

Proposed Reference Set for the South African hake resource to be used in OMP-2010 testing

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SUMMARY

A Reference Set (RS) of 12 scenarios is put forward as the primary basis to be used to simulation test candidates for the revised OMP for hake, OMP-2010. The principal uncertainty axes spanned by this RS are the central year for the switch from a primarily *M. capensis* to a primarily *M. paradoxus* fishery, values for natural mortality at age, and the form of the stock-recruitment relationship. The various data sets are generally reasonably fitted by these models, with the recent GLM-standardised CPUE series having the greatest influence.

INTRODUCTION

The principal aim of this paper is to present a set of assessments which are proposed to provide the Operating Models (OMs) to form a Reference Set (RS) to be used for testing a revised OMP for the hake resource (OMP-2010), which is due for adoption in September 2010.

Appendix I details the data used in these analyses, while the specifications and equations of the OMs are set out in Appendix II.

The following changes have been made to the Reference Case presented in Rademeyer and Butterworth (2009). These and related results presented further below take account of pertinent recommendations by the External Panel at the December 2009 international stock assessment workshop (specifically A.4, A.5, A.12, A.15, A.16 and A.18) (Punt *et al.*, 2009)..

- 1) An error in the code has been corrected.
- 2) The maturity-at-length for males, which was previously taken to be the same as the female maturity-at-length, has been updated to conform with the most recently available information (Fairweather, pers. commn).
- 3) The selectivities-at-age have been renormalized across the genders and not for each gender.
- 4) The standard deviations of length-at-age θ_a had been estimated directly for each of the ages 0 to 7, but hit an upper bound for ages 1 to 7. Furthermore, θ_a was not species and gender specific. θ_0 is now estimated directly for each species and gender, and for ages 1 and above a linear relationship is assumed: $\theta_a = \alpha + \beta a$, with species and gender-specific α and β estimated in the model fitting procedure.
- 5) The length-at-age distributions are assumed to follow a log-normal distribution rather than a normal distribution, as plots of these data were indicative of skew distributions.
- 6) The most recently available GLM-standardised CPUE series are used (Glazer, 2009), together with the associated updated species-split offshore trawl catches..
- 7) The centre year of the shift from a primarily *M. capensis* to a primarily *M. paradoxus* offshore trawl catch is taken as either 1950, 1958 or 1965, instead of 1950 only.
- 8) The recruitment variability parameter $\sigma_R=0.45$ instead of 0.25 (σ_R is still taken to decrease from this value to 0.1 over the last five years to statistically stabilise estimates of recent recruitment)..
- 9) The south coast offshore trawl scaling factor for the female *M. paradoxus* selectivity is taken as the average of the scaling factors estimated for the south coast spring and autumn surveys rather than being estimated directly, as the available data scarcely seem sufficient for such independent estimation..

- 10) The age-composition data (age-length keys – ALKs) used in the assessment have been restricted to one reading only for each otoliths (see Appendix I, section I.4). Furthermore, three sets of *M. paradoxus* age-length keys, which reflected many low ages at rather large lengths, have been omitted because they were inconsistent with the other sets. These are: i) 1997 West Coast summer survey, ii) 2004 West Coast summer and iii) 2006 West Coast summer data sets. (see Fig. App.I.5).
- 11) After the ALKs had been restricted to one reading only for each otolith, outliers were removed by excluding data outside (mean – 3SD; mean + 3SD). The means and SDs for each age were computed across all the data for each species. Less than 1% of these data were excluded for each species in this process.
- 12) The ALK likelihood downweighting factor was increased to 0.01 (from 0.001) as fits indicated an apparent lack of influence (underweighting).
- 13) A penalty has been added to $-\ln L$ to constrain the survey q 's for each species not to exceed 1 (see equation App.II.34); this amounts to the assumption that there is no substantial herding effect which is biasing the swept-area estimates of abundance from these trawl surveys, and precludes survey abundance estimates from (on average) exceeding the underlying available biomass.
- 14) Previously, different selectivity slopes at large lengths/ages were freely estimated for the second (1977-1984) and third (1993-2009) selectivity period for the offshore trawl fleet. However fitting always preferred a lower slope for the earlier years, which seems inconsistent with the movement of the fleet towards deeper waters (where larger hake are available) over time. Thus the slope for the second period was constrained not to be lower than that for the third.
- 15) A penalty was added to $-\ln L$ so that the mean of the estimated recruitment residuals is close to zero (see equation App.II.43). The reason for this is that fits to the last some 30 years for which these residuals could be estimated generally showed averages appreciably below zero for *M. capensis*. If such fits had been taken through to projections, this would have meant that immediate future recruitment for *M. capensis* would have been higher on average than over recent years, thus giving a likely spuriously positive impression of resource production. It was felt more appropriate to force this average level of future production to be similar to that over the past three decades. While the possibility that those decades constitute a regime of generally low *M. capensis* productivity cannot be excluded, the associated effective changes in K are considered better reserved for robustness tests.

RESULTS

Reference Set

The proposed Reference Set (RS) consists of 12 cases, detailed in Table 1. These 12 cases vary their choices of factors along three axes that contribute most variability to assessment results:

- a) the centre year of the shift from a primarily *M. capensis* to a primarily *M. paradoxus* offshore trawl catch (1950, 1958 or 1965);
- b) natural mortality at age specifications; and
- c) the stock-recruitment relationship (Beverton-Holt with steepness h estimated or fixed, or modified Ricker with γ estimated – see equations App.II.4a,b).

The primary design intended a full cross of 2 centre-years x 2 natural mortality vectors x 3 stock recruitment relationships, or 12 scenarios in all, but subject to the constraint that a fit with a $-\ln L$ difference of more than about 15 from that for the best of the fits would be excluded on the basis of poor compatibility with the data. (Of course, in strict likelihood terms such a large difference implies enormously different relative likelihoods across these scenarios, but that would be over-interpreting the likelihood function used here which has not attempted to take full account of non-independence amongst the data fitted.)

With the Beverton-Holt fits indicating estimates of steepness h at its upper bound of 0.98, it was considered important to include scenarios with lower values of h in the RS to admit greater possibilities of recruitment overfishing taking place, but the $-\ln L$ difference constraint excluded three of the associated four scenarios, leaving only RS10 amongst the RS.

Attempts to freely fit natural mortality at age vectors led to widely varying results from scenario to scenario, so it was considered best to fix two vectors which arguably span the plausible range: a high M scenario of $M_2=0.9$, $M_5=0.5$. and a low M scenario of $M_2 = 0.6$, $M_5=0.25$. The primary RS runs combined either both high M s or both low M s for the two species, *M. paradoxus* and *M. capensis*. Scenarios which crossed high and low M values across the two species were also investigated, but mainly found to fail to meet the $-\ln L$ difference criterion. However, one exception to this was a scenario (RS11) with both a good fit to the data and a qualitatively different trajectory for *M. capensis* (reflecting a rather more heavily depleted *M. capensis* resource than do the other scenarios). It is considered important to retain this in the RS, together with a variant with slightly different specifications of natural mortality at age for *M. capensis* (RS12) which also showed this different trajectory behaviour for *M. capensis*. In subsequent presentation of candidate OMP results, the RS will be split into two: RSa (RS1 to RS10) and RSb (RS11 to RS12), so as not to mix results across qualitatively different *M. capensis* trajectories.

The RS is completed by a “central” Reference Case (RC) scenario, corresponding to a mid-year choice for the shift from a primarily *M. capensis* to *M. paradoxus* fishery, and an average of the two M vectors for natural mortality at age. The modified Ricker was preferred to the Beverton-Holt stock recruitment relationship for this scenario because it tends to yield slightly better fits to the data. Most robustness tests are single factor variants of this RC. A detailed set of results for the RC, showing fits to all the input data, is given in Appendix III.

Table 2 summarises the key management quantity estimates across the RS, while Table 3 compares the different contributions to the total negative log-likelihood.

Fig. 1 plots the estimated spawning biomass trajectories for the RS. Fig. 2 shows their fits to the CPUE series. Only the CPUE series fits have been shown here, because as is evident from Table 3 it is fits to the CPUE, and particularly the more recent GLM-CPUE series, that are the main determinants of the overall likelihood of the scenario.

A matter that remains to be discussed is whether scenario RS4 should remain within the RS as proposed. While it is a member of the set provided by the cross of the dominant uncertainty factors, it does not meet the $-\ln L$ difference criterion.

Robustness tests

Table 4 details the robustness/sensitivity tests conducted to date. (Some of these tests should be considered as “sensitivities” rather than formal robustness tests to provide OMs for candidate OMP testing, because they are included more to indicate impacts of specification variation on results than as arguably alternative plausible representations of reality.)

Table 5 summarises the key management quantities for these robustness/sensitivity tests, while Table 6 compares their different contributions to the total negative log-likelihood.

Fig. 3 plots the estimated spawning biomass trajectories for these further tests.

Table 7 lists robustness tests which are still planned to be run.

DISCUSSION

Experience with implementation of the assessment methodology has led to some changes in the details of the Reference Set of OMs suggested in the December 2009 Expert Panel report (Punt *et al.*, 2009). Specifically statistical stability considerations dictated a different approach to handling alternative natural mortality schedules, and a lesser range of steepness than suggested earlier was necessitated because of otherwise large reductions in the likelihoods of the model fits to the data. However, the somewhat better fits obtained using a modified Ricker stock recruitment relationship in place of the Beverton-Holt led to including that form in the proposed RS.

The range for choices of the central year for the shift from a primarily *M. capensis* to primarily *M. paradoxus* trawl fishery was extended back to 1950, given the somewhat better likelihoods obtained for choices of earlier years for this parameter, though this basis for preferring earlier years does not seem as strong as in the past. Trends in catchability have yet to be considered, but the effect of such trends noted earlier (a more depleted *M. capensis* resource) are already captured by scenarios RS11 and RS12.

Fixing rather than estimating selectivity slopes at large lengths/ages has yet to be fully explored, though initial results suggest a large deterioration in the likelihood of the fits.

Scenarios with the lower value of 0.25 for M_{5+} often lead to arguably unrealistically high pristine spawning biomass values. These can however be reduced, with little impact on other important management-related variables, by postulating an increase in natural mortality at higher ages (detailed results for this possibility will be reported in due course).

Fits of the assessment model to the data are generally good. From Tables 3 and 6 it is evident that fits to the CPUE data and to the commercial catches-at-length are the primary determinants of the overall likelihood. The more recent GLM-standardised CPUE plays the greatest role, particularly for *M. paradoxus* where many of the model variants have some difficulty in matching the earliest and the very recent values.

The primary consideration in proposing a RS is that its component OMs should span most of the range of plausible possibilities for the underlying dynamics. Table 2 suggests that this criterion is reasonably satisfied for *M. paradoxus* depletion and productivity (reflected by MSY). There is lesser variability amongst the RSa depletion estimates for *M. capensis*, but the scenarios in RSb would seem adequate to cover the possibility that the RSa depletion estimates are misleading.

The robustness/sensitivity tests completed to date (Tables 4-6) broadly do not lead to stock status and dynamics estimates outside the range covered by the proposed RS, so that this proposed RS would seem adequate to provide the primary basis upon which to simulation test candidates for OMP-2010.

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Table 1: Description of the 12 cases forming the RS.

	Shift center	SR relationship	Natural mortality	
			<i>M. paradoxus</i>	<i>M. capensis</i>
RS1 (RC)	1958	BH, h estimated	$M_{2-}=0.75; M_{5+}=0.375$	$M_{2-}=0.75; M_{5+}=0.375$
RS2	1950	BH, h estimated	$M_{2-}=0.6; M_{5+}=0.25$	$M_{2-}=0.6; M_{5+}=0.25$
RS3	1950	BH, h estimated	$M_{2-}=0.9; M_{5+}=0.5$	$M_{2-}=0.9; M_{5+}=0.5$
RS4	1965	BH, h estimated	$M_{2-}=0.6; M_{5+}=0.25$	$M_{2-}=0.6; M_{5+}=0.25$
RS5	1965	BH, h estimated	$M_{2-}=0.9; M_{5+}=0.5$	$M_{2-}=0.9; M_{5+}=0.5$
RS6	1950	Modified Ricker	$M_{2-}=0.6; M_{5+}=0.25$	$M_{2-}=0.6; M_{5+}=0.25$
RS7	1950	Modified Ricker	$M_{2-}=0.9; M_{5+}=0.5$	$M_{2-}=0.9; M_{5+}=0.5$
RS8	1965	Modified Ricker	$M_{2-}=0.6; M_{5+}=0.25$	$M_{2-}=0.6; M_{5+}=0.25$
RS9	1965	Modified Ricker	$M_{2-}=0.9; M_{5+}=0.5$	$M_{2-}=0.9; M_{5+}=0.5$
RS10	1965	BH, $h = 0.7$	$M_{2-}=0.9; M_{5+}=0.5$	$M_{2-}=0.9; M_{5+}=0.5$
RS11	1950	BH, h estimated	$M_{2-}=0.6; M_{5+}=0.25$	$M_{2-}=0.9; M_{5+}=0.5$
RS12	1950	BH, h estimated	$M_{2-}=0.6; M_{5+}=0.25$	$M_{2-}=0.5; M_{5+}=0.5$

Table 2: Estimates of management quantities for the RS. Values in bold have been fixed. B_{2009}^{sp}/K^{sp} is for both genders combined, while B_{MSY}^{sp}/K^{sp} and $B_{2009}^{sp}/B_{MSY}^{sp}$ are in terms of the female only spawning biomass.

	-lnL	<i>M. paradoxus</i>								<i>M. capensis</i>								2009 species ratio B^{sp}
		K^{sp}	h	B_{2009}^{sp}/K^{sp}	B_{MSY}^{sp}/K^{sp}	$B_{2009}^{sp}/B_{MSY}^{sp}$	MSY	M_{2-}	M_{5+}	K^{sp}	h	B_{2009}^{sp}/K^{sp}	B_{MSY}^{sp}/K^{sp}	$B_{2009}^{sp}/B_{MSY}^{sp}$	MSY	M_{2-}	M_{5+}	
RS1	-94.5	1363	1.08	0.15	0.24	0.59	113	0.75	0.38	516	1.01	0.54	0.47	1.12	69	0.75	0.38	1.34
RS2	-86.6	3009	0.98*	0.10	0.24	0.45	119	0.60	0.25	1990	0.98*	0.57	0.20	2.88	89	0.60	0.25	3.80
RS3	-87.6	906	0.91	0.17	0.20	0.63	110	0.90	0.50	941	0.98*	0.59	0.17	3.41	119	0.90	0.50	3.65
RS4	-76.0	3474	0.98*	0.19	0.20	1.09	118	0.60	0.25	2853	0.98*	0.64	0.20	3.24	128	0.60	0.25	2.78
RS5	-85.3	962	0.98*	0.27	0.11	2.19	124	0.90	0.50	1061	0.98*	0.61	0.17	3.54	134	0.90	0.50	2.46
RS6	-99.6	2842	1.05	0.10	0.26	0.42	121	0.60	0.25	735	1.18	0.52	0.48	1.08	65	0.60	0.25	1.33
RS7	-92.0	967	0.86	0.16	0.19	0.65	110	0.90	0.50	367	0.62	0.58	0.61	0.91	63	0.90	0.50	1.37
RS8	-92.4	1683	1.50*	0.21	0.34	0.64	121	0.60	0.25	1793	1.50*	0.65	0.42	1.52	166	0.60	0.25	3.27
RS9	-92.3	662	1.14	0.30	0.37	0.68	111	0.90	0.50	442	1.50*	0.63	0.41	1.44	110	0.90	0.50	1.40
RS10	-82.8	1412	0.70	0.33	0.28	1.12	123	0.90	0.50	1861	0.70	0.65	0.30	2.10	170	0.90	0.50	2.57
RS11	-93.4	3024	0.98*	0.10	0.24	0.44	118	0.60	0.25	788	0.39	0.18	0.41	0.42	40	0.90	0.50	0.49
RS12	-96.0	3022	0.98*	0.10	0.24	0.45	118	0.60	0.25	804	0.39	0.17	0.41	0.39	40	0.50	0.50	0.45

* Constraint boundary

Table 3: For each contribution to the total negative log-likelihood (-lnL), differences in -lnL compared to the case with the lowest -lnL (RS6) across the RS.

	-lnL total	CPUE historic	CPUE GLM	Survey	Comm CAL	Survey CAL (sex-aggr.)	Survey CAL (sex-disaggr.)	ALK	Rec. penalty	Sel. smoothing penalty
RS1	5.1	1.8	5.8	1.0	-4.2	-0.2	0.5	-0.1	0.2	0.0
RS2	13.1	-0.4	10.6	-1.1	1.8	0.5	0.7	0.5	-0.1	0.5
RS3	12.0	3.2	15.1	3.1	-8.4	0.2	1.2	-2.0	-0.1	-0.2
RS4	23.7	0.6	20.8	2.7	-3.5	-0.4	-0.2	0.9	0.9	1.6
RS5	14.4	2.1	15.1	3.8	-8.1	-0.8	2.2	-1.1	0.5	0.2
RS6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
RS7	7.6	3.1	7.5	4.0	-6.4	-0.5	0.8	-2.2	1.7	-0.4
RS8	7.2	-0.6	6.2	0.2	-0.9	1.2	-0.7	1.7	-0.8	0.8
RS9	7.3	2.2	10.3	1.8	-8.7	-0.2	2.4	-1.1	0.0	0.2
RS10	16.8	4.9	17.2	5.1	-10.6	-0.7	0.1	-0.5	0.2	0.9
RS11	6.2	-0.5	7.2	-1.3	1.4	-0.3	2.1	-0.8	-0.5	-1.1
RS12	3.6	-0.4	7.3	-1.7	0.0	0.4	0.0	0.5	-0.6	-1.9

Table 4: Description of the robustness/sensitivity tests.

	Shift center	SR relationship	Natural mortality		Other
			<i>M. paradoxus</i>	<i>M. capensis</i>	
Rob1	1965	BH, h estimated	$M_{2-}=0.6; M_{5+}=0.25$	$M_{2-}=0.9; M_{5+}=0.5$	
Rob2	1950	BH, h estimated	$M_{2-}=0.9; M_{5+}=0.5$	$M_{2-}=0.6; M_{5+}=0.25$	
Rob3	1965	BH, h estimated	$M_{2-}=0.9; M_{5+}=0.5$	$M_{2-}=0.6; M_{5+}=0.25$	
Rob4	1950	True Ricker	$M_{2-}=0.6; M_{5+}=0.25$	$M_{2-}=0.6; M_{5+}=0.25$	
Rob5	1950	True Ricker	$M_{2-}=0.9; M_{5+}=0.5$	$M_{2-}=0.9; M_{5+}=0.5$	
Rob6			as RC		$2_R = 0.25$
Rob7			as RC		$W_{ALK} = 0.001$
Rob8			as RC		$W_{ALK} = 0.1$
Rob9			as RC		$W_{CAL} = 0.01$
Rob10			as RC		$W_{CAL} = 0.5$
Rob11			as RC		M gender dependent (+0.05 for males, -0.05 for females)

Table 5: Estimates of management quantities for the RC and the robustness/sensitivity tests. Values in bold have been fixed.

	-lnL	<i>M. paradoxus</i>								<i>M. capensis</i>								2009 species ratio B^{sp}
		K^{sp}	h	B^{sp}_{2009}/K^{sp}	B^{sp}_{MSY}/K^{sp}	$B^{sp}_{2009}/B^{sp}_{MSY}$	MSY	M_{2-}	M_{5+}	K^{sp}	h	B^{sp}_{2009}/K^{sp}	B^{sp}_{MSY}/K^{sp}	$B^{sp}_{2009}/B^{sp}_{MSY}$	MSY	M_{2-}	M_{5+}	
RS1	-94.5	1363	1.08	0.15	0.24	0.59	113	0.75	0.38	516	1.01	0.54	0.47	1.12	69	0.75	0.38	1.34
Rob1	-81.0	3511	0.98*	0.19	0.20	1.09	119	0.60	0.25	1030	0.98*	0.60	0.16	3.59	131	0.90	0.50	0.94
Rob2	-82.0	911	0.90	0.17	0.20	0.62	109	0.90	0.50	2083	0.98*	0.58	0.20	2.95	94	0.60	0.25	7.85
Rob3	-79.8	1049	0.92	0.28	0.17	1.47	122	0.90	0.50	3002	0.98*	0.64	0.20	3.28	134	0.60	0.25	6.52
Rob4	-82.3	2210	1.21	0.18	0.42	0.49	133	0.60	0.25	774	1.50*	0.50	0.38	1.30	68	0.60	0.25	0.95
Rob5	-72.3	779	0.91	0.26	0.41	0.53	118	0.90	0.50	413	1.01	0.56	0.41	1.30	68	0.90	0.50	1.14
Rob6	-85.5	1522	0.95	0.15	0.21	0.65	108	0.75	0.38	486	1.45	0.59	0.36	1.57	70	0.75	0.38	1.27
Rob7	-212.3	1514	1.03	0.15	0.25	0.62	116	0.75	0.38	449	0.95	0.57	0.48	1.11	70	0.75	0.38	1.09
Rob8	957.6	1563	0.96	0.08	0.20	0.24	116	0.75	0.38	490	1.50*	0.50	0.34	1.38	69	0.75	0.38	2.05
Rob9	-94.6	1616	0.97	0.08	0.18	0.31	128	0.75	0.38	596	1.40	0.51	0.31	1.57	73	0.75	0.38	2.23
Rob10	-330.3	809	1.31	0.26	0.26	0.75	111	0.75	0.38	674	0.44	0.62	0.83	0.73	65	0.75	0.38	2.02
Rob11	-92.1	1528	1.09	0.14	0.23	0.55	113	0.75 ⁺	0.38 ⁺	531	1.50*	0.51	0.33	1.43	70	0.75 ⁺	0.38 ⁺	1.24

* Constraint boundary

+ Average of the male M ($M_{2-}=0.8$, $M_{5+}=0.425$) and the female M ($M_{2-}=0.7$, $M_{5+}=0.325$)

Table 6: For each contribution to the total negative log-likelihood (-lnL), differences in -lnL compared to the case with the lowest -lnL (RS6).

	-lnL total	CPUE historic	CPUE GLM	Survey	Comm CAL	Survey CAL (sex-aggr.)	Survey CAL (sex-disaggr.)	ALK	Rec. penalty	Sel. smoothing penalty
Rob1	18.6	0.2	15.2	2.0	-3.4	-0.2	2.0	-0.6	1.1	1.8
Rob2	17.6	3.3	20.2	3.6	-8.1	1.4	-1.4	-0.4	-0.2	-0.7
Rob3	19.9	3.8	21.0	4.5	-9.5	0.3	-0.7	0.5	-0.4	0.2
Rob4	17.3	15.5	2.6	0.3	-0.5	0.6	-1.1	0.6	-0.8	0.2
Rob5	27.3	19.6	11.3	2.6	-5.7	-0.1	0.6	-1.3	0.8	-0.4
Rob6	14.2	-0.2	10.0	0.7	-2.0	-0.9	2.6	-1.2	4.9	-0.2
Rob7	-112.7*	1.1	4.1	-1.7	-2.0	-0.2	-6.5	-107.7*	1.0	-1.3
Rob8	1057.2*	-0.6	13.8	11.7	8.3	5.7	15.8	1001.9*	1.1	-0.8
Rob9	5.1*	-0.5	-11.9	-11.3	54.4*	9.0*	-13.9*	-4.7	-2.1	-14.1
Rob10	-230.6*	3.2	23.9	3.1	-249.8*	-9.1*	-12.4*	16.8	4.7	20.9
Rob11	7.6	1.3	5.3	0.1	-3.4	-0.9	3.5	2.4	-0.4	-0.6

* These likelihood contributions are not comparable to the others because of different weightings.

Table 7: Description of the further robustness/sensitivity tests still planned to be carried out.

	Shift	SR	Natural mortality		Other
	center	relationship	<i>M. paradoxus</i>	<i>M. capensis</i>	
1			as RC		Alternative assumptions about slope selectivity
2			as RC		Alternative depth stratification for GLM-CPUE
3			as RC		Commences in 1978
4			as RC		Change in <i>K</i>
5			as RC		Non 50/50 sex ratio at birth
6			as RC		Alternative species-split algorithms
7			as RC		Include discards
8			as RC		Increasing <i>M</i> at large ages
9			as RC		Updated CPUE and species-split data following database check
10			as RC		Added weighting to recent data to fit recent abundance indices more closely
11			as RC		Less shrinkage of recent recruitments towards the stock-recruitment relationship prediction
12			as RC		Efficiency change

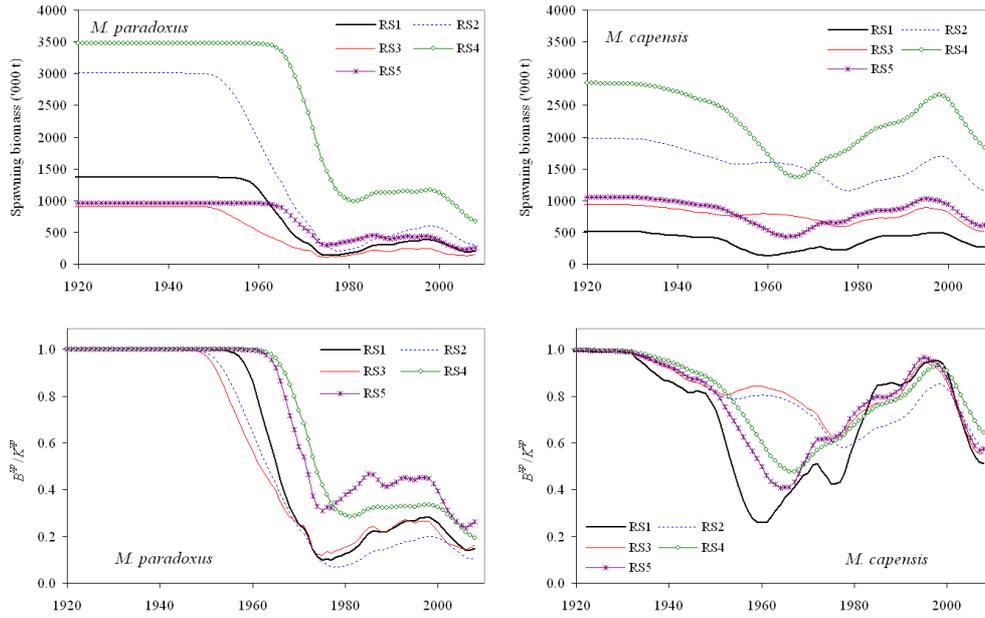


Fig. 1a: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for RS1 to RS5.

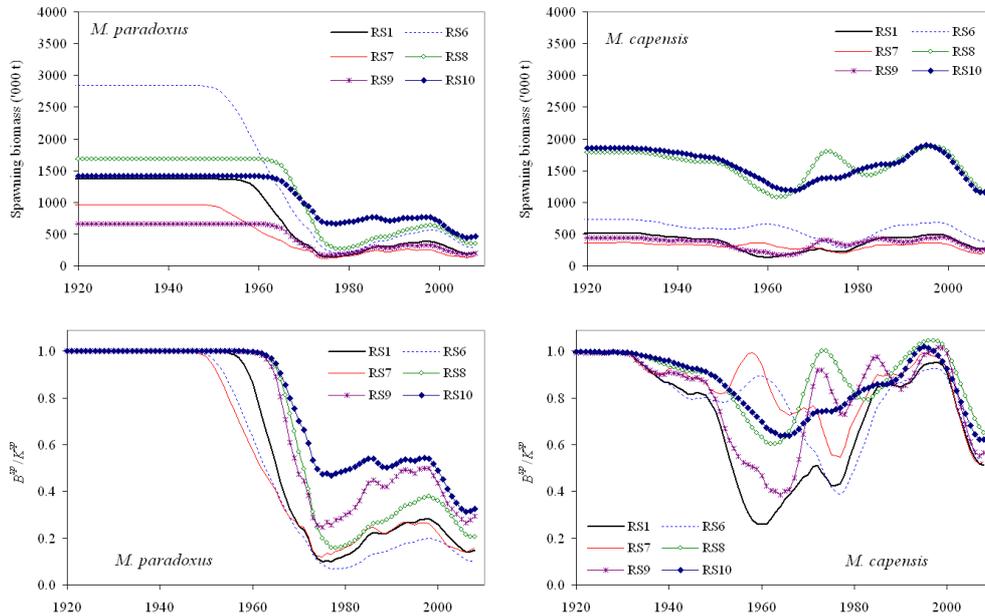


Fig. 1b: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for RS1 and RS6 to RS10.

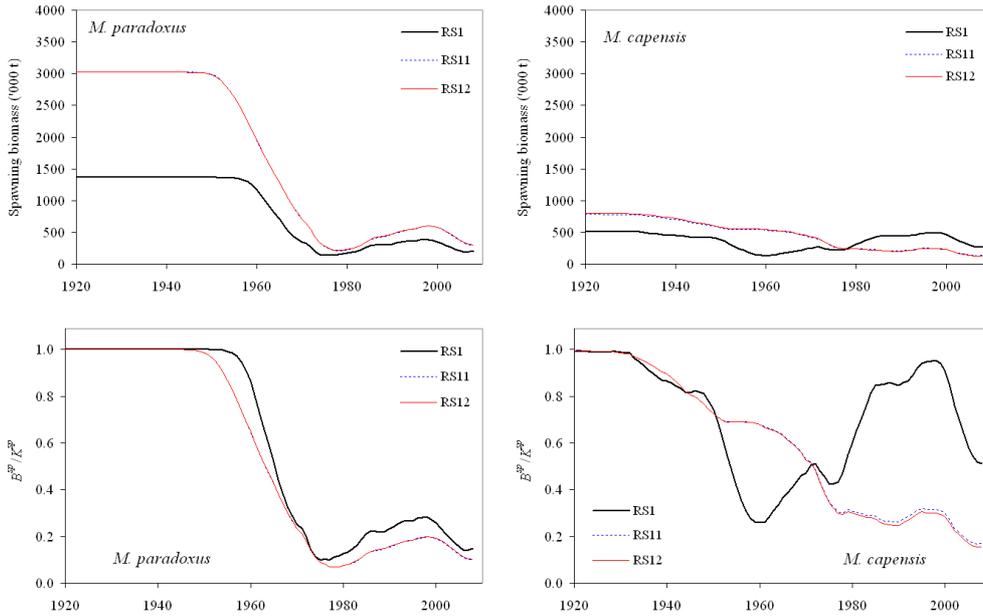


Fig. 1c: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for RS1, RS11 and RS12. Note that the RS11 and RS12 trajectories are basically on top of each other.

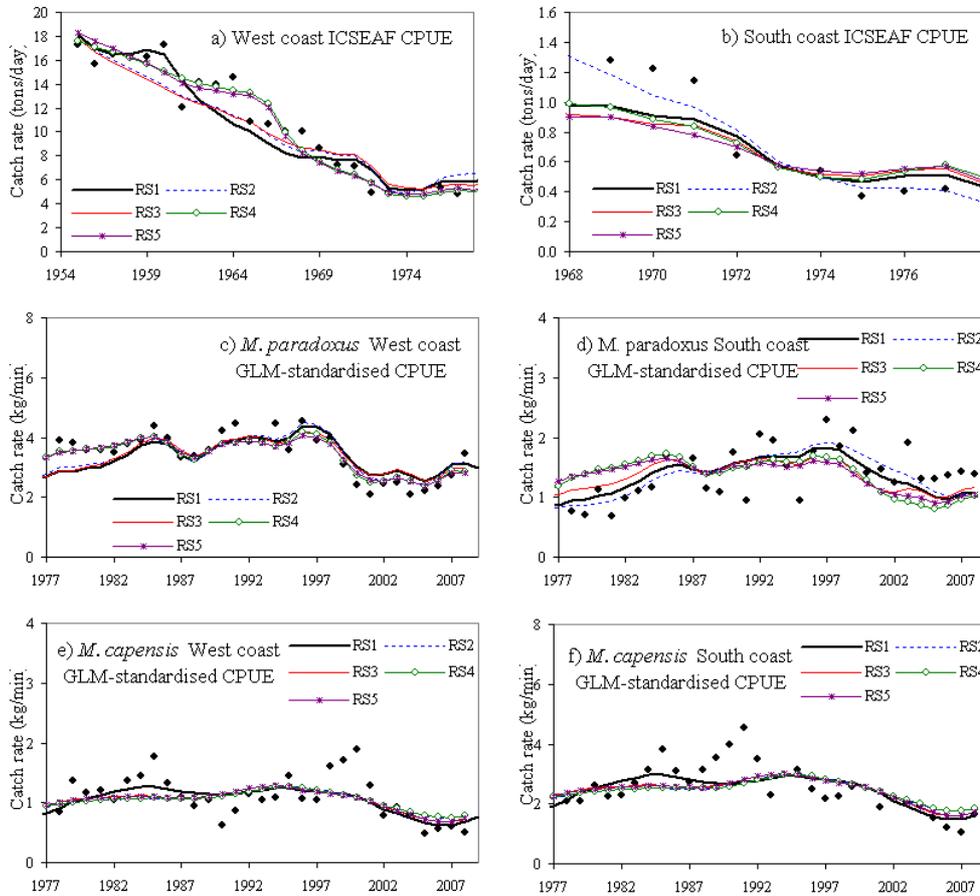


Fig. 2a: Fit to the CPUE data for RS1 to RS5.

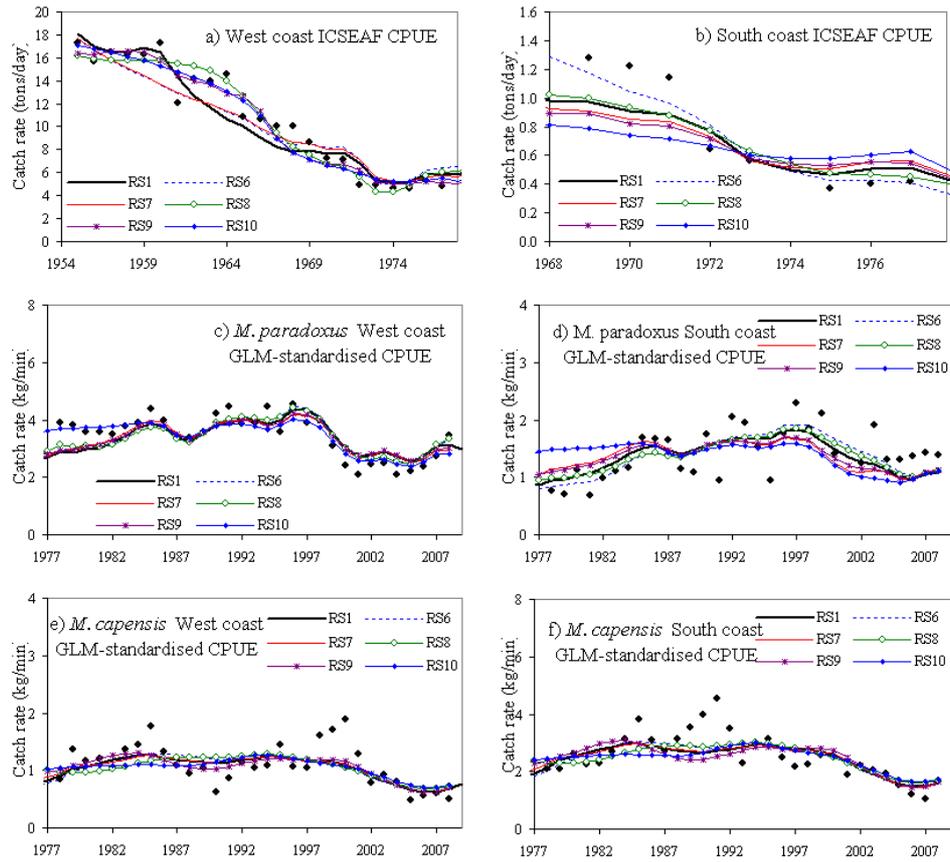


Fig. 2b: Fit to the CPUE data for RS1 and RS6 to RS10.

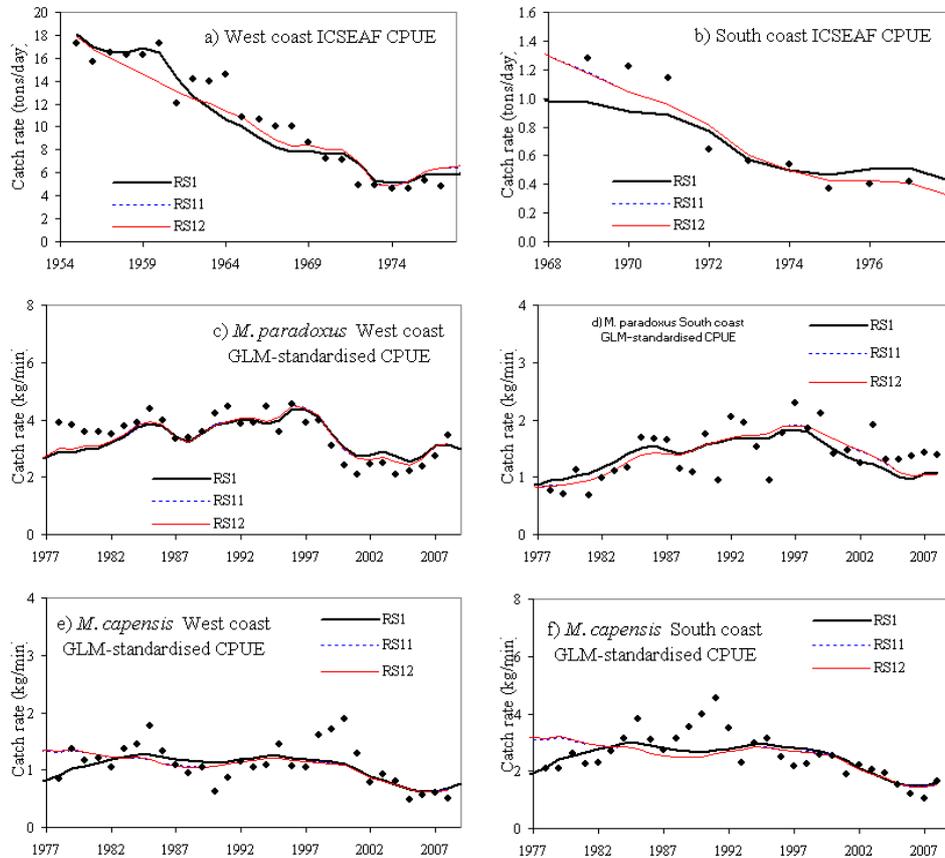


Fig. 2c: Fit to the CPUE data for RS1, RS11 and RS12

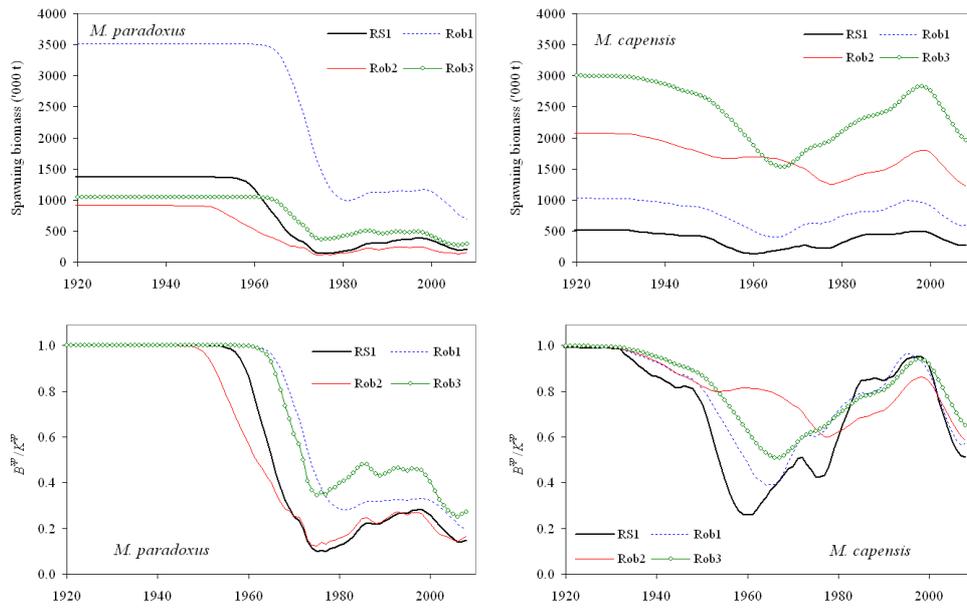


Fig. 3a: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for RS1 and Rob1 to Rob3 (scenarios where the two species have different natural mortality at age vectors).

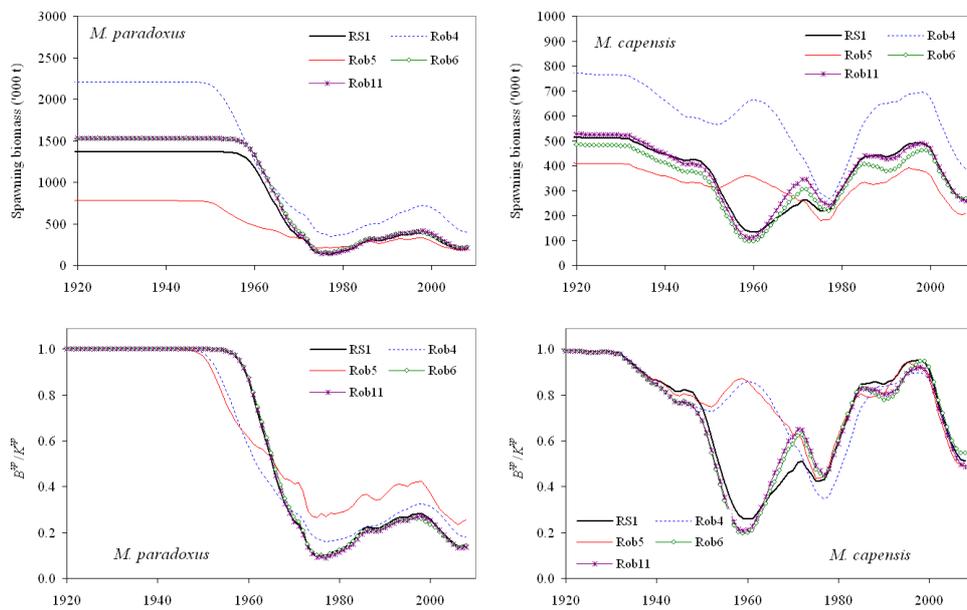


Fig. 3b: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for RS1, Rob4 to Rob6 and Rob11 (true Ricker, lower σ_R and gender-dependent M scenarios)

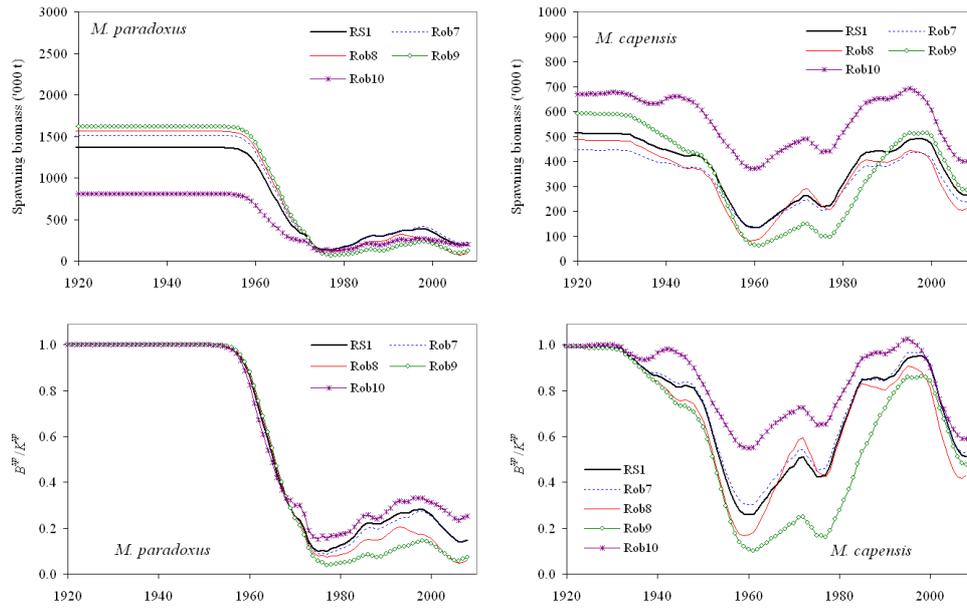


Fig. 3c: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for RS1 and Rob7 to Rob10 (scenarios for which the ALK or CAL data are given higher or lower weights in the overall negative log likelihood)..

APPENDIX I – The Data Utilized

I.1 Annual catches

The species-split of the catches is carried out external to the model. A summary of the assumptions made to disaggregate the catches by species for the Reference Set is given below. The reported or assumed catches by fleet and species are given in Table App.I.1 and plotted in Fig. App.I.1.

Offshore trawl fleet

From 1978 onwards, the catches made by the offshore trawl fleet have been split by species by applying the size-based species proportion-by-depth relationships for the west and south coasts which were updated by Gaylard and Bergh (2009) from research survey data.

Prior to 1978, there is no depth information recorded for the landings so that the proportion of *M. capensis* caught cannot be estimated using the method above. The catch data for the 1917-1977 period are split by assuming that the proportion of *M. capensis* caught follows a logistic function over this period, starting at 1 and then decreasing to stabilise at the 1978-1982 average value. As trawling was concentrated in inshore areas around Cape Town and to the east when the fishery began (i.e. probably catching *M. capensis* exclusively) and progressively moved offshore, this seems a more defensible approach. To reflect a change from a *M. capensis* only fishery to the species ratio in the catch in 1978, the changing proportion with year y of *M. capensis* in the offshore trawl catch on coast c is modelled by:

$$prop_{cy}^{prop} = \frac{1 - \Delta_c}{1 + \exp[(y - P_1)/P_2]} + \Delta_c \quad (\text{App.I.1})$$

where

Δ_c is the average proportion of *M. capensis* in the offshore catch over the 1978-1982 period for coast c (24% and 60% for the west and south coasts respectively), and

P_1, P_2 are parameters of the logistic function; P_1 is the year in which the proportion of *M. capensis* in the catch is mid-way between 100% and Δ_c , while P_2 determines how rapidly this change in proportion occurs.

The RS' OMs assume either $P_1=1950, 1958$ or 1965 and $P_2=1.5$.

Inshore trawl and handline fleets

Catches made by these fleets are assumed to consist of *M. capensis* only, as they operate in relatively shallow water on the south coast.

Longline fleet

Longline catches on the west coast are assumed to consist of 30% *M. capensis* for the whole period, while on the south coast, catches by this fleet are assumed to consist of *M. capensis* exclusively (Andrew Penney, PISCES, pers. commn).

The total catch in 2009 is assumed equal to the TAC for that year (118 600 t); it is split between the different fleets and species assuming the same proportions as in 2008.

I.2 Abundance indices

Six CPUE time-series are available for assessing the status of the resource (Table App.I.2): a CPUE series for each of the south and west coasts developed by the International Commission for South East Atlantic Fisheries (ICSEAF, 1989) and a GLM-standardised CPUE series for each coast, for each of *M. paradoxus* and *M. capensis* (Table App.I.2) from the offshore trawl fleet (Glazer, 2009). The two historical CPUE series cannot be disaggregated by species, as there are no effort-by-depth data available for this pre-1978 period. The GLM standardized CPUE indices are species-specific (the catch data being based on the Gaylard and Bergh (2009) algorithm).

Research surveys have been conducted on board the FRS *Africana* from 1986 in spring and/or autumn on the south coast and from 1985 in summer and/or winter on the west coast, and provide fully species-specific information. Since 2003, new fishing gear has occasionally been used on the *Africana*, for which a calibration factor is available. Survey biomass estimates and their estimated (sampling) standard errors are listed in Tables App.I.3-4 (Fairweather, 2009). Only surveys extending to the deepest depth (500m) normally included in the survey design are considered for reasons of comparability.

The surveys conducted on the West Coast in 2000 and 2001 by the *Nansen* research vessel have not been used in this analysis. As no calibration experiments were conducted at the time, these would have to be considered as a separate series and with only two data points would not be informative.

I.3 Length frequencies

Survey length frequencies are available disaggregated by species and in some years disaggregated by gender (Table App.I.5) (Fairweather *et al.*, 2009).

Sex-aggregated proportions-at-length for each survey stratum ($p_{yl}^{surv,i}$) are provided in 1cm length classes (Fairweather *et al.*, 2009). In some instances, the proportions of males and females for a particular survey stratum and length class are available ($q_{yl}^{g,surv,i}$, where $\sum_g q_{yl}^{g,surv,i} = 1$). These are converted to survey specific (i.e. aggregated over all strata for a particular cruise) proportions-at-lengths for males ($g=1$), females ($g=2$) and unsexed ($g=0$) (with $\sum_{g=0}^2 p_{yl}^{g,surv,i} = 1$) as follows:

The proportions-at-length are grouped into 2cm length classes.

a. For all length classes < 21 cm, the proportions-at-length are assumed to be unsexed;

b. For length classes > 20 cm:

- If there is no sex-information for either of the two 1 cm length classes to group (i.e. $\sum_g q_{yl}^{g,surv,i} = 0$ and $\sum_g q_{y,l+1}^{g,surv,i} = 0$), then the proportion for the resulting 2 cm length class is assumed to be unsexed:

$$p_{yL}^{g,surv,i} = \begin{cases} p_{yl}^{surv,i} + p_{y,l+1}^{surv,i} & \text{for } g = 0 \\ 0 & \text{for } g = 1/2 \end{cases} \quad (\text{App.I.1})$$

- If there is sex-information for one of the two 1 cm length classes to group (i.e. if $\sum_g q_{yl}^{g,surv,i} = 1$ or $\sum_g q_{y,l+1}^{g,surv,i} = 1$), then the sex-information from the one length class is used for both:

$$p_{yL}^{g,surv,i} = \begin{cases} 0 & \text{for } g = 0 \\ q_{yl}^{g,surv,i} (p_{yl}^{surv,i} + p_{y,l+1}^{surv,i}) & \text{for } g = 1/2 \end{cases} \quad (\text{App.I.2})$$

- If there is sex-information for both of the two 1 cm length classes to group (i.e. if $\sum_g q_{yl}^{g,surv,i} = 1$ and $\sum_g q_{y,l+1}^{g,surv,i} = 1$), then the sex-information is used directly:

$$p_{yL}^{g,surv,i} = \begin{cases} 0 & \text{for } g = 0 \\ q_{yl}^{g,surv,i} p_{yl}^{surv,i} + q_{y,l+1}^{g,surv,i} p_{y,l+1}^{surv,i} & \text{for } g = 1/2 \end{cases} \quad (\text{App.I.3})$$

c. The strata proportions-at-length are weighted by the estimated total number in the strata to obtain a survey specific gender-disaggregated proportions-at-length ($p_{yl}^{g,surv}$). The estimated total number in each stratum is calculated as:

$$N_y^{surv,i} = B_y^{surv,i} / \bar{W}_y^{surv,i} \quad (\text{App.I.4})$$

where

$B_y^{surv,i}$ is the survey biomass estimate for stratum i in survey $surv$, and

$\bar{W}_y^{surv,i}$ is the mean weight of fish for stratum i in survey $surv$, with

$$\bar{W}_y^{surv,i} = \sum_l (p_{yl}^{surv,i} \alpha l^\beta) \quad (\text{App.I.5})$$

d. For each 2 cm length class, if the unsexed proportion is less than 20% of the total proportion in that length class, the sexed proportion is used to split the unsexed proportion into males and females.

Figs. App.I.2-3 plot the survey length frequencies available.

Length frequency information from the commercial catch is not available by species, the reason being that it is often based on cleaned (headed and gutted) fish, which cannot be easily identified by species. As a result it is not possible to disaggregate the commercial length frequencies by species. Commercial catches-at-length for the offshore and for the inshore and longline fleets are shown in Tables App.II.10-12. The south coast inshore and longline fleet catches are assumed to consist of *M. capensis* only.

I.4 Age-Length Keys

Table App.I.6 lists the age-length keys available. Data from animals with frills on gills (FOG) have been discarded (<3% of the total). All aged animals less or equal to 20cm in length are assumed to be juveniles, i.e. of unknown gender. The few unsexed data from animals greater than 20cm have been discarded (<1% of the total), as well as the outliers, defined as the data points lying outside the mean \pm 3s.d. for each age (mean and s.d. calculated across all years and surveys). Three ALKs for *M. paradoxus* have been totally ignored in the model fitting as they seemed inconsistent with the other ALKs: i) 1997 West Coast summer survey, ii) 2004 West Coast summer and iii) 2006 West Coast summer. The data for these three sets are shown in Fig. App.I.5.

Most otoliths are read more than once, however only one reading for each otoliths is used in the fitting procedure. Table App.I.7 show which reader was selected in the event of more than one reading.

Table App.I.1: Species-disaggregated catches (in thousand tons) of South African hake from the south and west coasts (see text for details), assuming 1958 as the centre year of the shift from a primarily *M. capensis* to a primarily *M. paradoxus* offshore trawl catch.

	<i>M. paradoxus</i>			<i>M. capensis</i>					
	Offshore	Longline		Offshore	Inshore	Longline	Handline		
	West coast	South coast	West coast	West coast	South coast	South coast	West coast	South coast	South coast
1917				1.000					
1918				1.100					
1919				1.900					
1920				0.000					
1921				1.300					
1922				1.000					
1923				2.500					
1924				1.500					
1925				1.900					
1926				1.400					
1927				0.800					
1928				2.600					
1929				3.800					
1930				4.400					
1931				2.800					
1932				14.300					
1933				11.100					
1934				13.800					
1935				15.000					
1936				17.700					
1937				20.200					
1938				21.100					
1939				20.000					
1940				28.600					
1941				30.600					
1942	0.001			34.499					
1943	0.001			37.899					
1944	0.002			34.098					
1945	0.004			29.196					
1946	0.010			40.390					
1947	0.020			41.380					
1948	0.056			58.744					
1949	0.107			57.293					
1950	0.260			71.740					
1951	0.627			88.873					
1952	1.201			87.599					
1953	2.422			91.078					
1954	5.149			100.251					
1955	10.343			105.057					
1956	18.540			99.660					
1957	32.241			94.159					
1958	49.136			81.564					
1959	72.535			73.465					
1960	95.147			64.753		1.000			
1961	98.478			50.222		1.308			
1962	103.768			43.832		1.615			
1963	123.055			46.445		1.923			
1964	119.837			42.463		2.231			
1965	151.211			51.789		2.538			
1966	145.914			49.086		2.846			
1967	132.530	5.391		44.170	8.795	3.154			
1968	107.834	10.619		35.766	17.289	3.462			
1969	124.056	14.442		41.044	23.489	3.769			
1970	107.108	9.035		35.392	14.688	4.077			
1971	151.855	11.472		50.145	18.644	4.385			
1972	183.394	17.789		60.539	28.907	4.692			
1973	118.629	27.566		39.153	44.790	5.000			
1974	92.480	34.613		30.520	56.240	10.056			
1975	67.381	25.703		22.236	41.760	6.372			
1976	108.192	19.785		35.702	32.145	5.740			
1977	76.939	14.086		25.389	22.886	3.500			
1978	103.665	3.830		23.847	3.755	4.931			
1979	93.711	2.653		39.811	4.266	6.093			
1980	100.723	2.833		32.805	3.628	9.121			
1981	90.572	1.208		30.358	4.277	9.400			
1982	84.030	4.063		29.319	7.294	8.089			
1983	71.628	5.920	0.161	22.805	6.596	7.672	0.069		
1984	82.940	4.689	0.256	28.316	6.246	9.035	0.110	0.016	
1985	93.192	10.054	0.817	31.878	9.962	9.203	0.350	0.292	0.065
1986	105.097	9.974	0.965	28.708	5.991	8.724	0.413	0.302	0.084
1987	95.954	9.495	2.500	21.571	6.189	8.607	1.071	0.353	0.096
1988	83.910	7.184	3.628	22.672	7.332	8.417	1.555	0.331	0.071
1989	84.719	6.919	0.203	22.541	11.993	10.038	0.087	0.032	0.137
1990	89.976	11.636	0.270	13.660	11.155	10.012	0.116		0.348
1991	92.787	9.604		13.663	12.470	8.206		3.000	1.270
1992	89.638	19.260		13.649	7.202	9.252		1.500	1.099
1993	107.370	11.143		10.694	3.117	8.870			0.278
1994	112.355	7.842	1.130	11.512	3.210	9.569	0.484	0.626	0.449
1995	104.842	4.486	0.670	16.055	2.664	10.630	0.287	0.650	0.756
1996	119.889	10.467	1.676	9.286	2.822	11.062	0.718	1.828	1.515
1997	108.917	12.902	1.806	8.237	2.934	8.834	0.774	1.872	1.404
1998	115.290	11.165	0.647	12.363	2.988	8.283	0.277	1.471	1.738
1999	90.030	12.749	1.963	13.731	2.597	8.595	0.841	4.144	2.749
2000	91.366	8.777	3.456	26.336	4.753	10.906	1.481	2.077	5.500
2001	98.164	8.213	2.793	19.433	7.944	11.836	1.197	1.688	7.300
2002	95.122	13.629	4.772	9.809	4.955	9.581	2.045	3.945	3.500
2003	95.062	20.503	4.668	10.314	4.530	9.883	2.000	4.878	3.000
2004	86.340	28.805	3.758	11.891	5.965	10.004	1.611	4.429	1.600
2005	88.722	24.374	4.172	6.545	4.872	7.881	1.788	4.559	0.700
2006	84.951	19.923	3.592	8.547	4.705	5.524	1.539	4.032	0.400
2007	96.426	14.899	3.151	12.444	2.345	6.350	1.350	3.834	0.400
2008	92.445	13.861	2.170	6.930	3.646	5.496	0.930	2.740	0.231
2009	85.357	12.798	2.004	6.399	3.366	5.075	0.859	2.530	0.213

Table App.I.2: South and west coast historic (ICSEAF, 1989) and GLM standardized CPUE data (GLM3 of Glazer and Butterworth, 2009) for *M. paradoxus* and *M. capensis*. The historic CPUE series are for *M. capensis* and *M. paradoxus* combined.

Year	ICSEAF CPUE (t hr ⁻¹)		Year	GLM CPUE (kg min ⁻¹)			
	Species-aggregated			<i>M. paradoxus</i>		<i>M. capensis</i>	
	West Coast	South Coast		West Coast	South Coast	West Coast	South Coast
1955	17.31		1978	3.90	0.76	0.85	2.10
1956	15.64		1979	3.83	0.71	1.36	2.08
1957	16.47		1980	3.59	1.12	1.17	2.61
1958	16.26		1981	3.56	0.69	1.21	2.25
1959	16.26		1982	3.49	0.99	1.05	2.28
1960	17.31		1983	3.78	1.10	1.37	2.68
1961	12.09		1984	3.91	1.17	1.45	3.13
1962	14.18		1985	4.39	1.69	1.77	3.82
1963	13.97		1986	3.99	1.66	1.32	3.10
1964	14.60		1987	3.32	1.64	1.08	2.74
1965	10.84		1988	3.36	1.15	0.94	3.12
1966	10.63		1989	3.59	1.09	1.04	3.56
1967	10.01		1990	4.21	1.76	0.62	3.97
1968	10.01		1991	4.45	0.95	0.87	4.55
1969	8.62	1.28	1992	3.86	2.06	1.15	3.50
1970	7.23	1.22	1993	3.90	1.96	1.05	2.28
1971	7.09	1.14	1994	4.47	1.53	1.08	2.96
1972	4.90	0.64	1995	3.59	0.95	1.45	3.15
1973	4.97	0.56	1996	4.52	1.77	1.06	2.48
1974	4.65	0.54	1997	3.90	2.30	1.04	2.18
1975	4.66	0.37	1998	3.97	1.84	1.61	2.25
1976	5.35	0.40	1999	3.10	2.11	1.71	2.56
1977	4.84	0.42	2000	2.42	1.40	1.90	2.55
			2001	2.10	1.46	1.28	1.89
			2002	2.47	1.25	0.78	2.22
			2003	2.47	1.90	0.93	2.04
			2004	2.08	1.32	0.81	1.92
			2005	2.21	1.31	0.48	1.51
			2006	2.36	1.36	0.56	1.20
			2007	2.74	1.44	0.60	1.06
			2008	3.44	1.38	0.50	1.67

Table App.I.3: Survey abundance estimates and associated standard errors in thousand tons for *M. paradoxus* for the depth range 0-500m for the south coast and for the west coast. Values in bold are for the surveys conducted by the *Africana* with the new gear.

Year	West coast				South coast			
	Summer		Winter		Spring (Sept)		Autumn (Apr/May)	
	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)
1985	169.959	(36.680)	264.839	(52.949)	-	-	-	-
1986	196.111	(36.358)	172.477	(24.122)	13.758	(3.554)	-	-
1987	284.805	(53.101)	195.482	(44.415)	21.554	(4.605)	-	-
1988	158.758	(27.383)	233.041	(64.003)	-	-	30.316	(11.104)
1989	-	-	468.780	(124.830)	-	-	-	-
1990	282.174	(78.945)	226.862	(46.007)	-	-	-	-
1991	327.020	(82.180)	-	-	-	-	26.638	(10.460)
1992	226.687	(32.990)	-	-	-	-	24.304	(15.195)
1993	334.151	(50.234)	-	-	-	-	198.849	(98.452)
1994	330.270	(58.319)	-	-	-	-	111.469	(34.627)
1995	324.554	(80.357)	-	-	-	-	55.068	(22.380)
1996	430.908	(80.604)	-	-	-	-	85.546	(25.484)
1997	569.957	(108.200)	-	-	-	-	135.192	(51.031)
1998	-	-	-	-	-	-	-	-
1999	562.859	(116.302)	-	-	-	-	321.478	(113.557)
2000	-	-	-	-	-	-	-	-
2001	-	-	-	-	19.929	(9.956)	-	-
2002	267.487	(35.068)	-	-	-	-	-	-
2003	411.177	(69.431)	-	-	88.442	(36.051)	108.857	(37.528)
2004	259.527	(56.021)	-	-	63.900	(17.894)	48.898	(20.343)
2005	286.416	(39.849)	-	-	-	-	26.605	(7.952)
2006	315.310	(49.490)	-	-	72.415	(15.500)	34.799	(8.325)
2007	392.812	(70.043)	-	-	52.287	(19.231)	129.646	(60.661)
2008	246.542	(51.973)	-	-	24.816	(8.775)	39.505	(11.408)
2009	330.235	(28.526)	-	-	-	-	102.834	(28.670)

Table App.I.4: Survey abundance estimates and associated standard errors in thousand tons for *M. capensis* for the depth range 0-500m for the south coast and for the west coast. Values in bold are for the surveys conducted by the *Africana* with the new gear.

Year	West coast				South coast			
	Summer		Winter		Spring (Sept)		Autumn (Apr/May)	
	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)
1985	124.647	(22.707)	181.487	(27.476)	-	-	-	-
1986	117.810	(23.636)	119.587	(18.489)	121.197	(16.625)	-	-
1987	75.693	(10.241)	87.391	(11.198)	159.088	(17.233)	-	-
1988	66.725	(10.765)	47.120	(9.568)	-	-	165.939	(21.871)
1989	-	-	323.833	(67.295)	-	-	-	-
1990	455.798	(135.237)	157.800	(23.561)	-	-	-	-
1991	77.357	(14.995)	-	-	-	-	274.298	(44.395)
1992	95.407	(11.744)	-	-	-	-	138.085	(15.357)
1993	92.598	(14.589)	-	-	-	-	158.340	(13.733)
1994	121.257	(35.951)	-	-	-	-	160.555	(23.701)
1995	199.142	(26.812)	-	-	-	-	236.025	(31.840)
1996	83.337	(9.285)	-	-	-	-	244.410	(25.107)
1997	257.293	(46.056)	-	-	-	-	183.087	(18.906)
1998	-	-	-	-	-	-	-	-
1999	198.716	(32.467)	-	-	-	-	191.203	(14.952)
2000	-	-	-	-	-	-	-	-
2001	-	-	-	-	133.793	(20.858)	-	-
2002	106.253	(15.813)	-	-	-	-	-	-
2003	75.960	(13.314)	-	-	82.928	(9.010)	128.450	(20.062)
2004	205.939	(33.216)	-	-	106.119	(15.596)	99.902	(12.027)
2005	70.983	(13.845)	-	-	-	-	76.932	(5.965)
2006	88.420	(22.851)	-	-	99.867	(9.803)	130.900	(14.816)
2007	82.270	(11.441)	-	-	74.615	(7.383)	70.940	(5.615)
2008	50.877	(5.355)	-	-	94.232	(11.456)	108.195	(9.978)
2009	175.289	(39.920)	-	-	-	-	124.004	(11.808)

Table App. I.5: Survey length frequencies currently available.

Year	West coast				South coast			
	Summer		Winter		Spring (Sept)		Autumn (Apr/May)	
	Sex-aggr.	By sex	Sex-aggr.	By sex	Sex-aggr.	By sex	Sex-aggr.	By sex
1985	✓	-	✓	-	-	-	-	-
1986	✓	-	✓	-	✓	-	-	-
1987	✓	-	✓	-	✓	-	-	-
1988	✓	-	✓	-	-	-	✓	-
1989	-	-	✓	-	-	-	-	-
1990	✓	-	✓	-	-	-	-	-
1991	✓	-	-	-	-	-	✓	-
1992	✓	-	-	-	-	-	✓	-
1993	✓	✓	-	-	-	-	✓	✓
1994	✓	✓	-	-	-	-	✓	✓
1995	✓	✓	-	-	-	-	✓	✓
1996	✓	✓	-	-	-	-	✓	✓
1997	✓	✓	-	-	-	-	✓	✓
1998	-	-	-	-	-	-	-	-
1999	✓	✓	-	-	-	-	✓	-
2000	-	-	-	-	-	-	-	-
2001	-	-	-	-	✓	-	-	-
2002	✓	-	-	-	-	-	-	-
2003	✓	-	-	-	✓	-	✓	-
2004	✓	-	-	-	✓	-	✓	-
2005	✓	-	-	-	-	-	✓	-
2006	✓	✓	-	-	✓	✓	✓	✓
2007	✓	✓	-	-	✓	✓	✓	✓
2008	✓	✓	-	-	✓	✓	✓	✓
2009	✓	✓	-	-	-	-	✓	✓

Table App. I.6: Species- and sex-disaggregated age and length data currently available by reader.

	Year	<i>M. paradoxus</i>										<i>M. capensis</i>										
		UR	AD	LB	KG	JP	AP	DJ	PM	TA	KB	UR	AD	LB	KG	JP	AP	DJ	PM	TA	KB	
West coast summer survey	1990	351																			354	
	1991	349																				384
	1992				310	310	44								390	389	33					
	1993				313	311		49							2	353	352	62				
	1994				290	290		4								282	282	6				
	1995					303						303					368					368
	1996	292																				365
	1997	333		334																		334
	1999	268	307	299												319	352	359				
	2004			506																		
	2005			354												340						
	2006		465	468												163						
	2007		557	554												369	372					
2008		412	409												475	453						
West coast winter survey	1988	471																			354	
	1990	303																				
South coast spring survey	1994	10																				
	2004														808	808						
	2006		489	243											512							
	2007		116												441							
	2008		149												127							
South coast autumn survey	1991	109																			421	
	1992				40	40	5									329	329	91				
	1993				95	95		23								407	407	40				
	1994				95	69		27							5	390	391	83				
	1995	95													404							
	1996	60													373							
	1997	85													387							
	1999		139	139					140	140	140				266	264			408	406	400	
	2004														508							
	2005		194	193																		
	2006		444	358												740						
2007		215	214											629	626							
2008		137												643	643							
Offshore commercial	1992				521	521	46								260	260	28					
	1993				645	646		75							115	115		17				
	1994				330	330		38							5							
Longline comm.	1994			314	314		9								131	126		5				

Table App.I.7: For each set of readers, the reader shaded is the one which otoliths readings were used.

M. paradoxus

1	UR		
2	KG	JP	AP/DJ
3	UR	AD	LB
4	AD		
5	JP	KB	

M. capensis

1	UR				
2	KG	JP	AP/DJ		
3	JP	KB			
4	UR	AD	LB		
5	AD	LB	PM	TA	KB
6	PM	TA	KB		
5	LB				

The readers are: Alexia Daniels (AD), Luke Bester (LB), 'Unknown Reader' (UR), Kevin Gradie (KG), John Prinsloo (JP), Andy Payne/Dave Japp (AP/DJ), Phoeby Mullins (PM), Teresa Akkers (TA) and Kashif Booley (KB).

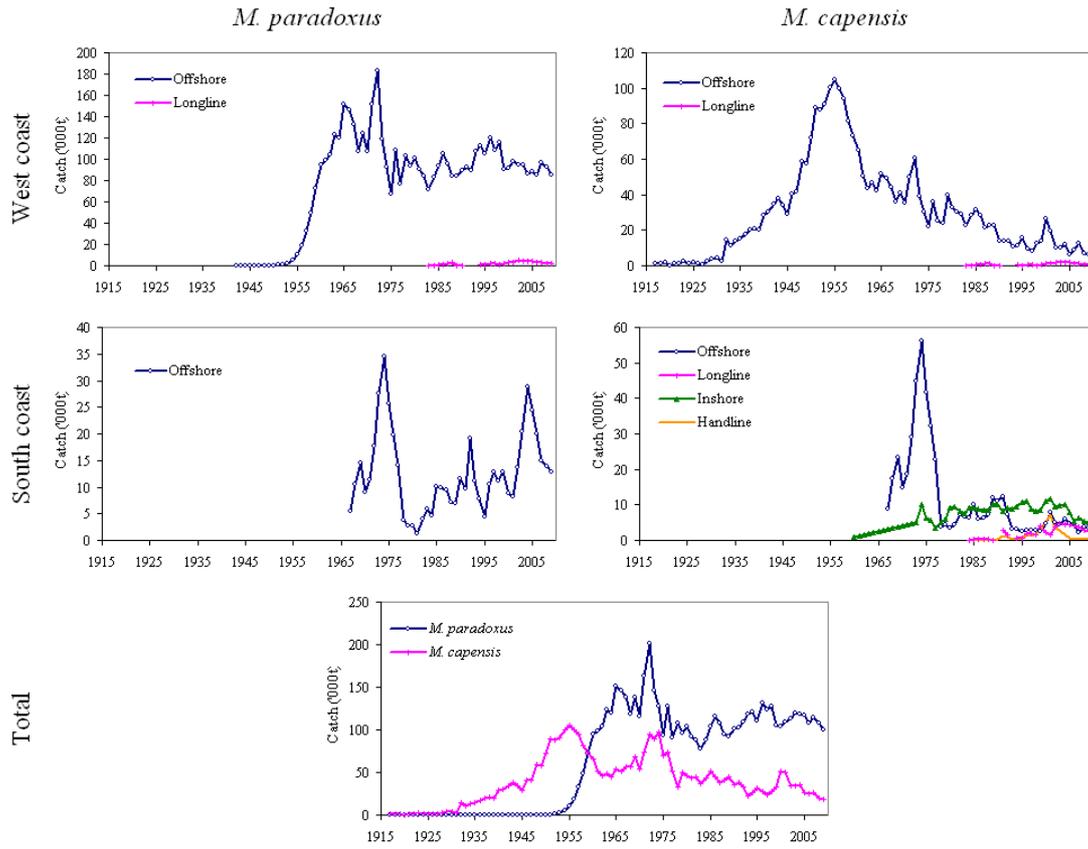


Fig. App.I.1: Annual catches, see text for details, assuming 1958 as the centre year of the shift from a primarily *M. capensis* to a primarily *M. paradoxus* offshore trawl catch..

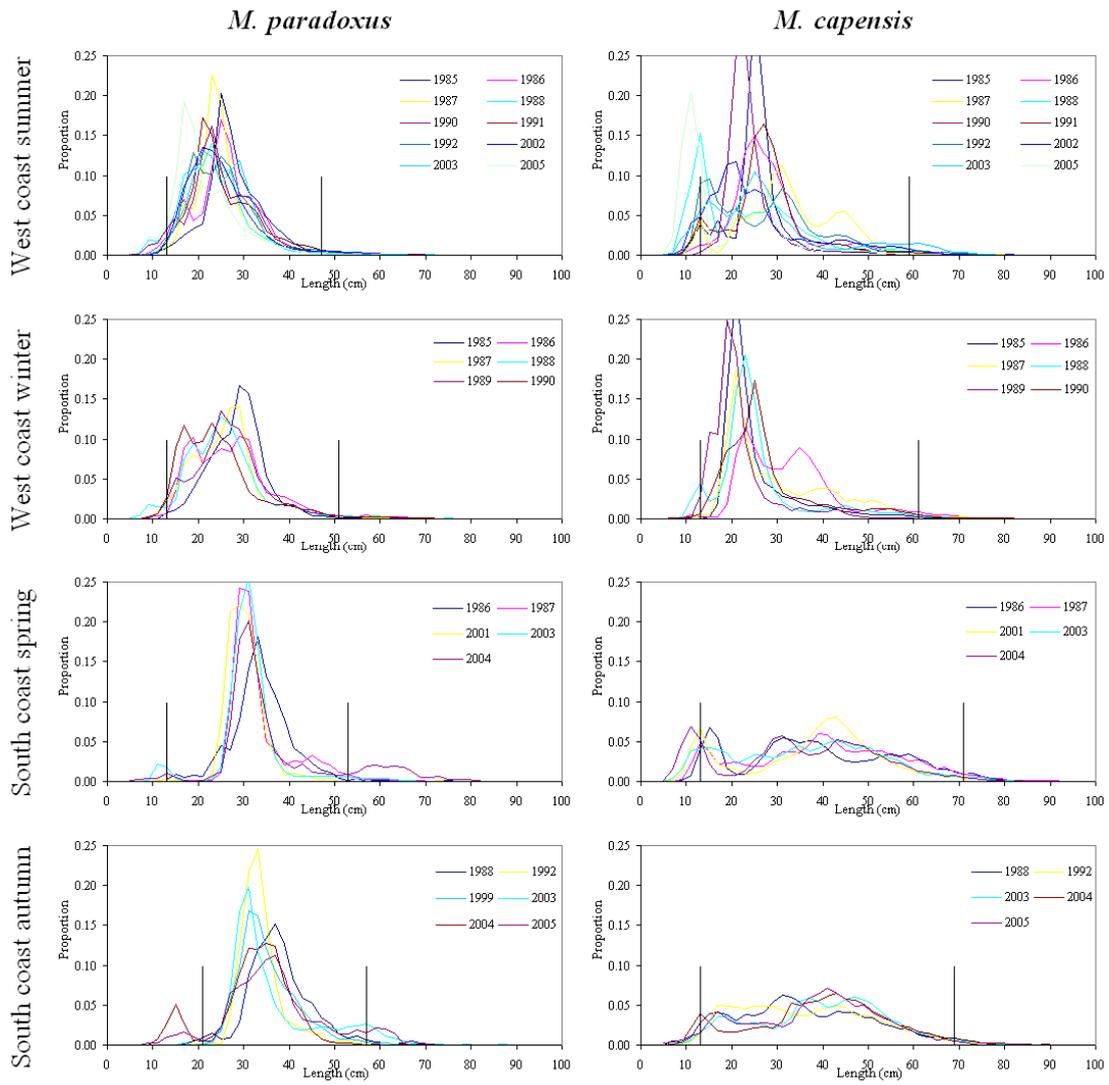


Fig. App.I.2: Sex-aggregated survey catch-at-length information. The vertical bars show the minus and plus groups used.

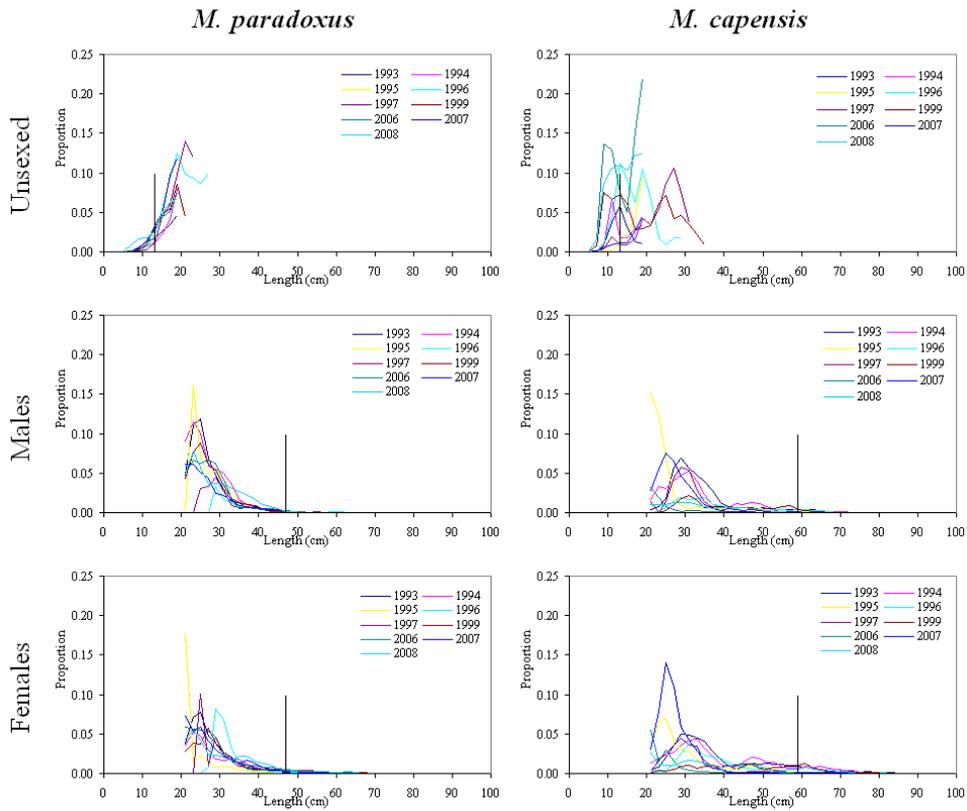


Fig App.I.3a: West coast summer gender-disaggregated survey catch-at-length information. The vertical bars show the minus and plus groups used.

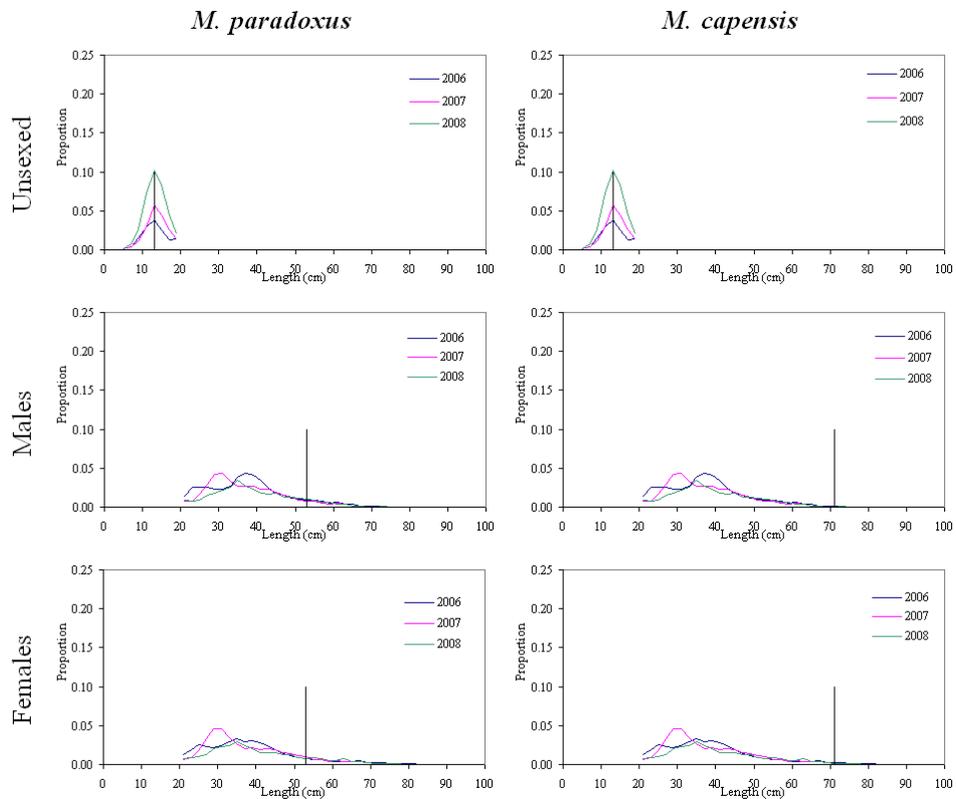


Fig App.I.3b: South coast spring gender-disaggregated survey catch-at-length information. The vertical bars show the minus and plus groups used.

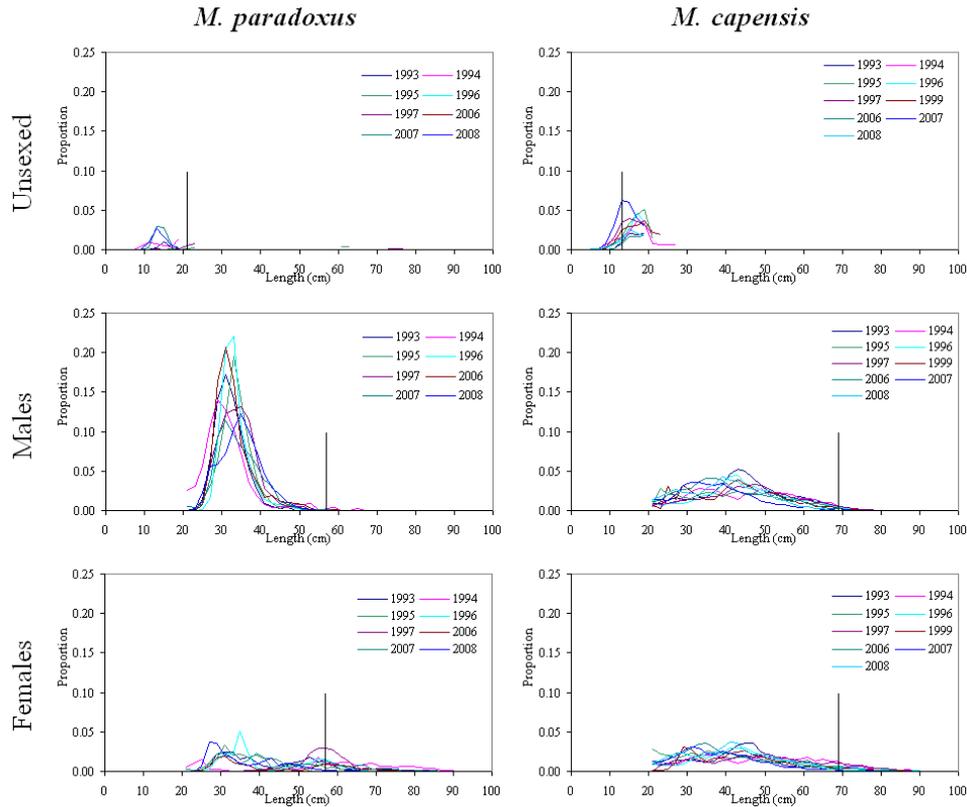


Fig App.I.3c: South coast autumn gender-disaggregated survey catch-at-length information. The vertical bars show the minus and plus groups used.

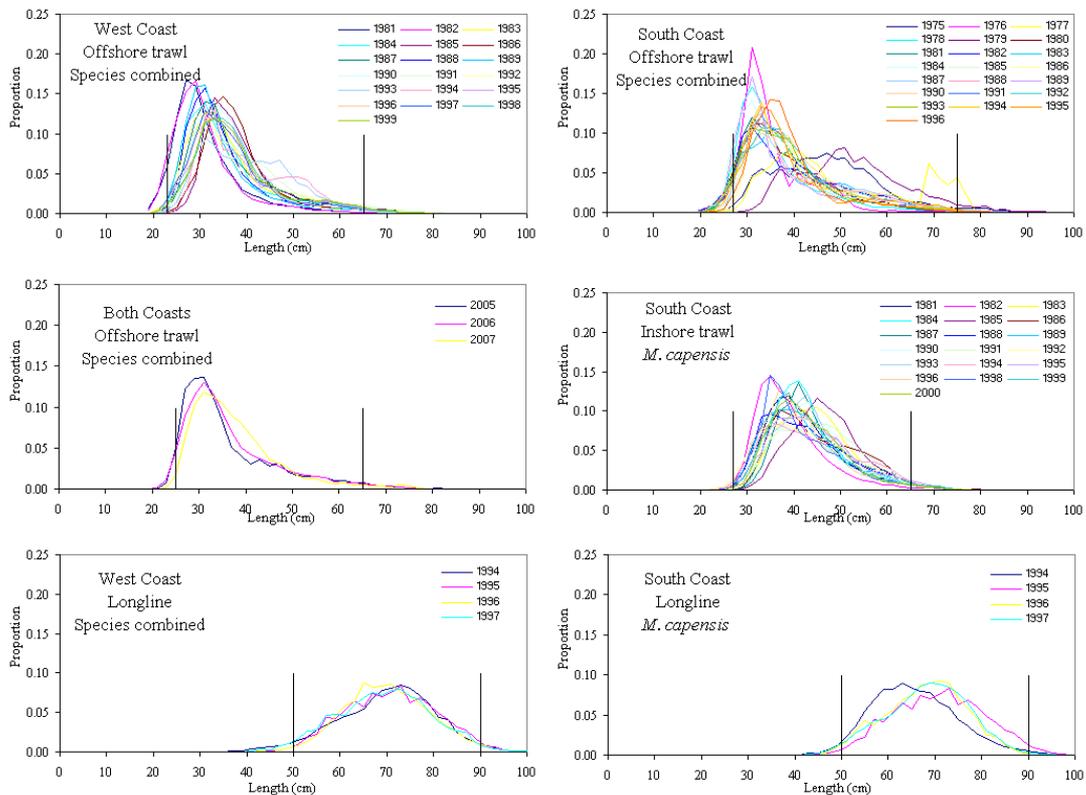


Fig App.I.4: Commercial catch-at-length information. The vertical bars show the minus and plus groups used.

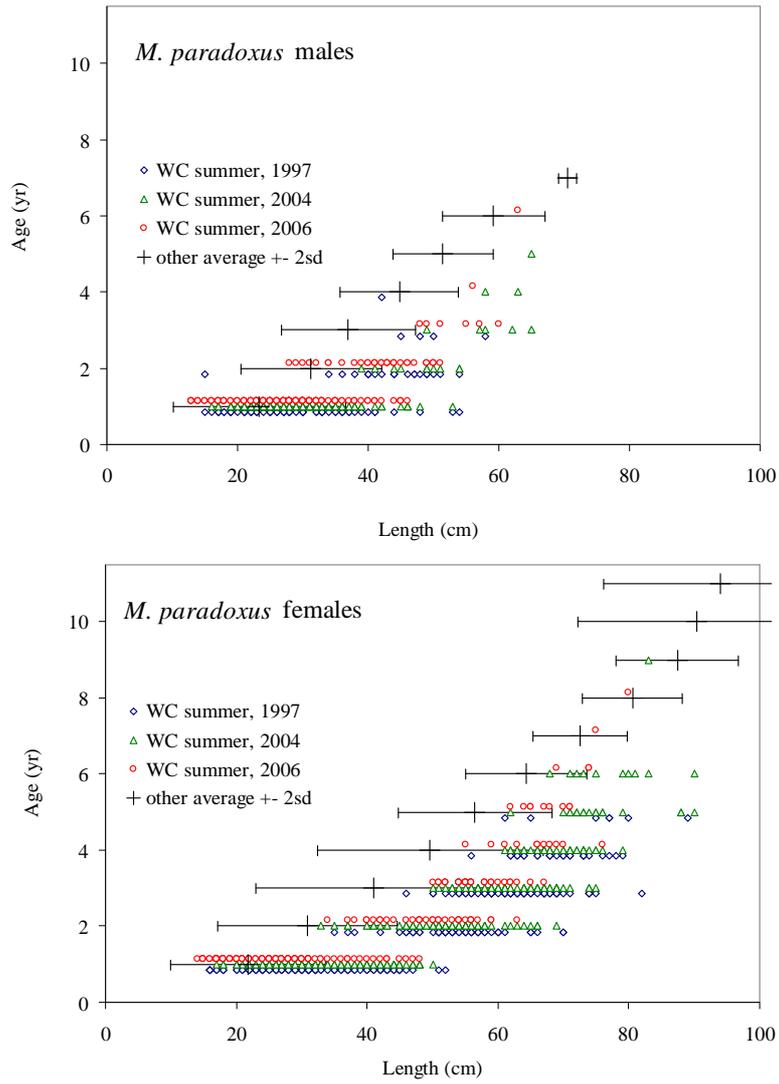


Fig. App.I.5: Data points for each gender separately for the three *M. paradoxus* ALKs that have been omitted from the model fitting. The average of the other ALKs is shown with the error bars representing the ± 2 s.d. range.

APPENDIX II – Gender-disaggregated, Age-Structured Production Model fitting to Age-Length Keys

The model used is a gender-disaggregated Age-Structured Production Model (ASPM), which is fitted directly to age-length keys (ALKs) and length frequencies. The model also involves assessing the two species as two independent stocks and is fitted to species-disaggregated data as well as species-combined data. The general specifications and equations of the overall model are set out below together with some key choices in the implementation of the methodology. Details of the contributions to the log-likelihood function from the different data considered are also given. Quasi-Newton minimisation is used to minimise the total negative log-likelihood function (implemented using AD Model Builder™, Otter Research, Ltd.).

Population Dynamics

Numbers-at-age

The resource dynamics of the two populations (*M. capensis* and *M. paradoxus*) of the South African hake are modelled by the following set of equations:

Note: for ease of reading, the ‘species’ subscript *s* has been omitted below where not relevant.

$$N_{y+1,0}^g = R_{y+1}^g \quad (\text{App.II.1})$$

$$N_{y+1,a+1}^g = \left(N_{ya}^g e^{-M_a^g/2} - \sum_f C_{fya}^g \right) e^{-M_a^g/2} \quad \text{for } 0 \leq a \leq m - 2 \quad (\text{App.II.2})$$

$$N_{y+1,m}^g = \left(N_{y,m-1}^g e^{-M_{m-1}^g/2} - \sum_f C_{f,y,m-1}^g \right) e^{-M_{m-1}^g/2} + \left(N_{ym}^g e^{-M_m^g/2} - \sum_f C_{fym}^g \right) e^{-M_m^g/2} \quad (\text{App.II.3})$$

where

N_{ya}^g is the number of fish of gender *g* and age *a* at the start of year y^l ,

R_y^g is the recruitment (number of 0-year-old fish) of fish of gender *g* at the start of year *y*,

m is the maximum age considered (taken to be a plus-group),

M_a^g denotes the natural mortality rate on fish of gender *g* and age *a*, and

C_{fya}^g is the number of hake of gender *g* and age *a* caught in year *y* by fleet *f*.

Recruitment

The number of recruits (i.e. new zero-year old fish) at the start of year *y* is assumed to be related to the corresponding **female** spawning stock size (i.e., the biomass of mature female fish) by means of the Beverton-Holt (Beverton and Holt, 1957) or a modified (generalised) form of the Ricker stock-recruitment relationship, parameterized in terms of the “steepness” of the stock-recruitment relationship, *h*, and the pre-exploitation equilibrium female spawning biomass, $K^{\text{♀sp}}$, and pre-exploitation recruitment, R_0 and assuming a 50:50 sex-split at recruitment.

¹ In the interests of less cumbersome notation, subscripts have been separated by commas only when this is necessary for clarity.

$$R_y^g = \frac{4hR_0 B_y^{\varnothing,sp}}{K^{\varnothing,sp}(1-h) + (5h-1)B_y^{\varnothing,sp}} e^{(\zeta_y - \sigma_R^2/2)} \quad (\text{App.II.4a})$$

for the Beverton-Holt stock-recruitment relationship and

$$R_y^g = \alpha B_y^{\varnothing,sp} \exp\left(-\beta (B_y^{\varnothing,sp})^\gamma\right) e^{(\zeta_y - \sigma_R^2/2)} \quad (\text{App.II.4b})$$

with

$$\alpha = R_0 \exp\left(\beta (K^{\varnothing,sp})^\gamma\right) \quad \text{and} \quad \beta = \frac{\ln(5h)}{(K^{\varnothing,sp})^\gamma (1-5^{-\gamma})}$$

for the modified Ricker relationship (for the true Ricker, $\gamma=1$) where

ζ_y reflects fluctuation about the expected recruitment in year y ;

$B_y^{\varnothing,sp}$ is the female spawning biomass at the start of year y , computed as:

$$B_y^{\varnothing,sp} = \sum_{a=1}^m f_a^{\varnothing} w_a^{\varnothing} N_{ya}^{\varnothing} \quad (\text{App.II.5})$$

where

w_a^g is the begin-year mass of fish of gender g and age a ;

f_a^g is the proportion of fish of gender g and age a that are mature; and

$$R_0 = K^{\varnothing,sp} / \left[\sum_{a=1}^{m-1} f_a^{\varnothing} w_a^{\varnothing} e^{-\sum_{a'=0}^{a-1} M_{a'}^g} + f_m^{\varnothing} w_m^{\varnothing} \frac{e^{-\sum_{a'=0}^{m-1} M_{a'}^g}}{1 - e^{-M_m^g}} \right] \quad (\text{App.II.6})$$

For the Beverton-Holt form, h is bounded above by 0.98 to preclude high recruitment at extremely low spawning biomass, whereas for the modified Ricker form, h is bounded above by 1.5 to preclude extreme compensatory behaviour.

Total catch and catches-at-age

The fleet-disaggregated catch by mass, in year y is given by:

$$C_{fy} = \sum_g \sum_{a=0}^m w_{a+1/2}^g C_{fya}^g = \sum_g \sum_{a=0}^m w_{a+1/2}^g N_{ya}^g e^{-M_a^g/2} F_{fy} \tilde{S}_{fya}^g \quad (\text{App.II.7})$$

where

C_{fya}^g is the catch-at-age, i.e. the number of fish of gender g and age a , caught in year y by fleet f ;

F_{fy} is the fishing mortality of a fully selected age class, for fleet f in year y (independent of g);

$$\tilde{S}_{fya}^g = \tilde{w}_{fy,a+1/2}^g / w_{a+1/2}^g \quad (\text{App.II.8})$$

\tilde{S}_{fya}^g is the effective commercial selectivity of gender g at age a for fleet f and year y ; with

$$\tilde{w}_{fy,a+1/2}^g = \sum_l S_{fyl}^g w_l^g P_{a+1/2,l}^g \quad (\text{App.II.9})$$

$\tilde{w}_{fy,a+1/2}^g$ is the selectivity-weighted mid-year weight-at-age a of gender g for fleet f and year y ;

w_l^g is the weight of fish of gender g and length l ;

$w_{a+1/2}^g$ is the mid-year weight of fish of gender g and age a , at median length for that age;

S_{fyl}^g is the commercial selectivity of gender g at length l for year y , and fleet f ;

$P_{a+1/2,l}^g$ is the mid-year proportion of fish of age a and gender g that fall in the length group l (i.e., $\sum_l P_{a+1/2,l}^g = 1$ for all ages a).

The matrix P is calculated under the assumption that length-at-age is log-normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$l_a \sim N \left[\ln \left(l_\infty \left(1 - e^{-\kappa(a-t_0)} \right) \right); \left(\frac{\theta_a}{l_\infty \left(1 - e^{-\kappa(a-t_0)} \right)} \right)^2 \right] \quad (\text{App.II.10})$$

where θ_a is the standard deviation of length-at-age a , which is estimated directly in the model fitting for age 0, and for ages 1 and above a linear relationship applies, with species and gender-specific α and β estimated in the model fitting procedure. A penalty is added so that θ_a is increasing with age.

Exploitable and survey biomasses

The model estimate of the mid-year exploitable (“available”) component of biomass for each species and fleet is calculated by converting the numbers-at-age into mid-year mass-at-age and applying natural and fishing mortality for half the year:

$$B_{fy}^{ex} = \sum_g \sum_{a=0}^m w_{a+1/2}^g \tilde{S}_{fya}^g N_{ya}^g e^{-M_a^g/2} \left(1 - \sum_f S_{fya}^g F_{fy} / 2 \right) \quad (\text{App.II.11})$$

The model estimate of the survey biomass at the start of the year (summer) is given by:

$$B_y^{surv} = \sum_g \sum_{a=0}^{m_s} w_a^g \tilde{S}_a^{g,sum} N_{ya}^g \quad (\text{App.II.12})$$

and in mid-year (winter):

$$B_y^{surv} = \sum_g \sum_{a=0}^m w_{a+1/2}^g \tilde{S}_a^{g,win} N_{ya}^g e^{-M_a^g/2} \left(1 - \sum_f S_{fya}^g F_{fy} / 2 \right) \quad (\text{App.II.13})$$

where

$\tilde{S}_a^{g,sum/win}$ is the effective survey selectivity of gender g for age a , converted from survey selectivity-at-length and selectivity-weighted weight-at-age in the same manner as for the commercial selectivity (eqns App.II.8 and App.II.9), taking account of the being-year ($\tilde{w}_{y,a}^{g,sum}$ from $P_{a,l}^g$) or mid-year ($\tilde{w}_{y,a+1/2}^{g,win}$ from $P_{a+1/2,l}^g$) nature of the surveys

Note that both the spring and autumn surveys are taken to correspond to winter (mid-year).

It is assumed that the resource is at the deterministic equilibrium that corresponds to an absence of harvesting at the start of the initial year considered, i.e., $B_1^{g,sp} = K^{g,sp}$, and year $y=1$ corresponds to 1917 when catches are taken to commence.

MSY and related quantities

The equilibrium catch for a fully selected fishing proportion F^* is calculated as:

$$C(F^*) = \sum_g \sum_a w_{a+1/2}^g \tilde{S}_a^g F^* N_a^g(F^*) e^{-((M_a^g + S_a^g F^*)/2)} \quad (\text{App.II.14})$$

where

S_a^g and \tilde{S}_a^g are average selectivities and effective selectivities across all fleets, for the most recent five years;

$$S_a^g = \frac{\sum_{y=2005}^{2009} \sum_f S_{fya}^g F_{fy}}{\max \left(\sum_{y=2005}^{2009} \sum_f S_{fya}^g F_{fy} \right)} \quad (\text{App.II.15})$$

$$\tilde{S}_a^g = \frac{\sum_{y=2005}^{2009} \sum_f \tilde{S}_{fya}^g F_{fy}}{\max \left(\sum_{y=2005}^{2009} \sum_f \tilde{S}_{fya}^g F_{fy} \right)} \quad (\text{App.II.16})$$

where the maximum is taken over genders and ages; and with

$$N_a^g(F^*) = \begin{cases} R_1(F^*) & \text{for } a = 1 \\ N_{a-1}^g(F^*) e^{-M_{a-1}^g (1 - S_{a-1}^g F^*)} & \text{for } 1 < a < m \\ \frac{N_{m-1}^g(F^*) e^{-M_{m-1}^g (1 - S_{m-1}^g F^*)}}{(1 - e^{-M_m^g (1 - S_m^g F^*)})} & \text{for } a = m \end{cases} \quad (\text{App.II.17})$$

where

$$R_1(F^*) = \frac{\alpha B^{\circ, sp}(F^*)}{\beta + B^{\circ, sp}(F^*)} \quad (\text{App.II.18})$$

for a Beverton-Holt stock–recruitment relationship.

The maximum of $C(F^*)$ is then found by searching over F^* to give F_{MSY}^* , with the associated female spawning biomass given by

$$B_{MSY}^{\circ, sp} = \sum_a f_a^{\circ} w_a^{\circ} N_a^{\circ}(F_{MSY}^*)$$

The likelihood function

The model is fit to CPUE and survey abundance indices, commercial and survey length frequencies, survey age-length keys, as well as to the stock-recruitment curve to estimate model parameters. Contributions by each of these to the negative of the log-likelihood ($-\ln L$) are as follows².

CPUE relative abundance data

The likelihood is calculated by assuming that the observed abundance index (here CPUE) is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \quad \text{or} \quad \varepsilon_y^i = \ln(I_y^i) - \ln(\hat{I}_y^i) \quad (\text{App.II.19})$$

where

I_y^i is the abundance index for year y and series i (which corresponds to a specified species and fleet)

$\hat{I}_y^i = \hat{q}^i \hat{B}_{fy}^{ex}$ is the corresponding model estimate, where \hat{B}_{fy}^{ex} is the model estimate of exploitable resource biomass, given by equation App.II.11,

\hat{q}^i is the constant of proportionality for abundance series i , and

$$\varepsilon_y^i \quad \text{from} \quad N\left(0, (\sigma_y^i)^2\right).$$

In cases where the CPUE series are based upon species-aggregated catches (as available pre-1978), the corresponding model estimate is derived by assuming two types of fishing zones: z1) an “*M. capensis* only zone”, corresponding to shallow water and z2) a “mixed zone” (Fig. App.II.1).

The total catch of hake of both species (*BS*) by fleet f in year y ($C_{BS, fy}$) can be written as:

$$C_{BS, fy} = C_{C, fy}^{z1} + C_{C, fy}^{z2} + C_{P, fy} \quad (\text{App.II.20})$$

where

$C_{C, fy}^{z1}$ is the *M. capensis* catch by fleet f in year y in the *M. capensis* only zone (z1),

$C_{C, fy}^{z2}$ is the *M. capensis* catch by fleet f in year y in the mixed zone (z2), and

$C_{P, fy}$ is the *M. paradoxus* catch by fleet f in year y in the mixed zone.

Catch rate is assumed to be proportional to exploitable biomass. Furthermore, let γ be the proportion of the *M. capensis* exploitable biomass in the mixed zone ($\gamma = B_{C, fy}^{ex, z2} / B_{C, fy}^{ex}$) (assumed to be constant throughout the period for simplicity) and ψ_{fy} be the proportion of the effort of fleet f in the mixed zone in year y ($\psi_{fy} = E_{fy}^{z2} / E_{fy}$), so that:

$$C_{C, fy}^{z1} = q_C^{i, z1} B_{C, fy}^{ex, z1} E_{fy}^{z1} = q_C^{i, z1} (1 - \gamma) B_{C, fy}^{ex} (1 - \psi_{fy}) E_{fy} \quad (\text{App.II.21})$$

$$C_{C, fy}^{z2} = q_C^{i, z2} B_{C, fy}^{ex, z2} E_{fy}^{z2} = q_C^{i, z2} \gamma B_{C, fy}^{ex} \psi_{fy} E_{fy} \quad \text{and} \quad (\text{App.II.22})$$

$$C_{P, fy} = q_P^i B_{P, fy}^{ex} E_{fy}^{z2} = q_P^i B_{P, fy}^{ex} \psi_{fy} E_{fy} \quad (\text{App.II.23})$$

where

² Strictly it is a penalised log-likelihood which is maximised in the fitting process, as some contributions that would correspond to priors in a Bayesian estimation process are added.

$E_{fy} = E_{fy}^{z1} + E_{fy}^{z2}$ is the total effort of fleet f , corresponding to combined-species CPUE series i which consists of the effort in the *M. capensis* only zone (E_{fy}^{z1}) and the effort in the mixed zone (E_{fy}^{z2}), and

$q_C^{i,zj}$ is the catchability for *M. capensis* (C) for abundance series i , and zone zj , and

q_P^i is the catchability for *M. paradoxus* (P) for abundance series i .

It follows that:

$$C_{C,fy} = B_{C,fy}^{ex} E_{fy} \left[q_C^{i,z1} (1-\gamma) (1-\psi_{fy}) + q_C^{i,z2} \gamma \psi_{fy} \right] \quad (\text{App.II.24})$$

$$C_{P,fy} = B_{P,fy}^{ex} E_{fy} q_P^i \psi_{fy} \quad (\text{App.II.25})$$

From solving equations App.II.24 and App.II.25:

$$s_{fy} = \frac{q_C^{i,z1} (1-\gamma)}{\left\{ \frac{C_{C,fy} B_{P,fy}^{ex} q_P^i}{B_{C,fy}^{ex} C_{P,fy}} - q_C^{i,z2} \gamma + q_C^{i,z1} (1-\gamma) \right\}} \quad (\text{App.II.26})$$

and:

$$\hat{y}^i = \frac{C_{fy}}{E_{fy}} = \frac{C_{fy} B_{P,fy}^{ex} q_P^i \psi_{fy}}{C_{P,fy}} \quad (\text{App.II.27})$$

Zone 1 (z1): <i>M. capensis</i> only	Zone 2 (z2): Mixed zone
<i>M. capensis</i> : biomass (B_C^{z1}), catch (C_C^{z1})	<i>M. capensis</i> : biomass (B_C^{z2}), catch (C_C^{z2})
	<i>M. paradoxus</i> : biomass (B_P), catch (C_P)
Effort in zone 1 (E^{z1})	Effort in zone 2 (E^{z2})

Fig. App.II.1: Diagrammatic representation of the two theoretical fishing zones.

Two species-aggregated CPUE indices are available: the ICSEAF west coast and the ICSEAF south coast series. For consistency, q 's for each species (and zone) are forced to be in the same proportion:

$$q_s^{SC} = r q_s^{WC} \quad (\text{App.II.28})$$

To correct for possible negative bias in estimates of variance (σ_y^i) and to avoid according unrealistically high precision (and so giving inappropriately high weight) to the CPUE data, lower bounds on the standard deviations of the residuals for the logarithm of the CPUE series have been enforced; for the historic ICSEAF CPUE series (separate west coast and south coast series) the lower bound is set to 0.25, and to 0.15 for the recent GLM-standardised CPUE series, i.e.: $\sigma^{ICSEAF} \geq 0.25$ and $\sigma^{GLM} \geq 0.15$.

The contribution of the CPUE data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ln L^{CPUE} = \sum_i \sum_y \left[\ln(\sigma_y^i) + (\varepsilon_y^i)^2 / 2(\sigma_y^i)^2 \right] \quad (\text{App.II.29})$$

where

σ_y^i is the standard deviation of the residuals for the logarithms of index i in year y .

Homoscedasticity of residuals for CPUE series is customarily assumed³, so that $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y (\ln(I_y^i) - \ln(\hat{I}_y^i))^2} \quad (\text{App.II.30})$$

where n_i is the number of data points for abundance index i .

In the case of the species-disaggregated CPUE series, the catchability coefficient q^i for abundance index i is estimated by its maximum likelihood value, which in the more general case of heteroscedastic residuals, is given by:

$$\ln \hat{q}^i = \frac{\sum_y (\ln I_y^i - \ln \hat{B}_{fy}^{ex}) / (\sigma_y^i)^2}{\sum_y 1 / (\sigma_y^i)^2} \quad (\text{App.II.31})$$

In the case of the species-combined CPUE, $q_C^{WC,z1}$, $q_C^{WC,z2}$, q_P^{WC} , r and γ are directly estimated in the fitting procedure.

Survey abundance data

Data from the research surveys are treated as relative abundance indices in a similar manner to the species-disaggregated CPUE series above, with survey selectivity function $S_a^{g,sum/win}$ replacing the commercial selectivity S_{fya}^g (see equations App.II.12 and App.II.13 above, which also take account of the begin- or mid-year nature of the survey).

An estimate of sampling variance is available for most surveys and the associated σ_y^i is generally taken to be given by the corresponding survey CV. However, these estimates likely fail to include all sources of variability, and unrealistically high precision (low variance and hence high weight) could hence be accorded to these indices. The contribution of the survey data to the negative log-likelihood is of the same form as that of the CPUE abundance data (see equation App.II.29). The procedure adopted takes into account an additional variance $(\sigma_A)^2$ which is treated as another estimable parameter in the minimisation process. This procedure is carried out enforcing the constraint that $(\sigma_A)^2 > 0$, i.e. the overall variance cannot be less than its externally input component.

In June 2003, the trawl gear on the *Africana* was changed and a different value for the multiplicative bias factor q is taken to apply to the surveys conducted with the new gear. Calibration experiments have been conducted between the *Africana* with the old gear (hereafter referred to as the “old *Africana*”) and the *Nansen*, and between the *Africana* with the new gear (“new *Africana*”) and the *Nansen*, in order to provide a basis to relate the multiplicative biases of the *Africana* with the two types of gear (q_{old} and q_{new}). A GLM analysis assuming negative binomial distributions for the catches made (Brandão *et al.*, 2004) provided the following estimates:

$$\Delta \ln q^{capensis} = -0.494 \quad \text{with } \sigma_{\Delta \ln q^{capensis}} = 0.141 \quad \text{i.e. } (q^{new} / q^{old})^{capensis} = 0.610 \quad \text{and}$$

³ There are insufficient data in any series to enable this to be tested with meaningful power.

$$\Delta \ln q^{\text{paradoxus}} = -0.053 \quad \text{with } \sigma_{\Delta \ln q^{\text{paradoxus}}} = 0.117 \quad \text{i.e. } (q^{\text{new}}/q^{\text{old}})^{\text{paradoxus}} = 0.948$$

where

$$\ln q_{\text{new}}^s = \ln q_{\text{old}}^s + \Delta \ln q^s \quad \text{with } s = \text{capensis or paradoxus} \quad (\text{App.II.32})$$

No plausible explanation has yet been found for the particularly large extent to which catch efficiency for *M. capensis* is estimated to have decreased for the new research survey trawl net. It was therefore recommended (BENEFIT, 2004) that the ratio of the catchability of the new to the previous *Africana* net be below 1, but not as low as the ratio estimated from the calibration experiments. $\Delta \ln q^{\text{capensis}}$ is therefore taken as -0.223, i.e. $(q^{\text{new}}/q^{\text{old}})^{\text{capensis}} = 0.8$.

The following contribution is therefore added as a penalty (or a prior in a Bayesian context) to the negative log-likelihood in the assessment:

$$- \ln L^{q\text{-ch}} = (\ln q_{\text{new}} - \ln q_{\text{old}} - \Delta \ln q)^2 / 2\sigma_{\Delta \ln q}^2 \quad (\text{App.II.33})$$

A different length-specific selectivity is estimated for the “old *Africana*” and the “new *Africana*”.

The survey’s coefficients of catchability q (for the survey with the old *Africana* gear) are constrained below 1:

$$\text{pen}^q = \sum_i (q_{\text{old}}^i - 1)^2 / 0.02^2 \quad \text{if} \quad q_{\text{old}}^i > 1 \quad (\text{App.II.34})$$

Commercial proportions at length

Commercial proportions at length cannot be disaggregated by species and gender. The model is therefore fit to the proportions at length as determined for both species and gender combined.

The catches at length are computed as:

$$C_{fyt} = \sum_s \sum_g \sum_{a=0}^m N_{sya}^g F_{syt} S_{syt}^g P_{s,a+1/2,t}^g e^{-M_{sa}^g/2} \left(1 - \sum_f S_{sya}^g F_{fy} / 2 \right) \quad (\text{App.II.35})$$

With the predicted proportions at length:

$$\hat{p}_{yl}^i = C_{fyt} / \sum_l C_{fyt} \quad (\text{App.II.36})$$

The contribution of the proportion at length data to the negative of the log-likelihood function when assuming an “adjusted” lognormal error distribution is given by:

$$- \ln L^{\text{length}} = 0.1 \sum_y \sum_l \left[\ln \left(\sigma_{len}^i / \sqrt{p_{yl}^i} \right) + p_{yl}^i \left(\ln p_{yl}^i - \ln \hat{p}_{yl}^i \right)^2 / 2 \left(\sigma_{len}^i \right)^2 \right] \quad (\text{App.II.37})$$

where

the superscript ‘ i ’ refers to a particular series of proportions at length data which reflect a specified fleet, and species (or combination thereof) and

σ_{len}^i is the standard deviation associated with the proportion at length data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{len}^i = \sqrt{\sum_y \sum_l p_{yl}^i \left(\ln p_{yl}^i - \ln \hat{p}_{yl}^i \right)^2 / \sum_y \sum_l 1} \quad (\text{App.II.38})$$

The initial 0.1 multiplicative factor is a somewhat arbitrary downweighting to allow for correlation between proportions in adjacent length groups. The coarse basis for this adjustment is the ratio of effective number of age-classes present to the number of length groups in the minimisation, under the argument that independence in variability is likely to be more closely related to the former.

Commercial proportions at length are incorporated in the likelihood function using equation App.II.37, for which the summation over length l is taken from length l_{minus} (considered as a minus group) to l_{plus} (a plus group). The length for the minus- and plus-groups are fleet specific and are chosen so that typically a few percent, but no more, of the fish sampled fall into these two groups.

Survey proportions at length

The survey proportions at length are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-age, assuming an adjusted log-normal error distribution (equation App.II.36). In this case however, data are disaggregated by species, and for some surveys further disaggregated by gender.

$P_{syl}^{g,surv} = \frac{C_{syl}^{g,surv}}{\sum_{l'} C_{syl'}^{g,surv}}$ is the observed proportion of fish of species s , gender g and length l from survey $surv$ in year y ,

$\hat{p}_{syl}^{g,surv}$ is the expected proportion of fish of species s , gender g and length l in year y in the survey $surv$, given by:

$$\hat{p}_{syl}^{g,surv} = \frac{\sum_a S_{sl}^{g,sum} P_{sal}^g N_{sya}^g}{\sum_{l'} \sum_a S_{sl'}^{g,sum} P_{sal'}^g N_{sya}^g} \quad (\text{App.II.39})$$

for begin-year (summer) surveys, or

$$\hat{p}_{syl}^{g,surv} = \frac{\sum_a S_{sl}^{g,win} P_{s,a+1/2,l}^g N_{sya}^g e^{-M_{sa}^g/2} \left(1 - \sum_f S_{sfya}^g F_{sfy} / 2\right)}{\sum_{l'} \sum_a S_{sl'}^{g,win} P_{s,a+1/2,l'}^g N_{sya}^g e^{-M_{sa}^g/2} \left(1 - \sum_f S_{sfya}^g F_{sfy} / 2\right)} \quad (\text{App.II.40})$$

for mid-year (autumn, winter or spring) surveys.

Age-length keys

Under the assumption that fish are sampled randomly with respect to age within each length-class, the contribution to the negative log-likelihood for the ALK data (ignoring constants) is:

$$-\ln L^{ALK} = -w \sum_i \sum_l \sum_a \left[A_{i,l,a}^{obs} \ln(\hat{A}_{i,l,a}) - A_{i,l,a}^{obs} \ln(A_{i,l,a}^{obs}) \right] \quad (\text{App.II.41})$$

where

w is a downweighting factor to allow for overdispersion in these data compared to the expectation for a multinomial distribution with independent data; for the moment this weight factor is set to 0.01,

$A_{i,a,l}^{obs}$ is the observed number of fish of age a that fall in the length class l , for ALK i (a specific combination of survey, year, species and gender),

$\hat{A}_{i,a,l}$ is the model estimate of $A_{i,a,l}^{obs}$, computed as:

$$\hat{A}_{i,a,l} = W_{i,l} \frac{C_{i,l} A_{a,l}}{\sum_a C_{i,l} A_{a,l}} \quad (\text{App.II.42})$$

where

$W_{i,l}$ is the number of fish in length class l that were aged for ALK i ,

$A_{a,l} = \sum_a P(a'|a)A_{a,l}$ is the ALK for age a and length l after accounting for age-reading error,

with $P(a'|a)$, the age-reading error matrix, representing the probability of an animal of true age a being aged to be that age or some other age a' .

Age-reading error matrices have been computed for each reader and for each species in Rademeyer (2009).

When multiple readers age the same fish, these data are considered to be independent information in the model fitting.

Stock-recruitment function residuals

The stock-recruitment residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative of the log-likelihood function is given by:

$$-\ln L^{SR} = \sum_s \left[\sum_{y=y1}^{y2} \zeta_{sy}^2 / 2\sigma_R^2 + \left(\sum_{y=y1}^{y2} \zeta_{sy} \right)^2 / 0.01^2 \right] \quad (\text{App.II.43})$$

where

ζ_{sy} is the recruitment residual for species s , and year y , which is assumed to be log-normally distributed with standard deviation σ_R and which is estimated for year $y1$ to $y2$ (see equation App.II.4) (estimating the stock-recruitment residuals is made possible by the availability of catch-at-age data, which give some indication of the age-structure of the population); and

σ_R is the standard deviation of the log-residuals, which is input.

The stock-recruitment residuals are estimated for years 1985 to 2006, with recruitment for other years being set deterministically (i.e. exactly as given by the estimated stock-recruitment curve) as there is insufficient catch-at-age information to allow reliable residual estimation for earlier years. A limit on the recent recruitment fluctuations is set by having the σ_R (which measures the extent of variability in recruitment – see equation – App.II.43) decreasing linearly from 0.45 in 2004 to 0.1 in 2009, effectively forcing recruitment over the last years to lie closer to the stock-recruitment relationship curve.

The second term on the right hand side is introduced to force the average of the residuals estimated over the period from $y1$ to $y2$ to be close to zero, for reasons elaborated in the main text.

Model parameters

Estimable parameters

The primary parameters estimated are the species-specific female virgin spawning biomass ($K_s^{\varphi sp}$) and “steepness” of the stock-recruitment relationship (h_s). The standard deviations σ^i for the CPUE series residuals (the species-combined as well as the GLM-standardised series) as well as the additional variance (σ_A^i)² for each survey abundance series are treated as estimable parameters in the minimisation process. Similarly, in the case of the species-combined CPUE, $q_C^{WC,z1}$, $q_C^{WC,z2}$, q_P^{WC} , r and γ are directly estimated in the fitting procedure.

The species- and gender-specific von Bertalanffy growth curve parameters (L_5 , κ and t_0) are estimated directly in the model fitting process, as well as θ_0 , θ_1 and θ_{14} , values used to compute the standard deviation of the length-at-age a .

The following parameters are also estimated in the model fits undertaken (if not specifically indicated as fixed).

Natural mortality:

Natural mortality (M_{sa}^g) is assumed to be age-specific and is calculated using the following functional form:

$$M_{sa}^{\ominus} = \begin{cases} M_{s2}^{\ominus} & \text{for } a \leq 1 \\ \alpha_s^M + \frac{\beta_s^M}{a+1} & \text{for } 2 \leq a \leq 5 \\ M_{s5}^{\ominus} & \text{for } a > 5 \end{cases} \quad (\text{App.II.44})$$

and

$$M_{sa}^{males} = \nu^s M_{sa}^{females} \quad (\text{App.II.45})$$

M_{s0} and M_{s1} are set equal to M_{s2} ($= \alpha_s^M + \beta_s^M / 3$) as there are no data (hake of ages younger than 2 are rare in catch and survey data) which would allow independent estimation of M_{s0} and M_{s1} .

When M values are estimated in the fit, a penalty is added to the total $-\ln L$ so that $M_{s2} \geq M_{s5}$:

$$pen^M = \sum_s (M_{s5} - M_{s2})^2 / 0.01^2 \quad \text{if } M_{s2} < M_{s5} \quad (\text{App.II.46})$$

Stock-recruitment residuals:

Stock-recruitment residuals ζ_{sy} are estimable parameters in the model fitting process. They are estimated separately for each species from 1985 to the present, and set to zero pre-1985 because there are no catch-at-length data for that period to provide the information necessary to inform estimation.

Table App.II.1 summarises the estimable parameters, excluding the selectivity parameters.

Survey fishing selectivity-at-length:

The survey selectivities are estimated directly for seven pre-determined lengths for *M. paradoxus* and *M. capensis*. When the model was fitted to proportion-at-age rather than proportion-at-length, survey selectivities were estimated directly for each age (i.e. seven age classes). The lengths at which selectivity is estimated directly are survey specific (linear between the minus and plus groups) and are given in Table App.II.2. Between these lengths, selectivity is assumed to change linearly. The slope from lengths l_{minus} to $l_{minus}+1$ is assumed to continue exponentially to lower lengths to length l , and similarly the slope from lengths $l_{plus}-1$ to l_{plus} for *M. paradoxus* and *M. capensis* to continue for greater lengths.

For the south coast spring and autumn surveys, gender-specific selectivities are estimated for *M. paradoxus*. Furthermore, the female selectivities are scaled down by a parameter estimated for each of these two surveys to allow for the male predominance in the survey catch.

A penalty is added to the total $-\ln L$ to smooth the selectivities:

$$pen^{survS} = \sum_i \sum_{L=L_1+1}^{L_1-1} 3(S_{L-1}^i - 2S_L^i + S_{L+1}^i)^2 \quad (\text{App.II.47})$$

where i is a combination of survey, species and gender.

Commercial fishing selectivity-at-length:

The fishing selectivity-at-length (gender independent) for each species and fleet, S_{sfl} , is estimated in terms of a logistic curve given by:

$$S_{sfl} = \left[1 + \exp\left(-\left(l - l_{sf}^c\right) / \delta_{sf}^c\right) \right]^{-1} \quad (\text{App.II.45})$$

where

l_{sf}^c cm is the length-at-50% selectivity,

δ_{sf}^c cm⁻¹ defines the steepness of the ascending limb of the selectivity curve.

The selectivity is sometimes modified to include a decrease in selectivity at larger lengths, as follows:

$$S_{sfl} = S_{s,f,l-1} e^{-s_{sfl}} \quad \text{for } l > l_{slope}, \quad (\text{App.II.46})$$

where

s_{sfl} measures the rate of decrease in selectivity with length for fish longer than l_{slope} for the fleet concerned, and is referred to as the “selectivity slope”.

l_{slope} is fixed externally from the model, values for each fleet and species are given in

Periods of fixed and changing selectivity have been assumed for the offshore trawl fleet to take account of the change in the selectivity at low ages over time in the commercial catches, likely due to the phasing out of the (illegal) use of net liners to enhance catch rates.

On the south coast, for *M. paradoxus*, the female offshore trawl selectivity (only the trawl fleet is assumed to catch *M. paradoxus* on the south coast) is scaled down by a factor taken as the average of those estimated for the south coast spring and autumn surveys. Although there is no gender information for the commercial catches, the south coast spring and autumn surveys catch a much higher proportion of male *M. paradoxus* than female (ratios of about 7:1 and 3.5:1 for spring and autumn respectively). This is assumed to reflect a difference in distribution of the two genders which would therefore affect the commercial fleet similarly.

Details of the fishing selectivities (including the number of parameters estimated) used in the assessment are shown in Table App.II.4.

Input parameters and other choice for application to hake*Age-at-maturity:*

The proportion of fish of species *s*, gender *g* and length *l* that are mature is assumed to follow a logistic curve with the parameter values given below (from Fairweather and Leslie, 2008, “stage 2, >40cm” for females and Fairweather, pers. commn for males):

	l_{50} (cm)	N
<i>M. paradoxus</i> :		
Males	28.63	5.07
Females	42.24	4.46
<i>M. capensis</i> :		
Males	34.35	7.38
Females	40.80	7.51

Maturity-at-length is then converted to maturity-at-age as follows:

$$f_{sa}^g = \sum_l f_{sl}^g P_{a,l}^g \quad (\text{App.II.47})$$

Weight-at-length:

The weight-at-length for each species and gender is calculated from the mass-at-length function, with values of the parameters for this function listed below (from Fairweather, 2008, taking the average of the west and south coasts):

	\perp (gm/cm ^{\perp})	\perp
<i>M. paradoxus</i> :		
Males	0.007541	2.988
Females	0.005836	3.065
<i>M. capensis</i> :		
Males	0.006307	3.061
Females	0.005786	3.085

Minus- and plus-groups

Because of a combination of gear selectivity and mortality, a relatively small number of fish in the smallest and largest length classes are caught. In consequence, there can be relatively larger errors (in terms of variance) associated with these data. To reduce this effect, the assessment is conducted with minus- and plus-groups obtained by summing the data over the lengths below and above l_{minus} and l_{plus} respectively. The minus- and plus-group used are given in Table App.II.5 (and plotted in Figs.I.2 and 3). Furthermore, the proportions at length data (both commercial and survey) are summed into 2cm length classes for the model fitting.

Table App.II.1: Parameters estimated in the model fitting procedure, excluding selectivity parameters.

	No of parameters	Parameters estimated
K^{φ}	2	$\ln(K_{cap}^{\varphi})$ and $\ln(K_{para}^{\varphi})$
h	2	h_{cap} and h_{para}
M_a	4 (6)*	For each species: M_2, M_5 (and ν)
Additional variance	2	$\sigma_{A_{cap}}$ and $\sigma_{A_{para}}$
Recruitment residuals	50	$\zeta_{cap,1985-2009}$ and $\zeta_{para,1985-2009}$
σ_{CPUE}	6	1 for each series (lower bounds imposed)
ICSEAF CPUE	5	$q_C^{WC,z1}, q_C^{WC,z2}, q_P^{WC}, r$ and γ
θ_a	12	For each species and gender: θ_0, θ_1 and θ_{14}
Growth	12	For each species and gender: L_5, κ and t_0

* if not fixed on input

Table App.II.2: Lengths (in cm) at which survey selectivity is estimated directly.

<i>M. paradoxus</i>	West coast summer	13	18	23	28	32	37	42	47
	West coast winter	13	18	24	29	35	40	46	51
	South coast spring	21	26	30	35	39	44	48	53
	South coast autumn	21	26	31	36	42	47	52	65
<i>M. capensis</i>	West coast summer	13	20	26	33	39	46	52	59
	West coast winter	13	17	21	30	40	47	54	61
	South coast spring	13	19	28	38	46	54	63	71
	South coast autumn	13	19	28	36	44	52	61	69

Table App.II.3: Length (cm) at which selectivity starts to decrease (l_{slope}) for each species and fleet.

	<i>M. paradoxus</i>	<i>M. capensis</i>
WC offshore trawl	40	70
SC offshore trawl	70	70
SC inshore trawl	-	55
WC longline	85	85
SC longline	-	85
SC handline	-	70

Table App.II.4: Details for the commercial selectivity-at-length for each fleet and species combination, as well as indications of what data are available.

	<i>M. paradoxus</i>		<i>M. capensis</i>		data available
	No of est. parameters	Comments	No of est. parameters	Comments	
1. West coast offshore					
1917-1976	0	set equal to 1989	0	set equal to 1989	
1977-1984	3	two logistic parameters estimated (same slope as 1993+)	0	differential shift compared to 1993+ as for paradoxus, slope 1/3 of inshore	species combined
1985-1992	0	linear change between 1984 and 1993 selectivity	0	linear change between 1984 and 1993 selectivity	species combined
1993-2009	2	two logistic + slope parameters estimated	0	same as SC inshore but shifted to the right by 5 cm, slope 1/3 of inshore	species combined
2. South coast offshore					
1917-1976	0	set equal to 1989	0	set equal to 1989	
1977-1984	3	differential shift compared to 1993+ as for WC (same slope as 1993+)	0	differential shift compared to 1993+ as for paradoxus, slope 1/3 of inshore	species combined
1985-1992	0	linear change between 1984 and 1993 selectivity	0	linear change between 1984 and 1993 selectivity	species combined
1993-2009	3	two logistic + slope parameters estimated	0	same as SC inshore but shifted to the right by 10 cm, slope 1/3 of inshore	species combined
	0	female downscaling factor (av. of SC spring and autumn surveys's factors)			
3. South coast inshore	-	-	3	two logistic + slope parameters estimated	<i>M. capensis</i>
4. West coast longline	3	two logistic + slope parameters estimated	0	same as South Coast longline	species combined
5. South coast longline	-	-	3	two logistic + slope parameters estimated	<i>M. capensis</i>
6. South coast handline	-	-	0	average of South Coast longline and inshore	
West coast summer survey					
<i>Africana</i> old	7	estimated for 7 specified lengths	7	estimated for 7 specified lengths	species disaggregated
<i>Africana</i> new	5	same slope as old	5	same slope as old	species disaggregated
West coast winter survey					
<i>Africana</i> old	7	estimated for 7 specified lengths	7	estimated for 7 specified lengths	species disaggregated
South coast spring survey					
<i>Africana</i> old	7	estimated for 7 specified lengths	7	estimated for 7 specified lengths	species disaggregated
<i>Africana</i> new	5	same slope as old	5	same slope as old	species disaggregated
	1	female downscaling factor			
South coast autumn survey					
<i>Africana</i> old	7	estimated for 7 specified lengths	7	estimated for 7 specified lengths	species disaggregated
<i>Africana</i> new	5	same slope as old	5	same slope as old	species disaggregated
	1	female downscaling factor			
Total	59		49		

Table App.II.5: Minus- and plus-groups taken for the surveys and commercial proportion at length data.

SURVEY DATA				
	<i>M. paradoxus</i>		<i>M. capensis</i>	
	Minus	Plus	Minus	Plus
West coast summer	13	47	13	59
West coast winter	13	51	13	61
South coast spring	21	53	13	71
South coast autumn	21	65	13	69

COMMERCIAL DATA		
	Minus	Plus
West coast offshore, species combined	23	65
South coast offshore, species combined	27	75
South coast inshore, <i>M. capensis</i>	27	65
West coast longline, species combined	51	91
South coast longline, <i>M. capensis</i>	51	91
Both coasts offshore, species combined	25	65

APPENDIX III – Detailed results for the Reference Case

Table App.III.1: Estimates of management quantities for the RC. The modified Ricker γ values are given in parenthesis next to the h values. The survey slopes given are for the West Coast summer and South Coast autumns surveys respectively (the two longest series).

-lnL total	-94.5			
CPUE historic	-36.9			
CPUE GLM	-136.4			
Survey	-33.9			
Commercial CAL	-51.3			
Survey CAL (sex-aggr.)	-6.6			
Survey CAL (sex-disaggr.)	20.4			
ALK	124.4			
Recruitment penalty	9.1			
Selectivity smoothing penalty	16.2			
		Both	Males	Females
<i>M. paradoxus</i>				
K^{sp}	1363		649	715
h	1.08		(0.18)	
B^{sp}_{2009}	208		107	102
B^{sp}_{2009}/K^{sp}	0.15		0.16	0.14
B^{sp}_{MSY}				174
B^{sp}_{MSY}/K^{sp}				0.24
$B^{sp}_{2009}/B^{sp}_{MSY}$				0.59
MSY	113			
M_{2-}	0.75			
M_{5+}	0.375			
survey slopes (cm^{-1})	0.002		0.141	
<i>M. capensis</i>				
K^{sp}	516		254	262
h	1.01		(1.58)	
B^{sp}_{2009}	279		142	137
B^{sp}_{2009}/K^{sp}	0.54		0.56	0.52
B^{sp}_{MSY}				122
B^{sp}_{MSY}/K^{sp}				0.47
$B^{sp}_{2009}/B^{sp}_{MSY}$				1.12
MSY	69			
M_{2-}	0.75			
M_{5+}	0.375			
survey slopes (cm^{-1})	0.008		0.071	
2009 species ratio B^{sp}	1.34	1.34	1.33	1.34

	Both	<i>paradoxus</i>	<i>capensis</i>
Survey q's:			
WC summer	1.00	0.39	
WC winter	0.96	0.53	
SC spring	0.37	0.67	
SC autumn	0.40	0.82	
Additional variance:	0.15	0.11	
survey CAL 0's:			
Sex-aggr. data:			
WC summer	0.08	0.14	
WC winter	0.08	0.13	
SC spring	0.13	0.06	
SC autumn	0.11	0.04	
Sex-disaggr. data:			
WC summer	0.07	0.11	
WC winter	-	-	
SC spring	0.07	0.05	
SC autumn	0.09	0.05	
CPUE 0's:			
WC ICSEAF	0.25		
SC ICSEAF	0.25		
WC GLM		0.15	0.24
SC GLM		0.25	0.19
com CAL 0's:			
WC offshore	0.07		
SC offshore	0.10		
SC inshore	0.07		
WC longline	0.04		
SC longline	0.06		
offshore	0.07		

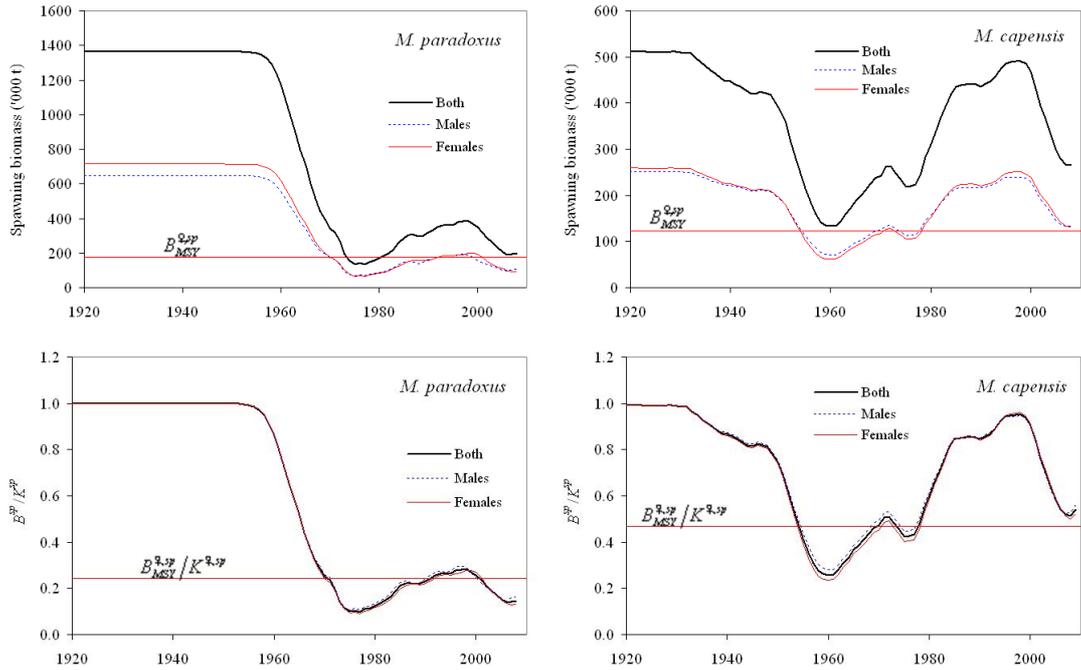


Fig. App.III.1: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for the RC.

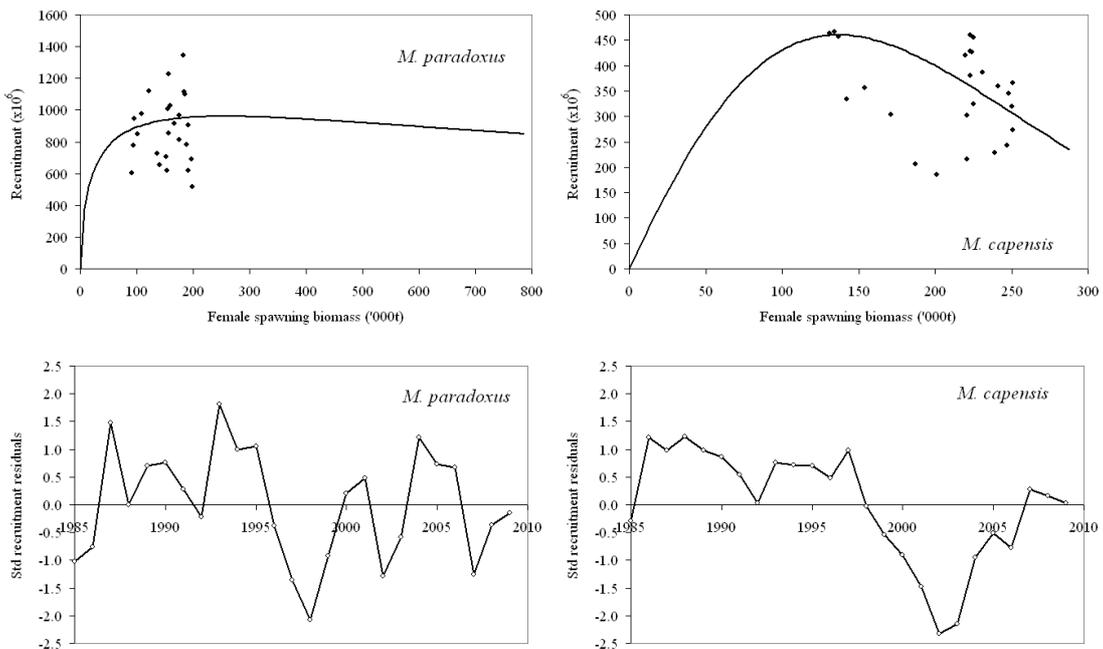


Fig. App.III.2: Estimated stock-recruitment relationships and time series of standardised stock-recruitment residuals for the RC.

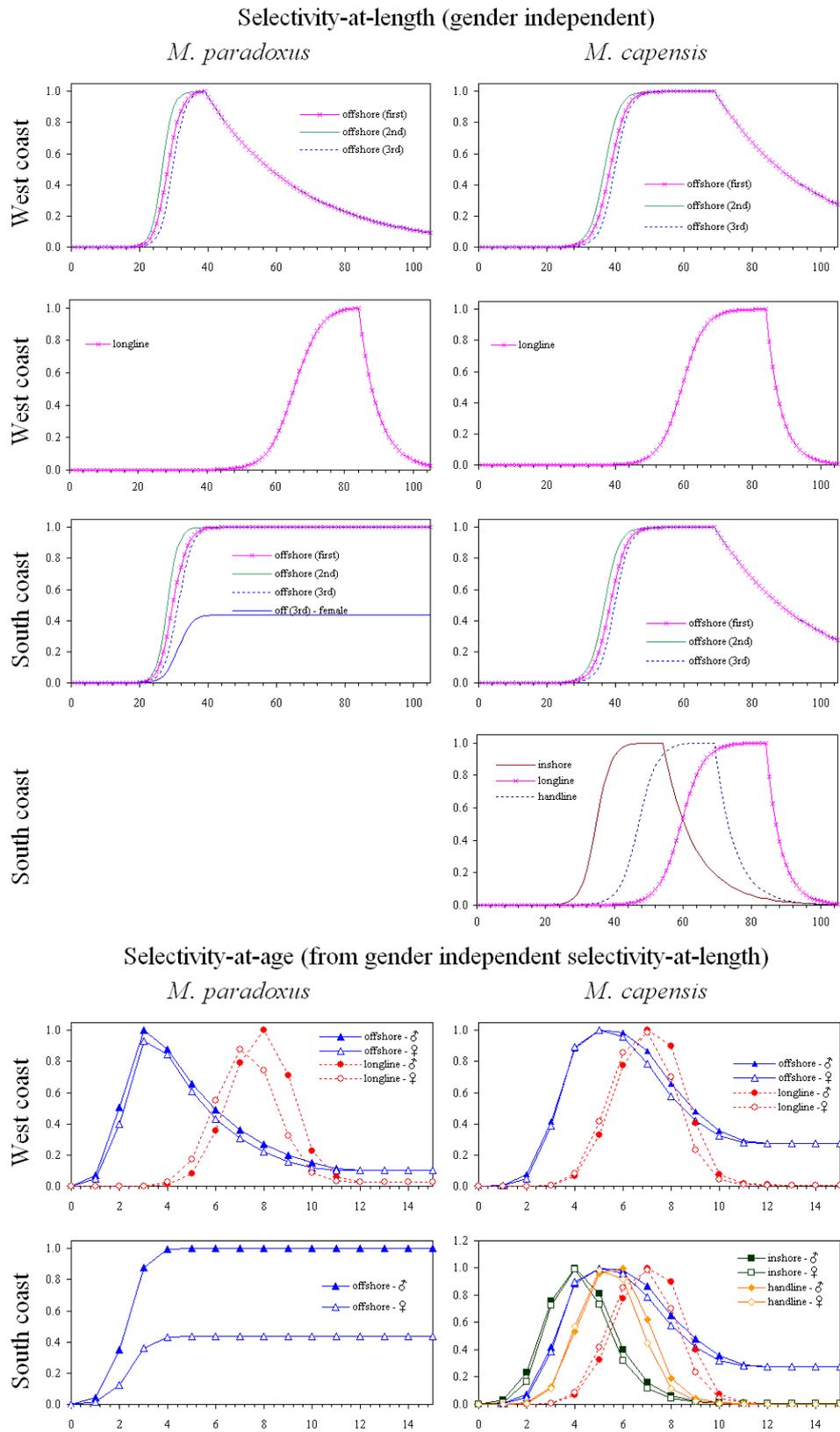


Fig. App.III.3: Commercial selectivities-at-length and selectivities-at-age for the RC.

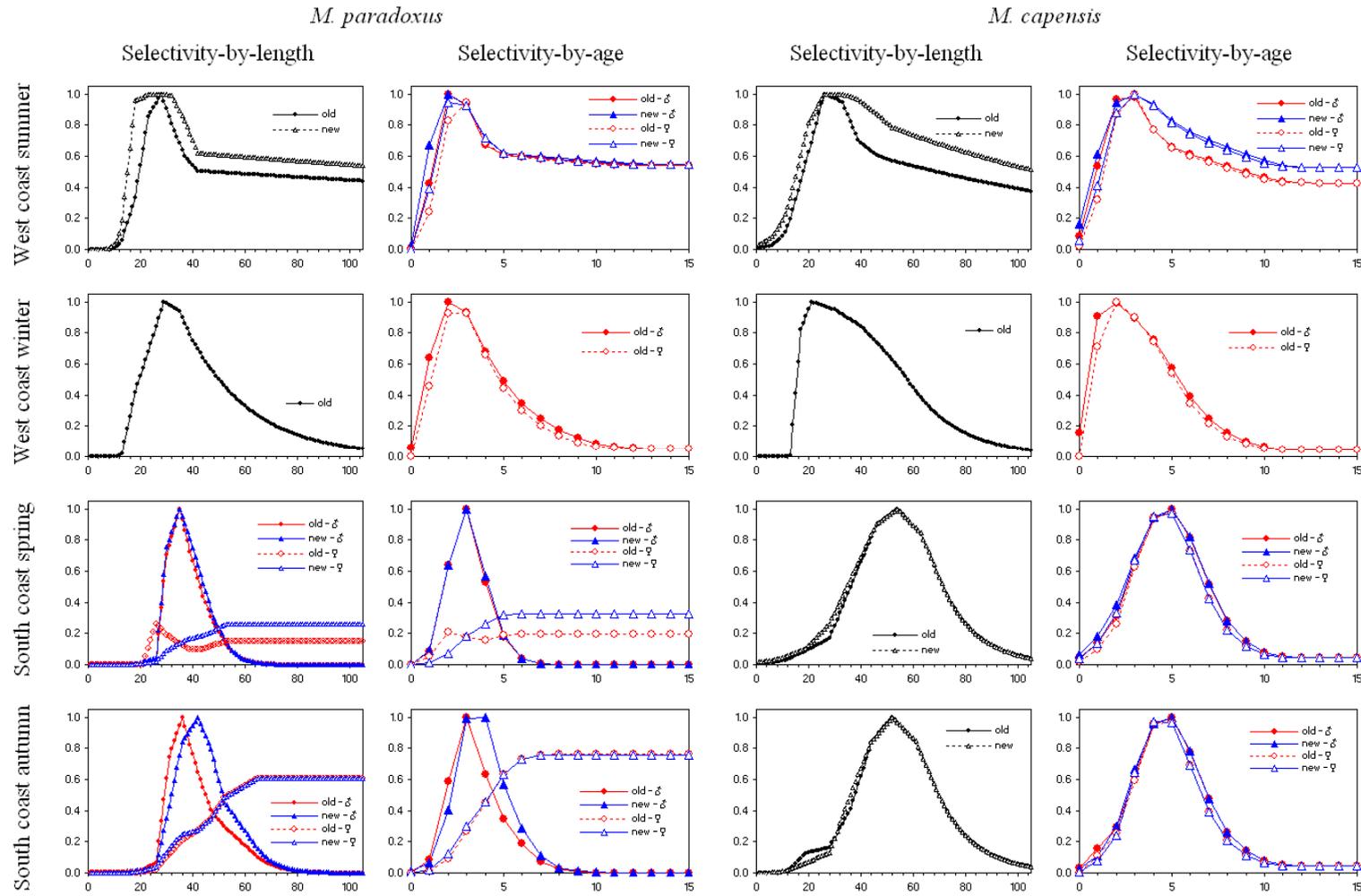


Fig. App.III.4: Survey selectivity-at-length and selectivity-at-age for each of the four surveys for *M. paradoxus* and *M. capensis* for the RC.

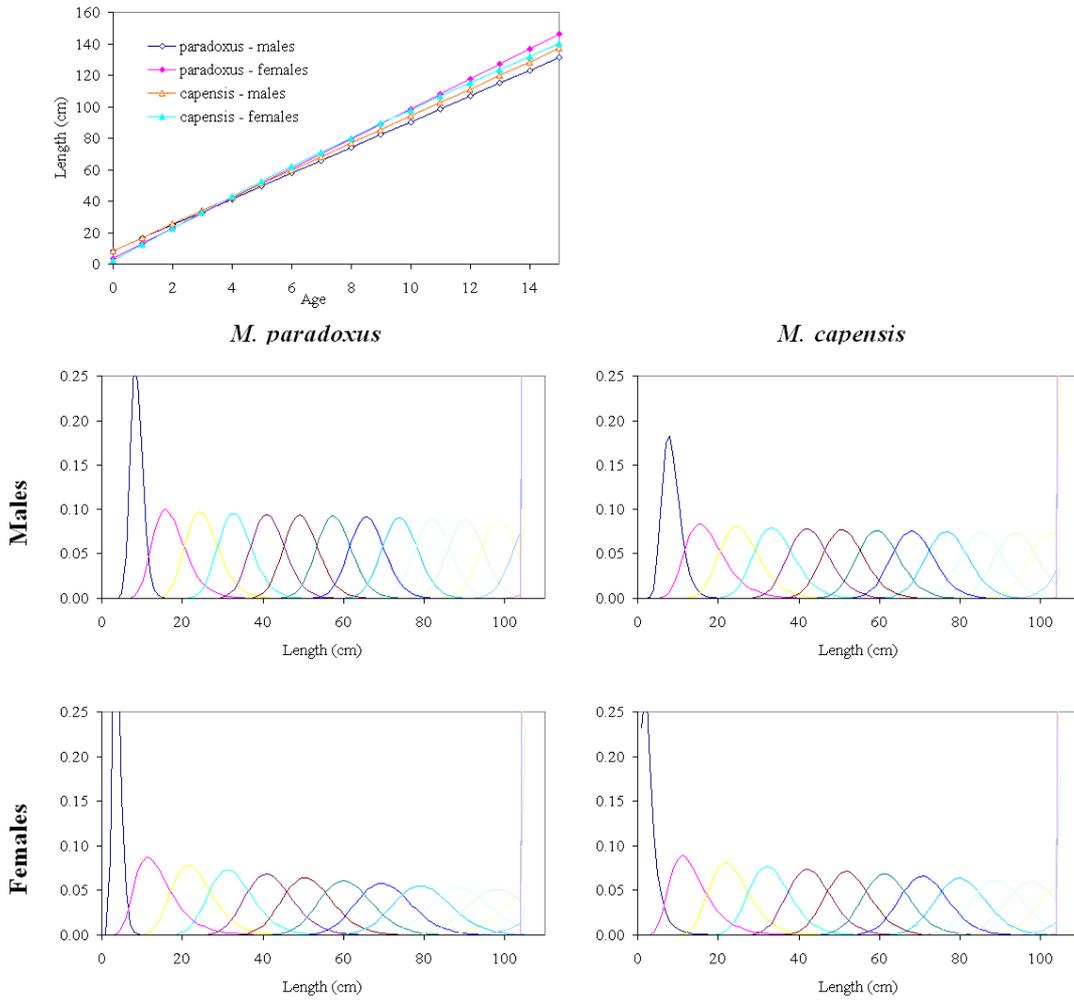


Fig. App.III.5: Estimated length-at-age relationship and resulting length-at-age distributions for males and females *M. paradoxus* and *M. capensis* for the RC. In the lower plots the distributions, starting from the left, correspond to ages 0, 1, 2, ...

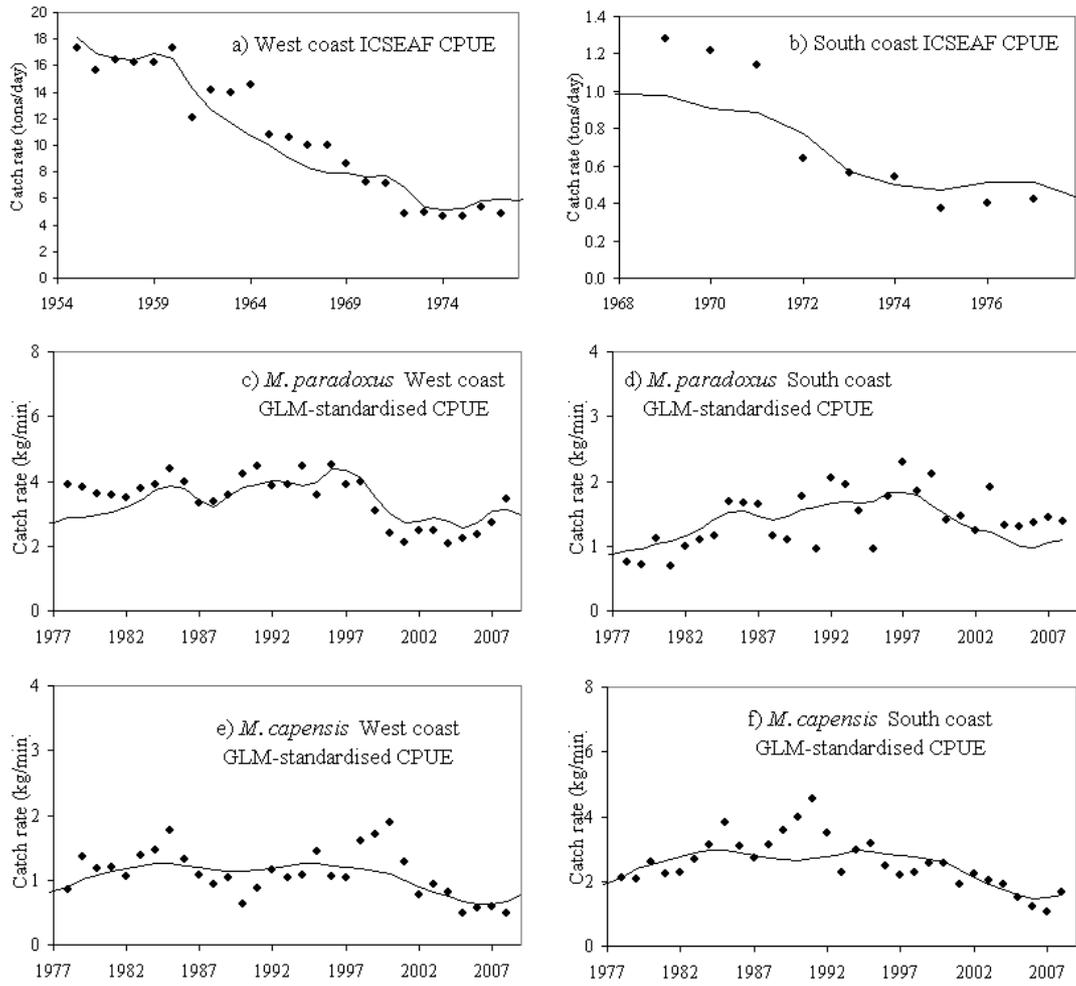


Fig. App.III.6: Fit of the RC to the CPUE data.

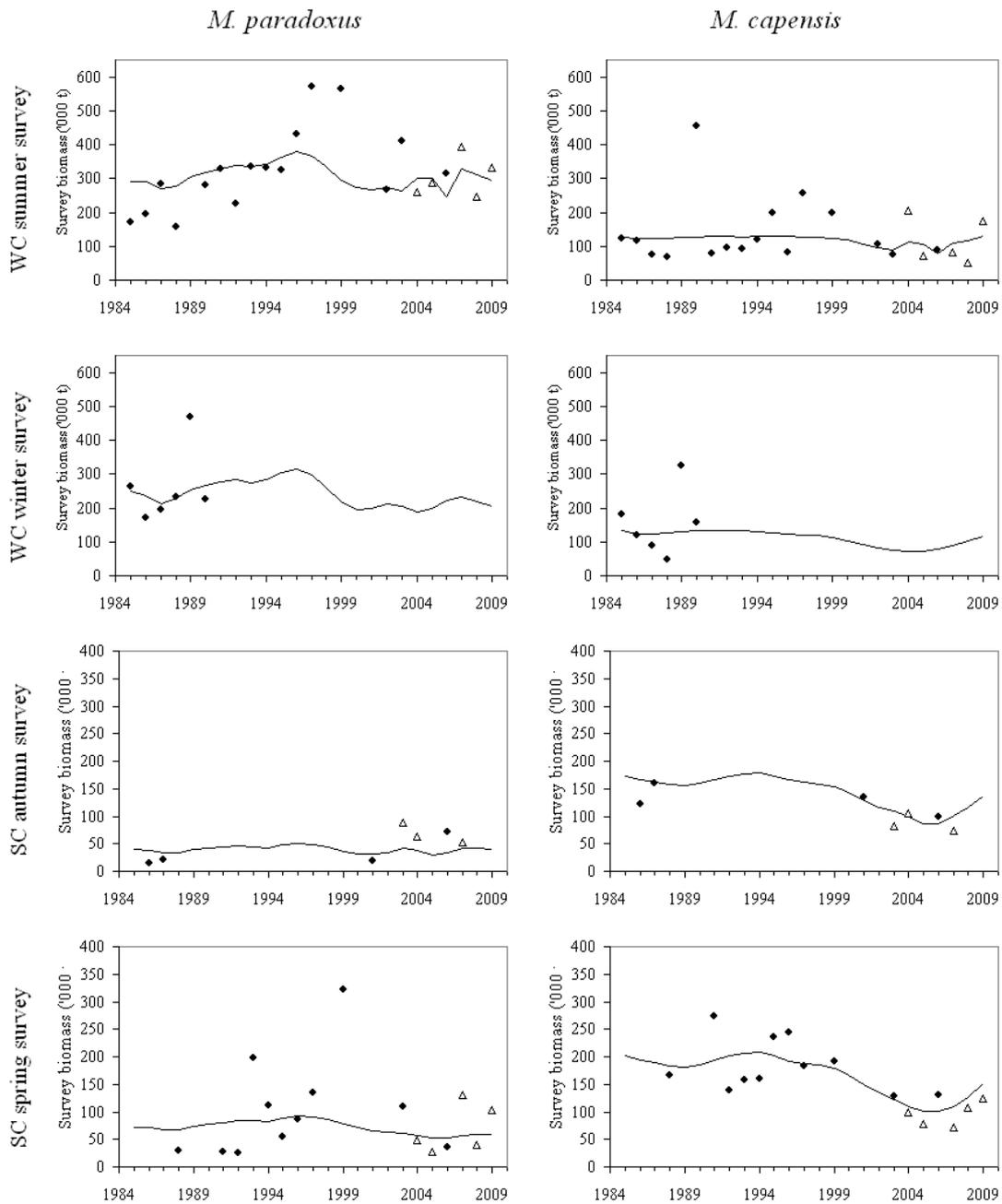


Fig. App.III.7: Fit of the model to the survey abundance indices for the RC. The triangles represent surveys that have been conducted with the new gear on the *Africana*. These are rescaled by the calibration factor for the species concerned to make them comparable to the other survey results.

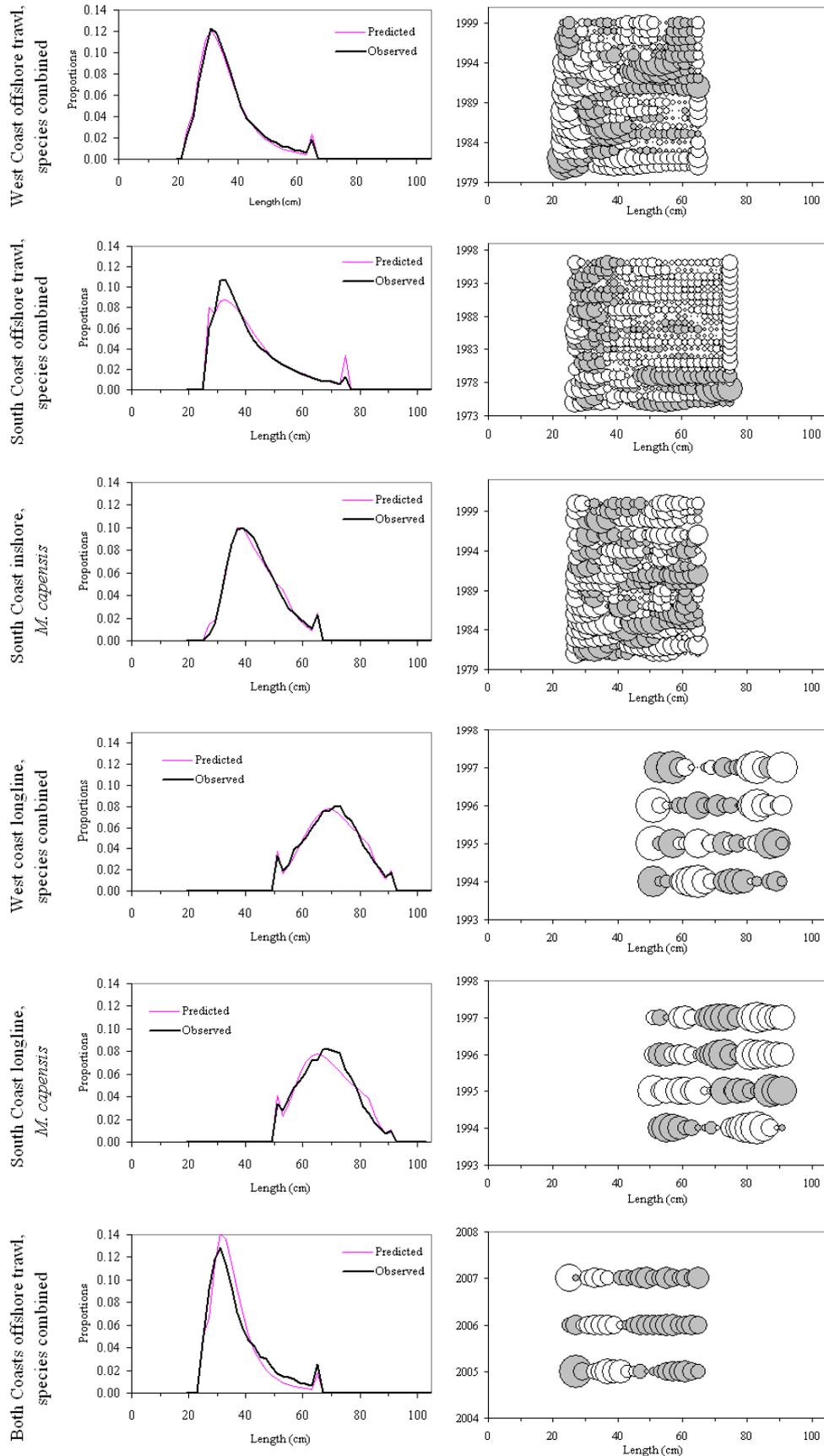


Fig. App.III.8: Fit of the RC to the commercial proportion-at-length data, aggregated over years for which data are available for the plots on the left.

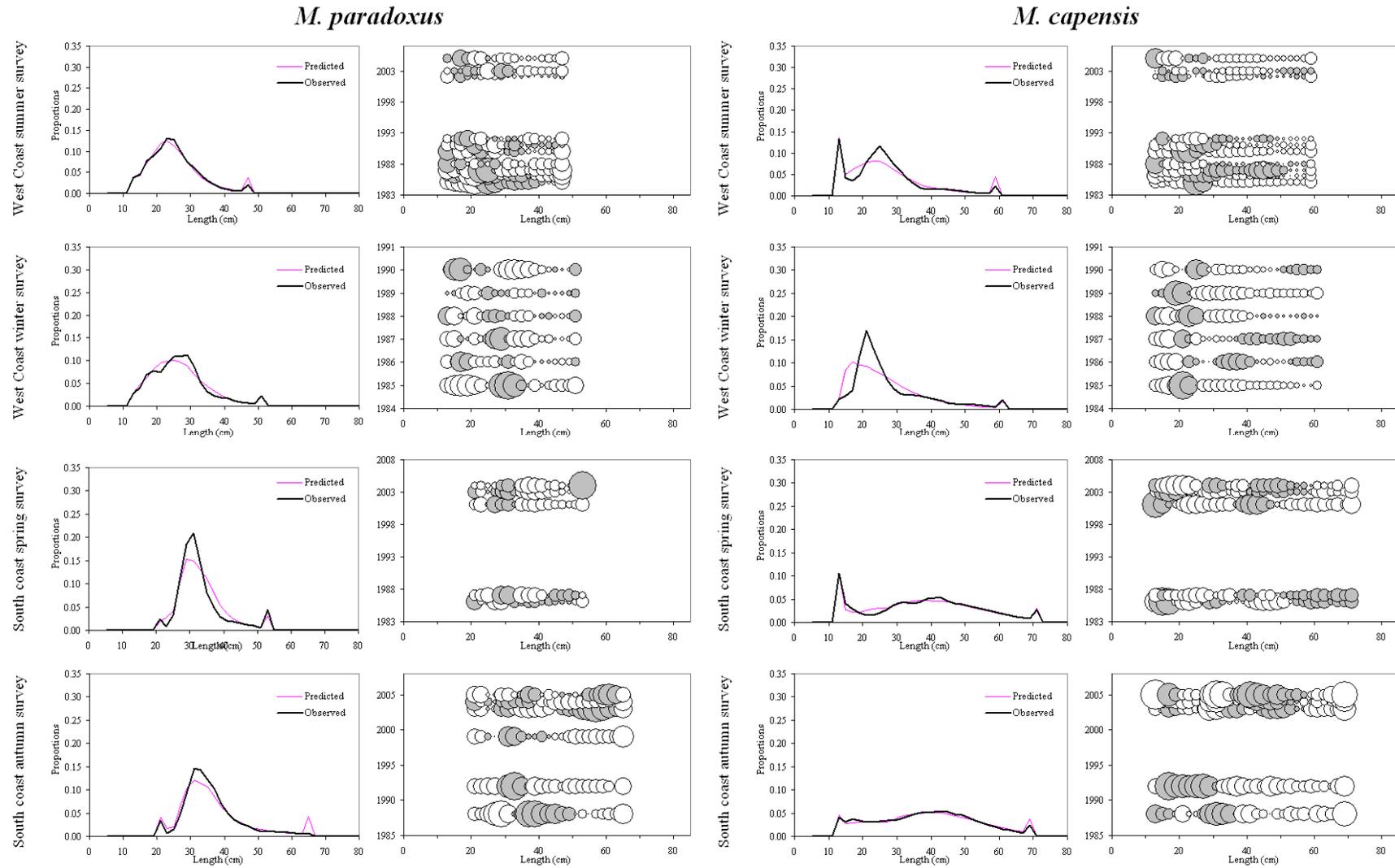


Fig. App.III.9: Fit of the updated RC to the survey gender-aggregated surveys proportion-at-length data (in some plots, aggregated over years for which data are available).

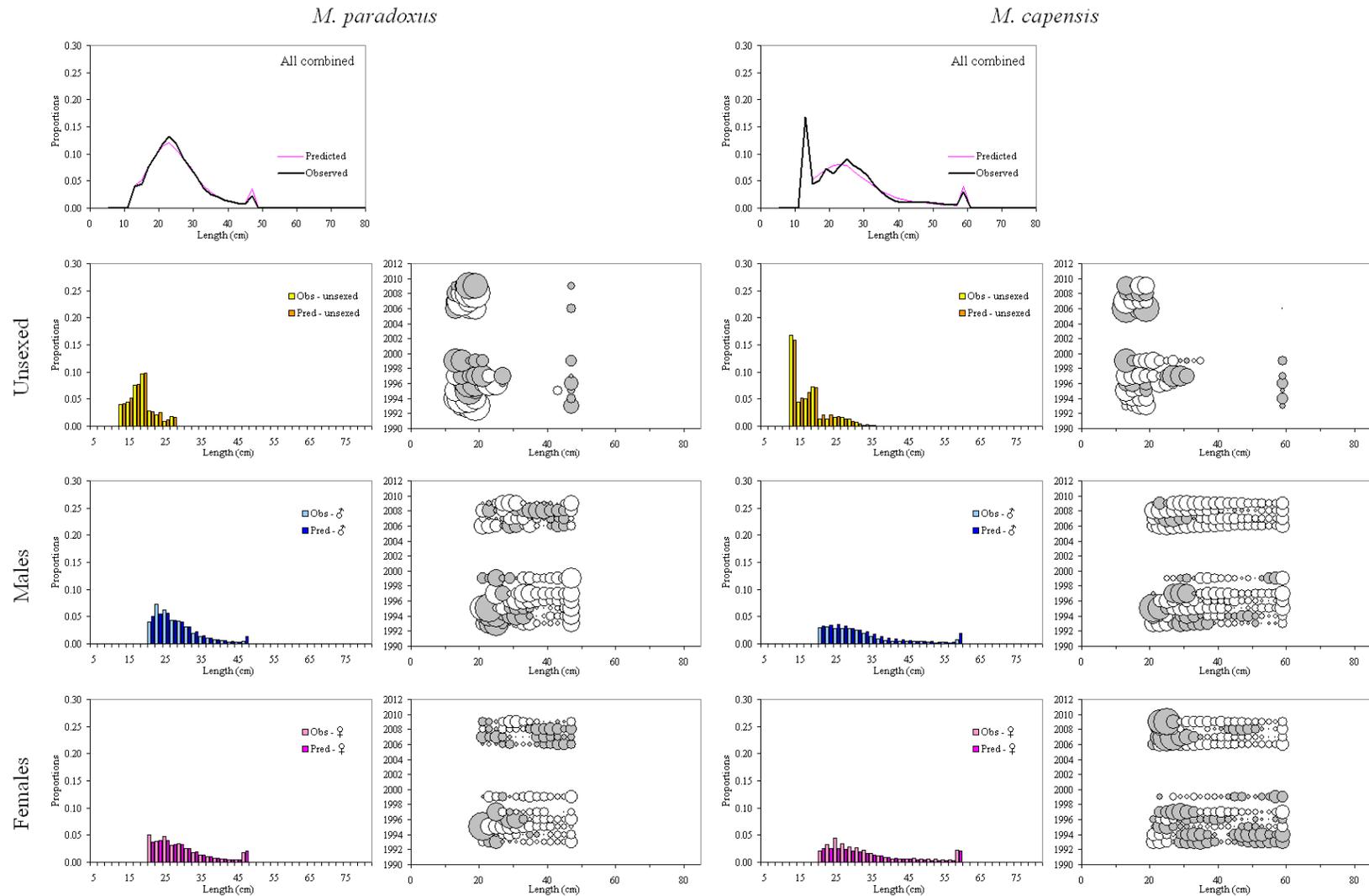


Fig. App.III.10a: Fit of the updated RC to the west coast summer survey gender-disaggregated proportion-at-length data (in some plots, aggregated over years for which data are available).

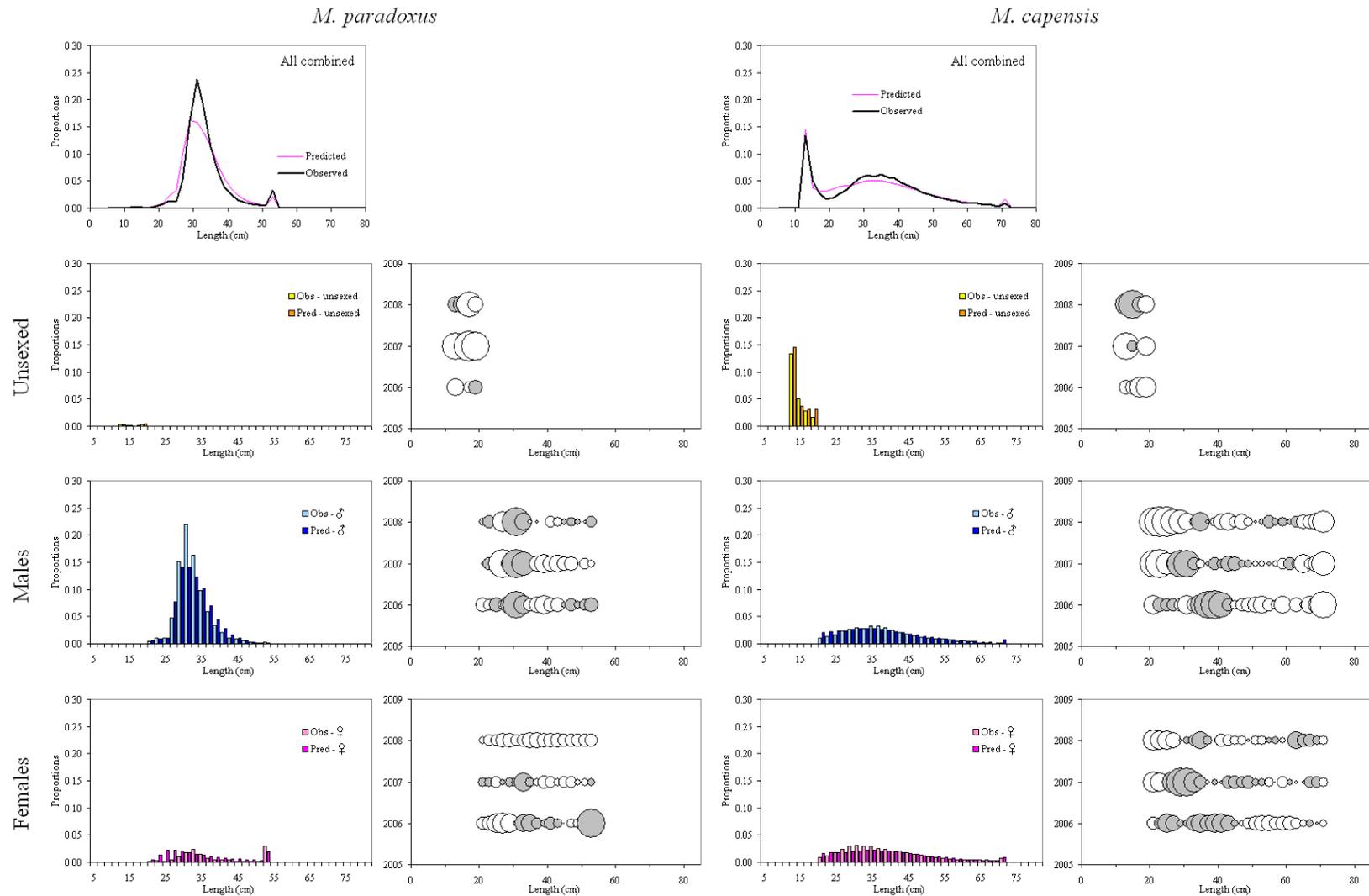


Fig. App.III.10b: Fit of the updated RC to the south coast spring survey gender-disaggregated proportion-at-length data (in some plots, aggregated over years for which data are available).

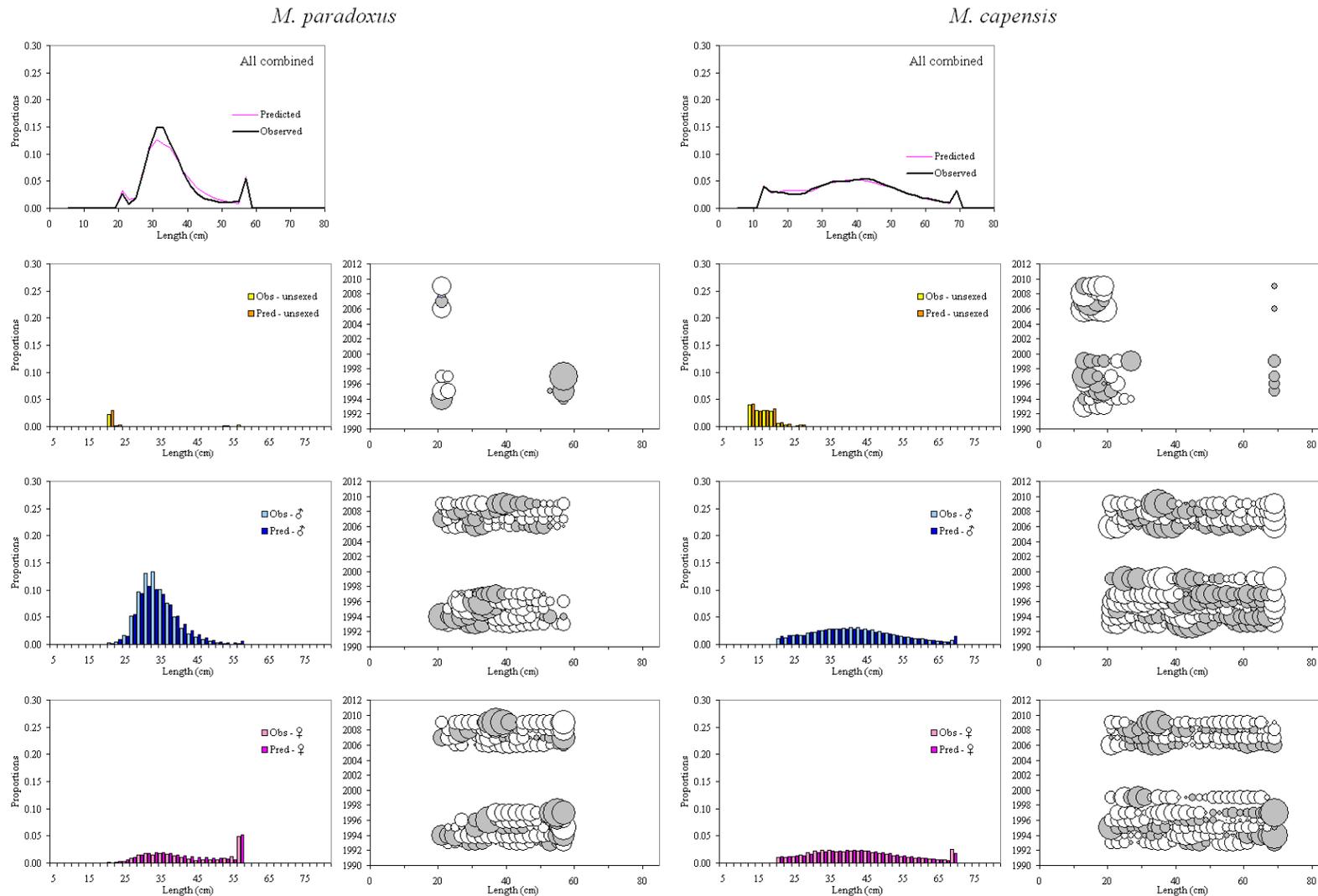


Fig. App.III.10c: Fit of the updated RC to the south coast autumn survey gender- disaggregated proportion-at-length data (in some plots, aggregated over years for which data are available).

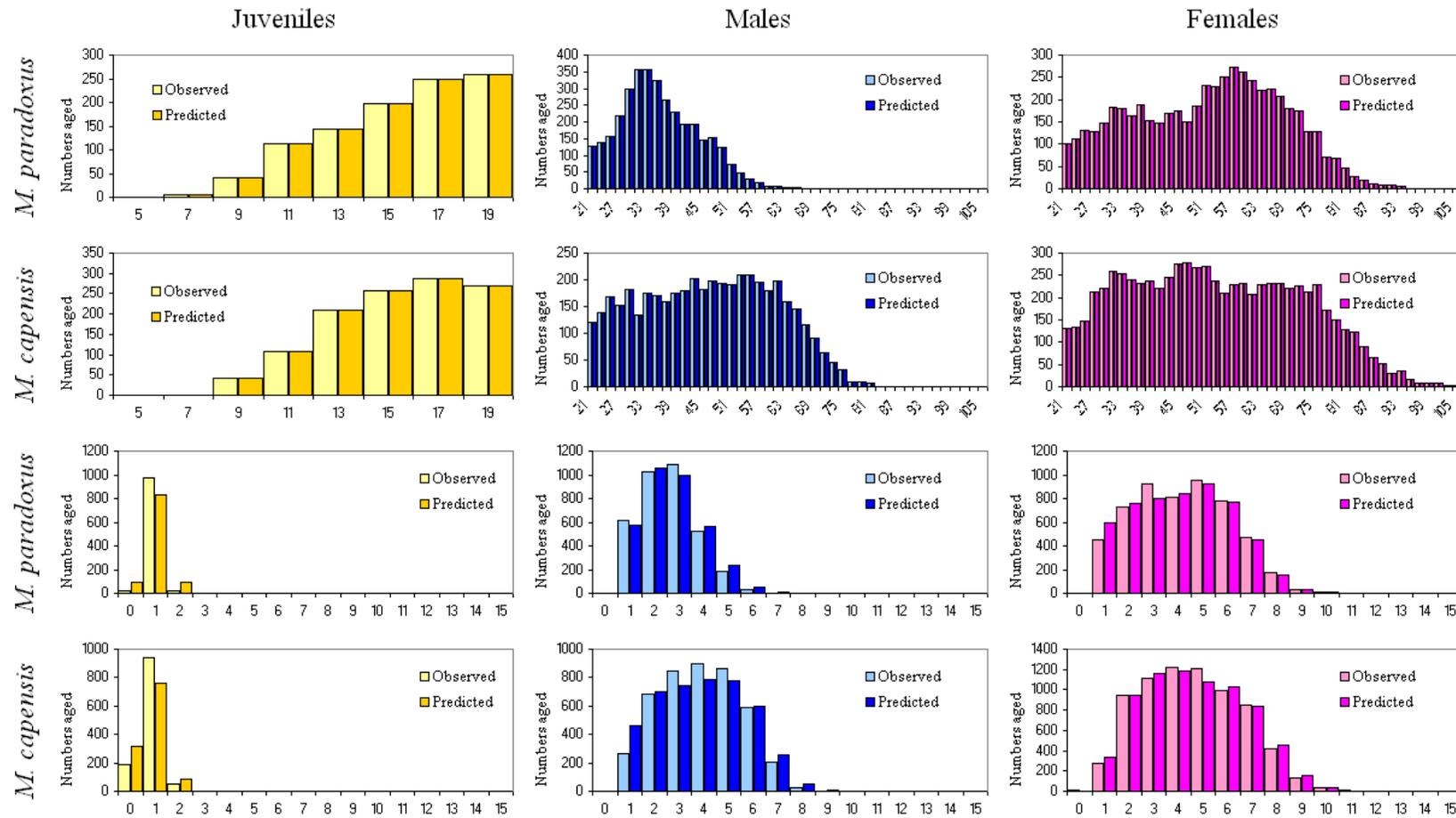


Fig. App.III.11: Fit of the RC to the ALKs, aggregated over all ALKs. The first two rows are summed over ages (so that model estimate and observation should be exactly equal by construction) and second two rows summed over lengths.

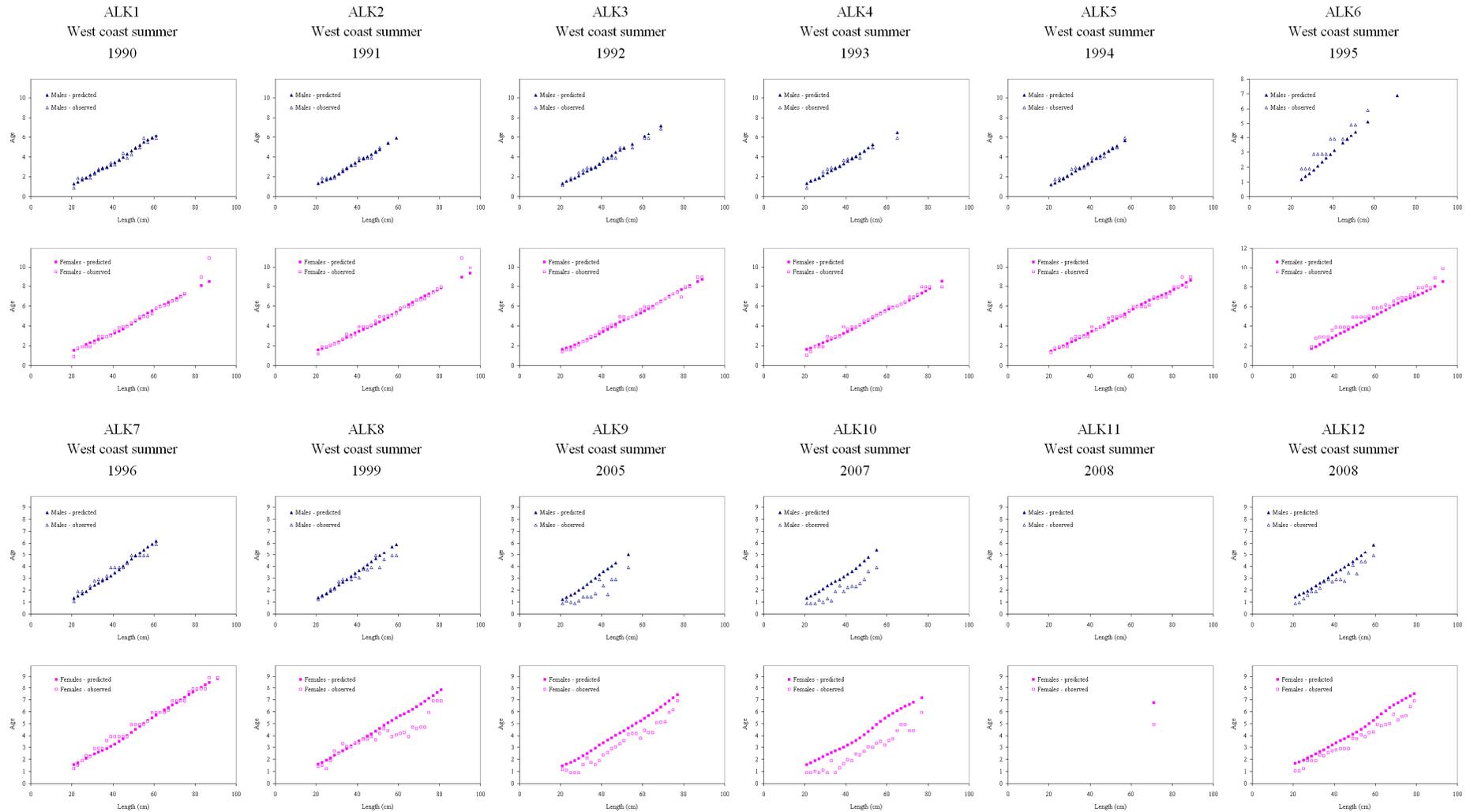


Fig. App.III.12a: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the west coast summer surveys.

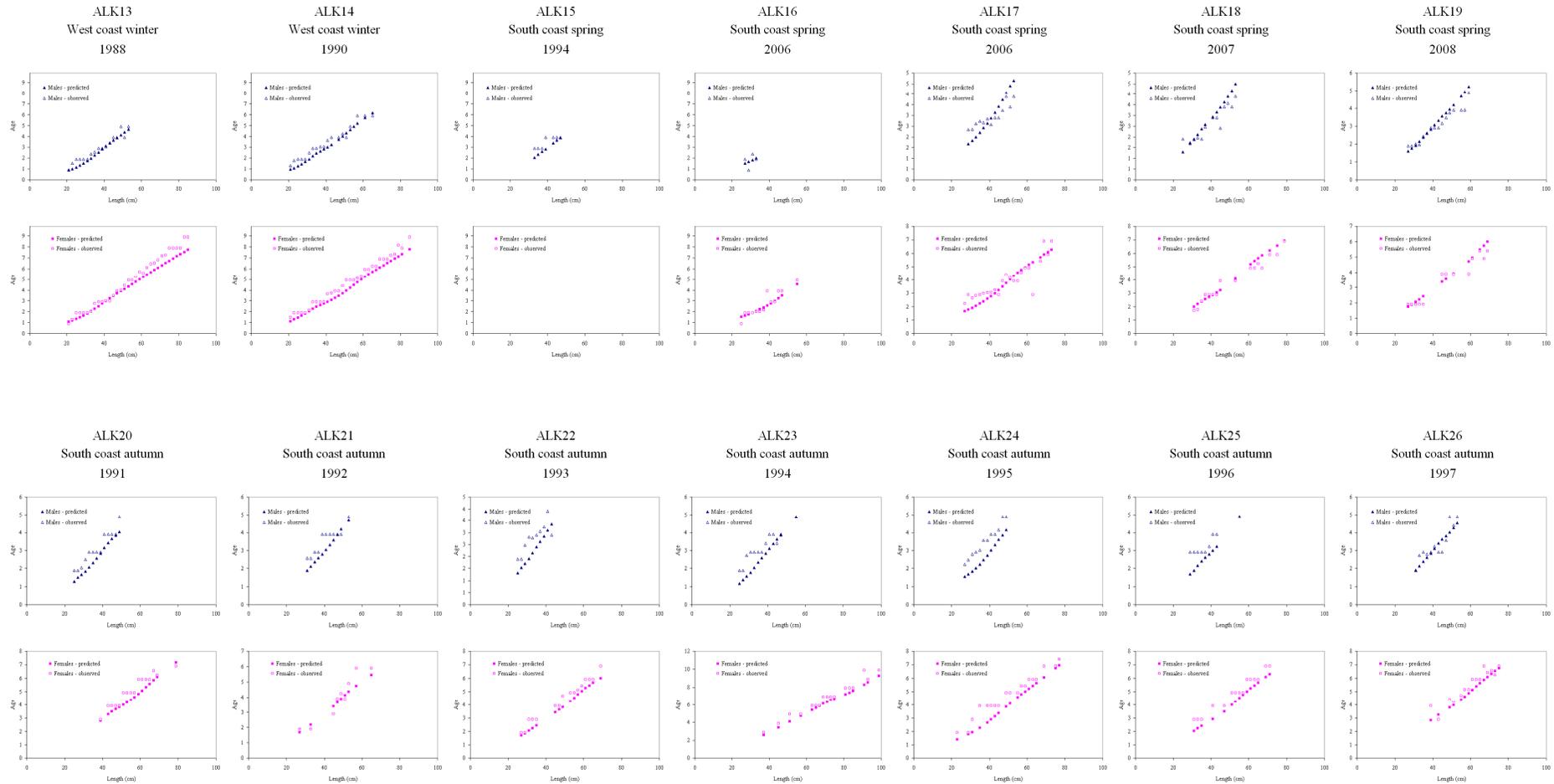


Fig. App.III.12b: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the West Coast winter, South Coast spring and South Coast autumn surveys.

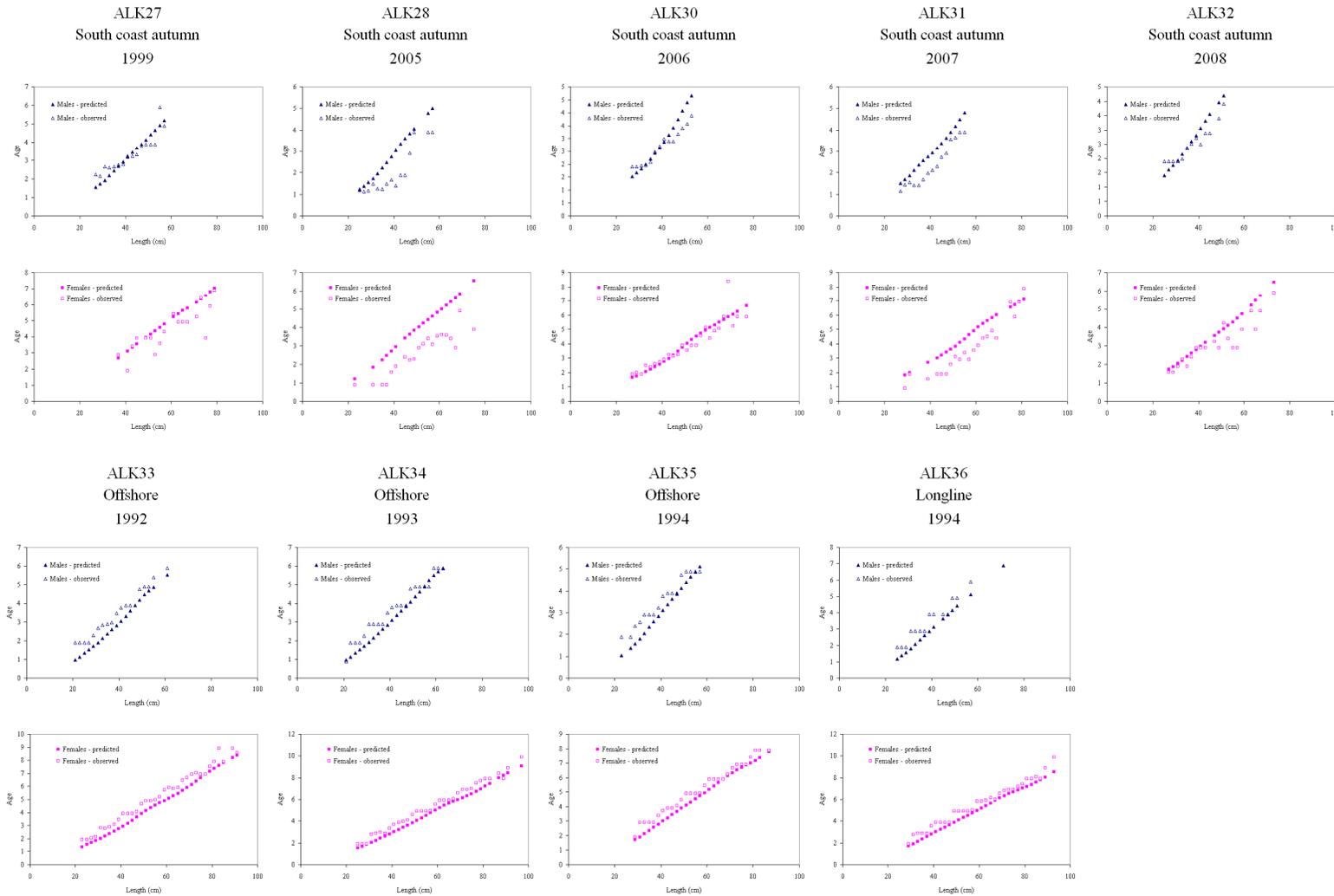


Fig. App.III.12c: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the South Coast autumn surveys, offshore commercial trawl and commercial longline.

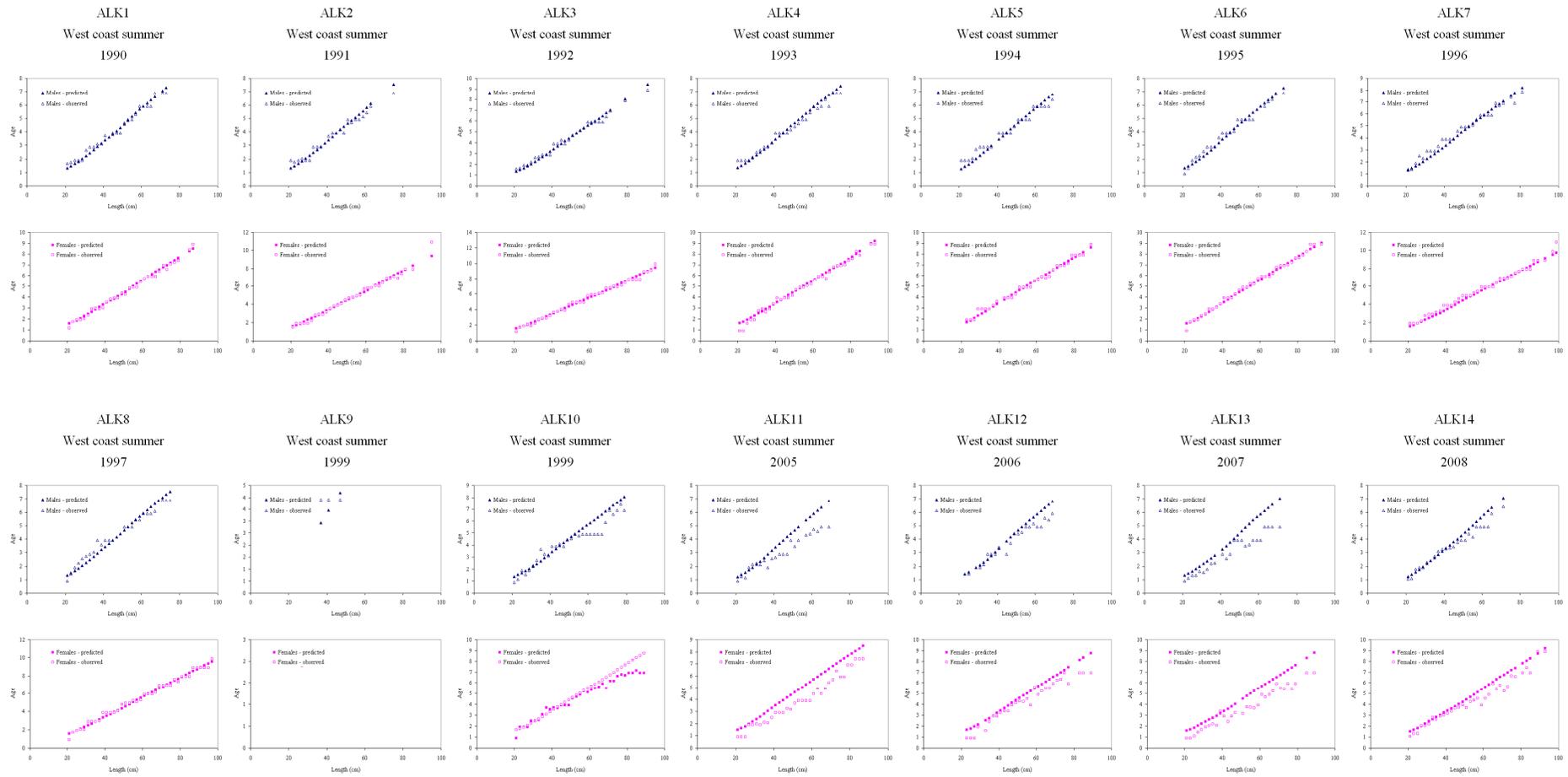


Fig. App.III.13a: Observed vs predicted mean age-at-length for *M. capensis* males and females for the West Coast summer surveys.

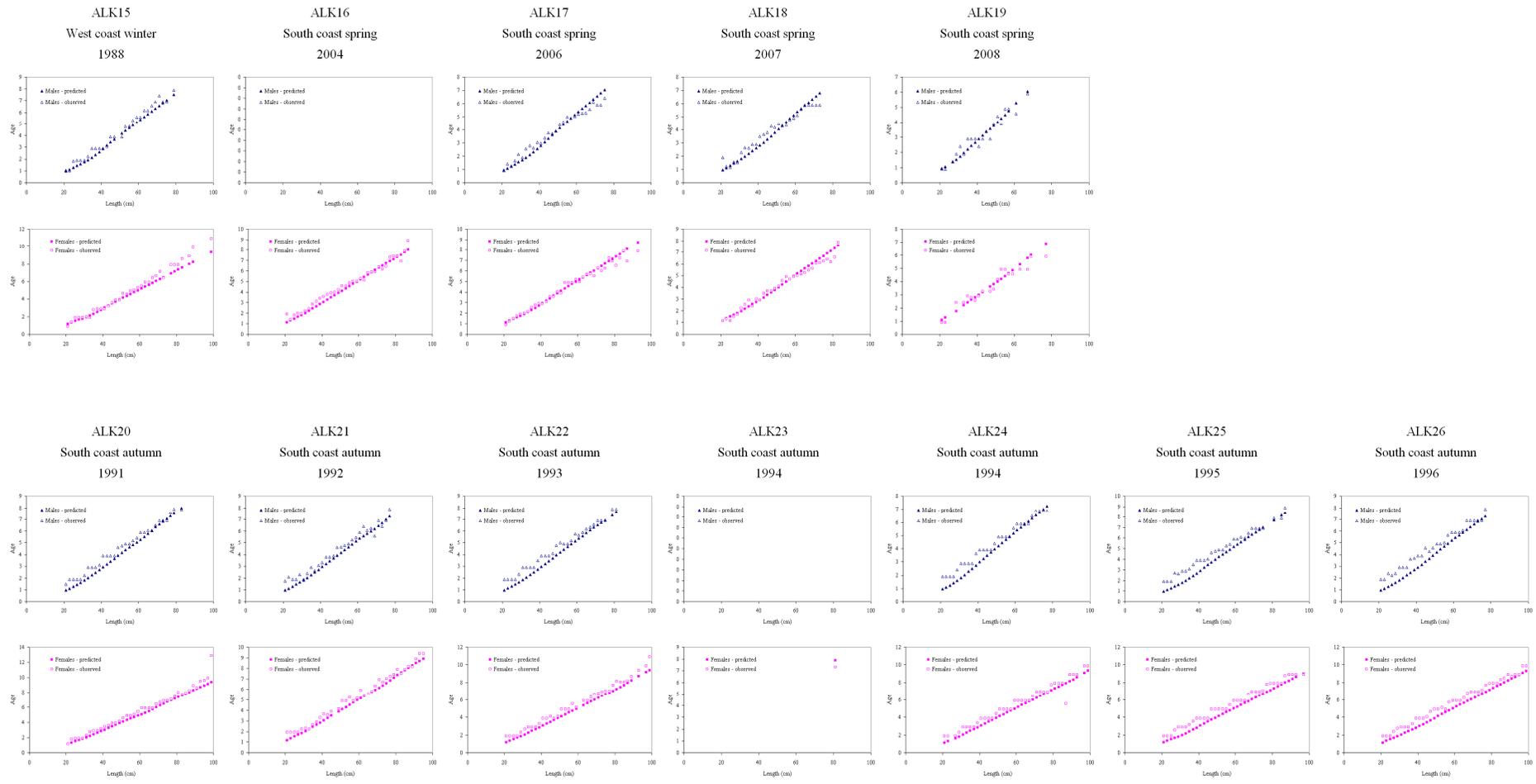


Fig. App.III.13b: Observed vs predicted mean age-at-length for *M. capensis* males and females for the West Coast winter, South Coast spring and South Coast autumn surveys.

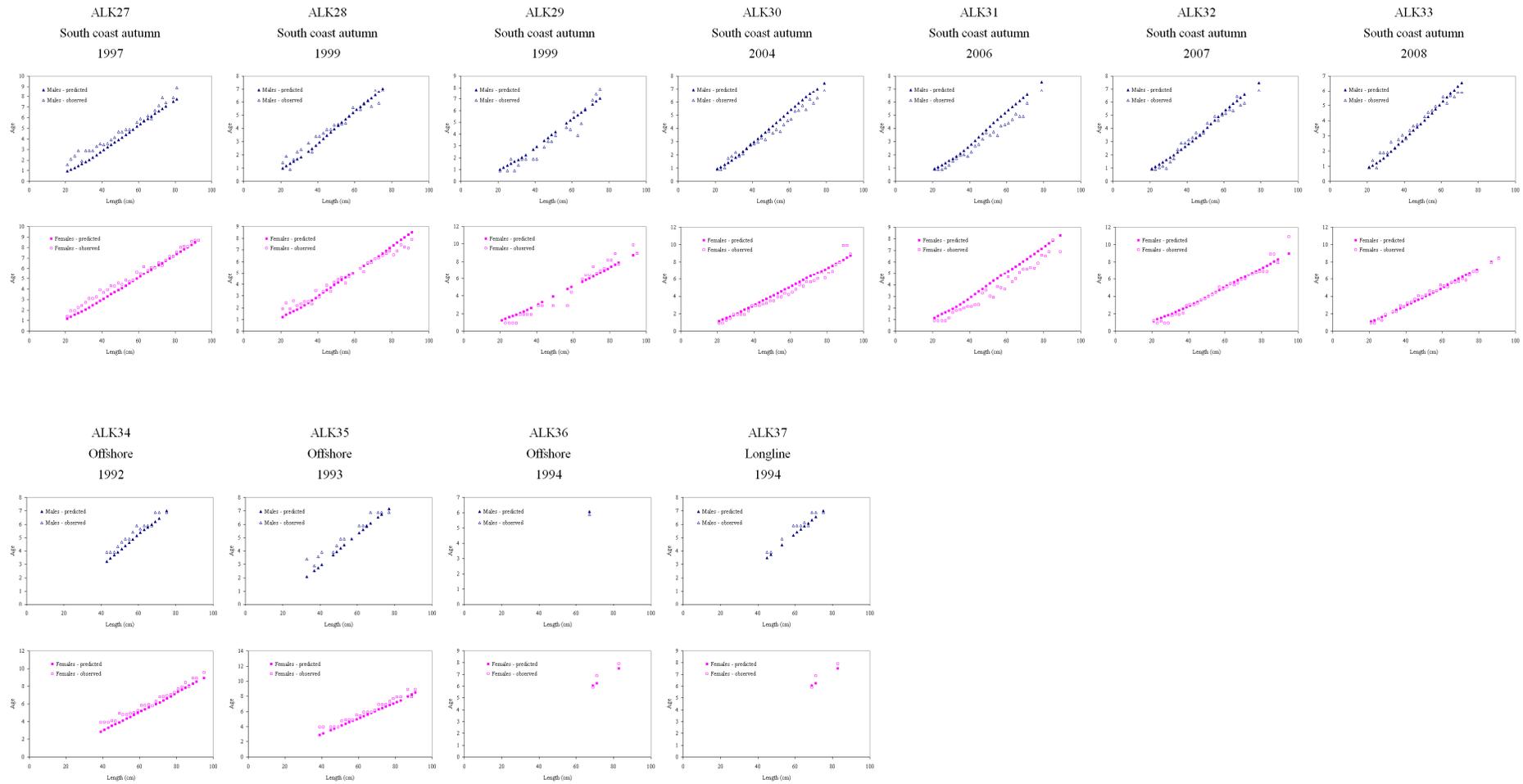


Fig. App.III.13c: Observed vs predicted mean age-at-length for *M. capensis* males and females for the South Coast autumn surveys, offshore commercial trawl and commercial longline.

ADDENDUM TO:

Proposed Reference Set for the South African hake resource to be used in OMP-2010 testing

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February 2010

Further robustness/sensitivity tests have been conducted; they are detailed in Table Add1. Table Add2 summarises the key management quantities for these robustness/sensitivity tests, while Table Add3 compares their different contributions to the total negative log-likelihood.

Fig. Add1 plots the estimated spawning biomass trajectories for these further tests. The fit of Rob14 (giving more weight to the recent CPUE and survey abundance series) to the CPUE and survey series are shown in Figs Add2 and Add3 and compared to the RC (= RS1) fit. The time-series of standardised recruitment residuals for Rob15 (no shrinkage of recent recruitment towards the stock-recruitment relationship prediction) are compared to those of the RC in Fig. Add4.

Comments

Rob12 (changed selectivity slopes)

The likelihood deteriorates, often substantially, but there is not much change to estimates of key management-related quantities (Tables Add2 and Add3).

Rob13 (decrease in K)

Productivity (MSY) estimates are lower, and *M. capensis* is estimated to be depleted to a greater extent (Table Add2).

Rob14 (more weight to fitting recent abundance index data)

The only notable difference to the fit is that the model better reflects recent higher CPUE values for *M. paradoxus* on the south coast. *M. paradoxus* is estimated to be depleted to a lesser, but *M. capensis* to a greater extent (Figs Add2 and Add3).

Rob15 (no shrinkage on recent recruitments)

Immediate recruitment to the fishery is estimated to be better for *M. capensis*, but worse for *M. paradoxus*, compared to the RC (Fig. Add4).

Rob16 (reduced M at larger ages for RS2)

This reduces the pre-exploitation biomass K , which might be considered unrealistically high for this scenario, without making much difference to estimates of key management-related quantities (Table Add2).

Table Add1: Description of the further robustness/sensitivity tests.

Shift center	SR relationship	<i>M</i>	Other
Rob12	as RC		All commercial and survey selectivity slopes (in cm ⁻¹): a)+0.04, b) +0.02, c) -0.04 and d) -0.02
Rob13	as RC		Change in <i>K</i> (30% linear decrease btw 1980 and 2000 for both spp)
Rob14	as RC		Added weighting to recent data to fit recent abundance indices more closely (5 times more weight on last 5 year's CPUE and survey abundance indices)
Rob15	as RC		No shrinkage of recent recruitments towards the stock-recruitment relationship prediction
Rob16	as RS2		Increasing <i>M</i> at large ages (linear from 0.25 at age 8 to 1 at age 15)

Table Add2: Estimates of management quantities for the RC (= RS1) and the further robustness/sensitivity tests. Values in bold have been fixed. Results for RS2 are included for comparison with Rob16. For Rob13, *K*^{sp} and quantities relative to it are in terms of the 1917 estimate.

	-lnL	<i>M. paradoxus</i>								<i>M. capensis</i>								2009 species ratio <i>B</i> ^{sp}
		<i>K</i> ^{sp}	<i>h</i>	<i>B</i> ^{sp} ₂₀₀₉ / <i>K</i> ^{sp}	<i>B</i> ^{sp} _{MSY} / <i>K</i> ^{sp}	<i>B</i> ^{sp} ₂₀₀₉ / <i>B</i> ^{sp} _{MSY}	<i>MSY</i>	<i>M</i> ₂₋	<i>M</i> ₅₊	<i>K</i> ^{sp}	<i>h</i>	<i>B</i> ^{sp} ₂₀₀₉ / <i>K</i> ^{sp}	<i>B</i> ^{sp} _{MSY} / <i>K</i> ^{sp}	<i>B</i> ^{sp} ₂₀₀₉ / <i>B</i> ^{sp} _{MSY}	<i>MSY</i>	<i>M</i> ₂₋	<i>M</i> ₅₊	
RS1	-94.5	1363	1.08	0.15	0.24	0.59	113	0.75	0.38	516	1.01	0.54	0.47	1.12	69	0.75	0.38	1.34
Rob12a	-76.5	1740	0.96	0.19	0.29	0.68	121	0.75	0.38	684	0.98*	0.55	0.42	1.27	75	0.75	0.38	1.14
Rob12b	-88.2	1573	1.02	0.17	0.26	0.66	117	0.75	0.38	572	0.87	0.55	0.50	1.08	68	0.75	0.38	1.17
Rob12c	-75.1	1081	1.00	0.18	0.17	0.88	103	0.75	0.38	417	1.50*	0.55	0.40	1.32	69	0.75	0.38	1.16
Rob12d	-90.2	1185	1.11	0.17	0.26	0.58	113	0.75	0.38	450	1.50*	0.53	0.37	1.37	69	0.75	0.38	1.17
Rob13	-54.9	1940	0.77	0.21	0.23	0.94	85	0.75	0.38	664	1.13	0.29	0.10	2.83	46	0.75	0.38	0.47
Rob14	-236.4	1208	1.23	0.19	0.24	0.72	114	0.75	0.38	484	1.16	0.49	0.45	1.05	70	0.75	0.38	1.05
Rob15	-96.5	1464	0.98	0.15	0.22	0.65	110	0.75	0.38	518	1.06	0.53	0.45	1.14	68	0.75	0.38	1.25
Rob16	-85.6	2302	0.93	0.11	0.27	0.41	123	0.60	0.25	1343	0.98*	0.52	0.22	2.38	88	0.60	0.25	2.80
RS2	-86.6	3009	0.98*	0.10	0.24	0.45	119	0.60	0.25	1990	0.98*	0.57	0.20	2.88	89	0.60	0.25	3.80

Table Add3: For each contribution to the total negative log-likelihood ($-\ln L$), differences in $-\ln L$ compared to the case with the lowest $-\ln L$ (RS6).

	$-\ln L$ total	CPUE historic	CPUE GLM	Survey	Comm CAL	Survey CAL (sex-aggr.)	Survey CAL (sex-disaggr.)	ALK	Rec. penalty	Sel. smoothing penalty
Rob12a	23.1	10.5	4.2	0.4	7.7	-1.8	1.7	0.2	-0.1	0.0
Rob12b	11.4	6.4	2.9	0.9	0.4	-1.1	1.0	0.1	0.4	0.0
Rob12c	24.5	1.2	11.6	3.6	1.5	2.6	-0.4	3.0	1.3	0.0
Rob12d	9.4	1.1	10.7	1.9	-4.4	0.5	-0.2	-0.1	-0.3	0.0
Rob13	44.7	12.4	5.9	4.7	1.2	1.1	0.9	4.7	12.5	1.0
Rob14	-136.8	1.1	-72.0*	-64.1*	-4.7	-0.1	1.0	0.2	1.3	0.1
Rob15	3.2	0.7	5.2	0.9	-3.8	-0.6	-0.2	0.0	0.6*	-0.1
Rob16	14.0	0.0	13.5	-1.2	-0.4	2.1	0.5	0.8	-1.3	0.0

* These likelihood contributions are not comparable to the others because of different weightings.

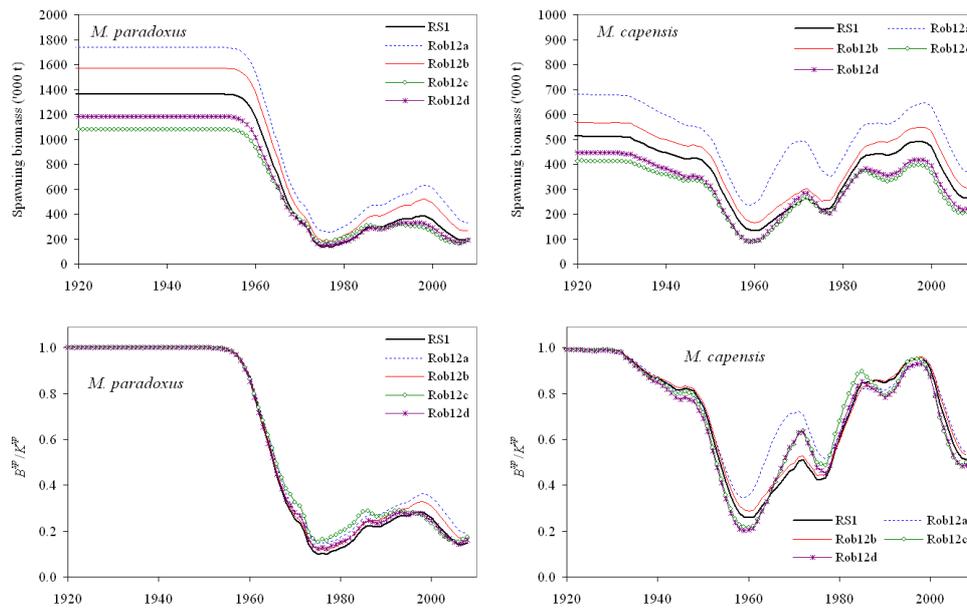


Fig. Add1a: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for the RC (= RS1) and Rob12a to Rob12d.

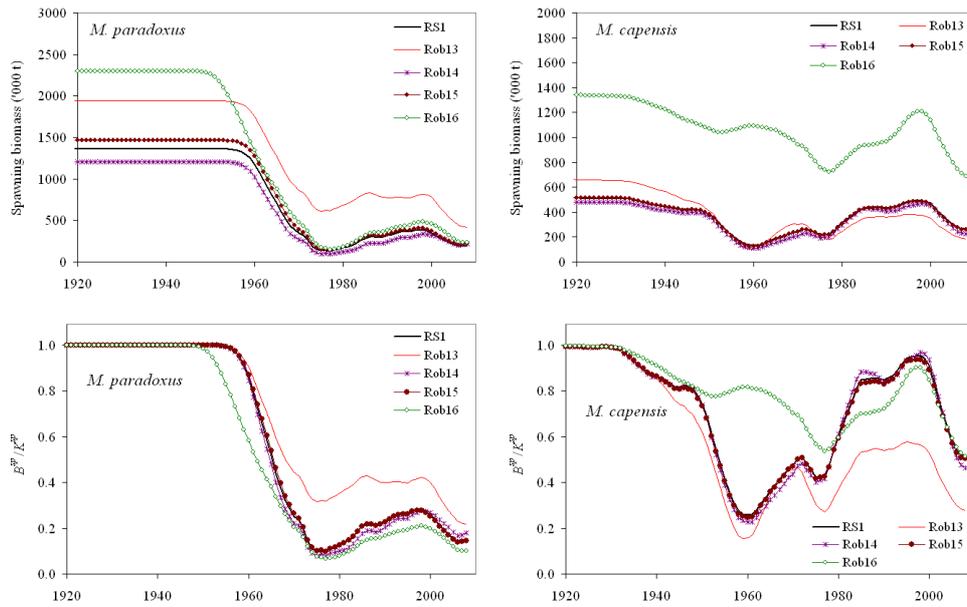


Fig. Add1b: Estimated spawning biomass trajectories for *M. paradoxus* and *M. capensis*, both in absolute terms and relative to the pre-exploitation level for the RC (= RS1) and Rob13 to Rob16. For Rob13, B^{sp}/K^{sp} is in terms of K^{sp} in 1917.

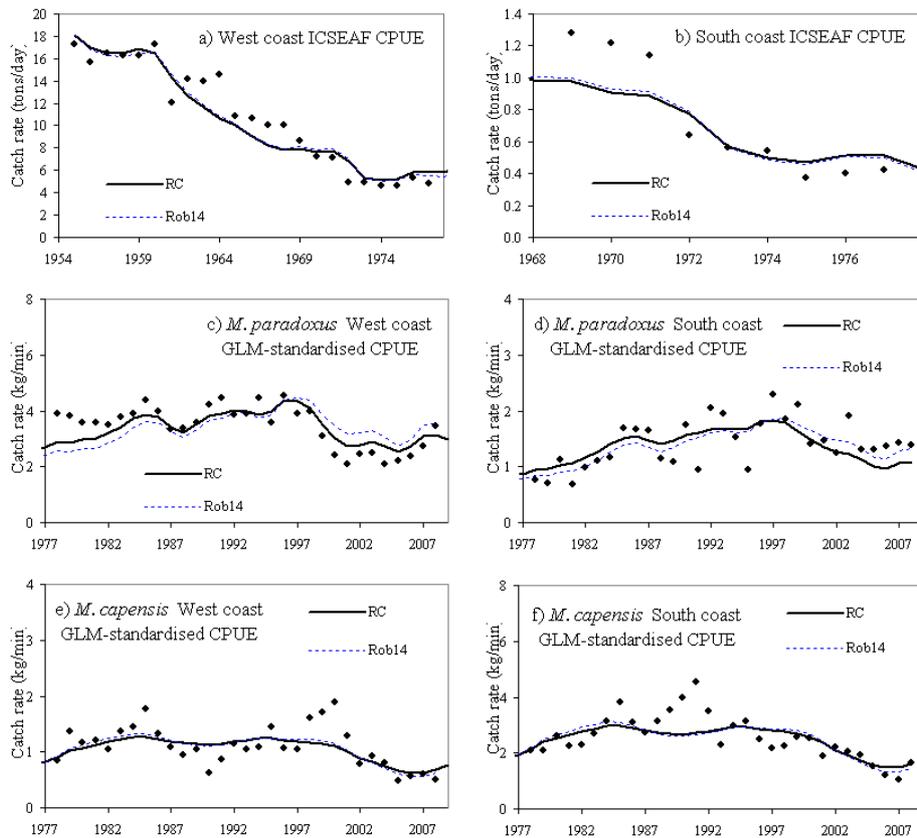


Fig. Add2: Fit of Rob14 to the CPUE series compared to the RC.

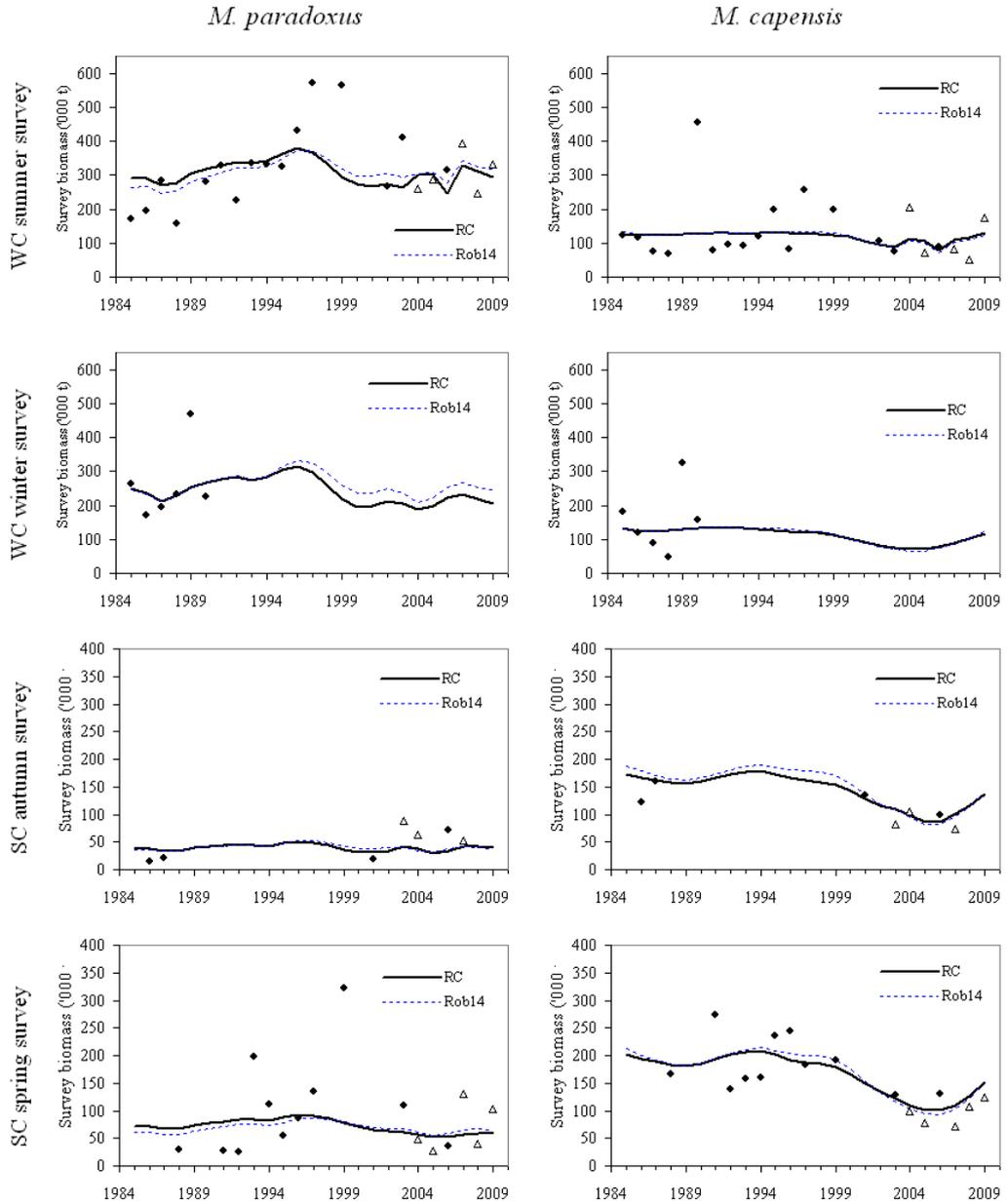


Fig. Add3: Fit of Rob14 to the survey series compared to the RC.

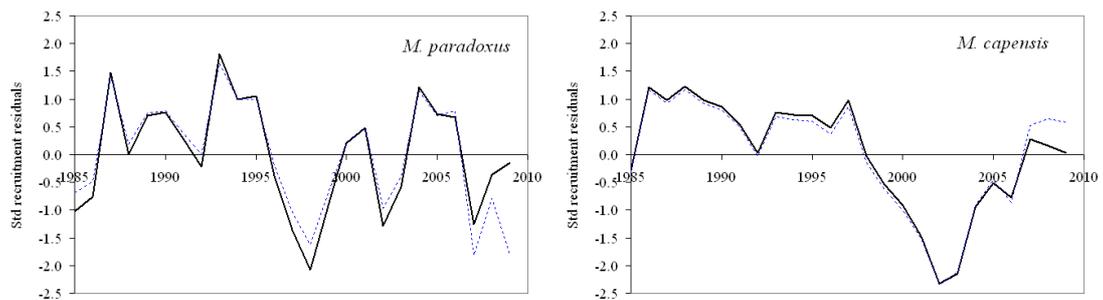


Fig. Add4: Time-series of standardised stock-recruitment residuals for the RC and Rob15.