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Results for Greenland Halibut Candidate Management Procedure Trials

by RA Rademeyer and DS Butterworth

Summary

The results of the trials of three CMPs are reported for a base case and six robustness trials developed from SCAA-based Operating Models.

NOTE: This document has been updated to include the changes to OM6 – see NAFO SCR Doc. 23/008REV, with the changes to the previous version being yellow highlighted.

Introduction

This paper reports results of the Candidate Management Procedure (CMP) trials for the SCAA-based baseline and robustness trials (Rademeyer and Butterworth, 2023). The robustness trials selected include the four that were used in the final MP testing in 2017, plus one robustness test based on the choice of the survey series used (see below).

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) for the CMPs is as follows:

OM1: Base Case,

OM2: Larger recruitment variability in the past and in the projections: standard deviation of log recruitment =0.6,

OM3: Base Case in the past, with first 8 years of projected recruitment taken as 50% of those predicted by stock-recruit relationship, OM4: "110% TAC", Base Case in the past, with all future catch taken as 110% of TAC recommended by CMP,

OM5: "0 selectivity on the plus group", Base Case in the past, with future commercial selectivity on ages 10 and above taken to be zero, and

OM6: "Survey sens1": Adding the EU 3L survey to the five surveys used in the Base Case.

The CMPs

The MP selected in 2017 uses results from five survey series as input to compute the TAC. These surveys' results are weighted according to the (inverses of the) variances estimated in the SCAA Base Case. Although the results for the base case historical halibut abundance trajectory for the updated SCAA assessment method differ little from those from 2017, there is one important change in the fit to the survey data. This concerns the variances of the survey data series about the expected abundance trend (which in turn impact the weights given to each survey in the MP TAC formula). Table 1 compares these variances (strictly standard deviations) and weights as in 2017 and now in 2023. Note the much larger variance for the EU 3M 0-1400m series; this is a consequence of the greater variability in the recent data for this series, as is clear from inspection of the OM fit to this series that is shown in Figure 1. There are therefore two options if the objective is to keep using a MP as close as possible to that adopted in 2017:

A) "OW" (Old Weights): Maintain the weights as in 2017 in the CMP, or
B) "NW" (New Weights): Switch to the new weights.

In both cases, the **new** variances are used in projecting further future data for the MP testing simulations, as those better reflect the extent of recent variabilities in the survey indices.

For completeness, CMPs have been tested with both weightings. Results for the following CMPs are therefore presented, with the values of their tuning parameters given in Table 2.:

1) "CMP17_OW" is the MP selected in 2017, and described in Appendix A,
2) "CMP17_NW": the only change from the MP selected in 2017 is the weighting of the surveys,
3) "CMP23_OW" and
4) "CMP23_NW".

with the TACs in CMP23_OW and CMP23_NW computed as follows:

For CMP23_OW:

$$TAC_{y+1} = \mu_{OW} TAC_{y+1}^{CMP17\_OW} \qquad (1)$$

where

$TAC_{y+1}^{CMP17\_OW}$ is the TAC in year y+1 computed using CMP17_OW and

μ_{OW} is a tuning parameter.

Similarly for CMP23_NW:

$$TAC_{y+1} = \mu_{NW} TAC_{y+1}^{CMP17\_NW} \qquad (2)$$

where

$TAC_{y+1}^{CMP17\_NW}$ is the TAC in year y+1 computed using CMP17_NW and

μ_{NW} is a tuning parameter.

The following values have been obtained for the tuning parameters:

$\mu_{OW} = 0.9873$ and $\mu_{NW} = 0.9890$

where these are selected to achieve a median $B^{5-9}_{2044}/B^{5-9}_{MSY}$ 1 in the target year of 2044.

The projection methodology applied is set out in Appendix B.

Results

The performance measures, as described in the April 2023 WG-RBMS Meeting report (NAFO, 2023), are given in **Table 3** for all OMs under each CMP, with some of the performance measures compared graphically in **Figure 2**.

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 each of the CMPs for OM1 to OM6 in **Figures 3a-f** respectively and under CMP23_NW for all OMs in **Figure 3g**.

Worm plots showing individual trajectories as well as 80% probability envelopes are given in **Figure 4** for catch, spawning and exploitable biomass, and F/F_{MSY} for the baseline OM (OM1) under CMP23_NW.

Discussion

The following points merit noting.

- There is a lesser rate of increase in TACs projected under the retuned CMPs.
- Basically the results between the two weighting options are indistinguishable.
- The lower 10%ile for exploitable biomass falls only slightly below $0.5B_{MSY}$.
- As to be expected, performance for OM2 (larger recruitment variability) scarcely differs in median terms from those for the base case OM1, with slightly wider probability intervals.
- OM3 (lower recruitment in the next 8 years) has the greater impact on future trajectories. The CMP reacts appropriately by reducing the TAC in sufficient time to compensate.
- As to be expected, projected biomass is slightly lower than for the base case for OM4 (110% TAC in the future).
- OM5 (zero selectivity on plus group) has little impact on the results compared to the base case OM1.
- Projected biomass relative to BMSY levels is very slightly lower for OM6 (which adds the EU 3L survey), but is not that far below the target by 2044.

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 Document no SCR23-008.

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	0.205	20.300	23.715	0.294	0.395
Can 3LNO spring	0.488	0.491	4.200	4.143	0.061	0.069
Can 3LNO autumn	0.257	0.260	15.140	14.845	0.220	0.247
EU 3M 0-1400m	0.211	0.294	22.400	11.558	0.325	0.192
EU 3NO	0.381	0.416	6.900	5.787	0.100	0.096

Table 2: 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		-	-	-	-	-	-	-
CMP17_OW	1.000	0.15	0.9720	1.00	2.00	-0.0056	0.1	0.1
CMP17_NW	1.000	0.15	0.9720	1.00	2.00	-0.0056	0.1	0.1
CMP23_OW	**0.9873**	0.15	0.9720	1.00	2.00	-0.0056	0.1	0.1
CMP23_NW	**0.9890**	0.15	0.9720	1.00	2.00	-0.0056	0.1	0.1

Table 3: Performance measures for a series of CMPs 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. Values shown in **bold** indicate 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		$B^{5-9}_{2044}/B^{5-9}_{msy}$	$B^{5-9}_{2044} < B^{5-9}_{msy}$	$B^{5-9}_{2030} < 0.8B^{5-9}_{msy}$	$B^{5-9}_{2044} < 0.8B^{5-9}_{msy}$	$B^{5-9}_{lowest}/B^{5-9}_{msy}$	$B^{5-9}_{2030} < B^{5-9}_{2025}$	$(F_{2025\text{-}2044} > F_{msy}) > 0.3$	$B^{sp}_{2044}/B^{sp}_{2025}$	$B^{5-9}_{2044}/B^{5-9}_{2025}$	$(B^{5-9}_{2025\text{-}2044} < 0.3B^{5-9}_{msy}) > 0.1$	$B^{5-9}_{lowest}/B^{5-9}_{msy} < 0.3$	avC: 2025-2029	avC: 2025-2034	avC: 2025-2044	$B^{5-9}_{2030} < 0.75B^{5-9}_{2025}$	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	1.57 (1.12; 2.23)	0.06	0.08	0.01	0.84 (0.67; 1.01)	0.20	0	6.13 (4.22; 9.07)	1.75 (1.20; 2.52)	0	0.00	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.01	-	-
OM1	CMP17_OW	0.85 (0.41; 1.33)	0.66	0.32	0.44	0.60 (0.38; 0.77)	0.27	9	1.95 (0.91; 3.47)	1.10 (0.47; 1.95)	0	0.05	13.24 (12.04; 14.39)	17.26 (15.07; 20.09)	22.19 (16.98; 29.53)	0.04	0.03 (0.01; 0.05)	0.04 (0.02; 0.07)
OM1	CMP23_OW	**1.00** (0.60; 1.52)	0.50	0.30	0.26	0.65 (0.47; 0.82)	0.26	5	2.54 (1.33; 4.26)	1.27 (0.72; 2.15)	0	0.02	12.59 (11.49; 13.74)	15.91 (13.93; 18.53)	19.54 (15.03; 26.36)	0.03	0.02 (0.01; 0.04)	0.04 (0.02; 0.06)
OM1	CMP17_NW	0.86 (0.43; 1.34)	0.63	0.32	0.41	0.61 (0.40; 0.77)	0.27	9	2.00 (0.97; 3.50)	1.11 (0.53; 1.94)	0	0.05	13.26 (12.10; 14.42)	17.21 (15.11; 20.09)	21.89 (16.90; 29.27)	0.04	0.03 (0.01; 0.05)	0.04 (0.02; 0.07)
OM1	CMP23_NW	**1.00** (0.61; 1.50)	0.50	0.30	0.25	0.65 (0.47; 0.82)	0.26	4	2.49 (1.34; 4.18)	1.27 (0.73; 2.13)	0	0.02	12.69 (11.59; 13.85)	16.03 (14.11; 18.72)	19.59 (15.19; 26.56)	0.03	0.02 (0.01; 0.04)	0.04 (0.02; 0.06)
OM2	C=0	1.52 (0.91; 2.56)	0.16	0.18	0.06	0.71 (0.52; 0.86)	0.20	0	6.41 (4.24; 9.55)	1.94 (1.12; 3.19)	0	0.00	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.03	-	-
OM2	CMP17_OW	0.83 (0.32; 1.61)	0.62	0.42	0.49	0.49 (0.25; 0.68)	0.26	10	2.17 (1.02; 4.14)	1.21 (0.46; 2.45)	0	0.16	13.08 (11.97; 14.16)	17.04 (14.97; 19.65)	22.24 (16.81; 29.90)	0.07	0.03 (0.01; 0.04)	0.05 (0.02; 0.07)
OM2	CMP23_OW	0.96 (0.46; 1.78)	0.54	0.41	0.34	0.53 (0.32; 0.71)	0.25	5	2.64 (1.42; 4.80)	1.40 (0.64; 2.67)	0	0.08	12.43 (11.42; 13.49)	15.74 (13.89; 18.10)	19.68 (14.89; 26.93)	0.06	0.02 (0.01; 0.04)	0.04 (0.02; 0.07)
OM2	CMP17_NW	0.83 (0.33; 1.62)	0.62	0.43	0.48	0.50 (0.26; 0.68)	0.26	9	2.17 (1.07; 4.14)	1.21 (0.48; 2.46)	0	0.15	13.14 (12.04; 14.25)	17.04 (15.01; 19.72)	22.04 (16.71; 29.52)	0.07	0.03 (0.01; 0.04)	0.04 (0.02; 0.07)
OM2	CMP23_NW	0.95 (0.46; 1.77)	0.53	0.41	0.34	0.53 (0.32; 0.71)	0.25	5	2.59 (1.39; 4.75)	1.41 (0.64; 2.68)	0	0.08	12.57 (11.55; 13.63)	15.88 (14.03; 18.40)	19.78 (15.04; 27.06)	0.06	0.02 (0.01; 0.04)	0.04 (0.02; 0.07)
OM3	C=0	1.51 (1.08; 2.14)	0.06	0.40	0.01	0.51 (0.37; 0.72)	0.59	0	4.81 (3.31; 7.29)	1.68 (1.16; 2.42)	0	0.02	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.16	-	-
OM3	CMP17_OW	0.85 (0.47; 1.30)	0.70	0.78	0.43	0.31 (0.17; 0.49)	0.77	13	1.21 (0.46; 2.52)	1.10 (0.58; 1.76)	8	0.48	13.23 (12.01; 14.36)	16.67 (14.55; 19.22)	16.98 (13.90; 21.33)	0.31	0.03 (0.01; 0.05)	0.02 (0.01; 0.04)
OM3	CMP23_OW	1.00 (0.68; 1.49)	0.50	0.76	0.24	0.34 (0.21; 0.53)	0.75	8	1.84 (0.80; 3.25)	1.29 (0.84; 1.97)	5	0.33	12.57 (11.47; 13.71)	15.37 (13.49; 17.74)	15.15 (12.45; 18.95)	0.28	0.02 (0.01; 0.04)	0.02 (0.01; 0.03)
OM3	CMP17_NW	0.87 (0.50; 1.34)	0.68	0.79	0.41	0.31 (0.17; 0.49)	0.77	12	1.26 (0.48; 2.58)	1.12 (0.64; 1.76)	7	0.45	13.23 (12.08; 14.38)	16.54 (14.56; 19.06)	16.79 (13.82; 21.03)	0.31	0.03 (0.01; 0.05)	0.02 (0.01; 0.04)
OM3	CMP23_NW	0.99 (0.67; 1.49)	0.51	0.77	0.24	0.34 (0.22; 0.52)	0.75	8	1.82 (0.80; 3.22)	1.29 (0.84; 1.96)	5	0.34	12.66 (11.57; 13.81)	15.43 (13.60; 17.83)	15.21 (12.54; 18.91)	0.28	0.02 (0.01; 0.04)	0.02 (0.01; 0.03)
OM4	C=0	1.57 (1.12; 2.22)	0.06	0.08	0.01	0.83 (0.66; 1.00)	0.17	0	6.35 (4.33; 9.48)	1.78 (1.22; 2.58)	0	0.00	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.00	-	-
OM4	CMP17_OW	0.77 (0.35; 1.25)	0.75	0.38	0.54	0.55 (0.31; 0.72)	0.28	13	1.69 (0.75; 3.14)	1.04 (0.39; 1.90)	0	0.09	13.14 (11.94; 14.29)	16.90 (14.73; 19.72)	20.76 (15.95; 28.15)	0.04	0.03 (0.01; 0.05)	0.04 (0.02; 0.06)
OM4	CMP23_OW	0.95 (0.54; 1.43)	0.57	0.35	0.29	0.62 (0.43; 0.78)	0.26	6	2.32 (1.14; 4.00)	1.25 (0.69; 2.15)	0	0.02	12.49 (11.41; 13.64)	15.60 (13.66; 18.18)	18.42 (14.19; 25.35)	0.03	0.02 (0.01; 0.04)	0.03 (0.02; 0.06)
OM4	CMP17_NW	0.79 (0.38; 1.27)	0.74	0.39	0.52	0.56 (0.32; 0.73)	0.28	13	1.75 (0.79; 3.13)	1.05 (0.43; 1.89)	0	0.09	13.15 (12.01; 14.32)	16.89 (14.80; 19.71)	20.62 (15.91; 27.95)	0.04	0.03 (0.01; 0.05)	0.04 (0.02; 0.06)
OM4	CMP23_NW	0.95 (0.55; 1.43)	0.58	0.35	0.30	0.61 (0.43; 0.78)	0.26	7	2.28 (1.15; 3.86)	1.25 (0.70; 2.14)	0	0.02	12.59 (11.50; 13.76)	15.75 (13.85; 18.38)	18.60 (14.38; 25.23)	0.03	0.02 (0.01; 0.04)	0.03 (0.02; 0.06)
OM5	C=0	1.67 (1.19; 2.36)	0.03	0.05	0.00	0.88 (0.70; 1.06)	0.17	0	6.19 (4.25; 9.16)	1.78 (1.22; 2.57)	0	0.00	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.00	-	-
OM5	CMP17_OW	0.80 (0.33; 1.32)	0.70	0.32	0.49	0.56 (0.29; 0.75)	0.31	13	1.78 (0.82; 3.18)	1.00 (0.38; 1.87)	0	0.10	13.15 (11.96; 14.31)	16.96 (14.84; 19.67)	20.79 (16.04; 27.98)	0.07	0.03 (0.01; 0.05)	0.04 (0.02; 0.06)
OM5	CMP23_OW	0.97 (0.51; 1.52)	0.53	0.30	0.30	0.63 (0.42; 0.81)	0.28	6	2.31 (1.19; 3.94)	1.22 (0.61; 2.09)	0	0.03	12.51 (11.44; 13.66)	15.65 (13.72; 18.18)	18.47 (14.28; 25.15)	0.05	0.02 (0.01; 0.04)	0.03 (0.02; 0.06)
OM5	CMP17_NW	0.81 (0.35; 1.33)	0.68	0.32	0.48	0.57 (0.31; 0.76)	0.31	13	1.81 (0.84; 3.16)	1.01 (0.42; 1.88)	0	0.09	13.18 (12.02; 14.34)	16.93 (14.86; 19.72)	20.70 (16.06; 27.71)	0.07	0.03 (0.01; 0.05)	0.04 (0.02; 0.06)
OM5	CMP23_NW	0.96 (0.53; 1.50)	0.54	0.30	0.30	0.63 (0.42; 0.81)	0.29	6	2.29 (1.19; 3.85)	1.20 (0.62; 2.08)	0	0.03	12.61 (11.52; 13.77)	15.78 (13.91; 18.39)	18.57 (14.50; 25.02)	0.06	0.02 (0.01; 0.04)	0.03 (0.02; 0.06)
OM6	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)	0.00 (0.00; 0.00)	0.00 (0.00; 0.00)	0.02	-	-
OM6	CMP17_OW	0.79 (0.36; 1.26)	0.72	0.37	0.51	0.57 (0.33; 0.75)	0.32	11	1.83 (0.87; 3.34)	1.01 (0.39; 1.82)	0	0.09	13.44 (12.21; 14.58)	17.77 (15.49; 20.71)	23.40 (17.90; 30.85)	0.06	0.03 (0.02; 0.05)	0.05 (0.02; 0.07)
OM6	CMP23_OW	0.95 (0.53; 1.45)	0.56	0.33	0.31	0.63 (0.45; 0.80)	0.30	6	2.45 (1.26; 4.12)	1.20 (0.64; 2.05)	0	0.02	12.77 (11.64; 13.96)	16.38 (14.30; 19.08)	20.75 (15.86; 27.65)	0.05	0.02 (0.01; 0.04)	0.04 (0.02; 0.07)
OM6	CMP17_NW	0.81 (0.40; 1.29)	0.70	0.37	0.48	0.58 (0.36; 0.75)	0.32	10	1.91 (0.91; 3.35)	1.04 (0.45; 1.86)	0	0.07	13.46 (12.27; 14.61)	17.70 (15.49; 20.64)	23.07 (17.74; 30.55)	0.06	0.03 (0.01; 0.05)	0.05 (0.02; 0.07)
OM6	CMP23_NW	0.96 (0.55; 1.45)	0.55	0.34	0.30	0.63 (0.46; 0.80)	0.30	5	2.43 (1.29; 4.08)	1.20 (0.66; 2.03)	0	0.02	12.88 (11.75; 14.05)	16.48 (14.48; 19.24)	20.71 (16.00; 27.98)	0.05	0.02 (0.01; 0.04)	0.04 (0.02; 0.06)

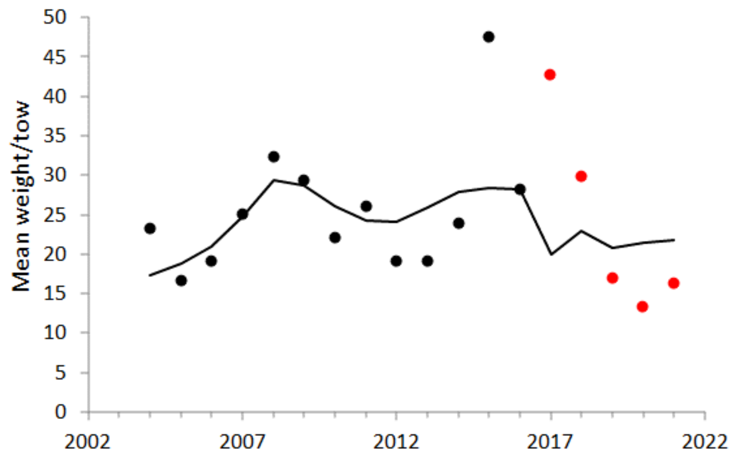

Figure 1. Fit to the EU 3M 0-1400m survey series for the 2023 base case OM. The data that became available after the 2017 assessment are shown in red.

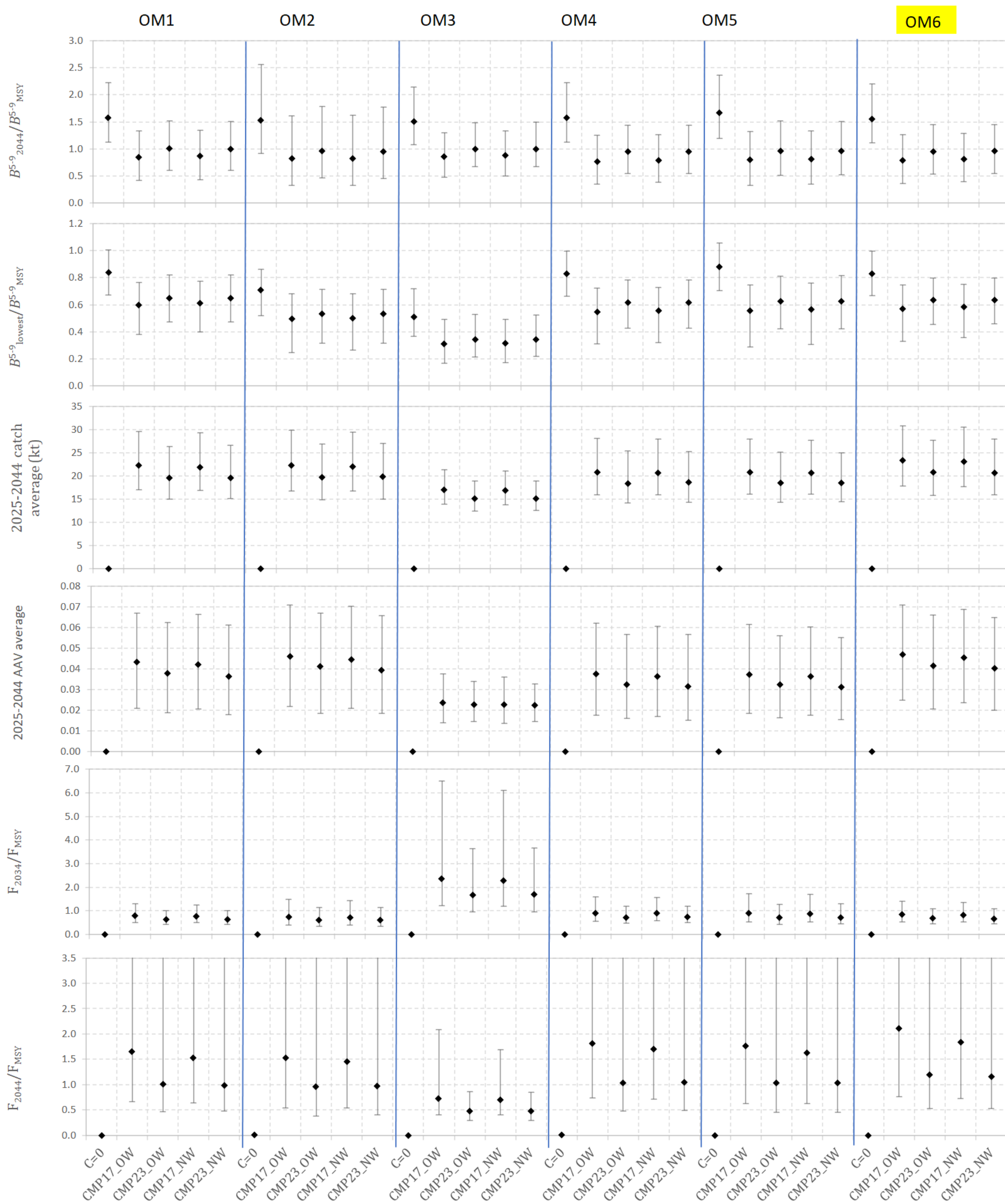

Figure 2: Projected median and 80% PIs for a series of performance statistics for each OM under a number of CMPs.

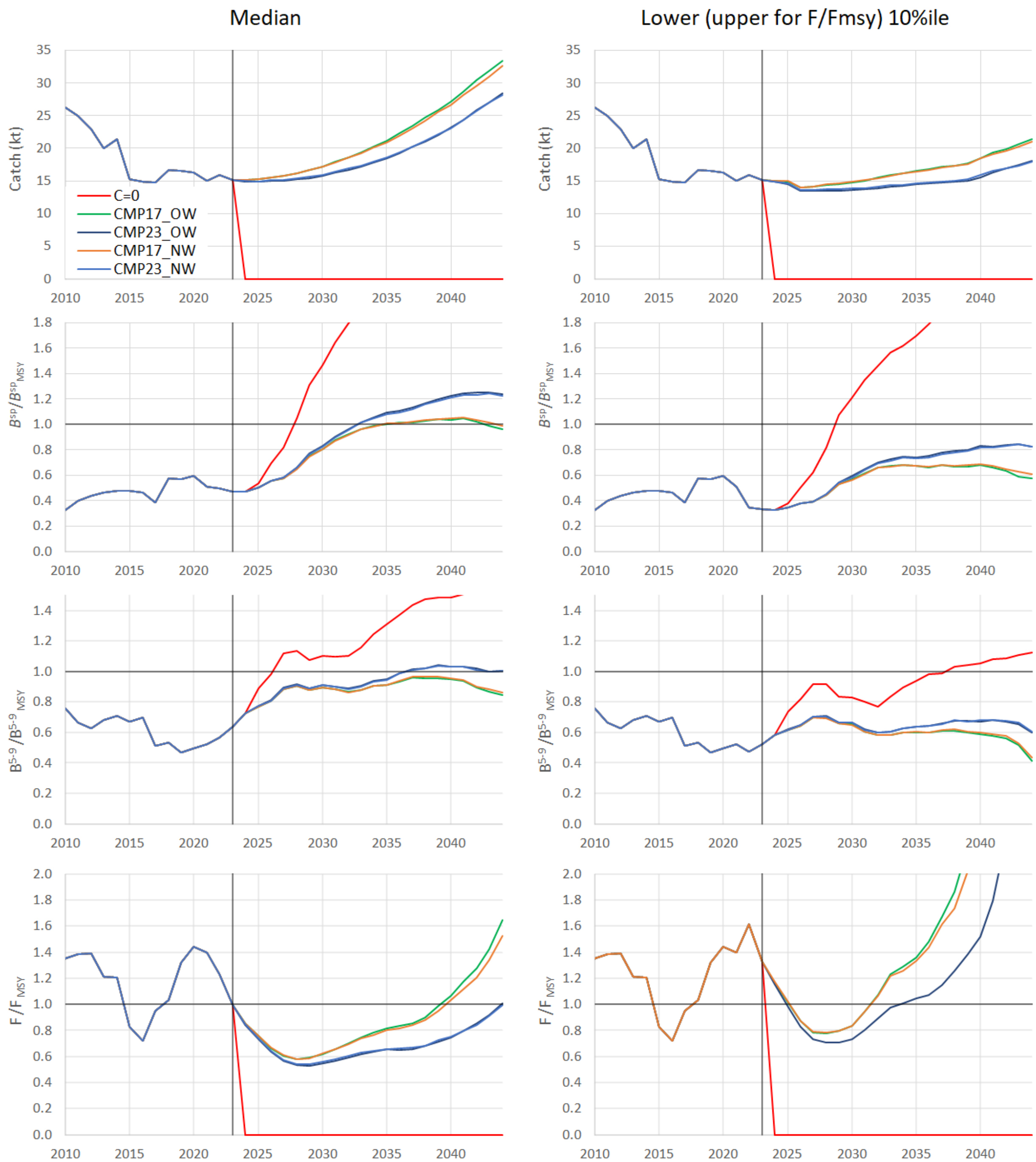

Figure 3a: Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM1** under a number of CMPs.

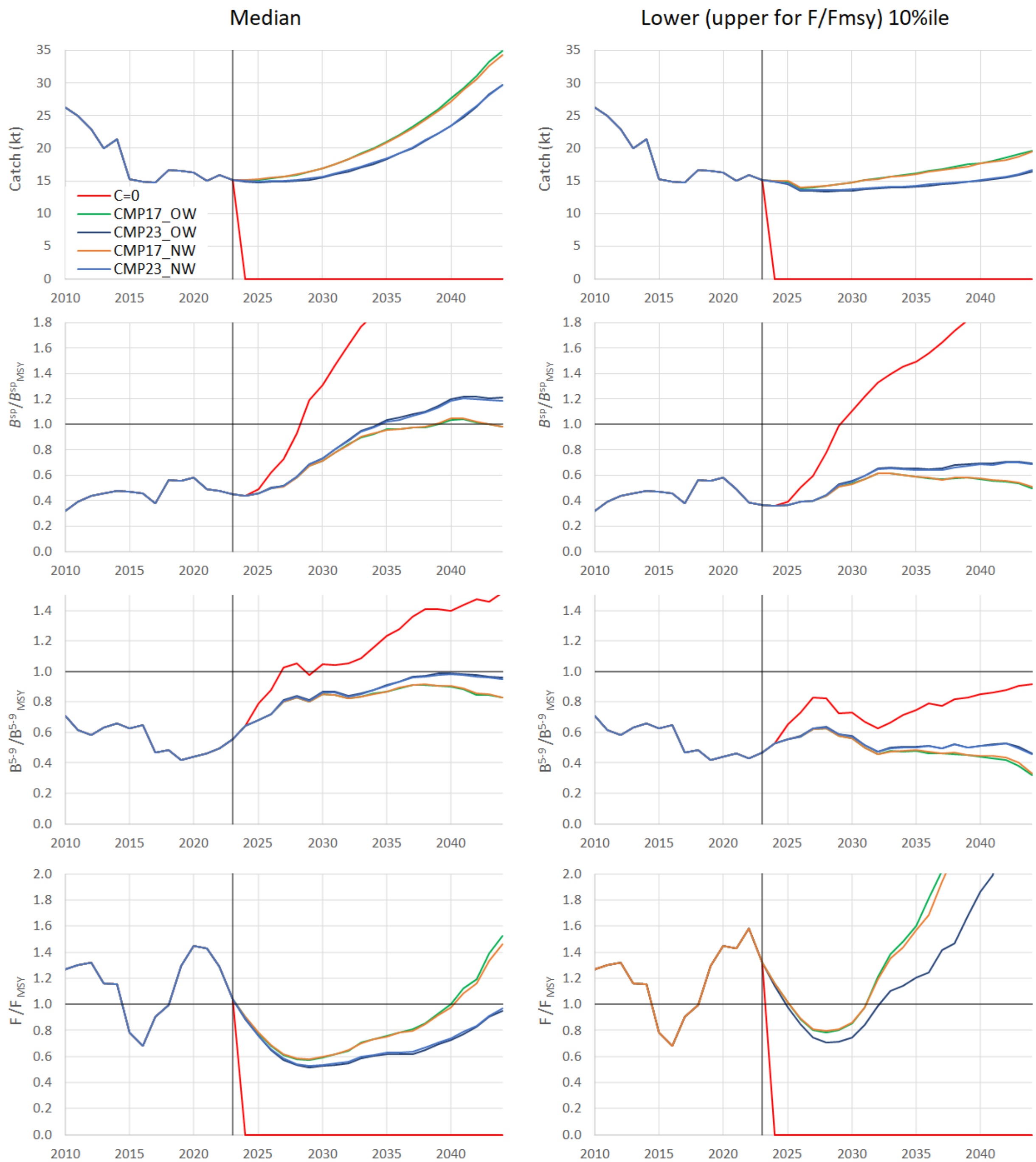

Figure 3b: Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM2** (larger recruitment variability) under a number of CMPs.

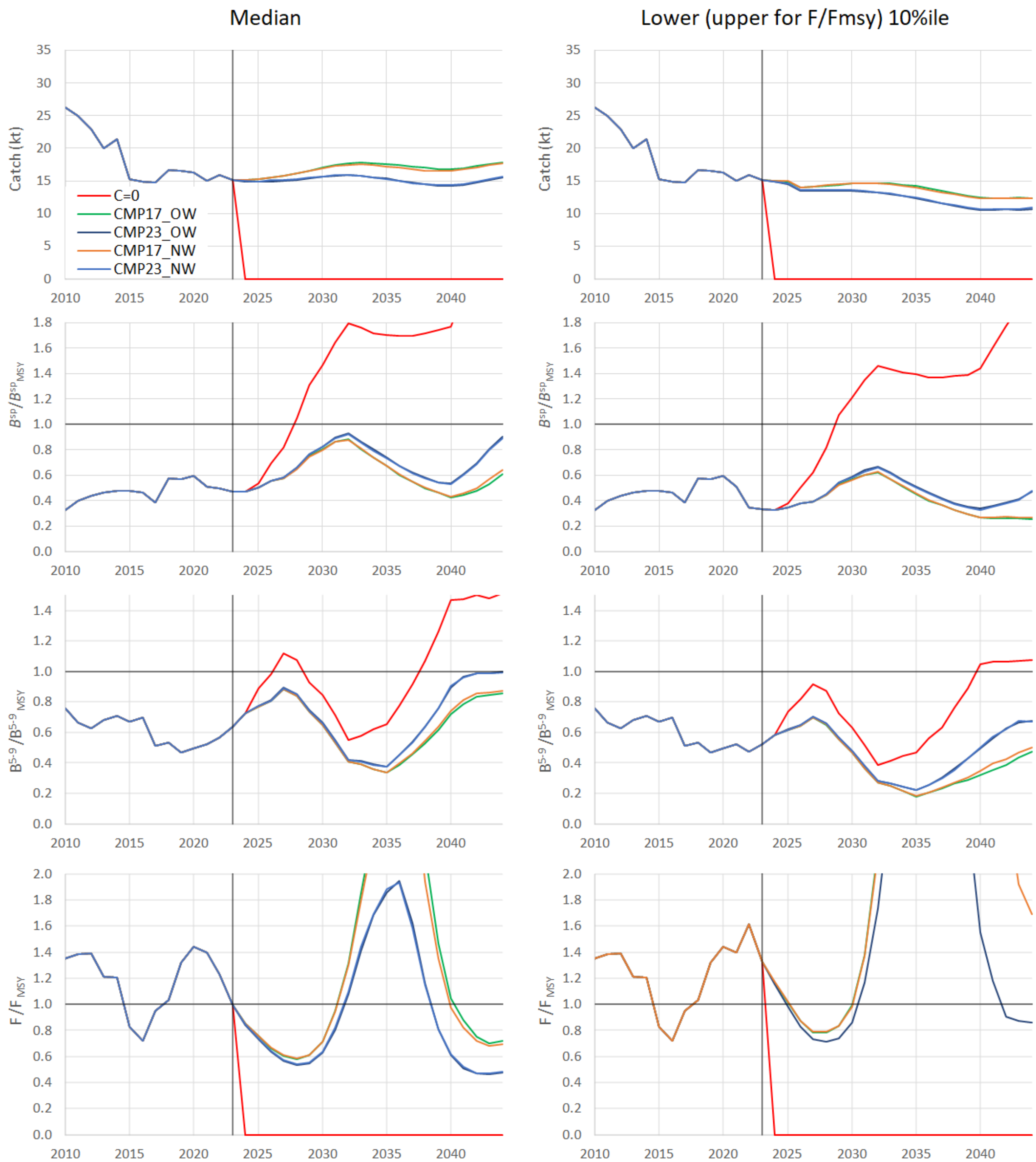

Figure 3c: Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM3** (lower recruitment in the first 8 years of projection) under a number of CMPs.

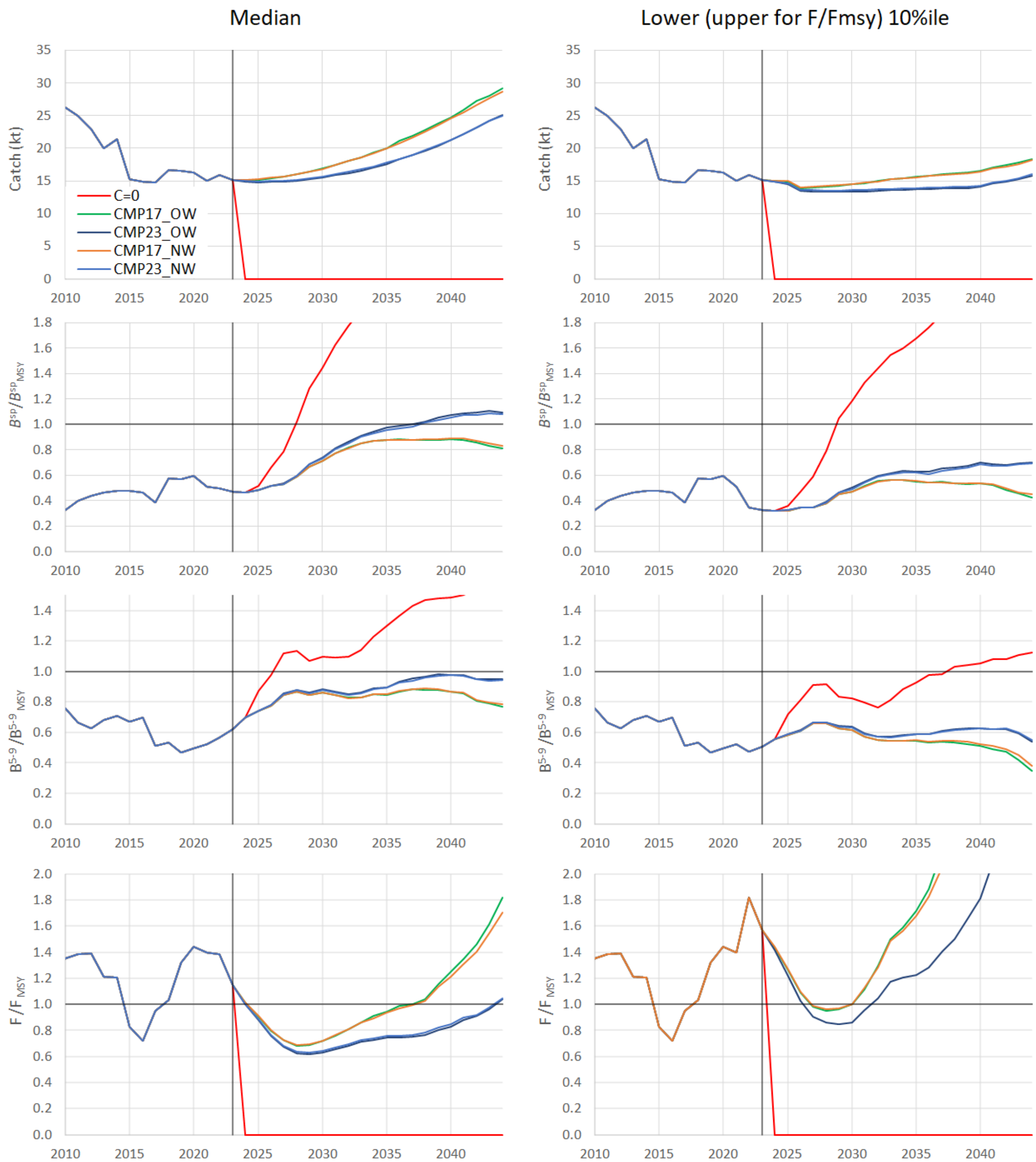

Figure 3d: Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM4** (110% TAC in the future) under a number of CMPs.

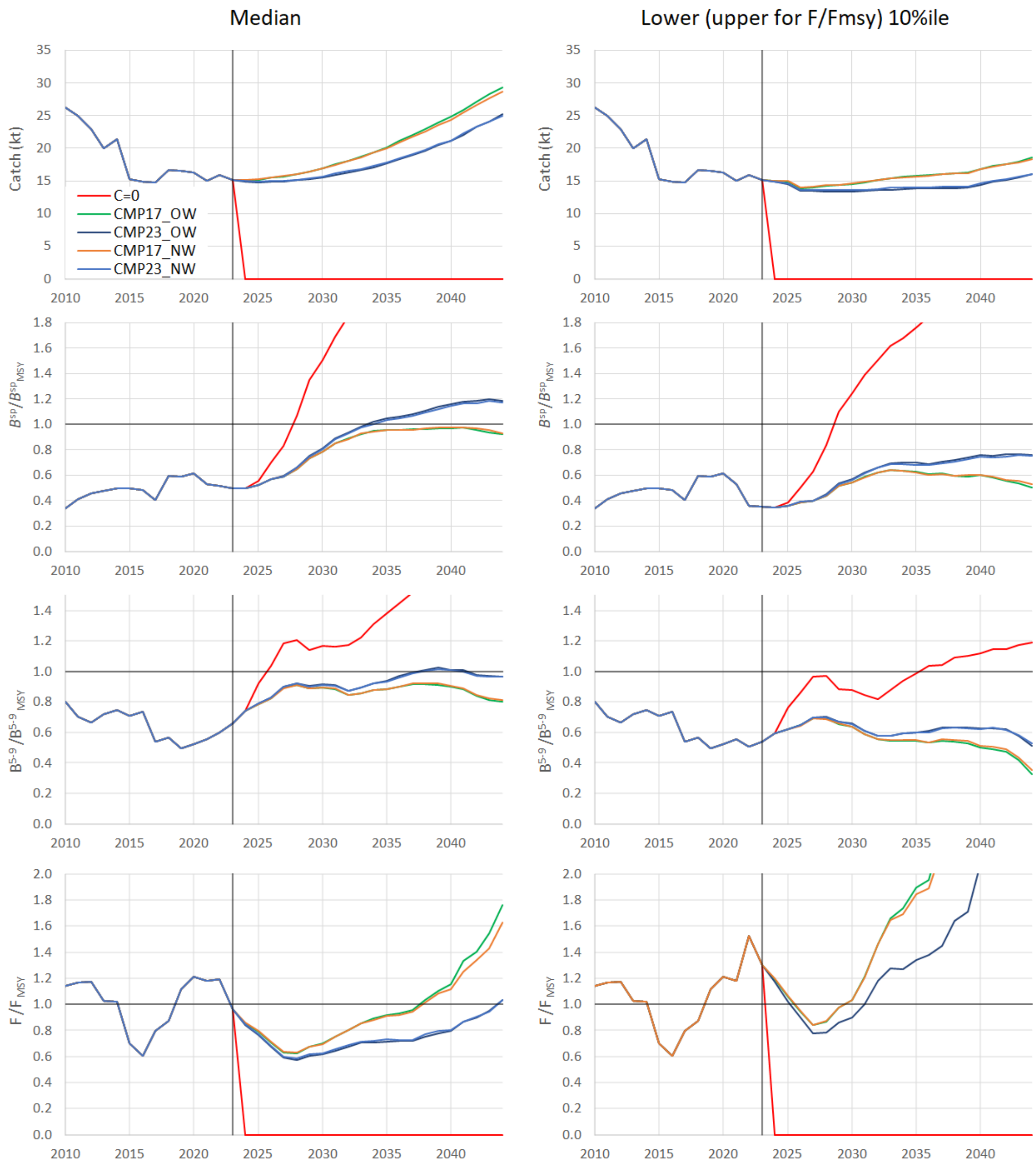

Figure 3e: Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM5** (zero future selectivity on the plus-group) under a number of CMPs.

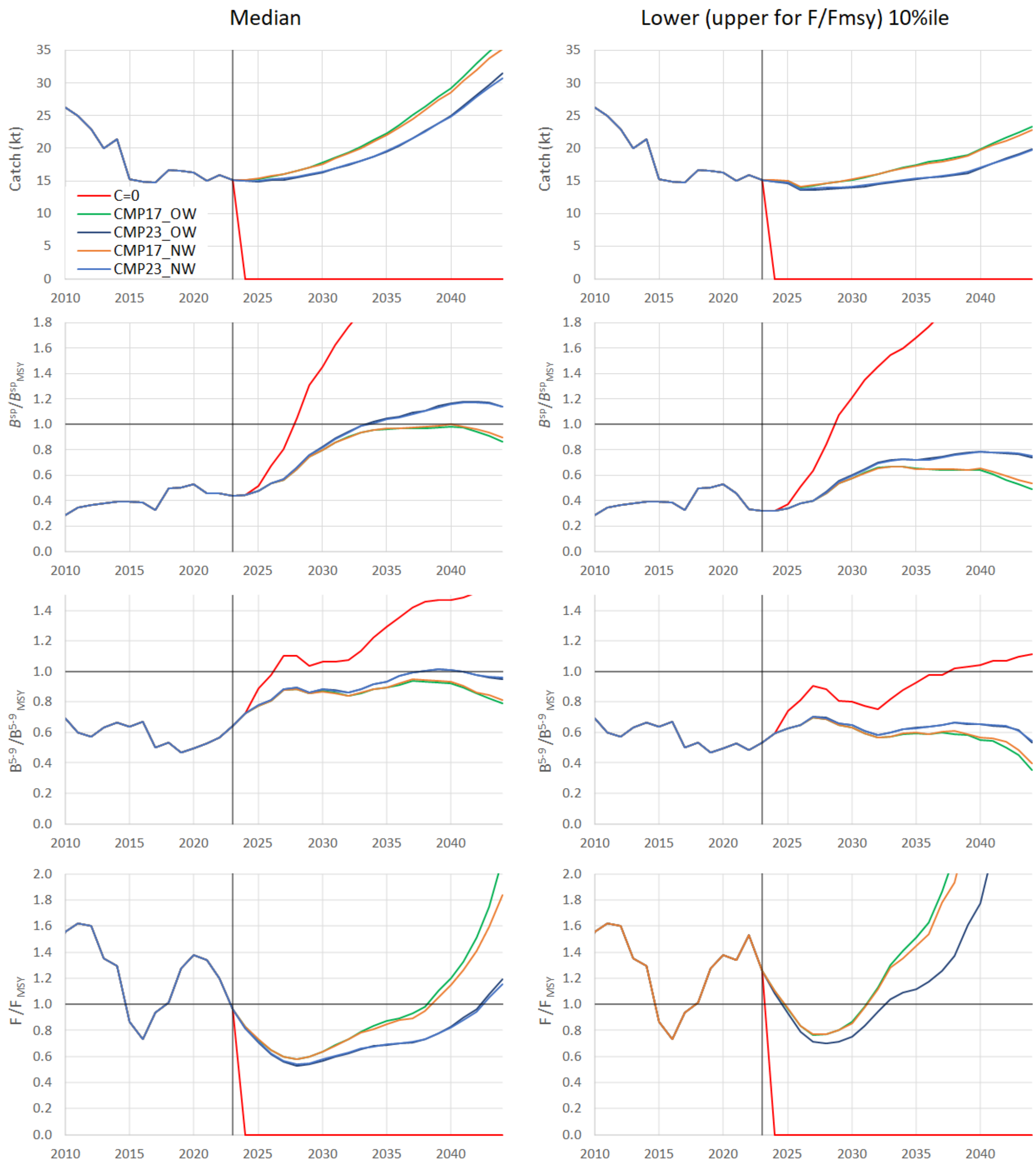

Figure 3f: Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM6** (including the EU 3L survey) under a number of CMPs.

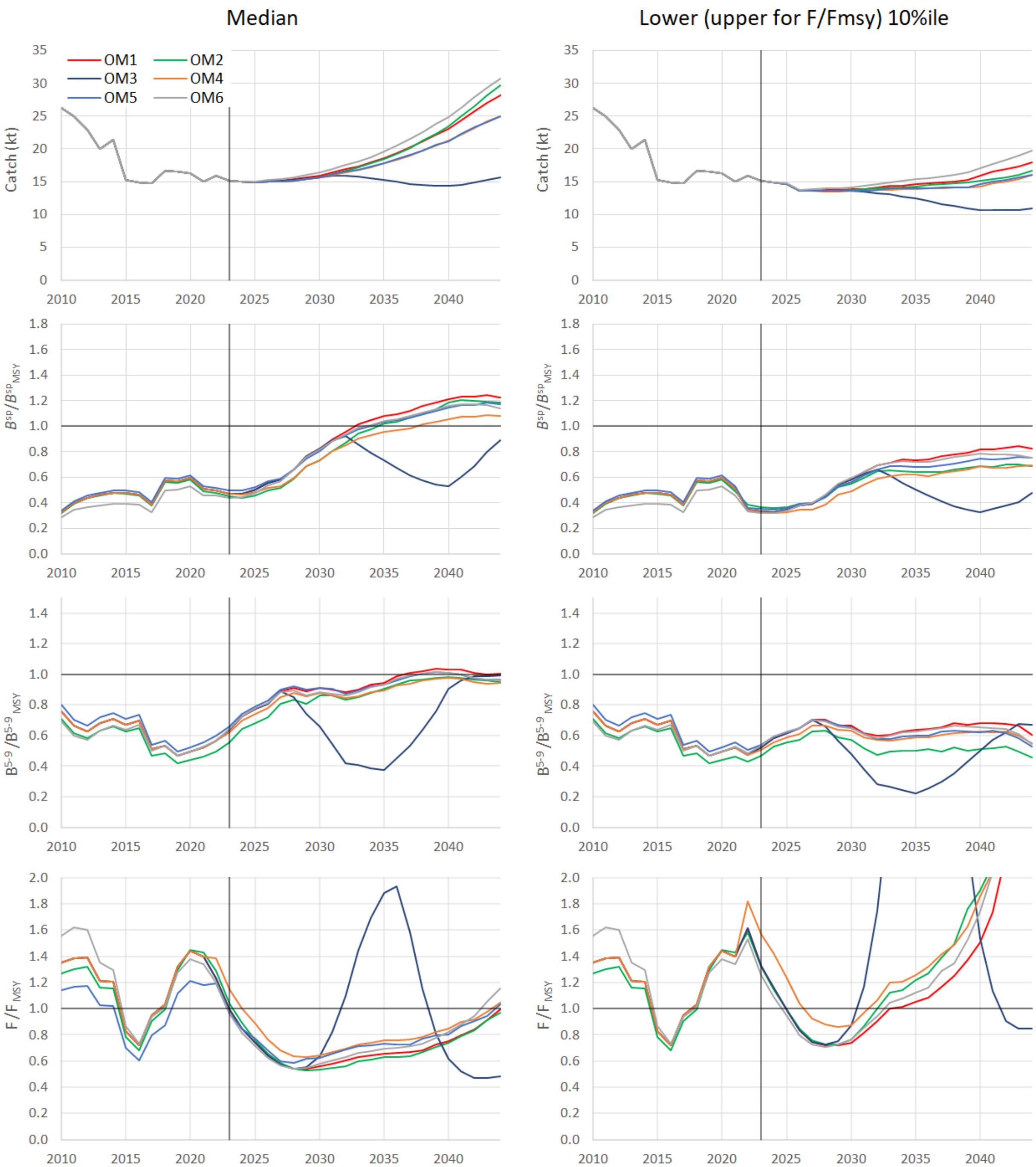

Figure 3g: Projected median and lower 10%iles for catch, spawning and exploitable biomass (both relative to B_{MSY}) and F/F_{MSY} (the upper 10%iles are plotted instead of lower 10%iles) for **OM1 to OM6** (the last including EU 3L survey) under **CMP23_NW**.

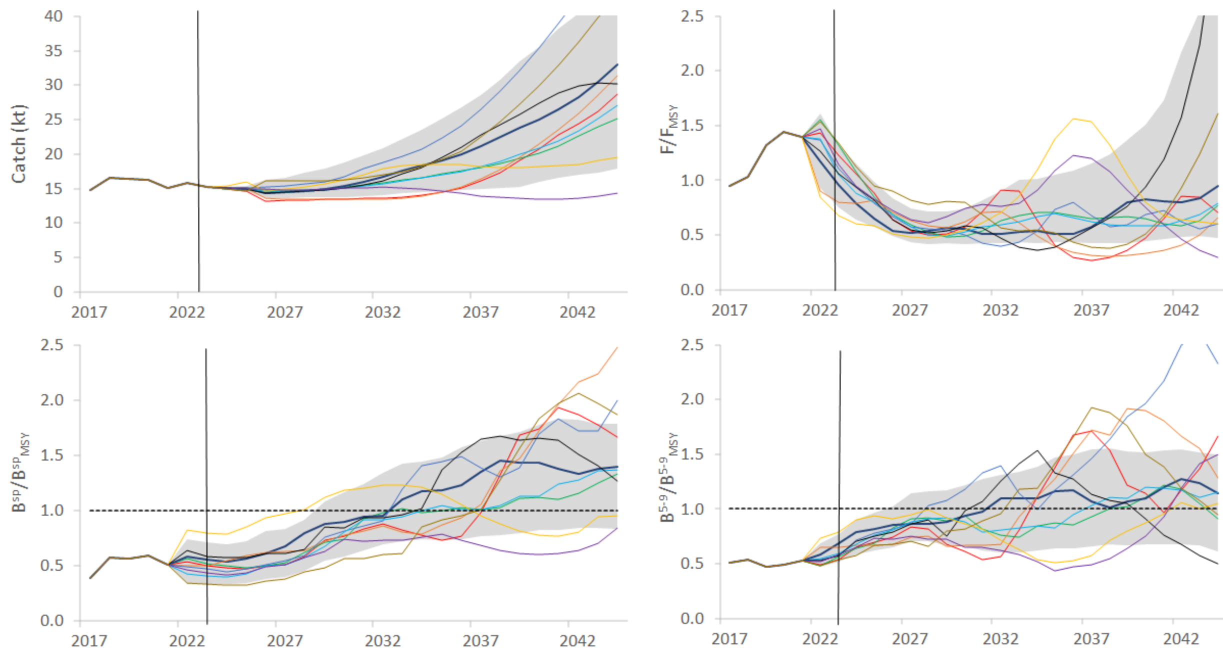

Figure 4: "Worm" plots showing individual trajectories as well as the 80% probability envelopes (grey shading) for catch, fishing mortality relative to F_{MSY}, and spawning and exploitable biomass (both relative to B_{MSY}), for the baseline OM (OM1) under **CMP23_NW.**

Appendix A: The CMPs

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

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

Target based part:

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

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, Canada Spring 3LNO, EU 3NO and Canada Fall 3LNO:

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

with

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

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

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

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:

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

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

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

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:

$$C_{2022} = 14864 \text{ t} \quad \text{(B2a)}$$

$$C_{2023} = 15156 \text{ t} \quad \text{(B2b)}$$

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:

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

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

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

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

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

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

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

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.

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.