An initial attempt at a spatially structured stock assessment for the South African hake resource

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INTRODUCTION

This document presents a first attempt at a spatially structured model for the South African hake (the model equations are set out in Appendix 1). It is currently assumed that *M. paradoxus* and *M. capensis* both consist of a single stock across the South African west and south coasts (and possibly extending to Namibia). From catch-at-length information, it is however clear that the fish are not distributed evenly in terms of age/length in different areas. *M. capensis* is usually found in depths of less than 400 m, with the largest biomass in the 100-200 m depth range, while the depth distribution of *M. paradoxus* ranges mainly from 150 m to 500 m. There is also a tendency for hake to move offshore into deeper water as they grow older. Age information from the surveys furthermore suggests that young (up to age 3) *M. capensis* are primarily restricted to the west coast. At intermediate ages, a large proportion of these fish move to the south coast. However, for the oldest fish (ages 6+), there is some movement back to the west coast. Similarly for *M. paradoxus*, the smaller fish tend to be found more on the west coast.

The current assessment of the resource treats the fish as homogeneously distributed throughout the whole region and explains the different age/length structure on the west and south coasts by assuming different fishing selectivities-at-age for the commercial and survey fleets (so selectivity here is combines both gear and availability effects). In this spatial model however, the survey and commercial fishing selectivities-at-age are taken to be the same across all regions. The regional differences in the age/length distributions of the catches are therefore explained by the different availability/presence of the age classes in each region.

The fish move across regions through the use of movement matrices, which reflect the probability that a fish of a particular age in region *r*' at the start of the year, moves to region *r* at the end of the year. These matrices are estimated for three age groups (rather than estimate a different matrix for each age class): a) ages 0-1, b) ages 2-4 and c) ages 5 and above; and are assumed to be constant over time (but variability in the form of random effects could also be included in the future if the data support their estimation).

Recruitment is a function of the total spawning biomass and is then distributed amongst regions on the basis of the movement matrix that redistributes ages 0 and 1 at the end of the year.

As in the current (new) baseline hake assessment (Rademeyer and Butterworth, 2008), the model is species-specific.

RESULTS AND DISCUSSION

<u>I. Two regions: west and south coasts</u>

In the first stage, the model includes two regions only, the west and south coasts.

The model is fitted to the same data as in the baseline hake assessment (some of which is species and region aggregated), except for the surveys for which catch-at-length information has been used for all years, rather than a mixture of catch-at-age and catch-at-length.

Results for this model are presented in Tables 1-2 and Figs 1-8.

II. Nine regions: five depth zones on the west coast and four depth zones on the south coast

This model comprises nine regions:

1. west coast, 0-100m;
2. west coast, 101-200m;
3. west coast, 201-300m;
4. west coast, 301-400m;
5. west coast, 401m+;
6. south coast, 0-50m;
7. south coast, 51-100m;
8. south coast, 101-200m; and
9. south coast, 200m+.

These nine regions follow the present survey area stratifications, so that all the survey data are readily available in that form. The commercial information was not available disaggregated into these nine regions and some crude assumptions have been made (not documented here as it is not the purpose of this document to present a complete assessment).

Fig. 9 plots the spawning biomass trajectories for both species.

REFERENCES

Rademeyer RA and Butterworth DS. 2008. Development of a new Baseline Assessment for the South African hake resource, incorporating catch-at-length information. Unpublished document, MCM, South Africa. MCM/2008/SEPT/SWG-DEM/52. 21pp.

Table 1: Estimates of management quantities for the 'two regions' model.

Likelihoods:		
Total	713.1	
historical_CPUE	-36.0	
GLM_CPUE	-150.5	
Survey	-34.2	
Commercial_CAA	-71.8	
Commercial_CAL	158.1	
Survey_CAL	832.2	
RecruitmentResiduals	12.6	
Selectivity_smoothing	2.7	
Negpen	0.0	
	M. paradoxus	*M. capensis*
K^{sp}	1450	736
B^{sp}_{2008}	337	443
B^{sp}_{2008}/K^{sp}	0.23	0.60
h	0.60	0.98
MSY	106	91
B^{sp}_{MSY}	470	247
$MSYL^{sp}$	0.32	0.34
M 0	0.91	1.00
1	0.91	1.00
2	0.91	1.00
3	0.68	0.74
4	0.54	0.58
5	0.45	0.48
6	0.45	0.48
7+	0.45	0.48

Table 2: Estimated movement matrices for the 'two regions' model.

	Ages 0-1		Ages 2-4		Ages 5+	
	in WC	in SC	in WC	in SC	in WC	in SC
M. paradoxus						
out WC	1.00	0.00	0.60	0.40	1.00	0.00
out SC	0.60	0.40	0.50	0.50	0.10	0.90
M. capensis						
out WC	1.00	0.00	0.89	0.11	0.67	0.33
out SC	0.71	0.29	0.00	1.00	0.88	0.12

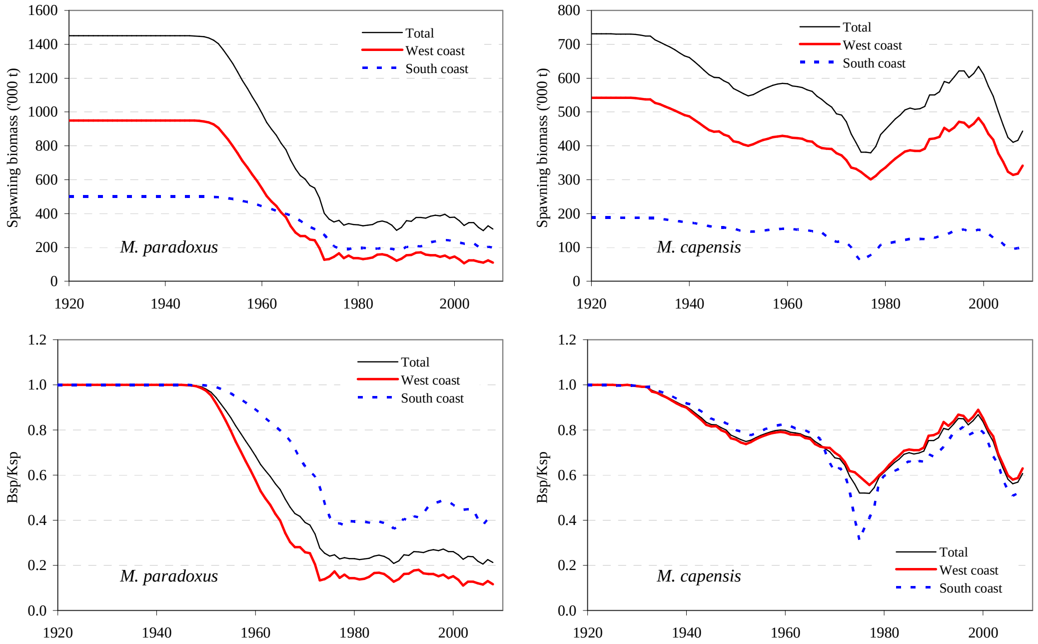

Fig. 1: Spawning biomass trajectories for the model with two regions.

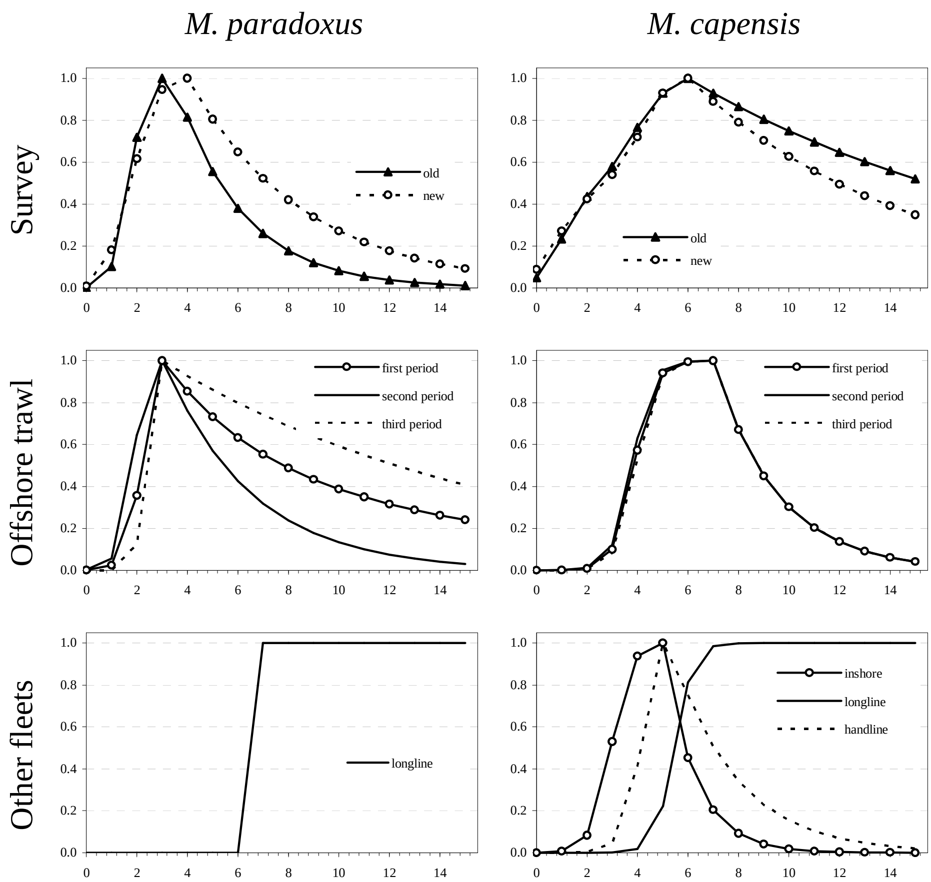

Fig 2: Survey and commercial fishing selectivities-at-age for the model with two regions (note that this model assumes selectivities to be region independent).

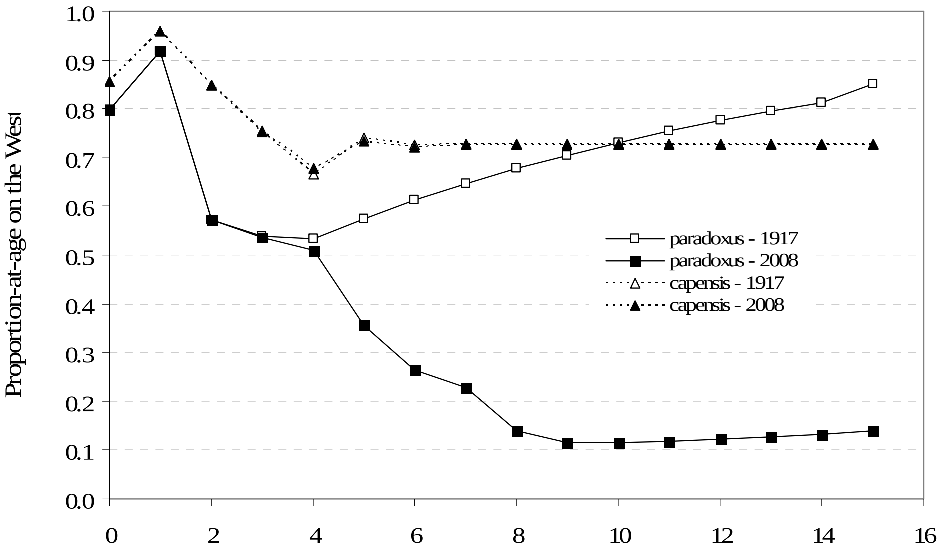

Fig. 3: Estimated proportions by age present on the west coast, pre-exploitation (1917) and currently (2008), for both species; the complementary proportions are present on the south coast.

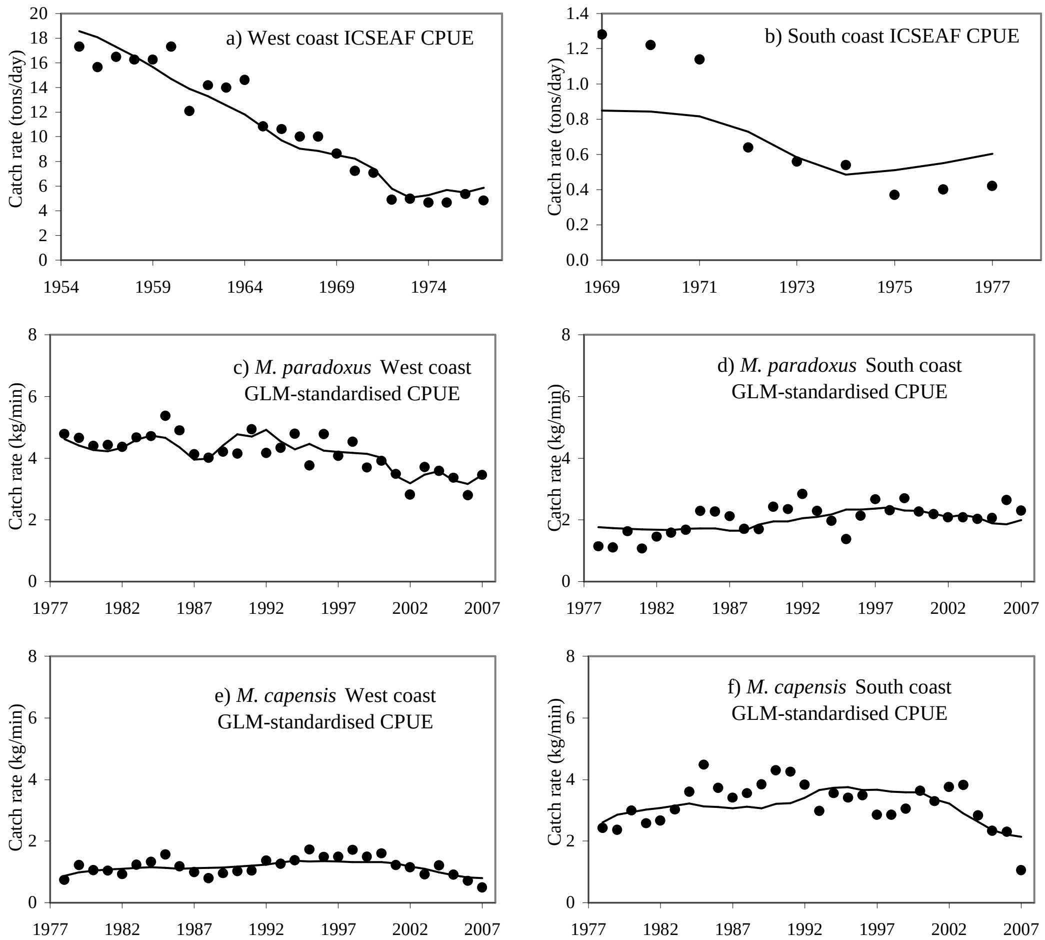

Fig. 4: Fit of the ‘two regions’ model to the historic and GLM-standardised CPUE series.

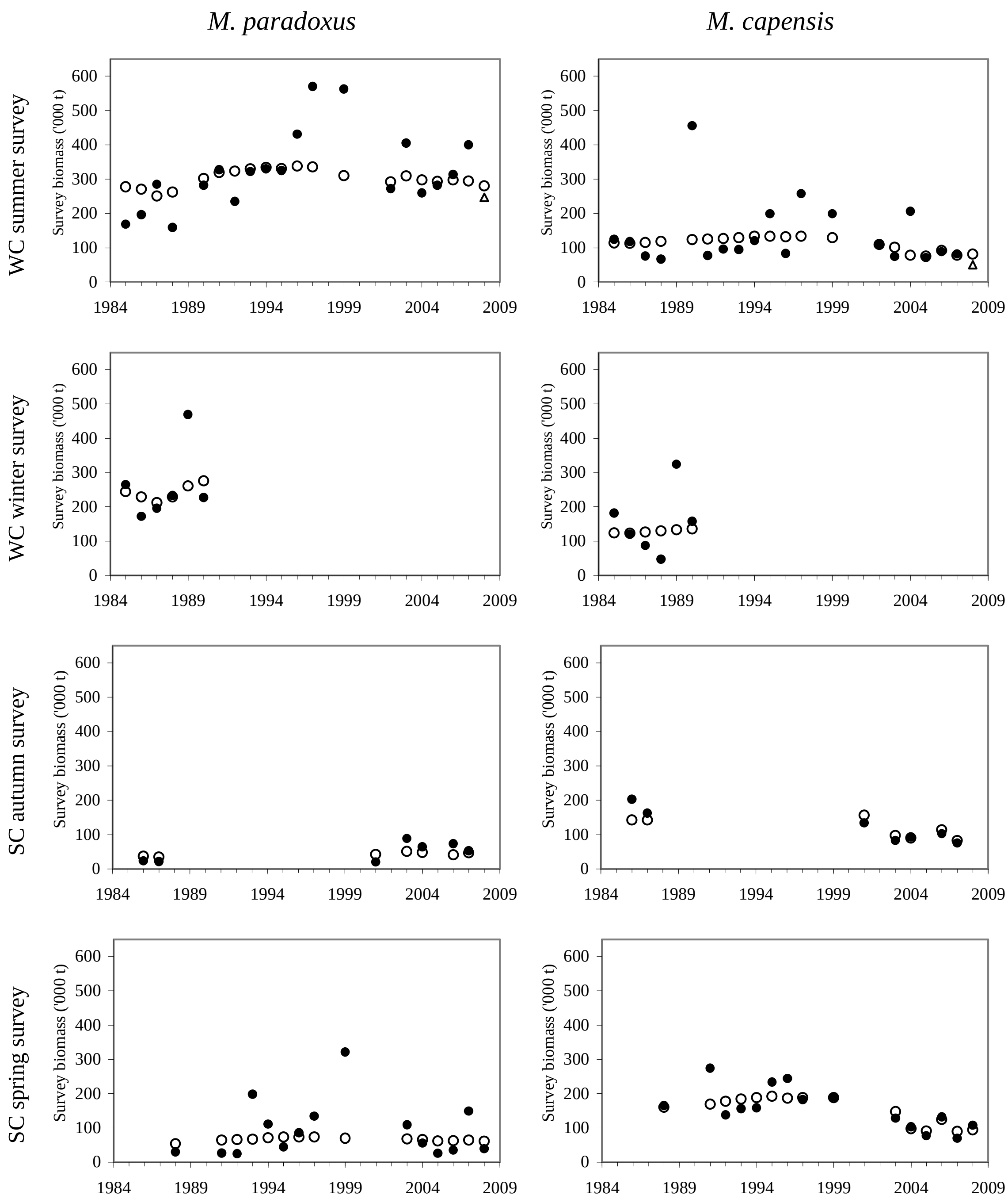

Fig. 5: Fit of the ‘two regions’ model to the survey abundance indices (Note: all plots have identical vertical scales).

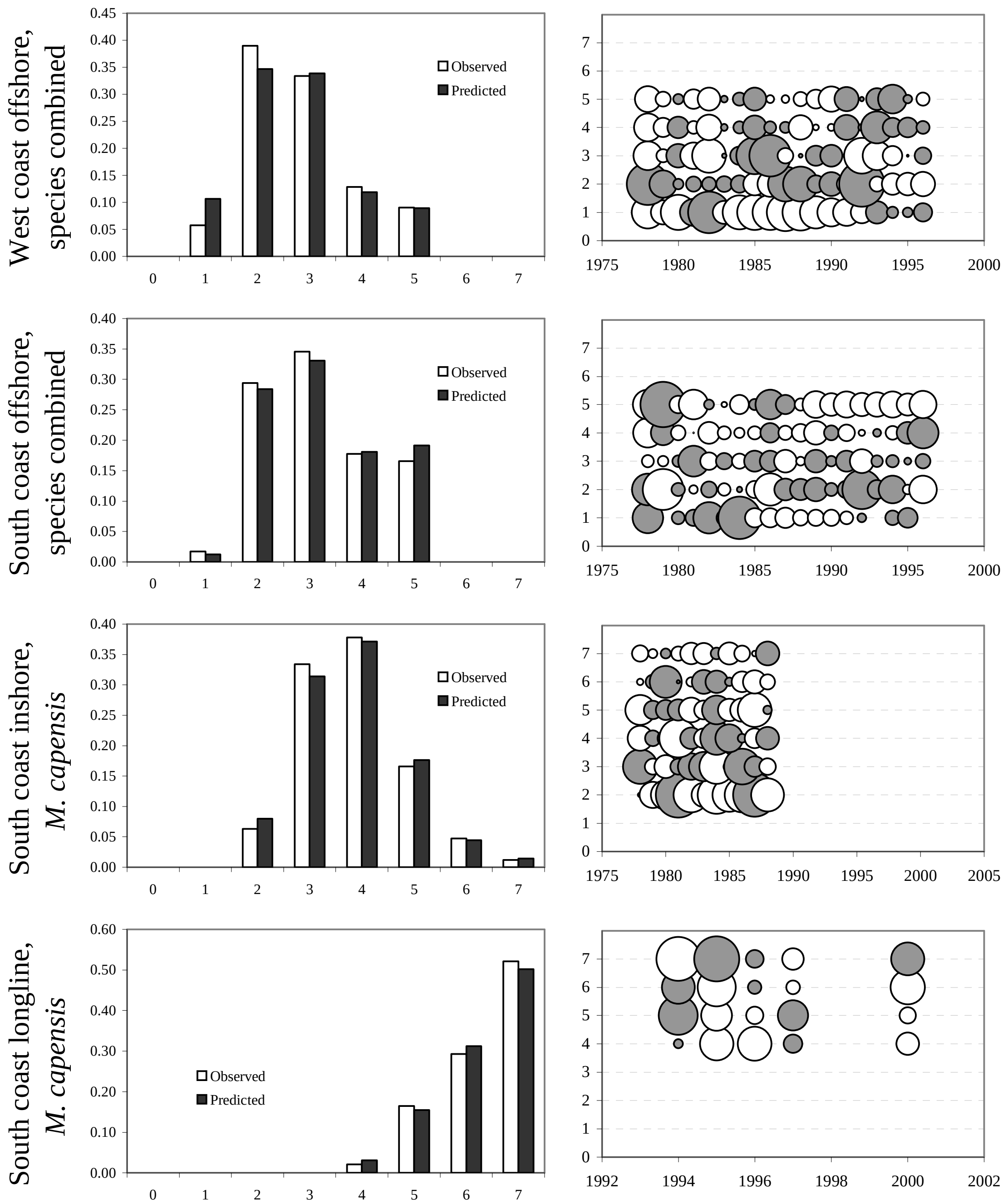

Fig. 6: Fit of the ‘two regions’ model to commercial CAA data. The bar plots show the observed and model-predicted CAA as averaged over all the years for which data are available, while the bubble plots show the standardised residuals

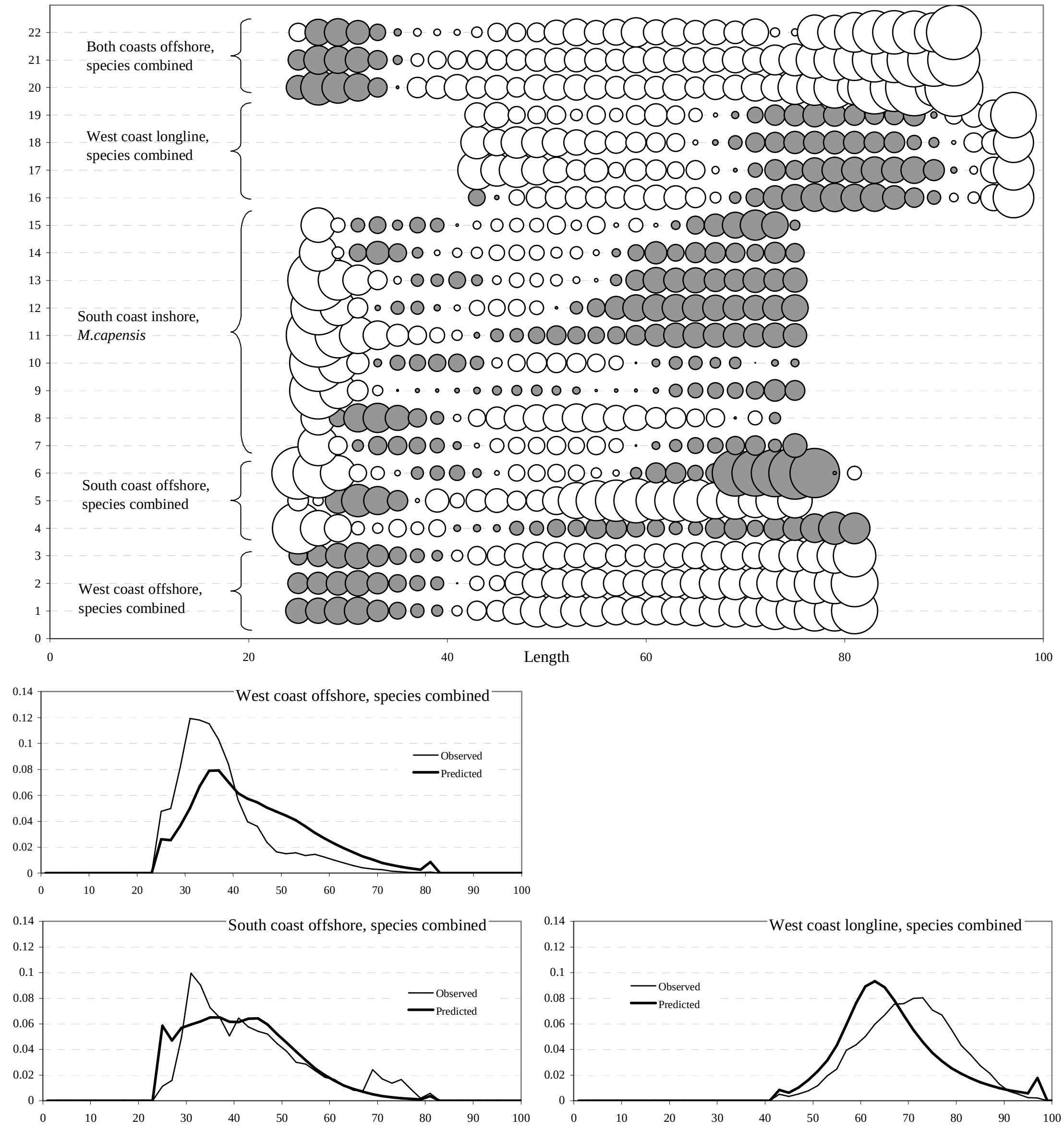

Fig. 7: Fit of the ‘two regions’ model to commercial CAL data. The line plots show the observed and model-predicted CAL as averaged over all the years for which data are available, while the bubble plots show the standardised residuals

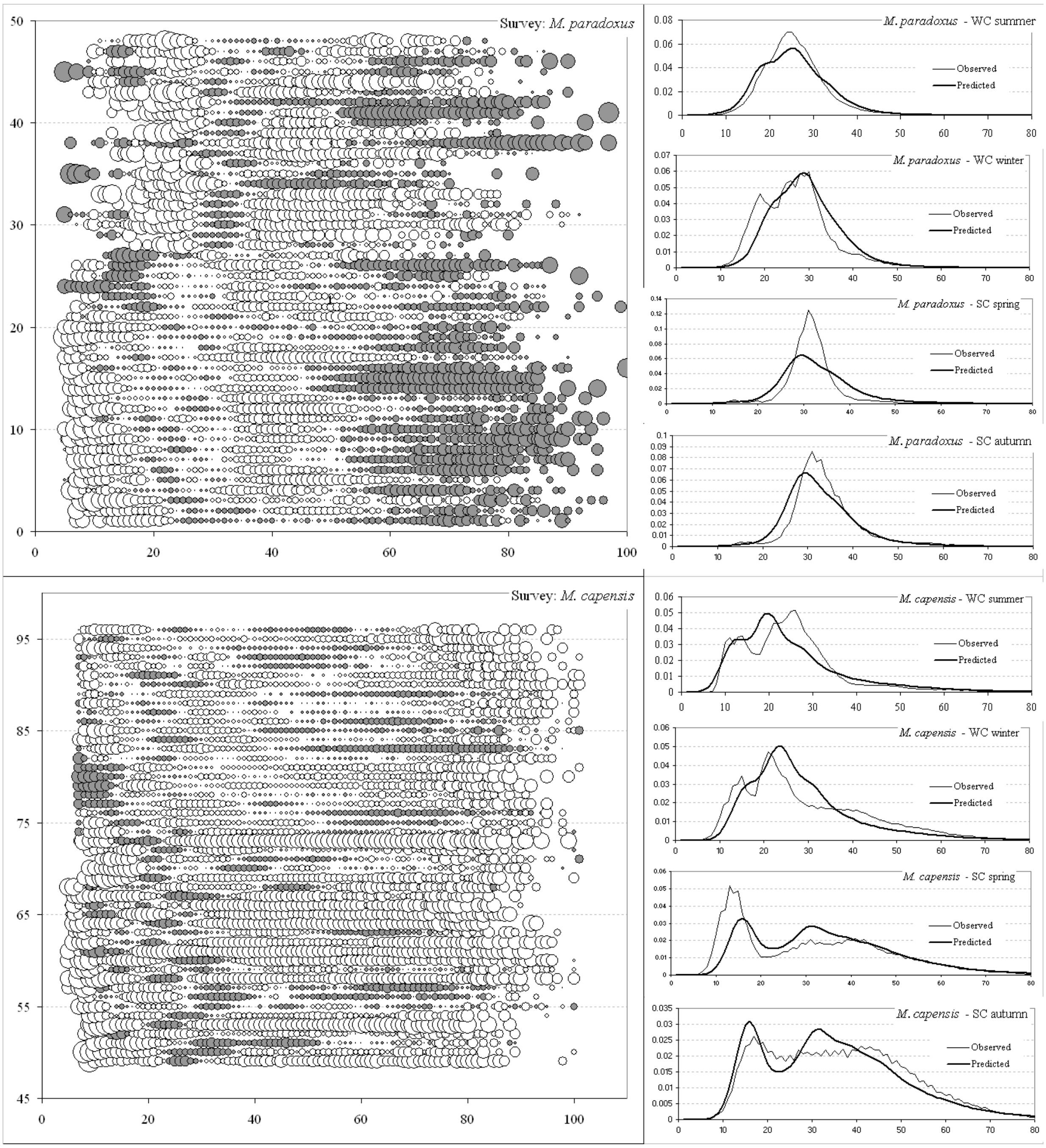

Fig. 8: Fit of the 'two regions' model to the survey CAL The line plots show the observed and model-predicted CAL as averaged over all the years for which data are available, while the bubble plots show the standardised residuals

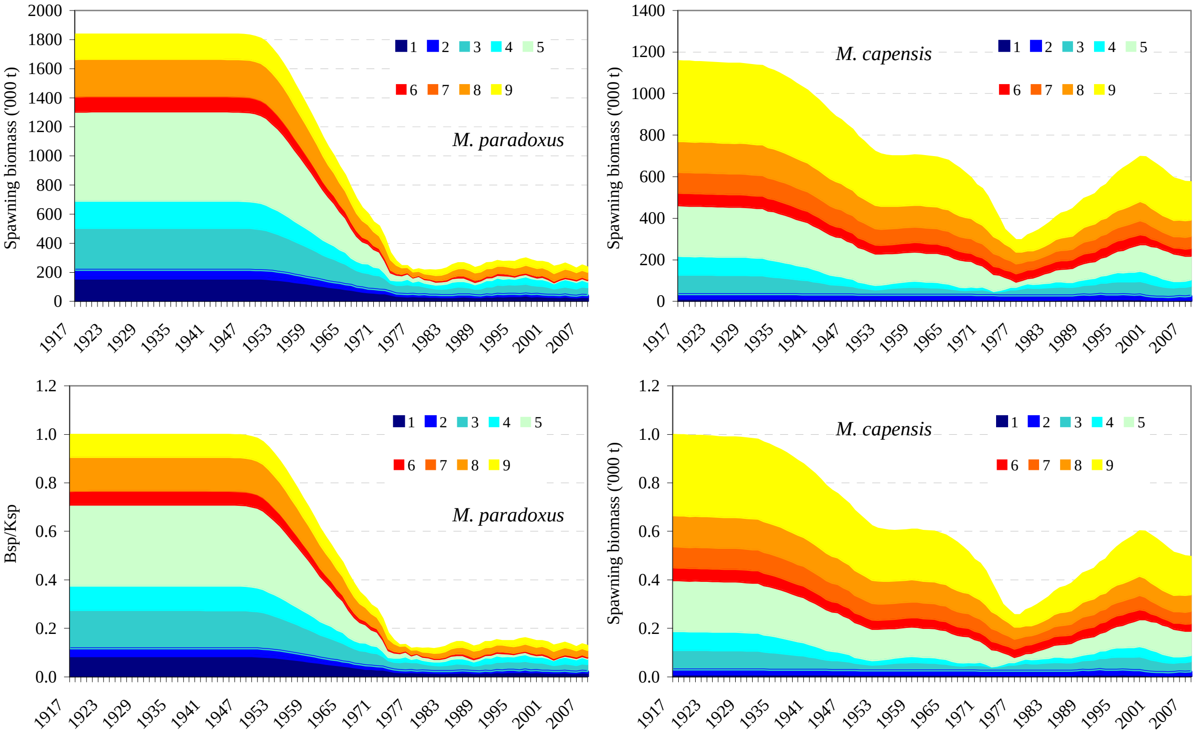

Fig. 9: Spawning biomass trajectories for the 'nine regions' model. Regions 1-5 are on the west coast, and 6-9 on the south coast, with lower numbers corresponding to shallower depth strata.

Appendix A – the model

Population Dynamics

r: an index for region, *r*=1,…, n_{region} (n_{region}=30, see Fig. 1)

y: an index for year

a: an index for age, *a*=1,…, *m* (*m* =15, a plus group)

f: an index for fleet, *f*=1,… n_{fleet} (n_{fleet}=4)

Numbers-at-age:

We use Pope's approximation

$$N^r_{y+1,0} = \left(\frac{1}{n_{region}} \sum_{r'}^{n_{region}} X^{\text{out } r', \text{in } r}_{y+1,0} \right) R_{y+1} \qquad \text{for } a=0 \qquad \textbf{(1)}$$

$$N^r_{y+1,a+1} = \sum_{r'}^{n_{region}} \left(\left[\left\{ N^{r'}_{y,a} e^{-M_a/2} - \sum_{f}^{n_{fleet}} C^{r'}_{f,y,a} \right\} e^{-M_a/2} \right] X^{\text{out } r', \text{in } r}_{y,a} \right) \qquad \text{for } 0 \le a \le m-2 \qquad \textbf{(2)}$$

$$\begin{aligned} N^r_{y+1,m} &= \sum_{r'}^{n_{region}} \left(\left[\left\{ N^{r'}_{y,m-1} e^{-M_{m-1}/2} - \sum_{f}^{n_{fleet}} C^{r'}_{f,y,m-1} \right\} e^{-M_{m-1}/2} \right] X^{\text{out } r', \text{in } r}_{y,m-1} \right) \\ &+ \sum_{r'}^{n_{region}} \left(\left[\left\{ N^{r',spp,s}_{y,m} e^{-M_m/2} - \sum_{f}^{n_{fleet}} C^{r'}_{f,y,m} \right\} e^{-M_m/2} \right] X^{\text{out } r', \text{in } r}_{y,m} \right) \end{aligned} \qquad \textbf{(3)}$$

i.e. 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 of the natural mortality, 5) move.

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

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

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

$X^{r',r}_{y,a}$: 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 ($X^{r,r}_{y,a}$ is the probability that a fish stays in region *r*).

For the moment, $X^{r,r'}_{y,a} = X^{r,r'}_{a}$, i.e the movement is the same across the years, but variability in the form of random effects could be included. Furthermore, at this stage,,movement is estimated for three age groups: a) ages 0-1, b) ages 2-4 and c) ages 5 and above. We could include some form of relationship (with random effects), such as forcing older fish offshore. The movement is not density dependent for now.

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

$$M_a = \begin{cases} M_2 & \text{for} \quad a \le 1 \\ \alpha^M + \dfrac{\beta^M}{a+1} & \text{for} \quad 2 \le a \le 5 \\ M_5 & \text{for} \quad a > 5 \end{cases} \qquad \textbf{(4)}$$

Recruitment:

$$R_y = f(SSB_y) \qquad \textbf{(5)}$$

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).

Beverton-Holt: $$f(SSB_y) = \frac{\alpha SSB_y}{\beta + SSB_y} e^{(\varsigma_y - \sigma_R^2/2)} \quad (6)$$

Modified Ricker: $$f(SSB_y) = \alpha SSB_y e^{-\beta (SSB_y)^\gamma} e^{(\varsigma_y - \sigma_R^2/2)} \quad (7)$$

Spawning biomass:

$$SSB_y = \sum_{r=1}^{n_{region}} \sum_{a=1}^{m} mat_a w_a^{spp} N_{y,a}^r \quad (8)$$

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

mat : the proportion of fish of age *a* that are mature

Catch:

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

$$C_{f,y}^r = \sum_a w_{a+1/2} C_{f,y,a}^r \quad (9)$$

$$C_{f,y,a}^r = N_{y,a}^r e^{-M_a/2} V_{f,y,a} F_{f,y}^r \quad (10)$$

$V_{f,y,a}$ is the commercial selectivity (not region specific) at age *a* for year *y* and fleet *f*; when $V_{f,y,a} = 1$, the age-class *a* is said to be fully selected.

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

The likelihood function

The model inputs past catch estimates by species and is fit to

1) region- and species-specific GLM-CPUE
2) historical CPUE (species aggregated but disaggregated over some regions (change over time?))
3) survey abundance indices (region and species)
4) commercial catch-at-age data (species aggregated and aggregated over some regions)
5) commercial catch-at-age length (species aggregated and aggregated over some regions)
6) survey catch-at-length data (region and species specific)
7) stock-recruitment curve
8) (in the future to ALKs as well)

The contributions by each of these to the negative of the log-likelihood are as in the baseline assessment, except for the fit to the catch-at-length data, which is assumed to follow a multinomial distribution rather than the log normal distribution.