Further results for the sex- and area-specific Age-Structured Production model for the South Coast rock lobster resource

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Background and Summary

This document provides an update on the development of sex- and area-specific operating models for testing candidate OMPs for the South Coast rock lobster resource. Models are needed which can provide reasonable fits to both the CPUE and catch-at-length data available. Generally this has required the introduction of either time-varying selectivity or effort saturation effects. For the former, two approaches have been suggested: "MARAM" and "OLRAC". This document presents improved results for the MARAM approach through use of a more complex selectivity function for Area 3 (Model 2), and also implements a version of the "OLRAC" approach (Model 3e). Implementations involving effort saturation are underway.

Introduction

Results presented here rely on the model specifications as described in WG/02/08/SCRL1, with certain modifications which are specified here.

Results are presented in detail for the following models:

- **Model 1**: time varying selectivity – MARAM method – Area 3 has 1 selectivity functional form
- **Model 2**: time varying selectivity – MARAM method – Area 3 has 2 selectivity functional forms
- **Model 3**: time varying selectivity – OLRAC method – Area 3 has 2 selectivity functional forms
- Results for **Model 4**: effort saturation have yet to be developed.

Data

The following input data are used in all models presented here:

1. Commercial catch data for each Area – reported in Glazer (2008a).
2. CPUE series for each Area from GLM analyses reported in Glazer (2008b).
3. Catch-at-length data for each Area and both sexes as reported in Glazer (2008c).

Model descriptions

Model 1: Time varying selectivity-at-length function – MARAM method – Area 3 has 1 selectivity functional form as have Areas 1 and 2

The selectivity function (which depends on length) is allowed to vary over the time period for which catch-at-age data are available (1994-2005). To effect this, the form of the selectivity function is generalised to:

$$S_{y,l}^{m/f,A} = \frac{1}{1+e^{-\ln 19(l-(l_{50}^{m/f,A}+\delta_y^{m/f,A}))/\Delta^{m/f,A}}} \qquad (1)$$

The estimable parameters are thus:

- $l_{50}^{m/f,A}$ (the expected length at 50% selectivity, when $\delta_y^{m/f,A}$ = 0), and
- $\Delta^{m/f,A}$ and for y = 1994-2005 (excluding 1999 as there are no catch-at-age data for 1999).

Note:

- the expected length at 95% selectivity ($l_{95}^{m/f,A}$, when $\delta_y^{m/f,A}$ = 0) is given by $l_{50}^{m/f,A} + \Delta^{m/f,A}$,
- $\delta_y^{m/f,A}$ for 1999 is calculated as the average of the $\delta_y^{m/f,A}$ values for 1998 and 2000, and
- $\delta_y^{m/f,A}$ for pre-1994 and 2006+ = 0.

An extra term is added to the likelihood function in order to smooth the extent of change in the selectivity, as follows:

$$-\ln L \rightarrow -\ln L + \sum_{m/f}\sum_{A}\sum_{y=1994}^{y=2005}\left(\frac{\delta_y^{m/f,A}}{\sigma_{sel}}\right)^2 \text{ (sum excludes 1999)} \qquad (2)$$

where the σ_{sel} is input (a value of 0.75 was found to provide reasonable performance).

An issue to be taken into account is that for equation (1), if $\delta_y^{m/f,A}$ decreases, this means that selectivity is increasing on younger lobsters; however given that the model fitting procedure assumes that:

$$C\hat{P}UE_y = q\sum_l w_l S_{l,a} N_{l,a} e^{-M/2} \qquad (3)$$

this situation seems implausible, in that an enhanced CPUE would result even if there was not any increase in abundance.

Presumably enhanced catches of younger animals are achieved by spatially redistributing effort on a scale finer than captured by the GLM standardisation of the CPUE. A standard method to adjust for this, while maintaining a constant catchability coefficient q, is to renormalise the selectivity function in some way:

$$S_{y,l}^{m/f,A} \rightarrow S_{y,l}^{*,m/f,A} = S_{y,l}^{m/f,A} / X_y^{m/f,A} \qquad (4)$$

where here as a simple initial approach we have chosen:

$$X_y^{m/f,A} = \sum_{l_1^{m/f,A}}^{l_2^{m/f,A}} \frac{S_{y,l}^{m/f,A}}{l_2^{m/f,A} - l_1^{m/f,A} + 1} \qquad (5)$$

i.e., normalising selectivity by its average over a certain length range, so that now if $\delta_y^{m/f,A}$ decreases, the $S_{y,l}^{*,m/f,A}$ will decrease for large *l* to compensate for the effort spread to locations where younger animals are found associated with the increase for smaller *l*.

The authors have fixed the values of $l_1^{m/f,A}$ and $l_2^{m/f,A}$ at the following values after examining the length frequency distributions, to ensure that the ranges associated with these *l* values cover the greater part of these distributions.

m/f	*A*	$l_1^{m/f,A}$	$l_2^{m/f,A}$
m	**1**	65mm	90mm
f	**1**	65mm	90mm
m	**2**	65mm	90mm
f	**2**	65mm	90mm
m	**3**	55mm	90mm
f	**3**	55mm	90mm

Model 2: Equivalent to Model 1 except allows for 2 alternate selectivity functional forms for Area 3.

Results of Model 1 show a relatively poor fit to Area 3 catch-at-length (CAL) data – see Figure 1. Examining the fits on a year-by-year basis, there appear to be many years for which a very large peak in CAL catch distribution was observed for smaller lobsters. The authors thus explored allowing a combination of two selectivity functional forms to be estimated for Area 3, and to allow the estimation process to determine their relative proportions which fitted the CAL data best. It was originally hoped that there would be a clear relationship between the proportion of lobsters caught in Area 3 during the Jan/Mar period (when recruits dominate), and the length corresponding to the "peak" proportion caught in the CAL distribution. Figures 2a and b show the plots of such data (for males a females separately), and it is clear the there is no clear relationship between the proportion caught in Jan/Mar and the "peak" length in the CAL distribution. It was thus decided that a year-independent second selectivity function, with the shape of a normal distribution would be modeled as the "second" selectivity function for Area 3.

Thus the selectivity for Area 3 is defined as follows:

$$S_{y,l}^{m/f,3} = (1-\lambda) S1_{y,l}^{m/f,3} + \lambda S2_l^{m/f,3} \qquad (6)$$

where

$S1_{y,l}^{m/f,3}$ is the original selectivity function (as used for other Areas)

$S2_l^{m/f,3} = e^{-\left(l-l_{m/f}^*\right)^2/\omega^2}$ (the second normal-shaped selectivity function)

(7)

Note that we now estimate the following further parameters: l_m^*, l_f^*, ω and λ.

This formulation is thus time-invariant (λ constant over time), but allows for a different male and female $S2$ selectivity function to be estimated for Area 3.

Model 3: Time varying selectivity-at-length function – OLRAC method – Area 3 has 2 selectivity functional forms

The time-varying selectivity function is as follows:

$$\bar{S}_l^{m/f,A} = \frac{1}{1+e^{-\ln 19(l-l_{50}^{m/f,A})/\Delta^{m/f,A}}} \tag{8}$$

$$S_{y,l}^{m/f,A} = \bar{S}_l^{m/f,A}\alpha_{y,l}^{m/f,A} \tag{9}$$

where

$$\alpha_{y,l}^{m/f,A} = \frac{x_y^{m/f,A}}{X_y^{m/f,A}} \qquad l \le 50 \tag{10}$$

$$\alpha_{y,l}^{m/f,A} = \frac{x_y^{m/f,A} + (l-50)(1-x_y^{m/f,A})/(l_{kink}-50)}{X_y^{m/f,A}} \qquad 50 \le l \le l_{kink} \tag{11}$$

$$\alpha_{y,l}^{m/f,A} = \frac{1}{X_y^{m/f,A}} \qquad l > l_{kink} \tag{12}$$

and where

$$X_y^{m/f,A} = \left\{\sum_{l=l1}^{50} x_y^{m/f,A} + \sum_{l=51}^{l_{kink}}\left[x_y^{m/f,A} + \frac{(l-50)(1-x_y^{m/f,A})}{l_{kink}-51}\right] + \sum_{l=l_{kink}}^{l2} l\right\}/(l2-l1+1) \tag{13}$$

The estimable parameters are thus: $l_{50}^{m/f,A}$, $\Delta^{m/f,A}$, and $x_y^{m/f,A}$ for y=1973-2005 where $x_y^{m/f,A} \ge 0$. It is assumed that for 2006+ the average of the 1973-2005 $x_y^{m/f,A}$ values applies.

Model 3 also allows for a second selectivity function for Area 3 to be estimated – as described for Model 2 above.

An extra term is added to the likelihood function in order to smooth the extent of change in the selectivity with time, as follows:

$$-\ln L \to -\ln L + w_{pen}\sum_{m/f}\sum_{A}\sum_{y=1973}^{2005}(x_y^{m/f,A} - x_{y+1}^{m/f,A})^2 \tag{14}$$

A number of fixed values of $l1$, $l2$ and l_{kink} were tested (see Table 1). The selected values for Model 3 (variant 3e), corresponding to the best fit achieved to the data, are $l1 = 40$, $l2 = 140$ and $l_{kink} = 80$. A selectivity penalty weighting value of $w_{pen} = 5$ was also selected, for reasonable estimation performance.

Results and Discussion

Tables 2-7: report the results for the following models:
Table 2: Model 1 (time varying selectivity MARAM method – one selectivity functional form for Area 3),
Table 3: Model 2 (time varying selectivity MARAM method – two selectivity functional forms for Area 3)
Table 4: Model 3 (time varying selectivity OLRAC method)
Table 5: provides comparisons between these various models for quantities of key interest.

Most of the graphical results produced in this document are for **Model 2**. Figure 4a shows the model estimated stock-recruit residuals, Figure 4b shows the selectivity functions estimated for 1973, Figure 4c shows the estimated time-varying areal-proportions of global recruitment for each Area, Figure 4d shows the estimated time-varying selectivity $\delta_y^{m/f,A}$ for each Area and sex, and Figure 4e shows the selectivity functions S1 and S2 estimated for Area 3.

Figure 5 shows the Model 2 fits to the observed CPUE trends for each Area. Figure 6 shows the Model 2 fits to the CAL data for male and female lobsters from each Area. Results here have been averaged over the data-fitting period.

Figure 7a shows the Model 2 estimated female spawning biomass trend, and Figure 7b shows the exploitable (m+f) biomass trends for each Area.

Figure 8 shows the Model 2 estimated fishing proportions for each Area.

Figures 9 and 10 correspond to Model 3e variant of the OLRAC approach for time-varying selectivity, showing fits to the observed CPUE and the CAL data respectively.

Projections
Each model is projected ahead under the current catch allocation, i.e.173 MT for Area 1, 134 MT for Area 2 and 74 MT for Area 3.

Other assumption regarding future projections are:

<u>Stock-recruit residuals</u>
For all models it is assumed that for 1998+ the stock-recruit residuals are zero.

<u>Total recruitment proportional split per Area</u>
It is assumed that for 2001+, the average of the estimated proportions (for the 1973-2000 period) apply.

<u>Selectivity</u>
Model 1 and 2 (time varying selectivity MARAM method) – it is assumed that for 2006+ $\delta_y^{m/f,A}=0$.

Model 3 (time-varying selectivity OLRAC method) - it is assumed that for 2006+ the average of the 1973-2005 $x_y^{m/f,A}$ values applies.

References

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Glazer, J. 2008a. South Coast rock lobster catches per area. MCM document, WG/03/08/SCL?.

Glazer, J. 2008b. South Coast rock lobster CPUE . MCM document, WG/03/08/SCL?.

Glazer, J. 2008c. Size composition of male and female South Coast rock lobster per season and area. MCM document, WG/03/08/SCL?.

Groeneveld, J.C., Glazer, J.P. and D.S. Butterworth. 1999. South Coast rock lobster effort experiment measures of effort and modeling of experimental CPUE. MCM document, WG/07/99/SCL16.

Table 1: Model 3 results for alternate values of $l1, l2$ and l_{kink} (see Figure 3 for diagram).

	3a	**3b**	**3c**	**3d**	**3e**
$l1$	40	40	40	40	40
$l2$	100	100	100	**120**	**140**
l_{kink}	70	**80**	**90**	80	80
Selectivity penalty multiplier w_{pen}	5	5	5	5	5
-lnL CPUE total	-169.36	-156.78	-124.27	-109.39	-89.72
-lnL CPUE Area 1	-113.05	-98.07	-62.86	-56.38	-43.57
-lnL CPUE Area 2	-32.96	-33.29	-37.94	-31.14	-31.70
-lnL CPUE Area 3	-23.35	-25.41	-23.47	-21.87	-14.45
σ CPUE Area 1	0.012	0.021	0.069	0.089	0.135
σ CPUE Area 2	0.195	0.192	0.164	0.207	0.203
σ CPUE Area 3	0.271	0.252	0.270	0.285	0.368
-lnL CAL total	-457.76	-526.57	-488.68	-584.86	-614.04
SR pen	2.30	6.38	3.17	5.29	4.35
Selectivity penalty	9.92	11.13	5.99	7.04	7.90
-lnL Total	**-562.96**	**-608.27**	**-563.23**	**-636.55**	**-639.73**
-lnL (CPUE+CAL+SR)	-624.82	-676.96	-609.78	-688.96	-699.41

Table 2: Model 1 (time varying selectivity MARAM method – one selectivity functional form for Area 3) estimated parameters and quantities of management interest. Biomass quantities are in MT.

Parameter/quantity	**Global**	**Area 1**	**Area 2**	**Area 3**
Total number of estimable parameters	202			
K^{sp} total female spawning biomass	889			
h S/R steepness parameter	0.809			
λ^A proportion R to Area A		0.38	0.38	0.24
μ^A rel. female scaling parameter for Area A		1.22	1.23	1.28
$l_{50}^{m,A}$ length at 50% selectivity for male lobsters in Area A (mm)		69.29	63.82	56.90
$l_{95}^{m,A}$ length at 95% selectivity for male lobsters in Area A (mm)		79.02	70.43	61.83
$l_{50}^{f,A}$ length at 50% selectivity for female lobsters in Area A (mm)		66.83	63.10	56.32
$l_{95}^{f,A}$ length at 95% selectivity for male lobsters in Area A (mm)		73.79	70.52	60.10
β^* growth function parameter	0.130			
$L_\infty^{m,A}$ L_∞ for male lobsters in Area A (mm)		104.01	107.03	113.67
$L_\infty^{f,A}$ L_∞ for female lobsters in Area A (mm)		99.63	100.31	112.29
κ growth curve parameter (yr^{-1})	0.079			
t_0 growth curve parameter (yr^{-1})	-1.93			
-ln L (CPUE)	-82.40	-38.41	-22.46	-21.53
CPUE σ		0.161	0.280	0.289
-ln L (CAL)	-428.3	-179.33	-132.13	-116.84
CAL σ		0.063	0.090	0.086
SR residual penalty (Eqn 37)	8.56			
Time varying selectivity penalty (Eqn 39)	7.89			
Growth parameters penalty (Eqn 36)	6.78			
Time varying recruitment penalty (Eqn 38)	8.72			
Total –ln$L$ value	-478.35			
B_{06}^{sp} / K^{sp}	0.44			
$B_{06}^{\exp,A} / K_{1973}^{\exp,A}$	0.37	0.34	0.29	0.49
$B_{06}^{\exp,A}$	717	185	227	304
$B_{2015}^{\exp,A} / B_{2006}^{\exp,A}$ *	0.35	0.26	0.2	0.56

* The basis for this projection under a total future annual catch of 381 tons is detailed in the text.

Table 3: Model 2 (time varying selectivity MARAM method – a combination of **two** selectivity functional forms for Area 3) estimated parameters and quantities of management interest. Biomass quantities are in MT.

Parameter/quantity		**Global**	**Area 1**	**Area 2**	**Area 3**
Total number of estimable parameters		206			
K^{sp}	total female spawning biomass	807			
h	S/R steepness parameter	0.683			
λ^A	proportion R to Area A		0.38	0.40	0.22
μ^A	rel. female scaling parameter for Area A		1.25	1.26	1.16
$l_{50}^{m,A}$	length at 50% selectivity for male lobsters in Area A (mm)		67.87	63.18	59.02
$l_{95}^{m,A}$	length at 95% selectivity for male lobsters in Area A (mm)		77.27	69.23	59.02
$l_{50}^{f,A}$	length at 50% selectivity for female lobsters in Area A (mm)		65.80	62.49	60.00
$l_{95}^{f,A}$	length at 95% selectivity for male lobsters in Area A (mm)		72.42	69.53	60.00
β^*	growth function parameter	0.105			
$L_\infty^{m,A}$	L_∞ for male lobsters in Area A (mm)		105.00	107.05	111.87
$L_\infty^{f,A}$	L_∞ for female lobsters in Area A (mm)		101.15	100.77	110.02
κ	growth curve parameter (yr^{-1})	0.089			
t_0	growth curve parameter (yr^{-1})	-1.96			
l_m^*		63.29			
l_f^*		61.94			
ϖ		7.07			
λ		0.76			
-ln L (CPUE)		-81.72	-35.93	-22.41	-23.38
CPUE σ			0.173	0.280	0.271
-ln L (CAL)		-516.68	-187.42	-129.35	-200.00
CAL σ			0.061	0.092	0.062
SR residual penalty (Eqn 37)		7.83			
Time varying selectivity penalty (Eqn 39)		4.33			
Growth parameters penalty (Eqn 36)		2.55			
Time varying recruitment penalty (Eqn 38)		17.90			
Total –ln$L$ value		-564.37			
B_{06}^{sp}/K^{sp}		0.35			
$B_{06}^{\exp,A}/K_{1973}^{\exp,A}$		0.30	0.32	0.28	0.30
$B_{06}^{\exp,A}$		521	179	195	147
$B_{2015}^{\exp,A}/B_{2006}^{\exp,A}$ *		0.27	0.25	0.25	0.33

* The basis for this projection under a total future annual catch of 381 tons is detailed in the text.

Table 4: Model 3 (time varying selectivity OLRAC method – variant 3e) estimated parameters and quantities of management interest. Biomass quantities are in MT.

Parameter/quantity	**Global**	**Area 1**	**Area 2**	**Area 3**
Total number of estimable parameters	332			
K^{sp} total female spawning biomass	1072			
h S/R steepness parameter	0.790			
λ^A proportion R to Area A		0.31	0.30	0.39
μ^A rel. female scaling parameter for Area A		1.27	1.63	1.40
$l_{50}^{m,A}$ length at 50% selectivity for male lobsters in Area A (mm)		65.57	61.31	50.12
$l_{95}^{m,A}$ length at 95% selectivity for male lobsters in Area A (mm)		75.26	65.28	50.13
$l_{50}^{f,A}$ length at 50% selectivity for female lobsters in Area A (mm)		65.46	61.25	56.70
$l_{95}^{f,A}$ length at 95% selectivity for male lobsters in Area A (mm)		71.62	68.38	72.47
β^* growth function parameter	0.081			
$L_\infty^{m,A}$ L_∞ for male lobsters in Area A (mm)		104.51	106.73	111.32
$L_\infty^{f,A}$ L_∞ for female lobsters in Area A (mm)		98.42	100.76	108.58
κ growth curve parameter (yr^{-1})	0.081			
t_0 growth curve parameter (yr^{-1})	-1.94			
l_m^*	64.12			
l_f^*	62.12			
ϖ	6.29			
λ	0.87			
-ln L (CPUE)	-89.72	-43.57	-31.70	-14.45
CPUE σ		0.135	0.203	0.368
-ln L (CAL)	-614.04	-177.93	-153.82	-282.29
CAL σ		0.064	0.081	0.044
SR residual penalty (Eqn 37)	4.36			
Time varying selectivity penalty (Eqn 39)	7.90			
Growth parameters penalty (Eqn 36)	5.64			
Time varying recruitment penalty (Eqn 38)	13.62			
Total –ln$L$ value	-639.73			
B_{06}^{sp} / K^{sp}	0.48			
$B_{06}^{\exp,A} / K_{1973}^{\exp,A}$	0.35	0.34	0.30	0.46
$B_{06}^{\exp,A}$	572	197	222	153
$B_{2015}^{\exp,A} / B_{2006}^{\exp,A}$ *	0.38	0.23	0.45	0.49

* The basis for this projection under a total future annual catch of 381 tons is detailed in the text.

Table 5: Comparisons between Models 1-3 of key parameters and quantities.

Parameter/quantity	**Model 1**	**Model 2**	**Model 3**
	TVS-MARAM	Model 1 with 2 selectivity functions for Area 3	TVS- OLRAC with 2 selectivity functions for Area 3
K^{sp} (total female spawning biomass)	889	807	1072
h (S/R steepness parameter)	0.809	0.683	0.790
-ln L (CPUE)	-82.40	-81.72	-89.72
-ln L (CAL)	-428.3	-516.68	-614.04
Total –ln$L$ values	-478.35	-564.37	-639.73
# estimable parameters	202	206	332
B_{06}^{sp} / K^{sp}	0.44	0.35	0.48
$B_{06}^{\exp,A} / K_{1973}^{\exp,A}$	0.37	0.30	0.35
$B_{06}^{\exp,A}$	717	521	572
$B_{2015}^{\exp} / B_{2006}^{\exp}$	0.35	0.27	0.38

Figure 1: Model 1 CAL fits for each Area.

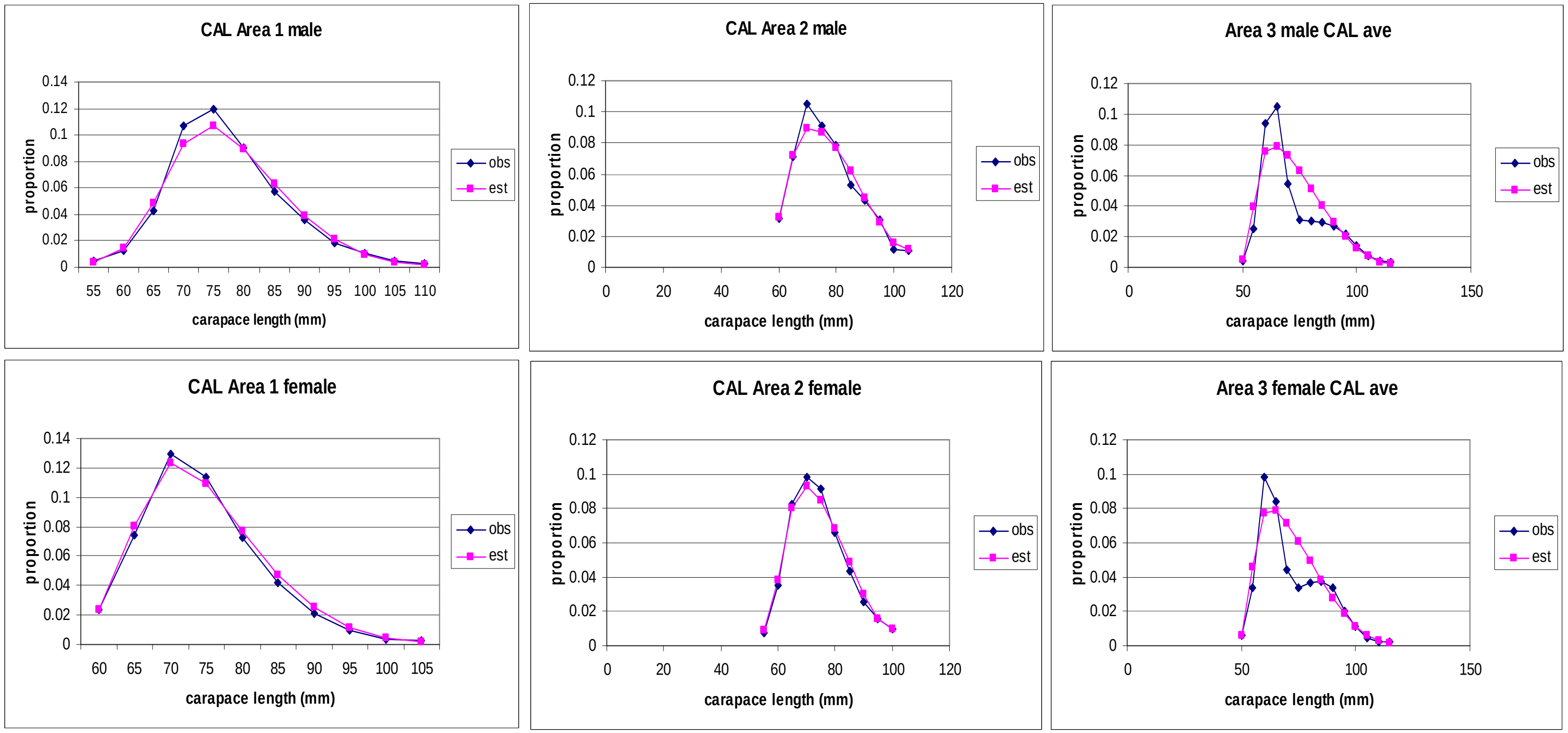


Figure 2a: Plot of the proportion of annual catch taken in the Jan/Mar period (horizontal-axis) against the length corresponding to the maximum proportion in the CAL distribution (vertical-axis) - Area 3 males.

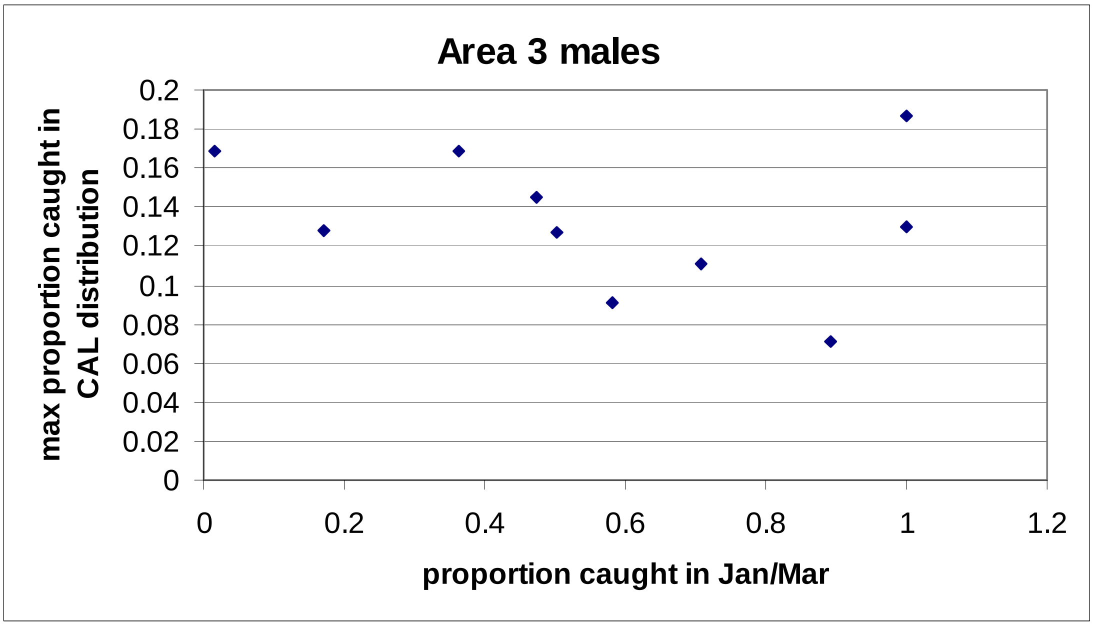


Figure 2b: Plot of the proportion of annual catch taken in the Jan/Mar period (horizontal-axis) against the length corresponding to the maximum proportion in the CAL distribution (vertical-axis) - Area 3 females.

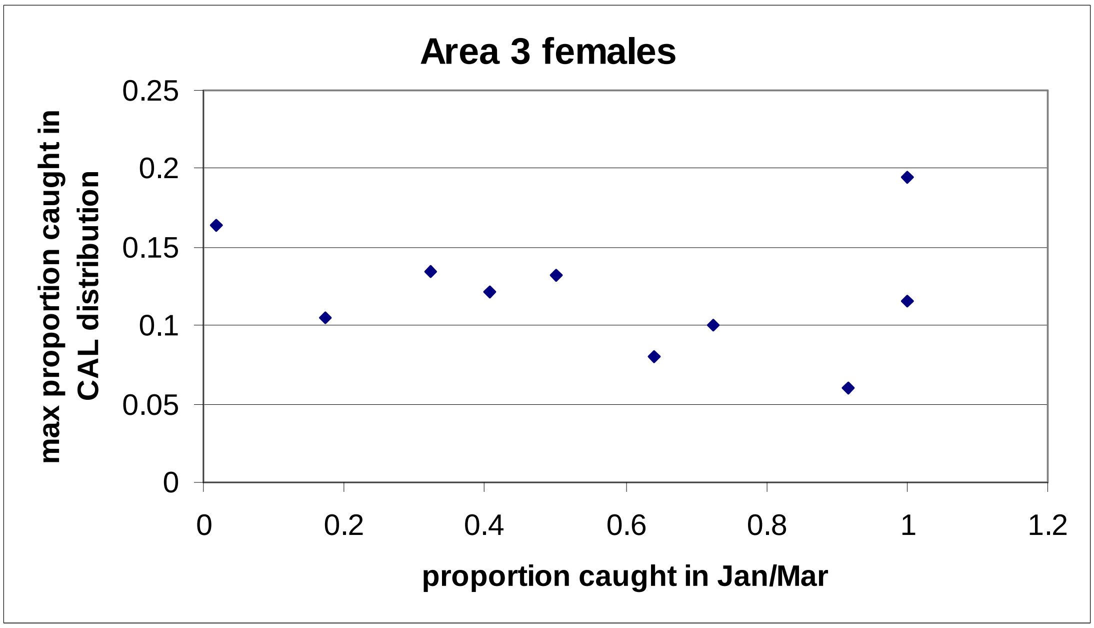


Figure 3: Model 3 shape of the $\alpha_{y,a}$ function; $x_y \geq 0$ is estimated for each year and can be either ≤ 1 or ≥ 1.

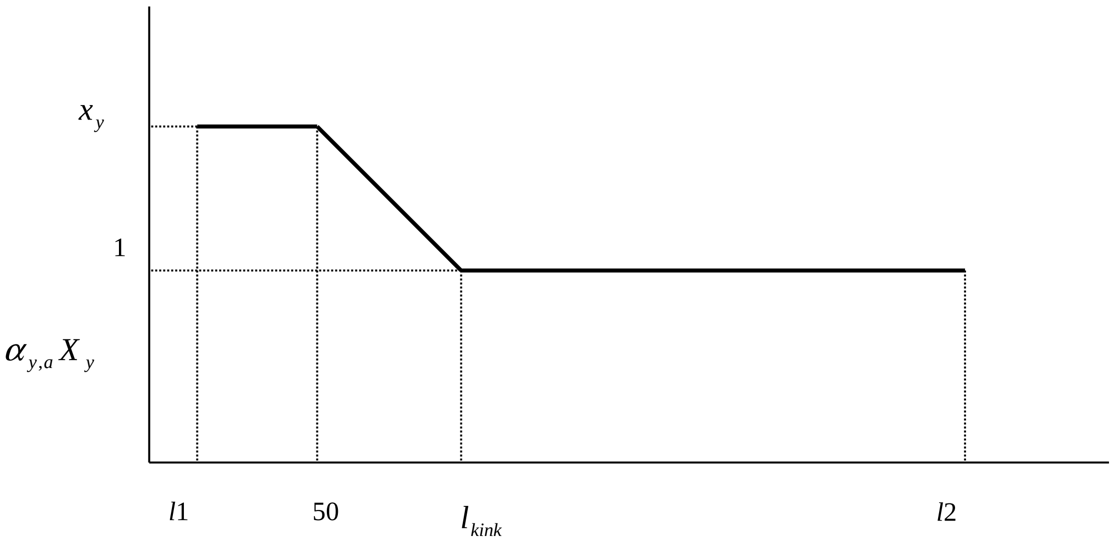


Figure 4a: Model 2 stock recruitment residuals.

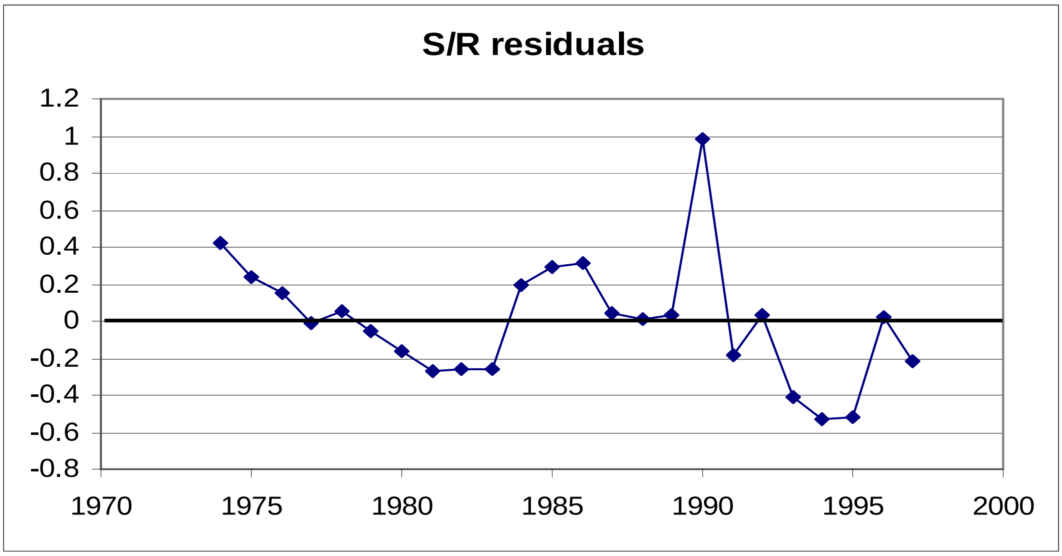


Figure 4b: Model 2 time-varying areal-proportions of global recruitment ($\lambda_y^{*,A}$). Values to the right of the vertical line are not estimated, but set equal to the 1973-2000 average.

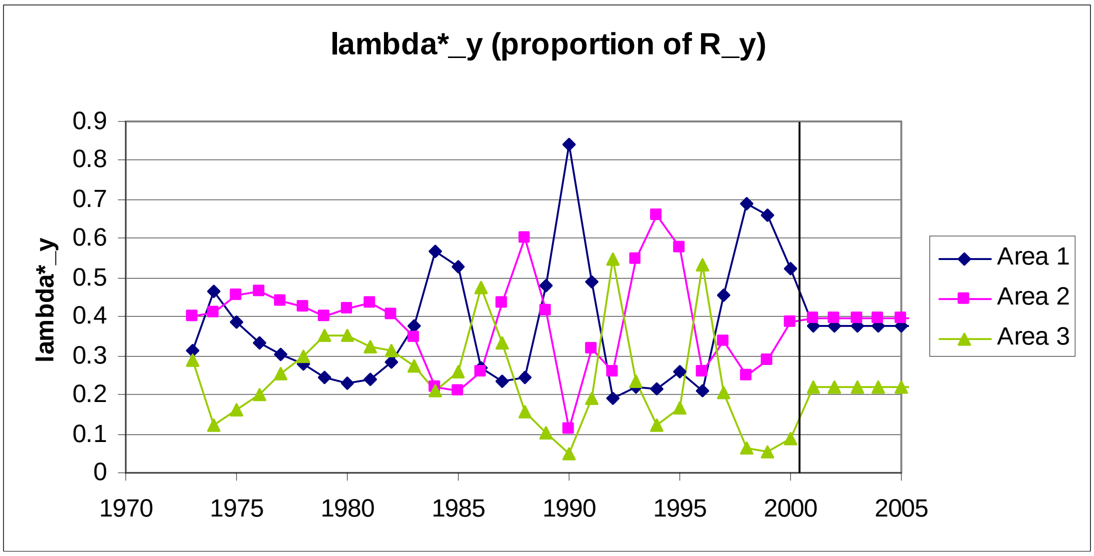


Figure 4c: Model 2 selectivity functions estimated for each Area for 1973.

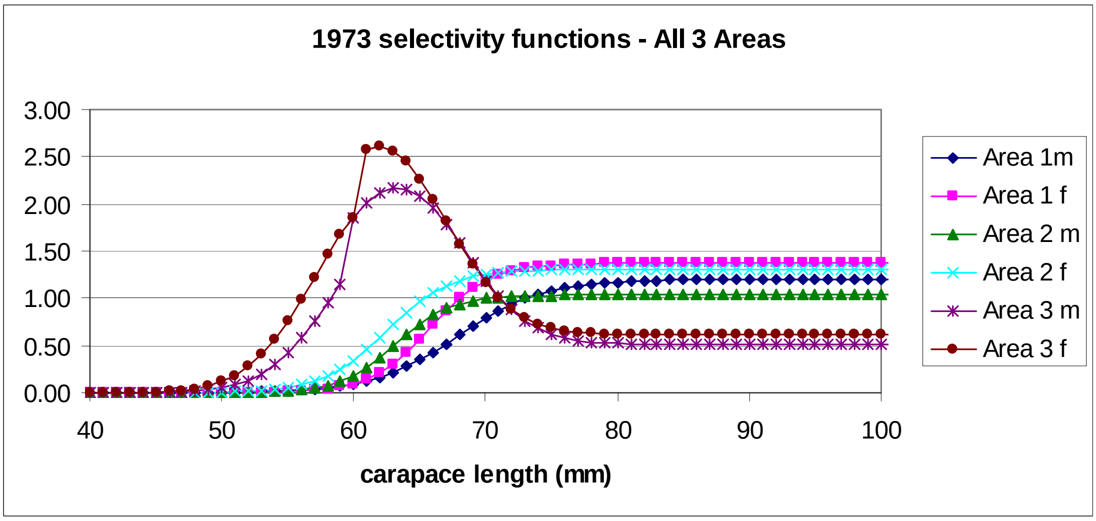


Figure 4d: Model 2 time varying selectivity $\delta_y^{m/f,A}$ values.

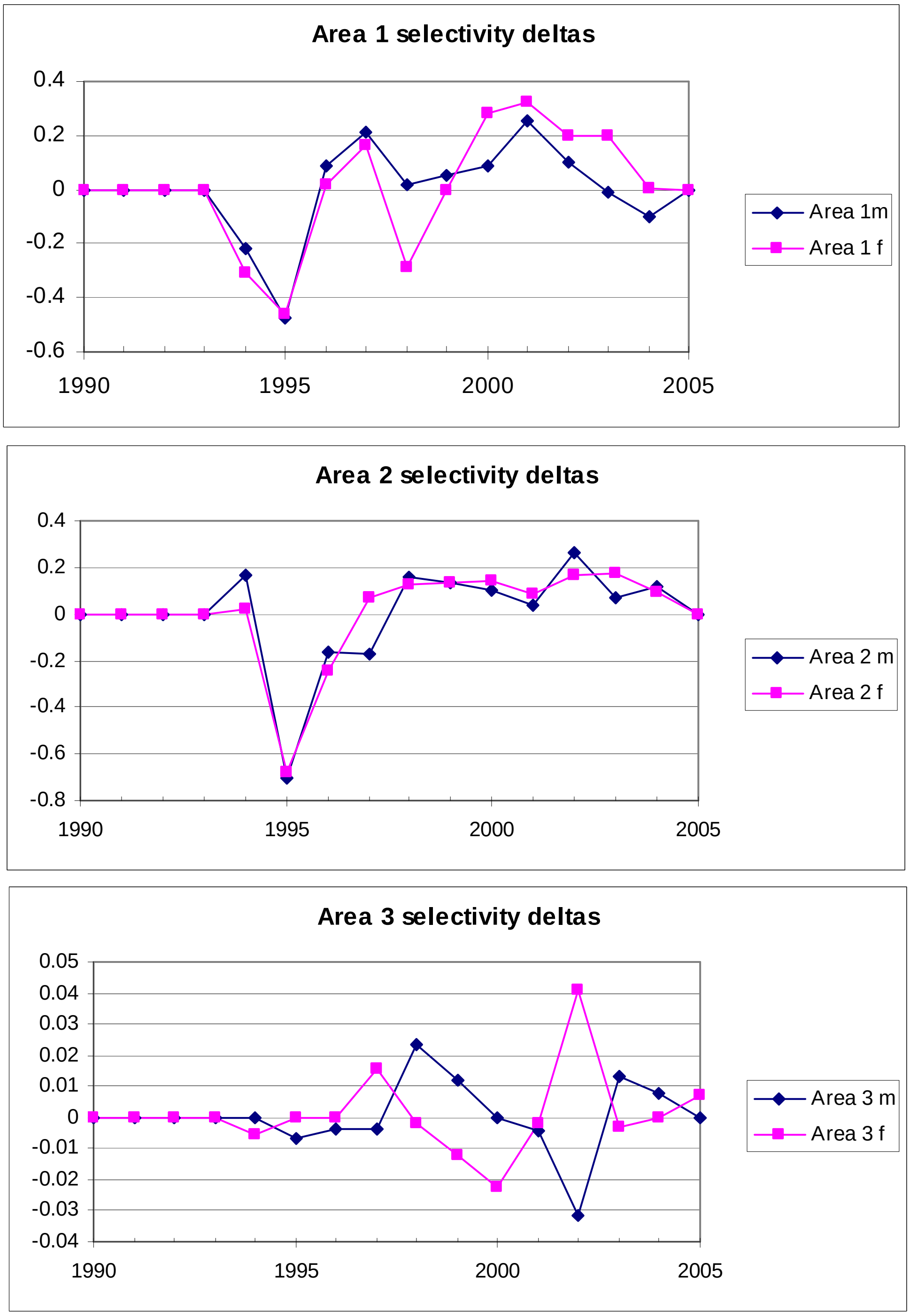
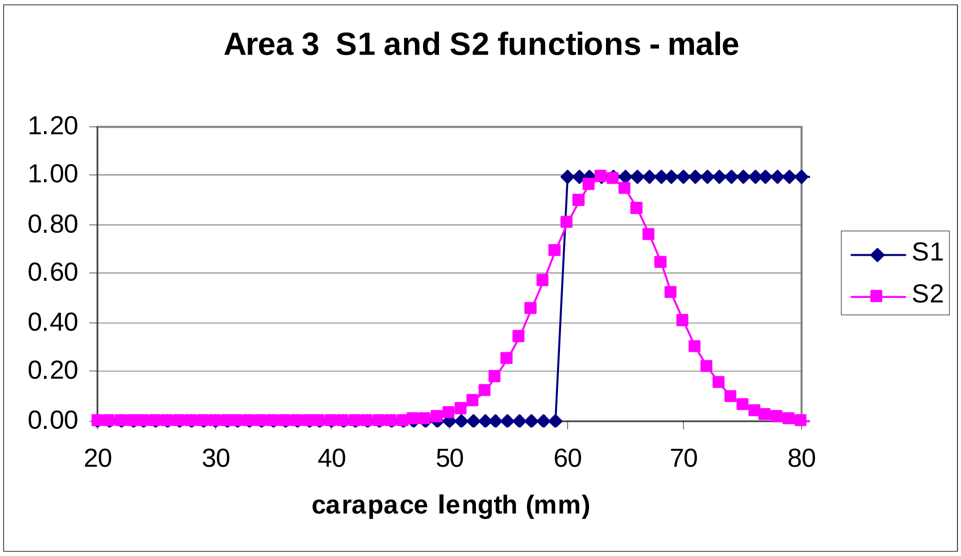


Figure 4e: Model 2 selectivity functions (S1 and S2) estimated for Area 3 – the S1 functions are for 1973.



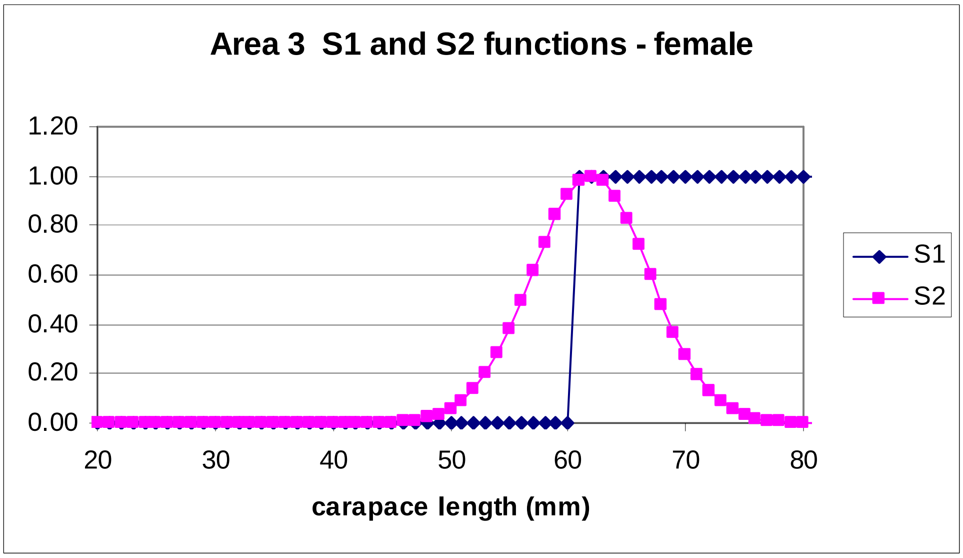


Figure 5: Model 2 fits to observed CPUE trends in each Area.

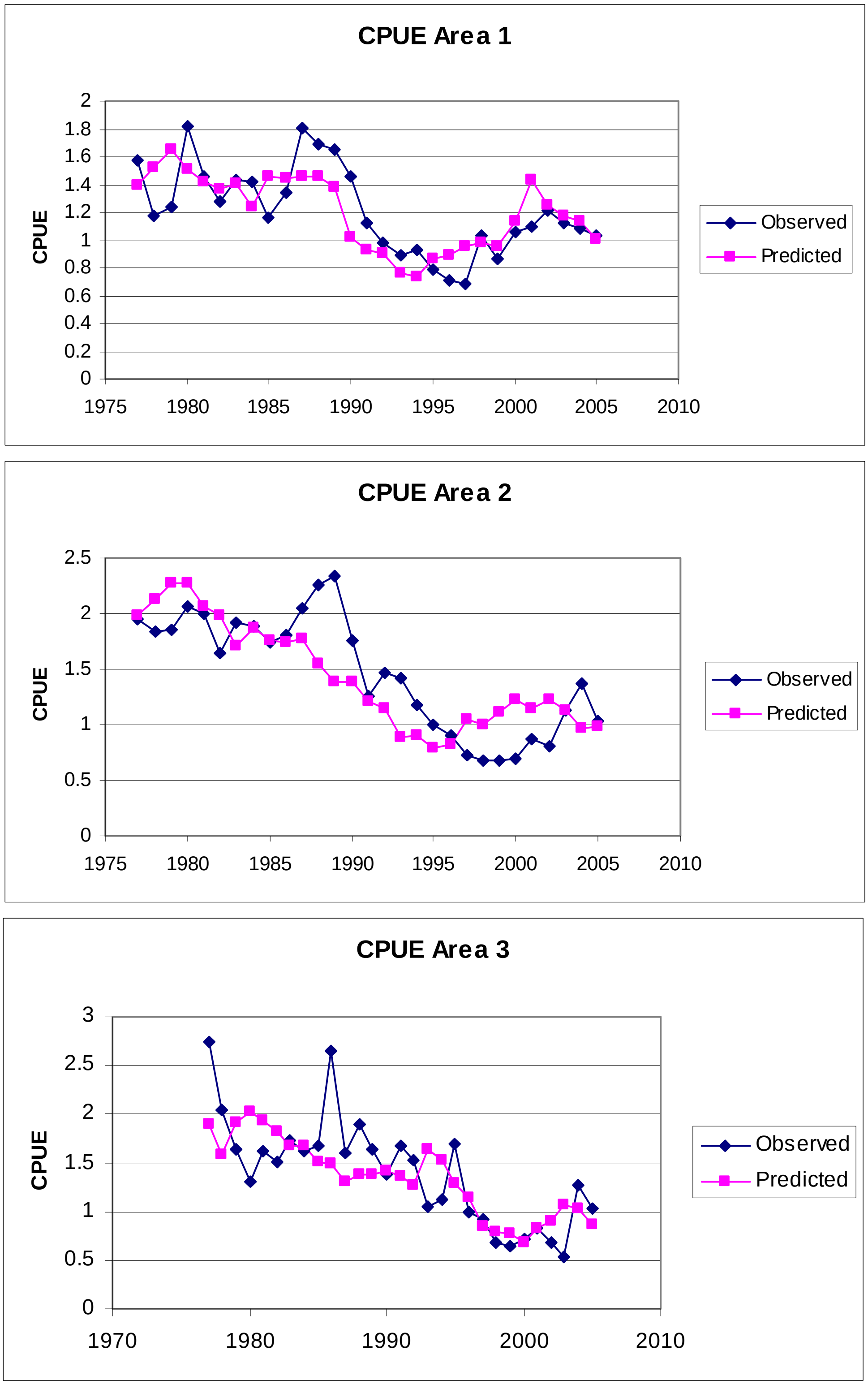


Figure 6: Model 2 fits to catch-at-length (CAL) data for male and female lobsters from Areas 1-3. Results have been averaged over the data-fitting period.

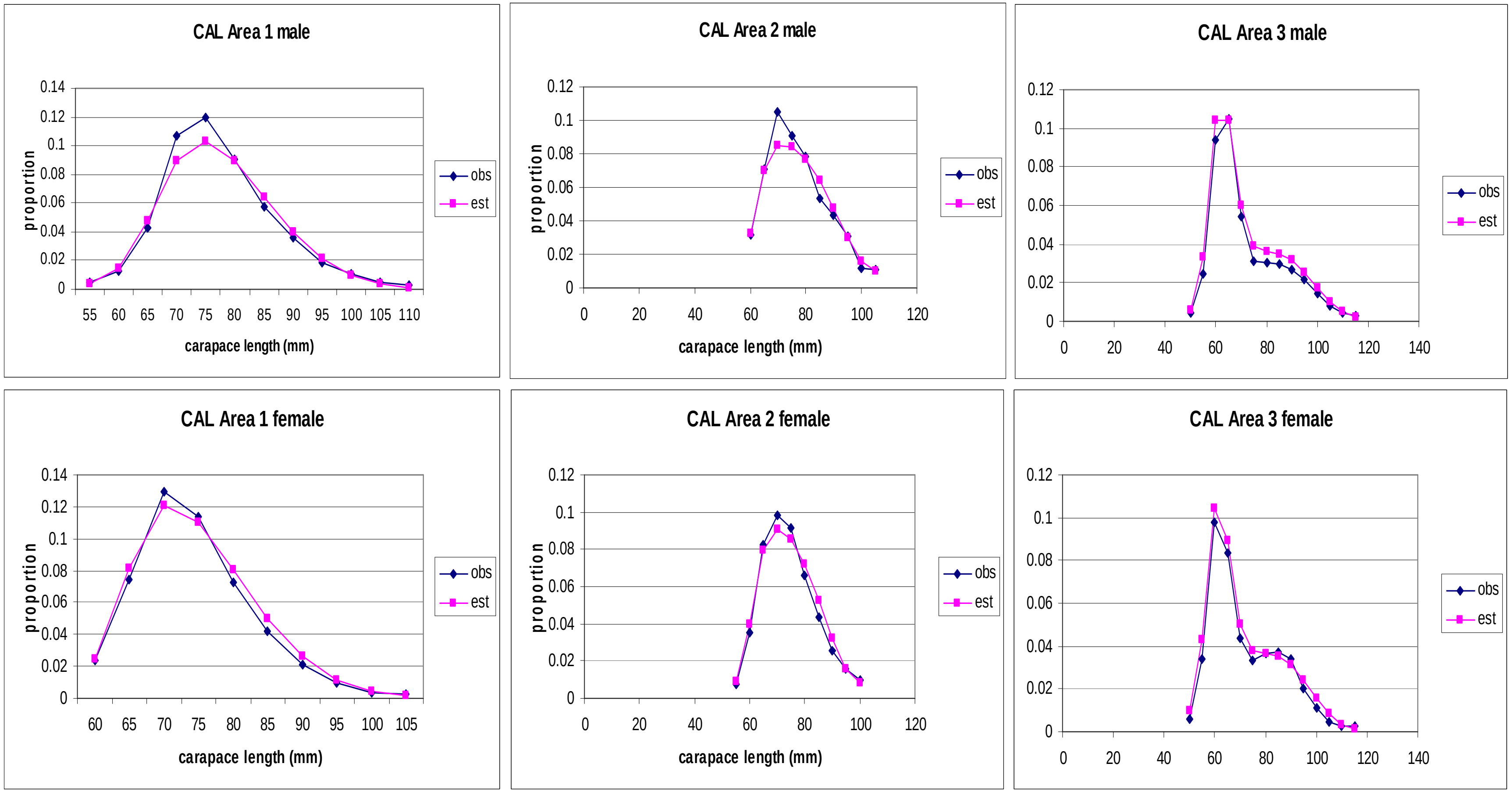


Figure 7a: Model 2 estimated female spawning biomass trend.

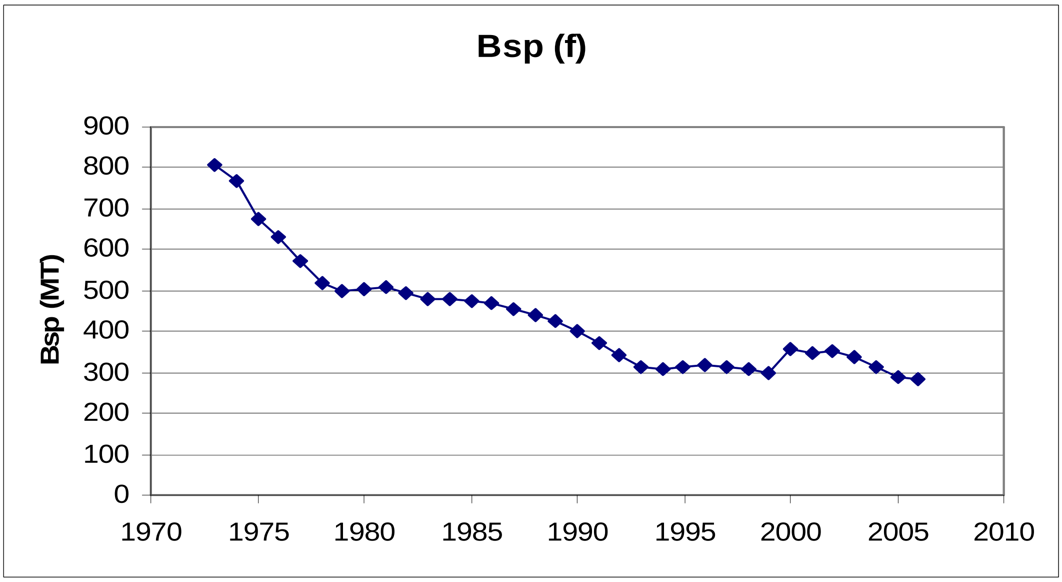


Figure 7b: Model 2 estimated exploitable (m+f) biomass trends for each Area.

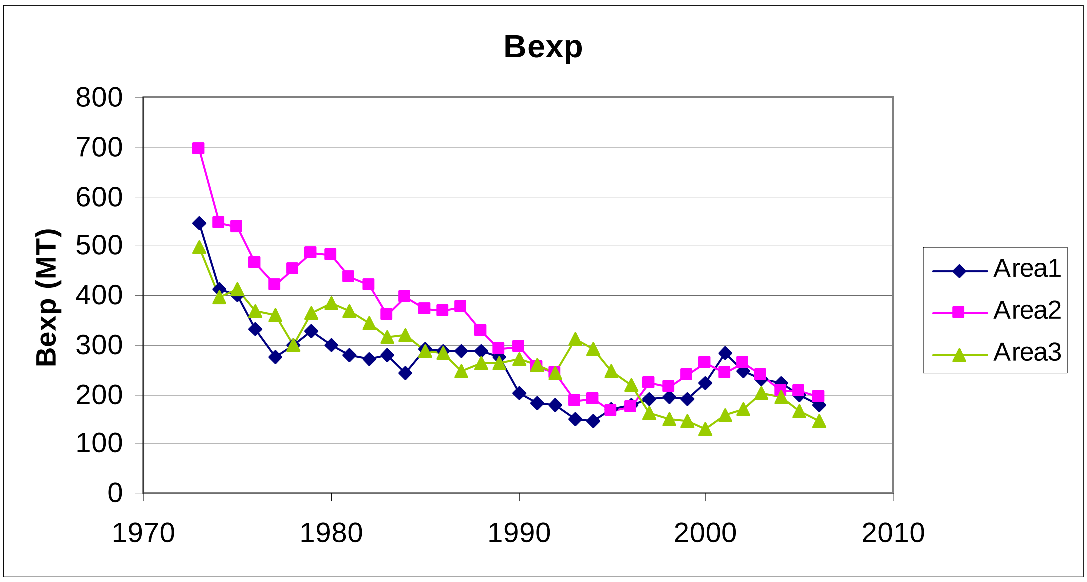


Figure 8: Model 2 estimated fishing proportions for each Area.

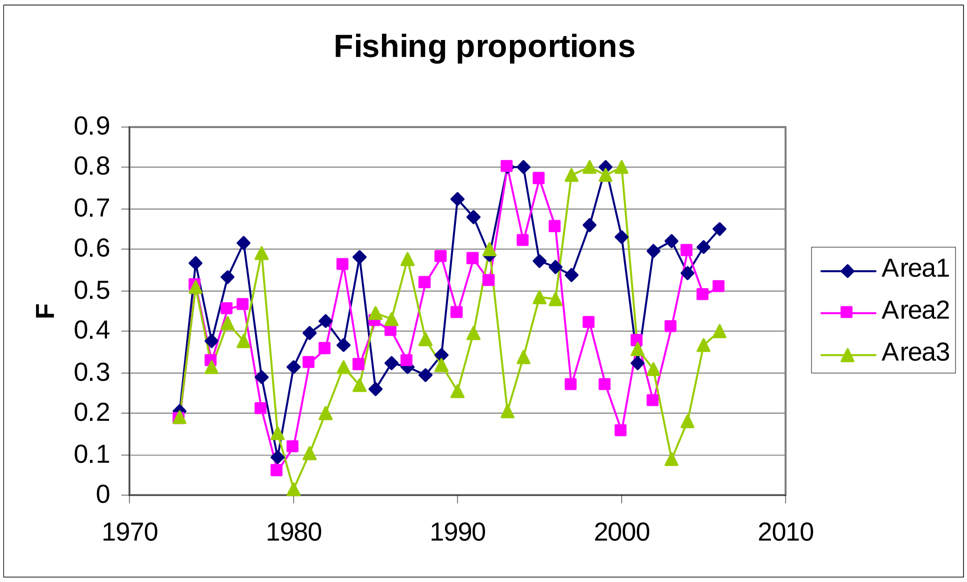
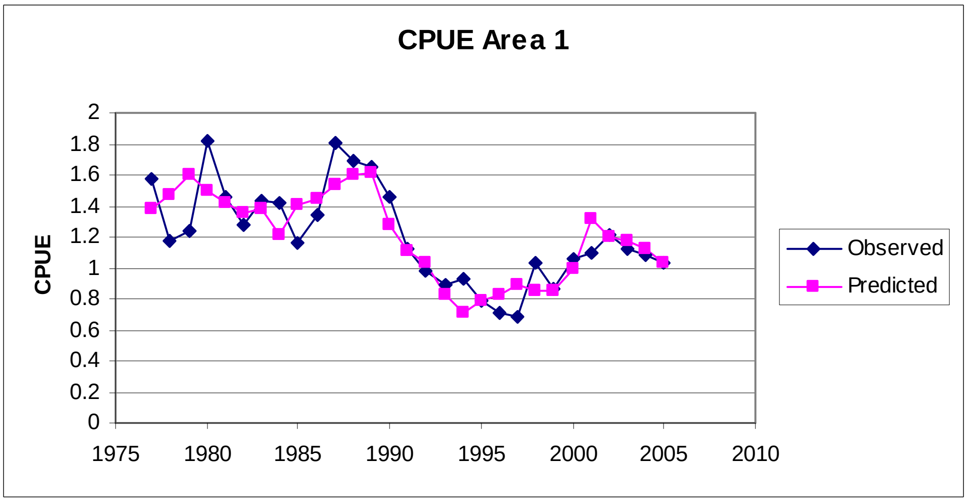
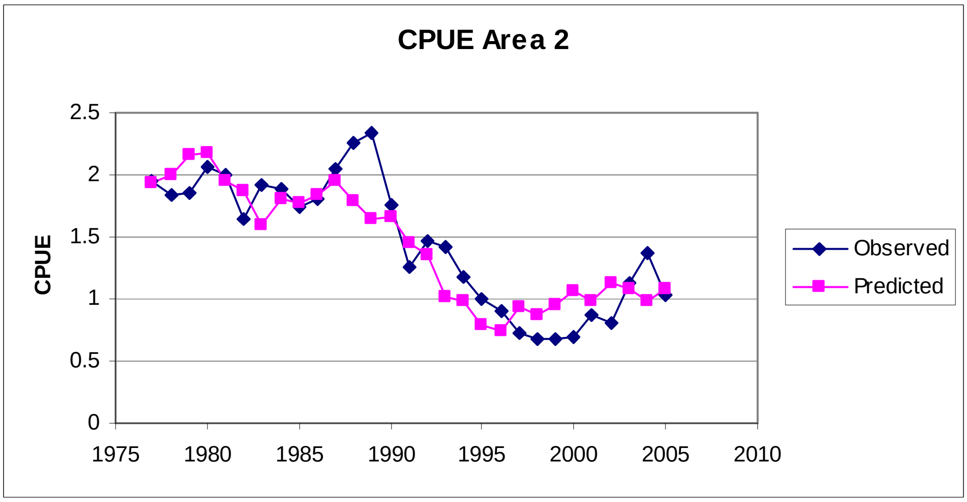


Figure 9: Model 3e (time-varying selectivity OLRAC method) estimated CPUE trends.





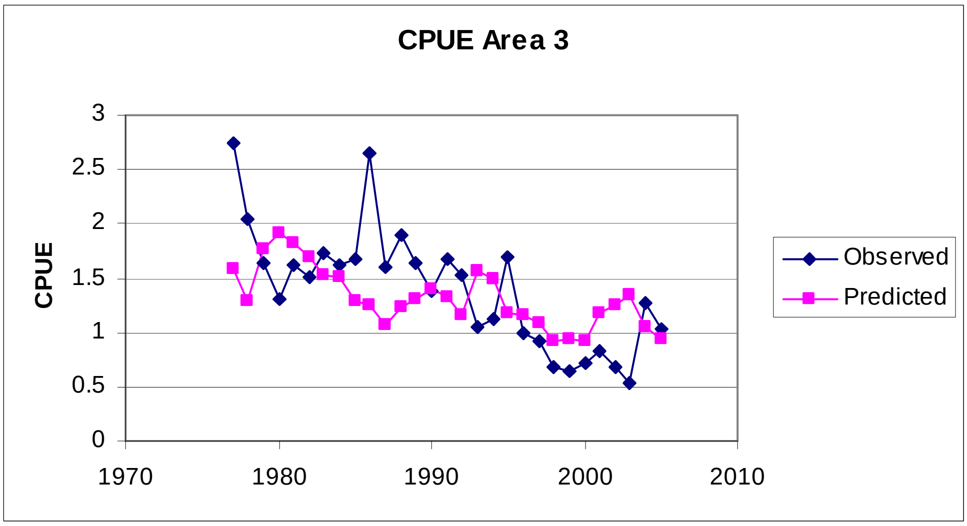


Figure 10: Model 3e (time-varying selectivity OLRAC method) fits to CAL data.