Detailed Methodology and Results for the Final Reference Set of the South African *Merluccius paradoxus* and *M. capensis* Resources for Use in OMP Testing

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Abstract

This document gives detailed methodology, data and results for the final Reference Set for the joint assessment of the South African *M. paradoxus* and *M. capensis* resources that will be used in OMP testing.

The Reference Set aims to take account of the factors that account for most of the uncertainty regarding the key considerations of resource status and productivity. This is achieved by including variations around four aspects of the assessment:

<u>M. Natural mortality</u>:

M1: upper bounds of 0.5 and 0.3 on ages 2 and 5/5+ respectively are implemented;
M4: upper bounds of 1.0 and 0.5 on ages 2 and 5/5+ respectively are implemented.

<u>C. Species split of the catch (see below for further explanation)</u>:

C3a: the logistic function used to split the pre-1978 offshore commercial catches by species has the parameters P_1=1950 and P_2=1.5;
C3b: the logistic function used to split the pre-1978 offshore commercial catches by species has the parameters P_1=1940 and P_2=1.5;
C3c: the logistic function used to split the pre-1978 offshore commercial catches by species has the parameters P_1=1957 and P_2=1.5.

[Note that scenarios which assume that the proportion of *M. capensis* in recent catches to have been negatively biased, previously named C6, will now be named C6a, b and c as corresponding equivalents to the above.]

<u>H. Steepness parameter</u>:

H1: the steepness parameters (h) for both *M. capensis* and *M. paradoxus* are estimated in the minimisation process;
H2: for *M. paradoxus*, h is fixed at 0.8 (lower than the 0.95 typically estimated), while this parameter is estimated for *M. capensis*;
H3: for *M. capensis*, h is fixed at 0.7 (lower than the 0.8-0.9 typically estimated), while this parameter is estimated for *M. paradoxus*;
H4: for *M. paradoxus*, h is fixed at 0.8, and for *M. capensis*, h is fixed at 0.7.

<u>SR. Recent stock-recruitment residuals</u>:

SR1: σ_R=0.25 throughout the period;
SR2: σ_R=0.25 from the beginning of the fishery to 2000 and then decreases linearly to 0.1 in 2004.

1. Data

The tables of data used are given in Appendix A.

1.1 Total catches

The South African hake stocks are fished by four fleets: the offshore trawl fleet and the longline fleet operate on both the south and west coasts, while the inshore trawl fleet and the handline fleet operate on the south coast only. The annual catches by mass assumed for each fleet and coast are given in Table A.1 for the period 1917 to 2004. A summary of the assumptions made to disaggregate the catches by species and fleet for the Reference Case is given below.

a) Offshore trawl fleet:

1978-2004:

The catches made by the offshore trawl fleet have been split by species by applying the size-based species proportion-by-depth relationships for the west and south coasts developed by Gaylard and Bergh (2004). This series is used as input for scenarios C3a-c. For scenarios C6-a-c, the assumption is made that the proportions of *M. capensis* in recent catches have been negatively biased. This constant bias is introduced as an error on d_s^* (see equations 2 and 3 of Glazer, 2005).

1917-1977:

Prior to 1978, there is no depth information recorded for the landings so that the proportion of *M. capensis* caught cannot be estimated using the method above. Previously, the proportion over the 1917-1977 period has been assumed to equal the average that pertained over the 1978-1982 in splitting the catches for these years. In this paper, the catch data for the 1917-1977 period are split by assuming that the proportion of *M. capensis* caught follows a logistic function over this period, starting at 1 and then decreasing to stabilise at the 1978-1982 average value. Indeed, trawling was concentrated in inshore areas around Cape Town when the fishery began (i.e. probably catching *M. capensis* exclusively) and progressively moved offshore, so that this seems a more defensible approach. The proportion of *M. capensis* in the offshore trawl catch in year *y* on coast *c* is thus given by:

$$prop_{cy}^{prop} = \frac{1-\Delta_c}{1+\exp[(y-P_1)/P_2]} + \Delta_c \qquad (1)$$

where

Δ_c is the average proportion of *M. capensis* in the offshore catch over the 1978-1982 period for coast *c* (24% and 60% on the west and south coasts respectively for scenarios C3a-c, and 30% and 65% on the west and south coasts respectively for scenarios C6a-c), and

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

The following scenarios have been included in the Reference Set:

C3a (C6a): P_1=1950 and P_2=1.5;

C3b (C6b): P_1=1940 and P_2=1.5;

C3c (C6c): P_1=1957 and P_2=1.5;

The proportion of *M. capensis* consequently assumed for the offshore trawl catches for scenarios C3a-c and C6a-c is shown in Fig. 1 for the west and for the south coasts.

b) Inshore trawl fleet:

The inshore trawl fleet operates on the south coast only. Catches made by this fleet are assumed to consist of *M. capensis* only, as it operates in relatively shallow water.

Because fleet-disaggregated catch data are not available prior to 1974, the assumption has been made that the annual catch of the inshore trawl fleet from 1960 to 1973 increased linearly from 1000t to 5000t, and that the balance of the total catch recorded was taken by the offshore trawl fleet.

c) Longline fleet:
Longline catches on the west coast are assumed to consist of 30% *M. capensis* for the whole period, while on the south coast, catches by this fleet are assumed to consist of *M. capensis* exclusively.

d) Handline fleet:
The handline fleet operates on the south coast only. As for the inshore fleet, catches made by this fleet are assumed to consist of *M. capensis* only.

The overall catch in 2004 is taken to be the TAC for that year, with the same proportion of each species as caught by each fleet in 2003 assumed.

1.2 Abundance indices

Historic and GLM-standardised CPUE data are given in Table A2. The historic CPUE series cannot be disaggregated by species, as there are no effort-by-depth data available for this pre-1978 period. The GLM standardized CPUE data used for scenarios C3a-c and C6a-c are from Glazer (2005); these are species-specific indices (and based also on the new Gaylard and Bergh estimated species-proportion *vs.* depth relationship).

Survey biomass estimates for the west and south coasts are shown in Table A3 for *M. paradoxus* and Table A4 for *M. capensis*.

1.3 Catches-at-age

Survey catch-at-age data are shown in Tables A5-A8 for *M. paradoxus* and in Tables A9-A13 for *M. capensis*.

Commercial catches-at-age for the offshore (both coasts combined) and for the inshore and longline (south coast only) fleets are shown in Table A14-A16. They cannot be split by species on an age-basis, but this is not a problem for the south coast inshore and longline fleets as their catches are assumed to consist of *M. capensis* only.

2. Methods

The model used in this analysis is an Age-Structured Production Model (ASPM) and is described in detail in Appendix B. This includes a new method introduced to model CPUE series based upon species-aggregated catches – see equations B14-20.

A summary of the specifications for each species for the Reference Case assessment is given below.

2.1 *M. paradoxus*

a) Plus-group:
Age 15 is used as the plus-group.

b) Natural mortality:
M_a is taken to be age-dependent (M_a) (with the form of equation as shown in B33). Upper bounds of 0.5 and 0.3 on ages 2 and 5 respectively are implemented for scenario M1 of the Reference Set, while upper bounds of 1.0 and 0.5 on ages 2 and 5 respectively are implemented for scenario M4 of the Reference Set. As there are not enough data to inform on the natural mortalities at ages above 5 for *M. paradoxus*, the natural mortality estimated for age 5 for *M. paradoxus* is assumed to apply to older ages as well.

c) Commercial selectivity-at-age:
The selectivities of the offshore and longline fleet (the two fleets assumed to catch *M. paradoxus*) take the form of a logistic curve (equation B35). As there is no information on the age-structure of the longline catches of *M. paradoxus* alone, the selectivity of the longline fleet for *M. paradoxus* is assumed to be of the same form as the longline selectivity for *M. capensis* (which can be estimated from the south coast longline catches-at-age – assumed to be *M. capensis* only). The selectivity for the longline fleet is assumed to be flat for older ages.

This assessment makes use of the offshore species-combined catch-at-age data (ignored in previous species-disaggregated assessments), so that if the selectivity of one of the species is known, the selectivity of the other species can be estimated. In this case, an assumption is made for the offshore selectivity for *M. capensis* (see below), and therefore the offshore selectivity for *M. paradoxus* can be estimated directly. Periods of fixed and changing selectivity have been assumed to take account for the change in the selectivity at low ages over time in the commercial catches, likely due to the phasing out of net liners. The first selectivity period is from 1917 to 1976 and with selectivities set equal to their 1989 values, as the use of net liners after 1976 would have caused a shift towards catching smaller fish. The second selectivity period is from 1977 to 1984 and the third from 1993 to the present, with the selectivities in the 1985-1992 period assumed to vary linearly between these 1984 and 1993 values. The offshore trawl selectivity is assumed to decrease exponentially from age 3 (equation B36), with a slope parameter estimated in the model fitting procedure. This exponential decrease is assumed to continue to age 15.

d) Survey selectivity-at-age
Because there are no catch-at-age data available from the west coast winter survey, the same selectivity is assumed to apply to both the summer and winter west coast surveys (conducted by the *Africana*). A separate selectivity function is estimated for the *Nansen* west coast summer survey. On the south coast, a single selectivity function is estimated for the spring and south coast surveys. The survey selectivities are estimated directly for each age.

An exponential decrease in selectivity is assumed from age 5 for *M. paradoxus* with the slope parameter fixed at 0.5. This value has been computed roughly from the average (over surveys and scenarios) decrease from age 4 to 5 for *M. paradoxus* estimated in scenarios C3 of Rademeyer and Butterworth (2005).

e) Stock-recruitment residuals
The residuals are assumed not to be serially correlated, i.e., $\rho = 0$. They are estimated from year 1985 to 2004. For scenario SR1 of the Reference Set, the variability level σ_R is fixed at 0.25 throughout the period. Scenario SR1 shows strong recruitment of *M. paradoxus* for the last two years. This signal is partly based on the catch-at-age information from the more recent surveys, but because of the change in gear on the *Africana*, and consequently a possible change in selectivity of the surveys, one cannot be entirely confident that this signal is quantitatively reliable. For this reason, scenario SR2 sets a limit on the recent recruitment fluctuations by having the σ_R decreasing linearly from 0.25 in 2000 to 0.1 in 2004, effectively forcing the last three years of recruitment closer towards the stock-recruitment relationship curve.

2.2 *M. capensis*

a)Plus-group:
Age 15 is used as the plus-group.

b) Natural mortality:
M_a is taken to be age-dependent (M_a) (with the form of equation B33). Scenarios M1 and M4 are as described for *M. paradoxus* above. The natural mortality estimated for age 7 for *M. capensis* is assumed to apply to older ages as well.

b) Commercial selectivity-at-age:
The selectivity patterns characterising each of the four fleets (offshore, inshore, longline and handline) all take the form of a logistic curve. For the inshore fleet, the selectivity is allowed to decrease exponentially from age 5, as this fleet does not fully select older fish because the distribution of hake extends deeper than its area of operation. This exponential decrease, which is estimated in the model fitting procedure is assumed to continue to age 15.

The selectivity for the offshore fleet for *M. capensis* is assumed to vary in the same way as for *M. paradoxus*; the selectivity over the 1977-1984 period is as the selectivity over the post-1993 period but shifted to the left by the same amount as the *M. paradoxus* selectivity, while the selectivity over the pre-1977 period is as the selectivity over the post-1993 period but shifted to the left by half the difference between the 1984 and 1993 selectivities. The selectivity post-1993 is assumed to be as that for the inshore fleet but shifted one year of age to the right (i.e. $a^c_{cap,off} = a^c_{cap,insh} + 1$ in equation B35) and with a flat selectivity for older ages.

Because the longline fishery targets principally older fish, the selectivity for that fleet is also assumed to be flat for older ages. Furthermore, the selectivity indicated by a logistic curve is multiplied by a factor λ for ages ≤ 4. Indeed, the selectivity for this fleet and these ages is so low that it is not adequately represented by a logistic curve. The parameter λ is treated as another estimable parameter in the likelihood maximisation process.

As is the case for the offshore fleet, there are no catch-at-age data available to estimate a selectivity vector for the handline fleet, so the assumption is made that the selectivity for this fleet is intermediate between the inshore trawl and longline selectivities (i.e. the average of the two a_{sf}^{c} and δ_{sf}^{c} - see equation B35 - is assumed to apply). The selectivity is allowed to decrease exponentially from age 5. This exponential decrease, which is taken as half of that of the inshore fleet is assumed to continue to age 15.

c) Survey selectivity-at-age

A different survey selectivity is estimated for each of the three survey series on the west coast, while on the south coast a single selectivity is estimated. The survey selectivities are estimated separately for each age.

An exponential decrease in selectivity is assumed from age 7 for *M. capensis* with the slope parameter fixed at 1.0. This value has been computed roughly from the average (over surveys and scenarios) decrease from age 6 to 7 for *M. capensis* estimated in scenarios C3 of Rademeyer and Butterworth (2005).

d) Stock-recruitment residuals

For simplicity, the residuals are assumed not to be serially correlated, i.e., $\rho = 0$. They are estimated from year 1985 to 2004. Scenarios SR1 and SR2 are as described for *M. paradoxus* above.

3. Results and Discussion

The overall average and range of estimates of management quantities for the Reference Set are shown in Table 1, while Table 2 gives the average over the individual factors (M, H, C and SR). The full set of results are given in Tables C1 and C2 of Appendix C. Fig. 2 plots the corresponding biomass trajectories, focusing on the median, maximum and minimum values for each year. Fig. 3 shows the survey and commercial fishing selectivities. Trajectories of fishing mortality for each fleet are plotted in Fig. 4 for the fully selected age-class (i.e. with selectivity of 1).

Trajectories of spawning biomass (*M. paradoxus* and *M. capensis* separately), offshore trawler exploitable biomass (species combined – a proxy for offshore trawler CPUE) and total catch are plotted for a fixed future catch scenario with the total catch staying at the current level of 150 000t. For each plot, the median is indicated by a thick dotted line, the 90^{th} percentiles are shaded, and the same ten (randomly selected) individual biomass and catch realisations are plotted. For comparison purposes, similar median trajectories of resource abundance and catch are plotted for three fixed future catch scenarios (142 000t, 150 000t and 158 000t) for the Reference Set.

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Table 1: Average and range in parenthesis of estimates of management quantities of the *M. paradoxus* and *M. capensis* coast-combined resources over 48 cases in the Reference Set. *MSY* and associated quantities are given in relation to the selectivity for the offshore fleet.

	-lnL total	-172.1	(-185.9; -153.2)
M. paradoxus	K^{sp}	2010	(980; 3327)
	h	0.87	(0.80; 0.95)
	MSY	144	(124; 171)
	B^{sp}_{2004}/K^{sp}	0.11	(0.07; 0.17)
	$B^{sp}_{2004}/MSYL^{sp}$	0.52	(0.33; 0.74)
	M 0	0.75	(0.50; 1.00)
	1	0.75	(0.50; 1.00)
	2	0.75	(0.50; 1.00)
	3	0.55	(0.40; 0.74)
	4	0.43	(0.34; 0.59)
	5+	0.36	(0.30; 0.49)
M. capensis	K^{sp}	812	(588; 1117)
	h	0.79	(0.70; 0.95)
	MSY	67	(57; 78)
	B^{sp}_{2004}/K^{sp}	0.45	(0.32; 0.57)
	$B^{sp}_{2004}/MSYL^{sp}$	1.66	(1.12; 2.58)
	M 0	0.75	(0.50; 1.00)
	1	0.75	(0.50; 1.00)
	2	0.75	(0.50; 1.00)
	3	0.57	(0.40; 0.75)
	4	0.47	(0.34; 0.60)
	5	0.40	(0.30; 0.50)
	6	0.40	(0.30; 0.50)
	7+	0.40	(0.30; 0.50)
	SC survey q	0.81	(0.61; 1.09)
2004 species ratio	B^{sp}	2.08	(0.72; 3.36)
	B^{2+}	1.18	(0.57; 1.79)

Table 2: Averages over individual factors of estimates of management quantities of the *M. paradoxus* and *M. capensis* coast-combined resources for the Reference Set. *MSY* and associated quantities are given in relation to the selectivity for the offshore fleet.

		Average over:										
		M1	M4	H1	H2	H3	H4	C3a	C3b	C3c	SR1	SR2
	-lnL total	-165.5	-178.8	-177.7	-169.9	-174.7	-166.3	-172.0	-172.1	-172.4	-175.3	-169.0
M. paradoxus	K^{sp}	2834	1186	1862	2178	1843	2157	2030	2043	1957	2011	2009
	h	0.87	0.87	0.95	0.80	0.95	0.80	0.87	0.87	0.87	0.87	0.87
	MSY	161	127	141	148	140	148	145	145	142	144	144
	B^{sp}_{2004}/K^{sp}	0.10	0.12	0.08	0.14	0.08	0.14	0.11	0.11	0.11	0.11	0.11
	$B^{sp}_{2004}/MSYL^{sp}$	0.41	0.62	0.45	0.59	0.45	0.59	0.51	0.50	0.55	0.52	0.52
	M 0	0.50	0.99	0.74	0.75	0.74	0.75	0.75	0.75	0.74	0.75	0.75
	1	0.50	0.99	0.74	0.75	0.74	0.75	0.75	0.75	0.74	0.75	0.75
	2	0.50	0.99	0.74	0.75	0.74	0.75	0.75	0.75	0.74	0.75	0.75
	3	0.40	0.70	0.53	0.57	0.54	0.57	0.55	0.55	0.55	0.55	0.55
	4	0.34	0.53	0.41	0.46	0.41	0.46	0.43	0.43	0.44	0.43	0.43
	5+	0.30	0.41	0.33	0.39	0.33	0.39	0.35	0.35	0.36	0.36	0.36
M. capensis	K^{sp}	982	641	760	760	874	854	786	786	864	813	811
	h	0.82	0.77	0.89	0.89	0.70	0.70	0.81	0.81	0.77	0.80	0.79
	MSY	61	73	70	69	66	64	65	66	70	67	67
	B^{sp}_{2004}/K^{sp}	0.39	0.52	0.46	0.43	0.48	0.45	0.44	0.46	0.46	0.46	0.45
	$B^{sp}_{2004}/MSYL^{sp}$	1.33	2.00	1.87	1.79	1.53	1.46	1.68	1.72	1.60	1.68	1.64
	M 0	0.50	1.00	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
	1	0.50	1.00	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
	2	0.50	1.00	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
	3	0.40	0.75	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.57
	4	0.34	0.59	0.47	0.46	0.47	0.47	0.46	0.47	0.47	0.47	0.47
	5	0.30	0.49	0.39	0.39	0.40	0.40	0.39	0.39	0.40	0.39	0.40
	6	0.30	0.49	0.39	0.39	0.40	0.40	0.39	0.39	0.40	0.39	0.40
	7+	0.30	0.49	0.39	0.39	0.40	0.40	0.39	0.39	0.40	0.39	0.40
	SC survey q	0.93	0.69	0.84	0.89	0.74	0.78	0.84	0.82	0.77	0.81	0.81
2004 species ratio	B^{sp}	1.69	2.47	2.48	1.37	2.95	1.52	1.98	2.03	2.24	2.08	2.08
	B^{2+}	1.05	1.31	1.32	0.85	1.56	0.97	1.12	1.15	1.26	1.15	1.21

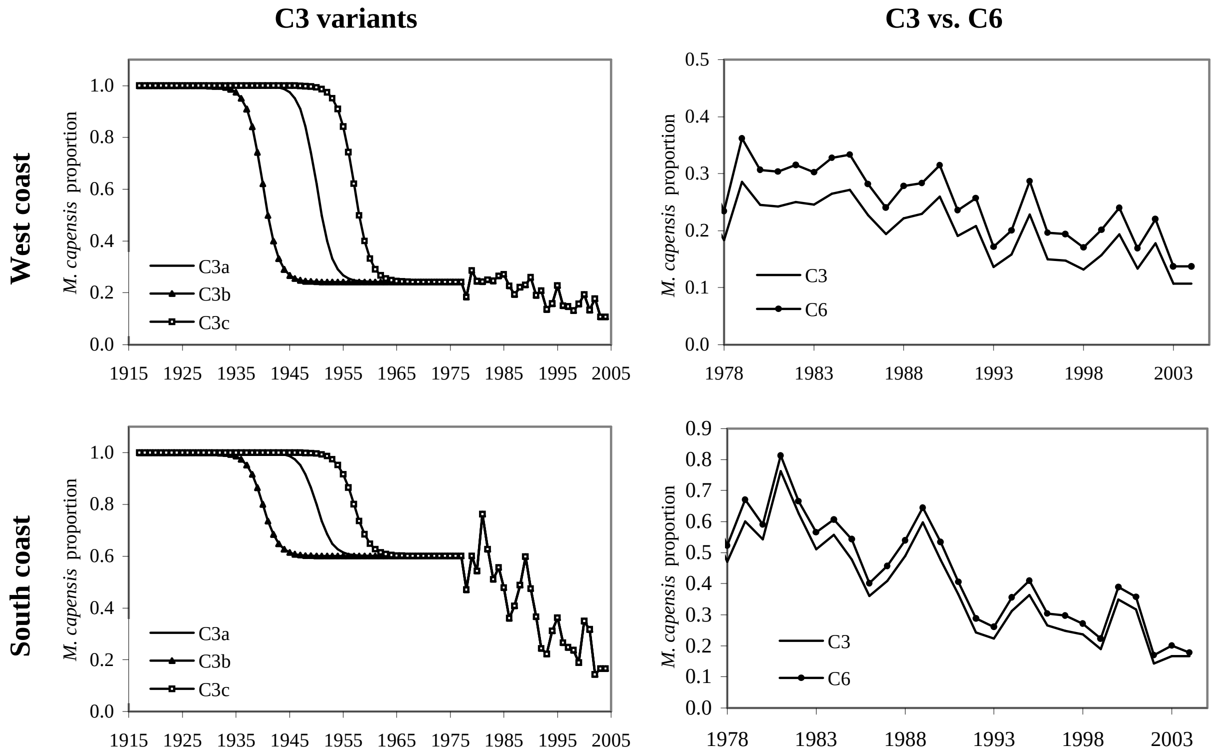

Fig. 1: Assumed proportion of *M. capensis* in the offshore catches for the west coast and south coast for the catch variants C3a, b and c and C6 (see text for details).

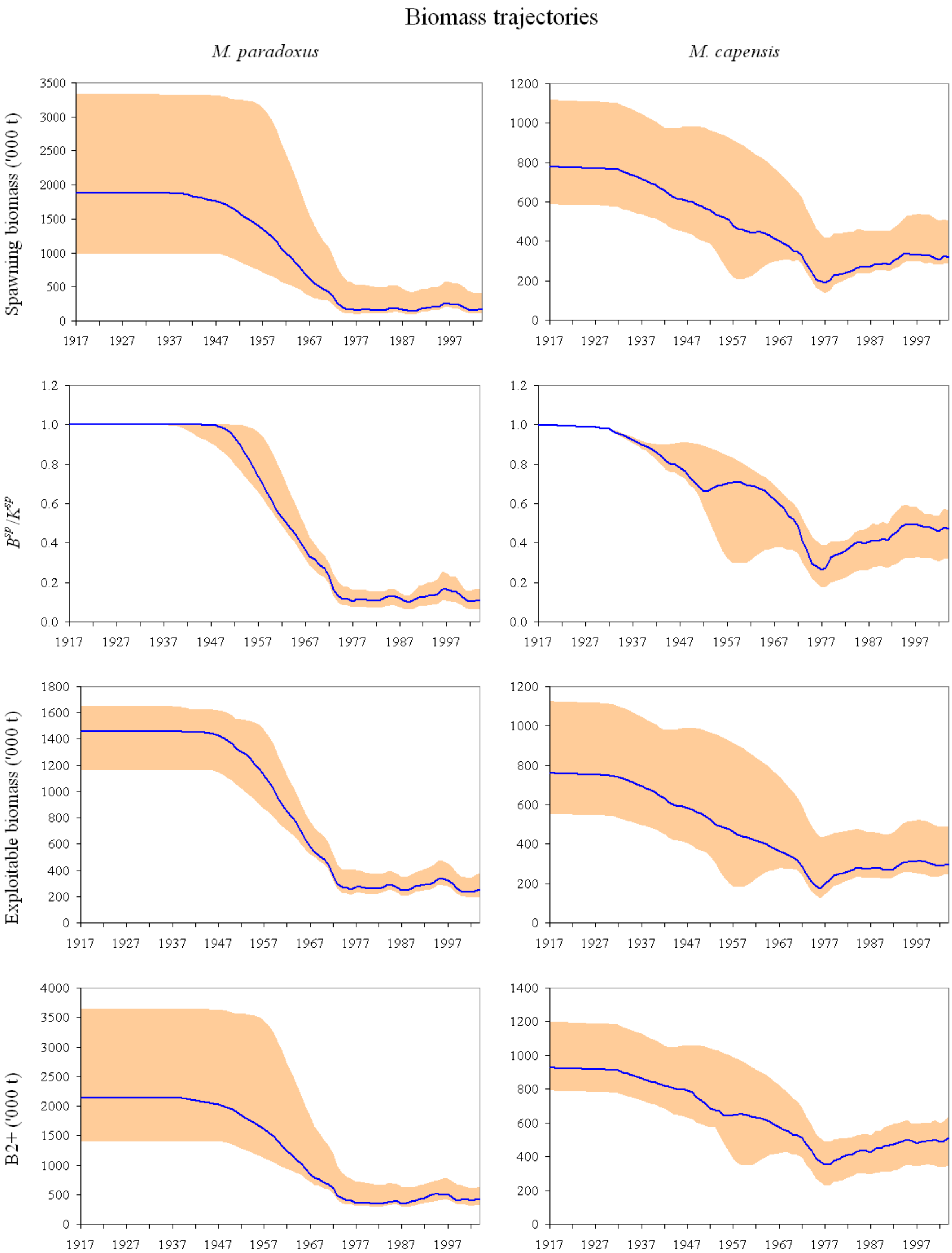

Fig. 2: Trajectories of resource abundance for the Reference Set. Resource abundance is expressed in terms of a) spawning biomass, b) spawning biomass as a proportion of its pre-exploitation level, c) exploitable biomass and d) biomass of fish of age 2 and above. The median is indicated by a thick line while the shaded area represents the full uncertainty of the Revised Reference Set (minimum and maximum for each year).

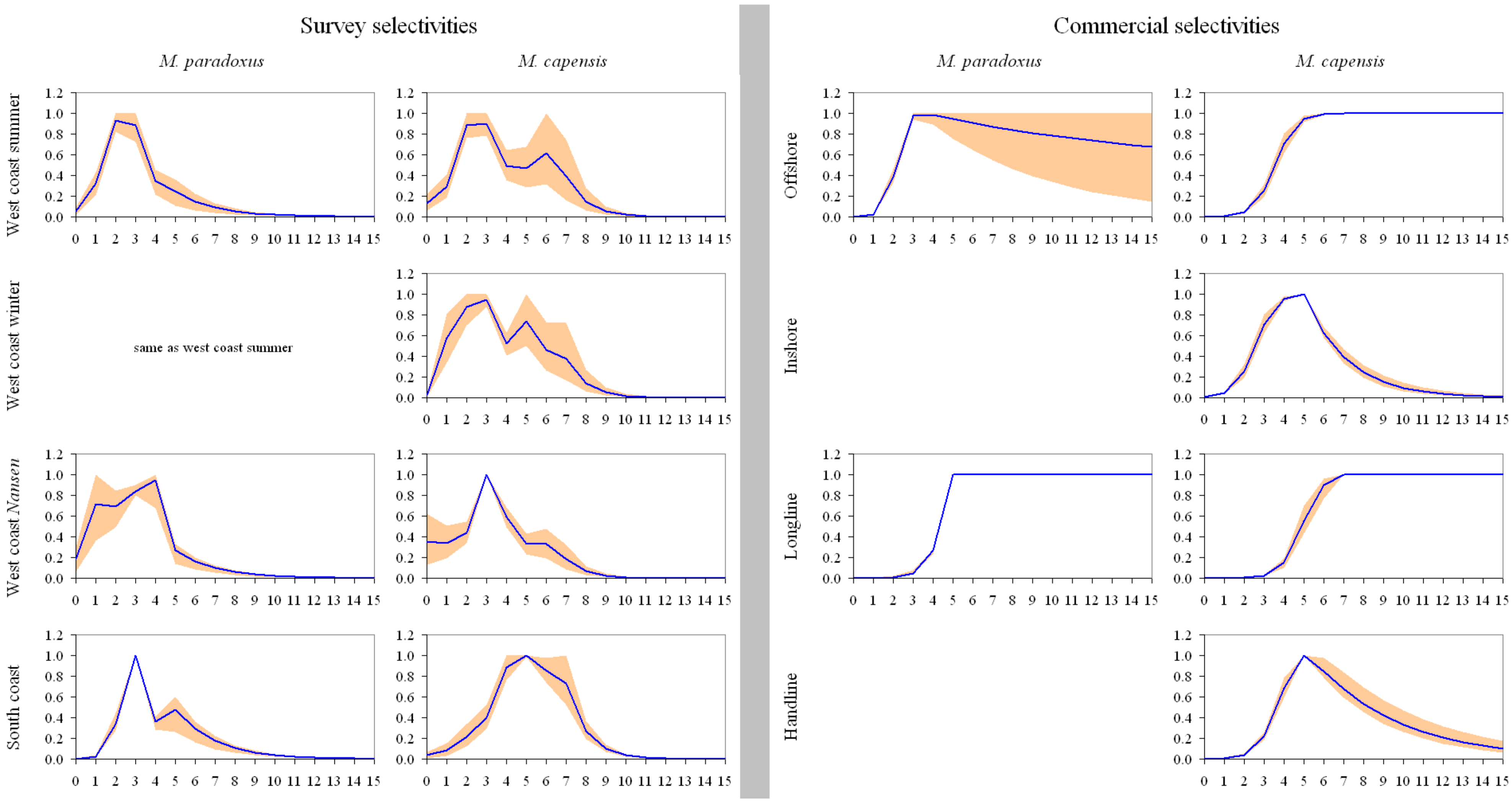

Fig. 3: Estimated survey and commercial fishing selectivities for the Revised Reference Set. The median is indicated by a thick line while the shaded area represents the full uncertainty of the Revised Reference Set (minimum and maximum for each age).

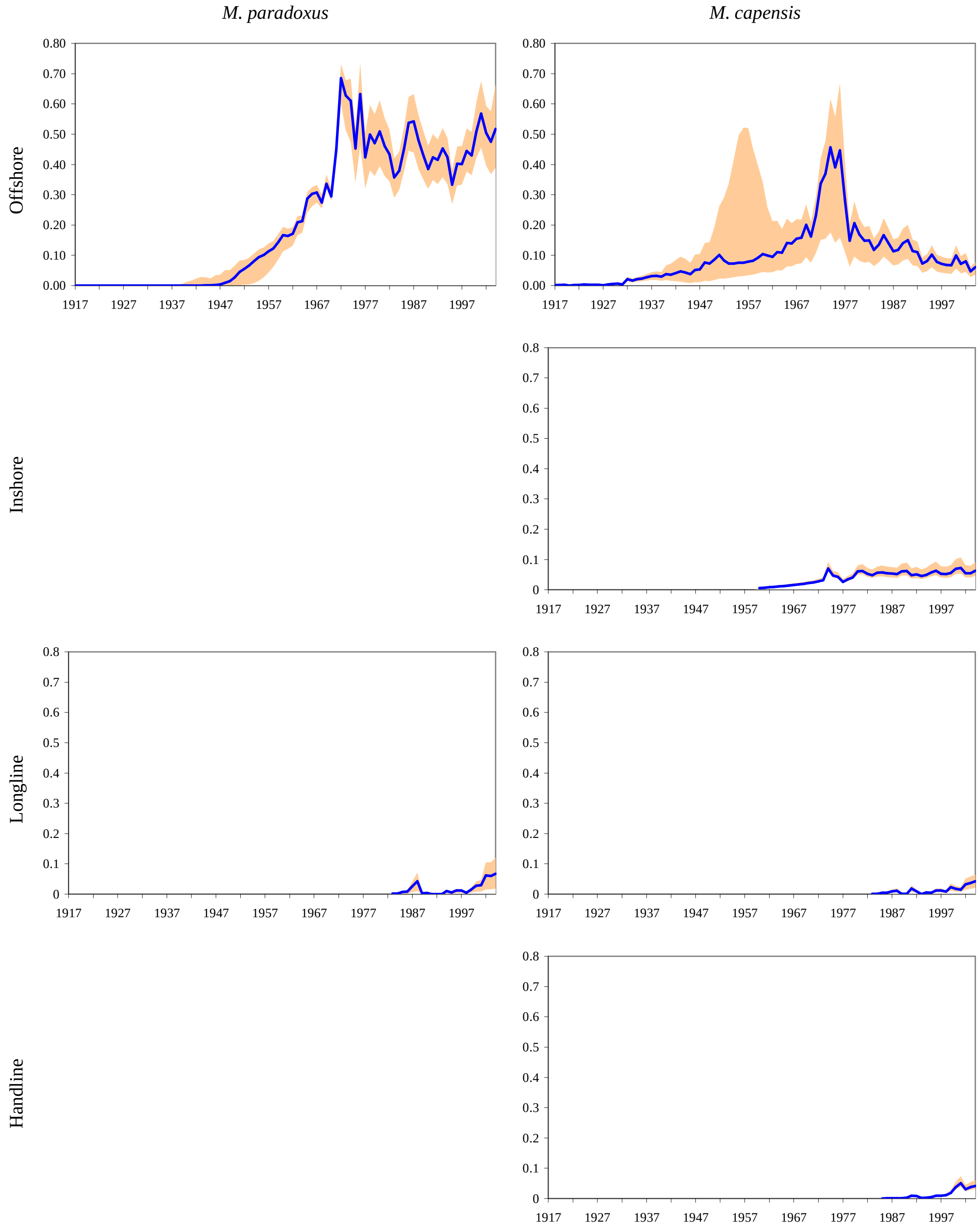

Fig. 4: Trajectories of fishing mortality for a fully selected age-class (i.e. with selectivity of 1) for the Reference Set for each of the four fleets. The median is indicated by a thick line while the shaded area represents the full uncertainty of the Revised Reference Set (minimum and maximum for each year).

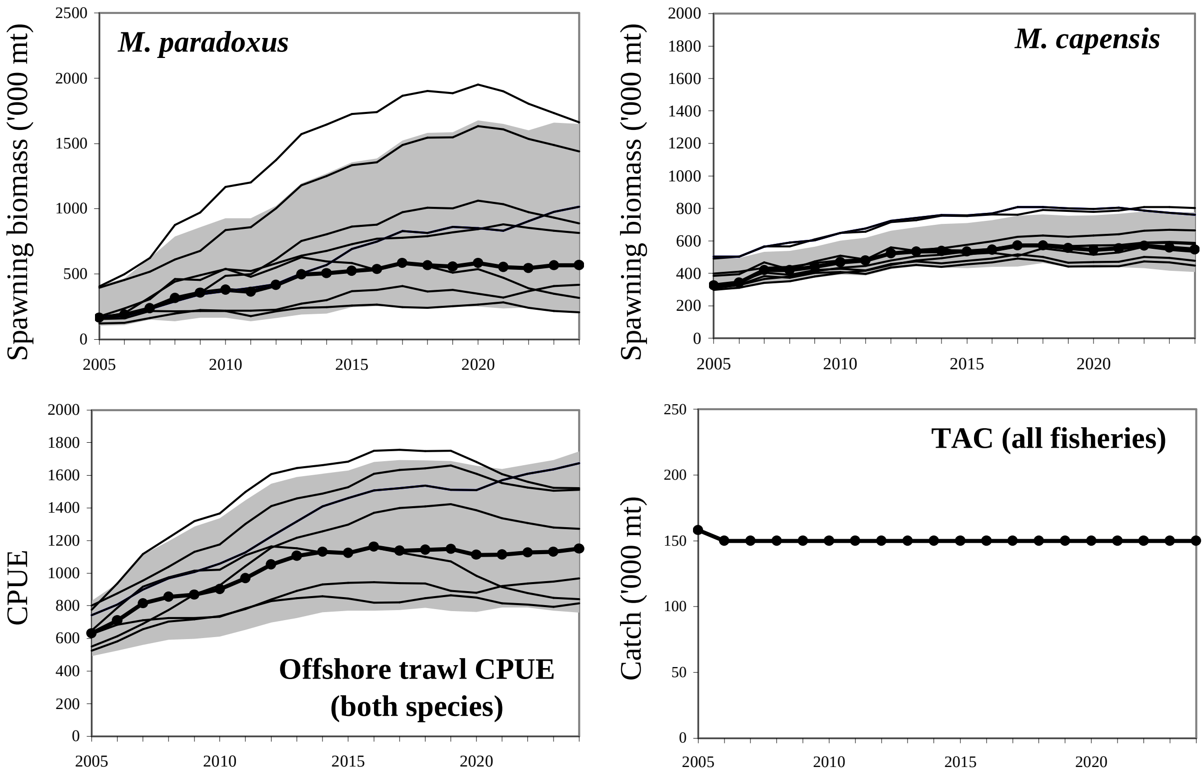

Fig. 5: Trajectories of spawning biomass (*M. paradoxus* and *M. capensis* separately), offshore trawler exploitable biomass (species combined - a proxy for offshore trawler CPUE) and total catch under a fixed future catch scenario with the total catch staying constant at the current level of 150 000t for the Reference Set. Ten individual trajectories are shown, with the median a dark dotted line; the shaded areas show 90% probability envelopes.

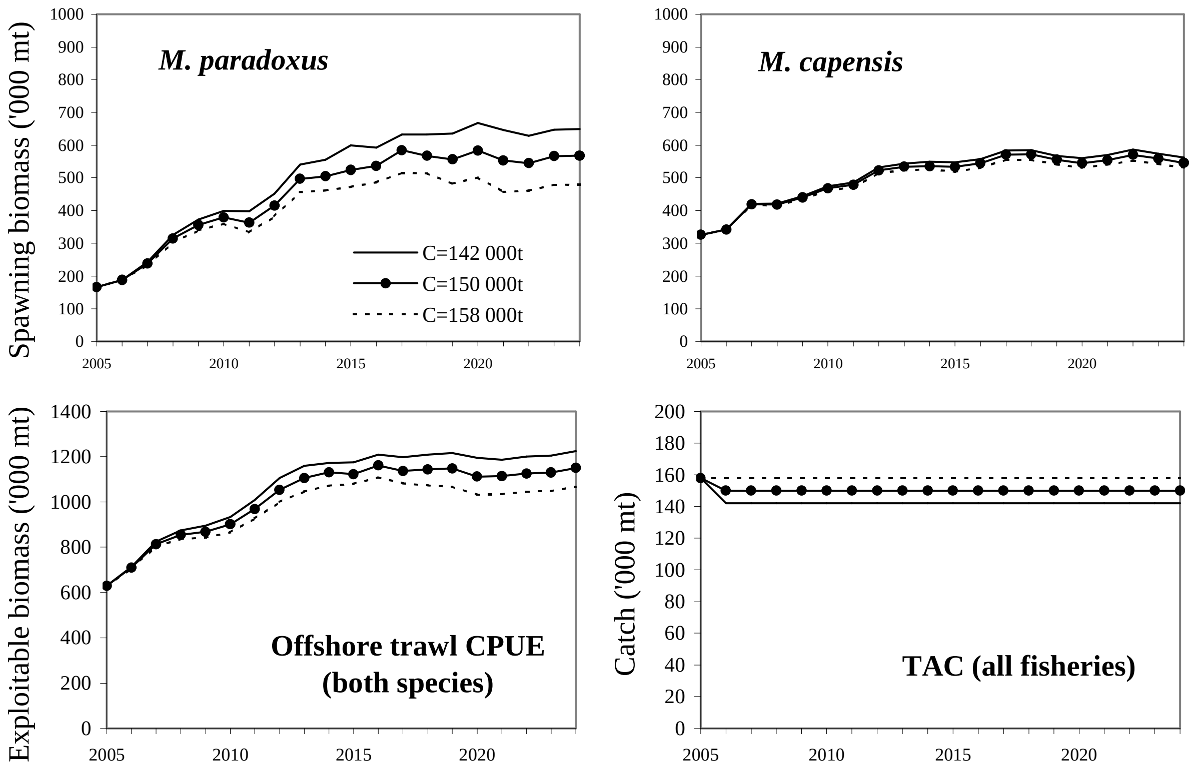

Fig. 6: Comparison of trajectories of spawning biomass (*M. paradoxus* and *M. capensis* separately), offshore trawler exploitable biomass (species combined - a proxy for offshore trawler CPUE) and total catch under three fixed future catch scenarios (142 000t, 150 000t and 158 000t) for the Reference Set.

Appendix A - Data Tables

Table A1a: Assumed total annual catches by species for the offshore fleet (for the three different scenarios - assuming different historic species split of the catches) and for the inshore fleet for the period 1917 to 1977 (see Data section of text for details) for the South African hake resource. Catches are given in thousand tons.

Year	Offshore						Inshore
	C3a, C6a scenarios		**C3b, C6b scenarios**		**C3c, C6c scenarios**		
	M. paradoxus	*M. capensis*	*M. paradoxus*	*M. capensis*	*M. paradoxus*	*M. capensis*	*M. capensis*
1917		1.000		1.000		1.000	
1918		1.100		1.100		1.100	
1919		1.900		1.900		1.900	
1920		0.000		0.000		0.000	
1921		1.300		1.300		1.300	
1922		1.000		1.000		1.000	
1923		2.500		2.500		2.500	
1924		1.500		1.500		1.500	
1925		1.900		1.900		1.900	
1926		1.400		1.400		1.400	
1927		0.800		0.800		0.800	
1928		2.600	0.001	2.599		2.600	
1929		3.800	0.002	3.798		3.800	
1930		4.400	0.004	4.396		4.400	
1931		2.800	0.005	2.795		2.800	
1932		14.300	0.052	14.248		14.300	
1933		11.100	0.078	11.022		11.100	
1934		13.800	0.188	13.612		13.800	
1935	0.001	14.999	0.392	14.608		15.000	
1936	0.001	17.699	0.872	16.828		17.700	
1937	0.003	20.197	1.826	18.374		20.200	
1938	0.005	21.095	3.339	17.761		21.100	
1939	0.010	19.990	5.146	14.854		20.000	
1940	0.028	28.572	10.847	17.753		28.600	
1941	0.057	30.543	15.336	15.264	0.001	30.599	
1942	0.126	34.374	20.709	13.791	0.001	34.499	
1943	0.268	37.632	25.321	12.579	0.003	37.897	
1944	0.465	33.635	24.185	9.915	0.004	34.096	
1945	0.763	28.437	21.385	7.815	0.007	29.193	
1946	1.991	38.409	30.092	10.308	0.020	40.380	
1947	3.743	37.657	31.110	10.290	0.040	41.360	
1948	9.304	49.496	44.386	14.414	0.110	58.690	
1949	14.770	42.630	43.431	13.969	0.209	57.191	
1950	27.306	44.694	54.543	17.457	0.509	71.491	
1951	44.856	44.644	67.842	21.658	1.221	88.279	
1952	53.304	35.496	67.333	21.467	2.320	86.480	
1953	62.466	31.034	70.908	22.592	4.608	88.892	
1954	74.752	30.648	79.939	25.461	9.530	95.870	
1955	84.517	30.883	87.528	27.872	18.260	97.140	
1956	88.043	30.157	89.653	28.547	30.415	87.785	
1957	94.982	31.418	95.874	30.526	47.938	78.462	
1958	98.660	32.040	99.136	31.564	65.505	65.195	
1959	110.468	35.532	110.742	35.258	87.640	58.360	
1960	121.131	38.769	121.285	38.615	106.828	53.072	1.000
1961	112.716	35.984	112.790	35.910	105.462	43.238	1.308
1962	111.918	35.682	111.955	35.645	108.099	39.501	1.615
1963	128.545	40.955	128.567	40.933	126.254	43.246	1.923
1964	123.095	39.205	123.106	39.194	121.959	40.341	2.231
1965	153.970	49.030	153.977	49.023	153.237	49.763	2.538
1966	147.905	47.095	147.909	47.091	147.543	47.457	2.846
1967	139.687	51.199	139.689	51.197	139.511	51.375	3.154
1968	120.057	51.451	120.058	51.450	119.980	51.529	3.462
1969	140.365	62.666	140.365	62.666	140.318	62.713	3.769
1970	117.553	48.670	117.554	48.670	117.533	48.690	4.077
1971	165.235	66.880	165.235	66.880	165.221	66.895	4.385
1972	203.658	86.971	203.658	86.971	203.649	86.980	4.692
1973	148.551	81.587	148.551	81.587	148.548	81.590	5.000
1974	129.550	84.303	129.550	84.303	129.548	84.305	10.056
1975	94.895	62.185	94.895	62.185	94.895	62.185	6.372
1976	129.867	65.957	129.867	65.957	129.866	65.958	5.740
1977	92.370	46.930	92.370	46.930	92.369	46.931	3.500

Table A1b: Assumed total annual catches by species for the offshore fleet (for the two different scenarios - assuming different species split of the catches) and for the inshore fleet for the period 1917 to 1977 (see Data section of text for details) for the South African hake resource. Catches are given in thousand tons.

Year	Offshore				Inshore	Longline		Handline
	Scenarios C3a, b, c		Scenarios C6a, b, c					
	M. paradoxus	*M. capensis*	*M. paradoxus*	*M. capensis*	*M. capensis*	*M. paradoxus*	*M. capensis*	*M. capensis*
1978	108.110	26.988	101.239	33.859	4.931			
1979	98.133	42.309	87.456	52.986	6.093			
1980	103.714	36.274	95.243	44.745	9.121			
1981	92.900	33.516	85.254	41.162	9.400			
1982	89.230	35.477	81.380	43.327	8.089			
1983	77.325	29.624	71.310	35.639	7.672	0.161	0.069	
1984	86.647	35.543	79.085	43.105	9.035	0.256	0.126	
1985	101.532	43.554	92.526	52.560	9.203	0.817	0.642	0.065
1986	113.619	36.151	105.621	44.149	8.724	0.965	0.715	0.084
1987	103.993	29.216	97.785	35.424	8.607	2.500	1.424	0.096
1988	90.389	30.709	83.627	37.471	8.417	3.628	1.886	0.071
1989	90.162	36.009	83.541	42.630	10.038	0.203	0.119	0.137
1990	88.679	37.749	81.635	44.793	10.012	0.270	0.116	0.348
1991	100.148	28.376	94.455	34.069	8.206	0.000	3.000	1.270
1992	101.802	27.947	95.611	34.138	9.252	0.000	1.500	1.099
1993	113.050	19.275	108.361	23.964	8.870	0.000	0.000	0.278
1994	111.927	22.992	106.177	28.742	9.569	1.130	1.111	0.449
1995	97.884	30.163	90.425	37.622	10.630	0.670	0.938	0.756
1996	119.576	22.888	113.065	29.399	11.062	1.676	2.546	1.515
1997	111.776	21.214	105.589	27.401	8.834	1.806	2.646	1.404
1998	121.650	20.156	116.194	25.612	8.283	0.647	1.748	1.738
1999	99.942	19.165	94.811	24.296	8.595	1.963	4.985	2.749
2000	103.982	27.250	97.975	33.256	10.906	3.456	3.558	5.500
2001	113.337	19.342	108.542	24.137	11.692	2.793	2.885	7.300
2002	101.575	21.297	96.569	26.303	9.448	4.772	5.990	4.500
2003	98.696	12.902	95.266	16.332	9.787	4.668	6.878	5.941
2004	112.609	16.771	109.594	19.786	11.346	5.411	7.974	6.888

Table A2: South and west coast historic and coast-combined GLM standardized (for the two different scenarios - assuming different species split of the catches) CPUE data (Glazer, 2005) for *M. paradoxus* and *M. capensis*. The historic CPUE series are for *M. capensis* and *M. paradoxus* combined.

	ICSEAF CPUE (tons/hr)		GLM CPUE (kg/min)			
			Scenarios C3a, b, c		Scenarios C6a, b, c	
	Species combined		*M. capensis*	*M. paradoxus*	*M. capensis*	*M. paradoxus*
Year	South Coast	West Coast	Both Coasts		Both Coasts	
1955		17.31				
1956		15.64				
1957		16.47				
1958		16.26				
1959		16.26				
1960		17.31				
1961		12.09				
1962		14.18				
1963		13.97				
1964		14.60				
1965		10.84				
1966		10.63				
1967		10.01				
1968		10.01				
1969	1.28	8.62				
1970	1.22	7.23				
1971	1.14	7.09				
1972	0.64	4.90				
1973	0.56	4.97				
1974	0.54	4.65				
1975	0.37	4.66				
1976	0.40	5.35				
1977	0.42	4.84				
1978			3.12	5.34	4.76	3.69
1979			3.50	5.18	4.50	4.22
1980			3.99	5.42	4.75	4.72
1981			3.55	4.95	4.37	4.16
1982			3.53	5.24	4.64	4.18
1983			4.18	5.66	4.99	4.89
1984			4.84	5.79	5.07	5.67
1985			5.95	6.96	5.98	6.99
1986			4.83	6.49	5.76	5.61
1987			4.31	5.64	4.98	5.01
1988			4.27	5.14	4.58	4.87
1989			4.71	5.33	4.70	5.41
1990			5.27	5.96	5.18	6.14
1991			5.29	6.59	5.85	6.00
1992			5.17	6.34	5.55	5.98
1993			4.24	5.98	5.32	4.89
1994			4.93	6.14	5.49	5.64
1995			5.10	4.67	4.09	5.75
1996			5.01	6.27	5.59	5.72
1997			4.51	6.07	5.31	5.23
1998			4.76	6.14	5.44	5.40
1999			4.90	5.68	4.96	5.54
2000			5.54	5.61	4.96	6.13
2001			4.61	5.31	4.73	5.24
2002			5.00	4.60	4.11	5.58
2003			4.84	5.37	4.83	5.53

Table A3: 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.

Year	South coast				West coast					
	Spring (Sept)		Autumn (Apr/May)		Summer		Winter		*Nansen* summer	
	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)
1985	-	-	-	-	168.139	(36.607)	264.916	(52.968)	-	-
1986	23.049	(5.946)	-	-	196.151	(36.366)	172.522	(24.129)	-	-
1987	21.545	(4.601)	-	-	284.859	(53.108)	195.530	(44.425)	-	-
1988	-	-	30.236	(11.084)	158.796	(27.390)	233.103	(64.016)	-	-
1989	-	-	-	-	-	-	468.928	(124.878)	-	-
1990	-	-	-	-	282.225	(78.956)	226.910	(46.016)	-	-
1991	-	-	26.604	(10.431)	327.105	(82.209)	-	-	-	-
1992	-	-	24.305	(15.197)	234.699	(33.963)	-	-	-	-
1993	-	-	198.403	(98.423)	321.782	(48.799)	-	-	-	-
1994	-	-	111.354	(34.622)	329.927	(58.332)	-	-	-	-
1995	-	-	44.618	(19.823)	324.626	(80.370)	-	-	-	-
1996	-	-	85.530	(25.485)	430.971	(80.614)	-	-	-	-
1997	-	-	134.656	(50.922)	570.091	(108.230)	-	-	-	-
1998	-	-	-	-	-	-	-	-	-	-
1999	-	-	321.328	(113.520)	562.988	(116.322)	-	-	-	-
2000	-	-	-	-	-	-	-	-	326.994	(36.816)
2001	19.930	(9.957)	-	-	-	-	-	-	276.604	(34.833)
2002	-	-	-	-	272.177	(35.586)	-	-	-	-
2003	88.431	(36.054)	108.756	(37.529)	405.457	(68.882)	-	-	-	-
2004			31.653	(25.906)	259.566	(56.034)	-	-	-	-

Table A4: 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.

Year	South coast				West coast					
	Spring (Sept)		Autumn (Apr/May)		Summer		Winter		*Nansen* summer	
	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)	Biomass	(s.e.)
1985	-	-	-	-	124.652	(22.709)	181.517	(27.480)	-	-
1986	202.871	(27.845)	-	-	117.829	(23.639)	119.609	(18.492)	-	-
1987	162.282	(17.512)	-	-	75.705	(10.242)	87.407	(11.201)	-	-
1988	-	-	165.184	(21.358)	66.737	(10.767)	47.129	(9.570)	-	-
1989	-	-	-	-	-	-	323.879	(67.303)	-	-
1990	-	-	-	-	455.861	(135.253)	157.826	(23.565)	-	-
1991	-	-	273.897	(44.363)	77.369	(14.997)	-	-	-	-
1992	-	-	137.798	(15.317)	95.568	(11.753)	-	-	-	-
1993	-	-	156.533	(13.628)	94.564	(17.346)	-	-	-	-
1994	-	-	158.243	(23.607)	120.206	(35.885)	-	-	-	-
1995	-	-	233.359	(31.862)	199.173	(26.816)	-	-	-	-
1996	-	-	243.934	(25.035)	83.347	(9.287)	-	-	-	-
1997	-	-	182.157	(18.601)	257.332	(46.062)	-	-	-	-
1998	-	-	-	-	-	-	-	-	-	-
1999	-	-	190.864	(14.929)	198.748	(32.471)	-	-	-	-
2000	-	-	-	-	-	-	-	-	316.105	(42.077)
2001	133.533	(20.845)	-	-	-	-	-	-	191.068	(25.780)
2002	-	-	-	-	108.025	(16.086)	-	-	-	-
2003	82.726	(89.940)	126.313	(19.986)	74.771	(12.989)	-	-	-	-
2004			104.763	(12.867)	205.976	(33.221)	-	-	-	-

Table A5: Summer survey catches-at-age (proportions) of ***M. paradoxus*** on the west coast for the 0-500m depth range.

	Proportions caught at age: *Merluccius paradoxus*					
Age	0	1	2	3	4	5+
1990	0.0285	0.3098	0.4918	0.1583	0.0088	0.0017
1991	0.0182	0.2777	0.5608	0.1069	0.0240	0.0079
1992	0.0098	0.3834	0.4847	0.0824	0.0231	0.0118
1993	0.0089	0.1995	0.5469	0.1866	0.0439	0.0097
1994	0.0107	0.2441	0.5508	0.1656	0.0174	0.0078
1995	0.0651	0.1905	0.4435	0.2583	0.0282	0.0096
1996	0.0572	0.3939	0.3018	0.2096	0.0298	0.0050
1997	0.0055	0.1708	0.5459	0.2564	0.0164	0.0032
1998	-	-	-	-	-	-
1999	0.1613	0.4099	0.3358	0.0808	0.0084	0.0026
2000	-	-	-	-	-	-
2001	-	-	-	-	-	-
2002	0.1828	0.4572	0.2551	0.0837	0.0132	0.0080
2003	0.1514	0.3704	0.3394	0.1184	0.0107	0.0098
2004	0.2144	0.3438	0.2842	0.1240	0.0262	0.0073

Table A6: *Nansen* summer survey catches-at-age (proportions) of ***M. paradoxus*** on the west coast for the 0-500m depth range.

	Proportions caught at age: *Merluccius paradoxus*					
Age	0	1	2	3	4	5+
2000	0.2612	0.4600	0.2041	0.0561	0.0151	0.0035
2001	0.1627	0.4360	0.2396	0.1191	0.0354	0.0072

Table A7: Spring survey catches-at-age (proportions) of ***M. paradoxus*** on the south coast for the 0-500m depth range.

	Proportions caught at age: *Merluccius paradoxus*					
Age	0	1	2	3	4	5+
2001	0.0066	0.0852	0.5182	0.3689	0.0154	0.0057
2002	-	-	-	-	-	-
2003	0.0083	0.0342	0.4936	0.4250	0.0244	0.0145

Table A8: Autumn survey catches-at-age (proportions) of ***M. paradoxus*** on the south coast for the 0-500m depth range.

	Proportions caught at age: *Merluccius paradoxus*					
Age	0	1	2	3	4	5+
1991	0.0038	0.0099	0.5219	0.2920	0.1162	0.0563
1992	0.0000	0.0006	0.3698	0.5407	0.0653	0.0236
1993	0.0000	0.0047	0.4157	0.5439	0.0260	0.0097
1994	0.0054	0.0898	0.6558	0.1857	0.0170	0.0463
1995	0.0002	0.0002	0.1241	0.7729	0.0886	0.0139
1996	0.0000	0.0000	0.0968	0.7494	0.0999	0.0539
1997	0.0002	0.0012	0.1108	0.5806	0.1055	0.2016
1998	-	-	-	-	-	-
1999	0.0001	0.0140	0.2155	0.5266	0.1898	0.0540
2000	-	-	-	-	-	-
2001	-	-	-	-	-	-
2002	-	-	-	-	-	-
2003	0.0003	0.0409	0.5624	0.3427	0.0333	0.0204
2004	0.0439	0.1365	0.4040	0.3684	0.0411	0.0060

Table A9: Summer survey catches-at-age (proportions) of ***M. capensis*** on the west coast for the 0-500m depth range.

	Proportions caught-at-age: *Merluccius capensis*							
Age	0	1	2	3	4	5	6	7+
1986	0.034	0.230	0.603	0.085	0.023	0.014	0.008	0.003
1987	0.024	0.113	0.465	0.223	0.139	0.022	0.010	0.004
1988	0.280	0.483	0.135	0.059	0.018	0.015	0.009	0.002
1989	-	-	-	-	-	-	-	-
1990	0.004	0.325	0.635	0.023	0.009	0.003	0.001	0.000
1991	0.072	0.122	0.644	0.097	0.038	0.017	0.009	0.002
1992	0.131	0.260	0.313	0.162	0.078	0.025	0.019	0.010
1993	0.038	0.176	0.207	0.399	0.088	0.057	0.024	0.011
1994	0.081	0.253	0.208	0.262	0.075	0.054	0.048	0.020
1995	0.001	0.147	0.739	0.066	0.021	0.018	0.005	0.003
1996	0.065	0.368	0.205	0.237	0.066	0.023	0.025	0.011
1997	0.036	0.141	0.384	0.407	0.014	0.010	0.004	0.003
1998	-	-	-	-	-	-	-	-
1999	0.867	0.059	0.024	0.026	0.011	0.008	0.005	0.001
2000	-	-	-	-	-	-	-	-
2001	-	-	-	-	-	-	-	-
2002	0.351	0.425	0.100	0.062	0.032	0.019	0.009	0.002
2003	0.250	0.225	0.223	0.142	0.053	0.054	0.039	0.014
2004	0.125	0.367	0.411	0.086	0.007	0.002	0.001	0.001

Table A10: Winter survey catches-at-age (proportions) of ***M. capensis*** on the west coast for the 0-500m depth range.

	Proportions caught-at-age: *Merluccius capensis*							
Age	0	1	2	3	4	5	6	7+
1985	-	-	-	-	-	-	-	-
1986	0.005	0.305	0.267	0.318	0.051	0.027	0.017	0.010
1987	0.010	0.477	0.202	0.171	0.072	0.048	0.011	0.009
1988	0.031	0.432	0.388	0.063	0.042	0.029	0.012	0.004
1989	0.079	0.676	0.213	0.022	0.008	0.001	0.001	0.000
1990	0.006	0.267	0.514	0.098	0.052	0.042	0.013	0.008

Table A11: *Nansen* summer survey catches-at-age (proportions) of ***M. capensis*** on the west coast for the 0-500m depth range.

	Proportions caught-at-age: *Merluccius capensis*							
Age	0	1	2	3	4	5	6	7+
2000	0.393	0.336	0.147	0.111	0.007	0.004	0.002	0.001
2001	0.427	0.123	0.179	0.184	0.058	0.018	0.008	0.004

Table A12: Spring survey catches-at-age (proportions) of ***M. capensis*** on the south coast for the 0-500m depth range.

	Proportions caught at age: *Merluccius capensis*							
Age	0	1	2	3	4	5	6	7+
2001	0.158	0.106	0.091	0.171	0.264	0.139	0.039	0.033
2002	-	-	-	-	-	-	-	-
2003	0.205	0.134	0.154	0.157	0.161	0.113	0.041	0.036

Table A13: Autumn survey catches-at-age (proportions) of ***M. capensis*** on the south coast for the 0-500m depth range.

	Proportions caught at age: *Merluccius capensis*							
Age	0	1	2	3	4	5	6	7+
1991	0.011	0.111	0.126	0.173	0.215	0.181	0.112	0.073
1992	0.015	0.203	0.358	0.145	0.118	0.110	0.038	0.014
1993	0.001	0.083	0.120	0.171	0.373	0.143	0.068	0.042
1994	0.061	0.140	0.123	0.219	0.137	0.159	0.116	0.045
1995	0.019	0.121	0.225	0.189	0.202	0.149	0.066	0.029
1996	0.005	0.104	0.188	0.192	0.288	0.131	0.061	0.031
1997	0.064	0.134	0.105	0.187	0.216	0.175	0.067	0.052
1998	-	-	-	-	-	-	-	-
1999	0.159	0.140	0.281	0.145	0.117	0.087	0.040	0.030
2000	-	-	-	-	-	-	-	-
2001	-	-	-	-	-	-	-	-
2002	-	-	-	-	-	-	-	-
2003	0.127	0.212	0.188	0.140	0.153	0.109	0.038	0.033
2004	0.115	0.109	0.131	0.174	0.218	0.152	0.054	0.047

Table A14: Offshore fleet catches-at-age (*M. capensis* and *M. paradoxus* **combined***)* for both coasts combined

	Proportions caught at age: species combined							
Age	0	1	2	3	4	5	6	7+
1975	0.000	0.038	0.151	0.242	0.249	0.189	0.058	0.073
1976	0.000	0.076	0.435	0.302	0.120	0.035	0.022	0.010
1977	0.000	0.119	0.499	0.223	0.081	0.051	0.023	0.005
1978	0.000	0.069	0.683	0.174	0.046	0.018	0.007	0.003
1979	0.000	0.095	0.468	0.218	0.095	0.078	0.029	0.016
1980	0.000	0.048	0.458	0.284	0.120	0.053	0.023	0.014
1981	0.004	0.204	0.459	0.184	0.092	0.034	0.015	0.008
1982	0.030	0.248	0.469	0.130	0.056	0.038	0.020	0.009
1983	0.001	0.097	0.457	0.256	0.099	0.056	0.025	0.010
1984	0.002	0.068	0.460	0.265	0.111	0.052	0.028	0.014
1985	0.000	0.007	0.347	0.380	0.135	0.077	0.036	0.019
1986	0.000	0.011	0.315	0.446	0.119	0.055	0.033	0.019
1987	0.000	0.019	0.502	0.273	0.109	0.059	0.025	0.013
1988	0.000	0.018	0.551	0.265	0.075	0.050	0.028	0.011
1989	0.000	0.011	0.411	0.399	0.097	0.049	0.026	0.008
1990	0.000	0.002	0.282	0.470	0.167	0.050	0.020	0.008
1991	0.000	0.003	0.264	0.379	0.213	0.079	0.045	0.018
1992	0.000	0.010	0.380	0.328	0.149	0.084	0.035	0.014
1993	0.000	0.002	0.152	0.407	0.286	0.112	0.031	0.011
1994	0.000	0.001	0.158	0.468	0.191	0.140	0.032	0.011
1995	0.000	0.001	0.107	0.533	0.218	0.074	0.049	0.018
1996	0.000	0.001	0.096	0.533	0.260	0.066	0.032	0.013

Table A15: Inshore fleet catches-at-age (assumed to consist of ***M. capensis*** only) on the south coast.

	Proportions caught at age: *Merluccius capensis*						
Age	1	2	3	4	5	6	7+
1989	0.000	0.081	0.478	0.285	0.109	0.039	0.008
1990	0.000	0.055	0.279	0.439	0.171	0.045	0.011
1991	0.000	0.053	0.281	0.367	0.219	0.067	0.014
1992	0.001	0.151	0.371	0.237	0.184	0.048	0.009
1993	0.000	0.026	0.332	0.457	0.139	0.039	0.006
1994	0.000	0.060	0.380	0.304	0.183	0.067	0.007
1995	0.000	0.015	0.232	0.455	0.209	0.072	0.018
1996	0.000	0.024	0.327	0.457	0.140	0.043	0.008
1997	0.000	0.034	0.369	0.394	0.159	0.034	0.011
1998	0.008	0.166	0.377	0.284	0.116	0.034	0.015
1999	0.012	0.190	0.365	0.248	0.116	0.044	0.024
2000	0.000	0.022	0.244	0.476	0.196	0.034	0.028

Table A16: Longline fleet catches-at-age (assumed to consist of ***M. capensis*** only) on the south coast.

	Proportions caught at age: *Merluccius capensis*						
Age	1	2	3	4	5	6	7+
1994	0.000	0.000	0.001	0.030	0.248	0.404	0.318
1995	0.000	0.000	0.000	0.006	0.093	0.262	0.638
1996	0.000	0.000	0.000	0.007	0.134	0.297	0.561
1997	0.000	0.000	0.002	0.036	0.201	0.298	0.464
2000	0.000	0.001	0.003	0.020	0.148	0.203	0.626

Appendix B - The Age-Structured Production Model

The model used in the assessment of the coast-wide South African *M. paradoxus* and *M. capensis* hake stocks is an ASPM. It involves assessing the two species as two independent stocks. The model is fitted to species-disaggregated data as well as species-combined data. The model equations and the general specifications of the model are described below, followed by details of the contributions to the log-likelihood function from the different data considered. Quasi-Newton minimisation is used to minimise the total negative log-likelihood function (implemented using AD Model Builder™, Otter Research, Ltd.).

B.1 Population Dynamics

B.1.1 Numbers-at-age

The resource dynamics of the South African hake stocks are modelled by the following set of population dynamics equations (Baranov, 1918):

$$N_{s,y+1,0} = R_{s,y+1} \qquad \text{(B1)}$$

$$N_{s,y+1,a+1} = N_{sya} e^{-Z_{sya}} \qquad \text{for } 0 \le a \le m_s - 2 \qquad \text{(B2)}$$

$$N_{s,y+1,m_s} = N_{sy,m_s-1} e^{-Z_{sy,m_s-1}} \Big/ e^{-Z_{sy,m_s}} \qquad \text{(B3)}$$

where

N_{sya} is the number of fish of species *s* and age *a* at the start of year *y*,

R_{sy} is the recruitment (number of 0-year-old fish) of species *s* at the start of year *y*,

m_s is the maximum age considered (taken to be a plus-group) for species *s*,

$Z_{sya} = \sum_f F_{sfy} S_{sfya} + M_{sa}$ is the total mortality in year *y* on fish of species *s* and age *a*, where:

M_{sa} denotes the natural mortality rate on fish of species *s* and age *a*,

F_{sfy} is the fishing mortality of a fully selected age class of species *s*, for fleet *f* in year *y* and

S_{sfya} is the commercial selectivity (i.e. vulnerability to fishing gear, which may depend not only on the gear itself, but also on distribution patterns of the fish by age compared to the areal distribution of fishing effort) of species *s* at age *a* for year *y*, and fleet *f*; when $S_{sfya} = 1$, the age-class *a* is said to be fully selected.

These equations simply state that for a closed population, i.e. with no immigration or emigration, the only sources of loss are natural mortality (predation, disease, etc.) and fishing mortality (catch).

B.1.2 Recruitment

Next year's recruitment depends upon the reproductive output of this year's fish. The number of recruits of each species (i.e. new zero-year old fish) at the start of year *y* is assumed to be related to the spawning stock size (i.e., the biomass of mature fish) by a stock-recruitment relationship. Traditionally, the Beverton-Holt function (Beverton and Holt, 1957) has been used for southern African hake assessments.

The Beverton-Holt stock-recruitment relationship, allowing for annual fluctuations, is written as:

$$R_{sy} = \frac{\alpha_s B_{sy}^{sp}}{\beta_s + B_{sy}^{sp}} e^{(\varsigma_{sy} - \sigma_R^2/2)} \qquad \text{(B4)}$$

where

α_s and β_s are spawning biomass-recruitment relationship parameters for species *s*, α being the maximum number of recruits produced, and β the spawning stock needed to produce a recruitment equal to $\alpha/2$, in the deterministic case;

ς_{sy} reflects fluctuation about the expected recruitment for species *s* in year *y*, which is assumed to be normally distributed with standard deviation σ_R (whose value is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process. 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. The $-\sigma_R^2/2$ term is to correct for bias given the skewness of the log-normal distribution; it ensures that, on average, recruitments will be as indicated by the deterministic component of the stock-recruitment relationship;

B_{sy}^{sp} is the spawning biomass of fish of species *s* at the start of year *y*, computed as:

$$B_{sy}^{sp} = \sum_{a=1}^{m} f_{sa} w_{sa} N_{sya} \qquad \text{(B5)}$$

where

w_{sa} is the begin-year mass of fish of species *s* and age *a*, and

f_{sa} is the proportion of fish of species *s* and age *a* that are mature.

In order to work with estimable parameters that are more biologically meaningful, the stock-recruitment relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning ("virgin") biomass, K_s^{sp}, and the "steepness", h_s, of the stock-recruitment relationship, which is the proportion of the virgin recruitment (R_{1s}) that is realised at a spawning biomass level of 20% of the virgin spawning biomass:

$$\alpha_s = \frac{4h_s R_{s1}}{5h_s - 1} \qquad \text{(B6)}$$

and

$$\beta_s = \frac{K_s^{sp}(1-h_s)}{5h_s - 1} \qquad \text{(B7)}$$

where

$$R_{s1} = K_s^{sp} / \left[\sum_{a=1}^{m_s-1} f_{sa} w_{sa}\, e^{-\sum_{a'=0}^{a-1} M_{sa'}} + f_{sm_s} w_{sm_s} \frac{e^{-\sum_{a'=0}^{m-1} M_{sa'}}}{1-e^{-M_{sm_s}}} \right] \qquad \text{(B8)}$$

In the fitting procedure, both h_s and K_s^{sp} are estimated. The steepness parameter is important, as the overall potential yield of a resource estimated by an ASPM depends primarily on the steepness of the stock-recruitment curve and on the natural mortality rate.

B.1.3 Total catch and catches-at-age

The fleet-disaggregated catch by mass for species *s*, in year is given by:

$$C_{sfy} = \sum_{a=0}^{m} w_{s,a+1/2}\, C_{sfya} = \sum_{a=0}^{m} w_{s,a+1/2}\, N_{sya} \left(1-e^{-Z_{sya}}\right) \qquad \text{(B9)}$$

where

$w_{s,a+1/2}$ denotes the mid-year mass of fish of species *s* and age *a*, which is assumed to be the same for each fleet (as there are no data available to discriminate between fleets), and

C_{sfya} is the catch-at-age, i.e. the number of fish of species *s* and age *a*, caught in year *y* by fleet *f*.

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 (using the mid-year individual weights) and applying natural and fishing mortality for half the year:

$$B_{sfy}^{ex} = \sum_{a=0}^{m_s} w_{s,a+1/2} S_{sfya} N_{sya} e^{-Z_{sya}/2} \qquad \text{(B10)}$$

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

$$B_{sy}^{surv} = \sum_{a=0}^{m_s} w_{sa} S_{sa}^{surv} N_{sya} \qquad \text{(B11)}$$

and in mid-year (winter):

$$B_{sy}^{surv} = \sum_{a-0}^{m_s} w_{s,a+1/2} S_{sa}^{surv} N_{sya} \; e^{-Z_{sya}/2} \qquad \text{(B12)}$$

where

S_{sa}^{surv} is the survey selectivity for age *a* for species *s*, and

$w_{s,a+1/2}$ is the mid-year weight of fish of species *s* and age *a* at the start of the 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., $B_{sy0}^{sp} = K_s^{sp}$.

B.2 The likelihood function

The model is fitted to CPUE and survey abundance indices, catch information and commercial and survey catch-at-age data, 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.

B.2.1 CPUE relative abundance data

The likelihood is calculated assuming that the observed abundance index is log-normally distributed about its expected value:

$$I_y^i = \hat{I}_y^i \exp\left(\varepsilon_y^i\right) \quad \text{or} \quad \varepsilon_y^i = \ell n\left(I_y^i\right) - \ell n\left(\hat{I}_y^i\right) \qquad \text{(B13)}$$

where

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

$\hat{I}_y^i = \hat{q}^i \hat{B}_{sfy}^{ex}$ is the corresponding model estimate, where $\hat{B}_{sfy}^{ex}$ is the model estimate of exploitable resource biomass, given by equation B10,

$\hat{q}^i$ is the constant of proportionality for abundance 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 the shallow water and z2) a "mixed zone" (see Fig. B1).

The total catch of hake of both species (*BS*) by fleet *f* in year *y* ($C_{BS,fy}$) can be written as $C_{BS,fy} = C_{Cz1,fy} + C_{Cz2,fy} + C_{P,fy}$, where

$C_{Cz1,fy}$ is the *M. capensis* catch by fleet *f* in year *y* in the *M. capensis* only zone,

$C_{Cz2,fy}$ is the *M. capensis* catch by fleet *f* in year *y* in the mixed zone, and

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

Catch rate is assumed to be proportional to exploitable biomass. Furthermore, let γ be the proportion of the *M. capensis* exploitable biomass in the mixed zone ($\gamma = B_{Cz2,fy}^{ex} \big/ B_{C,fy}^{ex}$) (assumed to be constant throughout the period) and s_{fy} be the proportion of the effort of fleet *f* in the mixed zone in year *y* ($s_{fy} = E_{fy}^{z2} \big/ E_{fy}$), so that:

$$C_{Cz1,fy} = q_{Cz1}^i B_{Cz1,fy}^{ex} E_{fy}^{z1} = q_{Cz1}^i (1-\gamma) B_{C,fy}^{ex} \left(1 - s_{fy}\right) E_{fy} \qquad \text{(B14)}$$

$C_{fy}^{Cz2} = q_{Cz2}^{i} B_{Cz2,fy}^{ex} E_{fy}^{z2} = q_{Cz2}^{i} \gamma B_{C,fy}^{ex} s_{fy} E_{fy}$ and (B15)

$$C_{fy}^{P} = q_{P}^{i} B_{P,fy}^{ex} E_{fy}^{z2} = q_{P}^{i} B_{P,fy}^{ex} s_{fy} E_{fy} \quad \text{(B16)}$$

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}).

It follows that:

$$C_{Cfy} = B_{Cfy}^{ex} E_{fy} \left[q_{C1}^{i} (1-\gamma)(1-s_y) + q_{C2}^{i} \gamma s_{fy} \right] \quad \text{(B17)}$$

$$C_{Pfy} = B_{Cfy}^{ex} E_{fy} q_{P}^{i} s_{fy} \quad \text{(B18)}$$

By solving equations B17 and B18, we get:

$$s_{fy} = \frac{q_{Cz1}^{i}(1-\gamma)}{\left\{ \dfrac{C_{Cfy} B_{Pfy}^{ex} q_{P}^{i}}{B_{Cfy}^{ex} C_{Pfy}} - q_{Cz2}^{i}\gamma + q_{Cz1}^{i}(1-\gamma) \right\}} \quad \text{(B19)}$$

so that:

$$\hat{I}_{y}^{i} = \frac{C_{fy}}{E_{fy}} = \frac{C_{fy} B_{Pfy}^{ex} q_{P}^{i} s_{fy}}{C_{Pfy}} \quad \text{(B20)}$$

Zone 1 (z1): *M. capensis* only	Zone 2 (z2): Mixed zone
M. capensis: biomass (B_{Cz1}), catch (C_{Cz1})	*M. capensis*: biomass (B_{Cz2}), catch (C_{Cz2}) *M. paradoxus*: biomass (B_P), catch (C_P)
Effort in zone 1 (E_{z1})	Effort in zone 1 (E_{z2})

Fig. B1: Diagrammatic representation of the two theoretical fishing zones.

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 ($\left(\sigma_A^i\right)^2$) 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 for the recent GLM-standardised CPUE series the lower bound is 0.15, 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:

$$-\ell n\, L^{CPUE} = \sum_{i} \sum_{y} \left\{ \ell n \sqrt{\left(\sigma_y^i\right)^2 + \left(\sigma_A^i\right)^2} + \left(\varepsilon_y^i\right)^2 / \left[2\left(\left(\sigma_y^i\right)^2 + \left(\sigma_A^i\right)^2 \right) \right] \right\} \quad \text{(B21)}$$

where

σ_y^i is the (minimum, when $\sigma_A^i = 0$) standard deviation of the residuals for the logarithms of index *i* in year *y*,

σ_A^i is the square root of the additional variance for abundance series *i*, which is an input value; alternatively, this can be used to as a means of specifying an effective lower bound for σ_y^i.

Homoscedasticity of residuals is usually assumed, so that $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell n(I_y^i) - \ell n(\hat{I}_y^i)\right)^2 - \left(\sigma_A^i\right)^2} \qquad \text{(B22)}$$

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

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

$$\ln \hat{q}^i = \frac{\sum_y \left[1 \Big/ \left\{\left(\sigma_y^i\right)^2 + \left(\sigma_A^i\right)^2\right\}\right]\left(\ln I_y^i - \ln \hat{B}_{srfy}^{ex}\right)}{\sum_y \left[1 \Big/ \left\{\left(\sigma_y^i\right)^2 + \left(\sigma_A^i\right)^2\right\}\right]} \qquad \text{(B23)}$$

While in the case of the species-combined CPUE, q_{Cz1}^i, q_{Cz2}^i, q_P^i and γ are directly estimated in the fitting procedure.

In the case of the South African hake, 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:

$$q_s^{SC} = r q_s^{WC} \qquad \text{(B24)}$$

B.2.2 Survey abundance data

Data from the research surveys are treated as relative abundance indices in a similar manner to the species-disaggregated CPUE series above, with survey selectivity function S_{sa}^{surv} replacing the commercial selectivity S_{sfya} (see equations B11 and B12 above). Account is also taken of the begin- or mid-year nature of the survey.

An estimate of sampling variance is available for most surveys and the associated σ_y^i is generally taken to be given by the corresponding survey CV. However, these estimates likely fail to include all sources of variability, and unrealistically high precision (low variance and hence high weight) could hence be accorded to these indices. The contribution of the survey data to the negative log-likelihood is of the same form as that of the CPUE abundance data (see equation B21). The procedure adopted takes into account an additional variance in the same manner as for the CPUE abundance indices, but instead of being input, the additional variance $\left(\sigma_A\right)^2$ 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) provides the following estimates:

$\Delta \ell n q^{capensis} = -0.494$ with $\sigma_{\Delta \ell n q^{capensis}} = 0.141$ and

$\Delta \ell n q^{paradoxus} = -0.053$ with $\sigma_{\Delta \ell n q^{paradoxus}} = 0.117$

where

$$\ell n q_{new}^i = \ell n q_{old}^i + \Delta \ell n q^i \quad \text{with } i = capensis \text{ or } paradoxus \qquad \text{(B25)}$$

No plausible explanation has yet been found on 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 Workshop, Dec 2004) that the ratio of the catchability of the new to the previous *F.R.S. Africana* net be below 1, but not as low as the ratio estimated from the calibration experiments. $\Delta \ell n q^{capensis}$ is therefore taken as 0.8.

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

$$-\ell nL^{q-ch} = \left(\ell nq_{new} - \ell nq_{old} - \Delta\ell nq\right)^2 \Big/ 2\sigma^2_{\Delta\ell nq} \qquad \text{(B26)}$$

This assessment assumes that the change from "old *Africana*" to "new *Africana*" involves a change in q alone, i.e. the pattern of age-specific selectivity remains unchanged.

B.2.3 Commercial catches-at-age

Catches-at-age cannot be disaggregated by species, the model is therefore fitted to the catches-at-age for both species. The contribution of the catch-at-age data to the negative of the log-likelihood function when assuming an "adjusted" lognormal error distribution is given by:

$$-\ell \text{n} L^{age} = \sum_i \sum_y \sum_a \left[\ell n \left(\sigma^i_{com} / \sqrt{p_{iya}} \right) + p_{iya} \left(\ell n\, p_{iya} - \ell n\, \hat{p}_{iya} \right)^2 / 2 \left(\sigma^i_{com} \right)^2 \right] \qquad \text{(B27)}$$

where

the subscript 'i' refers to a particular series of catch-at-age data which reflect a specific combination of fleet and coast.

$p_{iya} = \dfrac{C_{BS,fya}}{\sum_{a'} C_{BS,fya'}}$ is the observed proportion of fish (*M. capensis* and *M. paradoxus* combined) caught by fleet f in year y that are of age a,

$\hat{p}_{iya} = \dfrac{\hat{C}_{BS,fya}}{\sum_{a'} \hat{C}_{BS,fya'}} = \dfrac{\sum_s \hat{C}_{s,fya}}{\sum_{a'} \sum_s \hat{C}_{s,fya'}}$ is the model-predicted proportion of fish caught by fleet f in year y that are of age a, where:

$$\hat{C}_{sfya} = N_{sya}\, e^{-M_{sa}/2}\, S_{sfya}\, F_{sfya} \qquad \text{(B28)}$$

and

σ^i_{com} is the standard deviation associated with the catch-at-age data, which is estimated in the fitting procedure by:

$$\hat{\sigma}^i_{com} = \sqrt{\sum_y \sum_a p^i_{y,a} \left(\ln p^i_{y,a} - \ln \hat{p}^i_{y,a} \right)^2 / \sum_y \sum_a 1} \qquad \text{(B29)}$$

The log-normal error distribution underlying equation B27 is chosen on the grounds that (assuming no ageing error) variability is likely dominated by a combination of interannual variation in the distribution of fishing effort, and fluctuations (partly as a consequence of such variations) in selectivity-at-age, which suggests that the assumption of a constant coefficient of variation is appropriate. However, for ages poorly represented in the sample, sampling variability considerations must at some stage start to dominate the variance. To take this into account in a simple manner, motivated by multinomial distribution properties, Punt (pers. commn) advocates weighting by the observed proportions (as in equation B27) so that undue importance is not attached to data based upon a few samples only.

Commercial catches-at-age are incorporated in the likelihood function using equation B27, for which the summation over age a is taken from age a_{minus} (considered as a minus group) to a_{plus} (a plus group). The ages for the minus- and plus-groups are chosen so that typically a few percent, but no more, of the fish sampled fall into these two groups.

B.2.4 Survey catches-at-age

The survey catches-at-age 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 B27). In this case however, the data is available disaggregated by species.

$p^{surv}_{sya} = C^{surv}_{sya} / \sum_{a'} C^{surv}_{sya'}$ is the observed proportion of fish of species s and age a from survey *surv* in year,

$\hat{p}^{surv}_{sya}$ is the expected proportion of fish of species s and age a in year y in the survey *surv*, given by:

$$\hat{p}^{surv}_{sya} = \frac{S^{surv}_{sa} N_{sya}}{\sum_{a'=0}^{m_s} S^{surv}_{sa'} N_{sya'}} \qquad \text{(B30)}$$

for begin-year (summer) surveys, or

$$\hat{p}_{sya}^{surv} = \frac{S_{sa}^{surv} N_{sya} e^{-Z_{sya}/2}}{\sum_{a'=0}^{m_s} S_{sa'}^{surv} N_{sya'} e^{-Z_{sya'}/2}} \qquad \text{(B31)}$$

for mid-year (winter) surveys.

B2.5 Stock-recruitment function residuals

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

$$-\ell n L^{SR} = \sum_s \sum_{y=y1+1}^{y2} \left[\ell n \sigma_R + \left(\frac{\varsigma_{sy} - \rho \varsigma_{s,y-1}}{\sqrt{1-\rho^2}} \right)^2 \Big/ 2\sigma_R^2 \right] \qquad \text{(B32)}$$

where

$\varsigma_{sy} = \rho \varsigma_{s,y-1} + \sqrt{1-\rho^2}\, \varepsilon_{sy}$ is the recruitment residual for species *s*, and year *y*, which is estimated for year *y1* to *y2* (see equation B4),

ε_{sy} from $N(0,(\sigma_R)^2)$

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

ρ is the serial correlation coefficient, which is input.

In the interest of simplicity, equation B30 omits a term in $\varsigma_{s,y1}$ for the case when serial correlation is assumed ($\rho \neq 0$), which is generally of little quantitative consequence to values estimated (Cryer, 1986).

B.3 Model parameters

B3.1 Estimable parameters

While in the case of the species-combined CPUE, q_{C1}^i, q_{C2}^i, q_P^i and γ are directly estimated in the fitting procedure.

In addition to the species-specific virgin spawning biomass (K_s^{sp}) and "steepness" of the stock-recruitment relationship (h_s), the following parameters are also estimated in some of the model fits undertaken.

B3.1.1 Natural mortality:

Natural mortality (M_{sa}) is assumed either to be independent of age or age-specific, and input (fixed) or estimated using the following functional form in the latter case:

$$M_{sa} = \begin{cases} M_{s2} & \text{for} \quad a \le 1 \\ \alpha_s^M + \dfrac{\beta_s^M}{a+1} & \text{for} \quad a \ge 2 \end{cases} \qquad \text{(B33)}$$

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}.

B3.1.2 Fishing selectivity-at-age:

The fishing selectivity-at-age for each species and fleet, S_{sfa}, is either estimated directly:

$$S_{sfa} = \begin{cases} \text{estimated separately} & \text{for } a \le a_{est} \\ = 1 & \text{for } a > a_{est} \end{cases} \qquad \text{(B34)}$$

or in terms of a logistic curve given by:

$$S_{sfa} = \begin{cases} 0 & \text{for } a = 0 \\ \left[1 + \exp\left(-\left(a - a^c_{sf}\right) / \delta^c_{sf}\right)\right]^{-1} & \text{for } a \geq 1 \end{cases} \tag{B35}$$

where

a^c_{sf} years is the age-at-50% selectivity,

δ^c_{sf} year^{-1} defines the steepness of the ascending limb of the selectivity curve.

The selectivity is sometimes modified to include a decrease in selectivity at older ages, as follows:

$$S_{sfa} \rightarrow S_{sfa} \exp\left(-s_{sfa}\left(a - a_{slope}\right)\right) \quad \text{for } a > a_{slope}, \tag{B36}$$

where

s_{sfa} measures the rate of decrease in selectivity with age for fish older than a_{slope} for the fleet concerned, and is referred to as the "selectivity slope".

Time dependence may be incorporated into these specification, so that $S_{sfa} \rightarrow S_{sfya}$.

B3.2 Input parameters

B3.2.1 Age-at-maturity:

The proportion of fish of species *s* age *a* that are mature is approximated by

$$f_{sa} = \begin{cases} 0 & \text{for } a < a^{mat}_s \\ 1 & \text{for } a \geq a^{mat}_s \end{cases} \tag{B37}$$

where $a^{mat}_s = 4$ for the *M. capensis* and *M. paradoxus* stocks (Punt and Leslie, 1991).

B3.2.2 Weight-at-age:

The weight-at-age (begin and mid-year) for each species is calculated from the combination of the von Bertalanffy growth equation and the mass-at-length function.

Appendix C – Further Results for the Reference Set

Table C1: Estimates of management quantities of the *M. paradoxus* and *M. capensis* coast-combined resources for the Reference Set. *MSY* and associated quantities are given in relation to the selectivity for the offshore fleet.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		M1	M1	M1	M1	M4	M4	M4	M4	M1	M1	M1	M1	M4	M4	M4	M4
		C3	C3	C3	C3	C3	C3	C3	C3	C3b	C3b	C3b	C3b	C3b	C3b	C3b	C3b
		H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4
		SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1
	-lnL total	-175.8	-167.8	-169.5	-159.7	-185.6	-179.6	-184.9	-178.2	-175.4	-168.2	-168.8	-160.6	-185.8	-179.9	-184.7	-178.5
M. paradoxus	K^{sp}	2404	3316	2366	3278	1360	1092	1352	1080	2400	3323	2365	3286	1393	1104	1381	1103
	h	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80
	MSY	155	170	153	169	126	129	127	129	155	171	153	170	128	129	128	130
	B^{sp}_{2004}/K^{sp}	0.07	0.12	0.07	0.12	0.09	0.16	0.09	0.16	0.07	0.12	0.07	0.12	0.08	0.16	0.08	0.15
	$B^{sp}_{2004}/MSYL^{sp}$	0.34	0.46	0.34	0.47	0.54	0.69	0.53	0.68	0.34	0.46	0.34	0.47	0.51	0.68	0.51	0.67
	M 0	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	1	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	2	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	3	0.40	0.40	0.40	0.40	0.67	0.73	0.67	0.73	0.40	0.40	0.40	0.40	0.67	0.73	0.67	0.73
	4	0.34	0.34	0.34	0.34	0.47	0.57	0.48	0.57	0.34	0.34	0.34	0.34	0.47	0.57	0.47	0.57
	5+	0.30	0.30	0.30	0.30	0.34	0.46	0.35	0.47	0.30	0.30	0.30	0.30	0.34	0.46	0.34	0.46
M. capensis	K^{sp}	861	853	1081	1025	631	601	633	625	861	858	1080	1033	588	607	631	626
	h	0.95	0.95	0.70	0.70	0.92	0.89	0.70	0.70	0.95	0.95	0.70	0.70	0.86	0.90	0.70	0.70
	MSY	61	60	60	57	75	74	68	67	61	61	60	57	77	75	68	67
	B^{sp}_{2004}/K^{sp}	0.35	0.34	0.46	0.40	0.52	0.51	0.50	0.48	0.37	0.36	0.47	0.42	0.54	0.52	0.51	0.50
	$B^{sp}_{2004}/MSYL^{sp}$	1.41	1.35	1.39	1.21	2.58	2.36	1.71	1.64	1.45	1.43	1.42	1.29	2.39	2.46	1.72	1.69
	M 0	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	1	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	2	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	3	0.40	0.40	0.40	0.40	0.72	0.73	0.75	0.75	0.40	0.40	0.40	0.40	0.75	0.73	0.75	0.75
	4	0.34	0.34	0.34	0.34	0.56	0.57	0.60	0.60	0.34	0.34	0.34	0.34	0.60	0.57	0.60	0.60
	5	0.30	0.30	0.30	0.30	0.44	0.47	0.50	0.50	0.30	0.30	0.30	0.30	0.50	0.46	0.50	0.50
	6	0.30	0.30	0.30	0.30	0.44	0.47	0.50	0.50	0.30	0.30	0.30	0.30	0.50	0.46	0.50	0.50
	7+	0.30	0.30	0.30	0.30	0.44	0.47	0.50	0.50	0.30	0.30	0.30	0.30	0.50	0.46	0.50	0.50
	SC survey q	1.05	1.09	0.76	0.86	0.74	0.76	0.72	0.76	1.03	1.04	0.75	0.82	0.71	0.75	0.71	0.73
2004 species ratio	B^{sp}	1.88	0.73	3.10	1.02	2.77	1.79	2.76	1.80	1.97	0.78	3.21	1.10	2.72	1.82	2.76	1.84
	B^{2+}	1.06	0.57	1.65	0.77	1.31	0.99	1.37	1.02	1.09	0.61	1.70	0.82	1.36	1.00	1.37	1.05

Table C1: continued

		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
		M1	M1	M1	M1	M4	M4	M4	M4	M1	M1	M1	M1	M4	M4	M4	M4
		C3c	C3c	C3c	C3c	C3c	C3c	C3c	C3c	C3a	C3a	C3a	C3a	C3a	C3a	C3a	C3a
		H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4
		SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2
	-lnL total	-176.4	-165.6	-173.6	-162.8	-185.9	-177.3	-185.9	-177.3	-169.5	-161.4	-163.2	-153.2	-179.5	-173.2	-178.5	-171.8
M. paradoxus	K^{sp}	2401	3251	2382	3214	1221	987	1220	987	2406	3320	2369	3282	1360	1083	1346	1071
	h	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80
	MSY	153	165	152	164	125	124	125	124	155	171	153	169	127	129	127	129
	B^{sp}_{2004}/K^{sp}	0.07	0.13	0.07	0.13	0.10	0.17	0.10	0.17	0.07	0.12	0.07	0.12	0.08	0.16	0.08	0.15
	$B^{sp}_{2004}/MSYL^{sp}$	0.37	0.49	0.37	0.49	0.62	0.74	0.62	0.74	0.33	0.46	0.34	0.47	0.52	0.69	0.52	0.68
	M 0	0.50	0.50	0.50	0.50	0.97	1.00	0.97	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	1	0.50	0.50	0.50	0.50	0.97	1.00	0.97	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	2	0.50	0.50	0.50	0.50	0.97	1.00	0.97	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	3	0.40	0.40	0.40	0.40	0.67	0.74	0.67	0.74	0.40	0.40	0.40	0.40	0.67	0.73	0.67	0.74
	4	0.34	0.34	0.34	0.34	0.49	0.59	0.49	0.59	0.34	0.34	0.34	0.34	0.48	0.57	0.48	0.58
	5+	0.30	0.30	0.30	0.30	0.37	0.48	0.37	0.48	0.30	0.30	0.30	0.30	0.35	0.47	0.35	0.47
M. capensis	K^{sp}	955	954	1117	1112	683	685	703	703	860	853	1080	1025	592	603	632	624
	h	0.95	0.90	0.70	0.70	0.74	0.74	0.70	0.70	0.95	0.95	0.70	0.70	0.85	0.89	0.70	0.70
	MSY	67	64	62	62	78	78	76	76	61	60	60	57	76	74	68	67
	B^{sp}_{2004}/K^{sp}	0.40	0.33	0.39	0.37	0.56	0.57	0.55	0.55	0.35	0.33	0.45	0.40	0.53	0.50	0.49	0.48
	$B^{sp}_{2004}/MSYL^{sp}$	1.59	1.20	1.17	1.13	2.03	2.02	1.87	1.88	1.38	1.33	1.37	1.20	2.30	2.31	1.68	1.61
	M 0	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	1	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	2	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	3	0.40	0.40	0.40	0.40	0.75	0.75	0.75	0.75	0.40	0.40	0.40	0.40	0.75	0.73	0.75	0.75
	4	0.34	0.34	0.34	0.34	0.60	0.60	0.60	0.60	0.34	0.34	0.34	0.34	0.60	0.57	0.60	0.60
	5	0.30	0.30	0.30	0.30	0.50	0.50	0.50	0.50	0.30	0.30	0.30	0.30	0.49	0.47	0.50	0.50
	6	0.30	0.30	0.30	0.30	0.50	0.50	0.50	0.50	0.30	0.30	0.30	0.30	0.49	0.47	0.50	0.50
	7+	0.30	0.30	0.30	0.30	0.50	0.50	0.50	0.50	0.30	0.30	0.30	0.30	0.49	0.47	0.50	0.50
	SC survey q	0.92	1.06	0.84	0.86	0.61	0.61	0.61	0.61	1.06	1.09	0.77	0.86	0.72	0.77	0.72	0.77
2004 species ratio	B^{sp}	2.22	0.76	2.49	1.02	3.30	2.37	3.32	2.38	1.89	0.72	3.11	1.01	2.73	1.77	2.77	1.79
	B^{2+}	1.25	0.60	1.39	0.78	1.60	1.26	1.61	1.27	1.11	0.58	1.74	0.79	1.44	1.04	1.45	1.08

Table C1: continued

		33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
		M1	M1	M1	M1	M4	M4	M4	M4	M1	M1	M1	M1	M4	M4	M4	M4
		C3b	C3b	C3b	C3b	C3b	C3b	C3b	C3b	C3c	C3c	C3c	C3c	C3c	C3c	C3c	C3c
		H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4
		SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2
	-lnL total	-169.1	-161.8	-162.4	-154.2	-179.4	-173.6	-178.2	-172.2	-170.1	-159.2	-167.3	-156.4	-179.5	-171.0	-179.5	-170.9
M. paradoxus	K^{sp}	2402	3327	2367	3290	1387	1094	1375	1092	2404	3256	2384	3218	1211	980	1211	980
	h	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80	0.95	0.80
	MSY	155	171	153	170	128	129	128	130	153	166	152	164	125	125	125	125
	B^{sp}_{2004}/K^{sp}	0.07	0.12	0.07	0.12	0.08	0.16	0.08	0.15	0.07	0.13	0.07	0.13	0.09	0.16	0.09	0.16
	$B^{sp}_{2004}/MSYL^{sp}$	0.33	0.46	0.33	0.47	0.51	0.68	0.51	0.67	0.36	0.49	0.37	0.49	0.61	0.73	0.61	0.73
	M 0	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.96	1.00	0.96	1.00
	1	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.96	1.00	0.96	1.00
	2	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.96	1.00	0.96	1.00
	3	0.40	0.40	0.40	0.40	0.67	0.73	0.67	0.73	0.40	0.40	0.40	0.40	0.66	0.74	0.66	0.74
	4	0.34	0.34	0.34	0.34	0.47	0.57	0.48	0.57	0.34	0.34	0.34	0.34	0.49	0.59	0.49	0.59
	5+	0.30	0.30	0.30	0.30	0.34	0.46	0.34	0.47	0.30	0.30	0.30	0.30	0.37	0.49	0.37	0.49
M. capensis	K^{sp}	861	858	1080	1033	590	610	630	625	953	952	1117	1111	684	686	702	703
	h	0.95	0.95	0.70	0.70	0.86	0.90	0.70	0.70	0.95	0.90	0.70	0.70	0.74	0.74	0.70	0.70
	MSY	61	61	60	57	76	74	68	67	67	64	62	62	77	77	75	76
	B^{sp}_{2004}/K^{sp}	0.36	0.36	0.46	0.42	0.53	0.51	0.50	0.49	0.39	0.32	0.38	0.37	0.55	0.55	0.54	0.54
	$B^{sp}_{2004}/MSYL^{sp}$	1.43	1.41	1.40	1.27	2.34	2.41	1.69	1.66	1.56	1.18	1.15	1.12	1.98	1.97	1.83	1.84
	M 0	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	1	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	2	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00
	3	0.40	0.40	0.40	0.40	0.75	0.73	0.75	0.75	0.40	0.40	0.40	0.40	0.75	0.75	0.75	0.75
	4	0.34	0.34	0.34	0.34	0.60	0.57	0.60	0.60	0.34	0.34	0.34	0.34	0.60	0.60	0.60	0.60
	5	0.30	0.30	0.30	0.30	0.50	0.46	0.50	0.50	0.30	0.30	0.30	0.30	0.50	0.50	0.50	0.50
	6	0.30	0.30	0.30	0.30	0.50	0.46	0.50	0.50	0.30	0.30	0.30	0.30	0.50	0.50	0.50	0.50
	7+	0.30	0.30	0.30	0.30	0.50	0.46	0.50	0.50	0.30	0.30	0.30	0.30	0.50	0.50	0.50	0.50
	SC survey q	1.03	1.04	0.76	0.82	0.71	0.76	0.72	0.73	0.92	1.06	0.84	0.86	0.61	0.61	0.61	0.61
2004 species ratio	B^{sp}	1.97	0.77	3.23	1.09	2.73	1.81	2.78	1.83	2.22	0.74	2.50	1.01	3.35	2.36	3.36	2.37
	B^{2+}	1.15	0.62	1.79	0.84	1.44	1.05	1.46	1.10	1.31	0.61	1.47	0.80	1.72	1.33	1.73	1.34

Table C2: Log-likelihood contributions for the Reference Set.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
		M1	M1	M1	M1	M4	M4	M4	M4	M1	M1	M1	M1	M4	M4	M4	M4
		C3	C3	C3	C3	C3	C3	C3	C3	C3b	C3b	C3b	C3b	C3b	C3b	C3b	C3b
		H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4
		SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1
-lnL: Total		-175.8	-167.8	-169.5	-159.7	-185.6	-179.6	-184.9	-178.2	-175.4	-168.2	-168.8	-160.6	-185.8	-179.9	-184.7	-178.5
-lnL: CPUE	WC historic (spp combined)	-10.0	-9.8	-9.2	-8.6	-10.0	-9.9	-9.8	-9.9	-10.1	-10.0	-9.2	-9.0	-10.1	-10.0	-10.0	-9.8
	SC historic (spp combined)	-29.4	-27.9	-29.6	-27.3	-29.5	-28.6	-29.6	-28.5	-29.1	-28.4	-29.5	-28.1	-29.3	-28.7	-29.4	-28.7
	M. paradoxus GLM	-41.6	-41.9	-41.7	-41.9	-42.4	-43.0	-42.2	-42.9	-41.6	-41.9	-41.7	-42.0	-42.3	-43.1	-42.3	-43.0
	M. capensis GLM	-41.7	-41.6	-38.2	-37.1	-43.7	-43.8	-42.5	-42.5	-41.5	-41.4	-37.8	-37.0	-43.6	-43.7	-42.4	-42.3
-lnL: Survey	*M. paradoxus* , WC summer	-8.0	-7.4	-8.1	-7.4	-8.6	-8.7	-8.6	-8.7	-7.9	-7.4	-8.1	-7.4	-8.6	-8.7	-8.6	-8.7
	M. paradoxus , WC winter	-4.0	-3.8	-4.0	-3.8	-4.1	-4.1	-4.1	-4.1	-4.0	-3.8	-4.0	-3.8	-4.1	-4.1	-4.1	-4.1
	M. paradoxus , WC *Nansen*	-1.8	-1.7	-1.8	-1.8	-1.9	-1.9	-1.9	-1.9	-1.8	-1.7	-1.8	-1.7	-1.9	-1.9	-1.9	-1.9
	M. paradoxus , SC spring	-0.6	-0.5	-0.6	-0.5	-0.6	-0.6	-0.6	-0.6	-0.6	-0.5	-0.6	-0.5	-0.6	-0.6	-0.6	-0.6
	M. paradoxus , SC autumn	6.8	6.8	6.8	6.8	6.7	6.8	6.7	6.8	6.8	6.8	6.8	6.8	6.7	6.8	6.7	6.8
	M. capensis , WC summer	-1.9	-1.9	-1.8	-1.9	-1.9	-2.0	-2.1	-2.1	-1.8	-1.9	-1.8	-1.9	-2.0	-1.9	-2.1	-2.1
	M. capensis , WC winter	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4
	M. capensis , WC *Nansen*	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4
	M. capensis , SC spring	-1.6	-1.5	-1.5	-1.5	-1.5	-1.5	-1.4	-1.4	-1.6	-1.6	-1.6	-1.5	-1.5	-1.5	-1.4	-1.4
	M. capensis , SC autumn	-7.7	-7.7	-7.9	-7.8	-7.7	-7.6	-7.6	-7.6	-7.8	-7.8	-7.9	-7.9	-7.7	-7.7	-7.6	-7.6
-lnL: commercial CAA	species combined, offshore	-38.9	-35.2	-39.3	-35.7	-42.5	-39.4	-42.6	-39.8	-39.0	-35.2	-39.3	-35.6	-42.1	-39.5	-42.6	-39.8
	M. capensis , inshore	-22.5	-22.7	-21.0	-21.7	-25.5	-25.9	-26.6	-26.8	-22.4	-22.5	-20.9	-21.4	-26.3	-25.7	-26.6	-26.7
	M. capensis , longline	-14.4	-14.6	-12.9	-13.6	-15.3	-15.5	-15.6	-15.6	-14.3	-14.3	-12.8	-13.3	-15.6	-15.5	-15.6	-15.6
-lnL: survey CAA	*M. paradoxus* , WC summer	-16.5	-16.4	-16.3	-16.4	-15.6	-15.3	-15.6	-15.3	-16.5	-16.4	-16.3	-16.4	-15.7	-15.3	-15.7	-15.3
	M. paradoxus , WC *Nansen*	-10.9	-11.0	-11.0	-11.0	-11.0	-10.9	-11.0	-10.8	-10.9	-11.0	-11.0	-11.0	-11.0	-10.9	-11.0	-10.9
	M. paradoxus , SC spring	-4.2	-3.3	-4.3	-3.3	-3.6	-2.5	-3.7	-2.6	-4.2	-3.3	-4.3	-3.3	-3.6	-2.5	-3.7	-2.5
	M. paradoxus , SC autumn	28.8	29.5	28.9	29.5	28.3	29.3	28.4	29.4	28.8	29.5	28.9	29.5	28.3	29.3	28.4	29.4
	M. capensis , WC summer	83.6	83.6	83.5	83.7	83.9	84.0	84.2	84.2	83.6	83.6	83.5	83.7	84.1	83.9	84.2	84.3
	M. capensis , WC winter	7.0	7.1	6.7	7.0	7.2	7.2	7.6	7.7	6.9	7.0	6.7	6.9	7.2	7.1	7.6	7.7
	M. capensis , WC *Nansen*	-6.0	-5.9	-6.0	-6.0	-5.9	-5.9	-5.9	-5.8	-6.0	-6.0	-6.1	-6.0	-5.9	-5.9	-5.9	-5.8
	M. capensis , SC spring	-8.7	-8.7	-8.8	-8.8	-9.0	-9.1	-9.3	-9.3	-8.7	-8.7	-8.8	-8.8	-9.2	-9.1	-9.3	-9.3
	M. capensis , SC autumn	-29.9	-29.9	-29.5	-29.4	-29.7	-29.5	-29.3	-29.2	-29.9	-29.9	-29.5	-29.4	-29.4	-29.5	-29.2	-29.2
Recruit residual penalty		15.5	16.0	15.4	15.9	14.9	15.1	14.9	15.1	15.5	15.8	15.4	16.0	14.8	15.0	14.9	15.0

Table C2: continued

		17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
		M1	M1	M1	M1	M4	M4	M4	M4	M1	M1	M1	M1	M4	M4	M4	M4
		C3c	C3c	C3c	C3c	C3c	C3c	C3c	C3c	C3a	C3a	C3a	C3a	C3a	C3a	C3a	C3a
		H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4
		SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR1	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2
-lnL: Total		-176.4	-165.6	-173.6	-162.8	-185.9	-177.3	-185.9	-177.3	-169.5	-161.4	-163.2	-153.2	-179.5	-173.2	-178.5	-171.8
-lnL: CPUE	WC historic (spp combined)	-9.5	-7.0	-9.4	-6.6	-9.3	-6.7	-9.3	-6.7	-10.0	-9.8	-9.2	-8.6	-10.1	-9.9	-9.9	-9.9
	SC historic (spp combined)	-29.7	-28.2	-29.8	-28.3	-29.9	-29.4	-29.9	-29.4	-29.4	-27.9	-29.6	-27.3	-29.5	-28.6	-29.6	-28.5
	M. paradoxus GLM	-41.7	-41.5	-41.6	-41.5	-42.2	-42.8	-42.2	-42.8	-41.7	-42.0	-41.8	-42.1	-42.3	-43.2	-42.2	-43.0
	M. capensis GLM	-43.9	-43.5	-40.8	-40.6	-43.7	-43.7	-43.6	-43.6	-41.7	-41.6	-38.2	-37.1	-43.6	-43.8	-42.5	-42.5
-lnL: Survey	*M. paradoxus* , WC summer	-8.0	-7.6	-8.0	-7.5	-8.7	-8.9	-8.7	-8.9	-8.0	-7.5	-8.1	-7.5	-8.7	-8.8	-8.7	-8.8
	M. paradoxus , WC winter	-4.0	-3.9	-4.0	-3.9	-4.1	-4.1	-4.1	-4.1	-4.0	-3.8	-4.0	-3.8	-4.1	-4.1	-4.1	-4.1
	M. paradoxus , WC *Nansen*	-1.8	-1.8	-1.8	-1.8	-1.9	-2.0	-1.9	-2.0	-1.8	-1.8	-1.9	-1.8	-1.9	-1.9	-1.9	-1.9
	M. paradoxus , SC spring	-0.6	-0.5	-0.6	-0.5	-0.6	-0.7	-0.6	-0.7	-0.5	-0.3	-0.5	-0.3	-0.5	-0.5	-0.5	-0.5
	M. paradoxus , SC autumn	6.8	6.9	6.8	6.9	6.7	6.8	6.7	6.8	6.7	6.7	6.7	6.7	6.6	6.7	6.6	6.7
	M. capensis , WC summer	-1.8	-1.9	-1.9	-1.9	-2.0	-2.0	-2.0	-2.0	-1.8	-1.8	-1.7	-1.8	-1.9	-1.9	-2.0	-2.0
	M. capensis , WC winter	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4	0.4
	M. capensis , WC *Nansen*	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4
	M. capensis , SC spring	-1.6	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	-1.6	-1.6	-1.6	-1.5	-1.5	-1.5	-1.5	-1.4
	M. capensis , SC autumn	-7.6	-7.5	-7.7	-7.7	-7.6	-7.6	-7.6	-7.6	-7.8	-7.8	-7.9	-7.9	-7.7	-7.7	-7.7	-7.7
-lnL: commercial CAA	species combined, offshore	-38.7	-35.3	-39.2	-36.0	-42.6	-40.2	-42.7	-40.3	-38.9	-35.2	-39.3	-35.7	-42.1	-39.4	-42.6	-39.7
	M. capensis , inshore	-21.3	-22.1	-21.4	-21.5	-25.9	-25.8	-25.9	-25.9	-22.4	-22.7	-20.9	-21.6	-26.2	-25.8	-26.6	-26.7
	M. capensis , longline	-13.4	-14.2	-13.3	-13.4	-15.5	-15.5	-15.5	-15.5	-14.4	-14.6	-12.9	-13.6	-15.6	-15.6	-15.6	-15.7
-lnL: survey CAA	*M. paradoxus* , WC summer	-16.4	-16.2	-16.4	-16.2	-15.5	-15.0	-15.5	-15.0	-11.8	-11.6	-11.6	-11.5	-10.9	-10.5	-10.9	-10.5
	M. paradoxus , WC *Nansen*	-10.9	-11.0	-11.0	-11.1	-10.9	-10.8	-10.9	-10.8	-11.7	-11.8	-11.7	-11.8	-11.8	-11.8	-11.8	-11.8
	M. paradoxus , SC spring	-4.3	-3.4	-4.3	-3.4	-3.7	-2.5	-3.7	-2.5	-4.2	-3.2	-4.2	-3.2	-3.6	-2.5	-3.7	-2.5
	M. paradoxus , SC autumn	28.9	29.5	28.9	29.5	28.4	29.4	28.4	29.4	30.2	30.9	30.2	30.9	29.7	30.8	29.7	30.9
	M. capensis , WC summer	83.1	83.2	83.3	83.4	83.8	83.8	83.8	83.8	83.8	83.9	83.8	84.0	84.3	84.2	84.4	84.5
	M. capensis , WC winter	6.4	6.7	6.7	6.7	7.0	7.0	7.1	7.1	7.0	7.1	6.6	7.0	7.2	7.1	7.6	7.7
	M. capensis , WC *Nansen*	-6.0	-6.0	-6.0	-6.0	-5.9	-5.9	-5.9	-5.9	-6.2	-6.2	-6.3	-6.3	-6.2	-6.2	-6.2	-6.2
	M. capensis , SC spring	-8.7	-8.7	-8.8	-8.8	-9.1	-9.1	-9.2	-9.2	-7.6	-7.6	-7.6	-7.6	-7.9	-7.9	-7.9	-8.0
	M. capensis , SC autumn	-30.4	-30.4	-29.9	-29.9	-29.6	-29.5	-29.6	-29.5	-30.0	-30.0	-29.6	-29.5	-29.5	-29.6	-29.3	-29.3
Recruit residual penalty		16.0	17.2	15.3	15.9	14.9	15.2	15.0	15.3	10.9	11.1	10.7	11.0	10.0	10.2	10.1	10.2

Table C2: continued

		33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
		M1	M1	M1	M1	M4	M4	M4	M4	M1	M1	M1	M1	M4	M4	M4	M4
		C3b	C3b	C3b	C3b	C3b	C3b	C3b	C3b	C3c	C3c	C3c	C3c	C3c	C3c	C3c	C3c
		H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4	H1	H2	H3	H4
		SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2	SR2
-lnL: Total		-169.1	-161.8	-162.4	-154.2	-179.4	-173.6	-178.2	-172.2	-170.1	-159.2	-167.3	-156.4	-179.5	-171.0	-179.5	-170.9
-lnL: CPUE	WC historic (spp combined)	-10.1	-10.0	-9.2	-9.0	-10.1	-10.0	-10.0	-9.9	-9.5	-7.0	-9.4	-6.6	-9.4	-6.7	-9.4	-6.7
	SC historic (spp combined)	-29.1	-28.4	-29.5	-28.1	-29.3	-28.7	-29.4	-28.7	-29.7	-28.2	-29.8	-28.3	-29.9	-29.4	-29.9	-29.4
	M. paradoxus GLM	-41.7	-42.1	-41.8	-42.1	-42.3	-43.2	-42.3	-43.1	-41.7	-41.6	-41.7	-41.6	-42.2	-42.9	-42.2	-42.9
	M. capensis GLM	-41.5	-41.4	-37.8	-37.0	-43.6	-43.7	-42.4	-42.3	-43.9	-43.5	-40.8	-40.6	-43.7	-43.7	-43.6	-43.6
-lnL: Survey	*M. paradoxus*, WC summer	-8.0	-7.5	-8.1	-7.4	-8.7	-8.8	-8.7	-8.7	-8.1	-7.6	-8.0	-7.6	-8.8	-9.0	-8.8	-9.0
	M. paradoxus, WC winter	-4.0	-3.8	-4.0	-3.8	-4.1	-4.1	-4.1	-4.1	-4.0	-3.9	-4.0	-3.9	-4.1	-4.2	-4.1	-4.2
	M. paradoxus, WC *Nansen*	-1.8	-1.8	-1.9	-1.8	-1.9	-1.9	-1.9	-1.9	-1.8	-1.8	-1.8	-1.8	-1.9	-2.0	-1.9	-2.0
	M. paradoxus, SC spring	-0.5	-0.3	-0.5	-0.3	-0.5	-0.5	-0.5	-0.5	-0.5	-0.3	-0.5	-0.3	-0.5	-0.5	-0.5	-0.5
	M. paradoxus, SC autumn	6.7	6.7	6.7	6.7	6.6	6.7	6.6	6.7	6.7	6.8	6.7	6.8	6.6	6.8	6.6	6.8
	M. capensis, WC summer	-1.8	-1.8	-1.7	-1.8	-1.9	-1.8	-2.0	-2.0	-1.7	-1.8	-1.8	-1.8	-1.9	-1.9	-1.9	-1.9
	M. capensis, WC winter	0.4	0.4	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	M. capensis, WC *Nansen*	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4	-1.4
	M. capensis, SC spring	-1.6	-1.6	-1.6	-1.6	-1.5	-1.5	-1.5	-1.4	-1.6	-1.6	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5
	M. capensis, SC autumn	-7.8	-7.8	-7.9	-7.9	-7.7	-7.7	-7.7	-7.7	-7.7	-7.6	-7.8	-7.8	-7.7	-7.7	-7.7	-7.7
-lnL: commercial CAA	species combined, offshore	-39.0	-35.2	-39.3	-35.6	-42.1	-39.5	-42.6	-39.8	-38.8	-35.3	-39.2	-36.0	-42.5	-40.2	-42.6	-40.3
	M. capensis, inshore	-22.3	-22.4	-20.9	-21.4	-26.2	-25.6	-26.6	-26.6	-21.2	-22.1	-21.3	-21.4	-25.8	-25.8	-25.8	-25.8
	M. capensis, longline	-14.3	-14.4	-12.8	-13.3	-15.6	-15.6	-15.6	-15.7	-13.4	-14.3	-13.3	-13.5	-15.5	-15.5	-15.5	-15.5
-lnL: survey CAA	*M. paradoxus*, WC summer	-11.8	-11.6	-11.6	-11.6	-10.9	-10.5	-10.9	-10.5	-11.7	-11.4	-11.7	-11.4	-10.8	-10.2	-10.8	-10.2
	M. paradoxus, WC *Nansen*	-11.7	-11.8	-11.7	-11.8	-11.8	-11.8	-11.8	-11.8	-11.7	-11.8	-11.7	-11.9	-11.8	-11.8	-11.8	-11.8
	M. paradoxus, SC spring	-4.2	-3.2	-4.2	-3.2	-3.6	-2.5	-3.7	-2.5	-4.3	-3.2	-4.2	-3.2	-3.7	-2.5	-3.7	-2.5
	M. paradoxus, SC autumn	30.2	30.9	30.2	30.9	29.7	30.8	29.7	30.9	30.2	30.9	30.2	30.9	29.8	30.9	29.8	30.9
	M. capensis, WC summer	83.8	83.8	83.8	83.9	84.3	84.2	84.5	84.5	83.3	83.4	83.6	83.6	84.1	84.1	84.1	84.1
	M. capensis, WC winter	6.9	7.0	6.6	6.9	7.2	7.1	7.6	7.6	6.4	6.7	6.7	6.7	7.0	7.0	7.1	7.1
	M. capensis, WC *Nansen*	-6.2	-6.2	-6.3	-6.3	-6.2	-6.2	-6.2	-6.2	-6.2	-6.2	-6.3	-6.3	-6.2	-6.3	-6.2	-6.3
	M. capensis, SC spring	-7.6	-7.6	-7.6	-7.6	-7.9	-7.8	-7.9	-7.9	-7.6	-7.6	-7.6	-7.6	-7.9	-7.9	-7.9	-7.9
	M. capensis, SC autumn	-30.0	-30.0	-29.6	-29.5	-29.5	-29.6	-29.3	-29.2	-30.5	-30.5	-30.0	-30.0	-29.6	-29.6	-29.7	-29.6
Recruit residual penalty		10.9	11.0	10.7	11.1	10.0	10.1	10.1	10.1	11.5	12.5	10.7	11.0	10.1	10.3	10.1	10.4