Report on ongoing Progress in the Development of Candidate Management Procedures for the Canadian Pollock in the in the Western Component (4Xopqrs+5Zc)

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Abstract

Management Procedure testing is continued with the introduction of further robustness tests and the inclusion of a penalty term in the TAC formula if the survey abundance estimates fall below a threshold level. This penalty term does improve performance in terms of resource conservation risk for both the Reference Set of Operating Models and the robustness tests examined, though the improvement is slight even for relatively large sacrifices in catch. There is minimal increase in resource risk if reducing the interannual TAC change constraint from 20% to 15%,

Introduction

This document continues reporting on progress in the development of a Management Procedure for Canadian Pollock, building on the material presented in Rademeyer and Butterworth (2010, 2011), and implementing modifications agreed in discussions of those documents. In particular further agreed robustness tests are introduced, and the Candidate Management Procedures refined to include penalty terms which reduce the TAC still further if survey results fall below a specified (LRP-like) threshold level.

Methodology

Further updates from Rademeyer and Butterworth (2011) March document now incorporated are:

1) the catch in 2011 is assumed fixed at 6000t; and
2) a further statistic is reported: the probability of falling below 2xB_{2000} over the projection period.

Also a further OM/robustness test has also been constructed: in OM16 the natural mortality of fish of age 5 and above is fixed at 0.76 from 1996 onwards. Biomass, recruitment and fishing mortality trajectories are compared in Appendix A for a series of OMs. All the OMs are summarised in Table A1 in Appendix A.

Appendix B provides detailed technical specifications of the CMPs.

For ease of comparison of different forms of CMPs, the CMPs have been tuned to correspond to a common achieved median catch in 2016 for the Reference Set (RS) of Operating Models. The resultant tuning parameter values are reported in Table 1.

Broadly speaking this document examines four aspects of CMPs:

1) performance in relation to different targets for rate of increase of catches in the short term;
2) the introduction of TAC penalties if survey estimates of abundance drop below a threshold level;
3) alternative restrictions on the extent to which the TAC can vary from one year to the next; and

performance under some of the more pessimistic robustness tests.

Results

Projections results for a series of CMPs under the RS are given in Table 2. The CMPs have been tuned (i.e. had their control parameters adjusted) to achieve a median catch in 2016 of either 8000, 10000 or 12000t.

No penalty:

Shade plots, showing medians, 50%, 75% and 95% PI of a series of performance statistics, are shown in Fig. 1 for CMPc1a under the RS. CMPc1a-c have been tuned to three levels of median 2016 catch; the medians and lower 2.5%iles catch and biomass trajectories are compared in Fig. 2.

With penalty:

CMPe1a includes a penalty term if the survey results fall below a defined threshold level. Shade plots for CMPe1a under the RS are shown in Fig. 3. Fig. 4 compares the medians and lower 2.5%iles catch and biomass trajectories for CMPc1a (no penalty), CMPe1a (with penalty) and CMPe2a (with a stronger penalty). These three CMPs are all tuned to a median 2016 catch of 10000t. The corresponding trajectories under a catch of zero from 2012 onwards are also shown for comparison, and in particular to reflect the best results for future resource status that are feasible.

Interannual TAC change constraints

Fig. 5 compares the medians and lower 2.5%iles catch and biomass trajectories for CMPe1a (+-20% constraints on annual TAC change) and CMPe3a (+-15% constraints on annual TAC change).

Robustness tests

To check that the performance of the CMPs is reasonably robust to plausible variations of the OMs that constitute the RS, at this stage three robustness tests have been run for CMPc1a and CMPe1a:

i. OM15 which is a combination of the key features of OM8 (high *M*) and OM13 (recruitment from last 5 years data);
ii. OM16 which also combines a high *M* (0.76 from age 5 onwards) with the lower recruitment of OM13; and
iii. Rob3, a variant of the RS and probably the most pessimistic of the robustness tests, in which the recruitment over the first eight years of projections is assumed to be at the level of the lowest recruitment over the period from which the recruitment relationship is calculated (1999-2008 for OM1, OM2, OM3, OM8 and OM14 and 2004-2008 for OM13).

Results for these robustness tests are given in Table 3 and plotted in Fig. 6.

Summary

Fig. 7 summarises performance statistics and compares them under the different CMPs for the RS, while Fig. 8 compares the results under CMPc1a and CMPe1a for the RS and the three robustness tests.

Discussion

Fig. 2 contrasts the performances of three CMPs tuned for different levels of short-term TAC increase. As expected the one with the least immediate increase (CMPc1c) shows better biomass recovery in both median and lower 5%-ile terms, though the differences in the extent of such recovery are slight. The comparative plots shown for the zero future catch case are helpful in indicating the best conservation performance that could be achieved, and show that even in this case the lower 5%-ile for exploitable biomass decreases after 2017 to levels not greatly in excess of those for the three CMPs considered.

Fig. 4 shows the effect of introducing the penalty term (CMPe1a or CMPe2a) into the TAC formula. This can result in appreciable reductions in the TAC given poor survey results, but the improvement in the lower 5%-ile for the exploitable biomass is not substantial.

Fig. 5 contrasts TAC and exploitable biomass trends for limitations of 20% and 15% on annual TAC changes. The tighter restriction makes a scarcely perceptible difference in estimated future resource trends, and hence the 15% restriction on change in the interests of greater industrial stability would seem perfectly acceptable in resource risk terms. This result is also evident in Fig. 7 which compares performances of various CMPs for the RS of OMs. The trade-offs referenced above are also evident in Fig. 7, again indicating that considerable sacrifices in catch have to be made for enhanced exploitable biomass recovery.

Figs 6 and 8 compare the performances of CMPc1a and its equivalent with a penalty term (CMPe1a) for the RS and a number of robustness tests. The latter Figure does indicate that CMPe1a with its additional penalty term is more successful than CMPc1a in reducing catches under the scenarios of Rob3 with eight successive future years of poor recruitment. The difference in impact of CMPe1a compared to CMPc1a on TACs for the other robustness tests is less, but as evident from Fig. 6 this is in part because at the lower 5%-ile level the exploitable biomass is at levels only slightly less that the best achievable (under zero catch) for those scenarios.

In summary, the introduction of a penalty term in the MP TAC formula does improve performance in terms of resource conservation risk for both the RS and the robustness tests examined, though the improvement is slight even for relatively large sacrifices in catch if survey abundance indices drop low. There is minimal increase in resource risk in reducing the interannual TAC change constraint from 20% to 15%,

Future work

Further work will focus on refining the CMPs in the range of catch-recovery trades-offs desired as advised by stakeholders. This will include examining issues such as whether the choice of three years in calculating the J_y index for input to the MP formula (see Appendix B) is the most appropriate in terms of performance trade-offs.

References

Rademeyer RA and Butterworth DS. 2010. Progress on the development of Candidate Management Procedures for the Canadian Pollock in the Western Component (4Xopqrs+5Zc).

Rademeyer RA and Butterworth DS. 2011. And yet further progress on the development of Candidate Management Procedures for the Canadian pollock in the Western component (4Xopqrs+5Zc).

Stone H. 2010. Pollock assessment update for the Western Component (4Xopqrs5).

Table 1: Tuning parameter values for each CMP.

	Comment	Initial TAC	a	b	c	p_{2012}	p_{2022}	TAC 2012	Interannual change constraints	Cap
CMPc1a	Tuned to 2016 median catch of 10000t, no penalty	6500	17124	10000	-	-	-	≤7500t	+20%; -20%	20000t
CMPc1b	Tuned to 2016 median catch of 12000t, no penalty	6500	17655	8000	-	-	-	≤7500t	+20%; -20%	20000t
CMPc1c	Tuned to 2016 median catch of 8000t, no penalty	6500	16674	12000	-	-	-	≤7500t	+20%; -20%	20000t
CMPe1a	Tuned to 2016 median catch of 10000t, with penalty	6500	18661	12000	16000	0.0	1.0	≤7500t	+20%; -20%	20000t
CMPe1b	Tuned to 2016 median catch of 12000t, with penalty	6500	18415	9000	16000	0.0	1.0	≤7500t	+20%; -20%	20000t
CMPe1c	Tuned to 2016 median catch of 8000t, with penalty	6500	18371	14000	16000	0.0	1.0	≤7500t	+20%; -20%	20000t
CMPe2a	Tuned to 2016 median catch of 10000t, with penalty	6500	18681	12000	24000			≤7500t	+20%; -20%	20000t
CMPe3a	Tuned to 2016 median catch of 10000t, with penalty	6500	18849	12000	16000	0.0	1.0	≤7500t	+15%; -15%	20000t

Table 2: Projections results (median and 95% PI in parenthesis) for a series of performance statistics for different CMPs under the RS. For each CMP tuning parameters were adjusted to meet the performance criterion shown in bold.

		RS-CMPc1a		RS-CMPc1b		RS-CMPc1c		RS-CMPe1a		RS-CMPe1b		RS-CMPe1c		RS-CMPe2a		RS-CMPe3a	
P_{2021}/P_{target}	$B^{4\text{-}8}$	1.67	(0.32; 3.94)	1.58	(0.26; 3.82)	1.76	(0.39; 4.08)	1.66	(0.36; 3.93)	1.59	(0.27; 3.83)	1.75	(0.42; 4.07)	1.67	(0.36; 3.99)	1.68	(0.34; 3.95)
	B^{sp}	3.39	(0.34; 9.32)	2.88	(0.26; 8.73)	4.07	(0.68; 10.28)	3.43	(0.54; 9.34)	2.92	(0.31; 8.71)	4.04	(0.96; 10.45)	3.45	(0.60; 9.38)	3.46	(0.48; 9.56)
P_{2016}/P_{2000}	$B^{4\text{-}8}$	5.33	(1.65; 10.53)	5.01	(1.50; 10.06)	5.87	(2.10; 11.29)	5.36	(1.72; 10.54)	5.02	(1.51; 10.08)	5.89	(2.10; 11.33)	5.36	(1.73; 10.53)	5.36	(1.67; 10.57)
	B^{sp}	6.93	(2.15; 13.86)	6.46	(1.89; 13.26)	7.74	(2.77; 15.23)	7.02	(2.24; 14.06)	6.47	(1.89; 13.26)	7.80	(2.85; 15.37)	7.01	(2.25; 14.05)	7.03	(2.20; 14.16)
P_{2021}/P_{2000}	$B^{4\text{-}8}$	6.63	(1.37; 14.64)	6.29	(1.10; 13.94)	6.91	(1.67; 15.26)	6.66	(1.56; 14.49)	6.41	(1.17; 13.97)	6.90	(1.79; 15.20)	6.68	(1.56; 14.49)	6.68	(1.48; 14.76)
	B^{sp}	17.24	(1.82; 38.60)	14.80	(1.40; 35.08)	20.57	(3.64; 45.75)	17.49	(2.88; 38.84)	15.05	(1.61; 34.85)	20.68	(5.05; 46.01)	17.56	(3.18; 39.02)	17.65	(2.56; 39.91)
P_{2031}/P_{2000}	$B^{4\text{-}8}$	6.06	(0.68; 15.50)	5.90	(0.52; 15.33)	6.12	(0.72; 15.70)	6.11	(0.87; 15.80)	6.13	(0.88; 15.70)	6.11	(0.82; 15.60)	6.15	(0.87; 15.81)	6.10	(0.86; 15.67)
	B^{sp}	17.52	(0.82; 53.00)	16.60	(0.61; 52.45)	18.02	(0.98; 53.35)	18.67	(1.15; 53.07)	18.60	(1.38; 52.85)	18.49	(1.08; 53.37)	19.33	(1.47; 53.07)	18.80	(1.05; 53.16)
Prob<P_{2000}	$B^{4\text{-}8}$	0.00	(0.00; 0.33)	0.00	(0.00; 0.38)	0.00	(0.00; 0.29)	0.00	(0.00; 0.24)	0.00	(0.00; 0.29)	0.00	(0.00; 0.19)	0.00	(0.00; 0.19)	0.00	(0.00; 0.24)
	B^{sp}	0.00	(0.00; 0.19)	0.00	(0.00; 0.29)	0.00	(0.00; 0.10)	0.00	(0.00; 0.10)	0.00	(0.00; 0.10)	0.00	(0.00; 0.10)	0.00	(0.00; 0.10)	0.00	(0.00; 0.10)
Prob<1.5P_{2000}	$B^{4\text{-}8}$	0.10	(0.00; 0.57)	0.10	(0.00; 0.67)	0.10	(0.00; 0.48)	0.10	(0.00; 0.43)	0.10	(0.00; 0.52)	0.10	(0.00; 0.38)	0.10	(0.00; 0.43)	0.10	(0.00; 0.43)
	B^{sp}	0.05	(0.00; 0.34)	0.05	(0.00; 0.52)	0.05	(0.00; 0.19)	0.05	(0.00; 0.24)	0.05	(0.00; 0.29)	0.05	(0.00; 0.19)	0.05	(0.00; 0.24)	0.05	(0.00; 0.29)
Prob<2.0P_{2000}	$B^{4\text{-}8}$	0.10	(0.00; 0.72)	0.10	(0.00; 0.81)	0.10	(0.00; 0.62)	0.10	(0.00; 0.62)	0.10	(0.00; 0.62)	0.10	(0.00; 0.52)	0.10	(0.00; 0.57)	0.10	(0.00; 0.62)
	B^{sp}	0.10	(0.00; 0.52)	0.10	(0.00; 0.71)	0.10	(0.00; 0.29)	0.10	(0.00; 0.33)	0.10	(0.00; 0.48)	0.10	(0.00; 0.24)	0.10	(0.00; 0.33)	0.10	(0.00; 0.43)
C_{2011}		6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)
C_{2012}		7500	(7500; 7500)	7500	(7500; 7500)	6171	(5902; 7500)	7500	(7500; 7500)	7500	(7500; 7500)	6118	(5804; 7500)	7500	(7500; 7500)	7475	(7475; 7475)
C_{2013}		7959	(7409; 9000)	9000	(9000; 9000)	5686	(5025; 7890)	7663	(7003; 9000)	9000	(9000; 9000)	5552	(4782; 7920)	7683	(7023; 9000)	7851	(7191; 8596)
C_{2014}		8582	(7545; 10800)	10800	(9990; 10800)	6387	(5196; 9361)	8413	(7118; 10800)	10724	(9738; 10800)	6305	(4929; 9401)	8432	(7111; 10800)	8551	(7304; 9885)
C_{2015}		9252	(7628; 12960)	11335	(10058; 12960)	7130	(5344; 10696)	9088	(6913; 12960)	11306	(9510; 12960)	7130	(4837; 10924)	9106	(6755; 12960)	9218	(7098; 11368)
C_{2016}		**10000**	(7776; 14631)	**12000**	(10117; 15552)	**8000**	(5611; 12305)	**10000**	(6585; 15092)	**12000**	(9009; 15552)	**8000**	(4704; 12296)	**10000**	(6170; 15120)	**10000**	(6762; 13073)
C_{2021}		14736	(8077; 20000)	15236	(10153; 20000)	14310	(6904; 20000)	14648	(3816; 20000)	15013	(4238; 20000)	14706	(3704; 20000)	14512	(3212; 20000)	14246	(4273; 20000)
$C_{2011\text{-}2015}$		7877	(7252; 9252)	8904	(8522; 9252)	6311	(5554; 8110)	7759	(6962; 9252)	8885	(8370; 9252)	6245	(5356; 8195)	7772	(6938; 9252)	7832	(7068; 8665)
$C_{2016\text{-}2020}$		11857	(8216; 16410)	13296	(10366; 17502)	10328	(6508; 15336)	11913	(5769; 16998)	13162	(7582; 17747)	10459	(4518; 15842)	11811	(5270; 17010)	11625	(6153; 16232)
$C_{2011\text{-}2020}$		9870	(7881; 12565)	11093	(9509; 13337)	8296	(6221; 11392)	9808	(6620; 12764)	10981	(8067; 13449)	8303	(5160; 11811)	9754	(6266; 12775)	9690	(6765; 12448)
$C_{2021\text{-}2030}$		17566	(8366; 20000)	17583	(10306; 20000)	17659	(7318; 20000)	17572	(3216; 20000)	17120	(3117; 20000)	17870	(4056; 20000)	17335	(2590; 20000)	17432	(3815; 20000)
$AAV_{2011\text{-}2020}$		15.2	(9.4; 19.5)	15.5	(11.1; 19.8)	16.0	(10.5; 19.5)	16.6	(12.4; 20.1)	16.9	(13.4; 20.4)	17.0	(12.6; 20.0)	16.9	(12.8; 20.2)	15.2	(11.7; 17.7)
$AAV_{2012\text{-}2020}$		12.1	(5.7; 16.9)	12.4	(7.6; 17.2)	13.1	(6.9; 16.9)	13.7	(9.0; 17.6)	14.0	(10.1; 17.9)	14.2	(9.2; 17.5)	14.0	(9.5; 17.6)	12.1	(8.2; 14.9)
$AAV_{2021\text{-}2030}$		8.1	(0.0; 14.6)	6.4	(0.0; 12.1)	9.0	(0.7; 16.4)	9.9	(0.0; 20.0)	10.7	(0.0; 20.0)	9.4	(0.6; 20.0)	10.6	(0.0; 20.0)	8.8	(0.4; 15.0)

Table 3: Projections results (median and 95% PI in parenthesis) for a series of performance statistics for different CMPs under the RS and three robustness tests. For each CMP tuning parameters were adjusted to meet the performance criterion shown in bold for the RS.

		RS-CMPc1a		Rob3-CMPc1a		OM15-CMPc1a		OM16-CMPc1a		RS-CMPe1a		Rob3-CMPe1a		OM15-CMPe1a		OM16-CMPe1a	
P_{2021}/P_{target}	$B^{4\text{-}8}$	1.67	(0.32; 3.94)	0.54	(0.20; 1.00)	1.40	(0.25; 4.76)	1.62	(0.31; 5.83)	1.66	(0.36; 3.93)	0.62	(0.24; 1.08)	1.46	(0.28; 4.73)	1.68	(0.32; 5.81)
	B^{sp}	3.39	(0.34; 9.32)	0.56	(0.20; 1.13)	2.57	(0.41; 8.00)	3.18	(0.60; 9.79)	3.43	(0.54; 9.34)	0.71	(0.24; 1.32)	2.69	(0.48; 7.87)	3.17	(0.62; 9.67)
P_{2016}/P_{2000}	$B^{4\text{-}8}$	5.33	(1.65; 10.53)	1.22	(0.58; 2.73)	2.84	(1.13; 7.59)	2.51	(1.10; 7.30)	5.36	(1.72; 10.54)	1.23	(0.58; 2.76)	2.87	(1.14; 7.63)	2.52	(1.10; 7.33)
	B^{sp}	6.93	(2.15; 13.86)	1.75	(0.77; 6.02)	3.92	(1.54; 11.90)	3.71	(1.73; 11.17)	7.02	(2.24; 14.06)	1.80	(0.78; 6.07)	3.95	(1.60; 12.00)	3.75	(1.74; 11.21)
P_{2021}/P_{2000}	$B^{4\text{-}8}$	6.63	(1.37; 14.64)	2.33	(0.85; 4.28)	3.80	(0.67; 12.90)	3.38	(0.64; 12.19)	6.66	(1.56; 14.49)	2.70	(1.06; 4.66)	3.97	(0.77; 12.81)	3.50	(0.66; 12.14)
	B^{sp}	17.24	(1.82; 38.60)	2.99	(1.03; 5.90)	8.57	(1.38; 26.70)	8.19	(1.55; 25.25)	17.49	(2.88; 38.84)	3.74	(1.26; 6.98)	8.96	(1.59; 26.26)	8.17	(1.60; 24.96)
P_{2031}/P_{2000}	$B^{4\text{-}8}$	6.06	(0.68; 15.50)	6.05	(0.49; 14.87)	3.75	(0.62; 14.20)	3.66	(0.60; 14.51)	6.11	(0.87; 15.80)	7.25	(1.85; 16.87)	3.86	(0.70; 14.33)	3.67	(0.68; 14.56)
	B^{sp}	17.52	(0.82; 53.00)	17.02	(0.57; 47.87)	11.20	(0.96; 46.04)	12.25	(1.03; 50.15)	18.67	(1.15; 53.07)	29.34	(7.02; 61.93)	12.23	(1.03; 46.01)	12.72	(1.04; 50.14)
Prob<P_{2000}	$B^{4\text{-}8}$	0.00	(0.00; 0.33)	0.14	(0.00; 0.67)	0.05	(0.00; 0.50)	0.05	(0.00; 0.60)	0.00	(0.00; 0.24)	0.10	(0.00; 0.43)	0.05	(0.00; 0.38)	0.05	(0.00; 0.55)
	B^{sp}	0.00	(0.00; 0.19)	0.00	(0.00; 0.53)	0.00	(0.00; 0.27)	0.05	(0.00; 0.19)	0.00	(0.00; 0.10)	0.00	(0.00; 0.38)	0.00	(0.00; 0.12)	0.05	(0.00; 0.12)
Prob<1.5P_{2000}	$B^{4\text{-}8}$	0.10	(0.00; 0.57)	0.38	(0.00; 1.00)	0.14	(0.00; 0.93)	0.14	(0.00; 0.90)	0.10	(0.00; 0.43)	0.33	(0.00; 0.62)	0.14	(0.00; 0.76)	0.14	(0.00; 0.86)
	B^{sp}	0.05	(0.00; 0.34)	0.14	(0.00; 0.90)	0.10	(0.00; 0.62)	0.10	(0.00; 0.36)	0.05	(0.00; 0.24)	0.14	(0.00; 0.48)	0.05	(0.00; 0.33)	0.10	(0.00; 0.31)
Prob<2.0P_{2000}	$B^{4\text{-}8}$	0.10	(0.00; 0.72)	0.48	(0.00; 1.00)	0.24	(0.02; 1.00)	0.29	(0.05; 1.00)	0.10	(0.00; 0.62)	0.43	(0.00; 0.81)	0.24	(0.02; 0.91)	0.29	(0.05; 1.00)
	B^{sp}	0.10	(0.00; 0.52)	0.31	(0.00; 1.00)	0.14	(0.00; 0.86)	0.14	(0.00; 0.79)	0.10	(0.00; 0.33)	0.29	(0.00; 0.57)	0.14	(0.00; 0.55)	0.14	(0.00; 0.55)
C_{2011}		6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)	6000	(6000; 6000)
C_{2012}		7500	(7500; 7500)	7500	(7500; 7500)	7500	(7500; 7500)	7500	(7500; 7500)	7500	(7500; 7500)	7500	(7500; 7500)	7500	(7500; 7500)	7500	(7500; 7500)
C_{2013}		7959	(7409; 9000)	7902	(7361; 9000)	7923	(7434; 9000)	7972	(7469; 9000)	7663	(7003; 9000)	7624	(6974; 9000)	7648	(7062; 9000)	7707	(7103; 9000)
C_{2014}		8582	(7545; 10800)	8270	(7382; 10800)	8505	(7664; 10800)	8682	(7734; 10800)	8413	(7118; 10800)	8066	(6916; 10800)	8347	(7307; 10800)	8563	(7402; 10800)
C_{2015}		9252	(7628; 12960)	8296	(7355; 12179)	9220	(7800; 12960)	9654	(7946; 12960)	9088	(6913; 12960)	8003	(6480; 12751)	9176	(7231; 12960)	9453	(7465; 12960)
C_{2016}		**10000**	(7776; 14631)	8208	(7359; 12599)	9691	(7841; 15049)	10150	(8231; 15552)	**10000**	(6585; 15092)	7434	(5769; 13027)	9633	(6756; 15552)	10187	(7480; 15552)
C_{2021}		14736	(8077; 20000)	8176	(7380; 11348)	13402	(7915; 20000)	14285	(8902; 20000)	14648	(3816; 20000)	3321	(2014; 10205)	12480	(3706; 20000)	14056	(4394; 20000)
$C_{2011\text{-}2015}$		7877	(7252; 9252)	7616	(7124; 9095)	7844	(7322; 9252)	7933	(7376; 9252)	7759	(6962; 9252)	7452	(6781; 9207)	7734	(7081; 9252)	7858	(7157; 9252)
$C_{2016\text{-}2020}$		11857	(8216; 16410)	8200	(7446; 11031)	11224	(8369; 15667)	12028	(8794; 17385)	11913	(5769; 16998)	5913	(4075; 10861)	11029	(6185; 16523)	12185	(6903; 18061)
$C_{2011\text{-}2020}$		9870	(7881; 12565)	7920	(7315; 9828)	9504	(7963; 12285)	9897	(8266; 13175)	9808	(6620; 12764)	6664	(5517; 9769)	9334	(6821; 12654)	9917	(7205; 13459)
$C_{2021\text{-}2030}$		17566	(8366; 20000)	10329	(7606; 14531)	16393	(8129; 20000)	17062	(8787; 20000)	17572	(3216; 20000)	3770	(1205; 11190)	15666	(2579; 20000)	16873	(4045; 20000)
$AAV_{2011\text{-}2020}$		15.2	(9.4; 19.5)	10.1	(7.6; 17.4)	14.4	(9.7; 20.0)	15.4	(10.5; 19.9)	16.6	(12.4; 20.1)	16.0	(12.9; 21.1)	16.3	(11.7; 19.9)	16.8	(12.4; 20.0)
$AAV_{2012\text{-}2020}$		12.1	(5.7; 16.9)	6.5	(3.6; 14.6)	11.2	(6.0; 17.5)	12.4	(6.9; 17.3)	13.7	(9.0; 17.6)	13.0	(9.5; 18.7)	13.4	(8.2; 17.4)	13.9	(9.0; 17.4)
$AAV_{2021\text{-}2030}$		8.1	(0.0; 14.6)	8.7	(1.9; 13.9)	8.5	(0.9; 15.3)	8.0	(0.1; 14.1)	9.9	(0.0; 20.0)	20.0	(16.4; 20.0)	12.8	(0.5; 20.0)	10.4	(0.0; 20.0)

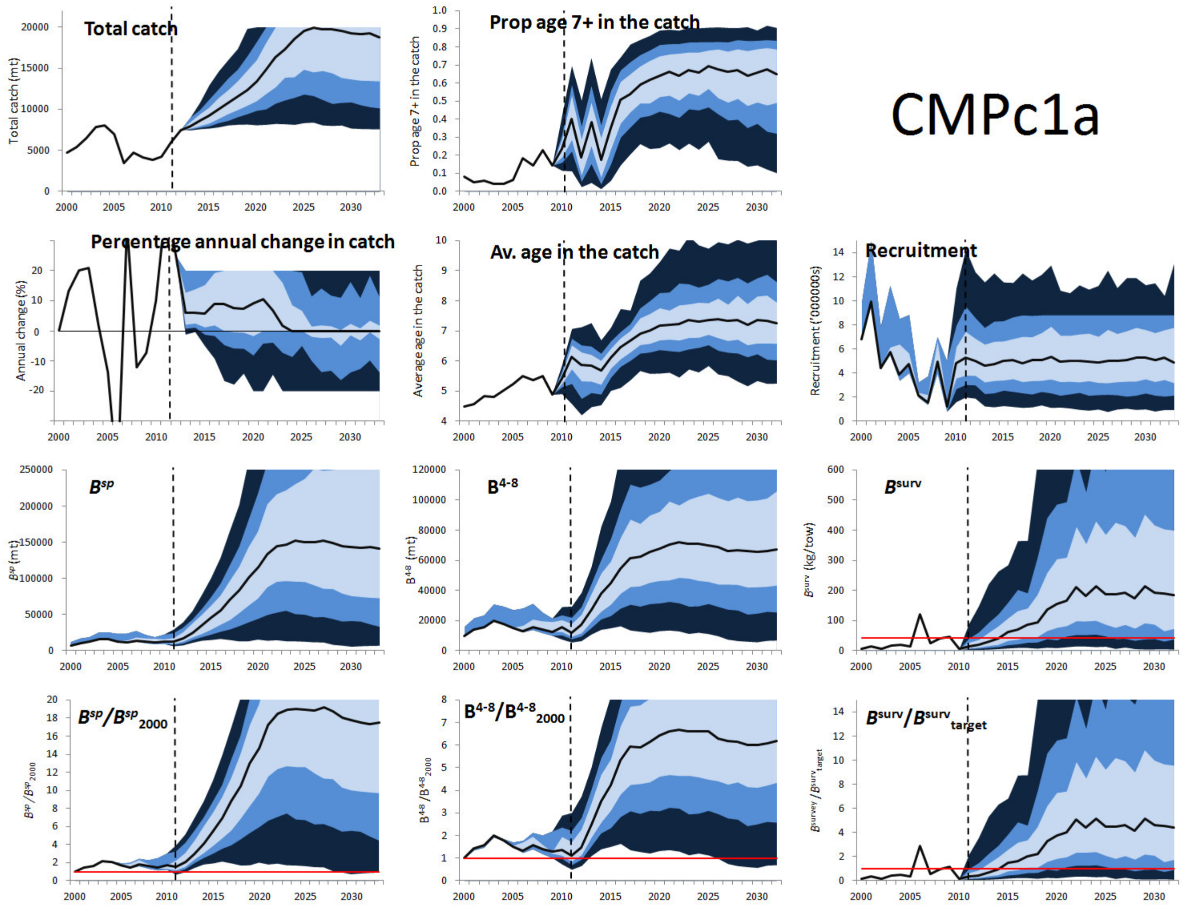

Fig. 1: 95, 75, 50% PI and median for a series of performance statistics for **CMPc1a** under the **RS**.

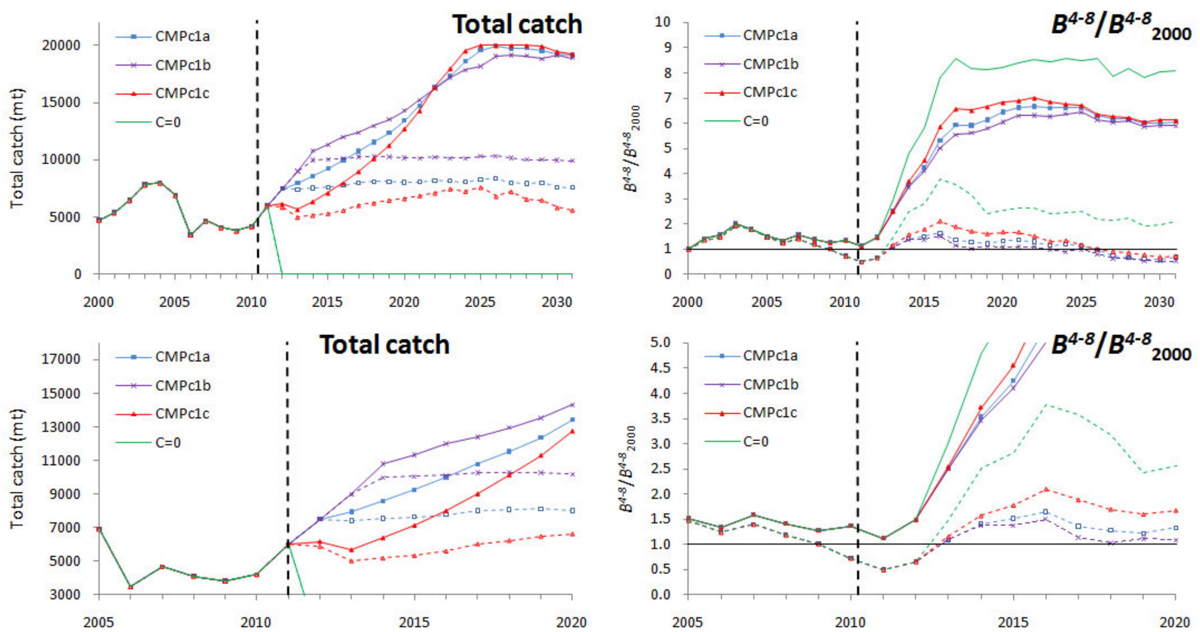

Fig. 2: Median (full lines) and lower 2.5%iles (dashed lines) TAC, spawning biomass and exploitable (ages 4 to 8) biomass (both in terms of 2000 level) for **CMPc1a** (tuned to 10000t 2016 median catch), **CMPc1b** (tuned to 12000t) and **CMPc1c** (tuned to 8000t) under the **RS**. The bottom row repeats the top row, but with different scales for improved discrimination.

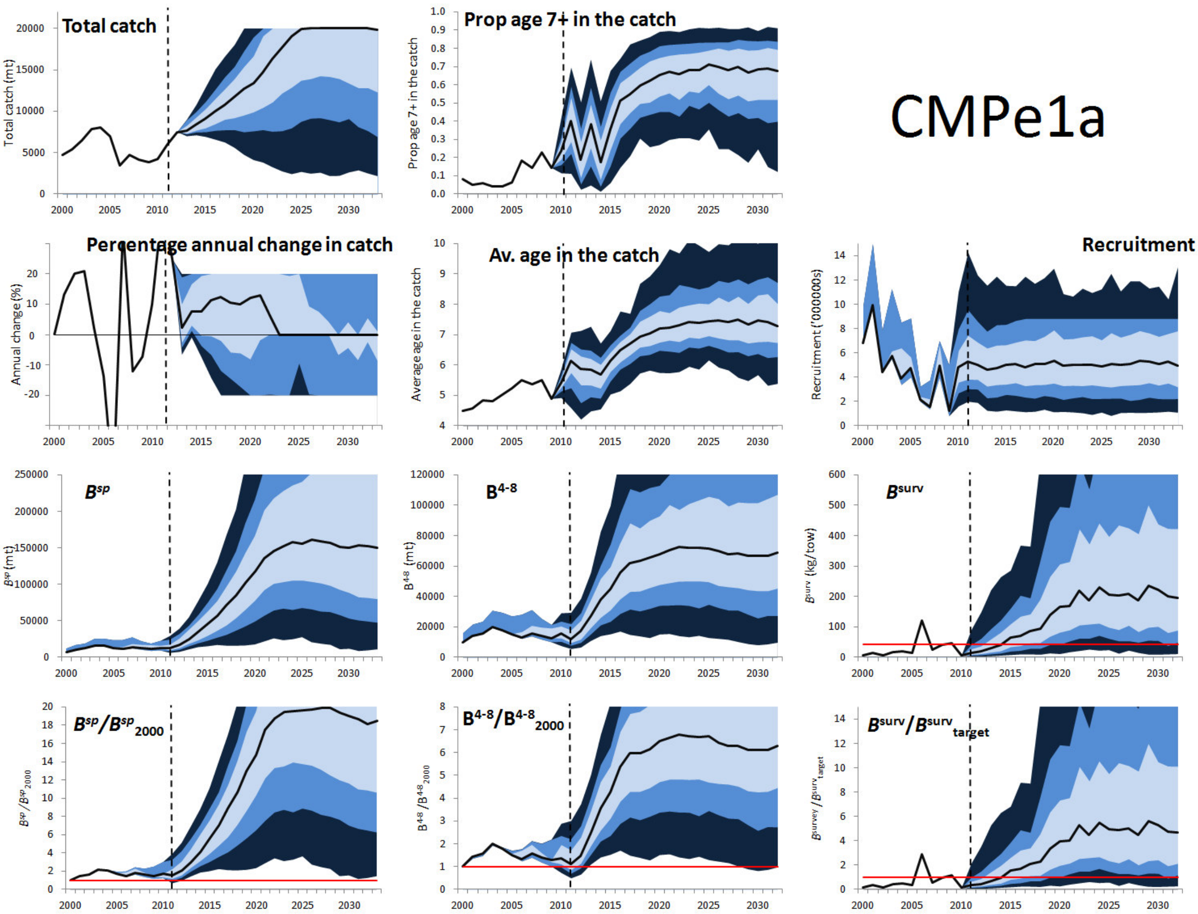

Fig. 3: 95, 75, 50% PI and median for a series of performance statistics for **CMPe1a** under the **RS**.

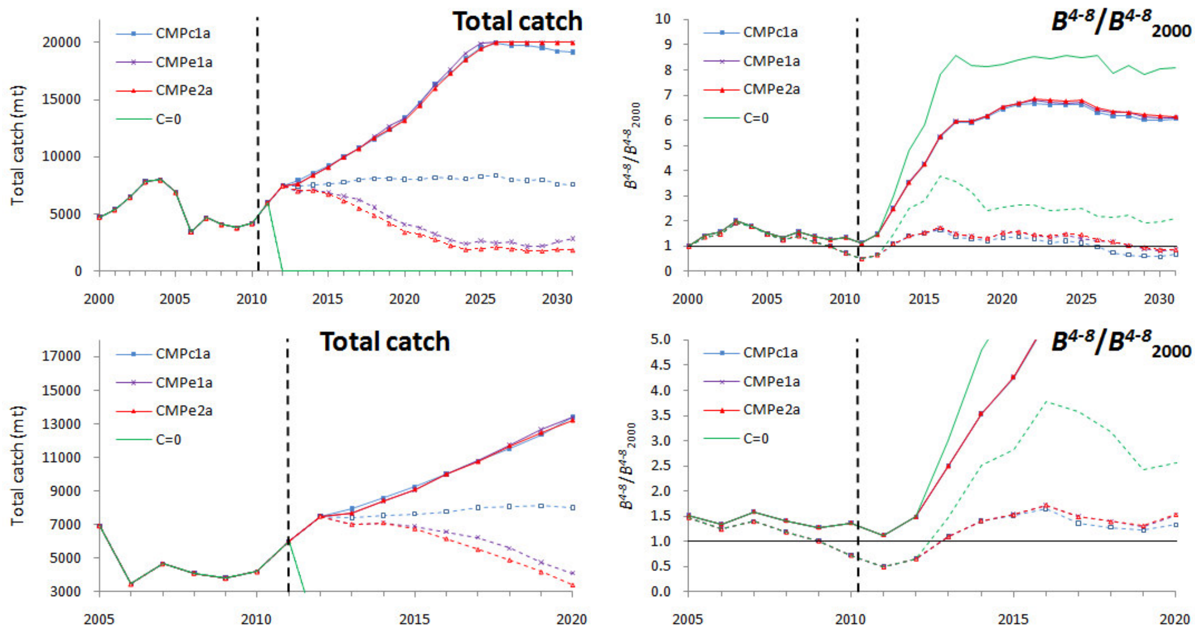

Fig. 4: Median (full lines) and lower 2.5%iles (dashed lines) TAC, spawning biomass and exploitable (ages 4 to 8) biomass (both in terms of 2000 level) for **CMPc1a**, **CMPe1a** and **CMPe2a** under the **RS**. The bottom row repeats the top row, but with different scales for improved discrimination.

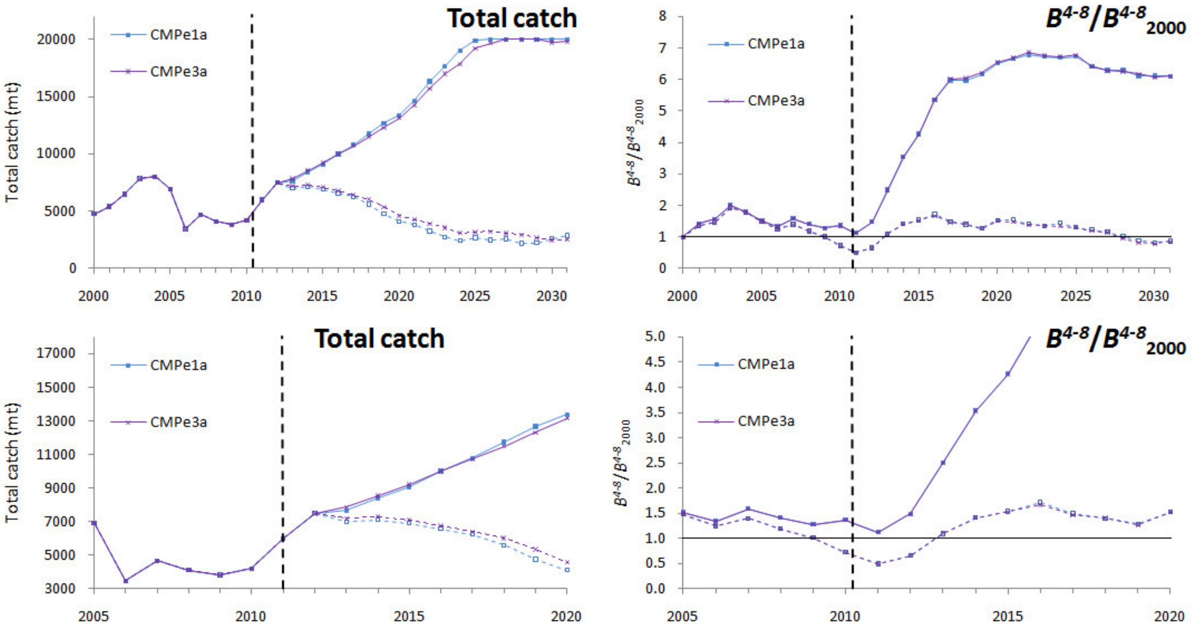

Fig. 5: Median (full lines) and lower 2.5%iles (dashed lines) TAC, spawning biomass and exploitable (ages 4 to 8) biomass (both in terms of 2000 level) for **CMPe1a** (interannual TAC catch constraints of +-20%) and **CMPe3c** (interannual TAC catch constraints of +-15%) under the **RS**. The bottom row repeats the top row, but with different scales for improved discrimination.

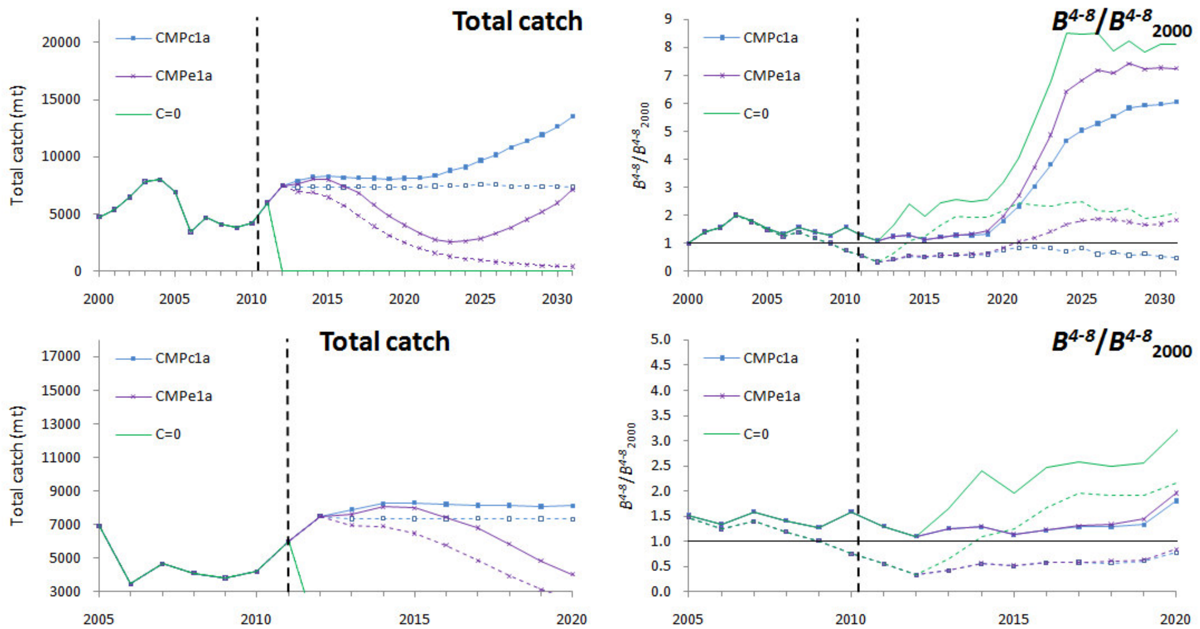

Fig. 6a: Median (full lines) and lower 2.5%iles (dashed lines) TAC, spawning biomass and exploitable (ages 4 to 8) biomass (both in terms of 2000 level) for **CMPc1a**, **CMPe1a** under **Rob3**. The bottom row repeats the top row, but with different scales for improved discrimination.

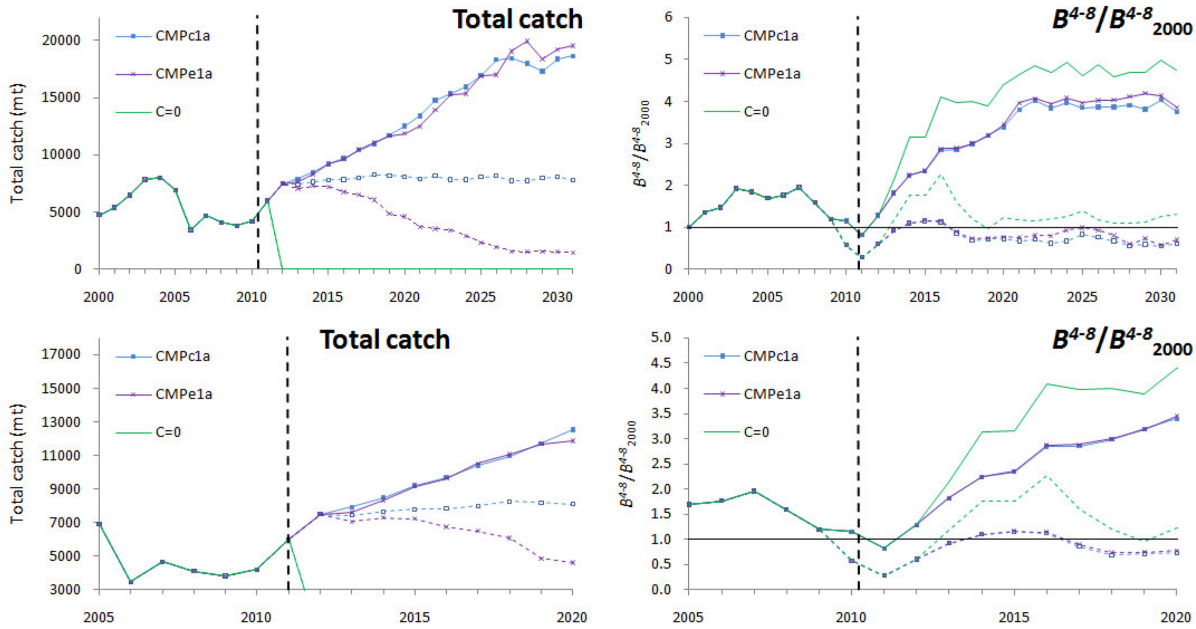

Fig. 6b: Median (full lines) and lower 2.5%iles (dashed lines) TAC, spawning biomass and exploitable (ages 4 to 8) biomass (both in terms of 2000 level) for **CMPc1a**, **CMPe1a** under **OM15**. The bottom row repeats the top row, but with different scales for improved discrimination.

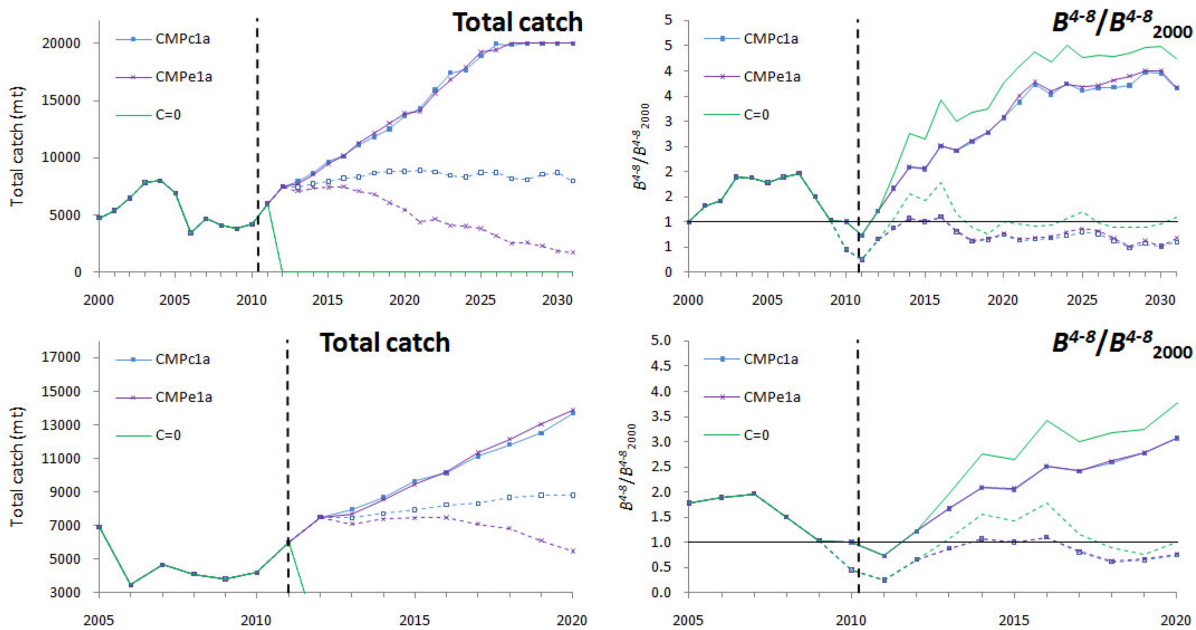

Fig. 6c: Median (full lines) and lower 2.5%iles (dashed lines) TAC, spawning biomass and exploitable (ages 4 to 8) biomass (both in terms of 2000 level) for **CMPc1a**, **CMPe1a** under **OM16**. The bottom row repeats the top row, but with different scales for improved discrimination.

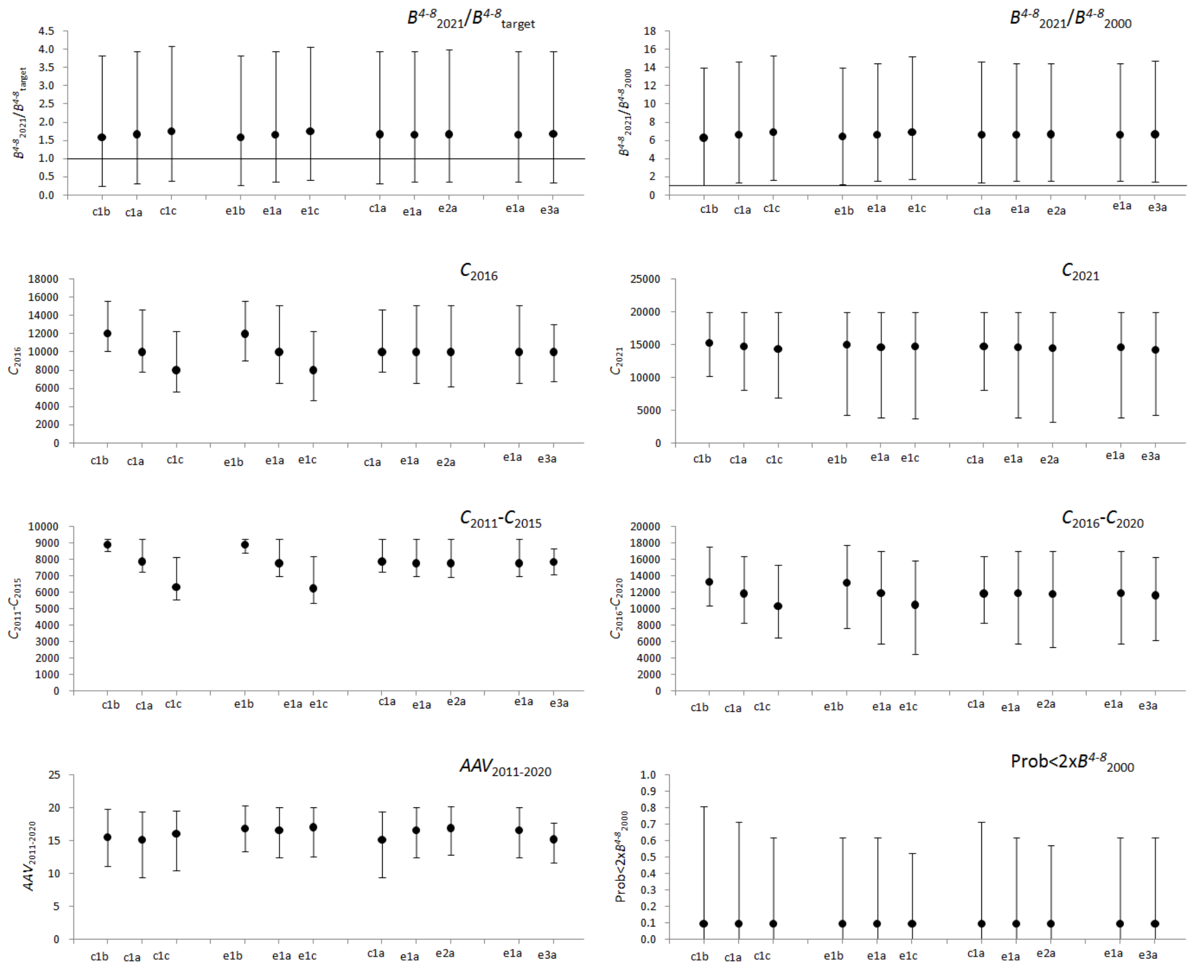

Fig. 7: Medians and 95% PI (error bars) for a series of performance statistic for different CMPs applied to the **RS**.

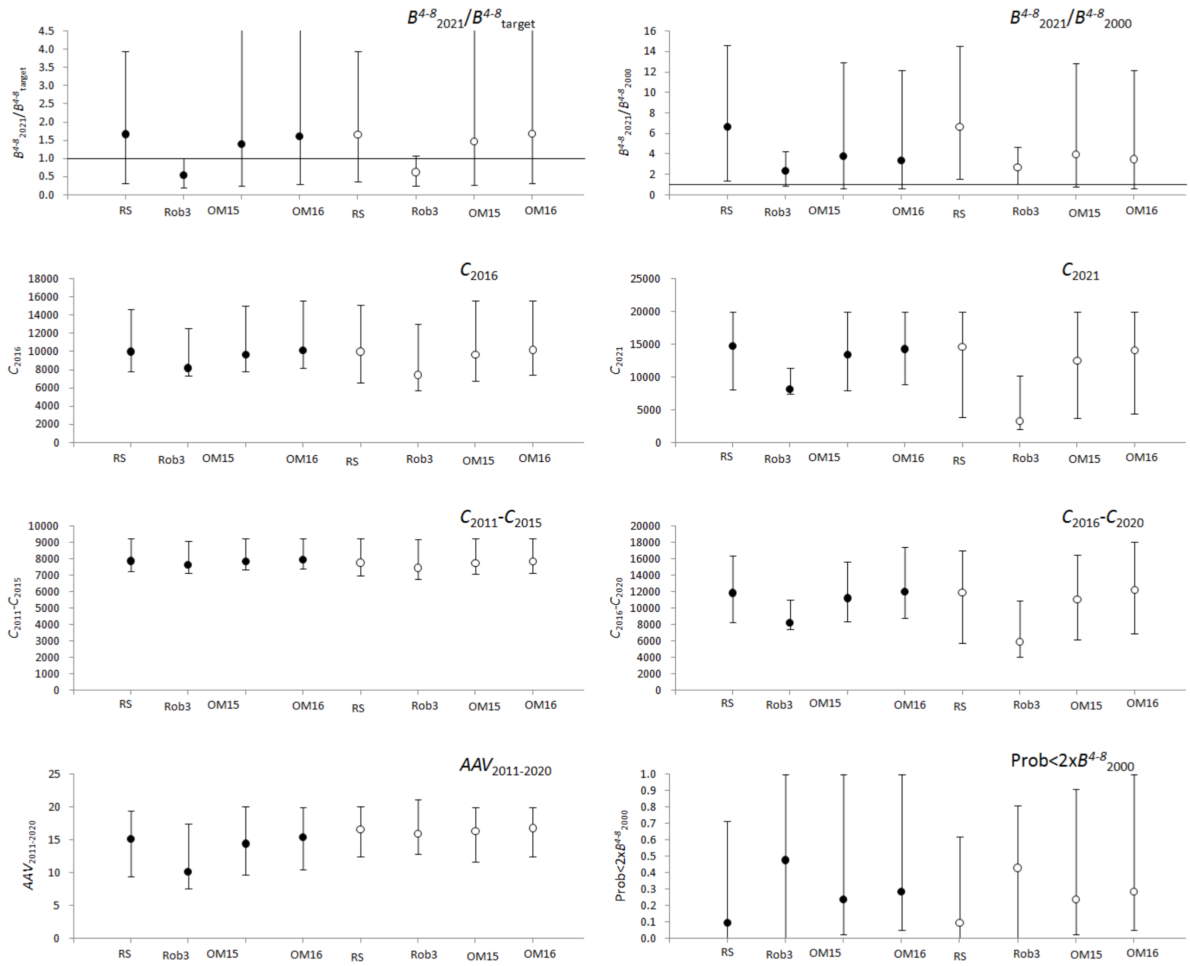

Fig. 8: Medians and 95% PI (error bars) for a series of performance statistic for **CMPc1a** (full circles) and **CMPe1a** (open circles) applied to the RS and a series of robustness tests.

APPENDIX A: Operating Model 16

Fig. A1 compares the trajectories for the proposed VPA Reference Set (RS = OM1, OM2, OM3, OM8, OM13 and OM14) with one further OM, OM16, in which the natural mortality for ages 5 and above is set to 0.76 from 1996 onwards.

Table A1 summarises the different OMs and Rob3.

Table A1: Summary of the different OMs and Rob3.

	Included in RS	Caracteristics	Stock-recruitment relationship
OM1	√	RAD1 (Rademeyer and Butterworth, 2010): no bias correction, *M* =0.2, including 2010 survey estimate	based on last 10 reliable years (1999-2008)
OM2	√	Stone (Stone, 2010): with bias correction, *M* =0.2, including 2010 survey estimate	based on last 10 reliable years (1999-2008)
OM3	√	Stone (Stone, 2010): with bias correction, *M* =0.2, excluding 2010 survey estimate;	based on last 10 reliable years (1999-2008)
OM4		Survey abundance: square root	based on last 10 reliable years (1999-2008)
OM5		Survey abundance: power (square)	based on last 10 reliable years (1999-2008)
OM6		Survey abundance: mixture distribution for future	based on last 10 reliable years (1999-2008)
OM7		*M* =0.2 age 6 or less, age 7-13 *M* =0.675 – no change in future	based on last 10 reliable years (1999-2008)
OM8	√	*M* =0.2 for ages 4 or less, *M* =0.579 for ages 5 and 6 and *M*= 0.617 for ages 7 and above - no change in future	based on last 10 reliable years (1999-2008)
OM9		*M* as in OM7 but all back to 0.2 after 5 years	based on last 10 reliable years (1999-2008)
OM10		*M* as in OM8 but all back to 0.2 after 5 years	based on last 10 reliable years (1999-2008)
OM12		Dome–shaped survey	based on last 10 reliable years (1999-2008)
OM13	√	As OM1	based on last five reliable years (2004-2008)
OM14	√	As OM1	Beverton-Holt, fit up to a max value corresponding to the average values for B^{sp} above 20 000t.
OM15		As OM8	based on last five reliable years (2004-2008)
OM16		*M* =0.2 age 6 or less, age 7-13 *M* =0.76 – no change in future	based on last five reliable years (2004-2008)
Rob3		for each OM in the RC	based on last 10 reliable years (1999-2008) but recruitment in the first eight years of projections is assumed to be at the level of the lowest recruitment over the 1999-2008 period

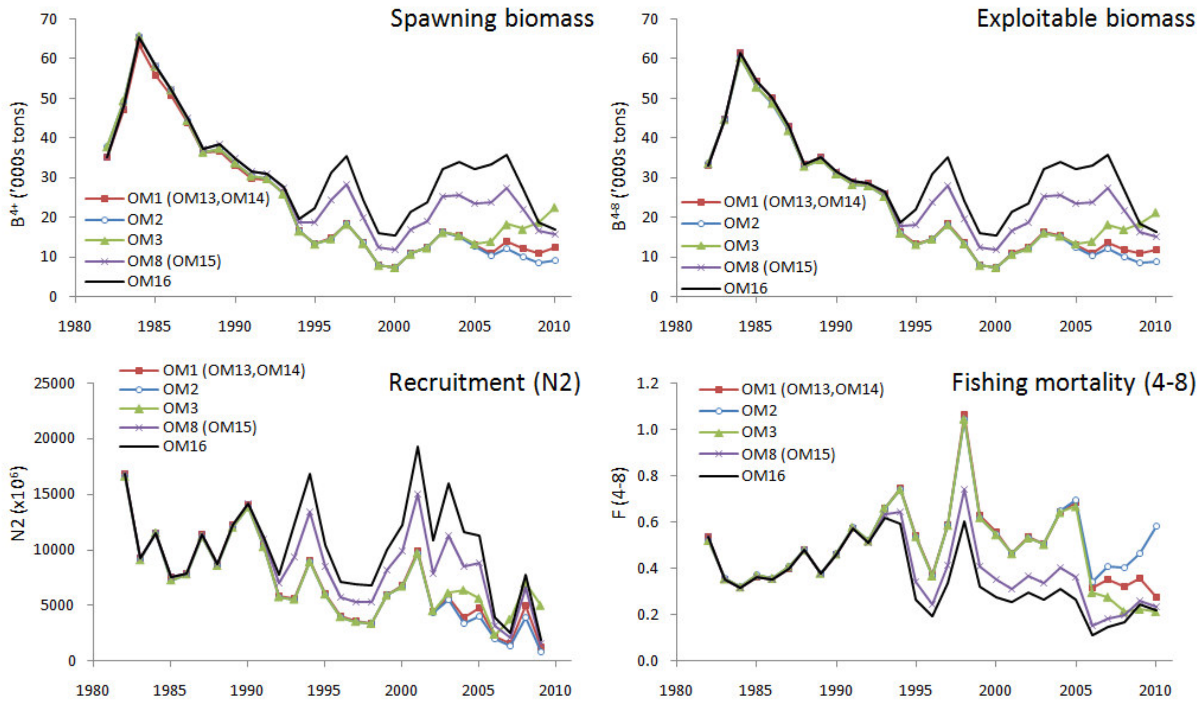

Fig. A1: Time-trajectories of spawning biomass (B4+), exploitable biomass (B4-8), recruitment (N2) and fishing mortality (ages 4-8) for the new RS of OMs.

APPENDIX B: Technical Specifications of Candidate Management Procedures

The target-based Candidate Management Procedures (CMPs) formulae for computing the TAC each year are as follows:

$$C_{y+1} = \left[a + b\left(J_y - 1\right)\right] - pen \qquad \text{(B1)}$$

with

$$pen = \begin{cases} 0 & \text{if } J_y \geq p_y \\ c\left(p_y - J_y\right) & \text{if } J_y < p_y \end{cases} \qquad \text{(B2)}$$

where

C_y is the total TAC recommended for year *y*,

a , b and c are tuning parameters,

p_y is a tuning parameter which increases linearly from 0 in 2012 to 1 in 2022 and is fixed thereafter, and

J_y is a measure of the immediate past level in the survey abundance index relative to a target level as available to use for calculations for year *y*:

$$J_y = \frac{\sum_{y-2}^{y} I_y \Big/ 3}{\sum_{1984}^{1994} I_y \Big/ 11}$$

where I_y is the survey abundance index in year *y*.

Constraints on the interannual TAC change have also been introduced and a cap (upper bound) on the TAC of 20,000 t has been imposed.