 2018b).

Description of proposed and alternative harvest control rules

The request proposed two catch rules, each with three reference levels for fishing mortality (no fishing, low F, and target F) and three reference levels for the biomass of age 1 and older individuals, B1+ (B_{low}, 80%B_{lim}, and B_{lim}). As ICES considers the Iberian sardine stock to be in a state of low productivity, a further two HCRs were evaluated using the re-estimated BRP values from the low productivity period.

ICES evaluated four harvest control rules.

- HCR1 as described in the request, with step changes in fishing mortality between trigger points, assuming a state of medium productivity (Figure 1);
- HCR2 as described in the request, with gradual change in fishing mortality between trigger points, assuming a state of medium productivity (Figure 1);
- HCR3 is similar to HCR1 but incorporating new values for target and trigger points (except for B_{low}) that correspond to a state of low productivity (Figure 2);

- HCR4 is similar to HCR2 but incorporating new values for target and trigger points (except for B_{low}) that correspond to a state of low productivity (Figure 2).

The harvest control rules were evaluated through full-feedback management strategy evaluations. The catch rules set a TAC for the fishing year y+1, dependent on the biomass of fish age 1 and older (B1+) in year y+1. All HCRs close the fishery in years when B1+ is below 112 900 tonnes (B_{low}).

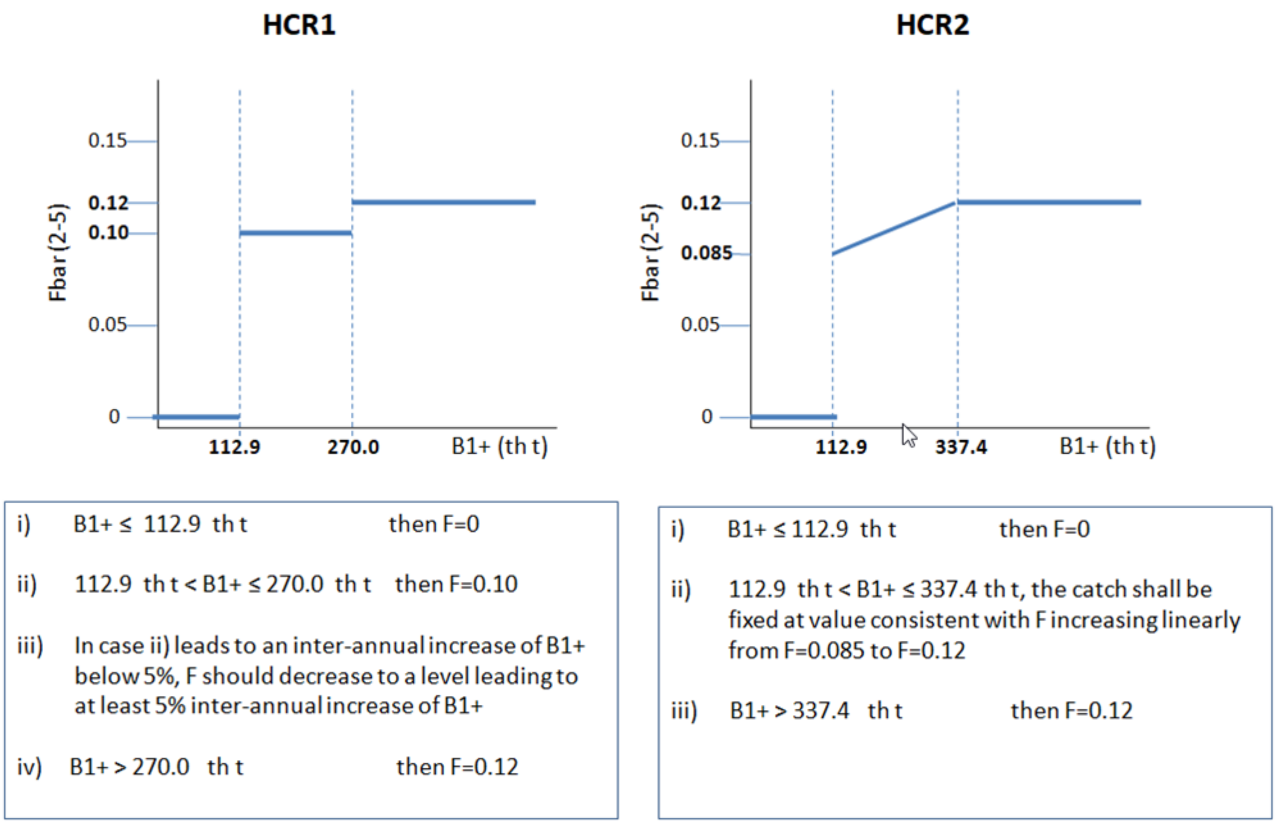


Figure 1 Graphical interpretations of the requested harvest control rules (items i to iv in the request), identified as HCR1 and HCR 2. The lowest biomass trigger point is B_{low} = 112 900 tonnes, the higher trigger point is 80% of B_{lim} = 270 000 tonnes for HCR1 and the previous B_{lim} = 337 400 tonnes for HCR2.

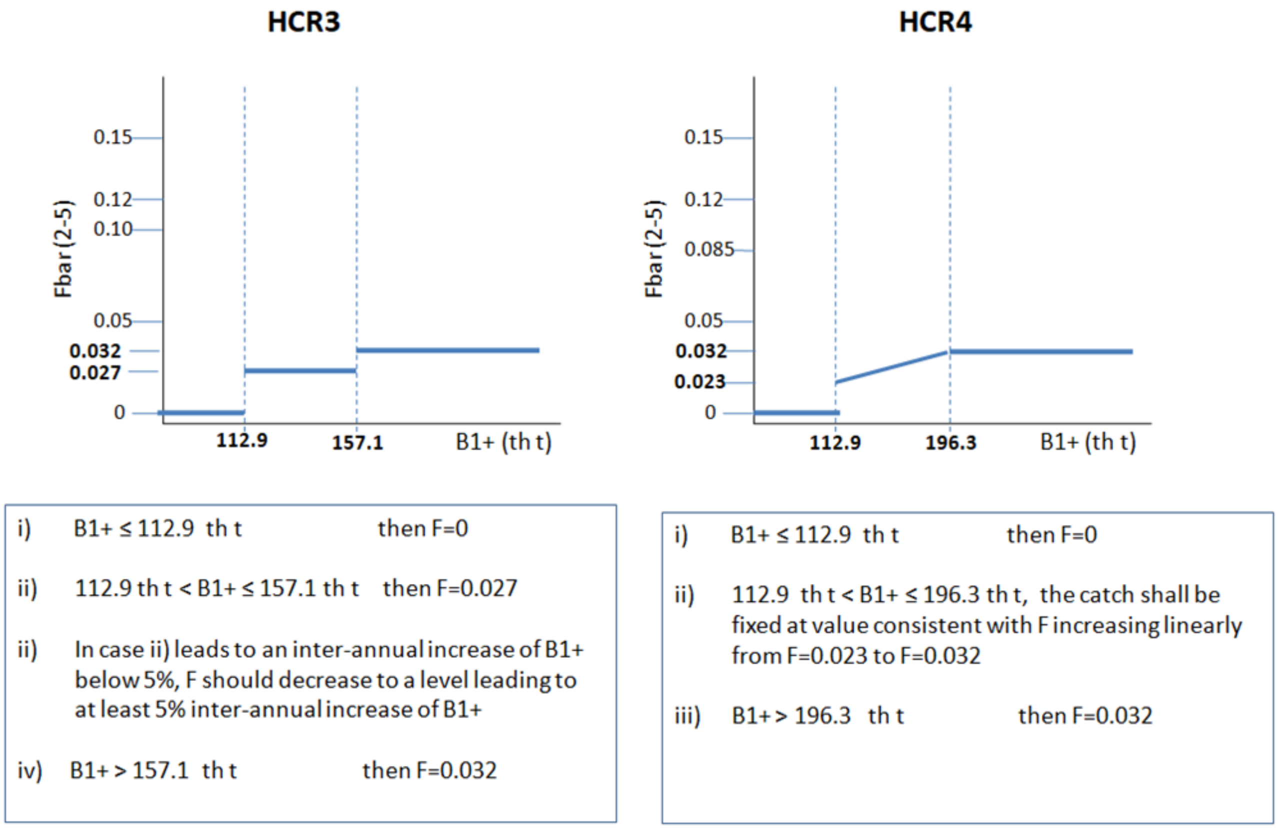


Figure 2 Graphical interpretations of the harvest control rules (items i to iv in the request) using the redefined values for BRPs, identified as HCR3 and HCR4. The lowest biomass trigger point is B_{low} = 112 900 tonnes, the higher trigger point is 80% of the new B_{lim} = 157 100 tonnes for HCR3 and the new B_{lim} = 196 300 tonnes for HCR4.

Evaluation of proposed and alternative harvest control rules against objectives

The evaluations suggest that HCR1 has an 95% probability of B1+ ≥ 80%B_{lim} in 2023, thus fulfilling the objective of the request, whereas HCR2 has an 85% probability of B1+ ≥ 80%B_{lim} in 2023 and is likely to reach this objective by 2026 (Table 2). Neither HCR1 or HCR2 would be considered precautionary in the long term using the ICES criterion of a < 5% probability of B1+ being below B_{lim}. HCR1 has a higher variability in $F_{2\text{–}5}$ and a higher frequency of closures (Figure 4). This higher frequency is mostly due to clause iii) in HCR1 which imposes a 5% interannual increase in B1+.

The evaluations suggest that HCR3 and HCR4 have a 95% probability of B1+ ≥ 80%B_{lim} in 2023 (Table 2). Both HCR3 and HCR4 would be considered precautionary in the long term if the ICES criterion of <5% probability of B1+ being below B_{lim} is used. The probability of fishery closure is < 2%.

The trigger point, 80% B_{lim}, is defined by the managers for a short-term recovery. ICES notes that 80% B_{lim} is associated with a high probability of impaired recruitment and potential loss of yield. The HCRs were evaluated both as recovery plans and as long-term management plans. The ICES precautionary criterion of spawning biomass (B1+) having a less than 5% probability of being below B_{lim} is not achievable within 30 years for HCR1 and HCR2, and achievable in approximately two generations for HCR3 and HCR4, if the state of low productivity persists.

Suggestions

When the advice is for an extremely low catch, it may be difficult to apply full implementation as assumed in the evaluation. It would therefore be beneficial to have information from a monitoring fishery with an associated sampling protocol to estimate the state of the stock.

Basis of the advice

Background

The biomass of the stock has experienced a large decline, from nearly 650 000 tonnes in 2006 to less than 150 000 tonnes in 2018. The stock is considered depleted and in need of a recovery plan.

Evaluation of harvest control rules

The performance of each HCR was evaluated using a full-feedback management strategy evaluation. An operating model assuming a state of low productivity was used in the evaluations. 1000 populations (iterations) were simulated 30 years into the future.

The performance of HCRs was evaluated against the indicators/outputs and criteria listed below.

- Median spawning biomass (B1+),
- Median $F_{(2–5)}$,
- Median catch,
- Interannual variability in the catch,
- Probability of closure of the fishery (the mean probability of TAC = 0),
- Probability that B1+ ≥ 80% of B_{lim} in 2023,
- First year that the probability of B1+ ≥ 80% B_{lim} is ≥ 90%,
- First year that the probability of B1+ ≥ B_{lim} is > 95%,
- The maximum probability of B1+ < B_{lim} in 2039–2048.

Results and conclusions

HCR1 and HCR2 result in an increase in median $F_{2–5}$ over time to 0.17, but with a slow increase (< 0.5% per year) in median B1+ (Figure 3). Individual iterations show greater variability over time (Figure 3).

HCR3 and HCR4 result in a low median $F_{2–5}$ and an increase (approx. 1.7% per year) in median B1+ (Figure 5). Median catch with both HCRs is estimated as 7000 tonnes in the short term, increasing to 12 000 tonnes in the long term. Interannual variability is low (approximately 1000 tonnes).

Figure 3 Recruitment (Rec, million individuals), biomass of fish age 1 and older(B1+, thousand tonnes), fishing mortality (F_{2-5}, year) and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for **HCR1** and **HCR2** under low productivity. Shaded areas represent the 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} (196 300 tonnes) and the previous B_{lim}, assuming medium productivity (337 400 tonnes). Vertical long dashed lines separate the historical from the projected period. The blue and red lines show the results from two simulated iterations selected randomly.

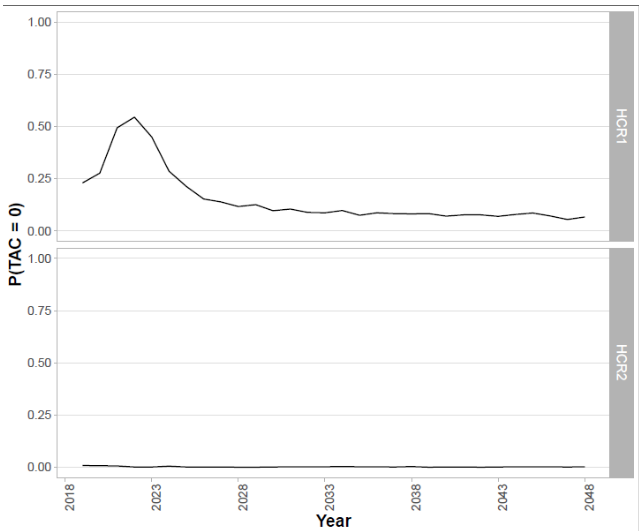


Figure 4 Probability of zero TAC by year for HCRs 1, 2, 3, and 4.

Figure 5 Recruitment (Rec, million individuals), biomass of fish age 1 and older (B1+, thousand tonnes), fishing mortality ($F_{2–5}$, year), and catch (thousand tonnes) for the assessment period (1978–2017) and during the projected period (2019–2048) for **HCR3** and **HCR4** under low productivity. Shaded area represents 90% confidence intervals. Horizontal dashed lines in B1+ show B_{lim} (196 300 tonnes) and the previous B_{lim}, assuming medium productivity (337 400 tonnes). Vertical long dashed lines separate the historical from the projected period. The blue and red lines show the results from two simulated iterations selected randomly.

Table 2 Summary of the performance statistics for HCRs 1, 2, 3, and 4, assuming persistent low productivity.

	Metrics	Period	HCR1	HCR2	HCR3	HCR4
Indicators/outputs	Median spawning biomass (B1+) thousand tonnes	2019–2023	207	190	207	207
		2019–2028	231	211	248	248
		2039–2048	228	220	295	296
	Median $F_{(2–5)}$	2019–2023	0.013	0.112	0.034	0.034
		2019–2028	0.104	0.121	0.035	0.035
		2039–2048	0.167	0.165	0.042	0.042
	Median catch, thousand tonnes	2019–2023	2	19	7	7
		2019–2028	28	23	8	8
		2039–2048	34	32	12	12
	Interannual variability in the catch, thousand tonnes ($Mean\ \lvert Catch_{t-1} - Catch_t \rvert$)	2019–2023	9	4	1	1
		2019–2028	10	4	1	1
		2039–2048	9	5	1	1
	Mean probability of closure of the fishery (TAC = 0)	2019–2023	40	0	2	0
		2019–2028	29	0	1	0
		2039–2048	7	0	0	0
Special Request objectives	Probability of B1+ ≥ 80% of B_{lim} in 2023 (%)	2023	95	85	95	95
	First year with probability of B1+ ≥ 80%B_{lim} is ≥ 90%	2019–2048	2022	2026	2022	2022
Additional criteria	First year with probability of B1+ ≥ B_{lim} being > 95%	2019–2048	Not achievable	Not achievable	2026	2027
	The maximum probability of B1+ < B_{lim} in 2039–2048 (%)	2039–2048	31	34	1	1

Methods

The request was evaluated through a workshop (ICES, 2019a).

The methodology used to estimate BRPs followed the framework proposed in ICES guidelines on fisheries management reference points (ICES, 2017). The influence of the retrospective bias in the stock assessment on the BRPs was evaluated and found to be negligible.

The management strategy evaluation (MSE) of the proposed Management and Recovery Plan (MRP) followed the recommendations of ICES (2019b) and was undertaken using FLBEIA (Bio-Economic Impact Assessment using FLR; García *et al*., 2017). The operating model, which generates the "true" future populations in the simulations, was conditioned on the ICES stock assessment. The biological and fishery parameters in the operating model were considered constant over time as there is no indication of significant trends. Future recruitment was estimated from the spawning–stock biomass following a hockey-stick relationship, and with variability introduced from a lognormal distribution.

The management procedure component included a stock assessment and an advice based on short-term forecasts in each assessment loop. The currently used age-based assessment model SS3 was included. Survey indices and catch data used as inputs in each assessment cycle were generated from the "true" population, with lognormal distributed errors to include observation error in the simulations. Full implementation of management advice was assumed (i.e. TAC advice is always fully implemented).

The MSE simulation carried out to analyse the performance of the proposed MRP is based on 1000 populations (iterations), each projected from 2019 to 2048. For comparison with the full-feedback MSE runs that show some bias in the assessment, the same MSE simulations were carried out without observation error and without assessment. Further details on the methodology and results are available in ICES (2019a). Code used for the simulation testing is available in GitHub (https://github.com/ssanchezAZTI/FLBEIA_mseIBpil).

The request specified two alternatives for the initial population in the simulation testing, assuming that the catch in 2018 would be 12 028 tonnes. This forces the initial population for the simulation testing to be the same in both alternatives. However, at the time of the workshop meeting, preliminary estimates of the 2018 catches were 14 060 tonnes. This value was therefore adopted for the analysis as it represented the actual catches and would be more realistic.

The mean generation time (the average time it takes for a mature female to be replaced by an offspring with the same reproductive capacity; it depends on fecundity and survivorship of each age group in the absence of fishing) of the Iberian sardine stock was estimated to be between 4 and 5 years (ICES, 2019a). The workshop calculated the number of generations required to achieve precautionary and requested objectives (see ICES, 2019a). The amount of time required to meet the requested objectives was also calculated.

Additional information

In the situation of no fishing and persistent low productivity, the criterion of 90% probability of B1+ ≥ 80% of B_{lim} is reached by 2021. ICES precautionary criterion will be reached by 2025.

The assumption of low productivity is mainly based on the observation of consistently low recruitment over the last decade and some further information that the ecosystem is changing. However, a causal direct mechanism has not been identified or modelled. In the case of clear signs of changes compared to the assumed productivity, BRPs and MSE should be re-evaluated.

Sources and references

García, D., Sánchez, S., Prellezo, R., Urtizberea, A., and Andrés, M. 2017. FLBEIA: A simulation model to conduct Bio-Economic evaluation of fisheries management strategies. SoftwareX, 6: 141–147.

https://doi.org/10.1016/j.softx.2017.06.001.

ICES. 2017. ICES fisheries management reference points for category 1 and 2 stocks. ICES Technical Guidelines. *In* Report of the ICES Advisory Committee, 2017. ICES Advice 2017, Book 12, Section 12.4.3.2. 19 pp. https://doi.org/10.17895/ices.pub.3036.

ICES. 2018a. Sardine (*Sardina pilchardus*) in divisions 8.c and 9.a (Cantabrian Sea and Atlantic Iberian waters). *In* Report of the ICES Advisory Committee, 2018. ICES Advice 2018, pil.27.8c9a. 8 pp. https://doi.org/10.17895/ices.pub.4495.

ICES. 2018b. Advice basis. In Report of the ICES Advisory Committee, 2018. ICES Advice 2018, Book 1, Section 1.2. https://doi.org/10.17895/ices.pub.4503.

ICES. 2019a. Workshop on the Iberian Sardine Management and Recovery Plan (WKSARMP). ICES Scientific Reports, 1:18. 125 pp. http://doi.org/10.17895/ices.pub.5251.

ICES. 2019b. Report of the Second Workshop on Guidelines for Management Strategy Evaluations (WKGMSE2), 4–8 February 2019, JRC, ISPRA, Italy. In prep.

Recommended citation: ICES. 2019. Request from Portugal and Spain to evaluate a management and recovery plan for the Iberian sardine stock (divisions 8.c and 9.a). In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, sr.2019.10, https://doi.org/10.17895/ices.advice.5275

AppendixB (Request and clarifications)

DGRM DIREÇÃO-GERAL DE RECURSOS NATURAIS, SEGURANÇA E SERVIÇOS MARÍTIMOS

To

Anne Christine Brusendorff

General Secretary ICES

H. C. Andersen

Boulevard 44-46, DK 1553

Copenhagen V,

Denmark

Cc: Dr. João Aguiar Machado

DGMARE

09.09.2019

Request to follow up the work done during WKSARMP (2019)

Portugal and Spain thank ICES for the extensive work carried out to answer the request to evaluate a management and recovery plan for the Iberian sardine.

The ICES advice on the management rules only considered precautionary the low productivity scenarios, among the set of management rules which were submitted by the WGSARMP.

The HCR advised by ICES corresponded to a low productivity scenario with a 1% probability of the spawning-stock biomass (SSB) falling below Blim on the long term. This level of risk is well below the 5% probability level, which is the threshold accepted by ICES to consider as precautionary a management and recovery plan.

Therefore, using the same HCR if we use the Blim and the Blow level adopted by ICES, but with higher Ftarget and Flow levels, long term sustainability can be ensured with a probability level of 95% and allowing short-term median catches larger than those initially assessed by ICES.

Preliminary calculations using a "short cut" simulation approach, point to the possibility of Ftarget between 0.08 and 0.09 and median catches on the short-term between 12kt- 14kt, with a moderate increase on the long-term, as expected by a low productivity scenario.

Nevertheless, there is a need to better clarify the performance of the management rules, particularly HCR4, applying the same approach and methodology already reviewed by ICES (full-feedback MSE). This will complete a full series of scenarios needed to allow the choice of the best strategy in terms of long-term sustainability of the stock, while preserving the sardine fishing activity in Portugal and Spain.

Therefore the Spanish and the Portuguese administrations would like to request to ICES to continue the WKSARMP work considering the HCR4 (low productivity) with Ftarget between 0.08 and 0.09 being the long term sustainability ensured with a probability level of 95% of not falling below Blim in the long term.

We request the revised HCR could be the basis of ICES advice on the catch opportunities for the Iberian sardine for 2020 in the bilateral management plan. Therefore and if it is necessary, we would like to ask ICES to present all the management alternatives, including long-term scenarios. We also would like to ask to ICES to update the 2019 advice, on the same basis.

Yours sincerely,

José Carlos Simão

Director General for Natural Resources

Safety and Maritime Services

PORTUGAL

Isabel Artime Garcia

Director General for Fisheries Resources

SPAIN

ICES proposed process to answer this request, as accepted by clients, is as follows:

- Carry out additioanl scenario runs to the ones inlcuded in the WKSARMP 2019 workshop:
  - Modifications of HCR4 will be explored with F_{target} between 0.08 and 0.09 and Flow between 0.06 and 0.065, respectively. No fishing (F=0) will still be triggered when B1+ is forecasted to be below or equal to B_{low}.
  - This evaluation should include simulations to determine the highest F_{target} precautionary (maximum risk of biomass $<B_{lim}$ of 5% in the long term).
- Include additional catch scenarios (e.g. F=0.08) to the advice for sardine in divisions 8c and 9a.

Appendix C (List of all Harvest Control Rules Tested)

Table C.1. Summary of performance statistics for harvest control rules HCR8 to HCR14 assuming the 'perceived' stock to be of Low productivity and the 'true' stock to be of Low productivity. The values presented for Risk3 were rounded following ICES rounding rules (values rounded to two significant figures when the first non-zero digit is 2 or larger; values rounded to three significant figures when the first non-zero digit is 1).

		Catch rule	HCR8	HCR9	HCR10	HCR11	HCR12	HCR13	HCR14
		F_{tgt}	0.08	0.065	0.0643	0.063	0.064	0.0644	0.0645
	Metrics	**Period**							
Indicators	**Spawning Biomass: B1+** (median, tonnes)	2019-2023	196956	200575	200614	202406	202422	200929	200608
		2019-2028	224612	231347	231940	232777	232265	232714	231723
		2039-2048	252576	265811	266264	268098	266330	265845	265691
	F (median)	2019-2023	0.085	0.069	0.068	0.067	0.068	0.068	0.068
		2019-2028	0.089	0.072	0.071	0.070	0.071	0.071	0.071
		2039-2048	0.111	0.089	0.087	0.085	0.087	0.088	0.088
	Catch (median, tonnes)	2019-2023	15569	12847	12828	12553	12805	12861	12869
		2019-2028	18188	15289	15188	14937	15170	15304	15264
		2039-2048	25422	21664	21433	21049	21367	21447	21463
ICES criterion	**Risk3 for Blim_low** (%)	2039-2048	13.4	6.1	5.1	5.0	5.0	6.0	5.8

Appendix D (Biological reference Points)

ICES adopted new reference points for the stock based on data from the period 2006–2017 which is considered representative of a state of low productivity (ICES, 2019). The updated BRPs include B_{lim} = 196 334 tonnes and F_{MSY} = 0.032 (Table D.1); these values are significantly different from the previous ones.

ICES was not able to predict the persistence of the current state of low productivity and therefore recommended that the state of productivity for this stock is monitored regularly to determine if the BRPs and the resulting harvest control rules associated with low productivity remain valid.

Table D.1. Currently adopted biological reference points.

Reference point	Value	Basis
B_{lim} (tonnes)	196 334	Change point of the Hockey-stick model fitted to the stock–recruitment data.
B_{pa} (tonnes)	252 523	Bpa = Blim * exp(1.645 * σ), σ = 0.17 (ICES, 2017)
F_{lim}	0.156	Stochastic long-term simulations (50% probability SSB < Blim)
F_{pa}	0.118	Fpa = Flim * exp(-1.645 *σ), σ = 0.233 (ICES, 2016) If Fpa< F_{MSY} then F_{MSY} = Fpa
F_{MSY}*	0.032	$F_{p0.5}$

*** The F that maximizes long-term yield under the constraint that the long-term probability of SSB < B_{lim} is ≤ 5% when applying the ICES MSY advice rule (ICES, 2018b).**

References

ICES. 2016. Report of the Workshop to consider F_{MSY} ranges for stocks in ICES categories 1 and 2 in western waters (WKMSYREF4), 13–16 October 2015, Brest, France. ICES CM 1025/ACOM:58. 187 pp.

ICES. 2017. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA), 6–10 February 2017, Lisbon, Portugal. ICES CM 2017/ACOM:35. 278 pp. https://doi.org/10.17895/ices.pub.5350

ICES. 2019. Request from Portugal and Spain to evaluate a management and recovery plan for the Iberian sardine stock (divisions 8.c and 9.a). In Report of the ICES Advisory Committee, 2019. ICES Advice 2019, sr.2019.10, https://doi.org/10.17895/ices.advice.5275

Annex 9: External reviewer report for Annex 8 of a workshop on the management and recovery plan for Iberian sardine (WKSARMP)

Martin Dorn and Sonia Sánchez acted as the external experts for a follow-up analysis from the workshop on the management and recovery plan for Iberian sardine (WKSARMP), in which additional harvest control rules (HCR) were tested at the request of Portugal and Spain. Iterative interactions between analysts, stakeholders, and managers are a typical feature of management strategy evaluations (MSE) as different tradeoffs are explored to achieve management objectives. The follow-up analysis is reported in Annex 8 and associated appendices of the WKSARMP report. A draft document was provided to the reviewers on 18 November, which afforded enough time to review the document. The basic intent of the request from managers was to identify harvest control rules that meet the ICES standard for being precautionary, but allow greater harvest over the short term and the long term than HCR4, which was one of the two harvest control rules determined to be precautionary in the original analysis.

The risk criteria applied in both the original analysis and in the follow-up analysis was that the maximum probability of the spawning–stock biomass being below B_{lim} during the period 2039–2048 could be no higher than 5%. This is a measure of long-term risk after the stock has rebuilt, and corresponds to the ICES standard from multi-year management plans.

Annex 8 used the same methods that had been developed in the WKSARMP workshop for a full-feedback MSE using FLBEIA and stock synthesis. The performance of each candidate harvest control rule was evaluated with 1000 iterations for the thirty-year period 2019–2049. Our review of results did not identify any new concerns or issues with methods. Therefore, we support the findings of the Annex 8 as being suitable for the management of the Iberian sardine stock. It is important to note that this is a highly variable stock that will require close monitoring for rebuilding progress, and checking for changes in stock productivity and reference points.

Below we provide additional specific comments on the MSE testing of alternative rules for the Iberian sardine. This report reflects solely the views of the external experts.

Specific comments

The additional harvest control rules tested were analysed with exactly the same procedure as the previous ones, so that the results are fully comparable. Additionally, the previously detected problem with the bias when using the full-feedback approach was also analysed showing same patterns as before.

To allow an easier comparison between the old rule (HCR4) and the new alternatives, it would have been helpful to see all the results together in the same summary table.

Although a number of rules were tested, only results for three of them were presented in the results section. However, the criteria of selecting these three among all the rest is not specified. Regarding the comparison between all the runs (Appendix C), it would be helpful to further evaluate the precision of the results, since not all results fall into line as expected. For example, it would be helpful to see a comparison of two runs (with 1000 iterations) for the same rule, to evaluate the number of significant digits in terms of risks. †

Because the request was so specific asking for testing exclusively changes in the F target levels (F_{tgt}), other potential approaches have not been tested. For example, other combinations of F_{low} and F_{tgt} could be evaluated that do not maintain the same ratio of reduction (i.e. changing the slope of the F increase between the biomass trigger points).

The problem of the bias in the assessment is an issue that should be further investigated, as although it in this case it is risk averse, it could result in underestimation of the fishing opportunities, of still unknown magnitude.

† The last two sentences of this paragraph were modified following ADGANSA (3–4 December 2019).