

## Results for the first few robustness tests for the hake OMP2018 review

A. Ross-Gillespie and D.S. Butterworth<sup>1</sup>

Email: mlland028@myuct.ac.za

### Summary

Results for six robustness tests are presented, where the tests were conducted for the RS02 Reference Case (RC) model. The robustness tests assume (1) no future surveys, (2) all future surveys are conducted by industry vessels, (3) future surveys take place every second year only, (4) the RC with an undetected increase of 2% p.a. in commercial catchability in the future, (5) no future surveys with this same undetected increase in catchability and (6) use of the old Algorithm 2013 species splitting algorithm. Assuming no future surveys has the biggest impact, with a marked reduction in TAC and increased inter-annual variation. However, if this CMP is retuned so that the risk is the same as the RC CMP, then the resulting TAC projections are in fact very similar to the RC – therefore this retuning would be an important exercise to conduct if it is known that future surveys will be less frequent or absent. Simulations suggest that the remaining robustness tests have relatively little impact on projected resource status and catches; even an undetected increase in commercial catchability, though resulting in lower future biomasses, does not seem too serious a concern as the lower 5%ile of biomass after 25 years remain above  $B_{MSY}$  for both species.

### Introduction

Results are presented for four robustness tests evaluated for the RC model (RS02 with Ricker stock-recruitment and central year 1958). The first test involves reconditioning the RC Operating Model (OM) using the data from the original Algorithm 2013 species splitting algorithm<sup>2</sup>. The next three relate to assumptions regarding future surveys. The RC model assumes that two surveys (West Coast (WC) and South Coast (SC)) will be conducted each year by the research vessel. The three robustness tests relating to survey  $q$ 's assume (1) no future surveys, (2) all future surveys are conducted by industry vessels and (3) two surveys (WC and SC) take place every second year only.

For missing surveys, the OMP formula for the TAC calculation is adjusted so that the survey indices are removed from the calculation and weighting. For the assumption that all future surveys are conducted by industry vessels, information from FISHERIES/2018/SEP/SWG-DEM/45 is taken into account, which provides estimates of the ratio of catchability coefficients for the survey vessel *RV Africana* to those for the industry vessels. The standard method for generating future survey indices is:

$$I_y^{surv} = q^{surv} B_y^{surv} e^{\epsilon_y} \quad (1)$$

where  $I_y^{surv}$  is the survey index generated for year  $y$ ,  $q^{surv}$  is the survey catchability coefficient estimated when fitting the Operating Model (OM),  $B_y^{surv}$  is the survey biomass for year  $y$  and  $e^{\epsilon_y}$  is an error term.

<sup>1</sup> Marine Resource Assessment and Management Group, Department of Mathematics and Applied Mathematics, University of Cape Town, Rondebosch.

<sup>2</sup> Species splitting Algorithm 2013 was used to split the catch by species prior to 2018. In 2018, an updated species splitting algorithm "Model A6b" was developed, which has been used for the RS models in the OMP2018 review. The use of this updated species splitting algorithm for the RS models lead to a marked improvement in the perception of the *M. paradoxus* resource status, see the bridge building document FISHERIES/2018/MAY/SWG-DEM/20.

FISHERIES/2018/SEP/SWG-DEM/45 reports that the ratio of research to industry catchability coefficients for *M. paradoxus* on the WC (calculated excluding a 2013 outlier) is 0.80 (se=0.20). To take this into account when assuming that future surveys are conducted with industry vessels, a further error term  $e^{\eta_y}$  is added to equation (1) with  $\eta_y \sim N(0.80, 0.2^2)$ , and the whole equation is scaled by a factor of  $e^{0.80}$  to account for the likely lower catchability of the industry vessels (this factor is included because this bias is known, so that in application the result from a future survey would be divided by this factor). Equation 1 consequently becomes:

$$I_y^{surv} = q^{surv} B_y^{surv} e^{\epsilon_y} e^{\eta_y} / e^{0.80} \quad (2)$$

For an undetected increase in commercial catchability, a steady increase of 2% p.a. in the CPUE  $q$  value was assumed, as this could be considered a likely extreme case scenario.

Note that all the CMPs now include a rule that the TAC in 2019 cannot be less than the 2018 TAC. Hence the RC results reported here differ slightly from those reported in FISHERIES/2018/SEP/SWG-DEM/46 where that rule had not been included.

## Results

Table 1a lists the resource status related performance statistics for the RC and the six robustness tests, while Table 1b lists the catch related performance statistics.

Figure 1a and b are collections of Zeh plots contrasting key performance statistics for the RC with those of the six robustness tests, for four different OMP rule assumptions (150 000t cap (i.e. OMP2014), 160 000t cap, 150 000t cap with tuning parameter  $b$  increased by 10% and 160 000t cap with tuning parameter  $b$  increased by 10%).

Figure 2a and b plot the median estimates and 90% probability intervals for the projected catch over the next four years (i.e. the planned life span of OMP2018).

For reasons given in the discussion section, the results in Figure 1 and Figure 2 can be misleading and a re-tuning of the robustness tests CMPs was required. This re-tuning was completed with respect to the CMP with a cap of 150 000t and no change in  $b$  only, and for the first four robustness tests only. Table 2a and b list the performance statistics for the re-tuned robustness tests, while Figure 3 and Figure 4 illustrate the performance statistics and TAC for the next four years for the retuned CMPs.

## Discussion

*Future survey assumptions* (Figure 1a and Figure 2a):

Assuming no future surveys has a marked impact on the projected catch, with substantially reduced TACs and increased interannual variability (column 2 of Figure 1 and Figure 2). The resource status is seemingly not greatly impacted by management without surveys, although both stocks are estimated to be slightly less depleted when future surveys are missing, presumably as a result of the reduced catches in this scenario.

Use of industry vessels appears to have very little impact the performance of the OMP. It should be noted that the RS02 OM does not distinguish between use of industry and survey vessels prior to 2018; ideally a sensitivity should be run for which the survey indices prior to 2018 are scaled by a factor of  $e^{0.80}$  for years in which an industry vessel was used to evaluate the impact this has on the OM conditioning and consequently on the projection results.

Finally, assuming that a WC and SC survey takes place every second year only seems to have relatively little impact on the projected resource status and catch levels. Thus, a survey pair every second year would seem to provide reasonably adequate management input.

*Undetected increase in commercial catchability*

Should an unexpected increase in the commercial catchability occur (both with and without future surveys) this will likely lead to higher overall TACs and consequently a somewhat more depleted *M. paradoxus* resource, although the lower 5<sup>th</sup> percentile of the  $B_{2042}/B_{MSY}$  estimate remains above or close to one in all cases. It would seem that the undetected increase in catchability is not likely to have serious management implications.

*Use of the original Algorithm 2013 species splitting algorithm (Figure 1, Figure 2):*

Interestingly, despite the more optimistic estimate of the status of depletion for *M. paradoxus* under the new Model A6b species splitting algorithm, there is very little difference between the two models in the short-term projected TAC values for the next few years. The 25-year TAC projections are actually more optimistic under the old species splitting algorithm (possibly because of the less depleted *M. capensis* and higher exploitable biomass estimated by this model). The simulations suggest that depletion levels for *M. paradoxus* are fairly similar after 25 years regardless of which species splitting algorithm has been assumed.

*Re-tuning of the CMPs*

These results may however be misleading, as both catches and final abundance change as the OM is changed. For “equivalent risk” results, the value for the *b* control parameter for each robustness test has been modified so that the lower 5%-ile on the final (2042) *M. paradoxus* depletion is identical to that for the RC. This has been done only for the OMP 2014 equivalent MP candidate.

The consequent results are shown in Figure 3 (performance statistics) and Figure 4 (TAC for the next four years). Table 2a includes the percentages by which the *b* parameters needed to be changed to match the RC risk. When the CMPs are re-tuned in this manner to account for reduced or entirely missing future surveys, the TAC projections end up being very similar to the RC projections. Thus, if surveys were not to take place in the future, the OMP would require re-tuning to avoid substantial reductions in TAC.

After re-tuning, the scenario of future surveys every second year remains fairly similar to the RC projections. If surveys are undertaken by industry vessel, this may result in slightly lower TACs in median terms over the next two years, but similar TACs thereafter.

The robustness test that assumes no future surveys and an undetected increase in commercial catchability was then re-run with the value of *b* from the re-tuned robustness tests that assumes no future surveys (where *b* was increased by 12.5% from the 2014 value so that the lower 5<sup>th</sup> percentile of  $B_{2042}/B_{MSY}$  for *M. paradoxus* matched that of the RC). The performance statistics for this are reported in Table 1a and b (the rows highlighted in grey), with key results repeated in Table 3, and illustrated graphically in Figure 5. The results of these simulations do not contradict the earlier conclusion that an undetected increase in commercial catchability seems unlikely to have serious management implications; although the *M. paradoxus* resource is estimated to be more depleted, its lower 5%ile is above  $B_{MSY}$  after 25 years (similarly for *M. capensis*).

Figure 6 and Figure 7 provide the effort and CPUE trajectories for the RC and all the robustness tests reported in the Tables. These suggest that in general a drop in effort and an increase in CPUE can be expected. Naturally the robustness test that assumes an undetected increase in catchability also projects a much higher CPUE than the other OMs, but this is not (entirely) reflecting an increase in abundance.

**Table 1a:** Performance statistics relating to the *M. paradoxus* and *M. capensis* resource status for the **untuned robustness tests**. Note that there is an additional row for robustness test five (highlighted in grey), where the projections were run for a value of *b* increased by 12.5% from the 2014 value, as this was the value of *b* from the re-tuning of robustness test (1) – this is because in such a situation the absence of future surveys would be known. The “Ref” column is just a numbering of the rows for the purposes of reference.

	Cap	b	Ref	M. paradoxus					M. capensis						
				B <sub>2042</sub> /B <sub>MSY</sub>		B <sub>2022</sub> /B <sub>MSY</sub>		B <sub>low</sub> /B <sub>MSY</sub>	B <sub>2042</sub> /B <sub>MSY</sub>		B <sub>2022</sub> /B <sub>MSY</sub>		B <sub>low</sub> /B <sub>MSY</sub>		
RC	150	+0%	1	2.44	(1.39,3.92)	2.33	(1.32,3.70)	1.59	(1.12,2.01)	2.74	(1.71,4.28)	2.86	(2.55,3.42)	2.13	(1.53,2.53)
		+10%	2	2.35	(1.34,3.93)	2.25	(1.22,3.64)	1.51	(0.99,1.99)	2.72	(1.68,4.20)	2.84	(2.52,3.41)	2.11	(1.50,2.52)
	160	+0%	3	2.33	(1.25,3.77)	2.31	(1.32,3.64)	1.47	(0.98,1.98)	2.74	(1.72,4.30)	2.86	(2.55,3.41)	2.05	(1.50,2.52)
		+10%	4	2.18	(1.15,3.69)	2.21	(1.19,3.53)	1.37	(0.87,1.92)	2.69	(1.66,4.23)	2.82	(2.51,3.39)	2.09	(1.49,2.52)
(1) No future surveys	150	+0%	5	2.63	(1.41,4.22)	2.44	(1.45,3.83)	1.67	(1.19,2.05)	2.82	(1.73,4.46)	2.90	(2.56,3.45)	2.09	(1.51,2.52)
		+10%	6	2.52	(1.41,4.07)	2.31	(1.34,3.68)	1.58	(1.07,2.01)	2.75	(1.68,4.45)	2.85	(2.52,3.42)	2.13	(1.54,2.52)
	160	+0%	7	2.54	(1.34,4.12)	2.44	(1.45,3.83)	1.58	(1.16,2.01)	2.84	(1.71,4.51)	2.90	(2.56,3.45)	2.06	(1.46,2.52)
		+10%	8	2.42	(1.26,4.02)	2.30	(1.34,3.62)	1.46	(1.03,1.99)	2.81	(1.71,4.53)	2.85	(2.52,3.41)	2.07	(1.45,2.52)
(2) All industry vessels	150	+0%	9	2.43	(1.33,3.91)	2.33	(1.33,3.68)	1.58	(1.10,2.01)	2.73	(1.72,4.28)	2.86	(2.56,3.42)	2.12	(1.51,2.53)
		+10%	10	2.33	(1.34,3.94)	2.26	(1.22,3.64)	1.53	(0.99,1.99)	2.72	(1.69,4.18)	2.84	(2.53,3.41)	2.11	(1.50,2.52)
	160	+0%	11	2.29	(1.24,3.77)	2.31	(1.33,3.60)	1.46	(0.96,1.96)	2.74	(1.71,4.30)	2.85	(2.56,3.41)	2.07	(1.50,2.52)
		+10%	12	2.18	(1.14,3.68)	2.22	(1.19,3.53)	1.35	(0.84,1.91)	2.69	(1.68,4.21)	2.82	(2.52,3.39)	2.09	(1.47,2.52)
(3) Every second year	150	+0%	13	2.46	(1.41,4.05)	2.35	(1.30,3.73)	1.60	(1.04,2.04)	2.75	(1.72,4.23)	2.87	(2.51,3.43)	2.12	(1.56,2.53)
		+10%	14	2.38	(1.34,3.97)	2.27	(1.25,3.65)	1.54	(0.97,2.00)	2.73	(1.68,4.19)	2.83	(2.50,3.41)	2.11	(1.56,2.53)
	160	+0%	15	2.32	(1.25,3.73)	2.33	(1.29,3.68)	1.48	(0.96,1.99)	2.76	(1.70,4.16)	2.86	(2.51,3.41)	2.08	(1.50,2.52)
		+10%	16	2.19	(1.21,3.75)	2.21	(1.19,3.55)	1.37	(0.93,1.94)	2.71	(1.67,4.22)	2.82	(2.47,3.39)	2.06	(1.53,2.52)
(4) RC + undetected catchability increase	150	+0%	17	2.29	(1.21,3.94)	2.32	(1.29,3.70)	1.49	(0.96,1.99)	2.72	(1.64,4.16)	2.86	(2.55,3.42)	2.09	(1.49,2.52)
		+10%	18	2.28	(1.23,3.96)	2.25	(1.22,3.64)	1.45	(0.92,1.99)	2.73	(1.63,4.15)	2.84	(2.52,3.41)	2.10	(1.49,2.52)
	160	+0%	19	2.08	(1.06,3.68)	2.30	(1.29,3.63)	1.35	(0.84,1.90)	2.70	(1.62,4.19)	2.85	(2.54,3.40)	2.04	(1.43,2.52)
		+10%	20	2.09	(0.96,3.69)	2.20	(1.19,3.53)	1.28	(0.82,1.90)	2.68	(1.60,4.14)	2.82	(2.51,3.39)	2.04	(1.43,2.52)
(5) No surveys + undetected catchability increase	150	+0%	21	2.32	(1.22,3.95)	2.41	(1.44,3.79)	1.54	(0.97,2.00)	2.73	(1.63,4.18)	2.89	(2.56,3.44)	2.05	(1.45,2.52)
		+10%	22	2.26	(1.23,3.97)	2.31	(1.33,3.65)	1.47	(0.93,1.99)	2.71	(1.62,4.14)	2.85	(2.52,3.41)	2.07	(1.46,2.52)
	160	+12.5%	23	2.24	(1.23,3.97)	2.31	(1.32,3.64)	1.46	(0.93,1.99)	2.72	(1.62,4.14)	2.85	(2.52,3.41)	2.07	(1.46,2.52)
		+0%	24	2.09	(1.00,3.71)	2.41	(1.44,3.79)	1.38	(0.90,1.91)	2.70	(1.60,4.22)	2.89	(2.56,3.44)	2.00	(1.39,2.52)
		+10%	25	2.08	(0.93,3.70)	2.29	(1.33,3.60)	1.33	(0.82,1.90)	2.66	(1.60,4.15)	2.85	(2.51,3.40)	2.01	(1.41,2.52)
(6) Original species splitting algorithm	150	+0%	26	2.41	(1.37,3.88)	2.01	(1.14,3.14)	1.50	(1.04,1.79)	3.15	(2.05,4.43)	3.14	(2.75,3.74)	2.64	(1.98,2.80)
		+10%	27	2.38	(1.28,3.87)	1.97	(1.06,3.08)	1.48	(0.95,1.79)	3.13	(2.05,4.44)	3.12	(2.73,3.73)	2.63	(1.94,2.80)
	160	+0%	28	2.20	(1.26,3.60)	2.00	(1.14,3.09)	1.42	(0.98,1.78)	3.12	(1.99,4.41)	3.14	(2.75,3.73)	2.59	(1.93,2.80)
		+10%	29	2.14	(1.11,3.59)	1.94	(1.04,2.99)	1.34	(0.85,1.74)	3.11	(1.99,4.36)	3.10	(2.72,3.71)	2.57	(1.88,2.80)

**Table 1b:** Performance statistics relating to the average catch (Cav) and interannual catch variability (AAV) for the **untuned robustness tests**.

	Cap	b	Ref	Species combined							
				Cav (25 yrs)		Cav (4 yrs)		AAV (25 years)		AAV (4 years)	
RC		+0%	1	144.59	(136.98,149.24)	144.13	(127.84,149.44)	0.024	(0.009,0.037)	0.031	(0.028,0.052)
	150	+10%	2	147.21	(140.70,150.09)	148.95	(135.19,149.44)	0.017	(0.005,0.032)	0.031	(0.031,0.047)
		+0%	3	150.42	(140.86,156.63)	146.91	(127.84,156.92)	0.033	(0.019,0.047)	0.048	(0.028,0.059)
	160	+10%	4	154.02	(145.76,159.20)	154.75	(135.19,156.94)	0.027	(0.011,0.040)	0.048	(0.041,0.060)
(1) No future surveys		+0%	5	139.52	(131.31,145.35)	134.84	(125.25,143.31)	0.035	(0.023,0.047)	0.044	(0.026,0.056)
	150	+10%	6	143.85	(136.97,148.44)	145.25	(136.69,147.98)	0.030	(0.016,0.044)	0.056	(0.037,0.065)
		+0%	7	142.72	(133.27,151.01)	134.84	(125.25,145.58)	0.042	(0.029,0.055)	0.046	(0.026,0.073)
	160	+10%	8	148.71	(139.52,154.71)	146.52	(136.69,152.59)	0.039	(0.025,0.051)	0.062	(0.048,0.073)
(2) All industry vessels		+0%	9	145.04	(137.56,149.43)	144.71	(126.68,149.44)	0.022	(0.008,0.040)	0.031	(0.026,0.052)
	150	+10%	10	147.70	(141.76,150.05)	148.97	(133.59,149.44)	0.016	(0.005,0.033)	0.031	(0.031,0.049)
		+0%	11	151.45	(140.18,157.44)	148.11	(126.68,156.94)	0.032	(0.016,0.047)	0.048	(0.026,0.060)
	160	+10%	12	154.77	(145.93,159.22)	154.72	(133.59,156.94)	0.026	(0.010,0.041)	0.048	(0.042,0.062)
(3) Every second year		+0%	13	144.36	(136.69,148.54)	144.76	(128.44,147.89)	0.026	(0.011,0.042)	0.031	(0.030,0.054)
	150	+10%	14	147.59	(141.58,149.96)	149.44	(138.32,149.44)	0.019	(0.007,0.035)	0.031	(0.031,0.059)
		+0%	15	150.00	(139.10,156.10)	148.16	(128.44,154.11)	0.035	(0.020,0.048)	0.048	(0.034,0.060)
	160	+10%	16	153.62	(145.75,158.70)	155.82	(138.32,156.94)	0.030	(0.013,0.045)	0.048	(0.047,0.073)
(4) RC + undetected catchability increase		+0%	17	148.42	(142.96,149.97)	145.01	(129.60,149.44)	0.012	(0.005,0.026)	0.031	(0.027,0.051)
	150	+10%	18	149.83	(145.77,150.12)	149.34	(137.17,149.44)	0.006	(0.005,0.022)	0.031	(0.031,0.053)
		+0%	19	155.56	(147.27,159.13)	148.49	(129.60,156.94)	0.021	(0.008,0.035)	0.048	(0.027,0.060)
	160	+10%	20	158.17	(151.28,159.71)	155.32	(137.32,156.94)	0.016	(0.008,0.032)	0.048	(0.045,0.058)
(5) No surveys + undetected catchability increase		+0%	21	147.10	(140.75,149.15)	137.63	(126.88,144.40)	0.016	(0.009,0.030)	0.050	(0.030,0.056)
		+10%	22	149.37	(144.15,149.96)	146.81	(137.51,149.00)	0.011	(0.005,0.026)	0.056	(0.031,0.065)
	150	+12.5%	23	149.56	(144.68,150.10)	146.85	(138.93,149.44)	0.010	(0.005,0.025)	0.056	(0.031,0.064)
		+0%	24	153.12	(145.77,157.25)	138.34	(126.88,146.37)	0.025	(0.012,0.039)	0.053	(0.030,0.073)
	160	+10%	25	156.75	(150.21,158.92)	149.44	(137.51,153.98)	0.019	(0.010,0.036)	0.066	(0.048,0.073)
(6) Original species splitting algorithm		+0%	26	147.62	(141.07,149.79)	143.98	(128.08,149.44)	0.015	(0.005,0.033)	0.031	(0.027,0.050)
	150	+10%	27	149.24	(143.84,150.12)	148.43	(135.70,149.44)	0.009	(0.005,0.026)	0.031	(0.031,0.047)
		+0%	28	154.17	(144.36,158.78)	146.75	(128.08,156.66)	0.025	(0.008,0.041)	0.048	(0.027,0.060)
	160	+10%	29	156.99	(149.12,159.71)	153.81	(135.70,156.94)	0.017	(0.008,0.036)	0.048	(0.038,0.060)

**Table 2a:** Performance statistics relating to the *M. paradoxus* and *M. capensis* resource status for the **re-tuned robustness tests**. The values reported in the *b* column are the values for which the *M. paradoxus*  $B_{2042}/B_{MSY}$  value of the robustness test in question matched that for the RC.

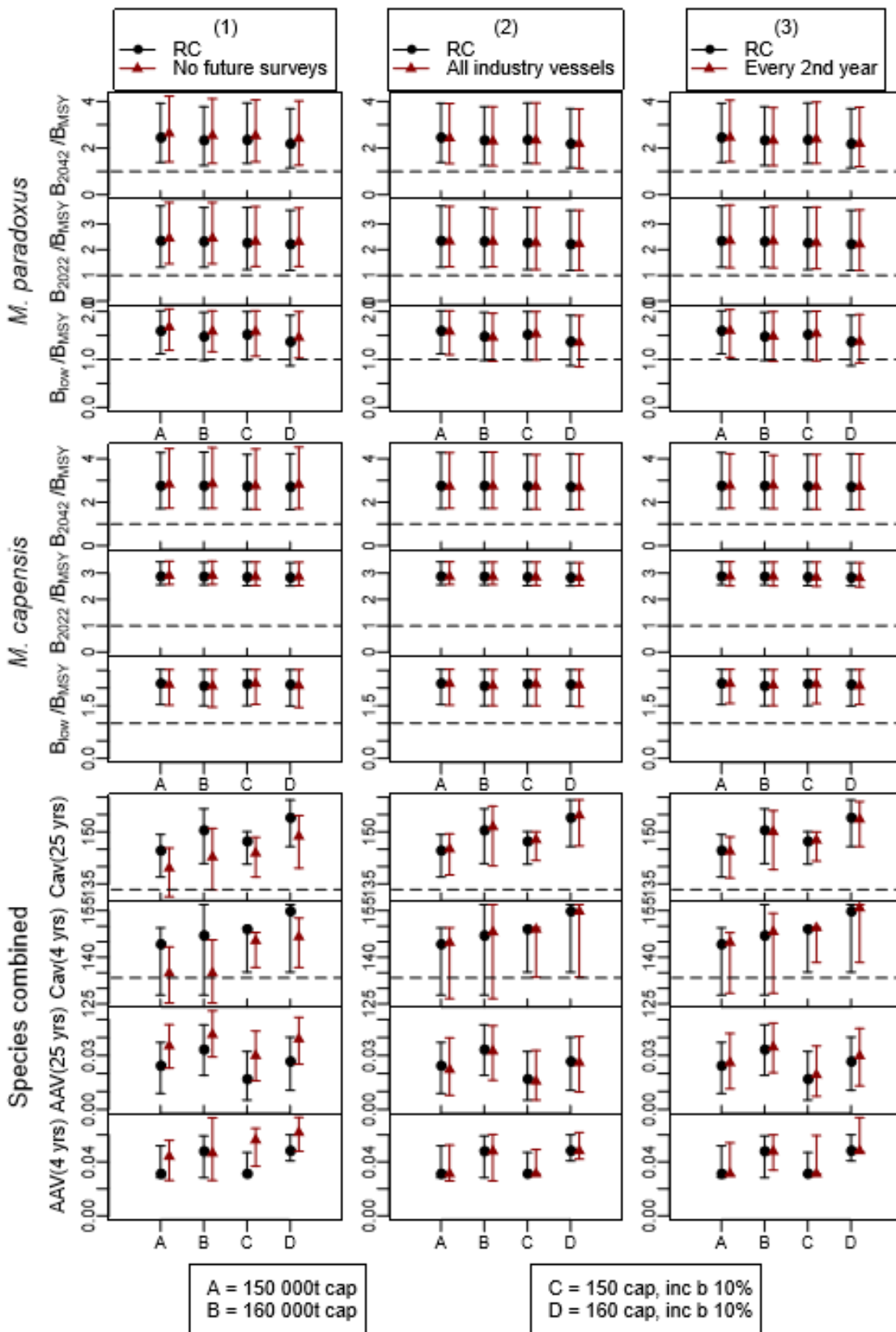
	Cap	b	M. paradoxus						M. capensis					
			$B_{2042}/B_{MSY}$		$B_{2022}/B_{MSY}$		$B_{low}/B_{MSY}$		$B_{2042}/B_{MSY}$		$B_{2022}/B_{MSY}$		$B_{low}/B_{MSY}$	
RC	150	+0%	2.44	(1.39,3.92)	2.33	(1.32,3.70)	1.59	(1.12,2.01)	2.74	(1.71,4.28)	2.86	(2.55,3.42)	2.13	(1.53,2.53)
No future surveys	150	+12.5%	2.50	(1.39,4.04)	2.31	(1.32,3.64)	1.57	(1.05,2.01)	2.75	(1.68,4.45)	2.85	(2.52,3.41)	2.12	(1.54,2.52)
All industry vessels	150	-3.75%	2.46	(1.38,3.92)	2.38	(1.36,3.72)	1.62	(1.15,2.01)	2.75	(1.74,4.33)	2.87	(2.57,3.43)	2.13	(1.53,2.53)
Every second year	150	+1.25%	2.43	(1.39,4.05)	2.33	(1.29,3.73)	1.59	(1.03,2.03)	2.75	(1.71,4.22)	2.86	(2.51,3.42)	2.13	(1.56,2.53)
Original species splitting algorithm	150	+2.5%	2.43	(1.39,3.92)	2.33	(1.30,3.70)	1.59	(1.08,2.01)	2.74	(1.72,4.25)	2.86	(2.55,3.42)	2.12	(1.52,2.53)

**Table 2b:** Performance statistics relating to the average catch (Cav) and interannual catch variability (AAV) for the **re-tuned robustness tests**.

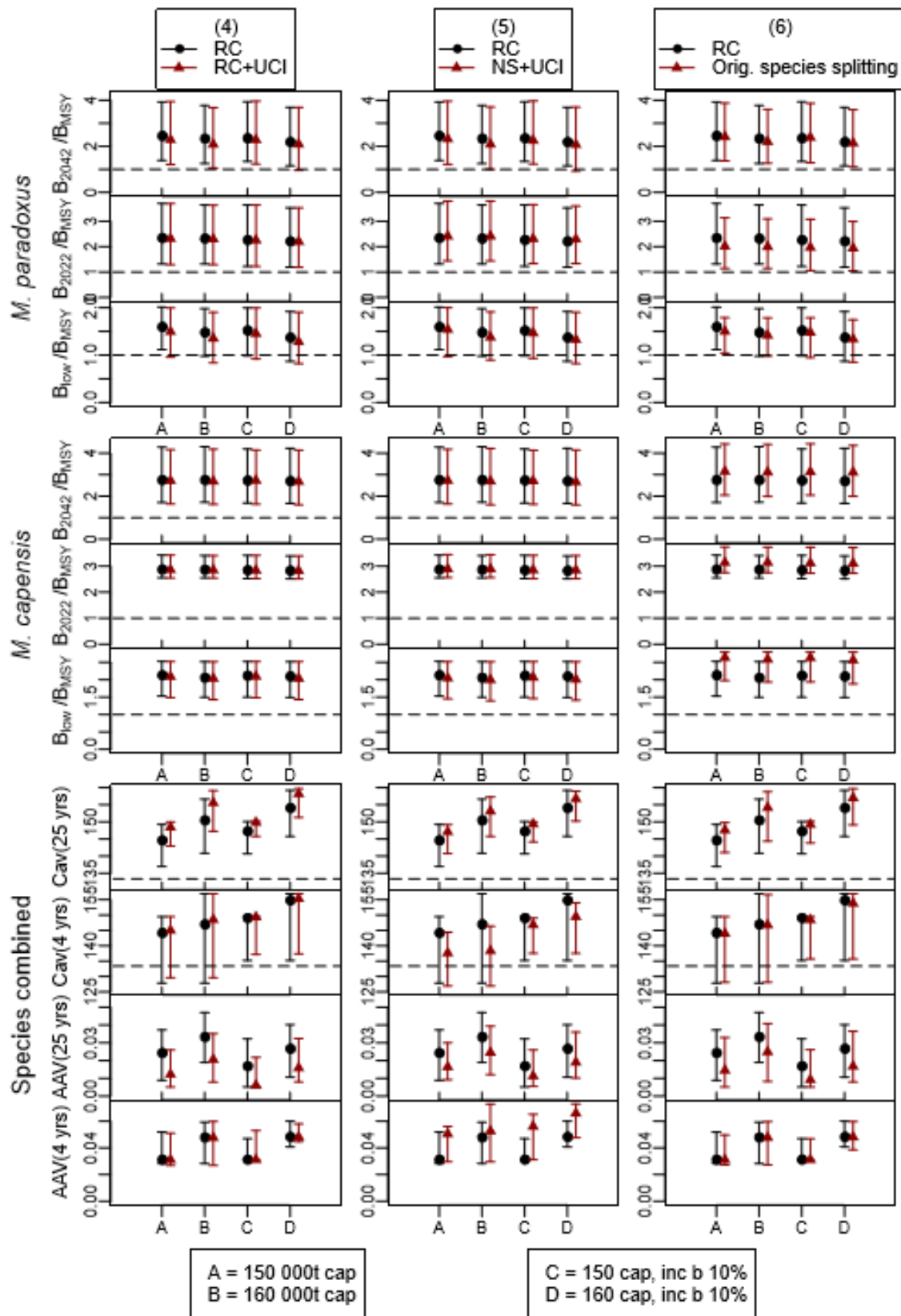
	Cap	b	Species combined							
			Cav (25 yrs)		Cav (4 yrs)		AAV (25 years)		AAV (4 years)	
RC	150	+0%	144.59	(136.98,149.24)	144.13	(127.84,149.44)	0.024	(0.009,0.037)	0.031	(0.028,0.052)
No future surveys	150	+12.5%	144.57	(137.71,148.92)	146.27	(136.69,149.22)	0.027	(0.012,0.042)	0.056	(0.031,0.067)
All industry vessels	150	-3.75%	143.63	(135.74,148.73)	142.58	(125.51,149.44)	0.026	(0.011,0.042)	0.031	(0.023,0.050)
Every second year	150	+1.25%	144.79	(137.57,148.90)	145.52	(129.56,148.33)	0.026	(0.011,0.042)	0.031	(0.030,0.056)
Original species splitting algorithm	150	+2.5%	145.07	(137.53,149.38)	144.48	(128.60,149.44)	0.023	(0.008,0.037)	0.031	(0.027,0.052)

**Table 3:** Key performance statistics relating to the undetected increase in catchability robustness tests (Figure 5) are repeated in the table below.

	Cap	b	<i>M. paradoxus</i>		Species combined	
			$B_{2042}/B_{MSY}$		Cav (25 yrs)	
RC	150	+0%	2.44	(1.39,3.92)	144.59	(136.98,149.24)
No future surveys	150	+12.5%	2.50	(1.39,4.04)	144.57	(137.71,148.92)
RC + undetected catchability increase	150	+0%	2.29	(1.21,3.94)	148.42	(142.96,149.97)
No surveys + undetected catchability increase	150	+12.5%	2.24	(1.23,3.97)	149.56	(144.68,150.10)



**Figure 1a:** Zeh plots of the performance statistics for the **first three (untuned) robustness tests** (columns 1-3) and four different OMP rule options (A-D within each plot). The statistics are  $B^{sp}/B_{MSY}$  for 2042 and 2022 (i.e. at the planned end of OMP2018 application),  $B^{sp(low)}/B_{MSY}$  (the lowest value of this statistic in the projection period to 2042),  $C_{av}$  (the average catch over the projection period (25 years) and over the next four years) and AAV (the average inter-annual proportional change in catch over the projection period (25 years) and over the next four years). Medians and 90% probability intervals are shown. The corresponding values can be found in rows 1-16 of Table 1a and b.



**Figure 1b:** Zeh plots of the performance statistics for the **last three (untuned) robustness tests**. In the legend, “NS” refers to “no future surveys” and “UCI” refers to the robustness test assuming a 2% p.a. undetected catchability increase. The corresponding values can be found in rows 17-29 of Table 1a and b.

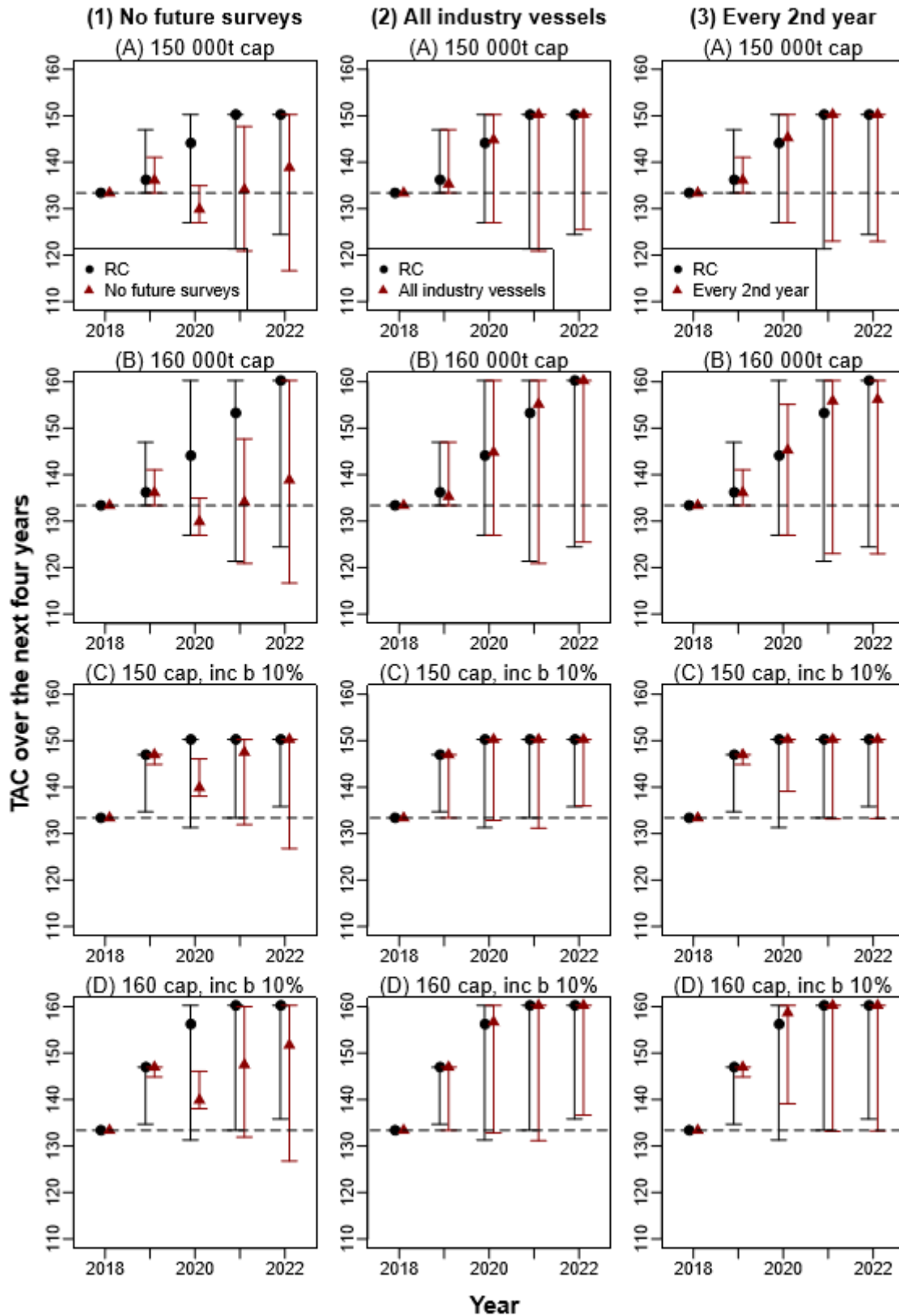
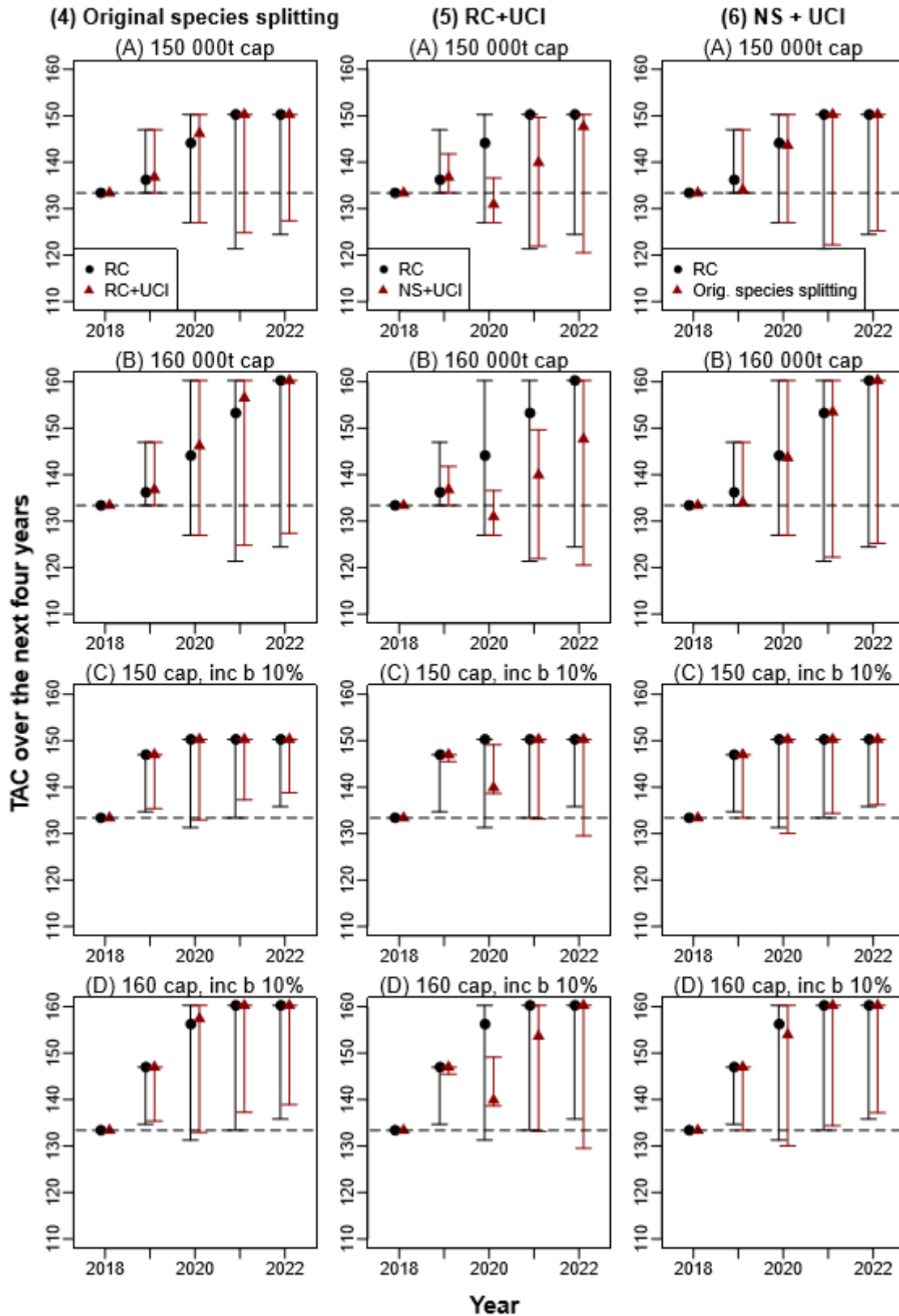
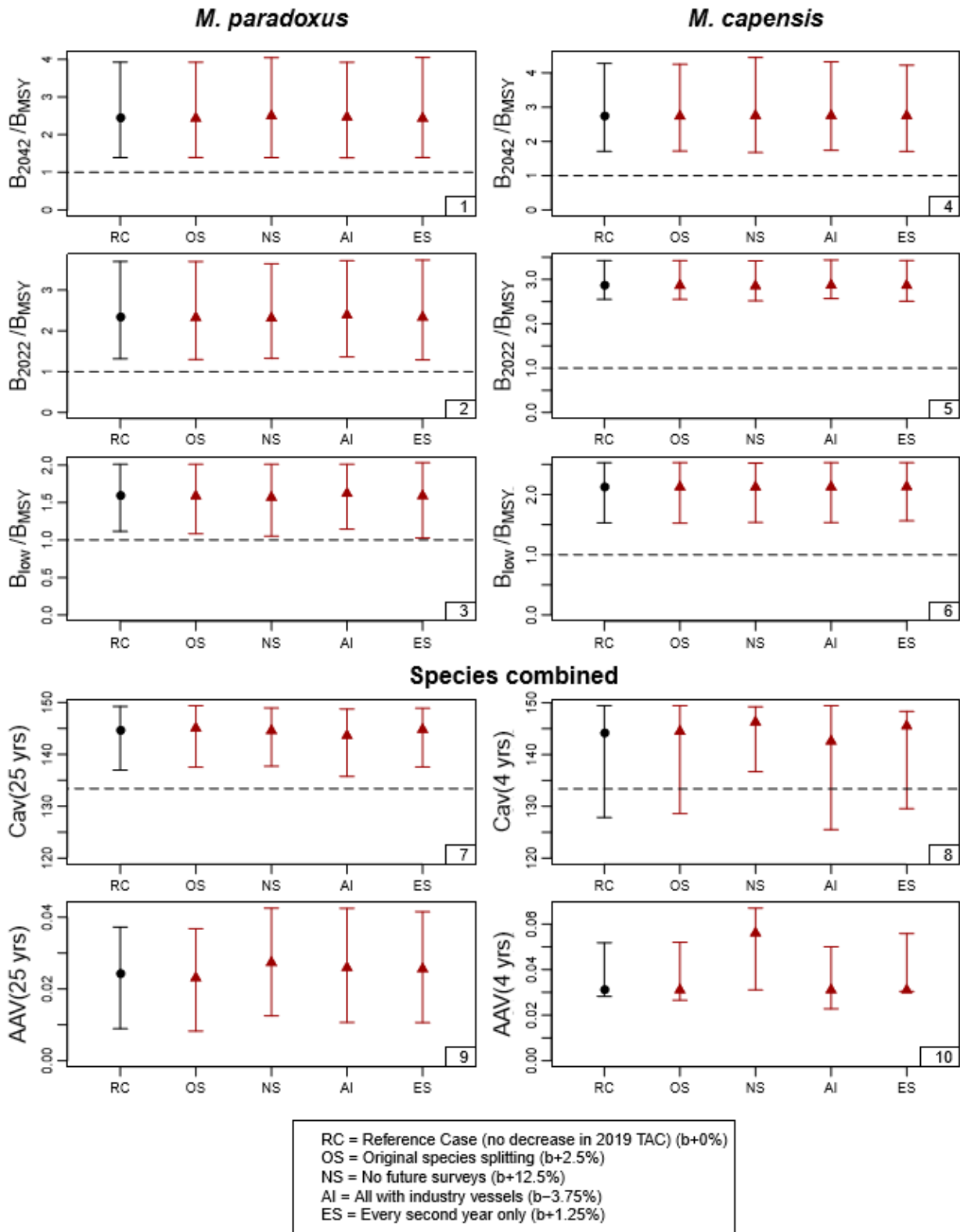


Figure 2a: Median estimates and 90% probability intervals for the projected catch over the next four years (i.e. the planned life span of OMP2018) for the first three (untuned) robustness tests and four OMP rule options.



**Figure 2b:** Median estimates and 90% probability intervals for the projected catch over the next four years (i.e. the planned life span of OMP2018) for the second three (untuned) robustness tests and four OMP rule options. As before “NS” refers to “no future surveys” and “UCI” refers to the robustness test assuming a 2% p.a. undetected catchability increase.



**Figure 3:** Zeh plots of the performance statistics for the re-tuned CMPs for the first four robustness tests. For each CMP, the *b* parameter was tuned so that the lower 5<sup>th</sup> percentile of *M. paradoxus* B(2042)/B<sub>MSY</sub> was within 0.5% of the Reference Case value, where this retuning was done only for the RC for the CMP with a cap of 150 000t and no change in *b*. The legend reports the percentage by which the *b* parameter had to be changed in each case to match the RC *M. paradoxus* depletion value. The corresponding values can be found Table 2 a and b.

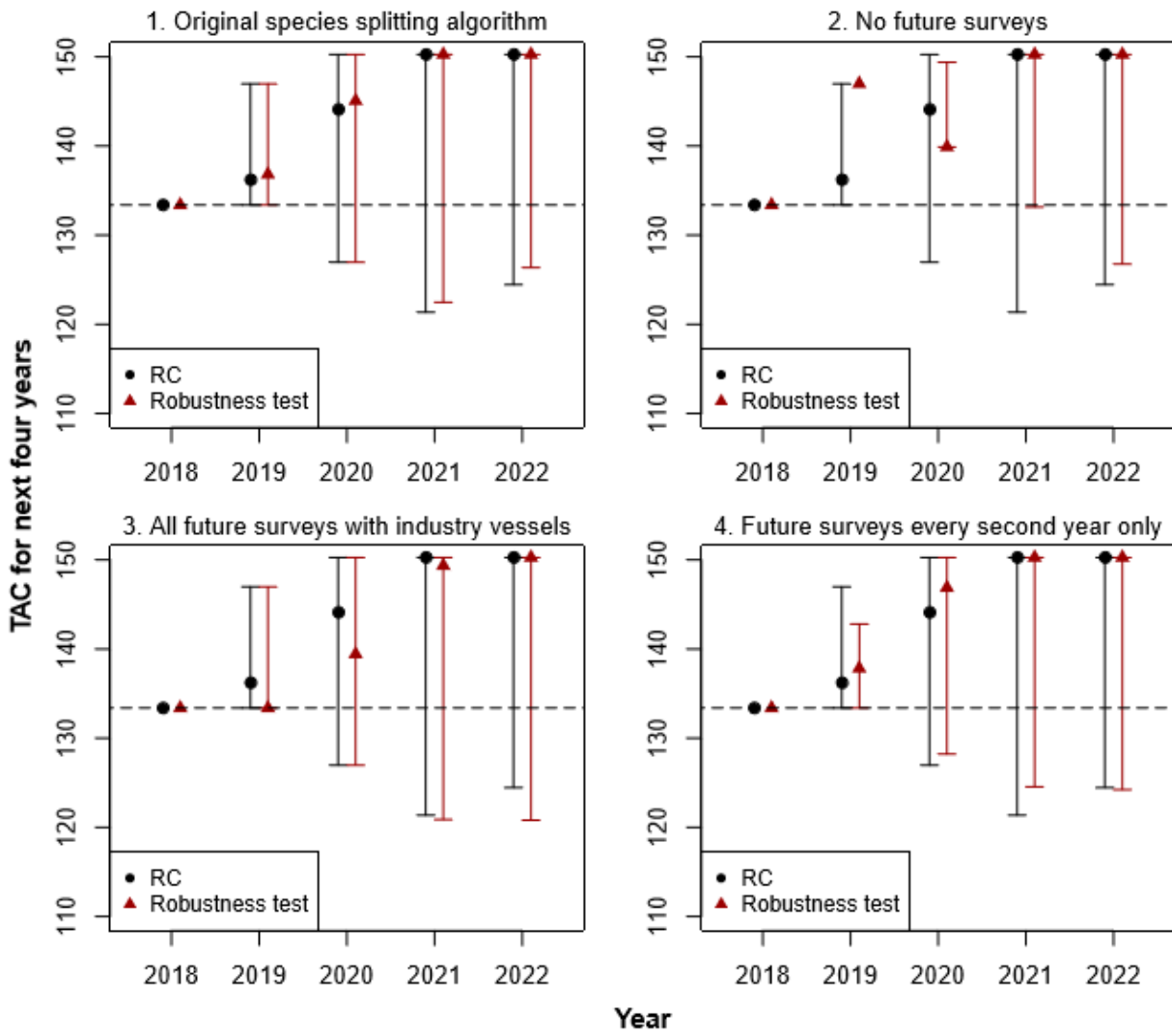
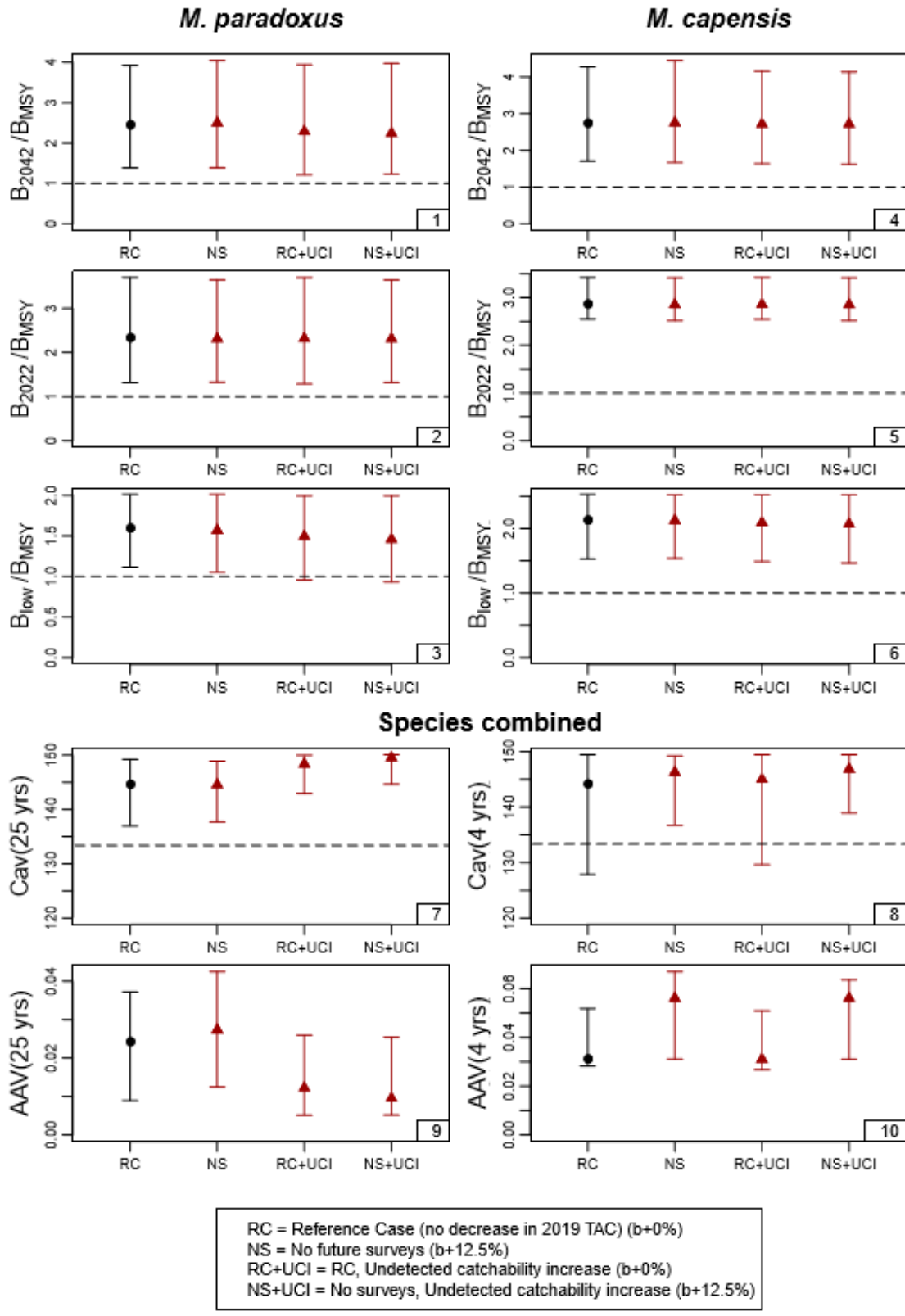
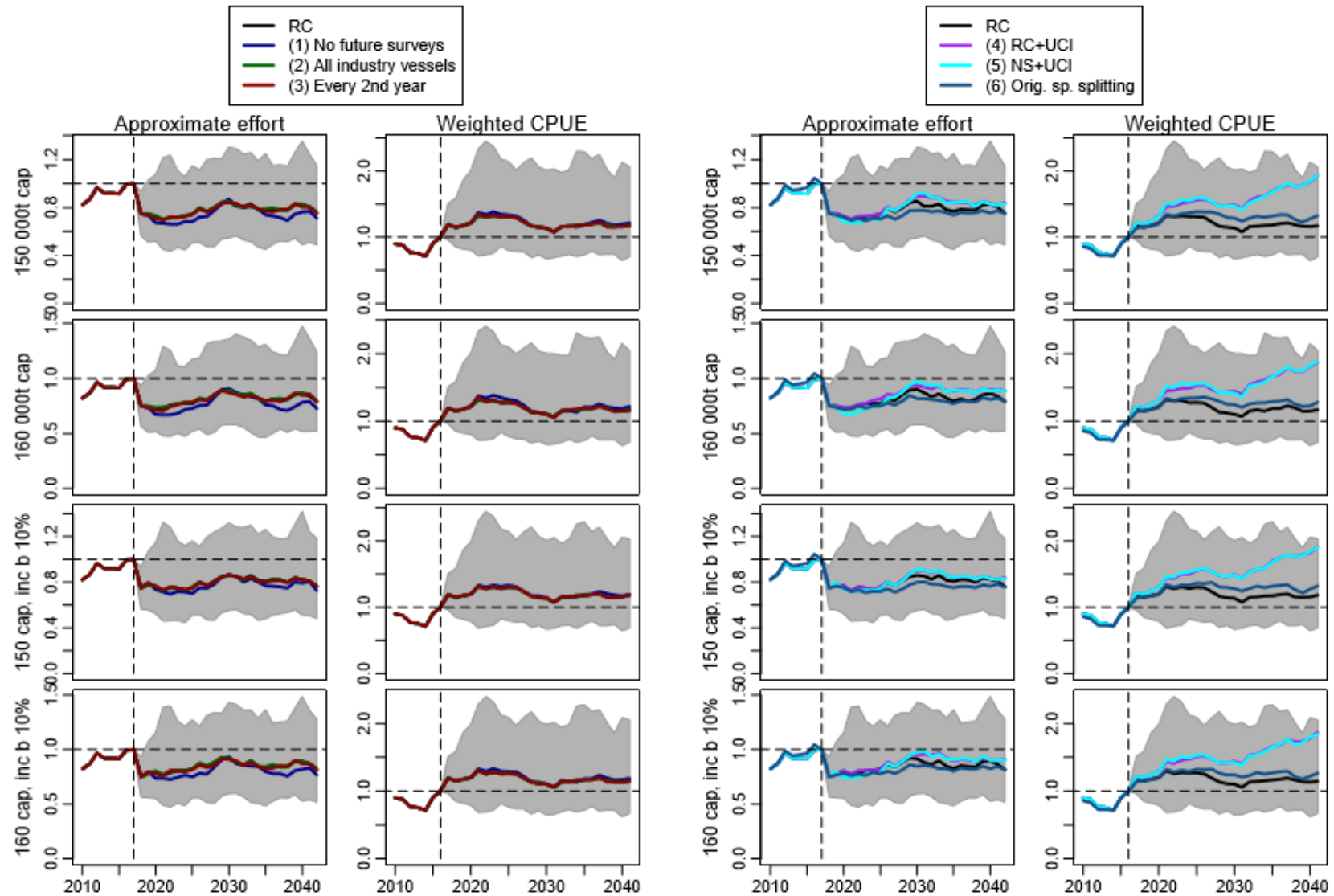


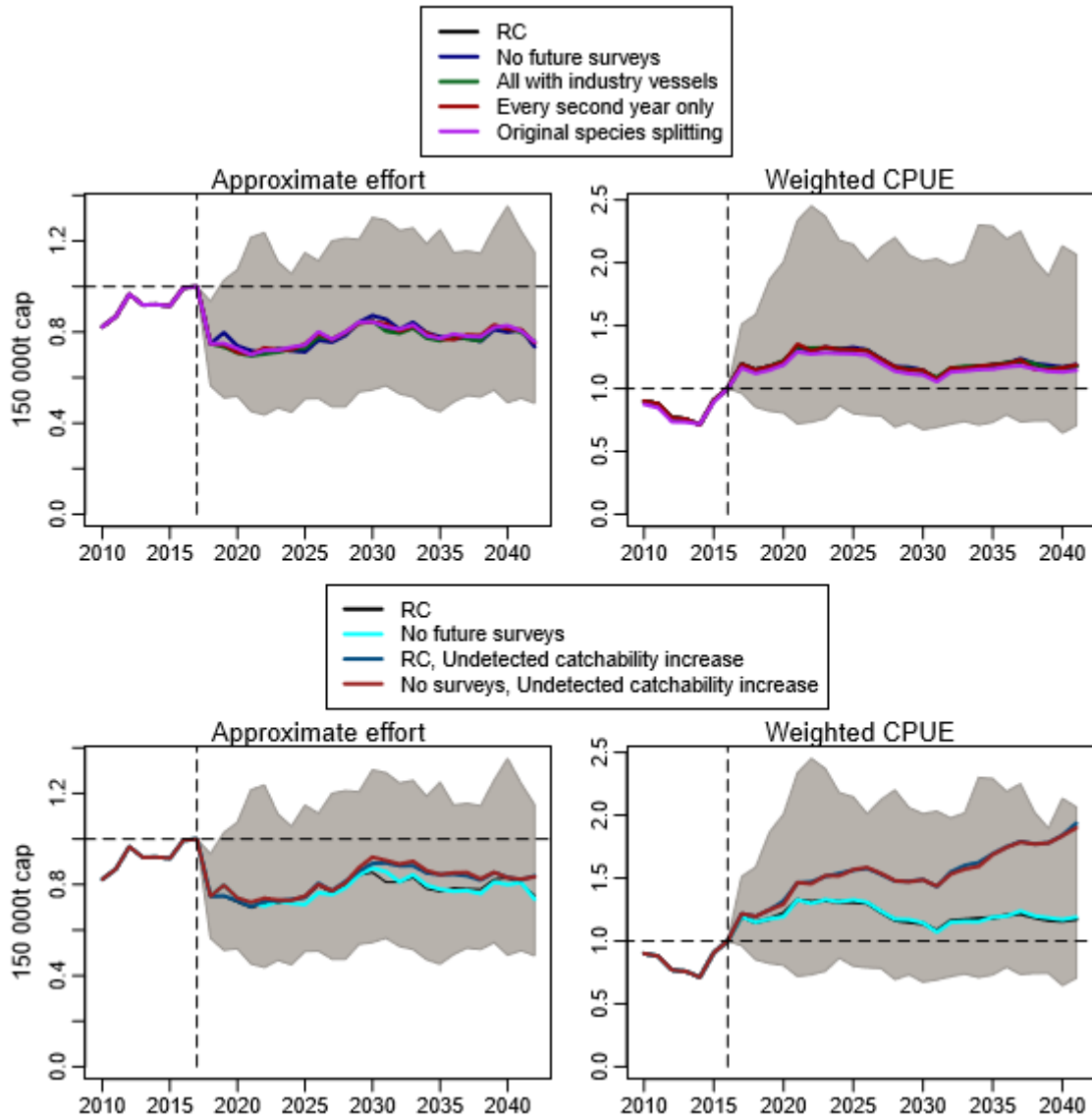
Figure 4: The immediate TAC projected for the next four years for the **four re-tuned robustness tests** from Figure 3. In each plot, the black circles correspond to the RC with a cap of 150 000t and no change in b.



**Figure 5:** Zeh plots of the performance statistics illustrating the impact of an **undetected increased in commercial catchability**. The four sets of results included are the RC, the re-tuned no future survey robustness test, the RC with an undetected increase in future catchability and no future surveys combined with an undetected increase in catchability (for the same change in *b* as the returned no surveys robustness test). The corresponding values can be found in rows 1 and 2 of Table 2a and b and rows 17 and 23 of Table 1a and b.



**Figure 6:** Median trajectories for approximate effort (taken as the *M. paradoxus* fishing mortality rate) and coast- and species-combined CPUE are shown for the RC and **the six untuned robustness tests** (i.e. corresponding to the results reported in Table 1a and b). The grey shaded area is the 90% probability envelope for the RC. The vertical dashed line marks 2017, and the series are normalised so that the values in 2017 are all one.



**Figure 7:** The top row of plots shows the median trajectories for effort and CPUE the RC and **retuned robustness tests** (i.e. corresponding to the results reported in Table 2 and b). The bottom row shows the same for the robustness tests relating to the undetected increase in catchability (i.e. corresponding to results in Table 3).