Further Candidate Management Procedure Testing for the South African Hake Resource

RA Rademeyer and DS Butterworth

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Introduction

This document provides a further progress report on the development of a revised Operational Management Procedure (OMP) for the South African hake resource. It follows on from Rademeyer and Butterworth (2010), and the discussion thereof recorded in the Aide Memoire of the DWG meeting held on 21-22 July, 2010 (FISHERIES/2010/JULY/SWG-DEM/35).

The specific issues listed for further attention in that Aide Memoire that are addressed here are:

- Implementing the restrictions on the range of options for average TAC – resource risk trade-offs agreed at that meeting.
- Developing an OMP that phases from a “slope only” (CMPa) to a “slope + target” (CMPb) form over time. This was considered in conjunction with requests to attempt smoother median TAC trends in the short-to-medium term and to reduce B_{MSY} overshoot.
- Alternative constraints on the maximum inter-annual TAC change and an upper bound (cap) on the TAC.
- Basing TACs on the average TAC over the past 5 years rather than the previous year’s TAC only.
- Subjecting CMPc1a to the more severe robustness tests.

In addition, results for the suggested updated Reference Case CMP (CMPc1a) are also shown as worm plots and in terms of absolute biomasses as requested.

Issues yet to be addressed are:

- The survey/CPUE discrepancy statistic.
- Specification of a abundance Limit Reference Point and indicating action to be taken if annual routine assessment updates indicate that it is being approached in the updated “Procedures for deviating from OMP output” document for hake.
- Impacts of alternative intensities for surveys.
- Implications of impacts on CPUE through the introduction of MPAs.
- Further robustness tests, including one to be specified by OLRAC.
- Impacts of rollover/under arrangements (if these are deemed likely to be sufficiently large to warrant attention in an OMP revision context).

Results and Discussion

For ease of reference, the full set of CMPs considered in this document are listed in Table 1a, with their control parameter values given in Table 1b.

Restricted range for TAC-risk trade-off options

This was considered in conjunction with the “phasing” option discussed immediately below.

Phasing from “slope only” to “slope + target”

CMPa (“slope only”) led to an undesirably wide 95% probability envelope for future TACs. CMPb (“slope + target”) provided considerable improvement on this score, but this was achieved at the expense of a likely lesser increase and further a substantial probability of an appreciable decrease in the TAC over the next few years. CMPc is an amalgamation of the two approaches which seeks to retain the desirable but exclude the less desirable features of OMPa and OMPb by using the first for the first two years and then phasing linearly to the second over the next three.

Results for this phasing approach are shown in Table 2a and Fig. 1, and indicate that it has eliminated the undesirable features of CMPa’s and CMPb’s behaviour for the Reference Case tuning to a median average TAC over the next decade of 135 000 tons (CMPc1a). This is at the expense of a one year delay in reaching B_{MSY} in median terms (see Table 2b), but extension from 2016 to 2017 in this regard seems acceptable.

Results for the three different tunings of CMPc1 (to median average TACs over the next decade of 127, 135 and 140 thousand tons) are shown in Table 1 and Fig. 2. The failure of the lower 2.5% probability envelope for the *M. paradoxus* spawning biomass for the 140 thousand ton tuning to keep increasing after 2017 under RSa suggests that this option might be queried in terms of satisfying MSC certification conditions.

In developing this phased approach, attempts were also made to adjust control parameters to achieve a smoother increase in the median TAC over time, and to reduce overshoot of B_{MSY} , but without much success (achieving these aims led to problematic performance in other respects). It is suggested that CMPc1 be accepted as the best compromise at this time. The matter of the B_{MSY} overshoot might be better dealt with during the next OMP review four years hence when further data and analyses may have reduced the uncertainties in the assessment in a manner that renders this problem more tractable.

Alternative constraints on the TAC and the extent of its inter-annual changes

Results for CMPc1a for the alternative TAC change constraints and the upper bound (cap) suggested for the TAC at the last DWG meeting are shown in Table 3 and Fig. 3.

These results suggest that the Reference Case restriction of annual TAC downward changes to 10% could be reduced to 5% without compromising resource risk, and furthermore that the imposition of a TAC cap would not provide any further risk benefits.

However, final decisions on whether the 5% downward constraint is acceptable need to await results for the various robustness tests.

Basing TACs on the average TAC over the last 5 years instead of the previous year's TAC only

Results for these two approaches are contrasted in Table 4 and Fig. 4. Use of the average TAC over the last five years may offer some advantages in terms of raising the lower 2.5%ile for future TACs. However this seems more than offset by higher risk (or a reduced average TAC over the next decade), coupled to a median TAC trajectory that first increases and then declines over the next few years.

The more severe robustness tests

The key set of more severe robustness tests have been run under CMPc1a, with the results shown in Table 5. Because this CMP does not perform well in some of these tests, an extra penalty is added if the CPUE falls below a fixed level. Furthermore, the constraint on the maximum inter-annual TAC change is loosened if the CPUE falls too low. The CMPs with these further penalties are referred to as CMPe:

if $J_y^{spp} \geq p^{spp}$

$$C_y^{spp} = w_y C_{y-1}^{*spp}\left[1+\lambda_{up/down}\left(s_y^{spp} - T^{spp}\right)\right] + \left(1-w_y\right)\left[a^{spp} + b^{spp}\left(J_y^{spp} - 1\right)\right]$$

if $J_y^{spp} < p^{spp}$ (1)

$$C_y^{spp} = w_y C_{y-1}^{*spp}\left[1+\lambda_{up/down}\left(s_y^{spp} - T^{spp}\right)\right] + \left(1-w_y\right)\left[a^{spp} + b^{spp}\left(J_y^{spp} - 1\right) - c^{spp}\left(J_y^{spp} - p^{spp}\right)^2\right]$$

where

$$J_y^{spp} = \frac{\sum_{y'=y-4}^{y-2}\left(I_y^{WC\_CPUE,spp} + I_y^{SC\_CPUE,spp}\right)}{\theta^{spp}\sum_{y=2006}^{2008}\left(I_y^{WC\_CPUE,spp} + I_y^{SC\_CPUE,spp}\right)}$$

with

θ^{para}= 1.67 and θ^{cap} = 1.50 (i.e. the target CPUE's are above their 2006-2008 average values by 67% and 50% for *M. paradoxus* and for *M. capensis* respectively) , and

w, a^{spp}, b^{spp} , c^{spp} and p^{spp} are tuning parameters.

$$MaxDecr_y = \begin{cases} x\% & \text{if } J_y > Q_{\min} \\ \text{linear between } x\% \text{ and } 25\% & \text{if } Q_{\min} - 0.2 \leq J_y \leq Q_{\min} \\ 25\% & \text{if } J_y < Q_{\min} - 0.2 \end{cases} \quad (2)$$

where

$$J_y = \frac{\sum_{y'=y-4}^{y-2}\left(I_y^{WC\_CPUE,para} + I_y^{SC\_CPUE,para} + I_y^{WC\_CPUE,cap} + I_y^{SC\_CPUE,cap}\right)}{\sum_{y=2006}^{2008}\left(I_y^{WC\_CPUE,para} + I_y^{SC\_CPUE,para} + I_y^{WC\_CPUE,cap} + I_y^{SC\_CPUE,cap}\right)}$$

and *x* is the value of the maximum downward TAC percentage change allowed under the CMP being modified.

The values of the control parameters p^{spp} and Q_{min} have been chosen to secure a minimal effect on performance under RSa and RSb, through their impacts only coming into play at CPUE values below the range expected under these Reference Sets.

Analyses to date have focussed on test Rob13 (decrease in *K* in the past) which led to the worst performance of all in terms to *M. paradoxus* depletion under CMPc1a. As evident from Tables 5a and c, and from Fig. 5a, the lower 2.5%ile envelope for *M. paradoxus* spawning biomass, which shows continuous decline under CMPc1a, has this decline arrested under CMPe1a, and reversed under CMPe2a. As also evident from these same Tables and Figure, these modifications to CMPc1a hardly alter its performance under RSa as intended.

For the other more severe robustness tests for *M. paradoxus*, changing from CMPc1a to CMPe1a arrests similar *M. paradoxus* envelope declines for Rob17 (start in 1978) and for Rob25 (lower steepness *h*), and also improves performance for Rob37 (future decrease in *K*) (see Fig. 5a). It has little impact on Rob31f (no future surveys and an undetected catchability trend for CPUE in the future) (see Fig. 5b), which is not too surprising as the misleading upward bias in CPUE prevents the adjustment of equation 1 coming into play.

This change from CMPc1a to CMPe1a also secures some improvement in risk-related statistics for *M. capensis* for more severe robustness tests related to RSb (see Table 5b and Fig. 5c).

Summary at this stage

We suggest first that CMPc1a is a clear improvement on CMPa1a and CMPb1a and for the moment should certainly replace CMPa1a as the reference case CMP. Further performance statistics plots for CMPc1a are shown in Fig. 6.

To reduce the number of options for future testing, it is necessary to debate and agree on some further possible modifications to CMPc1a to provide the reference case for such testing. We suggest the following:

- Regarding TAC and associated variability constraints, change to a -5%, +10% inter-annual TAC change limitation, and do not impose a cap on the TAC – on the basis of computations **to date,** there does not seem a basis to require more stringent limitations in these regards, but this will need review following further robustness tests.
- Move from CMPc1a to CMPe2a for improved performance in terms of resource risk under the more severe robustness tests – we opt for CMPe2a rather than CMPe1a because although the latter seems able to **stem** resource declines, the more stringent safeguards of

the former seem likely to be better able to **reverse** such declines (a feature that would be likely to engender more favourable reaction when the MSC review take place).

We also suggest that the acceptable range to be considered for median average TAC over the next decade under RSa be reduced from 127 – 140 to 127 – 135 thousand tons, to maintain an increase over time in the lower 2.5% probability envelope for *M. paradoxus* under RSa. The next round of results will be prepared for these two CMP tuning options, as the results for intermediate catch *vs* risk tunings should be readily evident through interpolation.

Reference

Rademeyer RA and Butterworth DS. 2010. Progress on the development of a Revised Operational Management Procedure (OMP) for the South African hake resource. Unpublished report, Marine and Coastal Management, South Africa. MCM/2010/JULY/SWG-DEM/33.

Table 1a: Summary of the CMPs tested. Unless otherwise indicated, the TAC annual change constraint is 10% (both up and down).

CMP	Description
C=119.8	catch = 119 800t, the 2010 TAC
CMP2006	OMP2006
CMPa1a	**Base Case a** (equation I.2, Rademeyer and Butterworth 2010), tuned to average catch of **135 000t** over 2011-2020
CMPa1aJ	As **Base Case a**, but use 5yr average TAC in CMP equation
CMPa1aJ*	As **Base Case a**, but use 5yr average TAC in CMP equation, tuned to same risk as CMPa1a
CMPb1a	**Base Case b** (equation I.5, Rademeyer and Butterworth 2010), tuned to average catch of **135 000t** over 2011-2020
CMPc1a	**Base Case c**, tuned to average catch of **135 000t** over 2011-2020
CMPc1b	**Base Case c**, tuned to **140 000t**
CMPc1c	**Base Case c**, tuned to **127 000t**
CMPc1aJ	As **Base Case c**, but use 5yr average TAC in CMP equation
CMPc1aJ*	As **Base Case c**, but use 5yr average TAC in CMP equation, tuned to same risk as CMPc1a
CMPc2a	As **Base Case c**, with TAC constraint changes of +-5%
CMPc3a	As **Base Case c**, with TAC constraint changes of -5%, +10%
CMPc4a	As **CMPc1a**, with TAC cap of 160 000t
CMPc5a	As **CMPc2a**, with TAC cap of 160 000t
CMPc6a	As **CMPc3a**, with TAC cap of 160 000t
CMPe1a	As **Base Case c**, with extra penalty (equation 1) and loosening of TAC interannual change constraint (equation 2)
CMPe2a	As **Base Case c**, with extra penalty (equation 1) and loosening of TAC interannual change constraint (equation 2)

Table 1b: Tuning parameter values for each CMP presented. For CMPb1a, T^{para} applies up to the year 2020 and then declines linearly to zero in year 2023, while for CMPc/d/e T^{para} applies up to the year 2015 and then declines linearly to zero in year 2018.

CMP	$\square_{up}$	$\square_{down}$	T^{para}	T^{cap}	w	a^{para}	a^{cap}	b^{para}	b^{cap}	c^{para}	c^{cap}	p^{para}	p^{cap}	Q_{min}	max TAC	Annual change constraints	
C=119.8																	
CMP2006	0.5-1.1	1.1-2.0	2.40%	0												+10%	-10%
CMPa1a	1.25	1.50	1.74%	0												+10%	-10%
CMPa1aJ	1.25	1.50	0.10%	0												+10%	-10%
CMPa1aJ*	1.25	1.50	4.50%	0												+10%	-10%
CMPb1a	1.25	1.50	1.74%	0	0.5	118.2	95.0	40.0	30.0							+10%	-10%
CMPc1a	1.25	1.50	1.00%	0	1-0.5	105.8	40.0	60.0	20.0							+10%	-10%
CMPc1b	1.25	1.50	1.00%	0	1-0.5	116.0	40.0	60.0	20.0							+10%	-10%
CMPc1c	1.25	1.50	1.00%	0	1-0.5	94.0	35.0	60.0	20.0							+10%	-10%
CMPc1aJ	1.25	1.50	1.00%	0	1-0.5	111.6	40.0	60.0	20.0							+10%	-10%
CMPc1aJ*	1.25	1.50	5.00%	0	1-0.5	105.0	35.0	60.0	20.0							+10%	-10%
CMPc2a	1.25	1.50	1.00%	0	1-0.5	108.3	40.0	60.0	20.0							+5%	-5%
CMPc3a	1.25	1.50	1.00%	0	1-0.5	105.2	40.0	60.0	20.0							+10%	-5%
CMPc4a	1.25	1.50	1.00%	0	1-0.5	105.8	40.0	60.0	20.0						160.0	+10%	-10%
CMPc5a	1.25	1.50	1.00%	0	1-0.5	108.3	40.0	60.0	20.0						160.0	+5%	-5%
CMPc6a	1.25	1.50	1.00%	0	1-0.5	105.2	40.0	60.0	20.0						160.0	+10%	-5%
CMPe1a	1.25	1.50	1.00%	0	1-0.5	105.8	40.0	60.0	20.0	180	20	0.7	0.8	0.75		+10%	-10%*
CMPe2a	1.25	1.50	1.00%	0	1-0.5	105.8	40.0	60.0	20.0	180	20	0.8	1.00	0.75		+10%	-10%*

* can change up to -25% following equation (2)

Table 2a: Projections results (either median or lower 2.5%ile) for a series of performance statistics for different CMPs under the RS. This Table focuses in particular on the process of **phasing over time from CMPa1 to CMPb1 yielding CMPc1**. Here and below results for the three reference CMPs (CMPa1a, CMPb1a and CMPc1a) are bolded.

			C=119.8	OMP2006	CMPa1a	CMPb1a	CMPc1c	CMPc1a	CMPc1b
		RSa							
median	BS	avC: 2011-2020	119.8	127.4	**135.0**	**135.0**	127.0	**135.0**	140.0
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	0.73	0.72	**0.71**	**0.74**	0.73	**0.72**	0.70
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	0.79	0.72	**0.72**	**0.71**	0.78	**0.75**	0.75
median	para	B^{sp}_{2020}/B_{MSY}	1.46	1.30	**1.14**	**1.14**	1.27	**1.12**	1.04
median	cap	B^{sp}_{2020}/B_{MSY}	2.98	2.93	**2.88**	**2.90**	2.92	**2.89**	2.86
median	BS	AAV	0.0	4.2	**4.7**	**4.1**	3.4	**3.4**	3.6
low	BS	lowest TAC (2011-2030)	119.8	88.7	**88.7**	**101.6**	95.6	**104.0**	106.3
		RSb							
median	BS	avC: 2011-2015	119.8	122.0	**127.7**	**129.0**	121.8	**129.8**	134.8
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	0.95	0.95	**0.94**	**0.95**	0.93	**0.93**	0.93
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	0.87	0.88	**0.82**	**0.84**	0.87	**0.82**	0.77
median	para	B^{sp}_{2020}/B_{MSY}	1.03	1.04	**0.94**	**0.96**	1.00	**0.91**	0.84
median	cap	B^{sp}_{2020}/B_{MSY}	0.60	0.60	**0.56**	**0.56**	0.58	**0.55**	0.52
median	BS	AAV	0.0	4.3	**4.4**	**3.7**	3.3	**3.2**	3.3
low	BS	lowest TAC (2011-2030)	119.8	87.1	**90.4**	**100.7**	95.4	**102.7**	106.4

Table 2b: Year in which the *M. paradoxus* spawning biomass is expected (in median terms) to first exceed B_{MSY} for a series of CMPs for RSa. OMP2006* is as applied in 2006 (i.e. to the 2006 RS), while OMP2006 has been run under the current RSa.

	Year *M. paradoxus* biomass > Bmsy
C=119.8	2015
OMP2006*	2024
OMP2006	2016
CMPa1a	2016
CMPb1a	2016
CMPc1c	2016
CMPc1a	2017
CMPc1b	2017

Table 3: Projections results (either median or lower 2.5%ile) for a series of performance statistics for different CMPs with **varying constraints on the annual TAC changes and with or without an upper bound (cap)** of 160 000t on the TAC .

			CMPc1a	CMPc2a	CMPc3a	CMPc4a	CMPc5a	CMPc6a
			no cap on TAC			cap of 160 000t on TAC		
			+-10%	+-5%	+10%,-5%	+-10%	+-5%	+10%,-5%
		RSa						
median	BS	avC: 2011-2020	**135.0**	135.0	135.0	135.0	135.0	135.0
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.72**	0.72	0.72	0.72	0.72	0.72
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.75**	0.74	0.75	0.75	0.74	0.75
median	para	B^{sp}_{2020}/B_{MSY}	**1.12**	1.14	1.13	1.13	1.15	1.13
median	cap	B^{sp}_{2020}/B_{MSY}	**2.89**	2.89	2.89	2.89	2.90	2.89
median	BS	AAV	**3.4**	3.1	3.3	3.2	2.9	3.1
low	BS	lowest TAC (2011-2030)	**104.0**	106.9	106.0	104.0	106.9	106.0
		RSb						
median	BS	avC: 2011-2015	**129.8**	129.8	129.9	129.8	129.8	129.9
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.93**	0.93	0.93	0.93	0.93	0.93
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.82**	0.83	0.82	0.82	0.83	0.82
median	para	B^{sp}_{2020}/B_{MSY}	**0.91**	0.90	0.91	0.91	0.90	0.91
median	cap	B^{sp}_{2020}/B_{MSY}	**0.55**	0.55	0.55	0.55	0.55	0.55
median	BS	AAV	**3.2**	3.0	3.1	2.9	2.7	2.8
low	BS	lowest TAC (2011-2030)	**102.7**	105.6	104.8	102.7	105.6	104.8

Table 4: Projections results (either median or lower 2.5%ile) for a series of performance statistics for different CMPs **using either last year's TAC (CMPa/c1a) or the average of the last 5 year's TAC (CMPa/c1aJ)**in the CMP equation.

				5yr av TAC			5yr av TAC	
			CMPa1a	CMPa1aJ	CMPa1aJ*	CMPc1a	CMPc1aJ	CMPc1aJ*
				tuned to catch	tuned to risk		tuned to catch	tuned to risk
		RSa						
median	BS	avC: 2011-2020	**135.0**	135.0	123.2	**135.0**	135.0	126.4
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.71**	0.68	0.71	**0.72**	0.68	0.72
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.72**	0.77	0.79	**0.75**	0.74	0.75
median	para	B^{sp}_{2020}/B_{MSY}	**1.14**	1.15	1.37	**1.12**	1.15	1.32
median	cap	B^{sp}_{2020}/B_{MSY}	**2.88**	2.89	2.96	**2.89**	2.89	2.94
median	BS	AAV	**4.7**	3.5	3.5	**3.4**	3.1	3.1
low	BS	lowest TAC (2011-2030)	**88.7**	110.5	96.3	**104.0**	112.4	103.6
		RSb						
median	BS	avC: 2011-2015	**127.7**	132.8	121.1	**129.8**	131.3	122.9
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.94**	0.91	0.92	**0.93**	0.91	0.93
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.82**	0.78	0.87	**0.82**	0.79	0.87
median	para	B^{sp}_{2020}/B_{MSY}	**0.94**	0.87	1.03	**0.91**	0.89	1.02
median	cap	B^{sp}_{2020}/B_{MSY}	**0.56**	0.53	0.58	**0.55**	0.54	0.58
median	BS	AAV	**4.4**	3.3	3.3	**3.2**	2.9	3.1
low	BS	lowest TAC (2011-2030)	**90.4**	111.7	100.5	**102.7**	111.0	103.0

Table 5a: Projections results (either median or lower 2.5%ile) for a series of performance statistics for a CMPc1a and CMPe1a for a series of more severe robustness tests related to *M. paradoxus* (Rob5 (True Ricker), Rob13 (decrease in *K* in the past), Rob17 (start in 1978), Rob25 (lower steepness *h*), Rob31f (case of no survey and an undetected catchability trend for CPUE in the future - the surveys are used in the computation of the slope until more than two data points (out of six) are missing for the regression.), Rob35 (undetected catchability trend for CPUE in the future) and Rob37 (future decrease in *K*)) under RSa.

			Based on RS1 only					Based on RSa			
CMPc1a		**RSa**	RS1	Rob5	Rob13	Rob17	Rob25	RSa	Rob31f	Rob35	Rob37
median	BS	avC: 2011-2020	137.0	130.9	102.4	118.1	119.5	135.0	144.7	140.2	134.1
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	0.85	0.71	0.03	0.31	0.27	0.72	0.58	0.65	0.38
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	1.01	0.96	0.16	1.07	1.07	0.75	0.73	0.72	0.34
median	para	B^{sp}_{2020}/B_{MSY}	1.07	0.79	0.34	0.56	0.54	1.12	0.98	1.04	1.37
median	cap	B^{sp}_{2020}/B_{MSY}	2.43	2.00	1.80	2.08	2.07	2.89	2.85	2.86	3.84
median	BS	AAV	3.3	3.2	4.6	4.0	3.4	3.4	3.7	3.7	4.1
low	BS	lowest TAC (2011-2030)	106.5	105.7	34.8	87.4	95.0	104.0	110.8	107.2	79.3
CMPe1a											
median	BS	avC: 2011-2020	136.8	130.2	92.4	114.5	114.5	134.8	144.6	140.1	133.7
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	0.85	0.71	0.22	0.54	0.54	0.73	0.58	0.65	0.45
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	1.01	0.96	1.01	1.07	1.07	0.75	0.73	0.73	0.34
median	para	B^{sp}_{2020}/B_{MSY}	1.07	0.80	0.57	0.57	0.57	1.13	0.98	1.04	1.39
median	cap	B^{sp}_{2020}/B_{MSY}	2.43	2.01	2.04	2.10	2.10	2.89	2.85	2.87	3.84
median	BS	AAV	3.4	3.3	6.0	4.5	4.5	3.5	3.8	3.7	4.7
low	BS	lowest TAC (2011-2030)	105.3	101.6	39.2	75.2	75.2	100.1	109.0	105.2	52.3

Table 5b: Projections results (either median or lower 2.5%ile) for a series of performance statistics for a for a series of more severe robustness tests under RSb (related to *M. capensis*).

			Based on RS11 only				
CMPc1a		**RSb**	RS11	Rob5	Rob13	Rob25	Rob37
median	BS	avC: 2011-2020	130.2	130.5	106.1	113.8	128.7
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	0.93	1.00	0.11	0.78	0.68
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	0.86	0.76	0.86	0.78	0.68
median	para	B^{sp}_{2020}/B_{MSY}	0.90	0.81	0.72	0.67	1.11
median	cap	B^{sp}_{2020}/B_{MSY}	0.58	0.53	2.50	0.47	0.75
median	BS	AAV	3.2	3.2	5.3	3.7	3.2
low	BS	lowest TAC (2011-2030)	103.1	107.8	75.0	85.5	90.3
CMPe1a		**RSb**	RS11	Rob5	Rob13	Rob25	Rob37
median	BS	avC: 2011-2020	129.9	130.5	97.8	110.8	128.4
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	0.93	1.00	0.40	0.83	0.77
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	0.86	0.76	0.95	0.83	0.69
median	para	B^{sp}_{2020}/B_{MSY}	0.91	0.81	0.92	0.69	1.12
median	cap	B^{sp}_{2020}/B_{MSY}	0.59	0.53	2.70	0.49	0.75
median	BS	AAV	3.3	3.2	7.5	4.1	3.6
low	BS	lowest TAC (2011-2030)	100.2	107.8	43.8	71.3	79.6

Table 5c: Projections results (either median or lower 2.5%ile) for a series of performance statistics for CMPc1a, CMPe1a and CMPe2a for RS1 and robustness test Rob13 (decrease in *K* in the past).

			RS1			Rob13		
CMPc1a		**RSa**	CMPc1a	CMPe1a	CMPe2a	CMPc1a	CMPe1a	CMPe2a
median	BS	avC: 2011-2020	137.0	136.8	136.0	102.4	92.4	86.9
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	0.85	0.85	0.85	0.03	0.22	0.32
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	1.01	1.01	1.01	0.16	1.01	1.01
median	para	B^{sp}_{2020}/B_{MSY}	1.07	1.07	1.10	0.34	0.57	0.67
median	cap	B^{sp}_{2020}/B_{MSY}	2.43	2.43	2.44	1.80	2.04	2.11
median	BS	AAV	3.3	3.4	3.6	4.6	6.0	6.9
low	BS	lowest TAC (2011-2030)	106.5	105.3	103.5	34.8	39.2	33.5

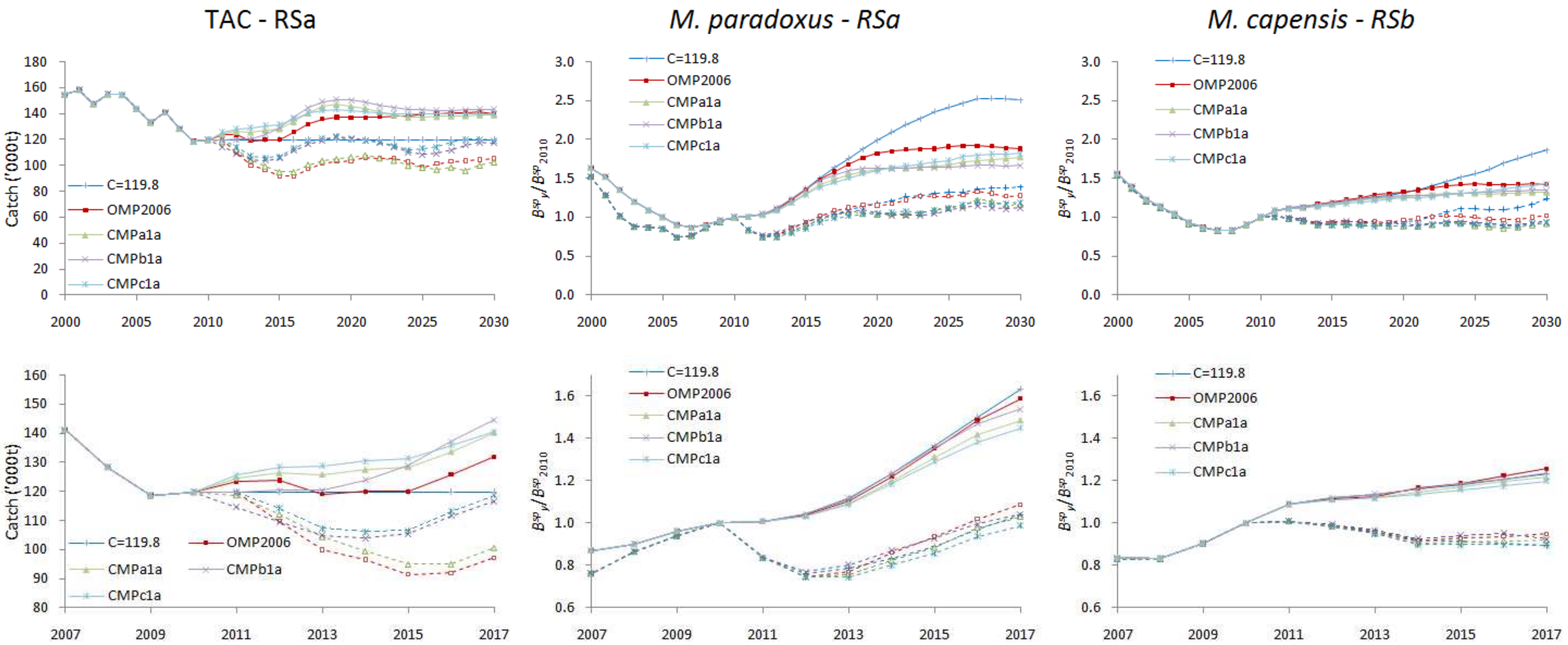

Fig. 1: Median (full lines) and lower 2.5%iles (dashed lines) TAC (RSa) and spawning biomass (in terms of 2010 level) for *M. paradoxus* (RSa) and *M. capensis* (RSb) for a series of CMPs **(constant catch, OMP2006 and three Reference Case CMP, where CMPc involves phasing from CMPa to CMPb)**. Note that all three Reference Case CMPs shown achieve a median averageTAC of 135 thousand tons over the next decade. The second row of plots reproduces the first row but with different scales.

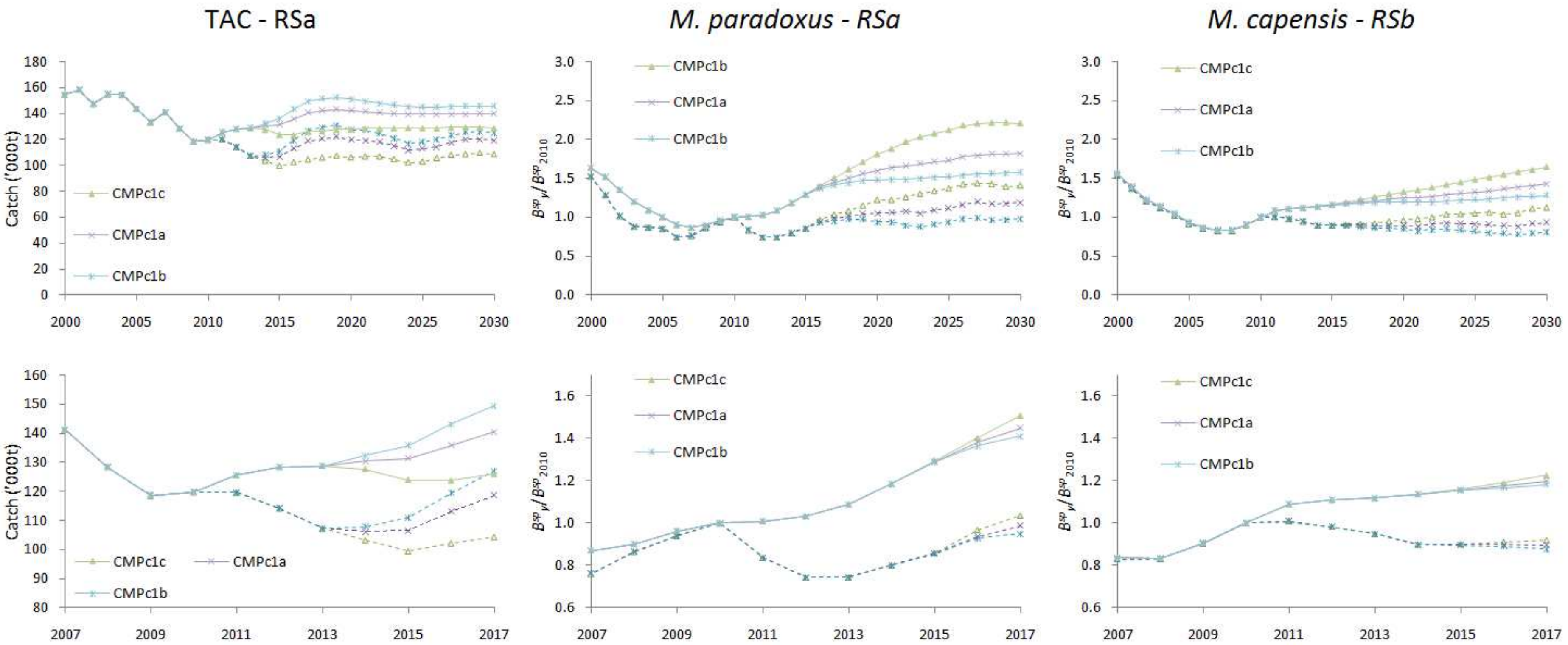

Fig. 2: Median (full lines) and lower 2.5%iles (dashed lines) TAC (RSa) and spawning biomass (in terms of 2010 level) for *M. paradoxus* (RSa) and *M. capensis* (RSb) for a series of CMP**c1 variants tuned to achieve different average TACs over the next decade**. Specifically CMPc1c/a/b achieve median average TACs over 2011-2020 of 127/135/140 thousand tons. The second row of plots reproduces the first row but with different scales.

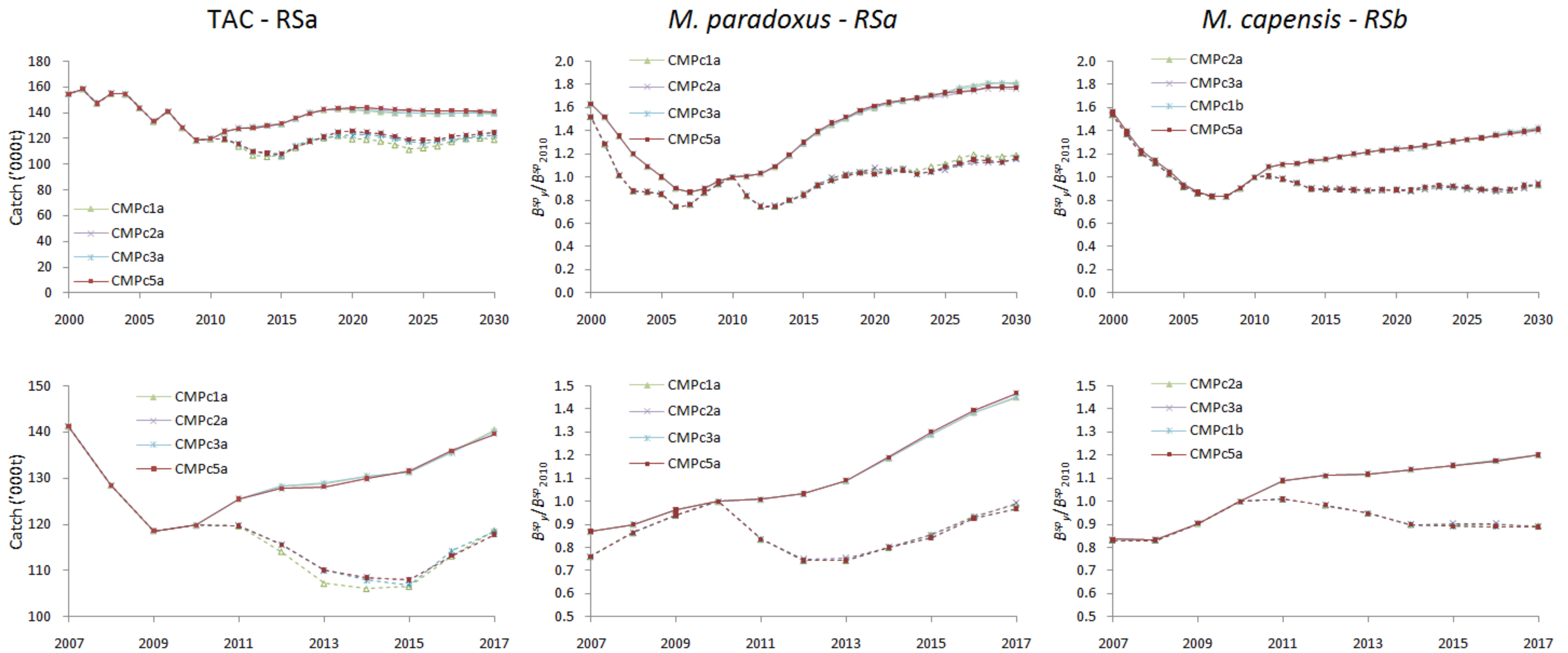

Fig. 3: Median (full lines) and lower 2.5%iles (dashed lines) TAC (RSa) and spawning biomass (in terms of 2010 level) for *M. paradoxus* (RSa) and *M. capensis* (RSb) for a series of CMPs **with different annual TAC change constraints and with/without a cap of 160 000t on the TAC**. Specifically CMPc1/2/3/a reflect constraints of +-10%, +-5% and +10, -5% respectively with no cap on the TAC, while CMPc5a reflects constraints of +-5% with a cap on the TAC. The second row of plots reproduces the first row but with different scales.

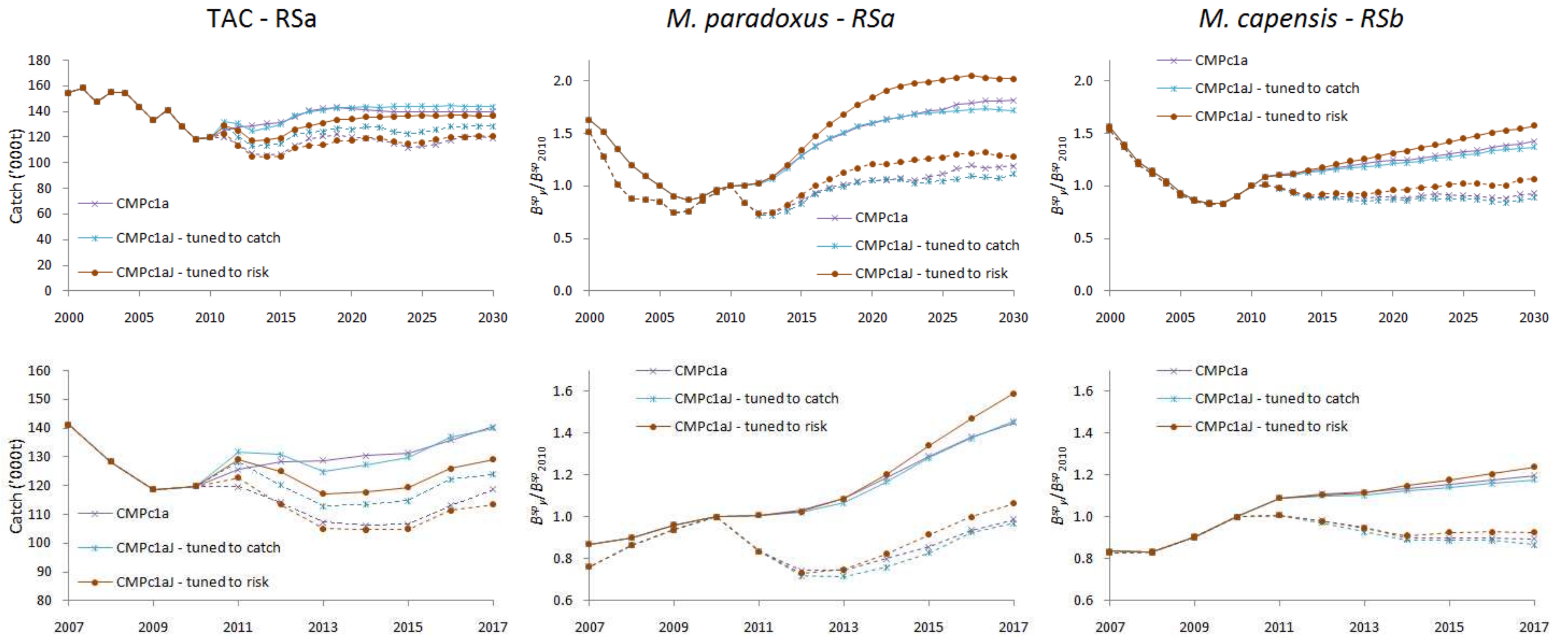

Fig. 4: Median (full lines) and lower 2.5%iles (dashed lines) TAC (RSa) and spawning biomass (in terms of 2010 level) for *M. paradoxus* (RSa) and *M. capensis* (RSb) for a series of CMPs that **contrast TAC setting based on the previous year's TAC (CMPc1a) to that based on the average of the last five years' TACs (CMPc1aJ)**. The second row of plots reproduces the first row but with different scales.

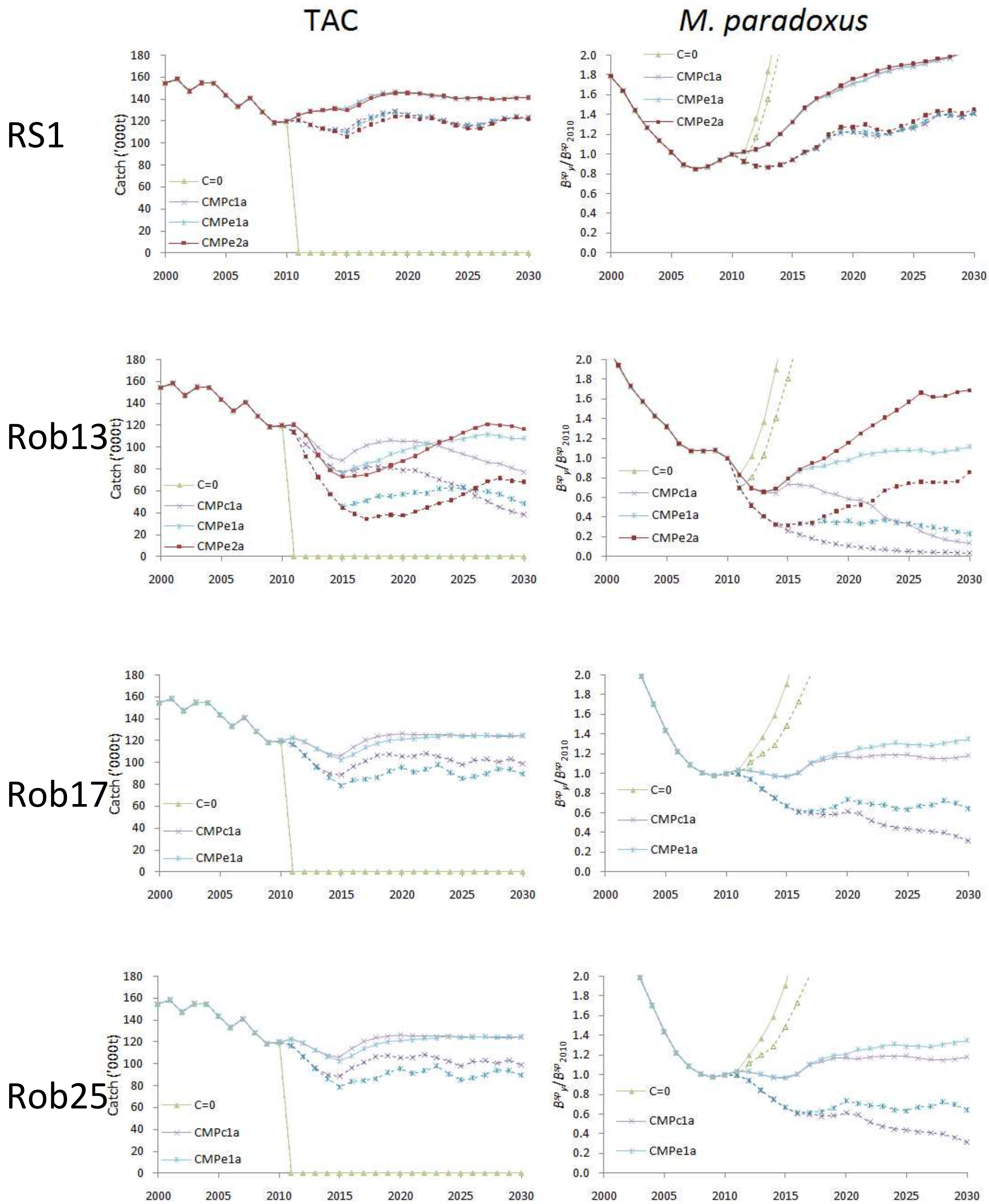

Fig. 5a: Median (full lines) and lower 2.5%iles (dashed lines) TAC and spawning biomass (in terms of 2010 level) for *M. paradoxus* for a series of CMPs and **more severe robustness tests** based on RS1 (Rob5 (True Ricker), Rob13 (decrease in *K* in the past), Rob17 (start in 1978) and Rob25 (lower steepness *h*)).

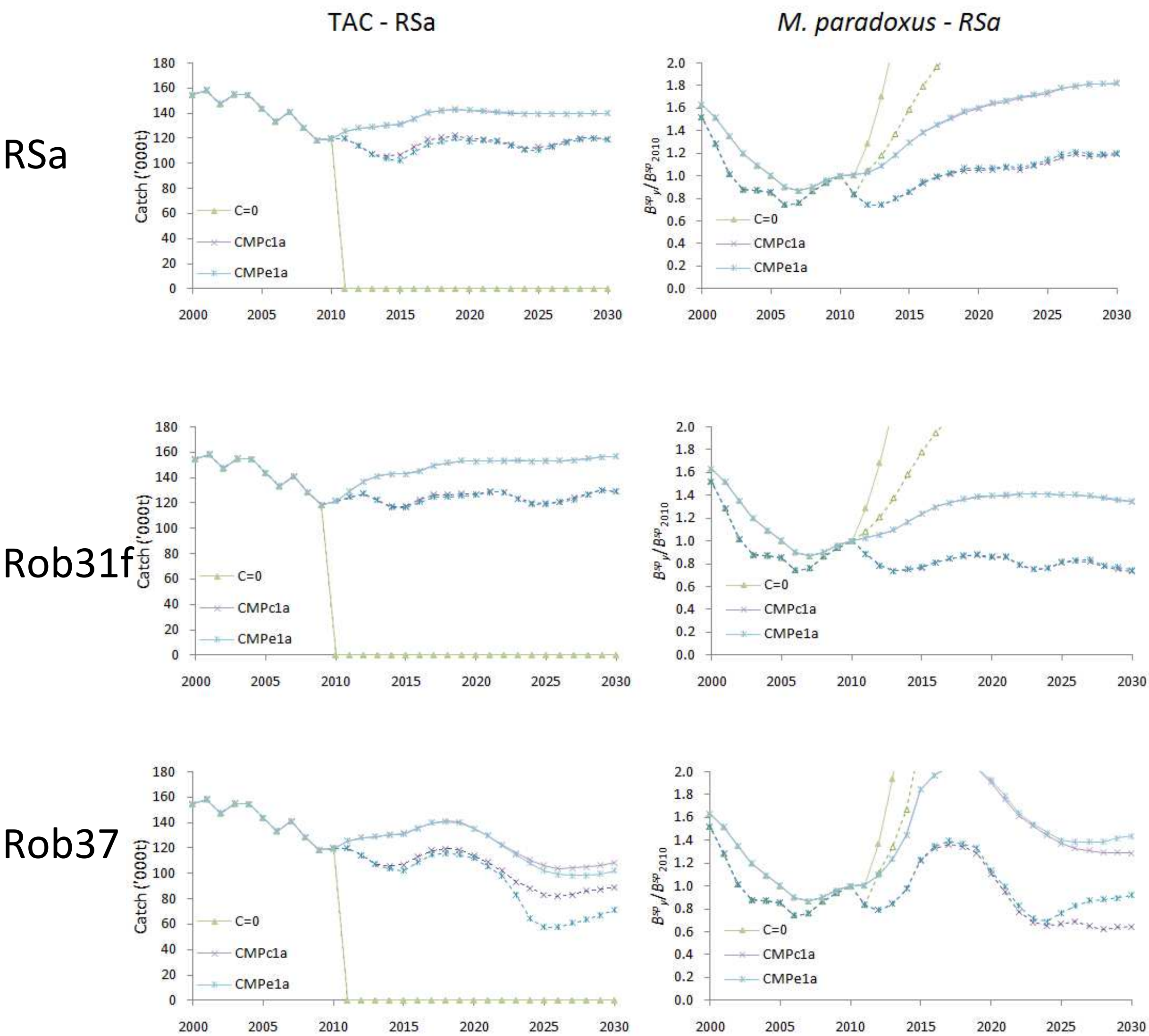

Fig. 5b: Median (full lines) and lower 2.5%iles (dashed lines) TAC and spawning biomass (in terms of 2010 level) for *M. paradoxus* for a series of CMPs and **more severe robustness tests** based on RSa (Rob31f (case of no survey and an undetected catchability trend for CPUE in the future), Rob35 (undetected catchability trend for CPUE in the future) and Rob37 (future decrease in *K*)).

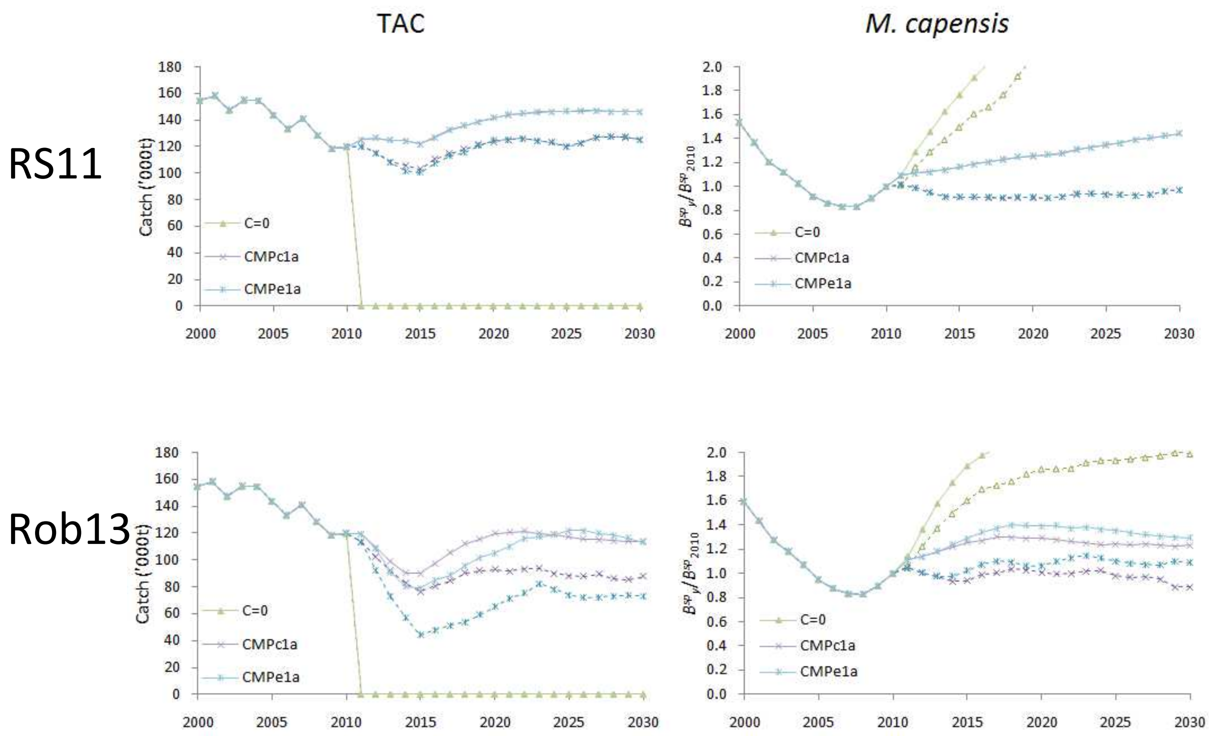

Fig. 5c: Median (full lines) and lower 2.5%iles (dashed lines) TAC and spawning biomass (in terms of 2010 level) for *M. capensis* for a series of CMPs for RS11 and **severe robustness test** Rob13 based on RS11(decrease in *K* in the past).

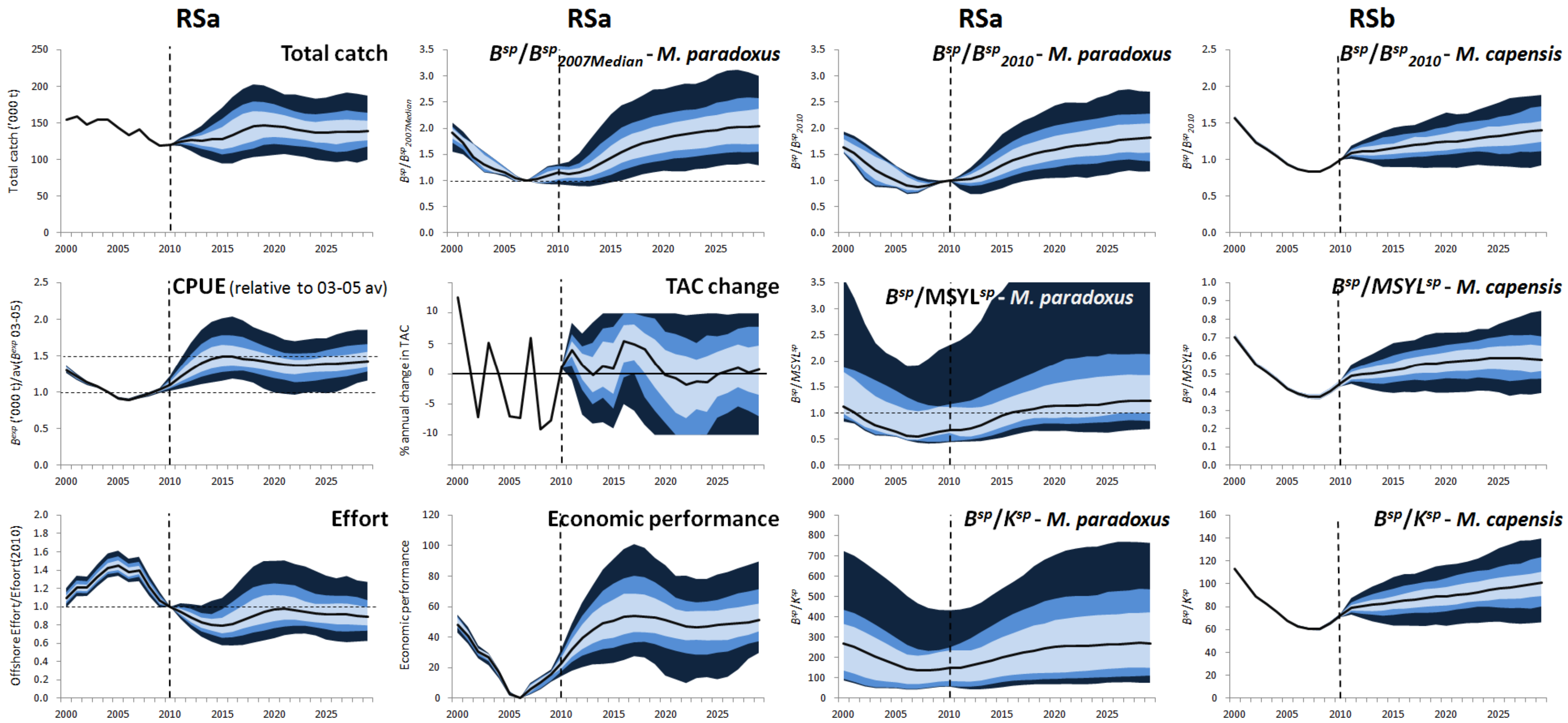

Fig. 6a: 95, 75, 50% PI and median for a series of performance statistics for **CMPc1a**.

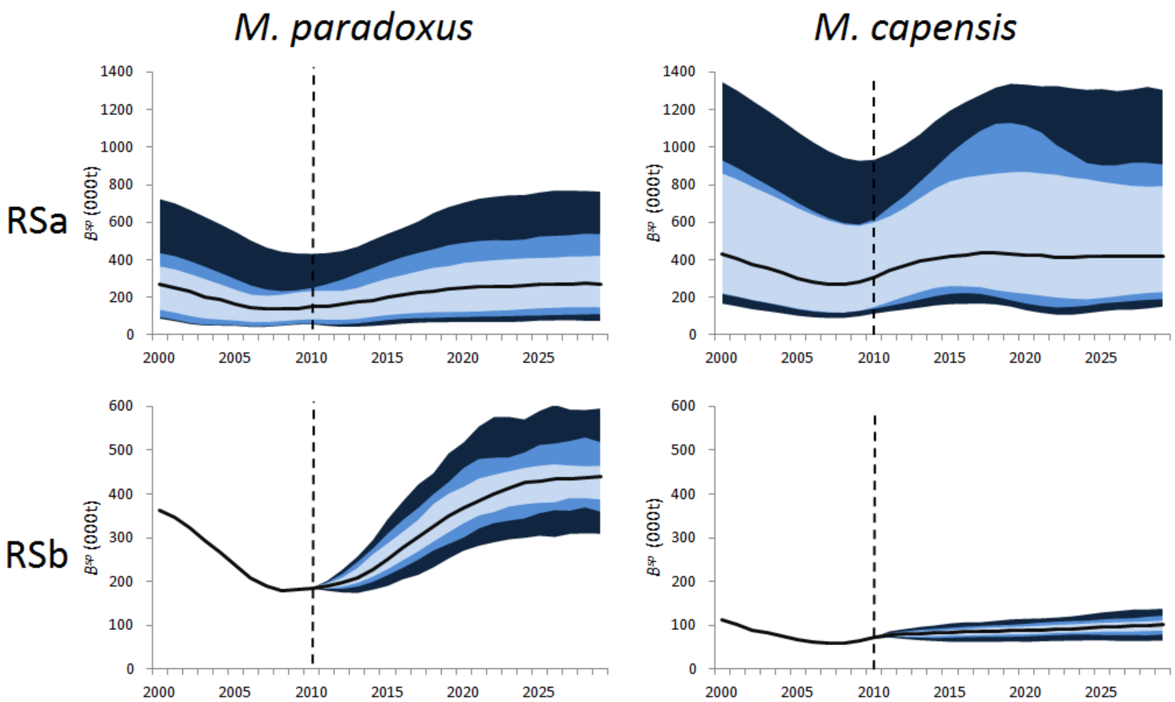

Fig. 6b: 95, 75, 50% PI and median for *M. paradoxus* and *M. capensis* spawning biomass in absolute term for **CMPc1a**.

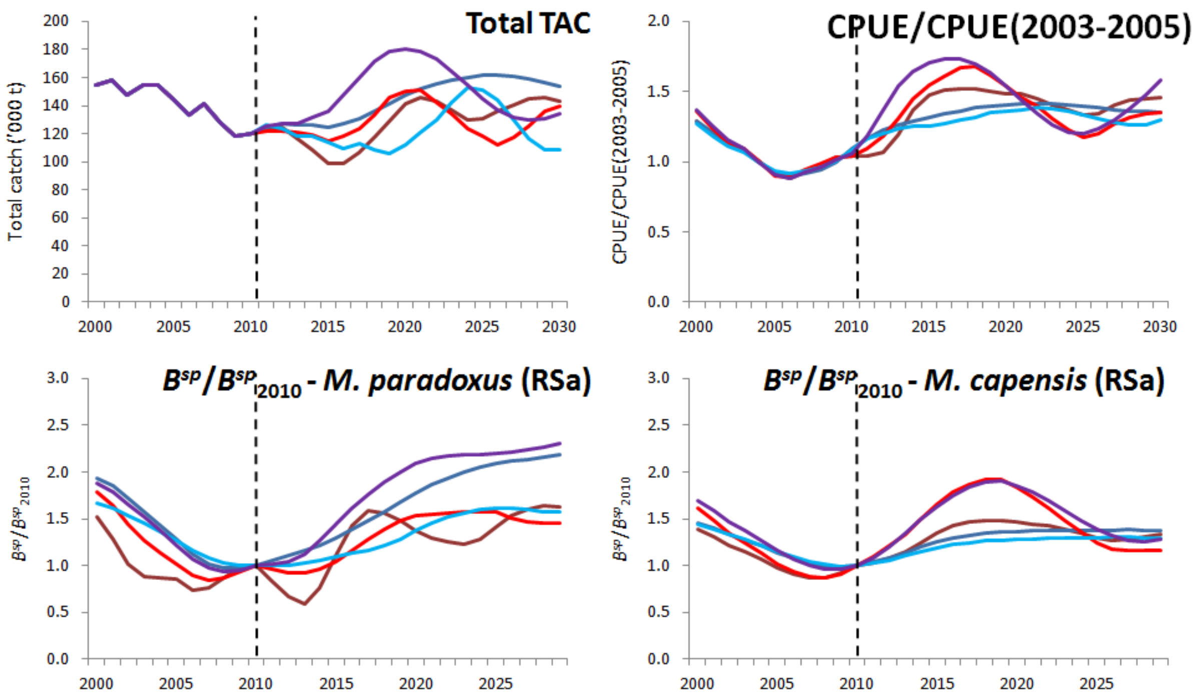

Fig. 6c: Worm plots of TAC, CPUE and B^{sp}/B^{sp}_{2010} for *M. paradoxus* and *M. capensis* under RSa