An initial attempt at a spatially structured stock assessment for the South African hake resource including movement based on a gravity model

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SUMMARY

The movement model for assessing the South African hake populations which was presented to last year's review workshop is simplified by applying the "gravity" method to model movement. This reduces the numbering of movement parameters estimated from 234 to 68. This results in recent biomass estimates which are slightly more precise and somewhat lower in both absolute terms and relative to estimated pre-exploitation levels. Areas for possible future research are discussed briefly.

INTRODUCTION

A spatially structured model for the South African hake which includes movement explicitly was presented last year (Rademeyer, 2014). In that analysis, the movement matrices were estimated directly for three age groups - requiring the estimation of 234 movement parameters. This paper documents an attempt at reducing the number of movement parameters. Movement between areas is parameterized using a simple gravity model that includes "gravity" and "residency" parameters which determine the degree of stock mixing among areas. For each species and age group, the probability of moving from region r to region r' $X_{y,a}^{r',r}$ is calculated by:

$$X_{y,a}^{r',r} = \frac{G_a^{r',r}}{\sum_r G_a^{r',r}}$$
(1)

Rather than directly estimating all of the $G_a^{r',r}$ terms, movement model complexity is reduced by simplifying this to a gravity term g_a^r for each region (and species and age group) and a residency parameter $v_a^{r'}$ for each region (and species and age group):

$$G_{s,a}^{r',r} = \begin{cases} \exp\!\left(g_{s,a}^r\right) & r' \neq r \\ \exp\!\left(v_{s,a}^{r'} + g_{s,a}^r\right) & r' = r \end{cases}$$
(2)

This reduces the number of estimable movement parameters for the South African hake model from 234 to 68. The rest of the model structure is the same as that described in Rademeyer (2014). Hereafter, the model described here is referred to as the "gravity model".

DATA AND METHODS

The data are described in Appendix A and the methods in Appendix B. The total catches by species and the catches disaggregated by region and species assumed are shown in Figs 1 and 2 respectively.

Some points to note concerning key elements of the methodology applied are as follows.

- Given that movement is modelled explicitly, any "selectivity" effect remaining should reflect gear selection only. Accordingly all commercial selectivities-at-length have been modelled by logistic functions (see

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Appendix B section B3.1.3). However fits to the data would not then accept a similar form for the survey selectivities-at-length, which were accordingly modelled using a more flexible form (see Appendix B section B3.1.2 for details).

- The Beverton-Holt stock-recruit relationship is used.
- Natural mortality was fixed for both species, with M_{2-}=0.75 and M_{5+}=0.375, and a linear trend between these ages. This is as for the Reference Case model for the existing South African hake assessment (Rademeyer and Butterworth, 2014).
- Although the model starts when catches commence in 1917, movement is introduced only from 1978 (see Appendix B) because the fewer data available before that date preclude more complex models for that period.

RESULTS AND DISCUSSION

Table 1 gives some results from the gravity model for *M. paradoxus* and *M. capensis*. The different contributions to the negative log-likelihood are given in Table 2. Table 3 shows the estimated multiplicative factors for each survey and species. Estimates of *q* values well above 1 for the south coast surveys, implying substantial herding of hake by the survey nets, are somewhat surprising and merit further investigation, and perhaps indicate a need for constraints on *q* in the fitting process.

The total spawning biomass trajectories estimated for each species are plotted in Fig. 3 and compared to the results obtained in Rademeyer (2013) for the more complex movement model. The gravity model results in somewhat lower recent biomasses for both M. *paradoxus* and *M. capensis*, both in absolute terms and relative to *K*. In Fig. 4, the spawning biomasses are shown disaggregated by region from 1978 onwards.

Since the model did not converge fully so that Hessian-based CVs are not available, a likelihood profile on the current *M. paradoxus* spawning biomass was run to provide some information on estimation variance. The *M. paradoxus* 2013 spawning biomass is estimated at 162 000 tons with 95% CI of 127-228 thousand tons, corresponding to a CV of about 16%, for the gravity model. Precision is thus slightly improved compared to the Rademeyer (2014) model which estimated a corresponding biomass of 241 400 tons with 95% CI of 178-362 thousand tons, corresponding to a CV of about 19%.

The estimated stock-recruitment curve and the recruitment trajectory for each species are plotted in Fig. 5 .

The survey and commercial selectivities-at-length estimated when fitting the model are shown in Fig. 6. Many of the logistic commercial selectivity curves estimated reflect near knife-edge selection. The curves for the surveys are strongly domed shaped. The reasons for this dome are unclear at this stage. It may be related to the surveys not covering areas deeper than 500 m where the largest hake predominate, but could also reflect some mis-specification of the model (e.g. even within the strata defined, neither commercial trawlers nor the survey cover the rocky ground where there seems to be a greater proportion of larger hake).

The fits to the CPUE series are plotted in Fig. 7, while Fig. 8 plots the fits to the region-disaggregated survey biomass indices. The fits to the CPUE data series are broadly reasonable, though the model shows the occasional surprising spike, which warrants further investigation. The fits to the survey indices are not entirely satisfactory (see Figure 8b), particularly for the west coast 400m+ region; this also warrants further investigation.

The fits to the commercial age- and length-distributions are shown in Fig. 9. They are also broadly reasonable but there seems to be a conflict between the longline catch-at-age and catch-at-length data, for which generally larger lengths are predicted than are observed. The fits to the region-disaggregated survey length-

distributions are shown in Fig. 10. For these data, there are areas in need of improvement, particularly as regards the model often suggesting much higher proportions in the minus- and/or plus-group than are observed.

The estimated movement matrices are given in Table 4, while the resulting proportions of each age in each region are given in Table 5.

AREAS FOR POSSIBLE FUTURE WORK

The potential and fundamental advantage of a model estimating movement explicitly is that gear-selectivity "should" be asymptotically flat, i.e. the confounding of emigration (causing selectivity doming) and fishing mortality in conventional models falls away. Some of the fits to size structure data suggest moving to more flexible selectivity models than the logistic, but this would re-introduce this confounding problem.

Starting the movement in 1978 only as in this gravity model (see Appendix B) is not ideal and may not be the best solution.

- The progressive movement of the offshore trawl fishery to deeper waters over the 1917-1977 period could be modeled internally; this would also provide a better way to model the ICSEAF CPUE series than the current method (Appendix B, section B.2.1).
- The pre-1978 selectivities are taken to be the same as post-1977, but the model is not region-disaggregated for this earlier period. The pattern of removals by length is thus not correctly represented over this period, leading to a bias in the 1978 age structure to which the movement model is then applied to project the two species through the following years.
- There is also the problem of how to distribute the fish in 1978. At the moment, the proportions in each region are computed from the movement matrices. The different proportions could rather be made estimable parameters with some functional relationships to reduce the number of parameters. Another solution might be to start moving the fish spatially before 1978 (let's say 20 years before), to have settled populations by 1978 - i.e. although the model is aggregated over regions (i.e. the catch is taken from the whole population), the model could keep track of the proportion of fish moving and multiply the resulting proportions by the numbers-at-age.

Leslie and Somhlaba (2013) provide revised assumptions to disaggregate the data from the longline fleet by species and regions. This information was not used here as this model was run as a direct comparison to the more complex movement model (Rademeyer, 2013) which did not use these data, but they should be considered for use in the future.

Since there is depth information for the offshore trawl catches from 1978, region-specific GLM-standardised CPUE series could be developed and fitted to in this model, rather than use coast-specific indices.

REFERENCES

Rademeyer RA. 2014. An initial attempt at a spatially structured stock assessment for the South African hake resource including explicit movement. MARAM/IWS/DEC13/Hake/P9.

Rademeyer RA and Butterworth DS. 2014. Specifications of the South African Hake 2014 Reference Case Assessment. MARAM/IWS/DEC14/Hake/P2.

Table 1: Results for *M. paradoxus* and *M. capensis*. Values fixed on input are shown bolded. (Values in parenthesis are the corresponding results for the 2013 movement - Rademeyer and Butterworth, 2013)

	M. paradoxus		*M. capensis*	
K^{sp}	1173	(1166)	759	(697)
h (BH)	0.79	(0.84)	0.55	(0.63)
B^{sp}_{2013}	162	(241)	303	(378)
B^{sp}_{2013}/K^{sp}	0.14	(0.21)	0.40	(0.54)
M_0	**0.750**	**(0.750)**	**0.750**	**(0.750)**
M_{7+}	**0.375**	**(0.375)**	**0.375**	**(0.375)**

Table 2: Negative log-likelihood contributions.

Negative log-likelihoods	
Total	6481.3
SC historic CPUE	-36.5
GLM CPUE	-117.6
Survey indices	-34.2
Commercial_CAA	-48.4
Commercial_CAL	28.1
Survey_CAL	6675.6
SR	10.7
Selectivity smoothing	3.1

Table 3: Survey *q*'s estimated for the *Africana* with the old gear.

Survey *q*'s	*M. paradoxus*		*M. capensis*	
	WC summer	WC winter	WC summer	WC winter
0-100m	-	-	0.866	1.344
101-200m	1.199	1.023	0.866	1.344
201-300m	1.199	1.023	0.866	1.344
301-400m	1.199	1.023	0.866	1.344
401m+	1.199	1.023	-	-
	SC autumn	SC spring	SC autumn	SC spring
0-50m	-	-	1.948	1.863
51-100m	-	-	1.948	1.863
101-200m	2.372	1.492	1.948	1.863
201m+	2.372	1.492	1.948	1.863

Table 4: Proportion of recruitment in each region and movement matrices estimated for *M. paradoxus* and *M. capensis*.

M. paradoxus

Age 0

out of	Prop.
0-100m	-
101-200m	0.38
201-300m	0.14
301-400m	-
401m+	-
0-50m	-
51-100m	-
101-200m	0.00
201m+	0.48

Age 1 — into

out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.65	0.34	0.00	-	-	-	0.00	0.00	1.00
201-300m	-	0.00	0.00	0.64	-	-	-	0.00	0.36	1.00
301-400m	-	0.00	0.99	0.01	-	-	-	0.00	0.01	1.00
401m+	-	-	-	-	-	-	-	-	-	
0-50m	-	-	-	-	-	-	-	-	-	
51-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.00	0.99	0.01	-	-	-	0.00	0.01	1.00
201m+	-	0.00	0.99	0.01	-	-	-	0.00	0.00	1.00

Ages 2-4 — into

out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.17	0.00	0.53	0.19	-	-	0.00	0.10	1.00
201-300m	-	0.00	0.62	0.24	0.09	-	-	0.00	0.04	1.00
301-400m	-	0.00	0.00	0.64	0.23	-	-	0.01	0.12	1.00
401m+	-	0.00	0.00	0.19	0.77	-	-	0.00	0.03	1.00
0-50m	-	-	-	-	-	-	-	-	-	
51-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.00	0.00	0.63	0.23	-	-	0.03	0.11	1.00
201m+	-	0.00	0.00	0.25	0.09	-	-	0.00	0.65	1.00

Ages 5+ — into

out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.00	0.01	0.08	0.80	-	-	0.01	0.11	1.00
201-300m	-	0.02	0.23	0.06	0.60	-	-	0.01	0.08	1.00
301-400m	-	0.03	0.01	0.07	0.78	-	-	0.01	0.10	1.00
401m+	-	0.13	0.03	0.34	0.00	-	-	0.03	0.47	1.00
0-50m	-	-	-	-	-	-	-	-	-	
51-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.03	0.01	0.08	0.78	-	-	0.00	0.10	1.00
201m+	-	0.03	0.01	0.08	0.87	-	-	0.01	0.00	1.00

M. capensis

Age 0

out of	Prop.
0-100m	0.19
101-200m	0.19
201-300m	0.04
301-400m	-
401m+	-
0-50m	0.01
51-100m	0.19
101-200m	0.19
201m+	0.19

Age 1 — into

out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	0.36	0.42	0.00	-	-	0.02	0.06	0.15	0.00	1.00
101-200m	0.13	0.87	0.00	-	-	0.00	0.00	0.00	0.00	1.00
201-300m	1.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00	1.00
301-400m	-	-	-	-	-	-	-	-	-	
401m+	-	-	-	-	-	-	-	-	-	
0-50m	1.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00	1.00
51-100m	1.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00	1.00
101-200m	1.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00	1.00
201m+	1.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00	1.00

Ages 2-4 — into

out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	0.34	0.35	0.10	0.00	-	0.00	0.04	0.17	0.00	1.00
101-200m	0.00	0.00	0.32	0.00	-	0.00	0.12	0.55	0.01	1.00
201-300m	0.00	0.63	0.00	0.00	-	0.00	0.06	0.30	0.00	1.00
301-400m	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	0.00	
401m+	-	-	-	-	-	-	-	-	-	
0-50m	0.00	0.28	0.08	0.00	-	0.48	0.03	0.13	0.00	1.00
51-100m	0.00	0.00	0.00	0.00	-	0.00	1.00	0.00	0.00	1.00
101-200m	0.00	0.54	0.15	0.00	-	0.00	0.05	0.26	0.00	1.00
201m+	0.00	0.37	0.10	0.00	-	0.00	0.04	0.18	0.30	1.00

Ages 5+ — into

out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	0.65	0.00	0.08	0.06	-	0.01	0.03	0.11	0.05	1.00
101-200m	0.00	0.40	0.14	0.11	-	0.01	0.06	0.19	0.08	1.00
201-300m	0.00	0.00	0.85	0.04	-	0.00	0.02	0.06	0.03	1.00
301-400m	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	0.00	
401m+	-	-	-	-	-	-	-	-	-	
0-50m	0.00	0.00	0.25	0.19	-	0.00	0.10	0.32	0.15	1.00
51-100m	0.00	0.00	0.19	0.14	-	0.02	0.30	0.24	0.11	1.00
101-200m	0.00	0.00	0.24	0.19	-	0.02	0.10	0.31	0.14	1.00
201m+	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	1.00	1.00

Table : Percentage (by numbers) by age group in each region for *M. paradoxus* and *M. capensis*, in 1978 and current (2013).

1978

| | Age | M. paradoxus | | | | M. capensis | | | |
		0-1	2-4	5+		0-1	2-4	5+
West coast	0-100m	-	-	-	-	0.19	0.49	0.04	0.08
	101-200m	0.38	0.26	0.03	0.04	0.19	0.19	0.27	0.05
	201-300m	0.14	0.40	0.10	0.05	0.04	0.02	0.09	0.22
	301-400m	0.00	0.07	0.41	0.12	-	-	0.13	0.22
	401m+	-	-	0.27	0.64	-	-	-	-
South coast	0-50m	-	-	-	-	0.01	0.01	0.06	0.01
	51-100m	-	-	-	-	0.19	0.10	0.17	0.08
	101-200m	0.00	0.00	0.01	0.01	0.19	0.11	0.20	0.15
	201m+	0.48	0.28	0.18	0.14	0.19	0.09	0.04	0.19
		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Current

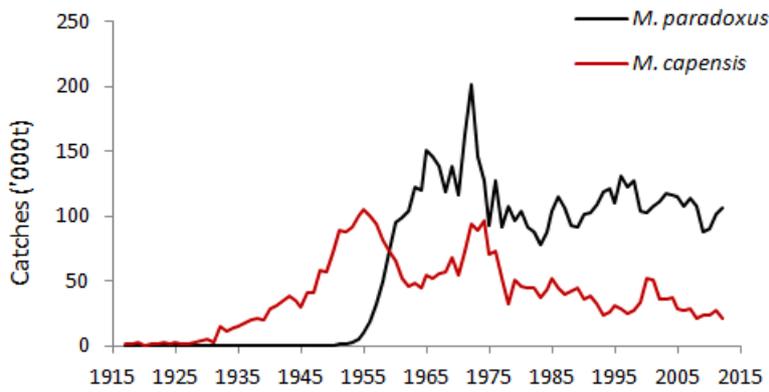| | Age | M. paradoxus | | | | M. capensis | | | |
		0-1	2-4	5+		0-1	2-4	5+
West coast	0-100m	-	-	-	-	0.19	0.45	0.12	0.00
	101-200m	0.38	0.32	0.02	0.07	0.19	0.22	0.29	0.02
	201-300m	0.14	0.37	0.28	0.03	0.04	0.02	0.15	0.23
	301-400m	0.00	0.05	0.39	0.19	-	-	0.00	0.36
	401m+	-	0.00	0.19	0.47	-	-	-	-
South coast	0-50m	-	-	-	-	0.01	0.01	0.00	0.00
	51-100m	-	-	-	-	0.19	0.10	0.13	0.03
	101-200m	0.00	0.00	0.00	0.02	0.19	0.11	0.30	0.06
	201m+	0.48	0.26	0.12	0.23	0.19	0.09	0.00	0.30
		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

6

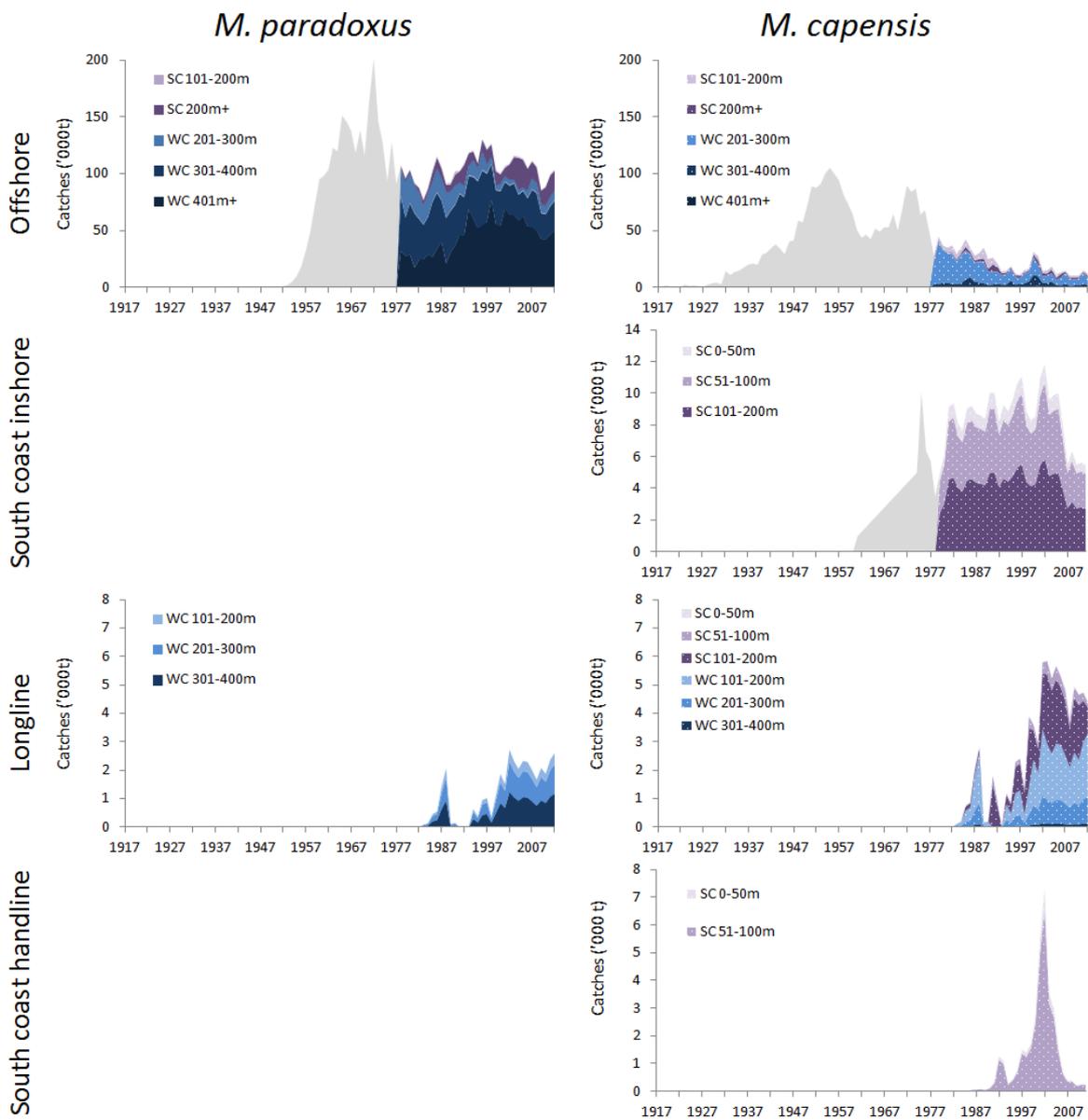Fig. 1: Total catches assumed for *M. paradoxus* and *M. capensis*.

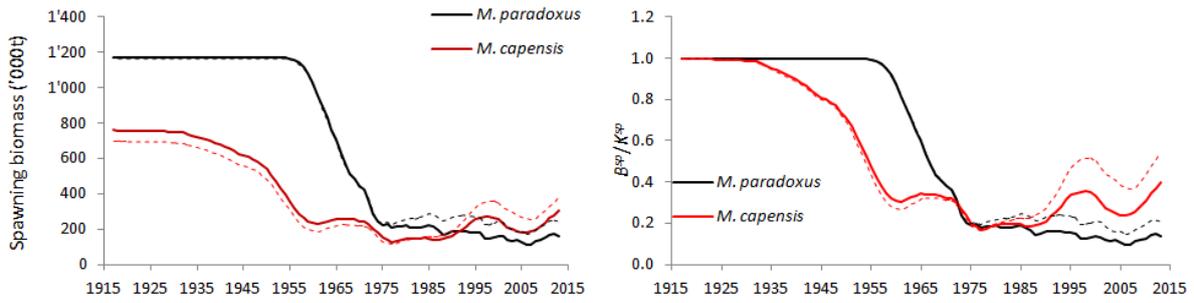Fig. 2: Catches assumed by fleet, region and species.

Fig. 3: Total spawning biomass trajectories (in absolute terms and relative to unexploited level) for *M. paradoxus* and *M. capensis* for this gravity model (full lines) and the 2013 model (dashed lines) (Rademeyer and Butterworth, 2013).
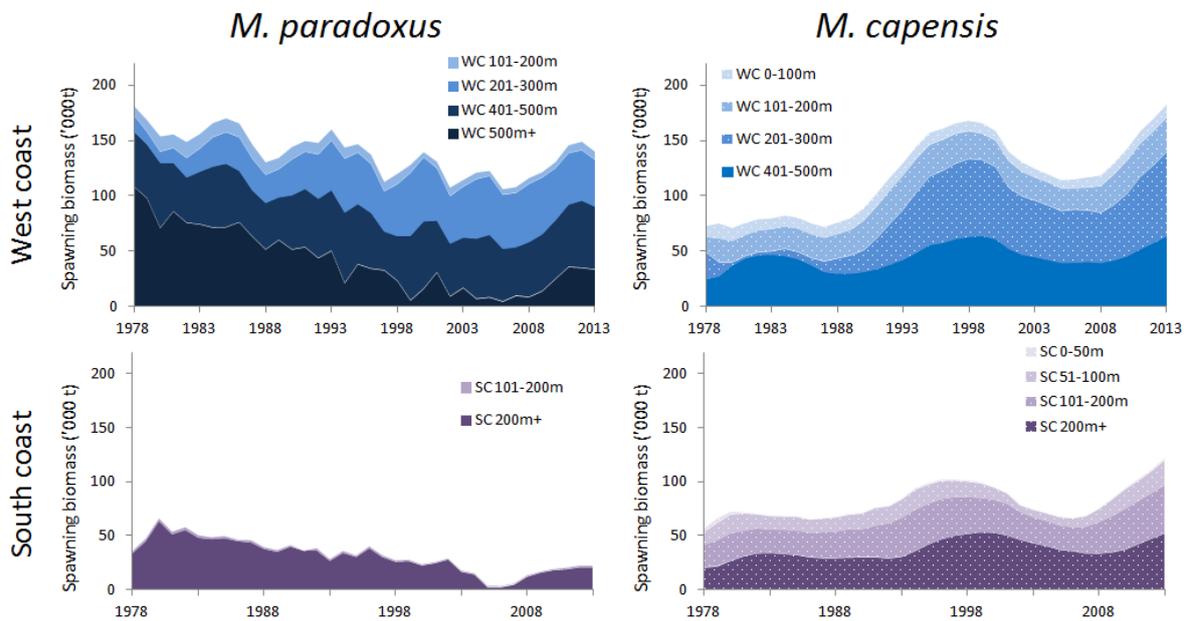

Fig. 4: Spawning biomass trajectories (in absolute terms) per regions for *M. paradoxus* and *M. capensis*.
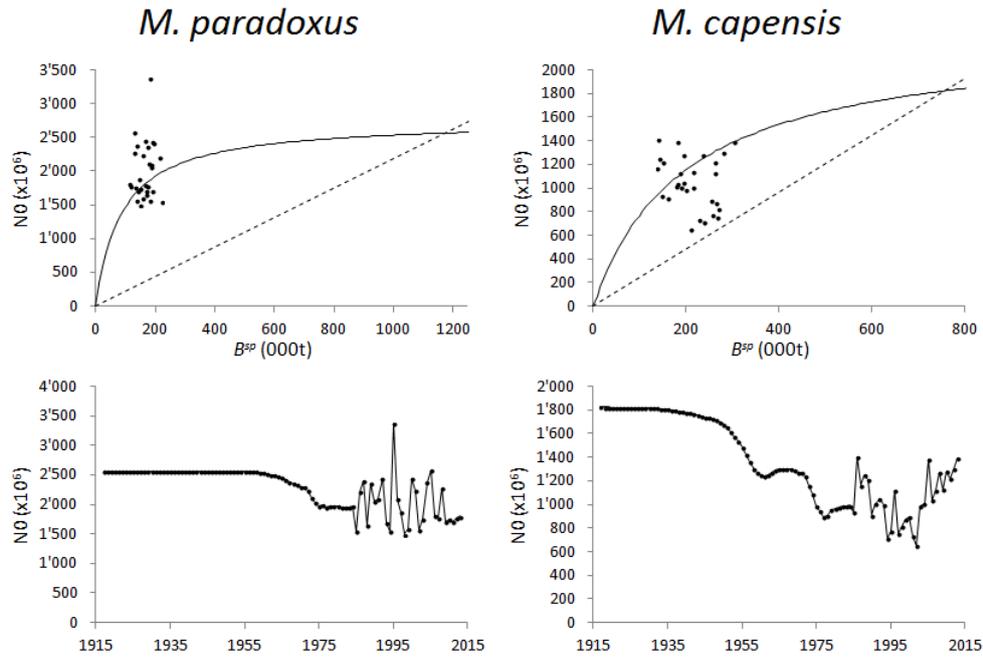
M. paradoxus

M. capensis

Fig. 5: Stock-recruitment relationship and time-series of recruitment.
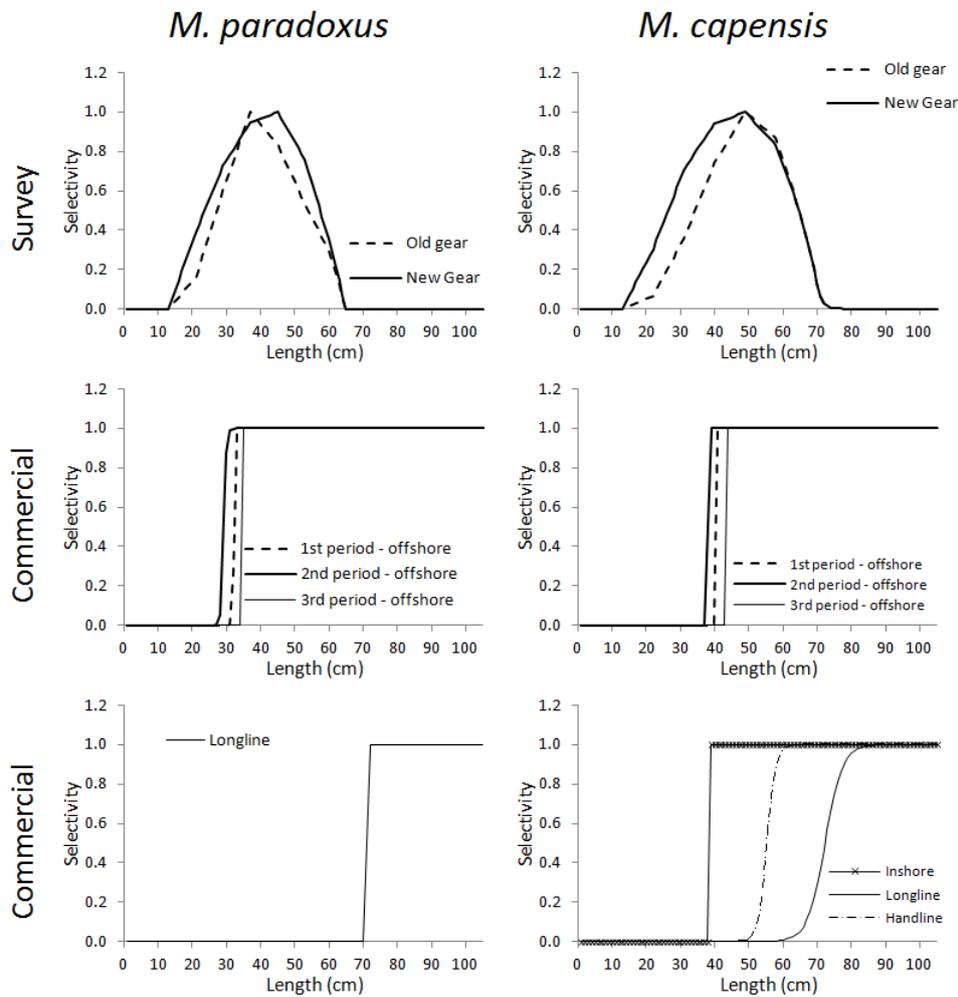
M. paradoxus

M. capensis

Fig. 6: Commercial and survey selectivity-at-length.
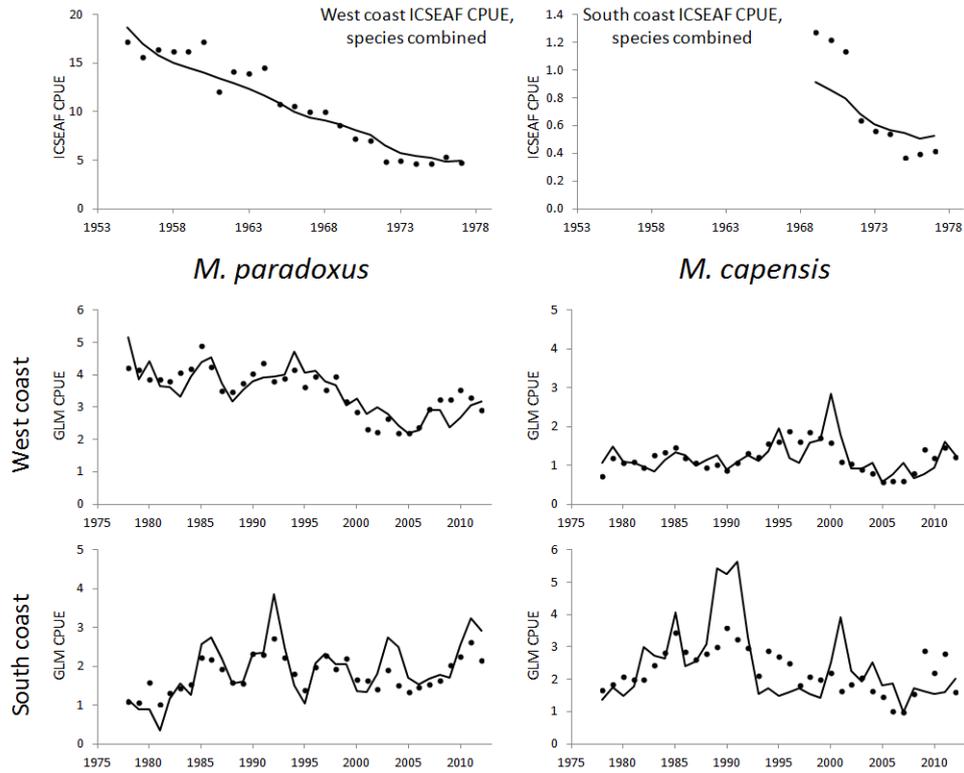
Fig. 7a: Fits to the ICSEAF CPUE and GLM-standardised CPUE series.
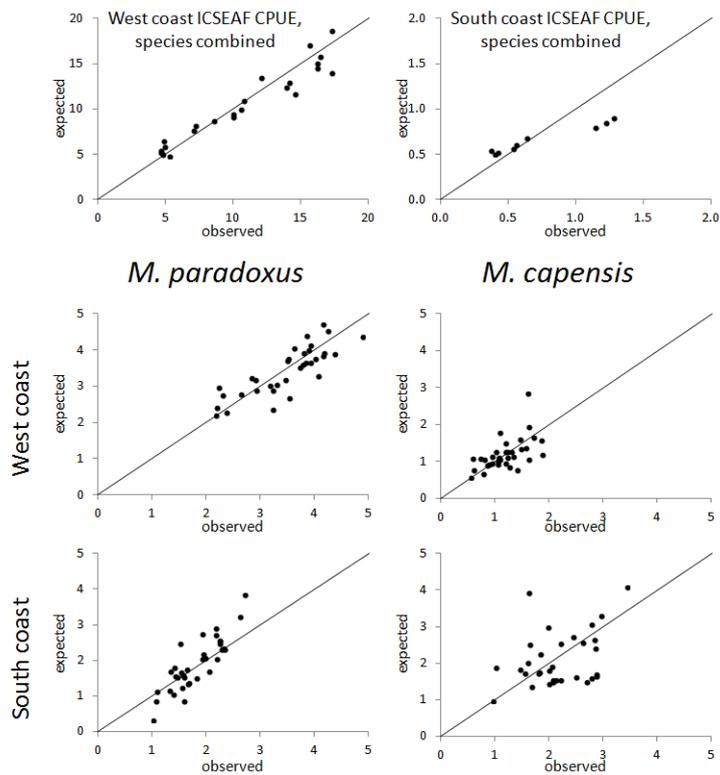
Fig. 7b: Observed *vs* predicted CPUE.
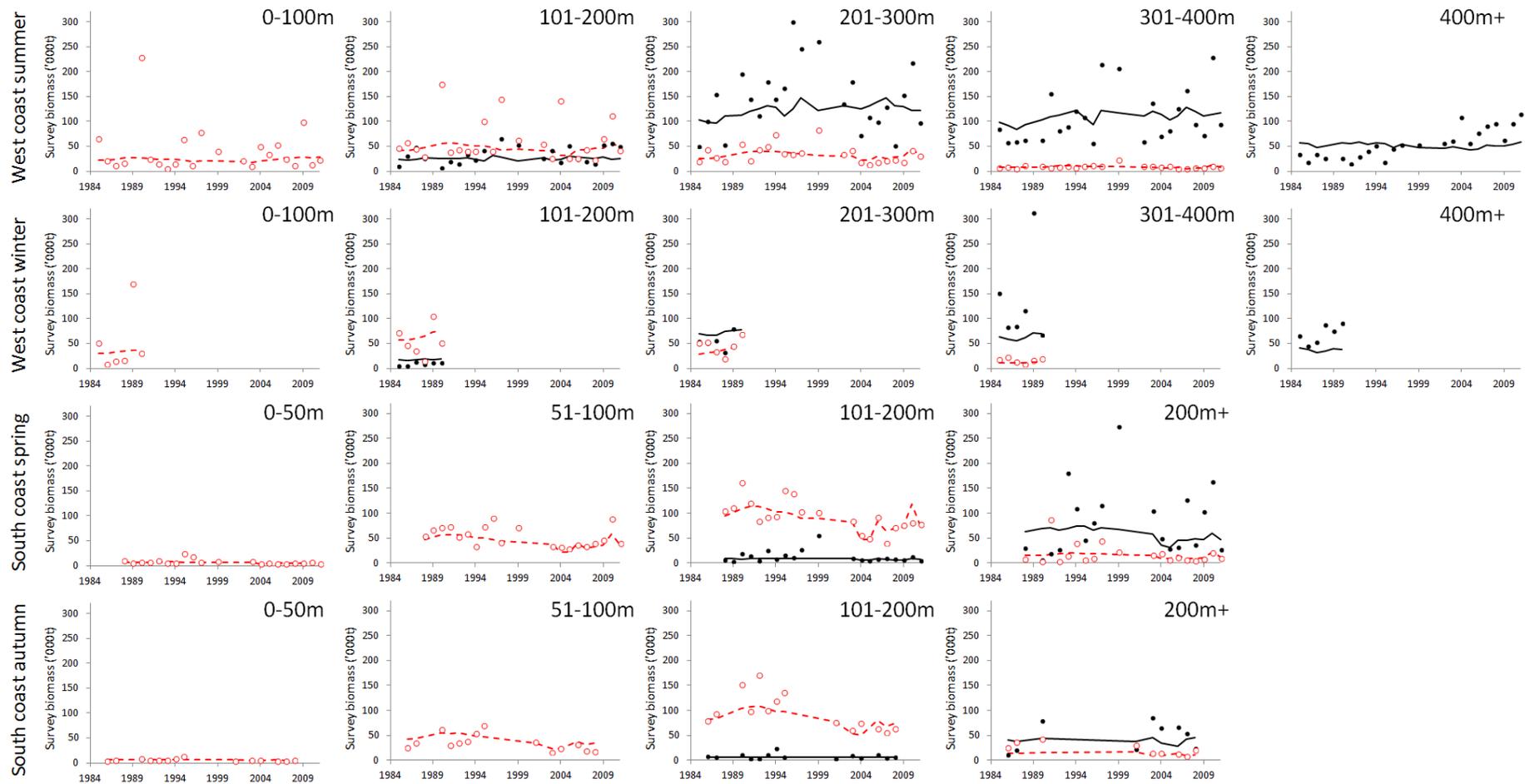
Fig. 8a: Fits to the survey biomass indices by region. *M. paradoxus* results are shown in black while *M. capensis* results are in red.
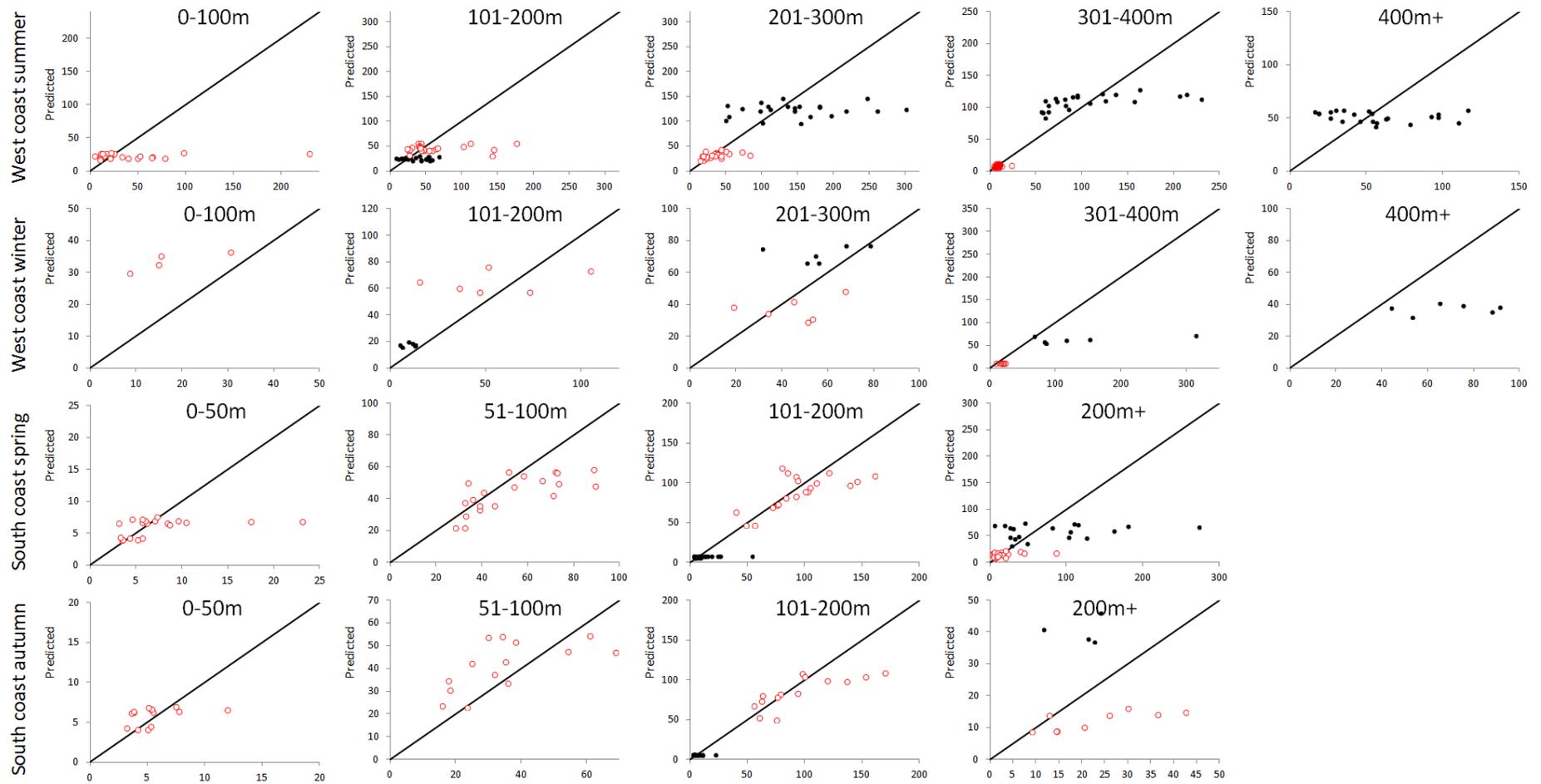
Fig. 8b: Observed *vs* predicted surveys by region (*M. paradoxus* in black, *M. capensis* in red)
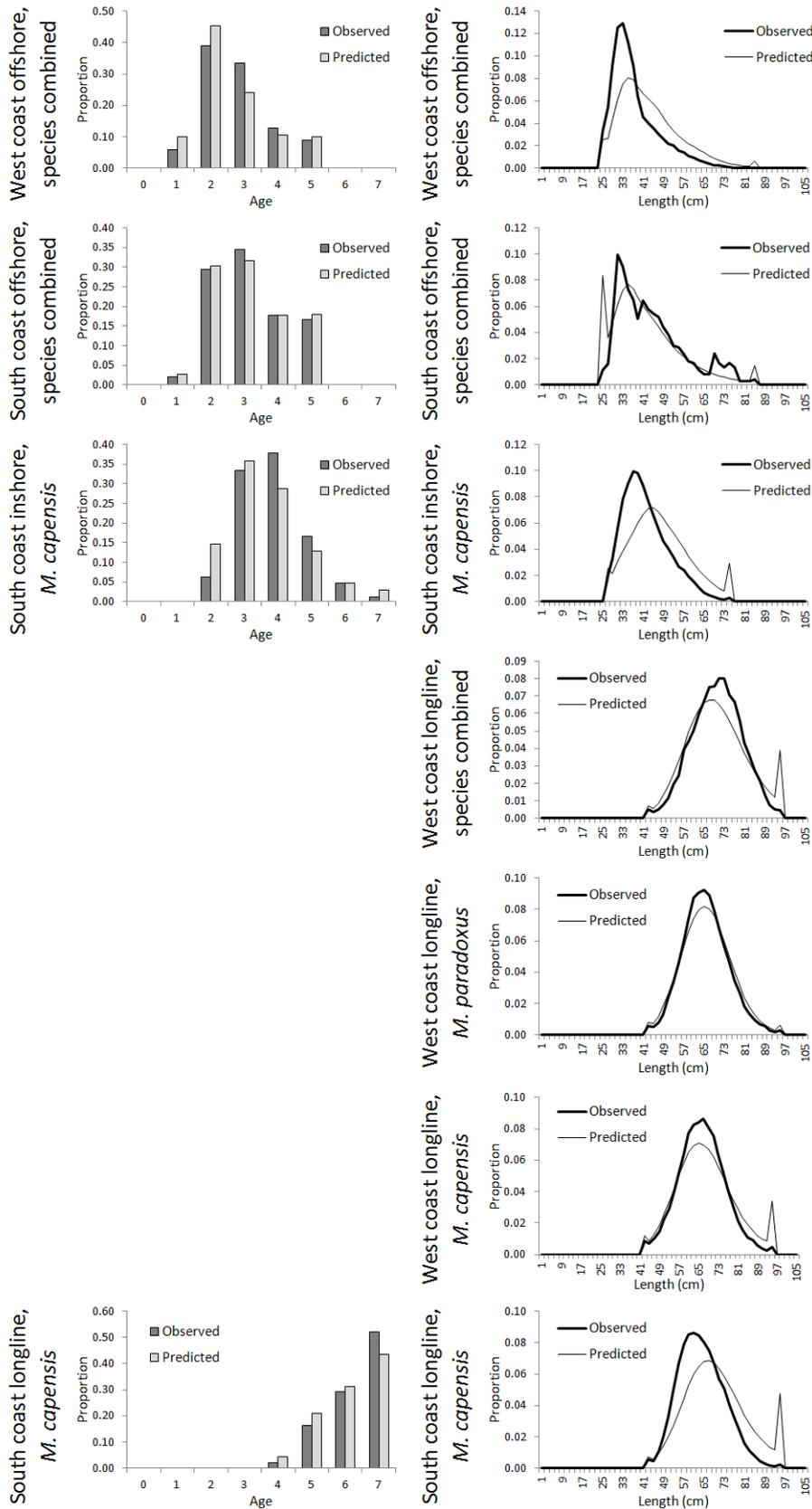
Fig. 9: Fits to the commercial catch-at-age and commercial catch-at-length data, averaged over all the years for which data are available.
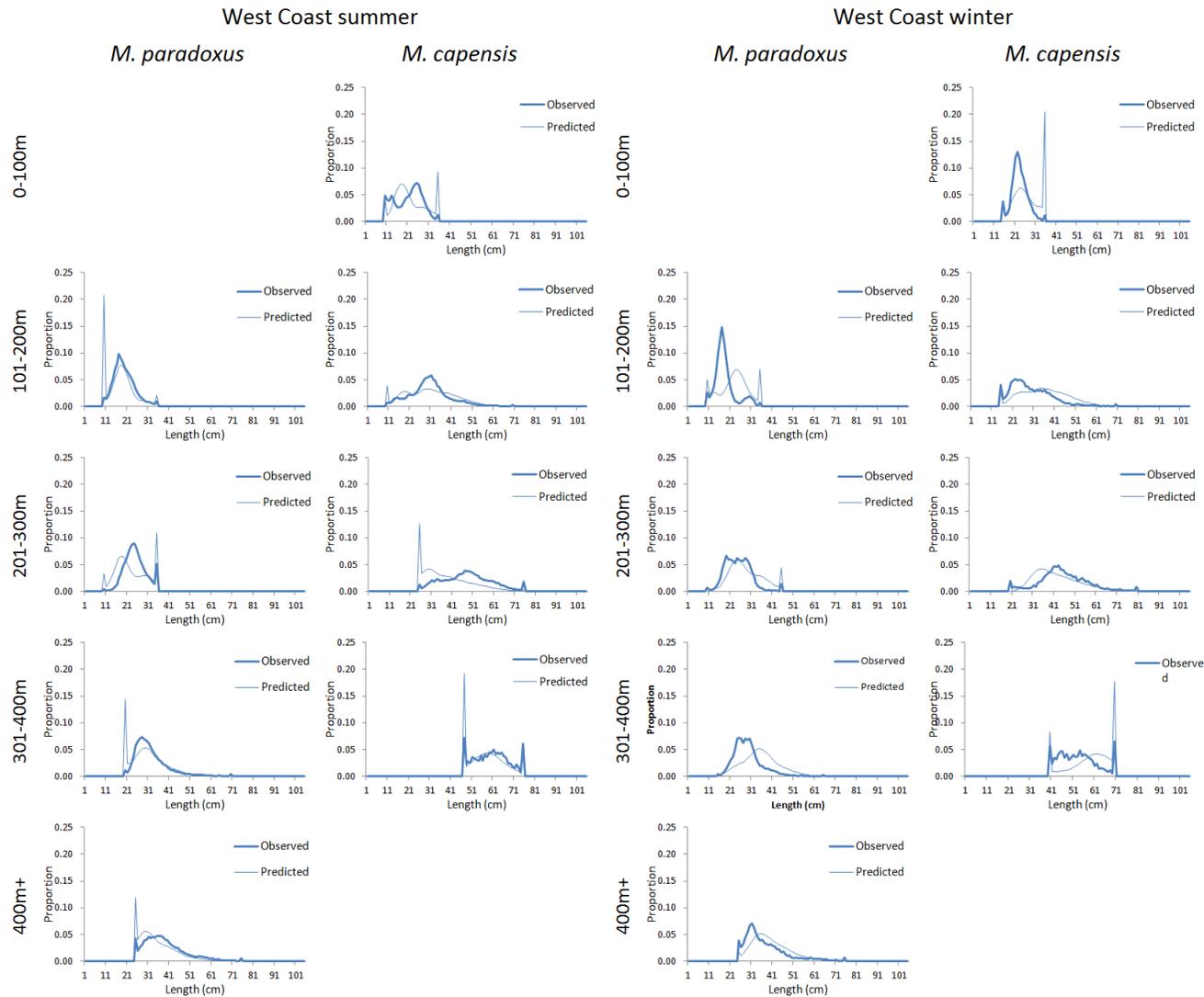
Fig. 10a: Fits to the west coast summer and west coast winter survey region specific catch-at-length data, as averaged over all the years for which data are available.
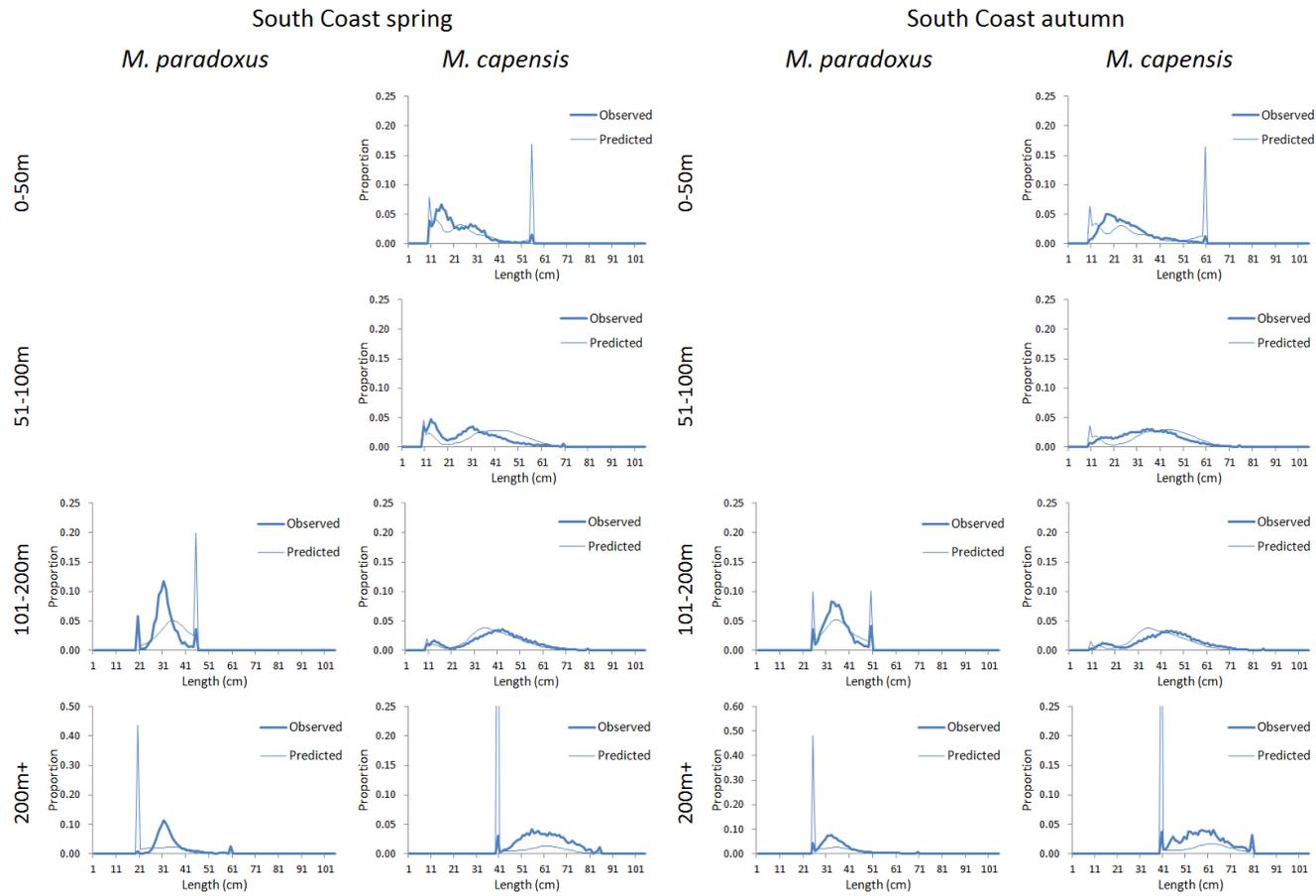
Fig. 10b: Fits to the south coast spring and south coast survey region specific catch-at-length data, as averaged over all the years for which data are available.

Appendix A: Data used

A.1 Catches

A.1.1 Offshore trawl

The offshore trawl catches from 1978 can be disaggregated by region using the catch and effort data base. These are given in Table A1. The offshore trawl fleet is assumed to operate in waters deeper than 200m on the West Coast and deeper than 100m on the South Coast. The catches actually recorded in shallower depths (average of 2% on the West Coast and 1% on the South Coast) were attributed to the "201-300m" region on the West Coast and to the "101-200m" region on the South Coast.

Since splitting the pre-1978 commercial data by regions and species would involve too many assumptions, it was decided rather to start disaggregation in terms of the assumed spatial structure in 1978. From 1917 to 1977 therefore, the model is a coast combined assessment; it uses the same assumptions to split the offshore trawl catches by species and fit the ICSEAF CPUE as in the current assessment (Rademeyer and Butterworth, 2013). The pre-1978 offshore trawl catches are given in Table A2.

A.1.2 Other fleets

To split the inshore trawl, longline and handline catch by region, some coarse assumptions need to be made - see Table A.3. To split the catches by species, the same assumptions are made as in the Reference Case, i.e. 100% *M. capensis* for the inshore, longline and handline catches on the South Coast and 30% *M. capensis* for the West Coast longline catches. The catches for each of these fleets are given in Table A.4.

A.1.3 CPUE

Six CPUE time-series are used: a historic CPUE series for each of the South and West coasts and a GLM-standardised CPUE series for each species and coast - see Table A.5.

A.1.4 Survey biomass indices

Survey biomass indices are available by species and by region for four surveys: West Coast summer, West Coast winter, South Coast spring and South Coast autumn - see Table A.6.

A.1.5 Commercial catches-at-age and -at-length

The commercial age and length distributions available are given in Table. A.7. These data are not disaggregated by region.

A.1.6 Survey catches-at-length

Survey length distributions are available by species and disaggregated by region. The data available are shown in Table A.8.

Table A1: Offshore trawl catches disaggregated by region from 1978 onwards.

| | M. paradoxus | | | | | M. capensis | | | | |
| | West Coast | | | South Coast | | West Coast | | | South Coast | |
	201-300m	301-400m	401m+	101-200m	200m+	201-300m	301-400m	401m+	101-200m	200m+
1978	23.387	47.920	32.359	0.174	3.657	20.829	2.968	0.050	2.529	1.226
1979	32.060	34.275	27.376	0.453	2.200	36.708	2.996	0.107	3.071	1.195
1980	26.479	44.859	29.385	0.098	2.735	28.523	4.170	0.111	2.768	0.860
1981	25.158	47.823	17.593	0.229	0.979	26.061	4.230	0.068	3.841	0.433
1982	23.525	36.077	24.428	0.309	3.755	26.070	3.173	0.075	6.113	1.181
1983	16.365	30.363	24.901	0.834	5.086	19.832	2.887	0.086	5.105	1.491
1984	20.790	33.168	28.982	0.634	4.055	24.322	3.879	0.114	4.672	1.574
1985	17.594	48.785	26.813	1.548	8.506	24.739	6.939	0.199	6.578	3.383
1986	21.759	49.227	34.113	0.664	9.312	19.457	8.907	0.345	3.792	2.194
1987	19.562	36.083	40.310	0.828	8.667	16.434	4.951	0.185	4.315	1.874
1988	22.636	40.000	21.274	0.639	6.545	18.054	4.457	0.161	5.430	1.901
1989	17.225	36.690	30.804	0.890	6.029	18.734	3.697	0.109	9.310	2.683
1990	17.188	35.875	36.914	2.133	9.503	11.211	2.304	0.145	8.424	2.732
1991	10.370	35.858	46.559	0.016	9.588	10.824	2.721	0.119	6.121	6.349
1992	10.014	34.285	45.339	0.849	18.411	10.069	3.364	0.216	2.734	4.468
1993	9.304	28.953	69.113	0.306	10.837	8.076	2.315	0.303	1.403	1.714
1994	14.987	37.084	60.284	0.368	7.474	8.832	2.495	0.185	1.817	1.393
1995	11.376	41.549	51.917	0.076	4.410	9.790	6.047	0.218	1.326	1.338
1996	16.866	47.730	55.293	0.182	10.286	6.562	2.632	0.092	1.398	1.424
1997	8.781	42.758	57.378	0.669	12.233	5.133	2.952	0.152	0.999	1.934
1998	7.055	31.024	77.210	0.359	10.806	8.642	3.441	0.281	2.088	0.899
1999	4.502	30.035	55.493	0.449	12.301	8.104	5.318	0.308	1.360	1.237
2000	6.589	30.820	54.028	0.534	8.239	14.873	10.593	0.799	2.481	2.278
2001	5.242	23.841	69.050	0.889	7.337	9.400	8.251	1.813	3.781	4.149
2002	5.494	25.772	63.850	0.346	13.285	5.933	3.621	0.261	2.463	2.491
2003	3.480	28.138	63.416	0.708	19.794	6.013	4.048	0.281	2.779	1.751
2004	4.220	23.227	58.446	0.390	28.427	7.221	4.717	0.400	2.486	3.466
2005	3.480	22.259	62.880	0.549	23.869	4.155	2.323	0.197	2.897	1.904
2006	6.381	25.189	53.352	0.331	19.598	6.753	1.723	0.121	1.596	3.081
2007	10.275	32.913	53.220	0.230	14.687	8.832	3.319	0.310	0.977	1.351
2008	9.473	32.672	50.284	0.396	13.481	5.327	1.560	0.084	2.251	1.354
2009	7.725	22.891	42.567	0.308	12.226	5.376	1.802	0.138	1.771	1.395
2010	7.607	22.543	41.919	0.412	16.334	5.751	1.928	0.147	1.548	1.218
2011	8.442	25.019	46.524	0.476	18.837	9.014	3.021	0.230	1.498	1.180
2012	9.030	26.758	49.758	0.439	17.375	6.587	2.208	0.168	1.758	1.383
2013	10.436	30.926	57.508	0.507	20.082	7.613	2.552	0.195	2.031	1.599

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Table A2: Offshore trawl catches pre-1978.

	M. paradoxus	M. capensis		M. paradoxus	M. capensis
1917	-	1.000	1948	0.059	58.741
1918	-	1.100	1949	0.113	57.287
1919	-	1.900	1950	0.275	71.725
1920	-	0.000	1951	0.662	88.838
1921	-	1.300	1952	1.268	87.532
1922	-	1.000	1953	2.558	90.942
1923	-	2.500	1954	5.438	99.962
1924	-	1.500	1955	10.924	104.476
1925	-	1.900	1956	19.581	98.619
1926	-	1.400	1957	34.052	92.348
1927	-	0.800	1958	51.895	78.805
1928	-	2.600	1959	76.609	69.391
1929	-	3.800	1960	100.490	59.410
1930	-	4.400	1961	104.009	44.691
1931	-	2.800	1962	109.596	38.004
1932	-	14.300	1963	129.966	39.534
1933	-	11.100	1964	126.567	35.733
1934	-	13.800	1965	159.704	43.296
1935	-	15.000	1966	154.109	40.891
1936	-	17.700	1967	147.060	43.826
1937	-	20.200	1968	127.848	43.660
1938	-	21.100	1969	150.005	53.025
1939	-	20.000	1970	124.999	41.224
1940	-	28.600	1971	175.462	56.653
1941	-	30.600	1972	217.076	73.553
1942	0.001	34.499	1973	161.524	68.614
1943	0.001	37.899	1974	143.170	70.683
1944	0.002	34.098	1975	104.949	52.131
1945	0.004	29.196	1976	140.273	55.551
1946	0.011	40.389	1977	99.775	39.525
1947	0.021	41.379			

Table A3: Assumptions made to disaggregate the inshore, longline and handline catches by depth, region and species from 1978.

		Inshore		Longline		Handline	
		% of catch by coast	M. capensis proportion	% of catch	M. capensis proportion	% of catch by coast	M. capensis proportion
West Coast	0-100m	-		-		-	
	101-200m	-		20%	85%	-	
	201-300m	-		50%	47%	-	
	301-400m	-		30%	10%	-	
	401m+	-		-		-	
South Coast	0-50m	10%	Assume 100% M. capensis	10%	Assume 100% M. capensis	30%	Assume 100% M. capensis
	51-100m	40%		40%		50%	
	101-200m	50%		50%		20%	
	201m+	-		-		-	

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Table A.4: South Coast inshore, West Coast and South Coast longline and South Coast handline catches by species.

| | M. paradoxus | | M. capensis | | |
| | Longline | Inshore | Longline | Longline | Handline |
	WC	SC	WC	SC	SC
1960	-	1.000	-	-	-
1961	-	1.308	-	-	-
1962	-	1.615	-	-	-
1963	-	1.923	-	-	-
1964	-	2.231	-	-	-
1965	-	2.538	-	-	-
1966	-	2.846	-	-	-
1967	-	3.154	-	-	-
1968	-	3.462	-	-	-
1969	-	3.769	-	-	-
1970	-	4.077	-	-	-
1971	-	4.385	-	-	-
1972	-	4.692	-	-	-
1973	-	5.000	-	-	-
1974	-	10.056	-	-	-
1975	-	6.372	-	-	-
1976	-	5.740	-	-	-
1977	-	3.500	-	-	-
1978	-	4.931	-	-	-
1979	-	6.093	-	-	-
1980	-	9.121	-	-	-
1981	-	9.400	-	-	-
1982	-	8.089	-	-	-
1983	0.161	7.672	0.069	-	-
1984	0.256	9.035	0.110	0.016	-
1985	0.817	9.203	0.350	0.292	0.065
1986	0.965	8.724	0.413	0.302	0.084
1987	2.500	8.607	1.071	0.353	0.096
1988	3.628	8.417	1.555	0.331	0.071
1989	0.203	10.038	0.087	0.032	0.137
1990	0.270	10.012	0.116	-	0.348
1991	-	8.206	-	3.000	1.270
1992	-	9.252	-	1.500	1.099
1993	-	8.870	-	0.000	0.278
1994	1.130	9.569	0.484	0.626	0.449
1995	0.670	10.630	0.287	0.650	0.756
1996	1.676	11.062	0.718	1.828	1.515
1997	1.806	8.834	0.774	1.872	1.404
1998	0.647	8.283	0.277	1.471	1.738
1999	1.963	8.595	0.841	4.144	2.749
2000	3.294	10.906	1.412	2.077	5.500
2001	2.656	11.836	1.138	1.688	7.300
2002	4.802	9.581	2.058	3.945	3.500
2003	4.081	9.883	1.749	4.878	3.000
2004	3.606	10.004	1.546	4.429	1.600
2005	4.105	7.881	1.759	4.559	0.700
2006	4.033	5.524	1.729	4.032	0.400
2007	3.525	6.350	1.511	3.834	0.400
2008	2.934	5.496	1.258	2.740	0.231
2009	3.667	5.639	1.571	3.841	0.265
2010	3.305	5.472	1.417	3.829	0.275
2011	4.176	6.013	1.790	2.914	0.185
2012	4.588	3.223	1.966	1.845	0.008
2013	5.634	3.958	2.415	2.266	0.010

Table A.5: South and west coast historic GLM standardized CPUE data 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

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Table A.6a: Survey abundance estimates and associated standard errors in thousand tons for *M. paradoxus* by depth range for the **West Coast summer and winter surveys**. Values in bold are for the surveys conducted by the *Africana* with the new gear.

| Year | West coast summer | | | | | | | | West coast summer | | | | | | | |
| | 101-200m | | 201-300m | | 301-400m | | 400m+ | | 101-200m | | 201-300m | | 301-400m | | 400m+ | |
	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)
1985	11.117	(3.78)	50.335	(14.55)	85.437	(32.42)	35.070	(8.28)	5.108	(0.61)	54.380	(14.18)	152.058	(47.79)	65.293	(17.83)
1986	30.872	(21.55)	101.225	(23.45)	57.453	(16.76)	18.561	(5.17)	6.311	(1.14)	50.685	(10.98)	83.270	(18.60)	44.210	(10.68)
1987	48.816	(15.65)	154.232	(45.98)	59.899	(13.22)	33.858	(16.92)	12.973	(2.34)	55.939	(22.82)	85.310	(25.92)	53.261	(27.83)
1988	27.620	(5.68)	53.726	(12.10)	63.187	(18.63)	26.226	(14.97)	9.254	(1.50)	31.533	(7.69)	116.333	(34.22)	87.920	(53.52)
1989	-	-	-	-	-	-	-	-	12.808	(2.35)	78.490	(19.55)	314.175	(119.24)	75.307	(31.25)
1990	8.240	(2.28)	196.712	(76.43)	63.123	(17.57)	26.099	(8.82)	11.594	(2.67)	67.653	(17.97)	68.182	(26.01)	91.434	(33.32)
1991	21.044	(6.53)	145.146	(36.39)	156.539	(73.29)	16.291	(3.89)	-	-	-	-	-	-	-	-
1992	15.470	(2.97)	112.219	(25.69)	80.978	(19.99)	30.021	(4.49)	-	-	-	-	-	-	-	-
1993	34.815	(13.73)	180.000	(37.89)	89.653	(26.35)	41.682	(14.33)	-	-	-	-	-	-	-	-
1994	24.171	(3.95)	145.208	(29.59)	121.534	(45.61)	51.357	(20.74)	-	-	-	-	-	-	-	-
1995	42.507	(10.88)	167.316	(72.84)	107.985	(31.81)	18.746	(4.58)	-	-	-	-	-	-	-	-
1996	40.182	(8.13)	301.230	(77.45)	55.892	(15.02)	45.603	(14.38)	-	-	-	-	-	-	-	-
1997	67.281	(18.01)	247.387	(67.76)	214.094	(80.58)	53.196	(17.28)	-	-	-	-	-	-	-	-
1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1999	54.259	(9.58)	260.742	(104.51)	206.051	(47.27)	53.807	(16.65)	-	-	-	-	-	-	-	-
2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	27.633	(9.76)	135.865	(27.73)	59.710	(15.82)	56.278	(10.74)	-	-	-	-	-	-	-	-
2003	42.421	(9.11)	179.999	(43.14)	136.481	(41.44)	62.255	(33.99)	-	-	-	-	-	-	-	-
2004	**18.560**	(4.06)	**72.253**	(15.25)	**70.936**	(14.94)	**109.777**	(51.63)	-	-	-	-	-	-	-	-
2005	**52.068**	(9.01)	**108.481**	(26.49)	**81.766**	(15.99)	**56.101**	(23.44)	-	-	-	-	-	-	-	-
2006	24.982	(4.13)	98.945	(17.07)	125.296	(40.13)	78.088	(23.03)	-	-	-	-	-	-	-	-
2007	**20.967**	(5.52)	**128.868**	(55.81)	**163.038**	(35.85)	**91.869**	(21.82)	-	-	-	-	-	-	-	-
2008	**15.328**	(3.58)	**52.353**	(8.25)	**94.339**	(18.31)	**96.522**	(47.80)	-	-	-	-	-	-	-	-
2009	**53.701**	(12.03)	**152.448**	(19.61)	**72.631**	(12.03)	**63.455**	(11.83)	-	-	-	-	-	-	-	-
2010	57.596	(12.42)	217.839	(51.02)	229.617	(59.65)	96.469	(32.04)	-	-	-	-	-	-	-	-
2011	**50.615**	(15.60)	**97.338**	(23.88)	**94.823**	(45.72)	**116.161**	(75.24)	-	-	-	-	-	-	-	-

Table A.6b: Survey abundance estimates and associated standard errors in thousand tons for **M. paradoxus** by depth range for the **South Coast spring and autumn surveys**. Values in bold are for the surveys conducted by the *Africana* with the new gear.

Year	West Coast spring				West Coast autumn			
	100-200m		200m+		100-200m		200m+	
	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)
1985	-	-	-	-	-	-	-	-
1986	5.091	(3.05)	8.667	(1.82)	-	-	-	-
1987	3.324	(2.39)	18.231	(3.93)	-	-	-	-
1988	-	-	-	-	2.997	(2.93)	27.318	(10.71)
1989	-	-	-	-	0.516	(0.362)		
1990	7.785	(6.43)	77.596	(15.52)	15.669	(12.41)	3.506	(3.51)
1991	-	-	-	-	10.278	(9.33)	16.361	(4.73)
1992	-	-	-	-	0.732	(0.49)	23.572	(15.19)
1993	7.694	(4.82)	-	-	21.230	(13.75)	177.619	(97.49)
1994	19.615	(19.61)	-	-	4.711	(3.49)	106.759	(34.45)
1995	3.563	(2.477)	-	-	12.606	(10.46)	42.462	(19.78)
1996	-	-	-	-	7.227	(4.50)	78.319	(25.08)
1997	-	-	-	-	23.019	(15.86)	112.174	(48.51)
1998	-	-	-	-	-	-	-	-
1999	-	-	-	-	51.224	(39.93)	270.253	(106.31)
2000	-	-	-	-	-	-	-	-
2001	0.369	(0.17)	19.561	(9.95)	-	-	-	-
2002	-	-	-	-	-	-	-	-
2003	**5.956**	(2.99)	**82.487**	(35.93)	6.856	(6.39)	102.002	(36.98)
2004	**1.203**	(0.71)	**62.697**	(17.88)	**3.049**	(2.05)	**45.849**	(20.24)
2005	-	-	-	-	**0.729**	(0.44)	**25.876**	(7.94)
2006	8.060	(3.69)	64.355	(15.05)	5.274	(2.72)	29.525	(7.87)
2007	**0.882**	(0.52)	**51.405**	(19.22)	**6.481**	(4.08)	**123.165**	(60.52)
2008	**3.776**	(1.87)	**21.041**	(8.57)	**5.178**	(3.55)	**34.327**	(10.84)
2009	-	-	-	-	**2.503**	(1.75)	**100.331**	(28.62)
2010	-	-	-	-	9.903	(5.52)	159.661	(67.42)
2011	-	-	-	-	**0.595**	(0.25)	**23.510**	(7.08)

Table A.6c: Survey abundance estimates and associated standard errors in thousand tons for **M. capensis** by depth range for the **West Coast summer and winter surveys**. Values in bold are for the surveys conducted by the *Africana* with the new gear.

	West coast summer								West coast summer							
Year	0-101m		101-200m		201-300m		301-400m		0-101m		101-200m		201-300m		301-400m	
	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)
1985	61.651	(20.53)	44.629	(9.26)	15.533	(2.68)	2.663	(1.11)	48.234	(22.29)	69.817	(10.08)	48.283	(9.74)	15.153	(7.85)
1986	17.934	(7.81)	55.371	(13.60)	39.600	(17.51)	4.905	(2.48)	5.757	(4.37)	43.948	(8.70)	50.463	(14.26)	19.328	(6.61)
1987	7.689	(5.04)	43.051	(7.44)	23.817	(4.90)	1.137	(0.46)	11.989	(6.72)	33.147	(6.25)	31.043	(4.11)	11.211	(4.92)
1988	13.495	(6.34)	27.398	(4.73)	17.005	(5.87)	8.827	(4.33)	12.431	(6.54)	12.573	(2.77)	16.109	(5.51)	6.007	(3.29)
1989	-	-	-	-	-	-	-	-	165.643	(60.10)	101.802	(24.73)	41.998	(14.14)	14.389	(10.26)
1990	225.763	(126.58)	173.224	(45.14)	50.653	(14.53)	5.914	(4.40)	27.643	(7.74)	48.202	(11.39)	64.726	(17.41)	17.005	(7.91)
1991	20.325	(12.44)	35.819	(7.71)	17.659	(2.49)	3.555	(2.10)	-	-	-	-	-	-	-	-
1992	10.732	(2.60)	40.548	(7.37)	39.663	(8.70)	4.403	(1.08)	-	-	-	-	-	-	-	-
1993	1.769	(0.51)	38.414	(7.94)	45.794	(11.49)	6.375	(4.19)	-	-	-	-	-	-	-	-
1994	10.777	(4.70)	37.320	(5.57)	69.426	(35.17)	3.273	(1.49)	-	-	-	-	-	-	-	-
1995	61.086	(18.58)	98.815	(17.81)	32.169	(7.20)	6.771	(2.09)	-	-	-	-	-	-	-	-
1996	7.464	(2.83)	37.636	(6.44)	30.492	(5.60)	7.561	(2.29)	-	-	-	-	-	-	-	-
1997	74.578	(28.39)	141.749	(35.48)	34.173	(7.33)	6.375	(1.71)	-	-	-	-	-	-	-	-
1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1999	36.769	(17.95)	60.419	(14.62)	80.415	(21.57)	20.075	(7.22)	-	-	-	-	-	-	-	-
2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2001	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	18.046	(4.80)	51.529	(13.19)	30.491	(6.48)	6.151	(3.32)	-	-	-	-	-	-	-	-
2003	7.009	(2.29)	23.152	(4.05)	39.077	(12.26)	6.356	(2.32)	-	-	-	-	-	-	-	-
2004	**46.523**	(14.52)	**138.956**	(29.71)	**14.957**	(2.60)	**4.684**	(1.60)	-	-	-	-	-	-	-	-
2005	**29.888**	(11.06)	**23.859**	(8.04)	**10.732**	(1.38)	**5.900**	(1.68)	-	-	-	-	-	-	-	-
2006	48.793	(22.31)	23.542	(3.99)	13.951	(2.83)	2.107	(0.62)	-	-	-	-	-	-	-	-
2007	**21.436**	(7.79)	**40.665**	(5.84)	**18.644**	(5.96)	**1.432**	(0.77)	-	-	-	-	-	-	-	-
2008	**7.503**	(3.02)	**21.095**	(2.41)	**19.153**	(3.60)	**3.126**	(0.92)	-	-	-	-	-	-	-	-
2009	**94.768**	(37.55)	**63.486**	(13.35)	**14.173**	(2.14)	**2.829**	(0.90)	-	-	-	-	-	-	-	-
2010	9.790	(3.85)	108.439	(30.73)	39.224	(14.90)	5.952	(2.20)	-	-	-	-	-	-	-	-
2011	**18.715**	(9.95)	**39.547**	(12.77)	**26.655**	(16.53)	**3.475**	(1.86)	-	-	-	-	-	-	-	-

Table A.6d: Survey abundance estimates and associated standard errors in thousand tons for **M. capensis** by depth range for the **South Coast spring and autumn surveys**. Values in bold are for the surveys conducted by the *Africana* with the new gear.

Year	South Coast spring 0-50m Biomass	(s.e.)	51-100m Biomass	(s.e.)	101-200m Biomass	(s.e.)	200m+ Biomass	(s.e.)	0-50m Biomass	(s.e.)	51-100m Biomass	(s.e.)	101-200m Biomass	(s.e.)	200m+ Biomass	(s.e.)
1985	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1986	0.773	(0.40)	21.704	(3.56)	75.763	(10.78)	22.957	(12.14)	-	-	-	-	-	-	-	-
1987	2.516	(1.86)	32.010	(5.26)	91.051	(11.87)	33.512	(11.18)	-	-	-	-	-	-	-	-
1988	-	-	-	-	-	-	-	-	7.447	(6.36)	51.023	(5.46)	101.829	(20.05)	5.640	(2.48)
1989	-	-	-	-	-	-	-	-	2.660	(1.158)	63.188	(14.601)	107.375	(14.745)	-	-
1990	4.729	(1.49)	57.827	(11.46)	149.793	(17.03)	39.577	(7.92)	3.201	(1.57)	69.029	(10.92)	157.946	(34.36)	-	-
1991	2.305	(1.318)	26.896	(5.059)	95.061	(17.058)	-	-	3.070	(0.69)	69.798	(9.93)	117.913	(21.22)	83.517	(37.70)
1992	2.380	(1.015)	31.143	(5.707)	167.354	(30.016)	-	-	6.609	(3.80)	48.614	(7.15)	81.832	(13.04)	1.030	(0.44)
1993	2.081	(0.68)	35.016	(4.220)	96.764	(18.06)	-	-	1.550	(0.56)	55.231	(6.35)	89.644	(10.81)	11.915	(5.57)
1994	4.482	(2.09)	51.136	(6.017)	116.523	(16.67)	-	-	2.728	(1.46)	30.891	(4.54)	90.589	(12.51)	36.347	(19.56)
1995	8.995	(3.778)	65.620	(11.972)	133.765	(22.208)	-	-	20.144	(10.96)	70.534	(15.45)	142.287	(25.48)	3.059	(2.36)
1996	-	-	-	-	-	-	-	-	14.525	(3.77)	86.525	(9.80)	136.439	(22.62)	6.921	(2.90)
1997	-	-	-	-	-	-	-	-	4.077	(1.25)	37.909	(4.83)	99.752	(14.44)	41.349	(11.14)
1998	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1999	-	-	-	-	-	-	-	-	5.454	(3.49)	68.099	(8.20)	97.867	(9.87)	19.782	(6.84)
2000	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2001	0.574	(0.43)	32.799	(10.25)	73.315	(9.55)	27.106	(15.45)	-	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2003	**1.105**	(0.62)	**12.853**	(2.11)	**57.322**	(6.57)	**11.648**	(5.76)	5.635	(3.65)	29.678	(4.14)	80.779	(18.79)	12.358	(4.35)
2004	**2.004**	(0.85)	**20.369**	(4.57)	**72.270**	(14.41)	**11.477**	(3.74)	**0.471**	(0.34)	**29.486**	(6.43)	**53.114**	(7.50)	**16.831**	(6.84)
2005	-	-	-	-	-	-	-	-	2.171	(1.49)	**25.657**	(3.49)	**45.829**	(4.36)	**3.275**	(1.47)
2006	0.766	(0.48)	28.617	(4.69)	60.564	(7.56)	9.920	(4.09)	0.181	(0.18)	32.887	(4.32)	89.396	(13.78)	8.437	(3.31)
2007	**0.218**	(0.18)	**15.080**	(3.21)	**53.115**	(6.18)	**6.203**	(2.45)	0.581	(0.52)	**29.812**	(3.69)	**37.427**	(3.97)	3.121	(1.35)
2008	**2.268**	(0.50)	**14.619**	(4.04)	**59.867**	(8.53)	**17.478**	(6.48)	1.319	(0.99)	**35.906**	(6.42)	**69.140**	(7.54)	**1.830**	(0.70)
2009	-	-	-	-	-	-	-	-	**2.666**	(1.98)	**42.644**	(6.35)	**73.472**	(9.35)	**5.222**	(2.79)
2010	-	-	-	-	-	-	-	-	4.288	(0.88)	85.778	(29.99)	77.571	(20.75)	17.322	(9.58)
2011	-	-	-	-	-	-	-	-	**0.305**	(0.22)	**36.141**	(7.08)	**74.179**	(9.35)	**6.597**	(1.72)

Table A.7: Commercial catch-at-age and catch-at-length data available.

| | 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	-	CAL	-	-	-	-	-
1976	-	CAL	-	-	-	-	-
1977	-	CAL	-	-	-	-	-
1978	CAA	CAA	-	-	-	-	-
1979	CAA	CAA	-	-	-	-	-
1980	CAA	CAA	-	-	-	-	-
1981	CAA	CAA	CAL	-	-	-	-
1982	CAA	CAA	CAL	-	-	-	-
1983	CAA	CAA	CAL	-	-	-	-
1984	CAA	CAA	CAL	-	-	-	-
1985	CAA	CAA	CAL	-	-	-	-
1986	CAA	CAA	CAL	-	-	-	-
1987	CAA	CAA	CAL	-	-	-	-
1988	CAA	CAA	CAL	-	-	-	-
1989	CAA	CAA	CAA	-	-	-	-
1990	CAA	CAA	CAA	-	-	-	-
1991	CAA	CAA	CAA	-	-	-	-
1992	CAA	CAA	CAA	-	-	-	-
1993	CAA	CAA	CAA	-	-	-	-
1994	CAA	CAA	CAA	CAL	-	-	CAA
1995	CAA	CAA	CAA	CAL	-	-	CAA
1996	CAA	CAA	CAA	CAL	-	-	CAA
1997	CAL		CAA	CAL	-	-	CAA
1998	CAL		CAA	-	-	-	-
1999	CAL		CAL	-	-	-	-
2000	-		CAA	-	CAL	CAL	CAL
2001	-		CAL	-	CAL	CAL	CAL
2002	-		-	-	CAL	CAL	CAL
2003	-		-	-	CAL	CAL	CAL
2004	-		-	-	CAL	CAL	CAL
2005	CAL		-	-	CAL	CAL	CAL
2006	CAL		-	-	CAL	CAL	CAL
2007	CAL		CAL	-	CAL	CAL	CAL
2008	CAL		CAL	-	CAL	CAL	CAL
2009	CAL		CAL	-	CAL	CAL	CAL
2010	CAL		CAL	-	CAL	CAL	CAL
2011	CAL		CAL	-	-	-	-
2012	CAL		CAL	-	-	-	-

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Table A.8: Survey catch-at-length data available.

	West coast		South coast	
Year	Summer	Winter	Spring	Autumn
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	✓	-	-	✓

Appendix B: Methods

B.1 Population Dynamics

r: an index for region, $r=1,\ldots, n_{region}$ (here $n_{region}=9$)

y: an index for year

a: an index for age, $a=0,\ldots, m$ ($m=15$, a plus group)

l: an index for length $l=1,\ldots, l_{max}$ ($l_{max}=105$)

f: an index for fleet, $f=1,\ldots n_{fleet}$ ($n_{fleet}=4$)

The equations below apply to each hake species, with different parameter values by species. The species indices have been omitted to avoid clutter.

Since too many assumptions would have to be made to disaggregate the catches by region and species pre-1978, the decision was made to model a single region pre-1978 and to include movement only from 1978 onwards.

B1.1 Numbers-at-age:

Pre-1978, the model is not region dependent:

$$N_{y+1,0} = R_{y+1} \tag{B1}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - \sum_f^{n_{fleet}} C_{y,a}^f \right) e^{-M_a/2} \qquad \text{for } 0 \le a \le m-2 \tag{B2}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{m-1}/2} - \sum_f^{n_{fleet}} C_{y,m-1}^f \right) e^{-M_{m-1}/2} + \left(N_{y,m}\, e^{-M_m/2} - \sum_f^{n_{fleet}} C_{y,m}^f \right) e^{-M_m/2} \tag{B3}$$

From 1978 onwards, region-disaggregation and movement between regions are included:

$$N_{y+1,0}^r = x^r R_{y+1} \qquad \text{for } a=0 \tag{B4}$$

$$N_{y+1,a+1}^r = \sum_{r'}^{n_{region}} \left(\left[\left\{ N_{y,a}^{r'} e^{-M_a/2} - \sum_f^{n_{fleet}} C_{f,y,a}^{r'} \right\} e^{-M_a/2} \right] X_{y,a}^{\text{out } r',\text{in } r} \right) \qquad \text{for } 0 \le a \le m-2 \tag{B5}$$

$$\begin{aligned} N_{y+1,m}^r &= \sum_{r'}^{n_{region}} \left(\left[\left\{ N_{y,m-1}^{r'} e^{-M_{m-1}/2} - \sum_f^{n_{fleet}} C_{f,y,m-1}^{r'} \right\} e^{-M_{m-1}/2} \right] X_{y,m-1}^{\text{out } r',\text{in } r} \right) \\ &+ \sum_{r'}^{n_{region}} \left(\left[\left\{ N_{y,m}^{r',spp,s} e^{-M_m/2} - \sum_f^{n_{fleet}} C_{f,y,m}^{r'} \right\} e^{-M_m/2} \right] X_{y,m}^{\text{out } r',\text{in } r} \right) \end{aligned} \tag{B6}$$

i.e. in order through the year: 1) recruit, 2) die of natural causes in first half of the year, 3) catch taken as pulse in the middle of the year, 4) second half year of natural mortality, 5) move.

$N_{y,a}^r$: the number of fish of age a at the start of year y in region r,

M_a : the natural mortality on fish of age a (assumed to be region independent)

$$M_a = \begin{cases} M_2 & \text{for} & a \le 1 \\ \alpha^M + \dfrac{\beta^M}{a+1} & \text{for} & 2 \le a \le 5 \\ M_5 & \text{for} & a > 5 \end{cases} \tag{B7}$$

$C_{f,y,a}^{r}$: the number of fish of species *spp*, and age *a* caught in year *y* and region *r* by fleet *f*,

$X_{y,a}^{r',r}$: the probability that a fish of age *a* in region *r'* at the start of year *y* moves to region *r* at the end of that year ($X_{y,a}^{r,r}$ is the probability that the fish stays in region *r*), and

x^{r} is the proportion of recruits in region *r* which is estimated directly in the model fitting,

where:

$$X_{y,a}^{r',r} = \frac{G_a^{r',r}}{\sum_r G_a^{r',r}}$$ (B8)

where

$$G_a^{r',r} = \begin{cases} \exp(g_a^r) & r' \neq r \\ \exp(v_a^{r'} + g_a^r) & r' = r \end{cases}$$ (B9)

g_a^r is the gravity term for region *r* and age group *a*,

$v_a^{r'}$ is the residency term for region r and age group *a*.

Distribution of the fish by region in 1978:

$$N_{1978,a}^r = \left(\frac{1}{n_{region}} \sum_{r'}^{n_{region}} X_{y+1,0}^{out\, r',in\, r} \right) N_{1978,a}^{tot}$$ (B10)

B1.2 Recruitment:

$$R_y = f(SSB_y)$$ (B11)

the recruitment (number of 0-year-old fish) at the start of year *y*, which is a function of the total spawning biomass (SSB_y):

$$R_y = \frac{4hR_0 SSB_y}{K^{sp}(1-h) + (5h-1)SSB_y} e^{(\varsigma_y - \sigma_R^2/2)}$$ (B12)

for the Beverton-Holt stock-recruitment relationship and

$$R_y = \alpha SSB_y \exp\left(-\beta(SSB_y)^\gamma\right) e^{(\varsigma_y - \sigma_R^2/2)}$$ (B13)

with

$$\alpha = R_0 \exp\left(\beta(SSB_y)^\gamma\right) \qquad \text{and} \qquad \beta = \frac{\ln(5h)}{(SSB_y)^\gamma(1 - 5^{-\gamma})}$$ (B14)

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

$$R_0 = SSB_y \left/ \left[\sum_{a=1}^{m-1} mat_a w_a e^{-\sum_{a'=0}^{a-1} M_{a'}} + mat_m w_m \frac{e^{-\sum_{a'=0}^{m-1} M_{a'}}}{1 - e^{-M_m}} \right] \right.$$ (B15)

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

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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) .

B1.3 Spawning biomass:

$$SSB_y = \sum_{r=1}^{n_{region}}\sum_{a=1}^{m} mat_a w_a N_{y,a}^r \qquad (B16)$$

w_a : the begin-year mass of fish of age a

mat_a : the proportion of fish of age a that are mature, converted from maturity-at-length as follows:

$$mat_a = \sum_l mat_l P_{a,l} \qquad (B17)$$

$P_{a,l}$ is the begin-year proportion of fish of age a and that fall in the length group l (i.e., $\sum_l P_{a,l} = 1$ for all

ages a).

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

$$l_a \sim N\left[l_\infty\left(1 - e^{-\kappa(a-t_0)}\right); \theta_a^2\right] \qquad (B18)$$

where θ_a is the standard deviation of length-at-age a, which is modelled to be proportional to the expected length-at-age a, i.e.:

$$\theta_a = \beta L_\infty\left(1 - e^{-\kappa(a-t_o)}\right) \qquad (B19)$$

with β an estimable parameter.

B1.4 Catch:

The fleet-disaggregated catch by mass in year y and region r is given by:

$$C_{f,y}^r = \sum_a \widetilde{w}_{a+1/2}\, C_{f,y,a}^r \qquad (B20)$$

$$C_{f,y,a}^r = N_{y,a}^r e^{-M_a/2} S_{f,y,a} F_{f,y}^r \qquad (B21)$$

$F_{f,y}^r$: the fished proportion of a fully selected age class for fleet f in year y and region r and

$$S_{f,y,a} = \sum_l S_{f,y,l} P_{a+1/2,l} \qquad (B22)$$

S_{fya} is the commercial selectivity (not region specific) at age a for fleet f and year y;

$$\widetilde{w}_{fy,a+1/2} = \sum_l S_{f,y,l} w_l P_{a+1/2,l} \Big/ \sum_l S_{f,y,l} P_{a+1/2,l} \qquad (B23)$$

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

w_l is the weight of fish of length l;

B.2 The likelihood function

The model is fit to CPUE and survey biomass indices, commercial and survey length frequencies, , as well as to the stock-recruitment curve to estimate model parameters. Contributions by each of these to the negative of the log-likelihood (- ℓnL) are as follows[1].

B.2.1 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:

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \quad \text{or} \quad \varepsilon_y^i = \ell n\left(I_y^i\right) - \ell n\left(\hat{I}_y^i\right) \tag{B24}$$

where

I_y^i is the biomass index for year y and series i (which corresponds to a specified species, fleet and sum of regions);

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

$$B_y^{ex} = \sum_r \sum_{a=0}^m \widetilde{w}_{y,a}^{mid} S_{y,a} N_{y,a}^r e^{-M_a/2} (1 - S_{y,a} F_y^r / 2) \tag{B25}$$

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

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

The GLM-CPUE series are coast- and species-specific but not disaggregated by region. The West Coast series are taken to apply to the regions "201-300m", "301-400m" and "400m+" combined. The South Coast series are taken to apply to the regions "101-200m" and "200m+" combined.

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:

$$C_{BS,fy} = C_{C,fy}^{z1} + C_{C,fy}^{z2} + C_{P,fy} \tag{B26}$$

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:

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[1] 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.

$$C_{C,fy}^{z1} = q_C^{i,z1} B_{Cfy}^{ex,z1} E_{fy}^{z1} = q_C^{i,z1}(1-\gamma)B_{C,fy}^{ex}(1-\psi_{fy})E_{fy} \tag{B27}$$

$$C_{C,fy}^{z2} = q_C^{i,z2} B_{C,fy}^{ex,z2} E_{fy}^{z2} = q_C^{i,z2}\gamma B_{C,fy}^{ex}\psi_{fy}E_{fy} \quad \text{and} \tag{B28}$$

$$C_{P,fy} = q_P^i B_{P,fy}^{ex} E_{fy}^{z2} = q_P^i B_{P,fy}^{ex}\psi_{fy}E_{fy} \tag{B29}$$

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

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

It follows that:

$$C_{C,fy} = B_{C,fy}^{ex}E_{fy}\left[q_C^{i,z1}(1-\gamma)(1-\psi_{fy})+q_C^{i,z2}\gamma\psi_{fy}\right] \tag{B30}$$

$$C_{P,fy} = B_{P,fy}^{ex}E_{fy}q_P^i\psi_{fy} \tag{B31}$$

From solving equations B30 and B31:

$$s_{fy} = \frac{q_C^{i,z1}(1-\gamma)}{\left\{\dfrac{C_{C,fy}B_{P,fy}^{ex}q_P^i}{B_{C,fy}^{ex}C_{P,fy}} - q_C^{i,z2}\gamma + q_C^{i,z1}(1-\gamma)\right\}} \tag{B32}$$

and:

$$\hat{I}_y^i = \frac{C_{fy}}{E_{fy}} = \frac{C_{fy}B_{P,fy}^{ex}q_P^i\psi_{fy}}{C_{P,fy}} \tag{B33}$$

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

$$q_s^{SC} = rq_s^{WC} \tag{B34}$$

To correct for possible negative bias in estimates of variance $\left(\sigma_y^i\right)$ 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:

$$-\lambda n\, L^{CPUE} = \sum_i \sum_y \left[\lambda n\left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2 \right]$$

(B35)

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

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

(B36)

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:

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

(B37)

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

B.2.2 Survey biomass data

Data from the research surveys are available by region. For each region, they are treated as relative biomass indices in a similar manner to the species-disaggregated CPUE series above, with survey selectivity function S_a^{surv} replacing the commercial selectivity S_{fya}:

$$B_y^{r,surv} = \sum_{a=0}^{m} \tilde{w}_a^{surv} S_a^{surv} N_{ya}^r e^{\frac{-\upsilon^{surv}}{12} M_a} \left(1 - \frac{\upsilon^{surv}}{12} \sum_f S_{fya} F_{fy}^r \right)$$

(B38)

where υ^{surv} is the month in which the survey is taking place

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 procedure adopted takes into account a species-specific 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.

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 B35). A single species-specific *q* per survey is estimated (i.e. same iq for all regions)

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

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

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:

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

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

where

$$\lambda nq^s_{new} = \lambda nq^s_{old} + \Delta \lambda nq^s \qquad \text{with } s = \textit{capensis} \text{ or } \textit{paradoxus} \tag{B39}$$

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. $\Delta \lambda nq^{capensis}$ 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:

$$-\lambda nL^{q-ch} = \left(\lambda nq_{new} - \lambda nq_{old} - \Delta \lambda nq\right)^2 / 2\sigma^2_{\Delta \lambda nq} \tag{B40}$$

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

B2.3 Commercial proportions at length

Commercial proportions at length are not disaggregated by region. The model is therefore fit to the proportions at length as determined for a combination of regions, and in cases where the data are not disaggregated by species, a combination of species as well.

The catches at length are computed as:

$$C_{fyl} = \sum_r \sum_s \sum_{a=0}^m N^r_{sya} F^r_{sfy} S_{sfyl} P_{s,a+1/2,l} e^{-M_{sa}/2} \left(1 - \sum_f S_{sfya} F^r_{sfy} / 2\right) \tag{B41}$$

with the predicted proportions at length:

$$\hat{p}^i_{yl} = C_{fyl} / \sum_{l'} C_{fyl'} \tag{B42}$$

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:

$$-\lambda n L^{\text{length}} = 0.01 \sum_y \sum_l \left[\lambda n \left(\sigma^i_{len} / \sqrt{p^i_{yl}} \right) + p^i_{yl} \left(\lambda np^i_{yl} - \lambda n \hat{p}^i_{yl} \right)^2 / 2\left(\sigma^i_{len}\right)^2 \right] \tag{B43}$$

where

the superscript '*i*' refers to a particular series of proportions at length data which reflect a specified fleet, combination of regions, 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:

$$\hat{\sigma}^i_{len} = \sqrt{\sum_y \sum_l p^i_{yl} \left(\ln p^i_{yl} - \ln \hat{p}^i_{yl} \right)^2 / \sum_y \sum_l 1} \tag{B44}$$

The initial 0.01 multiplicative factor is a somewhat arbitrary downweighting to allow for correlation between proportions in adjacent length groups.

Commercial proportions at length are incorporated in the likelihood function using equation B43, 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.

B2.4 Commercial proportions at age

As for the proportions at length, commercial proportions at age are not disaggregated by regions. The model is therefore fit to the proportions at age as determined for a combination of region and in cases where the data are not disaggregated by species, a combination of species as well.

The catches at age are computed as:

$$C_{fya} = \sum_r \sum_s \sum_{l=1}^{l\max} N_{sya}^r F_{sfy}^r S_{sfyl} P_{s,a+1/2,l} e^{-M_{sa}/2} \left(1 - \sum_f S_{sfya} F_{sfy}^r \Big/ 2 \right) \tag{B45}$$

with the predicted proportions at age:

$$\hat{p}_{ya}^i = C_{fya} \Big/ \sum_{a'} C_{fya'} \tag{B46}$$

The contribution of the proportion at age data is as for the proportions at length (equation B43), except that the multiplicative downweighting factor is fixed at 0.1 instead of 0.01.

B.2.5 Survey proportions at length

Survey proportions at length are available by region. They are incorporated into the negative of the log-likelihood in an analogous manner to the commercial catches-at-length, assuming an adjusted log-normal error distribution (equation B43). In this case however, data are disaggregated by species, and by region:

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

  y in region *r*; and

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

$$\hat{p}_{syl}^{r,surv} = \frac{\sum_a S_{sl}^{surv} P_{s,a+1/2,l} N_{sya}^r e^{\frac{-\upsilon^{surv}}{12} M_{sa}} \left(1 - \frac{\upsilon^{surv}}{12} \sum_f S_{sfya} F_{sfy}^r \right)}{\sum_{l'} \sum_a S_{sl'}^{surv} P_{s,a+1/2,l'} N_{sya}^r e^{\frac{-\upsilon^{surv}}{12} M_{sa}} \left(1 - \frac{\upsilon^{surv}}{12} \sum_f S_{sfya} F_{sfy}^r \right)} \tag{B47}$$

B.2.6 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:

$$-\ell n L^{SR} = \sum_s \left[\sum_{y=y1}^{y2} \varsigma_{sy}^2 \Big/ 2\sigma_R^2 \right] \tag{B48}$$

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* (estimating the stock-recruitment residuals is made possible by the availability of catch-at-length 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) decreasing linearly from 0.45 in 2004 to 0.1 in 2013, effectively forcing recruitment over the last years to lie closer to the stock-recruitment relationship curve.

B.3 Model parameters

B.3.1 Estimable parameters

The primary parameters estimated are the species-specific female virgin spawning biomass $\left(K_s^{\varsigma sp}\right)$ 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 species 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 value of β used to compute the standard deviation of the length-at-age *a* is also estimated in the fitting procedure.

Table B.1 summarises the estimable parameters, excluding the selectivity parameters.

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

B.3.1.1 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.

B.3.1.2 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 fit to proportion-at-age rather than proportion-at-length data, survey selectivities were estimated directly for each age (i.e. seven age classes). The lengths at which selectivity is estimated directly 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.

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) :

$$pen^{survS} = \sum_i \sum_{L=L_1+1}^{L_7-1} 3\left(S_{L-1}^s - 2S_L^s + S_{L+1}^s\right)^2 \tag{B49}$$

B.3.1.3 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:

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

(B50)

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.

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.

B.3.2 Input parameters and other choices for application to hake

B.3.2.1 Length-at-maturity

The proportion of fish of species *s* 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

B.3.2.2 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:	0.00669	3.02675
M. capensis:	0.00605	3.07313

B.3.2.3 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 B4. 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	Bounds enforced
K	2	$\ln(K^{\mathcal{G}}_{cap})$ and $\ln(K^{\mathcal{G}}_{para})$	(3.5; 9.0)
Stock-recruitment h	2	h_{cap} and h_{para}	(0.2; 0.98)
Stock-recruitment γ	2	γ_{cap} and γ_{para}	(0;10)
Additional variance	2	$\sigma_{A,cap}$ and $\sigma_{A,para}$	(0; 0.5)
Recruitment residuals	56	$\zeta_{cap,1985-2013}$ and $\zeta_{para,1985-2013}$	(-5; 5)
σ_{CPUE}	6	1 for each series	ICSEAF: (0.25; 1), GLM (0.15; 1)
ICSEAF CPUE	5	$q_C^{WC,z1}$, $q_C^{WC,z2}$, q_P^{WC}, ρ and γ	q and ρ: (0,10), and γ_R (0; 1)
Age-length distribution	2	For each species: β_i	(0.4;1.0)
Survey calibration	4	$\Delta \ell nq^{spp}$ and $\sigma_{\Delta \ell nq^{sp}}$ for each species	(-1;1) and (0;0.5)
Selectivities	34	see Table B3	
Prop. rec. in each region	10	x^r	(0; 1)
Movement parameters	68	g_a^r and v_a^r	(-20; 20)

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

M. paradoxus	13	21	29	37	45	53	60	65
M. capensis	13	22	31	40	49	58	65	71

Table B.3: Details for the commercial and survey selectivity-at-length for each fleet and species.

	M. paradoxus		*M. capensis*		data available
	No of est. parameters	Comments	No of est. parameters	Comments	
1. Offshore trawl					
1917-1976	0	set equal to 1989	0	set equal to 1989	
1977-1984	2	two logistic parameters estimated	0	differential shift compared to 1993+ as for paradoxus	species combined
1985-1992	0	linear change between 1984 and 1993 selectivity	0	linear change between 1984 and 1993 selectivity	species combined
1993-2013	2	two logisticestimated	0	same as SC inshore but shifted to the right by 5 cm	species combined
2. South coast inshore trawl	-	-	2	two logisticparameters estimated	*M. capensis*
3. Longline	2	two logistic parameters estimated	2	two logistic parameters estimated	species combined and species disaggregated
5. South coast handline	-	-	0	parameters taken as average of SC longline and inshore parameters	-
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
Total	18		16		

Table B4: Minus- and plus-groups taken for the surveys and commercial proportion at length data.

SURVEY CAL DATA

	M. paradoxus									
	0-100m		101-200m		201-300m		301-400m		401m+	
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus
West coast summer	-	-	10	35	10	35	20	70	25	75
West coast winter	-	-	10	35	10	45	15	65	25	75

	0-50m		51-100m		101-200m		200m+	
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus
South coast spring	-	-	-	-	20	45	20	60
South coast autumn	-	-	-	-	25	50	25	70

	M. capensis									
	0-100m		101-200m		201-300m		301-400m		401m+	
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus
West coast summer	10	35	10	70	25	75	47	75	-	-
West coast winter	15	35	15	70	20	80	40	70	-	-

	0-50m		51-100m		101-200m		200m+	
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus
South coast spring	10	55	10	70	10	80	40	85
South coast autumn	10	60	10	75	10	85	40	80

COMMERCIAL CAA DATA

	Spp combined		*M. paradoxus*		*M. capensis*	
	Minus	Plus	Minus	Plus	Minus	Plus
Offshore trawl	1	5	-	-	-	-
Inshore trawl	-	-	-	-	2	7
Longline	-	-	-	-	4	7

COMMERCIAL CAL DATA

	Spp combined		*M. paradoxus*		*M. capensis*	
	Minus	Plus	Minus	Plus	Minus	Plus
Offshore trawl	25	85	-	-	-	-
Inshore trawl	-	-	-	-	27	75
Longline	43	95	43	95	43	95