Progress on the Development of a Revised Operational Management Procedure (OMP) for the South African Hake Resource

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July 2010

Abstract

Initial results of the application of various Candidate Management Procedures to the agreed Reference Set of trials are presented. Provisional operational objectives have been used to limit the range of options considered, where these objectives take account of MSC certification requirements. A series of questions is posed for answers to guide the finalisation of the OMP revision.

Background

Any OMP revision exercise has to be closely linked to the objectives for the management of the resource. The objectives for the previous hake OMP adopted in 2006 were:

a) Improve catch rates in the short term, considered operationally as increase the expected CPUE for the offshore trawlers by 50% over its average for the 2003-2005 period by 2016.
b) Limit inter-annual TAC variations, with an operational implementation that these not exceed 10% p.a.
c) Recover the *M. paradoxus* resource, taken operationally to mean to reach its MSYL (B^{sp}_{MSY}) by 2027.
d) Have a low probability of further decline in the *M. paradoxus* resource, taken operationally to mean that the lower 2.5%-ile of the *M. paradoxus* spawning biomass should be above the corresponding 2007 level in 2027.

Note that projected probability distributions for associated performance statistics were evaluated over the 2006 Reference Set RS of Operating Models (OMs).

These objectives need to be reviewed and possibly amended, with performance statistics evaluated for the updated Reference Set of OMs, and also for associated robustness tests. This Reference Set was finally agreed at the May meeting of the DWG, and consists of two parts: the primary RSa of ten OMs for which, even though there has been a decline over recent years, the current status of *M. capensis* remains above MSYL in nearly all cases and is not a concern, and RSb which comprises two OMs for which *M. capensis* is well below MSYL.

In revising these earlier objectives, some of the requirements for continued MSC certification also need to be taken into account:

a) In the re-certification exercise just completed, the certification team emphasised the importance that recovery targets not be extended in time (MSC officials have also expressed concern about the length of the 20-year period set for the recovery of *M. paradoxus* to its MSYL in 2006).

b) A condition is attached to the re-certification awarded earlier this year:

"*Condition 7. Appropriate limit and target reference points for M. paradoxus based on stock biomass and/or fishing mortality*

Action required: The limit reference point is the lower 95% confidence interval of the recovery trajectory in the 2006 OMP meaning the limit reference point is not a constant, but a level that will vary over time. At its lowest point, a *M. paradoxus* spawning biomass might not be low enough to trigger management override of the default OMP response, risking recruitment failure.

SG 80 states: 'Limit and target/precautionary reference points should be justified based on stock biology (e.g. a stock-recruitment relationship) and measurable given data and assessment limitations. Reference points may be probability based'.

It is anticipated that the OMP will undergo revision during 2010. This condition could be addressed within this planning process and thereby formally linked to the harvest control rules (OMP) that will be used to set TACs for the period of certification. The OMP revision process in 2010 should explicitly consider limit control rules with that planning evaluation.

Timescale: Appropriate limit and target reference points enacted within one year of certification."

c) Cognisance needs to be taken of the continuing development of MSC conditions for certification. In future re-certification processes these may well include requirements along the lines of:

i) a high probability of being above the abundance where recruitment success may be impaired (essentially synonymous with the limit reference point concept), and

ii) where the resource is below its MSYL, recovery to MSYL should be targeted for a multiple (possibly a number in the range [2; 3]) of the time it would take to reach that level in the absence of any catches.

Basic approach

Operational Objectives Utilised in Initial Selections

The following were used for guidance in developing candidates Management Procedures (CMPs) to replace OMP-2006 (though, of course, one option is to retain OMP-2006 for a further four years).

i) Recovery of *M. paradoxus* to MSYL should not be slower than for OMP-2006.

ii) The lower 2.5%ile for B_{lowest} (the lowest value of B^{sp} in the future trajectory from 2010 under a CMP) should not fall below corresponding value for 2007 – since statistics are reported relative to 2010, and the lowest value for B_{2007}/B_{2010} across RSa is 0.76, CMPs were sought that kept this statistic, termed "low para", above 0.76 for RSa (note that this was argued as the effective limit reference point in the MSC re-certification).

iii) For RSb were the status of *M. capensis* is poor, the corresponding statistic termed "low cap" should drop as little as possible below 1.

iv) The lower 2.5%ile for TAC_{lowest} should be kept as high as possible for socio-economic reasons.

To reduce the volume of output statistics presented for multiple comparisons, a selected set of statistics has been chosen for inclusion in Tables that follow, taking cognisance of the operational objectives above.

CMPs and tuning

To illustrate the medium-term catch *vs* recovery trade-off, three tunings were selected corresponding to median average annual TACs over the next 10 years of 125, 135 and 145 thousand tons. Note that continued application of the existing OMP-2006 would achieve a median average annual catch of 127.4 thousand tons over the next decade (see **Table 2a**)

There are two Reference Case CMPs: CMPa1a based on recent trends in abundance indices only, and CMPb1a which includes also adjustments based on target CPUE values. For the first, alternative tunings for different average TACs over the next 10 years are achieved by varying the control parameter *T* for *M. paradoxus*, while for the second the control parameter *a* is varied (see **Table 1a and 1b** which list the CMPs for which results are reported and the values of their control parameters, and Appendix I which gives the formulaic specifications for these CMPs).

Summary of factors investigated to date

Steps 1 and 2: Compare simpler CMPs based abundance index trends to scenarios with C=0 (future catches set to zero) and continuation of the existing OMP-2006.

Step 3: Considers alternative relative weightings of CPUE and survey information.

Step 4: Develops a CMP with TAC adjustments based on a target CPUE value in addition to the existing OMP-2006 approach of using only trend information from the indices of abundance.

Step 5: Considers a TAC penalty over and above the existing control rule if CPUE drops too low, as a possible response to MSC condition 7.

Step 6: Considers alternative inter-annual TAC constraints.

Step 7: Increases in the extent to which the TAC changes given a change in the average trend value.

Results and Discussion

Step 1:

Results for C=0 and OMP-2006 (Rademeyer and Glazer, 2007) are given in **Table 2a**. **Table 2b** gives the year in which the *M. paradoxus* spawning biomass is expected (in median terms) to first exceed MSYL.

Fig. 1 plots median and lower 2.5%ile projections for the TAC and *M. paradoxus* for RSa, and for *M. capensis* for RSb.

Step 2:

OMP-2006 is simplified so that the λ parameter which multiples the average trend value is not time dependent to provide **CMPa1** (see Appendix I). Note though that the target increase rate parameter *T* can be time dependent, and is decreased linearly to zero from 2020 to 2023 and set to zero thereafter, where 2020 is roughly the time by which MSYL for *M. paradoxus* has been reached so that TACs can be increased as production need no longer be set aside for resource growth. Other differences from OMP-2006 are the relative weightings of the CPUE and survey series in calculating average trends across abundance indices (see Step 3 below), and the use coast-specific rather than coast-combined CPUE indices. Note however that the maximal +-10% TAC inter-annual change constraint of OMP-2006 is retained.

Results are shown in **Table 2a** and **Fig. 1** for three tunings of CMPa1 to median averages TACs over 2011-2020 under RSa of 125, 135, 145 thousand tons with the tuning to 135 thousand tons being treated as a Reference Case (CMPa1a). **Table 2b** lists the years in which each CMP sees MSYL reached. (Note that this result for OMP-2006 as evaluated under the 2006 RS is shown as 2024 rather than as 2027 in the OMP-2006 objectives listed above. This is for improved comparability. Unlike OMPa1 which slows recovery only after MSYL has been reached, OMP-2006 started slowing the rate before this, so the year in which MSYL would have been reached without this slowdown has been shown in Table 2b.)

Treating the lowest value of B_{2007} across RSa as the limit reference point, in interpreting the results of Table 2a and Fig. 1 one requires the range of values of B_{2007}/B_{2010} across RSa which is [0.761-1.078]. Both Fig 1 and Table 2a indicate that the first two tunings of CMPa1 nearly meet this limit point criterion, but CMPa1b tuned to a median ten-year average TAC of 145 thousand tons, for which the lower 2.5%ile of *B* for *M. paradoxus* also shows no improvement over time, fails heavily. The Reference Case CMPa1a is a little more aggressive than OMP-2006 in terms of anticipated future TACs.

Table 2b indicates that OMP2006 reaches MSYL (in median terms) for *M. paradoxus* in 2016, eight years earlier than estimated in 2006, which is a consequence of changed assumptions in the updated assessment together with improved survey and CPUE results over the past four years. The first two variants of CMPa1 reach MSYL at 2016. Thus both reach this target within 2 times the three years that would be taken if all fishing was immediately suspended, which falls within the range under consideration for possible future MSC certification requirements. CMPa1b however does not achieve MSYL in median terms by 2030, and is an option that would not seem to meet MSC certification requirements.

Step 3:

OMP-2006 gave equal weighting to CPUE and survey based abundance indices when averaging over the recent trends indicated by each to compute the trend *s* to input to its TAC formula. **Table 3** gives the weight given to the trend estimate for each abundance index in the case of equal weighting, exact inverse variance weighting and "mid-way" weighting. Inverse variance weighting relates to the precision of the trend estimates from past values of the index concerned – the caption to Table 3 specifies exactly how this was computed. The “mid-way” weighting, which is used for the OMPa1 results reported above, is an intermediate weighting between these two “extremes”.

Table 4 compares the performance under the RS of CMPa1a ("mid-way" weighting) with otherwise equivalent CMPs using equal and inverse variance weighting, where all are tuned to give the same median average annual TAC over the next decade. Of interest is the behaviour of the “risk” statistics, “low para” for RSa and “low cap” for RSb: one wants to choose an approach that see these as high as possible (and also shows a lower 2.5%ile for the lowest TAC projected as high as possible). The Table shows that mid-way weighting outperforms equal weighting in both regards.

Why not opt for inverse variance weighting which performs better still for the RS? The concern is that for various reasons CPUE may not provide an exactly comparable index of abundance over time. Table 4 also shows results for these CMPs applied to robustness test Rob35 for which the future CPUE data generated incorporate an undetected 2% annual increase in catchability and so provide positively biased estimates of trends in abundance. Under this scenario equal weighting provides a lower risk than mid-way weighting, for which risk is in turn less than for inverse variance weighting. Considering results for both the RS and Rob35 in combination, mid-way weighting seems to provide ca reasonable compromise.

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Step 4:

For this step a modification to the structure of the TAC formula for the CMP is considered where in addition to recent trends in indices of abundance, the TAC is also varied in relation to how CPUE averaged over three recent years compares to a target CPUE level. For **CMPb1** procedures, the TAC is also adjusted up or down by an amount proportional to how far this recent CPUE is above or below the chosen target level (see Appendix I).

Tables 2a and 2b as well as **Fig. 1** show results for the same three tunings of CMPb1 as developed for CMPa1, with the tuning to a median average catch of 135 thousand tons over the next decade under RSa (termed **CMPb1a**) being considered a further Reference Case CMP.

The attractive feature of CMPb1 results is the reduced range of TAC values to be expected. Thus comparing CMPa1a and CMPb1a, the latter reflects a lower 2.5%ile for the annual TAC that is more than 10 thousand tons greater than for the former. Risk in terms of “low para” under RSa is also reduced (Table 2a). However, these desirable features are 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 (Fig. 1), which may not be an attractive prospect for industry..

Step 5:

This step explores the consequences of adding an additional “safeguard” rule which pulls down the TAC further than would otherwise be the case under the standard feedback rules of the OMP. Specifically the TAC is further reduced by a “penalty” if recent average CPUE falls below its average value over 2006-2008, with the size of the reduction related to the magnitude of the shortfall (see Appendix I for details). This is in the spirit of a limit reference point approach where additional conservation measures are taken if resource abundance drops below a specified threshold, and is investigated here as a response to the MSC’s re-certification condition 7.

Results under the addition of this penalty rule are shown in **Table 5a**, where they are compared to the two Reference Case CMPs, CMPa1a and CMPb1a. If the additional rule is to reduce risk, “low para” under RSa and “low cap” under RSb need to increase given this added rule.

OMPa2a and OMPb2a simply add this rule without retuning these CMPs. Risk is reduced as sought, but the average TAC is also reduced, so that is not really an appropriate comparison – a safety net for extreme poor circumstances is required which hardly impacts TACs set when the resource is not under threat. Thus for **CMPa3a and CMPb3a**, the control parameters of the Reference Case CMPs are retuned to maintain a median 135 thousand ton average TAC over the next 10 years. However, for CMP3a, the *M paradoxus* risk then **becomes greater** from that before this extra rule was introduced, and risk for *M. capensis* **increases as well**! For CMPb3a there is a small risk reduction in terms of low para, but for low cap under RSb risk again **increases** slightly.

This suggests (for the RS OMs) that adding this further precautionary rule does **not** actually reduce risk; if one wants less risk, the tuning of the pre-penalty rule CMP has to be adjusted, and consequently the associated anticipated average TAC will fall.

But might this additional penalty rule reduce risk for some robustness tests? **Table 5b** and **Fig. 2** give results of these CMPs for scenarios where carrying capacity changes, which have been found (Rademeyer and Butterworth, 2010) to be the most taxing of such trials. (Note that here only the Reference Case OM, RS1, not the full RS, is used in calculations to reduce the programming burden.) Tabular results are a little difficult to interpret here, and it is perhaps better to consider the projected trajectories shown in Fig. 2. In essence for past changes in carrying capacity (robustness test Rob 13), the extra rule does reduce risk for *M. paradoxus* for CMPa3a,but for CMPb3a and for future changes (Rob 37) the additional rule hardly makes any difference. Thus these robustness tests also do not seem to provide much justification for including this additional precautionary rule.

Overall these results that the basic feedback structure of CMPs such as CMPa1a and CMPb1a (augmented by the provisions of the general Procedures for Deviating from OMP output which essentially mandate OMP review should future monitoring data fall outside the range anticipated under CMP testing – see Appendix 2 of Rademeyer *et al.* (2008)), provided the CMP is appropriately tuned, **already** include the limit reference point-type protection sought by the MSC's recertification Condition 7.

Step 6:

Table 6 shows results for variants (**CMPa4a and CMPa5a**) of the Reference Case CMPa1a which relax the constraints of a maximal + or -10% interannual TAC change to allow somewhat greater deviations upward and/or reduce the maximum downward change permitted.

These results suggest that an increased of the upward change constraint to 15% might be acceptable but this would also need to be checked in due course for some key robustness trials. Increasing the upward constraint to 20% and decreasing the downward constraint to 5% increases risk substantially.

Step 7:

Table 7 shows results for **CMPa6a** which increases the λ parameter multiplying average trend values in the TAC formula of CMPa1a.

This option does not seem to warrant further consideration, given that risk is increased and there is a substantial rise in the average annual TAC variation (the AAV statistic).

Summary

Fig. 3 shows consolidated projection plots with medians and probability interval envelopes for the three tunings of CMPa1 and the Reference Case tuning of CMPb1a.

Further features of interest evident from these plots are:

- Future median effort level estimates for the next decade are lower than at present, even for the most aggressive candidate CMPa1b which is likely unacceptable because of conflicts with MSC requirements. For the Reference Case CMPa1a, the reduction is about 20%.
- The offshore trawl CPUE is projected (in median terms) to increase by 50% over its average 2003-2005 level by 2015, but then drop slightly by amounts that differ amongst the four CMPs for which results are shown
- For RSa under CMPa1a, *M. paradoxus* reaches its MSYL in median terms in about 6 years, and after 15 years the lower 2.5%ile of B/MSYL is 0.64.
- Furthermore for CMPa1a, median B/K is 0.30 by 2020, with a lower 2.5%ile of 0.15.
- Under RSb, though there is some recovery of M. capensis in median terms, and the lower 2.5%ile does not drop below the 2007 level, there is no continuing increase of the median trajectory towards MSYL.

Immediate guidance and further work required

The DWG meeting on July 21 and 22 needs to give guidance on the following points to refine the scope of the CMPs to be considered further:

- Reduction of the range of catch vs. *M. paradoxus* recovery rates to be considered. Options with a median average annual TAC of 145 thousand tons (or more) over the next decade under RSa seem necessary to exclude to ensure that MSC certification requirements are met.
- Possible confirmation of the relative weighting for survey and CPUE abundance indices to be used when averaging trends for TAC control rules based on such inputs.
- Whether control rules be based on abundance index trends only (e.g. CMPa1), or whether they also seek to incorporate CPUE targets (e.g. CMPb1). If the latter's behaviour over the next few years ids considered unsatisfactory, should some phased changed from CMPa1 to CMPb1 be considered, e.g. via a time-dependent control parameter *w*?
- Whether the additional rule penalising the TAC if CPUE drops too low need be pursued further, or alternatively posed are simpler CMPs such as the Reference Cases CMPa1a or CMPb1a sufficient to meet the MSC's Condition 7?
- Is the current requirement under the general Procedures for Deviating from OMP output which essentially mandate OMP review should future monitoring data fall outside the range anticipated under CMP testing – see Appendix 2 of Rademeyer *et al.* (2008) – sufficient to meet the possible future MSC requirement of a high probability of being above a limit reference biomass level below which future recruitment success might be impaired?
- Whether time-dependence should be introduced for certain control parameters in order to attempt to further smooth median anticipated TAC and effort trends over the next decade.
- It seems unlikely that any CMP based on overall TAC control alone could secure recovery of *M. capensis* to its MSYL for RSb scenarios, because *M. capensis* constitutes a relatively small

proportion of the overall TAC. Since results suggest no major reduction of *M. capensis* under the Reference Case CMPs for RSb scenarios, which seem perhaps less likely to reflect reality than the RSa scenarios, should this aspect simply be monitored for the next few years through updated assessments, hopefully allowing further data to better determine the relative plausibility of the RSb scenarios?

- The CMPs for which results have been presented tend to overshoot MSYL. Should control parameters be adjusted to rather equilibrate at MSYL?
- What range of possible inter-annual TAC constraints should be investigated further?

After further calculations arising from the above, iterative discussion will need to select a rather small set of CMPs for final testing, which will need to include the full set of robustness trials (Rademeyer and Butterworth, 2010). This exercise will slightly adjust the control rule of equation I2 to remove the discontinuity that arises if λ_{up} and λ_{down} are not identical, and also include consideration of the implications of:

- Reduction in survey intensity (Rob32)
- The impact on CPUE, and consequently on CMP performance, of the possible introduction of offshore MPAs?

References

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Rademeyer RA and Butterworth DS. 2010. Conditioning of the full set of robustness tests for the South African hake resource to be used in OMP-2010 testing and constant catch projections. Unpublished document, Marine and Coastal Management, South Africa. MCM/2010/JUNE/SWG-DEM/

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

CMP	Description
C=0	catch = 0
CMP2006	OMP2006
CMPa1a	**Base Case a** (equation I.2), tuned to average catch of **135 000t** over 2011-2020
CMPa1b	**Base Case a**, tuned to **145 000t**
CMPa1c	**Base Case a**, tuned to **125 000t**
CMPa2a	**As CMPa1a** with penalty (equation I.6)
CMPa3a	**As CMPa2a**, tuned to **135 000t**
CMPa4a	**As CMPa1a** withTAC change constraints of +15% and -10% p.a.
CMPa5a	**As CMPa1a** withTAC change constraints of +20% and -5% p.a.
CMPa6a	**As CMPa1a** with larger λ
CMPb1a	**Base Case b** (equation I.5), tuned to average catch of **135 000t** over 2011-2020
CMPb1b	**Base Case b**, tuned to **145 000t**
CMPb1c	**Base Case b**, tuned to **125 000t**
CMPb2a	**As CMPb1a** with penalty (equation I.6)
CMPb3a	**As CMPb2a**, tuned to **135 000t**

Table 1b: Tuning parameter values for each CMP presented. T^{para} applies up to the year 2020 and then declines linearly to zero in year 2023.

CMP	λ_{up}	λ_{down}	T^{para}	T^{cap}	w	a^{para}	a^{cap}	b^{para}	b^{cap}	Δ	H	k	Annual change constraints	
C=0														
CMP2006	0.5-1.1	1.1-2.0	2.40%	0									+10%	-10%
CMPa1a	1.25	1.50	1.74%	0									+10%	-10%
CMPa1b	1.25	1.50	0.18%	0									+10%	-10%
CMPa1c	1.25	1.50	3.33%	0									+10%	-10%
CMPa2a	1.25	1.50	1.74%	0						1.1	0.5	12000	+10%	-10%
CMPa3a	1.25	1.50	1.20%	0						1.1	0.5	12000	+10%	-10%
CMPa4a	1.25	1.50	1.82%	0									+15%	-10%
CMPa5a	1.25	1.50	1.92%	0									+20%	-5%
CMPa6a	2.00	2.00	2.71%	0						1.1	0.5	12000	+10%	-10%
CMPb1a	1.25	1.50	1.74%	0	0.5	118.2	95.0	40.0	30.0				+10%	-10%
CMPb1b	1.25	1.50	0.18%	0	0.5	129.4	95.0	40.0	30.0				+10%	-10%
CMPb1c	1.25	1.50	3.33%	0	0.5	106.9	95.0	40.0	30.0				+10%	-10%
CMPb2a	1.25	1.50	1.74%	0	0.5	118.2	95.0	40.0	30.0	1.1	0.5	12000	+10%	-10%
CMPb3a	1.25	1.50	1.74%	0	0.5	132.5	95.0	40.0	30.0	1.1	0.5	12000	+10%	-10%

Table 2a: Projections results (either median or lower 2.5%ile) for a series of performance statistics for different CMPs under the RS. Here and below results for the two reference CMPs (CMPa1a and CMPb1a) are bolded. The meaning of some of the performance statistics is explained in the text.

			C=0	OMP2006	CMPa1c	CMPa1a	CMPa1b	CMPb1c	CMPb1a	CMPb1b
		RSa								
median	BS	avC: 2011-2020	0.0	127.4	125.0	**135.0**	145.0	125.0	**135.0**	145.0
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	0.84	0.72	0.74	**0.71**	0.56	0.79	**0.74**	0.61
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	0.76	0.72	0.74	**0.72**	0.69	0.71	**0.71**	0.72
median	para	B^{sp}_{2020}/B_{MSY}	3.58	1.30	1.33	**1.14**	0.96	1.35	**1.14**	0.94
median	cap	B^{sp}_{2020}/B_{MSY}	3.42	2.93	2.93	**2.88**	2.85	2.94	**2.90**	2.84
median	BS	AAV	100.0	4.2	4.5	**4.7**	5.1	4.6	**4.1**	4.2
low	BS	lowest TAC (2011-2030)	0.0	88.7	81.0	**88.7**	93.5	91.4	**101.6**	107.4
		RSb								
median	BS	avC: 2011-2015	0.0	122.0	118.4	**127.7**	137.4	120.0	**129.0**	137.8
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	0.96	0.95	0.95	**0.94**	0.83	0.96	**0.95**	0.92
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	1.01	0.88	0.90	**0.82**	0.61	0.93	**0.84**	0.69
median	para	B^{sp}_{2020}/B_{MSY}	2.93	1.04	1.06	**0.94**	0.81	1.12	**0.96**	0.79
median	cap	B^{sp}_{2020}/B_{MSY}	1.13	0.60	0.61	**0.56**	0.52	0.62	**0.56**	0.51
median	BS	AAV	0.0	4.3	4.3	**4.4**	4.7	4.5	**3.7**	3.6
low	BS	lowest TAC (2011-2030)	0.0	87.1	82.5	**90.4**	96.2	89.9	**100.7**	108.6

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=0	2013
OMP2006*	2024
OMP2006	2016
CMPa1c	2016
CMPa1a	2016
CMPa1b	>2030
CMPb1c	2015
CMPb1a	2016
CMPb1b	2029

Table 3: Weighting of the CPUE and survey series when computing s_y^{spp}, the measure of immediate past trend in the abundance indices. The variances for the various trend estimates were obtained from empirical estimates of variance for the slope in the log-linear fit of a trend to five successive points of the series in question. An average was taken over five such estimates: that for the most recent 5 years, and for CPUE those for such periods pushed earlier by one, two, three of four years. For surveys to push back was only up to three years for the west coast, and two years for the south coast, because of years without *Africana* surveys in the early 2000s.

		Equal Weigthing	Inverse variance weighting	Mid-way weighting
CPUE				
M. paradoxus	WC	1.00	1.00	1.00
	SC	1.00	0.40	0.75
M. capensis	WC	1.00	1.00	1.00
	SC	1.00	0.40	0.75
Survey				
M. paradoxus	WC	1.00	0.20	0.50
	SC	1.00	0.02	0.25
M. capensis	WC	1.00	0.20	0.50
	SC	1.00	1.00	1.00

Table 4: Projections results (either median or lower 2.5%ile) for a series of performance statistics for CMPa1a, CMPa1a with equal weighting of the CPUE and survey series in the slope calculation ("equal weighting") and CMPa1a with exact inverse variance weighting ("inverse variance weighting"). These results are presented for the RS and Rob35 (undetected 2% p.a. increase in catchability related to CPUE in the future).

			RS			Rob35		
			CMPa1a	equal weighting	inverse variance weighting	CMPa1a	equal weighting	inverse variance weighted
		RSa						
median	BS	avC: 2011-2020	**135.0**	135.0	135.0	**140.8**	139.3	142.5
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.71**	0.69	0.72	**0.61**	0.62	0.57
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.72**	0.73	0.74	**0.70**	0.72	0.71
median	para	B^{sp}_{2020}/B_{MSY}	**1.14**	1.15	1.11	**1.04**	1.08	0.99
median	cap	B^{sp}_{2020}/B_{MSY}	**2.88**	2.88	2.88	**2.87**	2.87	2.85
median	BS	AAV	**4.7**	5.1	4.5	**4.9**	5.3	4.8
low	BS	lowest TAC (2011-2030)	**88.7**	87.5	88.5	**95.4**	92.0	96.7
		RSb						
median	BS	avC: 2011-2015	**127.7**	127.9	129.3	**133.6**	132.1	136.6
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.94**	0.91	0.93	**0.85**	0.91	0.86
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.82**	0.80	0.83	**0.64**	0.69	0.62
median	para	B^{sp}_{2020}/B_{MSY}	**0.94**	0.95	0.89	**0.88**	0.90	0.82
median	cap	B^{sp}_{2020}/B_{MSY}	**0.56**	0.56	0.55	**0.54**	0.54	0.52
median	BS	AAV	**4.4**	5.0	4.3	**4.7**	5.1	4.4
low	BS	lowest TAC (2011-2030)	**90.4**	88.1	94.5	**94.1**	90.3	100.3

Table 5a: Projections results (either median or lower 2.5%ile) for a series of performance statistics for different CMPs with and without penalty under the RS.

			CMPa1a	CMPa2a	CMPa3a	CMPb1a	CMPb2a	CMPb3a
		RSa						
median	BS	avC: 2011-2020	**135.0**	128.9	135.0	**135.0**	123.4	135.0
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.71**	0.73	0.69	**0.74**	0.80	0.75
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.72**	0.73	0.73	**0.71**	0.70	0.70
median	para	B^{sp}_{2020}/B_{MSY}	**1.14**	1.27	1.16	**1.14**	1.39	1.16
median	cap	B^{sp}_{2020}/B_{MSY}	**2.88**	2.92	2.90	**2.90**	2.95	2.90
median	BS	AAV	**4.7**	4.7	4.9	**4.1**	5.5	4.9
low	BS	lowest TAC (2011-2030)	**88.7**	77.7	80.6	**101.6**	85.4	95.8
		RSb						
median	BS	avC: 2011-2015	**127.7**	123.1	128.8	**129.0**	119.5	129.7
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.94**	0.94	0.91	**0.95**	0.96	0.96
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.82**	0.86	0.77	**0.84**	0.94	0.82
median	para	B^{sp}_{2020}/B_{MSY}	**0.94**	1.00	0.93	**0.96**	1.16	0.97
median	cap	B^{sp}_{2020}/B_{MSY}	**0.56**	0.59	0.56	**0.56**	0.63	0.57
median	BS	AAV	**4.4**	4.4	4.5	**3.7**	5.5	4.6
low	BS	lowest TAC (2011-2030)	**90.4**	81.1	84.5	**100.7**	80.3	91.8

Table 5b: Projections results (either median or lower 2.5%ile) for a series of performance statistics for different CMPs with and without penalty under RS1 and the two robustness tests with changes in carrying capacity (Rob13: change in the past; Rob37: change in the future).

			RS1				Rob13				Rob37			
			CMPa1a	CMPa3a	CMPb1a	CMPb3a	CMPa1a	CMPa3a	CMPb1a	CMPb3a	CMPa1a	CMPa3a	CMPb1a	CMPb3a
median	BS	avC: 2011-2020	**137.3**	138.9	**137.3**	137.8	**88.9**	81.4	**99.0**	95.3	**136.2**	137.6	**136.4**	136.9
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.80**	0.79	**0.88**	0.87	**0.10**	0.18	**0.02**	0.03	**0.30**	0.25	**0.33**	0.26
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.97**	0.94	**0.97**	0.93	**0.98**	0.98	**0.63**	0.86	**0.42**	0.38	**0.46**	0.41
median	para	B^{sp}_{2020}/B_{MSY}	**1.07**	1.04	**1.10**	1.11	**0.58**	0.72	**0.46**	0.63	**1.33**	1.30	**1.37**	1.37
median	cap	B^{sp}_{2020}/B_{MSY}	**2.41**	2.40	**2.41**	2.42	**2.03**	2.12	**1.92**	2.00	**3.14**	3.13	**3.15**	3.14
median	BS	AAV	**4.6**	4.8	**4.2**	4.9	**6.1**	7.8	**4.7**	5.6	**5.8**	6.6	**5.4**	6.8
low	BS	lowest TAC (2011-2030)	**95.4**	92.6	**104.1**	99.3	**29.7**	15.4	**48.9**	47.6	**66.5**	53.5	**72.5**	62.1

Table 6: 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 (CMPa4a: +15%,-10%; CMPa5a: +20%,-5%) .

			CMPa1a	CMPa4a	CMPa5a
		RSa			
median	BS	avC: 2011-2020	**135.0**	135.0	135.0
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.71**	0.69	0.63
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.72**	0.71	0.68
median	para	B^{sp}_{2020}/B_{MSY}	**1.14**	1.13	1.14
median	cap	B^{sp}_{2020}/B_{MSY}	**2.88**	2.89	2.89
median	BS	AAV	**4.7**	4.8	4.2
low	BS	lowest TAC (2011-2030)	**88.7**	88.4	98.1
		RSb			
median	BS	avC: 2011-2015	**127.7**	127.7	127.8
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.94**	0.91	0.91
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.82**	0.83	0.72
median	para	B^{sp}_{2020}/B_{MSY}	**0.94**	0.94	0.94
median	cap	B^{sp}_{2020}/B_{MSY}	**0.56**	0.57	0.56
median	BS	AAV	**4.4**	4.4	4.1
low	BS	lowest TAC (2011-2030)	**90.4**	90.2	98.4

Table 7: Projections results (either median or lower 2.5%ile) for a series of performance statistics for a CMP with larger λ (CMPa6a: λ=2).

			CMPa1a	CMPa6a
		RSa		
median	BS	avC: 2011-2020	**135.0**	135.0
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.71**	0.67
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.72**	0.72
median	para	B^{sp}_{2020}/B_{MSY}	**1.14**	1.14
median	cap	B^{sp}_{2020}/B_{MSY}	**2.88**	2.89
median	BS	AAV	**4.7**	6.2
low	BS	lowest TAC (2011-2030)	**88.7**	79.6
		RSb		
median	BS	avC: 2011-2015	**127.7**	125.4
low	para	$B^{sp}_{low}/B^{sp}_{2010}$	**0.94**	0.91
low	cap	$B^{sp}_{low}/B^{sp}_{2010}$	**0.82**	0.73
median	para	B^{sp}_{2020}/B_{MSY}	**0.94**	0.98
median	cap	B^{sp}_{2020}/B_{MSY}	**0.56**	0.57
median	BS	AAV	**4.4**	6.2
low	BS	lowest TAC (2011-2030)	**90.4**	80.7

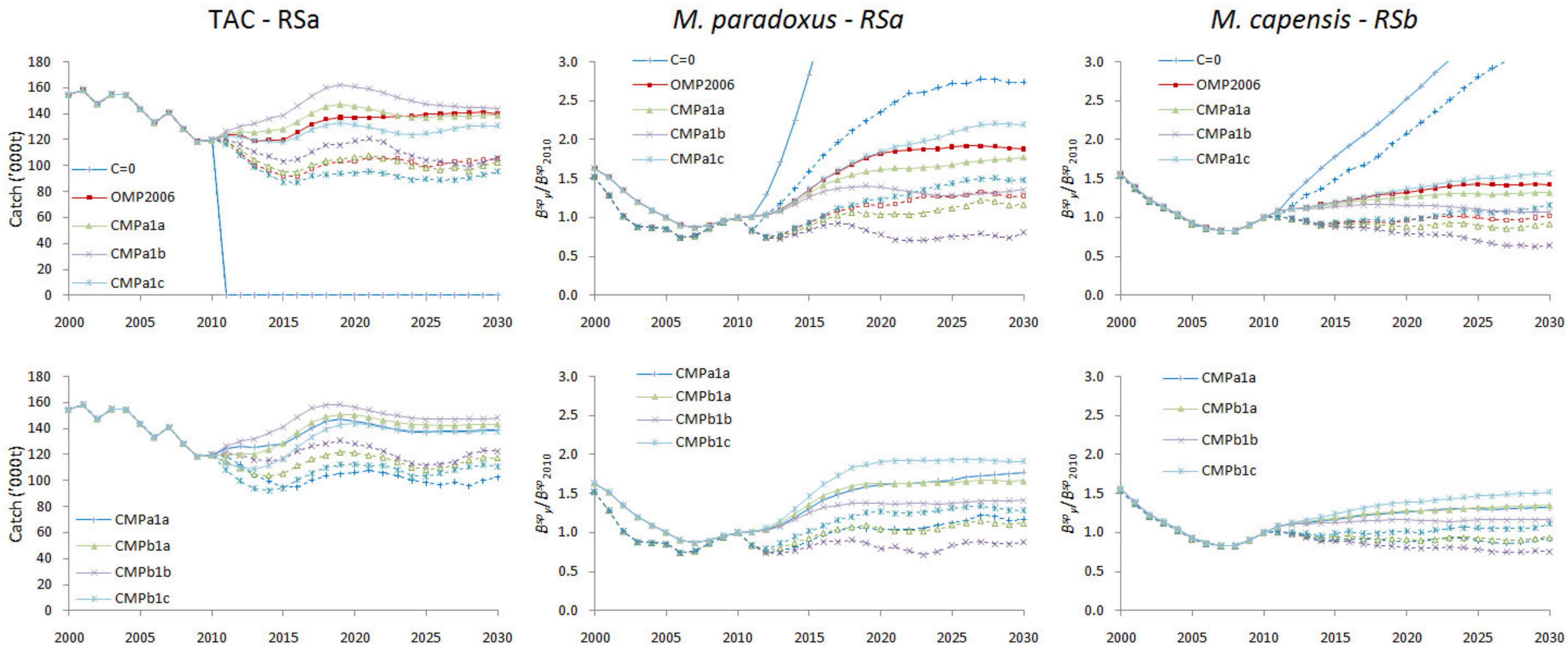

Fig. 1a: Median (full lines) and lower 2.5%iles (dashed lines) TAC (RSa) and spawning biomass (in terms of 2010 level) for *M. paradoxus* (RSa) and *M. capensis* (RSb) for a series of CMPs.

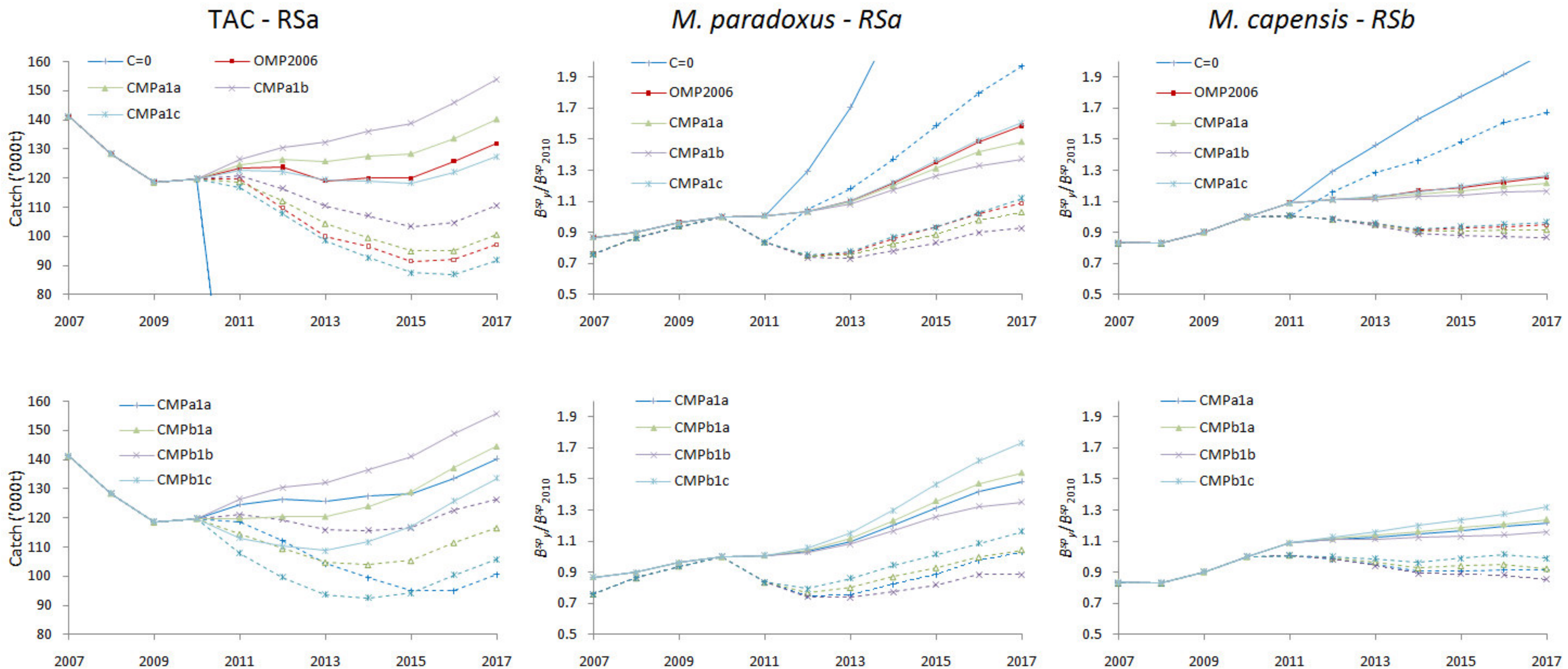

Fig. 1b: As 1a but different scales.

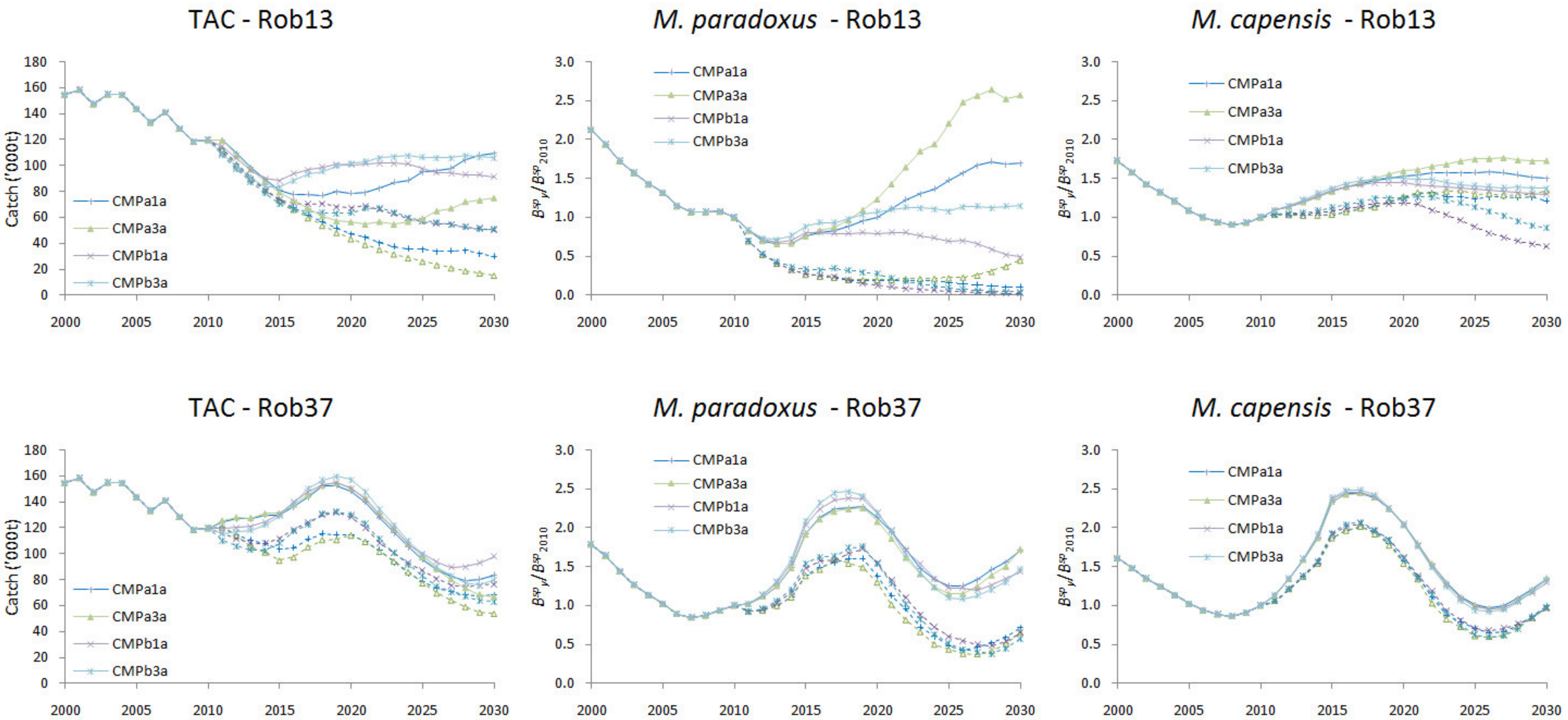

Fig. 2a: Median (full lines) and lower 2.5%iles (dashed lines) TAC and spawning biomass (in terms of 2010 level) for *M. paradoxus* and *M. capensis* under Rob13 (change in K in the past) and Rob37 (change in K in the future) for a series of CMPs with (CMPa/b3a) and without (CMPa/b1a) an additional penalty for low CPUE.

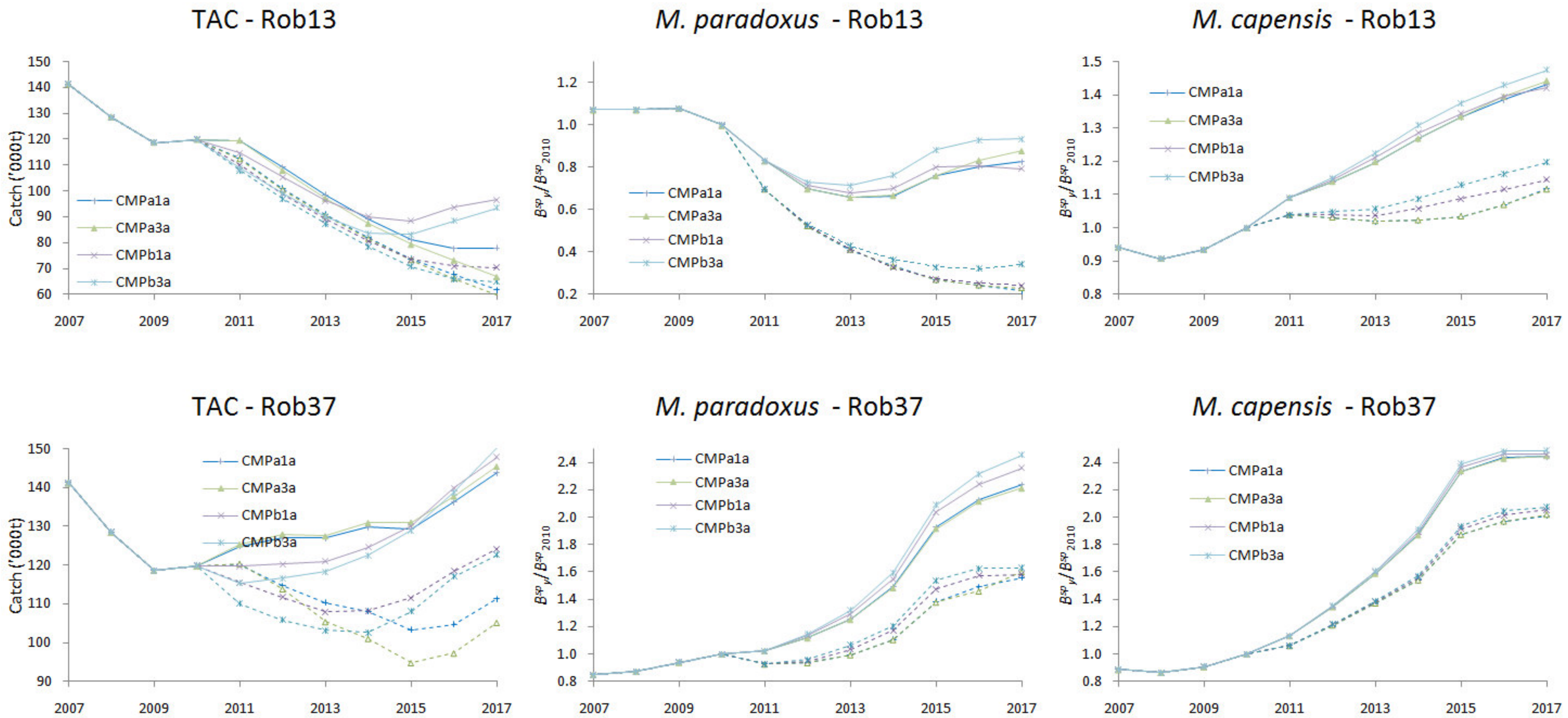

Fig. 2b: As 2a but difference scales.

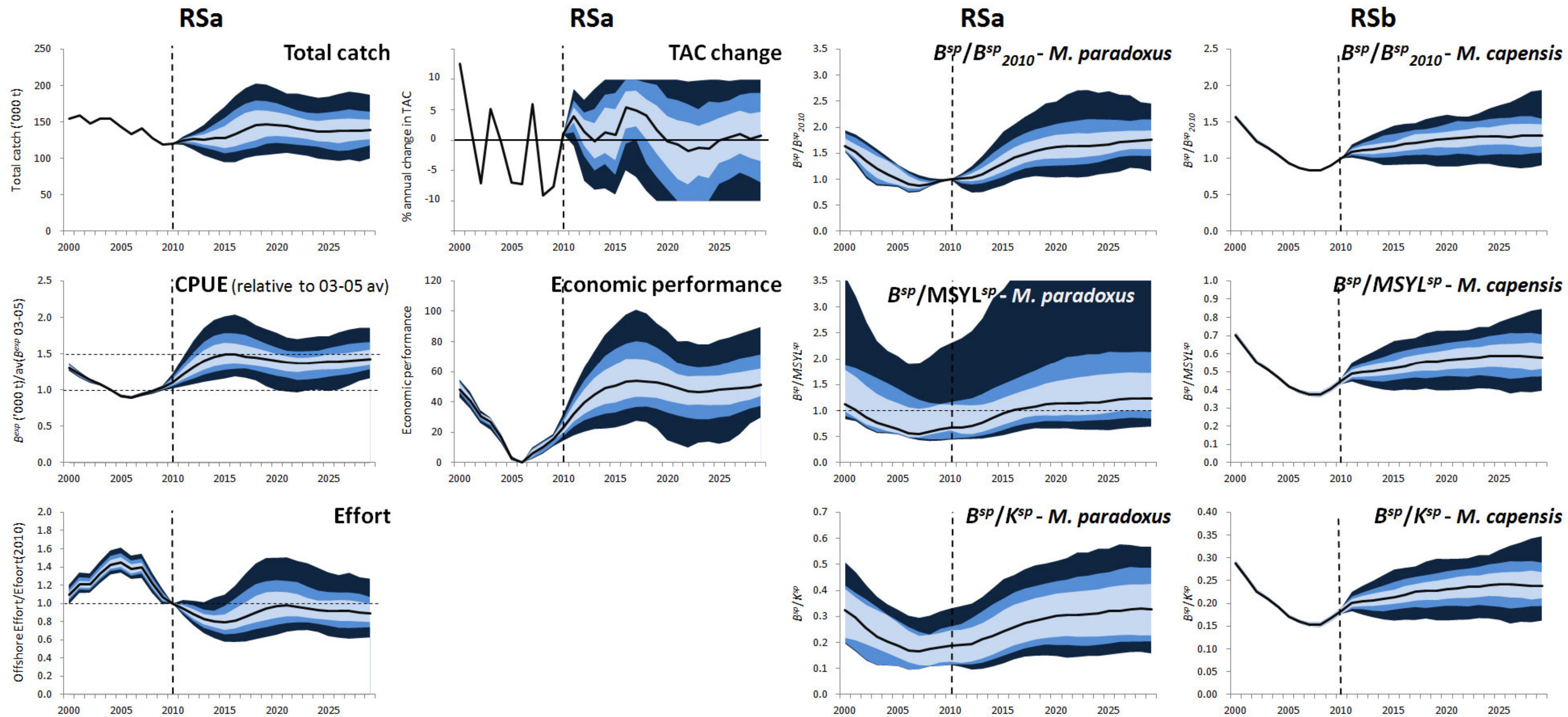

Fig. 3a: 95, 75, 50% PI and median for a series of performance statistics for **CMPa1a**.

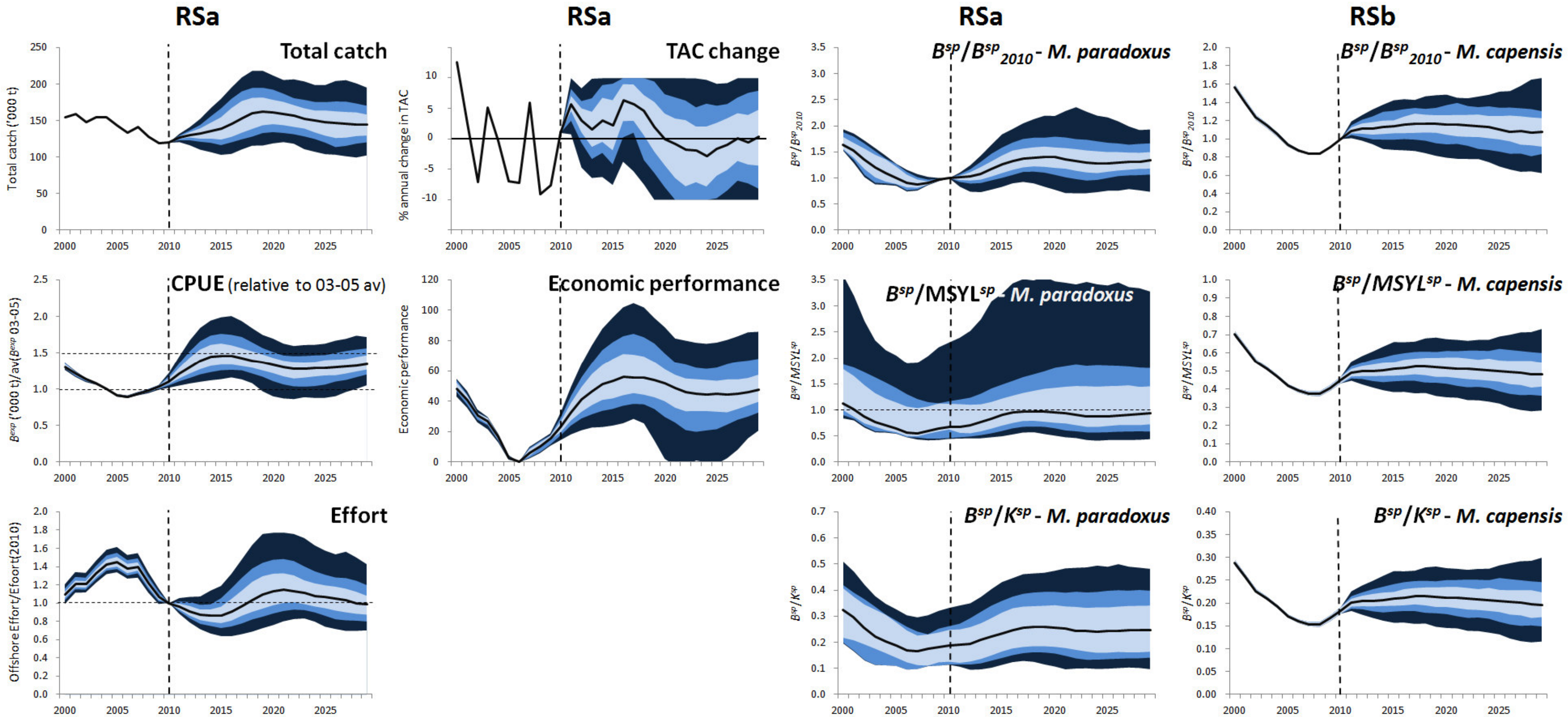

Fig. 3b: 95, 75, 50% PI and median for a series of performance statistics for **CMPa1b**.

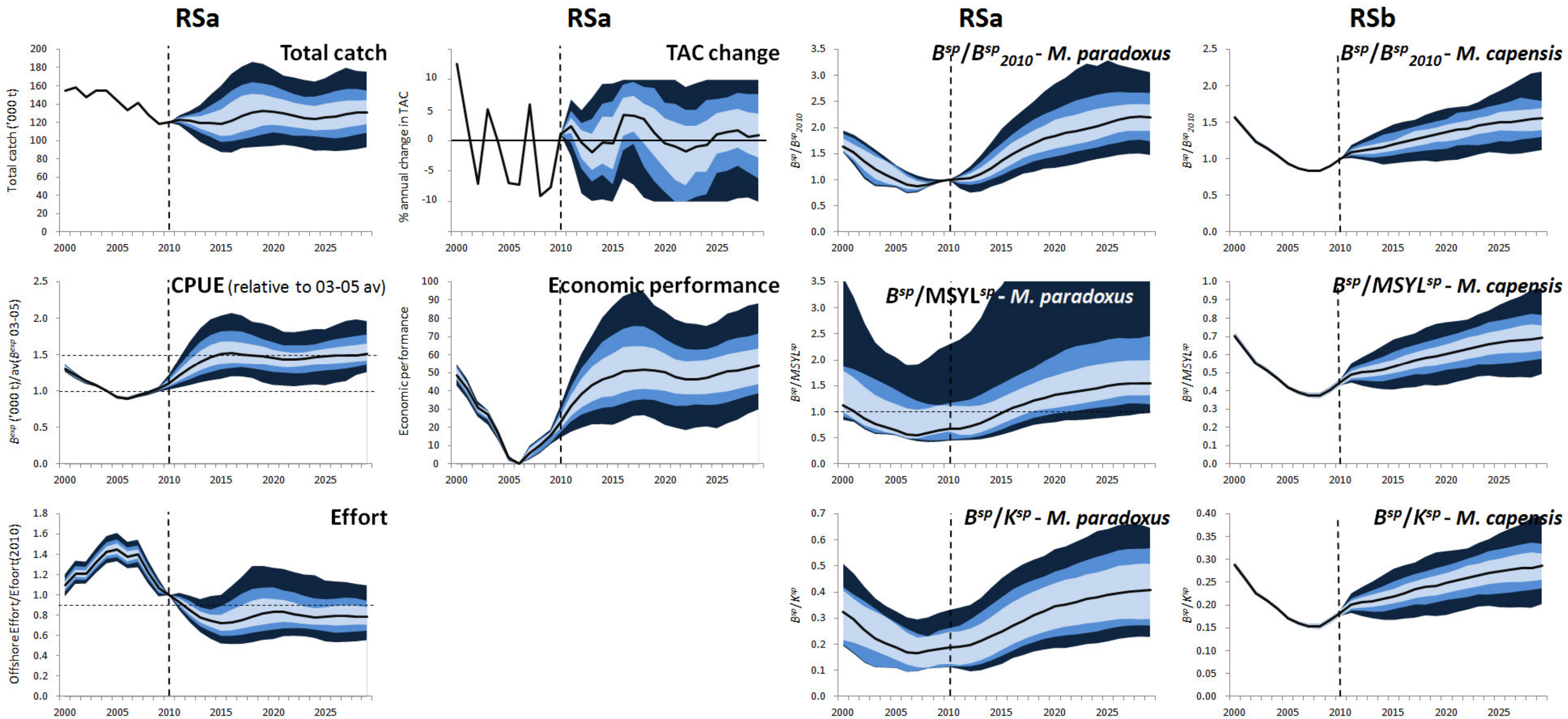

Fig. 3c: 95, 75, 50% PI and median for a series of performance statistics for **CMPa1c**.

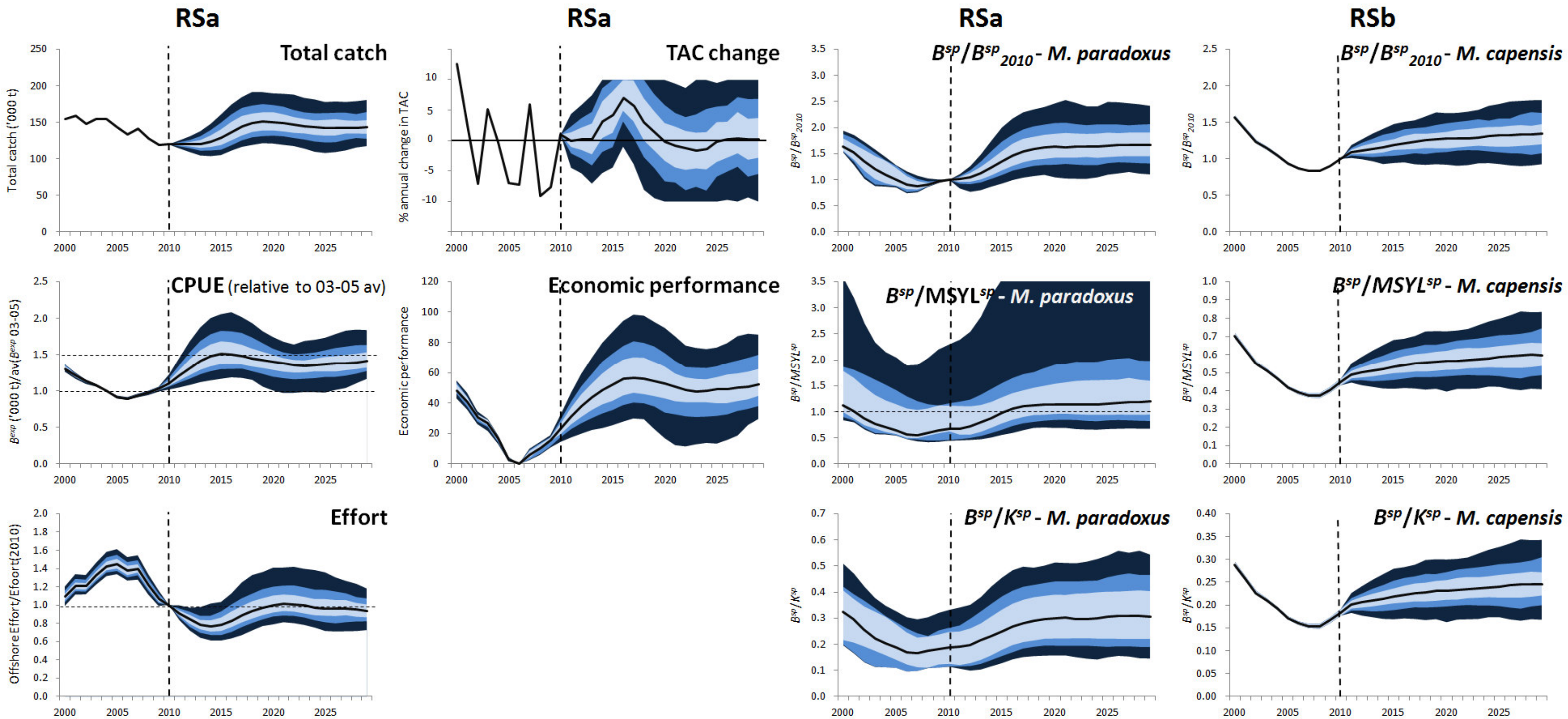

Fig. 3d: 95, 75, 50% PI and median for a series of performance statistics for **CMPb1a.**

APPENDIX I - Specification of the Candidate Management Procedures

Results include continued application of the existing OMP-2006. That OMP had only a single combined coast CPUE series available to it for each species. Now the operating model generates separate species-specific series for west and coast coasts. Thus to implement OMP-2006, these two CPUE series were added.

The **CMPa1** formula for computing the TAC recommendation is as follows:

$$TAC_y = C_y^{para} + C_y^{cap} \tag{I.1}$$

with

$$C_y^{spp} = \begin{cases} C_{y-1}^{*spp}\left[1+\lambda_{up}\left(s_y^{spp} - T_y^{spp}\right)\right] & s_y^{spp} \geq 0 \\ C_{y-1}^{*spp}\left[1+\lambda_{down}\left(s_y^{spp} - T_y^{spp}\right)\right] & s_y^{spp} < 0 \end{cases} \tag{I.2}$$

where

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

C_y^{spp} is the intended species-disaggregated TAC for year *y*,

C_{y-1}^{*spp} is the achieved catch[1] of species *spp* in year *y*-1,

λ_{up} and λ_{down} are tuning parameters,

T_y^{spp} is the target rate of increase for species *spp*, a constant to *y*=2021 with a linear decrease to 0 from 2021 to 2023, and,

s_y^{spp} is a measure of the immediate past trend in the abundance indices for species *spp* as available to use for calculations for year *y*.

This trend measure is computed as follows from the coast- and species-disaggregated GLM-CPUE ($I_y^{WC\_CPUE,spp}$ and $I_y^{SC\_CPUE,spp}$), west coast summer survey ($I_y^{WC\_surv,spp}$) and south coast autumn survey ($I_y^{SC\_surv,spp}$) indices:

- linearly regress $\ln I_y^{WC\_CPUE,spp}$ and $\ln I_y^{SC\_CPUE,spp}$ *vs* year *y'* for $y' = y - p - 1$ to $y' = y - 2$, to yield two regression slopes value $s_y^{WC\_CPUE,spp}$ and $s_y^{SC\_CPUE,spp}$,
- linearly regress $\ln I_y^{WC\_surv,spp}$ and $\ln I_y^{SC\_surv,spp}$ *vs* year *y'* for $y' = y - p$ to $y' = y - 1$, to yield two regression slope values $s_y^{WC\_surv,spp}$ and $s_y^{SC\_surv,spp}$,

[1] Implemented by applying the species ratio of the catch in year *y*-2 to the TAC for year *y*-1, as the species ratio for year *y*-1 would not yet be known by the time at which a recommendation for the TAC for year *y* would be required.

where p=6 is the length of the periods considered for these regressions. Note that the reason the trend for surveys is calculated for a period moved one year later than for CPUE is that by the time of year that the TAC recommendation would be computed for the following year, survey results for the current year would be known, but not CPUE as fishing for the year would not yet have been completed. Note also that surveys carried out using the old gear are made comparable to those carried out using the new gear by multiplying them by a species specific calibration factor (0.95 for *M. paradoxus* and 0.8 for *M. capensis*).

Then (see Table 3 re mid-way weighting)

$$s_y^{para} = \left(s_y^{WC\_CPUE,para} + 0.75 s_y^{SC\_CPUE,para} + 0.5 s_y^{WC\_surv,para} + 0.25 s_y^{SC\_surv,para}\right) / 2.5 \qquad \text{(I.3)}$$

$$s_y^{cap} = \left(s_y^{WC\_CPUE,cap} + 0.75 s_y^{SC\_CPUE,cap} + 0.5 s_y^{WC\_surv,cap} + s_y^{SC\_surv,cap}\right) / 3.25 \qquad \text{(I.4)}$$

CMPb (addition of CPUE target):

$$C_y^{spp} = \begin{cases} wC_{y-1}^{*spp}\left[1+\lambda_{up}\left(s_y^{spp} - T^{spp}\right)\right] + (1-w)\left[a^{spp} + b^{spp}\left(J_y^{spp} - 1\right)\right] & s_y^{spp} \geq 0 \\ wC_{y-1}^{*spp}\left[1+\lambda_{down}\left(s_y^{spp} - T^{spp}\right)\right] + (1-w)\left[a^{spp} + b^{spp}\left(J_y^{spp} - 1\right)\right] & s_y^{spp} < 0 \end{cases} \qquad \text{(I.5)}$$

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}= and b^{spp} are tuning parameters.

Additional TAC Penalty for low CPUE:

In some cases a catch penalty $f\left(I_y^{spp}\right)$ is subtracted if the future catch rate falls below the current catch rate (this subtraction occurs before the constraint on the maximum TAC reduction is applied):

$$f\left(I_y^{spp}\right) = \begin{cases} k\left[1 - \exp\left(-\left(\frac{I_y^{spp} - \Delta}{H}\right)\right)\right] & \text{if } I_y^{spp} < \Delta \\ 0 & \text{if } I_y^{spp} \geq \Delta \end{cases} \qquad \text{(I.6)}$$

where

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

Δ, *k* and *H* are tuning parameters