Management Procedure Robustness Tests for the South African *Merluccius paradoxus* and *M. capensis* Resources under a constant Catch Scenario

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The Reference Set (RS) of operating models for the South African *M. paradoxus* and *M. capensis* resources is the current "best" representation of the actual dynamics for these two resources and the associated major uncertainties. There are however some further uncertainties (in the data, as well as in some of the assumptions made in the RS) that need to be taken into account when testing the performance of candidate OMPs. Management quantities and log-likelihoods are compared for a series of robustness tests, and results for each under a fixed catch scenario are presented.

Robustness tests

A list of these robustness tests and the associated methodologies (developed from discussions in the Demersal Working Group) is given Appendix A. The robustness tests underlined are part of the "shortened list" of robustness tests in document WG/09/05/D:H:33 that was previously agreed by the Working Group, though this needs to be rechecked given subsequent changes to the RS.

Note: Robustness tests in categories I, II and III (see Appendix A) affect past dynamics. These tests have been run for only two of the 48 RS scenarios (as running all 48 scenarios for each robustness test would take too much time). These two cases are **M1**/C3a/H1/SR2 and **M4**/C3a/H1/SR2, except that for test A5 the M4/M1 are amended as appropriate. For robustness tests in category IV, the past estimates are not affected, and can be projected forward for all 48 scenarios constituting the RS without an excessive computational burden.

Results and Discussion

Robustness tests assessments

Table 2 compares the results of the different robustness tests which affect the past assessment (as distinct from the projections only), Table 2a is for scenario M1/C3a/H1/SR2 and Table 2b is for scenario M4/C3a/H1/SR2 (these two cases were chosen as perhaps the most plausible of these in the RS). To aid the reader, estimates of K^{sp}, MSY, B^{sp}_{2004}/K^{sp}, $B^{sp}_{2004}/MSLY^{sp}$ and the 2004 species ratios (B^{sp} and B^{4+}) for both species are highlighted where they differ by more than 15% from the RS estimates. The total log-likelihood and the contribution of each data source for each of these tests are compared in Tables 3a (scenario M1/C3a/H1/SR1) and 3b (M4/C3a/H1/SR2). Again, to aid the reader, cases are highlighted for which the negative log-likelihood differs by more than 5 points above that of the RS.

Fig. 1 compares the spawning biomass trajectories for the RS and robustness tests A7 (Ricker-like) and A8 (force depletion). Results for these two robustness tests only are shown because the estimate of current depletion differ markedly from that of the RS.

I. Different assumptions about discards and catch series

As expected, the productivity of both resources (but *M. paradoxus* particularly) is estimated to be higher when discards are assumed (A1a-c) than for the RS. MSY, which includes the discard contribution, is increased by more than 20 thousand tons for *M. paradoxus* and more than 5 thousand tons for *M. capensis*. In all three cases the likelihood is slightly improved.

Changing the catch series, either by including the unreported south coast catches (A2) or decreasing the recent line catches (A11) scarcely affect the assessments compared to the RS.

II. Different assumptions about biological information

In test A3, the variability of the stock-recruitment fluctuations is increased; this does not seem to affect the assessments substantially compared to the RS (note the negative log-likelihood is not comparable to that of the RS).

Changing the upper bounds for natural mortality to 1.0 and 0.3 for ages 2 and 5 respectively (test A5a) and to 0.5 for both ages (test A5b) leads to decreases in K and a slightly improved fit in most cases, but otherwise does not seem to affect the assessments much compared to the RS cases with comparable upper bounds at higher ages.

In robustness test A7, the stock-recruitment function is forced to take a “Ricker-like” shape. The results for *M. paradoxus* of this test are substantially different from those of the RS, both in terms of productivity (MSY increases by more than 100 thousand tons) and in terms of current depletion (current spawning biomass is estimated above 20% of pristine compared to less than 10% for the RS). Note also that in the M4/C3a/H1/SR2 case, the natural mortality for this species is substantially decreased for all age classes. Results for *M. capensis* are much less affected.

Assuming that some percentage of fish of age 3 are mature (tests A9a-b) leads to a slightly more optimistic view of the current status of both resources.

Assuming a size-dependence of the spawning output has a substantial effect on the results for *M. paradoxus* when the natural mortality is forced to be below 0.5 and 0.3 for ages 2 and 5 respectively (i.e. case M1/C3a/H1/SR2).

III. Others

Test A8 (current depletion is forced to 30% for *M. paradoxus* and 40% for *M. capensis*) affects the results appreciably.

Tests B4a-b (different calibration factor for the *Africana*) have very little effect on the assessment results.

Robustness tests projections

For the robustness tests for which only two scenarios have been considered (categories I, II and III), 50 replicates (for each scenario) have been run – giving a total of 100 trajectories. For comparison purposes, the same has been done for the two associated RS cases. For the robustness tests in grouping IV, 3 replicates of the whole RS have been run.

The full set of performance statistics under the scenario of a constant future catch of 142 thousand tons is shown graphically in Figs 2-5.

I. Different assumptions about discards and catch series – Fig. 2a-c

Tests A1a-c do not project the discarding in the future, which essentially represents a cut in the catches. This results in optimistic projections, for *M. paradoxus* particularly, compared to the RS. Tests B3a-c however, for which the discarding is assumed to continue in the future as in the past, show similar results to the RS, except for test B3c (in which future discarding of fish of age 3 – as well as ages 1 and 2 – occurs) which show problematic declines in *M. paradoxus* and even *M. capensis*.

Results for projections for tests A2 and A11 (changes in the catch series) are not substantially different from those of the RS

II. Different assumptions about biological information – Fig. 3a-c

Projections with the robustness tests which involve assumptions about the biology of the resources do not differ greatly from those of the RS. The only exception is test A7 (Ricker-like stock-recruitment curve) for *M. paradoxus*. In this test, *M. paradoxus* is estimated to be more productive than in the RS and this results in greater future recovery under fixed catches.

Comments on tests A10b-c are reserved at this stage, pending completion of all tests.

III. Others – Fig. 4a-c

Test B7, in which future variability in stock-recruitment fluctuations is increased in conjunction with increased variability in the past, has unsurprisingly wide probability intervals.

Tests A4, which assumes a 30% decrease in the carrying capacity in the past (test A4) has yet to be completed.

Test A8 (the depletion is forced up to 30% for *M. paradoxus* and down to 40% for *M. capensis*) is an interesting case as spawning biomass (in terms of pristine and current levels) for both species move in opposite directions relative to RS. Furthermore, not unexpectedly, results move in opposite directions for *M. paradoxus* and *M. capensis* compared to the RS.

The three catch strategies tested here are fixed catches scenarios, with no feedback mechanism using survey information for example. Assuming a different calibration factor for *Africana* with the old and new gear (B4a-b) has therefore no impact on the projections, computed here.

IV. Changes in the future – Fig. 5a-c

Note that the tests in this category are projected in the future using the whole RS, as opposed to two scenarios only for the tests above. This explains the wider probability intervals for the RS in Fig. 5 compared to those one in the previous three Figs 2-4.

Only a future decrease in carrying capacity (B8) provides appreciably different results to those of the RS, with both resources projected to decrease substantially under a constant catch of 142 thousand tons.

Table 1a: Estimates of management quantities of the *M. paradoxus* and *M. capensis* coast-combined resources for the robustness tests which affect the past assessment, for option M1/C3a/H1/SR2. MSY and associated quantities are given for the offshore fleet. Cells are shaded in cases where of K^{sp}, MSY, B^{sp}_{2004}/K^{sp} , $B^{sp}_{2004}/MSLY^{sp}$ and the 2004 species ratios (B^{sp} and B^{4+}) differ by more than 15%, or –lnL differs by more then 5 points, from the RS estimates.

		I					II								III			
	RS	A1a	A1b	A1c	A2	A11	A3	A5a	A7	A9a	A9b	A10a	A10b	A10c	A4	A8	B4a	B4b
		(disc1)	(disc2)	(disc3)	(SC unrep catches)	(line catches)	(σ_R= 0.4)	(M2)	(Ricker-like)	(dens dep mat)	(mat=3)	(size-dep spawn)	(size-dep spawn)	(size-dep spawn)	(decr K in past)	(force depl-etion)	(cal factor =0.6)	(cal factor =0.9)
-lnL total	-169.5	-171.6	-171.3	-170.9	-169.9	-169.4	-176.4	-174.6	-170.9	-171.6	-171.6	-167.1				-156.1	-168.7	-169.6
M. paradoxus																		
K^{sp}	2406	2947	2954	2959	2410	2406	2438	1710	1394	2300	2447	14701				4020	2407	2406
h	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95				0.80	0.95	0.95
MSY	155	186	186	187	156	155	158	130	272	151	152	223				192	155	155
B^{sp}_{2004}/K^{sp}	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.08	0.22	0.09	0.09	0.06				0.30	0.07	0.07
$B^{sp}_{2004}/MSYL^{sp}$	0.33	0.33	0.33	0.33	0.33	0.34	0.33	0.44	4.84	0.40	0.41	0.25				1.20	0.33	0.33
M 0	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	0.50	0.50	0.50	0.50				0.50	0.50	0.50
1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	0.50	0.50	0.50	0.50				0.50	0.50	0.50
2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	0.50	0.50	0.50	0.50				0.50	0.50	0.50
3	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.65	0.40	0.40	0.40	0.30				0.40	0.40	0.40
4	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.44	0.34	0.34	0.34	0.18				0.34	0.34	0.34
5+	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.10				0.30	0.30	0.30
M. capensis																		
K^{sp}	860	940	941	936	864	861	853	820	876	862	896	887				885	859	861
h	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95				0.95	0.95	0.95
MSY	61	66	66	66	61	61	60	60	62	61	61	59				62	61	61
B^{sp}_{2004}/K^{sp}	0.35	0.35	0.34	0.34	0.34	0.36	0.32	0.33	0.37	0.38	0.37	0.37				0.40	0.35	0.35
$B^{sp}_{2004}/MSYL^{sp}$	1.38	1.41	1.36	1.36	1.36	1.42	1.29	1.36	1.49	1.38	1.35	1.21				1.59	1.39	1.38
M 0	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	0.50	0.50	0.50	0.50				0.50	0.50	0.50
1	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	0.50	0.50	0.50	0.50				0.50	0.50	0.50
2	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	0.50	0.50	0.50	0.50				0.50	0.50	0.50
3	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.65	0.40	0.40	0.40	0.40				0.40	0.40	0.40
4	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.44	0.34	0.34	0.34	0.34				0.34	0.34	0.34
5	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30				0.30	0.30	0.30
6	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30				0.30	0.30	0.30
7+	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30				0.30	0.30	0.30
SC survey q	1.06	0.99	0.97	1.00	1.07	1.05	1.09	1.12	1.00	1.04	1.06	1.00				0.95	1.08	1.04
2004 species ratio B^{sp}	1.89	1.80	1.76	1.74	1.88	1.92	1.70	2.03	1.09	1.58	1.51	0.35				0.29	1.89	1.89
B^{2+}	1.11	1.10	1.08	1.06	1.10	1.13	1.01	1.02	0.76	1.26	1.20	0.36				0.28	1.11	1.11

Table 1b: Estimates of management quantities of the *M. paradoxus* and *M. capensis* coast-combined resources for the robustness tests which affect the past assessment, for option M4/C3a/H1/SR2. MSY and associated quantities are given for the offshore fleet. Cells are shaded in cases where of K^{sp}, MSY, $B^{sp}{}_{2004}/K^{sp}$, $B^{sp}{}_{2004}/MSLY^{sp}$ and the 2004 species ratios (B^{sp} and B^{4+}) differ by more than 15% or –lnL differs by more then 5 points, from the RS estimates.

			I					II								III			
		RS	A1a (disc1)	A1b (disc2)	A1c (disc3)	A2 (SC unrep catches)	A11 (line catches)	A3 (σ_R =0.4)	A5b (M2)	A7 (Ricker-like)	A9a (dens dep mat)	A9b (mat=3)	A10a (size-dep spawn)	A10b (size-dep spawn)	A10c (size-dep spawn)	A4 (decr K in past)	A8 (force depl-etion)	B4a (cal factor =0.6)	B4b (cal factor =0.9)
	-lnL total	-179.5	-183.7	-183.5	-182.6	-179.5	-179.4	-185.2	-179.0	-176.7	-181.5	-181.5	-175.3				-167.5	-178.7	-179.6
M. paradoxus	K^{sp}	1360	1285	1291	1337	1368	1360	1368	1126	1543	1409	1526	1230				1060	1362	1359
	h	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95				0.76	0.95	0.95
	MSY	127	152	153	153	127	127	127	136	265	126	126	128				133	127	127
	$B^{sp}{}_{2004}/K^{sp}$	0.08	0.09	0.08	0.08	0.08	0.09	0.08	0.09	0.19	0.14	0.13	0.12				0.30	0.08	0.08
	$B^{sp}{}_{2004}/MSYL^{sp}$	0.52	0.61	0.60	0.58	0.51	0.53	0.51	0.52	4.64	0.65	0.67	0.56				1.24	0.52	0.52
	M 0	1.00	0.96	0.97	0.97	1.00	1.00	1.00	0.50	0.92	1.00	1.00	1.00				1.00	1.00	1.00
	1	1.00	0.96	0.97	0.97	1.00	1.00	1.00	0.50	0.92	1.00	1.00	1.00				1.00	1.00	1.00
	2	1.00	0.96	0.97	0.97	1.00	1.00	1.00	0.50	0.92	1.00	1.00	1.00				1.00	1.00	1.00
	3	0.67	0.68	0.69	0.69	0.67	0.67	0.67	0.48	0.58	0.66	0.67	0.70				0.75	0.67	0.67
	4	0.48	0.52	0.52	0.51	0.48	0.48	0.48	0.47	0.37	0.46	0.46	0.51				0.60	0.48	0.48
	5+	0.35	0.41	0.41	0.40	0.34	0.35	0.34	0.46	0.24	0.33	0.33	0.39				0.50	0.35	0.35
M. capensis	K^{sp}	592	661	658	660	597	594	597	640	600	598	699	577				671	590	593
	h	0.85	0.91	0.89	0.89	0.84	0.86	0.84	0.95	0.85	0.79	0.81	0.95				0.95	0.84	0.86
	MSY	76	92	90	90	76	76	76	75	76	80	78	71				67	75	76
	$B^{sp}{}_{2004}/K^{sp}$	0.53	0.53	0.49	0.50	0.53	0.54	0.53	0.51	0.55	0.61	0.59	0.52				0.40	0.53	0.53
	$B^{sp}{}_{2004}/MSYL^{sp}$	2.30	2.67	2.38	2.40	2.25	2.38	2.25	2.48	2.34	1.87	2.10	1.79				1.94	2.25	2.32
	M 0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00	1.00				1.00	1.00	1.00
	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00	1.00				1.00	1.00	1.00
	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.50	1.00	1.00	1.00	1.00				1.00	1.00	1.00
	3	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.47	0.75	0.75	0.75	0.75				0.69	0.75	0.75
	4	0.60	0.60	0.60	0.60	0.60	0.59	0.60	0.46	0.60	0.60	0.59	0.60				0.51	0.60	0.59
	5	0.49	0.50	0.50	0.50	0.50	0.49	0.50	0.45	0.49	0.50	0.49	0.50				0.39	0.50	0.49
	6	0.49	0.50	0.50	0.50	0.50	0.49	0.50	0.45	0.49	0.50	0.49	0.50				0.39	0.50	0.49
	7+	0.49	0.50	0.50	0.50	0.50	0.49	0.50	0.45	0.49	0.50	0.49	0.50				0.39	0.50	0.49
	SC survey *q*	0.72	0.65	0.68	0.68	0.71	0.71	0.71	0.72	0.69	0.70	0.70	0.74				0.94	0.74	0.71
2004 species ratio	B^{sp}	2.73	3.14	2.99	3.00	2.77	2.75	2.77	3.25	1.12	1.89	2.06	2.07				0.85	2.73	2.73
	B^{2+}	1.44	1.56	1.48	1.48	1.46	1.45	1.46	1.54	0.95	1.55	1.54	1.23				0.59	1.45	1.43

Table 2a: Log-likelihood contributions for resources for the robustness tests which affect the past assessment, for scenario M1/C3a/H1/SR2. Cells are shaded in cases for which the negative log-likelihood differs by more than 5 points from that of the RS.

			I					II								III			
		RS	A1a (disc1)	A1b (disc2)	A1c (disc3)	A2 (SC unrep catches)	A11 (line catches)	A3 (σ_R= 0.4)	A5a (M2)	A7 (Ricker-like)	A9a (dens dep mat)	A9b (mat=3)	A10a (size-dep spawn)	A10b (size-dep spawn)	A10c (size-dep spawn)	A4 (decr K in past)	A8 (force depl-etion)	B4a (cal factor =0.6)	B4b (cal factor =0.9)
-lnL: Total		-169.5	-171.6	-171.3	-170.9	-169.9	-169.4	-176.4	-174.6	-170.9	-171.6	-171.6	-167.1				-156.1	-168.7	-169.6
-lnL: CPUE	WC historic (spp combined)	-10.0	-9.9	-9.9	-9.8	-9.9	-10.0	-10.0	-10.1	-10.6	-10.2	-10.2	-9.5				-10.0	-10.0	-10.0
	SC historic (spp combined)	-29.4	-29.1	-29.1	-29.1	-29.4	-29.4	-29.3	-29.3	-25.3	-29.2	-29.2	-28.9				-26.5	-29.4	-29.4
	M. paradoxus GLM	-41.7	-41.5	-41.5	-40.7	-41.7	-41.7	-40.1	-42.3	-38.8	-41.2	-41.3	-40.8				-42.8	-41.7	-41.7
	M. capensis GLM	-41.7	-40.9	-40.6	-40.8	-42.1	-41.7	-41.5	-42.4	-42.0	-41.8	-41.9	-40.6				-41.9	-41.7	-41.7
-lnL: Survey	*M. paradoxus* , WC summer	-8.0	-7.8	-7.9	-8.2	-8.0	-8.0	-7.4	-8.3	-6.8	-8.2	-8.1	-6.9				-6.7	-8.0	-8.0
	M. paradoxus , WC winter	-4.0	-3.9	-3.9	-3.9	-4.0	-4.0	-3.8	-4.0	-3.6	-4.0	-4.0	-3.7				-3.5	-4.0	-4.0
	M. paradoxus , WC *Nansen*	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.7	-1.9	-1.7	-1.9	-1.9	-1.7				-1.6	-1.8	-1.8
	M. paradoxus , SC spring	-0.5	-0.3	-0.3	-0.2	-0.5	-0.5	-0.5	-0.5	-0.3	-0.5	-0.5	-0.2				-0.2	-0.5	-0.5
	M. paradoxus , SC autumn	6.7	6.7	6.7	6.8	6.7	6.7	6.8	6.6	7.0	6.6	6.7	6.7				6.9	6.7	6.7
	M. capensis , WC summer	-1.8	-1.8	-1.8	-1.8	-1.8	-1.8	-1.7	-1.7	-1.7	-1.8	-1.8	-1.8				-1.8	-0.8	-2.1
	M. capensis , WC winter	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4				0.4	0.3	0.4
	M. capensis , WC *Nansen*	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4				-1.4	-1.4	-1.4
	M. capensis , SC spring	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6	-1.6				-1.5	-1.6	-1.5
	M. capensis , SC autumn	-7.8	-7.8	-7.9	-7.9	-7.8	-7.7	-7.8	-7.8	-7.8	-7.8	-7.8	-7.8				-7.8	-7.8	-7.6
-lnL: commercial CAA	species combined, offshore	-38.9	-40.5	-40.5	-40.3	-38.9	-38.9	-38.9	-42.3	-38.9	-39.8	-39.7	-37.2				-30.4	-38.9	-38.9
	M. capensis , inshore	-22.4	-22.2	-22.3	-22.4	-22.5	-22.4	-22.2	-23.5	-22.0	-22.4	-22.4	-22.2				-21.9	-22.5	-22.4
	M. capensis , longline	-14.4	-14.1	-14.3	-14.1	-14.4	-14.4	-14.8	-14.8	-14.1	-14.4	-14.4	-14.2				-14.0	-14.4	-14.4
-lnL: survey CAA	*M. paradoxus* , WC summer	-11.8	-12.6	-12.3	-11.6	-11.8	-11.8	-12.8	-11.1	-15.5	-11.9	-12.0	-13.2				-12.8	-11.8	-11.8
	M. paradoxus , WC *Nansen*	-11.7	-12.1	-12.2	-12.4	-11.7	-11.7	-12.1	-11.8	-11.1	-11.6	-11.6	-12.0				-11.8	-11.7	-11.7
	M. paradoxus , SC spring	-4.2	-4.7	-4.7	-5.6	-4.2	-4.2	-5.7	-3.4	-5.8	-4.9	-4.9	-5.3				-3.3	-4.2	-4.2
	M. paradoxus , SC autumn	30.2	30.2	30.3	30.6	30.2	30.2	29.5	29.8	29.0	29.8	29.9	29.1				31.1	30.2	30.2
	M. capensis , WC summer	83.8	83.6	83.8	83.6	83.8	83.9	82.9	83.9	83.7	83.8	83.8	83.8				83.7	83.7	83.8
	M. capensis , WC winter	7.0	6.8	6.8	6.8	7.0	7.0	6.5	7.1	6.8	7.0	7.0	7.0				6.7	7.0	7.0
	M. capensis , WC *Nansen*	-6.2	-6.2	-6.3	-6.3	-6.2	-6.1	-6.8	-6.2	-6.2	-6.2	-6.2	-6.2				-6.4	-6.3	-6.2
	M. capensis , SC spring	-7.6	-7.7	-7.7	-7.4	-7.6	-7.7	-6.9	-7.6	-7.6	-7.6	-7.6	-7.6				-7.4	-7.4	-7.7
	M. capensis , SC autumn	-30.0	-30.1	-29.8	-30.3	-30.1	-30.1	-30.0	-30.2	-30.1	-30.0	-30.1	-29.9				-29.9	-30.1	-30.0
Recruit residual penalty		10.9	11.0	10.6	10.1	11.1	11.0	7.0	10.8	10.4	10.8	10.9	11.6				11.3	11.0	10.9

Table 2b: Log-likelihood contributions for resources for the robustness tests which affect the past assessment, for scenario M4/C3a/H1/SR2. Cells are shaded in cases for which the negative log-likelihood increases by more than 5 points from that of the RS.

			I					II								III			
		RS	A1a	A1b	A1c	A2	A11	A3	A5b	A7	A9a	A9b	A10a	A10b	A10c	A4	A8	B4a	B4b
			(disc1)	(disc2)	(disc3)	(SC unrep catches)	(line catches)	(σ_R= 0.4)	(M2)	(Ricker-like)	(dens dep mat)	(mat=3)	(size-dep spawn)	(size-dep spawn)	(size-dep spawn)	(decr K in past)	(force depl-etion)	(cal factor =0.6)	(cal factor =0.9)
-lnL: Total		-179.5	-183.7	-183.5	-182.6	-179.5	-179.4	-185.2	-176.7	-179.0	-181.5	-181.5	-175.3				-167.5	-178.7	-179.6
-lnL: CPUE	WC historic (spp combined)	-10.1	-10.1	-10.2	-10.1	-10.0	-10.0	-10.2	-10.2	-10.4	-10.3	-10.3	-9.9				-10.2	-10.1	-10.0
	SC historic (spp combined)	-29.5	-29.2	-29.2	-29.2	-29.5	-29.5	-29.3	-29.4	-25.5	-29.1	-29.3	-29.1				-27.7	-29.4	-29.5
	M. paradoxus GLM	-42.3	-41.8	-41.8	-41.1	-42.3	-42.3	-40.9	-41.9	-38.9	-41.8	-41.8	-42.9				-43.0	-42.3	-42.3
	M. capensis GLM	-43.6	-43.9	-43.8	-43.8	-43.6	-43.6	-43.5	-43.6	-43.3	-43.5	-43.5	-43.6				-43.9	-43.6	-43.6
-lnL: Survey	*M. paradoxus* , WC summer	-8.7	-8.5	-8.6	-8.8	-8.7	-8.7	-8.1	-9.0	-6.8	-8.7	-8.7	-8.6				-8.2	-8.7	-8.7
	M. paradoxus , WC winter	-4.1	-4.0	-4.0	-4.0	-4.1	-4.1	-4.0	-4.1	-3.7	-4.1	-4.1	-4.0				-3.9	-4.1	-4.1
	M. paradoxus , WC *Nansen*	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.8	-2.0	-1.7	-1.9	-1.9	-1.9				-1.8	-1.9	-1.9
	M. paradoxus , SC spring	-0.5	-0.4	-0.3	-0.3	-0.5	-0.5	-0.5	-0.5	-0.4	-0.5	-0.5	-0.5				-0.6	-0.5	-0.5
	M. paradoxus , SC autumn	6.6	6.6	6.5	6.7	6.6	6.6	6.7	6.6	7.0	6.6	6.6	6.6				6.7	6.6	6.6
	M. capensis , WC summer	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.8	-1.9	-1.9	-1.9	-1.9				-1.8	-0.9	-2.2
	M. capensis , WC winter	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4				0.4	0.3	0.4
	M. capensis , WC *Nansen*	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4				-1.4	-1.4	-1.4
	M. capensis , SC spring	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5				-1.6	-1.5	-1.5
	M. capensis , SC autumn	-7.7	-7.7	-7.8	-7.8	-7.7	-7.7	-7.6	-7.8	-7.8	-7.7	-7.7	-7.7				-7.8	-7.8	-7.6
-lnL: commercial CAA	species combined, offshore	-42.1	-44.3	-44.3	-43.9	-42.1	-42.2	-42.1	-39.3	-41.0	-43.3	-43.3	-39.8				-36.2	-42.1	-42.1
	M. capensis , inshore	-26.2	-26.0	-26.3	-26.3	-26.2	-26.1	-25.6	-24.5	-26.1	-26.2	-26.1	-26.4				-24.8	-26.3	-26.1
	M. capensis , longline	-15.6	-15.5	-15.5	-15.5	-15.6	-15.6	-15.8	-15.5	-15.6	-15.6	-15.6	-15.6				-15.5	-15.6	-15.6
-lnL: survey CAA	*M. paradoxus* , WC summer	-10.9	-11.7	-11.3	-10.8	-10.9	-11.0	-11.8	-11.0	-15.6	-11.1	-11.1	-10.6				-10.5	-10.9	-10.9
	M. paradoxus , WC *Nansen*	-11.8	-12.1	-12.3	-12.4	-11.8	-11.7	-12.2	-11.7	-11.1	-11.7	-11.7	-11.6				-12.6	-11.8	-11.8
	M. paradoxus , SC spring	-3.6	-4.2	-4.5	-5.1	-3.6	-3.5	-4.9	-4.5	-5.7	-4.3	-4.3	-2.7				-2.3	-3.6	-3.6
	M. paradoxus , SC autumn	29.7	29.9	29.9	30.2	29.7	29.8	29.1	29.8	28.7	29.3	29.3	30.1				31.7	29.7	29.7
	M. capensis , WC summer	84.3	83.9	84.2	83.9	84.3	84.3	83.3	84.1	84.4	84.3	84.3	84.3				84.0	84.2	84.4
	M. capensis , WC winter	7.2	6.9	6.9	6.9	7.2	7.2	6.7	7.0	7.2	7.2	7.2	7.3				7.1	7.2	7.2
	M. capensis , WC *Nansen*	-6.2	-6.2	-6.3	-6.3	-6.2	-6.1	-6.8	-6.2	-6.2	-6.2	-6.2	-6.1				-6.1	-6.3	-6.2
	M. capensis , SC spring	-7.9	-7.9	-7.9	-7.7	-7.9	-8.0	-7.3	-7.8	-7.9	-7.8	-7.8	-7.9				-8.0	-7.7	-8.0
	M. capensis , SC autumn	-29.5	-29.8	-29.7	-30.1	-29.5	-29.5	-29.7	-29.6	-29.3	-29.5	-29.5	-29.5				-30.1	-29.6	-29.4
Recruit residual penalty		10.0	10.4	10.2	9.9	10.0	10.0	7.0	9.7	10.6	9.8	9.9	10.0				10.6	10.1	9.9

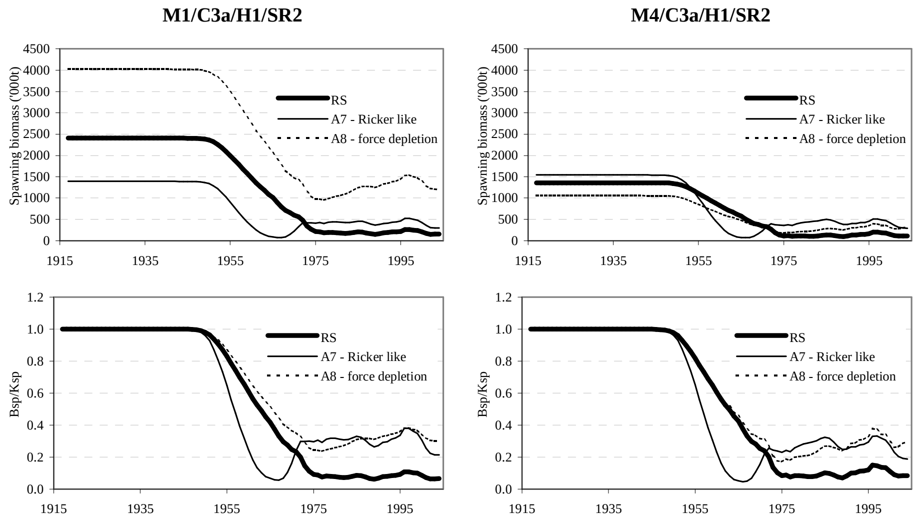


Fig. 1a: *M. paradoxus* Spawning biomass trajectories (in absolute terms and in terms of pre-exploitation level) for cases M1/C3a/H1/SR2 and M4/C3a/H1/SR2 of the Reference Set and, the A7 (Ricker-like) and A8 (force depletion) robustness tests.

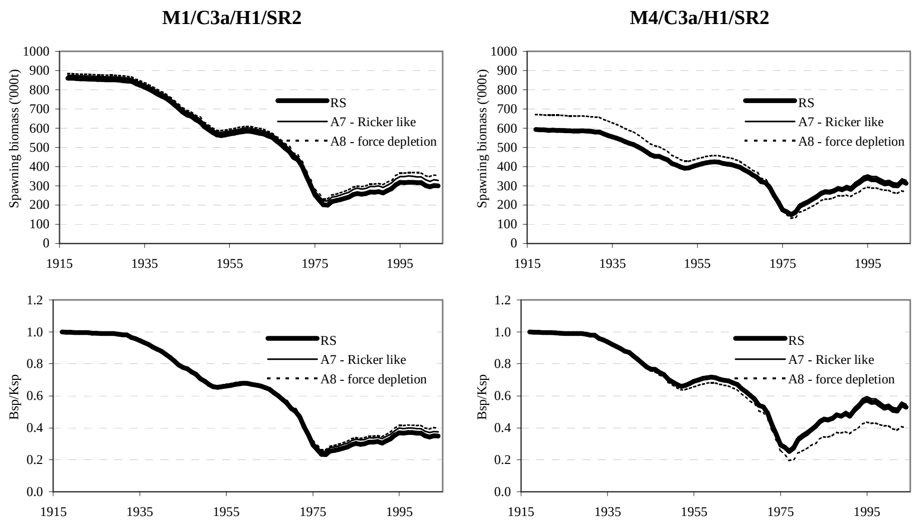


Fig. 1b: *M. capensis* Spawning biomass trajectories (in absolute terms and in terms of pre-exploitation level) for cases M1/C3a/H1/SR2 and M4/C3a/H1/SR2 of the Reference Set and the A7 (Ricker-like) and A8 (force depletion) robustness tests.

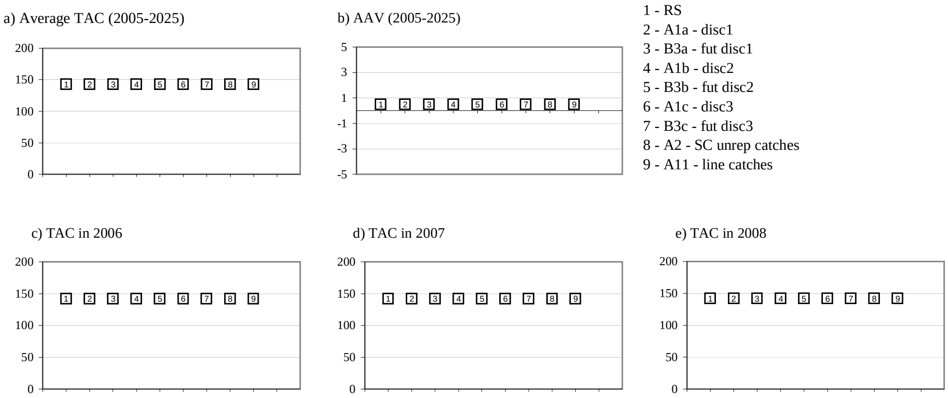
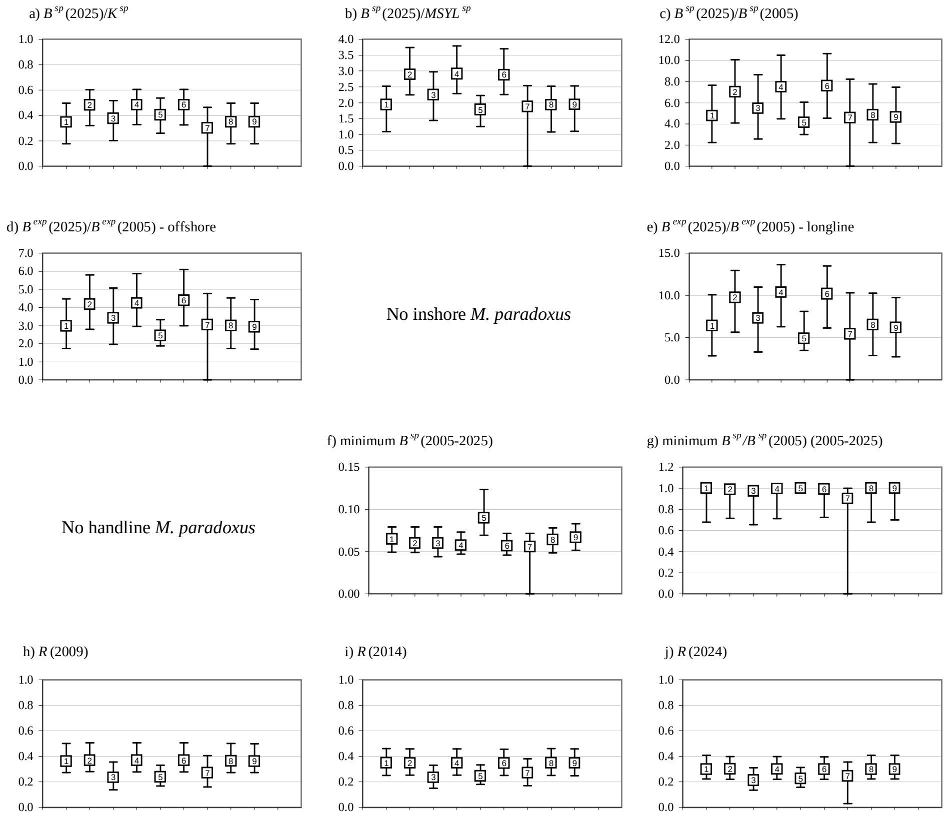


Fig. 2a: Graphical summary of catch performance statistics (median and 95% PI) under a future constant catch of 142 000 t, for a series of robustness tests with different assumptions about discards and catch series.

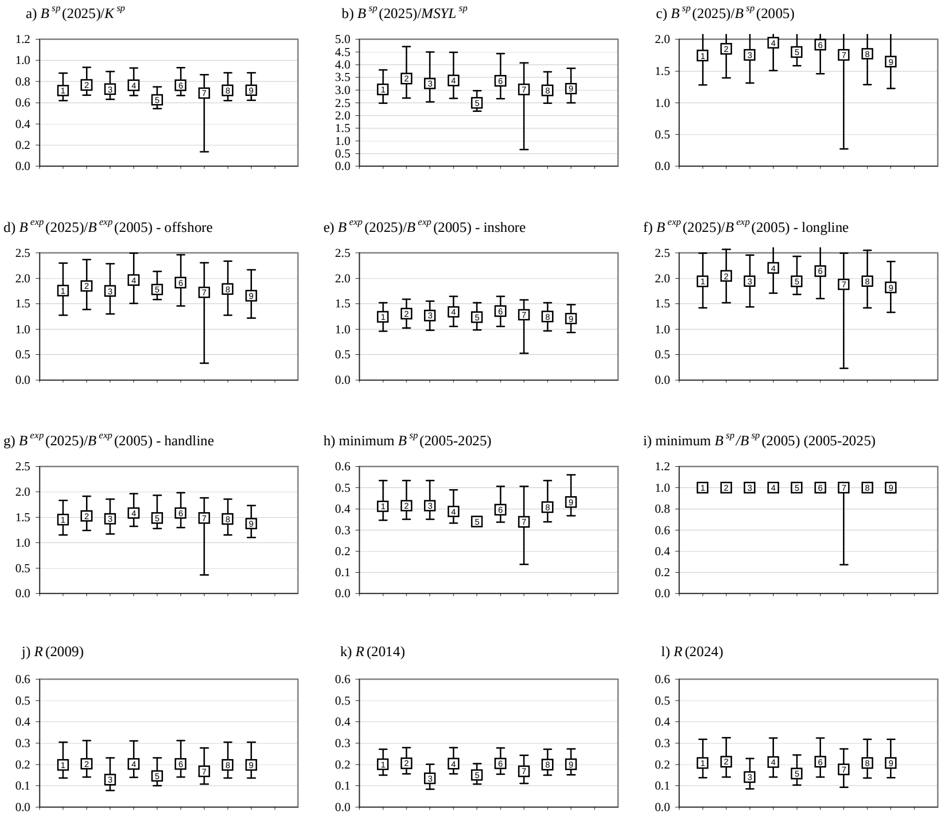
M. paradoxus



1 - RS
2 - A1a - disc1
3 - B3a - fut disc1
4 - A1b - disc2
5 - B3b - fut disc2
6 - A1c - disc3
7 - B3c - fut disc3
8 - A2 - SC unrep catches
9 - A11 - line catches

Fig. 2b. Graphical summary of performance statistics (median and 95% PI) for *M. paradoxus* under a future constant catch of 142 000 t for a series of robustness tests with different assumptions about discards and catch series. Note that the statistics R_{2009}, R_{2014}, R_{2024} represent the proportion by number in the catch that are 3 years old or less, to reflect change in size structure.

M. capensis



1 - RS
2 - A1a - disc1
3 - B3a - fut disc1
4 - A1b - disc2
5 - B3b - fut disc2
6 - A1c - disc3
7 - B3c - fut disc3
8 - A2 - SC unrep catches
9 - A11 - line catches

Fig. 2c. Graphical summary of performance statistics (median and 95% PI) for *M. capensis* under a future constant catch of 142 000 t for a series of robustness tests with different assumptions about discards and catch series. Note that the statistics R_{2009}, R_{2014}, R_{2024} represent the proportion by number in the catch that are 3 years old or less, to reflect change in size structure.

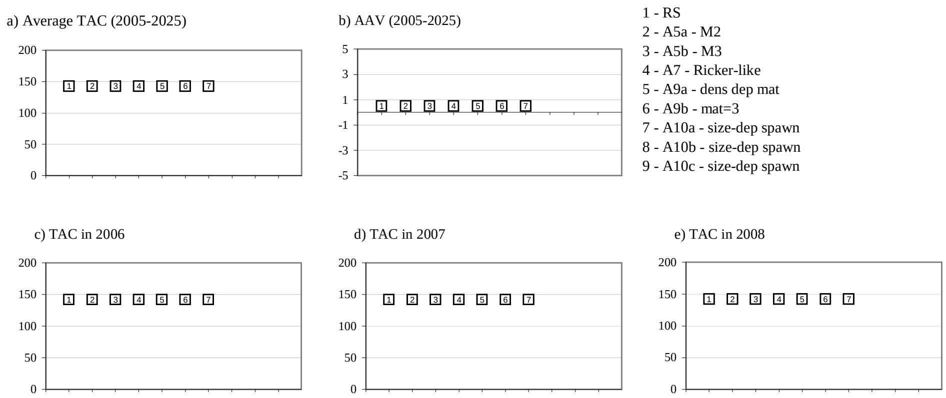
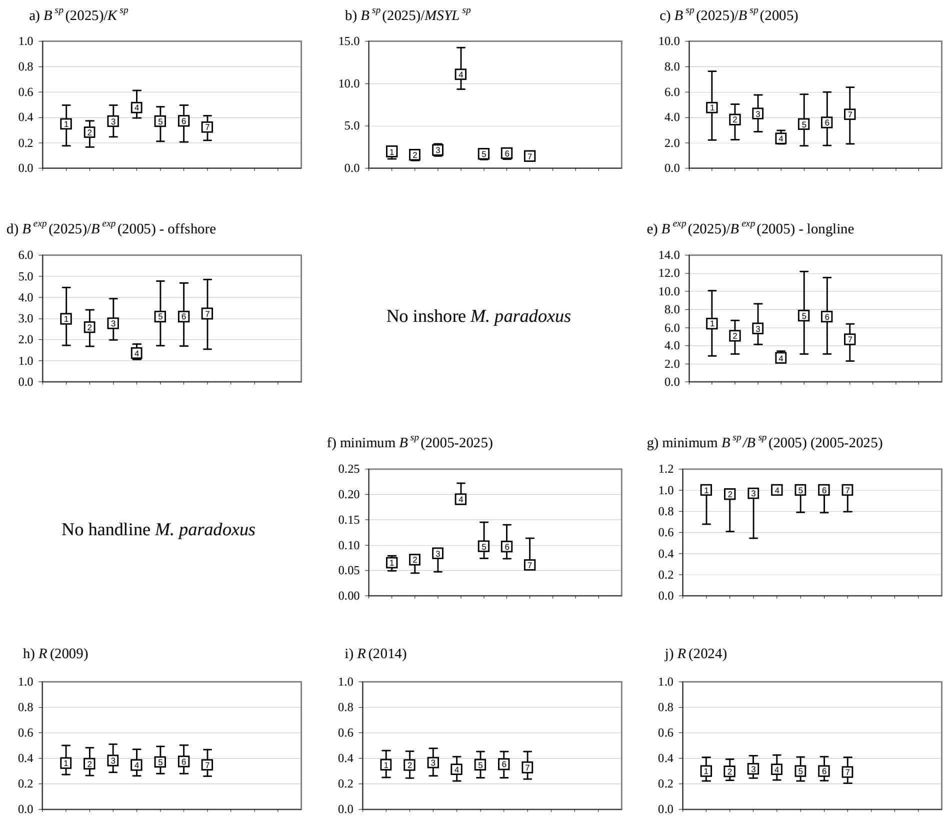


Fig. 3a: Graphical summary of catch performance statistics (median and 95% PI) under a future constant catch of 142 000 t for a series of robustness tests concerning biological assumptions.

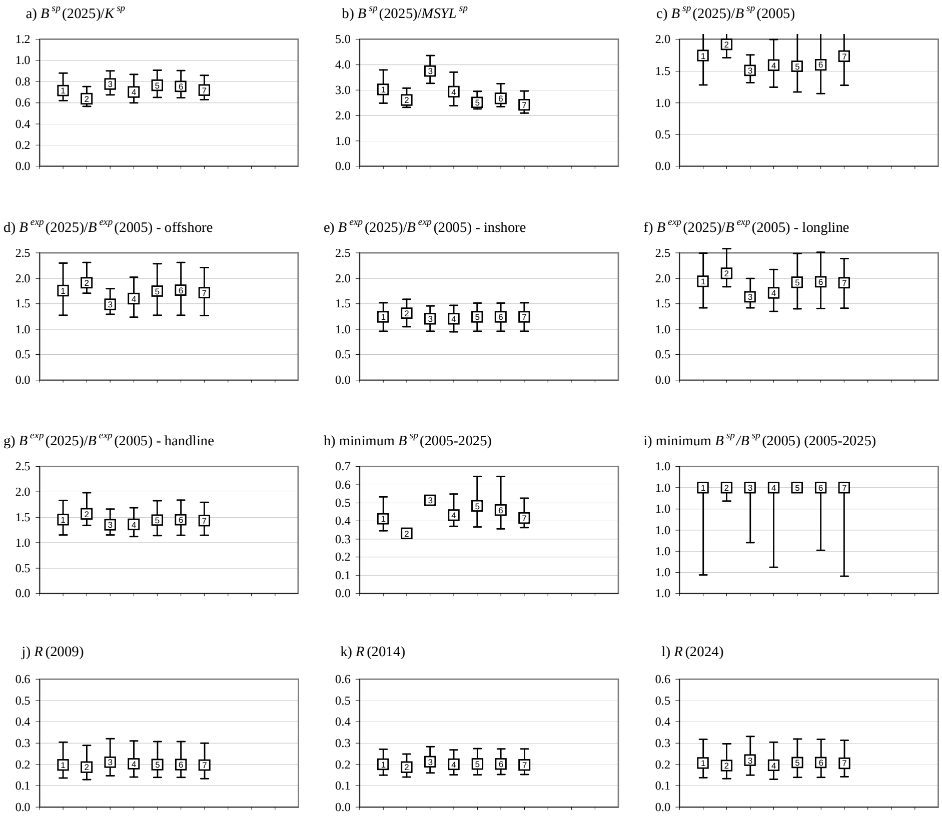
M. paradoxus



1 - RS
2 - A5a - M2
3 - A5b - M3
4 - A7 - Ricker-like
5 - A9a - dens dep mat
6 - A9b - mat=3
7 - A10a - size-dep spawn
8 - A10b - size-dep spawn
9 - A10c - size-dep spawn

Fig. 3b. Graphical summary of performance statistics (median and 95% PI) for *M. paradoxus* under a future constant catch of 142 000 t for a series of robustness tests concerning biological assumptions. Note that the statistics R_{2009}, R_{2014}, R_{2024} represent the proportion by number in the catch that are 3 years old or less, to reflect change in size structure.

M. capensis



1 - RS
2 - A5a - M2
3 - A5b - M3
4 - A7 - Ricker-like
5 - A9a - dens dep mat
6 - A9b - mat=3
7 - A10a - size-dep spawn
8 - A10b - size-dep spawn
9 - A10c - size-dep spawn

Fig. 3c. Graphical summary of performance statistics (median and 95% PI) for *M. capensis* under a future constant catch of 142 000 t for a series of robustness tests concerning biological assumptions. Note that the statistics R_{2009}, R_{2014}, R_{2024} represent the proportion by number in the catch that are 3 years old or less, to reflect change in size structure.

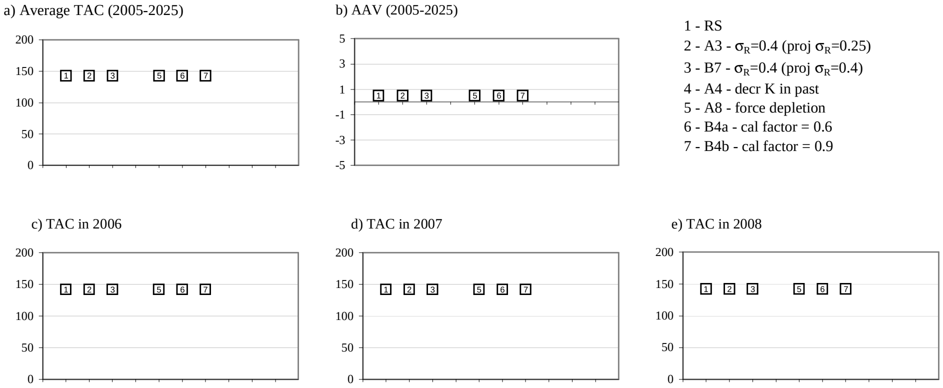
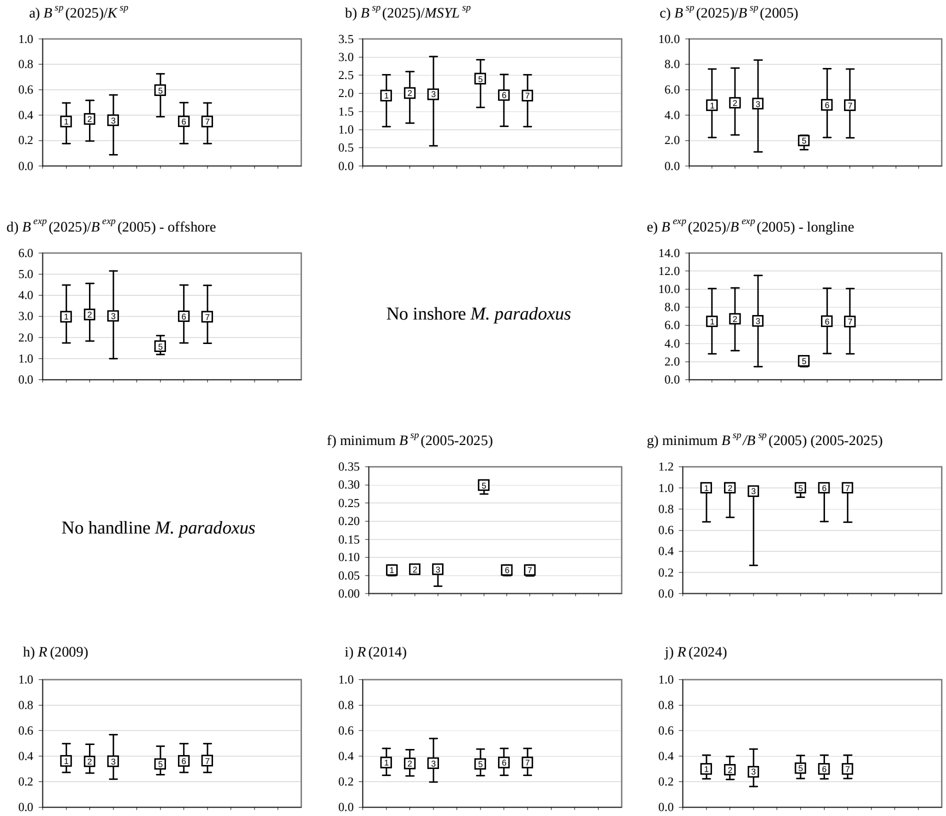


Fig. 4a: Graphical summary of catch performance statistics (median and 95% PI) under a future constant catch of 142 000 t for a series of robustness tests.

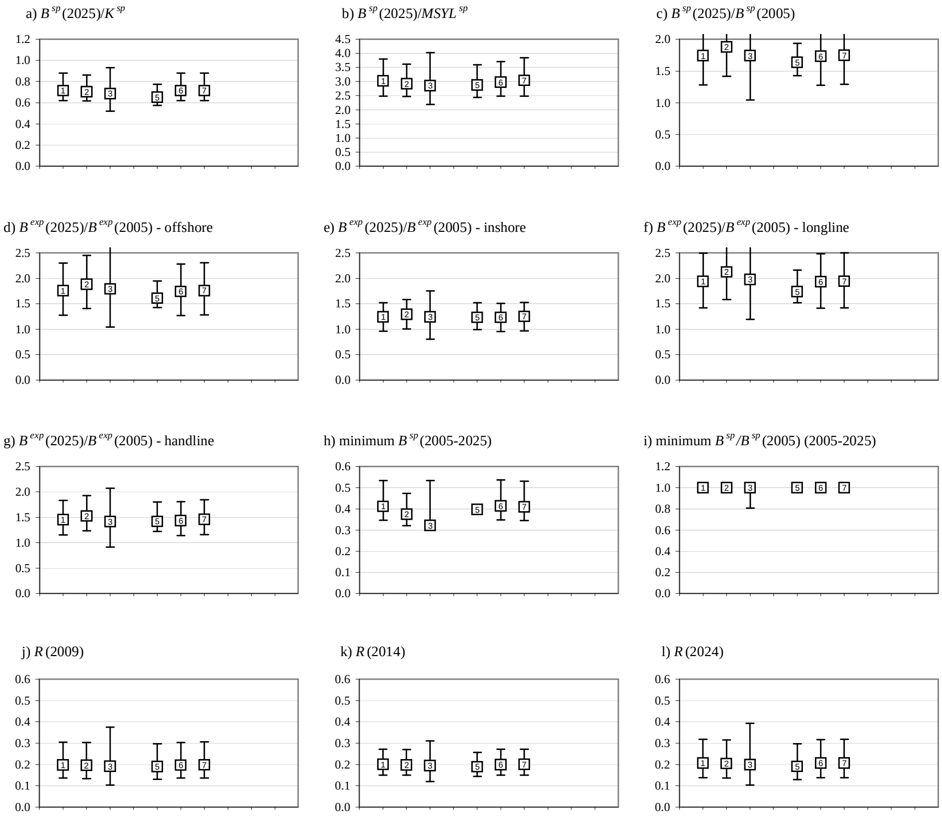
M. paradoxus



1 - RS
2 - A3 - σ_R=0.4 (proj σ_R=0.25)
3 - B7 - σ_R=0.4 (proj σ_R=0.4)
4 - A4 - decr K in past
5 - A8 - force depletion
6 - B4a - cal factor = 0.6
7 - B4b - cal factor = 0.9

Fig. 4b. Graphical summary of performance statistics (median and 95% PI) for *M. paradoxus* under a future constant catch of 142 000 t for a series of robustness tests. Note that the statistics R_{2009}, R_{2014}, R_{2024} represent the proportion by number in the catch that are 3 years old or less, to reflect change in size structure.

M. capensis



1 - RS
2 - A3 - σ_R=0.4 (proj σ_R=0.25)
3 - B7 - σ_R=0.4 (proj σ_R=0.4)
4 - A4 - decr K in past
5 - A8 - force depletion
6 - B4a - cal factor = 0.6
7 - B4b - cal factor = 0.9

Fig. 4c. Graphical summary of performance statistics (median and 95% PI) for *M. capensis* under a future constant catch of 142 000 t for a series of robustness tests. Note that the statistics R_{2009}, R_{2014}, R_{2024} represent the proportion by number in the catch that are 3 years old or less, to reflect change in size structure.

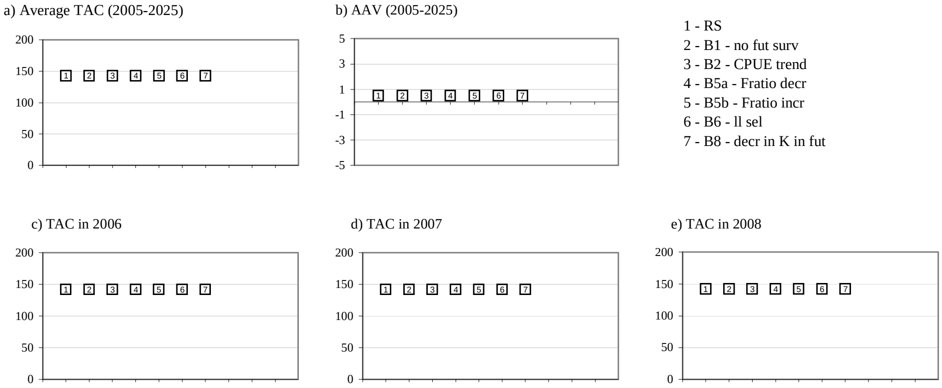
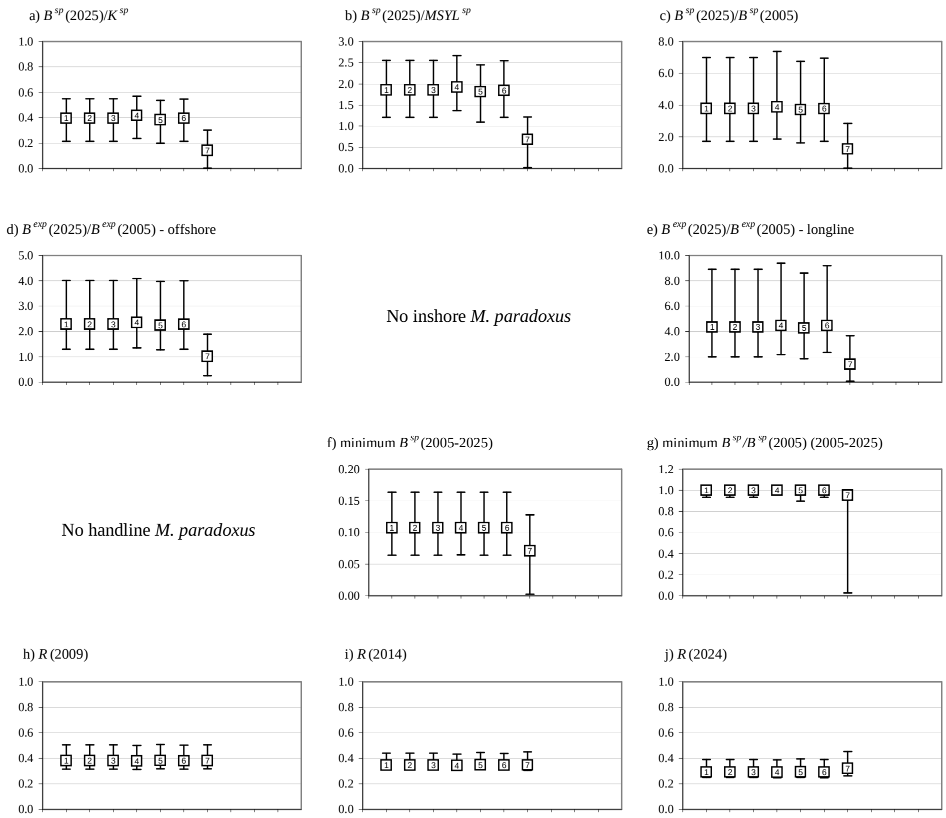


Fig. 5a: Graphical summary of catch performance statistics (median and 95% PI) under a future constant catch of 142 000 t for a series of robustness tests involving changes in the future.

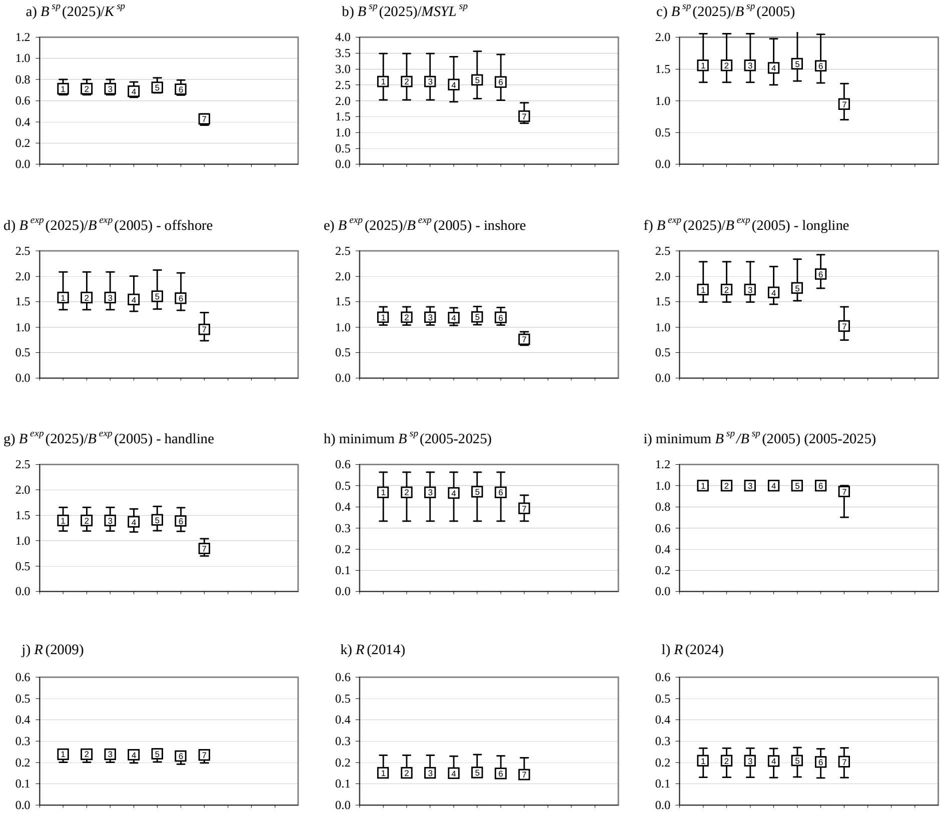
M. paradoxus



1 - RS
2 - B1 - no fut surv
3 - B2 - CPUE trend
4 - B5a - Fratio decr
5 - B5b - Fratio incr
6 - B6 - ll sel
7 - B8 - decr in K in fut

Fig. 5b. Graphical summary of performance statistics (median and 95% PI) for *M. paradoxus* under a future constant catch of 142 000 t for a series of robustness tests involving changes in the future. Note that the statistics R_{2009}, R_{2014}, R_{2024} represent the proportion by number in the catch that are 3 years old or less, to reflect change in size structure.

M. capensis



1 - RS
2 - B1 - no fut surv
3 - B2 - CPUE trend
4 - B5a - Fratio decr
5 - B5b - Fratio incr
6 - B6 - ll sel
7 - B8 - decr in K in fut

Fig. 5c. Graphical summary of performance statistics (median and 95% PI) for *M. capensis* under a future constant catch of 142 000 t for a series of robustness tests involving changes in the future. Note that the statistics R_{2009}, R_{2014}, R_{2024} represent the proportion by number in the catch that are 3 years old or less, to reflect change in size structure.

Appendix A – List of Robustness Tests

Robustness tests underlined below were part of the "shortened list" of robustness tests in document WG/09/05/D:H:33.

I. Different assumptions about discards and catch series

"**A1a – disc1**"
Discarding is considered to occur for the offshore and inshore trawlers only. Discarding for both fleets is modelled as an increase in commercial selectivity of 0.2 for ages 1 and 2 for catches of both *M. capensis* and *M. paradoxus*. Thus the amount of catch discarded is not an input, but computed within the assessment from the fishing mortality estimated for the offshore and inshore trawlers to take their recorded landings. This discarding is assumed to occur from the beginning of the fishery to the present.

"**A1b – disc2**"
As A1a above, discarding is considered to occur for the offshore and inshore trawlers, but the loss of fish from longlines is also included by doubling the fishing mortality from this fleet.

"**A1c – disc3**"
As A1a above, but from 1996 onwards, the offshore and inshore trawl fleets are assumed to discard age 3 as well. As in A1a above, this is modelled by increasing the commercial selectivity by 0.2 for age 3 for catches of both *M. capensis* and *M. paradoxus*.

In the above three robustness tests, discards are taken into account for the past only, so that projections in the future assume no discarding. In the following three robustness tests however, future discards are taken to occur in terms of the same assumptions as used for the past. These are then considered in conjunction with past discards.

"**B3a – disc1**"
Future discarding is assumed to occur in the offshore and inshore fleets only, as in A1a.

"**B3b – disc2**"
Future discarding is assumed to occur in the offshore and inshore fleets, as well as the longline fleet, as in A1b.

"**B3c – disc3**"
Discarding is assumed to occur in the offshore and inshore fleets as in A1c.

"**A2 – SC unrep catches**"
This robustness test includes unreported catches from the south coast offshore fleet; indeed, in the RS, offshore catches on the south coast are assumed to have started in 1967 only, but it is known that some vessels operated in the region right from the beginning of the 20^{th} century; these unreported catches are included here and are assumed to have increased linearly from 100t in 1917 to 5000t in 1967 (with the species-split based on the appropriate logistic equation).

"A11 – line catches"
The catch series for the longline and handline fisheries are modified for recent years. Estimates of handline catches are brought down from 5941t to 2500t in 2003 and from 6888t to 1600t in 2004.

II. Different assumptions about biological information

"A5a – M2"
The RS incorporates some uncertainty in the natural mortality estimates. In cases "M1", upper bounds on the natural mortality of 0.5 and 0.3 on ages 2 and 5/5+ respectively are implemented, while in cases "M4", upper bounds of 1.0 and 0.5 on ages 2 and 5/5+ respectively are implemented. In this robustness test, the following bounds are implemented: 1.0 and 0.3 for ages 2 and 5/5+ respectively.

"A5b – M3"

In this robustness test, the following bounds on the natural mortality estimates are implemented: 0.5 for both ages 2 and 5/5+.

"**A7 – Ricker-like**"

The stock-recruit relationship for the RS has the form $R = \dfrac{\alpha B_{sp}}{\beta + \left(B_{sp}\right)^{\gamma}}$, with γ fixed to 1.0 (Beverton-Holt) for both species. Here instead, γ is fixed to 1.5 for *M. paradoxus*, and $\gamma = 1.0$ for *M. capensis.*

"**A9a – dens dep mat**"
In the RS, the maturity-at-age is assumed to be independent of stock density for all ages. In this robustness test, the assumption is made that 0% of fish of age 3 are mature at B^{4+} = pristine, and 100% are mature at B^{4+}=0, with a linear relationship in between these two extremes.

"**A9b – mat=3**"
The age-at-maturity is taken to be 3+ throughout, instead of 4+ in the RS.

"**A10a – size-dep spawning**"
An egg production index is used for input to the stock-recruitment relationship instead of spawning biomass; this is obtained by multiplying numbers-at-age by an age-dependent fecundity index obtained from Osborne (2004):

M. paradoxus : $Y_a = 8.02 L_a^{2.67}$

M. capensis : $Y_a = 0.15 L_a^{3.49}$

"**A10b – size-dep spawning**"
As A10a, but to take into account that bigger fish make bigger eggs with a better survival rate, the fecundity index Y_a has been arbitrarily halved for fish of age 4 for *M. paradoxus* and for fish of age 4 and 5 for *M. capensis*.

"**A10c – size-dep spawning**"
As A10a, but Y_a is set to zero for age 4 for *M. paradoxus* and ages 4 and 5 for *M. capensis.*

III. Others

"A3 – σ_R=0.4"
The variability for stock-recruitment fluctuations in the past is increased from σ_R =0.25 in the RS to σ_R=0.4. For the projections, σ_R is kept at 0.25.

"**B7 – fut σ_R=0.4**"
In conjunction with increased variability for the stock-recruitment fluctuations in the past, future variability is also increased (σ_R=0.4).

"**A4 – decr K in past**"
The carrying capacity of both species is assumed to have decreased linearly by 30% over the 1980 to 2000 period.

"**A8 – force depletion**"
The spawning biomass of *M. paradoxus* in 2004 is forced upwards to 40% of its pre-exploitation level, while the spawning biomass of *M. capensis* is forced downwards to 30% of its pre-exploitation level, both through the use of penalty functions."

B4a – cal factor=0.6"
The calibration factor between the *Africana* with the old gear and the *Africana* with the new gear for *M. capensis* is decreased from 0.8 to 0.6.

"**B4b – cal factor=0.9**"

The calibration factor between the *Africana* with the old gear and the *Africana* with the new gear for *M. capensis* is increased from 0.8 to 0.9.

IV. Changes in the future

"**B1 – no fut surv**"
Biomass and catch-at-age information from research surveys are assumed not to become available in the future.

"**B2 – CPUE trend**"
Future changes in fishing efficiency are not detected. This is modelled by assuming an undetected upward trend in catching efficiency of 2% per year, so that for future data generated:

$$CPUE(y) \rightarrow CPUE(y)\exp[0.02(y-2004)]$$

"**B5a – Fratio decr**"
In the RS, future catches are disaggregated by species using a constant F_{ratio} ($F_{ratio} = F_{para} / F_{cap}$), which has been calculated as the average of the 2002-2004 estimates. In this robustness test, the F_{ratio} for the offshore fleet is decreased by 30% to model an increase in *M. capensis* catches.

"**B5b – Fratio incr**"

Here the F_{ratio} for the offshore fleet is increased by 30% to model a decrease in *M. capensis* catches.

"**B6 – ll sel**"
The selectivity for the longline fleet on ages 4 and 5 is assumed to increase linearly over a five year period commencing in 2005, to reach that on age 6+.

"**B8 – decr K in past**"
The carrying capacity K for both species is assumed to decrease linearly by 30%, starting in 2005, to reach the reduced level in 2009.