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Results for Greenland Halibut Candidate Management Procedure Trials for the final SCAA Reference Set trials

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Summary

The existing MP is slightly adjusted (one survey replaced and survey weights adjusted) and then retuned to meet the updated recovery target of median exploitable biomass equal to Bmsy by 2044 for the Base Case SCAA operating model. This requires a downward adjustment of 3.7% to the existing MP formula for the TAC. This target is generally closely achieved across a wide range of robustness tests.

Key words: Greenland halibut; management procedure; retuning; robustness trials; SCAA

Introduction

This paper reports results of the Candidate Management Procedure (CMP) trials for the updated SCAA-based baseline and robustness trials (Rademeyer and Butterworth, 2023).

The CMPs considered include the CMP selected in 2017 and three variants (see below). In addition, results are shown for a zero future catch (C=0) scenario to illustrate bounds on the extent of stock recovery which is possible.

Methodology Applied

The set of Trials:

The set of trials (Operating Models – OMs, as specified during the June 2023 SC meeting) for the CMPs includes the following:

OM1: Base Case,

Rob1: Larger recruitment variability in the past and in the projections: standard deviation of log recruitment =0.6, Rob2: Base Case in the past, with first 8 years of projected recruitment taken as 50% of those predicted by stock-recruit relationship,

Rob3: Base Case in the past, with all future catch taken as 110% of TAC recommended by CMP,

Rob4: Base Case in the past, with future commercial selectivity on ages 10 and above taken to be zero,

Rob5: Base Case in the past, decreasing starting values $N_{2022,a}$ by 10% for all ages a, to allow for a possible decrease in abundance while some surveys were not conducted,

Rob6: Base Case in the past, including future random error in $M_{y,a}$ with variance of the error as indicated by the SSM, which has a process error variance estimate of 0.16,

Rob7: Base Case in the past, increase the variance of $M_{y,a}$ for age groups 1 to 10 by multiplicative amounts that decrease linearly with age from 2 for age 1 to 1 for age 10. Keep the variance of 0.16 for still higher ages,

Rob8: SSM only robustness test.

Rob9: Assume senescence: M increases from 0.12 for age 9 to 0.5 for ages 10+,

Rob10: Assume that M follows an allometric shape (i.e., Lorenzen M), where M_a=0.12*WAA$^{-0.305}$,

Rob11: Decrease the doming in the commercial selectivities, by fixing the parameter values for the right side (higher ages) half-normal to double their values for the Base Case OM, so that commercial selectivity decreases at higher ages at half its previous rate, and

Rob12: Assume that M increases from 0.12 to 0.2 in the first 8 years of the projections.

The CMP

The MP selected in 2017 is modified as follows:

1) The Canadian 3LNO spring survey is not used anymore to compute the TAC,
2) The EU 3L survey is now included to compute the TAC,
3) The weights given to each survey in the MP TAC formula, computed from the variances of the survey data estimated are taken from the updated Base Case (see Table 1).
4) The MP is further modified as follows: $TAC_{y+1} = \mu TAC_{y+1}^{MP17*}$ where TAC_{y+1}^{MP17*} is the TAC in year y+1 computed using the 2017 MP modified by 1)-3) above, and μ is a tuning parameter.

This new CMP is named CMPts.

The projection methodology

The projection methodology applied is set out in Appendix B.

Because of a change in survey vessels for the Canadian RV surveys, results for these surveys are generated assuming random error in the relative catchability change (the calibration factor estimate), i.e., equation B10 is modified as follows:

$$I_y^i = q^i B_y^i e^{\varepsilon_y^i} e^{\vartheta^i} \qquad (1)$$

with

ϑ^i being the random error of the relative q change, generated from its distribution $\vartheta^i \sim N(\rho_B; \varepsilon)$ once for each 20-year replicate, remaining the same for each year in that replicate. The values for ρ_B and ε are survey specific and are given in Table 2.

Results

The revised tuning parameters for CMPts, to achieve the recovery target of Bmsy for the exploitable biomass component of the resource by 2044, are given in Table 3

The performance measures, as described in the April 2023 WG-RBMS Meeting report (NAFO, 2023), are given in **Table 4** for all OMs under zero catch and CMPts, with some of the performance measures compared graphically in **Figure 1**.

Medians and lower 10%iles for projected catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (for which the upper 10%iles are plotted instead of lower 10%iles) are compared under CMPts for all OMs in **Figures 3a-b**.

Worm plots showing individual trajectories as well as 80% probability envelopes are given in **Figure 3** for catch, spawning and exploitable biomass, and F/F_{MSY} for the baseline OM (OM1) under CMPts.

Discussion

The following points merit noting:

- The retuning requires setting TACs 3.7% lower than would previously have been the case.
- Under the Base Case, future catches are expected to increase slowly in median terms.
- As to be expected, performance for Rob1 (larger recruitment variability) scarcely differs in median terms from that for the base case OM1, with slightly wider probability intervals.
- Rob2 (lower recruitment in the next 8 years) is the test with the greatest impact on future trajectories. The CMP reacts appropriately by reducing the TAC in sufficient time to compensate and for the resource to recover.
- As to be expected, projected biomass is slightly lower than for the base case for Rob3 (110% TAC in the future).
- Rob4 (zero selectivity on plus group) has little impact on the results compared to the base case OM1.
- The CMP reacts appropriately in Rob5 (lower starting N(2022) values) by setting lower TACs initially.
- Including future random error in M (Rob6 and Rob7) result in lower future TAC but doesn't impact biomass trajectories much.
- Assuming senescence (Rob9) results in a more positive view of the resource, with future catches slightly higher than for the Base Case and biomass well above MSY level.
- Rob10 (Lorenzen *M*) results in lower future catches and little impact on biomass trajectories.
- Under Rob11 (less doming in commercial selectivities), current biomass is estimated to be further below MSY level than under the Base Case, but this still increases into the future.
- Rob12 (lower *M* in the next 8 years) is the other test with a large impact on future trajectories. Again, the CMP reacts appropriately by reducing the TAC in sufficient time to compensate.
- Some of the desired performance criteris cannot be met, even under an immediate closure of the fishery.

References

NAFO. 2023. Report of the NAFO Joint Commission-Scientific Council Working Group on Risk-Based Management Strategies (WG-RBMS) Meeting. 18-19 April 2023, Halifax, Nova Scotia.

Rademeyer RA and Butterworth DS. 2023. Updated SCAA Base Case Assessment and sensitivities. NAFO SCR Doc. 23/043

Table 1. Variances (shown as standard deviations of log residuals) of the survey data series about the expected abundance trend from the updated SCAA base case OM, and the related weights and weight ratios given to each survey in the MP TAC formula as in 2017 and now in 2023.

	σ_i		$w_i=1/\sigma_i^2$		w_i ratios	
	2017	2023	2017	2023	2017	2023
Can 2J3K autumn	0.222	0.230	20.300	18.962	0.294	0.274
Can 3LNO spring	0.488	-	4.200	-	0.061	-
Can 3LNO autumn	0.257	0.254	15.140	15.495	0.220	0.224
EU 3M 0-1400m	0.211	0.299	22.400	11.191	0.325	0.162
EU 3L	-	0.239	-	17.464	-	0.252
EU 3NO	0.381	0.405	6.900	6.099	0.100	0.088

Table 2. Biomass based conversion for MWPT and standard error of estimated conversion factor.

	ρ_B	ε
Can 2J3K autumn	0.9191	0.0394
Can 3LNO autumn	1.1122	0.0645

Table 3. Tuning parameters for the CMPs considered here. The parameters that are adjusted to achieve a median biomass equal to Bmsy for the exploitable component of the resource biomass in 2044, rather than being pre-fixed, are shown in **bold.**

	μ	γ	α	λ_{up}	λ_{down}	X	Δ_{up}	Δ_{down}
C=0		-	-	-	-	-	-	-
CMPts	**0.9630**	0.15	0.9720	1.00	2.00	-0.0056	0.1	0.1

Table 4. Performance measures for zero catch and CMPts for the different OMs; the pink highlights show instances where a desired performance criterion specified during the April WG-RBMS meeting (NAFO, 2023) has not been met. A value shown in **bold** indicates that the tuning parameter γ was adjusted to achieve that result for that OM/CMP combination.

	Management objective	1. Restore to within a prescribed period of time or maintain at Bmsy				2. The risk of failure to meet the Bmsy target and interim biomass targets within a prescribed period of time should be kept moderately low		3. Low risk of exceeding F_{msy}	4. Very low risk of going below an established threshold				5. Maximize yield in the short, medium and long term			6. The risk of steep decline of stock biomass should be kept moderately low	7. Keep inter annual TAC variation below "an established threshold"	
	Perf. stats	$B^{5\text{-}9}_{2044}/B^{5\text{-}9}_{msy}$	$B^{5\text{-}9}_{2044}<B^{5\text{-}9}_{msy}$	$B^{5\text{-}9}_{2030}<0.8B^{5\text{-}9}_{msy}$	$B^{5\text{-}9}_{2044}<0.8B^{5\text{-}9}_{msy}$	$B^{5\text{-}9}_{lowest}/B^{5\text{-}9}_{msy}$	$B^{5\text{-}9}_{2030}<B^{5\text{-}9}_{2025}$	$(F_{2025\text{-}2044}>F_{msy})>0.3$	$B^{sp}_{2044}/B^{sp}_{2025}$	$B^{5\text{-}9}_{2044}/B^{5\text{-}9}_{2025}$	$(B^{5\text{-}9}_{2025\text{-}2044}<0.3B^{5\text{-}9}_{msy})>0.1$	$B^{5\text{-}9}_{lowest}/B^{5\text{-}9}_{msy}<0.3$	avC: 2025-2029	avC: 2025-2034	avC: 2025-2044	$B^{5\text{-}9}_{2030}<0.75B^{5\text{-}9}_{2025}$	AAV: 2025-2029	AAV: 2025-2044
		median (80%PI)	Proportion	Proportion	Proportion	median (80%PI)	Proportion	Count	median (80%PI)	median (80%PI)	Count	Proportion	median (80%PI)	median (80%PI)	median (80%PI)	Proportion	median (80%PI)	median (80%PI)
	Criteria		<=0.5	<=0.25	<=0.25		<0.25					<=0.1						
OM1	C=0	1.55 (1.11; 2.20)	0.06	0.10	0.01	0.83 (0.67; 1.00)	0.23	0	6.35 (4.47; 9.16)	1.73 (1.19; 2.47)	0	0.00	0.00	0.00	0.00	0.02	-	-
Rob1	C=0	1.50 (0.90; 2.52)	0.16	0.21	0.06	0.69 (0.50; 0.87)	0.24	0	6.68 (4.29; 10.56)	1.87 (1.07; 3.11)	0	0.00	0.00	0.00	0.00	0.05	-	-
Rob2	C=0	1.49 (1.06; 2.11)	0.06	0.47	0.01	0.50 (0.36; 0.70)	0.67	0	5.01 (3.51; 7.37)	1.67 (1.15; 2.38)	0	0.02	0.00	0.00	0.00	0.19	-	-
Rob3	C=0	1.55 (1.11; 2.20)	0.06	0.11	0.01	0.82 (0.66; 0.98)	0.22	0	6.56 (4.59; 9.54)	1.76 (1.21; 2.52)	0	0.00	0.00	0.00	0.00	0.01	-	-
Rob4	C=0	1.55 (1.11; 2.20)	0.06	0.10	0.01	0.82 (0.66; 0.98)	0.21	0	6.41 (4.51; 9.25)	1.76 (1.21; 2.53)	0	0.00	0.00	0.00	0.00	0.01	-	-
Rob5	C=0	1.54 (1.10; 2.18)	0.06	0.18	0.01	0.74 (0.60; 0.89)	0.16	0	7.17 (5.02; 10.41)	1.98 (1.37; 2.86)	0	0.00	0.00	0.00	0.00	0.00	-	-
Rob6	C=0	1.53 (1.08; 2.17)	0.06	0.11	0.01	0.81 (0.66; 0.98)	0.21	0	6.31 (4.45; 9.19)	1.75 (1.21; 2.54)	0	0.00	0.00	0.00	0.00	0.01	-	-
Rob7	C=0	1.50 (1.05; 2.13)	0.07	0.12	0.01	0.80 (0.64; 0.97)	0.22	0	6.20 (4.34; 8.91)	1.72 (1.18; 2.51)	0	0.00	0.00	0.00	0.00	0.02	-	-
Rob9	C=0	1.68 (1.21; 2.36)	0.03	0.02	0.00	0.99 (0.80; 1.17)	0.23	0	4.23 (2.74; 7.02)	1.55 (1.07; 2.25)	0	0.00	0.00	0.00	0.00	0.01	-	-
Rob10	C=0	1.65 (1.17; 2.32)	0.03	0.10	0.01	0.84 (0.67; 1.00)	0.22	0	6.92 (4.95; 9.91)	1.84 (1.26; 2.64)	0	0.00	0.00	0.00	0.00	0.02	-	-
Rob11	C=0	1.38 (0.99; 1.94)	0.12	0.56	0.02	0.62 (0.51; 0.74)	0.25	0	8.17 (5.93; 10.99)	2.06 (1.43; 2.92)	0	0.00	0.00	0.00	0.00	0.02	-	-
Rob12	C=0	1.41 (1.01; 2.00)	0.09	0.93	0.02	0.51 (0.38; 0.67)	0.76	0	6.19 (4.31; 9.10)	2.09 (1.44; 2.98)	0	0.01	0.00	0.00	0.00	0.27	-	-
OM1	CMPts	**1.00** (0.61; 1.47)	0.50	0.38	0.27	0.63 (0.45; 0.77)	0.33	5	2.39 (1.40; 3.95)	1.27 (0.73; 2.10)	0	0.01	13.87 (12.03; 15.78)	18.03 (14.58; 22.50)	20.45 (15.34; 28.46)	0.06	0.05 (0.02; 0.08)	0.05 (0.04; 0.07)
Rob1	CMPts	0.95 (0.46; 1.74)	0.54	0.48	0.35	0.50 (0.30; 0.68)	0.30	5	2.57 (1.47; 4.75)	1.39 (0.64; 2.58)	0	0.09	13.74 (11.82; 15.71)	18.09 (14.32; 22.86)	20.81 (14.38; 31.26)	0.10	0.05 (0.02; 0.08)	0.06 (0.04; 0.08)
Rob2	CMPts	1.03 (0.73; 1.52)	0.45	0.85	0.16	0.35 (0.23; 0.49)	0.83	7	2.42 (1.46; 4.01)	1.35 (0.89; 2.01)	4	0.31	13.77 (11.93; 15.70)	16.23 (13.23; 19.85)	14.12 (11.03; 18.09)	0.37	0.04 (0.02; 0.07)	0.06 (0.05; 0.08)
Rob3	CMPts	0.97 (0.59; 1.44)	0.55	0.44	0.28	0.60 (0.44; 0.74)	0.33	8	2.32 (1.29; 3.90)	1.27 (0.75; 2.11)	0	0.02	13.49 (11.66; 15.60)	17.18 (13.87; 21.75)	18.79 (14.01; 26.44)	0.06	0.04 (0.02; 0.08)	0.05 (0.03; 0.07)
Rob4	CMPts	0.95 (0.56; 1.45)	0.57	0.49	0.31	0.58 (0.40; 0.72)	0.37	16	2.33 (1.37; 3.86)	1.26 (0.69; 2.12)	0	0.04	13.56 (11.68; 15.61)	17.19 (13.92; 21.61)	18.53 (13.95; 25.99)	0.08	0.04 (0.02; 0.08)	0.05 (0.03; 0.07)
Rob5	CMPts	0.97 (0.62; 1.46)	0.53	0.62	0.27	0.54 (0.41; 0.67)	0.26	12	2.81 (1.69; 4.56)	1.51 (0.89; 2.48)	0	0.02	12.41 (10.64; 14.45)	15.19 (12.35; 19.30)	16.57 (12.28; 23.03)	0.05	0.04 (0.02; 0.07)	0.05 (0.03; 0.07)
Rob6	CMPts	0.94 (0.56; 1.44)	0.58	0.51	0.31	0.57 (0.39; 0.71)	0.40	16	2.31 (1.39; 3.79)	1.26 (0.71; 2.10)	0	0.04	13.50 (11.62; 15.51)	17.05 (13.81; 21.53)	18.33 (13.83; 25.39)	0.07	0.04 (0.02; 0.07)	0.05 (0.03; 0.07)
Rob7	CMPts	0.93 (0.54; 1.42)	0.61	0.55	0.32	0.56 (0.39; 0.70)	0.42	17	2.29 (1.40; 3.73)	1.26 (0.70; 2.07)	0	0.04	13.42 (11.56; 15.48)	16.81 (13.65; 21.25)	17.82 (13.51; 24.83)	0.09	0.04 (0.02; 0.07)	0.05 (0.03; 0.07)
Rob9	CMPts	1.14 (0.73; 1.68)	0.33	0.12	0.15	0.77 (0.58; 0.94)	0.35	0	1.84 (0.74; 3.81)	1.17 (0.73; 1.92)	0	0.00	14.31 (12.44; 16.02)	18.83 (15.30; 22.89)	21.83 (16.28; 29.79)	0.06	0.05 (0.02; 0.08)	0.06 (0.04; 0.07)
Rob10	CMPts	0.97 (0.56; 1.48)	0.54	0.51	0.30	0.57 (0.40; 0.72)	0.44	19	2.39 (1.42; 3.84)	1.28 (0.68; 2.15)	0	0.04	13.43 (11.54; 15.62)	16.90 (13.56; 21.64)	18.26 (13.58; 25.65)	0.10	0.04 (0.02; 0.08)	0.05 (0.03; 0.07)
Rob11	CMPts	0.90 (0.61; 1.29)	0.63	0.83	0.32	0.52 (0.41; 0.62)	0.32	5	2.93 (1.61; 4.81)	1.52 (0.96; 2.36)	0	0.00	13.78 (12.17; 15.45)	17.85 (14.82; 22.03)	22.69 (16.83; 31.47)	0.04	0.04 (0.02; 0.07)	0.06 (0.04; 0.08)
Rob12	CMPts	0.85 (0.59; 1.32)	0.67	1.00	0.42	0.34 (0.22; 0.48)	0.90	9	2.63 (1.68; 3.90)	1.58 (1.02; 2.43)	6	0.32	11.12 (9.75; 12.86)	11.18 (9.56; 13.56)	9.72 (7.79; 12.97)	0.59	0.06 (0.03; 0.09)	0.06 (0.04; 0.07)

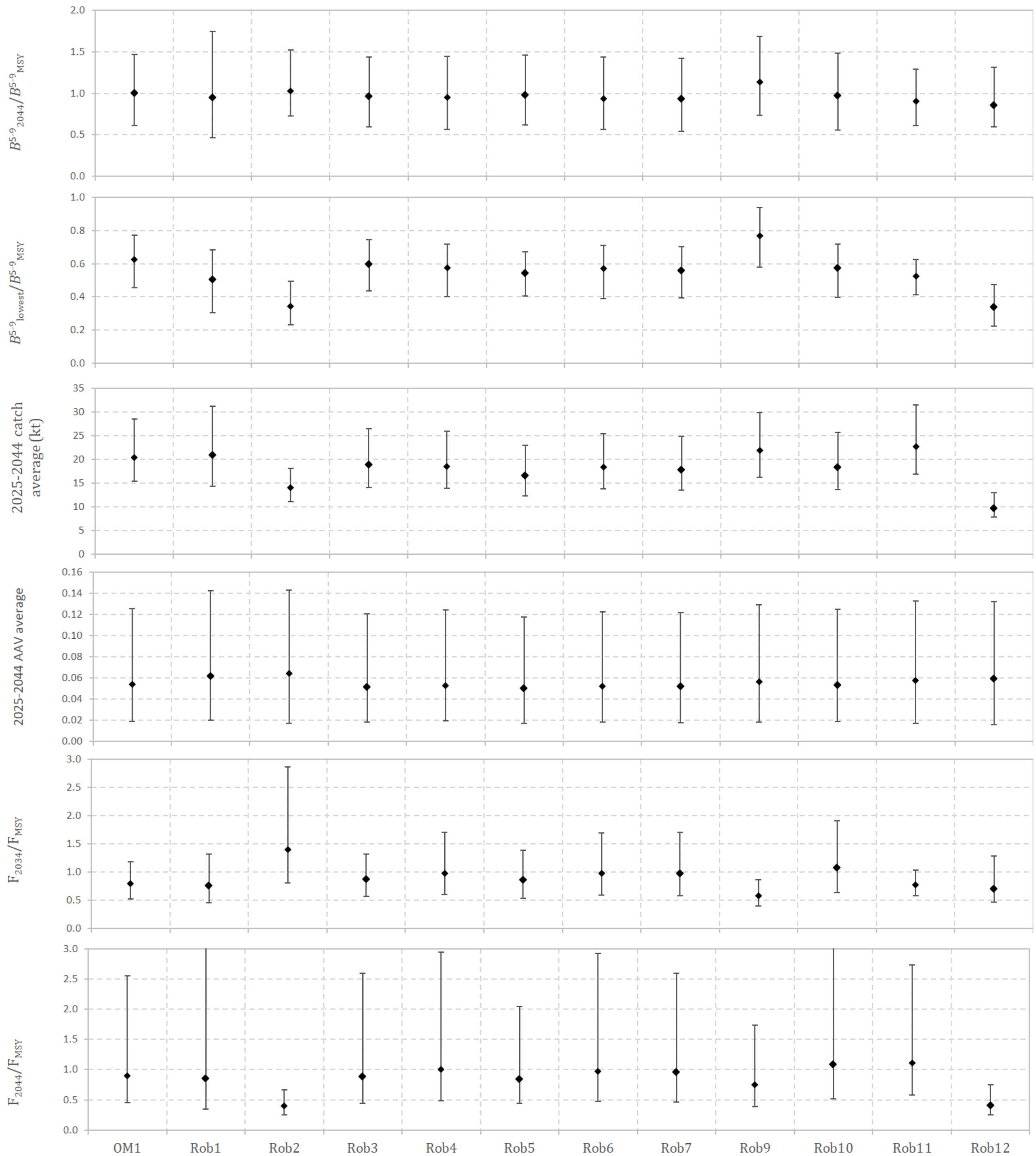

Figure 1. Projected median and 80% PIs for a series of performance statistics for each OM under CMPts.

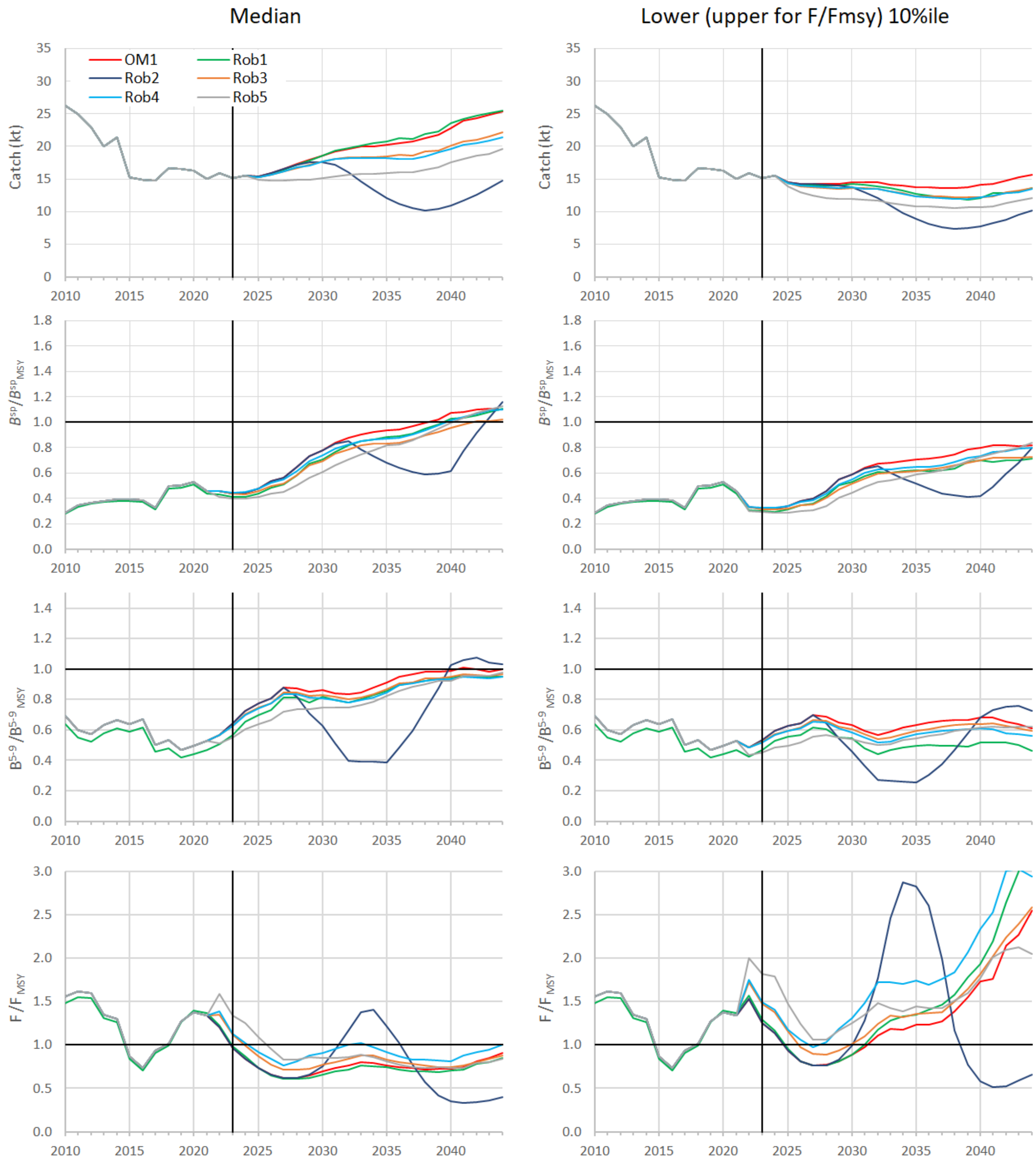

Figure 2a. Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM1 and Rob1 to Rob5** under CMPts.

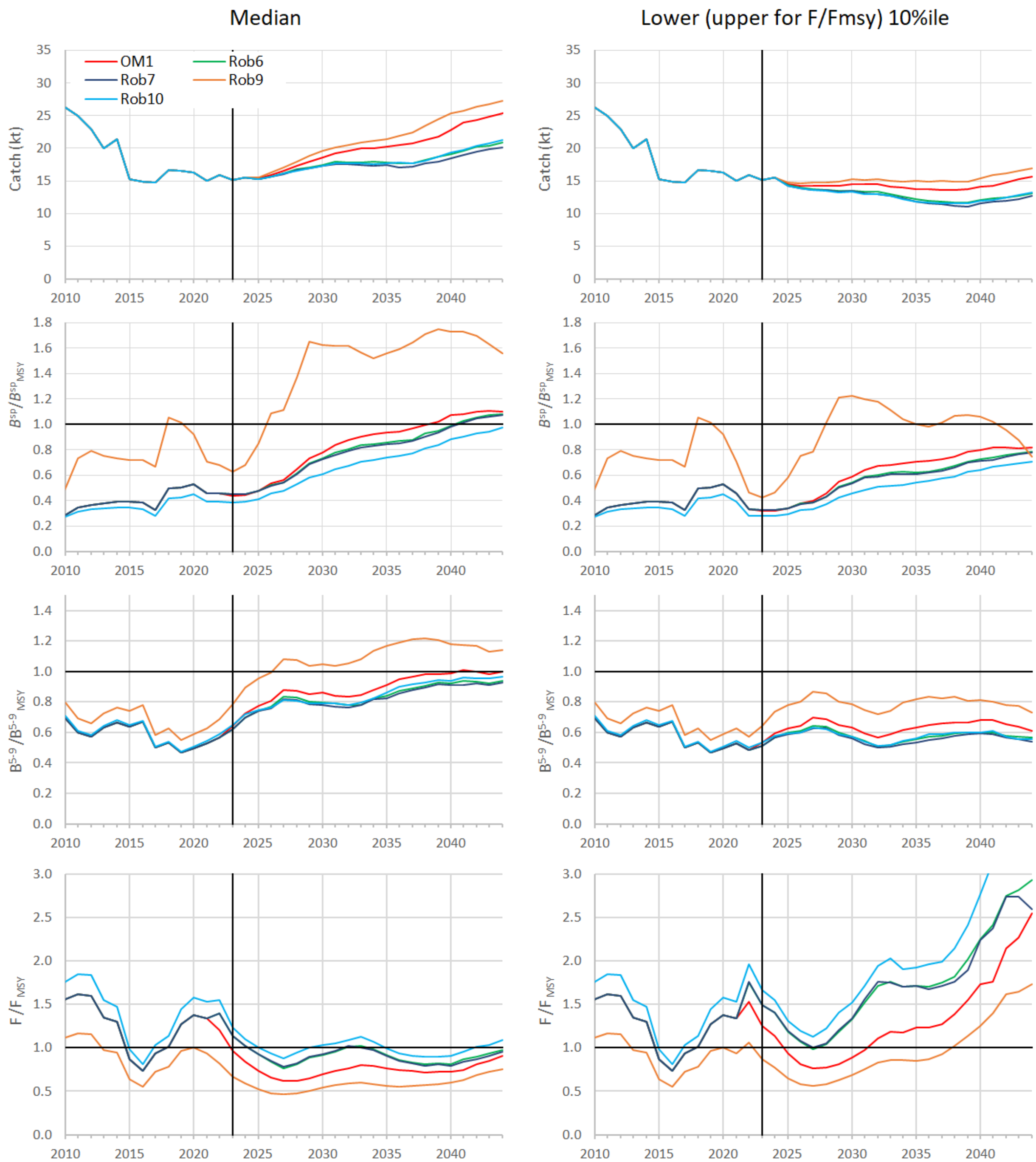

Figure 2b. Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM1 and Rob6 to Rob9** under CMPts.

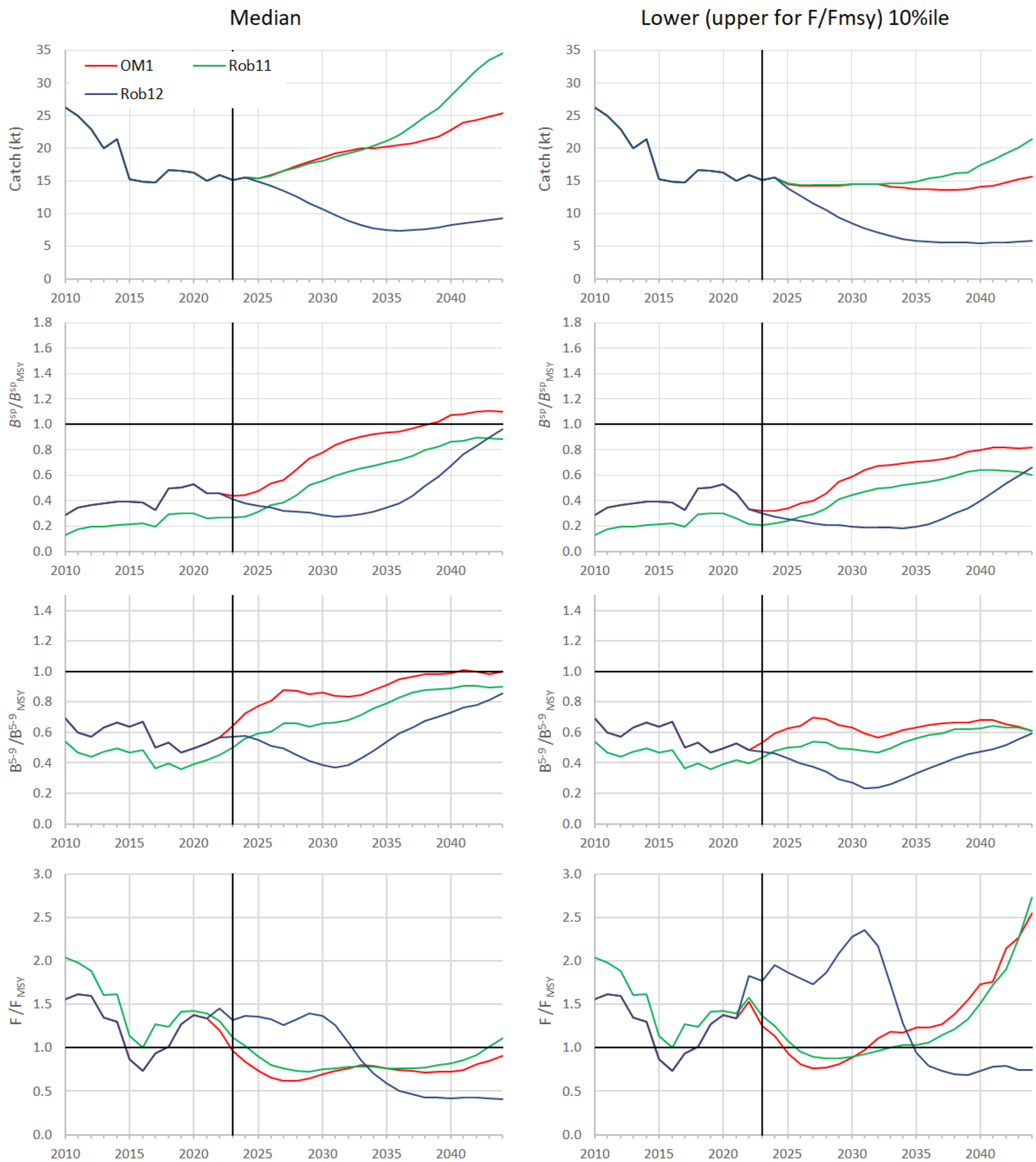

Figure 2c. Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM1 and Rob11 to 12** under CMPts.

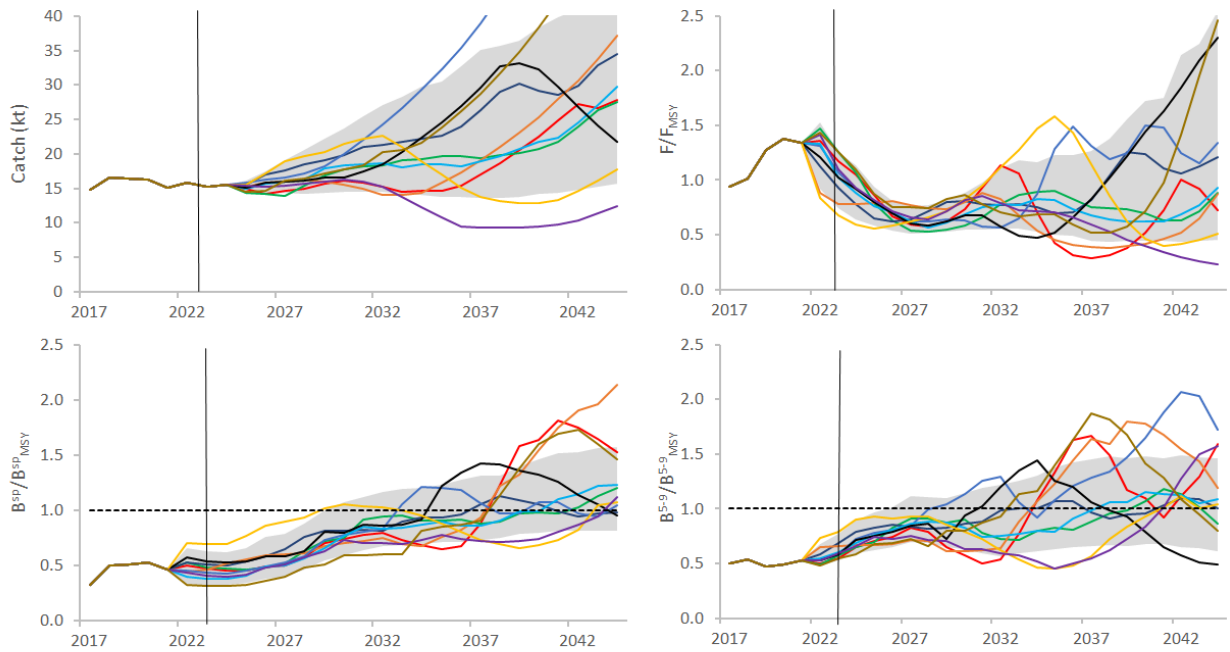

Figure 3. “Worm” plots showing individual trajectories as well as the 80% probability envelopes (grey shading) for catch, fishing mortality relative to F_{MSY}, and spawning and exploitable biomass (both relative to B_{MSY}), for the baseline OM (OM1) under CMPts.

Appendix A: The CMPs

The CMPs considered here are a combination of target based, slope based:

$$TAC_{y+1} = \left(TAC_{y+1}^{target} + TAC_{y+1}^{slope}\right)/2 \quad \text{(A1)}$$

Target based part:

$$TAC_{y+1}^{target} = TAC_y \left(1 + \gamma(J_y - 1)\right) \quad \text{(A2)}$$

where

TAC_y is the TAC recommended for year y,

γ is the "response strength" tuning parameter

J_y is a composite measure of the immediate past level in the abundance indices that are available to use for calculations for year *y*; for this base case CMP five series have been used, with *i* = 1, 2, 3, 4 and 5 corresponding respectively to Canada Fall 2J3K, EU 3M 0-1400m, EU 3L, EU 3NO and Canada Fall 3LNO:

$$J_y = \sum_{i=1}^{5} \frac{1}{(\sigma^i)^2} \frac{J_{curr,y}^i}{J_{target}^i} \bigg/ \sum_{i=1}^{5} \frac{1}{(\sigma^i)^2} \quad \text{(A3)}$$

with

$(\sigma^i)^2$ being the estimated variance for index *i* (estimated in the model fitting procedure, see **Table 1**)

$$J_{curr,y}^i = \frac{1}{q} \sum_{y'=y-q}^{y-1} I_{y'}^i \quad \text{(A4)}$$

$$J_{target}^i = \alpha \frac{1}{5} \sum_{y'=2011}^{2015} I_{y'}^i \quad \text{(where } \alpha \text{ is a control/tuning parameter for the CMP)} \quad \text{(A5)}$$

Note the assumption that when a TAC is set in year *y* for year *y*+1, indices will not at that time yet be available for the current year *y*.

Slope based part:

$$TAC_{y+1}^{slope} = TAC_y\left[1 + \lambda_{up/down}\left(s_y - X\right)\right] \quad \text{(A6)}$$

where

$\lambda_{up/down}$ and X are tuning parameters,

s_y is a measure of the immediate past trend in the survey-based abundance indices, computed by linearly regressing lnI_y^i vs year y' for $y' = y - 5$ to $y' = y - 1$, for each of the five surveys considered, with

$$s_y = \sum_{i=1}^{5} \frac{1}{(\sigma^i)^2} s_y \bigg/ \sum_{i=1}^{5} \frac{1}{(\sigma^i)^2} \quad \text{(A7)}$$

with the standard error of the residuals of the observed compared to model-predicted logarithm of survey index *i* (σ^i) estimated in the operating model.

Each year these TAC_{y+1}^{target} and TAC_{y+1}^{slope} are evaluated according to each rule separately, and then an arithmetic average is taken before applying the constraints below.

Constraints on the maximum allowable annual change in TAC are then applied, viz.:

if $TAC_{y+1} > TAC_y(1 + \Delta_{up})$ then $TAC_{y+1} = TAC_y(1 + \Delta_{up})$ (A8) and

if $TAC_{y+1} < TAC_y(1 - \Delta_{down})$ then $TAC_{y+1} = TAC_y(1 - \Delta_{down})$ (A9)

Tuning parameter values for each of the CMPs presented in this paper are given in **Table 2**.

Appendix B: Projection methodology

Projections into the future under a specific Candidate Management Procedure (CMP) are evaluated using the following steps.

Step 1: Begin-year numbers at age

The components of the numbers-at-age vector at the start of 2022 ($N_{2022,a}$: a = 0,…, m) are obtained from the MLEs for an assessment of the resource. Error is included for all ages to allow for estimation imprecision in the assessment through use of the Hessian to provide a variance-covariance matrix, i.e.:

$N_{2022,a} \rightarrow N_{2022,a} e^{\varepsilon_a}$

where ε_a is generated from the variance-covariance matrix. (B1)

Step 2: Catch

These numbers-at-age are projected one year forward at a time given a catch for the year concerned.

For 2022 and 2023 the 2022 catch and 2023 respectively are assumed:

$C_{2022} = 14864$ t (B2a)

$C_{2023} = 15156$ t (B2b)

From 2024 onwards:

C_y is as specified by the CMP.

This requires specification of how the catch is disaggregated by age to obtain $C_{y,a}$, and how future recruitments are specified.

Step 3: Catch-at-age (by number)

The $C_{y,a}$ values are obtained under the assumption that the commercial selectivity function estimated for the last period (2000 to 2021) continues in the future. F_y[1] is solved iteratively to achieve that the annual catch by mass:

$C_y = \sum_{a=0}^{m} w_{y,a}^{mid} N_{y,a} S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a}$ (B3)

where $w_{y,a}^{mid}$ is taken as the average of the last 10 years (2012-2021) weight-at-age vectors, and hence that:

$C_{y,a} = N_{y,a} S_{y,a} F_y \left(1 - e^{-Z_{y,a}}\right) / Z_{y,a}$ (B4)

The numbers-at-age can then be computed for the beginning of the following year (y+1):

$N_{y+1,0} = R_{y+1}$ (B5)

$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}}$ for $0 \le a \le m - 2$ (B6)

$N_{y+1,m} = N_{y,m-1} e^{-Z_{y,m-1}} + N_{y,m} e^{-Z_{y,m}}$ (B7)

The plus-group m is 14.

[1] An upper bound of 5 is imposed on fishing mortality.

Step 4: Recruitment

Future recruitments for the baseline and sensitivity SCAA operating models are provided by a Beverton-Holt stock-recruitment relationship:

$$R_y = \frac{4hR_0B_y^{sp}}{b_0(1-h)+(5h-1)B_y^{sp}} e^{(\varphi_y-(\sigma_R)^2/2)} \qquad \text{(B8)}$$

Log-normal fluctuations are introduced by generating φ_y factors which also take account of autocorrelation:

$$\varphi_y = \rho\varphi_{y-1} + \sqrt{1-\rho^2}\lambda_y$$

with λ_y from $N(0,(\sigma_R)^2)$ where σ_R is input (0.4) and ρ is fixed at 0.5 (based on results from the baseline assessment).

b_0 is as estimated for that Operating Model. For the baseline SCAA, h is fixed (0.8).

$$B_y^{sp} = \sum_{a=1}^{m} f_a\, w_{y,a}^{strt} N_{y,a} \qquad \text{(B9)}$$

where $w_{y,a}^{strt}$ is taken to be the average of the last 10 years (2012-2021) weight-at-age vectors.

Step5:

The information obtained in Step 1 is used to generate values of the abundance indices I_{2022}^i (in terms of biomass or of numbers), and similarly for following years. The EU survey is assumed to continue sampling the 0-1400m depth zone. Indices of abundance in future years will not be exactly proportional to true abundance, as they are subject to observation error. Log-normal observation error is therefore added to the expected value of the abundance index evaluated, i.e.:

$$I_y^i = q^i B_y^i e^{\varepsilon_y^i} \qquad \text{(B10)}$$

with

ε_y^i from $N(0,(\sigma^i)^2)$

where

B_y^i is the biomass available to the survey:

$$B_y^i = \sum_{a=0}^{m} w_{y,a}^i S_a^i N_{y,a} e^{-Z_{y,a}T^i/12} \qquad \text{(B11)}$$

The survey selectivities are assumed to remain unchanged over the projection period.

The constant of proportionality q^i and residual standard deviation σ^i are as were estimated directly in the associated assessment.

For 2022, the following survey results are input: 13.492 MWPT for EU 3M and 10.284 MWPT for EU 3LNO, with no results available for the Canadian surveys.

Step 6:

Given the new survey indices I_y^i compute TAC_{y+1} using the CMP (aside from the fixed values assumed for 2022 to 2023).

Step 7:

Steps 1-6 are repeated for each future year in turn for as long a period as desired, and at the end of that period the performance of the CMP under review is assessed by considering statistics such as the average catch taken over the period and the final spawning biomass of the resource.