A spatially structured stock assessment for the South African hake resource with movement based on a gravity model, and including fitting to outputs from the GeoPop Model

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SUMMARY

The gravity model of explicit spatial movement for the two South African hake species is extended to take account of advice from a mini-task group as on the plausibility of some earlier estimates of movement proportions and to incorporate information from the a GeoPop model to hake survey information over the 1998-2012 period. Addition of the GeoPop data leads to increasing *M. capensis* but decreasing *M. paradoxus* estimates of abundance over recent years. There is little impact on nearly all estimates of movement parameters.

INTRODUCTION

Clearly spatial distribution of both species of hake (*M. capensis* and *M. paradoxus*) change over time within the year, and as the fish age, so that these fish manifest systematic movements. The standard assessments of the South African resource account for this by allowing for selectivity to vary in space and time for catches and by space for surveys in a "fleets-as-areas" approach (e.g. Rademeyer and Butterworth, 2017).

One of the objectives of the ECOFISH program, particularly with eventual extension of the hake assessment to Namibia in mind, was to investigate models which account for these systematic hake movement patterns explicitly, rather than implicitly as in the "fleets-as-areas" approach. This was first attempted in Rademeyer and Butterworth (2011), but that model struggled to estimate the large number of movement parameters involved. Accordingly a more restricted model was attempted which used the "gravity" assumption for movement parameters to reduce the number of estimable parameters (Rademeyer, 2014). Some of the parameter values estimated were however considered to be unrealistic, so that a mini-task group was set up to review the situation and advise on the implementation of some further constraints.

Another component of the ECOFISH programme was the development of the GeoPop approach, which analysed survey results by means of a model incorporating spatial autocorrelation relationships (Jansen *et al*. 2016). This document addresses an approach to incorporate the outputs from GeoPop in the estimation process for the "gravity" model above.

This exercise takes account of advice provided by an International Review Panel (Dunn *et al.,* 2016) which recommended as follows.

> "The results from GeoPop could be used and included in spatial modelling for hake in the short-term, as follows.
> (a) Compare the spatial distributions by age from GeoPop with the raw survey data at the level of the spatial cells used in the spatial model (Rademeyer, 2013, 2014) to assess the extent to which GeoPop mimics the actual data.
> (b) Compare the outputs from the spatial model with those from GeoPop to assess whether the spatial model is able to replicate the patterns in distribution even without formally including the GeoPop results into the likelihood function (or in the form of penalty terms) for the spatial model.
> (c) Include the spatial distribution information from GeoPop into the likelihood function of the spatial model; it will then be necessary to downweight the spatial (but not trend) information from the survey data when formulating the likelihood function."

Appendix 1 summarises the equations of the gravity movement model of Rademeyer (2014).

METHODS

Model A: Update of the 2014 Gravity model (Rademeyer, 2014)

Model A is an update of the 2014 Gravity model (Rademeyer, 2014), including the following changes/updates.

Data

1) Updated catch data: to 2016.
2) Updated survey data: biomass estimates revised and updated to 2016, and corrected catch-at-length data, to 2016.
3) Updated GLM-standardised CPUE data by region.
4) Updated commercial CAL data: to 2015, CAA data have been substituted by CAL data because of an apparent conflict between the CAA and CAL data.

Constraints

A mini-task group met at DAFF in July 2016 to discuss imposing constraints on some of the movement parameters. These constraints were grouped into three types.

- *a.* Constraints on recruitment.
- *b.* Movement "forbidden", i.e. matrix cells set to zero.
- *c.* Matrix cells "flagged", i.e. values appeared unrealistic.

The model described here has constraints *a* and *b* applied.

5) Constraints on recruitment:
    a. *M. paradoxus* recruitment in 201m+ region on the South Coast is forced to be less than 20% of the total recruitment (imposed using a heavy penalty function),
    b. *M. capensis* recruitment in 201m+ on West and South Coasts set to 0.

Model B: Fitting to GeoPop outputs

Model B duplicates Model A, except that it includes two GeoPop contributions to the negative log-likelihood. Note that GeoPop provides a picture of the spatial distribution of the resource by length averaged over the 15-year period 1998 to 2012.

Average abundance index by region, for each species

The likelihood is calculated by assuming that the GeoPop index is a relative index and is log-normally distributed about its expected value:

$$\varepsilon_r = \ell n(I_r) - \ell n(\hat{I}_r) \qquad (1)$$

where

I_r is the index for region r;

$\hat{I}_r = \hat{q}\hat{B}_r$ is the corresponding model estimate, where $\widehat{B}_r$ is the model estimate of average survey abundance, given by:

$$B_y^{r,surv} = \frac{1}{15}\sum_{y=1998}^{2012}\sum_{a=0}^{m} S_a^{surv} N_{ya}^{r} e^{M_a/2}\left(1 - \sum_f S_{fya} F_{fy}^{r} / 2\right) \qquad (2)$$

$\hat{q}$ is the constant of proportionality; and

ε_r from $N(0,(\sigma)^2)$.

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

$$-\ell n\, L^{GPab} = \sum_r \left[\ell n(\sigma) + (\varepsilon_r)^2 / 2\sigma^2\right] \qquad (3)$$

where

σ is the standard deviation of the residuals for the logarithms of the index.

Average proportions-at-length by region, for each species

The contribution of the GeoPop proportion-at-length data to the negative of the log-likelihood function assuming a Punt-Kennedy (1997) error distribution is given by:

$$-\ell\text{n}\, L^{\text{GPlength}} = \sum_r \sum_l \left[\ell n\left(\sigma_{len} / \sqrt{p_{rl}}\right) + p_{rl}\left(\ell n p_{rl} - \ell n\, \hat{p}_{rl}\right)^2 / 2\left(\sigma_{len}\right)^2 \right] \tag{4}$$

where

p_{rl} is the GeoPop average proportion-at-length for region *r* and length *l*,

$\hat{p}_{rl}$ is the model predicted average proportion-at-length for region *r* and length *l*, computed as:

$p_{rl} = \frac{1}{15} \sum_{y=1998}^{2012} \frac{C_{ryl}}{\sum_{l'} C_{ryl'}}$ is the observed proportion of fish of species *s*, and length *l* from survey *surv* in year *y*, with

$$C_{ryl} = \sum_a S_l^{surv} P_{a+1/2,l} N_{ya}^r e^{M_a/2} \left(1 - \sum_f S_{fya} F_{fy}^r / 2\right) \tag{5}$$

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

$$\hat{\sigma}_{len} = \sqrt{\sum_r \sum_l p_{rl}\left(\ln\, p_{rl} - \ln\, \hat{p}_{rl}\right)^2 / \sum_r \sum_l 1} \tag{6}$$

Model C: Fitting to GeoPop outputs and downweighting the survey spatial information

Model C duplicates Model B, except that the survey spatial information is downweighted. This is to avoid double counting of certain data, as the GeoPop results are estimated by fitting to survey data.

Survey biomass data:

The contribution to the negative log-likelihood of the survey biomass data (for each region and species) is downweighted by a factor of 0.01. To retain the trend information of the data, the following contribution is added:

$$-\ell\text{n}\, L^{Survey} = \sum_i \sum_y \left[\ell\text{n}\left(\sqrt{\left(\sigma_y^i\right)^2 + \left(\sigma_A\right)^2} \right) + \left(\varepsilon_y^i\right)^2 / 2\left(\left(\sigma_y^i\right)^2 + \left(\sigma_A\right)^2\right) \right] \tag{7}$$

with $\varepsilon_y^i = \ell\text{n}\left(I_y^i\right) - \ell\text{n}\left(\hat{I}_y^i\right)$ (8)

where

I_y^i is the biomass index for year *y* and survey series *i*;

$\hat{I}_y^i = \hat{q}^i \sum_r \hat{B}_{ry}^{surv}$ is the corresponding model estimate

Survey proportion-at-length

The contribution to the negative log-likelihood of the survey proportion-at-length data (for each region and species) is downweighted by a factor of 0.01.

RESULTS

Comparing GeoPop output with raw survey data

The GeoPop outputs are average (over 1998-2012) catch rate estimates (in numbers) per length class and region for each species. They are plotted and compared to the raw survey data as recommended by the International Review Panel. **Figure 1** plots the proportions in each region of total average abundance (GeoPop) and total average biomass (raw data), while **Figure 2** compares the average proportions-at-length for both the GeoPop outputs and the raw data.

Models A, B and C

The full set of results for Models A, B and C are given in Appendices 2A, B and C respectively. **Table 1** compares estimate of management quantities for the three Models, while **Table 2** compares the different contributions to the total negative log-likelihood when the Models are fit.

Figure 3 compares the spawning biomass trajectories for each of the three Models.

Figure 4 plots the fit to the GeoPop total average abundance for each of the three Models, while **Figure 5** compares the fit to the GeoPop proportions-at-length in each region for each of the three Models. The fit to the GeoPop outputs is not included in the total likelihood for Model A, but the comparison is still shown.

Table 3 lists the differences in the estimated movement matrices between Models A and C, and **Figure 6** compares the movement parameters estimated for each of the three Models. Table 4 lists the differences between Models A and C in the estimated 1998-2012 average number of fish moving, and Figure 7 compares these for each of the three Models.

DISCUSSION

The comparison of raw survey data with GeoPop outputs recommended by the International Review Panel is confounded somewhat by these being in different units (mass and numbers respectively). Nevertheless abundance trends with region are broadly similar (Figure 1), and proportions-at-length match closely except for a few regions at the lowest length for *M. capensis*.

Since Model B is really an intermediate step only, and reflects double weighting of certain data, discussion here is restricted to a comparison of the results from Model A and Model C, and primarily in the context of what differs when the GeoPop output is taken into account on fitting the model.

Effects of including the GeoPop information:

- Current spawning biomass in absolute terms and as a proportion of Bmsy is lower for *M. paradoxus*, and higher (by a greater extent) for *M. capensis* (Table 1).
- These differences in spawning biomass are largest over the most recent five years (Figure 3).
- There is little effect on estimates of movement parameters except for 1-year olds on the west coast.
- For *M. paradoxus* 1-year olds in the 201-300m zone, the great majority move towards the 101-200m zone, instead of moving mostly to the 301-400m zone (Figure 6).
- For *M. capensis* 1-year olds in the 101-200m zone, instead of about half moving inshore, nearly all stay in the 101-200m zone (Figure 6).
- Survey selectivity for small length for new gear becomes high when including (see Figures 2A6 and 2C4 in Appendix 2) – this relates to the comment above about a poor match of data and model for the lowest lengths of small *M. capensis*.

REFERENCES

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Table 1: Results for each of the three models. The biomass values are in thousand tons.

		Model A	**Model B**	**Model C**
		Not fitted to GeoPop outputs	Fitted to GeoPop outputs	Fitted to GeoPop outputs, downweighting survey spatial information
M. paradoxus	K^{sp}	1278	1266	1270
	B^{sp}_{MSY}	377	378	350
	h (BH)	0.83	0.84	0.84
	B^{sp}_{2016}	152	133	126
	B^{sp}_{2016}/K^{sp}	0.12	0.10	0.10
	$B^{sp}_{2016}/B^{sp}_{MS}$	0.40	0.35	0.36
	MSY	108	109	109
	WCsummer q	1.07	1.05	1.10
	WC winter q	0.94	0.94	0.99
	SC spring q	0.92	0.85	0.86
	SC autumn q	2.03	1.86	1.92
M. capensis	K^{sp}	760	771	783
	B^{sp}_{MSY}	276	287	275
	h (BH)	0.53	0.53	0.52
	B^{sp}_{2016}	189	280	308
	B^{sp}_{2016}/K^{sp}	0.25	0.36	0.39
	$B^{sp}_{2016}/B^{sp}_{MS}$	0.68	0.97	1.12
	MSY	47	47	48
	WCsummer q	1.29	0.79	0.80
	WC winter q	1.97	1.23	1.24
	SC spring q	1.92	2.15	1.87
	SC autumn q	2.02	2.21	1.92

Table 2: Comparison of contributions to the total negative log-likelihood for each of the three models. For Model A, the GeoPop contributions are greyed out because they are not included in the total negative log-likelihood.

	Model A	**Model B**	**Model C**
Negative log-likelihoods	Not fitted to GeoPop outputs	Fitted to GeoPop outputs	Fitted to GeoPop outputs, downweighting survey spatial information
Total	4142.7	4406.6	114.5
SC historic CPUE	-36.3	-36.6	-37.0
GLM CPUE	-139.0	-143.6	-148.9
Survey indices	61.2	70.2	2.6
Commercial CAL	34.0	43.8	30.6
Survey CAL	4208.1	4228.4	42.8
SR	11.4	11.2	11.4
Selectivity smoothing	2.7	2.5	2.8
GeoPop abundance	3.0	4.7	0.3
GeoPop CAL	523.8	225.6	207.6
Survey trend	-	-	2.2

Table 3: **Model A – Model C** difference in proportion of recruitment in each region and movement matrices estimated for *M. paradoxus* and *M. capensis*. Here and in the next Figure, the tone of the shading is proportional to the size of the differences (i.e. the bigger the difference, the darker the tone), with negative values in red and positive values in green.

M. paradoxus

Age 0

	Prop.
0-100m	-
101-200m	-0.05
201-300m	0.05
301-400m	-
401m+	-
0-50m	-
51-100m	-
101-200m	0.00
201m+	-0.01

Age 1

into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	-	-	-	-	-	-	-	-	-
101-200m	-	-0.09	0.23	-0.14	-	-	-	0.00	0.00
201-300m	-	-0.99	0.03	0.96	-	-	-	0.00	0.00
301-400m	-	-0.93	0.94	-0.01	-	-	-	0.00	0.00
401m+	-	-	-	-	-	-	-	-	-
0-50m	-	-	-	-	-	-	-	-	-
51-100m	-	-	-	-	-	-	-	-	-
101-200m	-	-0.93	0.94	-0.01	-	-	-	0.00	0.00
201m+	-	-0.93	0.94	-0.01	-	-	-	0.00	0.00

Ages 2-4

into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.07	-0.05	0.14	-0.11	-	-	-0.01	-0.04
201-300m	-	0.00	0.17	0.14	-0.20	-	-	-0.01	-0.09
301-400m	-	0.00	-0.03	0.17	-0.10	-	-	-0.01	-0.03
401m+	-	0.00	-0.09	0.18	0.00	-	-	-0.01	-0.07
0-50m	-	-	-	-	-	-	-	-	-
51-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.00	-0.03	0.17	-0.10	-	-	0.00	0.18
201m+	-	0.00	-0.05	0.18	-0.13	-	-	0.03	0.00

Ages 5+

into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	-	-	-	-	-	-	-	-	-
101-200m	-	-0.05	0.00	0.00	0.06	-	-	0.00	0.00
201-300m	-	0.14	0.00	0.00	-0.14	-	-	0.00	0.00
301-400m	-	-	0.00	0.00	0.00	-	-	0.00	0.00
401m+	-	-	-0.07	0.18	-0.21	-	-	-0.01	0.10
0-50m	-	-	-	-	-	-	-	-	-
51-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.00	0.00	0.00	0.00	-	-	0.00	0.00
201m+	-	0.00	0.00	0.00	0.01	-	-	0.00	-0.01

M. capensis

Age 0

	Prop.
0-100m	0.16
101-200m	-0.17
201-300m	-
301-400m	-
401m+	-
0-50m	0.01
51-100m	0.00
101-200m	0.01
201m+	-

Age 1

into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	0.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00
101-200m	0.54	-0.56	0.02	-	-	0.01	0.00	0.00	0.00
201-300m	0.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00
301-400m	-	-	-	-	-	-	-	-	-
401m+	-	-	-	-	-	-	-	-	-
0-50m	0.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00
51-100m	0.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00
101-200m	0.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00
201m+	0.00	0.00	0.00	-	-	0.00	0.00	0.00	0.00

Ages 2-4

into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	0.09	0.00	0.00	0.00	-	0.00	-0.38	0.30	-0.01
101-200m	0.00	-0.09	0.01	0.00	-	0.00	-0.07	0.15	0.00
201-300m	0.00	0.00	0.00	0.00	-	0.00	-0.38	0.39	-0.01
301-400m	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00
401m+	-	-	-	-	-	-	-	-	-
0-50m	0.00	0.00	0.00	0.00	-	0.02	-0.08	0.06	0.00
51-100m	0.00	0.00	-0.13	-0.01	-	0.00	0.00	0.18	-0.04
101-200m	0.00	0.00	0.01	0.00	-	0.00	-0.35	0.34	-0.01
201m+	0.00	0.00	0.01	0.00	-	0.00	-0.36	0.34	0.00

Ages 5+

into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	0.00	0.01	-0.15	-0.01	-	0.00	0.03	0.08	0.03
101-200m	0.00	0.00	-0.14	0.00	-	0.00	0.03	0.08	0.03
201-300m	0.00	0.03	-0.02	-0.13	-	-0.01	0.08	0.08	-0.02
301-400m	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00
401m+	-	-	-	-	-	-	-	-	-
0-50m	0.00	0.00	0.07	0.01	-	-0.11	0.00	0.02	0.01
51-100m	0.00	0.01	-0.13	0.00	-	0.00	0.00	0.08	0.03
101-200m	0.00	0.01	-0.15	-0.01	-	0.00	0.03	0.08	0.03
201m+	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00

Table 4: **Model A – Model C** difference in number moving estimated for *M. paradoxus* and *M. capensis*.

M. paradoxus

Age 1		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	-500.3	87.8	-45.1	-	-	-	0.0	0.0
	201-300m	-	-80.7	-18.2	654.9	-	-	-	0.0	0.0
	301-400m	-	0.0	191.5	0.0	-	-	-	0.0	0.0
	401m+	-	-	-	-	-	-	-	-	-
	0-50m	-	-	-	-	-	-	-	-	-
	51-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	0.0	0.0	0.0	-	-	-	0.0	0.0
	201m+	-	0.0	0.0	0.0	-	-	-	0.0	0.0

Ages 2-4		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	0.3	1.0	-30.1	-45.6	-	-	-3.7	-27.7
	201-300m	-	0.0	-26.5	31.9	-6.7	-	-	-0.1	-0.2
	301-400m	-	0.0	-25.7	35.4	50.0	-	-	-1.6	-11.2
	401m+	-	0.0	50.0	60.4	0.0	-	-	3.3	24.9
	0-50m	-	-	-	-	-	-	-	-	-
	51-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	0.0	-47.7	-22.8	-38.1	-	-	-3.4	2.0
	201m+	-	0.0	33.4	40.3	22.9	-	-	2.2	0.0

Ages 5+		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	2.3	0.0	0.0	5.5	-	-	0.0	0.0
	201-300m	-	1.3	0.0	0.0	0.2	-	-	0.0	0.0
	301-400m	-	0.0	-3.2	-0.2	-3.9	-	-	-0.1	-0.3
	401m+	-	0.0	5.2	3.6	6.7	-	-	0.0	2.3
	0-50m	-	-	-	-	-	-	-	-	-
	51-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	0.0	0.0	0.0	0.0	-	-	1.3	-7.1
	201m+	-	0.0	0.0	0.0	0.1	-	-	0.0	7.8

M. capensis

Age 1		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	-21.1	-239.5	0.1	-	-	-0.3	0.0	0.0	-0.8
	101-200m	117.7	81.8	3.1	-	-	1.6	0.0	0.0	0.0
	201-300m	0.1	2.9	0.0	-	-	0.0	0.0	0.0	0.0
	301-400m	-	-	-	-	-	-	-	-	-
	401m+	-	-	-	-	-	-	-	-	-
	0-50m	0.0	1.5	0.0	-	-	0.0	0.0	0.0	0.0
	51-100m	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0
	101-200m	0.0	-0.6	0.0	-	-	0.0	0.0	0.0	0.0
	201m+	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0

Ages 2-4		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	0.4	-83.8	-5.0	-0.2	-	-0.1	-33.8	-12.7	-0.6
	101-200m	0.0	49.2	3.3	0.1	-	0.0	-2.3	11.9	-0.1
	201-300m	0.0	0.0	0.0	-0.9	-	0.0	6.5	10.4	0.1
	301-400m	0.0	0.0	0.0	1.6	-	0.0	0.0	0.0	0.0
	401m+	-	-	-	-	-	-	-	-	-
	0-50m	0.0	0.0	-20.4	-0.8	-	0.4	0.0	-56.9	-2.4
	51-100m	0.0	0.0	2.5	0.3	-	0.0	-34.3	26.8	-0.4
	101-200m	0.0	0.0	9.6	0.6	-	0.1	30.9	51.3	0.3
	201m+	0.0	0.0	0.1	0.0	-	0.0	0.2	0.3	0.0

Ages 5+		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	0.0	0.0	0.2	0.0	-	0.0	0.0	0.0	0.0
	101-200m	-1.6	0.0	-0.6	-3.8	-	-0.6	0.0	-5.2	-4.2
	201-300m	0.2	0.4	2.2	-7.5	-	0.4	1.1	4.9	2.9
	301-400m	0.0	0.0	0.0	6.9	-	0.0	0.0	0.0	0.0
	401m+	-	-	-	-	-	-	-	-	-
	0-50m	0.0	0.0	0.1	0.0	-	0.6	0.0	0.0	0.0
	51-100m	-0.2	0.0	-3.2	-0.3	-	0.0	0.0	-0.4	-0.4
	101-200m	0.0	0.1	3.8	0.4	-	0.1	0.2	0.8	-14.5
	201m+	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	10.7

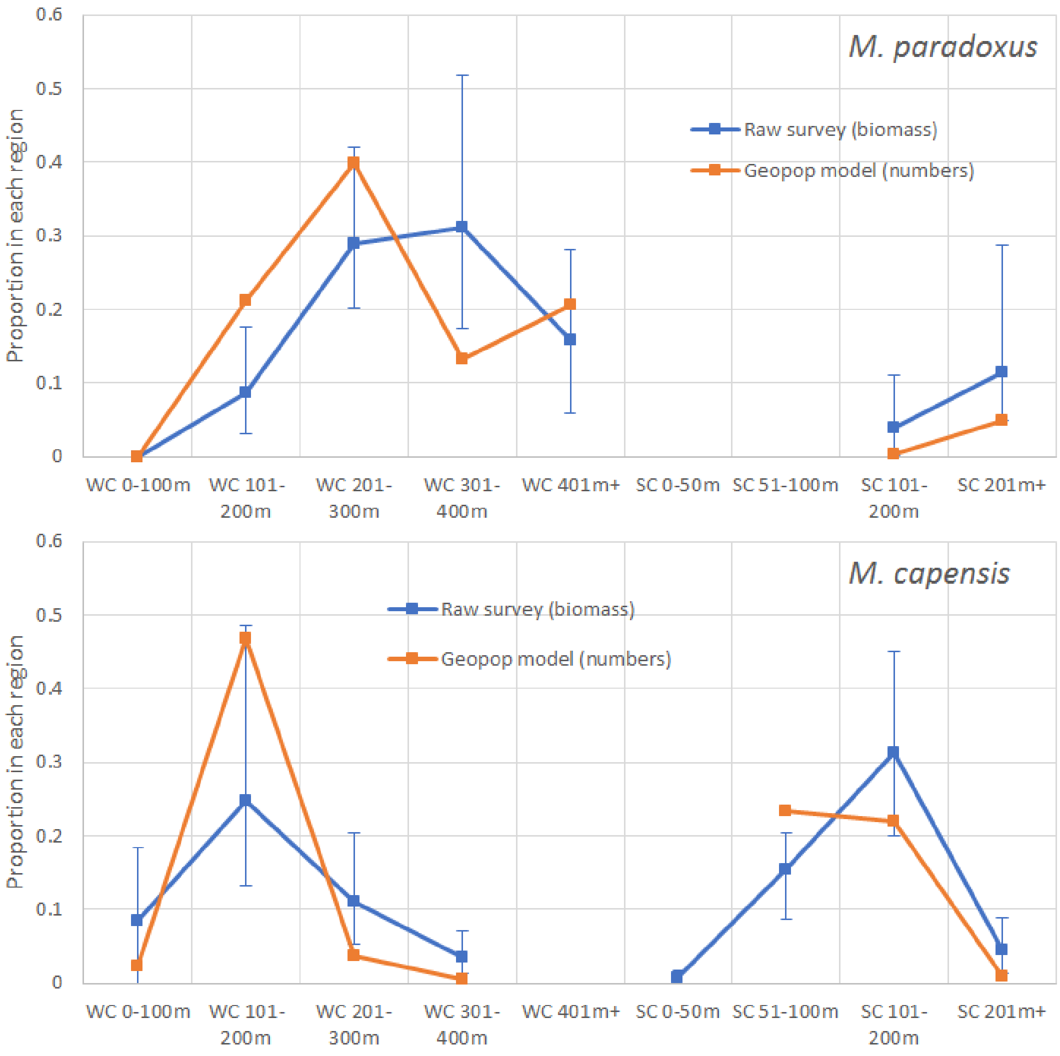

Figure 1: Proportions in each region of total abundance (average numbers over the 1998-2012 period, GeoPop) and total biomass (average biomass over the 1998-2012 period, raw survey data). The error bars for the raw data show the minimum and maximum values over the 1998-2012 period.

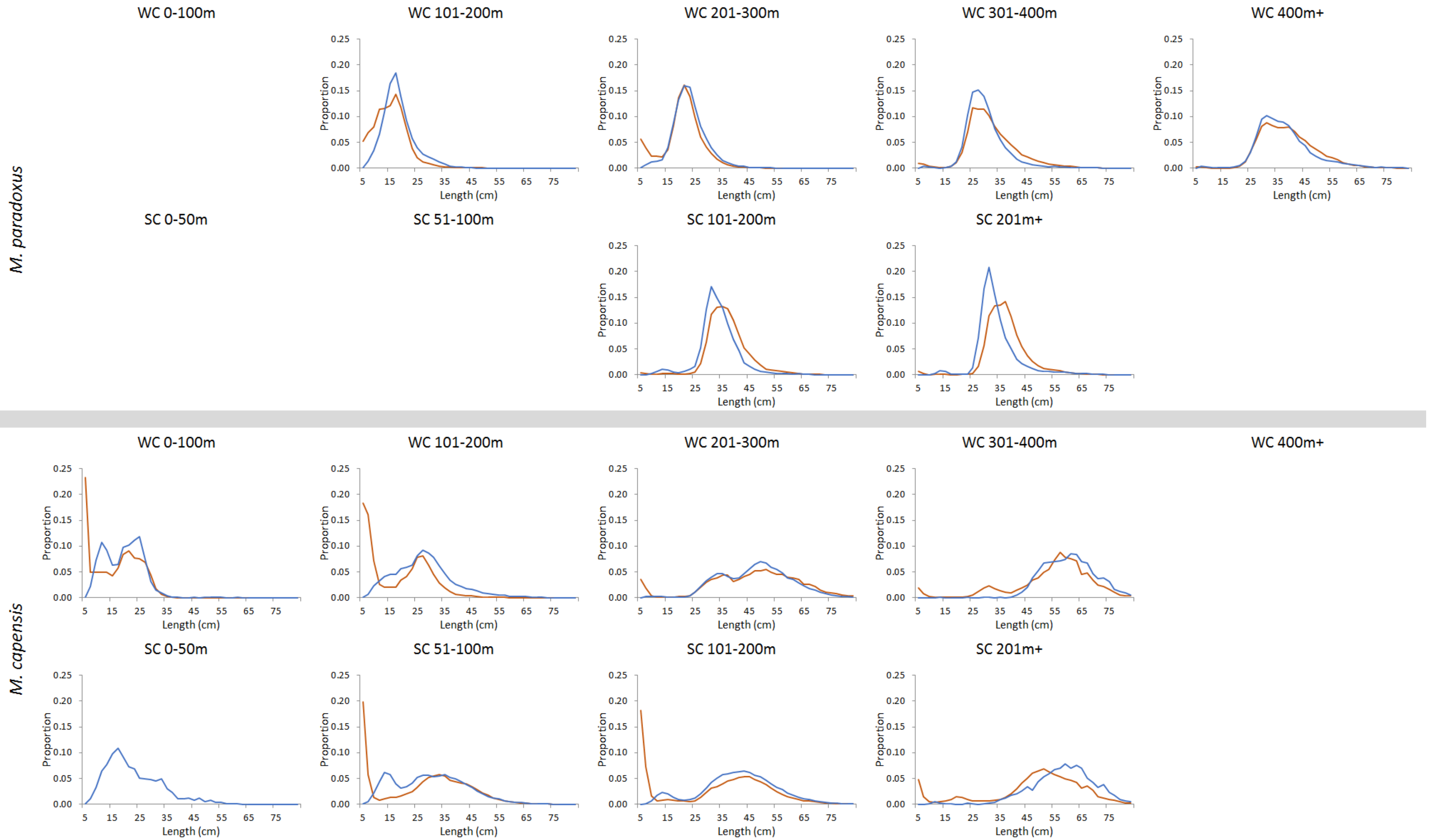

Figure 2: 1998-2012 average proportions-at-length from GeoPop (orange lines) and from the raw survey data.

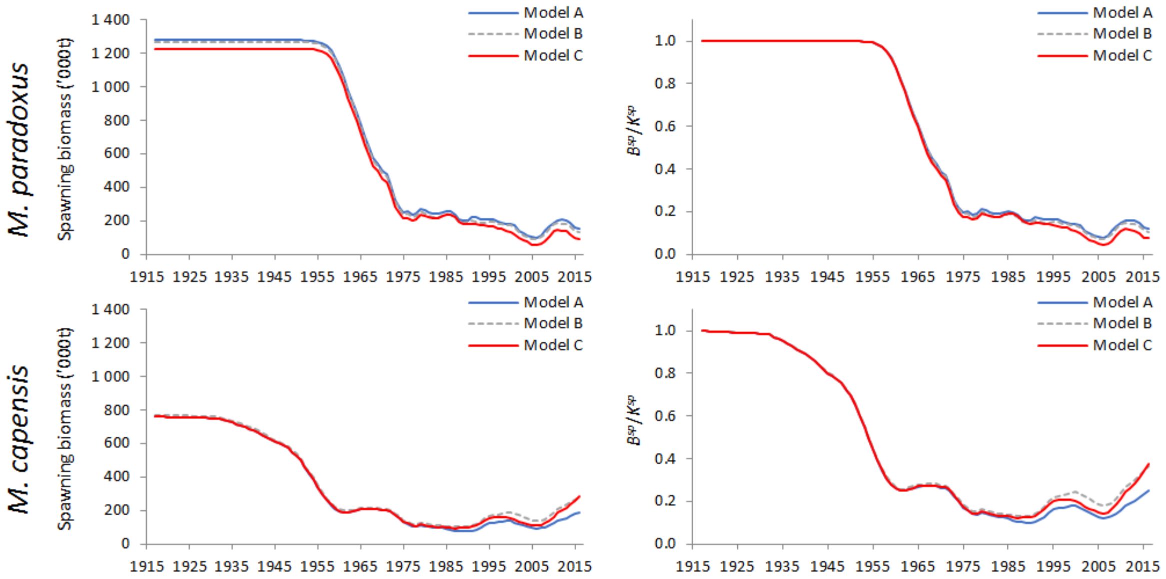

Figure 3: Spawning biomass trajectories (in absolute terms and relative to pre-exploitation level) for *M. paradoxus* and *M. capensis* for Models A, B and C.

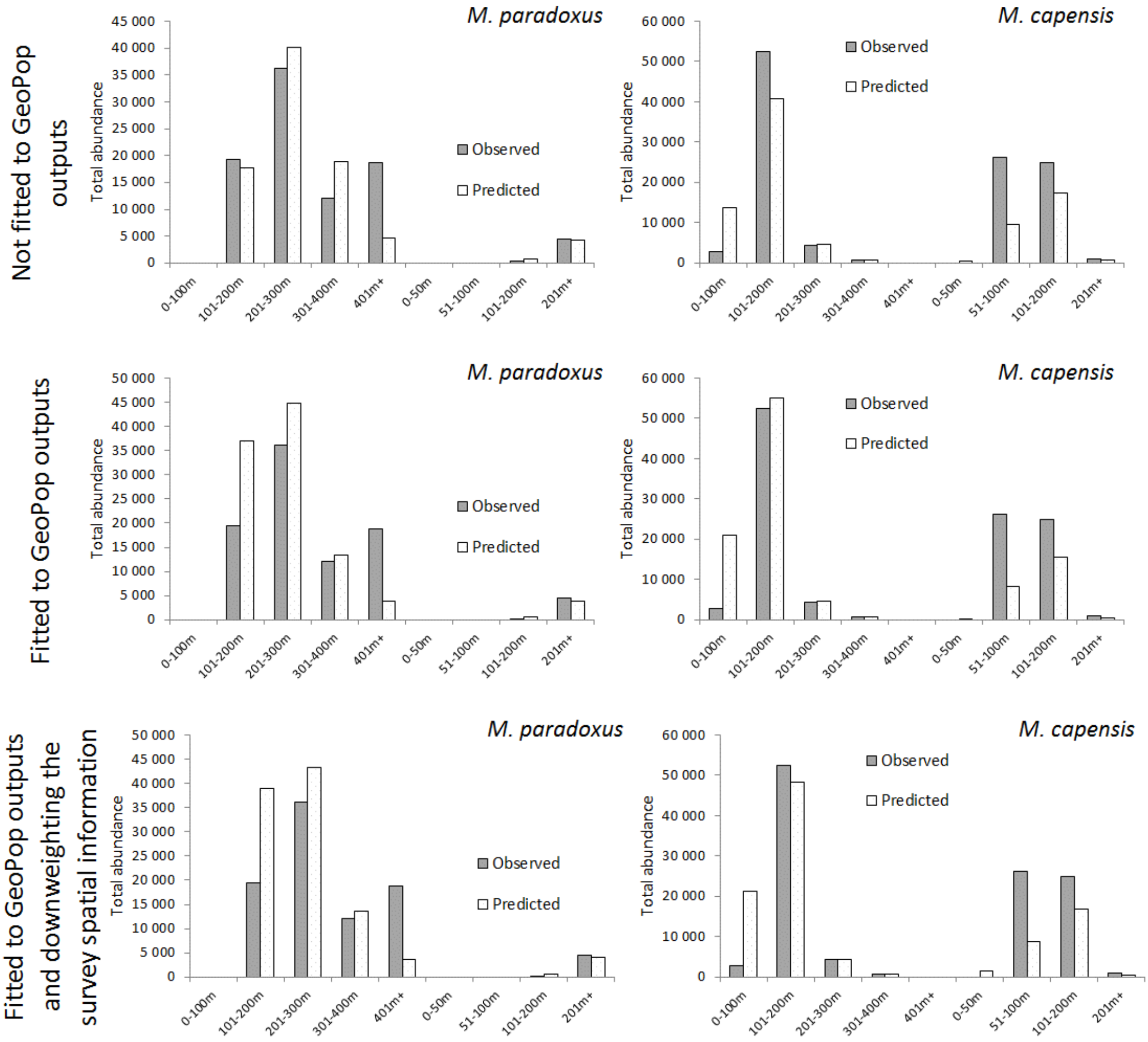

Figure 4: Comparison of model outputs to GeoPop total abundance in each region for the three different Models.

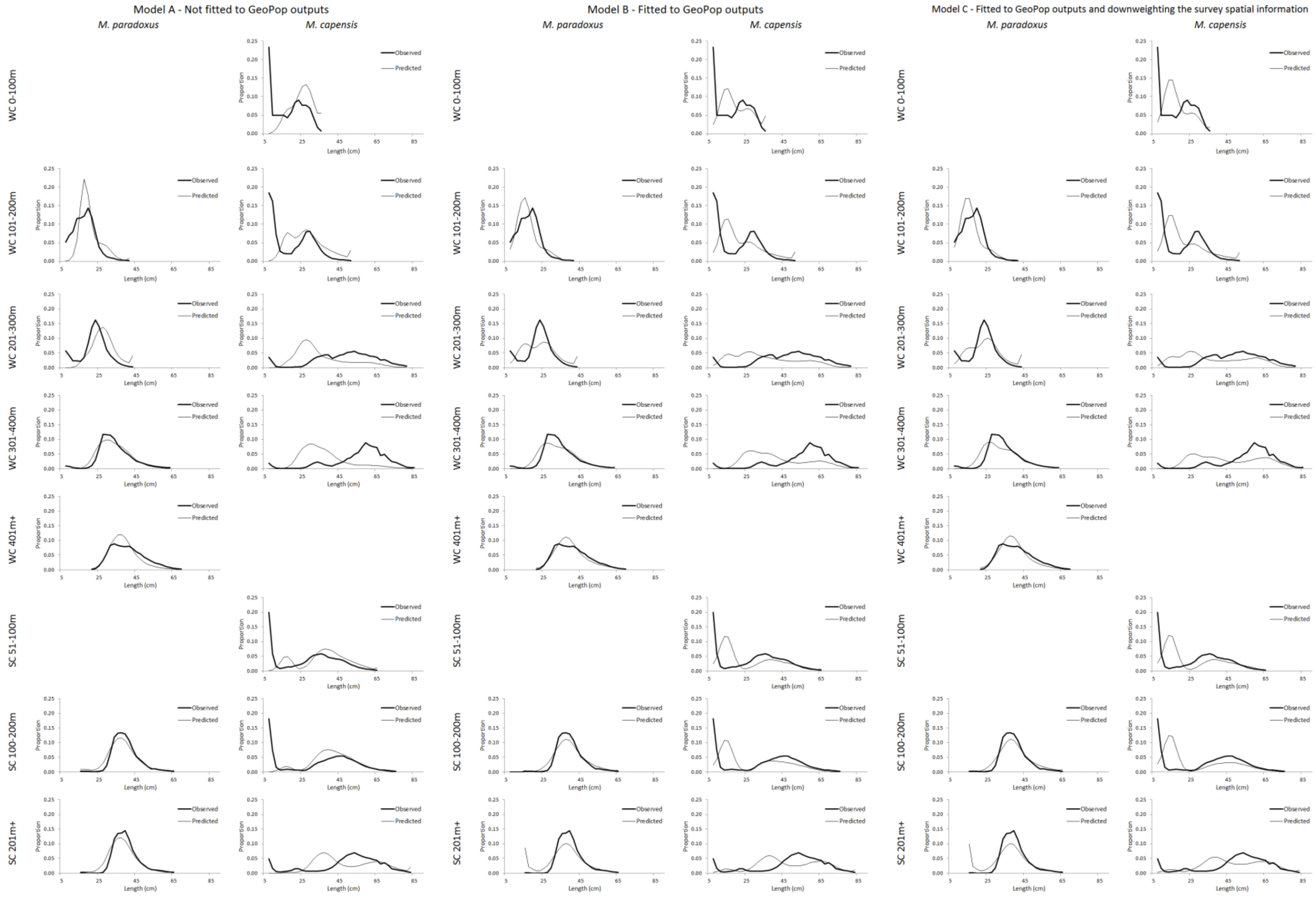

Figure 5: Comparison of model outputs to GeoPop proportion-at-length in each region for the three different Models.

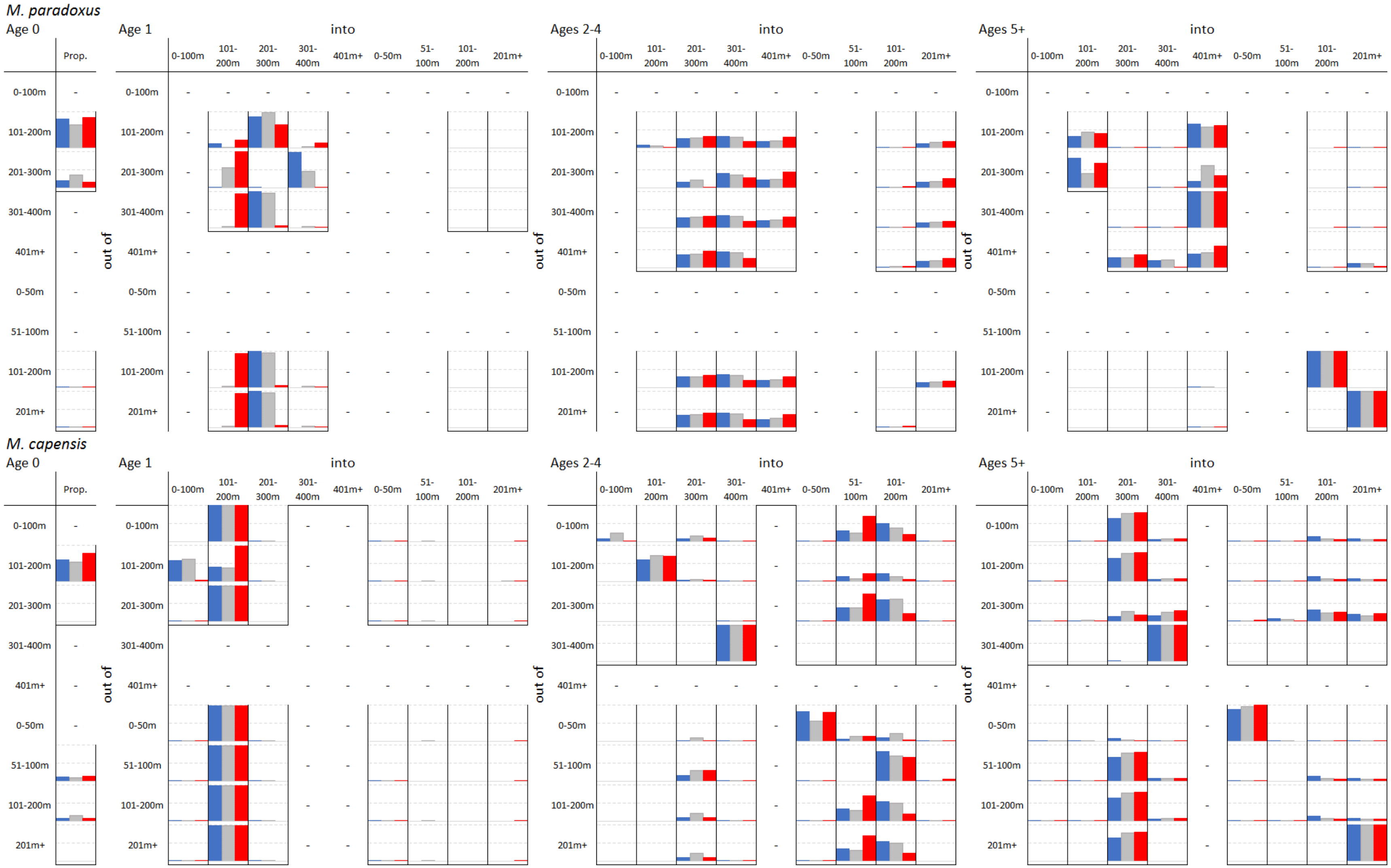

Figure 6: Bar plots of movement parameters for Model A (blue), Model B (grey) and Model C (red).

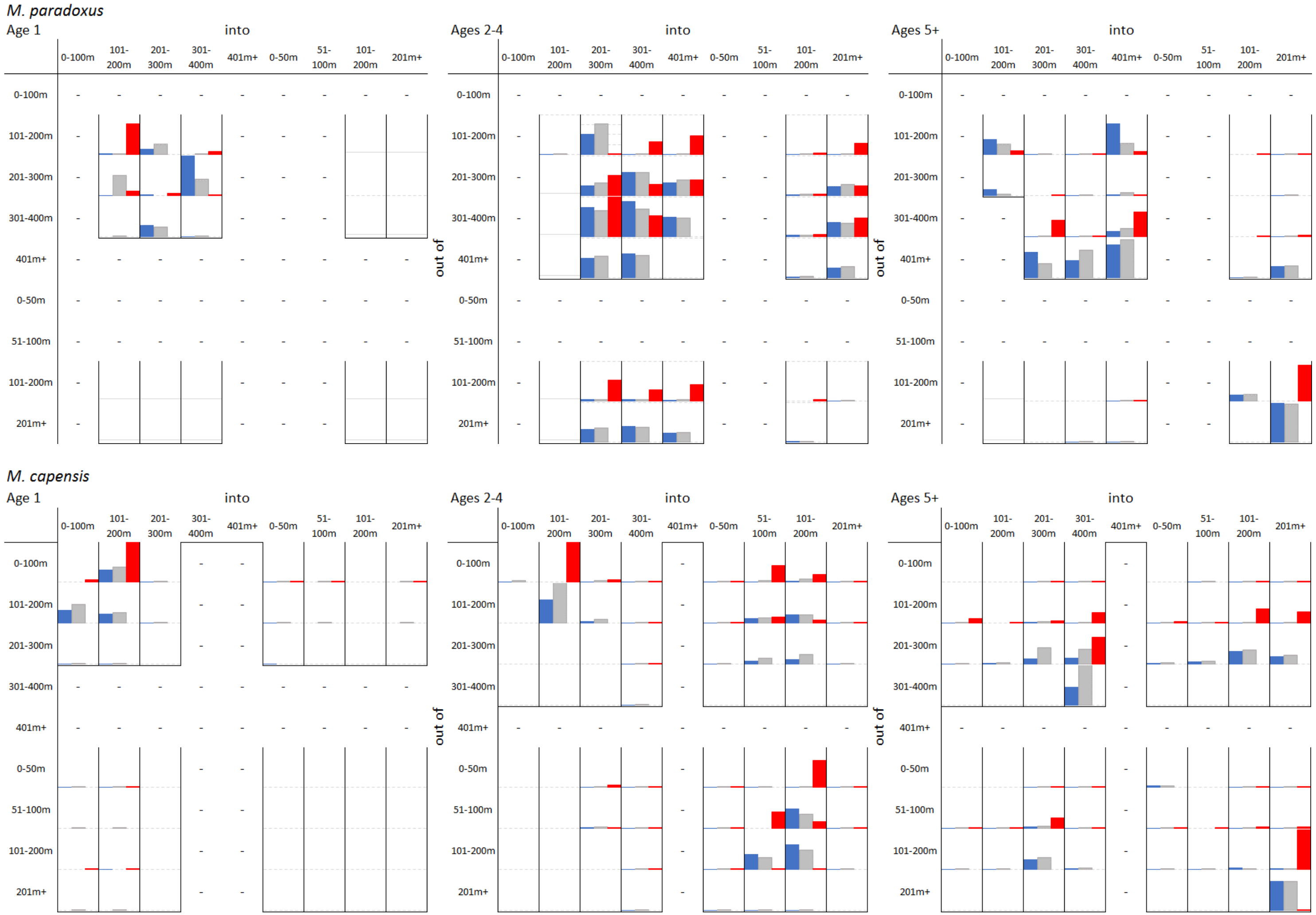

Figure 7: Bar plots of 1998-2012 average number of fish moving for Model A (blue), Model B (grey) and Model C (red). For the age group "2-4", the numbers correspond to the sum of fish of age 2, 3 and 4. Similarly, for the age group "5+", the numbers correspond to the sum of fish of age 5 and above. For each age group/species matrix, the maximum on the vertical axis of each plot corresponds to the maximum value for that matrix.

Appendix 1: Methods

App1.1 Population Dynamics

r: an index for region, *r*=1,…, n_{region} (here n_{region}=9)

y: an index for year

a: an index for age, *a*=0,…, *m* (*m* =15, a plus group)

l: an index for length *l*=1,..., l_{max} (l_{max}=105)

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

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

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

App1.1.1 Numbers-at-age:

Pre-1978, the model is not region dependent:

$$N_{y+1,0} = R_{y+1} \qquad \text{(App1.1)}$$

$$N_{y+1,a+1} = \left(N_{y,a}\, e^{-M_a/2} - \sum_{f}^{n_{fleet}} C^{f}_{y,a} \right) e^{-M_a/2} \qquad \text{for } 0 \le a \le m-2 \qquad \text{(App1.2)}$$

$$N_{y+1,m} = \left(N_{y,m-1}\, e^{-M_{m-1}/2} - \sum_{f}^{n_{fleet}} C^{f}_{y,m-1} \right) e^{-M_{m-1}/2} + \left(N_{y,m}\, e^{-M_m/2} - \sum_{f}^{n_{fleet}} C^{f}_{y,m} \right) e^{-M_m/2} \qquad \text{(App1.3)}$$

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

$$N^{r}_{y+1,0} = x^{r} R_{y+1} \qquad \text{for } a=0 \qquad \text{(App1.4)}$$

$$N^{r}_{y+1,a+1} = \sum_{r'}^{n_{region}} \left(\left[\left\{ N^{r'}_{y,a} e^{-M_a/2} - \sum_{f}^{n_{fleet}} C^{r'}_{f,y,a} \right\} e^{-M_a/2} \right] X^{\text{out } r',\text{in } r}_{y,a} \right) \qquad \text{for } 0 \le a \le m-2 \qquad \text{(App1.5)}$$

$$\begin{aligned} N^{r}_{y+1,m} &= \sum_{r'}^{n_{region}} \left(\left[\left\{ N^{r'}_{y,m-1} e^{-M_{m-1}/2} - \sum_{f}^{n_{fleet}} C^{r'}_{f,y,m-1} \right\} e^{-M_{m-1}/2} \right] X^{\text{out } r',\text{in } r}_{y,m-1} \right) \\ &+ \sum_{r'}^{n_{region}} \left(\left[\left\{ N^{r',spp,s}_{y,m} e^{-M_m/2} - \sum_{f}^{n_{fleet}} C^{r'}_{f,y,m} \right\} e^{-M_m/2} \right] X^{\text{out } r',\text{in } r}_{y,m} \right) \end{aligned} \qquad \text{(App1.6)}$$

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

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

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

$$M_a = \begin{cases} M_2 & \text{for} \quad a \le 1 \\ \alpha^M + \dfrac{\beta^M}{a+1} & \text{for} \quad 2 \le a \le 5 \\ M_5 & \text{for} \quad a > 5 \end{cases} \tag{App1.7}$$

$C^r_{f,y,a}$: the number of fish of species *spp*, 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 the fish stays in region *r*), and

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

where:

$$X^{r',r}_{y,a} = \frac{G^{r',r}_a}{\sum_r G^{r',r}_a} \tag{App1.8}$$

where

$$G^{r',r}_a = \begin{cases} \exp\left(g^r_a\right) & r' \neq r \\ \exp\left(v^{r'}_a + g^r_a\right) & r' = r \end{cases} \tag{App1.9}$$

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

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

Distribution of the fish by region in 1978:

$$N^r_{1978,a} = \left(\frac{1}{n_{region}} \sum_{r'}^{n_{region}} X^{\text{out } r',\text{in } r}_{y+1,0} \right) N^{tot}_{1978,a} \tag{App1.10}$$

<u>App1.1.2 Recruitment:</u>

$$R_y = f(SSB_y) \tag{App1.11}$$

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

$$R_y = \frac{4hR_0 SSB_y}{K^{sp}(1-h) + (5h-1)SSB_y} e^{(\varsigma_y - \sigma_R^2/2)} \tag{App1.12}$$

for the Beverton-Holt stock-recruitment relationship and

$$R_y = \alpha SSB_y \exp\left(-\beta\left(SSB_y\right)^\gamma\right) e^{(\varsigma_y - \sigma_R^2/2)} \tag{App1.13}$$

with

$$\alpha = R_0 \exp\left(\beta\left(SSB_y\right)^\gamma\right) \qquad \text{and} \qquad \beta = \frac{\ln(5h)}{\left(SSB_y\right)^\gamma \left(1 - 5^{-\gamma}\right)} \tag{App1.14}$$

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

$$R_0 = SSB_y \Big/ \left[\sum_{a=1}^{m-1} mat_a w_a \, e^{-\sum_{a'=0}^{a-1} M_{a'}} + mat_m w_m \frac{e^{-\sum_{a'=0}^{m-1} M_{a'}}}{1-e^{-M_m}} \right] \qquad \text{(App1.15)}$$

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

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

App1.1.3 Spawning biomass:

$$SSB_y = \sum_{r=1}^{n_{region}} \sum_{a=1}^{m} mat_a w_a N_{y,a}^r \qquad \text{(App1.16)}$$

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

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

$$mat_a = \sum_l mat_l P_{a,l} \qquad \text{(App1.17)}$$

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

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

$$l_a \sim N\left[l_\infty \left(1 - e^{-\kappa(a-t_0)}\right); \theta_a^2 \right] \qquad \text{(App1.18)}$$

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

$$\theta_a = \beta L_\infty \left(1 - e^{-\kappa(a-t_o)}\right) \qquad \text{(App1.19)}$$

with β an estimable parameter.

App1.1.4 Catch:

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

$$C_{f,y}^r = \sum_a \tilde{w}_{a+1/2} \, C_{f,y,a}^r \qquad \text{(App1.20)}$$

$$C_{f,y,a}^r = N_{y,a}^r e^{-M_a/2} S_{f,y,a} F_{f,y}^r \qquad \text{(App1.21)}$$

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

$$S_{f,y,a} = \sum_l S_{f,y,l} P_{a+1/2,l} \qquad \text{(App1.22)}$$

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

$$\tilde{w}_{fy,a+1/2} = \sum_l S_{f,y,l} w_l P_{a+1/2,l} \Big/ \sum_l S_{f,y,l} P_{a+1/2,l} \qquad \text{(App1.23)}$$

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

w_l is the weight of fish of length *l*;

App1.2 The likelihood function

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

App1.2.1 CPUE relative biomass data

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

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \quad \text{or} \quad \varepsilon_y^i = \ell n\left(I_y^i\right) - \ell n\left(\hat{I}_y^i\right) \qquad \text{(App1.24)}$$

where

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

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

$$B_y^{\text{ex}} = \sum_r \sum_{a=0}^{m} \tilde{w}_{y,a}^{\text{mid}} S_{y,a} N_{y,a}^r e^{-M_a/2} (1 - S_{y,a} F_y^r / 2) \qquad \text{(App1.25)}$$

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

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

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

In cases where the CPUE series are based upon species-aggregated catches (as available pre-1978), the corresponding model estimate is derived by assuming two types of fishing zones: z1) an "*M. capensis* only zone", corresponding to shallow-water and z2) a "mixed zone" (Figure App1.1).

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

$$C_{BS,fy} = C_{C,fy}^{z1} + C_{C,fy}^{z2} + C_{P,fy} \qquad \text{(App1.26)}$$

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

where

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

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

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

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

$$C^{z1}_{C,fy} = q^{i,z1}_{C} B^{ex,z1}_{Cfy} E^{z1}_{fy} = q^{i,z1}_{C}(1-\gamma) B^{ex}_{C,fy}(1-\psi_{fy}) E_{fy} \qquad \text{(App1.27)}$$

$$C^{z2}_{C,fy} = q^{i,z2}_{C} B^{ex,z2}_{C,fy} E^{z2}_{fy} = q^{i,z2}_{C} \gamma B^{ex}_{C,fy} \psi_{fy} E_{fy} \text{ and} \qquad \text{(App1.28)}$$

$$C_{P,fy} = q^{i}_{P} B^{ex}_{P,fy} E^{z2}_{fy} = q^{i}_{P} B^{ex}_{P,fy} \psi_{fy} E_{fy} \qquad \text{(App1.29)}$$

where

$E_{fy} = E^{z1}_{fy} + E^{z2}_{fy}$ 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^{z1}_{fy}) and the effort in the mixed zone (E^{z2}_{fy});

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

q^{i}_{P} is the catchability for *M. paradoxus* (*P*) for biomass series *i*.

It follows that:

$$C_{C,fy} = B^{ex}_{C,fy} E_{fy} \left[q^{i,z1}_{C}(1-\gamma)(1-\psi_{fy}) + q^{i,z2}_{C} \gamma \psi_{fy} \right] \qquad \text{(App1.B30)}$$

$$C_{P,fy} = B^{ex}_{P,fy} E_{fy} q^{i}_{P} \psi_{fy} \qquad \text{(App1.31)}$$

From solving equations B30 and B31:

$$s_{fy} = \frac{q^{i,z1}_{C}(1-\gamma)}{\left\{ \dfrac{C_{C,fy} B^{ex}_{P,fy} q^{i}_{P}}{B^{ex}_{C,fy} C_{P,fy}} - q^{i,z2}_{C}\gamma + q^{i,z1}_{C}(1-\gamma) \right\}} \qquad \text{(App1.32)}$$

and:

$$\hat{I}^{i}_{y} = \frac{C_{fy}}{E_{fy}} = \frac{C_{fy} B^{ex}_{P,fy} q^{i}_{P} \psi_{fy}}{C_{P,fy}} \qquad \text{(App1.33)}$$

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

Figure App1.1: Diagrammatic representation of the two conceptual fishing zones.

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

$$q_s^{SC} = rq_s^{WC} \tag{App1.34}$$

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

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

$$-\ell\text{n}\, L^{CPUE} = \sum_i \sum_y \left[\ell\text{n}\left(\sigma_y^i\right) + \left(\varepsilon_y^i\right)^2 / 2\left(\sigma_y^i\right)^2\right] \tag{App1.35}$$

where

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

Homoscedasticity of residuals for CPUE series is customarily assumed[2], so that $\sigma_y^i = \sigma^i$ is estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma}^i = \sqrt{1/n_i \sum_y \left(\ell\text{n}(I_y^i) - \ell\text{n}(\hat{I}_y^i)\right)^2} \tag{App1.36}$$

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

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

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

$$\ln \hat{q}^i = \frac{\sum_y \left(\ln I_y^i - \ln \hat{B}_{fy}^{ex}\right) / \left(\sigma_y^i\right)^2}{\sum_y 1 / \left(\sigma_y^i\right)^2} \qquad \text{(App1.37)}$$

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

App1.2.2 Survey biomass data

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

$$B_y^{r,surv} = \sum_{a=0}^{m} \tilde{w}_a^{surv} S_a^{surv} N_{ya}^r e^{\frac{-\upsilon^{surv}}{12} M_a} \left(1 - \frac{\upsilon^{surv}}{12} \sum_f S_{fya} F_{fy}^r\right) \qquad \text{(App1.38)}$$

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

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

The contribution of the survey data to the negative log-likelihood is of the same form as that of the CPUE biomass data (see equation App1.35). A single species-specific *q* per survey is estimated (i.e. same *q* for all regions)

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

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

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

where

$$\ell n q_{new}^s = \ell n q_{old}^s + \Delta \ell n q^s \quad \text{with } s = \textit{capensis} \text{ or } \textit{paradoxus} \qquad \text{(App1.39)}$$

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

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

$$-\ell nL^{q-ch} = \left(\ell nq_{new} - \ell nq_{old} - \Delta\ell nq\right)^2 \Big/ 2\sigma^2_{\Delta\ell nq} \qquad \text{(App1.40)}$$

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

App1.2.3 Commercial proportions at length

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

The catches at length are computed as:

$$C_{fyl} = \sum_r \sum_s \sum_{a=0}^{m} N^r_{sya} F^r_{sfy} S_{sfyl} P_{s,a+1/2,l} e^{-M_{sa}/2} \left(1 - \sum_f S_{sfya} F^r_{sfy} \Big/ 2\right) \qquad \text{(App1.41)}$$

with the predicted proportions at length:

$$\widehat{p}^i_{yl} = C_{fyl} \Big/ \sum_{l'} C_{fyl'} \qquad \text{(App1.42)}$$

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

$$-\ell\mathrm{n}\, L^{\mathrm{length}} = 0.01 \sum_y \sum_l \left[\ell n\left(\sigma^i_{len} / \sqrt{p^i_{yl}}\right) + p^i_{yl}\left(\ell np^i_{yl} - \ell n\, \hat{p}^i_{yl}\right)^2 / 2\left(\sigma^i_{len}\right)^2 \right] \qquad \text{(App1.43)}$$

where

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

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

$$\hat{\sigma}^i_{len} = \sqrt{\sum_y \sum_l p^i_{yl}\left(\ln p^i_{yl} - \ln \hat{p}^i_{yl}\right)^2 / \sum_y \sum_l 1} \qquad \text{(App1.44)}$$

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

Commercial proportions at length are incorporated in the likelihood function using equation B43, for which the summation over length *l* is taken from length l_{minus} (considered as a minus group) to l_{plus} (a plus group). The length for the minus- and plus-groups are fleet specific and are chosen so that typically a few percent, but no more, of the fish sampled fall into these two groups.

App1.2.4 Commercial proportions at age

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

The catches at age are computed as:

$$C_{fya} = \sum_r \sum_s \sum_{l=1}^{l\max} N_{sya}^r F_{sfy}^r S_{sfyl} P_{s,a+1/2,l} e^{-M_{sa}/2} \left(1 - \sum_f S_{sfya} F_{sfy}^r \Big/ 2 \right) \tag{App1.45}$$

with the predicted proportions at age:

$$\widehat{p}_{ya}^i = C_{fya} \Big/ \sum_{a'} C_{fya'} \tag{App1.B46}$$

The contribution of the proportion at age data is as for the proportions at length (equation App1.43), except that the multiplicative downweighting factor is fixed at 0.1 instead of 0.01.

App1.2.5 Survey proportions at length

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

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

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

$$\hat{p}_{syl}^{r,surv} = \frac{\sum_a S_{sl}^{surv} P_{s,a+1/2,l} N_{sya}^r e^{\frac{-\upsilon^{surv}}{12} M_{sa}} \left(1 - \frac{\upsilon^{surv}}{12} \sum_f S_{sfya} F_{sfy}^r \right)}{\sum_{l'} \sum_a S_{sl'}^{surv} P_{s,a+1/2,l'} N_{sya}^r e^{\frac{-\upsilon^{surv}}{12} M_{sa}} \left(1 - \frac{\upsilon^{surv}}{12} \sum_f S_{sfya} F_{sfy}^r \right)} \tag{App1.47}$$

App1.2.6 Stock-recruitment function residuals

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

$$-\ell n L^{SR} = \sum_s \left[\sum_{y=y1}^{y2} \varsigma_{sy}{}^2 \Big/ 2\sigma_R^2 \right] \tag{App1.48}$$

where

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

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

The stock-recruitment residuals are estimated for years 1985 to 2006, with recruitment for other years being set deterministically (i.e. exactly as given by the estimated stock-recruitment curve) as there is insufficient catch-at-age information to allow reliable residual estimation for earlier years. A limit on the recent recruitment fluctuations is set by having the σ_R (which measures the extent of variability in recruitment) decreasing linearly from 0.45 in 2004 to 0.1 in 2013, effectively forcing recruitment over the last years to lie closer to the stock-recruitment relationship curve.

App1.3 Model parameters

App1.3.1 Estimable parameters

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

The value of β used to compute the standard deviation of the length-at-age *a* is also estimated in the fitting procedure.

Table App1.1 summarises the estimable parameters, excluding the selectivity parameters.

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

App1.3.1.1 Stock-recruitment residuals

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

App1.3.1.2 Survey fishing selectivity-at-length

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

A penalty is added to the total *–lnL* to smooth the selectivities to smooth the selectivities by penalising deviations from straight line dependence (the choice of a weighting of 3 was made empirically to balance this term having sufficient but not undue influence) :

$$pen^{survS} = \sum_i \sum_{L=L_1+1}^{L_7-1} 3\left(S_{L-1}^s - 2S_L^s + S_{L+1}^s\right)^2 \qquad \text{(App1.49)}$$

App1.3.1.3 Commercial fishing selectivity-at-length

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

$$S_{sfl} = \left[1 + \exp\left(-\left(l - l_{sf}^c\right)/\delta_{sf}^c\right)\right]^{-1} \qquad \text{(App1.50)}$$

where

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

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

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

App1.3.2 Input parameters and other choices for application to hake

App1.3.2.1 Length-at-maturity

The proportion of fish of species *s* and length *l* that are mature is assumed to follow a logistic curve with the parameter values given below (from Singh et al. 2011)):

Table App1.1: Female maturity-at-length logistic curve parameter values for the new Reference Case.

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

App1.3.2.2 Weight-at-length

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

Table App1.2: Weight-at-length parameter values.

	α (gm/cm$^{\beta}$)	β
M. paradoxus:	0.00669	3.02675
M. capensis:	0.00605	3.07313

App1.3.2.3 Minus- and plus-groups

Because of a combination of gear selectivity and mortality, a relatively small number of fish in the smallest and largest length classes are caught. In consequence, there can be relatively larger errors (in terms of variance) associated with these data. To reduce this effect, the assessment is conducted with minus- and plus-groups obtained by summing the data over the lengths below and above l_{minus} and l_{plus} respectively. The minus- and plus-group used are given in Table App1.4. Furthermore, the proportions at length data (both commercial and survey) are summed into 2cm length classes for the model fitting.

Table App1.1: Parameters estimated in the model fitting procedure, excluding selectivity parameters.

	No of parameters	Parameters estimated	Bounds enforced
K	2	$\ln(K^{♀}_{cap})$ and $\ln(K^{♀}_{para})$	(3.5; 9.0)
Stock-recruitment h	2	h_{cap} and h_{para}	(0.2; 0.98)
Stock-recruitment γ	2	γ_{cap} and γ_{para}	(0;10)
Additional variance	2	$\sigma_{A,cap}$ and $\sigma_{A,para}$	(0; 0.5)
Recruitment residuals	64	$\zeta_{cap,1985\text{-}2016}$ and $\zeta_{para,1985\text{-}2016}$	(-5; 5)
σ_{CPUE}	6	1 for each series	ICSEAF: (0.25; 1), GLM (0.15; 1)
ICSEAF CPUE	5	$q_C^{WC,z1}$, $q_C^{WC,z2}$, q_P^{WC}, ρ and γ	q and ρ: (0,10), and γ_R (0; 1)
Age-length distribution	2	For each species: β_i	(0.4;1.0)
Survey calibration	4	$\Delta\ell nq^{spp}$ and $\sigma_{\Delta\ell nq^{sp}}$ for each species	(-1;1) and (0;0.5)
Selectivities	34	see Table App.1.3	
Prop. Rec. in each region	7	x^r	(0; 1)
Movement parameters	68	g_a^r and v_a^r	(-20,20)

Table App1.2: Lengths (in cm) at which survey selectivity is estimated directly.

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

Table App1.3: Details for the commercial and survey selectivity-at-length for each fleet and species.

	M. paradoxus		*M. capensis*		data available
	No of est. parameters	Comments	No of est. parameters	Comments	
1. Offshore trawl					
1917-1976	0	set equal to 1989	0	set equal to 1989	
1977-1984	2	two logistic parameters estimated	0	differential shift compared to 1993+ as for paradoxus	species combined
1985-1992	0	linear change between 1984 and 1993 selectivity	0	linear change between 1984 and 1993 selectivity	species combined
1993-2013	2	two logisticestimated	0	same as SC inshore but shifted to the right by 5 cm	species combined
2. South coast inshore trawl	-	-	2	two logisticparameters estimated	*M. capensis*
3. Longline	2	two logistic parameters estimated	2	two logistic parameters estimated	species combined and species disaggregated
5. South coast handline	-	-	0	parameters taken as average of SC longline and inshore parameters	-
Survey					
Africana old	7	estimated for 7 specified lengths	7	estimated for 7 specified lengths	species disaggregated
Africana new	5	same slope as old	5	same slope as old	species disaggregated
Total	18		16		

Table App1.4: Minus- and plus-groups taken for the surveys and commercial proportion at length data.

SURVEY CAL DATA

	M. paradoxus									
	0-100m		101-200m		201-300m		301-400m		401m+	
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus
West coast summer	-	-	10	35	10	35	20	70	25	75
West coast winter	-	-	10	35	10	45	15	65	25	75
	0-50m		51-100m		101-200m		200m+			
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus		
South coast spring	-	-	-	-	20	45	20	60		
South coast autumn	-	-	-	-	25	50	25	70		

	M. capensis									
	0-100m		101-200m		201-300m		301-400m		401m+	
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus
West coast summer	10	35	10	70	25	75	47	75	-	-
West coast winter	15	35	15	70	20	80	40	70	-	-
	0-50m		51-100m		101-200m		200m+			
	Minus	Plus	Minus	Plus	Minus	Plus	Minus	Plus		
South coast spring	10	55	10	70	10	80	40	85		
South coast autumn	10	60	10	75	10	85	40	80		

COMMERCIAL CAL DATA

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

Appendix 2A: Full results for the model not fitting to the GeoPop output

M. paradoxus

Age 0

	Prop.
0-100m	-
101-200m	0.79
201-300m	0.20
301-400m	-
401m+	-
0-50m	-
51-100m	-
101-200m	0.00
201m+	0.00

Age 1 into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.13	0.87	0.00	-	-	-	0.00	0.00	1.00
	201-300m	-	0.00	0.03	0.97	-	-	-	0.00	0.00	1.00
	301-400m	-	0.00	1.00	0.00	-	-	-	0.00	0.00	1.00
	401m+	-	-	-	-	-	-	-	-	-	
	0-50m	-	-	-	-	-	-	-	-	-	
	51-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.00	1.00	0.00	-	-	-	0.00	0.00	1.00
	201m+	-	0.00	1.00	0.00	-	-	-	0.00	0.00	1.00

Ages 2-4 into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.08	0.27	0.32	0.18	-	-	0.02	0.13	1.00
	201-300m	-	0.00	0.17	0.41	0.23	-	-	0.02	0.17	1.00
	301-400m	-	0.00	0.29	0.35	0.20	-	-	0.02	0.14	1.00
	401m+	-	0.00	0.36	0.44	0.00	-	-	0.02	0.18	1.00
	0-50m	-	-	-	-	-	-	-	-	-	
	51-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.00	0.29	0.36	0.20	-	-	0.00	0.15	1.00
	201m+	-	0.00	0.34	0.41	0.23	-	-	0.02	0.00	1.00

Ages 5+ into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.33	0.00	0.00	0.67	-	-	0.00	0.00	1.00
	201-300m	-	0.81	0.00	0.00	0.19	-	-	0.00	0.00	1.00
	301-400m	-	0.00	0.00	0.00	1.00	-	-	0.00	0.00	1.00
	401m+	-	0.00	0.29	0.20	0.38	-	-	0.00	0.13	1.00
	0-50m	-	-	-	-	-	-	-	-	-	
	51-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.00	0.00	0.00	0.00	-	-	1.00	0.00	1.00
	201m+	-	0.00	0.00	0.00	0.01	-	-	0.00	0.99	1.00

M. capensis

Age 0

	Prop.
0-100m	0.18
101-200m	0.59
201-300m	-
301-400m	-
401m+	-
0-50m	0.01
51-100m	0.12
101-200m	0.09
201m+	-

Age 1 into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	0.00	1.00	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	101-200m	0.58	0.40	0.02	-	-	0.01	0.00	0.00	0.00	1.00
	201-300m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	301-400m	-	-	-	-	-	-	-	-	-	
	401m+	-	-	-	-	-	-	-	-	-	
	0-50m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	51-100m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	101-200m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	201m+	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00

Ages 2-4 into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	0.09	0.00	0.09	0.01	-	0.00	0.31	0.50	0.00	1.00
	101-200m	0.00	0.60	0.04	0.00	-	0.00	0.13	0.22	0.00	1.00
	201-300m	0.00	0.00	0.00	0.01	-	0.00	0.38	0.61	0.00	1.00
	301-400m	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	0.00	1.00
	401m+	-	-	-	-	-	-	-	-	-	
	0-50m	0.00	0.00	0.02	0.00	-	0.82	0.06	0.10	0.00	1.00
	51-100m	0.00	0.00	0.16	0.01	-	0.00	0.00	0.83	0.00	1.00
	101-200m	0.00	0.00	0.10	0.01	-	0.00	0.34	0.55	0.00	1.00
	201m+	0.00	0.00	0.10	0.01	-	0.00	0.34	0.55	0.00	1.00

Ages 5+ into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	0.00	0.01	0.64	0.07	-	0.01	0.03	0.14	0.08	1.00
	101-200m	0.01	0.00	0.65	0.07	-	0.01	0.03	0.14	0.08	1.00
	201-300m	0.01	0.03	0.15	0.17	-	0.03	0.08	0.33	0.20	1.00
	301-400m	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	0.00	1.00
	401m+	-	-	-	-	-	-	-	-	-	
	0-50m	0.00	0.00	0.08	0.01	-	0.88	0.00	0.02	0.01	1.00
	51-100m	0.01	0.01	0.66	0.08	-	0.01	0.00	0.15	0.09	1.00
	101-200m	0.01	0.01	0.64	0.07	-	0.01	0.03	0.14	0.08	1.00
	201m+	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	1.00	1.00

Table 2A1: Proportion of recruitment in each region and movement matrices estimated for *M. paradoxus* and *M. capensis* for the **Model A** (not fitting to the GeoPop outputs).

M. paradoxus

Age 1		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	13.2	87.8	0.0	-	-	-	0.0	0.0
	201-300m	-	0.2	17.7	662.0	-	-	-	0.0	0.0
	301-400m	-	0.0	191.5	0.0	-	-	-	0.0	0.0
	401m+	-	-	-	-	-	-	-	-	-
	0-50m	-	-	-	-	-	-	-	-	-
	51-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	0.0	0.0	0.0	-	-	-	0.0	0.0
	201m+	-	0.0	0.0	0.0	-	-	-	0.0	0.0

Ages 2-4		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	0.3	1.0	1.2	0.7	-	-	0.1	0.5
	201-300m	-	0.0	24.4	59.1	33.5	-	-	3.2	24.3
	301-400m	-	0.0	73.0	88.2	50.0	-	-	4.8	36.3
	401m+	-	0.0	50.0	60.4	0.0	-	-	3.3	24.9
	0-50m	-	-	-	-	-	-	-	-	-
	51-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	0.0	4.0	4.8	2.7	-	-	0.0	2.0
	201m+	-	0.0	33.4	40.3	22.9	-	-	2.2	0.0

Ages 5+		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	3.1	0.0	0.0	6.2	-	-	0.0	0.0
	201-300m	-	1.3	0.0	0.0	0.3	-	-	0.0	0.0
	301-400m	-	0.0	0.0	0.0	1.1	-	-	0.0	0.0
	401m+	-	0.0	5.2	3.6	6.7	-	-	0.0	2.3
	0-50m	-	-	-	-	-	-	-	-	-
	51-100m	-	-	-	-	-	-	-	-	-
	101-200m	-	0.0	0.0	0.0	0.0	-	-	1.3	0.0
	201m+	-	0.0	0.0	0.0	0.1	-	-	0.0	7.8

M. capensis

Age 1		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	0.0	110.9	0.1	-	-	0.0	0.0	0.0	0.0
	101-200m	117.7	81.8	3.1	-	-	1.6	0.0	0.0	0.0
	201-300m	0.1	2.9	0.0	-	-	0.0	0.0	0.0	0.0
	301-400m	-	-	-	-	-	-	-	-	-
	401m+	-	-	-	-	-	-	-	-	-
	0-50m	0.0	1.5	0.0	-	-	0.0	0.0	0.0	0.0
	51-100m	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0
	101-200m	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0
	201m+	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0

Ages 2-4		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	0.4	0.0	0.4	0.0	-	0.0	1.5	2.4	0.0
	101-200m	0.0	49.2	3.3	0.2	-	0.0	10.9	17.5	0.1
	201-300m	0.0	0.0	0.0	0.1	-	0.0	6.5	10.4	0.1
	301-400m	0.0	0.0	0.0	1.6	-	0.0	0.0	0.0	0.0
	401m+	-	-	-	-	-	-	-	-	-
	0-50m	0.0	0.0	0.0	0.0	-	0.6	0.0	0.1	0.0
	51-100m	0.0	0.0	7.8	0.5	-	0.1	0.0	41.4	0.2
	101-200m	0.0	0.0	9.8	0.6	-	0.1	32.3	52.0	0.3
	201m+	0.0	0.0	0.1	0.0	-	0.0	0.2	0.3	0.0

Ages 5+		into								
		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
out of	0-100m	0.0	0.0	0.2	0.0	-	0.0	0.0	0.0	0.0
	101-200m	0.0	0.0	0.3	0.0	-	0.0	0.0	0.1	0.0
	201-300m	0.2	0.4	2.2	2.5	-	0.4	1.1	4.9	2.9
	301-400m	0.0	0.0	0.0	6.9	-	0.0	0.0	0.0	0.0
	401m+	-	-	-	-	-	-	-	-	-
	0-50m	0.0	0.0	0.1	0.0	-	0.6	0.0	0.0	0.0
	51-100m	0.0	0.0	0.8	0.1	-	0.0	0.0	0.2	0.1
	101-200m	0.0	0.1	3.8	0.4	-	0.1	0.2	0.8	0.5
	201m+	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	11.0

Table 2A2: 1998-2012 average number (in millions) of fish moving estimated for *M. paradoxus* and *M. capensis* for the **Model A** (not fitting to the GeoPop outputs). For the age group "2-4", the numbers correspond to the sum of fish of age 2, 3 and 4. Similarly, for the age group "5+", the numbers correspond to the sum of fish of age 5 and above.

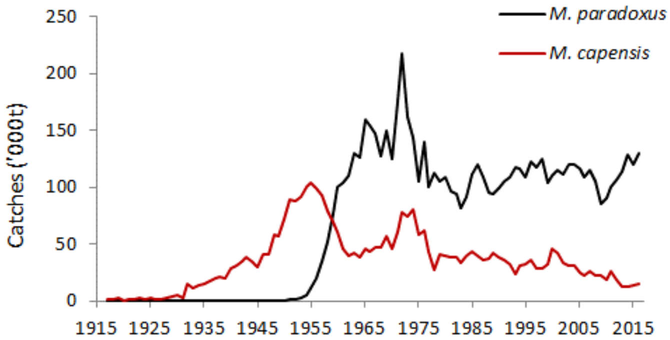


Figure 2A1: Total catches assumed for *M. paradoxus* and *M. capensis* for all Models presented in this paper.

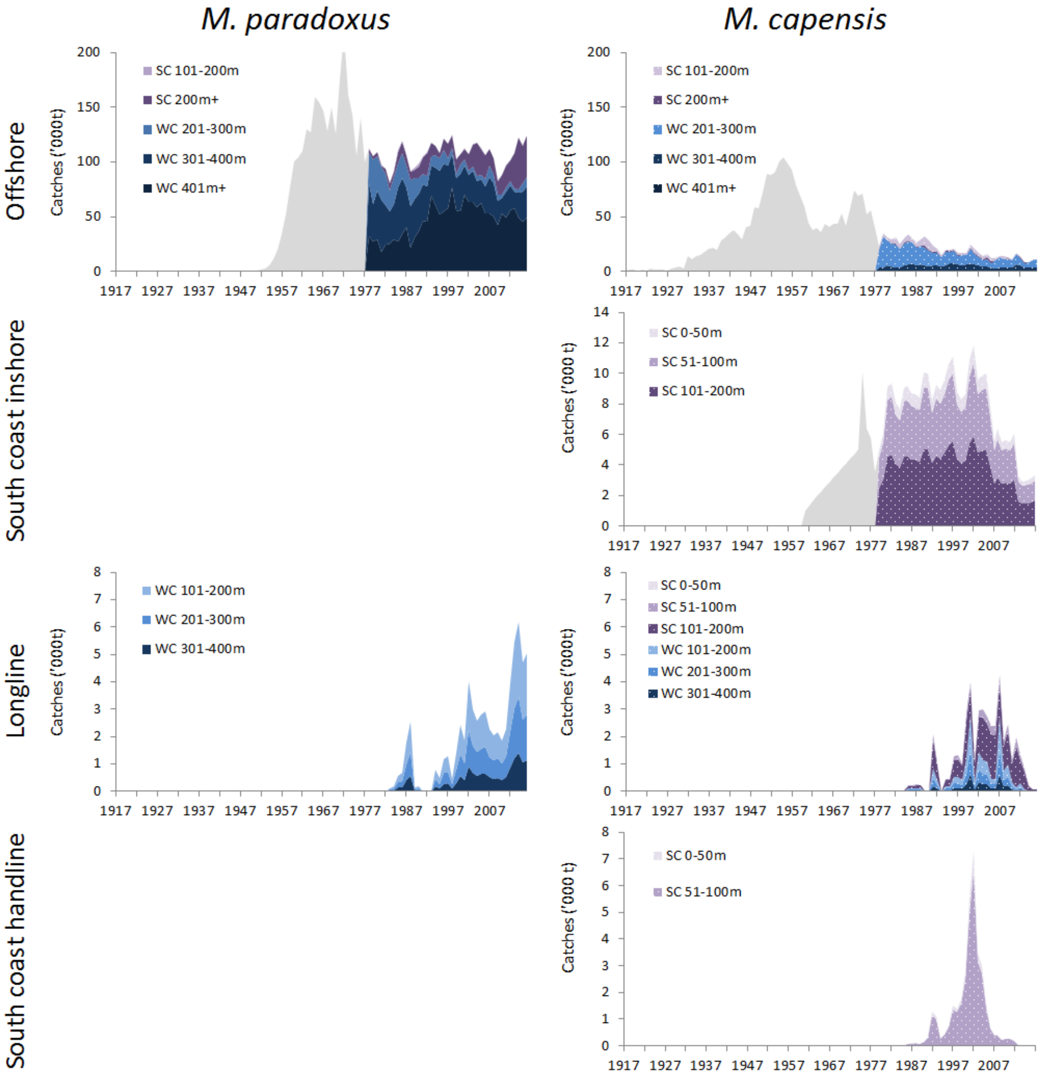


Figure 2A2: Catches assumed by fleet, region and species for all Models presented in this paper.

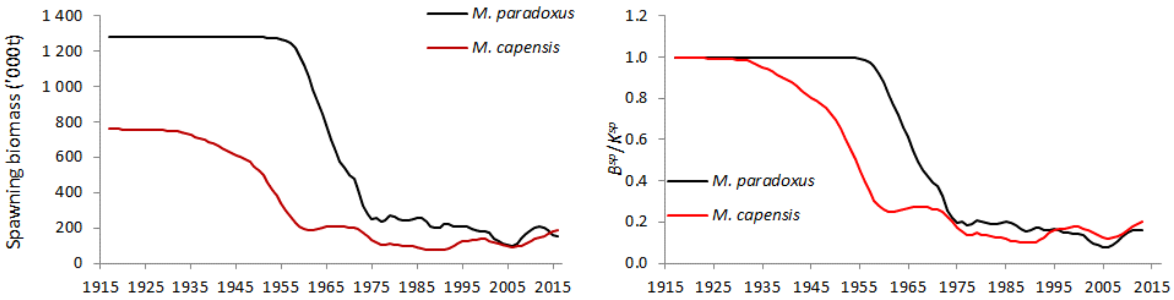


Figure 2A3: Total spawning biomass trajectories (in absolute terms and relative to unexploited level) for *M. paradoxus* and *M. capensis* for the **Model A** (not fitting to the GeoPop outputs).

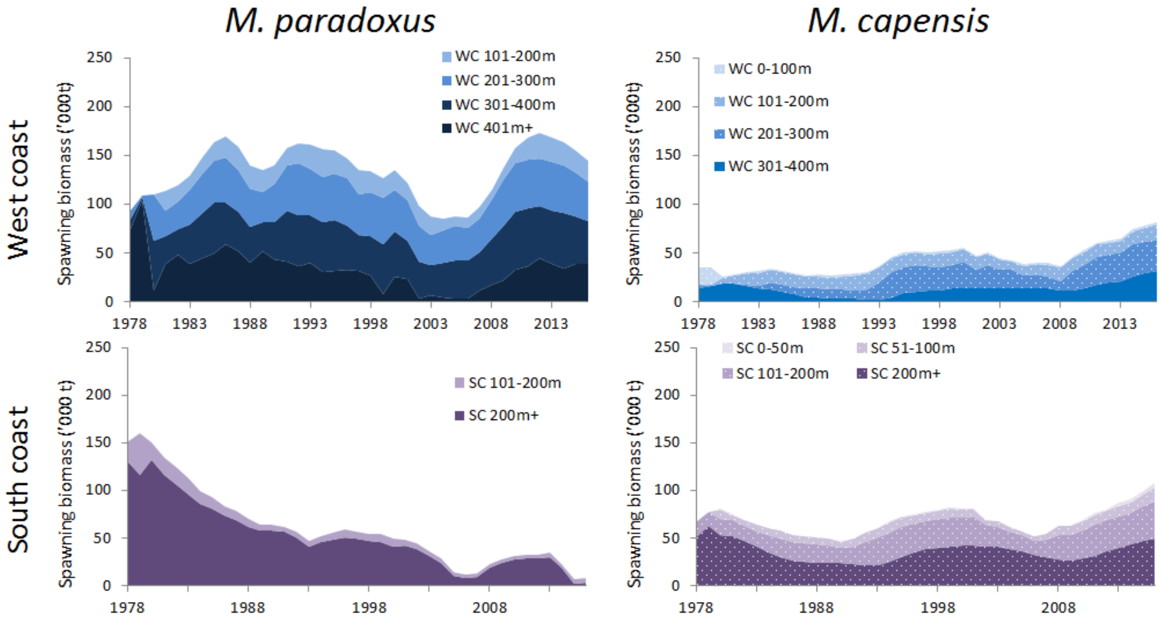


Figure 2A4: Spawning biomass trajectories (in absolute terms) per regions for *M. paradoxus* and *M. capensis* for the **Model A** (not fitting to the GeoPop outputs).

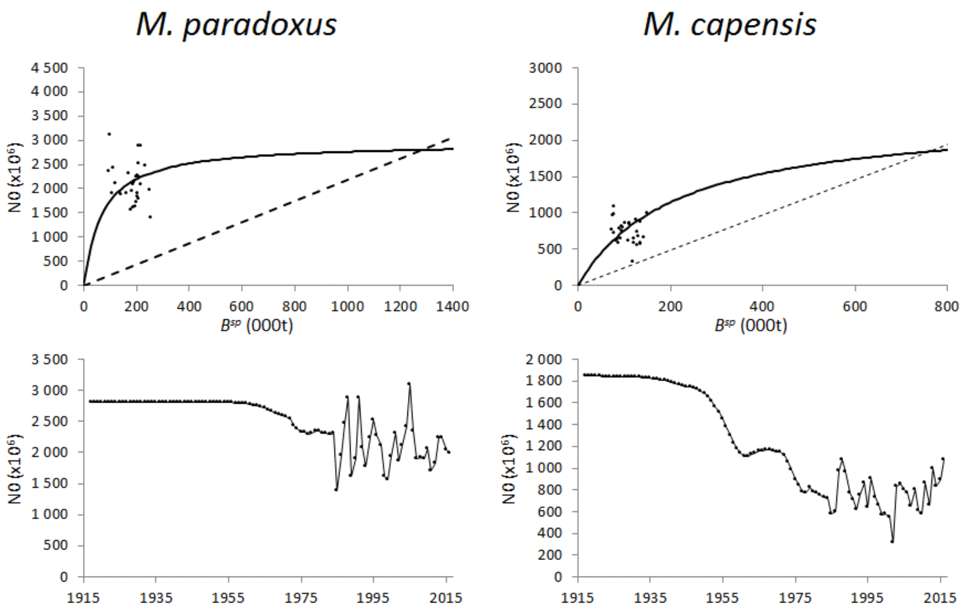


Figure 2A5: Stock-recruitment relationship and time-series of recruitment for the **Model A** (not fitting to the GeoPop outputs).

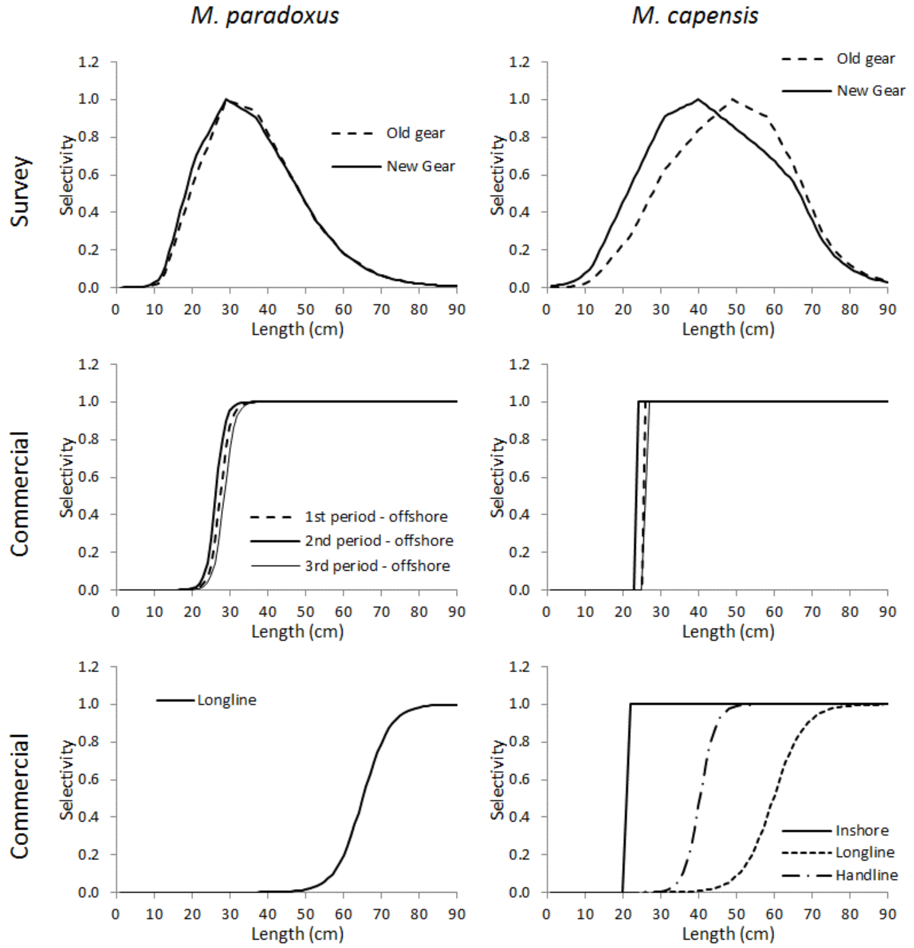


Figure 2A6: Commercial and survey selectivity-at-length for the **Model A** (not fitting to the GeoPop outputs).

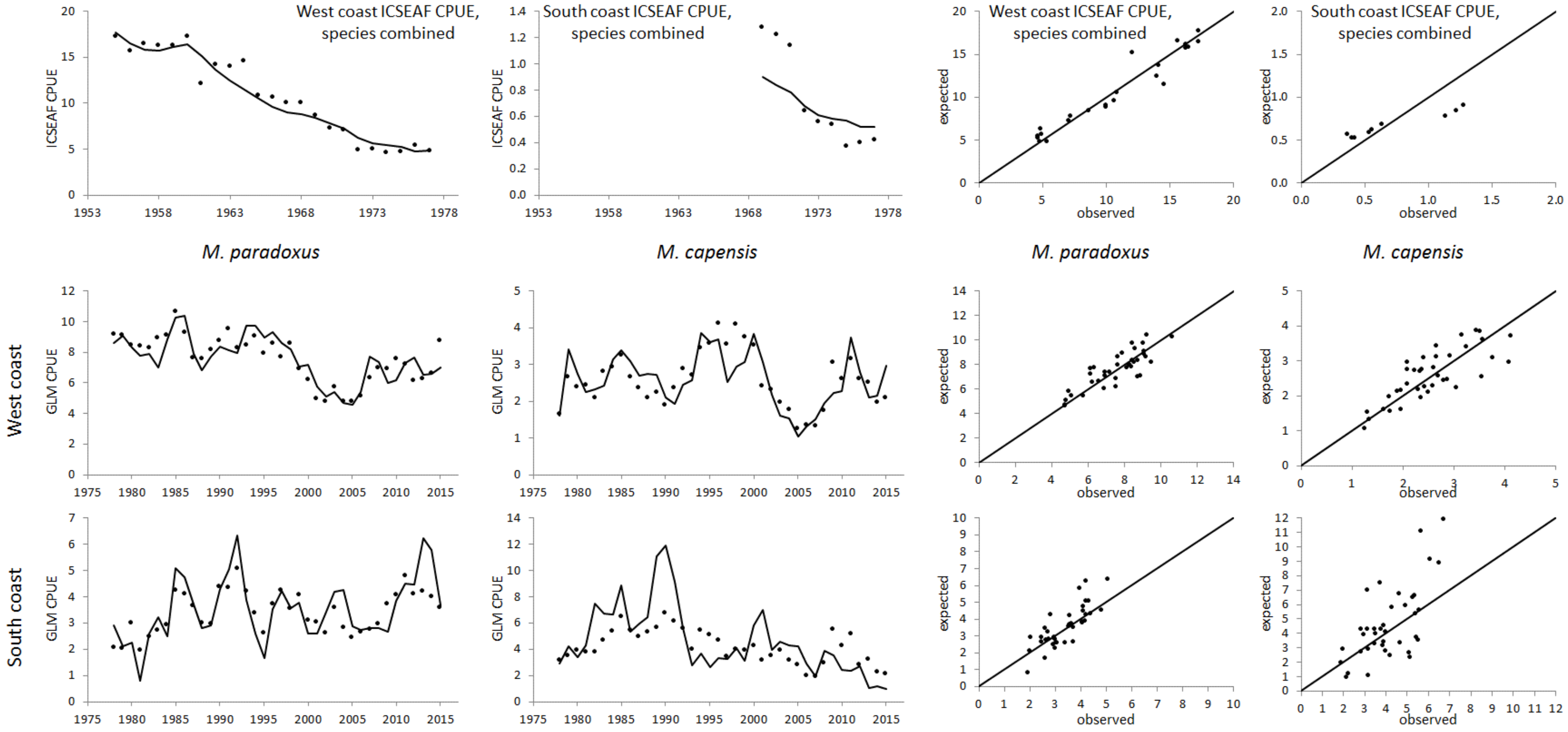


Figure 2A7: Fits to the ICSEAF CPUE and GLM-standardised CPUE series for the **Model A** (not fitting to the GeoPop outputs).

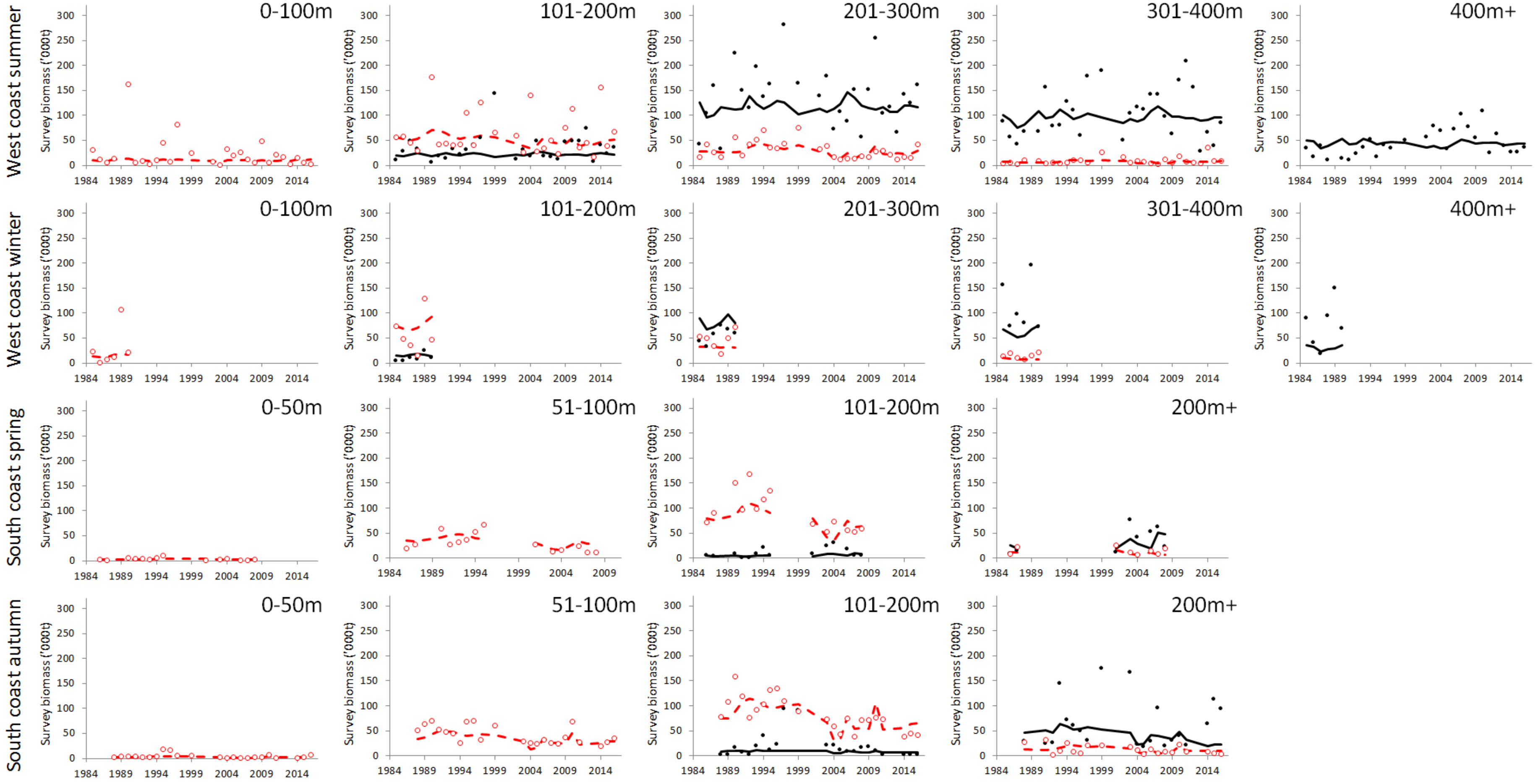


Figure 2A8a: Fits to the survey biomass indices by region. *M. paradoxus* results are shown in black while *M. capensis* results are in red for the **Model A** (not fitting to the GeoPop outputs).

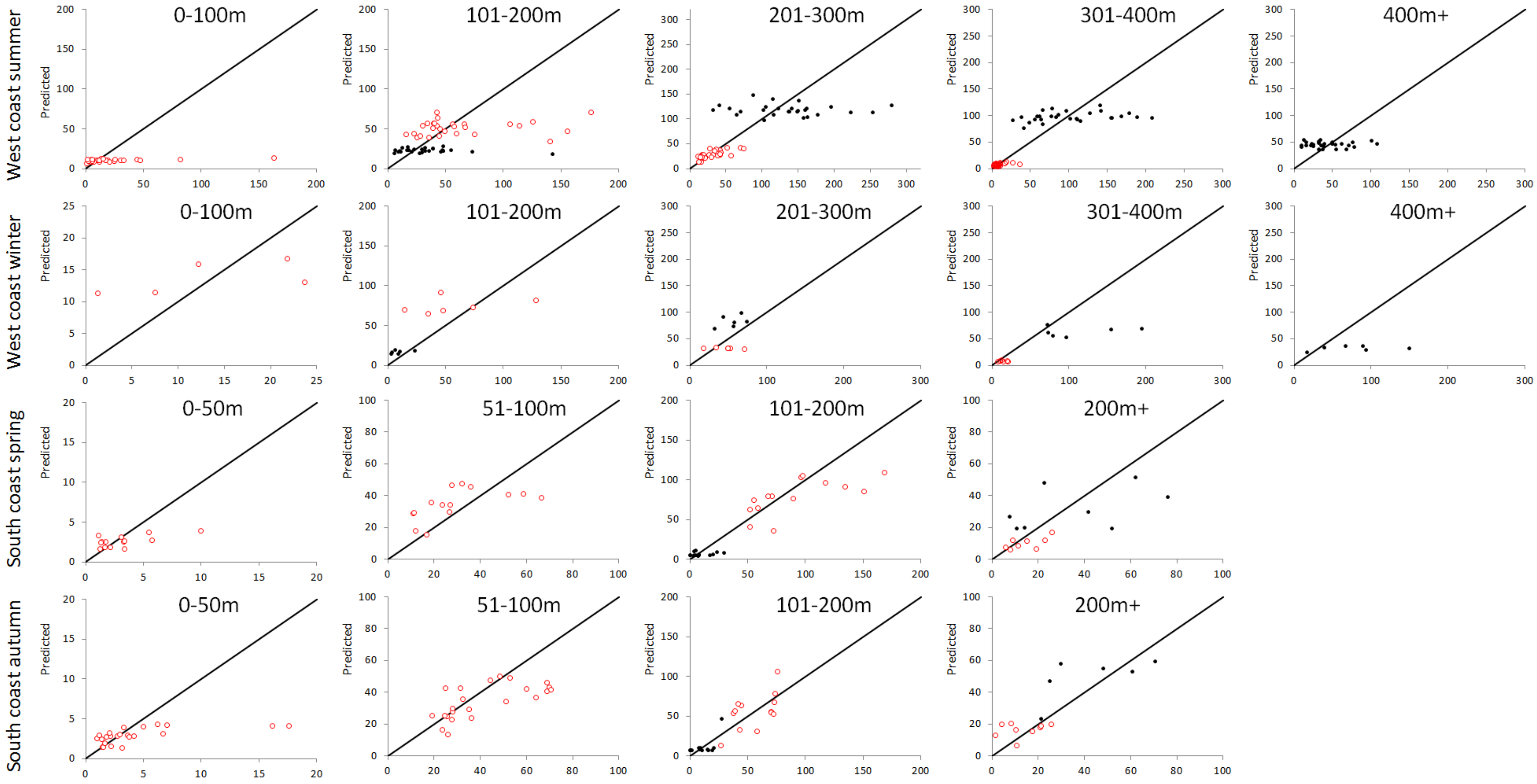
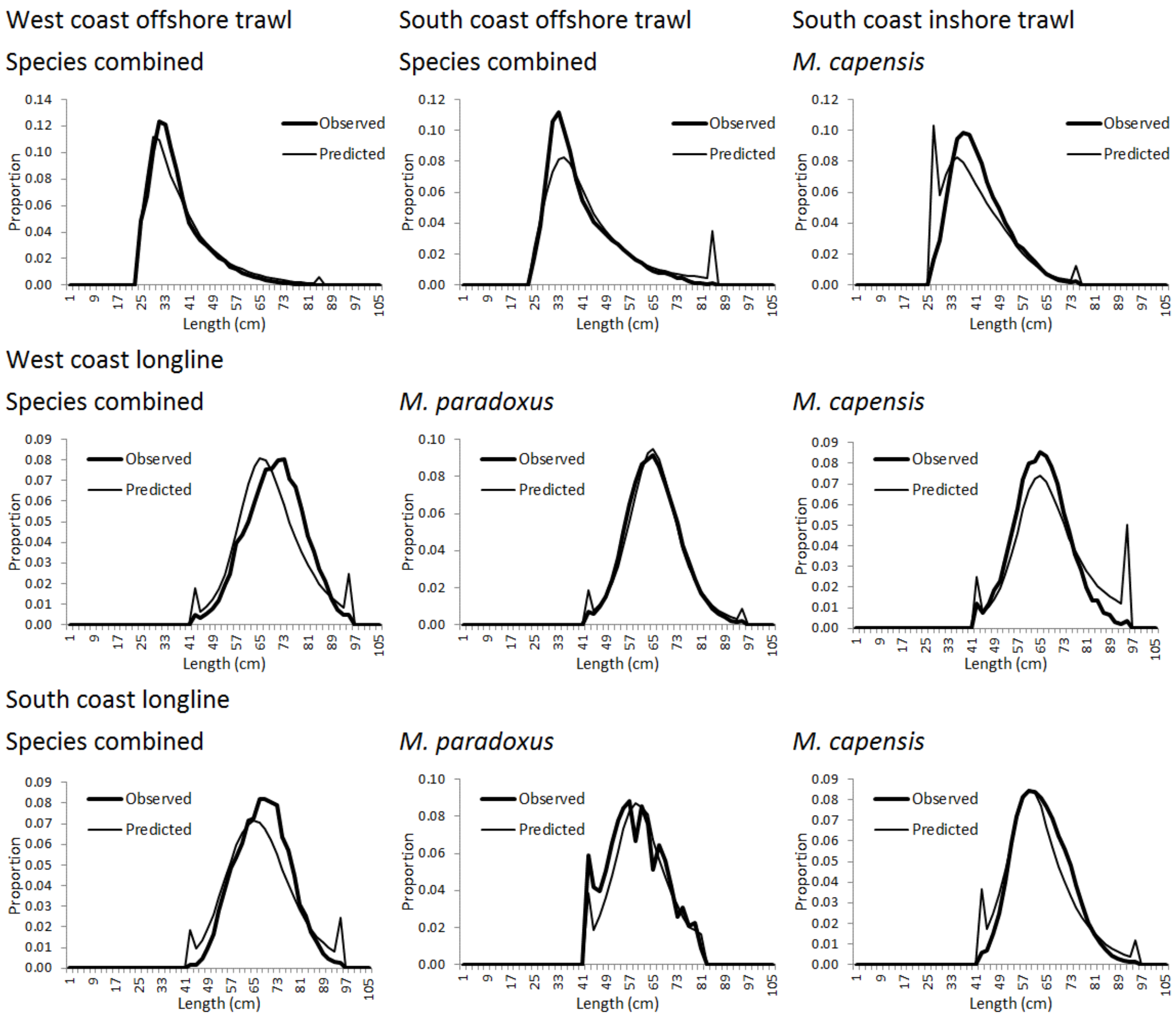


Figure 2A8b: Observed *vs* predicted surveys by region (*M. paradoxus* in black, *M. capensis* in red) for the **Model A** (not fitting to the GeoPop outputs).



West coast offshore trawl

Species combined

South coast offshore trawl

Species combined

South coast inshore trawl

M. capensis

West coast longline

Species combined

M. paradoxus

M. capensis

South coast longline

Species combined

M. paradoxus

M. capensis

Figure 2A9: Fits to the commercial catch-at-length data, averaged over all the years for which data are available for the **Model A** (not fitting to the GeoPop outputs).

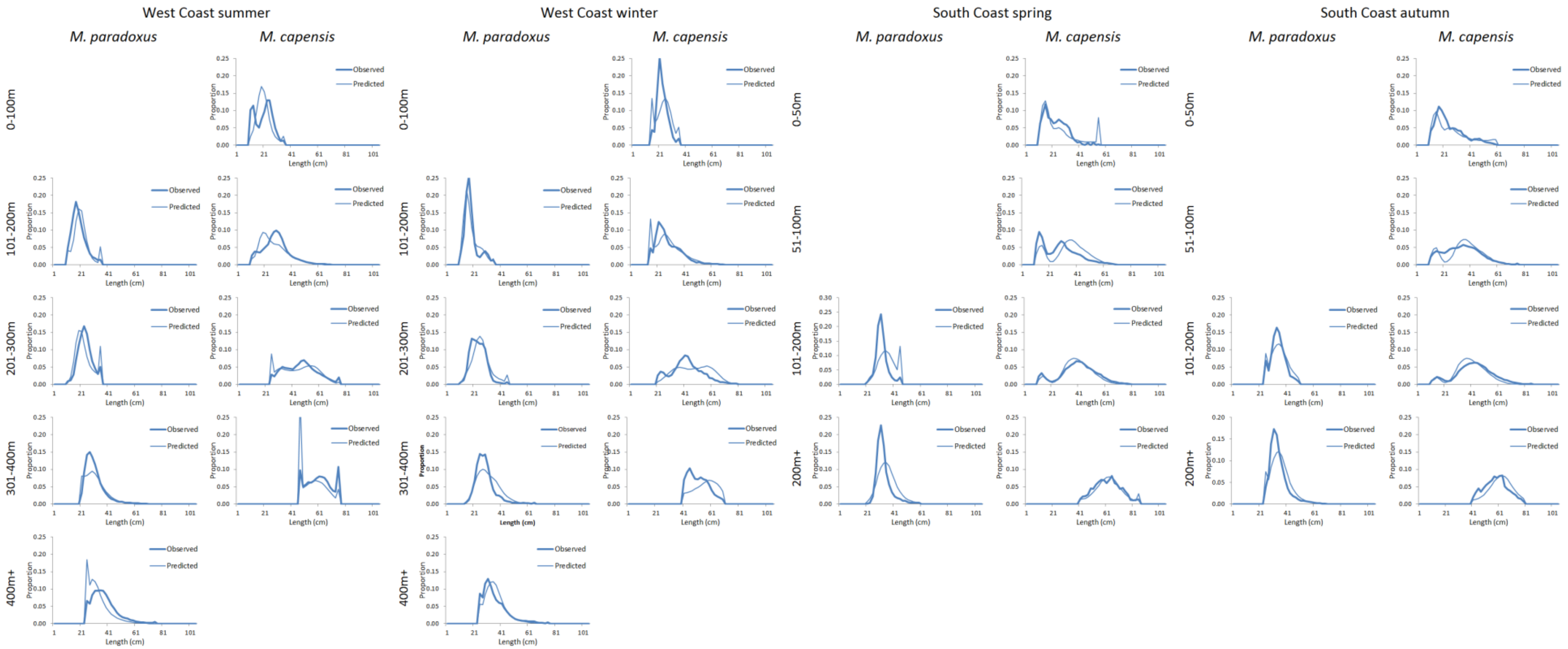


Figure 2A10: Fits to the survey region specific catch-at-length data, as averaged over all the years for which data are available for the **Model A** (not fitting to the GeoPop outputs).

Appendix 2B: Full results for the Model B fitting to the GeoPop outputs

M. paradoxus

Age 0

	Prop.
0-100m	-
101-200m	0.64
201-300m	0.35
301-400m	-
401m+	-
0-50m	-
51-100m	-
101-200m	0.00
201m+	0.01

Age 1

	into									
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.01	0.97	0.03	-	-	-	0.00	0.00	1.00
201-300m	-	0.54	0.00	0.46	-	-	-	0.00	0.00	1.00
301-400m	-	0.03	0.94	0.03	-	-	-	0.00	0.00	1.00
401m+	-	-	-	-	-	-	-	-	-	
0-50m	-	-	-	-	-	-	-	-	-	
51-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.03	0.94	0.03	-	-	-	0.00	0.00	1.00
201m+	-	0.03	0.94	0.03	-	-	-	0.00	0.00	1.00

Ages 2-4

	into									
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.06	0.28	0.30	0.20	-	-	0.02	0.15	1.00
201-300m	-	0.00	0.21	0.36	0.24	-	-	0.02	0.17	1.00
301-400m	-	0.00	0.29	0.32	0.21	-	-	0.02	0.15	1.00
401m+	-	0.00	0.37	0.40	0.00	-	-	0.03	0.20	1.00
0-50m	-	-	-	-	-	-	-	-	-	
51-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.00	0.30	0.33	0.22	-	-	0.00	0.16	1.00
201m+	-	0.00	0.35	0.38	0.25	-	-	0.02	0.00	1.00

Ages 5+

	into									
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.43	0.00	0.00	0.57	-	-	0.00	0.00	1.00
201-300m	-	0.40	0.00	0.00	0.60	-	-	0.00	0.00	1.00
301-400m	-	0.00	0.00	0.00	1.00	-	-	0.00	0.00	1.00
401m+	-	0.00	0.27	0.20	0.41	-	-	0.00	0.11	1.00
0-50m	-	-	-	-	-	-	-	-	-	
51-100m	-	-	-	-	-	-	-	-	-	
101-200m	-	0.00	0.00	0.00	0.00	-	-	1.00	0.00	1.00
201m+	-	0.00	0.00	0.00	0.01	-	-	0.00	0.99	1.00

M. capensis

Age 0

	Prop.
0-100m	0.22
101-200m	0.53
201-300m	-
301-400m	-
401m+	-
0-50m	0.00
51-100m	0.09
101-200m	0.15
201m+	-

Age 1

	into									
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	0.00	1.00	0.00	-	-	0.00	0.00	0.00	0.00	1.00
101-200m	0.61	0.36	0.01	-	-	0.01	0.01	0.00	0.00	1.00
201-300m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
301-400m	-	-	-	-	-	-	-	-	-	
401m+	-	-	-	-	-	-	-	-	-	
0-50m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
51-100m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
101-200m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
201m+	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00

Ages 2-4

	into									
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	0.23	0.00	0.16	0.01	-	0.00	0.22	0.37	0.00	1.00
101-200m	0.00	0.72	0.06	0.00	-	0.00	0.08	0.14	0.00	1.00
201-300m	0.00	0.00	0.00	0.01	-	0.00	0.37	0.61	0.01	1.00
301-400m	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	0.00	1.00
401m+	-	-	-	-	-	-	-	-	-	
0-50m	0.00	0.00	0.09	0.00	-	0.55	0.13	0.22	0.00	1.00
51-100m	0.00	0.00	0.29	0.01	-	0.00	0.00	0.69	0.01	1.00
101-200m	0.00	0.00	0.21	0.01	-	0.00	0.29	0.49	0.01	1.00
201m+	0.00	0.00	0.21	0.01	-	0.00	0.29	0.49	0.00	1.00

Ages 5+

	into									
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
0-100m	0.00	0.01	0.77	0.08	-	0.01	0.01	0.08	0.05	1.00
101-200m	0.00	0.00	0.78	0.08	-	0.01	0.01	0.08	0.05	1.00
201-300m	0.00	0.03	0.27	0.25	-	0.02	0.05	0.24	0.15	1.00
301-400m	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	0.00	1.00
401m+	-	-	-	-	-	-	-	-	-	
0-50m	0.00	0.00	0.04	0.00	-	0.94	0.00	0.00	0.00	1.00
51-100m	0.00	0.01	0.78	0.08	-	0.01	0.00	0.08	0.05	1.00
101-200m	0.00	0.01	0.77	0.08	-	0.01	0.01	0.08	0.05	1.00
201m+	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	1.00	1.00

Table 2B1: Proportion of recruitment in each region and movement matrices estimated for *M. paradoxus* and *M. capensis* for the **Model B** (fitting to the GeoPop outputs).

M. paradoxus

Age 1 — into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.3	179.6	5.5	-	-	-	0.0	0.0
201-300m	-	335.4	0.0	273.4	-	-	-	0.0	0.0
301-400m	-	5.9	157.8	4.8	-	-	-	0.0	0.0
401m+	-	-	-	-	-	-	-	-	-
0-50m	-	-	-	-	-	-	-	-	-
51-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.0	0.0	0.0	-	-	-	0.0	0.0
201m+	-	0.0	0.0	0.0	-	-	-	0.0	0.0

Ages 2-4 — into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.3	1.5	1.6	1.1	-	-	0.1	0.8
201-300m	-	0.0	32.5	57.3	38.4	-	-	3.7	27.6
301-400m	-	0.0	65.8	68.8	46.2	-	-	4.4	33.1
401m+	-	0.0	54.1	56.5	0.0	-	-	3.6	27.2
0-50m	-	-	-	-	-	-	-	-	-
51-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.0	4.3	4.5	3.0	-	-	0.0	2.2
201m+	-	0.0	35.4	37.0	24.9	-	-	2.4	0.0

Ages 5+ — into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	-	-	-	-	-	-	-	-	-
101-200m	-	2.1	0.0	0.0	2.3	-	-	0.0	0.0
201-300m	-	0.3	0.0	0.0	0.6	-	-	0.0	0.0
301-400m	-	0.0	0.0	0.0	1.7	-	-	0.0	0.0
401m+	-	0.0	2.8	5.5	7.6	-	-	0.0	2.3
0-50m	-	-	-	-	-	-	-	-	-
51-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.0	0.0	0.0	0.0	-	-	1.4	0.0
201m+	-	0.0	0.0	0.0	0.2	-	-	0.0	7.6

M. capensis

Age 1 — into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	0.0	133.1	0.0	-	-	0.0	0.0	0.0	0.0
101-200m	162.8	94.1	1.5	-	-	2.0	1.8	0.0	0.2
201-300m	0.0	1.2	0.0	-	-	0.0	0.0	0.0	0.0
301-400m	-	-	-	-	-	-	-	-	-
401m+	-	-	-	-	-	-	-	-	-
0-50m	0.0	1.7	0.0	-	-	0.0	0.0	0.0	0.0
51-100m	0.0	1.5	0.0	-	-	0.0	0.0	0.0	0.0
101-200m	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0
201m+	0.0	0.1	0.0	-	-	0.0	0.0	0.0	0.0

Ages 2-4 — into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	3.8	0.0	2.6	0.1	-	0.0	3.7	6.1	0.1
101-200m	0.0	94.5	7.6	0.3	-	0.1	10.7	17.8	0.2
201-300m	0.0	0.0	0.0	0.3	-	0.1	12.1	20.1	0.2
301-400m	0.0	0.0	0.0	1.8	-	0.0	0.0	0.0	0.0
401m+	-	-	-	-	-	-	-	-	-
0-50m	0.0	0.0	0.1	0.0	-	0.4	0.1	0.1	0.0
51-100m	0.0	0.0	13.0	0.4	-	0.1	0.0	30.6	0.4
101-200m	0.0	0.0	17.5	0.6	-	0.1	24.8	41.2	0.5
201m+	0.0	0.0	0.2	0.0	-	0.0	0.3	0.5	0.0

Ages 5+ — into

out of

	0-100m	101-200m	201-300m	301-400m	401m +	0-50m	51-100m	101-200m	201m +
0-100m	0.0	0.0	0.1	0.0	-	0.0	0.0	0.0	0.0
101-200m	0.0	0.0	0.5	0.0	-	0.0	0.0	0.0	0.0
201-300m	0.1	0.7	6.1	5.7	-	0.5	1.1	5.4	3.4
301-400m	0.0	0.0	0.0	16.3	-	0.0	0.0	0.0	0.0
401m+	-	-	-	-	-	-	-	-	-
0-50m	0.0	0.0	0.0	0.0	-	0.7	0.0	0.0	0.0
51-100m	0.0	0.0	0.8	0.1	-	0.0	0.0	0.1	0.0
101-200m	0.0	0.1	4.4	0.4	-	0.0	0.1	0.4	0.3
201m+	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	11.0

Table 2B2: 1998-2012 average number (in millions) of fish moving estimated for *M. paradoxus* and *M. capensis* for the **Model B** (fitting to the GeoPop outputs). For the age group “2-4”, the numbers correspond to the sum of fish of age 2, 3 and 4. Similarly, for the age group “5+”, the numbers correspond to the sum of fish of age 5 and above.

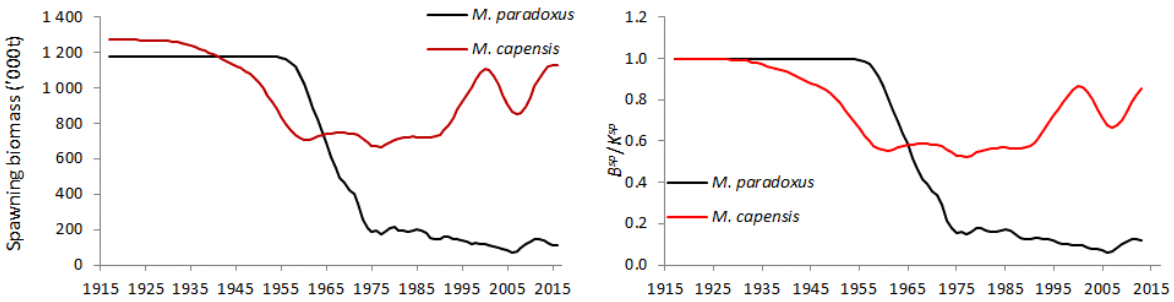


Figure 2B1: Total spawning biomass trajectories (in absolute terms and relative to unexploited level) for *M. paradoxus* and *M. capensis* for the **Model B** (fitting to the GeoPop outputs).

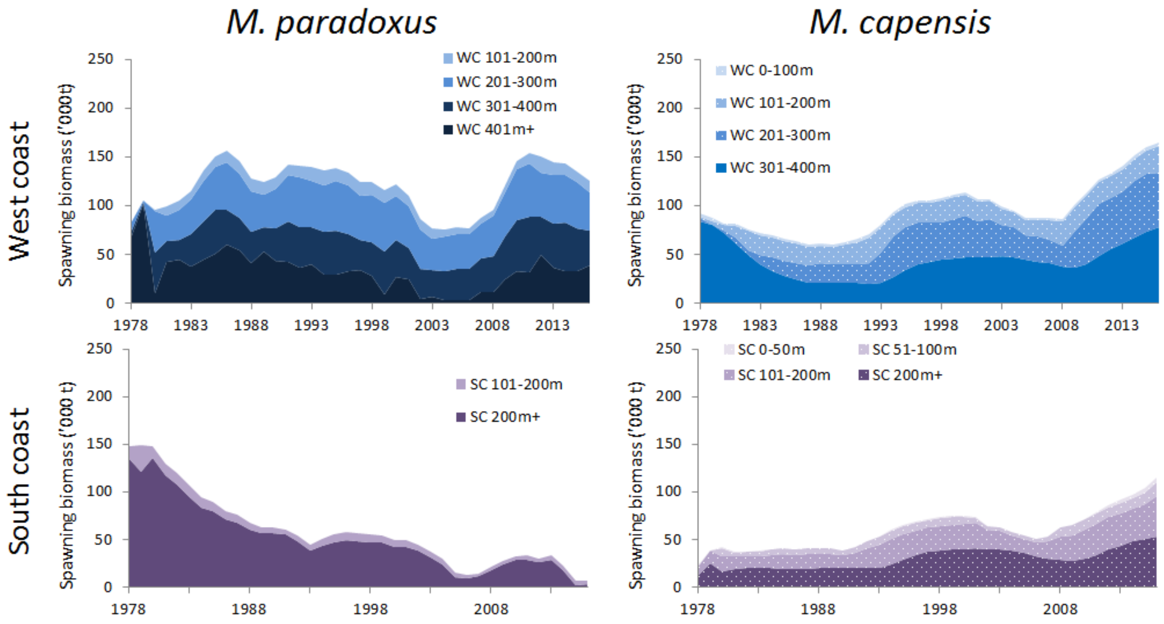


Figure 2B2: Spawning biomass trajectories (in absolute terms) per regions for *M. paradoxus* and *M. capensis* for the **Model B** (fitting to the GeoPop outputs).

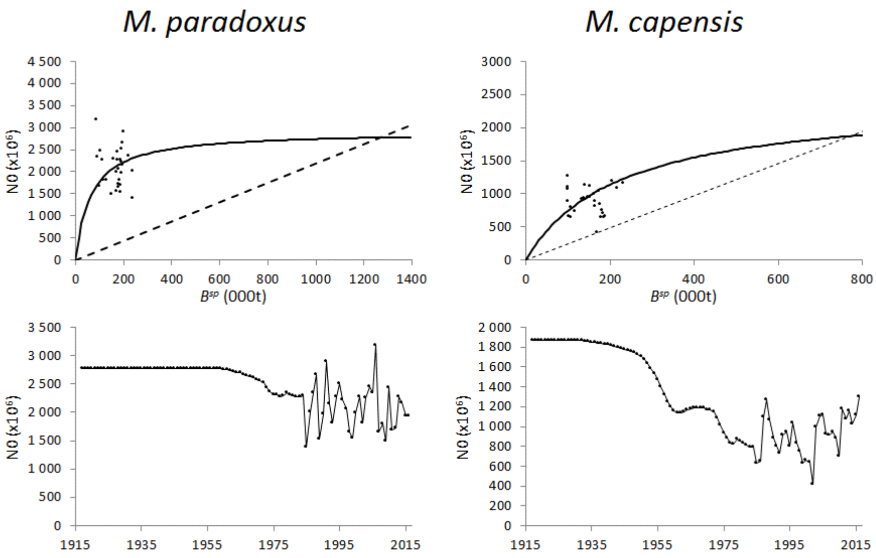


Figure 2B3: Stock-recruitment relationship and time-series of recruitment for the **Model B** (fitting to the GeoPop outputs)..

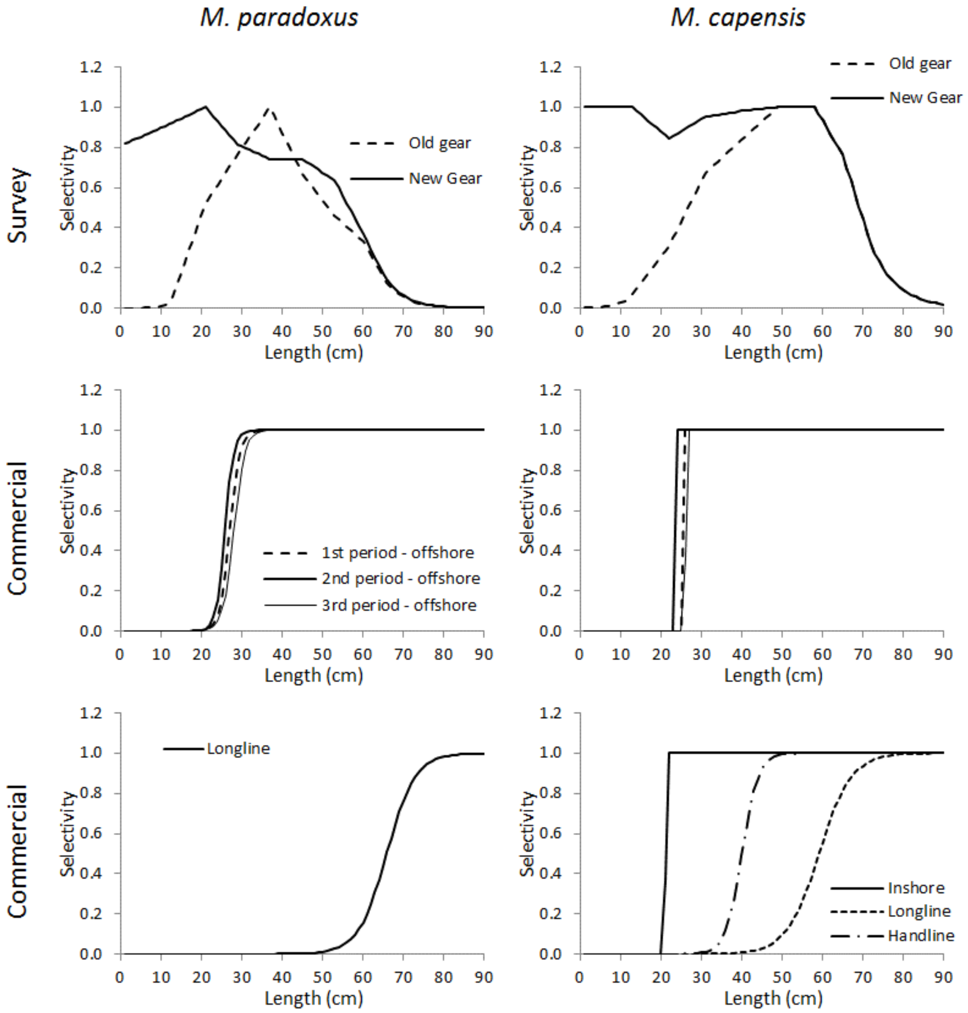


Figure 2B4: Commercial and survey selectivity-at-length for the **Model B** (fitting to the GeoPop outputs).

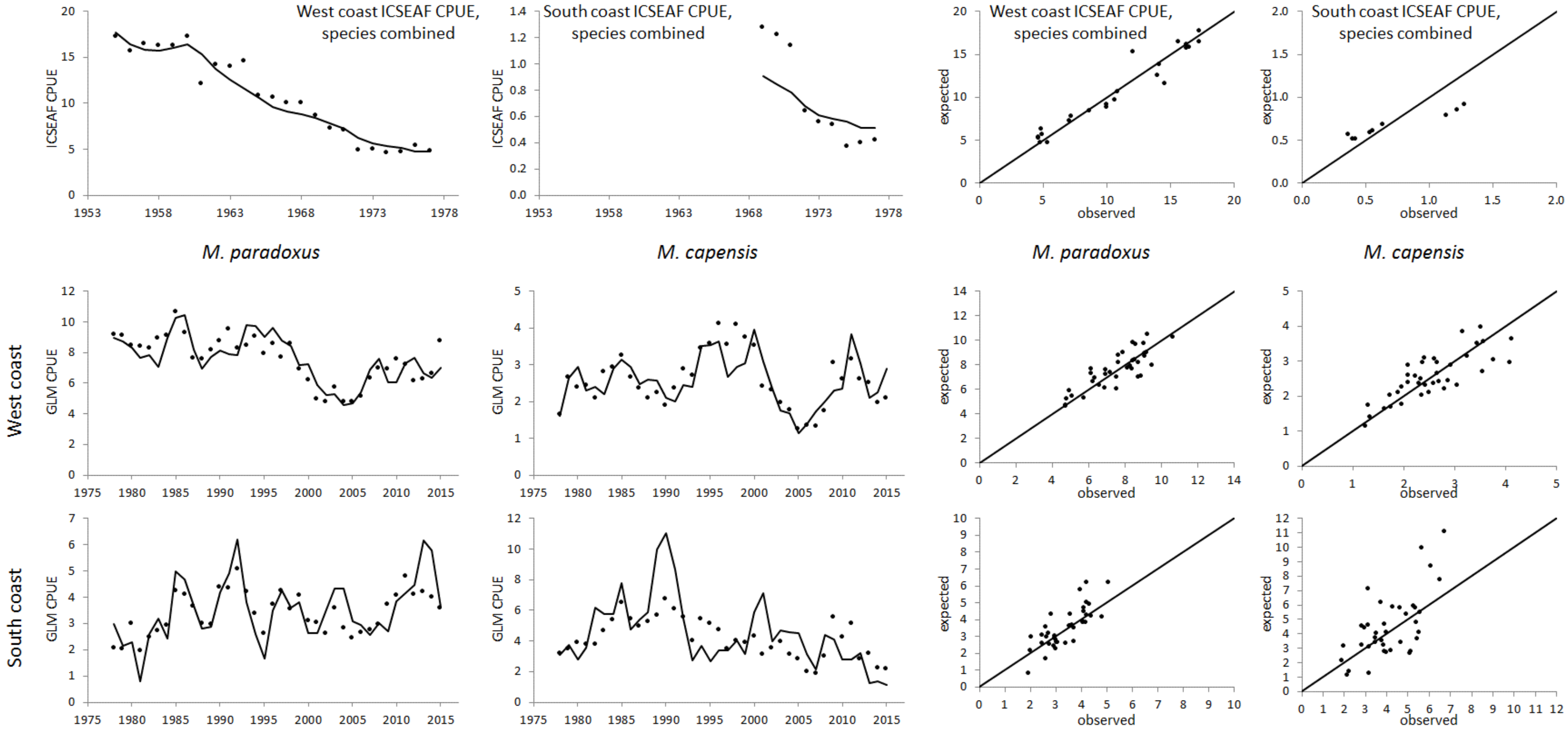


Figure 2B5: Fits to the ICSEAF CPUE and GLM-standardised CPUE series for the **Model B** (fitting to the GeoPop outputs).

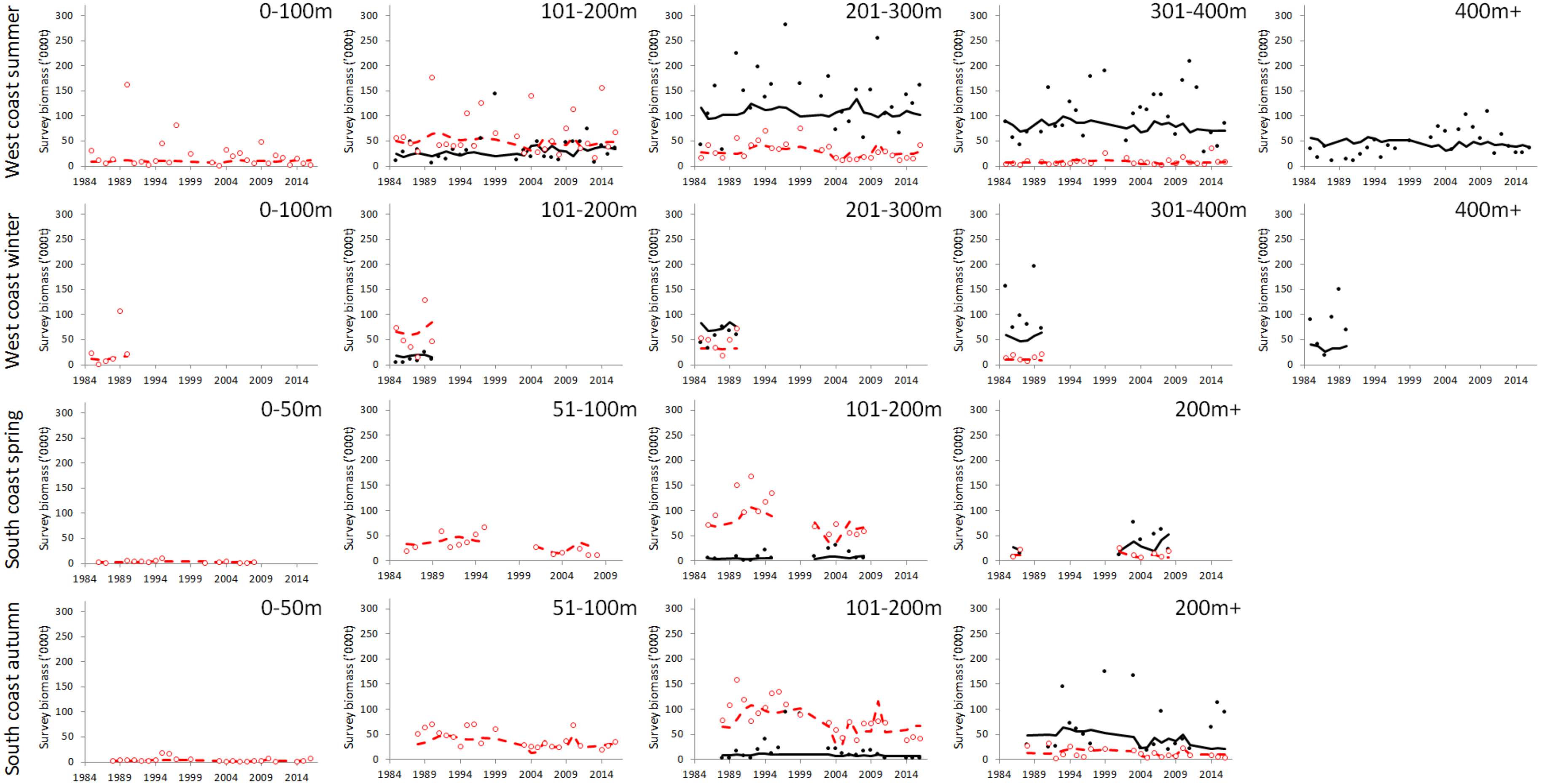


Figure 2B6a: Fits to the survey biomass indices by region. *M. paradoxus* results are shown in black while *M. capensis* results are in red for the **Model B** (fitting to the GeoPop outputs).

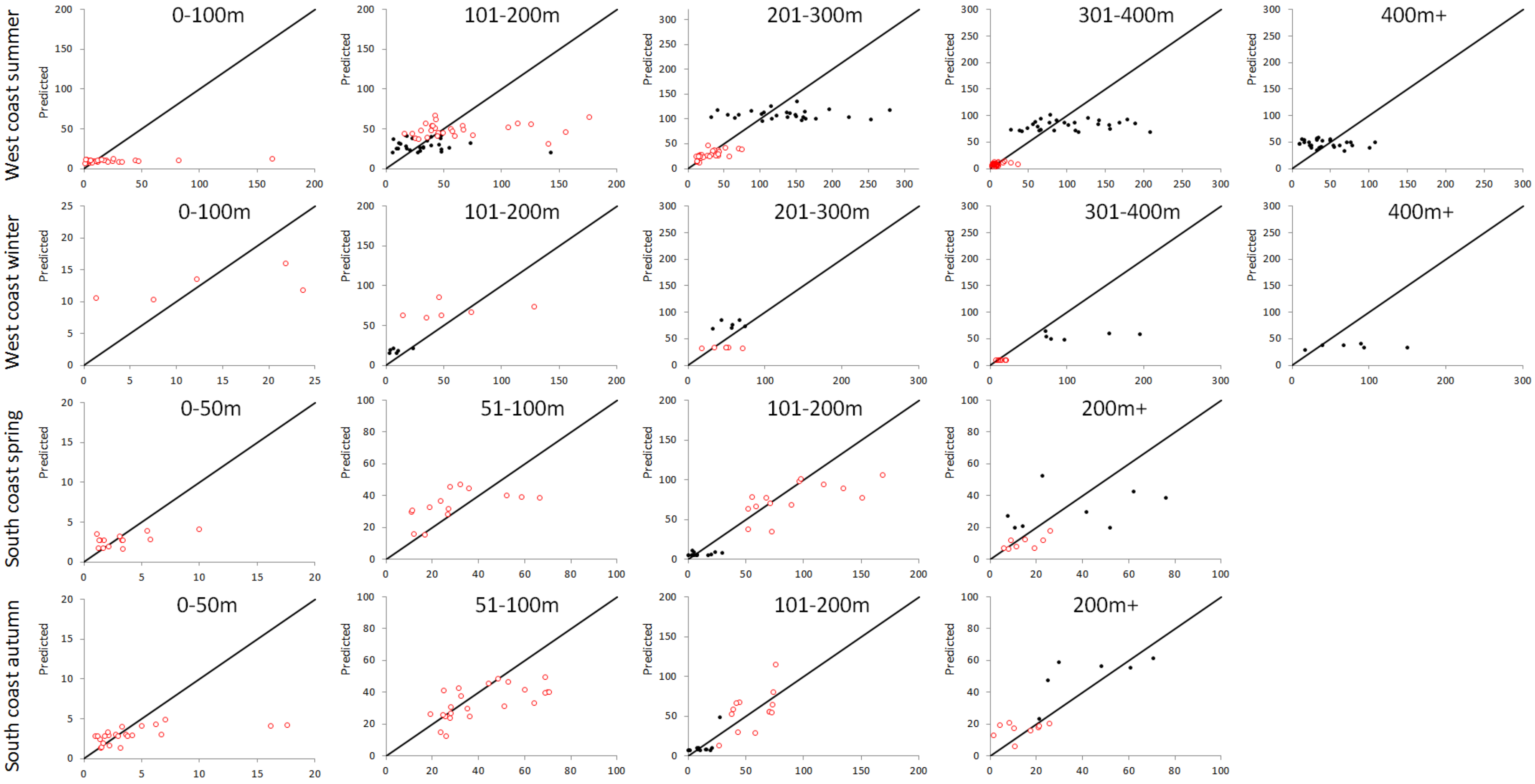


Figure 2B6b: Observed *vs* predicted surveys by region (*M. paradoxus* in black, *M. capensis* in red) for the **Model B** (fitting to the GeoPop outputs).

West coast offshore trawl

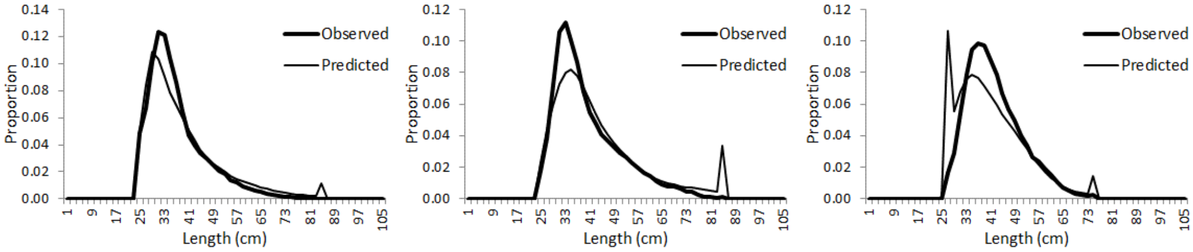
Species combined

South coast offshore trawl

Species combined

South coast inshore trawl

M. capensis

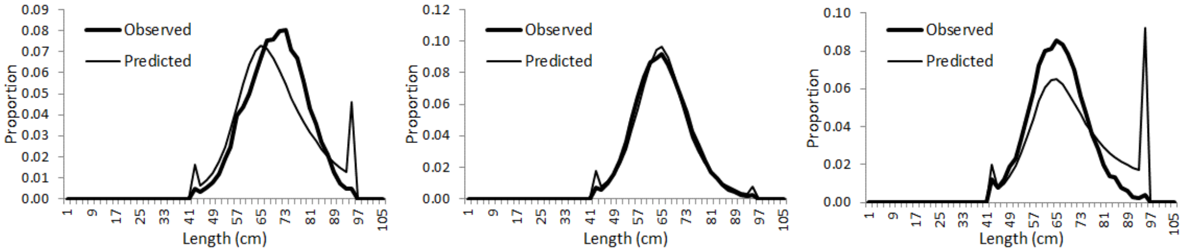


West coast longline

Species combined

M. paradoxus

M. capensis



South coast longline

Species combined

M. paradoxus

M. capensis

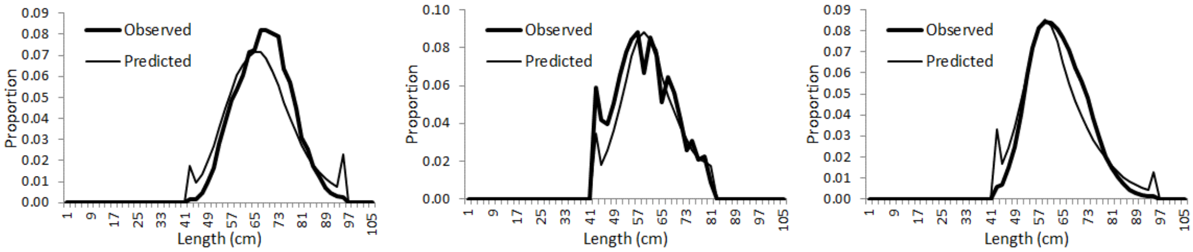


Figure 2B7: Fits to the commercial catch-at-length data, averaged over all the years for which data are available for the **Model B** (fitting to the GeoPop outputs).

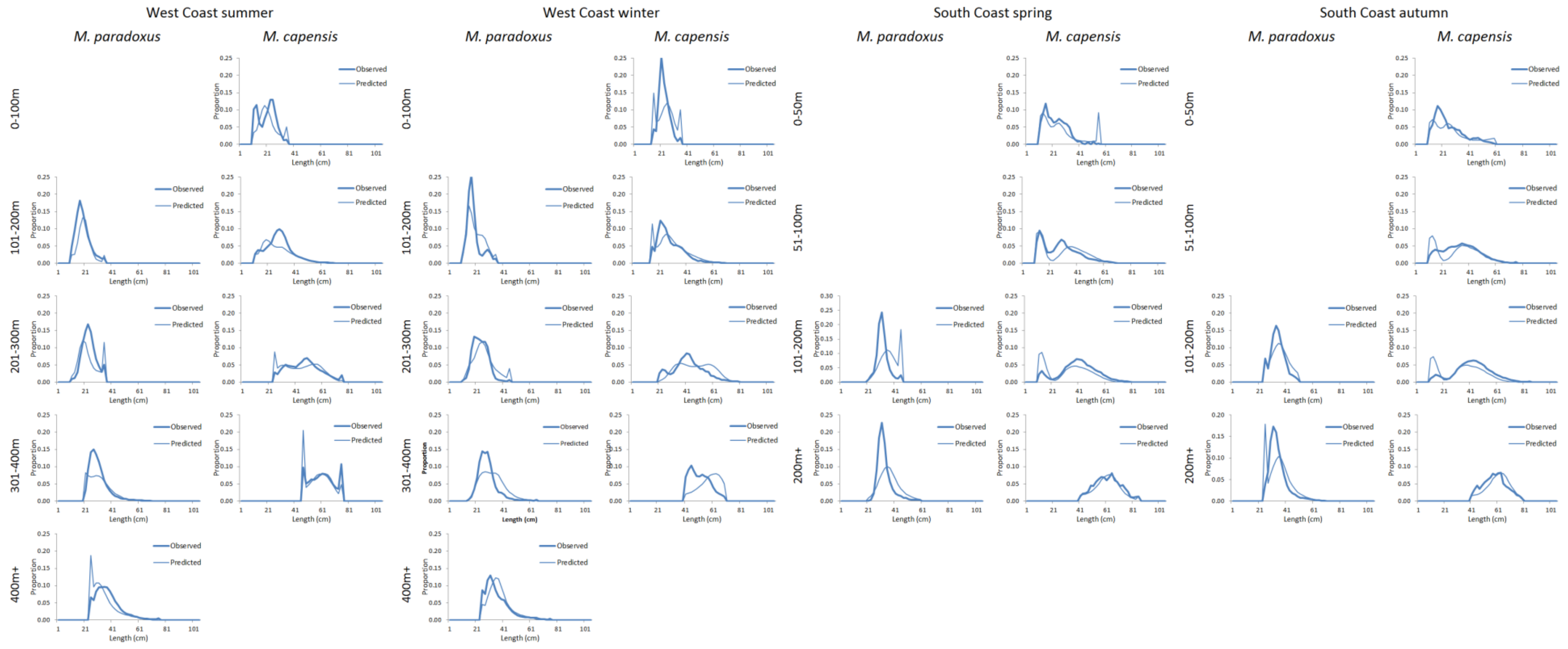


Figure 2B8: Fits to the survey region specific catch-at-length data, as averaged over all the years for which data are available for the **Model B** (fitting to the GeoPop outputs).

Appendix 2C: Full results for the Model C fitting to the GeoPop outputs and downweighting the survey spatial information

M. paradoxus

Age 0

	Prop.
0-100m	-
101-200m	0.84
201-300m	0.15
301-400m	-
401m+	-
0-50m	-
51-100m	-
101-200m	0.00
201m+	0.01

Age 1 — into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.22	0.64	0.14	-	-	-	0.00	0.00	1.00
	201-300m	-	0.99	0.00	0.01	-	-	-	0.00	0.00	1.00
	301-400m	-	0.93	0.06	0.01	-	-	-	0.00	0.00	1.00
	401m+	-	-	-	-	-	-	-	-	-	
	0-50m	-	-	-	-	-	-	-	-	-	
	51-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.93	0.06	0.01	-	-	-	0.00	0.00	1.00
	201m+	-	0.93	0.06	0.01	-	-	-	0.00	0.00	1.00

Ages 2-4 — into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.01	0.32	0.18	0.29	-	-	0.02	0.18	1.00
	201-300m	-	0.00	0.00	0.27	0.43	-	-	0.04	0.26	1.00
	301-400m	-	0.00	0.32	0.18	0.29	-	-	0.02	0.18	1.00
	401m+	-	0.00	0.45	0.26	0.00	-	-	0.03	0.25	1.00
	0-50m	-	-	-	-	-	-	-	-	-	
	51-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.00	0.33	0.19	0.30	-	-	0.00	0.18	1.00
	201m+	-	0.00	0.39	0.22	0.36	-	-	0.03	0.00	1.00

Ages 5+ — into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.39	0.00	0.00	0.61	-	-	0.00	0.00	1.00
	201-300m	-	0.67	0.00	0.00	0.33	-	-	0.00	0.00	1.00
	301-400m	-	-	0.00	0.00	1.00	-	-	0.00	0.00	1.00
	401m+	-	-	0.36	0.02	0.58	-	-	0.01	0.03	1.00
	0-50m	-	-	-	-	-	-	-	-	-	
	51-100m	-	-	-	-	-	-	-	-	-	
	101-200m	-	0.00	0.00	0.00	0.00	-	-	1.00	0.00	1.00
	201m+	-	0.00	0.00	0.00	0.00	-	-	0.00	1.00	1.00

M. capensis

Age 0

	Prop.
0-100m	0.03
101-200m	0.76
201-300m	-
301-400m	-
401m+	-
0-50m	0.00
51-100m	0.13
101-200m	0.08
201m+	-

Age 1 — into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	0.00	1.00	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	101-200m	0.04	0.96	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	201-300m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	301-400m	-	-	-	-	-	-	-	-	-	
	401m+	-	-	-	-	-	-	-	-	-	
	0-50m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	51-100m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	101-200m	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00
	201m+	0.02	0.98	0.00	-	-	0.00	0.00	0.00	0.00	1.00

Ages 2-4 — into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	0.00	0.00	0.09	0.01	-	0.00	0.69	0.20	0.01	1.00
	101-200m	0.00	0.70	0.03	0.00	-	0.00	0.21	0.06	0.00	1.00
	201-300m	0.00	0.00	0.00	0.01	-	0.00	0.75	0.22	0.02	1.00
	301-400m	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	0.00	1.00
	401m+	-	-	-	-	-	-	-	-	-	
	0-50m	0.00	0.00	0.02	0.00	-	0.79	0.14	0.04	0.00	1.00
	51-100m	0.00	0.00	0.29	0.02	-	0.00	0.00	0.65	0.05	1.00
	101-200m	0.00	0.00	0.09	0.01	-	0.00	0.69	0.20	0.01	1.00
	201m+	0.00	0.00	0.09	0.01	-	0.00	0.70	0.21	0.00	1.00

Ages 5+ — into

		0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+	
out of	0-100m	0.00	0.00	0.79	0.08	-	0.01	0.00	0.06	0.06	1.00
	101-200m	0.00	0.00	0.79	0.08	-	0.01	0.00	0.06	0.06	1.00
	201-300m	0.02	0.00	0.17	0.30	-	0.04	0.00	0.25	0.22	1.00
	301-400m	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	0.00	1.00
	401m+	-	-	-	-	-	-	-	-	-	
	0-50m	0.00	0.00	0.01	0.00	-	0.99	0.00	0.00	0.00	1.00
	51-100m	0.00	0.00	0.79	0.08	-	0.01	0.00	0.06	0.06	1.00
	101-200m	0.00	0.00	0.79	0.08	-	0.01	0.00	0.06	0.06	1.00
	201m+	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	1.00	1.00

Table 2C1: Proportion of recruitment in each region and movement matrices estimated for *M. paradoxus* and *M. capensis* for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).

M. paradoxus

Age 1	into								
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
0-100m	-	-	-	-	-	-	-	-	-
101-200m	-	513.6	0.0	45.1	-	-	-	0.0	0.0
201-300m	-	80.9	35.9	7.1	-	-	-	0.0	0.0
301-400m	-	0.0	0.0	0.0	-	-	-	0.0	0.0
401m+	-	-	-	-	-	-	-	-	-
0-50m	-	-	-	-	-	-	-	-	-
51-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.0	0.0	0.0	-	-	-	0.0	0.0
201m+	-	0.0	0.0	0.0	-	-	-	0.0	0.0

Ages 2-4	into								
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
0-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.0	0.0	31.3	46.3	-	-	3.8	28.2
201-300m	-	0.0	50.9	27.2	40.2	-	-	3.3	24.5
301-400m	-	0.0	98.7	52.8	0.0	-	-	6.4	47.5
401m+	-	0.0	0.0	0.0	0.0	-	-	0.0	0.0
0-50m	-	-	-	-	-	-	-	-	-
51-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.0	51.7	27.7	40.9	-	-	3.4	0.0
201m+	-	0.0	0.0	0.0	0.0	-	-	0.0	0.0

Ages 5+	into								
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
0-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.8	0.0	0.0	0.7	-	-	0.0	0.0
201-300m	-	0.0	0.0	0.0	0.1	-	-	0.0	0.0
301-400m	-	0.0	3.2	0.2	5.0	-	-	0.1	0.3
401m+	-	0.0	0.0	0.0	0.0	-	-	0.0	0.0
0-50m	-	-	-	-	-	-	-	-	-
51-100m	-	-	-	-	-	-	-	-	-
101-200m	-	0.0	0.0	0.0	0.0	-	-	0.0	7.1
201m+	-	0.0	0.0	0.0	0.0	-	-	0.0	0.0

M. capensis

Age 1	into								
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
0-100m	21.1	350.4	0.0	-	-	0.3	0.0	0.0	0.8
101-200m	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0
201-300m	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0
301-400m	-	-	-	-	-	-	-	-	-
401m+	-	-	-	-	-	-	-	-	-
0-50m	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0
51-100m	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0
101-200m	0.0	0.6	0.0	-	-	0.0	0.0	0.0	0.0
201m+	0.0	0.0	0.0	-	-	0.0	0.0	0.0	0.0

Ages 2-4	into								
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
0-100m	0.0	83.8	5.4	0.2	-	0.1	35.3	15.0	0.6
101-200m	0.0	0.0	0.0	0.1	-	0.0	13.2	5.6	0.2
201-300m	0.0	0.0	0.0	1.0	-	0.0	0.0	0.0	0.0
301-400m	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0
401m+	-	-	-	-	-	-	-	-	-
0-50m	0.0	0.0	20.5	0.8	-	0.2	0.0	57.0	2.4
51-100m	0.0	0.0	5.3	0.2	-	0.1	34.3	14.7	0.6
101-200m	0.0	0.0	0.2	0.0	-	0.0	1.4	0.6	0.0
201m+	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0

Ages 5+	into								
out of	0-100m	101-200m	201-300m	301-400m	401m+	0-50m	51-100m	101-200m	201m+
0-100m	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0
101-200m	1.6	0.0	0.9	3.8	-	0.6	0.0	5.3	4.3
201-300m	0.0	0.0	0.0	10.0	-	0.0	0.0	0.0	0.0
301-400m	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0
401m+	-	-	-	-	-	-	-	-	-
0-50m	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0
51-100m	0.2	0.0	4.0	0.4	-	0.1	0.0	0.6	0.5
101-200m	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	15.0
201m+	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.3

Table 2C2: 1998-2012 average number (in millions) of fish moving estimated for *M. paradoxus* and *M. capensis* for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information). For the age group "2-4", the numbers correspond to the sum of fish of age 2, 3 and 4. Similarly, for the age group "5+", the numbers correspond to the sum of fish of age 5 and above.

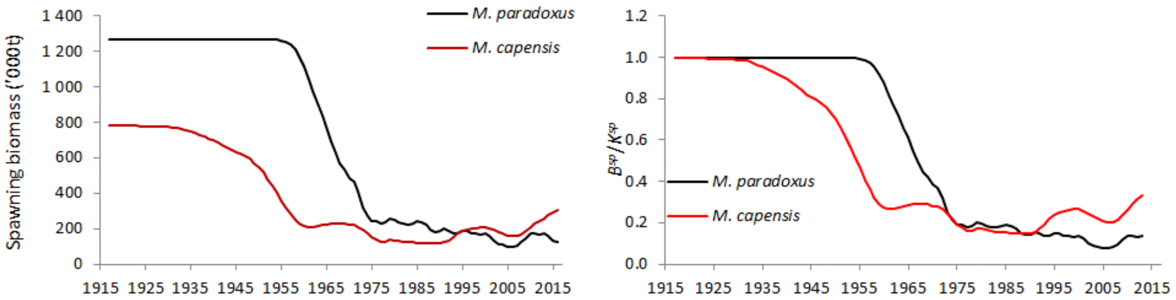


Figure 2C1: Total spawning biomass trajectories (in absolute terms and relative to unexploited level) for *M. paradoxus* and *M. capensis* for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).

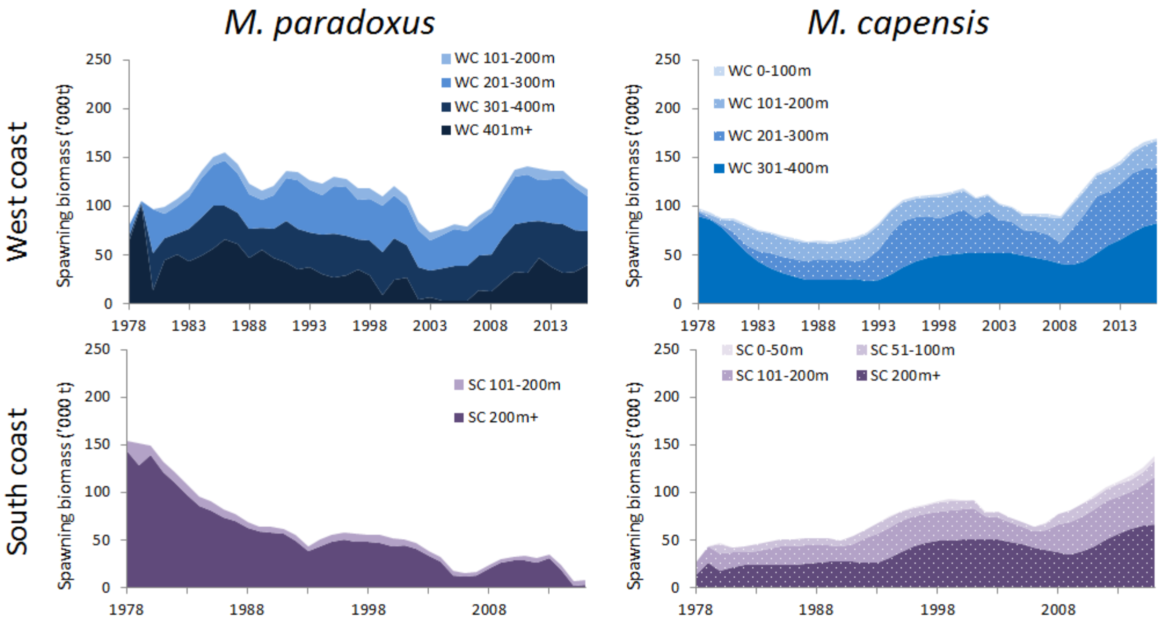


Figure 2C2: Spawning biomass trajectories (in absolute terms) per regions for *M. paradoxus* and *M. capensis* for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).

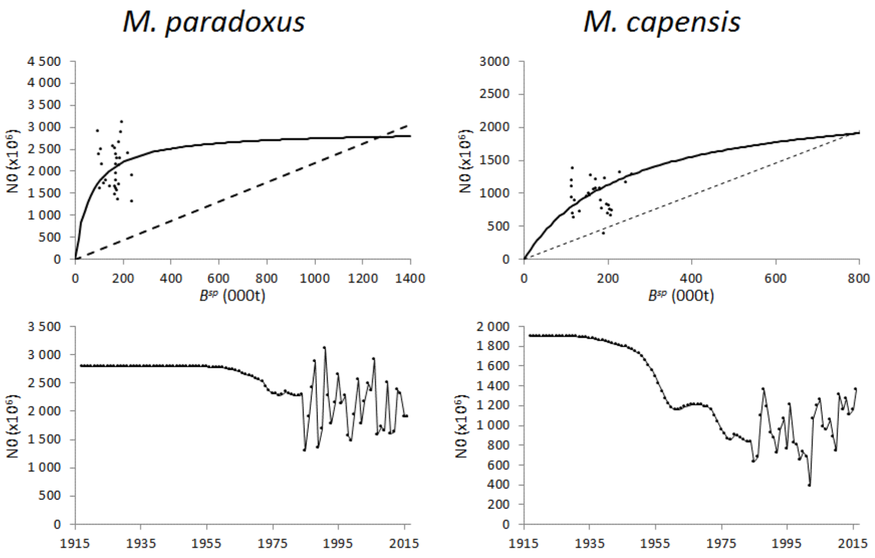


Figure 2C3: Stock-recruitment relationship and time-series of recruitment for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).

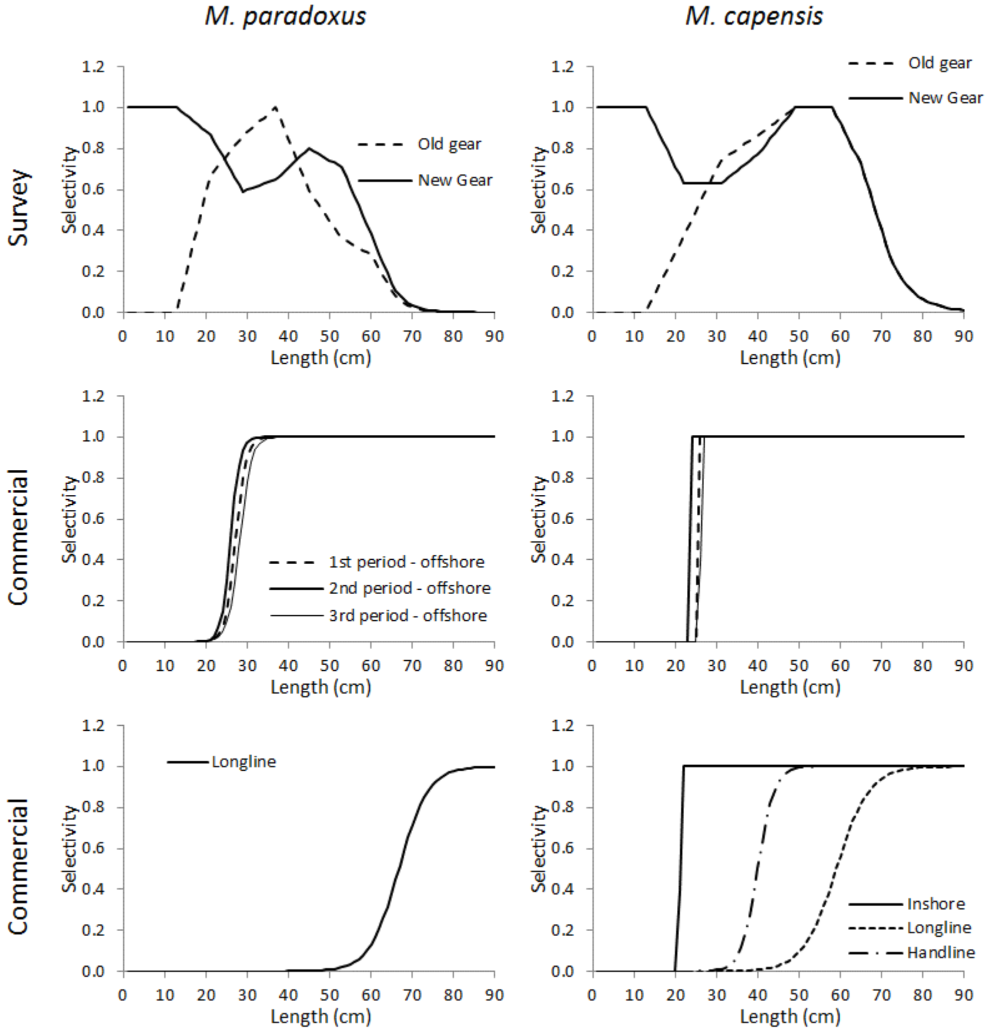


Figure 2C4: Commercial and survey selectivity-at-length for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).

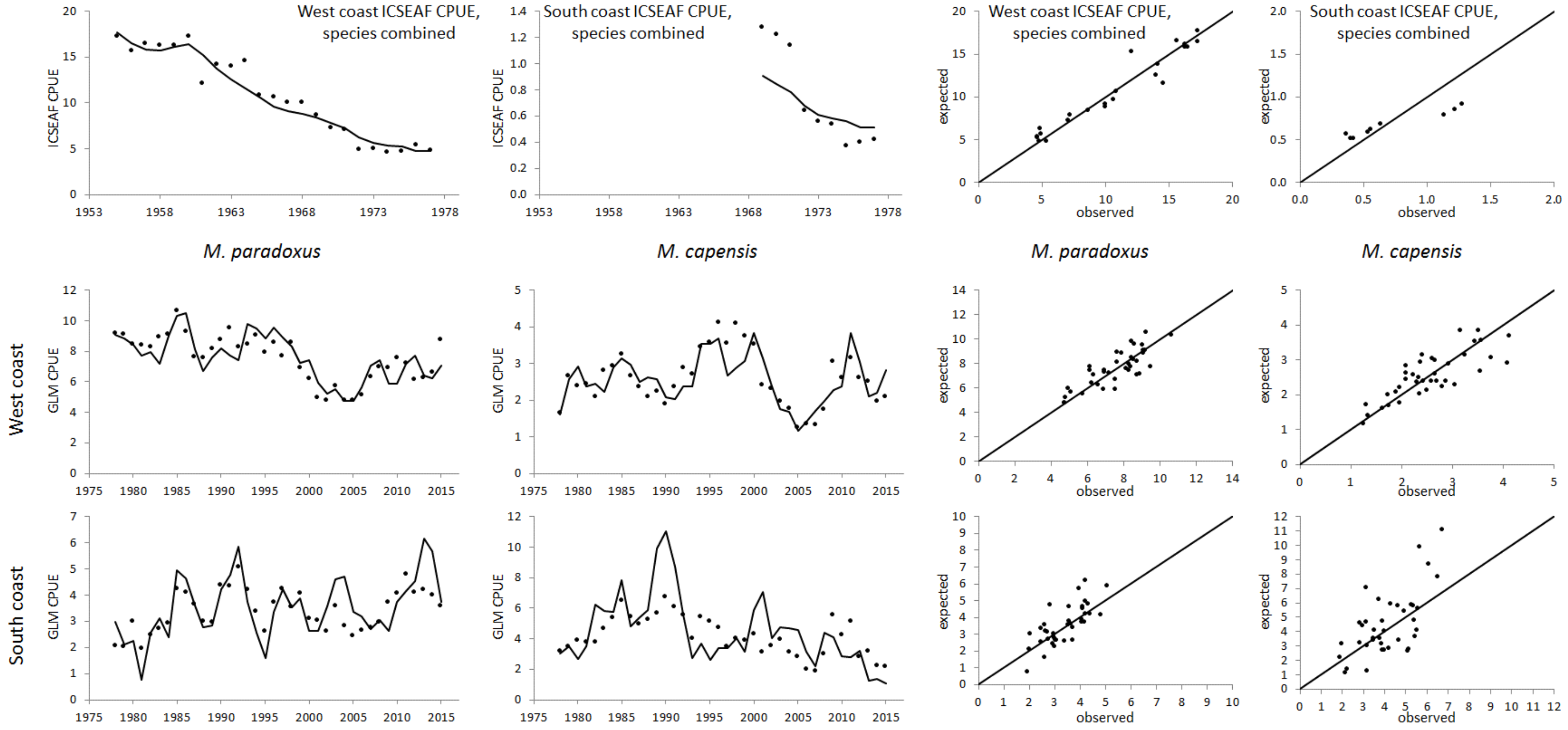


Figure 2C5: Fits to the ICSEAF CPUE and GLM-standardised CPUE series for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).

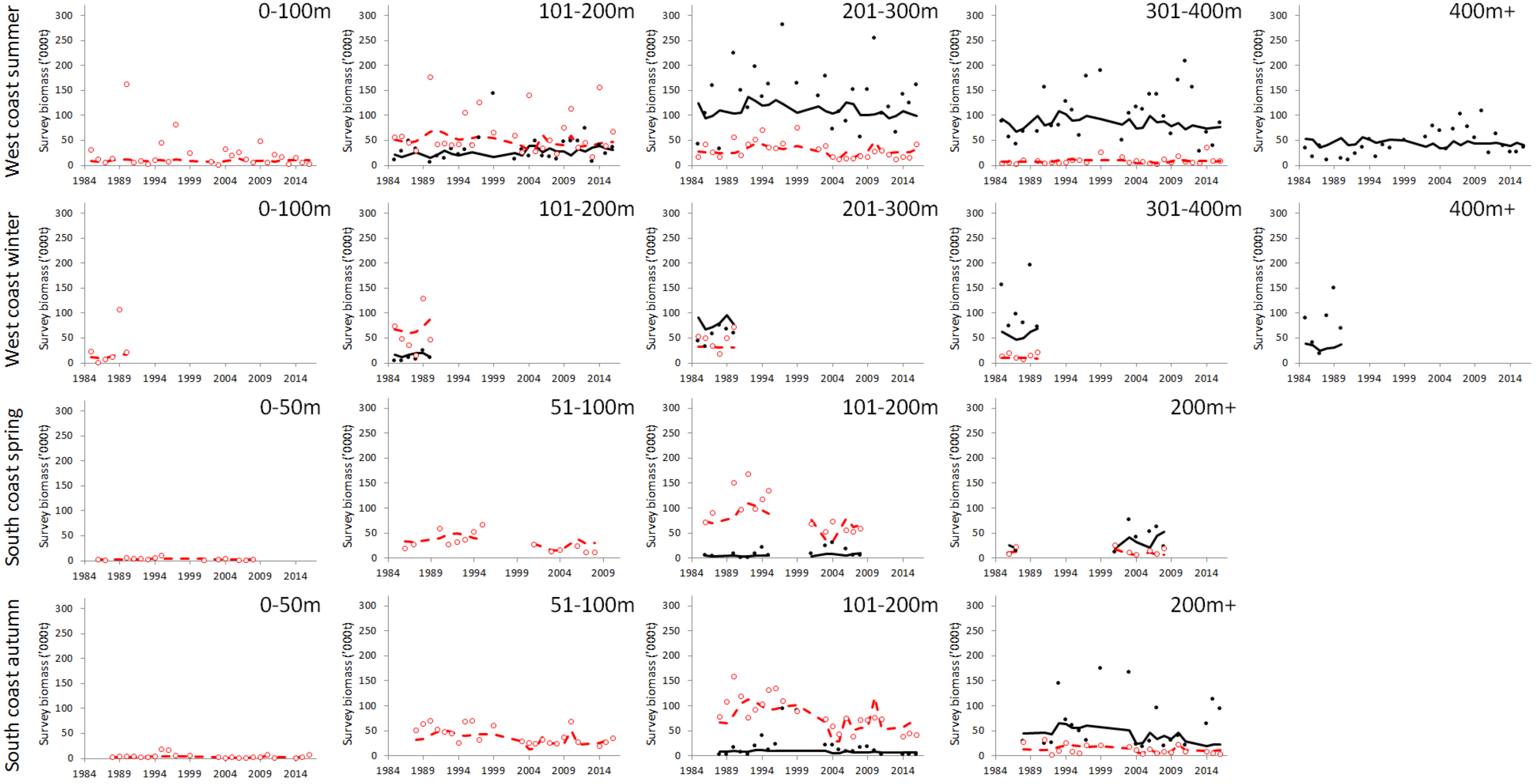


Figure 2C6a: Fits to the survey biomass indices by region. *M. paradoxus* results are shown in black while *M. capensis* results are in red for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).

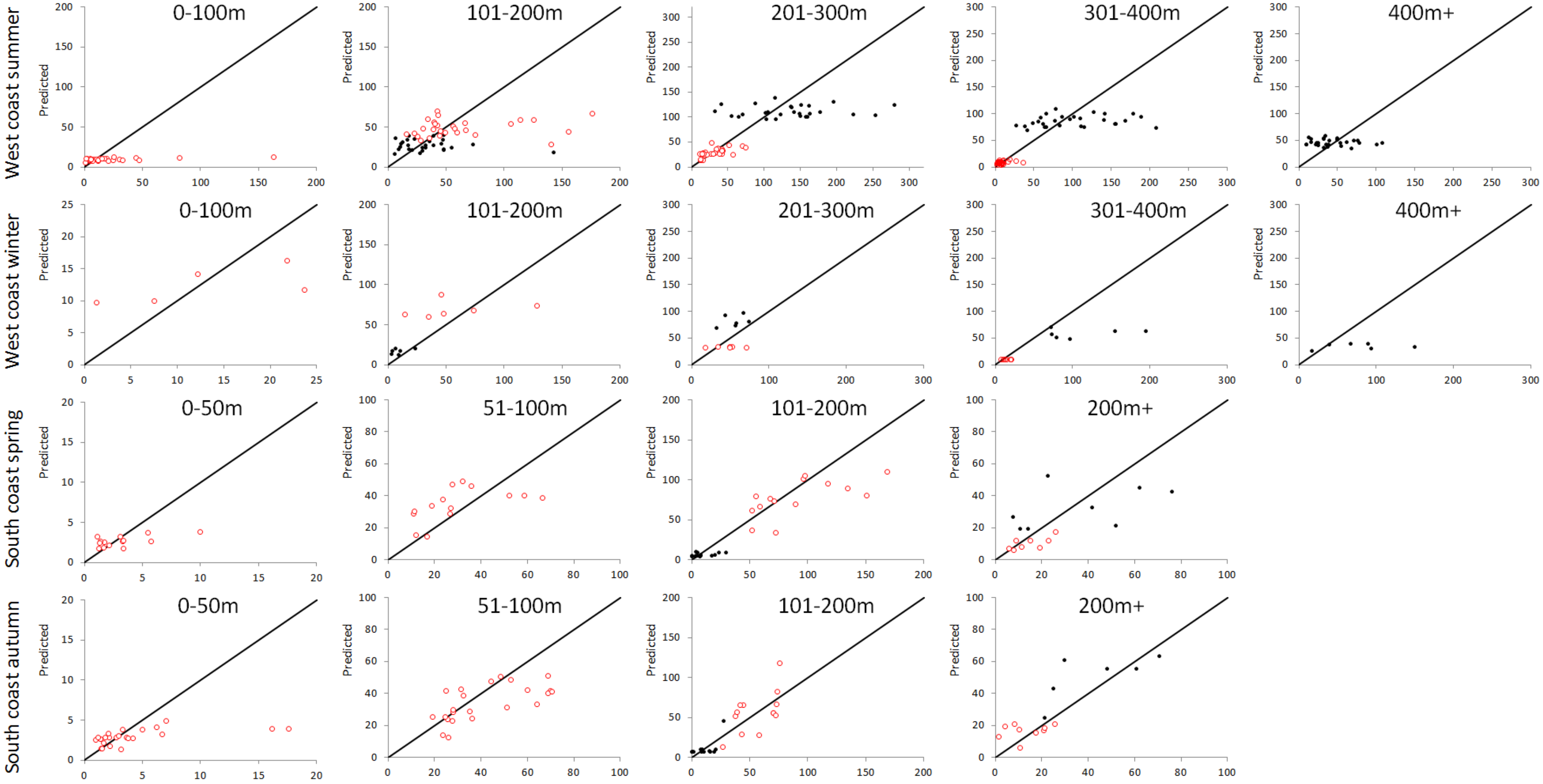
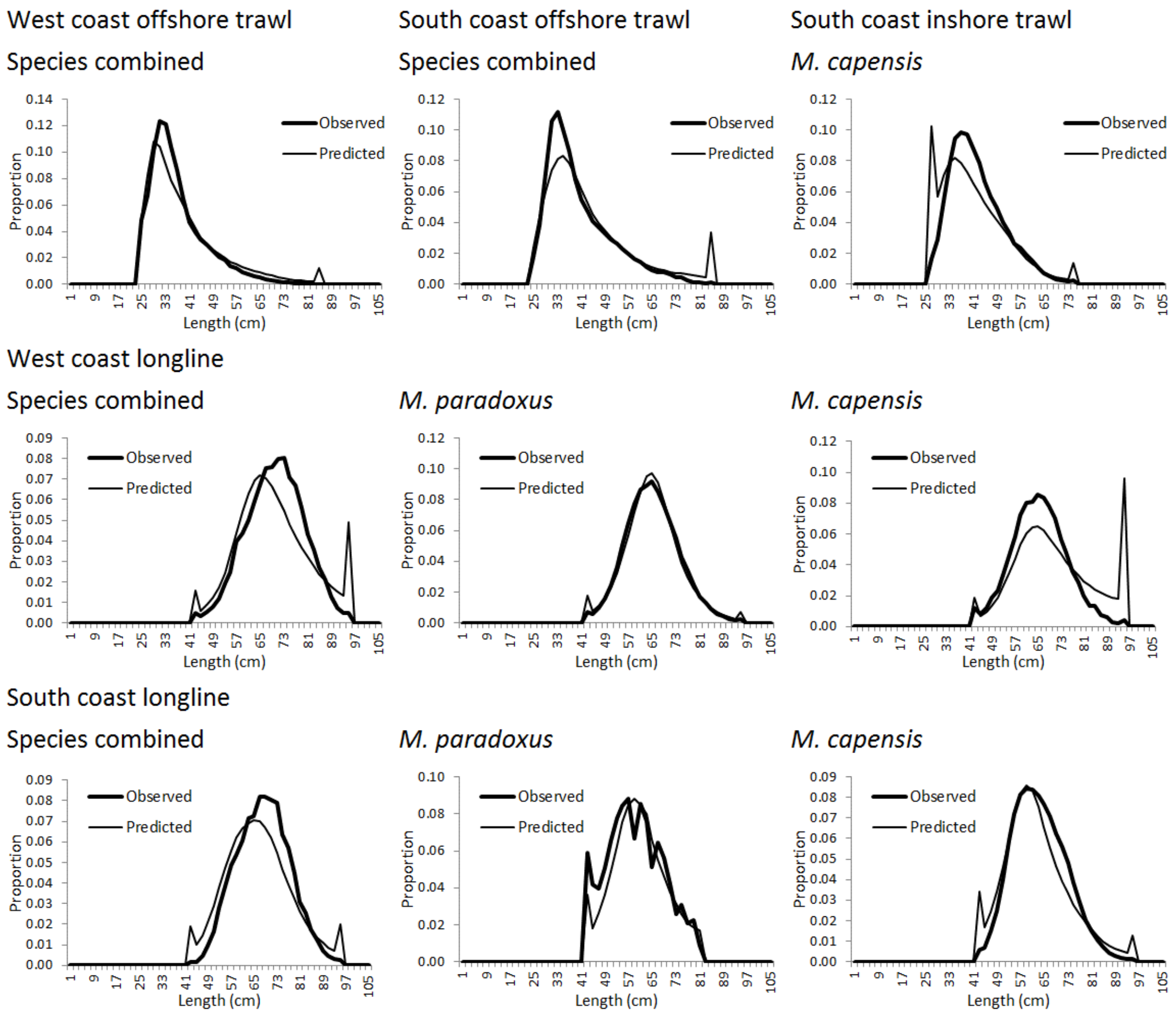


Figure 2C6b: Observed *vs* predicted surveys by region (*M. paradoxus* in black, *M. capensis* in red) for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).



West coast offshore trawl

Species combined

South coast offshore trawl

Species combined

South coast inshore trawl

M. capensis

West coast longline

Species combined

M. paradoxus

M. capensis

South coast longline

Species combined

M. paradoxus

M. capensis

Figure 2C7: Fits to the commercial catch-at-length data, averaged over all the years for which data are available for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).

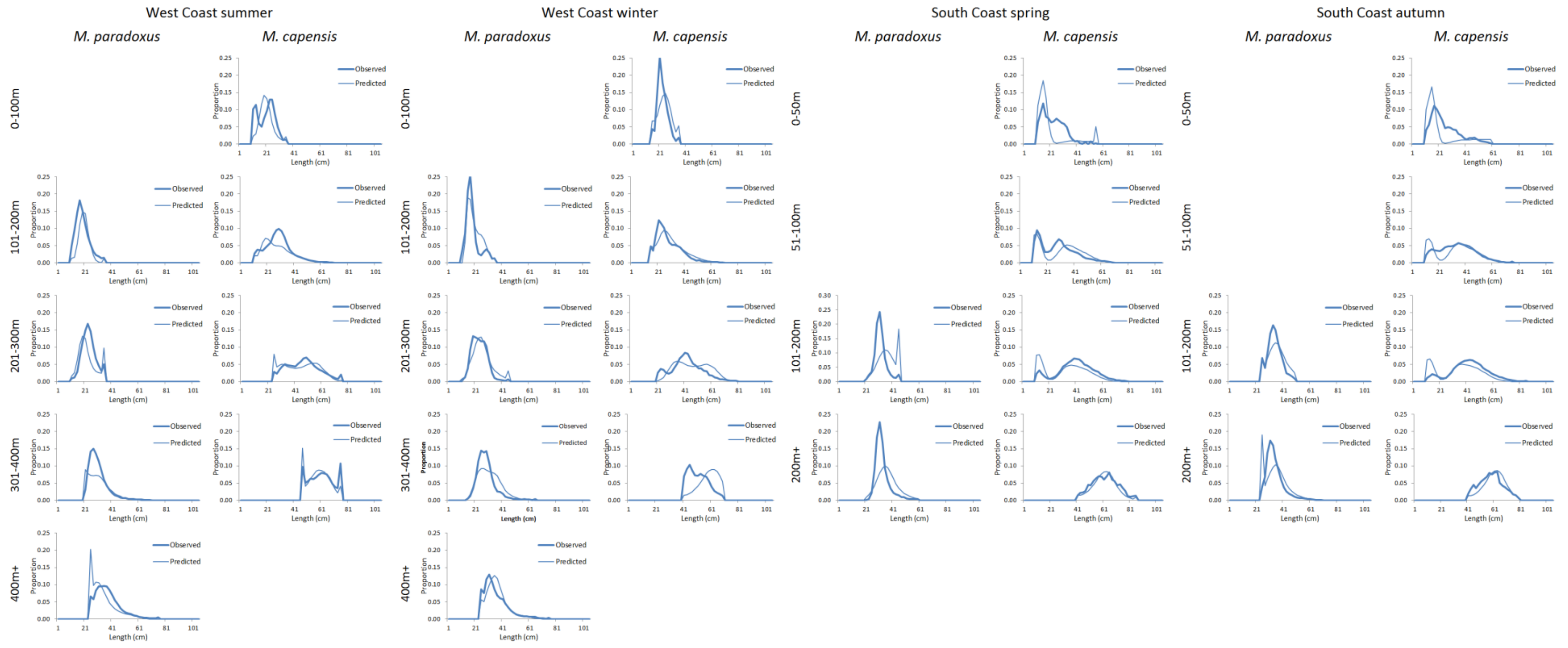


Figure 2C8: Fits to the survey region specific catch-at-length data, as averaged over all the years for which data are available for the **Model C** (fitting to the GeoPop outputs, downweighting survey spatial information).