2013 Update of the South African Hake Reference Case Assessment

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Summary

The Reference Case assessment of the SA hake resource is updated using unchanged methodology from that used in developing the existing OMP, but with revised and updated data sets. The only change of particular note is the inclusion of new longline catch-at-length data subsequent to 2000 results in a somewhat reduced estimate of current the *M. paradoxus* spawning biomass.

INTRODUCTION

This paper presents an update of the South African hake Reference Case assessment (RS1) (Rademeyer and Butterworth, 2010). Compared to the 2012 routine update of this assessment (Rademeyer, 2012), it includes new commercial (catches, length distribution and CPUE) data, but no new survey data are available.

METHODOLOGY and DATA

The updated data are listed in Appendix A. The methodology is detailed in Appendix B.

Six assessments are compared:

1) **RS1-2012**: the 2012 routine update presented last year (Rademeyer, 2012);
2) **RS1-2013a**: the comparable assessment to RS1-2012 with updated catches and CPUE data to 2012;
3) **RS1-2013b**: as RS1-2013a, with updated maturity-at-length (Singh *et al*. 2011) and length-weight parameters (Singh 2013);
4) **RS1-2013c**: as RS1-2013b, with further commercial offshore trawl CAL data (see Appendix 1 for details);
5) **RS1-2013d:** as RS1-2013c, with further commercial longline CAL data (see Appendix 1 for details);
6) **RS1-2013e:** as RS1-2013d, with different selectivity curves estimated for the longline fleet on the West and South Coasts for *M. capensis* (in RS1-2013d, the longline selectivity curve for *M. capensis* is taken to be the same on the West and South Coasts) and with three periods with different selectivity curves for the longline fleet: i) pre-2000, ii) 2000-2005 and iii) 2006 to current. The changes in selectivity are reflected by shifts of the ascending limb of the logistic curve , separately for each species and coast, while the steepness of the limb and the slope at older ages are kept the same (i.e. seven further parameters estimated compared to RS1-2013d). The choice of the years for the changes in selectivity was made by inspection of plots of residuals. This assessment is termed the “new Reference Case” (new RC);

RESULTS and DISCUSSION

From the 2012 assessment to the 2013 new RC

Table 1 compares estimates of management quantities for the six assessments, while Fig. 1 plots the spawning biomass trajectories. Fig. 2 compares the recruitment trajectories and Fig. 3 plots the estimated stock-recruitment relationships.

Figs 4 and 5 compare the fits to the CPUE and survey abundance indices for RS1-2012 and the new RC. The fits are reasonable for all series, but there are indications of correlation in residuals over time.

The 2013 new RC

The estimated commercial and survey selectivity curves for the new RC are shown in Figs 6a and 6b respectively. Apart from *M. paradoxus* on the South Coast, the male and female selectivities-at-length are assumed to be the same and are then converted to gender-specific selectivities-at-age. Because of selectivity differences between males and females evident for the South Coast surveys for *M. paradoxus*, gender-specific selectivities are estimated for this species in the South Coast autumn and spring surveys, with the female selectivities (for *M. paradoxus* only) scaled downwards for these two surveys by a common factor across lengths which is estimated in the model fitting procedure. This gender difference is assumed to effect the commercial fleet as well, and the female selectivity for the South Coast offshore trawl fleet (the only fleet assumed to catch *M. paradoxus* on the South Coast) is therefore also scaled downwards by a factor estimated in the model fitting. The female selectivity scaling factors estimated for the South Coast spring and autumn surveys are 0.42 and 0.90 respectively. The scaling factor for the offshore trawl fleet is taken to be the average of these two values.

All the commercial selectivity curves show a decrease for large fish, apart for the South Coast offshore trawl fleet for *M. paradoxus*. This decrease is estimated for all fleets apart from the offshore trawl and South Coast handline fleets for *M. capensis*. For the *M. capensis* offshore trawl fleet, the selectivity slope (the rate of decrease of selectivity at larger sizes) is fixed to 1/3 of that estimated for the inshore trawl fleet, while for the handline fleet, this slope is taken to be the average of the estimated South Coast longline and inshore fleet slopes. (It should be noted that the RC makes particular assumptions about the values of the natural mortality-at-age schedule, specifically the natural mortality is fixed at 0.75 for ages 0 and 1 and fixed at 0.375 for ages 6 and above, with a linear trend between these two values for ages 2 to 5. Selectivities will change if these assumptions are changed; results for such changes will be reported in a following paper.)

The fits to the survey gender-aggregated and gender-disaggregated catch-at-length data are shown in Figs 7 and 8 respectively. These fits are broadly reasonable.

The fits to the commercial catch-at-length data are shown in Fig. 9. The fits are averaged over all the years for which data are available, and are reasonable for all the data sets. There are however some patterns evident in the bubble plots of residuals which could perhaps be improved by adding further periods between which selectivities change.

Figs 10 and 11 plot the gender-specific growth curves and length-at-age distributions estimated in the new RC. The difference between male and female growth curves is estimated to be greater for *M. paradoxus* than for *M. capensis*. *M. capensis* is estimated to grow to slightly larger sizes than *M. paradoxus*.

The fits to the ALKs are given in Appendix B.

Including the new (2000 onwards) longline catch-at-length data

Although results do change with the inclusion of the updated catches, CPUE (RS1-2013a), with the change in the maturity-at-length and length weight relationships (RS1-2013b) and with the inclusion of the new offshore trawl catches (RS1-2013c), the magnitude of the changes is not large. The current status of the resource s is broadly unchanged, with *M. paradoxus* close to MSY level and *M. capensis* well above it. The picture however is rather different for *M. paradoxus* when the new longline CAL data are included (RS1-2013d and RS1-2013e).

When these new longline data are included, it is evident that a change in selectivity over time is necessary for the model to fit to the data (Fig. 12). Two changes have been made to the manner in which longline selectivities are modelled compared to preceding analyses in moving to RS1-2013e. The first is that with the availability of species-disaggregated longline data for the West Coast, a selectivity curve can be estimated directly for *M. capensis*, rather than assuming the same selectivity curve as on the South Coast. Secondly, three periods of differing selectivities have been assumed to better reflect the patterns in these CAL data, namely pre-2000, 2000-2005 and 2006 onwards. The differing-selectivity periods are taken to apply to both *M. paradoxus* and *M. capensis*. The changes in selectivity curves are reflected by estimating a shift of the ascending limb of the logistic curve separately for each species and coast. The steepness of the limb and the slope at older ages are kept the same (i.e. seven further parameters estimated compared to RS1-2013d). The choice of the years for the changes in selectivity was made by inspecting plots of residuals. These changes are largely justified in AIC terms with an improvement of over 19 likelihood points. Fig. 12 compares the residuals for the fit to the longline proportion-at-length with and without these changes. The patterns in the residuals are much reduced in the new RC compared to RS1-2013d. Note that the trend in the pattern of these selectivity curves (see Fig. 6a) is compatible with general perceptions – that over time this fishery has shifted its focus to include more of the smaller hake.

The question remains as to why including new longline CAL data results in a rather different perception of the current status of *M. paradoxus*. To investigate this further, the new RC was also run downweighting the new longline CAL data in the negative log-likelihood (with w=0.0001 instead of w=0.1 – recall that CAL data are routinely downweighted by this 10% multiplicative factor for reasons detailed in Appendix B – see text following equation B.37). The results are compared to the new RC results in Table 2 and the contributions to the total negative log-likelihood compared in Table 3. Fig. 14 shows that some of the CAL misfit in the downweighting case is corrected to a fair extent when these data are given full weight. Comparison of the negative log-likelihood contributions in Table 1 for RS1-2013c and RS1-2013e shows that the changed result is linked to some "tension" between the abundance indices and the commercial CAL data. In changing from the former to the latter assessment, the fits to all the abundance indices deteriorate, but improve for both the commercial trawl (slightly) and the longline CAL data. In adding further commercial CAL data, the net weight accorded to these data increases relative to the abundance index data, leading to the change in results.

CONCLUDING REMARKS

Developing further commentary on the results of these assessments has been deferred in the interests of early circulation. The result of particular note is the somewhat worse status estimated for *M. paradoxus* when the further commercial longline CAL data are taken into account. This will be explored further in a subsequent paper examining various sensitivities to the new RC, which will also include estimates of precision for the results for the new RC.

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Singh L., Melo Y and Glazer J. 2011. *Merluccius capensis* and *M. paradoxus* length-at-50% maturity based on histological analyses of gonads from surveys. Unpublished report. FISHERIES/2011/JUL/SWG-DEM/33.

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Table 1: Comparison of estimates of management quantities of the *M. paradoxus* and *M. capensis* coast-combined resources for the six assessments. *MSY* and associated quantities are given for the offshore trawl fleet. Biomass units are thousand tons. Note that not all the –lnL values are comparable given that different data are used. K^{sp}, B_y^{sp}/K^{sp}, B_{MSY}^{sp}/K^{sp} and B_y^{sp}/B_{MSY}^{sp} are all in terms of the female component of the spawning biomass only.

		RS1-2012	RS1-2013a	RS1-2013b	RS1-2013c	RS1-2013d	RS1-2013e
	-lnL total	-58.1	-123.4	-117.3	-124.0	-153.2	-172.3
	CPUE historic	-38.1	-40.2	-40.3	-40.2	-39.8	-39.9
	CPUE GLM	-143.0	-170.3	-172.2	-170.2	-169.5	-168.6
	Survey	-38.0	-33.8	-33.3	-33.4	-31.3	-32.1
	Commercial CAL - trawl	-35.7	-44.1	-35.1	-44.9	-42.9	-45.1
	Commercial CAL - longline	-16.2	-16.0	-16.1	-16.1	-50.5	-68.9
	Survey CAL (sex-aggr.)	-2.3	-5.2	-4.6	-5.2	-2.9	-3.0
	Survey CAL (sex-disaggr.)	66.7	43.1	42.7	43.0	43.0	42.9
	ALK	124.0	118.2	118.2	118.4	116.3	117.4
	Recruitment penalty	8.8	8.7	7.6	8.4	8.9	8.6
	Selectivity smoothing penalty	15.5	16.0	15.5	16.0	15.4	15.5
M. paradoxus	K^{sp}	586	834	875	859	729	754
	h	1.23	0.93	0.92	0.93	0.97	0.96
	$B^{sp}{}_{2012}$	134	161	149	165	104	114
	$B^{sp}{}_{2012}/K^{sp}$	0.23	0.19	0.17	0.19	0.14	0.15
	$B^{sp}{}_{2013}$	-	158	147	162	98	108
	$B^{sp}{}_{2013}/K^{sp}$	-	0.19	0.17	0.19	0.13	0.14
	$B^{sp}{}_{MSY}$	134	164	172	174	152	158
	$B^{sp}{}_{MSY}/K^{sp}$	0.23	0.20	0.20	0.20	0.21	0.21
	$B^{sp}{}_{2012}/B^{sp}{}_{MSY}$	0.98	0.98	0.87	0.95	0.69	0.72
	$B^{sp}{}_{2013}/B^{sp}{}_{MSY}$	-	0.96	0.85	0.93	0.65	0.68
	MSY	113	116	117	116	111	113
M. capensis	K^{sp}	251	288	244	244	240	239
	h	1.40	1.02	0.99	0.99	1.04	1.03
	$B^{sp}{}_{2012}$	240	186	156	154	151	152
	$B^{sp}{}_{2012}/K^{sp}$	0.96	0.65	0.64	0.63	0.63	0.64
	$B^{sp}{}_{2013}$	-	207	174	172	170	170
	$B^{sp}{}_{2013}/K^{sp}$	-	0.72	0.71	0.71	0.71	0.71
	$B^{sp}{}_{MSY}$	89	109	100	100	95	96
	$B^{sp}{}_{MSY}/K^{sp}$	0.36	0.38	0.41	0.41	0.39	0.40
	$B^{sp}{}_{2012}/B^{sp}{}_{MSY}$	2.00	1.71	1.56	1.54	1.60	1.58
	$B^{sp}{}_{2013}/B^{sp}{}_{MSY}$	-	1.91	1.74	1.72	1.80	1.76
	MSY	70	62	63	64	63	63

Table 2: Comparison of estimates of management quantities of the *M. paradoxus* and *M. capensis* coast-combined resources for the new RC (RS1-2013e) and the run downweighting the new longline CAL data. *MSY* and associated quantities are given for the offshore trawl fleet. Biomass units are thousand tons. Note that the –lnL values are not comparable given that different data are used. K^{sp}, B_y^{sp}/K^{sp}, B_{MSY}^{sp}/K^{sp} and B_y^{sp}/B_{MSY}^{sp} are all in terms of the female component of the spawning biomass only.

		RS1-2013e	Down-weighting new longline CAL
	-lnL total	-172.3	-125.3
	CPUE historic	-39.9	-40.2
	CPUE GLM	-168.6	-170.2
	Survey	-32.1	-33.4
	Commercial CAL - trawl	-45.1	-44.9
	Commercial CAL - longline	-68.9	-17.4
	Survey CAL (sex-aggr.)	-3.0	-5.3
	Survey CAL (sex-disaggr.)	42.9	43.1
	ALK	117.4	118.4
	Recruitment penalty	8.6	8.5
	Selectivity smoothing penalty	15.5	15.9
M. paradoxus	K^{sp}	754	854
	h	0.96	0.93
	B^{sp}_{2012}	114	163
	B^{sp}_{2012}/K^{sp}	0.15	0.19
	B^{sp}_{2013}	108	160
	B^{sp}_{2013}/K^{sp}	0.14	0.19
	B^{sp}_{MSY}	158	173
	B^{sp}_{MSY}/K^{sp}	0.21	0.20
	$B^{sp}_{2012}/B^{sp}_{MSY}$	0.72	0.94
	$B^{sp}_{2013}/B^{sp}_{MSY}$	0.68	0.92
	MSY	113	116
M. capensis	K^{sp}	239	243
	h	1.03	0.99
	B^{sp}_{2012}	152	154
	B^{sp}_{2012}/K^{sp}	0.64	0.63
	B^{sp}_{2013}	170	172
	B^{sp}_{2013}/K^{sp}	0.71	0.71
	B^{sp}_{MSY}	96	100
	B^{sp}_{MSY}/K^{sp}	0.40	0.41
	$B^{sp}_{2012}/B^{sp}_{MSY}$	1.58	1.54
	$B^{sp}_{2013}/B^{sp}_{MSY}$	1.76	1.72
	MSY	63	63

Table 3: Contribution to the negative log-likelihood for the new RC (RS1-2013e) and the assessment downweighting the new longline CAL data.

		RS1-2013e			Downweighting new LL CAL		
		spp combined	para	cap	spp combined	para	cap
-lnL total	WC	-172.30			-125.26		
CPUE historic	WC	-29.61			-29.74		
	SC	-10.31			-10.44		
CPUE GLM	WC		-49.83	-38.21		-47.04	-39.51
	SC		-42.65	-37.86		-46.59	-37.09
Survey	WC summer		-11.21	-3.94		-12.00	-4.03
	WC winter		-3.22	1.01		-3.33	1.02
	SC autumn		1.69	-7.49		1.98	-7.56
	SC spring		6.72	-15.62		6.31	-15.78
Commercial CAL	WC offshore	-22.52			-22.92		
	SC offshore	2.24			2.37		
	BC offshore	-3.19			-3.39		
	SC inshore			-21.61			-20.98
	WC longline (1994-1997)	-11.08			-11.27		
	WC longline (2000+)		-0.24	-0.13		-0.16	-0.09
	SC longline (1994-1997)			-4.79			-5.75
	SC longline (2000+)			-0.16			-0.10
Survey CAL							
Sex-aggregated	WC summer		-6.89	11.65		-7.40	11.38
	WC winter		-2.96	6.02		-3.07	5.87
	SC autumn		2.64	-6.31		2.53	-7.04
	SC spring		3.69	-10.81		3.62	-11.24
Sex-disaggregated	WC summer		-0.41	51.57		-1.07	51.07
	WC winter		-	-		-	-
	SC autumn		3.07	-5.66		3.09	-5.31
	SC spring		17.64	-23.26		18.43	-23.11
ALK		117.41			118.41		
Recruitment penalty			3.65	4.96		3.40	5.06
Sel. smoothing penalty		15.47			15.95		

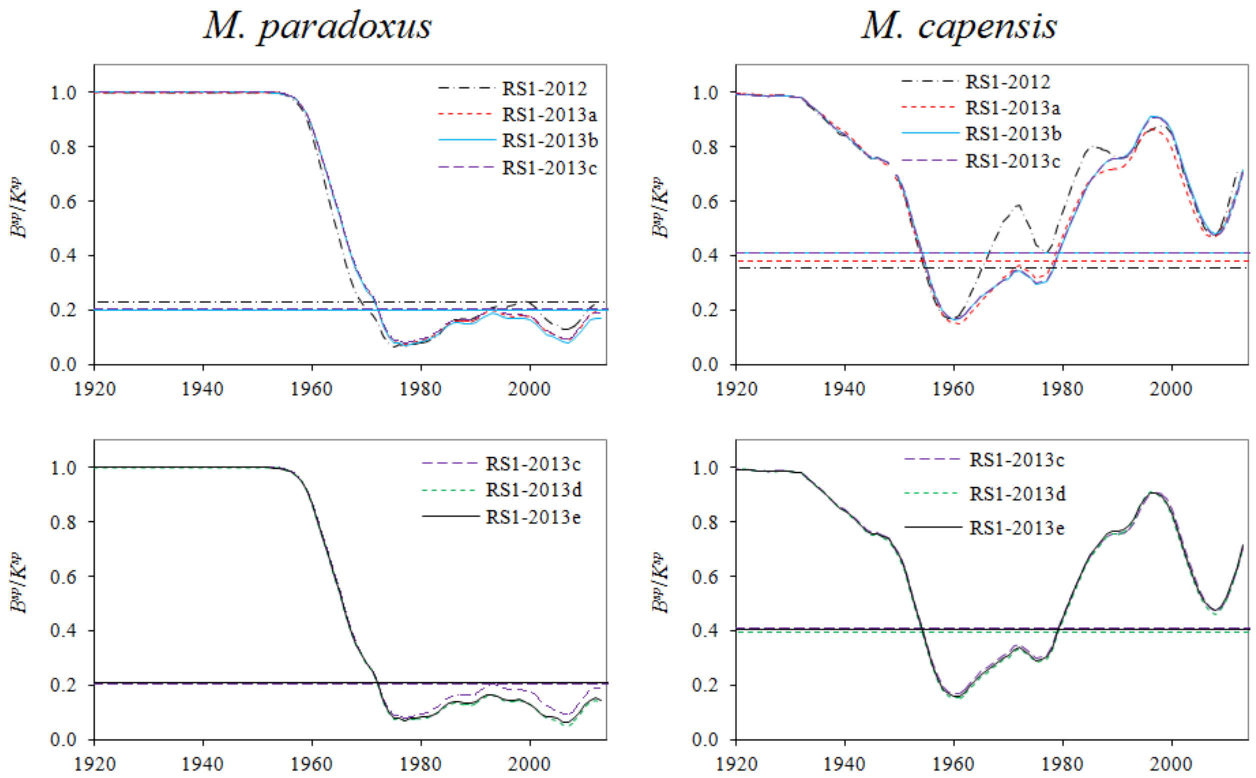


Fig. 1a: Trajectories of female spawning biomass (in terms of its pre-exploitation level) for the five assessments.The horizontal lines represent *MSYL*.

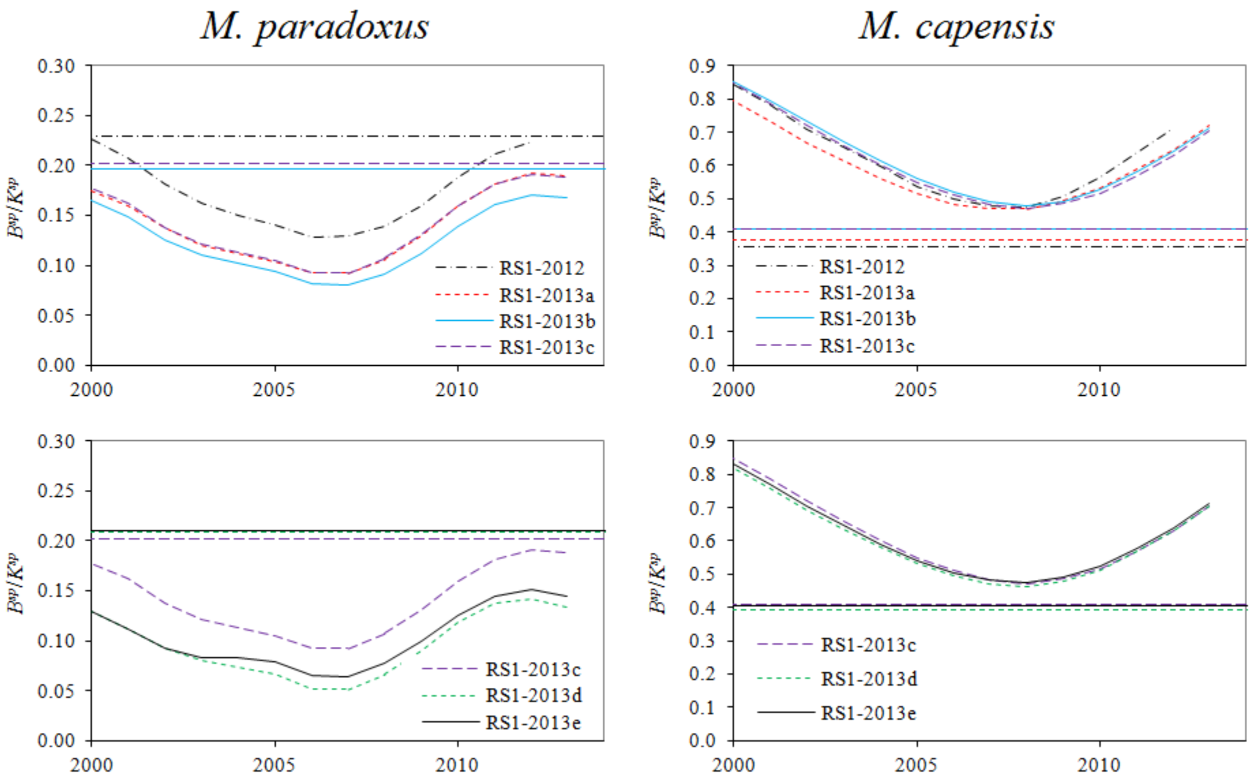


Fig. 1b: As above but with different scales on both axes to focus on more recent trends.

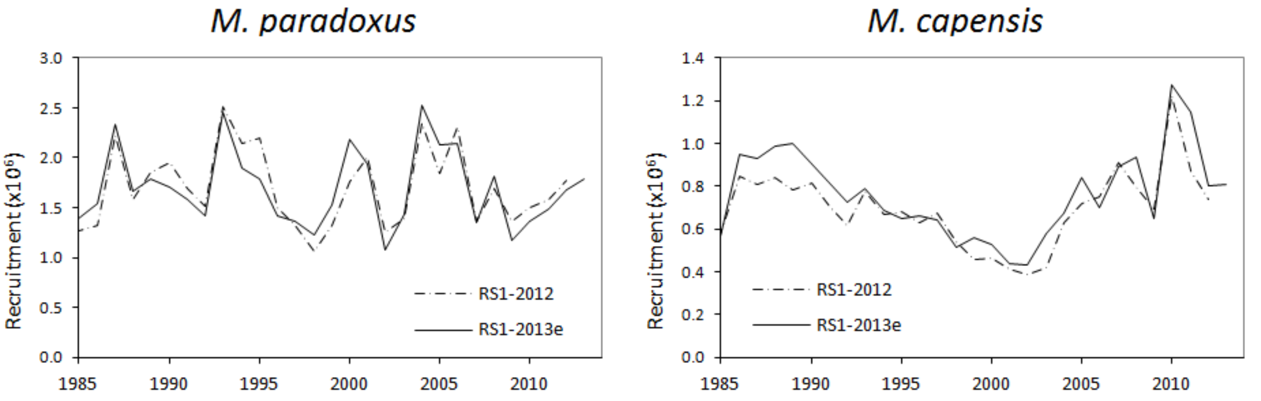


Fig. 2: Time series of recruitment for the new RC (RS1-2013e) compared to RS1-2012. Note that the decrease in σ_R from 0.25 to 0.1 has been moved one year forward for the new RC compared to RS1-2012.

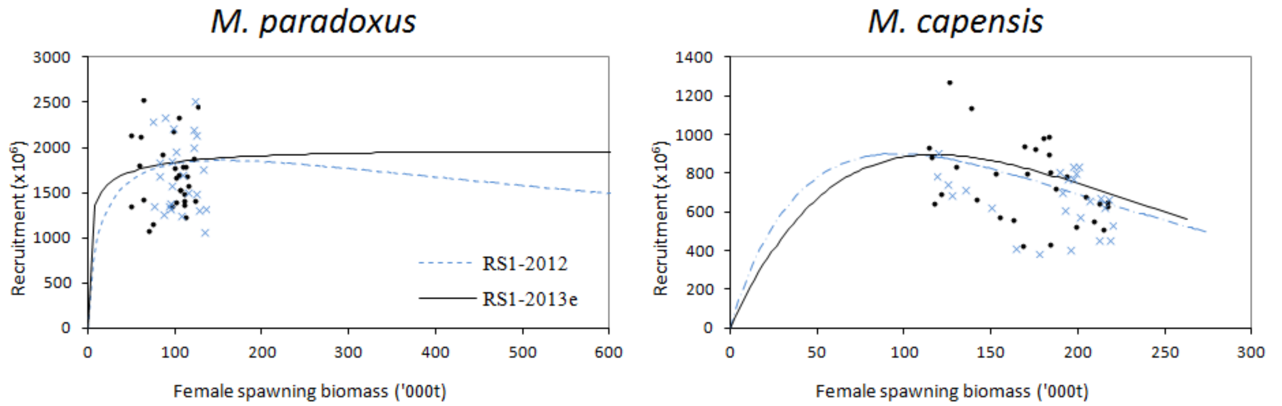


Fig. 3: Estimated stock-recruitment relationships for RS1-2012 (dashed blue line and blue crosses) and the new RC (RS1-2013e) (solid black line and black dots).

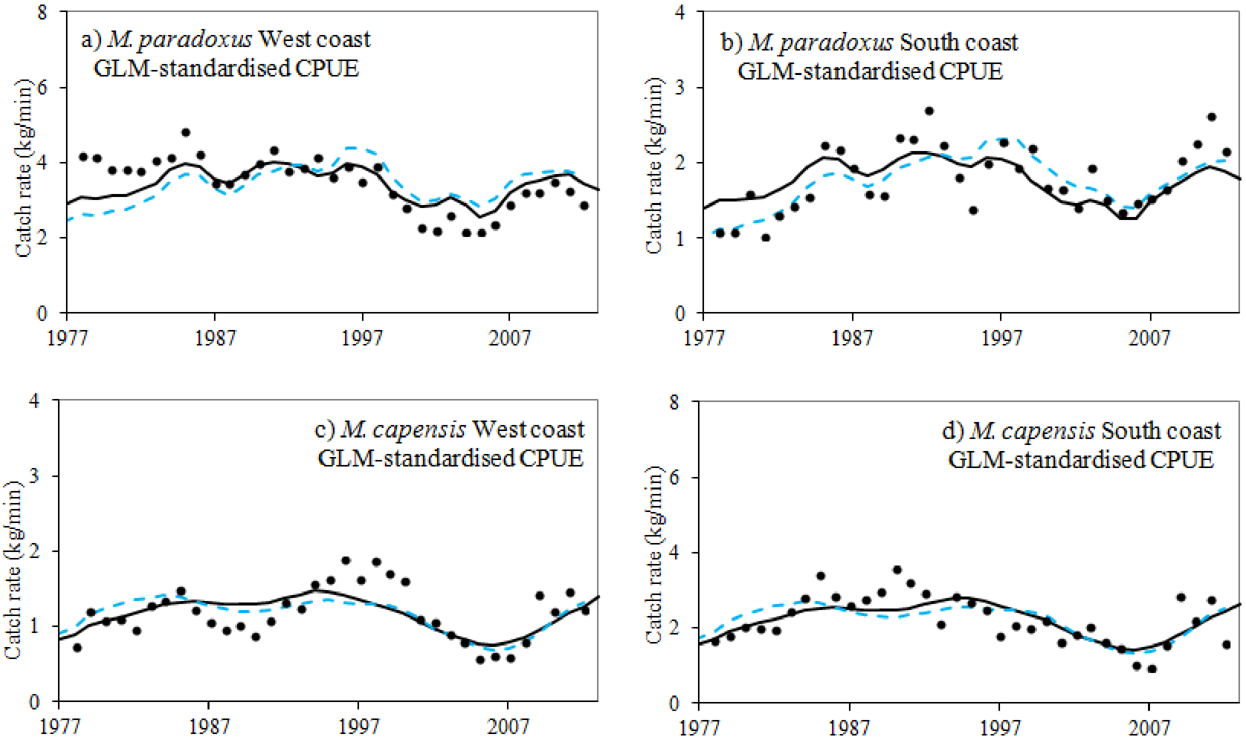


Fig. 4: Fits to the CPUE abundance indices for the RS1-2012 (dashed blue line) and the new RC (solid black line).

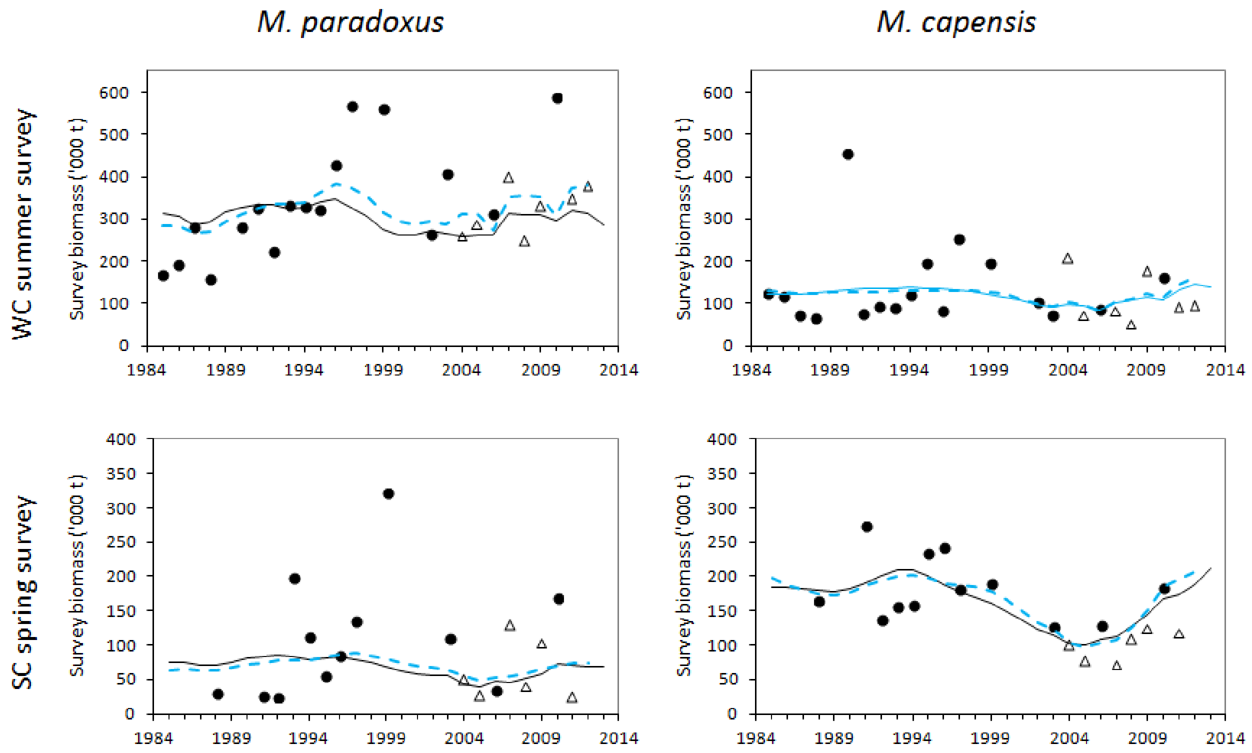


Fig. 5: Fits to the west coast summer and south coast autumn abundance series from surveys by *Africana* (the two longest series) for the RS1-2012 (dashed blue line) and the new RC (solid black line) assessments. The observed values shown as Δ were conducted by the *Africana* with the new gear and have been rescaled by the agreed calibration factor for the species concerned.

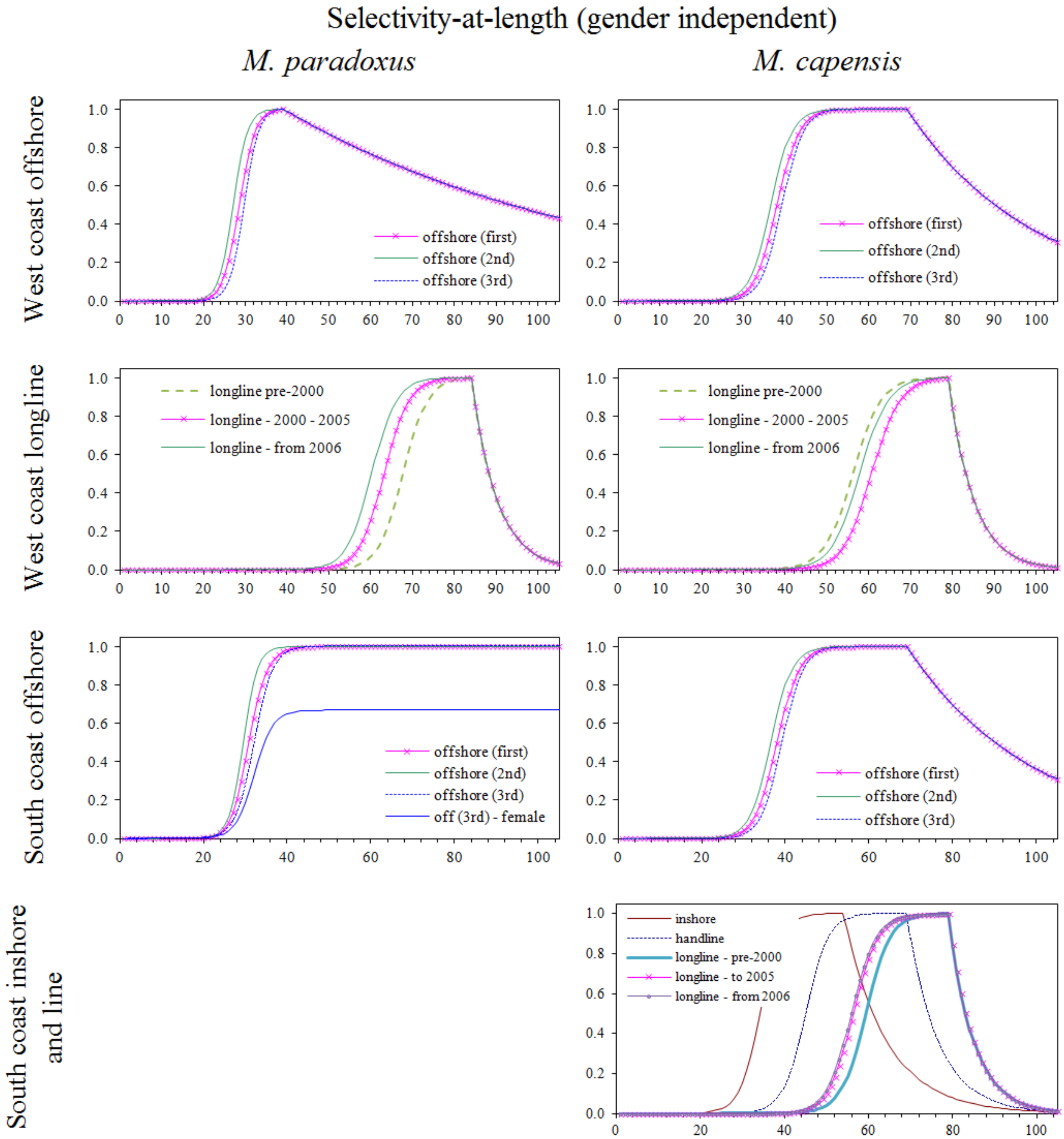


Fig. 6a: **Commercial** selectivities-at-length estimated for the new RC. For the offshore trawl fleet, the selectivity periods are as follows: i) first period: 1917-1976, ii) second period: 1977-1984 and iii) third period: 1993-2013. A linear change is taken between 1984 and 1993.

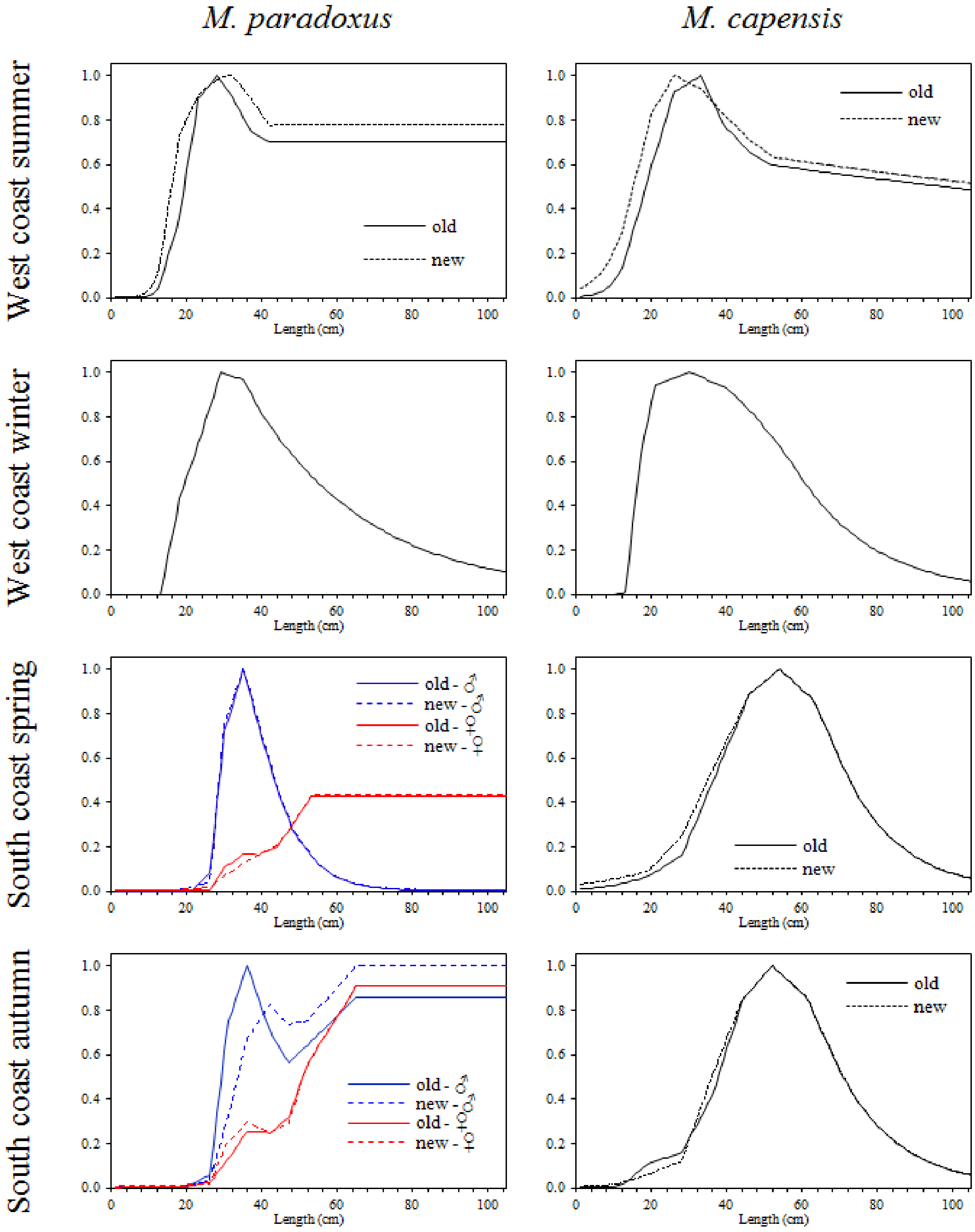


Fig. 6b: **Survey** selectivities-at-length estimated for the new RC.

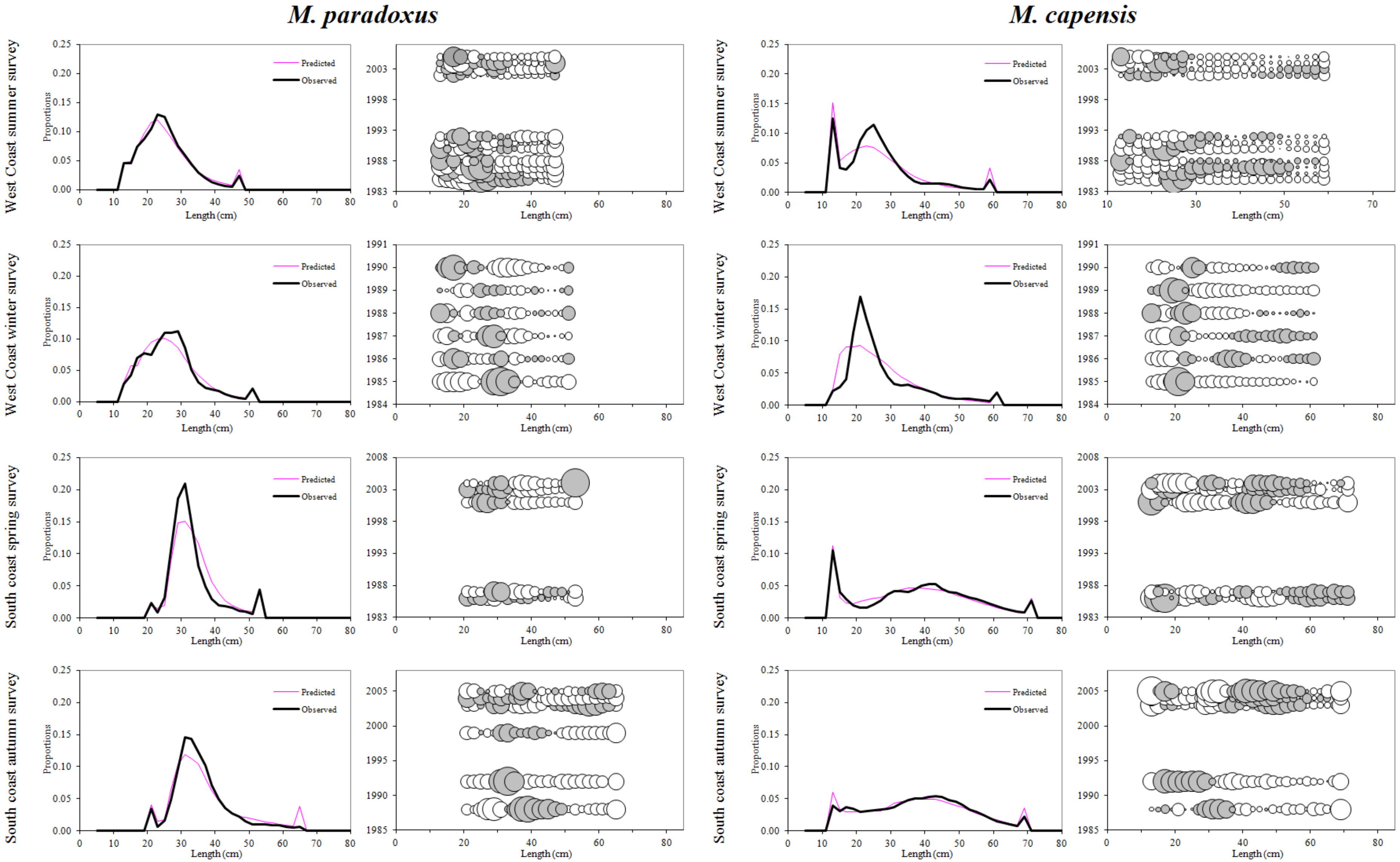


Fig. 7: Fit of RS1-2013e to the **survey** gender-aggregated surveys proportion-at-length data, aggregated over years for which data are available. Bubble plots of the corresponding residuals are shown. Here and in the figures following, the area of the bubble is proportional to the magnitude of the corresponding residuals. For positive residuals the bubbles are grey, whereas for negative residuals the bubbles are white.

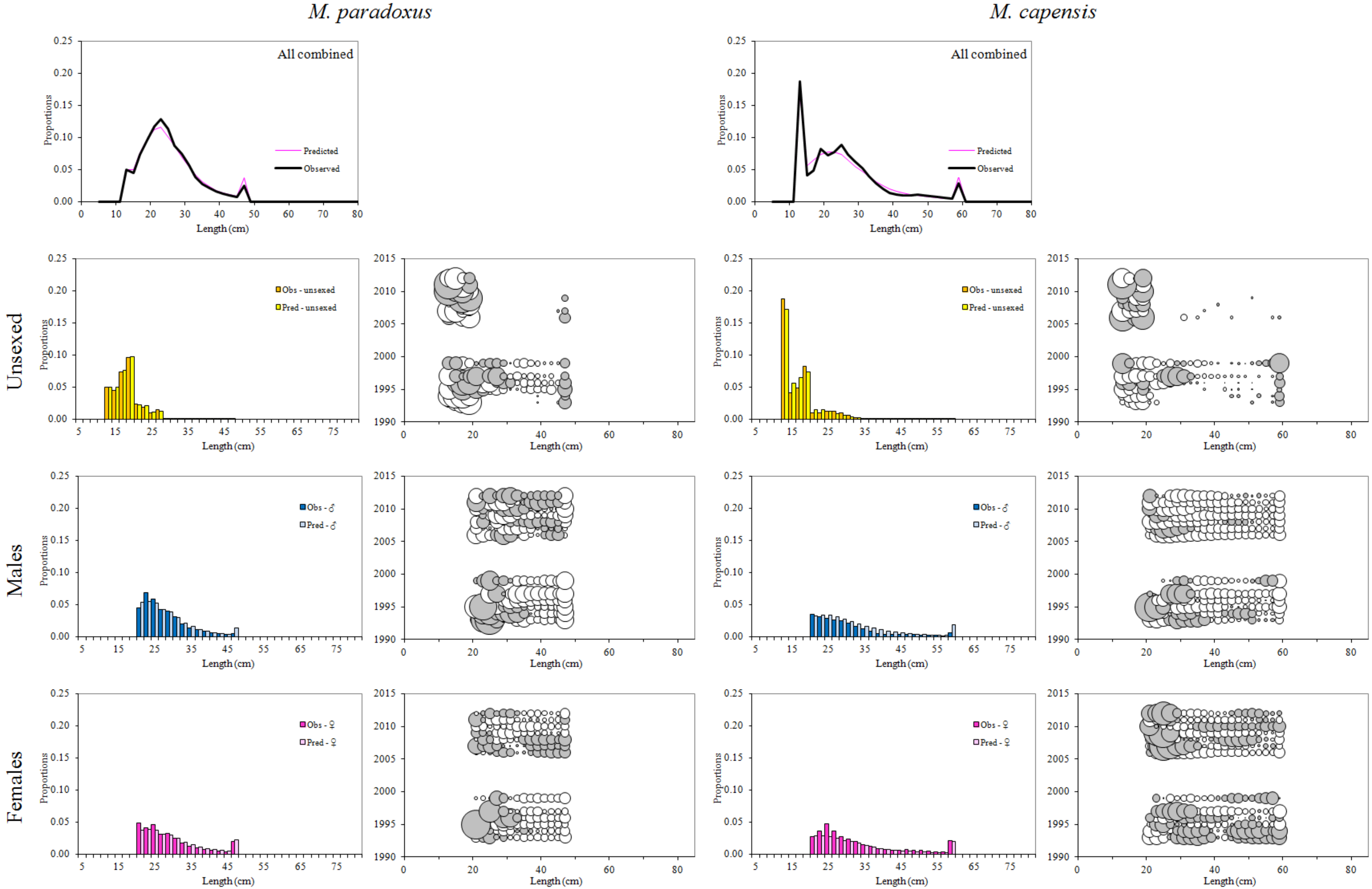


Fig. 8a: Fit of RS1-2013e to the west coast summer **survey** gender-disaggregated proportion-at-length data (in some plots, aggregated over years for which data are available).

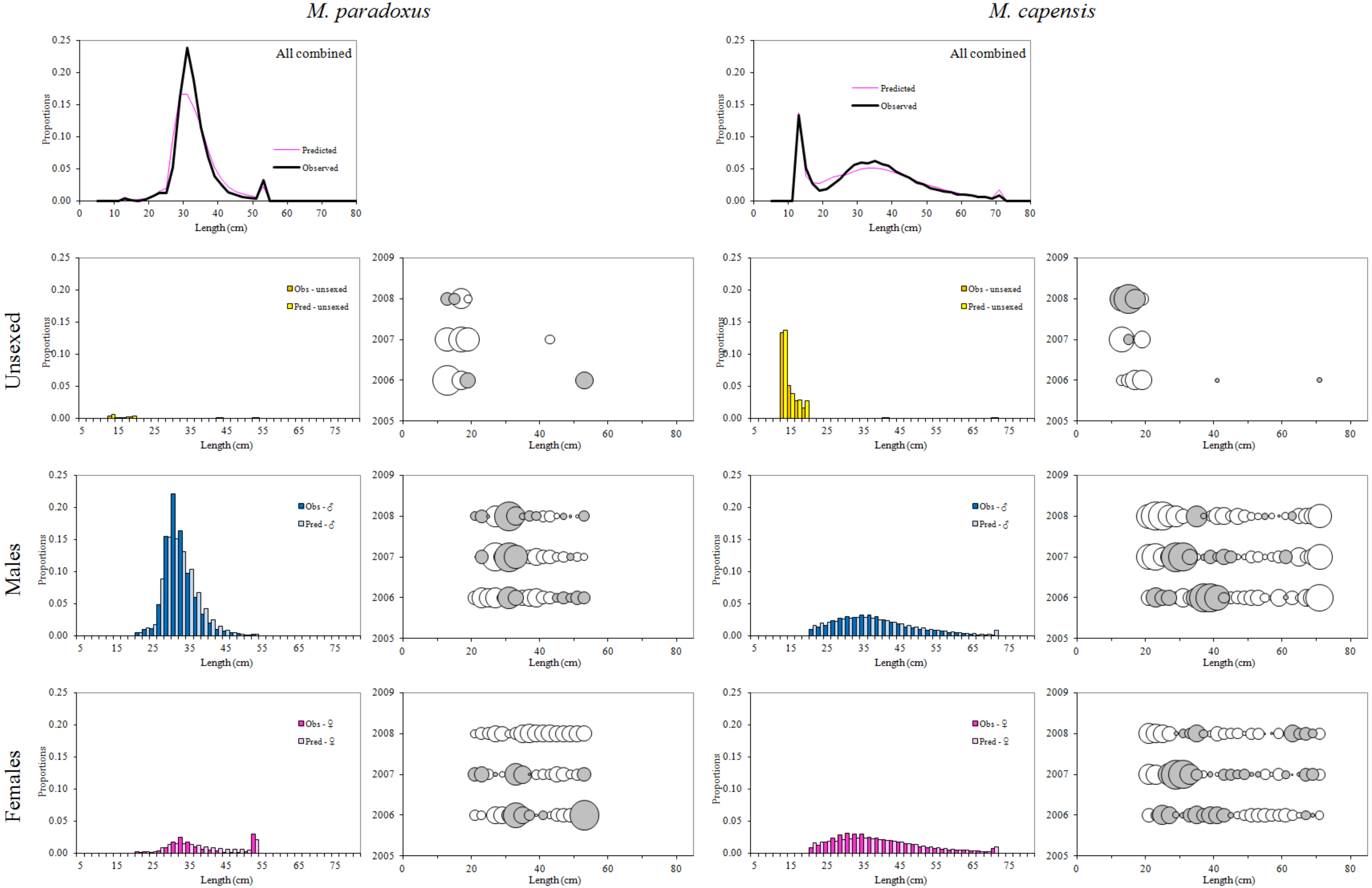


Fig. 8b: Fit of RS1-2013e to the south coast spring **survey** gender-disaggregated proportion-at-length data (in some plots, aggregated over years for which data are available).

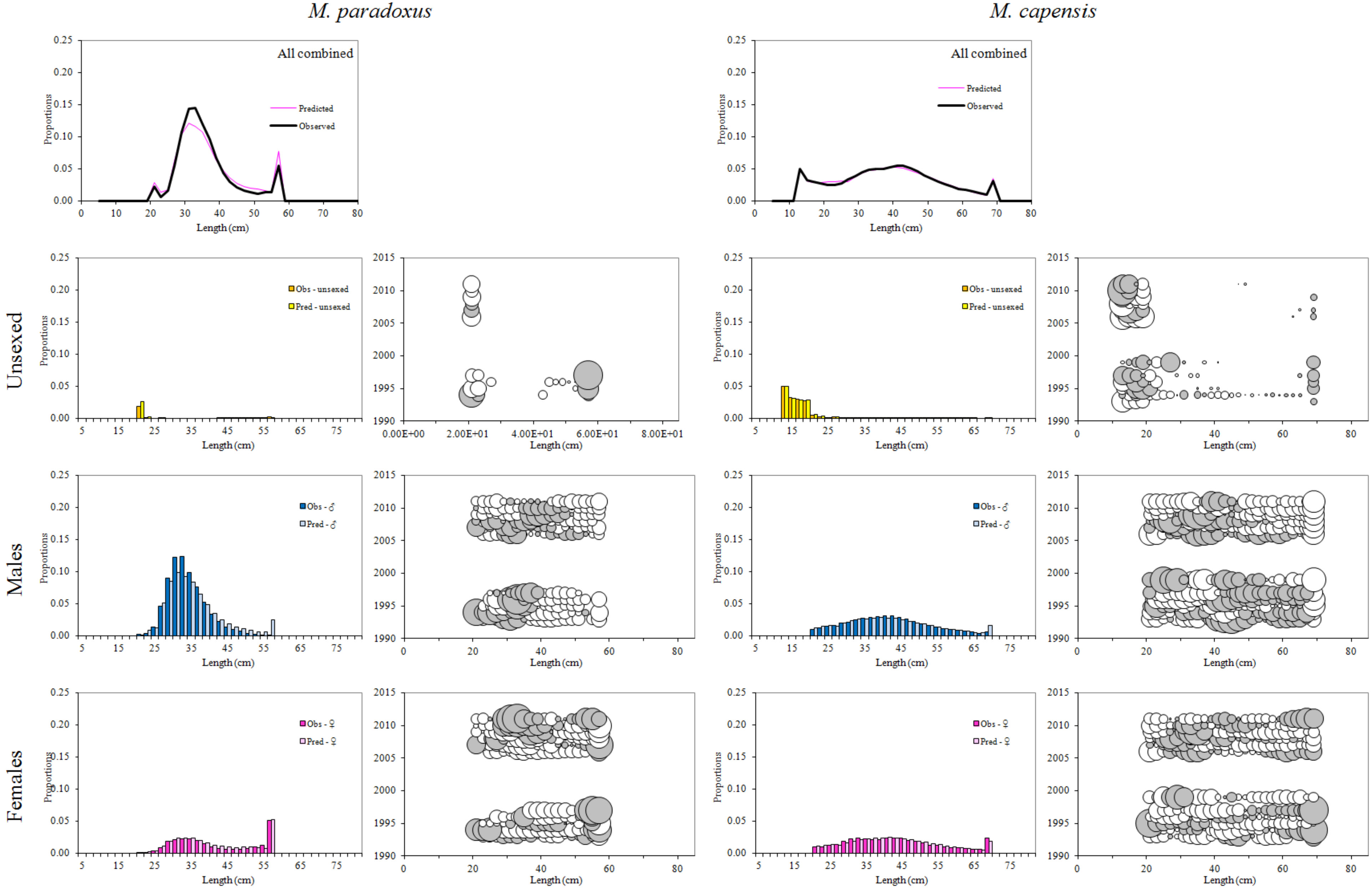


Fig. 8c: Fit of RS1-2013e to the south coast autumn **survey** gender-disaggregated proportion-at-length data (in some plots, aggregated over years for which data are available).

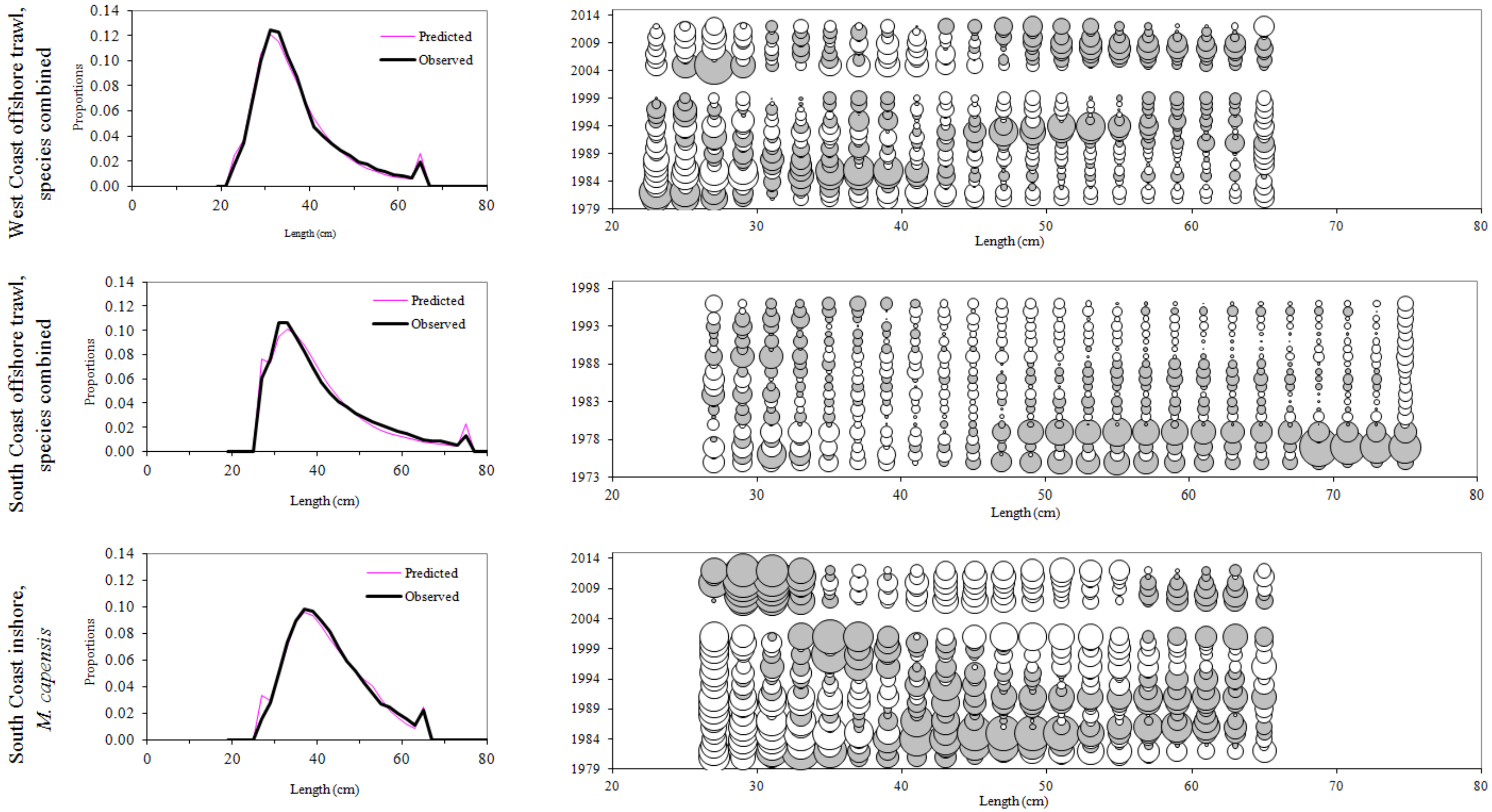


Fig. 9a: Fit of RS1-2013e to the **commercial** offshore and inshore trawl proportion-at-length data, aggregated over years for which data are available. Bubble plots of the corresponding residuals are shown.

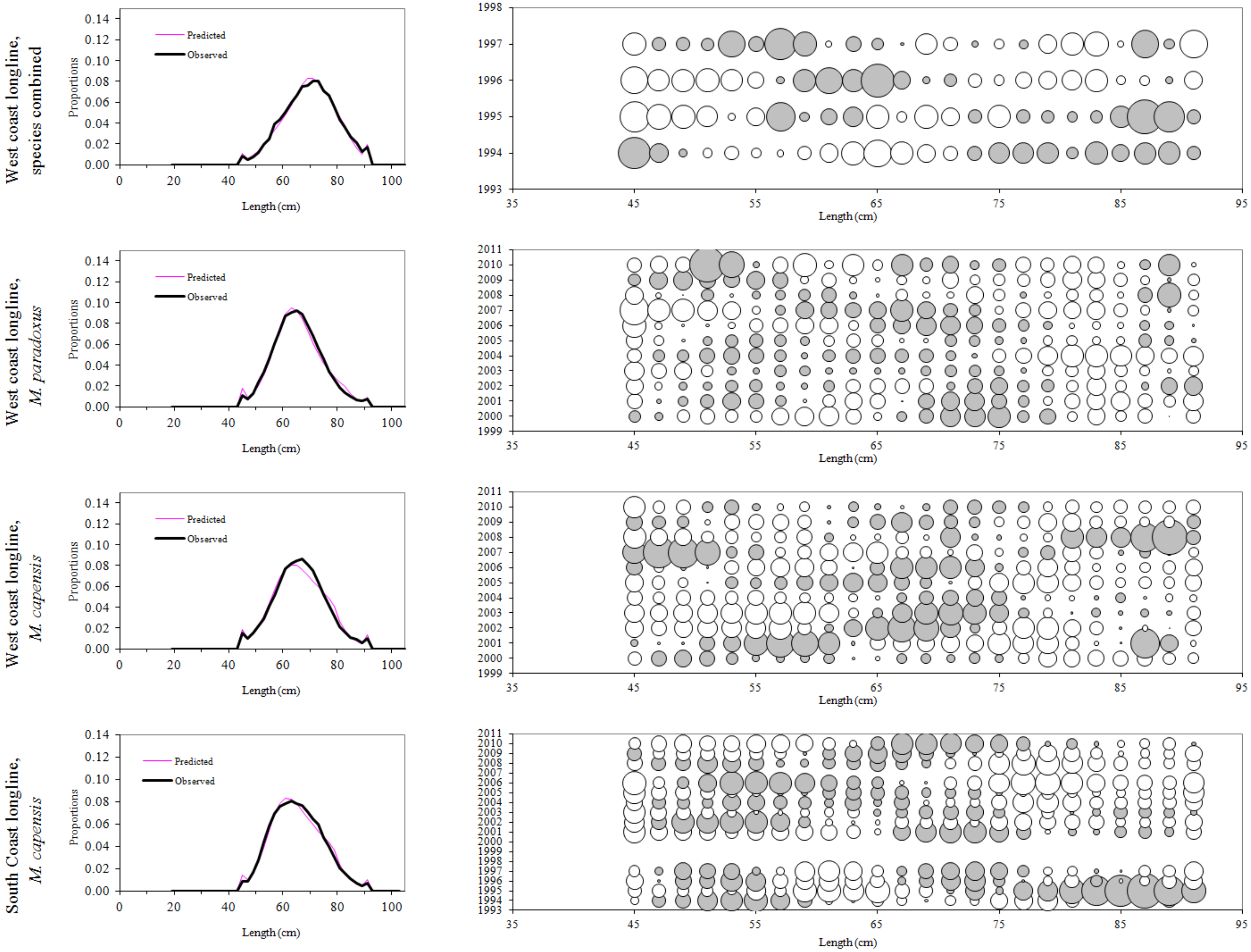


Fig. 9b: Fit of RS1-2013e to the **commercial longline** proportion-at-length data, aggregated over years for which data are available. Bubble plots of the corresponding residuals are shown.

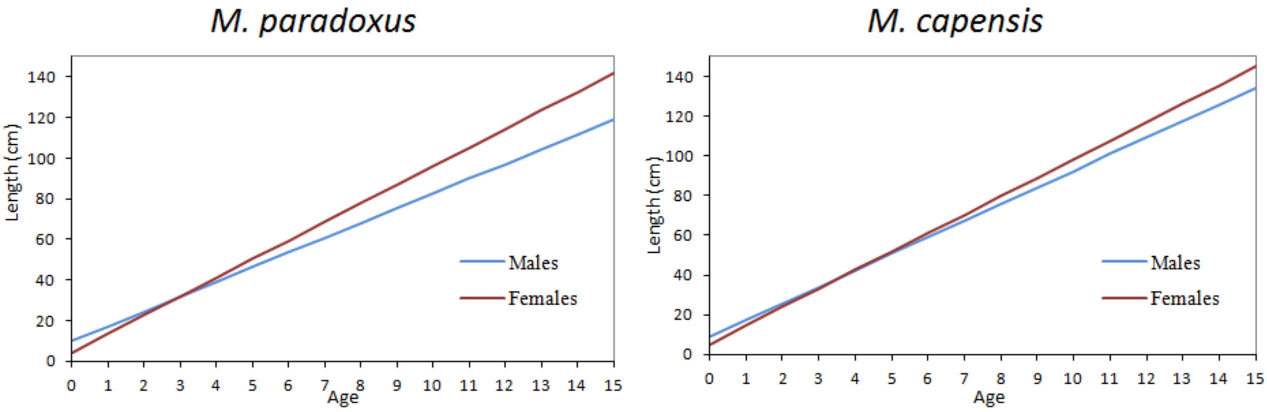


Fig. 10: Estimated growth curves for the new RC (RS1-2013e).

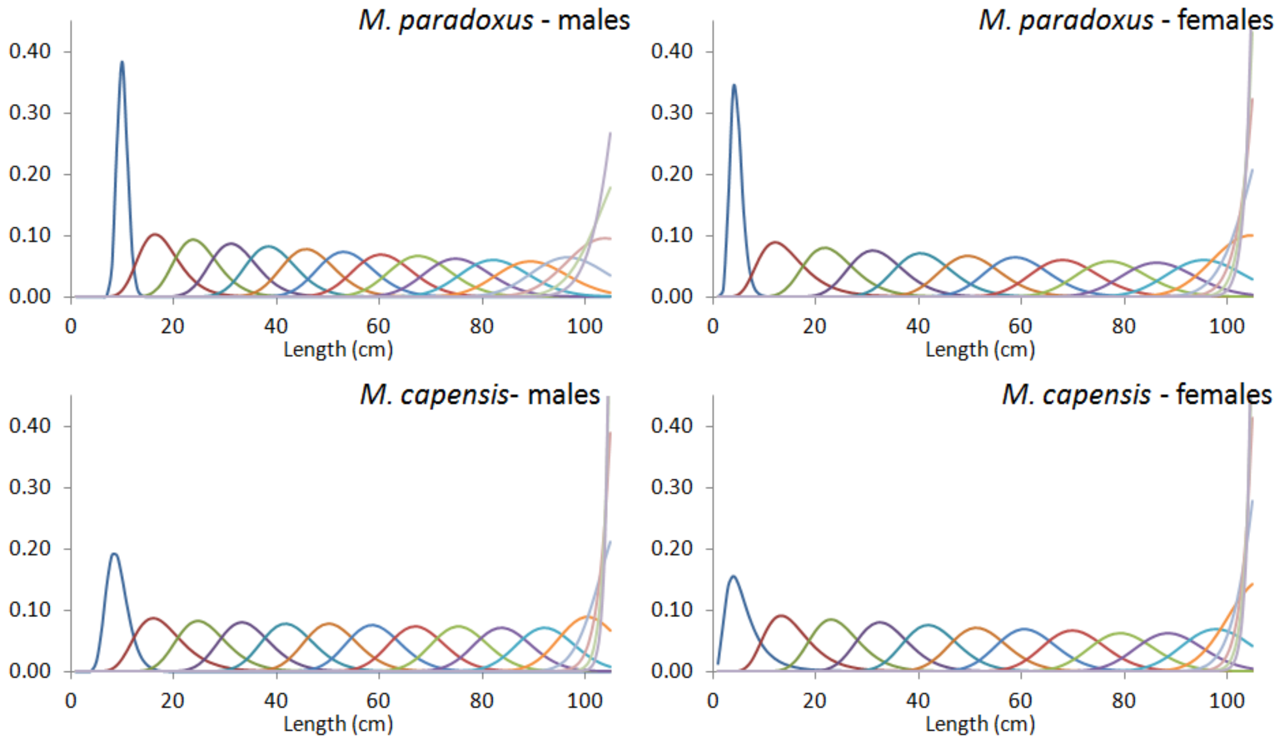
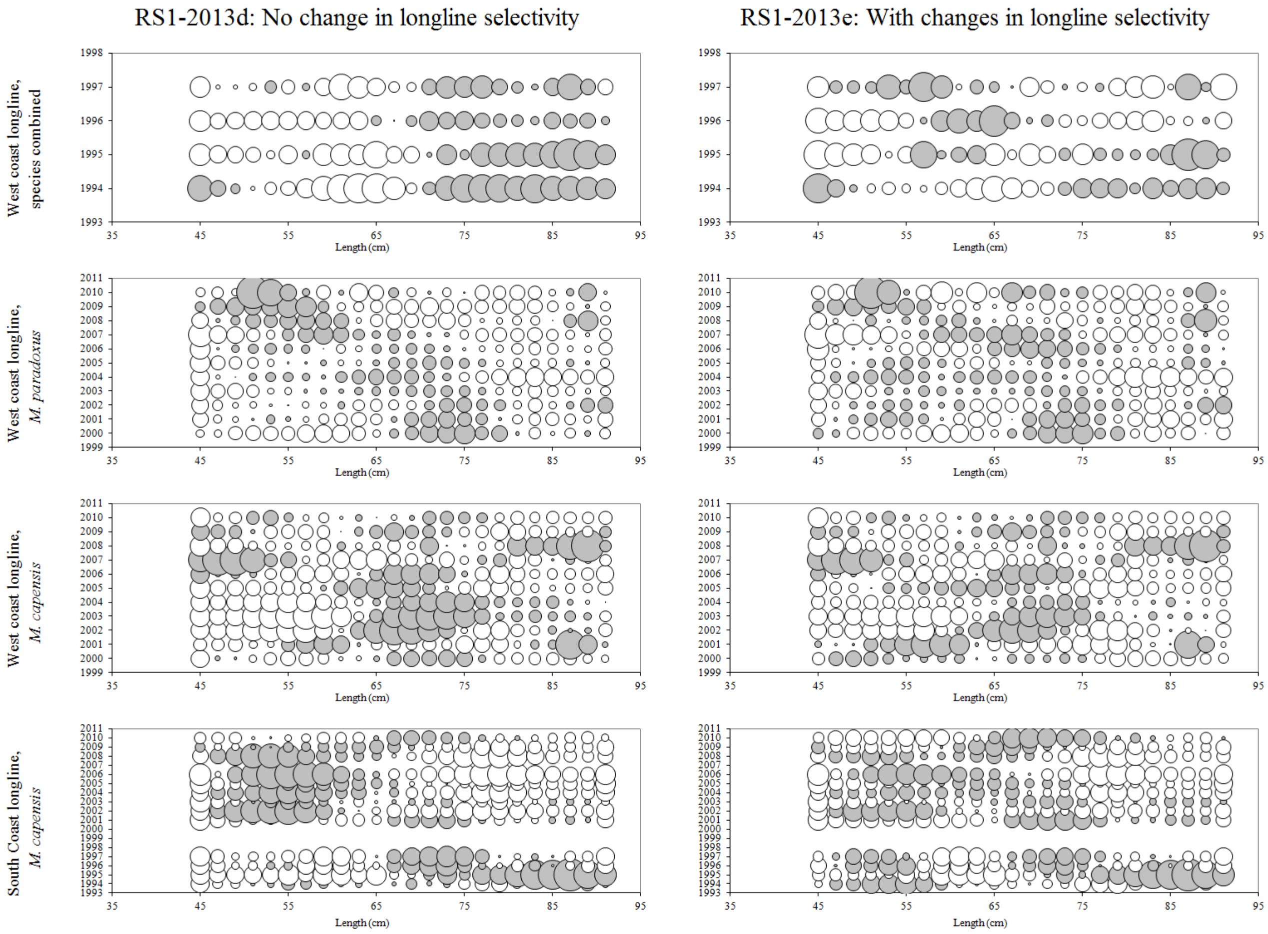


Fig. 11: Estimated distribution of length-at-age for the new RC (RS1-2013e).


RS1-2013d: No change in longline selectivity

RS1-2013e: With changes in longline selectivity

Fig. 12: Comparison of bubble plots of residuals for the fit to the **longline** proportion-at-length data with constant selectivity RS1-2013d, left-hand plots) and with a changes in selectivity in 1999/2000 and 2005/2006 (RS1-2013e, right-hand plots).

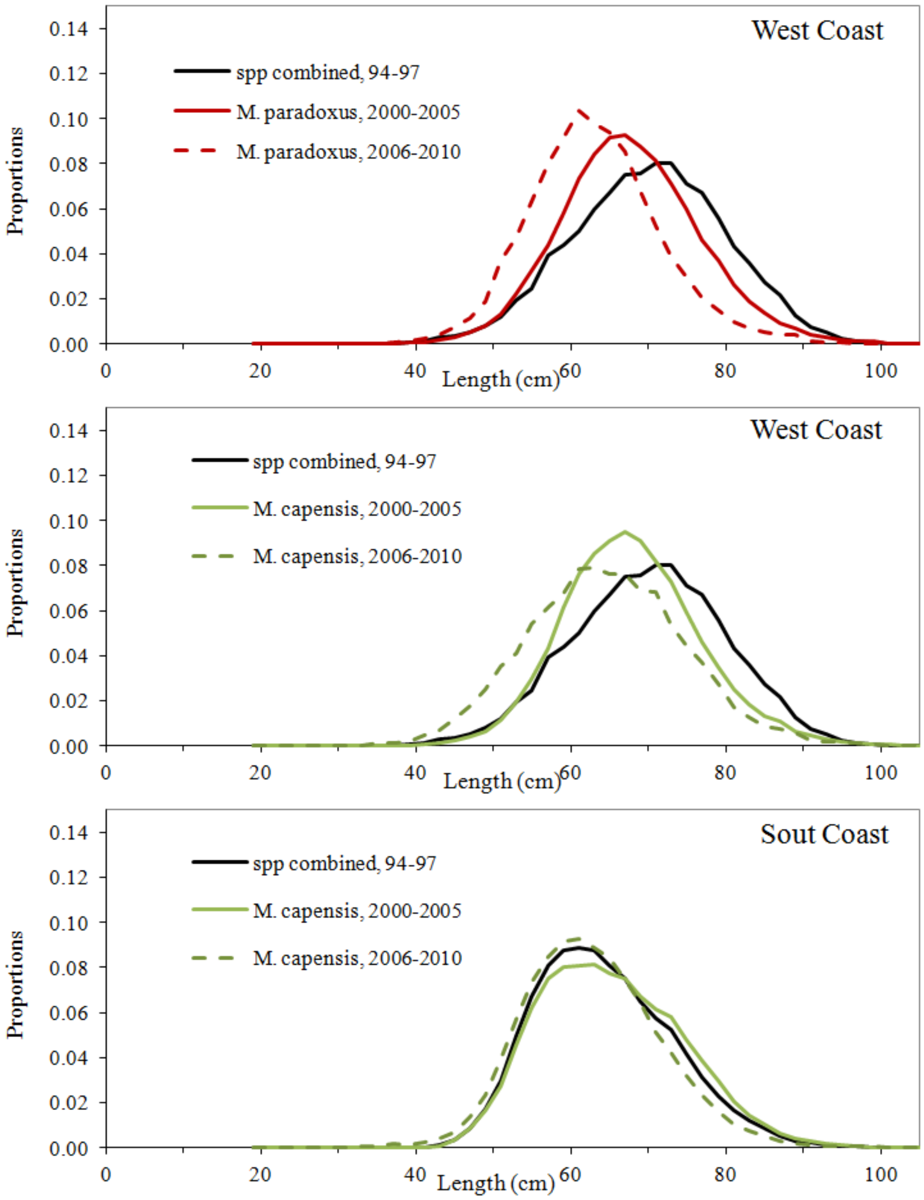


Fig. 13: **Longline** CAL data input to the assessment, averaged over the years indicated.

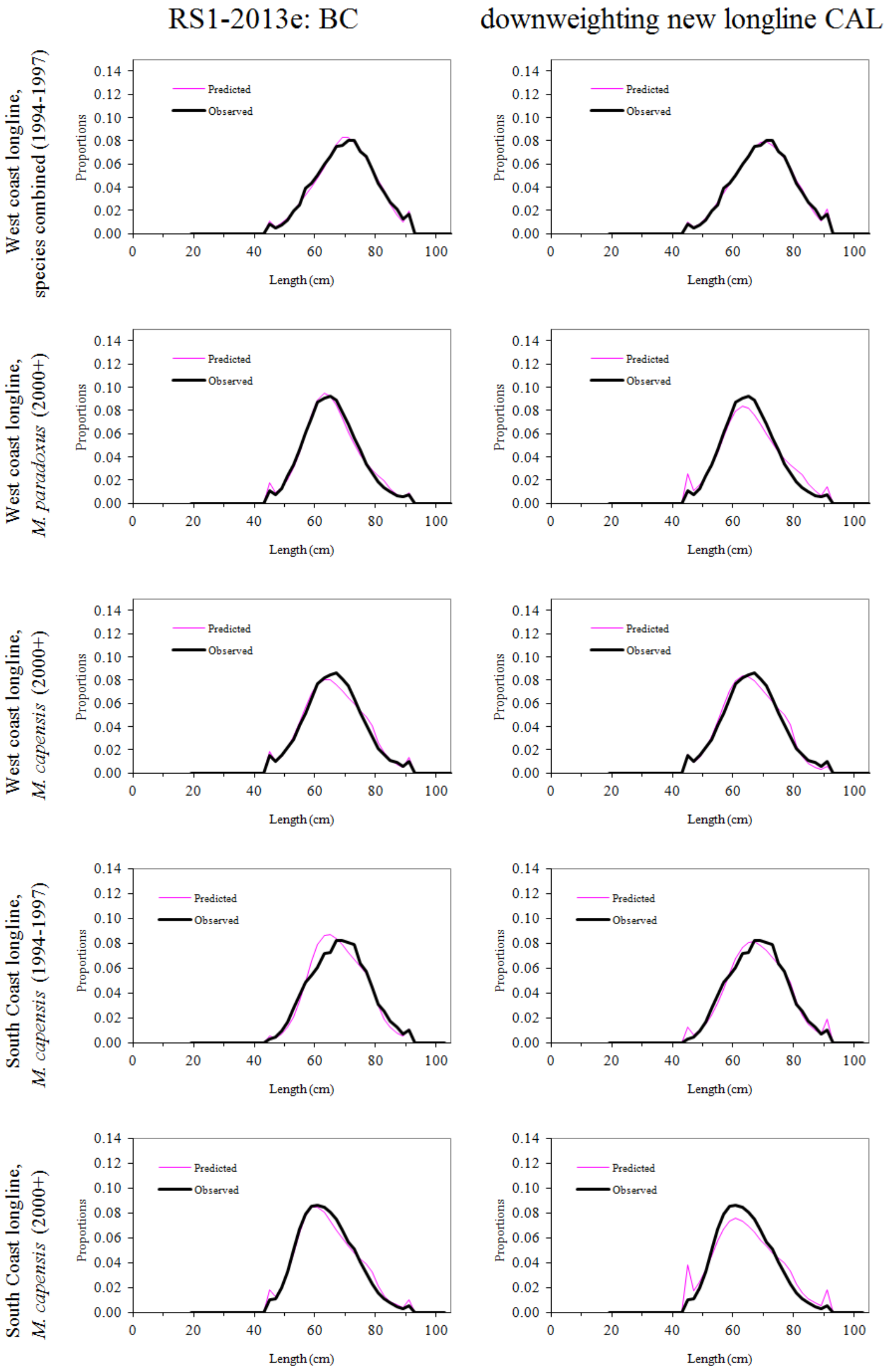


Fig. 14: Comparison of fit to the **longline** proportion-at-length data, aggregated over years for which data are available, for the new RC (RS1-2013e) and the assessment downweighting the new (2000+) CAL longline data.

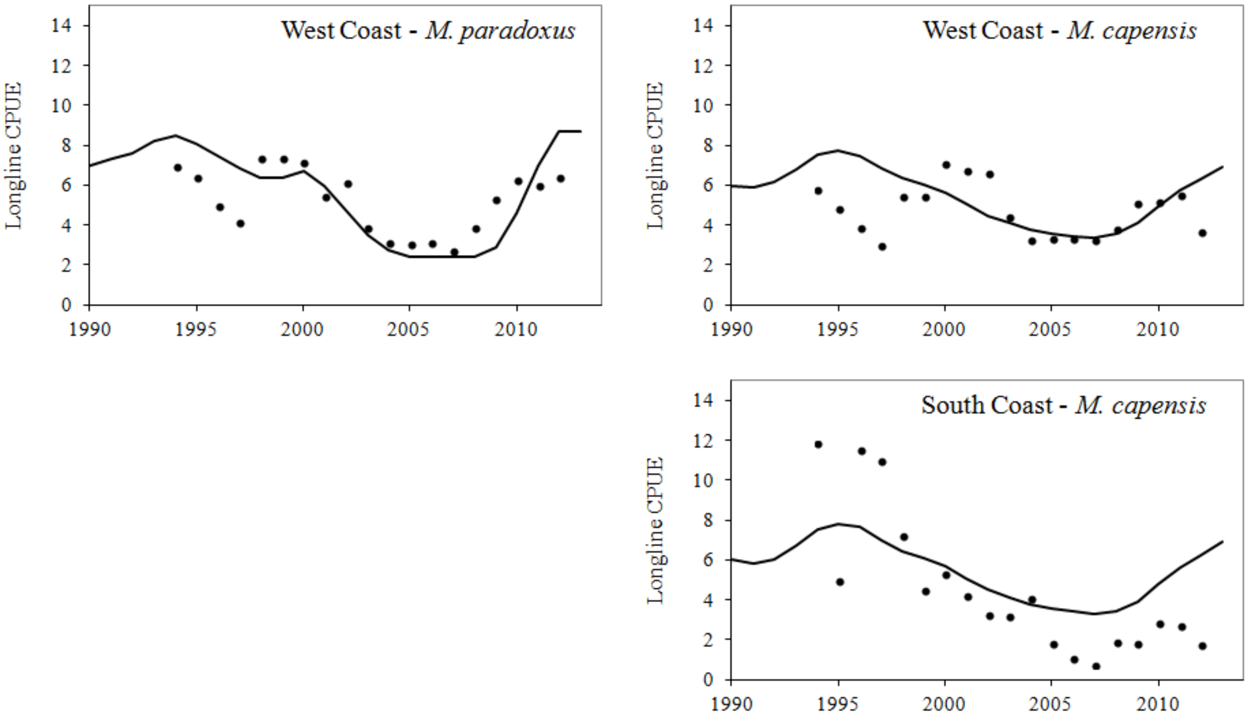


Fig. 15: Comparison of model predicted (new RC) and observed longline CPUE (Somhlaba, pers. commn). These data are not fitted in the new RC as they are from a dated analysis (the GLM-standardisation of more recent data is under finalisation).

Appendix A - Data Tables

Data that are shaded represent new or revised information since the 2012 assessment (Rademeyer, 2012).

Table App.A.1a: Species-disaggregated catches (in thousand tons) by fleet of South African hake from the south and west coasts for the period 1917-1977. The baseline assessment assumes 1958 as the centre year of the shift from a primarily *M. capensis* to a primarily *M. paradoxus* in the offshore trawl catches.

	M. paradoxus	*M. capensis*
	Offshore	Offshore
	WC	WC
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	0.011	40.389
1947	0.021	41.379

	M. paradoxus		*M. capensis*		
	Offshore		Offshore		Inshore
	WC	SC	WC	SC	SC
1948	0.059	-	58.741	-	-
1949	0.113	-	57.287	-	-
1950	0.275	-	71.725	-	-
1951	0.662	-	88.838	-	-
1952	1.268	-	87.532	-	-
1953	2.558	-	90.942	-	-
1954	5.438	-	99.962	-	-
1955	10.924	-	104.476	-	-
1956	19.581	-	98.619	-	-
1957	34.052	-	92.348	-	-
1958	51.895	-	78.805	-	-
1959	76.609	-	69.391	-	-
1960	100.490	-	59.410	-	1.000
1961	104.009	-	44.691	-	1.308
1962	109.596	-	38.004	-	1.615
1963	129.966	-	39.534	-	1.923
1964	126.567	-	35.733	-	2.231
1965	159.704	-	43.296	-	2.538
1966	154.109	-	40.891	-	2.846
1967	139.973	7.086	36.727	7.100	3.154
1968	113.890	13.958	29.710	13.950	3.462
1969	131.023	18.982	34.077	18.948	3.769
1970	113.124	11.876	29.376	11.847	4.077
1971	160.384	15.078	41.616	15.037	4.385
1972	193.694	23.382	50.239	23.314	4.692
1973	125.292	36.232	32.490	36.124	5.000
1974	97.674	45.496	25.326	45.357	10.056
1975	71.165	33.783	18.452	33.680	6.372
1976	114.268	26.005	29.626	25.925	5.740
1977	81.260	18.515	21.068	18.457	3.500

Table App.A.1b: Species-disaggregated catches (in thousand tons) by fleet of South African hake from the south and west coasts for the period 1978-present. The new/revised offshore trawl catches are from Glazer (2013) (the catches in Glazer, 2013, were subsequently updated to include 2012, Glazer, pers. commn), the new inshore and handline catches are from Rob Cooper (pers. comm.) and the new longline catches from Sobahle Somhlaba (pers. comm.). For 2013, the catches are taken as the 2013 TAC with the same proportion by species and fleet as in 2012.

	M. paradoxus			*M. capensis*					
	Offshore		Longline	Offshore		Inshore	Longline		Handline
	WC	SC	WC	WC	SC	SC	WC	SC	SC
1978	107.701	4.937	-	19.812	2.648	4.931	-	-	-
1979	101.890	3.575	-	31.633	3.345	6.093	-	-	-
1980	105.483	3.676	-	28.045	2.784	9.121	-	-	-
1981	95.330	1.767	-	25.601	3.719	9.400	-	-	-
1982	88.933	5.057	-	24.417	6.300	8.089	-	-	-
1983	74.173	7.034	0.161	20.260	5.482	7.672	0.069	-	-
1984	86.045	5.718	0.256	25.210	5.217	9.035	0.110	0.016	-
1985	98.283	12.694	0.817	26.788	7.322	9.203	0.350	0.292	0.065
1986	107.907	11.539	0.965	25.898	4.427	8.724	0.413	0.302	0.084
1987	96.162	10.536	2.500	21.363	5.148	8.607	1.071	0.353	0.096
1988	83.606	8.664	3.628	22.976	5.852	8.417	1.555	0.331	0.071
1989	85.298	9.039	0.203	21.961	9.873	10.038	0.087	0.032	0.137
1990	84.969	13.622	0.270	18.668	9.169	10.012	0.116	-	0.348
1991	89.371	15.955	-	17.079	6.119	8.206	-	3.000	1.270
1992	86.777	22.368	-	16.510	4.094	9.252	-	1.500	1.099
1993	105.114	12.472	-	12.951	1.789	8.870	-	0.000	0.278
1994	106.287	8.588	1.130	17.580	2.464	9.569	0.484	0.626	0.449
1995	102.877	5.395	0.670	18.020	1.755	10.630	0.287	0.650	0.756
1996	110.460	11.080	1.676	18.715	2.209	11.062	0.718	1.828	1.515
1997	103.035	13.651	1.806	14.119	2.185	8.834	0.774	1.872	1.404
1998	113.083	11.703	0.647	14.570	2.450	8.283	0.277	1.471	1.738
1999	89.147	13.435	1.963	14.614	1.912	8.595	0.841	4.144	2.749
2000	97.417	9.920	3.294	20.285	3.610	10.906	1.412	2.077	5.500
2001	101.990	11.016	2.656	15.606	5.141	11.836	1.138	1.688	7.300
2002	91.720	15.445	4.802	13.211	3.140	9.581	2.058	3.945	3.500
2003	95.143	21.107	4.081	10.233	3.926	9.883	1.749	4.878	3.000
2004	86.916	30.746	3.606	11.315	4.024	10.004	1.546	4.429	1.600
2005	87.540	25.051	4.105	7.727	4.195	7.881	1.759	4.559	0.700
2006	83.840	22.133	4.033	9.657	2.494	5.524	1.729	4.032	0.400
2007	96.332	15.825	3.525	12.537	1.420	6.350	1.511	3.834	0.400
2008	88.290	14.940	2.934	11.085	2.567	5.496	1.258	2.740	0.231
2009	69.716	13.269	3.667	10.783	2.431	5.639	1.571	3.841	0.265
2010	70.156	17.863	3.305	9.738	1.649	5.472	1.417	3.829	0.275
2011	76.744	20.447	4.176	15.505	1.543	6.013	1.790	2.914	0.185
2012	82.531	19.204	4.588	11.978	1.751	3.223	1.966	1.845	0.008
2013	101.350	23.583	5.634	14.709	2.151	3.958	2.415	2.266	0.010

Table App.A.2: South and west coast historic (ICSEAF 1989) GLM standardized CPUE data (Glazer, 2013) (the indices in Glazer, 2013, were subsequently updated to include 2012, Glazer, pers. commn) for *M. paradoxus* and *M. capensis*.

	GLM CPUE (kg min^{-1})			GLM CPUE (kg min^{-1})			
	Species combined			*M. paradoxus*		*M. capensis*	
Year	West Coast	South Coast	Year	West Coast	South Coast	West Coast	South Coast
1955	17.31	-	1978	4.20	1.09	0.74	1.68
1956	15.64	-	1979	4.16	1.08	1.21	1.84
1957	16.47	-	1980	3.86	1.59	1.08	2.07
1958	16.26	-	1981	3.85	1.03	1.11	2.01
1959	16.26	-	1982	3.79	1.31	0.95	1.99
1960	17.31	-	1983	4.08	1.43	1.28	2.46
1961	12.09	-	1984	4.17	1.55	1.35	2.84
1962	14.18	-	1985	4.88	2.24	1.49	3.45
1963	13.97	-	1986	4.25	2.18	1.22	2.87
1964	14.60	-	1987	3.50	1.94	1.07	2.63
1965	10.84	-	1988	3.46	1.60	0.96	2.79
1966	10.63	-	1989	3.74	1.57	1.03	3.00
1967	10.01	-	1990	4.02	2.34	0.87	3.59
1968	10.01	-	1991	4.37	2.32	1.08	3.24
1969	8.62	1.28	1992	3.81	2.72	1.32	2.96
1970	7.23	1.22	1993	3.89	2.25	1.24	2.13
1971	7.09	1.14	1994	4.16	1.81	1.58	2.88
1972	4.90	0.64	1995	3.63	1.39	1.63	2.71
1973	4.97	0.56	1996	3.94	1.99	1.89	2.50
1974	4.65	0.54	1997	3.52	2.28	1.64	1.82
1975	4.66	0.37	1998	3.93	1.93	1.87	2.09
1976	5.35	0.40	1999	3.19	2.20	1.72	2.00
1977	4.84	0.42	2000	2.84	1.67	1.61	2.22
			2001	2.30	1.65	1.10	1.64
			2002	2.23	1.41	1.06	1.84
			2003	2.64	1.93	0.90	2.07
			2004	2.20	1.52	0.81	1.65
			2005	2.19	1.34	0.58	1.48
			2006	2.38	1.46	0.62	1.03
			2007	2.92	1.53	0.60	0.98
			2008	3.23	1.65	0.81	1.56
			2009	3.23	2.05	1.42	2.89
			2010	3.54	2.25	1.22	2.22
			2011	3.30	2.62	1.47	2.79
			2012	2.92	2.17	1.24	1.62

Table App.A.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. These have not been updated from Fairweather (2012).

	West coast				South coast			
Year	Summer		Winter		Spring (Sept)		Autumn (Apr/May)	
	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)
1985	166.294	(35.299)	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	569.364	(114.536)	-	-	-	-	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	**397.049**	(71.564)	-	-	**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)
2010	589.533	(85.686)	-	-	-	-	169.560	(67.650)
2011	**347.082**	(92.540)	-	-	-	-	**24.105**	(7.089)
2012	**377.515**	(50.690)	-	-	-	-	-	-
2013	-	-	-	-	-	-	-	-

Table App.A.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. These have not been updated from Fairweather (2012).

	West coast				South coast			
Year	Summer		Winter		Spring (Sept)		Autumn (Apr/May)	
	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)
1985	125.028	(22.719)	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	196.992	(32.059)	-	-	-	-	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	**82.040**	(11.491)	-	-	**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)
2010	163.545	(34.444)	-	-	-	-	184.960	(37.720)
2011	**89.392**	(23.218)	-	-	-	-	**117.222**	(11.857)
2012	**92.588**	(11.926)	-	-	-	-	-	-
2013	-	-	-	-	-	-	-	-

Table App.A.5: Commercial length frequencies available in November 2013.

	Offshore trawl		Inshore trawl	Longline	Longline	Longline	Longline
	Species combined		*M. capensis*	Spp combined	*M. paradoxus*	*M. capensis*	*M. capensis*
	WC	SC	SC	WC	WC	WC	SC
1975	-	✓	-	-	-	-	-
1976	-	✓	-	-	-	-	-
1977	-	✓	-	-	-	-	-
1978	-	✓	-	-	-	-	-
1979	-	✓	-	-	-	-	-
1980	-	✓	-	-	-	-	-
1981	✓	✓	✓	-	-	-	-
1982	✓	✓	✓	-	-	-	-
1983	✓	✓	✓	-	-	-	-
1984	✓	✓	✓	-	-	-	-
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	✓	-	✓	-	✓	✓	✓
2010	✓	-	✓	-	✓	✓	✓
2011	✓	-	✓	-	-	-	-
2012	✓	-	✓	-	-	-	-

Table App.A.6: Survey length frequencies available in November 2013.

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	✓	✓	-	-	-	-	✓	✓
2010	✓	✓	-	-	-	-	✓	✓
2011	✓	✓	-	-	-	-	✓	✓
2012	✓	✓	-	-	-	-	✓	✓
2013	-	-	-	-	-	-	-	-

Table App.A.7: Species- and sex-disaggregated age and length data available in November 2013 by reader.

		M. paradoxus										*M. capensis*									
	Year	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.A.8: Female maturity-at-length ogive parameter estimates (from Singh *et al*. 2011).

	l_{50} (cm)	Δ
M. paradoxus	41.53	2.98
M. capensis	53.83	10.14

Table App.A.9: Length-weight relationship estimates (from Singh 2013).

	α (gm/cm$^{\beta}$)	β
M. paradoxus:		
Males	0.007750	2.977
Females	0.005700	3.071
M. capensis:		
Males	0.006750	3.044
Females	0.005950	3.075

APPENDIX B: 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 assesses 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^{TM}, Otter Research, Ltd. (Fournier *et al.* 2011)).

App.B.1 Population Dynamics

App.B1..1 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 equations are identical for the two species.

$$N^g_{y+1,0} = R^g_{y+1} \tag{B.1}$$

$$N^g_{y+1,a+1} = \left(N^g_{ya} e^{-M^g_a/2} - \sum_f C^g_{fya} \right) e^{-M^g_a/2} \qquad \text{for } 0 \le a \le m-2 \tag{B.2}$$

$$\begin{aligned} N^g_{y+1,m} = & \left(N^g_{y,m-1} e^{-M^g_{m-1}/2} - \sum_f C^g_{f,y,m-1} \right) e^{-M^g_{m-1}/2} \\ & + \left(N^g_{ym} e^{-M^g_m/2} - \sum_f C^g_{fym} \right) e^{-M^g_m/2} \end{aligned} \tag{B.3}$$

where

N^g_{ya} is the number of fish of gender *g* and age *a* at the start of year *y*[1];

R^g_y 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^g_a denotes the natural mortality rate on fish of gender *g* and age *a*; and

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

App.B.1.2 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). The underlying assumptions are that female spawning output can limit subsequent recruitment, but that there are always sufficient males to provide adequate fertilisation. The recruitment and corresponding female spawning stock size are related by means of the Beverton-Holt (Beverton and Holt 1957) or a modified (generalised) form of the Ricker stock-recruitment relationship. These

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

forms are parameterized in terms of the "steepness" of the stock-recruitment relationship, h, the pre-exploitation equilibrium female spawning biomass, $K^{\text{♀}sp}$, and the pre-exploitation recruitment, R_0 and assuming a 50:50 sex-split at recruitment.

$$R_y^g = \frac{4hR_0 B_y^{\text{♀},sp}}{K^{\text{♀},sp}(1-h)+(5h-1)B_y^{\text{♀},sp}} e^{(\varsigma_y - \sigma_R^2/2)} \qquad \text{(B.4a)}$$

for the Beverton-Holt stock-recruitment relationship and

$$R_y^g = \alpha B_y^{\text{♀},sp} \exp\left(-\beta \left(B_y^{\text{♀},sp}\right)^\gamma\right) e^{(\varsigma_y - \sigma_R^2/2)} \qquad \text{(B.4b)}$$

with

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

for the modified Ricker relationship (for the true Ricker, γ=1) where

ς_y reflects fluctuation about the expected recruitment in year *y*;

σ_R is the standard deviation of the log-residuals, which is input ($\sigma_R = 0.45$ and is taken to decrease from this value to 0.1 over the last five years to statistically stabilise estimates of recent recruitment) .

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

$$B_y^{\text{♀},sp} = \sum_{a=1}^{m} f_a^{\text{♀}} w_a^{\text{♀}} N_{ya}^{\text{♀}} \qquad \text{(B.5)}$$

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 (converted from maturity-at-length, see equation App.B.47); and

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

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.

App.B.1.3 Total catch and catches-at-age

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

$$C_{fy} = \sum_g \sum_{a=0}^{m} \tilde{w}_{fy,a+1/2}^g \, C_{fya}^g = \sum_g \sum_{a=0}^{m} \tilde{w}_{fy,a+1/2}^g \, N_{ya}^g e^{-M_a^g/2} F_{fy} S_{fya}^g \qquad \text{(B.7)}$$

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*) ;

$$S^g_{fya} = \sum_l S^g_{fyl} P^g_{a+1/2,l} \tag{B.8}$$

S^g_{fya} is the commercial selectivity of gender *g* at age *a* for fleet *f* and year *y*;

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

$$\tilde{w}^g_{fy,a+1/2} = \sum_l S^g_{fyl} w^g_l P^g_{a+1/2,l} \Big/ \sum_l S^g_{fyl} P^g_{a+1/2,l} \tag{B.9}$$

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

w^g_l is the weight of fish of gender *g* and length *l*;

$P^g_{a+1/2,l}$ is the mid-year proportion of fish of age *a* and gender *g* that fall in the length group *l* (i.e., $\sum_l P^g_{a+1/2,l} = 1$ 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.:

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

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:

$$\theta_a = \begin{cases} B_0 & \text{for } a = 0 \\ (\beta a + \alpha) & \text{for } 1 \le a \le m \end{cases}$$

with species and gender-specific B_0, β and α estimated in the model fitting procedure. A penalty is added so that θ_a is increasing with age, i.e. β>0.

App.B.1.4 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:

$$B^{ex}_{fy} = \sum_g \sum_{a=0}^{m} \tilde{w}^g_{fy,a+1/2} S^g_{fya} N^g_{ya} e^{-M^g_a/2}\left(1-\sum_f S^g_{fya} F_{fy} \Big/ 2\right) \tag{B.11}$$

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

$$B^{surv}_y = \sum_g \sum_{a=0}^{m_s} \tilde{w}^{g,sum}_a S^{g,sum}_a N^g_{ya} \tag{B.12}$$

and in mid-year (winter):

$$B^{surv}_y = \sum_g \sum_{a=0}^{m} \tilde{w}^{g,win}_{a+1/2} S^{g,win}_a N^g_{ya} e^{-M^g_a/2}\left(1-\sum_f S^g_{fya} F_{fy} \Big/ 2\right) \tag{B.13}$$

where

$S^{g,sum/win}_a$ is the survey selectivity of gender *g* for age *a,* converted from survey selectivity-at-length in the same manner as for the commercial selectivity (eqn B.8);

$\tilde{w}^{g,i}_a$ is the survey selectivity-weighted weight-at-age a of gender g for survey i, computed in the same manner as for the commercial selectivity-weight-at-age (equation App.II.9) and taking account of the begin-year ($\tilde{w}^{g,sum}_{y,a}$ from $P^g_{a,l}$) or mid-year ($\tilde{w}^{g,win}_{y,a+1/2}$ from $P^g_{a+1/2,l}$) 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., $B^{g,sp}_1 = K^{g,sp}$, and the year y=1 corresponds to 1917 when catches commence.

App.B.2 MSY and related quantities

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

$$C(F^*) = \sum_g \sum_a \tilde{w}^g_{a+1/2} S^g_a F^* N^g_a (F^*) e^{-\left(\left(M^g_a + S^g_a F^*\right)/2\right)} \qquad \text{(B.14)}$$

where

S^g_a is the average selectivity across all fleets, for the most recent five years;

$$S^g_a = \frac{\sum_{y=2005}^{2009} \sum_f S^g_{fya} F_{fy}}{\max\left(\sum_{y=2005}^{2009} \sum_f S^g_{fya} F_{fy} \right)} \qquad \text{(B.15)}$$

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

$$N^g_a(F^*) = \begin{cases} R_1(F^*) & \text{for } a = 1 \\ N^g_{a-1}(F^*) e^{-M^g_{a-1}} \left(1 - S^g_{a-1} F^*\right) & \text{for } 1 < a < m \\ \dfrac{N^g_{m-1}(F^*) e^{-M^g_{m-1}} \left(1 - S^g_{m-1} F^*\right)}{\left(1 - e^{-M^g_m} \left(1 - S^g_m F^*\right)\right)} & \text{for } a = m \end{cases} \qquad \text{(B.16)}$$

where

$$R_1(F^*) = \frac{\alpha B^{\female,sp}(F^*)}{\beta + B^{\female,sp}(F^*)} \qquad \text{(B.17)}$$

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:

$$B^{\female,sp}_{MSY} = \sum_a f^{\female}_a w^{\female}_a N^{\female}_a \left(F^*_{\text{MSY}}\right)$$

App.B.3 The likelihood function

The model is fit to CPUE and survey biomass 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 (- $\ell n L$) are as follows[2].

App.B.3.1 CPUE relative biomass data

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

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \quad \text{or} \quad \varepsilon_y^i = \ell n\left(I_y^i\right) - \ell n\left(\hat{I}_y^i\right) \tag{B.18}$$

where

I_y^i is the biomass 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 $\widehat{B}_{fy}^{ex}$ is the model estimate of exploitable resource biomass, given by equation B.11;

$\hat{q}^i$ is the constant of proportionality for biomass series *I*; and

ε_y^i from $N\left(0, \left(\sigma_y^i\right)^2\right)$.

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” (Figure B.1).

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

$$C_{BS,fy} = C_{C,fy}^{z1} + C_{C,fy}^{z2} + C_{P,fy} \tag{B.19}$$

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 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:

$$C_{C,fy}^{z1} = q_C^{i,z1} B_{Cfy}^{ex,z1} E_{fy}^{z1} = q_C^{i,z1} (1-\gamma) B_{C,fy}^{ex} (1-\psi_{fy}) E_{fy} \tag{B.20}$$

$$C_{C,fy}^{z2} = q_C^{i,z2} B_{C,fy}^{ex,z2} E_{fy}^{z2} = q_C^{i,z2} \gamma B_{C,fy}^{ex} \psi_{fy} E_{fy} \quad \text{and} \tag{B.21}$$

$$C_{P,fy} = q_P^i B_{P,fy}^{ex} E_{fy}^{z2} = q_P^i B_{P,fy}^{ex} \psi_{fy} E_{fy} \tag{B.22}$$

where

$E_{fy} = E_{fy}^{z1} + E_{fy}^{z2}$ 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});

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

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[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.

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

It follows that:

$$C_{C,fy} = B_{C,fy}^{ex} E_{fy} \left[q_C^{i,z1} (1-\gamma)(1-\psi_{fy}) + q_C^{i,z2} \gamma \psi_{fy} \right] \quad \text{(B.23)}$$

$$C_{P,fy} = B_{P,fy}^{ex} E_{fy} q_P^i \psi_{fy} \quad \text{(B.24)}$$

From solving equations B.23 and B.24:

$$s_{fy} = \frac{q_C^{i,z1}(1-\gamma)}{\left\{ \dfrac{C_{C,fy} B_{P,fy}^{ex} q_P^i}{B_{C,fy}^{ex} C_{P,fy}} - q_C^{i,z2}\gamma + q_C^{i,z1}(1-\gamma) \right\}} \quad \text{(B.25)}$$

and:

$$\hat{I}_y^i = \frac{C_{fy}}{E_{fy}} = \frac{C_{fy} B_{P,fy}^{ex} q_P^i \psi_{fy}}{C_{P,fy}} \quad \text{(B.26)}$$

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

Figure B.1: Diagrammatic representation of the two conceptual 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:

$$q_s^{SC} = r q_s^{WC} \quad \text{(B.27)}$$

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:

$$-\ell\text{n}\, L^{CPUE} = \sum_i \sum_y \left[\ell\text{n}(\sigma_y^i) + (\varepsilon_y^i)^2 / 2(\sigma_y^i)^2 \right] \quad \text{(B.28)}$$

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 assumed[3], so that $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell n(I_y^i) - \ell n(\hat{I}_y^i)\right)^2} \tag{B.29}$$

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

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

$$\ln \hat{q}^i = \frac{\sum_y \left(\ln I_y^i - \ln \hat{B}_{fy}^{ex}\right)/\left(\sigma_y^i\right)^2}{\sum_y 1/\left(\sigma_y^i\right)^2} \tag{B.30}$$

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

App.B.3.2 Survey biomass data

Data from the research surveys are treated as relative biomass 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 B.12 and B.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 biomass data (see equation B.28). The procedure adopted takes into account an additional variance $\left(\sigma_A\right)^2$ which is treated as another estimable parameter in the minimisation process. This procedure is carried out enforcing the constraint that $\left(\sigma_A\right)^2$ >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:

$\Delta \ell n q^{capensis} = -0.494$ with $\sigma_{\Delta \ell n q^{capensis}} = 0.141$ i.e. $\left(q^{new}/q^{old}\right)^{capensis} = 0.610$ and

$\Delta \ell n q^{paradoxus} = -0.053$ with $\sigma_{\Delta \ell n q^{paradoxus}} = 0.117$ i.e. $\left(q^{new}/q^{old}\right)^{paradoxus} = 0.948$

where

$$\ell n q_{new}^s = \ell n q_{old}^s + \Delta \ell n q^s \quad \text{with } s = \textit{capensis} \text{ or } \textit{paradoxus} \tag{B.31}$$

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)

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

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. $\Delta\ell nq^{capensis}$ is therefore taken as -0.223, i.e. $\left(q^{new}/q^{old}\right)^{capensis} = 0.8$.

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

$$-\ell nL^{q-ch} = \left(\ell nq_{new} - \ell nq_{old} - \Delta\ell nq\right)^2 / 2\sigma^2_{\Delta\ell nq} \qquad \text{(B.32)}$$

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 to values below 1 (i.e. it is assumed that the nets do not herd the hake):

$$pen^q = \sum_i \left(q^i_{old} - 1\right)^2 / 0.02^2 \quad \text{if} \quad q^i_{old} > 1 \qquad \text{(B.33)}$$

App.B.3.3 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:

$$C_{fyl} = \sum_s \sum_g \sum_{a=0}^{m} N^g_{sya} F_{sfy} S^g_{sfyl} P^g_{s,a+1/2,l} e^{-M^g_{sa}/2} \left(1 - \sum_f S^g_{sfya} F_{fy} \Big/ 2\right) \qquad \text{(B.34)}$$

with the predicted proportions at length:

$$\widehat{p}^i_{yl} = C_{fyl} \Big/ \sum_{l'} C_{fyl'} \qquad \text{(B.35)}$$

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:

$$-\ell\text{n}\, L^{\text{length}} = 0.1 \sum_y \sum_l \left[\ell n\left(\sigma^i_{len} / \sqrt{p^i_{yl}}\right) + p^i_{yl}\left(\ell np^i_{yl} - \ell n\, \hat{p}^i_{yl}\right)^2 / 2\left(\sigma^i_{len}\right)^2\right] \qquad \text{(B.36)}$$

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

$$\hat{\sigma}^i_{len} = \sqrt{\sum_y \sum_l p^i_{yl}\left(\ln p^i_{yl} - \ln \hat{p}^i_{yl}\right)^2 / \sum_y \sum_l 1} \qquad \text{(B.37)}$$

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 B.36, 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.

App.B.3.4 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 B.36). In this case however, data are disaggregated by species, and for some surveys further disaggregated by gender:

$p^{g,surv}_{syl} = \frac{C^{g,surv}_{syl}}{\sum_g \sum_{l'} C^{g,surv}_{syl'}}$ is the observed proportion of fish of species *s*, gender *g* and length *l* from survey *surv* in year *y*; and

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

$$\hat{p}^{g,surv}_{syl} = \frac{\sum_a S^{g,sum}_{sl} P^g_{sal} N^g_{sya}}{\sum_g \sum_{l'} \sum_a S^{g,sum}_{sl'} P^g_{sal'} N^g_{sya}} \qquad \text{(B.38)}$$

for begin-year (summer) surveys, or

$$\hat{p}^{g,surv}_{syl} = \frac{\sum_a S^{g,win}_{sl} P^g_{s,a+1/2,l} N^g_{sya} e^{-M^g_{sa}/2} \left(1 - \sum_f S^g_{sfya} F_{sfy} \Big/ 2\right)}{\sum_g \sum_{l'} \sum_a S^{g,win}_{sl'} P^g_{s,a+1/2,l'} N^g_{sya} e^{-M^g_{sa}/2} \left(1 - \sum_f S^g_{sfya} F_{sfy} \Big/ 2\right)} \qquad \text{(B.39)}$$

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

8.II.3.5 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:

$$-\ln L^{ALK} = -w \sum_i \sum_l \sum_a \left[A^{obs}_{i,l,a} \ln\left(\hat{A}_{i,l,a}\right) - A^{obs}_{i,l,a} \ln\left(A^{obs}_{i,l,a}\right) \right] \qquad \text{(B.40)}$$

where

w is a downweighting factor to allow for overdispersion in these data compared to the expectation for a multinomial distribution with independent data; this weight factor is somewhat arbitrarily set to 0.01 to avoid these data overriding trend information in the indices of biomass;

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

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

$$\hat{A}_{i,a,l} = W_{i,l} \frac{C_{i,a,l} \tilde{A}_{a,l}}{\sum_{a'} C_{i,a',l} \tilde{A}_{a',l}} \qquad \text{(B.41)}$$

where

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

$\tilde{A}_{a,l} = \sum_a P(a'|a) A_{a,l}$ 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 as reported in Appendix 8.III.

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

App.B.3.6 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:

$$-\ell nL^{SR}=\sum_{s}\left[\sum_{y=y1}^{y2}\varsigma_{sy}^{\ 2}\Big/2\sigma_R^2+\left(\sum_{y=y1}^{y2}\varsigma_{sy}\right)^2\Big/0.01^2\right] \qquad \text{(B.42)}$$

where

ς_{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 B.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 ▯$_R$ (which measures the extent of variability in recruitment – see equation – App.II.42) 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.

App.B.4 Model parameters

App.B.4.1 Estimable parameters

The primary parameters estimated are the species-specific female virgin spawning biomass $\left(K_s^{♀sp}\right)$ 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 $\left(\sigma_A^i\right)^2$ for each survey biomass 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 ▯ are directly estimated in the fitting procedure.

The species- and gender-specific von Bertalanffy growth curve parameters (l_∞, κ and t_0) are estimated directly in the model fitting process, as well as B_0 ,▯▯ and ▯, 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):

App.B.4.1.1 Natural mortality:

Natural mortality (M_{sa}^{g}) is assumed to be age-specific and is calculated using the following functional form (the selection of the specific form here is based on convenience and is somewhat arbitrary):

$$M_{sa}^{♀} = \begin{cases} M_{s2}^{♀} & \text{for} \quad a \le 1 \\ \alpha_s^M + \dfrac{\beta_s^M}{a+1} & \text{for} \quad 2 \le a \le 5 \\ M_{s5}^{♀} & \text{for} \quad a > 5 \end{cases} \tag{B.43}$$

and

$$M_{sa}^{males} = \upsilon^s M_{sa}^{females} \tag{B.44}$$

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 –lnL so that $M_{s2} \ge M_{s5}$:

$$pen^M = \sum_s (M_{s5} - M_{s2})^2 / 0.01^2 \qquad \text{if } M_{s2} < M_{s5} \tag{B.45}$$

App.B.4.1.2 Stock-recruitment residuals:

Stock-recruitment residuals ς_{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 B.1 summarises the estimable parameters, excluding the selectivity parameters.

App.B.4.1.3 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 (at constant intervals between the minus and plus groups) and are given in Table B.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 down to length *1*, 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 –lnL to smooth the selectivities to smooth the selectivities by penalising deviations from straight line dependence (the choice of a weighting of 3 was made empirically to balance this term having sufficient but not undue influence) :

$$pen^{survS} = \sum_i \sum_{L=L_1+1}^{L_7-1} 3\left(S_{L-1}^i - 2S_L^i + S_{L+1}^i\right)^2 \tag{B.46}$$

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

App.B.4.1.4 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:

$$S_{sfl} = \left[1 + \exp\left(-\left(l - l_{sf}^c\right) / \delta_{sf}^c\right)\right]^{-1} \tag{B.47}$$

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:

$$S_{sfl} = S_{s,f,l-1} e^{-s_{sfl}} \qquad \text{for } l > l_{slope}, \tag{B.48}$$

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"; and

l_{slope} is fixed externally from the model, values for each fleet and species are given in Table B.2.

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) that are used in the assessment are shown in Table B.4.

App.B.4.2 Input parameters and other choice for application to hake

App.B.4.2.1 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 Singh et al. 2011)):

Table B.1: Female maturity-at-length logistic curve parameter values for the new Reference Case.

	l_{50} (cm)	Δ
M. paradoxus	41.53	2.98
M. capensis	53.83	10.14

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

$$f_{sa}^{g} = \sum_{l} f_{sl}^{g} P_{a,l}^{g} \tag{B.49}$$

App.B.4.2.2 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):

Table B.2: Weight-at-length parameter values.

	α (gm/cm$^{\beta}$)	β
M. paradoxus:		
Males	0.00775	2.977
Females	0.00570	3.071
M. capensis:		
Males	0.00675	3.044
Females	0.00595	3.075

App.B.4.2.3 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 B.5. Furthermore, the proportions at length data (both commercial and survey) are summed into 2cm length classes for the model fitting.

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

	No of parameters	Parameters estimated
$K^{♀}$	2	$\ln(K^{♀}_{cap})$ and $\ln(K^{♀}_{para})$
h	2	h_{cap} and h_{para}
M_a	4 (6)*	For each species: M_2, M_5 (and υ)
Additional variance	2	$\sigma_{A,cap}$ and $\sigma_{A,para}$
Recruitment residuals	50	$\varsigma_{\mathrm{cap},1985\text{-}2009}$ and $\varsigma_{para,1985\text{-}2009}$
σ_{CPUE}	6	1 for each series (lower bounds imposed)
ICSEAF CPUE	5	$q_{\mathrm{C}}^{WC,z1}$, $q_{\mathrm{C}}^{\mathrm{WC,z2}}$, $q_{\mathrm{P}}^{\mathrm{WC}}$, 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 B.2: Lengths (in cm) at which survey selectivity is estimated directly.

M. paradoxus	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
M. capensis	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 B.3: Length (cm) at which selectivity starts to decrease (l_{slope}) for each species and fleet.

	M. paradoxus	*M. capensis*
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 B.4: Details for the commercial selectivity-at-length for each fleet and species combination for the new RC, as well as indications of what data are available.

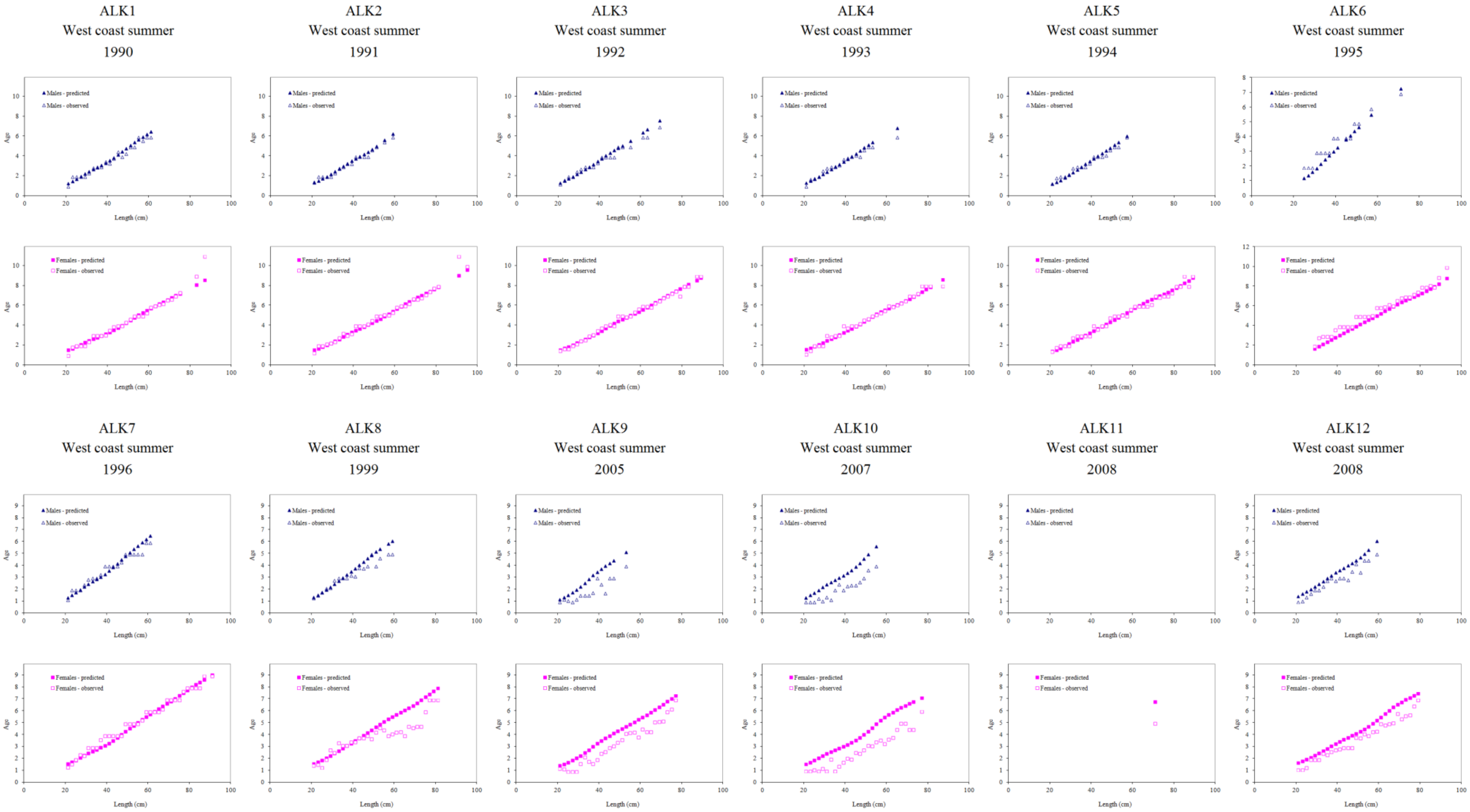
	M. paradoxus		*M. capensis*		data available
	No of est. parameters	Comments	No of est. parameters	Comments	
1. West coast offshore					
1917-1976	0	set equal to 1989	0	set equal to 1989	
1977-1984	2	two logistic parameters estimated (same slope as 1993+)	0	differential shift compared to 1993+ as for 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
1993-2013	3	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	0	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
1993-2013	3	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
	0	female downscaling factor (av. of SC spring and autumn surveys's factors)			
3. South coast inshore	-	-	3	two logistic + slope parameters estimated	*M. capensis*
4. West coast longline					
1984-1999	3	two logistic + slope parameters estimated	3	two logistic + slope parameters estimated	species combined
2000-2005	1	shift of the ascending limb	1	shift of the ascending limb	species disaggregated
2006-2013	1	shift of the ascending limb	1	shift of the ascending limb	species disaggregated
5. South coast longline					
1984-1999	-	-	3	two logistic + slope parameters estimated	species combined
2000-2005	-	-	1	shift of the ascending limb	species disaggregated
2006-2013	-	-	1	shift of the ascending limb	species disaggregated
6. South coast handline	-	-	0	parameters taken as average of SC longline and inshore parameters	
West coast summer survey					
Africana old	7	estimated for 7 specified lengths	7	estimated for 7 specified lengths	species disaggregated
Africana new	5	same slope as old	5	same slope as old	species disaggregated
West coast winter survey					
Africana old	7	estimated for 7 specified lengths	7	estimated for 7 specified lengths	species disaggregated
South coast spring survey					
Africana old	7	estimated for 7 specified lengths	7	estimated for 7 specified lengths	species disaggregated
Africana new	5	same slope as old	5	same slope as old	species disaggregated
	1	female downscaling factor			
South coast autumn					
Africana old	7	estimated for 7 specified lengths	7	estimated for 7 specified lengths	species disaggregated
Africana new	5	same slope as old	5	same slope as old	species disaggregated
	1	female downscaling factor			
Total	58		56		

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

SURVEY DATA	*M. paradoxus*		*M. capensis*	
	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, *M. capensis*	27	65
West coast longline, species combined	51	91
South coast longline, *M. capensis*	51	91
Both coasts offshore, species combined	25	65

Appendix C - Base Case fit to Age-Length Keys



ALK1 West coast summer 1990

ALK2 West coast summer 1991

ALK3 West coast summer 1992

ALK4 West coast summer 1993

ALK5 West coast summer 1994

ALK6 West coast summer 1995

ALK7 West coast summer 1996

ALK8 West coast summer 1999

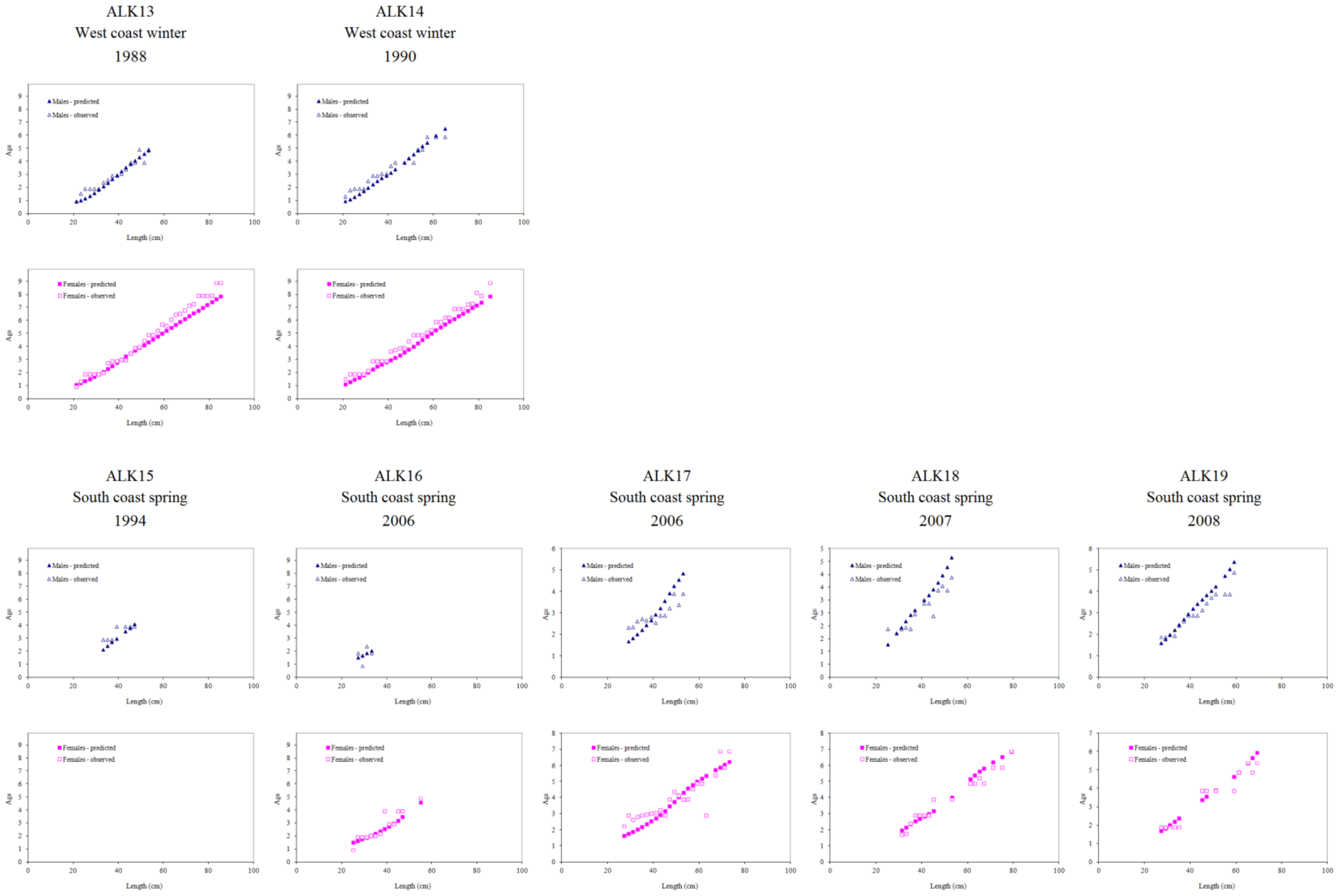
ALK9 West coast summer 2005

ALK10 West coast summer 2007

ALK11 West coast summer 2008

ALK12 West coast summer 2008

Fig. App.B.1a: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the west coast summer surveys.



ALK13
West coast winter
1988

ALK14
West coast winter
1990

ALK15
South coast spring
1994

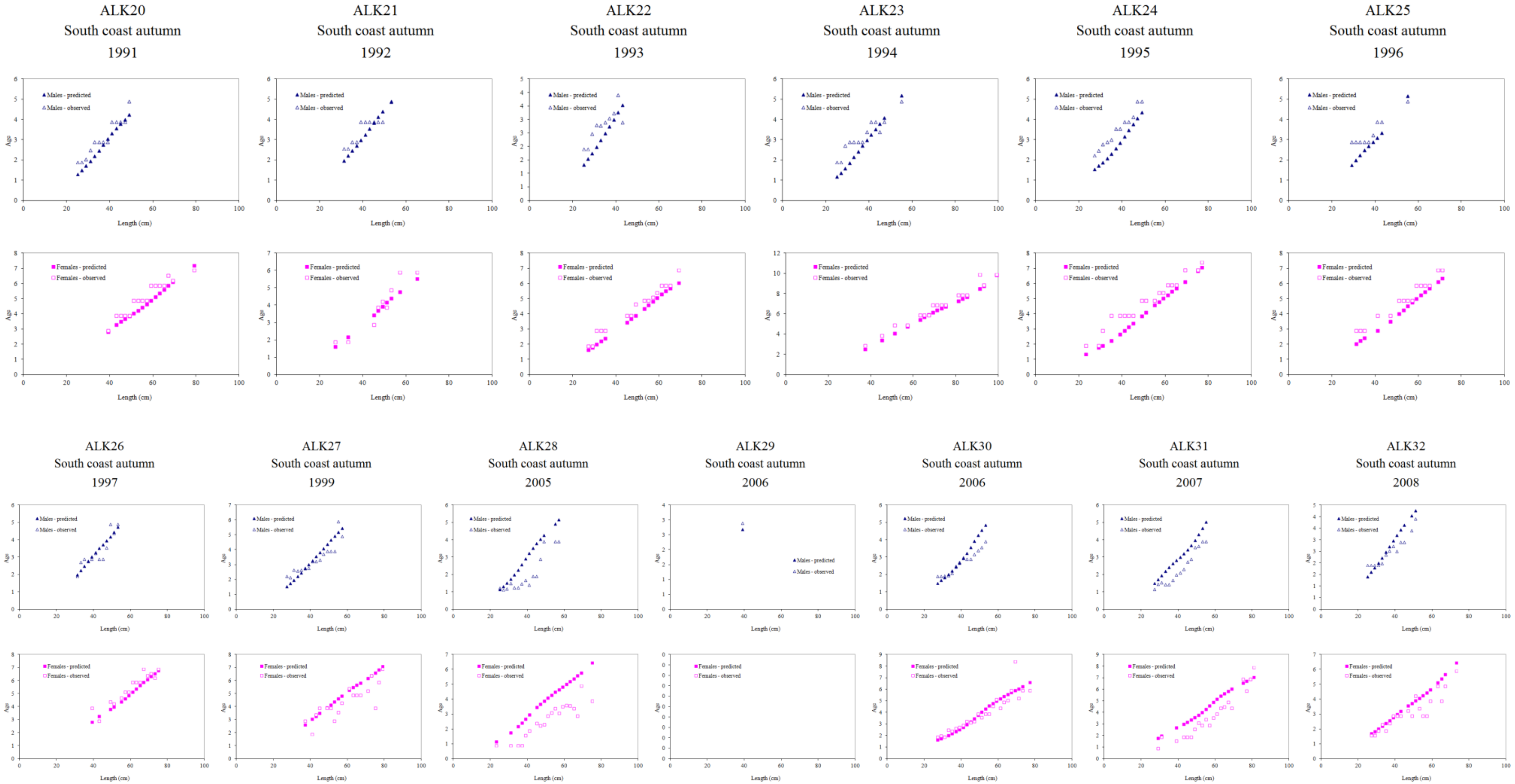
ALK16
South coast spring
2006

ALK17
South coast spring
2006

ALK18
South coast spring
2007

ALK19
South coast spring
2008

Fig. App.B.1b: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the west coast winter and south coast spring surveys.



ALK20 South coast autumn 1991

ALK21 South coast autumn 1992

ALK22 South coast autumn 1993

ALK23 South coast autumn 1994

ALK24 South coast autumn 1995

ALK25 South coast autumn 1996

ALK26 South coast autumn 1997

ALK27 South coast autumn 1999

ALK28 South coast autumn 2005

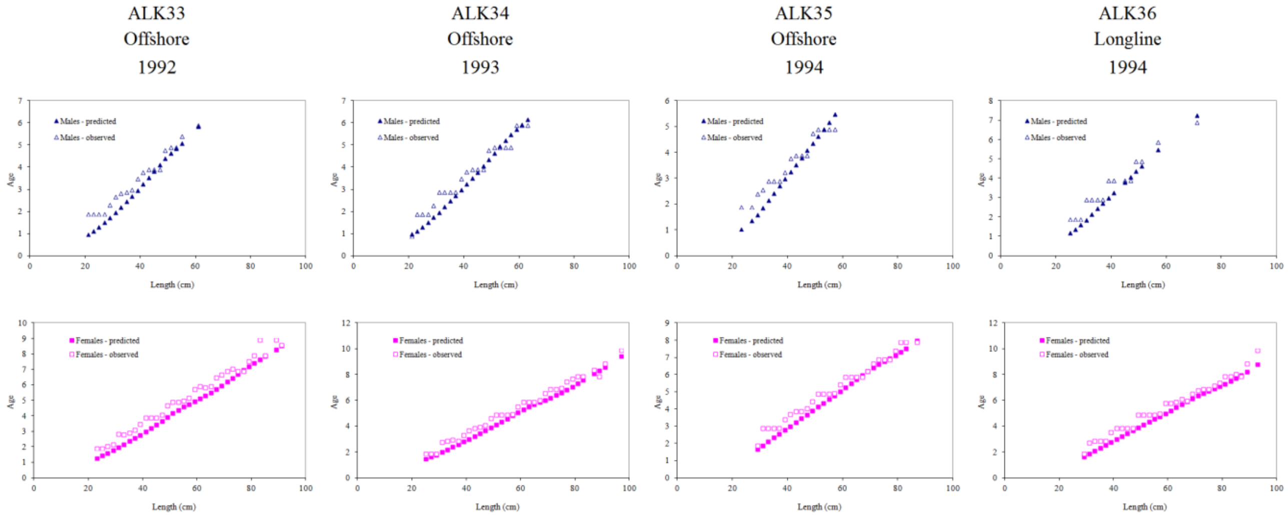
ALK29 South coast autumn 2006

ALK30 South coast autumn 2006

ALK31 South coast autumn 2007

ALK32 South coast autumn 2008

Fig. App.B.1c: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the south coast autumn surveys.



ALK33
Offshore
1992

ALK34
Offshore
1993

ALK35
Offshore
1994

ALK36
Longline
1994

Fig. App.B.1d: Observed vs predicted mean age-at-length for *M. paradoxus* males and females for the commercial offshore trawl and commercial longline.

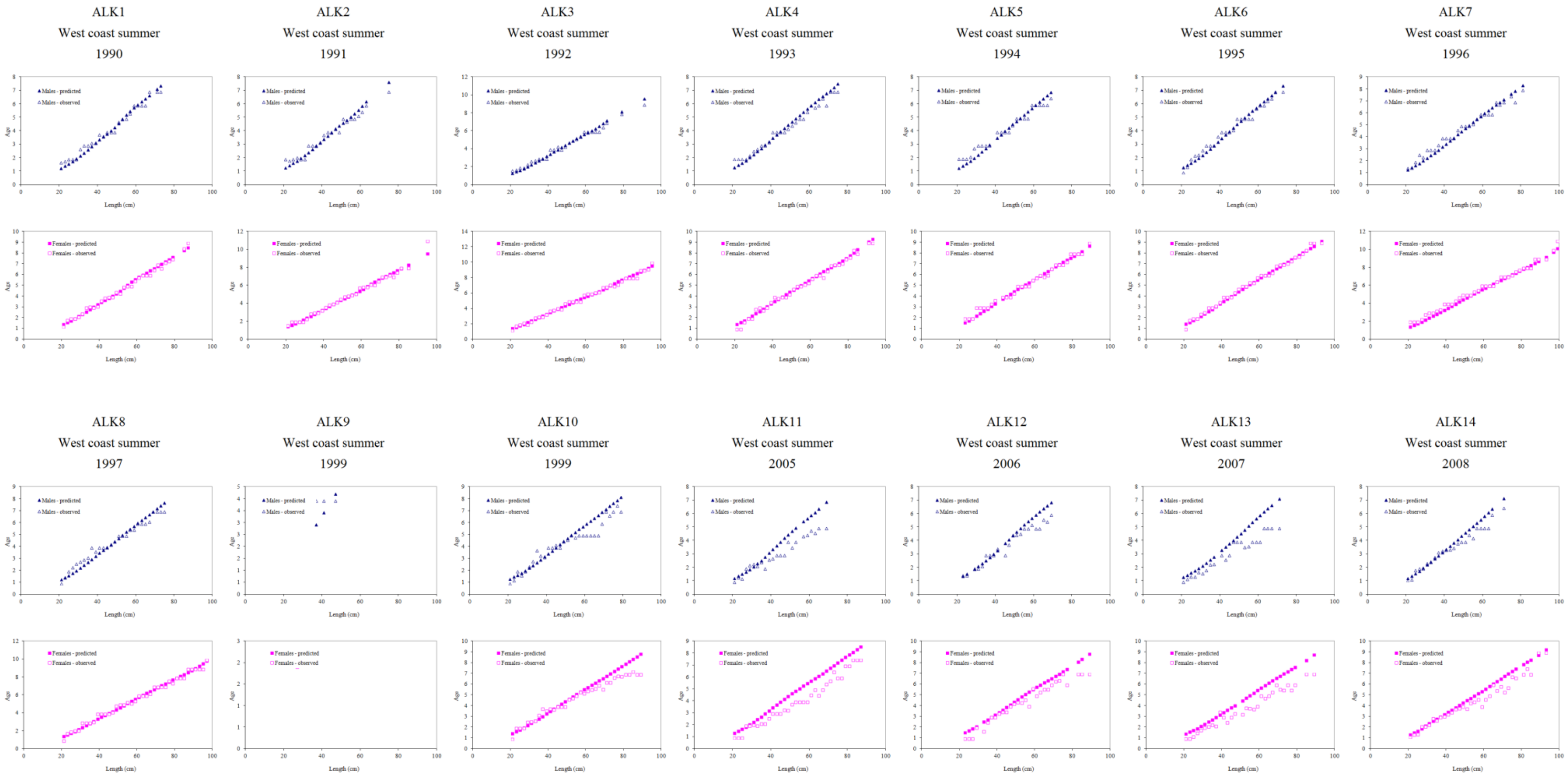
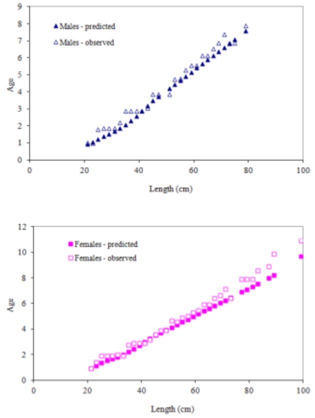
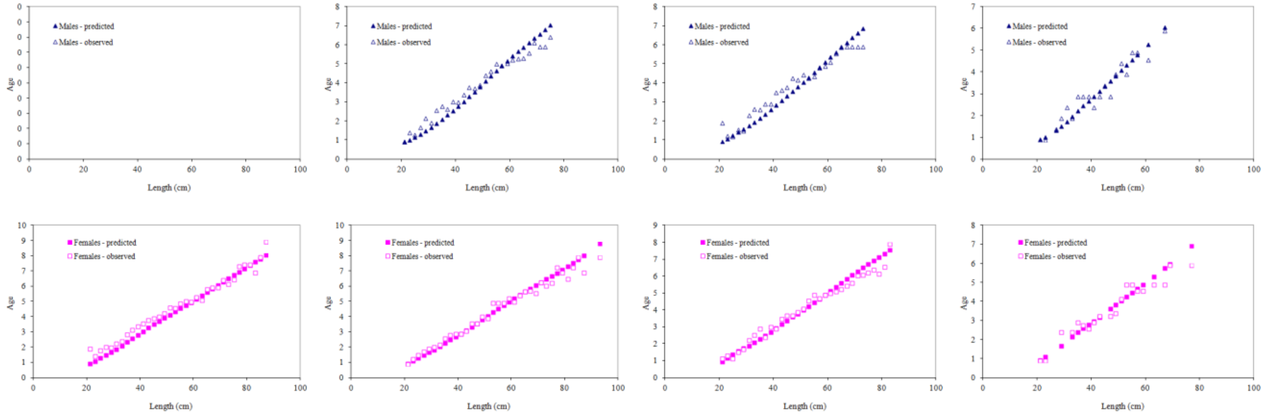


Fig. App.B.2a: Observed vs predicted mean age-at-length for *M. capensis* males and females for the west coast summer surveys.


ALK15
West coast winter
1988


ALK16
South coast spring
2004

ALK17
South coast spring
2006

ALK18
South coast spring
2007

ALK19
South coast spring
2008

Fig. App.B.2b: Observed vs predicted mean age-at-length for *M. capensis* males and females for the west coast winter and south coast spring surveys.

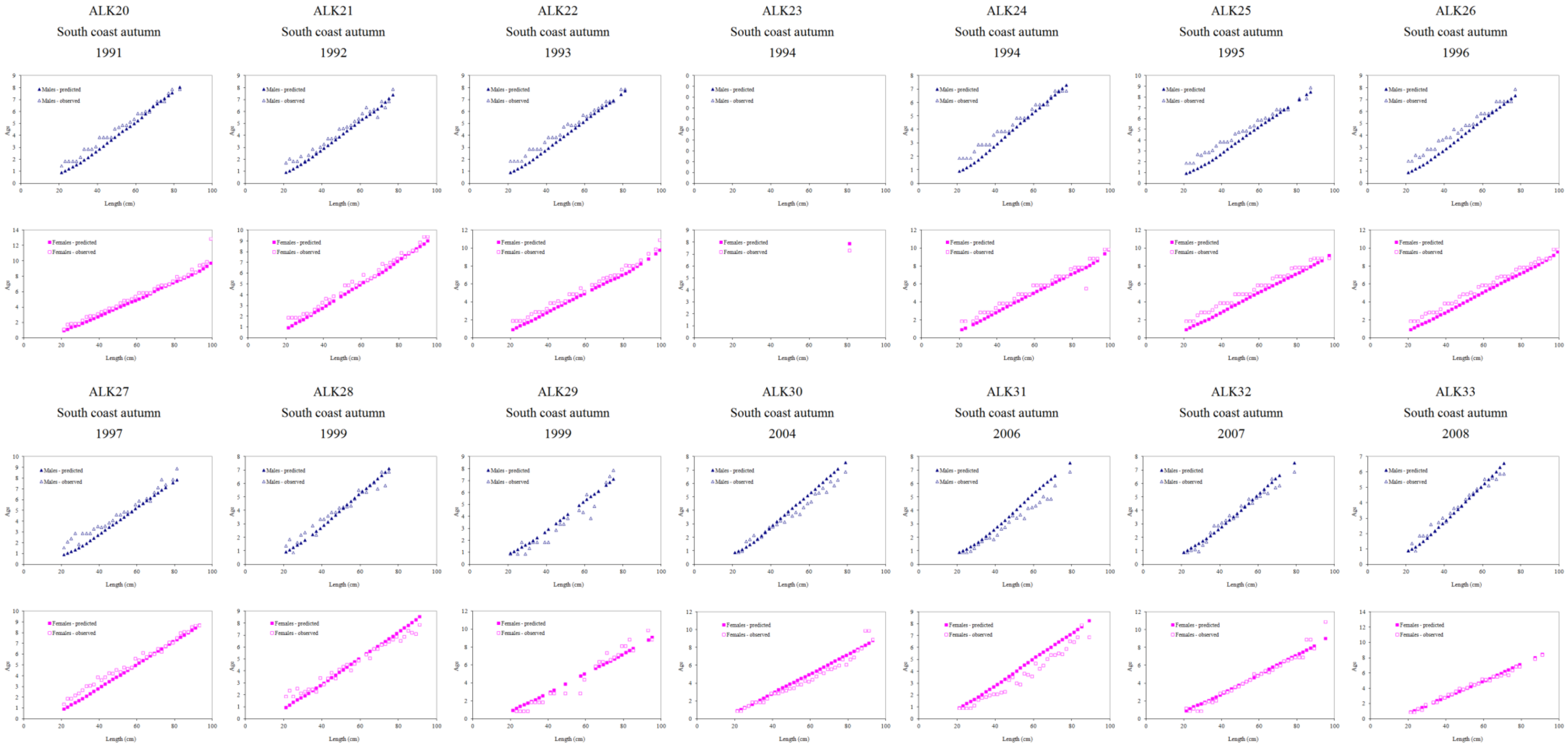


Fig. App.B.2c: Observed vs predicted mean age-at-length for *M. capensis* males and females for the south coast autumn surveys.

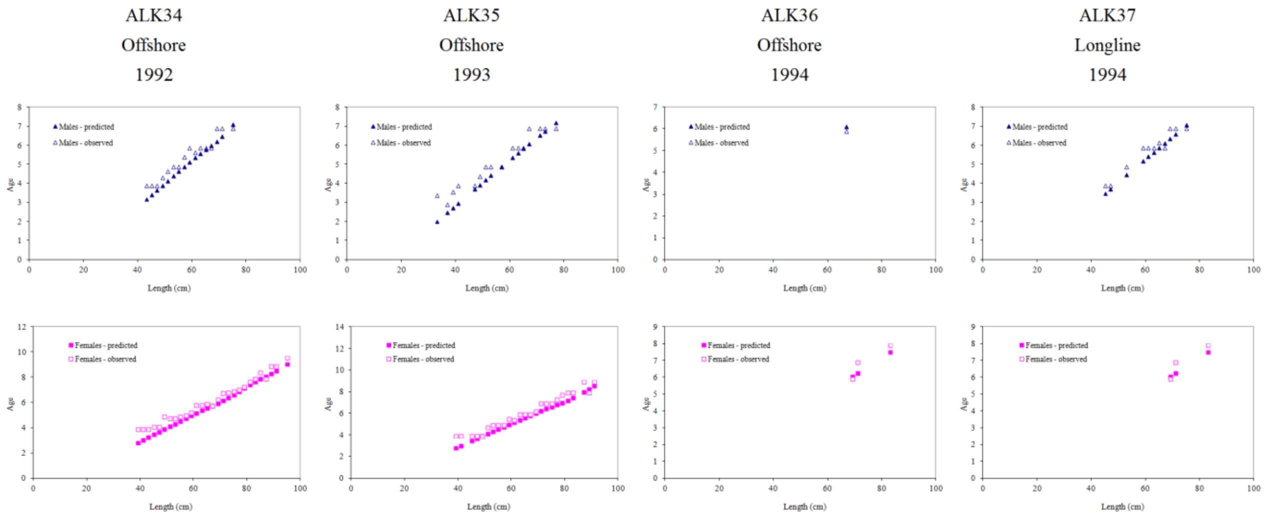


Fig. App.B.2d: Observed vs predicted mean age-at-length for *M. capensis* males and females for the commercial offshore trawl and commercial longline.