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Management Strategy Evaluation (MSE) of cod in NAFO Div. 3M to test the proposed NAFO Precautionary Approach Framework (NAFO-PAF)

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Abstract

The NAFO Precautionary Approach Framework (PAF) is essential for managing fishery resources in the Convention Area sustainably, aiming to maintain or rebuild stocks while minimizing risks to biological productivity. This report assesses the effectiveness of the proposed NAFO's leaf PAF using the 3M cod Bayesian Statistical Catch-at-Age (BSCAA) model. There is a lot of similarity between the three lines in the long-term performance of the stock, however in the short-term there is considerable difference in TAC. We suggest that in the initial years of PA implementation, F should not significantly deviate from the current F applied to the stock. The simulation output showed that when the PA's three lines were applied, the stock stabilized within the cautious zone over the simulation time period of 25 years.

The zone where the SSB stabilizes depends on the applied F-levels, which are influenced by the Ftarget. In the current application, the Fbar from the PA is higher than the level required for stock growth, necessitating a reduction in the Ftarget for better performance. Concerns were raised that the Fmsy used in the analysis is perhaps too high, and an alternate method was recommended to estimate the Fmsy and Ftarget. The SC, therefore, recommended repeating the analyses following further re-estimation of Fmsy using a different approach.

Introduction

The NAFO Precautionary Approach Framework (PAF) has been an important development towards creating a unified approach for the sustainable management of fishery resources in the Convention Area. At the overarching level, the goals of the PA framework are to maintain or promote the rebuilding of depleted stocks to a level where the risk of impaired biological productivity is minimal (the "safe zone"). Maintaining stocks in the safe zone requires identifying the biological limits (Blim and Flim), target reference points (Bmsy and Ftarget), and an appropriate harvest control rule (HCR) that are sustainable and robust enough to handle uncertainties in stock productivity. The PA framework serves as a tool for management to identify whether fishing is a significant driver in determining stock status.

After evaluation of several possible PA frameworks, the NAFO PA working group (PAWG) proposed a PA 'leaf' framework. Mathematical details about PA 'leaf' framework can be explored in NAFO (**2024**). PAWG discussed various leaf widths to be tested. Three possible leaf widths were proposed, where the 'leaf' argument x50=0.25 for the upper leaf and x50=0.75 for the upper leaf. The PAWG observed that the narrow option closely resembled the linear model, while the wide option could cause sharp changes in the curve, potentially leading to significant fluctuations in TAC and practical issues. Consequently, the PAWG recommended initially testing the mid option (option 2). If feasible, the other two options could be evaluated later (**NAFO, 2024**).

1. **Wide**: $X_{50}^{\mathrm{up}} = 0.1, X_{50}^{\mathrm{low}} = 0.9$
2. **Mid**: $X_{50}^{\mathrm{up}} = 0.25, X_{50}^{\mathrm{low}} = 0.75$
3. **Narrow**: $X_{50}^{\mathrm{up}} = 0.4, X_{50}^{\mathrm{low}} = 0.6$

The NAFO PAWG has decided on two approaches to test the approved PAF (Figure 1) : (1) a generic approach and (2) a stock-specific Management Strategy Evaluation (MSE) approach. For the stock-specific MSE, two stocks, namely 3M cod and 3NO Witch Flounder, have been identified as candidate stocks. The 3M cod stock is managed using a Bayesian Statistical Catch-at-Age (BSCAA) model, while the 3NO Witch Flounder is managed using a Bayesian Surplus Production (BSP) model.

This report describes the implementation of the MSE, and the performance of the approved PAF using the 3M cod BSCAA model approved at the NAFO June SC meeting in 2023 (**Garrido et al., 2023**).

Methods

A Bayesian statistical catch-at-age model (BSCAA) was used to assess the cod stock in NAFO Division 3M. The primary inputs for the model included: (1) Annual Total Catch and Catch-at-age, (2) Survey Indices categorized by age from EU survey, (3) Mean weight-at-age, and (4) Maturity-at-age. Data spanning from 1988 to 2022 were used to calibrate the model to both catch and survey data.

MSE implementation

Operating model (OM)

The Operating Model (OM) used for the MSE simulations is based on the latest assessment completed in 2023, incorporating data up to 2022. More information about the assessment model can be found in **NAFO SCR Doc. 23/009**.

1. State equation: The first year is initialized in 2022 using 350 samples from the MCMC outputs of abundance-at-age, fishing mortality-at-age (F), natural mortality-at-age (M) using 350 samples from the MCMC output of the BSCAA. From 2023, the simulation process generates new data. Beverton-Holt (BH) and Ricker stock recruitment (SR) relations were fit to the model output of SSB and recruitment at several different fixed steepness values (**Gullage et al., 2024**). Of these SR curves, the June 2024 NAFO SC meeting judged the steepness of 0.7 for both the BH and Ricker SR curves to be suitable for testing the PA. Reference points were calculated using the recruitment pattern described by these curves. Therefore, the simulations are run on two sets of SR and Reference point combinations.

$$N_{2022,a} = N_{2022,a} \qquad (1)$$

From year 2023 onwards, the population is projected forward using the model state equation.
- Age 1 – recruits are sampled from a Beverton-Holt (BH) SR function (base case). Additional simulation are run using a Ricker Stock Recruit function,
- Age 2+ - follows cohort equation with age 8 as plus group.

$$N_{a,t} = \begin{cases} BH\left(SSB_{y-1}, logR0, h\right), & \text{if} \quad a = 1 \\ N_{a-1,t-1}e^{-Z_{a-1,t-1}}, & \text{if} \quad 1 < a < 7 \\ \Sigma_{a=7}^{8} N_{a,t-1}e^{Z_{a,t-1}}, & \text{if} \quad a \geq 8 \end{cases} \qquad (2)$$

The spawning stock biomass in each year is the sumproduct of abundance-at-age, maturity-at-age (assumed to be the average of the last three years),and stock weights-at-age (assumed to be the average of the last three years). The SSB in a year are used to calculate the recruitment in the following year as an input into the BH or Ricker SR functions.

$$SSB_y = \Sigma_{a=1}^{8}\left[N_{a,y} mat_{a,y} Sw_a\right] \qquad (3)$$

2. Observation model: Calculate the indices-at-age for the EU survey using the estimated catchability and observation error standard deviation estimates. In the equation below α and β correspond to the timing of the survey in July. Values for the parameters ϕ and γ are obtained from the assessment approved in 2023.

$$I_{y,a} = \phi_a\left[N_{a,y}\frac{e^{-\alpha Z_{a,y}} - e^{-\beta Z_{a,y}}}{(\beta - \alpha)Z_{a,y}}\right]e^{\gamma_a} \qquad (3)$$

7. Fishery model: Landings information for the stock till year 2023 is used in the projection year,

the TAC of 11,708 tonnes for the year 2024 is used in the projections. TAC determined by the application of the PA framework is applied from year 2025 onwards. In order to calculate F from TAC:

i. Selectivity calculated by scaling the fishing mortality estimates from the SCAA. The median across MCMC outputs for each age is used as the constant selectivity for the simulation inside OM.

$$Sel_a = \frac{F_a}{\frac{\Sigma_{a=3}^{5} F_a}{3}} \qquad (4)$$

ii. Weight-at-age in catch is the average of the last three years.

iii. For first year of the simulation: F, selectivity and weight-at-age vector for 2022 are taken directly from SCAA output for 2023.

iv. TAC values are used to calculate the F and yield in a given year.
- For years 2023 to 2024, TACs were specified (6100t, 11708t).
- For years 2025 to 2050, TACs in OM are those obtained from the application of PA in the simulation.
- Calculate corresponding F by minimizing the difference between proposed TAC and expected yield.
- Calculate catch numbers and yield based on Baranov's catch equation.

$$C_{a,t} = \frac{F_{a,t}}{Z_{a,t}}(1 - e^{-Z_{a,t}})N_{a,t} \qquad (5)$$

$$Y_t = \Sigma_{a=1}^{8} C_{a,t} w_{a,t} \qquad (6)$$

4. Application of the PA leaf formulation. As with the other case study on Witch Flounder, the PA implementation process begins in the current year 2024 wherin advice is generated for 2025. The BSCAA model is run within the simulation every year starting 2023 to follow the assessment cycle for the stock.

i. The first step in modelling the application of PA is preparing the data for running the assessment model inside the simulation. This step includes adding the simulated indices-at-age for the EU survey. In addition, an additional year of catch-at-age information, landings, catch-weights, stock-weights, maturity, is added to create a new dataset.

ii. Determination of stock status: The BSCAA model is rerun with the newly updated dataset in every year and every simulation of the MSE with the same controls as is run for the annual assessment.

iii. Model the fisheries management process and apply the PA: The stock status determined from the assessment is projected forward two years. The two year projection is done to account for the time between the last year of data available in the assessment and the advice year. For example, at the 2024 assessment, data up to 2023 will be available for running the assessment, and advice would be provided for 2025; so after running the assessment within the simulation, prior to applying the PA, the stock would need to be projected to 2025, the advise year. This projection uses the state equation and the TAC available for the projection year (i.e. 2024).

iv. NAFO leaf HCR description: In the critical zone, where SSB is below Blim, the F is set to zero. In the healthy zone, where SSB is greater than Btrigger, the Fbar is equal to Ftrigger (0.8/5*Fmsy). In the proposed PA formulation of the leaf shape is applied within the caution Zone of the PAF is designed to manage average fishing mortality (Fbar) as a function of spawning stock biomass (Figure 1). The HCR is denoted as in the equation below, and for detailed description of PA “leaf” function, please refer to NAFO (**2024**). The projected biomass in the advice year is applied to to this PA function to obtain the Fbar value for the advice year, and this Fbar value from the PA is used to provide the TAC advice.

$$Fbar_{t+2} = fPA\left(SSB_{t+2}^{p}\right) \quad \text{where } SSB^{p} \quad \text{is projected SSB} \qquad (7)$$

A TAC advice is generated based on the Fbar using information on the projected Numbers-at-age, selectivity and M from the assessment model produced in step (ii) above,

$$TAC_{t+2} = \Sigma_{a=1}^{8}\left[\frac{Fbar_{t+2}Sel'_{a,t}}{Fbar_{t+2}Sel'_{a,t} + M'_{a,t}}\left(1 - e^{\left(-Fbar_{t+2}Sel'_{a,t}+M'_{a,t}\right)}\right)N_{a,t+2}^{p}Cw_{a}\right] \qquad (8)$$

3. Implementation model – implements TAC decisions to calculate actual annual removals. Implementation is assumed to be accurate; this means that the catch taken is the same as the TAC advised.

Results

We observe that the three lines of the leaf exhibit similar performance and tend to stabilize at similar levels at the end of the simulation (Figures 2, Figures 3). In the short-term though, we saw considerable variability in the TAC from the three different leaf shapes (Figures 8, Figures 9). We therefore suggest that in the initial year of PA implementation, the F should not deviate too far from the current F-levels estimated for stock.

It was noted that the stock remained in the cautious zone at the end of the simulation, with the lower leaf showing a slightly better performance than the upper leaf (Figures 2, Figures 3), owing to the lower F levels on the trajectory towards Btrigger. F levels stayed above current levels, and the catches stabilized at levels below the MSY. Performance was similar between the OMs generating recruitment using the BH and Ricker SR relation. More results are in the section on performance metrics, see “Appendix: Performance Statistics”.

Discussion

Since we notice, difference in TAC values in the early years, we suggest that in the initial years of PA implementation, the F should not deviate too far from the current F levels applied to the stock in order to avoid large variability in TAC.

It is noted here that the SSB can stabilize within the cautious zone, depending on the F-levels applied on the stock. Since the Ftarget value is based on Fmsy, concerns were therefore raised about the Fmsy calculated for the stock. Fmsy used in this analysis was generated using the yield per recruit method and an analysis equilibrium recruits at different fishing levels on the stock (**Gullage et al., 2024**). In doing the calculations, all life history parameters used were averaged over the entire time series of the stock. Hence, it is possible that the Fmsy calculated for the analysis is not representative of current conditions.

The NAFO SC recommended an alternate analysis for estimation of reference points which involves simulating the stock forward from current conditions (average of last three years) for around 100 years. This will be done at different F levels and the F level that generates the highest catches (MSY) under equilibrium will be used as Fmsy in the next repeat of the MSE analysis for testing the PA. Some initial long term projections were explored. Our findings indicate the following: at F=0, the stock increases to levels higher than those historically observed; at F=0.05, the stock quickly clears the cautious zone; at F=0.1, the stock almost reaches the healthy zone by the end of 25 years, especially under BH SRR.

For PA implementation, the Ftarget, should be set at a value that allows the stock to increase in the cautious zone. The PA testing uses 0.85 Fmsy as Ftarget, hence the Fmsy (and other reference point) calculations have a big influence on the success of the PA. These observations highlight the significant impact of different F levels on stock dynamics and underline the necessity of setting appropriate Ftarget to ensure sustainable stock management.

Figures

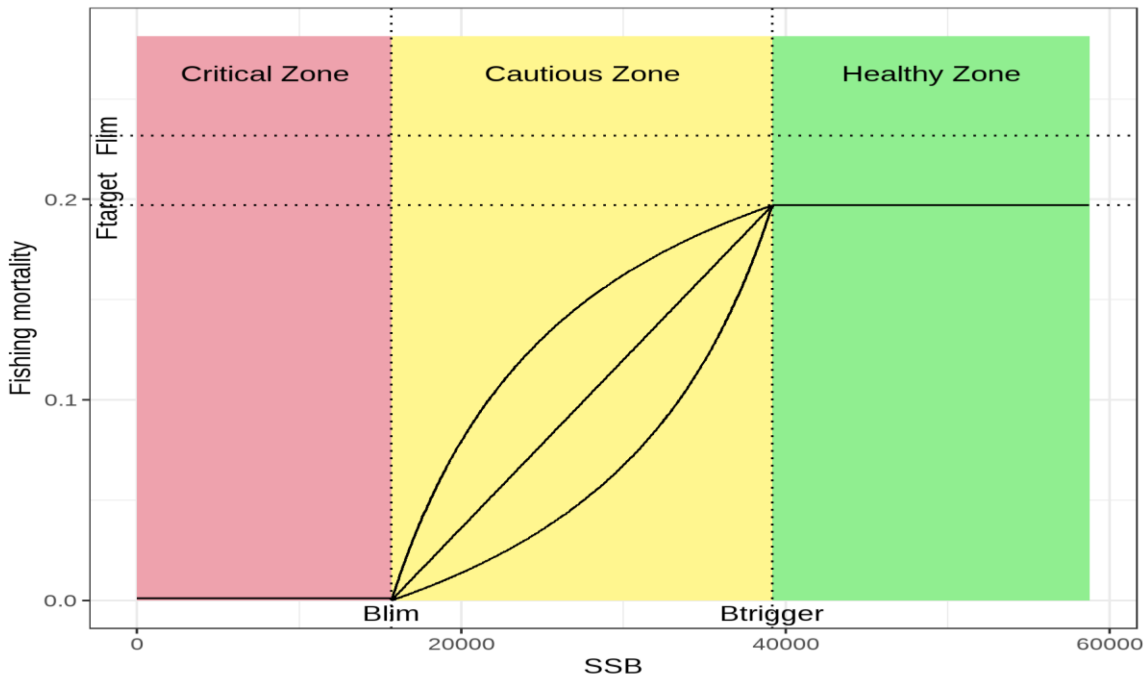

Figure 1. The ‘the mid-width leafs’ PA Framework to be tested for 3M cod. Reference points are calculated based on Beverton-Holt SR model with the fixed steepness value of 0.70.

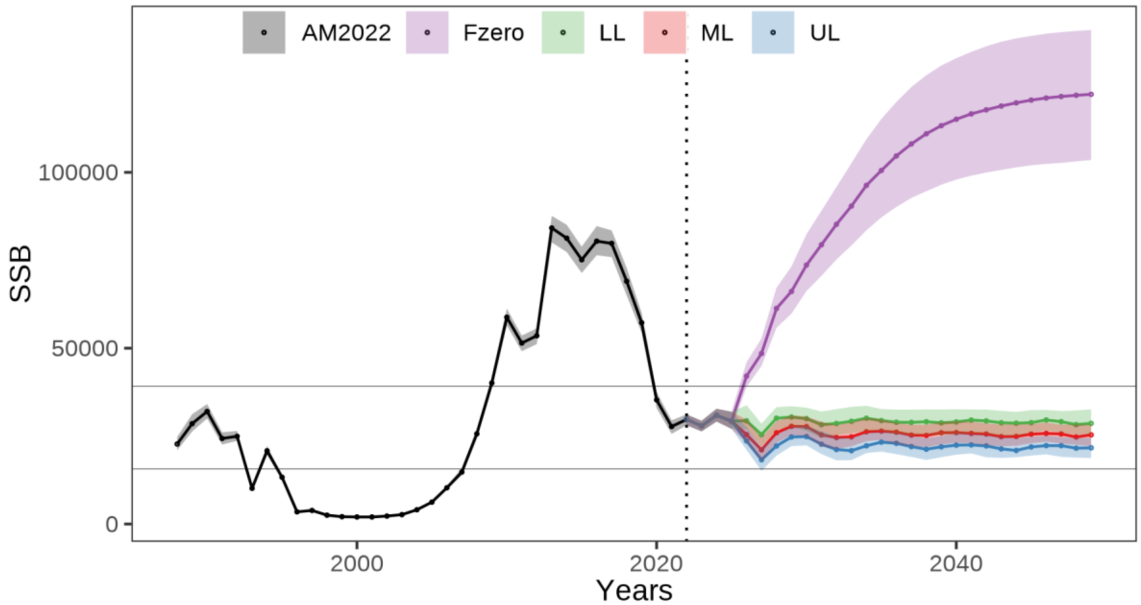

Figure 2. 25-year 3M cod MSE simulation output for SSB under the assumption of BH SR relationship. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model. LL denotes the lower leaf, ML the middle leaf, and UL the upper leaf. Fzero is a projection from the OM with F set to zero.

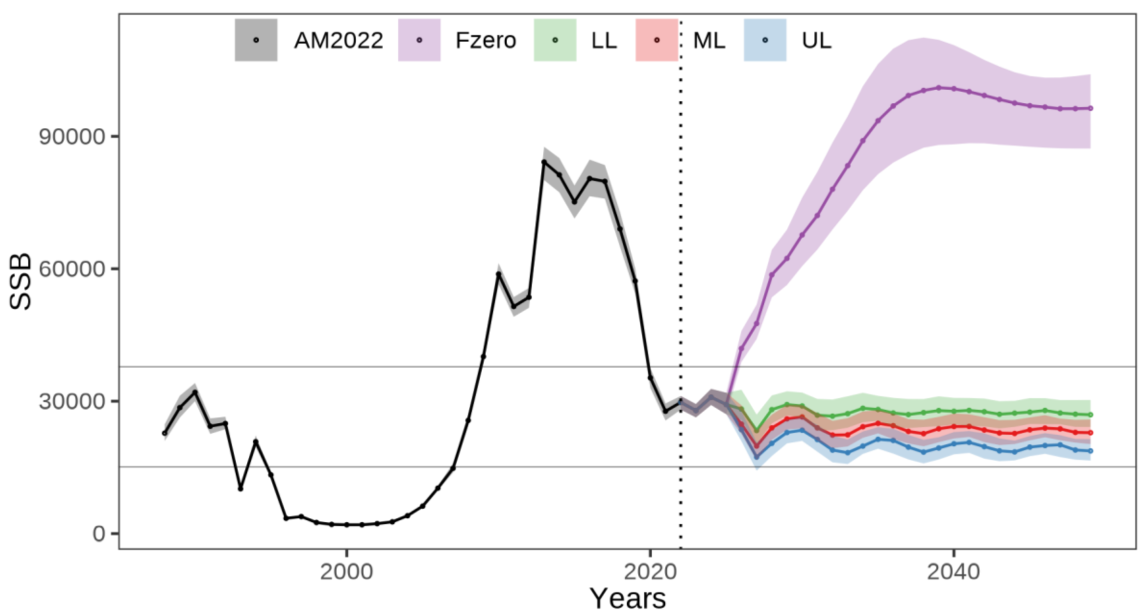

Figure 3. 25-year 3M cod MSE simulation output for SSB under the assumption of Ricker SR relationship. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model. LL denotes the lower leaf, ML the middle leaf, and UL the upper leaf. Fzero is a projection from the OM with F set to zero.

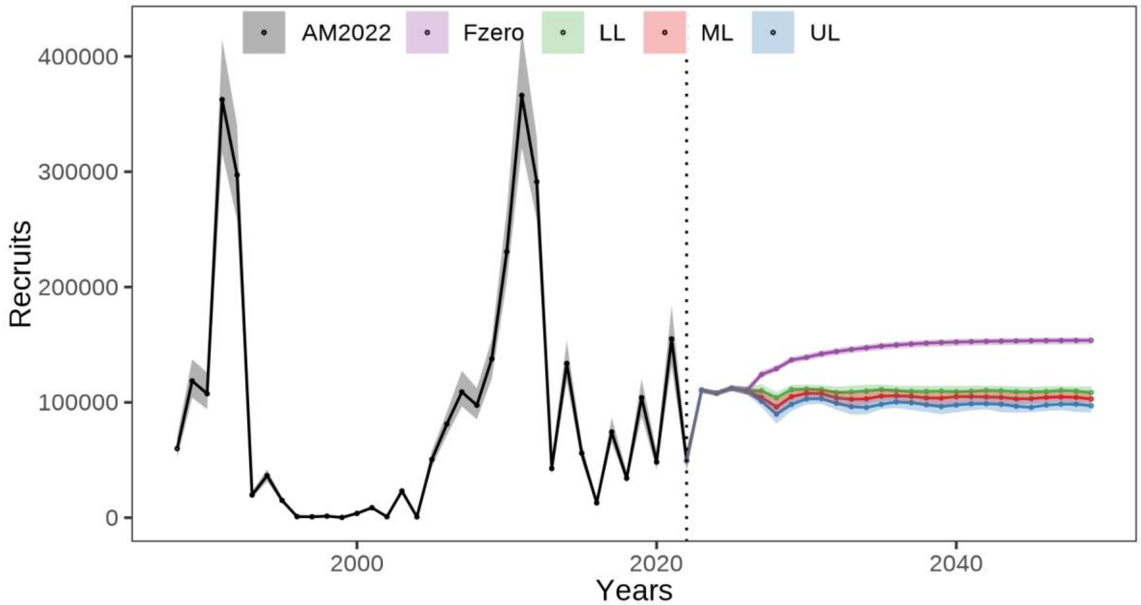

Figure 4. 25-year 3M cod MSE simulation output for Recruitments under the assumption of BH SR relationship. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model. LL denotes the lower leaf, ML the middle leaf, and UL the upper leaf. Fzero is a projection from the OM with F set to zero.

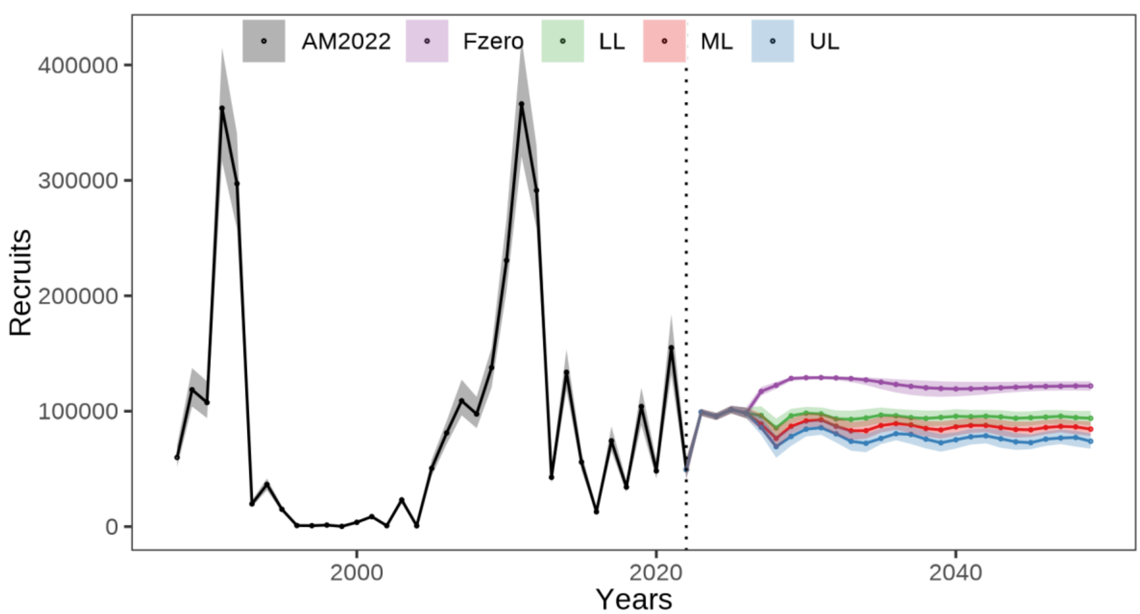

Figure 5. 25-year 3M cod MSE simulation output for Recruitments under the assumption of Ricker SR relationship. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model. LL denotes the lower leaf, ML the middle leaf, and UL the upper leaf. Fzero is a projection from the OM with F set to zero.

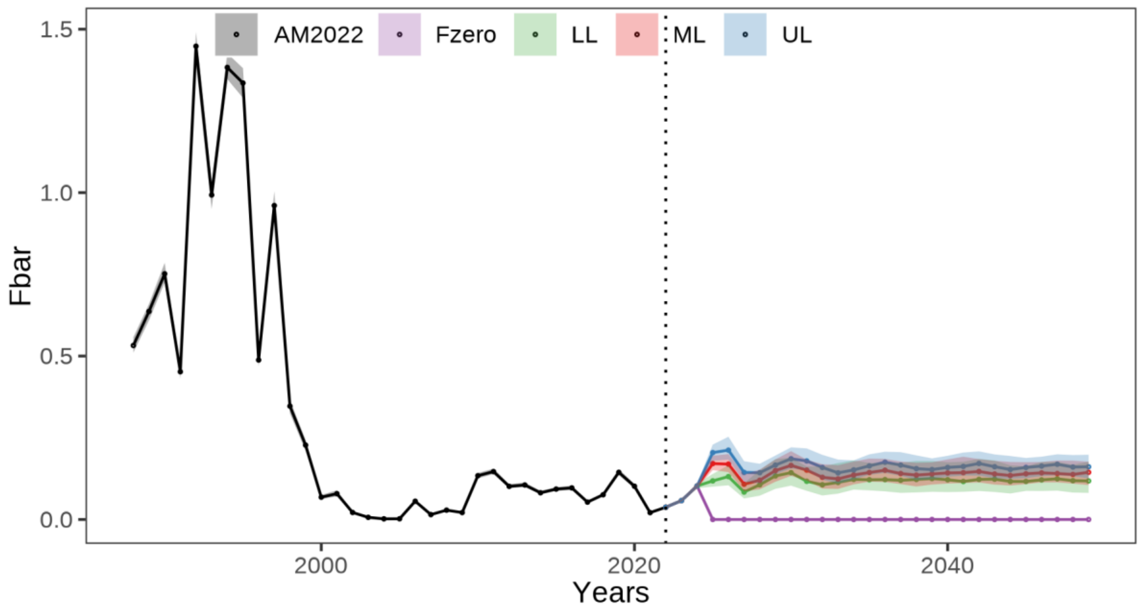

Figure 6. 25-year 3M cod MSE simulation output for Fbar under the assumption of BH SR relationship. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model. LL denotes the lower leaf, ML the middle leaf, and UL the upper leaf. Fzero is a projection from the OM with F set to zero.

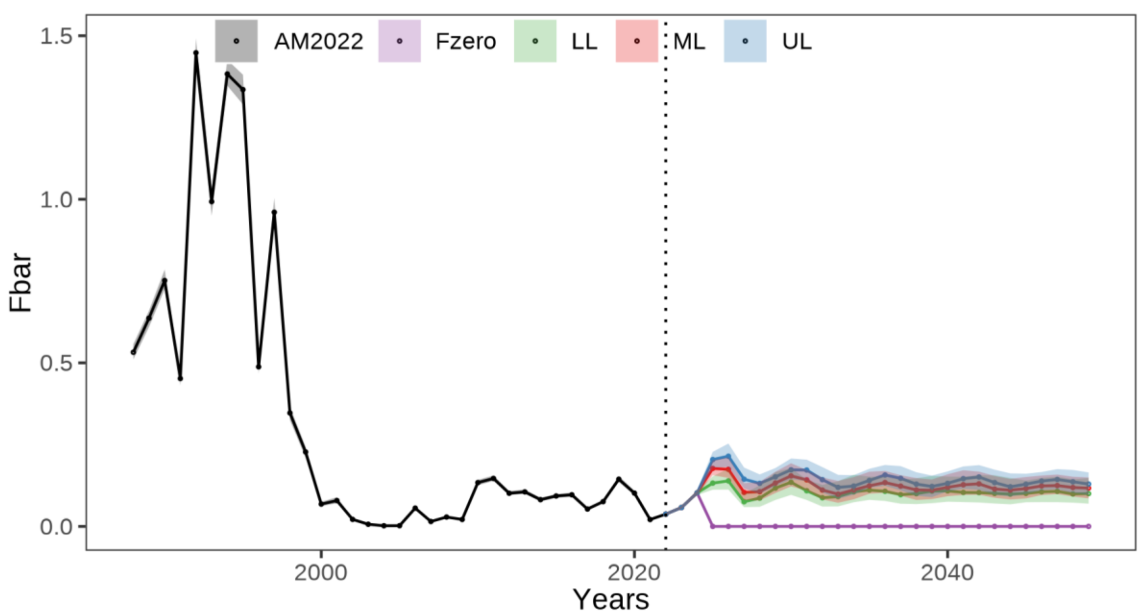

Figure 7. 25-year 3M cod MSE simulation output for Fbar under the assumption of Ricker SR. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model. LL denotes the lower leaf, ML the middle leaf, and UL the upper leaf. Fzero is a projection from the OM with F set to zero.

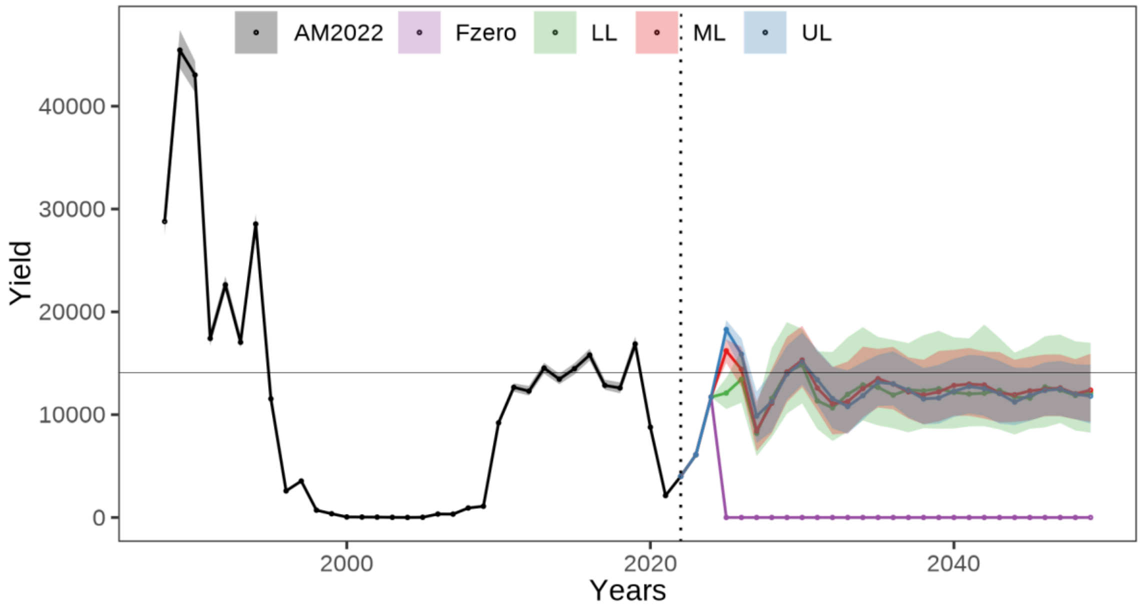

Figure 8. 25-year 3M cod MSE simulation output for Yield under the assumption of BH SR. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model. LL denotes the lower leaf, ML the middle leaf, and UL the upper leaf. Fzero is a projection from the OM with F set to zero.

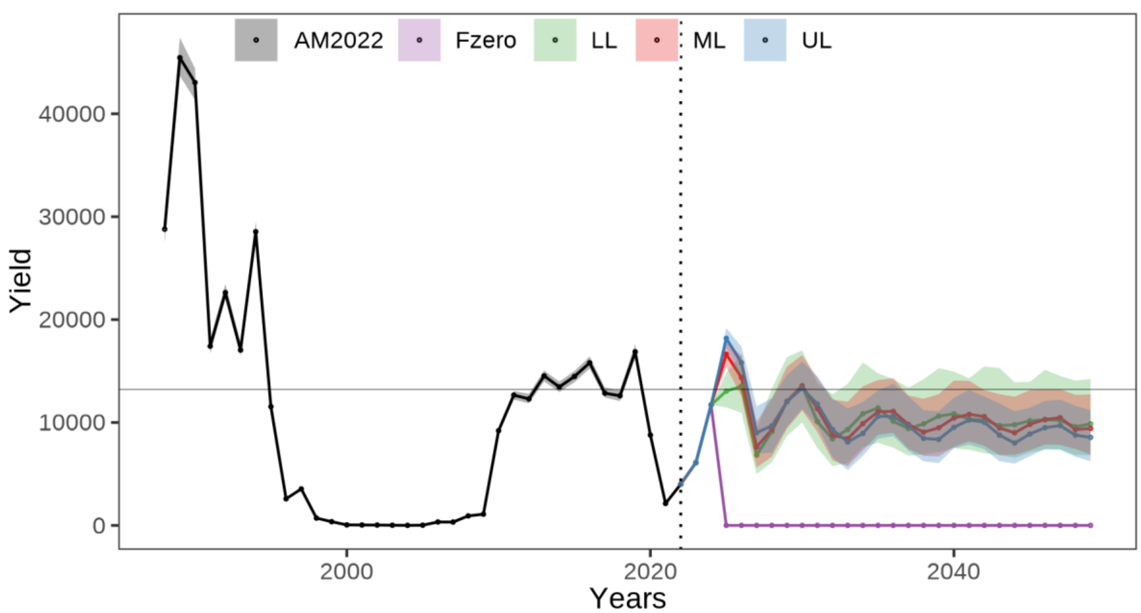

Figure 9. 25-year 3M cod MSE simulation output for Yield under the assumption of Ricker SR relationship. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model. LL denotes the lower leaf, ML the middle leaf, and UL the upper leaf. Fzero is a projection from the OM with F set to zero.

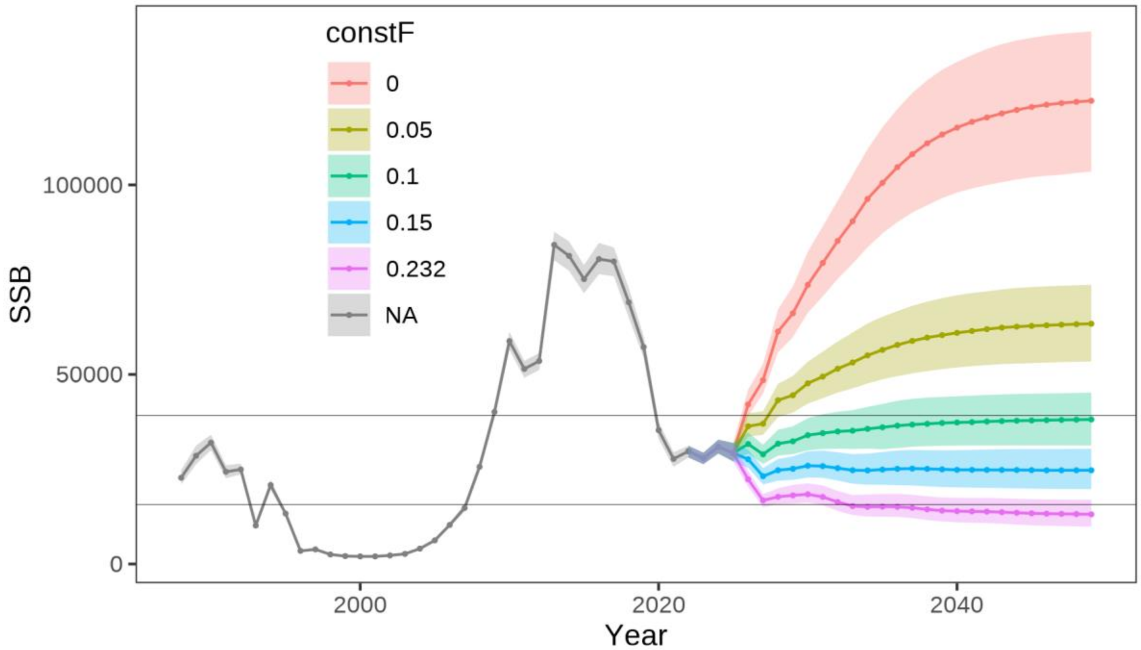

Figure 10. 25-year 3M cod simulation at a range of constant F levels for SSB under Beverton-Holt stock-recruitment relationship. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model.

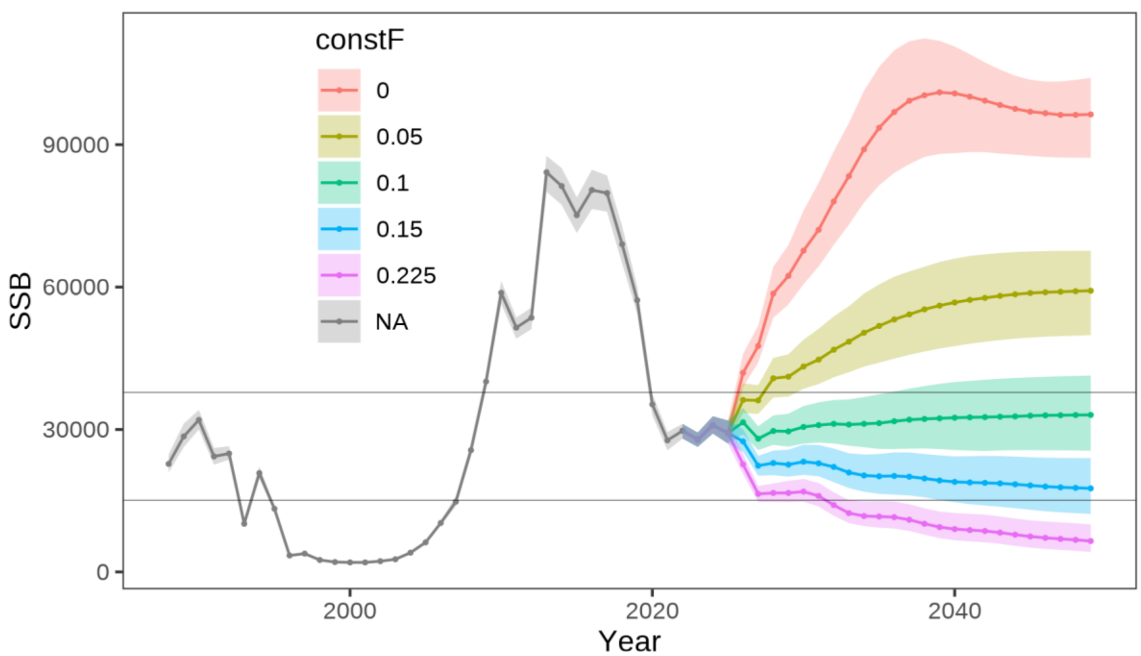

Figure 11. 25-year 3M cod simulation at a range of constant F levels for SSB under Ricker stock-recruitment relationship. Median CI is calculation using 350 iterations. The estimate upto 2022 (shown in black) is from 2023 assessment model.

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Appendix: Performance Statistics

Fourteen performance Metrics (PMs) were tested for the 3M cod MSE, each with their own criterion to determine objective success or failure. Each PM was derived for all HCRs, including the $F = 0$ run, to determine how each HCR performed. Below is a brief list of the PMs:

(1) Very low risk of stock depletion

$$Prop(B < B_{lim}) \leq 0.10$$

(2) Risk of stock falling below $B_{trigger}$

$$Prop(B < B_{trigger}) \leq 0.30$$

(3) Maintain stocks above B_{MSY}

$$Prop(B > B_{MSY}) \geq 0.75$$

(4) Low risk of overfishing

$$Prop(F < F_{MSY}) \geq 0.70$$

(5) Rebuild stocks to the vicinity of B_{MSY}

$$Prop(\bar{\mu}(B_{(T-10):T}) > B_{trigger}) \geq 0.80$$

(6) Monitor short term growth

$$Prop(B_{t=5} > B_{t=1}) \geq 0.75$$

(7) Monitor medium term growth

$$Prop(B_{t=15} > B_{t=1}) \geq 0.75$$

(8) Monitor medium term growth

$$Prop(B_{t=25} > B_{t=1}) \geq 0.75$$

(9) Absolute time to recovery

$$Count_t(B \rightarrow B_{trigger})$$

(10) Relative time to recovery

$$\frac{Count_t^{F=HCR}(B \rightarrow B_{trigger})}{Count_t^{F=0}(B \rightarrow B_{trigger})} \leq 1.2$$

(11) Extra time to recovery

$$Count_t^{F=HCR}(B \rightarrow B_{trigger}) - Count_t^{F=0}(B \rightarrow B_{trigger})$$

(12) Maintain approximately MSY catches in the long-term

$$Prop\left(0.8 \geq \frac{Meidan\left(C_{(T-10):T}\right)}{MSY} < 1.2\right) \geq 0.80$$

(13) Measure the inter-annual TAC variation

$$Median\left(\frac{|C_{t+1} - C_t|}{C_t}\right) \leq 0.20$$

(14) Catch during the maximum recovery window

$$\frac{\sum_{1:t_{max}} C_t}{t_{max}}$$

For the BH SRR, many PMs passed their respective criterion for success regardless of which HCR was used, and most others others failed regardless of HCR choice, with some exceptions. The zero catch (i.e. F = 0) HCR passed all SSB-based PM objectives and failed all catch-based PM objectives. All HCRs (i.e., F_{upper}, F_{linear}, and F_{lower}) had a very low risk of stock depletion *(1)*, but also had a very high risk of being below B_{MSY} *(2)*, and no HCRs maintained B_{MSY} *(3)* or rebuilt to B_{MSY} *(5)*. All HCRs had a low risk of overfishing *(4)*, but no HCRs maintained a long-term catch close to MSY *(12)*. No HCRs achieved growth in the short- *(6)*, medium- *(7)*, or long-term *(8)*. The absolute *(9)* and extra *(11)* times to recovery does not have criteria for objective success, but values are lowest for the F_{upper} HCR and highest for the F_{lower} (besides F = 0), with the $F = 0$ HCR having an absolute time to recovery of 3 years. A similar trend occurs for the relative time to recovery *(10)*, but all HCRs failed the objective. However, for all HCRs, most iterations did not achieve a $SSB > B_{trigger}$ at any point in the timeline (this is especially true for the F_{upper} HCR which only exceeded $B_{trigger}$ in 11 iterations), and so estimates of recovery time are likely biased low because many projections may reach $B_{trigger}$ with longer projection times. The median inter-annual variability in TAC *(13)* passed the objective only for the F_{upper} HCR, and failed for both the F_{linear} and F_{lower} HCRs. Catch of maximum recovery *(14)* does not have an assigned success criterion, but all HCRs have a average catch within 500 tons of one another (excluding $F = 0$, which only has catches in 2024).

For the RK SRR, many of the conclusions are similar to that for the BH SRR, but in general the performance of the RK simulation is slightly worse. The only difference in objective success is the relative time to recovery *(10)* for the F_{upper} HCR, which passes its criterion for success. The absolute *(9)*, relative *(10)*, and extra *(11)* times to recovery are also more biased than their BH counterparts due to SSB in fewer iterations reaching $B_{trigger}$ and lower overall SSB compared to the BH runs.

Table 1. Performance Metrics for each HCR for the 3M cod BH OM.

Description	Performance Metric	OM	F_{linear}	F_{upper}	F_{lower}	F = 0
Very low risk of stock depletion	$Prop(B < B_{lim}) \leq 0.10$	BH	0.000	0.040	0.000	0.000
Risk of stock falling below $B_{trigger}$	$Prop(B < B_{trigger}) \leq 0.30$	BH	1.000	1.000	1.000	0.040
Maintain stocks above B_{MSY} more often than not	$Prop(B > B_{MSY}) \geq 0.75$	BH	0.000	0.000	0.000	0.880
Low risk of overfishing	$Prop(F < F_{MSY}) \geq 0.70$	BH	0.960	0.920	0.960	1.000
Rebuild stocks to the vicinity of B_{MSY}	$Prop(\bar{\mu}(B_{(T-10):T}) > B_{trigger}) \geq 0.80$	BH	0.000	0.000	0.000	1.000
Monitor short term growth	$Prop(B_{t=5} > B_{t=1}) \geq 0.75$	BH	0.409	0.171	0.597	1.000
Monitor medium term growth	$Prop(B_{t=15} > B_{t=1}) \geq 0.75$	BH	0.269	0.071	0.446	1.000
Monitor long term growth	$Prop(B_{t=25} > B_{t=1}) \geq 0.75$	BH	0.200	0.083	0.466	1.000
Time to recovery (absolute)	$Count_t(B \rightarrow B_{trigger})$	BH	8	5	9	2
Time to recovery (relative)	$\frac{Count_t^{F=HCR}(B \rightarrow B_{trigger})}{Count_t^{F=0}(B \rightarrow B_{trigger})} \leq 1.2$	BH	4.0	2.5	4.0	1.0
Time to recovery (additional years)	$Count_t^{F=HCR}(B \rightarrow B_{trigger}) - Count_t^{F=0}(B \rightarrow B_{trigger})$	BH	6	3	7	0
Maintain approximately MSY catches in the long-term	$Prop\left(0.8 \geq \frac{Meidan(C_{(T-10):T})}{MSY} < 1.2\right) \geq 0.80$	BH	0.540	0.517	0.474	0.000
Measure the inter-annual TAC variation	$Median\left(\frac{\lvert C_{t+1} - C_t \rvert}{C_t}\right) \leq 0.20$	BH	0.204	0.170	0.327	-
Catch during the maximum recovery window	$\frac{\sum_{1:t_{max}} C_t}{t_{max}}$	BH	12,915	12,585	13,099	0

Table 2. Performance Metrics for each HCR for the 3M cod RK OM.

Description	Performance Metric	OM	F_{linear}	F_{upper}	F_{lower}	F = 0
Very low risk of stock depletion	$Prop(B < B_{lim}) \leq 0.10$	RK	0.000	0.040	0.000	0.000
Risk of stock falling below $B_{trigger}$	$Prop(B < B_{trigger}) \leq 0.30$	RK	1.000	1.000	1.000	0.040
Maintain stocks above B_{MSY} more often than not	$Prop(B > B_{MSY}) \geq 0.75$	RK	0.000	0.000	0.000	0.880
Low risk of overfishing	$Prop(F < F_{MSY}) \geq 0.70$	RK	0.960	0.920	0.960	1.000
Rebuild stocks to the vicinity of B_{MSY}	$Prop(\bar{\mu}(B_{(T-10):T}) > B_{trigger}) \geq 0.80$	RK	0.000	0.000	0.000	1.000
Monitor short term growth	$Prop(B_{t=5} > B_{t=1}) \geq 0.75$	RK	0.263	0.086	0.509	1.000
Monitor medium term growth	$Prop(B_{t=15} > B_{t=1}) \geq 0.75$	RK	0.137	0.020	0.369	1.000
Monitor long term growth	$Prop(B_{t=25} > B_{t=1}) \geq 0.75$	RK	0.131	0.026	0.326	1.000
Time to recovery (absolute)	$Count_t(B \rightarrow B_{trigger})$	RK	4	1	6	2
Time to recovery (relative)	$\frac{Count_t^{F=HCR}(B \rightarrow B_{trigger})}{Count_t^{F=0}(B \rightarrow B_{trigger})} \leq 1.2$	RK	2.0	1.0	3.0	1.0
Time to recovery (additional years)	$Count_t^{F=HCR}(B \rightarrow B_{trigger}) - Count_t^{F=0}(B \rightarrow B_{trigger})$	RK	2	0	4	0
Maintain approximately MSY catches in the long-term	$Prop\left(0.8 \geq \frac{Meidan(C_{(T-10):T})}{MSY} < 1.2\right) \geq 0.80$	RK	0.406	0.311	0.386	0.000
Measure the inter-annual TAC variation	$Median\left(\frac{\lvert C_{t+1} - C_t \rvert}{C_t}\right) \leq 0.20$	RK	0.217	0.194	0.318	
Catch during the maximum recovery window	$\frac{\sum_{1:t_{max}} C_t}{t_{max}}$	RK	10,824	10,267	11,172	0