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Report of the Workshop on a long-term management strategy for Norwegian Spring-spawning herring (WKNSSHMSE)

26-27 August 2018

Torshavn, Faroe Islands

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1 Introduction

The workshop on management strategy evaluation for the Norwegian spring-spawning herring (*Clupea harengus*) in subareas 1, 2, and 5, and in divisions 4.a and 14.a, WKNSSHMSE, was convened to prepare the technical basis needed by ICES to respond to the request from NEAFC. The request is listed in Annex 1 of this report. The workshop was given the following terms of reference:

a) Evaluate the proposed harvest control rules (HCRs) for a long-term management strategy for Herring (*Clupea harengus*) in subareas 1, 2, 5 and divisions 4.a and 14.a, Norwegian spring-spawning herring (the Northeast Atlantic and Arctic Ocean), as specified in the request and
b) Prepare the first draft of the advice for the special request on NSSH in North East Atlantic.

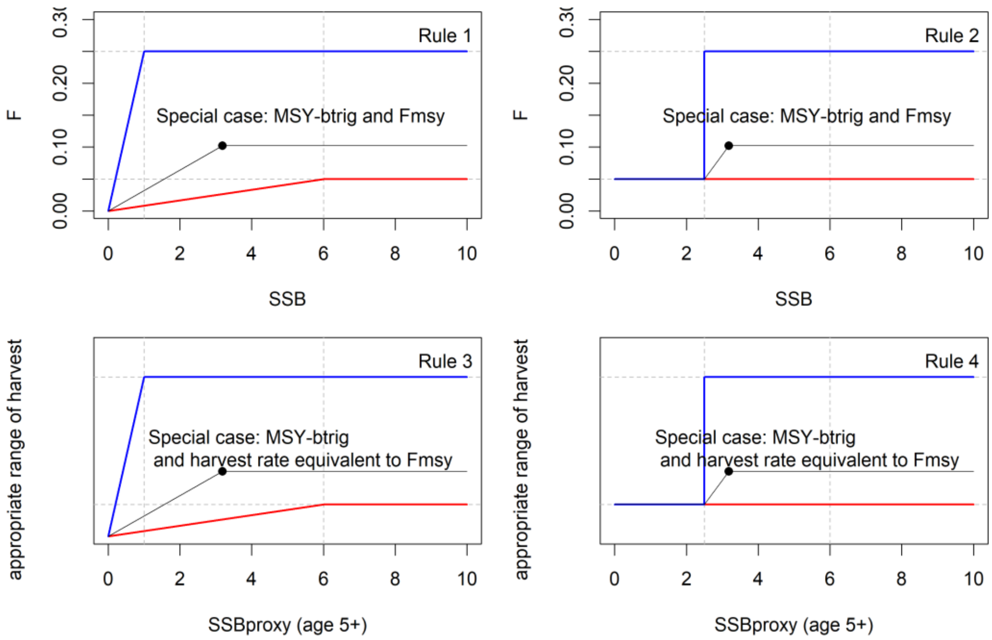

Figure 1.1: Graphical presentation of the four HCRs that the request specifies. Blue and red lines indicate the ranges to evaluate and the black dot and line are the special cases to evaluate for each rule.

The workshop addressed the terms of reference and the findings are recorded in this report. The report is organised as follows: The methodological framework is presented in Section 2 while section 3 covers updated work on reference points. Results are found in Section 4 while section 5 presents overall workshop conclusions and section 6 lists the references. Several annexes are included in the report. Annex 1 is the request received by ICES. Annex 2 contains the working documents that were presented to the workshop. Annex 3 contains all summary output tables corresponding to the final results for the evaluation and performance criteria indicated in the request, for the short term, medium term and long term. Annex 4 pro-vides a list of participants and Annex 5 provides the summary table of the HCR eval-uation. Finally, Annex 6 provides a preliminary knowledge quality assessment – this work was not presented at the workshop, but it was decided to include the Annex as it may help guide the appropriate level of precision to report findings in future work using the simulation model and data. Annex 7 includes the reviewers' reports.

While working with the Management Strategy Evaluation, the group encountered issues with the reference point simulations from earlier this year (ICES, 2018), and therefore these issues have been revisited by WKNSSHMSE. This took considerable time, and since the time schedule for answering the request was already very tight it was decided to prioritize and first focus on issues that were considered most important and then finish the other issues in the request if there was enough time. The plan was, however, to answer all issues in the request if possible.

Unfortunately, during the meeting in Torshavn it became clear that there was not enough time to include all aspects of the Request in detail. Below is a list of deviations from the request and an explanation for the prioritization made:

1) All four rules should be tested without constraint and with two different types of constraint on the inter-annual variation of TAC.

One of the prioritizations made due to time issues was to first test the effect of the TAC constraint only on rule 1 and rule 3 (one F–rule and one HR rule). The reason for prioritizing rule 1 and 3 was that they have the form of the standard ICES MSY rule with F/HR = 0 when SSB = 0 and the results should illustrate the effect on inter-annual variability in catch of including the two different TAC constraints.

2) Test the effect of allowing a maximum of 10% to be banked or borrowed any year.

This was unfortunately not done. It was unclear how banking and borrowing should be implemented, and it was decided to prioritize getting the code ready and quality checked for running the simulations with the 8 selected scenarios and to put banking/borrowing on the list of issues that could be done if time allowed after finishing the prioritized issues. In the end, there was no time to do this. Banking/borrowing could, however, be checked at a later stage when clients have decided on a HCR. It should be noted that MSEs for other stocks have shown that the impact of 10% banking or borrowing on the performance of the harvest control rules is insignificant (e.g. flatfish in North Sea (Brunel and Miller 2013); blue whiting (ICES 2016b); *Pandalus* (ICES 2016c).

3) The request asks for special cases such as F = 0.102 (F_{MSY} as defined by WKNSSHREF) to be tested.

Due to the issues with the reference points simulations (WKNSSHREF) that were encountered, the simulations were conducted without the old and new F_{MSY} estimates. These values have, however, been included in the evaluation tables by splining the data (see section 4).

A draft advice for the special request was prepared by the workshop chairs after the workshop.

2 The MSE framework

The work is based on a simulation model using the results of the assessment model (XSAM) used in ICES to conduct annual assessments for this stock. In the assessment, the model is run for ages 2–12+ and for the years 1988–present (ICES, 2018). To establish the basis for MSE, the model is run from 1950–present to obtain a sufficiently long time series to establish an appropriate stock recruitment relationship (see ICES, 2018 (WKNSSHREF) for details). Technical details are given in WD 2 (status MSE). The settings were as in WKNSSHREF with a few important exceptions:

The XSAM model is a state space model having fixed M but variable selectivity. In the model the following time series model describes development of F.

$$log(F_{a,y}) = V_y + \alpha_{aU} + U_{a,y} + \delta 1_{a,y}$$

i.e. a separable model with deviations where the age coefficient is called _{aU} in the code.

The deviations from a separable model are modelled as first order AR model

$$U_{a,y} = \beta_U \times U_{y-1,a} + \delta 2_{a,y}$$

The variance-covariance matrix of the inherited changes in selection $\delta 2_{a,y}$ (Σ_2) and the transient changes $\delta 1_{a,y}$ (Σ_1) are assumed diagonal i.e. no correlation between age groups. Also, all the elements of Σ_1 and Σ_2 are assumed to be the same. The use of diagonal variance-covariance matrices can be justified here as the yearfactor V_y introduces strong positive correlation and predicting on correlations of $U_{a,y}$ is difficult.

The effort in XSAM follows a time series model

$$V_y = Y_y + \delta 3_y$$

$$Y_y = \beta_y \underset{y-1}{\times} + \delta 4_y$$

$\delta 3_y$ denotes transient variability in effort and is not used in the herring model (variance set to 0)

The observation model in XSAM is somewhat different from most other assessment models as the variance covariance matrix of survey residuals is calculated for each year based on bootstrapping the data, (using the program STOX). As sampling variability (variability in acoustic values and pelagic trawl samples) does not include all variability, the values are estimated by an estimated number (one for each of the main surveys)

The XSAM model was used to generate stochastic set of the estimated parameters from the estimated Hessian matrix. In N stochastic simulations N sets of the estimated parameters in the equations above are given and a time series of selection patterns generated. The set of estimated parameters estimated this way is initial number in stock and F (2017 values), parameters for equations describing development of selection pattern ($\Sigma_1$and Σ_2,α_{aU},β_U above).

The effort V_y does not need to be included in time series model as the simulations will always be calculated from the catch given by the HCR. It is included in the code but later scaled out by division to get the selection.

Most of the parameters of the selection model are variances, used by the models for F and selectivity U above in each simulation.

The selection patterns estimated historically are quite variable (somewhere between VPA and separable model) and those generated in the stochastic simulations are also quite variable.

The Hessian matrix of XSAM is used to generate covariance matrix between $B_{ref,assy}$ and $B_{trigger,assy}$ for biomass rule andSSB_{assy+1},$N_{y+1,1:A}$ and $F_{y+1,1:A}$ for the F rules. These matrices are then used to generate assessment error (using the function mvr-norm) that is used to calculate predicted values of the measures used to calculate TAC (Tables 1-4 in WD2 status MSE). No autocorrelation of assessment error is included.

The most important part of the simulations is the stock - recruitment model. Deterministic values of SSB_y and $N0_y$ were generated from XSAM and used in the same way as in EQsim and described by Simmonds et al. (2011) called AIC smoothing.

$N_{2,y+2}$ used was in the beginning the same value as $N_{0,y} \times e^{-2\times 0.9}$. It turned out that this value of age 2 had to be corrected for heavy fisheries of age 0 and 1 in the fifties and sixties (age 0 and 1 are not caught today), especially on the small year classes. Age 0 for a year-class was back calculated, Popes equation from age 2 estimated from XSAM, catch in numbers and M=0.9/year. The calculations included 3 steps/year dividing the catches equally between steps. Age 2 for the stock-recruitment model was then calculated by

$$N_{2,y+2} = N_{0,y} \times e^{-1.8}$$

Autocorrelation of recruitment residuals used in the simulations was based on residuals from the fit to the data in correct order (EQSIM method).

Catches of age 0 and 1 were not included when F_{MSY} was evaluated at WKNSSHREF. Also, the number of iterations was increased from what was used at WKNSSHREF (see section 3).

For comparison, HCR simulations were also conducted with a separable (SEP) or VPA model described in WD1 and used for many Icelandic stocks. That model is a combined assessment and simulation model where parameters of the stock-recruitment function (including autocorrelation) are estimated in the assessment phase. The model is therefore in many ways different from the EQSIM/XSAM type simulation model that was the basis for the work in WKNSSHMSE.

2.1 Bias

One difference between the XSAM and SEP model was that the latter model included considerably more assessment error and biological variability was included. In the XSAM model the assessment error was based on the estimated Hessian matrix, both for the assessment year and prediction year while the CV of the assessment error in the SEP model was based on analytical retros done in 2015. The effect of those terms on estimated F_{MSY} is though small as long as bias in the assessment is not included but bias in assessment was an important topic in the 2013 HCR evaluations (ICES, 2013). 10% positive bias does simply mean 10% lower F_{MSY}.

Analysis of retrospective patterns is sometimes used to establish autocorrelation in assessment errors. For herring, the retrospective pattern is largely driven by incomplete time series (e.g. the spawning survey which is available and used in the years 1988–1989, 1994–1996, 1998–2000, 2005–2008, 2015–2018) since introduction or removal of this data source will cause the retrospective fits to shift due to the relative difference in signals on stock size compared to the other data sources. The retrospective pattern for the last 3 years is remarkably stable when data from this survey has been included. If it is assumed that all surveys will be conducted and included in the assessment in the years to come, we have little basis in the retrospective analysis to decide on autocorrelation in assessment error, except for the last years. Although a retrospective analysis based on 2015-2018 may be considered to represent too few years to conclude, it is noted that these fits indicate negligible autocorrelation in the deviations. On this basis, the autocorrelation in the XSAM model is set to 0.

In order to evaluate effects of bias on the MSE, a subset of $F_{target}/B_{trigger}$ combinations for Rules 1 and 3 was run with 10% and 15% bias, assuming that 10% bias would lead to $F_{realised} = F_{intended}*1.1$ and effective $B_{trigger} = B_{trigger}/1.1$. The HCRs were therefore run by scaling $F/HR_{targets}$ and $B_{trigger}$ by the constant bias.

2.2 Biological variability

Biological variability was not implemented in the simulations, but the effects of these parameters were investigated. Below are some results from these investigations.

There is limited amount of documented results on the mechanisms for variation in biological parameters for NSS herring. Based on the assumption that variation is stochastic and independent on other stock parameters, the effect of variation in biological parameters, values for mean stock weight, catch weight and proportion mature at age were examined by resampling respective empirical age specific mean values across years at random with replacement for the years 1988-2018. Figure 2.1 and Table 2.1 shows the effect for Rule 1 with $B_{trigger}$=3184 and F_{target}=0.157. The effect is marginal, although the risk is increased, most notably in the short term, and then the difference decreases with time. However, the difference in the medium term, were the risk is highest, is 0.006, i.e. on the third digit (Table 2.1). The effects on median recruitment, SSB and yield are relatively smaller than for risk, but variable biological parameters appear to cause marginally lower median values (Table 2.1), although the differences are hardly visible visually (Figure 2.1). The reason for the very modest effect of variability in biological parameters is because the variability is overruled by the large recruitment variability. The same result is found for the other harvest control rule (not shown). Thus, this effect is relatively smaller than other differences caused by changes in assumptions made for stock recruitment (see section 3 below) and is therefore not considered a critical factor for the evaluation.

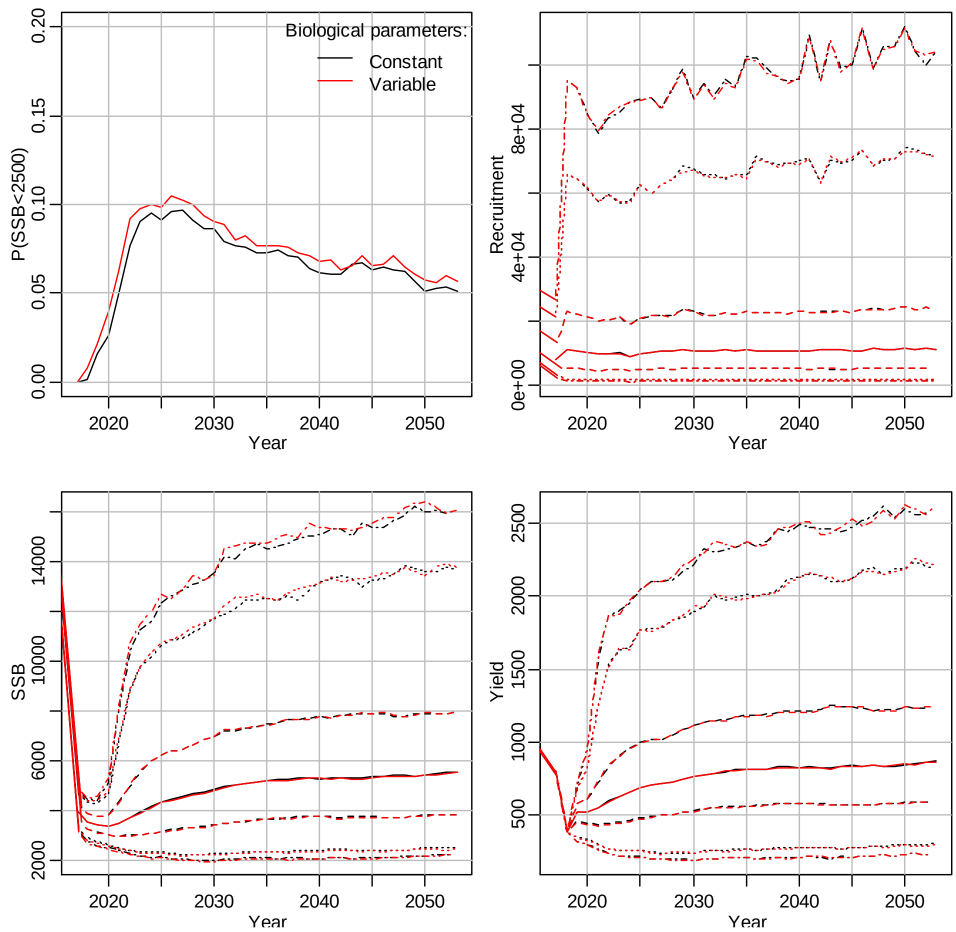

Figure 2.1. Comparing risk (P(SSB<2500)), median recruitment, SSB and yield for the years specified in the request using constant biological parameters (age specific means of stock- and catch weights and proportion mature for 1988–2017) (black lines) and variable biological parameters (red lines). Variability is obtained by resampling respective age specific values at random over years with replacement. The results are shown for harvest control rule 1 with $B_{trigger}$=3184 and F_{target}=0.157. The broken lines capture the 95%, 80% and 50% intervals of the respective distributions.

Table 2.1. Comparing risk (P(SSB<2500)), median recruitment, SSB and yield for short, medium and long term as defined by the request using constant biological parameters (age specific means of stock- and catch weights and proportion mature for 1988-2017) and variable biological parameters. Variability is obtained by resampling respective age specific values at random over years with replacement. The results are shown for harvest control rule 1 with $B_{trigger}$=3184 and F_{target}=0.157

Biological parameters	P(SSB<2500)			Median Recruitment			Median SSB			Median yield		
	Short	Med	Long	Short	Med	Long	Short	Med	Long	Short	Med	Long
Constant	0.052	0.087	0.063	10052	10413	10933	3503	4657	5326	548	738	835
Variable	0.063	0.093	0.067	10043	10384	10906	3491	4614	5300	545	736	832

3 Evaluation of new fishing mortality reference points

Since 1999 the management plan for this stock has been using F target of 0.125 and $B_{trigger}$=5 million tonnes. ICES first defined F_{MSY} for this stock in 2010, estimated as F=0.15 using stochastic simulations assuming a Beverton-Holt stock recruit relationship (ICES, 2010–WGWIDE report). Despite this, a re-evaluation of the management plan in 2013 did not lead to a change in the management plan target F. The 2013 report put considerable effort in describing bias in assessment that had been substantial (>20%) in the last 2 decades before that.

The problem of F_{MSY} and management plan was revisited in 2016 (ICES, 2016a) and again the bias problem was revisited. At that time survey 1 was introduced after being discontinued for 6 years. Re-introduction of the survey lead to upwards revision of the stock, removed part of the bias but was somewhat questionable taking into account 1 data point following 6-year time gap. Therefore, the bias problem is still an issue though it was not discussed much at the WKNSSHMSE meeting.

How well the F_{MSY} evaluations done in 2010 and 2013 match comparable work done today is difficult to say, the guidelines for evaluating F_{MSY} have evolved during that time and is now defined as the lower of F giving maximum median yield and F_{p05} with $B_{trigger}$=B_{pa}. The $B_{trigger}$ (B_{pa}) value defined at WKNSSHREF 2018 is 3184 thousand tonnes compared to 5000 thousand tonnes before that.

The F_{MSY} value of 0.15 defined in 2010 was maintained until new reference points were defined for the stock at WKNSSHREF in early 2018 (ICES, 2018). Here, F_{MSY} without precautionary constraints was found to be near the previous 0.15 value, but it was reduced to 0.102 due to the limitation of P(SSB<B_{lim}) < 5% (i.e. F_{MSY} was set as F_{p05}=0.102).

Low values of F_{p05} are inherently unstable and sensitive to small changes in input data and assumptions as they depend on low quantiles of predicted recruitment that are never reliable even when the time series is 65 year. Changes in SRR parameters, affect the results, especially the parameters σ and ϱ characterising the recruitment standard deviation and autocorrelation of the recruitment residuals, respectively. High value of σ leads to small cohorts becoming very small and difficult/impossible to satisfy SSB >B_{lim} in long periods of only small year-classes.

The same simulation framework partly based on the XSAM model that was used at WKNSSHREF has been adapted to carry out the MSE simulations for the current request (see Section 2). However, after WKNSSHREF, two changes were made:

1) Numbers at age 2 from XSAM were adjusted to account for catches at ages 0 and 1. (see section 2).

2) Numerical stability in the simulations was improved by increasing the number of iterations in the simulation.

Adjusting the numbers at age 2 (*N*2) in this way resulted in a proportionally significant increase in the very low recruitment values seen at SSB>B_{lim} during the period before the collapse (Figure 3.1). A targeted fishery on these age groups has not occurred after the collapse due to minimum landing size being established. Overall the corrected values of *N*2 result in higher mean recruitment with less variability, particularly for high values of SSB. This leads to a reduction in the proportion of Ricker models and an increase in the proportion of Beverton-Holt models when using the model averaging based on AIC (Table 3.1).

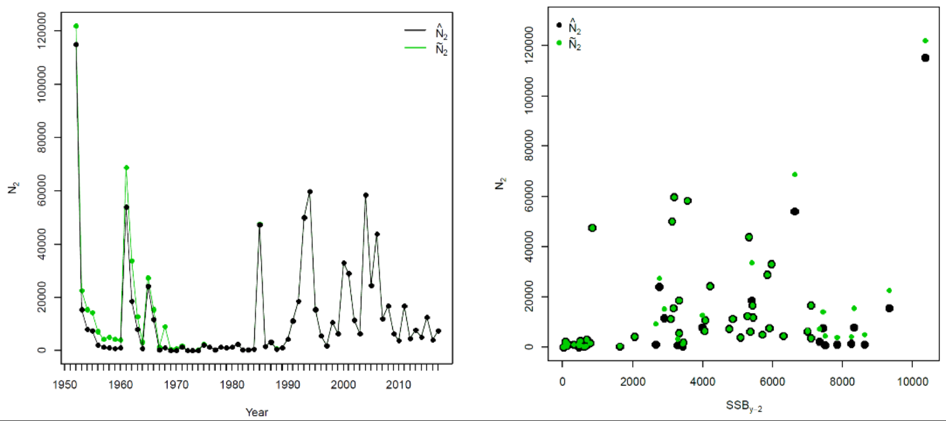

Figure 3.1. LEFT: Numbers at age 2 in the time period 1952-2017. RIGHT: Spawning stock versus recruits at age 2. The black dots are the estimated numbers by the XSAM fit to the data for 1950-2017, while the green dots are the same numbers corrected for the number of 0 and 1 that were fished.

Table 3.1. Percentage of type of recruitment model with lowest AIC based on 5000 resamples of pairs of stock recruitment.

DATA	BEVERTON HOLT	HOCKEY STICK	RICKER
$\hat{N}$ 2	43	25	32
$\tilde{N}$ 2	61	25	14

The procedure for evaluating F_{MSY} is identical to the procedure used to evaluate Harvest Rule 1 in the request when $B_{trigger}$=B_{pa} and no stabiliser is used. The only difference is that the F_{MSY} calculations are based on really long term (equilibrium) while the management plan evaluations end in 2053.

3.1 Further evaluation of numerical instability.

The initial MSE analysis (without the corrected numbers at age 2) using HCRs with F_{target} close to $F_{P0.5}$=0.102 gave higher risks than anticipated. Therefore, it was necessary to revisit the analysis and results made at WKNSSHREF. The issue appeared to be numerical instability due to too few resamples.

At WKNSSHREF 1000 resamples of parameters (stock recruitment) were used and each HCR was simulated for 500 years, discarding the first 250 to ensure the process had reached equilibrium. A test was made to ensure numerical stability of the results, but it turned out that an error with the use of random seeds shortened the time effective time span of the time series used (the seed was set to equal values in a sequence within each time series). Effectively, the results became independent of the changes made in number of resamples and number of years, and this potential problem was thus not discovered.

Increasing the number of iterations to 2000 appears sufficient for numerical stability of statistics for short, medium and long term (Figure 3.1.1), whilst also maintaining the distribution of recruitment models used for the AIC smoothing.

To be able to finally conclude on the third digit in the estimates of F targets, it may be necessary with more simulations (increasing number of resamples as well as increasing the length of the time series beyond 500 time steps). Since this is computer intensive and require relative much storage place and memory the time constraints have restricted this task. On the other hand, precision at the level of third digit of F_{P05} is much less troublesome than any other assumption made about e.g. biological parameters (weights, proportion mature and natural mortality at age) and is an argument for reducing number of digits. It should be noted that the most troublesome statistic to estimate with numerical stability is risk factors such as low values of P(B<Blim) or in other words the F_{P05} (Figure 3.1.1, top left).

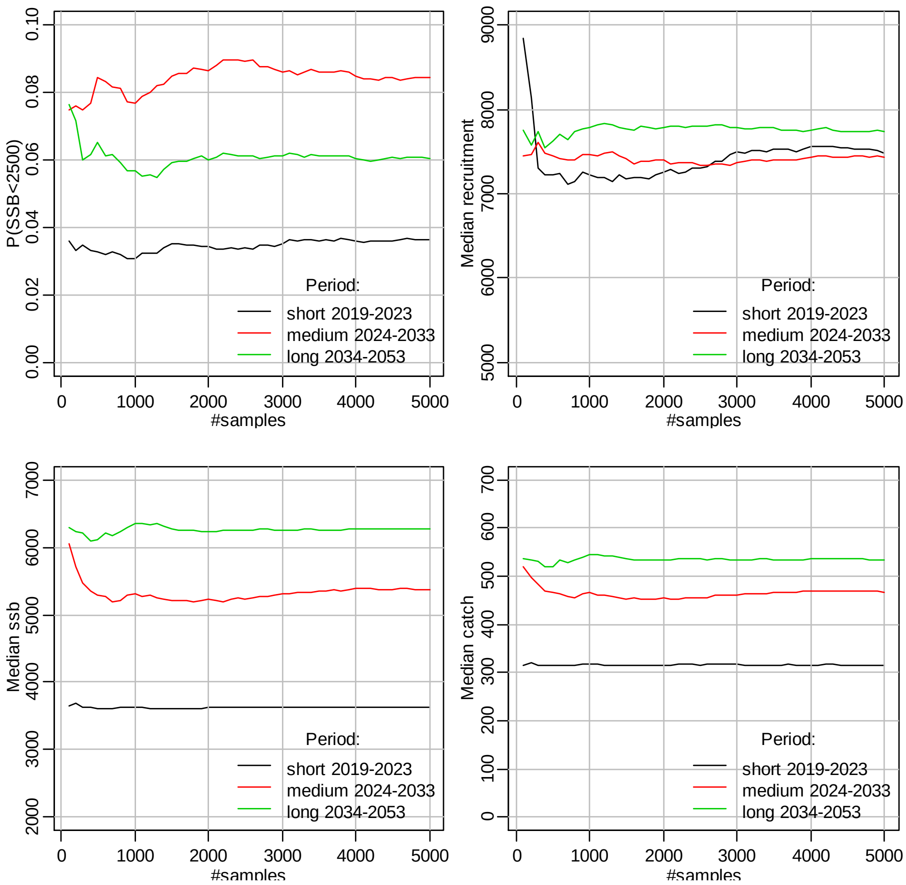

Figure 3.1.1. The impact of number of iterations run on the estimates of the probability of SSB<2500 (top left), median recruitment (top right), SSB (bottom left) and catch (bottom right) for short (black lines), medium (red lines) and long (green lines) term. The HCR used in this example correspond to rule 1 with F_{target}=0.1 and $B_{trigger}$=3184.

3.2 New reference points

Based on the two changes described above, the reference point analyses conducted at WKNSSHREF were updated, keeping all other assumptions and inputs the same as were used at WKNSSHREF.

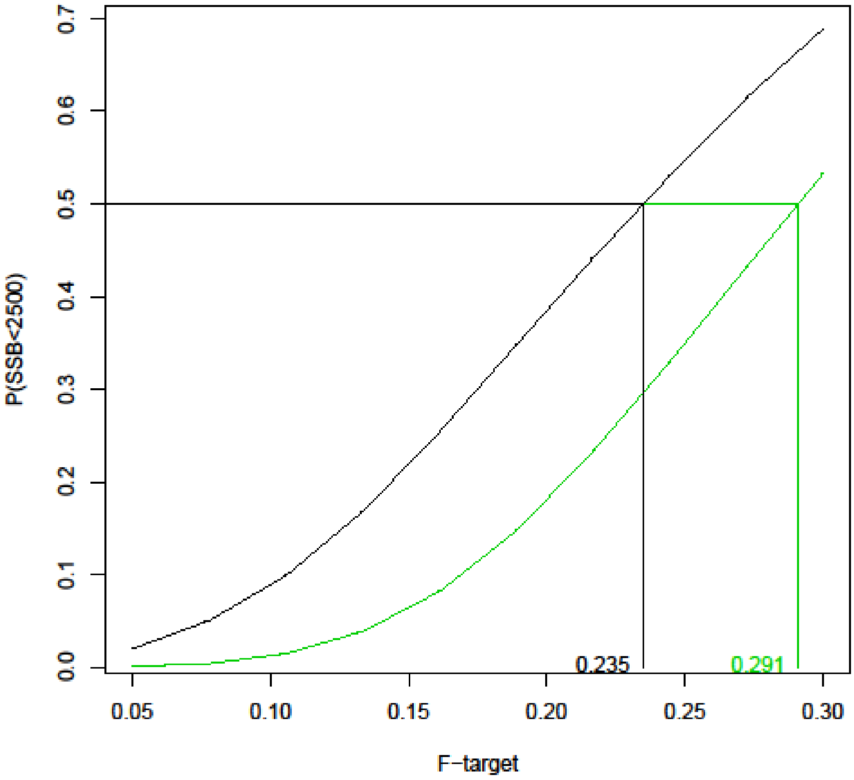

Figure 3.2.1.F_{lim} using corrected N2 (left). Comparing F_{lim} using uncorrected N2 (black) and corrected N2 (green).

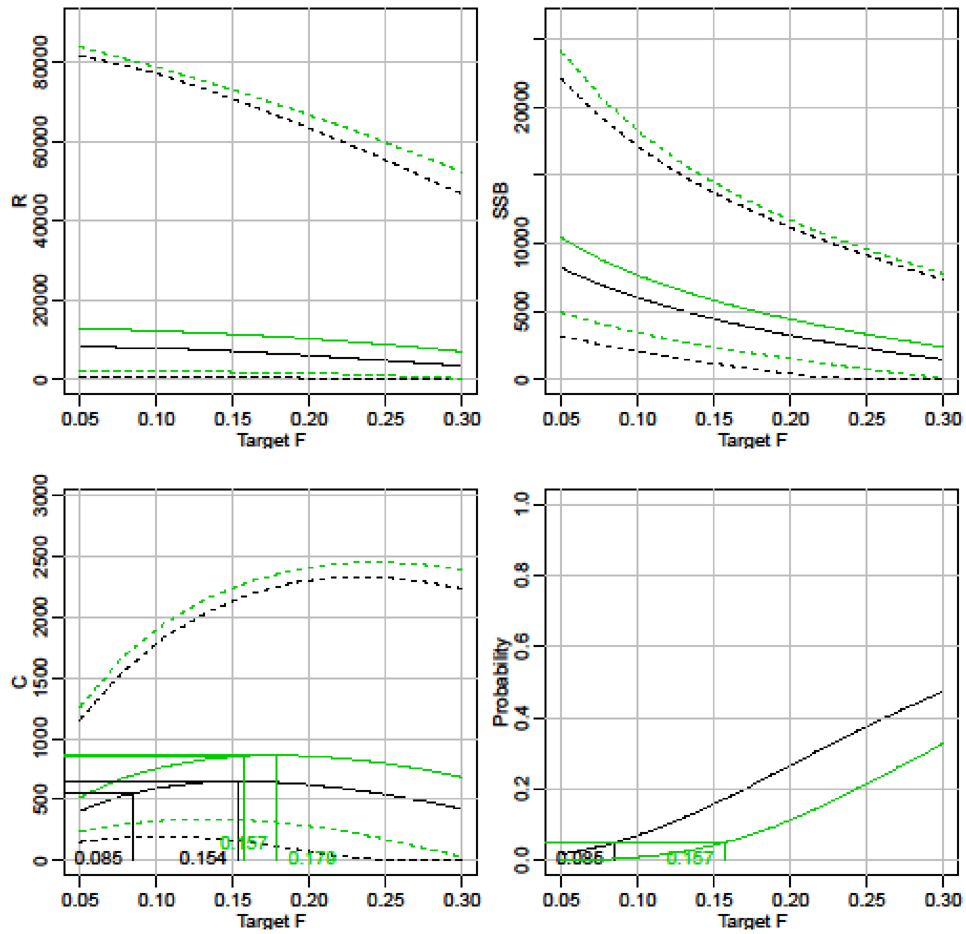

Figure 3.2.2.Comparing summary plot for F_{p05} and F_{MSY} points using corrected N2 (green lines) with using uncorrected N2 values (black lines).

The inclusion of the catches at ages 0 and 1 have a large impact on our estimates of F_{p05}, and therefore F_{MSY} (Table 3.2.1 and Figures 3.2.1 and 3.2.2). This is mainly through the impact on the average size of small year classes, rather than changes in the magnitude of large year classes. Small year classes are predicted to be larger on the average, decreasing the probability of SSB<B_{lim} in periods where all year-classes are small.

Table 3.2.1. Final estimated reference points for NSSH. Weights in million t, mean F for ages 5–12.

Reference points.	MSY $B_{TRIGGER}$	BPA	B_{LIM}	FPA	FLIM	Unconstrained F_{MSY}	F_{P05}	F_{MSY}
WKNSSHREF value	3.184	3.184	2.500	0.182	0.234	0.152	0.102	0.102
WKNSSHREF value) (uncorrected N2)	3.184	3.184	2.500	0.183	0.235	0.154	0.085	0.085
WKNSSHMSE value (XSAM)	3.184	3.184	2.500	0.227	0.291	0.179	0.157	0.157

3.3 Conclusion

The current analyses indicate that F_{MSY}(0.157, Table 3.2.1) is higher than the value that was estimated at WKNSSHREF.

Similar analyses on a different platform (using a separable model, results not shown – but presented in WD 1) show similar behaviour when accounting for the catches at age 0 and 1.

The new values are considered by WKNSSHMSE to be more appropriate, both in terms of the adjusted SR pairs and the improved numerical stability gained through using more iterations.

The WKNSSHREF reference points have not yet been used in advice for this stock but were used by the Coastal States as a basis to formulate the current HCR options being evaluated in this request.

In reference point analyses the assumptions we make have a big impact on the results we obtain. The estimate of F_{p05} is sensitive to how the spawning stock – recruitment relationship is modelled and can be anywhere between 0.1 and 0.15 depending on inputs used and assumptions made.

Bias in assessment has been a problem in the past but did not get much attention at the WKNSSHMSE meeting. This is though not an indication that the problem has disappeared.

The comparative analyses with SCA platform together with the XSAM analyses suggest that the input scenario with no catch for ages 0 and 1 leads to an outlier value of F_{MSY} among the other scenarios (WD 1). The current management plan target of 0.125, which has been used for nearly two decades without driving the stock below B_{lim} still seems appropriate given this reference point estimation uncertainty.

3.3.1 Proposed F_{MSY} in context to estimates from separable model and current F_{target}

ICES procedures for evaluating F_{MSY} do not seem to include much about basing results on more than one model/number of settings, something that is necessary for increasing reliability of the work. The range of plausible F_{MSY} values presented at the WKNSSHMSE is between 0.100–0.157. Evaluations of the management plan based on the settings that give F_{MSY} = 0.157 also leads to F_{target} ≈ 0.120 based on type III risk (maximum in a year) and 0.124 based on medium term (2023–2032). These values lie in the middle of plausible values according to the simulations by WKNSSHMSE and almost identical to the F_{target} used since 1999.

3.3.2 Recommendation

If rules 3 or 4 will be selected as the basis for advice HR_{MSY} should be defined instead of F_{MSY}.

WKNSSHMSE proposes that the new fishing mortality reference point estimates from this workshop should replace those established at WKNSSHREF. Not changing them would lead to inconsistencies between the MSE simulations and the ICES reference points. While changing them so soon after issuing advice with new reference points is not ideal, it reflects the reality of how uncertain estimates of these reference points are.

4 Full set of MSE results

This section presents a selection of results for the configuration selected to form the basis of the MSE.

Although harvest proportions is the correct term to describe fishing mortality in the biomass rules, in this section the term harvest rates (HR) has been used to comply with the nomenclature in the request.

When comparing the four different Rules, $B_{trigger}$ = 3184 was used, and when comparing different $B_{trigger}$ and/or values of F_{target}, Rule 1 was used. The reason for presenting rule 1 was that it has the form of the standard ICES MSY rule with F = 0 when SSB = 0. Some of the figures have been based on F_{target}= 0.125. This may be confusing, since this is neither the new F_{MSY} nor the requested special case. The main reasons are, that the simulations were made before the discussions on F_{MSY} were finalised and F_{MSY} was not among the simulated $F_{targets}$. It is still possible to make general conclusions about the HCRs with and without catch constraints based on F_{target} = 0.125.

In some figures, F-rules and biomass rules are presented in the same plot-area. F_{target} and HR_{target} cannot be directly compared, and therefore the biomass rules have in most of these figures been presented based on the median F_{bar} obtained for a given HR_{target}.

The simulations were conducted with F-values ranging from 0.10 to 0.20 with increments in F being 0.01 or 0.02. In order to answer the Request with regards to F_{MSY} (0.102 in Request and 0.157 after re-estimating F_{MSY}), F_{target} = 0.102 and F_{target} = 0.157 have been added to the tables based on splining (non-linear interpolation).

The main findings from the MSE are presented in section 5.

4.1 Scenarios evaluated and performance statistics

There were four different rules to test, and they are illustrated graphically in section 1 and given in full in Annex 1.

The Harvest Control Rules (HCRs) were evaluated under a range of $B_{trigger}$ values and target Fs/target HRs, as indicated in the Request, although both ranges have been narrowed, such that $B_{trigger}$ ranges from 2.5 to 5 million tonnes and F_{target} ranges from 0.10 to 0.20 and HR_{target} from 0.07 to 0.15.

As described in the introduction, there was not enough time for the group to investigate all scenarios for all rules. Two sets of constraints of inter-annual variation of TAC were applied to two of the rules – the F- and HR-rule going through 0,0. Simulations with banking and borrowing were also requested, but these were not conducted due to time limitations.

Table 4.1 below describes the simulated rules.

Abbreviation	Description of Rules
HCRr1	F-rule going through 0,0
HCRr1CC1 or Rule 1 – Type 1	F-rule with TAC-constraint average of TAC in current and TAC-year
HCRr1CC2 or Rule 1 – Type 2	F-rule with TAC-constraint +25%/-20% between current and TAC-year
HCRr2	F-rule with F_{min} = 0.05
HCRr3	Biomass-rule going through 0,0
HCRr3CC1 or Rule 3 – Type 1	Biomass-rule with TAC-constraint average of TAC in current and TAC-year
HCRr3CC2 or Rule 3 – Type 2	Biomass-rule with TAC-constraint +25%/-20% between current and TAC-year
HCRr4	Biomass rule with HR_{min} = 0.05

The following time periods were considered in the evaluation, as requested:

- Short term: 2019–2023 (short-term years stated in the request)
- Medium term: 2024–2033 (medium-term years stated in the request)
- Long term: 2034–2053 (long-term years stated in the request) *

  * This long term is, however, not the near-equilibrium long term.

4.1.1 P(SSB<B_{lim})

According to the ICES guidelines, an HCR is considered precautionary if the maximum of the annual risks (P(SSB<B_{lim})) is ≤5%.

- The P(SSB<B_{lim}) was calculated as the proportion of the 3000 iterations in the simulation for which SSB was <B_{lim} for each year individually. Prob3 was then calculated as the maximum probability of being below B_{lim} in the short, medium and long term.
- The P(SSB<B_{lim}) was also calculated as the proportion of the 3000 iterations in the simulation for which SSB was <B_{lim} (*Prob1*) This was done for the short, medium and long term. These tables are not shown.
- In some of the figures P(SSB <B_{lim}) is presented as the annual risk of SSB <B_{lim}.

4.1.2 Median Yield and Median SSB

For each period of years in the short, medium and long term, the median was taken over the years in that period and the iterations (3000) in the simulation. In some of the figures median yield and SSB have been presented as annual values.

4.1.3 Indicator for inter-annual variability of Yield and SSB

For each year and iteration in the simulation, the Inter-Annual Variability (IAV) statis-tic for

$$iav_y = \text{abs}(\frac{C_{y+1} - C_y}{C_y})x100$$

Where C_y is catch in the year y. Inter-annual variability can in the same way be found for other metrics than catch, and was also calculated for SSB.

The median was then taken over the years in the short, medium and long term and the iterations (3000) in the simulation. In some of the figures median inter-annual variability in yield has been presented as annual values.

4.1.4 Realised F

In the Request, it is stated that "ICES is also requested to assess what, if any, other measures in addition to those contained in the present Management Strategy might contribute to attaining the objectives of the strategy, and provide estimates of their efficiency".

The TAC constraints being tested will lead to median realized fishing mortality being different from target fishing mortality. In order to better illustrate how the TAC constraint will affect the fishing mortality of the different rules, it was decided to present realised fishing mortality for all rules. This makes it also easier to compare the biomass rules to the F rules.

4.1.5 Comparison of the main model with a separable model

The main results of this report have been cross-validated by running similar scenarios with another model. The main results of these comparisons are given in section 4.2.5.

4.1.6 Comparison of MSE simulations with historical stock trend

The Rule 1 scenario for $B_{trigger}$ = 3184 thousand tonnes and F_{target} = 0.125 have been combined with the assessment results for 2017 to show how the simulation behave compared with the historical pattern.

4.1.7 Bias

For evaluating the effect of bias on the MSE, two of the Rules (Rule 1 and Rule 3) were run with 10% and 15% bias for a subset of the F/HP_{target},$B_{trigger}$ combinations. Bias was assumed to overestimate SSB and underestimate F as described in section 2.1.

4.2 MSE results

Most results are presented in this result section, but the tables are listed in Annex 3.

Four summary tables are presented below (Tables 4.2.1–4.2.4) showing the F/HR on the margin of being precautionary for different rules and value of different metrics at this value. Tables 4.2.1 and 4.2.2 are based on maximum risk per year and lead to lower F_{p05} and HRp05 than the results given in tables 4.2.3 and 4.2.4 that are based on average risk in medium term (2023–2032). The highest risk for an individual year is in 2023 and will then be conclusive when type III risk is used. The request is on the other hand based on medium term risk and leads to little lower F_{p05}.

Table 4.2.1.F_{p05} for the F rules based on risk< 5% (Risk 3). 5 different metrics when fishing at the value of F shown with $B_{trigger}$=3184 thousand tonnes.

STABILISER RULE	F_{P05}	MEDTERM CATCH	LONGTERM CATCH	LONGTERM C05	IAV MEDIAN	IAV 90%
none-Rule1	0.119	640	758	285	18.0	48.2
Avg-Rule1	0.121	651	779	280	10.0	31.1
%-Rule1	0.121	628	761	283	19.1	25.0
none-Rule2	0.146	716	818	185	20.0	63.8

Table 4.2.2.HR$_{p05}$ for the biomass rules based on risk< 5% (Risk 3). 5 different metrics when fishing at the value of HR shown with B$_{trigger}$=3184 thousand tonnes.

STABILISER RULE	HR05	MEDTERM CATCH	LONGTERM CATCH	LONGTERM C05	IAV MEDIAN	IAV 90%
none-Rule3	0.097	616	746	287	9.8	26.8
Avg-Rule3	0.096	603	751	272	7.5	21.5
%-Rule3	0.097	599	737	288	11.0	25.0
none-Rule4	0.107	658	782	222	10.5	34.3

Table 4.2.3. F$_{p05}$ for the F rules based on risk< 5% in medium term. 5 different metrics when fishing at the value of F shown with B$_{trigger}$= 3184 thousand tonnes.

STABILISER RULE	F$_{P05}$	MEDTERM CATCH	LONGTERM CATCH	LONGTERM C05	IAV MEDIAN	IAV 90%
none-Rule1	0.124	653	769	282	18.2	48.9
Avg-Rule1	0.127	669	793	277	10.2	32.5
%-Rule1	0.127	645	775	280	19.5	25
none-Rule2	0.158	742	837	156	20.8	68.9

Table 4.2.4. HRp05 for the biomass rules based on risk< 5% in medium term. 5 different metrics when fishing at the value of HR shown with B$_{trigger}$= 3184 thousand tonnes.

STABILISER RULE	HR$_{P05}$	MEDTERM CATCH	LONGTERM CATCH	LONGTERM C05	IAV MEDIAN	IAV 90%
none-Rule3	0.102	633	760	281	10	27.8
Avg-Rule3	0.101	625	768	267	7.8	22.6
%-Rule3	0.102	617	752	283	11.3	25
none-Rule4	0.116	687	804	192	11	37.9

Figure 4.2.1 shows the trajectory of SSB in Rule 1 based on 3000 simulations together with one randomly selected individual run. B$_{lim}$ (2.5 million tonnes) is illustrated as a horizontal line, whereas the medium term period (2024-2033) is illustrated as two black vertical lines. The NSS herring stock has been decreasing over nearly a decade. In the medium term the simulations predict a gradual recovery of the SSB, but the range in individual runs is large with resulting wide confidence limits around the estimate. Due to this, it is understandable that the risk of SSB falling below B$_{lim}$ in the medium term is larger than in the short and long term.

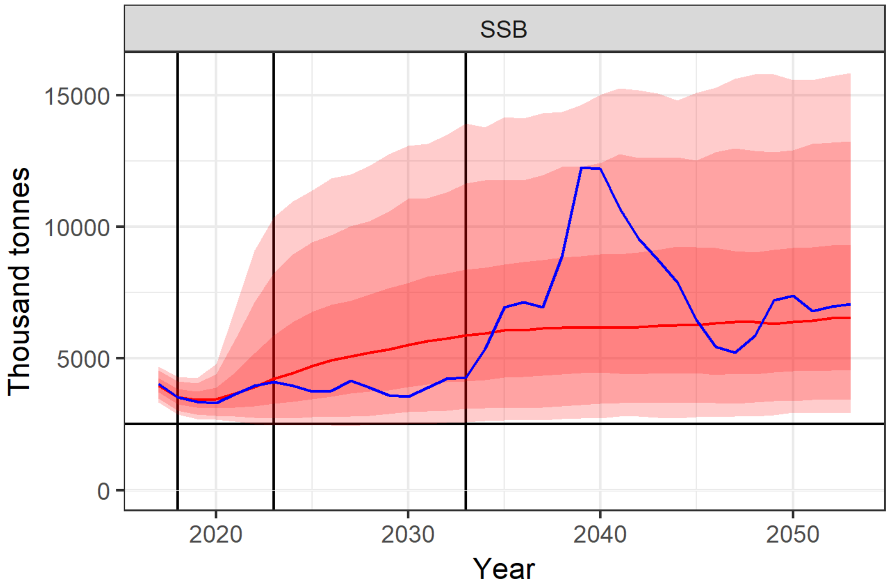

Figure 4.2.1.Example of simulated SSB in the simulation period (vertical lines separate short term 2019-2023, medium term 2024-2033, and long term 2034-2053) as simulated with Rule 1 with $B_{trigger}$ = 3184 and F_{target} = 0.125.

4.2.1 P(SSB <Blim)

Comparing short, medium and long term tables, for the HCRs without a TAC constraint, a main message is that, for any given (F_{target}, $B_{trigger}$) combination, the P(SSB<B_{lim}) is largest for the medium term for all rules (Tables A.3.1 and A.3.2). This is as expected given the current low stock size. For ICES to consider an HCR precautionary, this probability should be ≤5% in all time periods and really in all years. This means that the table for the medium term is the relevant table to examine for determining if an HCR is precautionary.

From examination of the medium term, tables for all rules in Tables A.3.1 and A.3.2, it is clear that there is a “diagonal” borderline in the table for the 5% risk, whereby larger values of F_{target} are associated with larger values of $B_{trigger}$.

In general, the rules going through 0,0 appear to have higher risks than the rules with F_{min}/HR_{min}. And in general, there is little difference in risk of falling below B_{lim} between the rules with and without constraints in inter-annual TAC change.

It may appear contradictory that F_{MSY} is not precautionary in the Rule 1 scenario of the MSE at MSY $B_{trigger}$. This is probably mainly because the simulations have not reached equilibrium in the long term defined in the request.

Figure 4.2.1.1 displays the P(SSB<B_{lim}) in the medium term for all rules. For Rule 1 the risk is slightly lower when the TAC-constraints are applied, but for Rule 3 there is barely any difference between the runs with and without TAC-constraints. The rules with F_{min}/HR_{min} are associated with lower risks most likely because these rules have a steeper reduction of F below $B_{trigger}$.

The effects of the TAC constraint are not necessarily easy to anticipate, but it should be born in mind that the constraint only applies when SSB is forecast to be above $B_{trigger}$, and this may be part of the reason why it results in some reduction of risk.

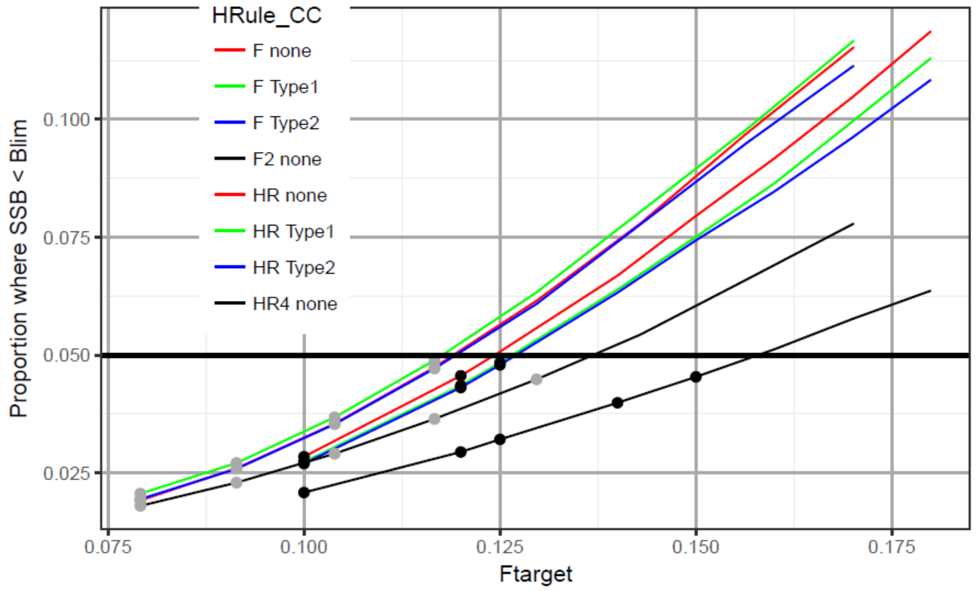

Figure 4.2.1.1.Risk, P(SSB<B_{lim}), expressed as proportion for F and biomass rules in the medium term. The points are the precautionary options – grey points are biomass rules and black points are F-rules. F is not a target in the biomass rule but rather median F obtained for a given HR_{target}. Rules 2 and 4 are without catch constraint.

4.2.2 Yield and SSB

Table A.3.3 shows the median yield for the F-rules with and without TAC-constraints and Table A.3.4 shows the median yield for biomass rules without and with TAC-constraint. The green colours identify the (F_{target}, $B_{trigger}$) combinations that correspond to yield that is ≥95% of the maximum yield among the precautionary (F_{target}, $B_{trigger}$) combinations. In general, high F_{target} – high $B_{trigger}$ combinations give the highest yield. At the highest fishing targets the rules going through 0,0 and the TAC-constraint with 25/20% give lower yield than the other options. Yield is also graphically presented in Figures 4.2.2.1 and 4.2.2.2.

Median SSB is shown in Tables A.3.5 and A.3.6. In the short term, there is little variability in realised SSB, but in the medium and long term realised SSB is highest for the lowest F/$HR_{targets}$, whereas SSB does not vary as much with increasing $B_{trigger}$.

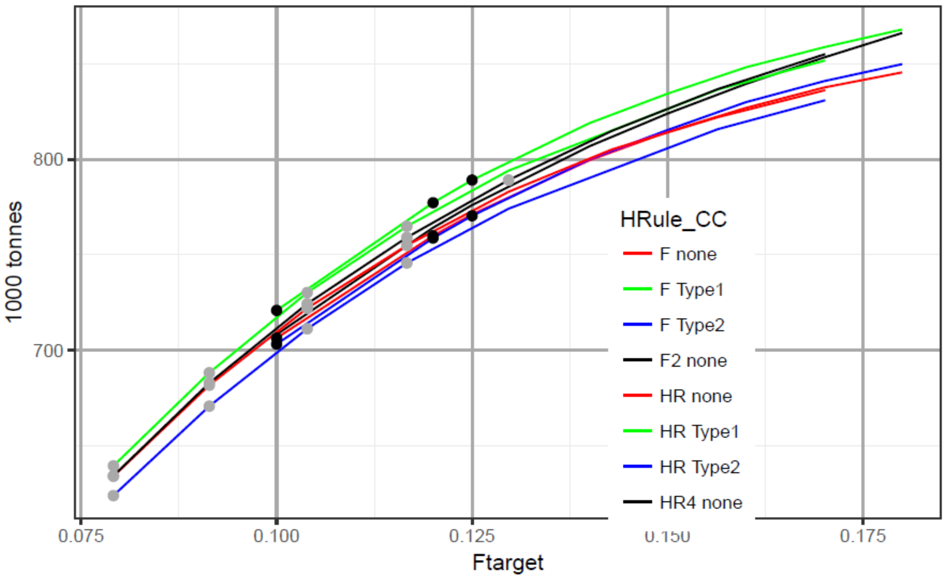

Figure 4.2.2.1. Median Yield (kt) vs. Ftarget in the medium term for all rules without and with constraint. The points are the precautionary options – grey points are biomass rules and black points are F-rules. F is not a target in the biomass rule but rather median F obtained for a given HR_{target}. Rules 2 and 4 are without catch constraint.

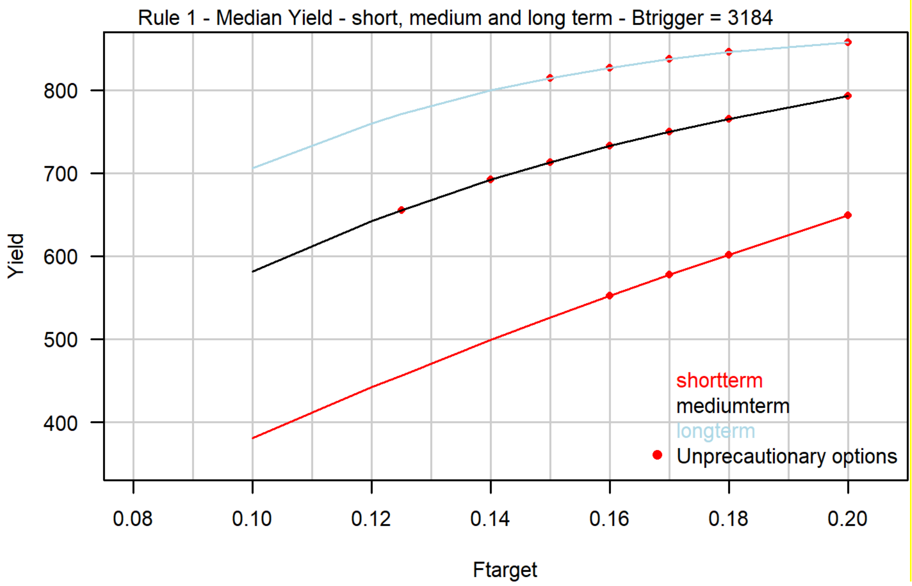

Figure 4.2.2.2. Median Yield (kt) vs. F_{target} for F-rules in the short medium and long term.

4.2.3 Interannual variability in yield and SSB

Increasing the F_{target} or the $B_{trigger}$ in the HCR leads to increased inter-annual variability (IAV, defined here as % change between any two consecutive years; see formula in subsection 4.1.3) in yield. When no TAC constraint is included on F-rules, the interannual variability (median value across years and iterations) ranges from about 17% for (low F_{target}, low $B_{trigger}$) combinations to about 30% for (high F_{target}, high $B_{trigger}$) precautionary combinations (Table A.3.7). When an averaging TAC constraint is included, the range is approximately 9%–18% and when a +25%/-20% TAC constraint was included the range was 19%-25%. For the biomass rules (Table A.3.8), the variability for rules without TAC-constraint varied between 8% and 16%, for averaging TAC-constraint the variability was 6%-12% and for the +25%/-20% TAC constraint the variability was 10%-17%.

Increasing F_{target} lead to increased inter-annual variability in SSB, whereas increasing $B_{trigger}$ lead to decreased variability (Tables A.3.9 and A.3.10). The inter-annual variability in SSB was less than in yield, though.

A graphical illustration of median inter-annual variability is provided for $B_{trigger}$= 3184 in Figure 4.2.3.1.

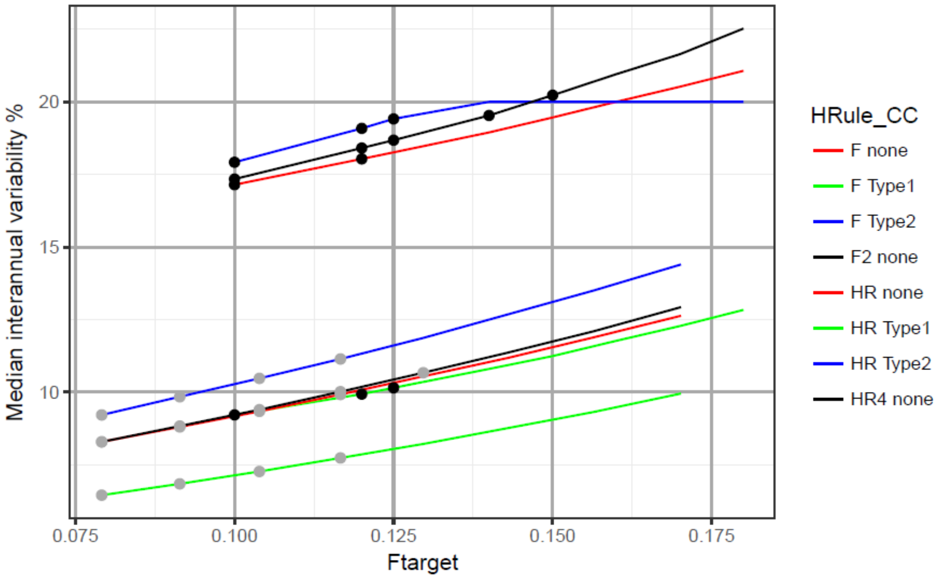

Figure 4.2.3.1. Median of the IAV in Yield vs. fishing mortality, in the medium term, without and with constraint. The points are the precautionary options – grey points are biomass rules and black points are F-rules. F is not a target in the biomass rule but rather median F obtained for a given HRtarget. Rules 2 and 4 are without catch constraint.

As Figures 4.2.3.2, 4.2.3.3 and 4.2.3.4 illustrate, for any given (F_{target}, $B_{trigger}$) combination, there is a wide range of yield and inter-annual yield variability values that may occur in the future. This means that future values of yield could be quite different from the medians reported in Tables A.3.3-A.3.4. The range of possible future values widens as the F target increases. For inter-annual yield variability (Figure 4.2.3.1) the range widens considerably with increases in either the F target or the $B_{trigger}$, and inter-annual yield variability values that are much higher than the medians reported in the tables cannot be ruled out in those cases.

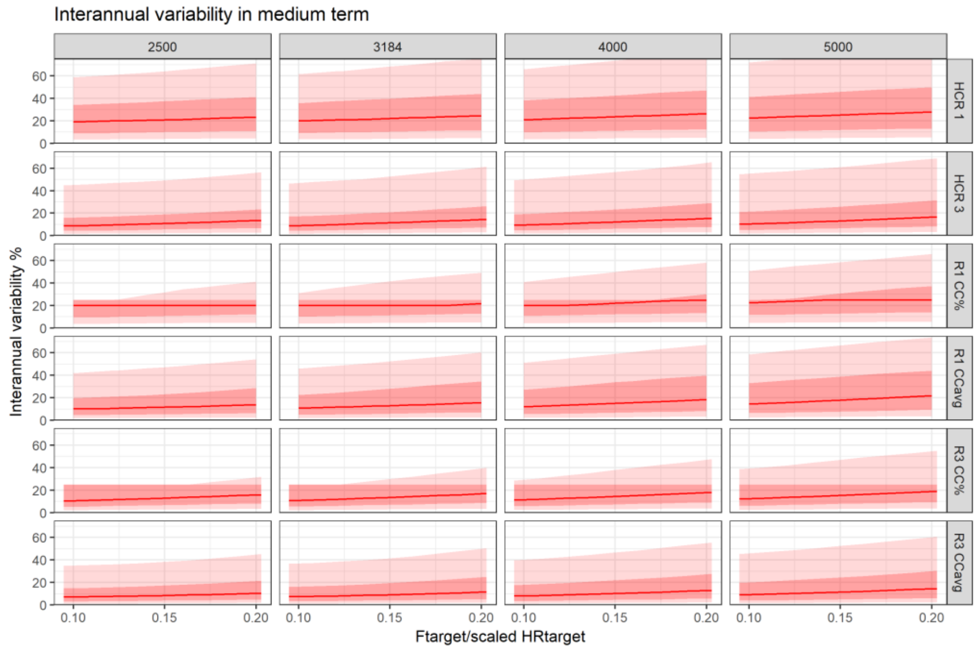

Figure 4.2.3.2.Interannual variability in medium term yield versus F_{target} for rules without and with TAC constraint. From left to right, the panels correspond to $B_{trigger}$ = 2.5, 3.184, 4 and 5 million t. The figures show the 5th, 25th, 50th, 75th and 95th percentiles of the medium term distribution. (Caution: HR_{target} not scaled precisely to F_{target}.)

Figures 4.2.3.3–4.2.3.4show the simulated distribution of SSB, catch (i.e. yield), Fbar, and the P(SSB<B_{lim}), for years 2019–2053, for $B_{trigger}$ = 3184, without or with the constraint on inter-annual TAC change. The panels corresponding to the realised SSB, catch and F_{bar} show percentiles of the simulated distribution. The range of variation covered by the 3000 iterations in the simulation, which results from the combination of the uncertainty in the assessment / forecast and the natural variability of the herring stock, is very large, as depicted by the shaded transparent areas in the figures. Therefore, the stock may follow a trajectory very different from the one represented by the median, as illustrated by the randomly selected trajectory of a single iteration (Figures 4.2.1 and 4.2.6.1).

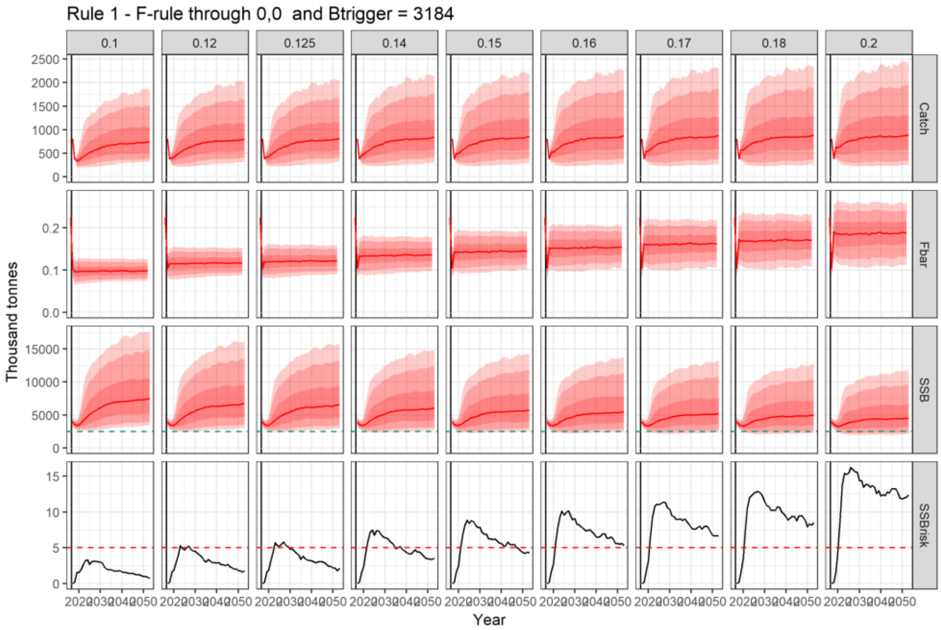

Figure 4.2.3.3. Simulation results for 2019–2053, for Rule 1 with Btrigger = 3184 kt and without constraint in interannual TAC change. Each column corresponds to the F_{target} value indicated in the column's heading. The top three rows correspond to the realised SSB (horizontal green line is B_{lim}), Catch and F_{bar}(ages 4–8), and show the 5th, 25th, 50th, 75th and 95th percentiles of their distribution. The bottom row shows the P(SSB<B_{lim}), with the horizontal red line at 5 (i.e. 5%).

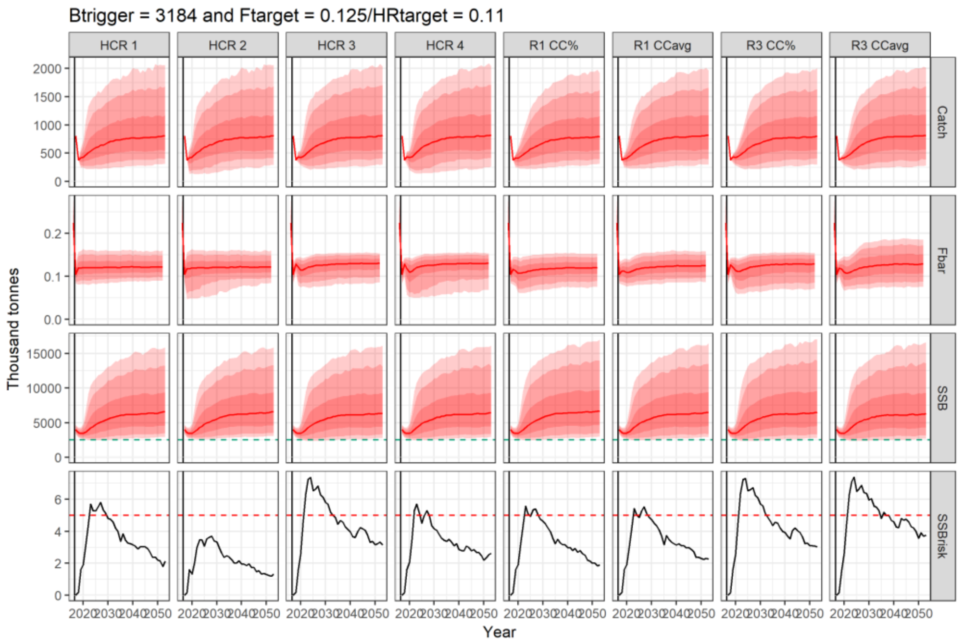

Figure 4.2.3.4. Simulation results for 2019-2053, for all tested rules without and with constraint in interannual TAC change. Each column corresponds to the rules. The four rows correspond to the realised Catch,F_{bar}(ages 5-12), SSB and p(SSB<B_{lim}), and show the 5th, 25th, 50th, 75th and 95th percentiles of their distribution. (Caution: HR_{target}= 0.11 is not equal to F_{target} = 0.125.)

4.2.4 Realised F

Table A.3.11 shows realised F in the medium term for all rules. Note, that also for the biomass rules these tables are expressed as median F. In general, F decreases as $B_{trigger}$ increases. Figure 4.2.4.1 summarises this information for $B_{trigger}$ = 3184 kt. Figure 4.2.4.2 illustrates the distribution of Fs for the F-rules with and without TAC-constraints. The TAC-constraint with +25%/-20% leads to a relatively higher frequency of lower F as compared to the non-constrained scenario or constrained by averaging between current and TAC-year. The reason for this low tail is that the constraint is switched off when the stock is perceived to be below $B_{trigger}$.

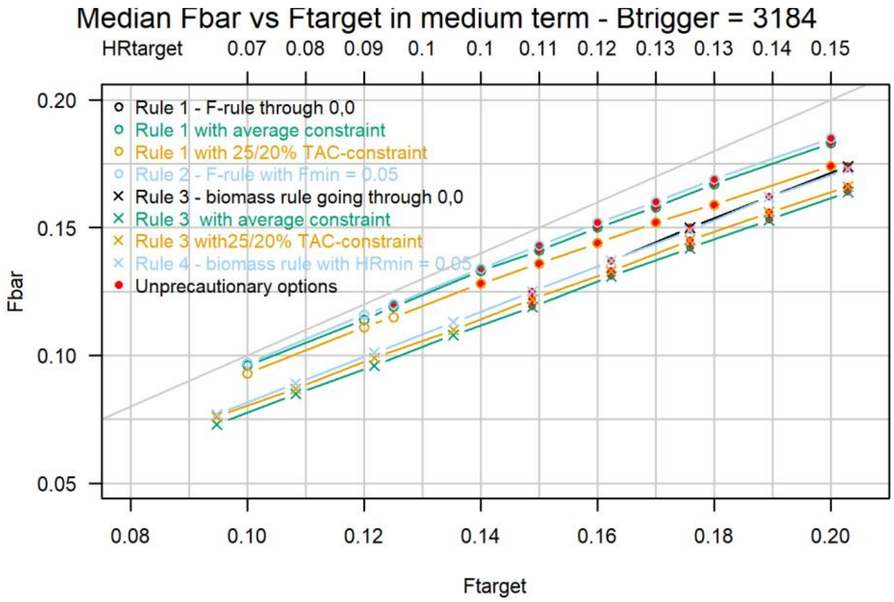

Figure 4.2.4.1.Median of the real Fvs.F_{target}/HR_{target}, in the medium term, without and with constraint. The figure is with $B_{trigger}$= 3184 kt. (Caution: HR_{target} not scaled precisely to F_{target}.)

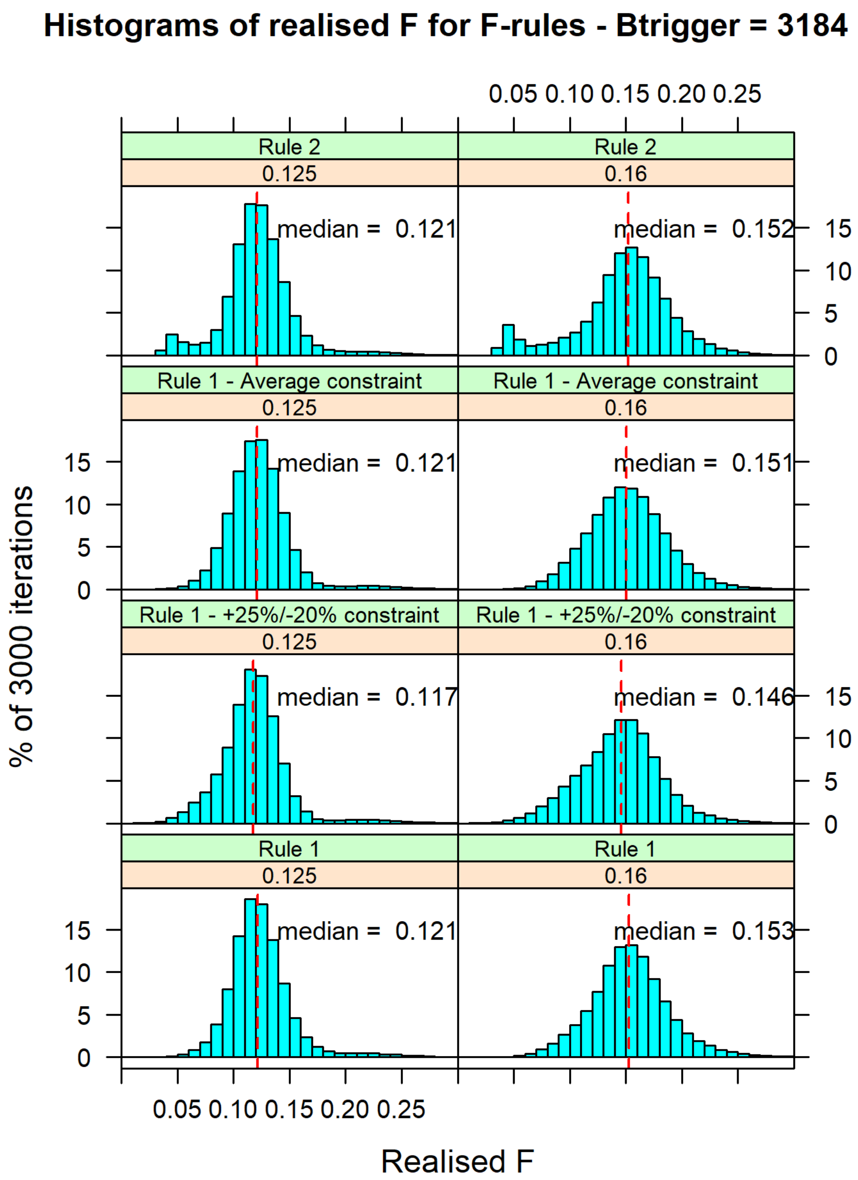

Figure 4.2.4.2.Histograms of realised Fs for F-rules for $B_{trigger}$ = 3184 (kt) and F_{target} = 0.125 and 0.16.

4.2.5 Comparisons with a separable model

The 2 models XSAM and the separable model operate in considerably different ways (section 2). Comparing median catch and SSB shows very similar results for both models (Figure 15, WD 1). Looking at the lower quantiles of SSB and catch XSAM shows higher values. This difference is driven by recruitment, which was more variable in the separable model. Checking the results against "reality" the median recruitment since 1950 in years where SSB > 2.5 million tonnes was 10.2 milliard herring at age 2 and the lower quantile 1.6 milliard. The predicted numbers are lower but though similar. Higher variability in recruitment when spawning stock is low might affect CV of recruitment. The XSAM numbers show less variability than indicated in the separable model assessment. They are based on XSAM stock assessment that could be somewhat different, especially with regard to the small cohort. When looking at the so called "reality" it must be kept in mind that the years where SSB > 2500 are only 47, rather few years for a reliable fifth percent quantile. The "truth" is somewhere between the red and blue lines, but it must be remembered that XSAM was fitted to a different "truth".

The two harvest control rules F rule and biomass rule (HR) give similar results for both models (Figure 4.2.5.1). Fishing mortality is of course not the key parameter in the biomass rule but can be derived from the results, so the plots become comparable. The results indicate that the harvest control rules perform equally well in terms of the metrics shown in the figure.

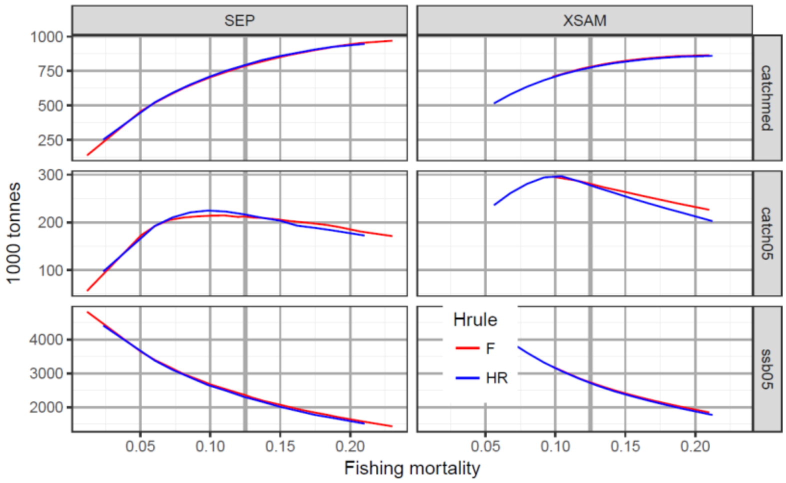

Figure 4.2.5.1.Comparison between two models (separable model and XSAM) and between F-rules and biomass rules.

4.2.5.1 Conclusions regarding comparison between the two models

Although there were some differences between the main model used in the MSE and the separable model it was compared to, most of the comparisons gave similar results. This was especially true in relative terms between results from different harvest rules using the same model; the SEP model did though usually give lower precautionary fishing mortality. The group concluded that there was no reason to believe that the configuration of the XSAM software was wrong.

4.2.6 Extending back in time with latest assessment

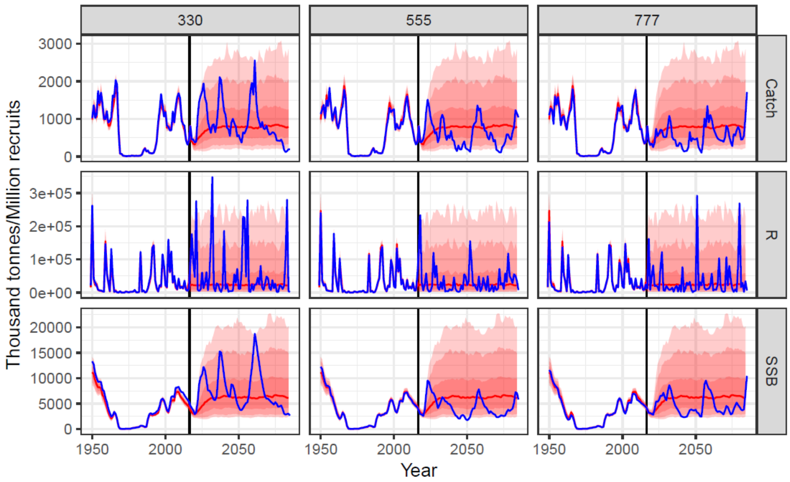

Figure 4.2.6.1. Simulation results for 2019-2053 together with the historical assessment, for Rule 1 ($B_{trigger}$ = 3184 thousand tonnes, F_{target} = 0.125). The three rows correspond to the realised Catch, Recruitment and SSB, and show the 5th, 25th, 50th, 75th and 95th percentiles of their distribution. The columns correspond to three particular realisations (numbered on top, selected semi-randomly).

Figure 4.2.6.1 shows three individual realisations of simulations results from Rule 1 on top of the median from all 3000 iterations, and extended back in time with latest assessment results. This figure illustrates how varying the individual simulations are when large year classes enter the stock and in how large these year-classes are. It is this variability that is reflected in the wide range between the 5th and 95th percentiles around the median. The figure also indicates that predicted recruitment pattern matches historical recruitment pattern reasonably well.

4.2.7 Bias

When bias was included, the risk of SSB being below B_{lim} increased for any given F/HR_{target}, $B_{trigger}$ combination (Tables A.3.12 and A.3.13). Including 10% bias increased the risk of SSB being below B_{lim} in the medium term for Rule 1 for the combination Ftarget = 0.157, Btrigger = 3184 from 9.7% to 13.0%. For 15% bias this risk increased to 15.1%.

5 Main findings from the Workshop

5.1 Main findings with regards to F_{MSY}

While working with the Management Strategy Evaluation, the group encountered issues with the reference point simulations from earlier this year (ICES, 2018), and therefore these issues have been revisited by WKNSSHMSE. One of the issues was related to catches of age 0 and 1 in the past. While catches of age 0 and 1 fish have been very low since the collapse, catches in the 1950s and 1960s did include large amounts of these young fish. Excluding these catches affects the calculation of F_{MSY} through the impact on the estimated recruitment at age 2. If these catches are ignored like they were in the WKNSSHREF simulations the model estimates lower recruitment to age 2 during the early period. Adjusting the numbers at age 2 in this way resulted in a substantial increase in the very low recruitment values seen at high SSB during the period before the collapse but did not affect the large year classes much. Overall the corrected values result in slightly higher mean recruitment with considerably less variability, particularly for high values of SSB.

The second issue was related to numerical instability. At WKNSSHREF 1000 resamples of parameters (stock recruitment) were used and each HCR was simulated for 500 years, discarding the first 250 to ensure the process had reached equilibrium. A test was made to ensure numerical stability of the final results, but it turned out that an error with the use of random seeds shortened the effective time span used (the seed was set to equal values in a sequence within each time series). Effectively the results became independent of the changes made in number of resamples and number of years, and this potential problem was thus not discovered. Increasing the number of iterations to 2000 appeared sufficient for numerical stability of statistics for short, medium and long term.

Based on the two changes described above, the reference point analyses conducted at WKNSSHREF were updated, keeping all other assumptions and inputs the same as were used at WKNSSHREF. The changes had a minor effect on the biomass reference points which were kept unchanged, but fishing mortality reference points were changed: F_{MSY} was revised to 0.157 (Figure 1), F_{lim} was revised to 0.291 and F_{pa} was revised to 0.227.

In reference point analyses the assumptions made have a big impact on the results. The estimates of F_{MSY} (=F_{p05}) range between 0.1 and 0.15 depending on inputs used and assumptions made. The current management plan target of 0.125, which has been used for nearly two decades without driving the stock below B_{lim}, still seems appropriate given this reference point estimation uncertainty.

5.2 Main findings with regards to MSE

The target fishing mortality values evaluated are in the range of 0.10 to 0.20. These were used in combination with $B_{trigger}$ values in the range of 2.5–5 million tonnes, including MSY $B_{trigger}$ = 3.184 million t. The target harvest rate values evaluated range from 0.07 to 0.15. Comparing short, medium and long term tables, for the HCRs without a TAC constraint, a main result is that, for any given (F_{target}, $B_{trigger}$) or (HR_{target}, $B_{trigger}$) combination, the P(SSB<B_{lim}) is largest in the medium term (Tables A.3.1 and A.3.2). This is as expected given the current low stock size.

For rule 1 (F rule with one break point), F_{target} values around 0.15 to 0.18 combined with $B_{trigger}$ values around 4.0 to 5.0 million t resulted in the highest median long term yield

(Table A.3.3). Similar results were found for the medium term, although yield is generally lower in the medium term than in the long term. In the short term, the median yield is even lower because of the current low stock size and highest yields were found at F_{target} values around 0.125 to 0.17 combined with $B_{trigger}$ values around 3.5 to 5 million t.

For rule 2 (F rule with two break points), a higher number of F_{target} – $B_{trigger}$ combinations were found precautionary compared to rule 1, likely because rule 2 has a steeper reduction in F below $B_{trigger}$. For rule 2, the highest median long term yields were at F_{target} values around 0.17 to 0.20 combined with $B_{trigger}$ values around 4.0 to 5 million t (Table A.3.3). In the medium term, highest median yields were at F_{target} values around 0.18 to 0.20 combined with $B_{trigger}$ values around 4 to 5 million t. In the short term, highest median yields were found at F_{target} values around 0.16 to 0.20 combined with $B_{trigger}$ values around 3.5 to 4 million t.

For rule 3 (biomass rule with one break point), HR_{target} values around 0.12 to 0.14 in combination with $B_{trigger}$ values around 4.5 to 5 million t resulted in highest median long term yields while in the medium term this was achieved at HR_{target} values around 0.12 to 0.13 combined with $B_{trigger}$ values around 4.5 to 5 million t (Table A.3.4). Short term median yield was highest with combinations of HR_{target} values around 0.12 to 0.13 and $B_{trigger}$ values around 4.5 to 5 million t.

Similar to the F rules (rule 1 and 2) the biomass rule with two break points (rule 4) had a higher number of precautionary combinations compared to rule 3. Highest median long term yields for rule 4 were found at HR_{target} values round 0.13 to 0.15 combined with $B_{trigger}$ values around 4 to 5 million t (Table A.3.4). In the medium term highest median yield was achieved at HR_{target} values round 0.14 to 0.15 combined with $B_{trigger}$ values around 4.5 to 5 million t, while in the short term highest median yield was achieved at HR_{target} value around 0.11 to 0.13 combined with $B_{trigger}$ values around 3.5 to 4 million t.

Increasing the F_{target}, HR_{target} or the $B_{trigger}$ in the HCR leads to increased inter-annual variability (IAV, defined here as % change between any two consecutive years) in yield. When no TAC constraint is included on F-rules, the interannual variability ranges from about 17% for (low F_{target}, low $B_{trigger}$) combinations to about 30% for (high F_{target}, high $B_{trigger}$) precautionary combinations (Table A.3.7). When an averaging TAC constraint is included, the range is approximately 9%–17% and when a +25%/-20% TAC constraint was included the range was 19-21%. For the biomass rules (Table A.3.8), the variability for rules without TAC-constraint varied between 9% and 16%, for averaging TAC-constraint the variability was 7%-12% and for the +25%/-20% TAC constraint the variability was 10%-16%.

SSB was not much affected by changing F_{target}, HR_{target} or the $B_{trigger}$ in the short term, but in the medium and long term increasing F_{target} or HR_{target} lead to lower realised SSB, whereas increasing $B_{trigger}$ lead to higher SSB. Inter-annual variability in SSB was generally lower than inter-annual variability in yield.

It is important to note that (high F_{target}, high $B_{trigger}$) combinations result in actual Fs that can, on average, be substantially lower than the target F (Table A.3.11). This is because the F used to set the catch according to the HCR is reduced below the F_{target} whenever the SSB is forecasted to be below $B_{trigger}$. So rules with higher target F do not necessarily result in overall higher Fs in reality, but will result in higher inter-annual changes in both F and yield.

For any given (F_{target}, $B_{trigger}$) or (HR_{target}, $B_{trigger}$) combination, the interannual yield variability range widens considerably with increases in either the F_{target}/HR_{target} or the $B_{trigger}$, and inter-annual yield variability values that are much higher than the medians reported in the tables cannot be ruled out in those cases.

Precautionary (F_{target}, $B_{trigger}$) combinations were identified. There is a set of "borderline" combinations, corresponding to the 5% risk (i.e. probability of SSB falling below B_{lim}), in which larger values of F_{target} were associated with larger values of $B_{trigger}$ (for the same 5% risk) and *vice versa*. The evaluated precautionary F_{target} values associated with the lowest and highest $B_{trigger}$ values and with MSY $B_{trigger}$ are shown in Table 5.2.1. Tables 4.2.1-4.2.4 further list the highest precautionary F/$HR_{targets}$ associated with MSY $B_{trigger}$ (3184 kt), beyond which the risk of SSB being below B_{lim} was higher than 5%.

Table 5.2.1. Precautionary combinations of F_{target} and $B_{trigger}$ for lowest, MSY and highest $B_{trigger}$.

	$B_{TRIGGER}$ = 2.5 MILLION T	$B_{TRIGGER}$ = MSY $B_{TRIGGER}$ = 3.184 MILLION T	$B_{TRIGGER}$ = 5 MILLION T
Rule 1 - F-rule through 0,0	0.10	0.10	0.17
Rule 1 with 25/20% TAC-constraint	0.10	0.12	0.17
Rule 1 with average constraint	0.10	0.12	0.17
Rule 2 - F-rule with Fmin = 0.05	0.12	0.14	0.20
Rule 3 - biomass rule going through 0,0	0.08	0.09	0.13
Rule 3 with average constraint	0.08	0.09	0.13
Rule 3 with25/20% TAC-constraint	0.08	0.09	0.13
Rule 4 - biomass rule with HRmin= 0.05	0.09	0.10	0.15

6 References

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ICES. 2016b. NEAFC request to ICES to evaluate a long-term management strategy for the fisheries on the blue whiting (*Micromesistius poutassou*) stock. (http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2016/Special_Requests/NEAFC_Blue_whiting_LTM_strategy_evaluation.pdf)

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ICES.2018. Report of the Workshop on a long-term management strategy for Norwegian Spring-spawning herring (WKNSSHMSE), 26-27 August 2018, Torshavn, Faroe Islands.ICES CM 2018/ACOM: 53.

ICES. 2018. Report of the Workshop on the determination of reference points for Nor-wegian Spring Spawning Herring (WKNSSHREF), 10–11 April 2018, ICES Headquarters, Copenhagen, Denmark. ICES CM 2018/ACOM:45. 83 pp.

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Annex 1: Special Request

ICES Request Form

Request from	North East Atlantic Fisheries Commission (NEAFC)
Committee making the request	Coastal States on Norwegian spring-spawning herring
Contact within organisation	Darius Campbell (darius@neafc.org; NEAFC Secretary)
Content contact person	SigurgeirThorgeirsson, Ministry of Industries and Innovation, Skulagata 4, 150 Reykjavik, Iceland - E-mail: st@anr.is - cell phone: +354 896 5787
Request announced	22 May 2018
Request received	[completed by ICES]
Outcome of request required by client	As soon as is practicable, to be discussed with the chair of the coastal consultations on the NSSH
Request code (client)	
Request code (ICES)	[completed by ICES]
Details of request	***Request to ICES concerning a long-term management strategy for Norwegian spring-spawning herring***

In order to revise the long-term management plan for Norwegian spring-spawning herring consistent with the new stock assessment model (ICES 2016; 2017) and the corresponding updated reference points (ICES 2018a; 2018b), a Management Strategy Evaluation is needed. The objective is to ensure harvest of the stock within safe biological limits. The Parties therefore request ICES to evaluate the following harvest control rules.

Rule 1

- *A range of $B_{trigger}$ from 1 to 6 million tonnes with a range of target Fs from 0.05 to 0.25.*
- *The fishing mortality is the average for age groups 5 to 12+ weighted by stock numbers.*
- *Time of comparison for SSB is the same as used in the assessment.*
- *A harvest control rule with a fishing mortality equal to the target F when SSB is at or above $B_{trigger}$.*
- *In the case that the SSB is forecast to be less than $B_{trigger}$, the TAC shall be fixed consistently with a fishing mortality that is given by:*
  $F = F_{target}*SSB/B_{trigger}$
- *The following special case is to be evaluated: $B_{trigger}$=3.184 (=MSY $B_{trigger}$=B_{pa}) and the target fishing mortality of 0.102 (F_{MSY}).*

Rule 2

- *A range of $B_{trigger}$ from 2.5 to 6 million tonnes with a range of target Fs from 0.05 to 0.25.*
- *The fishing mortality is the average for age groups 5 to 12+ weighted by stock numbers.*
- *Time of comparison for SSB is the same as used in the assessment.*
- *A harvest control rule with a fishing mortality equal to the target F when SSB is at or above $B_{trigger}$.*
- *In the case that the SSB is forecast to be less than B_{lim}, the target F is 0.05.*
- *In the case that the SSB is forecast to be between B_{lim} and $B_{trigger}$, the target F will decrease linearly between those two points.*
- *The following special case is to be evaluated: $B_{trigger}$=3.184 (=MSY $B_{trigger}$=B_{pa}) and the target fishing mortality of 0.102 (F_{MSY}).*

Rule 3

- *A proxy for SSB (SSB_{proxy}) is defined as the biomass of herring aged 5 and older or an appropriate age range as identified by ICES.*
- *The reference biomass (B_{ref}) is defined as the biomass of herring aged 4 and older or an appropriate age range as identified by ICES.*
- *Time of comparison for SSB_{proxy} is the same as used for SSB in the assessment.*
- *A range of $B_{trigger}$ from 1 to 6 million tonnes with an approriate range of harvest rate (HR_{target}).*
- *A harvest control rule with TAC=$HR_{target}*B_{ref}$ when SSB_{proxy} is at or above $B_{trigger}$.*
- *In the case that the SSB_{proxy} is forecast to be less than $B_{trigger}$, the TAC = $HR_{target}*B_{ref} * (SSB_{proxy}/B_{trigger})$*
- *The following special case is to be evaluated: Btrigger=3.184 (=MSY $B_{trigger}$=B_{pa}) and a harvest rate equivalent to 0.102 (F_{MSY}).*

Rule 4

A biomass rule intended to be equivalent to Rule 2 with two levels of harvest rate: target harvest rate = HR_{target} when SSB_{proxy} is greater than $B_{trigger}$; harvest rate = HR_{lowest} when SSB_{proxy} is below B_{lim}; and harvest rate decreasing linearly between these bounds.

Evaluation and performance criteria

Starting point of the evaluations should be the current stock status as estimated by the most recent assessment and be consistent across time.

Each alternative shall be assessed in relation to how it performs in the short term (2019-2023), medium term (2024-2033) and long term (2034-2053) in relation to:

- *Average SSB*

- *Average yield*
- *Indicator for year to year variability in SSB and yield*
- *Risk of SSB falling below B_{lim}*

Evaluation of the management strategies shall be simulated:

- *With no constraint on the inter-annual variation of TAC.*
- *With a constraint on the inter-annual variation of TAC:*
  - *When the rules would lead to a TAC, which deviates by more than 20% below or 25% above the TAC of the preceding year, the TAC is to be set respectively no more than 20% less or 25% more than the TAC of the preceding year.*
  - *The TAC is to be set as the average of a) the current TAC and b) the TAC that would result from the application of the harvest control rule without constraint for the TAC year.*
- *The TAC constraint shall not apply if the SSB (rule 1 and 2) or SSB_{proxy} (rule 3 and 4) in the year for which the TAC is to be set is less or equal to Btrigger.*
- *Allowing a maximum of 10% to be banked or borrowed any year.*

ICES is also requested to assess what, if any, other measures in addition to those contained in the present Management Strategy might contribute to attaining the objectives of the strategy, and provide estimates of their efficiency.

Finally, it is expected that the Parties will, as appropriate, review and revise these management measures and strategies on the basis of any new advice provided by ICES.

References:

ICES. 2016. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA), 29 February–4 March 2016, ICES Headquarters, Copenhagen, Denmark. ICES CM 2016/ACOM:34. 106 pp.

ICES. 2017. Report of the Working Group on Widely Distributed Stocks (WGWIDE), 30 August–5 September 2017, ICES Headquarters, Copenhagen, Denmark. ICES CM 2017/ACOM:23. 994 pp.

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ICES. 2018b. *Special Request Advice Northeast Atlantic and Arctic Ocean Ecoregions, 26 April 2018 sr.2018.06*

https://doi.org/10.17895/ices.pub.4295

Intended use of the	*In order to revise the long-term management plan for Norwegian spring-spawning herring consistent with the new stock assessment model (ICES*

request output	*2016; 2017) and the corresponding updated reference points (ICES 2018a; 2018b), a Management Strategy Evaluation is needed. The objective is to ensure harvest of the stock within safe biological limits*
Planning ICES	[completed by ICES]
Request (budget) accepted	[completed by ICES]
ICES contact person	[completed by ICES]
WG(s) involved	[completed by ICES]
Preparation timing	[completed by ICES]
Review group	[completed by ICES]
Advice drafting group	[completed by ICES]
ACOM Web-conference	[completed by ICES]
Release date	[completed by ICES]

Annex 2: Working documents presented to the workshop

- WD 1: Höskuldur Björnsson, 2018. Norwegian spring spawning herring.
- WD 2: SondreAanes, 2018. Status MSE.
- WD 3 Höskuldur Björnsson, Extra Work: Norwegian spring spawning her-ring How to reach conclusions from the work done so far, Working for WKNSSHMSE 2018

Norwegian spring spawning herring

HCR simulations based on a separable and VPA models and comparison with XSAM results.

Working document 1 for WKNSSHMSE 2018

Höskuldur Björnsson

September 1st 2018

1 Introduction

The work shown here is just an update of earlier work and described in working documents 13, 9 and 1 in WKPELA 2016 (WD 9 and 13 were also put on the sharepoint for WKNSSH-2018) and similar paper was also described in WKNSSHREF in March 2018.The model that is described in WD-13 has been used for HCR evaluation for many other stocks both, last time NEA mackerel. The model has not changed sinces 2 years ago but the data have changed as 2 more years of data were added and survey 1 was not included in the work 2 years ago. The prediction part for a F rule has changed from 2 years ago when the F was implemented as a F-multiplier in the advisory year (the year following the assessment year). Now the stock in the assessment year is multiplied by an assessment error and the "perturbed stock" simulated one year using the TAC from last year. The predicted "perturbed stock" is then used to calculate the TAC for the advisory year. In the end the "real stock" is projected one year using the TAC generated last year. The assessment error used here is therefore the uncertainty in the stock biomass in the beginning of the assessment year. This method leads to consistency in the assessment error in biomass rules based on the biomass in the beginning of the assessment year and F rules.

Most of the runs done here were just updates from 2016 and March 2018 but few more options added. As an example the simulation periods in earlier work where either 1975-2014 or 1907-2014 but here the periods 1975-2017, 1950-2017 and 1907-2017 were investigated . The period 1935 - 2017 could also be investigated but a problem with the data before 1935 is that mean weights at age are constant.

In the end most emphasis was put on runs based on age 12 as a plus group and the period 1950 - 2017 to be in line with the work done using XSAM. Considerable part of the report is based on comparing the results from the separable model and XSAM.

WD-9 from 2016 shows more details about the runs, stock - recruitment functions etc, what is shown here are mainly summaries.

Nearly all the work is based on a Hockey stick stock - recruitment function. The reason is that the author likes this function that does not promise anything as long as your are above the break point. With stochastic breakpoint it could be argued that it approaches the Beverton-Holt function as the increase in average recruitment is gradual when the ssb exceeds higher and higher proportion of the breakpoints.

The model can also be used as VPA model by changing one number in the input files. Then the separable model is run first and the F of the oldest group used by the VPA. All survey and stock-recruitment modules are the same. When the VPA option is used the oldest age should preferrably be as old as possible which is not the case with forward running models.

2 Reference points

For this stock B_{lim} was set to 2.5 million tonnes in 199?. After the collapse the first large yearclass (1983) increased the spawning stock from 600 thous. to 3 million tonnes in 2 years so relatively little information is available from recent data on exactly where the break point in a Hockey stick function is.

Therefore, older data are used with the known limitation that selection pattern in earlier period is very different from what is has been last 3 decades, with substantial fishing of ages 0-2 that have not been caught recently. Catches of age 0 were not included in the runs from 2016 but they were tested to have relatively small effect on estimated reference points while including age 1 changed more. Including age 0 does though have more effect when running from 1950 (not done in 2016) as the catch of age 0 was relatively high in the period 1950-1965. The value of assumed M for ages 0-2 (0.9) does have some effect here, high M makes the effect of fisheries on ages 0-2 less increases the recruitment before the collapse compared to the postcollapse period.

	FirstY	nsel	age	rmax	ssbbr	cvbr	CV	acf	cvacf
1	1975	4	1-15	64.6	2242	0.10	1.01	0.00	0.00
2	1975	4	1-15	64.6	2233	0.11	1.01	0.21	0.73
3	1975	4	1-12	66.5	2382	0.11	1.02	0.00	0.00
4	1950	5	1-15	56.5	2238	0.36	1.33	0.00	0.00
5	1950	5	1-15	58.1	2324	0.13	1.35	0.30	0.40
6	1950	5	1-12	59.9	2443	0.49	1.36	0.32	0.38
7	1950	5	0-12	61.9	2116	0.18	1.28	0.27	0.47
8	1950	5	2-12	51.3	2571	0.14	1.52	0.39	0.30
9	1907	6	1-12	70.9	2380	0.20	1.17	0.31	0.30
10	1950	VPA	0-12	76.8	2688	0.10	1.21	0.34	0.35

Table 1: Estimated parameters of a hockeystick stock-recruitment function for various model settings and data

Looking at the relationship between SSB_{break} and R_{max} the usual positive relationship appears (figure 2). The runs starting in 1950 (runs 4-8) show lower estimated R_{max} indicating relatively low productivity in the period 1950-1975, something that is probably expected (exclusion of age 0 from the catches in some runs might explain part of the difference). The runs with the lowest and highest breakpoint are the runs where age 0 from the catches is used and where only ages 2 and older are used (runs 7 and 8 in figure 2. The run from 1950 excluding ages 0 and 1 from the catches (run 8) has the lowest R_{max} but when age 0 in the catches is added it approaches the value obtained from the data since 1975.

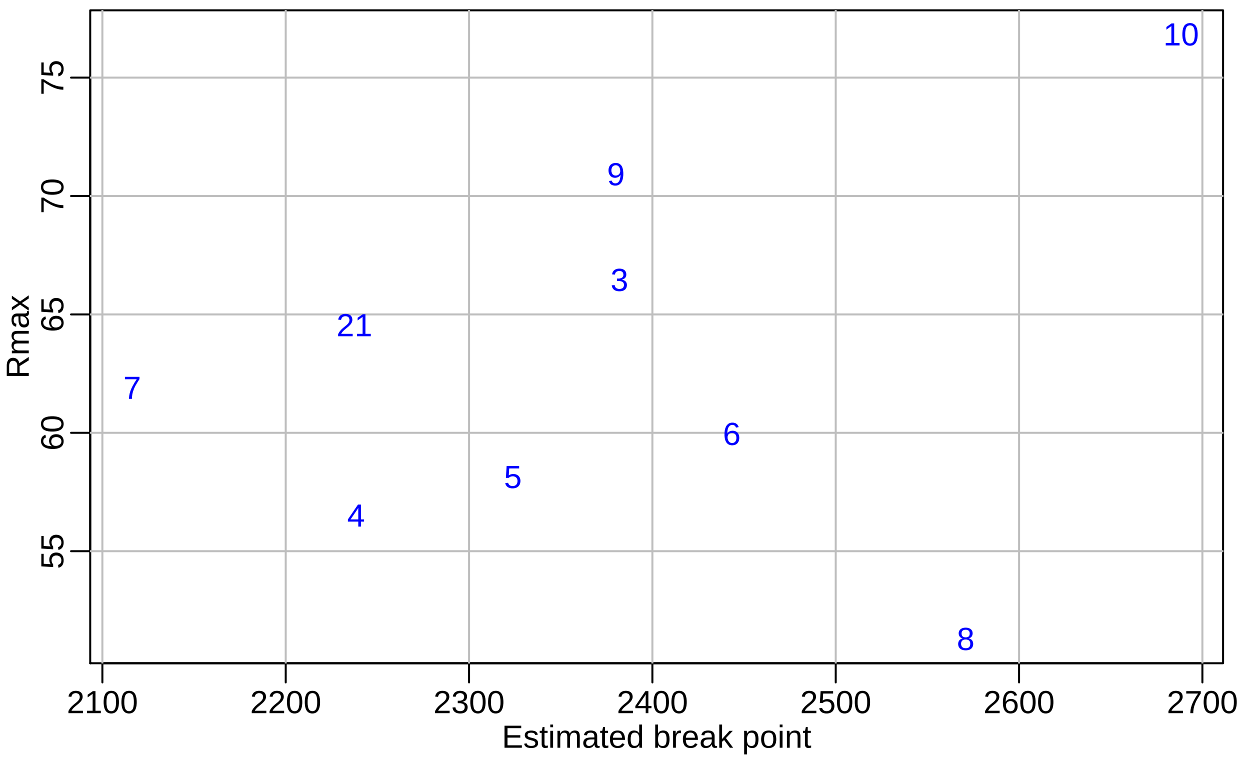

Figure 1: R_{max} as function of SSB_{break}. Text shows number of the run referred to table 1

Standard error in SSB_{break} is sometimes relatively low (≈ 0.1). This is the standard error obtained from the Hessian matrix, standard error from mcmc simulations is always somewhere around (≈ 0.3). The reason for this problem is not clear.

The main conclusion from table is 1 is that estimated SSB_{break} is close to or little lower than the current value of B_{lim} that is2500 thous. tonnes. It could be argued that taking into account positive correlation between SSB_{break} and R_{max} higher B_{lim} should be used in high R_{max} runs, something that does not fit well into current framework for advice. The run with the highest values of R_{max} and SSB_{break} is the VPA run while the separable model base on same data (run 7) has the lowest estimated break.

3 Assessment results

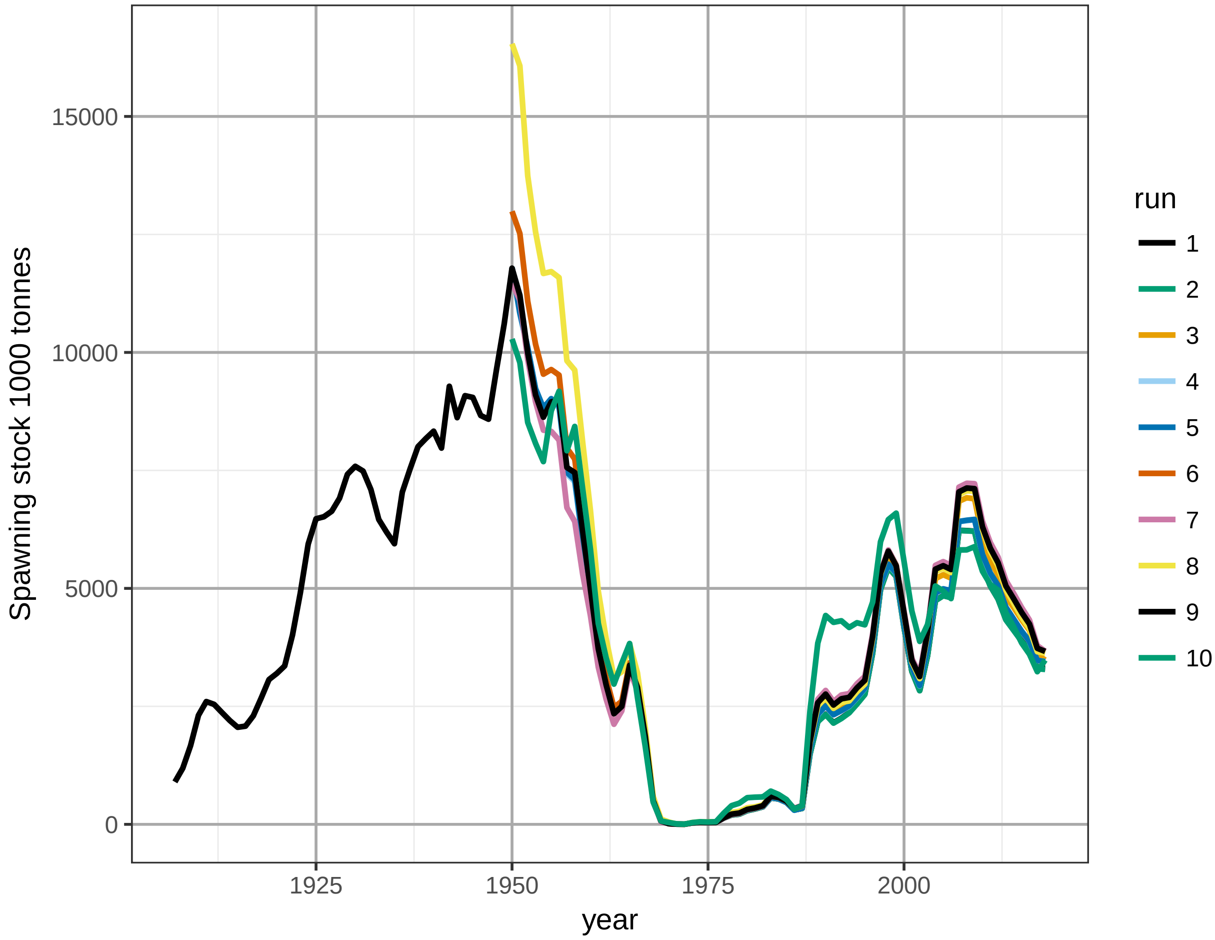

Figure 2: Spawning stock from different runs. Numbers refer to table 1

Spawning stock from different runs is shown in figure 2. Many of the runs lead to exactly the same historical results (those with and without estimated ρ_{rec}). The run with the largest SSB in 1950 is the run starting in 1950, ignoring catches of age 0 and 1. Runs 5 and 6 are identical except age range is 1:15 vs 1:12. They lead to similar parameters but there is some difference in SSB in 1950 (figure 2) All the runs shown treat the surveys in the same way and the selection pattern is allowed to change in the same years so getting identical results is not surprising

Even though the runs lead to exactly the same spawning stock, the spawning stock - recruitment function can be quite different and therefore results from HCR simulations. The rule is that SSB-rec function has little effect on historical assessment except historical data are very poor that they are not for this stock.

4 Estimating F_{msy}

Simulations were conducted based on the model configurations shown in figure 2 and table 1. CV of assessment error was set to 0.2 based on estimated model uncertainty and analytical retros (work done in 2015 excluding survey 1). This assessment error applies to biomass in the assessment year but the model takes care of the "amplification of uncertainty" through the assessment year. Autocorrelation of assessment error was set to 0.7 based on analysis of retrospective pattern. Autocorrelation of recruitment was set to 0.3 (estimate in R based on data since 1907) or as estimated when estimation of first order AR model was included in the assessment which was in most cases (table 1). Mean weight at age was stochastic around the average of last 30 years. The stochastic multiplier was a lognormal yearfactor with $\sigma = 0.08$ and $\rho = 0.7$.

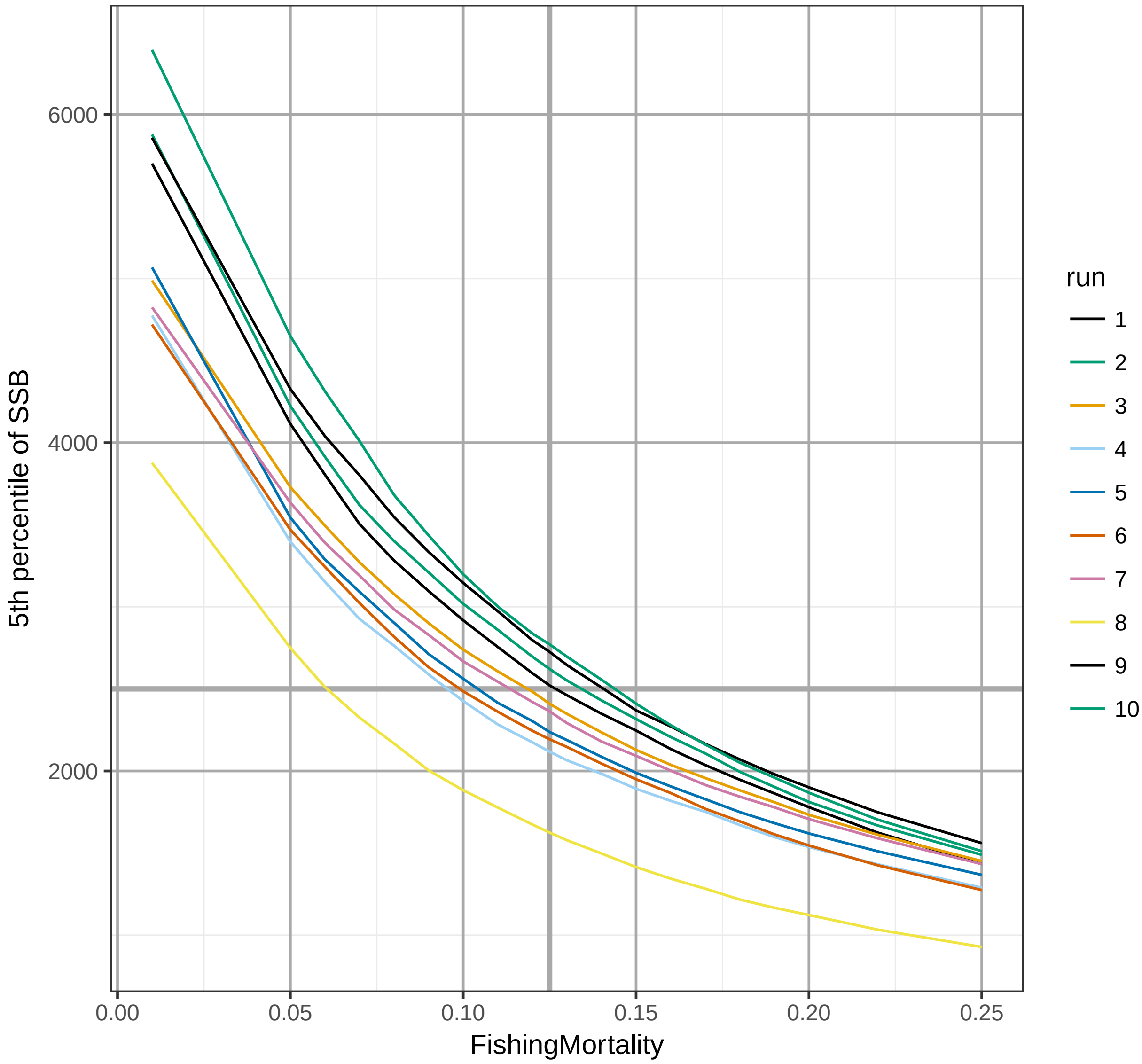

Figure 3: Fifth percentile of SSB as function of target fishing mortality, using $B_{trigger}$=3184 thous tonnes Numbers refer to table 1

	FirstY	age	nsel	acf	Fmsy1	Fmsy2	F05	F05a	catchmed	catchmean
1	1975	1-15	4	0.35	0.197	20	0.127	0.119	808	0
2	1975	1-15	4	Est	0.203	20	0.134	0.117	882	0
3	1975	1-12	4	0.35	0.196	20	0.119	0.108	823	0
4	1950	1-15	5	0.35	0.214	20	0.096	0.088	792	0
5	1950	1-15	5	Est	0.207	20	0.104	0.093	884	0
6	1950	1-12	5	Est	0.205	20	0.099	0.088	872	0
7	1950	0-12	5	Est	0.229	20	0.114	0.105	907	0
8	1950	2-12	5	Est	0.156	20	0.061	0.058	764	0
9	1907	1-12	6	Est	0.191	20	0.140	0.131	954	0
10	1950	0-12	VPA	Est	0.199	20	0.144	0.132	1009	0

Table 2: Summary HCR/Fmsy evaluations

In table 2 $Fmsy1$ is F leading to maximum median yield, $Fmsy2$ F leading to maximum average yield, $F05a$ F leading to fifth percentile of the spawning stock $= B_{lim}$ when $B_{trigger} = 0$, *catchmed* maximum median catch and *catchmean* maximum average catch. Those values are all based on no $B_{trigger}$ while $F05$ is fishing mortality leading to fifth percentile of spawning stock $= B_{lim}$ when $B_{trigger}$=3184 thous. tonnes. $F05$ would in all cases be what would be defined by ICES as F_{msy} as it is lower than the values maximising median catch.

$P(SSB < B_{lim}) < 0.05)$ is the limiting criterion in determinition of F_{msy} for this stock. Based on $B_{trigger} =$

3184 (B_{pa}) the range of estimated F_{05} is between 0.061 and 0.144 (figure 3 and table 2). The lowest value for F_{05} is when the simulations are based the period 1950-2017 using catchdata for ages 2 and older (the same was seen in XSAM simulations). The second lowest value is 0.093. Using the period 1950-2015 and catchdata for age 1 and older leads to F_{05} in the range $0.096 - 0.104$ but if the catchdata for age 0 is included F_{05} is 0.114. Using the period 1975-2015 leads to F_{05} in the range 0.119-0.134. The highest values 0.14 and obtained when using data since 1907 and using a VPA model based on data since 1950 ages 0-15 (similar to the seetings in XSAM). There is little difference between using 1-15 and 1-12+ in the simulations. ***

Using the period since 1950 does usually to lowest F_{msy} but the catch is not nessecarily less. What makes the period from 1950 onwards special is extremely large contribution of one cohort (1950) and including that cohort leads more variablity in predicted recruitment. Unusually large catches of age 0 and 1 (not included in some runs) in that period might also have an effect but these catches removed large proportion of small yearclasses making them even smaller. Estimated CV is probably higher when catches of age 0 and or 1 are ignored as the model works on log scale.

5 Effect of stock recruitment function

Two of the most imortant differences between the model used here and XSAM relate to the treatment of the stock - recruitment function

In the separable model (SEP) the stock-recruitment function is part of the likelihood function in the assessment part of the model which is not the case in XSAM where historical spawning stock and recruitment is bootstrapped and all 3 types of stock-recruitment function fitted for each replica (same method as in EQSIM). The stock-recruitment function fitting best is used for each replica while only one function is used in each model run in the separable model In the SEP model the autocorrelation of recruitment residuals is one of the parameters fitted and the fitting therefore by maximimizing multivariate normal likelihood, possibly leading to fewer effective data points. The treatment of the stock-recruitment function in the SEP model is more an integral part of the model than in XSAM and does probably lead to more variability. But at least it is a different method that might be better than the "AIC smoothing" method and probably better where serial correlation of residuals is expected.

It does though turn out that the form of the SSB-recruitment function is not most important but rather the paramters σ and ρ describing the residuals. The estimate of σ depends a lot on the estimate of the small yearclasses and VPA type approach on age 0 and 1 fisheries seems to be the only plausible way to model them. Estimated of recruitment at age 1 done in 1916 by the model (using VPA) indicates that modelling the recruitment as lognormal is not a disaster (figure 4)

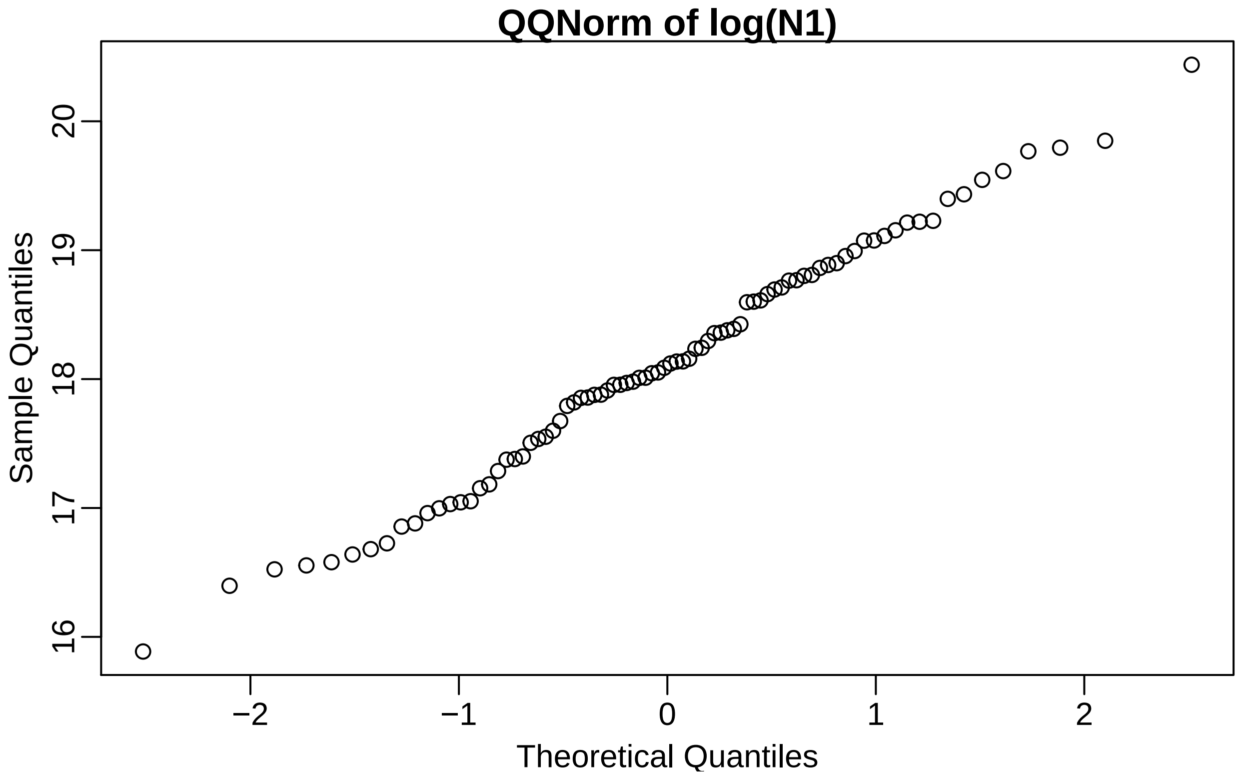

Figure 4: QQplot of estimated recruitment age age 1 from 1907 based on VPA approach.

To see the effect of the type of the shape of the stock-recruitment function the model was run with the same settings except apart from the stock-recruitment function. The settings were .

- Years 1950-2017, age 0-12+
- Autocorrelation of recruitment estimated
- 5 selection patterns

The results show that the Beverton and Holt function leads to lower estimate of F_{05} and median catch compared to the other functions (figures 5 and 6).

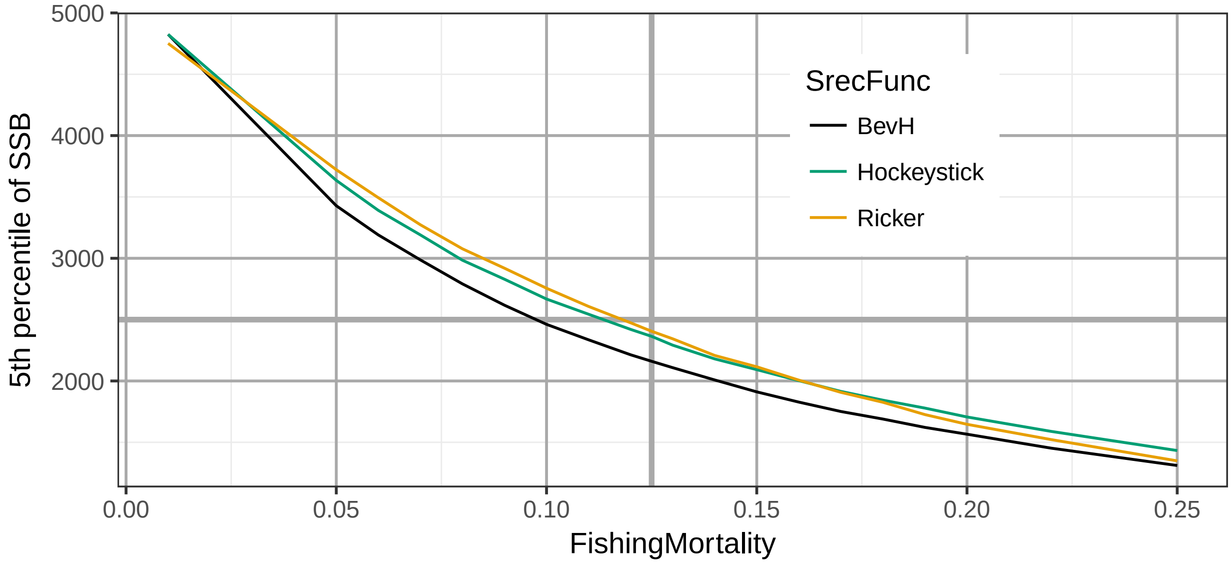

Figure 5: Fifth percentile of SSB as function of target fishing mortality, using $B_{trigger}$=3184 thous tonnes and different stock-recruitment functions.

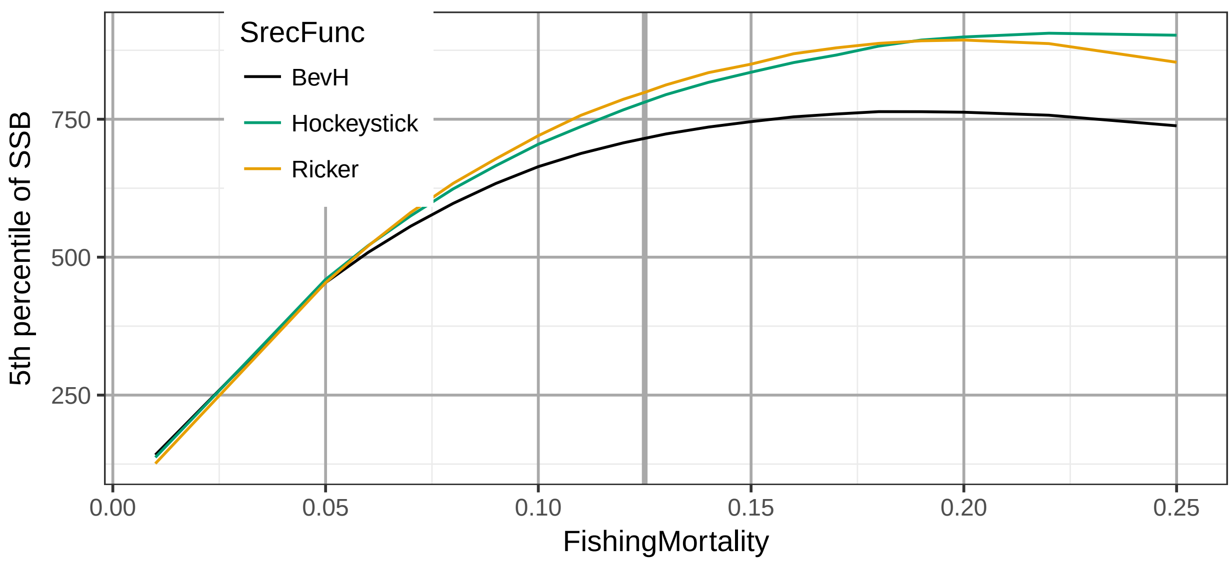

Figure 6: Median catch as function of target fishing mortality, using $B_{trigger} = 0$ and different stock-recruitment functions.

6 Problems with the stock-recruitment function in the low SSB-period

Recruitment in the simulations is lognormally distributed around a geometric mean obtained from a stock - recruitment function. Four parameters of the stock-recruitment function are estimated i.e 2 shape parameters CV and 1 AR parameter. Looking at the log of recruitment residuals the CV is higher when the spawning stock is small. The model has the possibility of having the CV function of the spawning stock, estimating one additional parameter (this optionsused in HCR evaluations for Icelandic herring). As the range of spawning stock is large a parameter of this type might have an effect. Two runs were conducted setting with variable recruitment CV (differently formulated in terms of range of spawning stock where this applies) and the results compared to fixed CV. The variable CV leads to lower recruitment variability when the spawning stock is above B_{lim} but the results on F_{05} (F_{msy}) are to reduce it a little (figure 7). Median catch is also less when the variability in recruitment is modelled. (figure 8). It needs to be mentioned that when CV of recruitment is a function of SSB 5 parameters in the SSB-rec function are estimated.

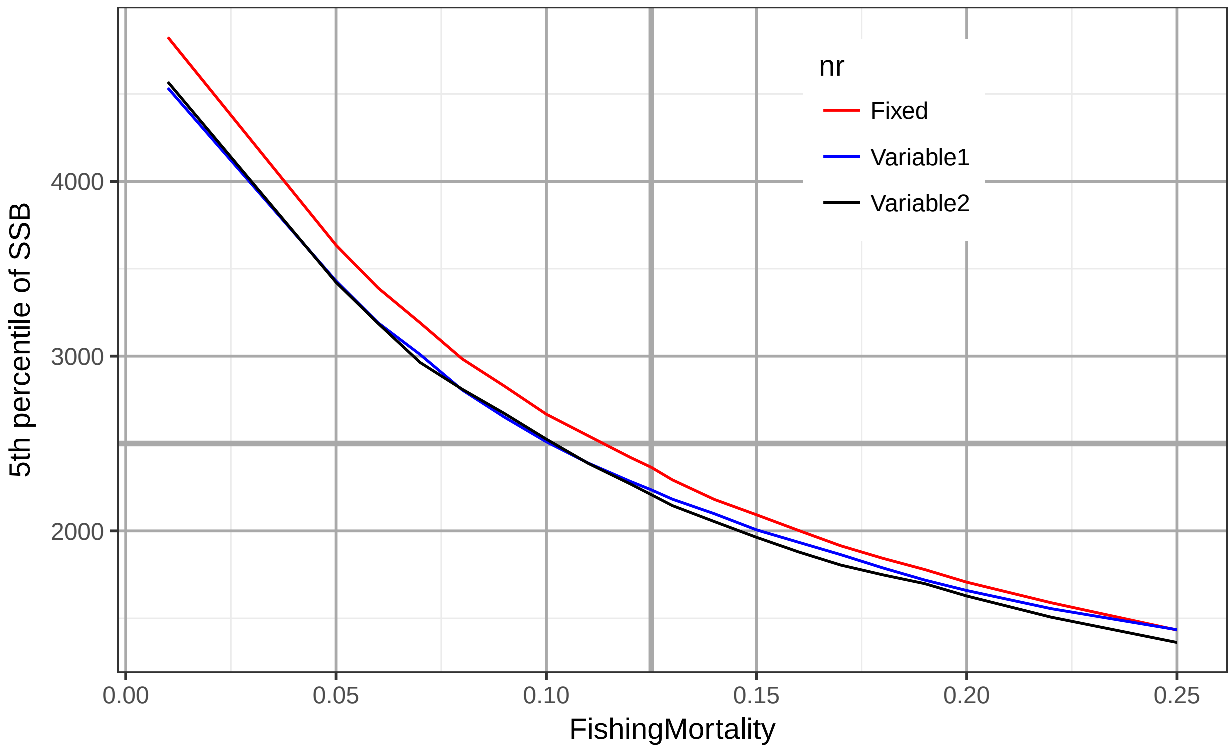

Figure 7: Fifth percentile of SSB as function of target fishing mortality, using $B_{trigger}$=3184 thous tonnes and different formulations of recruitment variability as function of spawning stock.

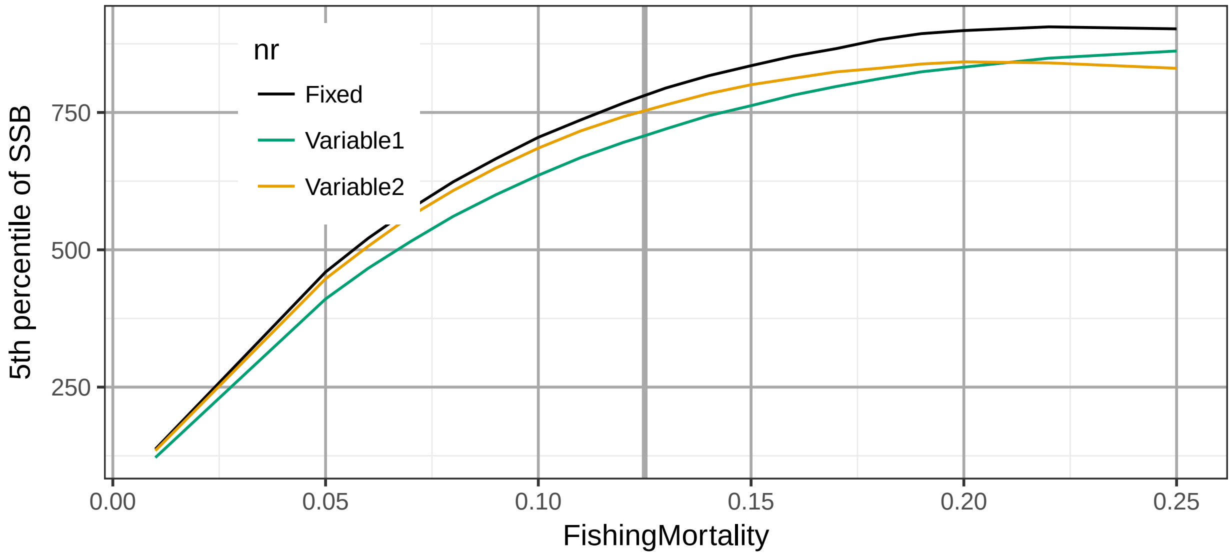

Figure 8: Median catch as function of target fishing mortality, using $B_{trigger=0}$ and different stock-recruitment functions and different formulations of recruitment variability as function of spawning stock.

7 MCMC algorithm settings

Settings of the mcmc algorithm in ADMB can occasionally be an issue, more so if data are poor which is not the case here. The high recruitment variability in the spring spawning herring can though cause some problems. The mcrb parameter used to reduce correlation in the covariance matrix (used as proposal distribution) was reduced to see if it affected the results. The results (figure 9) show that changing *mcrb* to 2 change the results for fixed CV. (2 is relatively low value reducing the correlation much)

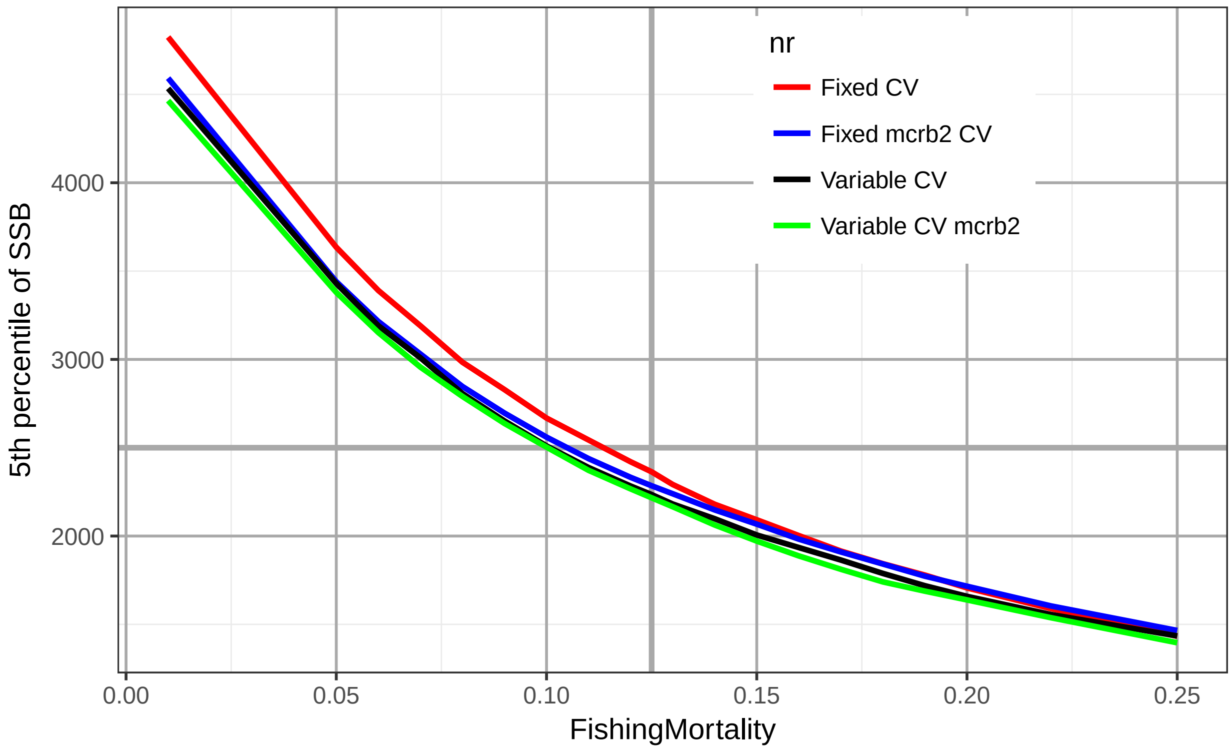

Figure 9: Fifth percentile of SSB as function of target fishing mortality, using $B_{trigger}$=3184 thous tonnes changing the settings of the MCMC simulations in ADMB.

8 Effect of biological parameters and assessment error

The assessment error used here is uncertainty in the stock size in the beginning of the assessment year. The settings most often used are lognormal with $\sigma = 0.2$ (no bias correction) and $\rho = 0.7$ (1st order AR). This translates to F_{5-12} in the advisory year having CV around 0.3 for F in the range 0.1-0.15. There is some bias in F (0.033 when the target is 0.125) but it must be remembered that F is a strange measure, especially when it is high and can be biased even though the stock size is not. Reducing CV to 0.1 does not change the results much but increasing it to 0.25-0.3 has considerable effect. 0.13 - 0.2 is most likely the plausible range for the CV of stock size in the beginning of the assessment year.

Investigation of real time retrospective pattern demonstrates some bias and more uncertainty than obtained by the model. This bias is mostly caused by fiddling around with the assessment among that including and excluding surveys. Introducing bias in the assessment does of course have major effect on the results, 10% bias simply means 10% lower F_{target}.

Similar considerations apply to uncertainty in biological parameters. In the model they are put in as autocorrelated lognormal noise around selected average values (yearfactor). What has most effect here is what is used as basis for the average (10, 20 or 30 years). The variability has to be really high or autocorrelation high ($\rho \approx 0.9$) to have major effect on the result.

Some variation in maturity has been observed, the main feature is that large cohort mature later than small. The way that maturity at age is compiled leads to final values being delayed by 2-3 years. Therefore the biomass rules are based on using B_{5+} as proxy for trigger but B_{5+} is very close to SSB on the average. Also the trigger in the biomass rule is in the assessment year, but one year later in the F rules.

The reason for relatively low effect of assessment error and "biological noise" is the CV of these noise terms is always an order of magnitude less than variability in recruitment that is the dominating stochastic factor. With uncorrelated stochastic terms variances are added.

Any structure like overestimation when stock is large or density dependent growth will have more effect.

To see the difference between the separable model settings and XSAM CV of assessement error was reduced to 0.1 (close to what is used in XSAM) and variability in weights not included. The results (figure 10) show that ≈ 0.01 of the difference in estimates of F_{05} between XSAM and SEP could be caused by those factors, especially the assessment error.

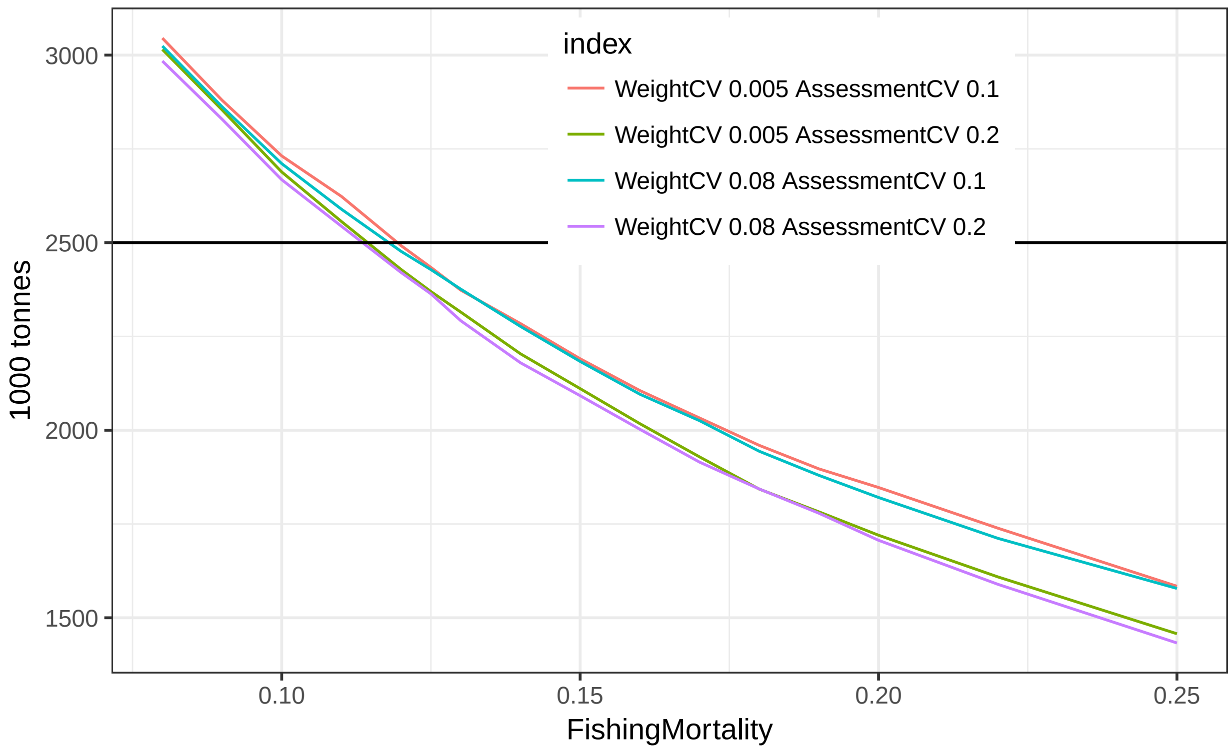

Figure 10: Fifth percentile of SSB with 2 levels of CV of assessment error and with and without variability in weights

9 Measures of fishing effort

Currently advice for this stock is based on weighted average fishing mortality of ages 5-12 where the fishing mortality is weighted by stock numbers. At the meeting other measures were discussed like unweighted fishing mortality or harvest rates. 3 different measures are shown in figure 11 all showing similar main trends. Deviations are related to large cohorts recruiting to the stock.

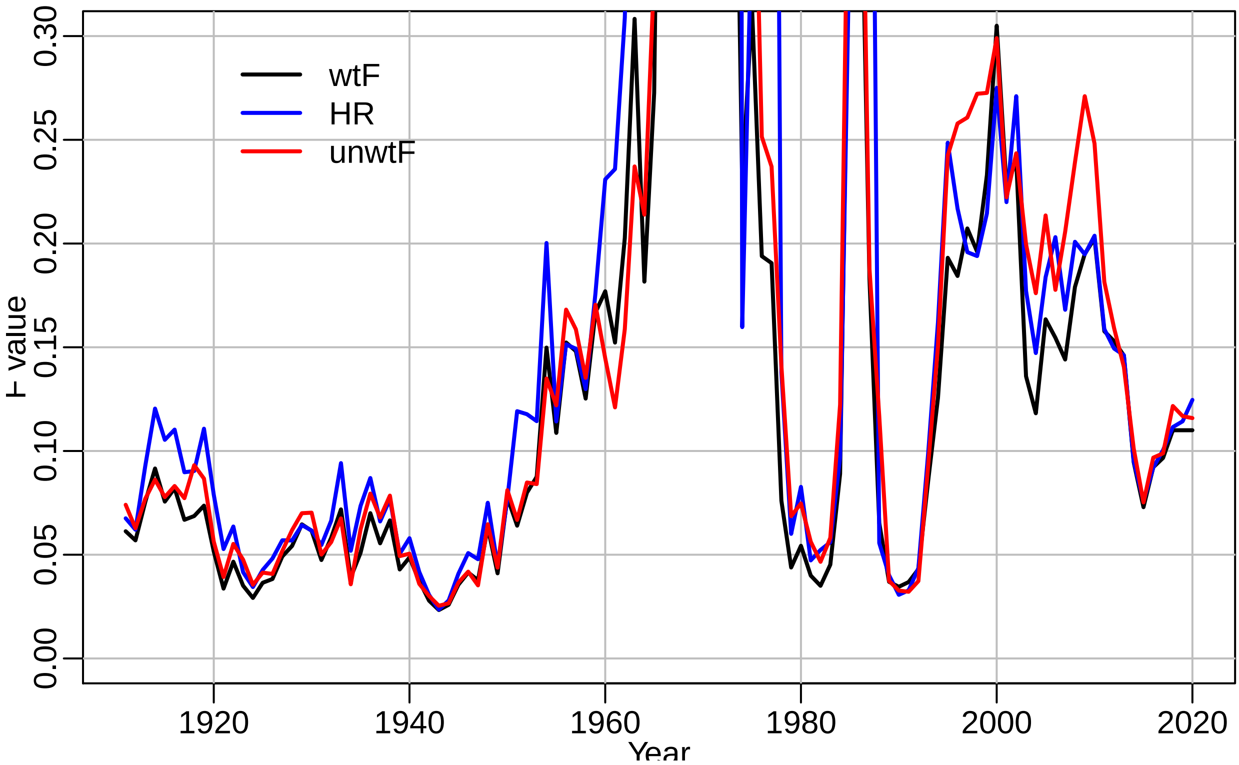

Figure 11: Development of different measures of fishing effort since 1907. High values outside any plausible management plan fall outside the plot. The measures shown are F_{5-12} weighted by stock numbers, F_{5-12} unweighted and harvest rate based on B_{4+}

The harvest rate in figure 11 is shown as proportion of B_{5+} but B_{5+} is a reasonable proxy for the fishable stock and SSB. If the advice was based on biomass one year earlier (the assessment year) B_{4+} might be a better candidate and some version of the HCR for Icelandic cod could be used.

Delay of maturity data would make B_{5+} a good candidate for $B_{trigger}$, it is not the correct SSB but relatively close and it is available at the time of assessment. Still criteria in HCR simulations would be based on "real SSB".

Figure 12 based on data since 1990 gives F that is on the average 8.7% higher than harvest rate (based on Sep results).

Looking at XSAM results target harvest rate of 0.11 and $Btrigger = 2500$ lead to mean F of 0.127 and median F of 0.130 in the long term. The median of harvest rate is 0.11 and the average 0.109. CV of harvest rate is 0.064 but CV of F_{bar} 0.18. In the separable model the median harvest rate in the same situation is 0.109, the average 0.111 and CV (sd log) 0.24. Assessment error was set to 0.2 and getting higher CV on harvest rate is expected as prediction error of mean weight at age is included and the reference biomass goes into the denominator. Median F is 0.139, average F 0.137 and CV of F 0.27. All numbers are much more variable than in XSAM.

To summarize the ratio between Harvest rate and fishing mortality is 1.24 in the separable model but 1.17 in XSAM. The difference in the separable model is higher than obtained from historical data.

Looking at results from XSAM where target fishing mortality is 0.125 and $B_{trigger} = 2500$ the average fishing mortality is 0.124 and the median 0.122. Mean harvest rate is 0.108 and median 0.105. Ratio between fishing mortality and harvest rate 1.18. CV of harvest rate 0.206.

Doing the same thing for the separable model with $F_{target} = 0.125$ and $B_{trigger} = 2500$ leads to median harvest rate of 0.100, average 0.103, average F of 0.126 and median F of 0.123, CV of F is 0.27 as is CV of harvest rate. Ratio between Fishing mortality and harvest rate is 1.25.

For both models the ratio between F and HR is the same in F rules and HR rules (error check). The ratio is higher for the separble model and higher than what is obtained from historical data. Uncertainy in values seems more consistent in the Sep model than in XSAM where the uncertainty in the biomass rule is surprisingly low.

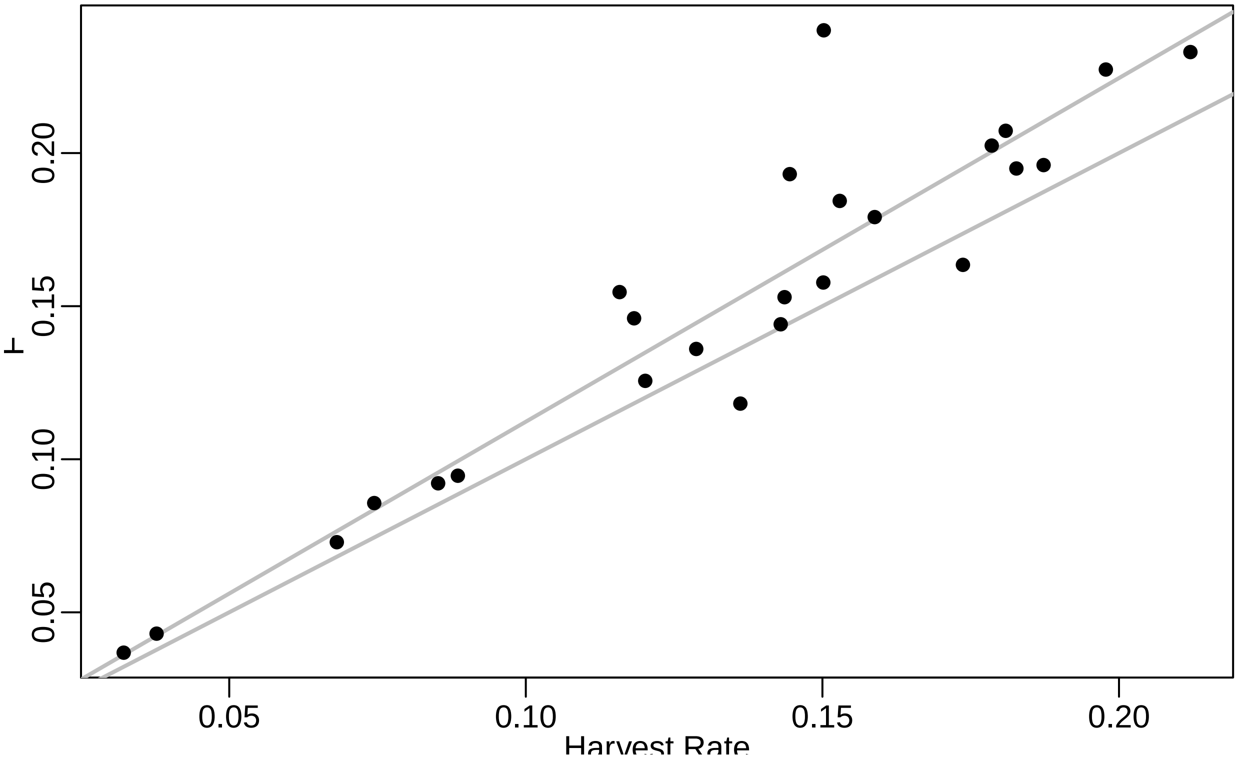

Figure 12: Fishing mortality aginst Harvest rate based on dat in the period 1990-2017. Regression lines has a slope of 1.087

10 Comparison with XSAM

The 2 models XSAM and the separable model operate in considerably different way as described before. Comparing median catch and SSB shows very similar results for both models (figure 16). Looking at the lower quantiles of SSB and catch XSAM shows higher values. This difference is driven by recruitment, that is as shown more variable in the separable model. Checking the results against "reality" the median recruitment since 1950 in years where SSB $>$ 2.5 million tonnes is 10.2 milliard herring at age 2 and the lower quantile 1.6 milliard. The predicted numbers are lower but though similar. As described earlier higher variability in recruitment when spawning stock is low might affect CV of recruitment. The XSAM numbers show less variability than indicated in the separable model assessment. They are based on XSAM stock assessment that could be somewhat different, escpecially with regard to the small cohort. When looking at the socalled "reality" it must be kept in mind that the years where SSB $>$ 2500 are only 47, rather few years for a reliable fifth percent quantile. The "truth" is somewhere between the red and blue lines but it must be rememebered that XSAM was fitted to a different "truth".

11 Comparison of XSAM, SEP and VPA based on data since 1950 from age 0

What drives the results of the different models is estimated variability in recruitment. Here only the cases where the spawning stock is reasonably large is taken, what is selected is $SSB > 2$ million tonnes. Standard error of recruitment $\sigma(log(R))$ is shown for the 3 models and different time intervals. Recruitment of age 2 has considerably lower standard error in the XSAM and VPA results compared to the SEP model but in both VPA and XSAM catch of 0 and 1 is modelled like VPA. The catches of 0 and 1 are extremely variable so the SEP model (or any other model than VPA) has no way of modelling those catches. Interestingly the varability of age 0 is lower than variability of age 2 in the period 1988-2016. The reason seems to be fisheries on age 1 in 2008, 2010 and 2011.

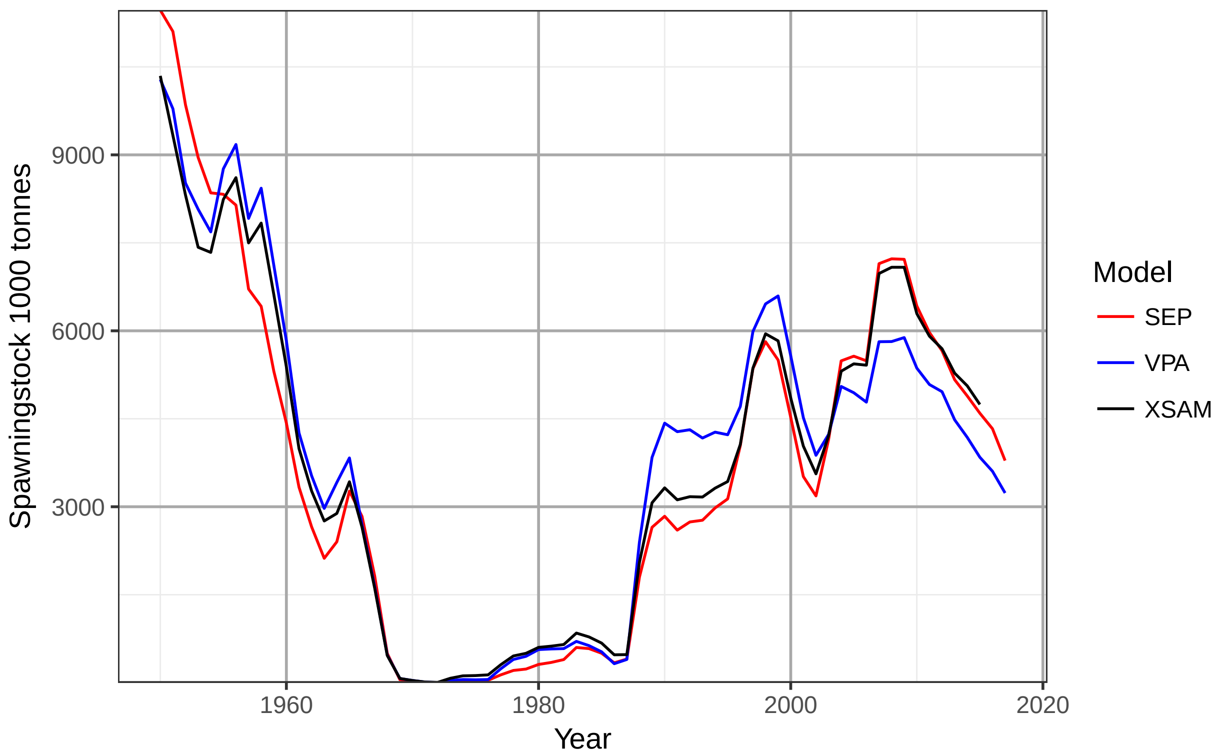

Figure 13: SSB from the 3 models

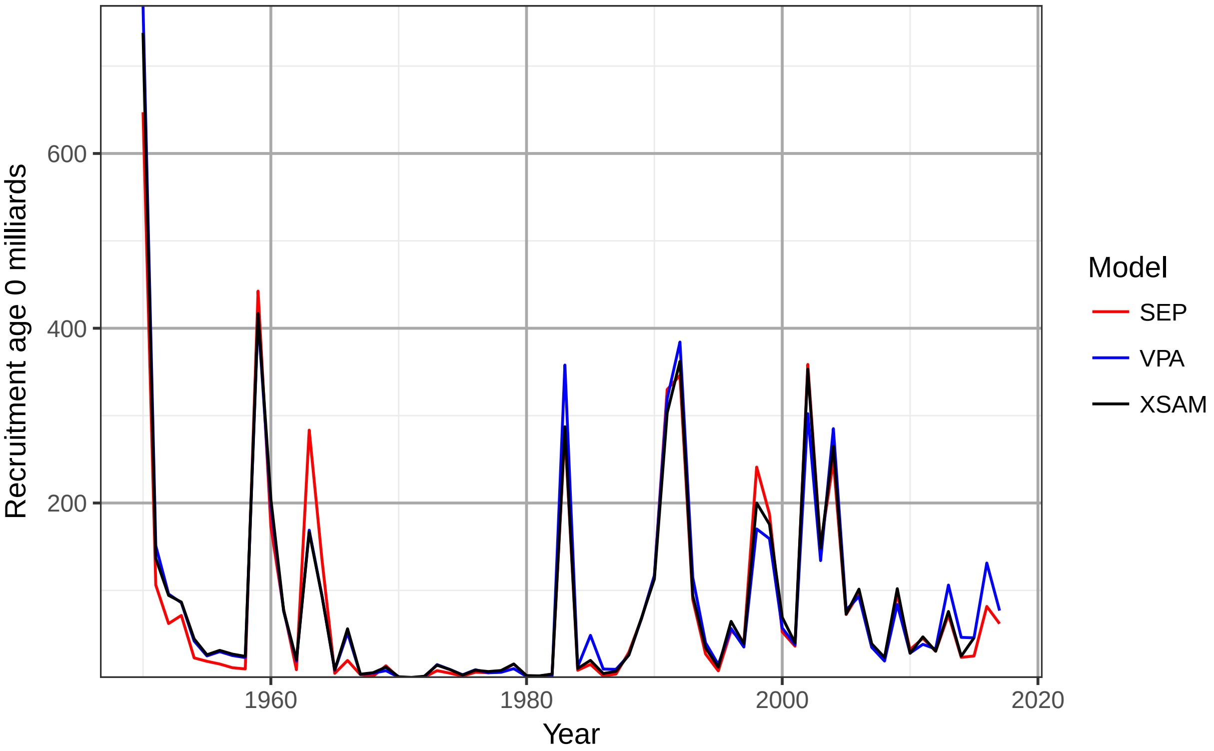

Figure 14: Recruitment at age 0 from the 3 models plotted on normal scale

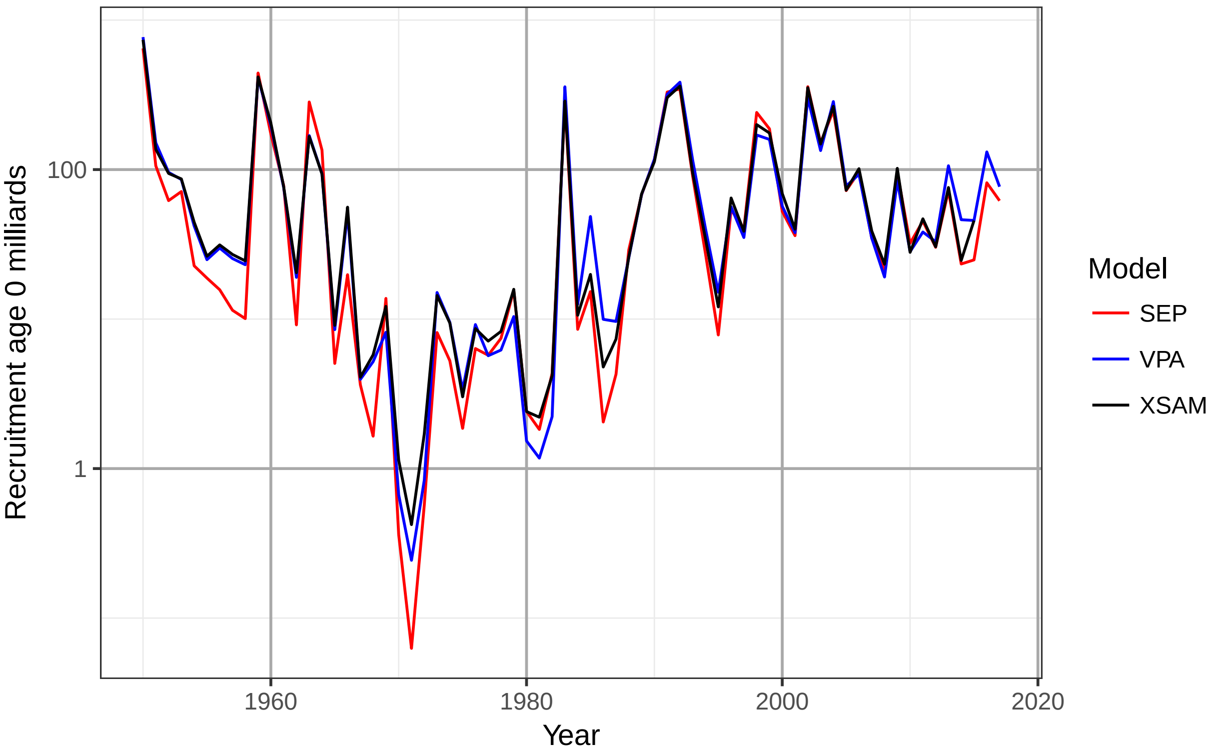

Figure 15: Recruitment at age 0 from the 3 models plotted on log scale

Comparison of SSB shows some difference between the models figure 13) shows some differerence between VPA and the other models. This difference has to do with the amount of the 1983 yearclass that was left at age 15 (the VPA model uses 15 as oldest age the other 2). Assumptions in the VPA about how much is left of this yearclass make difference about the size of spawning stock earlier and affect later result through survey 1 that extends back into the late eighties.

Recruitment is reasonably similar 14). The difference for the 1985 yearclass is artifact of wrong age readings at ages 13-15 that do not affect the models using 0 -12. The difference in recruitment on log scale is noticeable especially as the small yearclasses in the early period are smaller in the SEP model (XSAM and VPA are partly the same model in this period)

The analysis presented show similar assessment with the 3 selected model but some differences caused by variable fisheries on young fish (0-2) and relatively large abundance of the 1983 at age 15. F on this yearclass was usually low so assumptions about it at oldest age have large effect few years earlier.

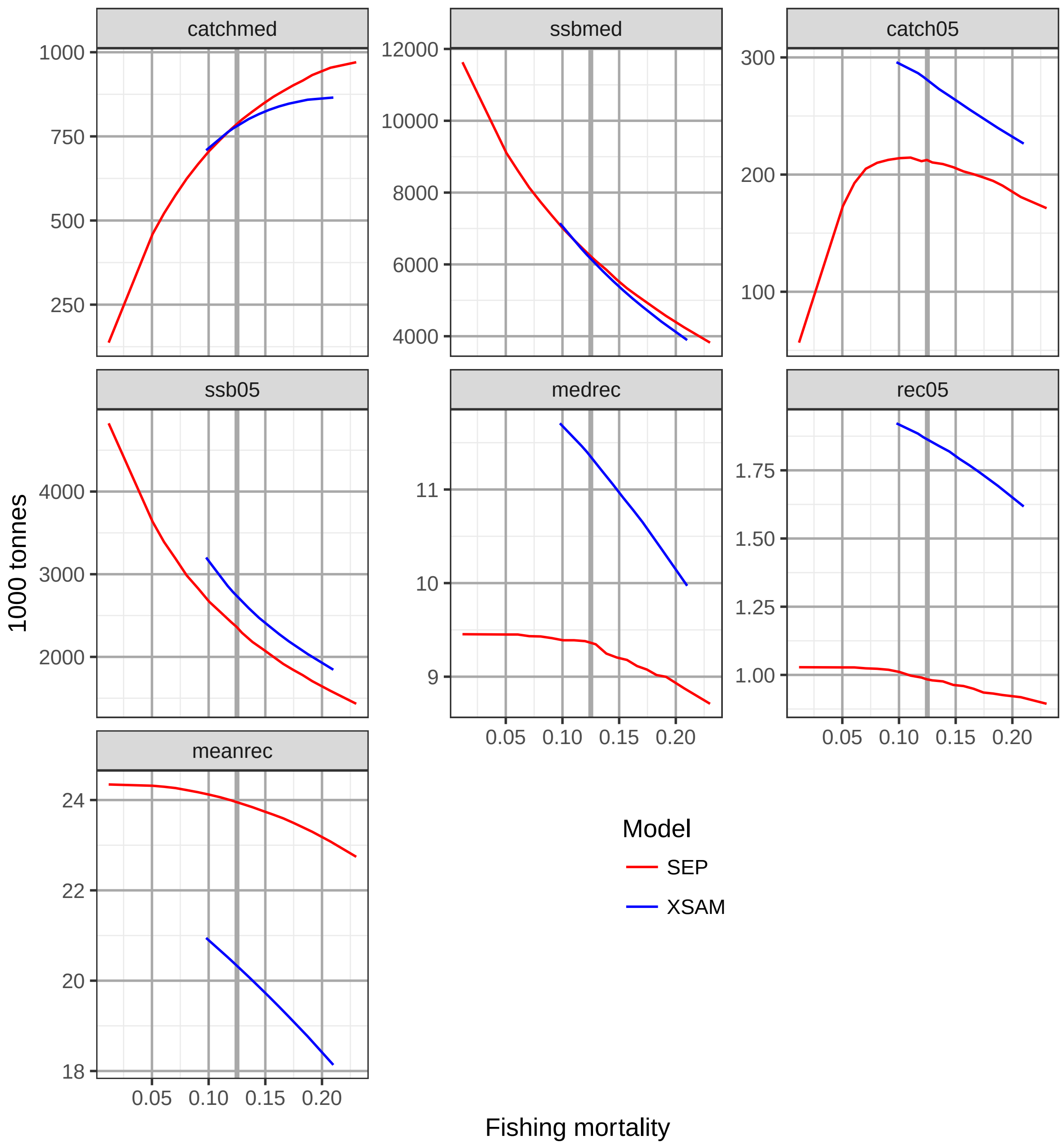

Figure 16: Comparison of catch, spawning stock and recruitment from the 2 models using $B_{trigger} = 3184$ thous tonnes and a F rule .

Comparing SSB vs Harvest rate leads to more difference than in fishing mortalities as shown in figure 17 but HR_{05} is 0.09 vs 0.12. Part of the difference (0.01) is the low variability in the XSAM results.

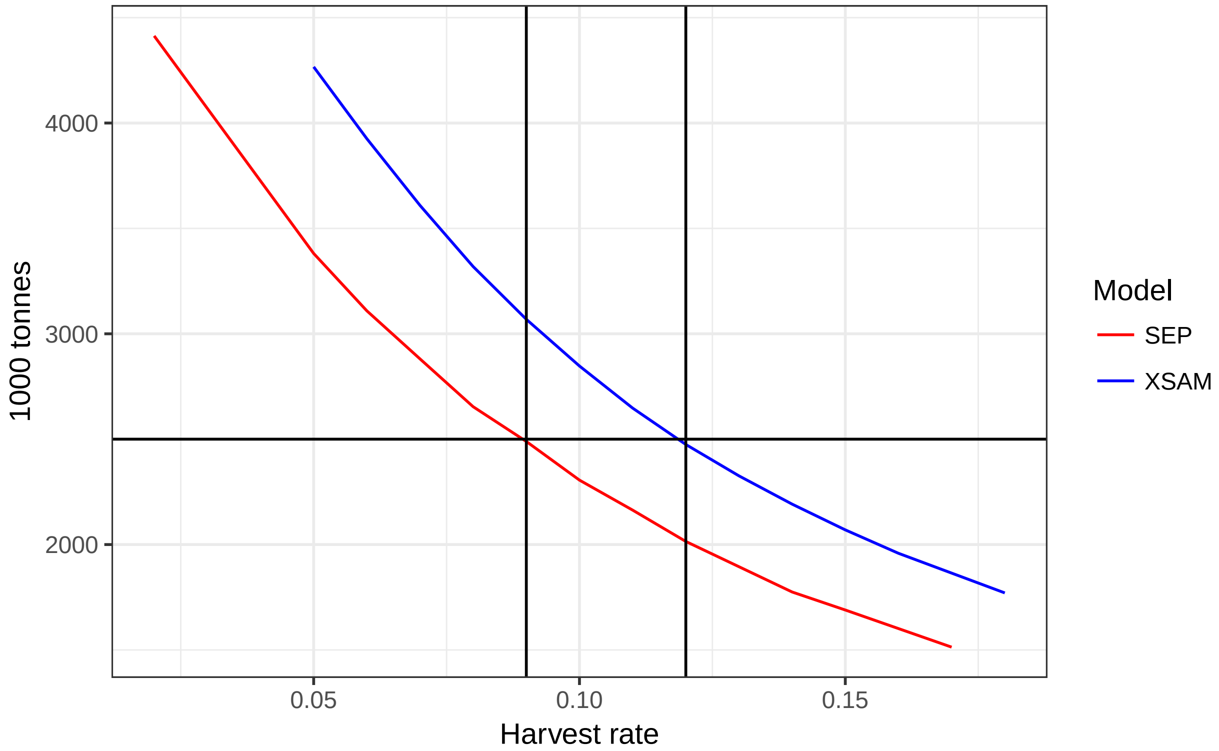

Figure 17: Fifth percentile of spawning stock aginst harvest rate. $B_{trigger} = 3184$

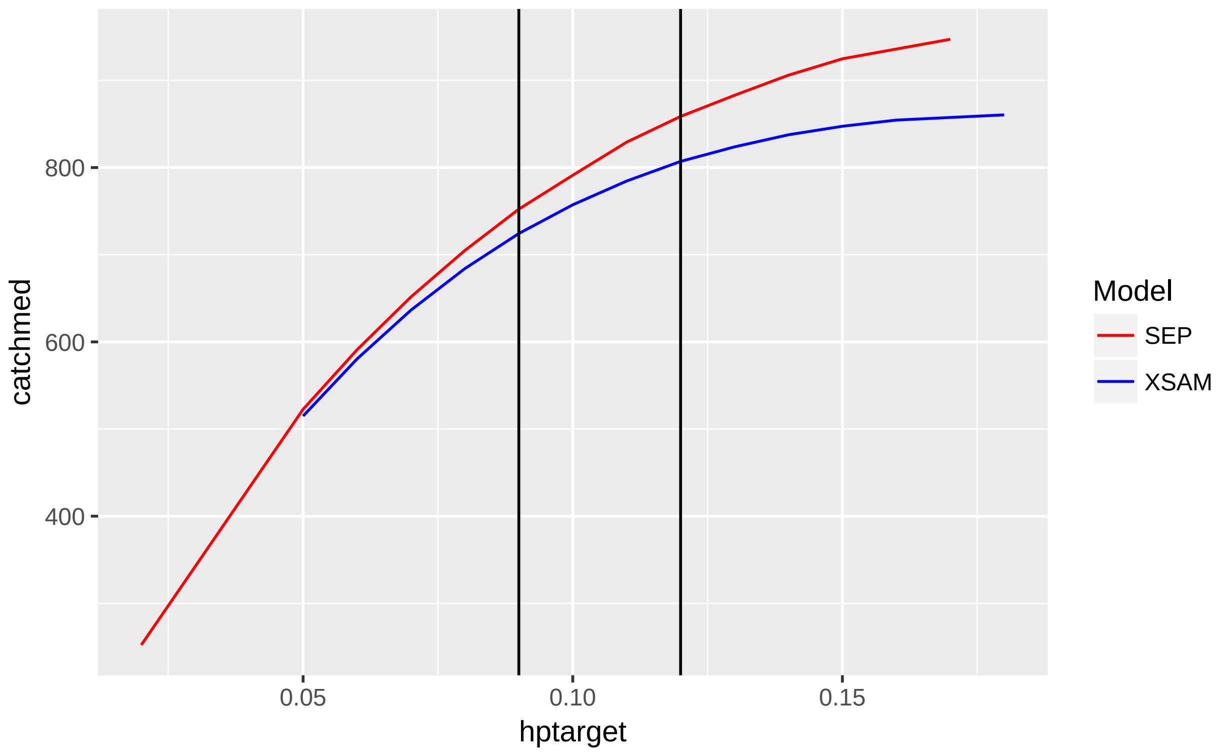

Figure 18: Median catch aginst harvest rate. $B_{trigger} = 3184$

12 Comparison between harvest rules

The 2 Harvest control rules F rule and biomass rule (HR) give similar results for both models (figure 19). Fishing mortality is of course not the key parameter in the biomass rule but can be derived from the results so the plots become comparable. The results indicate that the harvest control rules perform equally well in terms of the metrices shown in the figure.

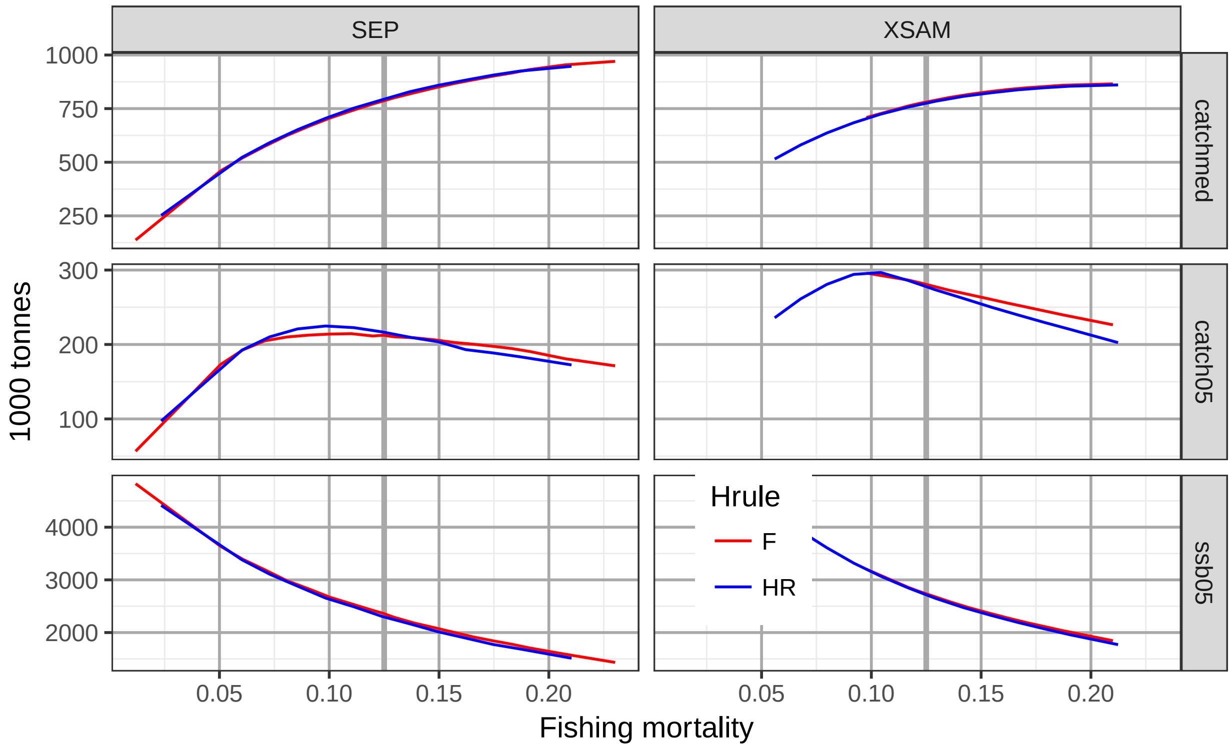

Figure 19: Comparison of 3 metrics using the 2 models and 2 types of harvest control rules. $B_{trigger} = 3184$. No stabilizer.

Looking in details on the behaviour of HR and F rules from XSAM shows that median catch in the long term increases with F_{target} and and to get maximum median yield means getting the highest F that is precautionary which in this case turns out to be in the medium term. Both rules give medium catch for given F (figure 20) but the F rule is precautionary over little more range (tables 3 and 4)

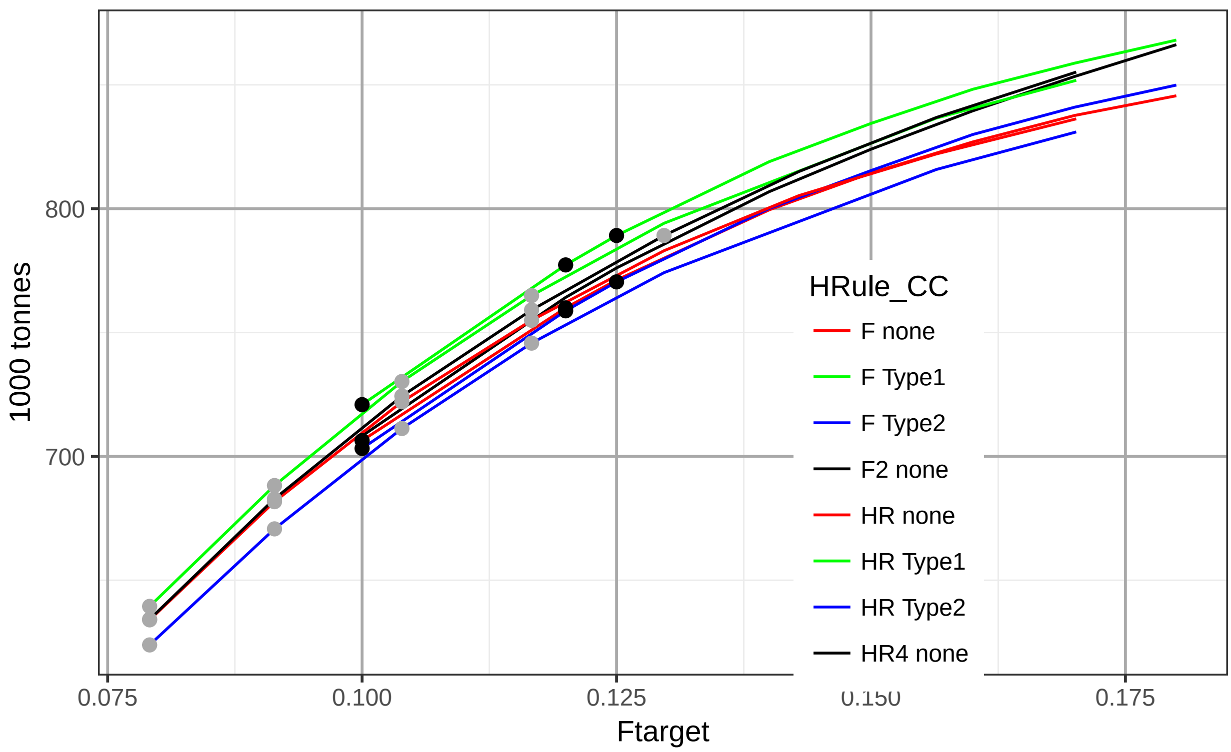

Figure 20: Medium of catch in the long term vs fishing mortality for F and HR rules. The points are in the area that is precautionary, grey points are HR rules but black points F rules. F is not a target in the HR rule but rather median F obtained for a given HR. Rules 2 and 4 only shown without stabiliser

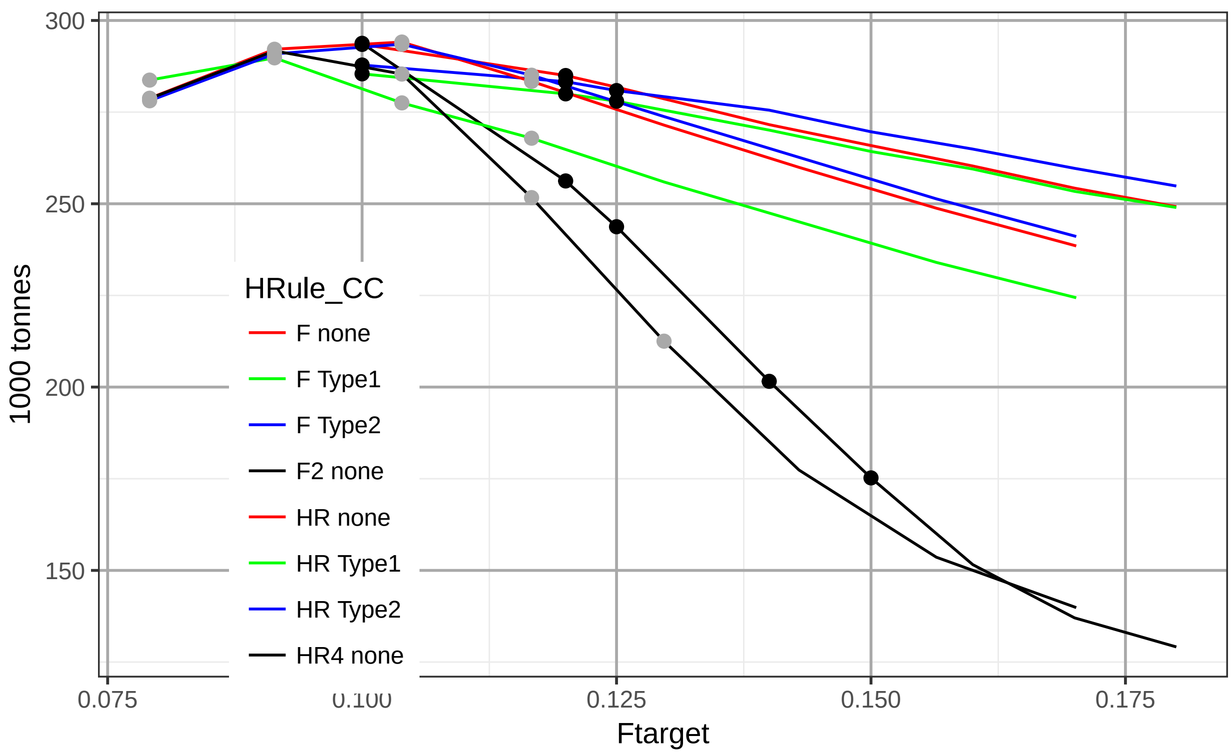

Figure 21: 5th percentile of catch in the long term vs fishing mortality for F and HR rules. The points are in the area that is precautionary, grey points are HR rules but black points F rules. F is not a target in the HR rule but rather median F obtained for a given HR. Rules 2 and 4 only shown without stabiliser

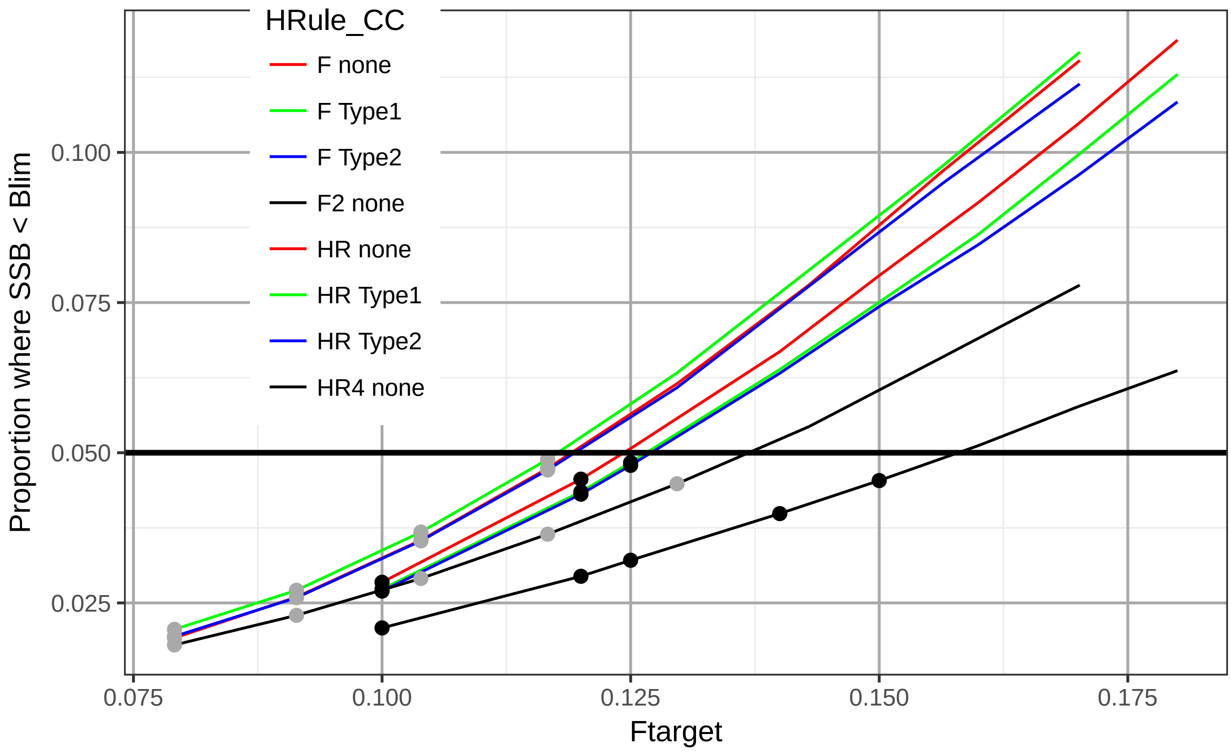

Figure 22: Risk vs fishing mortality for F and HR rules. The points are in the area that is precautionary, grey points are HR rules but black points F rules. F is not a target in the HR rule but rather median F obtained for a given HR. Rules 2 and 4 only shown without stabiliser

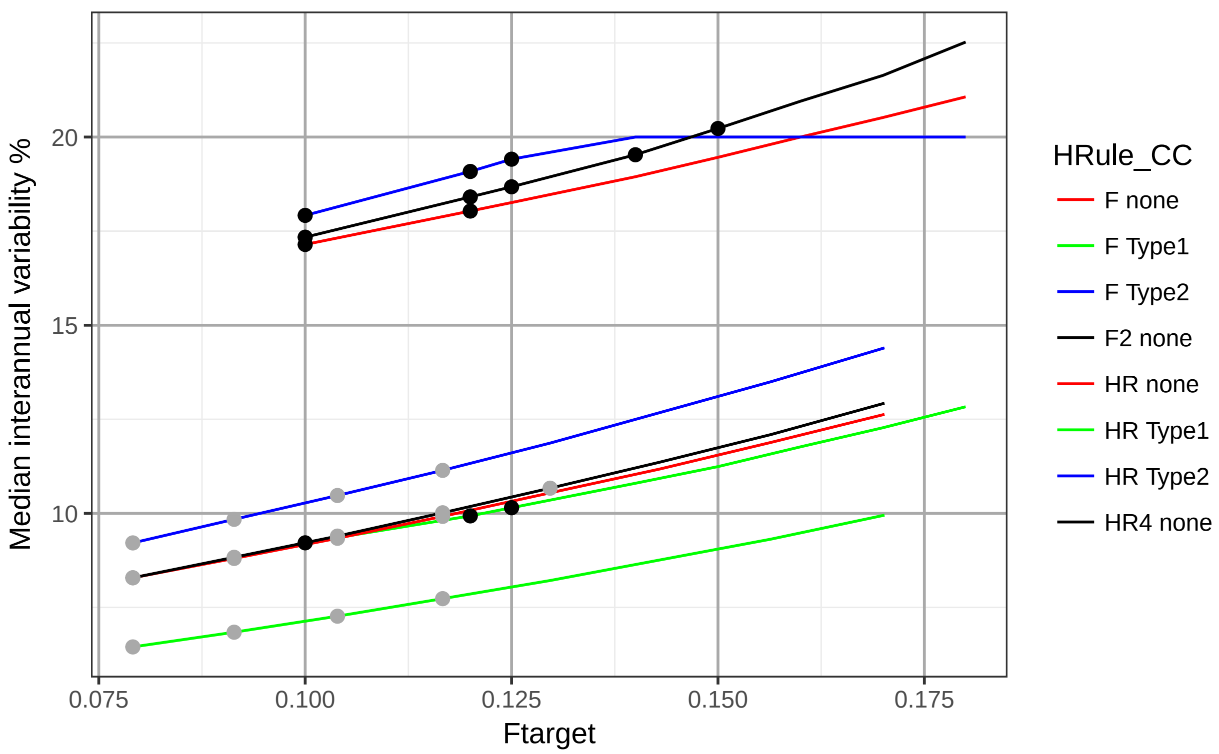

Figure 23: Median of interannual variability vs fishing mortality for F and HR rules. The points are in the area that is precautionary, grey points are HR rules but black points F rules. F is not a target in the HR rule but rather median F obtained for a given HR. Rules 2 and 4 only shown without stabiliser

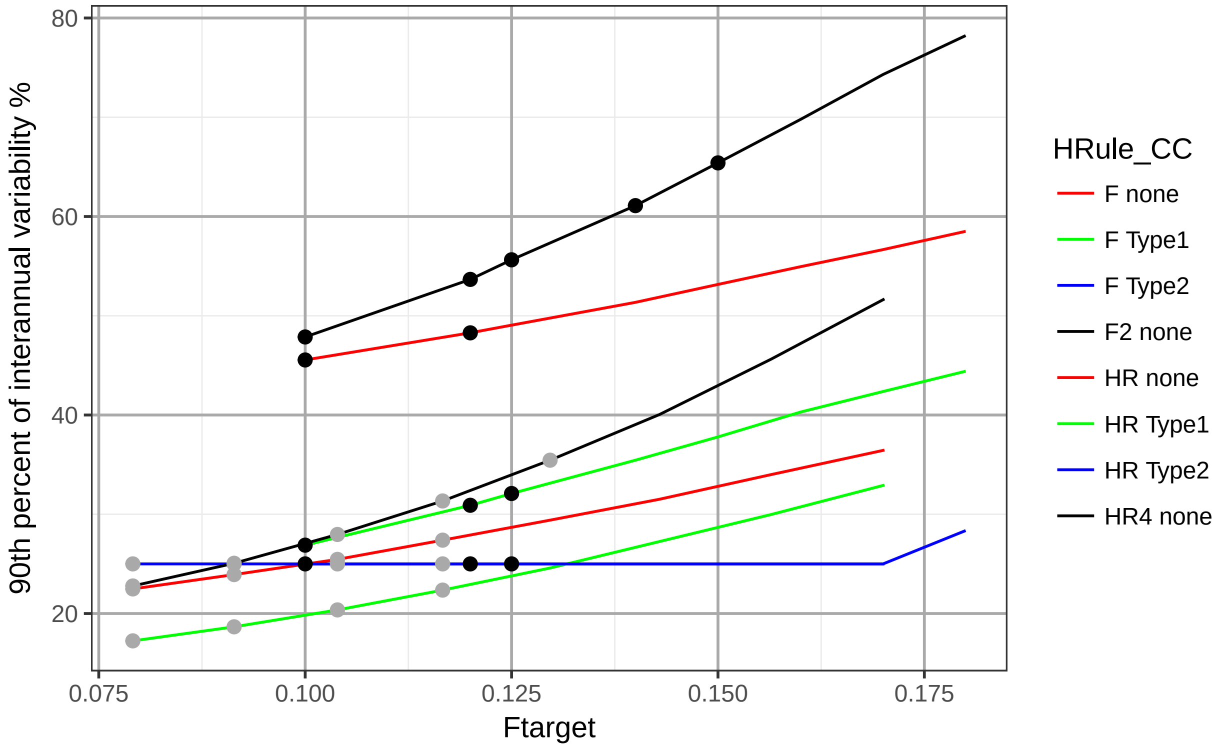

Figure 24: 90th percentile of interannual variability vs fishing mortality for F and HR rules. The points are in the area that is precautionary, grey points are HR rules but black points F rules. F is not a target in the HR rule but rather median F obtained for a given HR. Rules 2 and 4 only shown without stabiliser

	Hrule-CC	Cmedt	Clongt	C05longt	iav	iav90	NA
1	Rule1-none	0.124	653.000	769.000	282.000	18.200	48.900
2	Rule1-Type1	0.127	669.000	793.000	277.000	10.200	32.500
3	Rule1-Type2	0.127	645.000	775.000	280.000	19.500	25.000
4	Rule2-none	0.158	742.000	837.000	156.000	20.800	68.900

Table 3: Estimated F05 for F rule with catch stabilisers, median catch in medium an long term, 5th percentile of long term catch, median interannual variablity and 90th percentile of interannual variability at those points

	Hrule-CC	Cmedt	Clongt	C05longt	iav	iav90	NA
1	Rule3-none	0.102	633.000	760.000	281.000	10.000	27.800
2	Rule3-Type1	0.101	625.000	768.000	267.000	7.800	22.600
3	Rule3-Type2	0.102	617.000	752.000	283.000	11.300	25.000
4	Rule4-none	0.116	687.000	804.000	192.000	11.000	37.900

Table 4: Estimated HR05 for biomass rule rule with catch stabilisers, median catch in medium an long term, 5th percentile of long term catch, median interannual variablity and 90th percentile of interannual variability at those points

In terms of interannual variability the biomass rule seems to perform better than F rule, especially in the XSAM model (figure 25). Why the difference is so large for the XSAM model is not clear but the SEP model does also show lower interannual variability with the biomass rule.It can also be seen that the assessment error has some effect on interannual variability. (figures 26 and 27). Figure 27 does though show that assessment error and stochastic weights do not explain that the difference between interannual variability between F and HR rule is much more in XSAM than the SEP model (figure 25)

Summary from biomass and F rules operating at maximum F/HR that is sustainable in the median term (tables 4 and 3) show the F rule superior in term of some metrics the biomass rule in terms of other. The difference in the "precaution" is most likely in $B_{trigger}$ that is defined in the assessment year for the biomass rule (1 year earlier) and is not exactly in terms of SSB. The biomass rule is still much less complicated an performance more or less the same. F obtained from type III risk is little lower than F based on medium term (the year with highest risk is 2023).

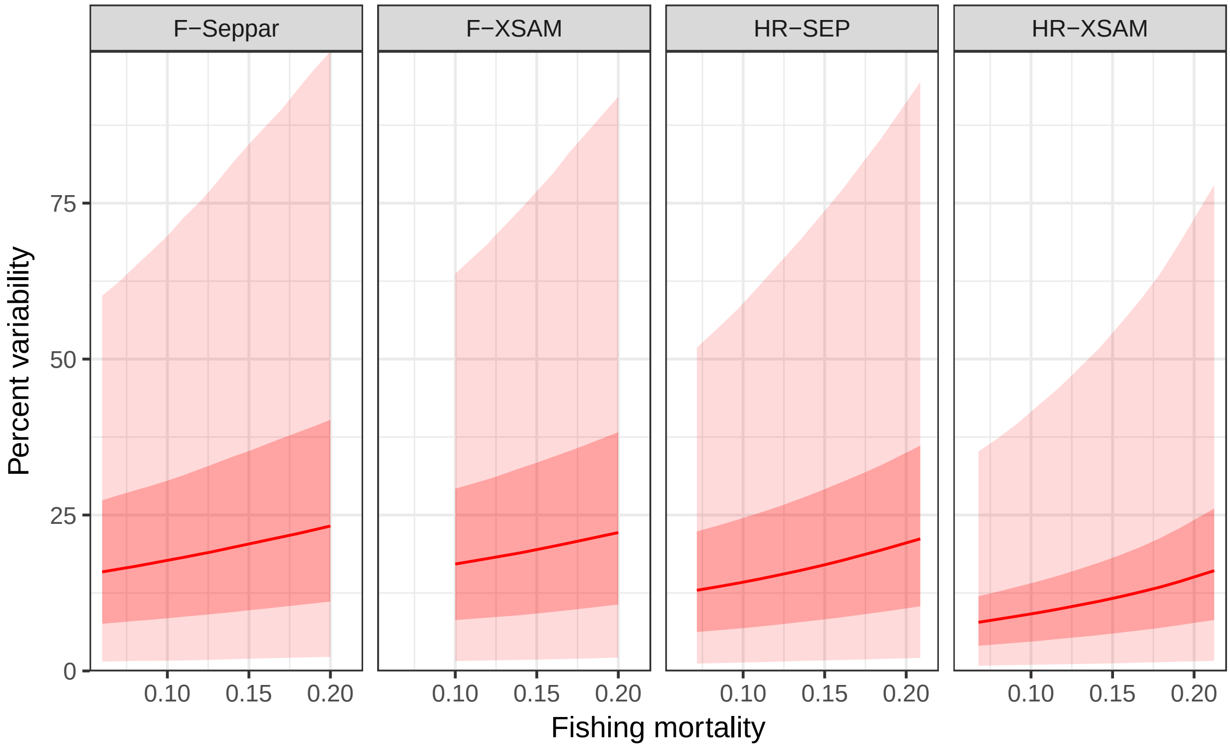

Figure 25: Interannual variability of catches. The shaded areas show 5th, 25th, 75th and 95th probability. The red line shows the median. No stabilizer, $B_{trigger} = 3184$.

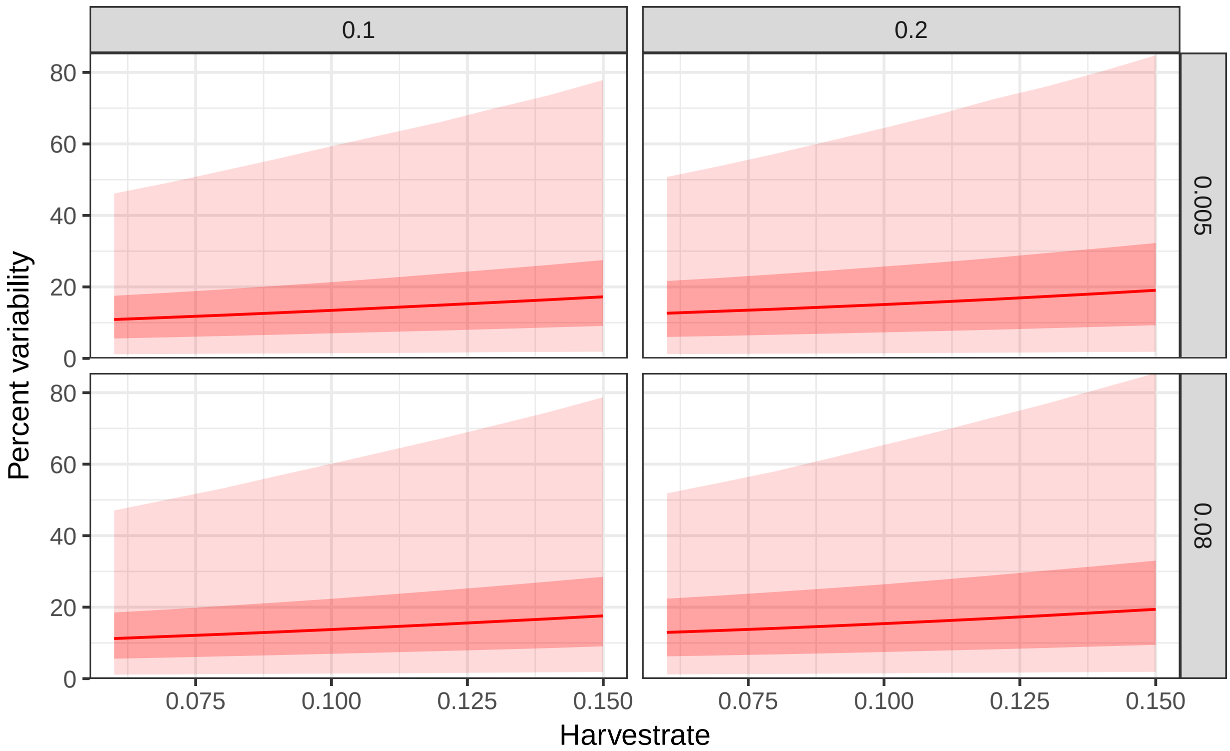

Figure 26: Interannual variability of catches for CV of assessment error 0.1 and 0.2 and CV of weights 0.005 and 0.08. SEP modle with no no stabiliser.

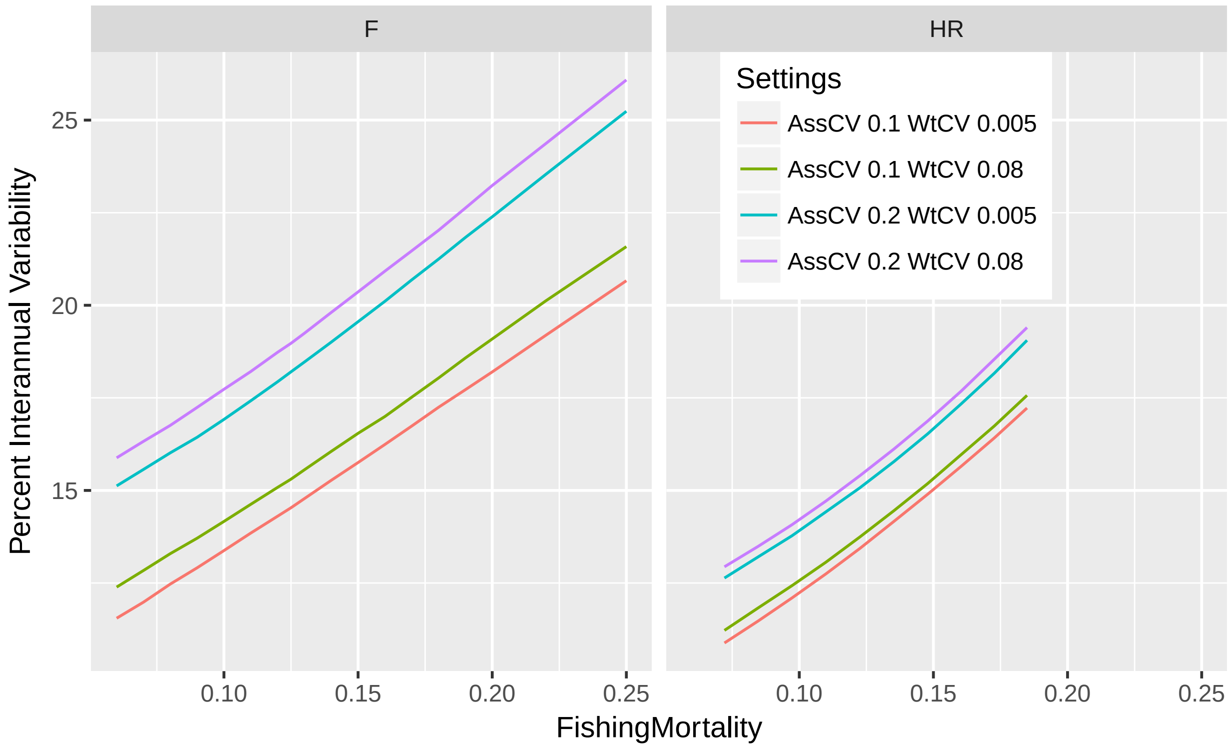

Figure 27: Median of percent individual variability for fishing mortality and harvest rate rules. Results are shown for different level of assessment error and stochasicity in weight. Results based on the SEP model without stabilizer

The request asks for stabilisers to reduce the interannual variability in catches. The request is for 20% percent down 25% up stabiliser but a catch stabiliser where the TAC is the average of last years TAC and what the F_{target}/H_{target} gives was also tested. In the SEP model the weight of last years TAC (0.5) is reduced gradually below $B_{trigger}$ but in XSAM the stabiliser is turned off below $B_{trigger}$ (according to the request). The results are shown in figures 28 and 29 and show that the stabiliser works with no unexpected problems that usually occur when the stabilizer is turned abruptly off around $B_{trigger}$.

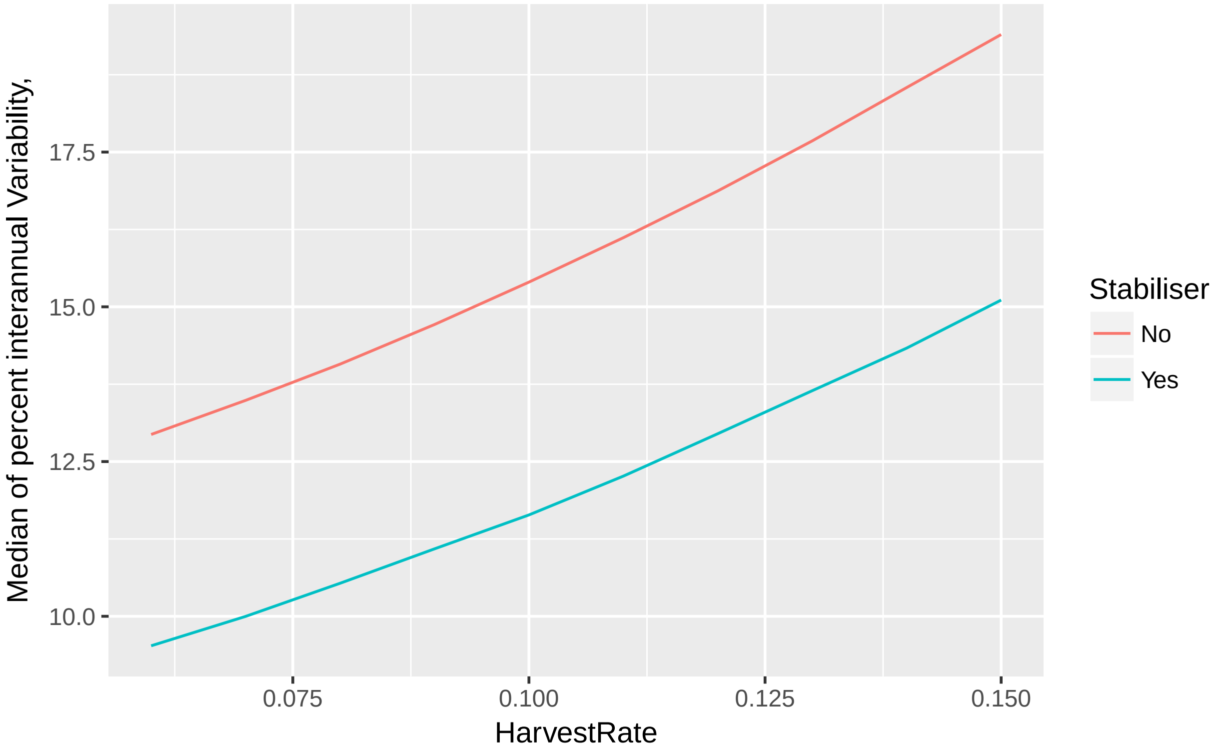

Figure 28: Comparison of median of interannual variability in a Harvest rule with and without a stabilizer. SEP model, Assessment CV 0.2, Weight CV 0.08.

13 Results

The XSAM model is run forward from 2017 until 2054, that is strictly not long enough but most likely enough considering other uncertainty in the work. The development of the spawning stock (figure 30). The figure demonstrates that the risk is highest in the medium term and the selected combinations marginal in that period while they are precautionary in the long term.

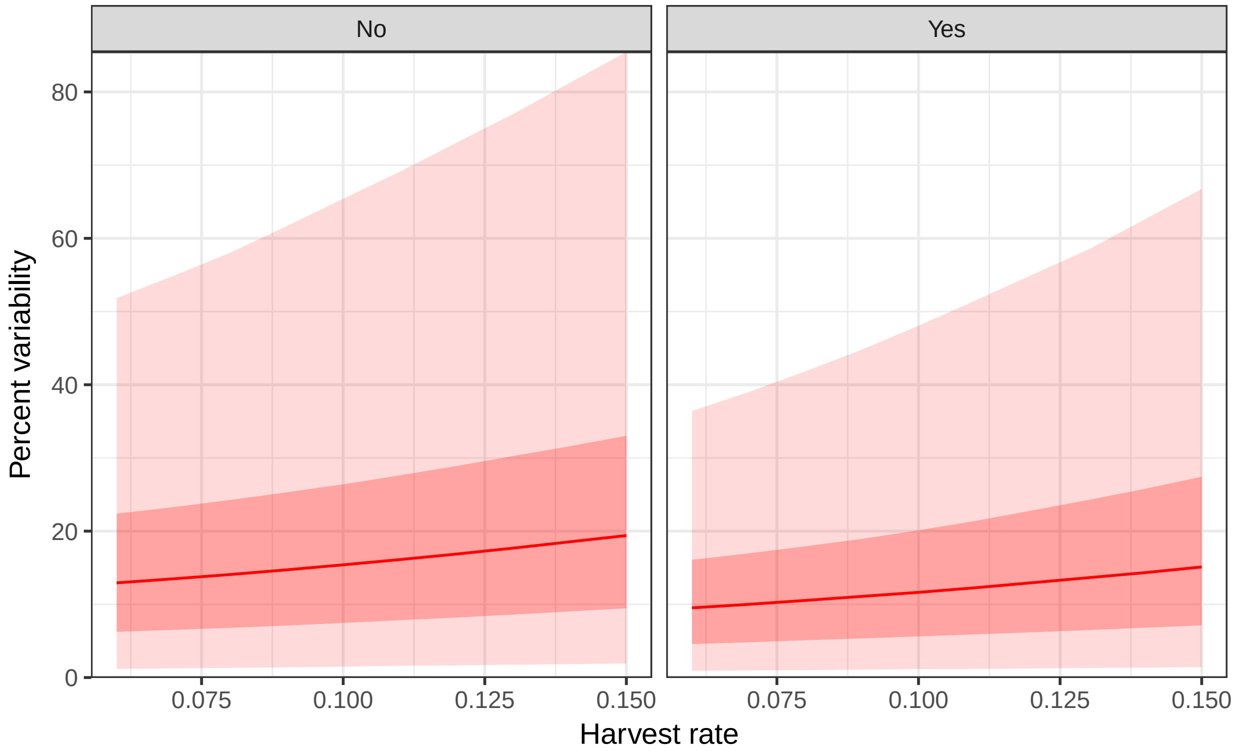

Figure 29: Comparison of median of interannual variability in a Harvest rule with and without a stabilizer. SEP model, Assessment CV 0.2, Weight CV 0.08.

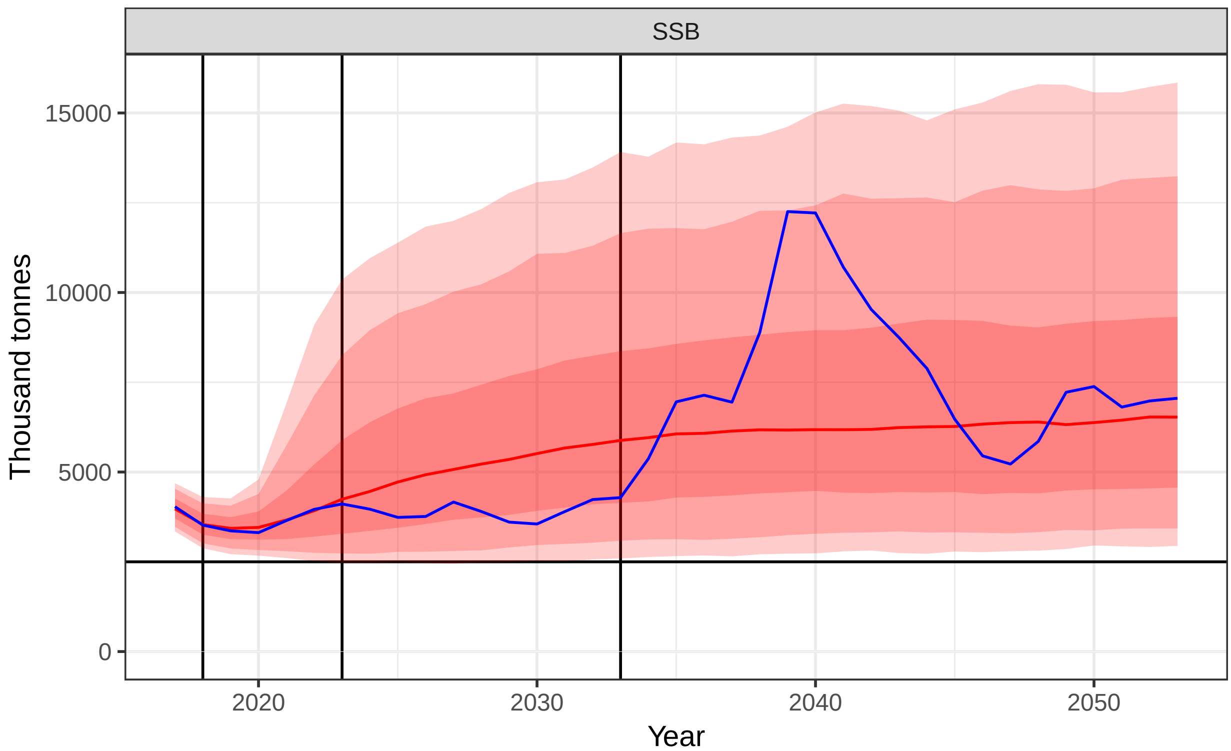

Figure 30: Development of spawning stock 2017 - 2054 based on XSAM with $F_{target} = 0.125$ and $B_{trigger} = 3184$ The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the red line the median. The black vertical line show what is called short, median and long term and the black horizontal line shows B_{lim}. The blue lines shows one iteration.

14 Conclusions

Using estimated breakpoint from a Hockey stick fit as candidate for B_{lim} is not a perfect solution but does a better method exist. For this stock the value of the break point turns out to be relatively robust to model settings but standard error of the estimate is close to 0.3. Compared to most other stocks the breakpoint is relatively well defined.

Basing runs on the timeperiod 1950-2017 makes the results sensitive to inclusion of catches of ages 0 and 1. Having to include those agegroups is in itself a problem as the effect of the fisheries on ages 0 and 1 depend much on the assued M for those ages. In the runs shown here (table 2) maximum median yield is reasonably constant for different estimation periods.

Comparison of the XSAM and SEP results do indicate lower F_{05} from the latter model. The range is between 0.1-0.15 in the long term for most of the settings tested. For exactly the run presented from XSAM the values are 0.115 and 0.147. Most of the difference is caused by different method of modelling the stock - recruitment function and how ages 0 and 1 are modelled in the assessment. Larger assessment error used and biological variability could explain around 0.01 of the difference.

The models are based on different assessments (same data) where the SEP assessment gives 12% smaller spawning stock in 2017 leading to little more risk in the short term. The variability in historical recruitment from the XSAM model when SSB exceeds B_{lim} is lower than in the SEP model. Running the SEP model in VPA mode reduces variability, again the catches of age 0 and 1 matter. Increased recruitment variability means increased risk.

Using $B_{trigger} = 3184$ lead to a F_{05} of 0.147 based on the long term but 0.125 in the medium term (XSAM). The latter value should be used as candidate for F_{msy} but it does barely fit in the range of candidate reference points obtained by the SEP model in the long term. Running the XSAM model for very long term leads to F=0.157 that is then defined as F_{msy}, value considered as outlier compared to other values obtained here. In terms of harvest rates HR_{msy} would be 0.102 based on medium term but 0.118 based on long term. In short and medium term the SEP model and VPA version of it lead to $F_{target} \approx 0.1$

The request calls for testing different combinations of $B_{trigger}$, stabilisers and type of actions below $B_{trigger}$. The results are that there are a number of combinations that are precautionary and F_{target} can usually be increased if $B_{trigger}$ is high or action below $B_{trigger}$ rapid as it is in rules 2 and 4.

Comparing F and Biomass rules they lead to similar median catch for the same F but F/HR but F that is precautionary is a little higher for the F rule so medium catch is lower. Interannual variability in catches is though much lower when the biomass rules is used.

The form used in rules 1 and 3 gives the most gradual reduction in F below $B_{trigger}$ but the cost to pay is that F/HR can not be as high. A stabiliser of some form can be recommened for this stock but turning the stabiliser off below B_{tigger} is questionable although it does not matter for low F, low $B_{trigger}$ rules. Stabiliser of type 1 works and there are versions of it where it is gradually turned off. In F rules the selection used to calculate TAC should be a part of the rule.

But the reccomended combinations are either F=0.125, B=3184 or HR=0.1, B=3184, both with type I stabiliser i.e last years TAC gets 50% weight both as target and socalled F_{msy}.

15 Individual runs

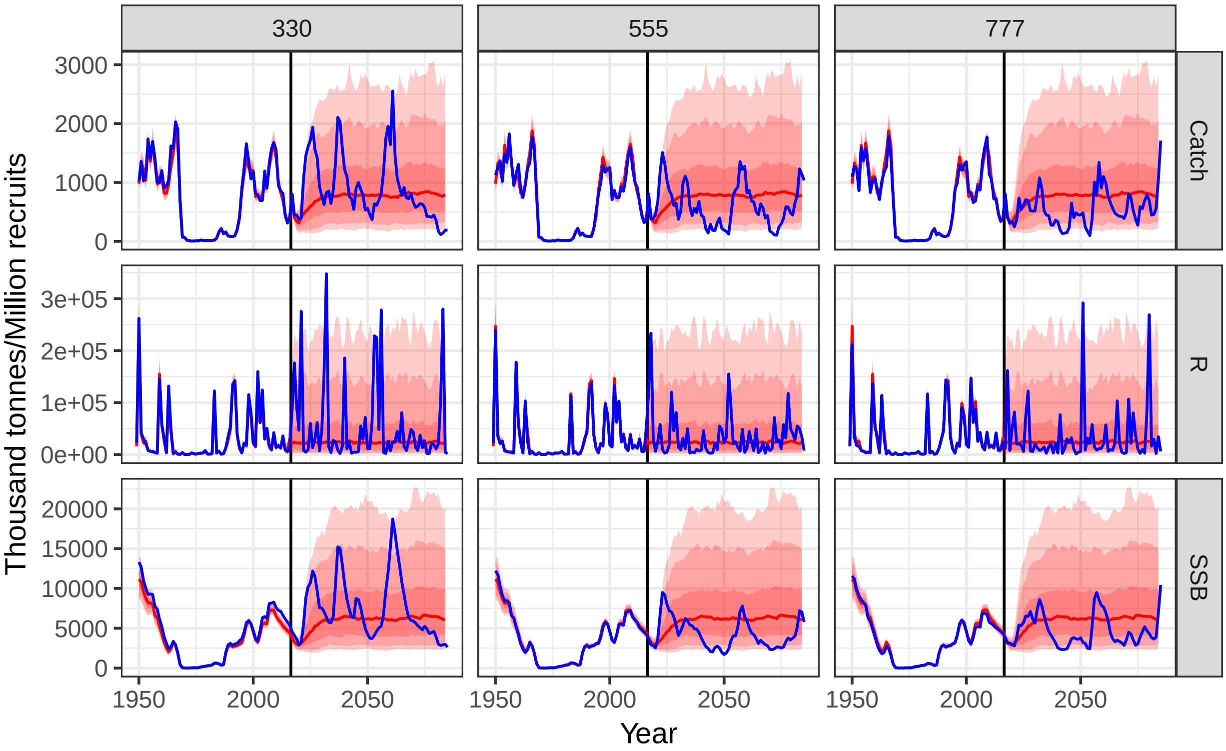

Figure 31: Summaries of spawning stock, recruitment and catch when target fishing mortality is 0.125 and Btrigger 3184. The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the red line the median. 3 individual runs are shown. Hockey stick function with autocorrelation of recruitment estimated. Mean weight average 1988-2016

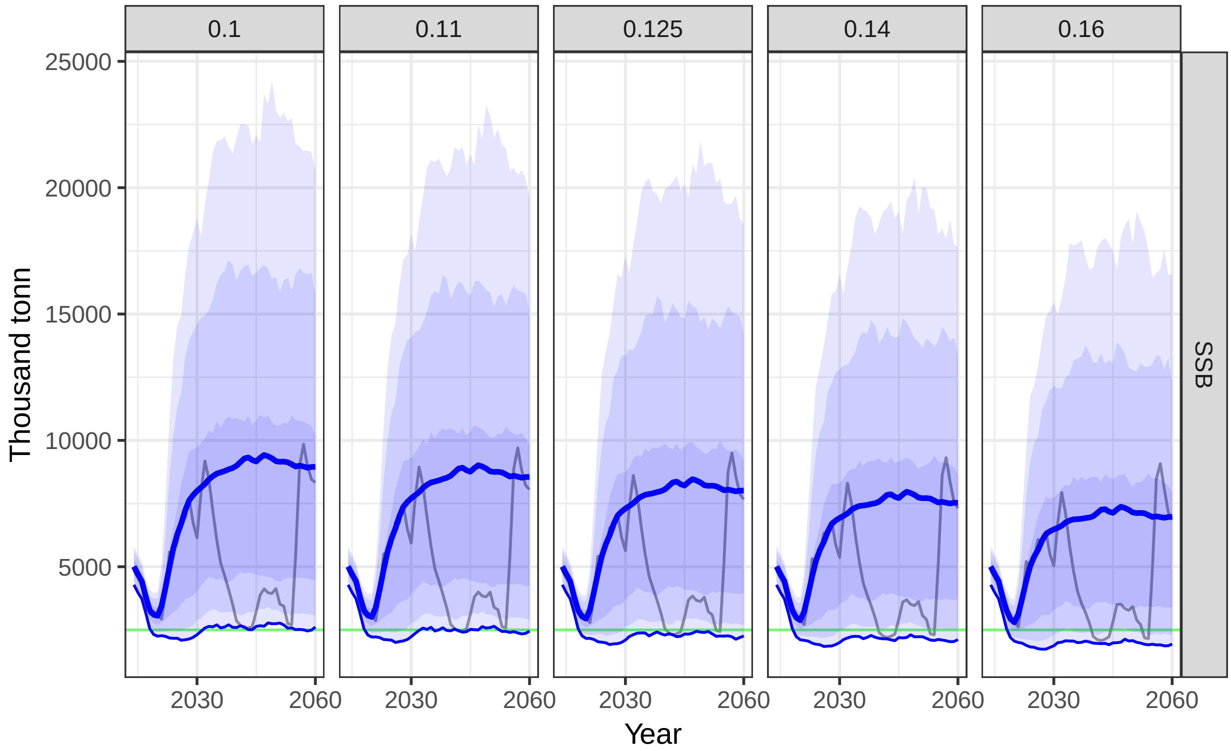

Figure 32: Development of spawning stock for 5 different target fishing mortalities. The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the blue lines the median. One individual run is shown. The horizonal lines shows B_{lim}=2500 thous. tonnes. Hockey stick function with autocorrelation estimated

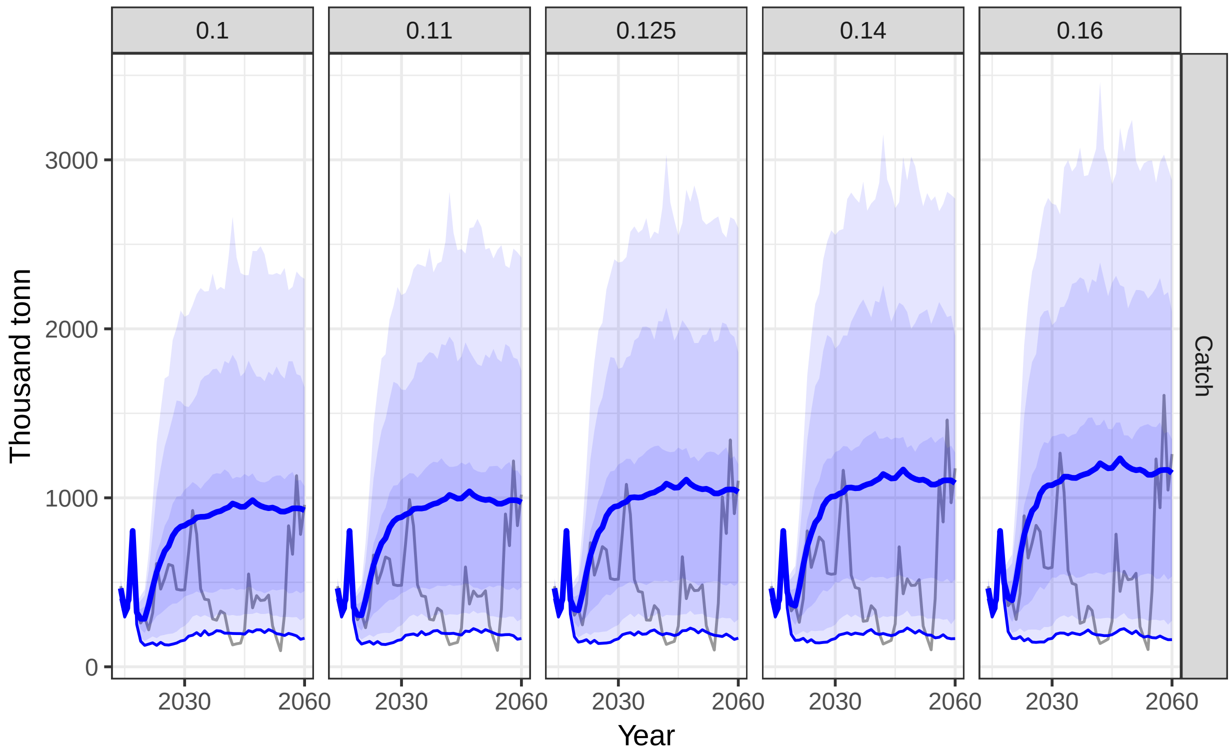

Figure 33: Development of catch for 5 different target fishing mortalities. The shaded areas show 5, 10, 25, 75 90 and 95th percentiles and the blue lines the median. One individual run is shown. Hockey stick function with autocorrelation estimated. Mean weight average of 2011-2015.

STATUS MSE by 26/6-2018

Sondre Aanes

The request is too ambitious to fully answer until WGWIDE 2018.

To be able to at least partly answer the request the scope is narrowed.

The R-code is updated to include all 4 rules in the request and currently include only one option for catch constraint, setting TAC in the quota year as the average of the TAC in the assessment year and the TAC given by the HCR. The code should be quality checked by others to reduce the probability of bugs! The code is available on sharepoint with a working example for estimation of $F_{P0.5}$. If time allow, others catch constraints can be considered.

In the initial analysis a slight bias in the $F_{P0.5}$ established at WKNSSHREF was detected as the value 0.102 gave higher risk levels than anticipated for the HCRs examined here (particularly for rule 1 using F_{target}=0.102 with $B_{trigger}$=3184). It turns out that $F_{P0.5}$ is close to 0.085 as the value 0.102 is biased. The reason for the bias is numerical instabilities due to number of resamples and is elaborated on below. This means a change in harvest proportion of 1.6% (harvest proportion from 1-exp(-0.102)=0.097 to 1-exp(0.085)=0.081 for the revised value. Therefore, the value 0.085 is added to the list of F_{target}'s to consider.

Settings

Use the same settings as in WKNSSHREF unless otherwise noted:

SSB-recruitment model data and model

Use the same age range (2-12+), time range (1950-2017) and model (AIC smoothed SSB-recruit) with 1 order dependency in residuals.

Mean weights and proportion mature at age

Long term unweighted means 1988-2017.

Exploitation pattern

As estimated by XSAM using data 1988-2017 (i.e. exploitation pattern follows the same model).

Assessment/predication error

A full feedback approach will be too elaborate, but provided the cv's and correlations among the estimated and predicted values it is accounted for (see below).

Initial values for MSE

Assessment 2017 and quota for 2018.

Random initial values

Is obtained from the assessment model fit: provides the approximated simultaneous distribution of all parameters and stock sizes such that initial values can be sampled from this approximated distribution. Apply quota for 2018 as catch for 2018. For 2019 onwards catches are given by the management strategies.

One simulation:

Sample one stock size, (and parameters for F etc…) for stock sizes 1. January 2018 from the assessment made in 2017 (initial values). Sample one set of parameters for the spawning stock recruitment model by the same approach as used in WKNSSHREF independently from stock sizes (see *Details on stock recruitment* below for justification). For one set of initial values and set of parameters for spawning stock recruitment, run the model forward with for a given management strategy (using assessment and prediction errors as outlined) until 2053. Repeat this procedure a sufficient number of times until performance criteria have stabilized. The statistics as a function of sample size (number of replicates) are shown in Figure 1. A visual inspection suggests that the sample sizes should be kept above 2000. I have chosen 3000 replicates which on average take slightly more than 1 minute on my computer.

Details on HCR's

Notation

Assessment year: y

Quota year: $y+1$

Prediction of biomass or spawning biomass in year $y+1$: $\tilde{B}_{y+1}$ and $\widetilde{SSB}_{y+1}$, respectively.

A mathematical formulation of all rules follows to be very precise on how to interpret the rules (and avoid confusion later)

Rule 1

The quota is given by

$$F_{y+1} = \begin{cases} F_{target} \times \widetilde{SSB}_{y+1} / B_{trigger}, & \widetilde{SSB}_{y+1} < B_{trigger} \\ F_{target}, & \widetilde{SSB}_{y+1} \geq B_{trigger} \end{cases}$$

Rule 2

$$F_{y+1} = \begin{cases} F_{min}, & \widetilde{SSB}_{y+1} \leq B_{lim} \\ \alpha + \beta \times \widetilde{SSB}_{y+1}, & B_{lim} < \widetilde{SSB}_{y+1} < B_{trigger} \\ F_{target}, & \widetilde{SSB}_{y+1} \geq B_{trigger} \end{cases}$$

Where the slope $\beta = (F_{target} - F_{min})/(B_{trigger} - B_{lim})$ and intercept $\alpha = F_{target} - \beta \times B_{trigger}$.

Note that rule 1 is a special case of rule 2 with $F_{min} = B_{lim} = 0$ and setting $B_{trigger} = 0$ means fishing with a constant F.

Rule 3

$$TAC_{y+1} = \begin{cases} HR_{target} \times B_{ref,y}, & \widetilde{SSB}_{proxy,y} \geq B_{trigger} \\ HR_{target} \times B_{ref,y} \times \widetilde{SSB}_{proxy,y} / B_{trigger}, & \widetilde{SSB}_{proxy,y} < B_{trigger} \end{cases}$$

Rule 4

$$TAC_{y+1} = \begin{cases} HR_{lowest} \times B_{ref,y}, & \widetilde{SSB}_{proxy,y} \leq B_{lim} \\ \alpha + \beta \times B_{ref,y} \times \widetilde{SSB}_{proxy,y}/B_{trigger}, & B_{lim} < \widetilde{SSB}_{proxy,y} < B_{trigger} \\ HR_{target} \times B_{ref,y}, & \widetilde{SSB}_{proxy,y} \geq B_{trigger} \end{cases}$$

With constraints

$$\alpha + \beta \times B_{ref,y} \times B_{lim}/B_{trigger} = HR_{lowest} \times B_{ref,y}$$

and

$$\alpha + \beta \times B_{ref,y} \times B_{trigger}/B_{trigger} = HR_{target} \times B_{ref,y}$$

Which has solution

$$\alpha = HR_{lowest} \times B_{ref,y} - \beta \times B_{ref,y} \times B_{lim}/B_{trigger} = \left(HR_{lowest} - \beta \times B_{lim}/B_{trigger}\right) \times B_{ref,y}$$

And

$$\beta = \frac{HR_{target} - HR_{lowest}}{B_{trigger} - B_{lim}} \times B_{trigger}$$

Note that Rule 3 is a special case of Rule 4 with $HR_{lowest} = B_{lim} = 0$ and setting $B_{trigger} = 0$ means fishing with a constant harvest proportion HR_{target}.

Details on F rules

An F rule gives the F in the quota year from which the correspond quota is found F_{y+1}. The F_{y+1} correspond to a specified age range and represent a weighted average over some reference ages

$F_{y+1} = \sum_{a=a_{Fmin}}^{a_{Fmax}} w_{a,y+1}^{F} F_{a,y+1} / \sum_{a=a_{Fmin}}^{a_{Fmax}} w_{a,y+1}^{F}$, where $w_{a,y+1}^{F}$ represent the weights (usually $w_{a,y+1}^{F} = N_{a,y+1}$ i.e. weighted by stock numbers). Write $F_{a,y+1} = F_{mult,y+1} \times s_{a,y+1}$ where $s_{a,y+1}$ is the fishing pattern and $F_{mult,y+1}$ the multiplier to scale the fishing pattern to the corresponding fishing mortality. Then the $F_{a,y+1}$'s are found by solving

$$\begin{aligned} F_{y+1} &= \sum_{a=a_{Fmin}}^{a_{Fmax}} w_{a,y+1}^{F} F_{a,y+1} \Big/ \sum_{a=a_{Fmin}}^{a_{Fmax}} w_{a,y+1}^{F} \\ &= F_{mult,y+1} \sum_{a=a_{Fmin}}^{a_{Fmax}} w_{a,y+1}^{F} s_{a,y+1} \Big/ \sum_{a=a_{Fmin}}^{a_{Fmax}} w_{a,y+1}^{F} \end{aligned}$$

For $F_{mult,y+1}$, i.e.

$$F_{mult,y+1} = F_{y+1} \Big/ \left(\sum_{a=a_{Fmin}}^{a_{Fmax}} w_{a,y+1}^{F} s_{a,y+1} \Big/ \sum_{a=a_{Fmin}}^{a_{Fmax}} w_{a,y+1}^{F} \right)$$

And all $F_{a,y+1}$ is specified by $F_{a,y+1} = F_{mult,y+1} \times s_{a,y+1}$ for all ages provided known $s_{a,y+1}$.

Then the total catch at age in numbers is given by the catch equation

$$C_{a,y+1} = \frac{F_{a,y+1}}{F_{a,y+1} + M_{a,y+1}} (1 - e^{-F_{a,y+1} - M_{a,y+1}}) N_{a,y+1}$$

And the corresponding TAC is given by

$$TAC_{y+1} = \sum_a w_{a,y+1} C_{a,y+1}$$

Where $w_{a,y+1}$ is the mean weight at age in catch at age in the quota year.

Implications of prediction error

As described above, the target F is given by the predicted SSB which contains error.

Then the F multiplier will be affected by the error in the weighting factors $w_{a,y+1}^F$ and selection pattern $s_{a,y+1}$. Finally, the TAC will be affected by the projected $N_{a,y+1}$ which gives $C_{a,y+1}$ in addition to the weight at age in the prediction

Therefore to fully implement error in TAC: generate SSB with error, generate selection with error, generate $N_{a,y+1}$ with error. This will fully reflect the error incorporated in the TAC. The predicted values of SSB_{y+1}, $N_{a,y+1}$ and $s_{a,y+1}$ are generally correlated. In case of positive correlation, the error induced in TAC generated by the F-rule will be larger than if they are independent and is thus important to take into account. The normal approximation of the covariance structure is available from TMB and can be utilized.

Assessment/prediction error

Provided RSE for each variable used in the prediction and corresponding correlations, the prediction error matrix is parameterized as following

Since $Var(x) = [E(x)]^2(e^{\sigma^2} - 1)$ we have that $RSE(x) = SD(x)/E(x) = \sqrt{e^{\sigma^2} - 1}$ and thus $\sigma^2 = ln([RSE(x)]^2 + 1)$. Furthermore, for a multivariate variable

$$\Sigma_p = \sigma R \sigma$$

Table 1. XSAM estimates of CV for predictions of variables entering the HCR for 2018

SSB	$\tilde{N}_{2,2018}$	$\tilde{N}_{3,2018}$	$\tilde{N}_{4,2018}$	$\tilde{N}_{5,2018}$	$\tilde{N}_{6,2018}$	$\tilde{N}_{7,2018}$	$\tilde{N}_{8,2018}$	$\tilde{N}_{9,2018}$	$\tilde{N}_{10,2018}$	$\tilde{N}_{11,2018}$	$\tilde{N}_{12,2018}$
0.12	1.27	0.69	0.45	0.25	0.25	0.21	0.22	0.19	0.24	0.25	0.22

$\tilde{F}_{2,2018}$	$\tilde{F}_{3,2018}$	$\tilde{F}_{4,2018}$	$\tilde{F}_{5,2018}$	$\tilde{F}_{6,2018}$	$\tilde{F}_{7,2018}$	$\tilde{F}_{8,2018}$	$\tilde{F}_{9,2018}$	$\tilde{F}_{10,2018}$	$\tilde{F}_{11,2018}$	$\tilde{F}_{12,2018}$
0.45	0.43	0.41	0.38	0.39	0.39	0.41	0.37	0.40	0.44	0.44

Table 2. XSAM estimates of correlation of predicted values for 2018 in the 2017 asessment

	SSB	$\tilde{N}_{2,201}$	$\tilde{N}_{3,201}$	$\tilde{N}_{4,201}$	$\tilde{N}_{5,201}$	$\tilde{N}_{6,201}$	$\tilde{N}_{7,201}$	$\tilde{N}_{8,201}$	$\tilde{N}_{9,201}$	$\tilde{N}_{10,20}$	$\tilde{N}_{11,20}$	$\tilde{N}_{12,20}$	$\tilde{F}_{2,201}$	$\tilde{F}_{3,201}$	$\tilde{F}_{4,201}$	$\tilde{F}_{5,201}$	$\tilde{F}_{6,201}$	$\tilde{F}_{7,201}$	$\tilde{F}_{8,201}$	$\tilde{F}_{9,201}$	$\tilde{F}_{10,20}$	$\tilde{F}_{11,20}$	$\tilde{F}_{12,20}$
SSB	1.00	0.04	0.04	0.23	0.58	0.44	0.47	0.46	0.56	0.43	0.46	0.60	-0.27	-0.32	-0.29	-0.30	-0.28	-0.32	-0.27	-0.30	-0.30	-0.34	-0.34
$\tilde{N}_{2,201}$	0.04	1.00	0.01	0.05	0.05	0.01	0.04	0.05	0.00	0.01	-0.04	0.00	-0.03	-0.04	-0.03	-0.04	-0.03	-0.02	-0.01	-0.01	-0.02	-0.02	-0.02
$\tilde{N}_{3,201}$	0.04	0.01	1.00	0.11	-0.01	0.00	-0.03	0.01	0.02	0.03	0.08	0.04	-0.06	-0.06	-0.05	-0.04	-0.05	-0.05	-0.06	-0.04	-0.08	-0.04	-0.04
$\tilde{N}_{4,201}$	0.23	0.05	0.11	1.00	0.02	0.11	0.06	0.08	0.04	0.09	0.07	0.07	-0.09	-0.09	-0.01	-0.08	-0.03	-0.07	-0.05	-0.06	-0.06	-0.08	-0.08
$\tilde{N}_{5,201}$	0.58	0.05	-0.01	0.02	1.00	0.15	0.15	0.16	0.20	0.15	0.14	0.08	-0.25	-0.31	-0.27	-0.19	-0.23	-0.21	-0.21	-0.23	-0.21	-0.06	-0.06
$\tilde{N}_{6,201}$	0.44	0.01	0.00	0.11	0.15	1.00	0.26	0.18	0.20	0.18	0.21	0.07	-0.19	-0.23	-0.28	-0.29	-0.16	-0.17	-0.16	-0.20	-0.17	-0.01	-0.01
$\tilde{N}_{7,201}$	0.47	0.04	-0.03	0.06	0.15	0.26	1.00	0.36	0.34	0.26	0.28	-0.01	-0.29	-0.32	-0.31	-0.40	-0.42	-0.28	-0.25	-0.28	-0.26	0.12	0.12
$\tilde{N}_{8,201}$	0.46	0.05	0.01	0.08	0.16	0.18	0.36	1.00	0.39	0.34	0.34	0.07	-0.28	-0.25	-0.26	-0.28	-0.38	-0.45	-0.25	-0.26	-0.29	0.07	0.07
$\tilde{N}_{9,201}$	0.56	0.00	0.02	0.04	0.20	0.20	0.34	0.39	1.00	0.50	0.41	0.04	-0.36	-0.38	-0.40	-0.41	-0.40	-0.47	-0.58	-0.41	-0.40	0.15	0.15
$\tilde{N}_{10,20}$	0.43	0.01	0.03	0.09	0.15	0.18	0.26	0.34	0.50	1.00	0.49	0.06	-0.31	-0.31	-0.31	-0.36	-0.33	-0.36	-0.38	-0.57	-0.32	0.19	0.19

$\tilde{N}_{11,20}$	0.46	-0.04	0.08	0.07	0.14	0.21	0.28	0.34	0.41	0.49	1.00	0.13	-0.32	-0.34	-0.33	-0.39	-0.35	-0.37	-0.34	-0.46	-0.61	0.14	0.14
$\tilde{N}_{12,20}$	0.60	0.00	0.04	0.07	0.08	0.07	-0.01	0.07	0.04	0.06	0.13	1.00	0.18	0.16	0.18	0.19	0.21	0.14	0.22	0.15	0.12	-0.75	-0.75
$\tilde{F}_{2,201}$	-0.27	-0.03	-0.06	-0.09	-0.25	-0.19	-0.29	-0.28	-0.36	-0.31	-0.32	0.18	1.00	0.50	0.53	0.46	0.55	0.53	0.51	0.49	0.51	-0.46	-0.46
$\tilde{F}_{3,201}$	-0.32	-0.04	-0.06	-0.09	-0.31	-0.23	-0.32	-0.25	-0.38	-0.31	-0.34	0.16	0.50	1.00	0.53	0.55	0.54	0.54	0.50	0.50	0.55	-0.46	-0.46
$\tilde{F}_{4,201}$	-0.29	-0.03	-0.05	-0.01	-0.27	-0.28	-0.31	-0.26	-0.40	-0.31	-0.33	0.18	0.53	0.53	1.00	0.50	0.56	0.57	0.54	0.52	0.56	-0.48	-0.48
$\tilde{F}_{5,201}$	-0.30	-0.04	-0.04	-0.08	-0.19	-0.29	-0.40	-0.28	-0.41	-0.36	-0.39	0.19	0.46	0.55	0.50	1.00	0.51	0.51	0.50	0.49	0.53	-0.56	-0.56
$\tilde{F}_{6,201}$	-0.28	-0.03	-0.05	-0.03	-0.23	-0.16	-0.42	-0.38	-0.40	-0.33	-0.35	0.21	0.55	0.54	0.56	0.51	1.00	0.55	0.55	0.53	0.54	-0.54	-0.54
$\tilde{F}_{7,201}$	-0.32	-0.02	-0.05	-0.07	-0.21	-0.17	-0.28	-0.45	-0.47	-0.36	-0.37	0.14	0.53	0.54	0.57	0.51	0.55	1.00	0.52	0.50	0.55	-0.49	-0.49
$\tilde{F}_{8,201}$	-0.27	-0.01	-0.06	-0.05	-0.21	-0.16	-0.25	-0.25	-0.58	-0.38	-0.34	0.22	0.51	0.50	0.54	0.50	0.55	0.52	1.00	0.53	0.54	-0.51	-0.51
$\tilde{F}_{9,201}$	-0.30	-0.01	-0.04	-0.06	-0.23	-0.20	-0.28	-0.26	-0.41	-0.57	-0.46	0.15	0.49	0.50	0.52	0.49	0.53	0.50	0.53	1.00	0.54	-0.55	-0.55
$\tilde{F}_{10,20}$	-0.30	-0.02	-0.08	-0.06	-0.21	-0.17	-0.26	-0.29	-0.40	-0.32	-0.61	0.12	0.51	0.55	0.56	0.53	0.54	0.55	0.54	0.54	1.00	-0.47	-0.47
$\tilde{F}_{11,20}$	-0.34	-0.02	-0.04	-0.08	-0.06	-0.01	0.12	0.07	0.15	0.19	0.14	-0.75	-0.46	-0.46	-0.48	-0.56	-0.54	-0.49	-0.51	-0.55	-0.47	1.00	1.00
$\tilde{F}_{12,20}$	-0.34	-0.02	-0.04	-0.08	-0.06	-0.01	0.12	0.07	0.15	0.19	0.14	-0.75	-0.46	-0.46	-0.48	-0.56	-0.54	-0.49	-0.51	-0.55	-0.47	1.00	1.00

Table 3. XSAM estimates of CV for estimates of biomass 4+ and 5+ in 2017

$\hat{B}_{4+,2017}$	$\hat{B}_{5+,2017}$
0.103	0.104

Table 4. XSAM estimates of correlation between estimates of biomass 4+ and 5+ in 2017

	$\hat{B}_{4+,2017}$	$\hat{B}_{5+,2017}$
$\hat{B}_{4+,2017}$	1.000	0.903
$\hat{B}_{5+,2017}$	0.903	1.000

Details on stock recruitment

For stock recruitment uncertainty in parameters has been accounted for by considering the distribution of parameters based on point estimates of pairs of stock recruitment data. Provided the distribution of each point estimates are available, this could be incorporated in the analysis by e.g. using the entire distribution of data when examining the parameters. However, the uncertainty in the point estimates is already accounted for, at least implicitly. To see this, write the true stock recruitment as $R_t = f\left(S_{t-a_R}; \theta, \sigma\right)$,

Where θ is the parameters for the deterministic part of the process and σ the environmental noise (i.e. the variability around mean recruitment for a given spawning stock $E\left(R_t|S_{t-a_R}\right)$). However R_t and S_{t-a_R} are not precisely known since only estimates are available.

Subject to some assumptions it can be shown that

$$\hat{R}_t = f(\hat{S}_{t-a_R}; \theta, \sigma^*)$$

Where now θ is the same as before while σ^* will includes environmental noise as before in addition to variability depending on the level of uncertainty in the estimates such that $\sigma^* \geq \sigma$. If the uncertainties in the estimates are small compared to the environmental noise, then $\sigma^* \approx \sigma$, and all parameters θ and σ can be estimated based on $\hat{R}_t$ and $\hat{S}_{t-a_R}$ and the uncertainty in parameters in the process can be evaluated by methods such as resampling techniques (e.g. bootstrapping) and will include the uncertainty due to uncertainty in the data used for estimation. It is well known that uncertainty in input data may account for bias in inference if the uncertainty is large, but preliminary tests specifying the sampling distributions of $\hat{R}_t$ and $\hat{S}_{t-a_R}$ as log normal, and treating R_t and S_{t-a_R}

as latent variables estimates of the parameters θ and σ showed only marginal differences of estimates of θ and σ compared to the much simpler approach estimating θ and σ based on $\hat{R}_t$ and $\hat{S}_{t-a_R}$ directly (obtained by TMB). Therefore, the simplified approach is used to estimate θ and σ while the distribution of the parameters is found by bootstrapping based on similar methods as Simmonds et al xxxx as outlined in Aanes et al. WKNSSHREF 2018.

Initial analysis

The initial MSE analysis using HCRs with Ftargets close to $F_{P0.5}$=0.102 gave higher risks than anticipated. Therefore, it was necessary to revisit the analysis and results made for the last run at WKNSSHREF. I find that the $F_{P0.5}$=0.102 is slightly biased upwards. This has one major cause which essentially boils down to numerical instability due to too few resamples. Going into the technical details this can be broken into two factors:

1. At WKNSSHREF we used 1000 resamples of parameters (stock recruitment) and simulating each HCR for 500 years, discarding the first 250 to ensure the process had reached equilibrium. This conclusion was based on the WD presented at WKNSSHREF (Aanes et al 2018). At WKNSSHREF a number of changes to the original analysis (i.e. as in the WD) were made that effected that conclusion, including the definition of risk (average of risk within each time series versus risk across all time series) which was changed to a more common 'ICES definition', changes in biological parameters etc. One test was made to ensure numerical stability of the final results, but it turned out that an error with the use of random seeds shortened the time effective time span of the time series used (the seed was set to equal values in a sequence within each time series) and effectively the results became independent of the changes made in number of resamples and number of years, and this potential problem was thus not discovered.
2. This also resulted in a slight bias in stock recruitment (using the aic smoothed approach, the relative proportion of SSB-R models in use (Beverton Holt, Ricker and Segmented Regression) became biased, and hence the smoothed estimate biased.

Increasing the number of iterations to 2000 appear sufficient for numerical stability of statistics for short, medium and long term (Figure 1) (and also maintain the distribution of recruitment models used for the AIC smoothing). On this basis, the simulations for the reference point were rerun using 2000 replicates each of length 500 and discarding the first 200 gives the results in Figure 2 which suggest a somewhat lower value of $F_{P0.5}$ (~0.085). It is important to notice that this is a minor change, since it means a change in harvest proportion of 1.6% (harvest proportion from 1-exp(-0.102)=0.097 to 1-exp(0.085)=0.081). The result did not appear to be sensitive to the change in use of prediction error (using the estimated simultaneous distribution of the parameters entering the F-rule, see *comments to F-rules* above). On this basis, the MSE evaluation also includes the F target value of 0.085. To be able to finally conclude on the 3d digit, it may be necessary with more simulations (increasing number of resamples as well as increasing the length of the time series beyond 500 time steps). Since this is computer intensive and require relative much storage place and memory the time constraints as restricted this task. On the other hand, precision at the level of third digit of $F_{P0.5}$ is much less troublesome than any other assumption made about e.g. biological parameters (weights, proportion mature and natural mortality at age) and is an argument for reducing number of digits. It should be noted that the most troublesome statistic to estimate with numerical stability is risk factors such as low values of P(B<Blim) or in other words the $F_{P0.5}$ (see also Figure 1). Here, it is necessary with at least 2000 resamples of parameters to keep the results numerical stable within the 3d or 4th digit for a specified year range (e.g. short, medium or long term as defined by the request for the MSE) (see Figure 1).

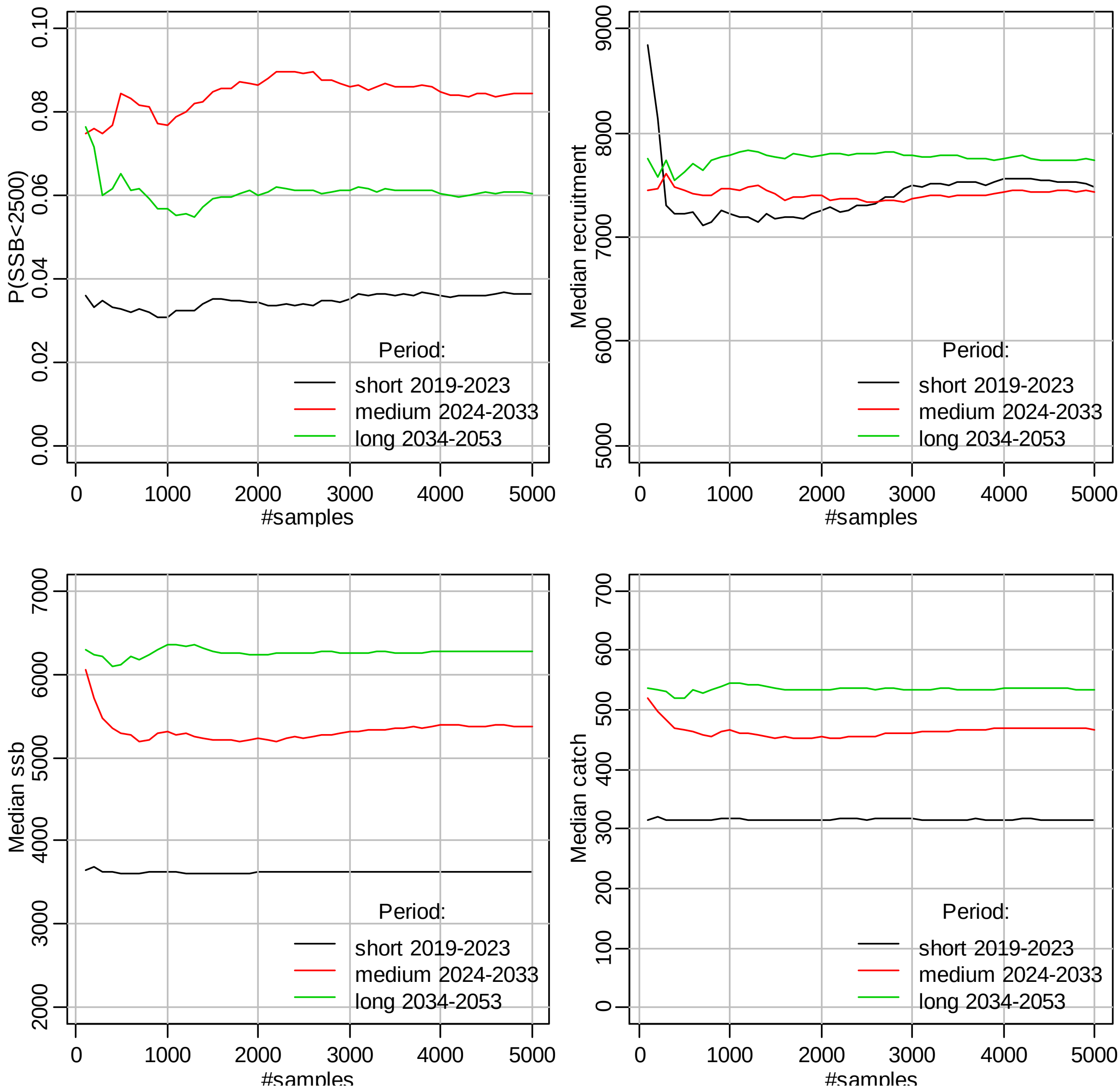

Figure 1. Probability of SSB<2500, median recruitment, ssb and catch for short (black lines), medium (red lines) and long (green lines) term versus number of samples used for calculating the statistics. The HCR used in this example correspond to rule 1 with Ftrigger=0.1 and Btrigger=3184.

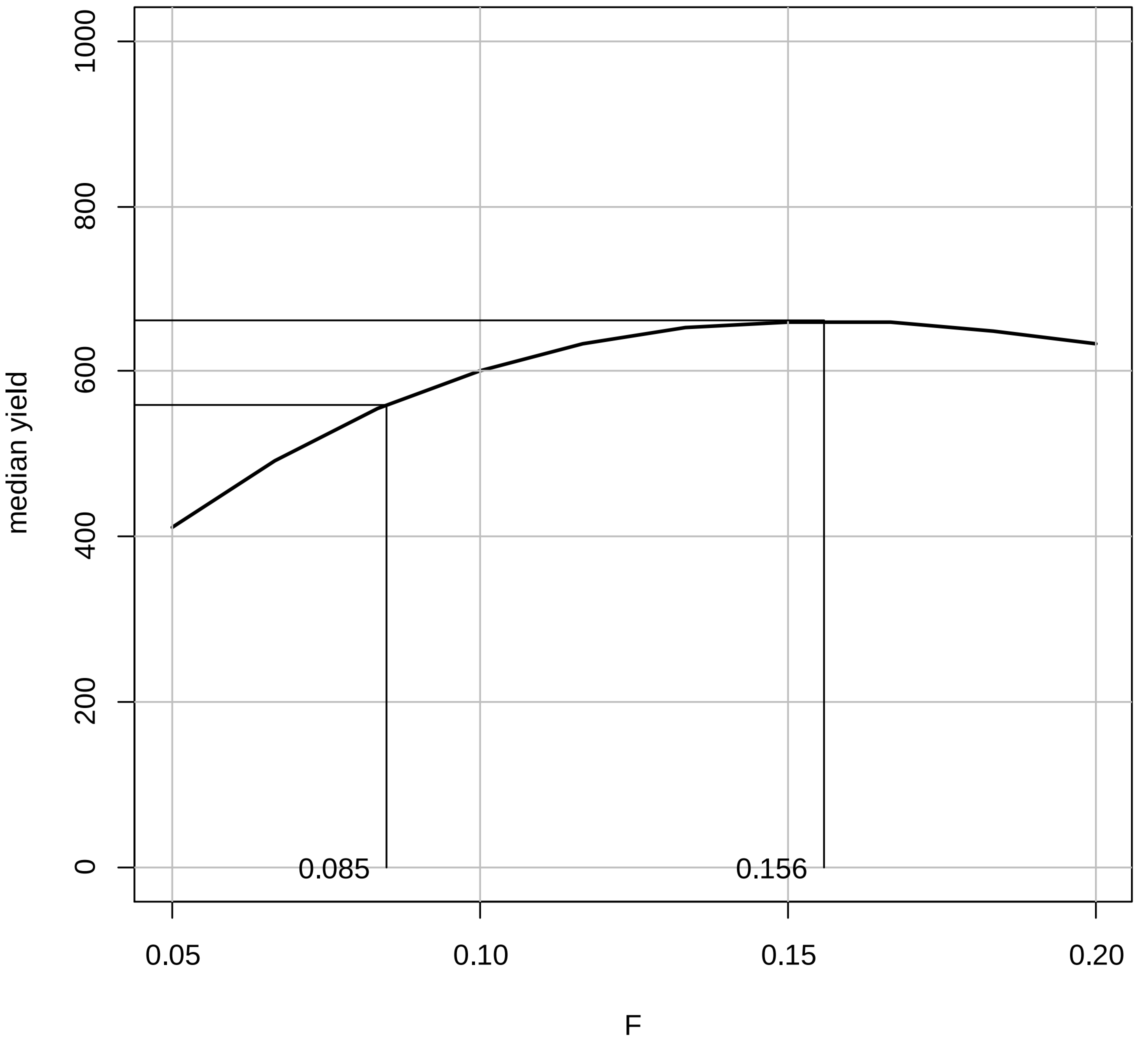

Figure 2. Median catch as a function of Ftarget (weighted average ages 5-12) with no Btrigger.

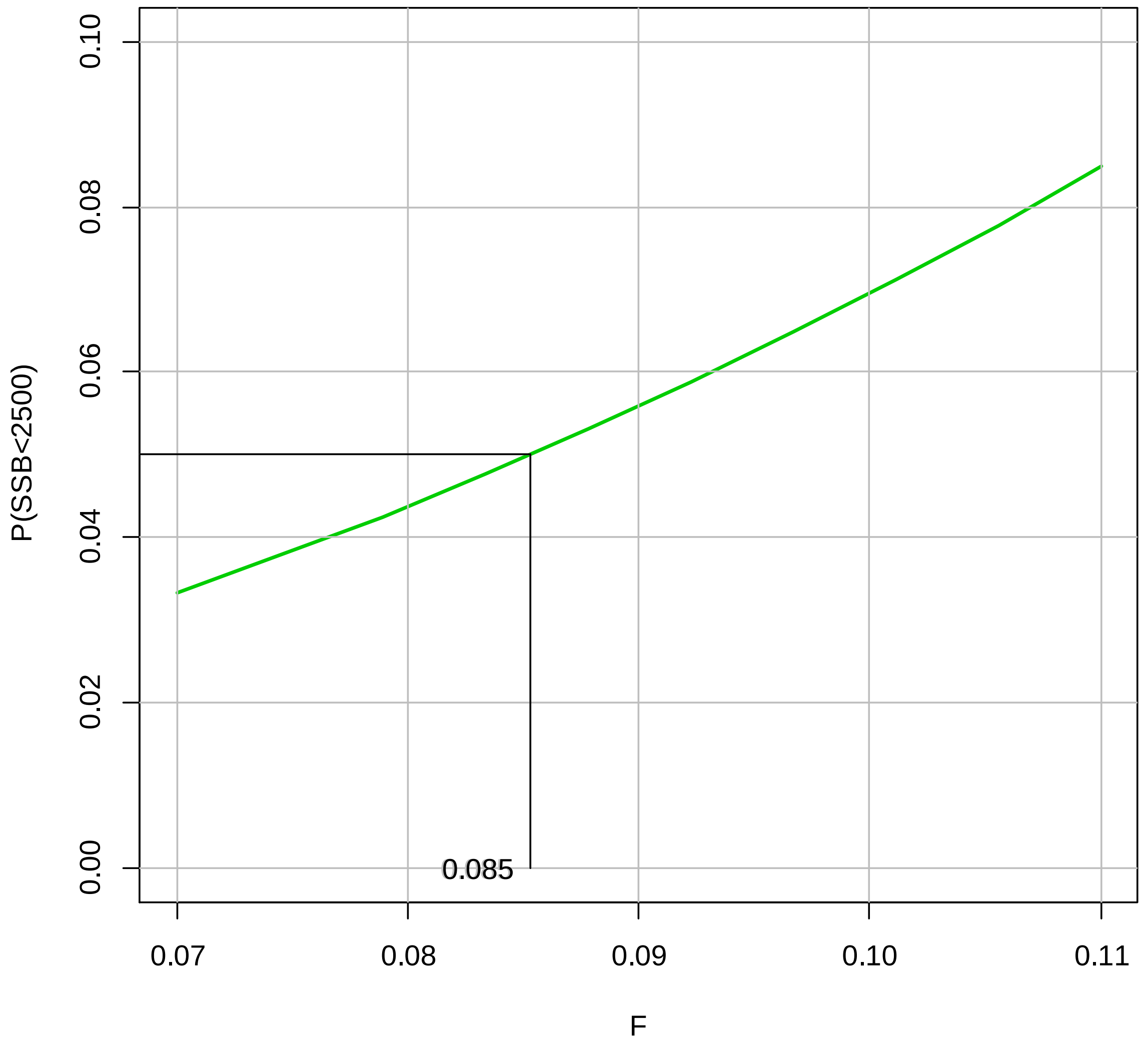

Figure 3. Median catch as a function of Ftarget (weighted average ages 5-12) with Btrigger=3184 using prediction error as described in the text.

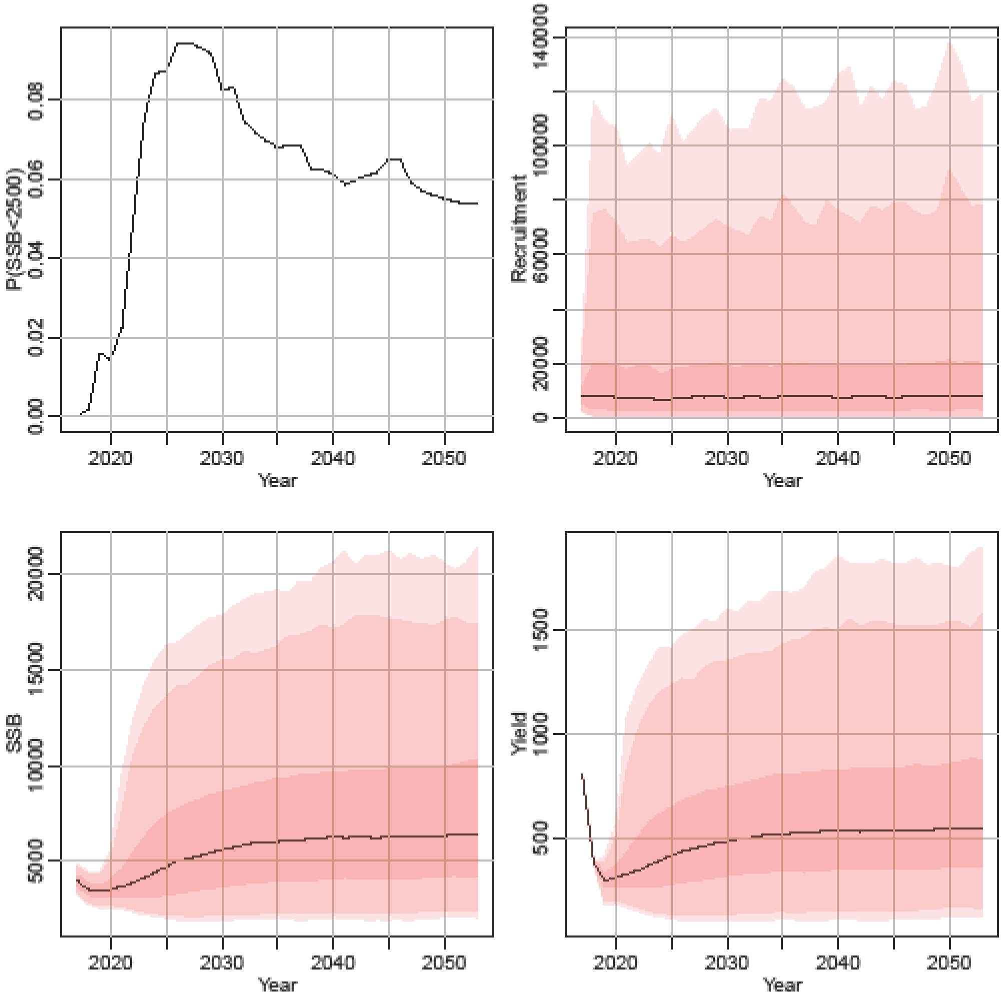

Figure 4. Probability of SSB<2500, recruitment, SSB and yield by years (2017-2053). The solid line for recruitment, SSB and yield is the median value while the shaded areas are 95, 80 and 50% prediction intervals, respectively. The HCR correspond to rule 1 with Ftarget=0.085 and Btrigger=3184

Simulations done with results to be compiled:

Rule 1

All combinations of

Ftargets={0.06, 0.07 ,0.08 ,0.085 ,0.9 ,0.102 ,0.125 ,0.14 ,0.15}

Btriggers={2500, 3184, 3500, 4000, 4500, 5000}

Results in 54 different combinations

Rule 2

All combinations of

Ftargets={0.06, 0.07 ,0.08 ,0.085 ,0.9 ,0.102 ,0.125 ,0.14 ,0.15}

Btriggers={2500, 3184, 3500, 4000, 4500, 5000}

Blim=2500

Fmin={0,0.025,0.05}

Results in 162 different combinations

Rule 3

All combinations of

Harvest proportions 1-exp(-Ftarget), where Ftarget is defined as for Rule 1 and 2

Btriggers={2500, 3184, 3500, 4000, 4500, 5000}

Results in 54 different combinations

Rule 4

All combinations of

Harvest proportions 1-exp(-Ftarget), where Ftarget is defined as for Rule 1 and 2

Btriggers={2500, 3184, 3500, 4000, 4500, 5000}

Blim=2500

Minimum harvest proportions 1-exp(-Fmin), where Fmin is defined as for rule 2

Results in 162 different combinations

Remains: some simulations using catch constraints.

Extra Work

Norwegian spring spawning herring

How to reach conclusions from the work done sofar.

Working for WKNSSHMSE 2018

Höskuldur Björnsson

September 1st 2018

One of the problems with assessment of the spring spawning herring has been consistent overestimation of the stock as shown by the empirical retros from ICES data base. It looks like the empirical retros have improved recently but what happened is that in 2015 the spawning survey that had been discontinued for 6 years was restarted. The first years in the retrospective series are difficult to use as the fishing mortality was really low and the 1983 yearclass was accounting for large proportion of the catches.

Looking at the potential bias, SSB is on the average overestimated by 50% while F is underestimated by 30% from 1996-2010. If the plan is to have F=0.125 and $B_{trigger} = 3184$ the F value will be 0.125/0.7=0.178 until the spawning stock is below $\frac{B_{trigger}}{1.5} = 2122$ i.e the trigger action does not occurr until the stock is well below $B_{trigger}$.

Here a more modest but still quite bad example i.e 25% overestimation of SSB and $F_{est} = \frac{F_{real}}{1.25}$ will be selected. One of the reasons is that $B_{trigger} = 3184$ tonnes becomes in reality close to 2500 tonnes and $F_{realized} = 1.25 * F_{intended}$. Calculations are available for $B_{trigger} = B_{lim} = 2500$ million tonnes that can then be used to present $B_{trigger} = 3184$ with 25% bias. Without bias F_{05} (type III risk) is 0.118 but 0.084 with bias. (figure 1)

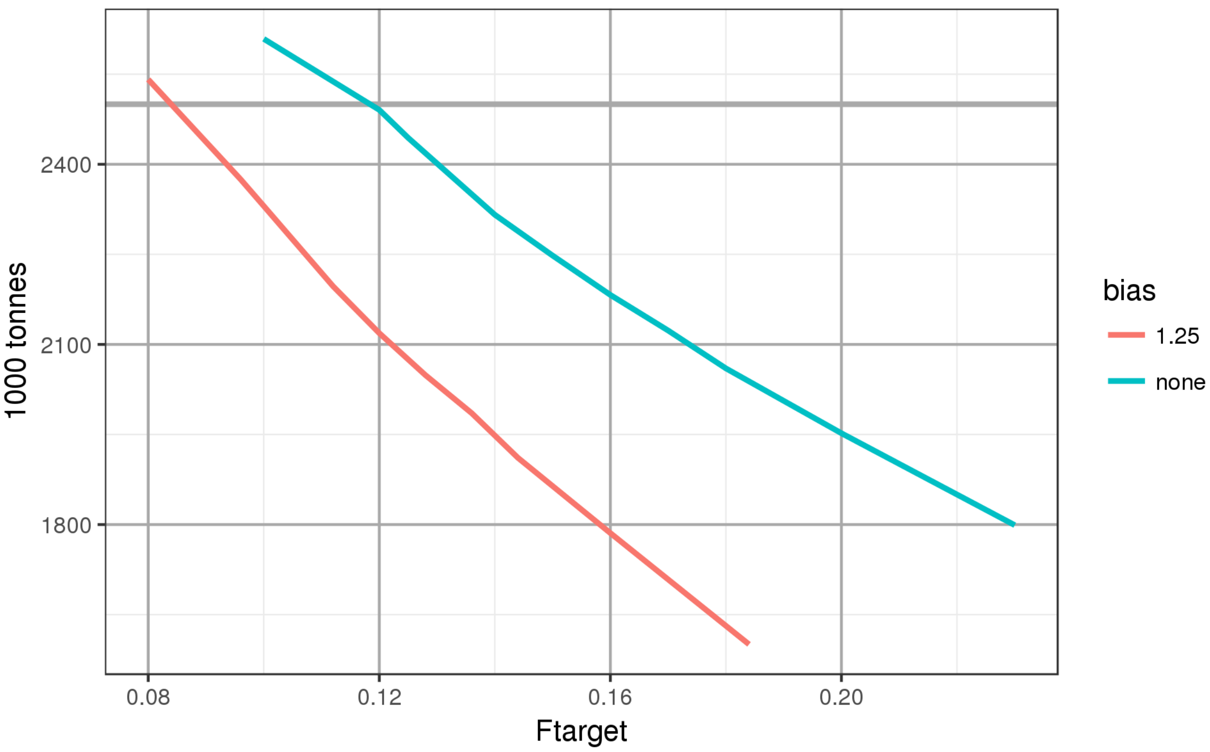

Figure 1: Fifth percentile of SSB against intended F with no bias and 25% bias. Type III risk i.e minimum SSB_{05} in the year giving minimum SSB_{05}.

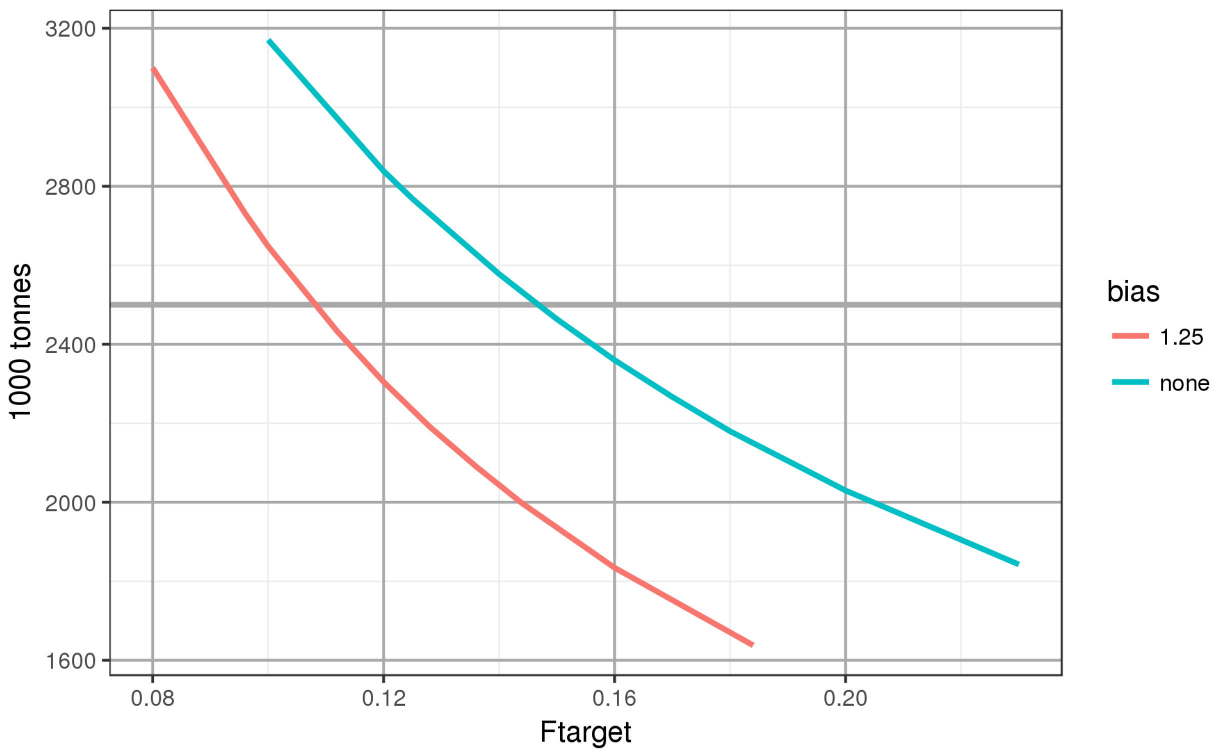

Figure 2: Fifth percentile of SSB against intended F with no bias and 25% bias based on the years 2033-2054.

As may be seen in figure 2 25% bias decreases F_{05} from 0.147 to 0.108 in the long term The realised F is 36% higher than intended F. Similar things happen in the medium term (figure 1) and if a bias is included the starting point might be biased and risk in the short term considerable.

The most interesting thing about the bias is that it does not show up when using analytical retros using only surveys 4 and 5 (see WD from 2016). Part of the problem seems to be related to other surveys conducted irregularly and the last one of those was added in 2015 (survey 1 ssb survey) and that survey does indicate higher stock than survey 5.

All analysis of retrospective bias for this stock are hampered by slow convergence of assessment caused by low F, in recent years. F has recently been particularly low due to steep reduction in adviced F below the current value of $B_{trigger}$. How will the rule of basing "Mohns rho" calculations on last 5 years work for this stock?

To be able to look a little better ath those factors a smoother was set up. (not working perfectly) With a bias of 0.15 F_{05} based on type 3 risk changed from 0.124 to 0.101 (figure 3). Comparable numbers for long term risk (2033-2054) are 0.151 and 0.122. The numbers are not exactly the same as in the simulations as the smoother is not accurate but the ratios are OK. Selected numbers should be run again.

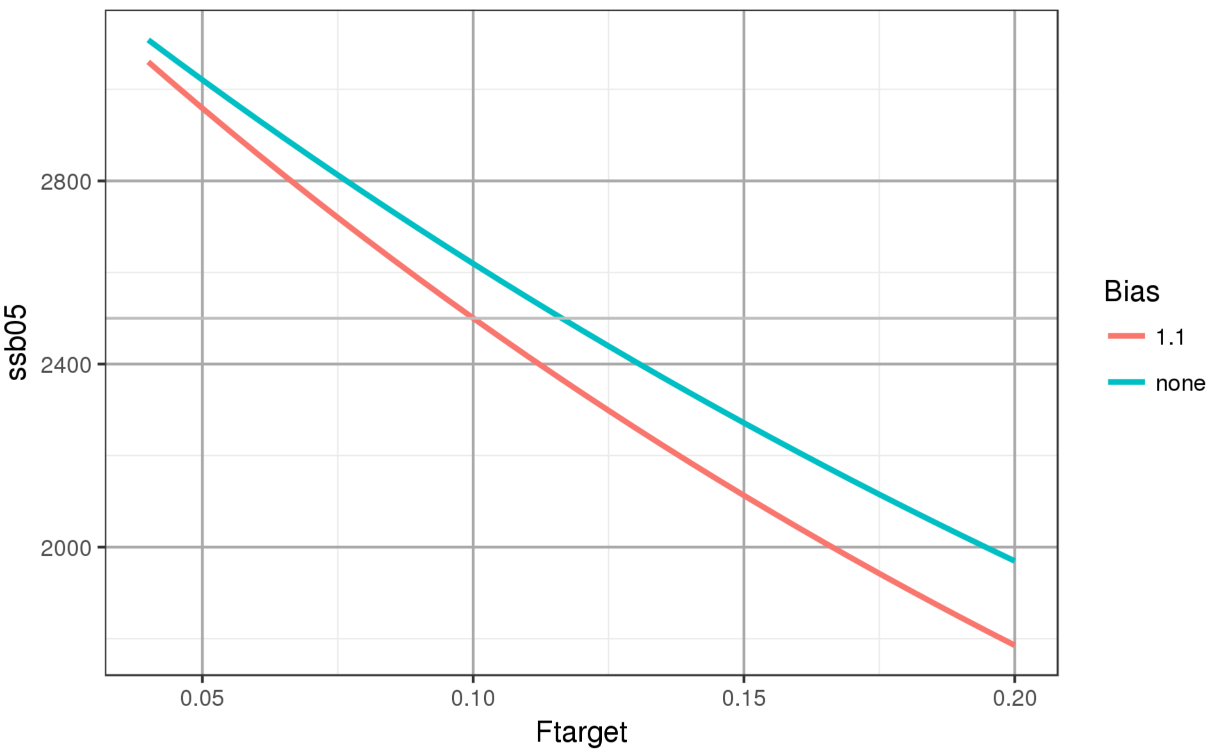

Figure 3: 5th percentile of SSB based on type 3 risk (lowest in any year) with and without 15% bias

10% bias changes F_{05} based on the long term from 0.151 to 0.131 (15%) and F_{05} based on type III from 0.125 to 0.108, again with the reservation that the numbers are not exact.

For Icelandic summer spawning herring advice from ICES was based on historical bias as was done for Icelandic cod in 2009. In both those cases the bias used was on the lower side compared to indications from historical retros (10% for cod, 15% for the Herring). For the spring spawning herring 10-15% seems to be appropriate value to use for bias.

So where do we end.

1. $B_{trigger}$= 3184 kt reduced from 5000 kt.
2. F_{msy} based on different models and configurations 0.1-0.157. Higher values 0.125-0.157 seem more plausible as they are based on VPA modelling of the fisheries of age 0 and 1 before collapse. Using $B_{trigger} = 5000kt$ Fp_{05} is estimated to be 0.2.
3. Short and medium term considerations lead to $Fp_{05} = 0.118$ (type 3 risk) 0.121 if the average over medium term (2023-2032) is used
4. Assessment error in the simulations is on the lower side and biological variability not included. Changing this would lead to reduction in F reference points by approximately 0.01.
5. 10% bias in assessment reduces Fp_{05} values by $\approx$ 15%. 0.157 would change by to 0.136 and then again to 0.126 by including biological variablity. 10% bias is not much looking at empirical.
6. Taking type III risk, bias, and biological variability would lead to $F_{target} \approx 0.1$.
7. Summarizing these points leads to $F_{target} \approx 0.12$, $B_{trigger} = 3184$ both for F_{msy} and F_{target}.
8. Type I catch stabiliser should be used and a type III biomass rule with harvest rate selected to realised F is 0.12 above $B_{trigger}$.

The proposed values of $F = 0.12$ and $B_{trigger} = 3184$ lead to substantial increase in risk from earlier management plan. ($F = 0.125$ and $B_{trigger} = 5000$).

In the end it must be mentioned that many of the factors included here can not be analysed for most stocks, the reason is the length of the data series (including collapse of the stock) and series of historical assessments. Even though the data are good they do not lead to one magic number and the resulting advice should be based on a combination of many factors, among them being in line with earlier work from 1998-2014 that is not obsolete. Perhaps the proposed values lead to too much increase in risk compared to earlier work. A much simpler way would have been to make one EQSIM run and believe the results.

Annex 3: Full set of MSE results

The simulation output tables are found in full on the following pages of Annex 3.

Table A.3.1. Risk,P(SSB<B_{lim}), expressed as % in short, medium and long term for F-rules without and with constraint in interannual TAC change. Unshaded cells correspond to the precautionary (F_{target}, $B_{trigger}$) combinations (P(SSB<B_{lim})<5%).Tables are shown for Prob3 (named here Risk 3).

Risk3 tables for F-rules

Rule 1 - F-rule through 0,0

shortterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	4.2	4.4	6.2	6.7	8.7	9.8	11.0	11.7	13.0	14.9	18.6
3184	3.2	3.4	5.3	5.7	7.1	8.2	8.9	9.3	10.8	12.0	15.4
3500	2.7	2.9	4.5	4.9	6.3	7.3	7.9	8.1	9.2	10.4	13.2
4000	2.1	2.2	3.0	3.5	4.8	5.6	6.3	6.6	7.4	8.2	10.2
4500	1.7	1.8	2.5	2.7	3.5	4.4	4.8	4.9	5.9	6.7	8.1
5000	1.6	1.6	2.0	2.1	2.7	3.0	3.6	3.9	4.5	5.1	6.7

mediumterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	4.2	4.4	6.3	7.0	9.2	10.8	11.9	12.2	14.0	15.7	19.1
3184	3.3	3.5	5.2	5.8	7.5	8.9	9.7	10.2	11.4	12.9	16.2
3500	2.8	3.0	4.5	4.9	6.6	7.5	8.4	8.8	10.1	11.3	14.2
4000	2.3	2.3	3.3	3.7	5.2	6.1	6.8	6.9	8.1	9.2	11.4
4500	1.7	1.8	2.6	2.9	3.7	4.7	5.2	5.5	6.3	7.2	9.1
5000	1.3	1.4	2.0	2.3	3.0	3.5	3.9	4.1	4.8	5.7	7.2

longterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	2.5	2.7	4.7	5.1	6.6	8.0	9.2	9.8	11.7	13.2	17.1
3184	2.0	2.1	3.4	4.0	5.4	6.3	7.3	7.7	9.0	10.7	13.8
3500	1.6	1.7	2.9	3.3	4.5	5.4	6.2	6.5	7.9	9.2	12.1
4000	1.3	1.4	2.3	2.5	3.5	4.3	4.8	4.9	5.9	7.1	9.7
4500	1.1	1.1	1.6	1.8	2.5	3.2	3.7	4.0	4.6	5.4	7.3
5000	0.9	0.9	1.3	1.4	2.0	2.4	2.8	3.0	3.6	4.2	5.4

Rule 1 with average constraint

shortterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	5.0	5.1	6.4	6.7	8.3	9.4	10.3	10.7	12.1	13.2	16.1
3184	3.1	3.3	5.2	5.4	6.3	7.7	8.2	8.5	9.5	11.1	13.5
3500	2.6	2.8	4.2	4.7	5.9	6.7	7.4	7.7	8.6	9.7	12.1
4000	2.1	2.2	3.0	3.4	4.7	5.5	6.1	6.4	7.1	8.0	9.9
4500	1.7	1.8	2.5	2.7	3.5	4.4	4.8	4.9	5.9	6.5	8.0
5000	1.6	1.6	2.0	2.1	2.7	3.0	3.6	3.9	4.5	5.1	6.7

mediumterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	4.5	4.6	6.3	7.1	9.0	10.4	11.4	11.8	13.2	15.0	18.4
3184	3.3	3.4	4.9	5.5	7.0	8.2	9.1	9.5	10.7	12.2	15.0
3500	2.7	2.9	4.3	4.7	6.3	7.1	8.0	8.3	9.5	10.8	13.4
4000	2.3	2.3	3.2	3.6	5.0	5.9	6.5	6.7	7.7	8.8	11.0
4500	1.6	1.7	2.5	2.9	3.7	4.6	5.1	5.3	6.2	7.0	8.9
5000	1.3	1.4	2.0	2.3	3.0	3.4	3.9	4.0	4.8	5.6	7.1

longterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	2.6	2.8	4.8	5.3	7.1	8.6	9.6	10.1	11.8	13.6	18.0
3184	1.9	2.0	3.3	3.7	5.2	6.3	7.2	7.6	9.2	10.7	13.9
3500	1.6	1.7	2.8	3.2	4.4	5.3	6.1	6.4	7.6	9.1	11.8
4000	1.3	1.4	2.2	2.5	3.5	4.2	4.7	4.8	5.9	6.8	9.7
4500	1.1	1.1	1.5	1.7	2.6	3.3	3.7	3.8	4.6	5.2	7.2
5000	0.9	0.9	1.3	1.4	1.9	2.4	2.8	3.0	3.6	4.2	5.4

Rule 1 with 25/20% TAC-constraint

shortterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	4.3	4.5	6.2	6.7	8.4	9.9	10.6	10.9	12.2	13.6	15.7
3184	3.1	3.3	5.1	5.6	6.9	7.7	8.4	8.6	9.6	11.1	13.1
3500	2.7	2.8	4.4	4.8	6.1	6.8	7.4	7.7	8.5	9.5	11.8
4000	2.1	2.2	3.0	3.4	4.7	5.5	6.1	6.3	7.1	7.9	9.8
4500	1.7	1.8	2.5	2.7	3.5	4.4	4.8	4.9	5.8	6.5	7.9
5000	1.6	1.6	2.0	2.1	2.7	3.0	3.6	3.9	4.5	5.1	6.7

mediumterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	4.1	4.3	6.2	6.7	8.9	10.2	11.2	11.5	13.0	14.5	17.5
3184	3.3	3.4	4.9	5.4	7.0	8.2	9.0	9.3	10.6	11.7	14.5
3500	2.7	2.9	4.3	4.7	6.2	7.1	7.9	8.2	9.4	10.5	12.8
4000	2.3	2.3	3.2	3.7	4.9	5.8	6.4	6.6	7.6	8.6	10.8
4500	1.6	1.7	2.5	2.8	3.7	4.5	5.0	5.2	6.1	7.0	8.7
5000	1.3	1.4	2.0	2.3	3.0	3.4	3.9	4.0	4.8	5.6	7.1

longterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	2.4	2.6	4.4	5.0	6.5	7.7	8.7	9.1	10.8	12.3	16.0
3184	1.7	1.9	3.1	3.6	5.1	6.0	6.8	7.1	8.5	9.8	12.8
3500	1.5	1.6	2.7	3.1	4.2	5.2	5.8	6.1	7.2	8.5	11.3
4000	1.3	1.4	2.2	2.4	3.3	4.0	4.5	4.7	5.4	6.6	8.9
4500	1.1	1.1	1.5	1.7	2.5	3.2	3.6	3.7	4.5	5.0	6.9
5000	0.8	0.9	1.3	1.4	1.8	2.4	2.7	2.9	3.4	4.2	5.3

Rule 2 - F-rule with Fmin = 0.05

shortterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	3.2	3.4	5.0	5.5	6.7	7.7	8.3	8.6	9.4	10.9	13.3
3184	2.4	2.4	3.2	3.5	4.3	5.1	5.4	5.5	6.2	6.9	8.1
3500	2.1	2.1	2.5	2.6	3.3	3.9	4.2	4.4	4.8	5.4	6.3
4000	1.8	1.8	2.1	2.2	2.4	2.6	2.8	2.9	3.3	3.5	4.4
4500	1.6	1.6	1.9	1.9	2.1	2.3	2.3	2.3	2.5	2.6	3.0
5000	1.6	1.6	1.6	1.7	1.9	2.0	2.1	2.1	2.2	2.3	2.5

mediumterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	3.3	3.4	4.9	5.2	7.0	8.2	8.8	8.9	10.1	11.2	13.5
3184	2.4	2.5	3.4	3.7	4.6	5.3	5.8	6.0	6.7	7.2	8.6
3500	2.1	2.1	2.9	3.0	3.9	4.4	4.8	4.9	5.3	6.1	7.0
4000	1.8	1.8	2.3	2.4	2.8	3.2	3.4	3.5	4.0	4.4	5.1
4500	1.5	1.6	1.8	2.0	2.4	2.5	2.7	2.8	3.0	3.4	3.8
5000	1.3	1.4	1.6	1.6	1.9	2.1	2.2	2.3	2.5	2.7	3.1

longterm risk

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	2.0	2.1	3.5	3.7	4.8	5.5	6.2	6.4	7.6	8.8	10.7
3184	1.5	1.5	2.2	2.5	3.2	3.6	4.0	4.1	4.9	5.6	6.7
3500	1.3	1.3	1.7	1.9	2.6	3.0	3.3	3.4	3.8	4.4	5.6
4000	1.1	1.2	1.4	1.5	1.9	2.2	2.4	2.5	2.9	3.2	3.9
4500	1.0	1.1	1.3	1.3	1.5	1.7	1.9	2.0	2.2	2.4	3.0
5000	0.9	0.9	1.1	1.1	1.3	1.4	1.5	1.5	1.9	2.0	2.3

Table A.3.2. Risk,P(SSB<Blim), expressed as % in short, medium and long term for biomass rules without and with constraint in interannual TAC change. Unshaded cells correspond to the precautionary (F_{target}, $B_{trigger}$) combinations (P(SSB<Blim)<5%). Tables are shown for Prob3 (named here Risk 3).

Risk3 tables for biomass rules

Rule 3 - biomass rule going through 0.0

shortterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	2.9	4.1	5.3	6.5	8.3	10.6	12.7	15.3	17.6
3184	2.5	3.4	4.8	5.8	7.3	9.2	11.2	13.3	15.6
3500	2.2	2.9	4.1	5.1	6.2	7.8	10.0	11.7	13.7
4000	1.7	2.3	2.9	4.0	5.0	6.1	7.3	9.0	10.9
4500	1.6	1.8	2.3	2.9	3.7	4.9	5.5	6.5	8.0
5000	1.6	1.6	1.8	2.3	2.8	3.4	4.6	5.3	6.2

mediumterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	2.8	3.7	5.0	6.6	8.6	10.8	12.8	15.2	18.0
3184	2.4	3.1	4.0	5.4	7.4	9.1	11.2	12.9	15.2
3500	2.0	2.7	3.6	4.7	6.0	7.8	9.8	11.6	13.3
4000	1.5	2.1	2.8	3.7	4.5	6.0	7.2	8.8	10.7
4500	1.1	1.5	2.1	2.8	3.6	4.3	5.6	6.8	8.1
5000	0.9	1.2	1.6	2.2	2.7	3.5	4.1	5.2	6.6

longterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	1.4	2.0	3.1	4.4	6.0	7.7	10.0	12.1	14.8
3184	1.1	1.6	2.7	3.5	4.9	6.4	8.3	10.4	12.4
3500	1.0	1.4	2.3	3.1	4.2	5.6	7.2	9.1	11.2
4000	0.8	1.1	1.7	2.4	3.3	4.3	5.5	7.1	9.0
4500	0.6	1.0	1.3	1.8	2.6	3.2	4.2	5.2	6.7
5000	0.5	0.7	1.0	1.3	1.8	2.5	3.3	4.1	5.1

Rule 3 with average constraint

shortterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	4.0	4.9	5.9	7.1	8.8	10.4	12.1	14.2	15.8
3184	2.8	3.9	5.0	5.8	7.1	8.9	10.7	12.6	14.3
3500	2.3	3.1	4.2	5.1	6.1	7.5	9.4	11.3	12.9
4000	1.7	2.3	2.9	3.9	5.0	6.0	7.1	8.7	10.8
4500	1.6	1.8	2.3	2.9	3.7	4.9	5.5	6.5	7.8
5000	1.6	1.6	1.8	2.3	2.8	3.4	4.6	5.3	6.2

mediumterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	3.4	4.3	5.5	7.1	9.0	10.9	12.7	14.6	16.7
3184	2.7	3.2	4.2	5.5	7.4	9.0	10.7	12.4	14.5
3500	2.2	2.8	3.6	4.6	6.0	7.6	9.6	11.1	13.1
4000	1.5	2.2	2.8	3.7	4.4	6.0	7.2	8.8	10.5
4500	1.1	1.5	2.1	2.8	3.6	4.3	5.6	6.8	8.0
5000	0.9	1.2	1.6	2.1	2.7	3.5	4.1	5.1	6.5

longterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	1.6	2.4	3.6	5.1	6.6	8.9	11.1	13.6	16.7
3184	1.2	1.9	2.8	3.9	5.3	6.9	9.3	11.4	13.7
3500	1.1	1.6	2.4	3.4	4.5	5.9	8.0	9.9	12.1
4000	0.8	1.3	1.7	2.6	3.3	4.6	5.9	7.7	9.7
4500	0.6	1.0	1.3	1.9	2.6	3.4	4.4	5.8	7.3
5000	0.5	0.7	1.0	1.4	2.0	2.6	3.4	4.3	5.7

Rule 3 with25/20% TAC-constraint

shortterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	3.3	4.2	5.3	6.4	8.3	10.5	12.5	14.3	16.1
3184	2.5	3.5	4.8	5.7	7.2	9.1	11.0	12.6	14.3
3500	2.2	2.9	4.1	5.1	6.2	7.7	9.6	11.2	12.7
4000	1.7	2.3	2.9	4.0	5.0	6.0	7.1	8.7	10.5
4500	1.6	1.8	2.3	2.9	3.7	4.9	5.5	6.5	7.8
5000	1.6	1.6	1.8	2.3	2.8	3.4	4.6	5.3	6.2

mediumterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	2.9	3.8	5.1	6.6	8.5	10.7	12.6	14.5	16.9
3184	2.5	3.1	4.0	5.4	7.3	9.1	10.9	12.5	14.4
3500	2.1	2.7	3.5	4.6	5.9	7.8	9.7	11.1	12.9
4000	1.5	2.1	2.8	3.7	4.4	6.0	7.1	8.7	10.5
4500	1.1	1.5	2.1	2.8	3.6	4.2	5.5	6.8	8.0
5000	0.9	1.2	1.6	2.1	2.7	3.5	4.1	5.1	6.5

longterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	1.4	2.0	3.0	4.2	5.9	7.5	9.6	11.7	14.2
3184	1.1	1.6	2.6	3.5	4.6	6.3	7.9	10.1	12.0
3500	1.0	1.4	2.2	3.0	4.2	5.5	7.1	9.0	10.9
4000	0.8	1.1	1.7	2.3	3.2	4.3	5.5	6.9	8.9
4500	0.6	1.0	1.3	1.8	2.5	3.2	4.1	5.3	6.6
5000	0.5	0.7	1.0	1.3	1.8	2.5	3.2	4.0	5.1

Rule 4 - biomass rule with HRmin = 0.05

shortterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	2.7	3.9	5.0	6.1	7.7	9.6	11.4	13.8	15.7
3184	2.2	3.1	3.9	4.8	5.7	6.8	8.4	9.9	12.0
3500	2.2	2.6	3.2	4.1	4.8	5.7	6.5	7.8	9.2
4000	2.0	2.3	2.6	2.9	3.6	4.3	4.8	5.2	6.2
4500	1.8	2.0	2.3	2.5	2.8	3.1	3.7	4.2	4.5
5000	1.8	1.9	2.1	2.3	2.5	2.7	2.9	3.2	3.7

mediumterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	2.6	3.4	4.5	5.8	7.5	9.1	10.8	12.5	14.5
3184	2.2	2.7	3.3	4.2	5.3	6.3	7.9	8.9	10.1
3500	2.0	2.4	2.9	3.5	4.3	5.5	6.3	7.3	8.4
4000	1.6	2.1	2.4	2.9	3.4	3.8	4.7	5.7	6.6
4500	1.5	1.7	2.1	2.3	2.7	3.2	3.5	4.2	4.9
5000	1.4	1.6	1.7	2.1	2.3	2.6	3.0	3.4	3.9

longterm risk

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	1.2	1.8	2.7	3.6	4.6	6.0	7.6	9.1	10.8
3184	1.1	1.4	2.2	2.7	3.5	4.5	5.5	6.6	8.1
3500	1.0	1.3	1.8	2.4	3.0	3.8	4.6	5.7	6.8
4000	1.0	1.1	1.4	1.9	2.4	3.0	3.6	4.2	5.3
4500	0.9	1.0	1.3	1.6	2.0	2.4	2.9	3.3	4.0
5000	0.8	1.0	1.2	1.4	1.6	2.1	2.4	2.7	3.0

Table A.3.3. Yield, expressed as median catch (kt), in short, medium and long term for F-rules without and with a constraint in interannual TAC change. Unshaded cells correspond to the precautionary (F_{target}, $B_{trigger}$) combinations (P(SSB<B_{lim})<5%). Cells shaded in green colours indicate the combinations that result in yield ≥95% of the maximum yield among the precautionary combinations. Tables are shown for Prob3 (named here Risk 3).

Yield tables for F-rules with Risk3

Rule 1 - F-rule through 0,0

shortterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	381	387	442	456	499	527	545	553	578	603	651
3184	381	387	442	456	499	526	545	552	578	602	649
3500	381	387	441	455	495	521	539	546	570	593	636
4000	365	370	418	430	466	488	503	509	531	550	589
4500	333	338	383	394	428	449	463	469	489	507	544
5000	307	311	353	364	396	416	430	436	454	472	507

mediumterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	579	586	640	652	688	708	720	725	742	757	782
3184	581	588	642	656	692	713	727	733	750	766	793
3500	583	590	645	658	696	718	732	738	755	772	799
4000	587	594	650	665	703	726	741	747	765	782	808
4500	592	598	657	671	710	733	747	752	769	782	798
5000	596	603	661	676	712	732	743	747	757	764	771

longterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	704	710	757	768	795	808	816	819	827	833	841
3184	706	712	760	771	800	814	823	827	838	846	858
3500	708	713	762	774	803	818	828	832	843	853	866
4000	711	716	767	778	809	826	836	841	854	864	880
4500	714	720	771	784	816	834	846	851	864	875	888
5000	717	724	778	790	824	843	854	859	871	879	880

Rule 1 with average constraint

shortterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	377	382	424	435	468	491	506	512	533	554	593
3184	375	379	421	433	467	489	504	510	532	552	591
3500	371	376	419	431	465	488	503	510	531	552	591
4000	356	362	411	423	458	481	496	502	523	543	581
4500	333	338	383	395	429	451	465	471	491	510	547
5000	307	312	353	364	396	416	430	436	456	473	508

mediumterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	579	586	644	659	700	723	739	745	765	782	815
3184	582	589	649	663	704	728	743	749	770	789	820
3500	584	591	651	666	707	731	747	753	774	791	821
4000	587	594	655	670	711	735	750	756	775	791	814
4500	590	597	658	673	713	735	748	753	767	779	797
5000	592	599	659	673	706	725	735	740	753	764	779

longterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	718	724	773	784	812	826	835	838	847	855	864
3184	721	727	777	789	819	834	844	848	859	868	881
3500	722	728	780	792	822	839	849	853	865	875	887
4000	725	731	785	797	829	847	858	862	874	883	892
4500	729	735	789	802	835	854	864	868	876	882	881
5000	732	739	794	807	841	855	862	864	869	870	870

Rule 1 with 25/20% TAC-constraint

shortterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	375	381	433	448	480	480	499	504	528	551	598
3184	368	373	427	442	480	480	493	491	514	536	580
3500	362	368	420	434	475	480	489	485	507	530	572
4000	345	351	399	412	448	472	479	480	496	516	554
4500	323	328	373	385	419	441	455	463	480	494	530
5000	301	306	349	360	392	412	426	432	450	469	502

mediumterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	564	571	626	640	677	699	714	720	740	758	793
3184	565	571	626	639	678	701	717	723	742	761	793
3500	565	572	626	641	679	702	718	725	744	761	791
4000	566	573	630	644	683	705	719	725	744	760	788
4500	568	574	631	645	683	705	719	724	741	756	779
5000	568	575	632	646	680	702	714	719	733	746	765

longterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	701	707	756	767	795	810	818	822	832	840	852
3184	703	709	759	770	800	815	826	830	841	850	864
3500	705	710	761	773	803	819	829	833	845	855	868
4000	707	713	764	776	807	824	835	839	851	860	872
4500	709	715	767	779	811	829	838	842	853	863	871
5000	711	717	770	783	815	831	841	845	855	861	865

Rule 2 - F-rule with Fmin = 0.05

shortterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	381	388	443	457	501	528	547	555	581	605	655
3184	382	388	444	459	502	529	548	556	582	606	655
3500	381	387	442	456	497	523	541	549	572	595	636
4000	361	366	409	420	450	469	481	487	503	517	546
4500	328	332	366	375	401	417	427	431	445	459	484
5000	307	310	339	346	369	384	393	397	409	421	444

mediumterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	581	587	642	655	692	715	729	735	754	771	801
3184	584	590	646	661	701	724	740	747	767	785	820
3500	586	593	650	665	705	730	746	753	773	794	829
4000	589	596	656	672	713	739	756	763	785	806	841
4500	593	600	662	678	721	746	763	770	790	807	832
5000	596	603	666	681	722	745	758	763	777	788	792

longterm yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	706	712	760	772	801	817	827	830	842	852	869
3184	708	714	764	776	807	824	835	840	853	866	888
3500	710	716	767	779	810	829	840	845	860	873	897
4000	712	718	770	783	817	836	849	854	871	886	912
4500	715	721	775	788	824	845	858	864	880	897	920
5000	717	724	780	794	831	852	866	872	888	900	912

Table A.3.4. Yield, expressed as median catch (kt), in short, medium and long term for biomass rules without and with a constraint in interannual TAC change. Unshaded cells correspond to the precautionary (Ftarget, Btrigger) combinations (P(SSB<Blim)<5%). Cells shaded in green colours indicate the combinations that result in yield ≥95% of the maximum yield among the precautionary combinations. Tables are shown for Prob3 (named here Risk 3).

Yield tables for biomass rules with Risk3

Rule 3 - biomass rule going through 0,0

shortterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	293	333	372	411	449	486	524	561	598
3184	292	331	370	408	446	483	520	556	591
3500	289	328	366	403	440	477	512	548	582
4000	270	305	339	372	404	435	466	496	526
4500	243	274	305	335	364	392	420	448	474
5000	220	249	277	305	332	358	383	409	434

mediumterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	493	541	584	623	657	687	714	737	758
3184	494	542	586	626	661	692	721	745	766
3500	496	545	589	629	664	696	725	750	773
4000	499	549	594	635	672	706	736	762	784
4500	502	553	600	642	679	714	743	769	791
5000	506	557	604	646	683	717	745	767	781

longterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	633	680	720	751	778	799	814	825	833
3184	634	682	722	755	783	805	822	836	846
3500	635	683	724	758	786	809	828	842	853
4000	637	686	727	762	792	817	837	852	865
4500	639	689	731	767	797	824	845	861	875
5000	641	692	735	771	803	830	851	868	880

Rule 3 with average constraint

shortterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	318	346	374	402	430	459	489	518	547
3184	317	346	374	402	431	459	488	517	545
3500	310	344	372	400	427	454	481	510	539
4000	269	305	339	372	405	437	467	495	523
4500	242	274	305	335	364	393	421	448	475
5000	220	249	277	305	332	358	383	409	434

mediumterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	478	528	574	617	655	691	724	752	778
3184	480	531	578	621	660	697	730	760	787
3500	483	534	581	624	664	701	735	765	791
4000	488	539	587	631	672	710	743	772	796
4500	492	545	594	639	680	717	749	775	792
5000	497	550	600	645	685	718	746	762	773

longterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	638	686	727	761	788	810	825	837	846
3184	639	688	730	765	794	818	837	852	864
3500	641	690	732	768	798	822	843	860	873
4000	643	693	736	773	805	832	855	874	886
4500	646	697	741	779	813	841	865	883	892
5000	649	701	747	787	821	850	872	882	879

Rule 3 with25/20% TAC-constraint

shortterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	307	331	370	408	447	480	491	526	562
3184	307	330	369	407	445	480	482	515	550
3500	303	327	365	402	439	477	480	499	531
4000	270	305	338	371	404	436	468	480	506
4500	242	274	304	335	364	392	421	448	475
5000	220	249	277	305	332	358	383	409	434

mediumterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	475	522	565	603	639	670	700	726	751
3184	478	526	570	609	645	678	707	735	760
3500	480	529	574	613	649	683	713	741	766
4000	485	534	579	620	659	693	723	749	773
4500	490	540	585	627	665	698	729	754	775
5000	493	543	589	631	669	702	730	755	770

longterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	622	669	708	741	767	788	805	819	829
3184	624	671	711	746	774	797	816	831	844
3500	625	672	714	748	777	802	821	838	852
4000	628	676	718	754	784	810	831	848	862
4500	631	680	723	759	791	817	839	856	871
5000	633	684	727	765	796	822	845	862	874

Rule 4 - biomass rule with HRmin = 0.05

shortterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	293	332	372	410	448	486	523	560	596
3184	292	330	368	406	443	480	516	552	586
3500	289	327	364	401	436	471	505	537	570
4000	274	304	332	357	383	407	428	449	469
4500	258	281	303	324	343	362	380	398	414
5000	249	267	285	302	319	335	350	365	380

mediumterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	493	542	585	625	660	692	722	748	773
3184	495	544	589	630	667	702	734	762	789
3500	496	546	592	634	672	708	740	770	798
4000	498	549	596	640	680	717	751	781	809
4500	499	552	600	645	686	724	756	787	814
5000	500	554	602	646	687	725	757	782	802

longterm yield

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	634	681	722	755	784	807	827	843	856
3184	634	683	724	759	789	815	837	855	872
3500	635	684	726	761	792	819	842	861	878
4000	636	686	728	765	797	826	849	870	888
4500	637	687	731	769	802	831	855	877	895
5000	638	689	733	771	805	835	860	881	897

Table A.3.5. SSB, expressed as median (million tonnes), in short, medium and long term for F-rules without and with a constraint in interannual TAC change. Cells shaded red correspond to the non precautionary (Ftarget, Btrigger) combinations (P(SSB<Blim)>=5%). Cells shaded greyindicate the combinations that result in SSB ≥95% of the maximum achievable SSB among the precautionary combinations. Tables are shown for Prob3 (named here Risk 3).

SSB tables for F-rules with Risk3

Rule 1 - F-rule through 0,0

shortterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	3.7	3.7	3.6	3.6	3.6	3.5	3.5	3.5	3.5	3.4	3.4
3184	3.7	3.7	3.6	3.6	3.6	3.5	3.5	3.5	3.5	3.4	3.4
3500	3.7	3.7	3.7	3.6	3.6	3.6	3.5	3.5	3.5	3.5	3.4
4000	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.5	3.5	3.5
4500	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.5
5000	3.8	3.8	3.8	3.7	3.7	3.7	3.7	3.7	3.6	3.6	3.6

mediumterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	5.7	5.7	5.3	5.2	4.9	4.7	4.6	4.6	4.4	4.3	4.0
3184	5.8	5.7	5.3	5.2	5.0	4.8	4.7	4.6	4.5	4.3	4.1
3500	5.8	5.7	5.4	5.3	5.0	4.8	4.7	4.7	4.5	4.4	4.1
4000	5.8	5.8	5.4	5.3	5.1	4.9	4.8	4.7	4.6	4.5	4.2
4500	5.9	5.8	5.5	5.4	5.1	5.0	4.9	4.8	4.7	4.6	4.3
5000	5.9	5.9	5.5	5.5	5.2	5.1	5.0	4.9	4.8	4.7	4.4

longterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.1	7.0	6.4	6.2	5.8	5.5	5.3	5.2	5.0	4.7	4.3
3184	7.1	7.0	6.4	6.3	5.8	5.5	5.4	5.3	5.0	4.8	4.4
3500	7.1	7.1	6.4	6.3	5.8	5.6	5.4	5.3	5.1	4.9	4.5
4000	7.2	7.1	6.5	6.3	5.9	5.6	5.4	5.4	5.1	4.9	4.6
4500	7.2	7.1	6.5	6.4	5.9	5.7	5.5	5.4	5.2	5.0	4.7
5000	7.2	7.2	6.6	6.4	6.0	5.8	5.6	5.5	5.3	5.1	4.8

Rule 1 with average constraint

shortterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.6	3.5	3.5	3.5
3184	3.7	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.5	3.5	3.5
3500	3.7	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.5	3.5	3.5
4000	3.8	3.8	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.5	3.5
4500	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.5
5000	3.8	3.8	3.8	3.7	3.7	3.7	3.7	3.7	3.6	3.6	3.6

mediumterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	5.8	5.8	5.4	5.3	5.0	4.9	4.7	4.7	4.5	4.4	4.1
3184	5.9	5.8	5.5	5.4	5.1	4.9	4.8	4.7	4.6	4.4	4.2
3500	5.9	5.8	5.5	5.4	5.1	4.9	4.8	4.8	4.6	4.5	4.2
4000	5.9	5.9	5.5	5.4	5.2	5.0	4.9	4.8	4.7	4.5	4.3
4500	6.0	5.9	5.6	5.5	5.2	5.1	4.9	4.9	4.8	4.6	4.4
5000	6.0	6.0	5.6	5.5	5.3	5.1	5.0	5.0	4.9	4.7	4.5

longterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.1	7.0	6.4	6.2	5.7	5.5	5.3	5.2	4.9	4.7	4.3
3184	7.1	7.1	6.4	6.3	5.8	5.5	5.3	5.3	5.0	4.8	4.4
3500	7.2	7.1	6.4	6.3	5.8	5.6	5.4	5.3	5.1	4.9	4.5
4000	7.2	7.1	6.5	6.3	5.9	5.6	5.5	5.4	5.2	4.9	4.6
4500	7.2	7.2	6.5	6.4	6.0	5.7	5.5	5.5	5.2	5.0	4.7
5000	7.3	7.2	6.6	6.4	6.0	5.8	5.6	5.6	5.3	5.2	4.8

Rule 1 with 25/20% TAC-constraint

shortterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.5	3.5	3.5	3.5
3184	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.5	3.5	3.5
3500	3.7	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.5	3.5
4000	3.8	3.8	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.5	3.5
4500	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.5
5000	3.8	3.8	3.8	3.7	3.7	3.7	3.7	3.7	3.6	3.6	3.6

mediumterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	5.9	5.8	5.5	5.4	5.1	4.9	4.8	4.8	4.7	4.5	4.3
3184	5.9	5.9	5.5	5.4	5.2	5.0	4.9	4.9	4.7	4.6	4.3
3500	6.0	5.9	5.6	5.5	5.2	5.1	4.9	4.9	4.8	4.6	4.4
4000	6.0	6.0	5.6	5.5	5.3	5.1	5.0	5.0	4.8	4.7	4.4
4500	6.1	6.0	5.7	5.6	5.3	5.2	5.1	5.0	4.9	4.7	4.5
5000	6.1	6.1	5.7	5.6	5.4	5.2	5.1	5.1	5.0	4.8	4.6

longterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.3	7.2	6.6	6.4	5.9	5.7	5.5	5.4	5.2	5.0	4.5
3184	7.3	7.2	6.6	6.4	6.0	5.7	5.6	5.5	5.3	5.0	4.6
3500	7.3	7.2	6.6	6.5	6.0	5.8	5.6	5.5	5.3	5.1	4.7
4000	7.3	7.3	6.7	6.5	6.1	5.8	5.7	5.6	5.4	5.2	4.8
4500	7.4	7.3	6.7	6.6	6.2	5.9	5.7	5.7	5.4	5.2	4.9
5000	7.4	7.4	6.8	6.6	6.2	6.0	5.8	5.7	5.5	5.3	5.0

Rule 2 - F-rule with Fmin = 0.05

shortterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	3.7	3.7	3.6	3.6	3.6	3.5	3.5	3.5	3.5	3.4	3.4
3184	3.7	3.7	3.7	3.6	3.6	3.6	3.5	3.5	3.5	3.5	3.4
3500	3.7	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.5	3.5	3.5
4000	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.6	3.6	3.5
4500	3.8	3.8	3.8	3.7	3.7	3.7	3.7	3.7	3.7	3.6	3.6
5000	3.8	3.8	3.8	3.8	3.7	3.7	3.7	3.7	3.7	3.7	3.6

mediumterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	5.8	5.7	5.3	5.2	5.0	4.8	4.7	4.6	4.5	4.3	4.1
3184	5.8	5.7	5.4	5.3	5.0	4.9	4.8	4.7	4.6	4.4	4.2
3500	5.8	5.8	5.4	5.3	5.1	4.9	4.8	4.8	4.6	4.5	4.3
4000	5.8	5.8	5.5	5.4	5.1	5.0	4.9	4.8	4.7	4.6	4.4
4500	5.9	5.8	5.5	5.4	5.2	5.1	5.0	4.9	4.8	4.7	4.5
5000	5.9	5.9	5.6	5.5	5.3	5.2	5.1	5.0	4.9	4.8	4.6

longterm SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.1	7.0	6.4	6.3	5.8	5.5	5.4	5.3	5.1	4.8	4.5
3184	7.1	7.1	6.5	6.3	5.9	5.6	5.4	5.4	5.1	4.9	4.6
3500	7.2	7.1	6.5	6.3	5.9	5.6	5.5	5.4	5.2	5.0	4.6
4000	7.2	7.1	6.5	6.4	5.9	5.7	5.5	5.5	5.3	5.1	4.7
4500	7.2	7.1	6.6	6.4	6.0	5.8	5.6	5.5	5.3	5.1	4.8
5000	7.2	7.2	6.6	6.5	6.1	5.8	5.7	5.6	5.4	5.2	4.9

Table A.3.6. SSB, expressed as median (million tonnes), in short, medium and long term for biomass rules without and with a constraint in interannual TAC change. Cells shaded red correspond to the non precautionary (Ftarget, Btrigger) combinations (P(SSB<Blim)>=5%). Cells shaded grey indicate the combinations that result in SSB ≥95% of the maximum achievable SSB among the precautionary combinations. Tables are shown for Prob3 (named here Risk 3).

SSB tables for biomass rules with Risk3

Rule 3 - biomass rule going through 0.0

shortterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	3.8	3.7	3.7	3.6	3.6	3.6	3.5	3.5	3.4
3184	3.8	3.7	3.7	3.7	3.6	3.6	3.5	3.5	3.4
3500	3.8	3.8	3.7	3.7	3.6	3.6	3.5	3.5	3.4
4000	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.5	3.5
4500	3.9	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6
5000	3.9	3.9	3.8	3.8	3.7	3.7	3.7	3.6	3.6

mediumterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	6.4	6.1	5.8	5.5	5.2	5.0	4.7	4.5	4.3
3184	6.4	6.1	5.8	5.5	5.3	5.0	4.8	4.6	4.4
3500	6.4	6.1	5.8	5.6	5.3	5.1	4.8	4.6	4.4
4000	6.4	6.2	5.9	5.6	5.4	5.2	4.9	4.7	4.5
4500	6.5	6.2	6.0	5.7	5.5	5.3	5.1	4.9	4.7
5000	6.6	6.3	6.0	5.8	5.6	5.4	5.2	5.0	4.8

longterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	8.0	7.5	7.0	6.5	6.1	5.7	5.3	5.0	4.7
3184	8.0	7.5	7.0	6.6	6.1	5.8	5.4	5.1	4.8
3500	8.0	7.5	7.0	6.6	6.2	5.8	5.4	5.1	4.8
4000	8.1	7.5	7.1	6.6	6.2	5.9	5.5	5.2	4.9
4500	8.1	7.6	7.1	6.7	6.3	5.9	5.6	5.3	5.0
5000	8.1	7.6	7.2	6.8	6.4	6.0	5.7	5.4	5.1

Rule 3 with average constraint

shortterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.5	3.5
3184	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.5	3.5
3500	3.8	3.8	3.7	3.7	3.6	3.6	3.6	3.5	3.5
4000	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.5
4500	3.9	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6
5000	3.9	3.9	3.8	3.8	3.7	3.7	3.7	3.6	3.6

mediumterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	6.4	6.1	5.8	5.6	5.3	5.1	4.8	4.6	4.4
3184	6.4	6.2	5.9	5.6	5.4	5.1	4.9	4.7	4.5
3500	6.5	6.2	5.9	5.6	5.4	5.1	4.9	4.7	4.5
4000	6.5	6.2	6.0	5.7	5.5	5.2	5.0	4.8	4.6
4500	6.6	6.3	6.0	5.8	5.5	5.3	5.1	4.9	4.7
5000	6.6	6.3	6.1	5.9	5.6	5.4	5.2	5.0	4.8

longterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	8.0	7.5	7.0	6.5	6.1	5.7	5.3	4.9	4.6
3184	8.0	7.5	7.0	6.6	6.1	5.7	5.4	5.0	4.7
3500	8.0	7.5	7.0	6.6	6.1	5.8	5.4	5.1	4.8
4000	8.1	7.5	7.1	6.6	6.2	5.8	5.5	5.2	4.9
4500	8.1	7.6	7.1	6.7	6.3	5.9	5.6	5.3	5.0
5000	8.1	7.6	7.2	6.7	6.3	6.0	5.7	5.4	5.1

Rule 3 with25/20% TAC-constraint

shortterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	3.8	3.7	3.7	3.7	3.6	3.6	3.5	3.5	3.5
3184	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.5	3.5
3500	3.8	3.8	3.7	3.7	3.6	3.6	3.6	3.5	3.5
4000	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6	3.5
4500	3.9	3.8	3.8	3.7	3.7	3.7	3.6	3.6	3.6
5000	3.9	3.9	3.8	3.8	3.7	3.7	3.7	3.6	3.6

mediumterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	6.4	6.1	5.9	5.6	5.3	5.1	4.9	4.7	4.4
3184	6.4	6.1	5.9	5.6	5.4	5.1	4.9	4.7	4.5
3500	6.4	6.2	5.9	5.6	5.4	5.2	4.9	4.7	4.6
4000	6.5	6.2	6.0	5.7	5.5	5.2	5.0	4.8	4.7
4500	6.6	6.3	6.0	5.8	5.6	5.4	5.1	5.0	4.8
5000	6.6	6.4	6.1	5.9	5.7	5.5	5.3	5.1	4.9

longterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	8.1	7.6	7.1	6.7	6.3	5.9	5.5	5.1	4.8
3184	8.1	7.6	7.1	6.7	6.3	5.9	5.5	5.2	4.9
3500	8.1	7.6	7.1	6.7	6.3	5.9	5.6	5.2	5.0
4000	8.1	7.6	7.2	6.7	6.3	6.0	5.6	5.3	5.0
4500	8.2	7.7	7.2	6.8	6.4	6.0	5.7	5.4	5.1
5000	8.2	7.7	7.3	6.8	6.5	6.1	5.8	5.5	5.3

Rule 4 - biomass rule with HRmin = 0.05

shortterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	3.8	3.7	3.7	3.7	3.6	3.6	3.5	3.5	3.4
3184	3.8	3.8	3.7	3.7	3.6	3.6	3.5	3.5	3.5
3500	3.8	3.8	3.7	3.7	3.6	3.6	3.6	3.5	3.5
4000	3.8	3.8	3.8	3.7	3.7	3.6	3.6	3.6	3.6
4500	3.8	3.8	3.8	3.8	3.7	3.7	3.7	3.6	3.6
5000	3.9	3.8	3.8	3.8	3.8	3.7	3.7	3.7	3.7

mediumterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	6.4	6.1	5.8	5.5	5.3	5.0	4.8	4.6	4.4
3184	6.4	6.1	5.8	5.6	5.3	5.1	4.9	4.7	4.5
3500	6.4	6.1	5.9	5.6	5.4	5.2	5.0	4.8	4.6
4000	6.4	6.2	5.9	5.7	5.5	5.3	5.1	4.9	4.7
4500	6.5	6.2	6.0	5.7	5.5	5.3	5.2	5.0	4.8
5000	6.5	6.2	6.0	5.8	5.6	5.4	5.2	5.1	4.9

longterm ssb

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	8.0	7.5	7.0	6.6	6.2	5.8	5.4	5.1	4.8
3184	8.0	7.5	7.0	6.6	6.2	5.8	5.5	5.2	4.9
3500	8.0	7.5	7.1	6.6	6.2	5.9	5.5	5.2	5.0
4000	8.1	7.5	7.1	6.7	6.3	5.9	5.6	5.3	5.1
4500	8.1	7.6	7.1	6.7	6.3	6.0	5.7	5.4	5.2
5000	8.1	7.6	7.2	6.8	6.4	6.0	5.8	5.5	5.3

Table A.3.7. Median Inter-Annual Variability (IAV, expressed as a %) in Yield in the short, medium and long term for F-rules without and with a constraint in interannual TAC change. Unshaded cells correspond to the precautionary (F_{target}, $B_{trigger}$) combinations (P(SSB<B_{lim})≤5% in Table A.3.1). Tables are shown for Prob3 (named here Risk 3).

Interannual variability in yield - F-rules - Risk3

Rule 1 - F-rule through 0,0

shortterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	18.5	18.6	18.9	18.9	19.3	19.6	19.8	19.9	20.2	20.5	21.1
3184	21.3	21.3	21.8	21.9	22.4	22.7	23.0	23.1	23.5	23.8	24.5
3500	23.1	23.1	23.7	23.8	24.3	24.7	24.9	25.0	25.2	25.6	26.5
4000	25.8	25.9	26.3	26.4	26.8	27.0	27.3	27.4	27.7	27.9	28.4
4500	27.9	27.9	28.2	28.2	28.4	28.5	28.6	28.6	28.9	29.1	29.5
5000	29.1	29.1	29.3	29.2	29.3	29.3	29.4	29.5	29.7	29.8	30.1

mediumterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	17.7	17.8	18.4	18.6	19.1	19.5	19.8	19.9	20.4	20.8	21.8
3184	18.4	18.5	19.3	19.5	20.2	20.6	20.9	21.1	21.6	22.1	23.1
3500	18.8	18.9	19.7	20.0	20.7	21.1	21.5	21.7	22.2	22.7	23.7
4000	19.4	19.5	20.5	20.7	21.5	22.1	22.4	22.6	23.1	23.6	24.7
4500	20.1	20.2	21.2	21.5	22.3	22.9	23.2	23.4	23.9	24.4	25.4
5000	20.9	21.0	22.0	22.3	23.0	23.6	24.0	24.2	24.6	25.1	26.1

longterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	16.8	16.9	17.6	17.8	18.4	18.8	19.1	19.2	19.7	20.1	21.1
3184	17.1	17.2	18.0	18.3	18.9	19.5	19.8	20.0	20.5	21.1	22.2
3500	17.3	17.4	18.3	18.5	19.3	19.8	20.2	20.4	21.0	21.5	22.7
4000	17.7	17.8	18.8	19.0	19.9	20.5	20.9	21.1	21.7	22.3	23.5
4500	18.2	18.3	19.3	19.6	20.5	21.2	21.6	21.8	22.4	23.1	24.3
5000	18.7	18.8	19.9	20.2	21.2	21.8	22.3	22.5	23.1	23.7	25.0

Rule 1 with average constraint

shortterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	9.5	9.6	10.0	10.2	10.8	11.1	11.4	11.5	11.9	12.3	13.0
3184	13.9	14.0	14.6	14.8	15.5	15.8	16.2	16.3	16.7	17.1	18.0
3500	16.9	17.0	17.5	17.7	18.1	18.5	18.7	18.9	19.3	19.7	20.5
4000	21.0	21.1	21.8	21.8	22.3	22.5	22.7	22.7	23.0	23.3	23.9
4500	24.1	24.2	24.6	24.8	25.1	25.2	25.4	25.4	25.6	25.9	26.3
5000	26.5	26.5	26.8	26.8	27.0	27.1	27.2	27.2	27.3	27.4	27.8

mediumterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	9.2	9.2	9.7	9.9	10.3	10.7	10.9	11.0	11.4	11.8	12.6
3184	9.9	10.0	10.6	10.8	11.4	11.8	12.2	12.3	12.8	13.3	14.4
3500	10.2	10.3	11.0	11.3	12.0	12.5	12.9	13.0	13.5	14.1	15.2
4000	11.0	11.1	12.0	12.3	13.1	13.7	14.1	14.2	14.8	15.5	16.7
4500	11.9	12.1	13.1	13.3	14.2	14.9	15.4	15.6	16.2	16.9	18.3
5000	13.0	13.1	14.2	14.5	15.6	16.3	16.8	17.0	17.7	18.4	19.9

longterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	8.9	8.9	9.5	9.6	10.1	10.5	10.8	10.9	11.4	11.8	12.7
3184	9.2	9.3	9.9	10.1	10.8	11.2	11.6	11.8	12.3	12.8	14.0
3500	9.4	9.5	10.2	10.4	11.2	11.7	12.1	12.2	12.8	13.4	14.6
4000	9.8	9.9	10.8	11.0	11.9	12.5	12.9	13.1	13.7	14.4	15.7
4500	10.3	10.4	11.4	11.7	12.6	13.3	13.8	14.0	14.7	15.4	16.9
5000	10.9	11.0	12.1	12.5	13.5	14.3	14.8	15.0	15.8	16.6	18.1

Rule 1 with 25/20% TAC-constraint

shortterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	19.9	19.9	20.0	20.0	20.0	20.0	20.6	20.4	22.4	24.4	25.0
3184	23.3	23.3	23.8	24.1	25.0	25.0	25.1	25.0	25.0	25.0	25.0
3500	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
4000	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
4500	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
5000	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0

mediumterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	19.0	19.1	19.9	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
3184	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
3500	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.7
4000	20.0	20.0	20.0	20.0	20.0	20.0	20.1	20.0	20.8	21.6	23.2
4500	20.0	20.0	20.0	20.0	20.6	21.5	22.0	22.3	23.0	23.7	25.0
5000	20.0	20.1	21.1	21.5	22.7	23.3	23.9	24.0	24.6	25.0	25.0

longterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	17.5	17.6	18.5	18.8	19.7	20.0	20.1	20.0	20.0	20.0	20.0
3184	17.9	18.0	19.1	19.4	20.0	20.0	20.1	20.0	20.0	20.0	20.0
3500	18.2	18.3	19.4	19.7	20.0	20.0	20.0	20.0	20.0	20.0	20.0
4000	18.6	18.8	19.9	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
4500	19.1	19.2	20.0	20.0	20.0	20.0	19.9	20.0	20.0	20.0	21.3
5000	19.7	19.7	20.0	20.0	20.0	20.0	19.9	20.0	20.0	20.8	23.0

Rule 2 - F-rule with Fmin = 0.05

shortterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	19.2	19.3	19.7	19.9	20.3	20.8	21.1	21.3	21.8	22.2	23.2
3184	23.7	23.8	25.6	26.1	27.6	28.8	29.5	29.8	31.1	32.3	34.6
3500	26.3	26.5	28.7	29.4	31.3	32.4	33.3	33.6	34.8	36.0	38.8
4000	28.2	28.5	31.4	32.0	33.8	35.2	36.0	36.5	37.7	38.8	41.1
4500	29.0	29.3	31.7	32.5	34.4	35.6	36.5	36.8	38.0	39.0	40.9
5000	28.8	29.1	31.5	32.1	33.9	35.0	35.7	36.0	36.9	37.9	39.7

mediumterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	17.9	18.0	18.7	18.9	19.4	19.9	20.2	20.3	20.8	21.3	22.2
3184	18.9	19.0	20.0	20.4	21.4	22.0	22.5	22.7	23.4	24.3	25.9
3500	19.3	19.4	20.6	21.0	22.0	22.8	23.3	23.6	24.4	25.3	27.1
4000	19.9	20.0	21.3	21.7	22.9	23.8	24.4	24.8	25.6	26.6	28.5
4500	20.3	20.5	22.0	22.4	23.8	24.6	25.3	25.6	26.5	27.4	29.3
5000	20.7	20.9	22.5	22.9	24.3	25.2	25.8	26.0	27.1	28.0	29.8

longterm IAV-Yield

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	16.9	17.0	17.7	17.9	18.5	18.9	19.2	19.4	19.9	20.4	21.4
3184	17.3	17.4	18.4	18.7	19.5	20.2	20.7	21.0	21.6	22.5	24.3
3500	17.5	17.6	18.7	19.0	20.1	20.8	21.4	21.6	22.5	23.4	25.2
4000	17.9	18.0	19.2	19.6	20.8	21.6	22.3	22.5	23.5	24.4	26.4
4500	18.2	18.4	19.7	20.1	21.4	22.3	23.0	23.3	24.3	25.2	27.3
5000	18.6	18.8	20.3	20.7	22.0	22.9	23.6	23.9	24.8	25.8	27.9

Table A.3.8. Median Inter-Annual Variability (IAV, expressed as a %) in Yield in the short, medium and long term for biomass-rules without and with constraint in interannual TAC change. Unshaded cells correspond to the precautionary (F_{target}, $B_{trigger}$) combinations (P(SSB<B_{lim})≤5% in Table A.3.2).Tables are shown for Prob3 (named here Risk 3).

Interannual variability in yield - biomass rules - Risk3

Rule 3 - biomass rule going through 0.0

shortterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.6	7.8	8.0	8.2	8.4	8.7	9.0	9.3	9.7
3184	8.6	8.8	9.1	9.4	9.7	10.1	10.4	10.8	11.3
3500	10.0	10.2	10.5	10.8	11.1	11.5	12.0	12.4	13.0
4000	12.4	12.6	12.8	13.1	13.4	13.5	13.9	14.2	14.7
4500	13.6	13.7	13.8	14.0	14.2	14.4	14.6	14.7	15.0
5000	14.1	14.1	14.2	14.3	14.4	14.6	14.7	14.9	15.0

mediumterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.9	8.3	8.9	9.4	10.0	10.6	11.3	12.0	12.7
3184	8.1	8.7	9.2	9.9	10.5	11.2	11.9	12.7	13.5
3500	8.3	8.9	9.5	10.1	10.8	11.5	12.3	13.0	13.9
4000	8.6	9.2	9.8	10.5	11.2	12.0	12.8	13.6	14.4
4500	8.9	9.5	10.2	11.0	11.7	12.4	13.2	14.1	14.9
5000	9.2	9.9	10.6	11.3	12.1	12.9	13.7	14.5	15.4

longterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	8.2	8.7	9.2	9.7	10.3	10.8	11.4	12.1	12.8
3184	8.3	8.8	9.3	9.9	10.5	11.2	11.9	12.6	13.4
3500	8.4	8.9	9.5	10.1	10.7	11.4	12.1	12.9	13.8
4000	8.5	9.1	9.7	10.3	11.0	11.8	12.6	13.4	14.3
4500	8.6	9.3	9.9	10.6	11.4	12.2	13.1	13.9	14.8
5000	8.8	9.5	10.2	11.0	11.8	12.6	13.5	14.4	15.3

Rule 3 with average constraint

shortterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.9	6.8	6.0	5.6	5.8	6.3	7.0	7.8	8.6
3184	8.9	8.0	7.5	7.8	8.1	8.6	9.3	10.1	11.0
3500	10.3	10.1	9.9	9.9	10.1	10.5	11.3	12.1	13.0
4000	12.6	12.4	12.4	12.6	12.8	13.2	13.5	14.0	14.6
4500	13.6	13.6	13.7	13.8	14.0	14.3	14.6	14.8	15.0
5000	14.3	14.3	14.3	14.5	14.6	14.8	14.9	15.1	15.2

mediumterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	6.3	6.6	6.9	7.2	7.6	8.0	8.4	8.9	9.4
3184	6.5	6.9	7.2	7.6	8.1	8.6	9.2	9.8	10.4
3500	6.7	7.1	7.5	8.0	8.5	9.0	9.6	10.2	10.9
4000	7.1	7.5	7.9	8.4	8.9	9.5	10.3	10.9	11.7
4500	7.5	7.9	8.4	9.0	9.6	10.2	10.9	11.7	12.4
5000	7.9	8.4	8.9	9.5	10.2	10.8	11.6	12.3	13.1

longterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	6.3	6.7	7.1	7.5	7.9	8.3	8.8	9.4	9.9
3184	6.5	6.8	7.3	7.7	8.2	8.7	9.3	10.0	10.6
3500	6.5	6.9	7.4	7.9	8.4	9.0	9.6	10.3	11.0
4000	6.6	7.1	7.6	8.1	8.8	9.4	10.1	10.9	11.7
4500	6.8	7.3	7.9	8.5	9.2	9.9	10.7	11.4	12.3
5000	7.0	7.6	8.2	8.9	9.6	10.4	11.2	12.0	12.9

Rule 3 with25/20% TAC-constraint

shortterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	11.0	9.3	8.9	9.1	9.4	10.1	11.5	13.1	15.6
3184	11.5	10.0	10.0	10.3	10.8	11.7	13.2	15.2	17.7
3500	12.1	11.1	11.3	11.7	12.2	13.2	14.5	16.0	17.9
4000	13.6	13.6	13.8	14.0	14.4	14.8	15.5	16.3	17.0
4500	14.8	14.8	14.9	15.0	15.1	15.4	15.7	16.0	16.3
5000	15.2	15.1	15.1	15.2	15.3	15.5	15.6	15.7	15.9

mediumterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	9.6	10.1	10.7	11.3	11.9	12.6	13.4	14.2	14.9
3184	9.8	10.4	11.0	11.7	12.4	13.2	14.0	14.9	15.9
3500	9.9	10.5	11.2	12.0	12.7	13.5	14.4	15.3	16.2
4000	10.3	10.9	11.7	12.5	13.3	14.0	14.9	15.8	16.7
4500	10.6	11.3	12.1	12.9	13.7	14.5	15.4	16.3	17.1
5000	11.0	11.7	12.5	13.3	14.1	14.9	15.7	16.6	17.4

longterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	9.1	9.7	10.3	11.0	11.6	12.3	13.1	13.9	14.7
3184	9.2	9.8	10.5	11.1	11.9	12.6	13.5	14.4	15.4
3500	9.3	9.9	10.5	11.3	12.0	12.8	13.7	14.7	15.7
4000	9.4	10.0	10.7	11.5	12.3	13.2	14.1	15.1	16.1
4500	9.5	10.2	11.0	11.8	12.7	13.6	14.6	15.5	16.6
5000	9.7	10.5	11.3	12.2	13.1	14.0	14.9	16.0	17.0

Rule 4 - biomass rule with HRmin = 0.05

shortterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.8	8.0	8.2	8.4	8.7	9.0	9.3	9.7	10.1
3184	8.9	9.6	10.2	10.8	11.5	12.4	13.4	14.3	15.4
3500	10.1	11.1	12.2	13.4	14.7	16.0	17.4	18.7	20.2
4000	11.2	12.8	14.2	15.5	16.9	18.1	19.4	20.5	21.8
4500	11.2	12.6	13.9	15.2	16.4	17.4	18.4	19.3	20.3
5000	10.9	12.1	13.3	14.4	15.4	16.4	17.3	18.2	18.9

mediumterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.9	8.3	8.9	9.4	10.0	10.6	11.2	11.9	12.5
3184	8.1	8.7	9.4	10.1	10.7	11.5	12.3	13.1	14.0
3500	8.2	8.9	9.6	10.3	11.1	11.9	12.8	13.6	14.6
4000	8.4	9.1	9.9	10.7	11.6	12.4	13.4	14.4	15.5
4500	8.6	9.4	10.2	11.0	11.9	12.9	13.9	14.9	16.0
5000	8.7	9.5	10.4	11.3	12.2	13.2	14.2	15.3	16.4

longterm IAV

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	8.2	8.7	9.2	9.7	10.2	10.8	11.4	12.0	12.7
3184	8.3	8.8	9.4	10.0	10.7	11.4	12.1	12.9	13.8
3500	8.3	8.9	9.5	10.2	10.9	11.6	12.5	13.3	14.3
4000	8.4	9.1	9.7	10.4	11.2	12.1	13.0	14.0	15.1
4500	8.5	9.2	9.9	10.7	11.5	12.5	13.5	14.6	15.7
5000	8.6	9.3	10.1	11.0	11.9	12.8	13.9	15.0	16.1

Table A.3.9. Median Inter-Annual Variability (IAV, expressed as a %) in SSB in the short, medium and long term for F-rules without and with a constraint in interannual TAC change. Unshaded cells correspond to the precautionary (F_{target}, $B_{trigger}$) combinations (P(SSB<B_{lim})≤5% in Table A.3.1). Tables are shown for Prob3 (named here Risk 3).

Interannual variability in SSB - F-rules with Risk 3

Rule 1 - F-rule through 0,0

shortterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.5	7.5	7.7	7.8	8.1	8.4	8.5	8.5	8.8	9.1	9.6
3184	7.4	7.5	7.6	7.7	7.9	8.2	8.3	8.4	8.6	8.9	9.3
3500	7.4	7.4	7.6	7.6	7.9	8.0	8.1	8.2	8.4	8.7	9.1
4000	7.5	7.5	7.5	7.5	7.7	7.8	7.9	7.9	8.1	8.2	8.6
4500	7.4	7.4	7.4	7.4	7.6	7.7	7.7	7.7	7.8	8.0	8.2
5000	7.5	7.5	7.4	7.4	7.4	7.5	7.5	7.6	7.6	7.7	8.0

mediumterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.8	7.8	8.3	8.4	8.8	9.0	9.2	9.2	9.5	9.7	10.2
3184	7.7	7.8	8.2	8.3	8.6	8.9	9.0	9.1	9.3	9.5	9.9
3500	7.7	7.7	8.2	8.3	8.6	8.8	8.9	9.0	9.2	9.4	9.8
4000	7.6	7.7	8.0	8.2	8.5	8.7	8.8	8.9	9.1	9.3	9.6
4500	7.5	7.6	8.0	8.1	8.4	8.6	8.7	8.8	9.0	9.1	9.5
5000	7.5	7.5	7.9	8.0	8.3	8.5	8.6	8.7	8.8	9.0	9.3

longterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.8	7.9	8.4	8.5	8.9	9.1	9.3	9.3	9.6	9.8	10.3
3184	7.8	7.9	8.3	8.5	8.8	9.0	9.2	9.3	9.5	9.7	10.1
3500	7.8	7.9	8.3	8.4	8.8	9.0	9.1	9.2	9.4	9.6	10.0
4000	7.8	7.8	8.3	8.4	8.7	8.9	9.1	9.1	9.3	9.5	9.8
4500	7.7	7.8	8.2	8.3	8.6	8.8	9.0	9.0	9.2	9.4	9.7
5000	7.7	7.7	8.1	8.2	8.5	8.7	8.9	8.9	9.1	9.2	9.5

Rule 1 with average constraint

shortterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.8	7.8	7.9	7.9	8.2	8.2	8.4	8.4	8.6	8.8	9.2
3184	7.7	7.7	7.7	7.8	8.0	8.1	8.2	8.2	8.5	8.6	9.0
3500	7.6	7.6	7.7	7.7	7.8	8.0	8.1	8.1	8.3	8.6	8.9
4000	7.6	7.6	7.6	7.7	7.8	7.9	8.0	8.0	8.2	8.3	8.6
4500	7.6	7.6	7.5	7.5	7.7	7.8	7.8	7.9	7.9	8.1	8.3
5000	7.6	7.6	7.5	7.5	7.5	7.6	7.7	7.7	7.8	7.9	8.0

mediumterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	8.2	8.2	8.7	8.9	9.3	9.6	9.8	9.8	10.1	10.3	10.9
3184	8.1	8.1	8.6	8.7	9.1	9.3	9.5	9.6	9.8	10.0	10.4
3500	8.0	8.1	8.5	8.7	9.0	9.3	9.4	9.4	9.7	9.9	10.3
4000	7.9	8.0	8.4	8.5	8.8	9.1	9.2	9.3	9.4	9.6	10.0
4500	7.9	7.9	8.3	8.4	8.7	8.9	9.0	9.1	9.3	9.4	9.7
5000	7.8	7.8	8.2	8.3	8.5	8.7	8.9	8.9	9.1	9.2	9.5

longterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	8.3	8.4	9.0	9.1	9.5	9.8	10.0	10.1	10.3	10.6	11.0
3184	8.3	8.3	8.9	9.0	9.4	9.7	9.8	9.9	10.1	10.3	10.7
3500	8.2	8.3	8.8	9.0	9.3	9.6	9.7	9.8	10.0	10.2	10.6
4000	8.2	8.3	8.7	8.9	9.2	9.4	9.6	9.6	9.8	10.0	10.3
4500	8.1	8.2	8.6	8.7	9.1	9.3	9.4	9.5	9.6	9.8	10.1
5000	8.0	8.1	8.5	8.6	8.9	9.1	9.2	9.3	9.4	9.6	9.9

Rule 1 with 25/20% TAC-constraint

shortterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.7	7.8	7.9	8.0	8.2	8.4	8.5	8.6	8.7	8.9	9.2
3184	7.7	7.7	7.9	7.9	8.1	8.3	8.3	8.4	8.5	8.7	9.0
3500	7.7	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.6	8.9
4000	7.7	7.7	7.7	7.8	7.9	8.0	8.0	8.1	8.2	8.4	8.7
4500	7.7	7.7	7.6	7.6	7.8	7.8	7.9	7.9	8.1	8.2	8.4
5000	7.7	7.7	7.6	7.6	7.6	7.7	7.7	7.8	7.8	7.9	8.1

mediumterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	8.1	8.1	8.6	8.8	9.2	9.5	9.6	9.7	9.9	10.2	10.7
3184	8.0	8.1	8.5	8.7	9.0	9.3	9.4	9.5	9.7	10.0	10.4
3500	8.0	8.0	8.5	8.6	8.9	9.2	9.3	9.4	9.6	9.8	10.3
4000	7.9	7.9	8.4	8.5	8.8	9.0	9.2	9.2	9.4	9.6	10.0
4500	7.8	7.8	8.2	8.3	8.7	8.9	9.0	9.1	9.3	9.4	9.8
5000	7.7	7.8	8.1	8.2	8.6	8.7	8.9	8.9	9.1	9.3	9.6

longterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	8.1	8.2	8.7	8.9	9.3	9.6	9.8	9.9	10.2	10.4	10.9
3184	8.1	8.2	8.7	8.8	9.2	9.5	9.7	9.8	10.0	10.2	10.6
3500	8.1	8.2	8.7	8.8	9.2	9.5	9.6	9.7	9.9	10.1	10.5
4000	8.1	8.1	8.6	8.7	9.1	9.3	9.5	9.6	9.8	9.9	10.3
4500	8.0	8.1	8.5	8.7	9.0	9.2	9.4	9.4	9.6	9.8	10.1
5000	8.0	8.0	8.4	8.5	8.9	9.1	9.2	9.3	9.4	9.6	9.9

Rule 2 - F-rule with Fmin = 0.05

shortterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.5	7.5	7.7	7.8	8.1	8.4	8.5	8.6	8.8	9.1	9.7
3184	7.4	7.4	7.6	7.7	7.9	8.1	8.2	8.2	8.4	8.7	9.0
3500	7.4	7.5	7.6	7.6	7.8	8.0	8.0	8.1	8.2	8.4	8.8
4000	7.5	7.5	7.5	7.5	7.7	7.7	7.8	7.8	7.9	8.0	8.3
4500	7.4	7.4	7.4	7.4	7.5	7.5	7.6	7.6	7.7	7.7	7.9
5000	7.5	7.4	7.4	7.4	7.4	7.4	7.5	7.4	7.5	7.6	7.7

mediumterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.7	7.8	8.2	8.3	8.7	8.9	9.1	9.2	9.4	9.6	10.1
3184	7.7	7.7	8.1	8.2	8.5	8.8	8.9	9.0	9.2	9.3	9.8
3500	7.6	7.7	8.1	8.2	8.5	8.7	8.8	8.9	9.1	9.3	9.6
4000	7.6	7.6	8.0	8.1	8.4	8.6	8.7	8.7	8.9	9.1	9.4
4500	7.5	7.6	7.9	8.0	8.3	8.5	8.6	8.6	8.8	8.9	9.2
5000	7.5	7.5	7.8	7.9	8.2	8.4	8.5	8.5	8.6	8.8	9.1

longterm IAV-SSB

Btrigger \ Ftarget	0.1	0.102	0.12	0.125	0.14	0.15	0.157	0.16	0.17	0.18	0.2
2500	7.8	7.9	8.3	8.5	8.8	9.1	9.2	9.3	9.5	9.8	10.3
3184	7.8	7.9	8.3	8.4	8.7	9.0	9.1	9.2	9.4	9.6	10.0
3500	7.8	7.8	8.3	8.4	8.7	8.9	9.1	9.1	9.3	9.5	9.8
4000	7.8	7.8	8.2	8.3	8.6	8.8	9.0	9.0	9.2	9.4	9.6
4500	7.7	7.8	8.2	8.3	8.6	8.7	8.9	8.9	9.1	9.2	9.5
5000	7.7	7.7	8.1	8.2	8.5	8.6	8.8	8.8	8.9	9.1	9.3

Table A.3.10. Median Inter-Annual Variability (IAV, expressed as a %) in SSB in the short, medium and long term for biomass rules without and with a constraint in interannual TAC change. Unshaded cells correspond to the precautionary (Ftarget, Btrigger) combinations (P(SSB<Blim)≤5% in Table A.3.2). Tables are shown for Prob3 (named here Risk 3).

Interannual variability in SSB - biomass rules - Risk 3

Rule 3 - biomass rule going through 0.0

shortterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.9	7.9	8.0	8.2	8.5	8.8	9.2	9.6	10.1
3184	7.9	7.9	8.0	8.2	8.5	8.8	9.2	9.6	10.1
3500	8.0	8.0	8.0	8.2	8.5	8.7	9.1	9.5	9.9
4000	8.1	8.0	8.1	8.2	8.4	8.6	8.9	9.2	9.5
4500	8.3	8.1	8.1	8.2	8.3	8.4	8.6	8.9	9.1
5000	8.4	8.3	8.1	8.1	8.2	8.3	8.4	8.6	8.8

mediumterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.6	8.1	8.4	8.9	9.3	9.7	10.2	10.7	11.1
3184	7.6	8.1	8.4	8.8	9.2	9.7	10.1	10.6	11.0
3500	7.6	8.0	8.4	8.8	9.2	9.7	10.1	10.5	11.0
4000	7.6	8.0	8.4	8.8	9.2	9.6	10.0	10.4	10.8
4500	7.6	7.9	8.3	8.7	9.1	9.5	9.9	10.3	10.7
5000	7.6	7.9	8.3	8.6	9.0	9.4	9.8	10.2	10.6

longterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.7	8.1	8.6	9.0	9.5	9.9	10.3	10.8	11.3
3184	7.7	8.1	8.6	9.0	9.4	9.9	10.3	10.8	11.2
3500	7.7	8.1	8.6	9.0	9.4	9.8	10.3	10.7	11.2
4000	7.7	8.1	8.5	9.0	9.4	9.8	10.3	10.7	11.1
4500	7.7	8.1	8.5	8.9	9.4	9.8	10.2	10.6	11.0
5000	7.7	8.1	8.5	8.9	9.3	9.7	10.1	10.5	10.9

Rule 3 with average constraint

shortterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	8.1	8.1	8.2	8.3	8.5	8.7	8.9	9.2	9.5
3184	8.1	8.1	8.2	8.2	8.4	8.6	8.9	9.1	9.4
3500	8.1	8.1	8.2	8.2	8.3	8.5	8.8	9.1	9.4
4000	8.2	8.1	8.1	8.2	8.3	8.5	8.7	8.9	9.3
4500	8.3	8.1	8.1	8.1	8.2	8.4	8.5	8.8	9.0
5000	8.4	8.3	8.1	8.1	8.1	8.3	8.4	8.6	8.7

mediumterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.8	8.2	8.7	9.1	9.5	10.0	10.5	11.0	11.5
3184	7.8	8.2	8.6	9.0	9.5	9.9	10.3	10.8	11.3
3500	7.7	8.2	8.6	9.0	9.4	9.8	10.3	10.7	11.1
4000	7.7	8.1	8.5	8.9	9.3	9.7	10.1	10.5	10.9
4500	7.7	8.1	8.4	8.8	9.2	9.6	10.0	10.4	10.8
5000	7.6	8.0	8.3	8.7	9.1	9.4	9.8	10.2	10.6

longterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	8.0	8.4	8.9	9.4	9.8	10.4	10.8	11.3	11.8
3184	8.0	8.4	8.9	9.3	9.8	10.3	10.8	11.2	11.7
3500	7.9	8.4	8.9	9.3	9.8	10.3	10.7	11.1	11.6
4000	7.9	8.4	8.8	9.3	9.7	10.2	10.6	11.0	11.4
4500	7.9	8.3	8.8	9.2	9.6	10.0	10.4	10.8	11.2
5000	7.9	8.3	8.7	9.1	9.5	9.9	10.3	10.7	11.0

Rule 3 with25/20% TAC-constraint

shortterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	8.0	8.0	8.1	8.3	8.6	8.9	9.1	9.3	9.6
3184	8.0	8.0	8.1	8.3	8.5	8.8	9.0	9.2	9.5
3500	8.1	8.1	8.1	8.3	8.5	8.7	8.9	9.1	9.4
4000	8.1	8.1	8.1	8.2	8.4	8.6	8.7	9.0	9.2
4500	8.3	8.1	8.1	8.2	8.3	8.4	8.6	8.8	9.0
5000	8.5	8.3	8.1	8.1	8.1	8.3	8.4	8.6	8.8

mediumterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.7	8.1	8.5	8.9	9.3	9.8	10.2	10.7	11.2
3184	7.7	8.1	8.5	8.9	9.3	9.8	10.2	10.6	11.0
3500	7.7	8.1	8.5	8.9	9.3	9.7	10.1	10.5	10.9
4000	7.7	8.0	8.4	8.8	9.2	9.6	10.0	10.4	10.7
4500	7.6	8.0	8.3	8.7	9.1	9.5	9.8	10.2	10.6
5000	7.6	7.9	8.3	8.6	9.0	9.4	9.7	10.1	10.5

longterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.8	8.2	8.7	9.1	9.5	10.0	10.4	10.9	11.3
3184	7.8	8.2	8.7	9.1	9.5	9.9	10.4	10.8	11.3
3500	7.8	8.2	8.7	9.1	9.5	9.9	10.4	10.8	11.2
4000	7.8	8.2	8.6	9.1	9.5	9.9	10.3	10.7	11.1
4500	7.8	8.2	8.6	9.0	9.4	9.8	10.2	10.6	11.0
5000	7.8	8.2	8.6	9.0	9.4	9.7	10.1	10.5	10.9

Rule 4 - biomass rule with HRmin = 0.05

shortterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.9	7.9	8.0	8.2	8.6	8.9	9.3	9.8	10.3
3184	8.0	8.0	8.1	8.3	8.6	8.9	9.2	9.6	10.2
3500	8.0	8.0	8.1	8.3	8.6	8.9	9.2	9.5	9.9
4000	8.0	8.0	8.1	8.3	8.5	8.7	8.9	9.1	9.4
4500	8.1	8.1	8.1	8.2	8.3	8.5	8.6	8.8	9.0
5000	8.1	8.1	8.0	8.1	8.2	8.3	8.4	8.6	8.7

mediumterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.6	8.1	8.4	8.9	9.3	9.8	10.3	10.8	11.3
3184	7.6	8.0	8.4	8.8	9.2	9.7	10.2	10.6	11.1
3500	7.6	8.0	8.4	8.8	9.2	9.7	10.1	10.6	11.0
4000	7.6	8.0	8.3	8.7	9.1	9.6	10.0	10.4	10.9
4500	7.6	8.0	8.3	8.7	9.1	9.5	9.9	10.3	10.7
5000	7.6	7.9	8.3	8.6	9.0	9.4	9.8	10.2	10.6

longterm IAV-SSB

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	7.7	8.1	8.6	9.0	9.5	9.9	10.4	10.9	11.4
3184	7.7	8.1	8.6	9.0	9.4	9.9	10.4	10.8	11.3
3500	7.7	8.1	8.5	9.0	9.4	9.9	10.3	10.8	11.3
4000	7.7	8.1	8.5	9.0	9.4	9.8	10.3	10.7	11.2
4500	7.7	8.1	8.5	8.9	9.4	9.8	10.2	10.6	11.0
5000	7.7	8.1	8.5	8.9	9.3	9.7	10.1	10.5	10.9

Table A.3.11. Median of the real F in medium term for HCRs without and with a constraint in interannual TAC change. Unshaded cells correspond to the precautionary (Ftarget, Btrigger) or (HRtarget, $B_{trigger}$) combinations (P(SSB<Blim)<5% in Table A.3.1 and A.3.2). OBS!! The values for the biomass options are also shown as real F – not harvest rate. Tables are shown for Prob3 (named here Risk 3).

Realised F for all tested rules with Risk3

Rule 1 - F-rule through 0,0

Btrigger \ Ftarget	0.1	0.12	0.125	0.14	0.15	0.16	0.17	0.18	0.2
2500	0.10	0.12	0.12	0.14	0.15	0.15	0.16	0.17	0.19
3184	0.10	0.12	0.12	0.13	0.14	0.15	0.16	0.17	0.19
3500	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18
4000	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.16	0.18
4500	0.09	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17
5000	0.09	0.11	0.11	0.13	0.13	0.14	0.15	0.15	0.17

Rule 3 - biomass rule going through 0,0

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	0.08	0.09	0.10	0.11	0.13	0.14	0.15	0.17	0.18
3184	0.08	0.09	0.10	0.11	0.13	0.14	0.15	0.16	0.17
3500	0.08	0.09	0.10	0.11	0.12	0.14	0.15	0.16	0.17
4000	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.16	0.17
4500	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16
5000	0.07	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.15

Rule 1 with average constraint

Btrigger \ Ftarget	0.1	0.12	0.125	0.14	0.15	0.16	0.17	0.18	0.2
2500	0.10	0.12	0.12	0.14	0.15	0.15	0.16	0.17	0.19
3184	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18
3500	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.16	0.18
4000	0.09	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17
4500	0.09	0.11	0.11	0.12	0.13	0.14	0.15	0.15	0.17
5000	0.09	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.16

Rule 3 with average constraint

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	0.07	0.09	0.10	0.11	0.12	0.13	0.15	0.16	0.17
3184	0.07	0.08	0.10	0.11	0.12	0.13	0.14	0.15	0.16
3500	0.07	0.08	0.10	0.11	0.12	0.13	0.14	0.15	0.16
4000	0.07	0.08	0.09	0.10	0.11	0.13	0.14	0.15	0.15
4500	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
5000	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.14

Rule 1 with 25/20% TAC-constraint

Btrigger \ Ftarget	0.1	0.12	0.125	0.14	0.15	0.16	0.17	0.18	0.2
2500	0.09	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18
3184	0.09	0.11	0.11	0.13	0.14	0.14	0.15	0.16	0.17
3500	0.09	0.11	0.11	0.13	0.13	0.14	0.15	0.16	0.17
4000	0.09	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.16
4500	0.09	0.10	0.11	0.12	0.13	0.13	0.14	0.15	0.16
5000	0.09	0.10	0.11	0.12	0.12	0.13	0.14	0.14	0.15

Rule 3 with25/20% TAC-constraint

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	0.08	0.09	0.10	0.11	0.12	0.14	0.15	0.16	0.17
3184	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.16	0.17
3500	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16
4000	0.07	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16
4500	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
5000	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.14

Rule 2 - F-rule with Fmin = 0.05

Btrigger \ Ftarget	0.1	0.12	0.125	0.14	0.15	0.16	0.17	0.18	0.2
2500	0.10	0.12	0.12	0.14	0.15	0.15	0.16	0.17	0.19
3184	0.10	0.12	0.12	0.13	0.14	0.15	0.16	0.17	0.19
3500	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18
4000	0.10	0.11	0.12	0.13	0.14	0.15	0.15	0.16	0.18
4500	0.09	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17
5000	0.09	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.16

Rule 4 - biomass rule with HRmin = 0.05

Btrigger \ HRtarget	0.07	0.08	0.09	0.1	0.11	0.12	0.13	0.14	0.15
2500	0.08	0.09	0.10	0.11	0.13	0.14	0.15	0.17	0.18
3184	0.08	0.09	0.10	0.11	0.12	0.14	0.15	0.16	0.17
3500	0.08	0.09	0.10	0.11	0.12	0.14	0.15	0.16	0.17
4000	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.16	0.17
4500	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.16
5000	0.07	0.09	0.10	0.11	0.12	0.13	0.14	0.15	0.15

Table A.3.12. Risk and yield for a selection of the(Ftarget, Btrigger) or (HRtarget, $B_{trigger}$) combinations in Rule 1 and Rule 3 including 10% bias. Red shaded cells correspond to the non-precautionary (Ftarget, Btrigger) or (HRtarget, $B_{trigger}$) combinations (P(SSB<Blim)<5%. Cells shaded in green colours indicate the combinations that result in yield ≥95% of the maximum yield among the precautionary combinations. Tables are shown for Prob3 (named here Risk 3).

10% bias

rule1_short.term risk

Btrigger \ Ftarget	0.102	0.125	0.156	0.2
2500	5.7	8.5	13.8	22.1
3184	5.1	7.5	12.4	20.0
5000	2.1	3.1	6.0	9.6

rule1_medium.term risk

Btrigger \ Ftarget	0.102	0.125	0.156	0.2
2500	5.5	9.2	14.8	23.6
3184	5.0	8.2	13.0	20.9
5000	2.2	3.5	6.4	10.9

rule1_long.term risk

Btrigger \ Ftarget	0.102	0.125	0.156	0.2
2500	3.6	6.6	12.6	22.6
3184	3.0	5.7	10.6	19.4
5000	1.3	2.4	4.6	9.5

rule1_short.term yield

Btrigger \ Ftarget	0.102	0.125	0.156	0.2
2500	433	504	592	694
3184	434	505	593	692
5000	385	443	512	582

rule1_medium.term yield

Btrigger \ Ftarget	0.102	0.125	0.156	0.2
2500	618	679	738	789
3184	620	681	744	799
5000	634	704	768	784

rule1_long.term yield

Btrigger \ Ftarget	0.102	0.125	0.156	0.2
2500	738	789	824	834
3184	740	793	833	850
5000	751	812	867	877

rule3_short.term risk

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	5.0	8.4	13.2	18.7
3184	4.7	8.1	12.5	17.6
5000	2.2	3.5	5.6	8.5

rule3_medium.term risk

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	4.7	8.7	13.4	19.2
3184	4.3	8.1	12.3	17.5
5000	1.8	3.5	5.7	8.3

rule3_long.term risk

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	2.9	6.1	10.7	16.6
3184	2.6	5.4	9.4	14.5
5000	1.2	2.5	4.2	7.1

rule3_short.term yield

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	369	451	531	611
3184	368	449	526	611
5000	286	353	423	494

rule3_medium.term yield

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	586	666	726	769
3184	587	669	732	777
5000	604	693	762	807

rule3_long.term yield

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	712	774	812	828
3184	713	778	819	841
5000	722	796	847	878

Table A.3.13. Risk and yield for a selection of the(Ftarget, Btrigger) or (HRtarget, Btrigger) combinations in Rule 1 and Rule 3 including 15% bias. Red shaded cells correspond to the non-precautionary (Ftarget, Btrigger) or (HRtarget, Btrigger) combinations (P(SSB<Blim)<5%. Cells shaded in green colours indicate the combinations that result in yield ≥95% of the maximum yield among the precautionary combinations. Tables are shown for Prob3 (named here Risk 3).

15% bias

rule1_short.term risk

Btrigger \ Ftarget	0.102	0.124	0.157	0.2
2500	6.0	9.3	15.4	24.0
3184	5.8	8.7	14.1	22.2
5000	2.6	4.3	7.2	11.8

rule1_medium.term risk

Btrigger \ Ftarget	0.102	0.124	0.157	0.2
2500	6.2	10.1	16.5	25.9
3184	5.7	9.3	15.1	23.4
5000	2.6	4.6	7.7	13.1

rule1_long.term risk

Btrigger \ Ftarget	0.102	0.124	0.157	0.2
2500	4.6	7.5	14.0	26.4
3184	3.8	6.6	12.5	22.5
5000	1.6	3.1	5.9	11.4

rule1_short.term yield

Btrigger \ Ftarget	0.102	0.124	0.157	0.2
2500	448	521	610	719
3184	449	521	611	718
5000	410	470	539	611

rule1_medium.term yield

Btrigger \ Ftarget	0.102	0.124	0.157	0.2
2500	632	691	747	799
3184	634	693	751	805
5000	647	715	780	795

rule1_long.term yield

Btrigger \ Ftarget	0.102	0.124	0.157	0.2
2500	749	796	827	832
3184	753	801	836	847
5000	763	820	871	877

rule3_short.term risk

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	5.6	9.6	14.9	20.8
3184	5.4	9.3	14.2	20.0
5000	2.6	4.8	6.9	10.6

rule3_medium.term risk

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	5.4	9.8	14.9	21.0
3184	4.9	9.3	13.9	20.1
5000	2.4	4.1	7.0	10.8

rule3_long.term risk

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	3.5	7.0	12.4	18.8
3184	3.2	6.4	11.2	16.9
5000	1.4	3.1	5.5	9.5

rule3_short.term yield

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	384	470	552	638
3184	383	469	549	638
5000	309	385	462	529

rule3_medium.term yield

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	602	681	737	777
3184	603	683	744	786
5000	619	707	774	817

rule3_long.term yield

Btrigger \ HPtarget	0.08	0.1	0.12	0.14
2500	724	784	817	829
3184	727	788	824	842
5000	735	809	855	880

Annex 4: List of participants

Workshop on a long-term management strategy for Norwegian Spring-spawning herring (WKNSSHMSE)

26-27 August 2018, Faroe Islands

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Annex 5: Summary table of the HCR evaluation

Stock: **Norwegian spring spawning herring**

Background		
Motive/ initiative/ background	NEAFC, on behalf of the Coastal States have in May 2018 submitted a request for ICES to evaluate options for NSSH long term management plan. This followed on from the advice on the revision of NSSH reference points issues in the beginning off 2018 (WKNSSHREF).	
Main objectives	The objective is to ensure harvest of the stock within safe biological limits.	
Formal framework	ICES on request from NEAFC.	
Who did the evaluation work	WKNSSHMSE 2018	
Method		
Software Name, brief outline include ref. or documentation	XSAM based simulation framework. Age structured operating model, no full assessment in the loop.	
Type of stock	Long life span, pelagic, straddling, very valuable	
Knowledge base *	Analytic assessment	
Type of regulation	TAC	
Operating model conditioning		
	Function, source of data	Stochastic? - how (distribution, source of variability)
Recruitment	Beverton-Holt, Ricker and segmented regression SRRs, with lowest AIC based on 5000 resamples of pairs of stock recruitment (SSB-Age2) from1950 onwards, including the collapse period 1968-87. Includes 1st order dependency in residuals.	Log-normal
Growth & maturity	Weight in catch: resampled from 1988-2016 Weight in stock: resampled from 1988-2016 no density dependence in growth Maturity: maturity ogive for a normal year class	Resampling from past values
Natural mortality	For age 2 M = 0.9, ages 3+ M = 0.15	No
Selectivity	As estimated by XSAM using data 1988-2017 (i.e. exploitation pattern follows the same model).	Yes
Initial stock numbers	From assessment	Obtained from the assessment model fit: provides the approximated simultaneous distribution of all parameters and stock sizes such that initial values can be sampled from this approximated distribution.
Decision basis **	SSB or Bref (4+ biomass) in the TAC year	
Number of iterations	3000	
Projection time	35 years	
Observation and implementation models		
Type of noise	CVs and correlations among the estimated and predicted values is accounted for. The F	Yes

	multiplier will be affected by the error in the weighting factors $w^F_{a,y+1}$ and selection pattern $s_{a,y+1}$. Finally, the TAC will be affected by the projected $N_{a,y+1}$ which gives $C_{a,y+1}$ in addition to the weight at age in the prediction	
*** Comparison with ordinary assessment?	Based on ordinary assessment.	
Projection: If yes - how?	No STF conducted (not full feedback).	
Projection: Deviations from WG practice?	N/A	
Implementation	First F given by the HCR is found based on the perceived SSB. Then a TAC is calculated, and this TAC is translated into catch numbers at age, accounting for the selection at age and weights at age. i.e. prediction error is accounted for, but no implementation error is assumed	
Harvest rule		
Harvest rule design	Four rules were studied, with different parameterisations (see request).	
Stabilizers	Two catch stabilising mechanisms were requested: 1. 20% down / 25% up restrictions 2. TAC = mean of currrent TAC and HR TAC	
Duration of decisions	Annual	
Revision clause	No clause for when the MP should be revised.	
Presentation of results		
Interest parameters	Short term (2019-2023), medium term (2024-2033) and long term (2034-2053): • Average SSB • Average yield • Indicator for year to year variability in SSB and yield • Risk of SSB falling below Blim	

**** Risk type and time interval	Risk type 3 as defined by WKGMSE 2013; the maximum probability that SSB is below B_{lim}, where the maximum (of the annual probabilities) is taken over the relevant years). For short, medium and long term and quasi-equilibrium (see definitions above).
Precautionary risk level	5% of risk type 3.
Experiences and comments	
Review, acceptance:	The current management plan has been in effect since 2001.
Experiences and comments	

Annex 6: Preliminary knowledge quality assessment of ICES Advice for NSSH Fishery

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Introduction

A preliminary knowledge quality assessment of the Norwegian spring-spawning herring fishery recommendations provided by the ICES WKNSSHMSE is presented in this annex. First, major sources of uncertainty in the quantification of fishing mortality and other limit reference points are reviewed. A pedigree analysis of the XSAM conceptual model used in the MSE framework follows. This is a proof-of-concept analysis, as there was not sufficient time for the entire working group to be involved in the pedigree scoring. Hence, this annex illustrates the utility of including a knowledge quality assessment with ICES scientific advice to communicate scientific uncertainty and the policy implications underlying the calculated Harvest Control Rules (HCR).

Major Sources of Uncertainty

The XSAM (state-space Stock AssessMent) model, commonly used by ICES, was used here for the NSSH stock assessments and in the management strategy evaluation (MSE) framework. It is a state-space single-species stock assessment model with fixed natural mortality (*M*) and variable fishing selectivity used to compute annually updated fishing mortalities (*F*).SAM models are fully stochastic that allow fishing selectivity to vary gradually with time, but have well-constrained error structures and employ fewer model parameters than fully parametric models (Koster et al. 2011). XSAM was developed by Sondre Aanes, Norwegian Computing Centre (ICES 2016a, 2016b; Valstad 2017).

Model specification uncertainty associated with the XSAM model results has been evaluated by comparing it with the separable (SEP) or virtual population analysis (VPA) stock assessment model described in WD1 (Björnsson 2018), but not with other models widely used in fisheries. These include statistical catch-at-age (SCAA) stock assessment models, such as Stock Synthesis, a statistical age-structured population dynamics modelling framework favoured by the National Oceanic and Atmospheric Administration in the USA (Methot and Wetzel 2013). A future improvement would be to compare the MSE modelling results here to incorporate ecosystem impacts through ecosystem-based modelling, such as Ecopath with Ecosim (EwE) and Atlantis (Plagányi 2007). In the EwE framework (Christensen and Walters 2004), Ecopath creates, using the principle of mass balance, a static food web model that serves as a platform for calculating ecological metrics and dynamic ecosystem simulations in Ecosim. EwE has been expanded to include a sophisticated MSE module (Mackinson et al. 2018). Meanwhile, Atlantis is a biogeochemical, whole-ecosystem, spatially explicit, age-structured, and deterministic model whose overall structure is based around the MSE approach (https://research.csiro.au/atlantis/).

The XSAM results are particularly sensitive to the input parameters because of the uncertainty in the natural mortality and stock-recruitment (S-R) relationship. In XSAM, the natural mortality has been assumed to be fixed, set at $M = 0.9$ for age 2 and $M = 0.15$ for ages 3+, which neglects a significant uncertainty in the differential mortality effects of predators, as well as other sources of natural mortality, including disease, parasites and old age. The S-R relationship was investigated in the current simulations using segmented regression (hockey-stick), Beverton-Holt, and Ricker models. The input data obtained from NSSH surveys is of reasonable quality, though retrospective analysis of spawning stock biomass (SSB) has shown SSB to deviate by as much as 30% for various Northeast Atlantic stocks (Hauge 2011). The choice of time series used in the stock assessments (1988 – present) and to determine the S-R relationship (1950 – present) introduces another source of uncertainty stemming from assumptions about the stability of environmental conditions and their influence on herring populations. Other potential sources of uncertainty include bias in the assessments, which has already been noted in the introduction, and age-weighted *F*s in the reference point calculations, as per WKNSSHREF (ICES 2018).

Pedigree Analysis

In light of these uncertainties, we evaluated the tenability of the XSAM simulation model used for the NSSH assessments and MSE using a so-called pedigree analysis, which is part of the Numeral, Unit, Spread, Assessment and Pedigree (NUSAP) approach (Van der Sluijs 2017).

NUSAP is a notational system, proposed by Funtowicz and Ravetz (1990), to improve uncertainty assessment and communication of issues characterized by high systems uncertainty and high decision stakes (called "post-normal science"). NUSAP aims to provide an analysis and diagnosis of uncertainty and quality in science for policy. The NUSAP system structures the systematic appraisal and communication of three dimensions of uncertainty: technical (inexactness), methodological (unreliability) and epistemological (border with ignorance). It provides a heuristic for good practice addressing uncertainty in quantitative information. NUSAP extends the statistical approach to uncertainty with methodological and epistemological dimensions by adding expert judgment of reliability (Assessment) and systematic multi-criteria evaluation of the underpinning of numbers (Pedigree).

Pedigree conveys an evaluative account of the production process of information, and indicates different aspects of the underpinning of the numbers and scientific status of the knowledge used. Pedigree is expressed as a set of criteria and assessed using qualitative expert judgment. Arbitrariness and subjectivity in measuring strength are minimised by using a Pedigree matrix to code qualitative expert judgments for each criterion into a ordinal scale from 0 (weak) to 4 (strong) accompanied by linguistic descriptors or modes. Each special sort of information has its own aspects that are key to its Pedigree, so different Pedigree matrices using different criteria can be used to qualify different sorts of information (Van der Sluijs 2017). For an illustrative Pedigree analysis of the XSAM model applied in this report, we selected the Pedigree matrix for evaluating models (Refsgaard *et al.* 2006) that is presented in Table 1.

Table 1: Pedigree matrix for evaluating the tenability of the XSAM conceptual model (after Refsgaard et al. 2006).

Score	Supporting Empirical Evidence		Theoretical Understanding	Representation of understood underlying mechanisms	Plausibility	Colleague Consensus
	Proxy	Quality & Quantity				
4	Exact measures of the modelled quantities	Controlled experiments and large sample; direct measurements	Well established theory	Model equations reflect high mechanistic process detail	Highly plausible	All but cranks
3	Good fits or measures of the modelled quantities	Historical/field data; uncontrolled experiments; small sample; direct measurements	Accepted theory with partial nature (in view of the phenomenon it describes)	Model equations reflect acceptable mechanistic process detail	Reasonably plausible	All but rebels
2	Well correlated but not measuring the same thing	Modelled/derived data; indirect measurements	Accepted theory with partial nature and limited consensus on reliability	Aggregated parametrized meta model	Somewhat plausible	Competing schools
1	Weak correlation but commonalities in measure	Educated guesses; indirect approximate rule of thumb estimate	Preliminary theory	Grey box model	Not very plausible	Embryonic field
0	Not correlated and not clearly related	Crude speculation	Crude speculation	Black box model	Not at all plausible	No opinion

The pedigree scoring, visualized in Figure 1, is preliminary and has been done by the authors of this appendix, mainly to illustrate the approach

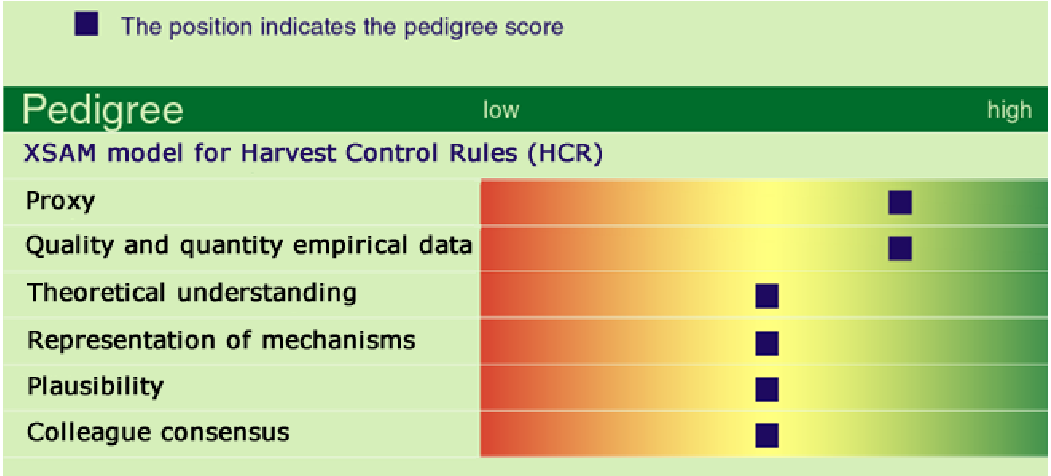

Figure 1: Pedigree scores for XSAM model for Harvest Control Rules (HCR)

The supporting empirical evidence (proxy and quality & quantity) scores for XSAM were both evaluated as 3. The proxy score reflects the 10 - 30% uncertainty often assessed for key measures of the state of the stock in ICES assessments (Skagen and Hauge 2002). The quality and quantity scores reflect the general representativeness and quality of the NSSH survey data, respectively. Each of the remaining criteria, i.e., theoretical understanding, representation of understood underlying mechanisms, plausibility, and colleague consensus, was scored slightly lower at 2. Theoretical understanding and predictability of the natural fluctuations of herring population dynamics are still poor. Single-species stock assessment models such as XSAM omit predator-prey and other ecosystem interactions in its calculations of herring reference point limits, which gives it a low score for its representation of understood underlying mechanisms. Consequently, the plausibility and colleague consensus are also scored low, given alternative single-species stock assessment and ecosystem-based modelling approaches commonly used within the fisheries community. Note that in this preliminary knowledge quality assessment, we have only examined technical (inexactness) and methodological (unreliability) dimensions of uncertainty for the XSAM model, not epistemological (ignorance) or societal (limited social robustness) uncertainty (Maxim and van der Sluijs 2011). Neglecting these additional sources of uncertainty leads to “hyper-precision” in the ICES framework for quota advice (Hauge 2011).

Implications

The implications of this preliminary knowledge quality assessment of the results reported by the WKNSSHMSE suggest that the precision of the recommended reference limits for the HCR considered here (that is, the number of significant digits) should be restricted to below what is recommended by ICES guidelines to avoid the pitfalls of hyper-precision. Hence, a range of F_{MSY} = 0.10–0.15 has been given in the conclusions to reflect the sensitivity of the modelled outputs to the input parameters and other sources of XSAM model uncertainty in the MSE framework.

The analysis here shows a problematic mismatch between the number of significant digits that can scientifically be justified given the many uncertainties, complexities and limitations to knowledge quality in fisheries stock assessments, and the precision required by the political process of fish-quota negotiations. If, for instance, only one significant digit is warranted from a scientific point of view, 10% to 100% fluctuations in quota from year to year could occur, which is politically unacceptable. The practice and guidelines of ICES for significant digits in this field of tension needs more critical reflection and dialogue to develop responsible ways forward in dealing with uncertainty and limits to achievable knowledge quality in fishery science for policy.

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Annex 7: Joint Reviewers' comments

WKNSSHMSE Review,

10 September 2018

N. Hintzen, Wageningen Marine Research

General remarks:

The MSE does not seem to be executed in line with best practices on MSEs. There are a number of conceptual mistakes or simplifications in the MSE evaluated here, related to including productivity, error structures, uncertainty in biological parameters that have not been appropriately considered. I focus on 4 points especially:

1) Biological variability in weights-at-age, maturity-at-age is not included in the MSE. The authors claim they have investigated this aspect but do not present any proof of why ignoring this is justified. I am suspicious of their conclusion as my experience in MSE has shown me clearly that variability usually plays a very important role.

2) There is a substantial retrospective pattern in the assessment which is ignored in the MSE. Even if retrospective error is low in recent year, there seems to be no bias implementation error (just simple well balanced noise). Given the already high medium term risk, we need to be precautionary and include known sources of bias into the MSE

3) The SR-pairs that were used provide far too optimistic predictions. This is also shown in their results indicating a direct growth of the stock and potential to observe SSBs and Recruitments well above anything observed in the entire time-series. Provided that recruitment is low in the recent decade, this should be reflected in this MSE

4) There is a lot of confusion on the estimation of F_{MSY} and what methods finally have been used to derive F_{MSY}. It seems an XSAM simulation has been used, but results seem not to agree with MSE results, only adding to the confusion.

All together do I not see this MSE fit for advisory purposes. These concerns were noted by the authors but simply all ignored without further justification. If justification of why these points can be ignored is given I'm happy to change my views.

Other specific comments were made on a draft of the report; these have also been addressed by the group in Annex 8.

REVIEW of WKNSSHMSE_2018_DRAFT05Sep

Fan Zhang

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I've reviewed the Report of the Workshop on management strategy evaluation for the Norwegian spring spawning herring (WKNSSHMSE) in subareas 1, 2 and 5, and in divisions 4.a and 14.a (hereinafter referred to as "Report"). WKNSSHMSE was convened to prepare the technical basis needed by ICES to respond to the request from North East Atlantic Fisheries Commission (NEAFC) concerning a long-term management strategy for Norwegian spring spawning herring (hereinafter referred to as "Request"). As requested, this review mainly focused on evaluating whether the Report is sufficient to address the issues raised by the Request.

In general, the Report addressed many important issues in the Request, but several key aspects were missing. In particular, three major issues need to be modified and improved to fully address the Request.

ISSUE 1. Incomplete simulation scenarios of harvest control rules

The Request asks for Management Strategy Evaluation (MSE) simulations involving 4 Harvest Control rules (HCRs) and 3 scenarios of inter-annual variations in Total Allowable Catch (TAC). This lead to 12 simulation scenarios:

1. F-rule through 0 with no constraint of TAC variation.
2. F-rule through 0 with TAC-constraint average of TAC in current and TAC-year.
3. F-rule through 0 with TAC-constraint +25%/-20% between current and TAC-year.
4. F-rule with F_{min} with no constraint of TAC variation.
5. F-rule with F_{min} with TAC-constraint average of TAC in current and TAC-year.
6. F-rule with F_{min} with TAC-constraint +25%/-20% between current and TAC-year.
7. B-rule through 0 with no constraint of TAC variation.
8. B-rule through 0 with TAC-constraint average of TAC in current and TAC-year.
9. B-rule through 0 with TAC-constraint +25%/-20% between current and TAC-year.
10. B-rule with HR_{min} with no constraint of TAC variation.
11. B-rule with HR_{min} with TAC-constraint average of TAC in current and TAC-year.
12. B-rule with HR_{min} with TAC-constraint +25%/-20% between current and TAC-year.

In the Report, only 8 out of 12 simulation scenarios were simulated (scenarios 5, 6, 11 and 12 were excluded; see Table 4.1 in the Report). Time constraint is described as the reason for this simplification, but it needs to be explained why these specific simulation scenarios were ignored and how this simplification will affect the ability of the Report to address this Request.

For the 8 simulation scenarios described in the Report, scenarios 3 and 9 were not included in the MSE source code (line 330 in MSEcode.R clearly states "The only catchconstraint option currently provided is 'CCType==1' (Average of last year and the one given by the HCR)!!"). This makes me curious how the results relevant to scenarios 3 and 9 were generated if they are not included in the simulation code. The inconsistency between Rcode and Report needs to be explained and clarified.

In the Request, there are two conditions to apply to the TAC variations:

1. The TAC constraint shall not apply if the SSB/SSB_{proxy} in the year for which the TAC is to be set is less or equal to Btrigger.
2. Allowing a maximum of 10% to be banked or borrowed any year.

In the Report, it seems condition 1 was applied (see section 4.2.1). However, it is unclear how this was implemented in the code (MSEcode.R). I didn't find the code corresponding to this condition (apology if I missed them). Condition 2 was not applied at all, but without detailed explanation. Admittedly, condition 2 is a bit vague and needs to be further clarified in the Request. The Report should at least have some discussions over this or provide some options of simulation, rather than simply ignoring condition 2.

ISSUE 2. Change of special case scenario without sufficient details

The Request specifically asked for special case simulations at *: $B_{trigger}$=3.184 (=MSY $B_{trigger}$=B_{pa}) and the target fishing mortality of 0.102 (F_{MSY}).*

In the Report, F_{MSY} was re-calculated as 0.157 by WKNSSHMSE, and was claimed to be more appropriate than the 0.102 calculated by WKNSSHREF. On basis of this, the simulation used F_{MSY}=0.157 and F=0.12 for the special case simulation. F=0.102 (value specified in the Request) was not tested as a special case at all.

This represents a major mismatch between the Request and Report, and a detailed justification needs to be provided to support this change. However, I feel the justifications provided in the Report are not sufficient.

It is unclear why F=0.12 was chosen as a special case. If the special case is for $B_{trigger}$ and F_{MSY}, why testing other F values and why 0.12 in particular? More explanations are needed.

The difference between F_{MSY} calculated by WKNSSHMSE and WKNSSHREF was attributed to corrected-N2 and increased simulation iterations.

First, as noted in the Report, accounting for age-0 and age-1 catches seems to have stronger impact on recruitment in early years (lead to greater recruitment when recruitment was high) than in recent years (basically no change in recruitment when recruitment was low). More details need to be provided to justify this correction is appropriate to reduce bias, rather than introducing other sources of bias.

Second, the Report noted numerical instability in the simulation with insufficient iterations, but then stated "Since this is computer intensive and require relative much storage place and memory the time constraints have restricted this task". In section 3.2, it is unclear how the problem is addressed. Evaluating numerical instability by visual check of only a few plots seems not to be very convincing. More detailed and rigorous tests are needed to justify the current WKNSSEMSE simulations have addressed the problem of numerical instability.

ISSUE 3. Incomplete results and conclusions

The Request specifies 5 performance criteria over 3 terms, which lead to 15 performance statistics (PSs):

1. Average SSB in short term (2019-2023).
2. Average SSB in medium term (2024-2033).
3. Average SSB in long term (2034-2053).
4. Average yield in short term (2019-2023).
5. Average yield in medium term (2024-2033).
6. Average yield in long term (2034-2053).
7. Inter-annual variability in SSB in short term (2019-2023).
8. Inter-annual variability in SSB in medium term (2024-2033).
9. Inter-annual variability in SSB in long term (2034-2053).
10. Inter-annual variability in yield in short term (2019-2023).
11. Inter-annual variability in yield in medium term (2024-2033).
12. Inter-annual variability in yield in long term (2034-2053).
13. Risk of SSB falling below B_{lim} in short term (2019-2023).
14. Risk of SSB falling below B_{lim} in medium term (2024-2033).
15. Risk of SSB falling below B_{lim} in long term (2034-2053).

The Report included 12 out of 15 PSs (PS 7, 8 and 9 regarding inter-annual variation in SSB were excluded; see section 4.2.3), and no explanation was given.

The Request mentioned "ICES is also requested to assess what, if any, other measures in addition to those contained in the present Management Strategy might contribute to attaining the objectives of the strategy, and provide estimates of their efficiency".

In the Report, Realised F was used as an additional PS, but no explanation was given on why to use it or how it could help to achieve the objective in the Request (see section 4.1.4).

The conclusion of the Report should fully correspond to the Request. However, the section 5.2 just listed scattered results from the simulation, which makes it difficult to understand how the conclusions of this Report will address the Request.

In summary, I don't think the Report has sufficiently addressed the Request in its current form. Time constraint was frequently raised as reason for these simplifications, but that couldn't justify this Report as an appropriate answer to the Request. If more time is needed to complete the task, negotiations of time extension should be considered between WKNSSHMSE and NEAFC.

Annex 8: Answer to the reviews of the WKNSSHMSE report

Reviewer: Fan Zhang

ISSUE 1. Incomplete simulation scenarios of harvest control rules

It is correct that not all the questions in the Request were answered due to time limitations. We have now added text in the Introduction section regarding the deviations from the Request and tried to explain the decisions made.

Source code: It appears the reviewer did not have access to updated source code. Both TAC constraints are included, but they were only rested for rule 1 and 3.

ISSUE 2. Change of special case scenario without sufficient details

It is correct that this was not included in the first edition of the report. Since we encountered issues with the estimate of F_{MSY} from WKNSSHREF, the special case with F_{MSY}=0.102 was not included at first. However, following the reviewers comments this has been done now and included in the report, both for F_{MSY} = 0.102 (from WKNSSHREF) and for F_{MSY}=0.157 (from WKNSSHMSE).

Regarding catches on young fish

Have added text to explain why catches on young fish is only relevant in the past since a minimum landing size was established after the collapse.

ISSUE 3. Incomplete results and conclusions

Criteria related to inter annual variability in SSB is now included and we have explained why realized F is included (section 4.1.4), even though not asked for in the request.

Section 5 in the report has been edited to better communicate the main findings.

Reviewer N. Hintzen

1) Biological variability

We have now included text, table and figure in the report (in section2) to explain that including variability in biological parameters have marginal effects and are therefore not included in the simulations.

2) Retrospective pattern

This is correct. We do not, however, know the sources of the bias, but have now included a paragraph where the effects of such a bias is discussed

See ExtraWork WD for the examination of the effect of including bias in the simulations.

3) SR pair being too optimistic.

Here we disagree. The recruitment scenario is not too optimistic. One can look at the recruitment pattern historically to see long periods of poor (normal) recruitment and large cohorts in between.

Keep in mind that the last 10 years is already included in the data and it is not the mean values that will have the largest impact on estimates of risk (and subsequently Fp05), but the tails of the distribution.

Since year-class 2005, we have not had any large year-classes. The median year-class is (in numbers) 7.4 milliards, the smallest 3.85 milliards and the average 8.5 milliards. Over the historic time since 1950, taking the years when the SSB has been above 2 million tonnes, the median is 11.4, 10th percentile 3.9 and 5th percentile 2.2 milliard fishes. The average is of course much higher as there are 7 year-classes > 40 milliards in the historic time series.

We conclude that there is no empirical evidence that the recruitment has changed in a way such that it is necessary to change the recruitment function. If you simulate 1000 years of recruits, it is possible to find periods with recruitment of 10 years that is similar to the dynamics since 2005 and there is no basis to state that recruitment is overly optimistic in the simulations.

4) Confusion regarding the estimation of FMSY

F_{MSY} = 0.157 estimation was based on equilibrium situation, as per ICES guidelines. It is not surprising that different results regarding precautionary levels of F are obtained on the time-scales presented in the Request, particularly for short term = 2019–2023 and medium term = 2024–2033 simulations, which are not equilibrium situations. Hope this is now better explained in the report

Annex 9: Follow-up request from the Coastal States concerning a long-term management strategy for Norwegian Spring-Spawning (Atlanto-Scandian) Herring

Following the advice concerning the management strategy evaluation of harvest control rule (HCR) options released by ICES, 28th September 2018 (ICES, 2018), the Coastal States sent a new request to ICES regarding further evaluation of their selected harvest control rule (see below), that had not been included in the advice of 28th September.

Request to ICES

Request to ICES concerning a long-term management strategy for Norwegian Spring-Spawning (Atlanto-Scandian) Herring

With basis in the advice released by ICES on 28th of September 2018 regarding LTMS for Norwegian Spring Spawning (Atlanto-Scandian) Herring, ICES is requested to evaluate the following LTMS:

- Rule 2 with a $B_{trigger}$=B_{pa} = 3,184,000 tonnes and $F_{management}$= 0.14
    - Interannual variation constraint: When the rules would lead to a TAC, which deviates by more than 20% below or 25% above the TAC of the preceding year, the TAC is to be set respectively no more than 20% less or 25% more than the TAC of the preceding year.
    - The TAC constraint shall not apply if the SSB for the year for which the TAC is to be set is forecast to be less or equal to Btrigger.
    - Allowing a maximum of 10% to be banked or borrowed any year. However, borrowing shall not be allowed when the stock is forecast to be under Btrigger at the end of the TAC year.

The above LTMS shall be assessed in relation to how it performs in the short term (2019-2023), medium term (2024-2033) and long term (2034–2053) in relation to:

- Average SSB
- Average yield
- Indicator for year to year variability in SSB and yield
- Risk of SSB falling below B_{lim}

In case the above LTMS is consistent with the precautionary approach, ICES is requested to apply the LTMS as basis for the advice for 2019 and onward. However, for 2019, the interannual variation constraints shall not be applied.

In case ICES evaluates banking not to be consistent with the precautionary approach when the stock is below $B_{trigger}$, ICES is asked to provide advice for 2019 according to Rule 2 but without the banking provision if the SSB is below Btrigger.

ICES is asked to provide advice by October 22nd 2018.

Methodology

To answer the request, the basis was the same as in WKNSSHMSE: assessment in 2017 using sum of national quotas for catch in 2017 (~805 thousand t) and catch advice for 2018 (~384 thousand t).

The code was updated to include a TAC constraint (+25%/-20%) and a 10% banking and borrowing for the specific rule chosen by the Coastal States (rule 2 with breakpoints at Blim=2500 and B_{pa}=3184, and with minimum F=0.05 and target F=0.14).

Banking/borrowing is implemented to affect the TAC after application of the catch constraint. It was simulated to take effect on the TAC from 2018 onwards, with the following scenarios

- Scenario 1: banking 10% in every year from 2018 onwards (scenario 2 in Brunel and Miller 2013)
- Scenario 2: borrowing 10% in every year from 2018 onwards (scenario 3 in Brunel and Miller 2013)

Results

Results from simulations with F-rule with two break-points, $B_{trigger}$ = 3184 and F_{target} = 0.14. Four different scenarios were evaluated:

- **No** banking and borrowing, **no** catch constraints
- **No** banking and borrowing, catch constraints
- **Banking** every year, catch constraints
- **Borrowing** every year, catch constraints

All scenarios gave P(SSB<B_{lim}) less than 5% (Table 1, Figure 1). Including +25%/-20% catch constraint slightly decreased the risk of falling below B_{lim}. The yield was also lower when including the catch constraint; the difference was largest in the short term and smallest in the long term. Median SSB was lower in the short term but larger in the medium and long term.

Including banking and borrowing induced very small changes. For median ssb, yield and IAV in ssb changes were generally less than 1 %, and for P(SSB<B_{lim}) generally less than 5%. IAV in yield decreases by about 10% for banking every year, and increases by about 10% for borrowing every year.

Table 1. Results from the four scenarios in short, medium and long term.

		P(SSB <B_{LIM})	SSB (KT)	YIELD (KT)	INTERANNUAL VARIATION IN SSB (%)	INTERANNUAL VARIATION IN YIELD (%)
		MAX. ANNUAL %	MEDIAN	MEDIAN	MEDIAN	MEDIAN
1. No banking or borrowing, **No** catch constraints	Short term - 2019-2023	4.3	3622	502	8.1	27.6
	Medium term - 2024-2033	4.6	5049	701	8.5	21.4
	Long term - 2034-2037	3.2	5856	807	8.7	19.5
2. No banking or borrowing, Catch constraints	Short term - 2019-2023	3.8	3681	461	8.3	25
	Medium term - 2024-2033	3.9	5474	673	8.9	20
	Long term - 2034-2037	2.4	6183	810	9.2	20
3. Banking every year, Catch constraints	Short term - 2019-2023	3.8	3734	461	8.3	22.5
	Medium term - 2024-2033	3.7	5510	675	8.9	18
	Long term - 2034-2037	2.6	6206	810	9.3	18
4. Borrowing every year, Catch constraints	Short term - 2019-2023	3.8	3655	458	8.4	27.5
	Medium term - 2024-2033	3.7	5463	673	8.9	22
	Long term - 2034-2037	2.4	6174	808	9.2	22

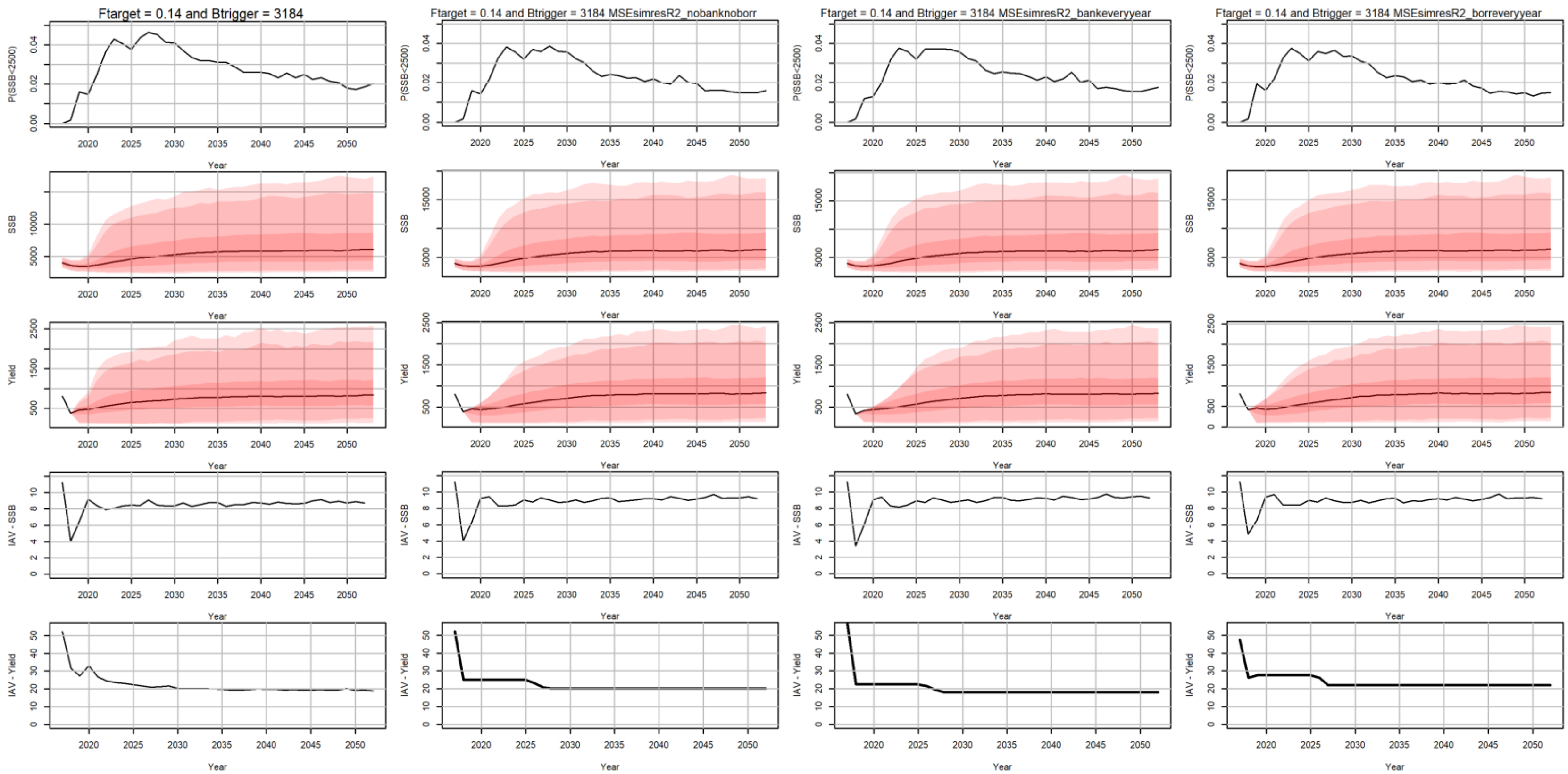

Figure 1. Performance statistics for the four scenarios examined: No banking or borrowing or catch constraints (Scenario 1, Far left); No banking or borrowing with catch constraints (Scenario 2, centre left); Banking every year with catch constraints (Scenario 3, centre right); and Borrowing every year with catch constraints (Scenario 4, far right). Results are shown from 2017 to 2053 for: the probability of SSB being below B_{lim} (top), SSB (second from top), Yield (middle), interannual variation in SSB (second from bottom) and interannual variation in yield (bottom). Solid black lines represent medians, and the SSB and Yield plots include confidence ranges (outermost = 95% range).

Conclusion

The HCR proposed for the LTMS is found to be consistent with the precautionary approach (the maximum annual probability of SSB being below B_{lim} is less than 5% in any of the years simulated). In addition, the HCR remains precautionary when constraints on interannual TAC change are added, and is also robust to 10% banking or borrowing of quota between years.

References

Brunel, T., and Miller, D.C.M. 2013. An Evaluation of the Impact of Inter-annual Quota Flexibility (Banking and Borrowing) on the Performance of the North Sea Flatfish Long Term Management Plan, June 2013, ICES Headquarters, Copenhagen. ICES CM 2013/ACOM:64. 39 pp.

ICES. 2018. NEAFC request concerning long-term management strategy for herring in the Northeast Atlantic (Norwegian spring-spawning herring). In Report of ICES Advisory Committee, 2018. ICES Advice 2018, sr.2018.17.