Preliminary specifications for the sex- and area-specific Operating Models for testing OMPs for the South Coast rock lobster resource

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Introduction

Johnston and Butterworth (2008b) presented some initial results for sex- and area-specific age structured production models intended to serve as operating models for testing OMPs for the south coast rock lobster resource. Here the authors update those results as well as produce results for a model which takes effort saturation into account.

Results are presented in detail for the following models:

- **Model 1**: no time-varying selectivity or effort saturation effects, but does have the two selectivity functional forms for Area 3.
- **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. Scenario Model 3e is presented here (see Johnston and Butterworth 2008b for details of Model 3e parameters).
- **Model 4**: Model 1 but with effort saturation effects.

Data

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

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

Model descriptions

Models 1-3 are described in full in Johnston and Butterworth (2008b).

Model 4: Effort saturation – reported here in conjunction with Model 1
This scenario examines the possibility that the proportional relationship between CPUE and biomass does not hold true at high levels of effort due to competition between units of effort – i.e. effort saturation occurs. This effort saturation effect is taken into account here by allowing the constant of proportionality between the GLM

derived CPUE index and exploitable biomass, q, to become a declining function of fishing effort once effort exceeds a certain level.

For this application, three further parameters $E^{'A}$ are estimated, as well as $q^{'A}$ for each Area.

When the possibility of "effort saturation" is taken into account, the CPUE abundance relationship is modified as follows:

$$CPUE_y^A = q_y^A B_y^A e^{\varepsilon_y^A} \text{ or } \varepsilon_y^A = \ln(CPUE_y^A) - \ln(q_y^A B_y^A) \quad (1)$$

where

$$q_y^A = q'^A \frac{E'^A}{E_y^A} \qquad \text{if } E_y^A > X\,E'^A \quad (2)$$

$$q_y^A = q'^A \left[(1-\alpha) + \frac{\alpha E'^A}{E_y^A}\right] \qquad \text{if } E'^A \le E_y^A \le X\,E'^A \quad (3)$$

$$q_y^A = q'^A \qquad \text{if } E_y^A < E'^A \quad (4)$$

where

$$\alpha = (\frac{E_y^A}{E'^A} - 1)/(X-1)\,; \quad (5)$$

$CPUE_y^A$ is the "observed" GLM standardised CPUE data given in Glazer (2008a),

E_y^A is the estimated effort given by $\dfrac{C_y^A}{CPUE_y^A}$,

$E^{'A}$ is the threshold effort above which "effort saturation" sets in for Area *A*.

The Catch, Effort and CPUE trends for each of the three Areas are shown in Appendix 1 (Figure A1.1) and for the resource as a whole (Figure A1.2). It would appear from these Figures that Areas 1 and 3 are the most likely candidates for effort saturation, followed by Area 2.

Note that Area 3 has a relatively small catch compared to Area 1. Model 4 presented here has X = 2.0, and fits $E^{'A}$ and $q^{'A}$ for each Area.

CC Projections under best fits

To provide some indication of the current sustainable yields associated with each of the operating model candidates, 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. These projections make the following assumptions:

Stock-recruit residuals

For all models it is assumed that for 1998+ the stock-recruit residuals are zero.

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

Selectivity
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.

More pertinent measures of sustainable yield are provided by replacement yield (RY) estimates. These will in due course be calculated for each model such that $B_{2015}^{sp} = B_{2006}^{sp}$. The RY will be assumed to be a constant catch which is applied each year (2007+) to each Area with the same current relative areal proportional breakdown (Area 1 = 45.4%, Area 2 = 35.2% and Area 3 = 19.4%).

Proposed Reference Set (RS) and Robustness tests

It is proposed that the Reference Set (RS) of underlying operating models, under which alternate candidate OMPs for the resource will be tested will consist of the following:

RC A: Model 2 – MARAM time-varying selectivity
RC B: Model 3 – OLRAC time-varying selectivity
RC C: Model 4 – Effort saturation

Robustness tests will also be required which reflect uncertainty in the values of productivity (reflected by *h*) and current abundance. In an exploratory exercise towards this end, Model 2 was re-fit to the data forcing $h = \hat{h} \pm 0.1$, where $\hat{h}$ is the best fit value. Similarly, for B_{2006}^{sp}, the Model 2 was re-fit to the data forcing $B_{2006}^{sp} = \hat{B}_{2006}^{sp} * 1.1$ or $B_{2006}^{sp} = \hat{B}_{2006}^{sp} * 0.95$ (convergence problems were encountered for lower values).

The associated results are presented in Table 6.

Given these results, it is proposed that robustness tests be defined as follows:

R1: RC A with $h = \hat{h} + 0.1$
R2: RC A with $h = \hat{h} - 0.1$ (or possibly $h = \hat{h} - 0.2$)

R3: RC A with $B_{2006}^{sp} = \hat{B}_{2006}^{sp} * 1.1$ (or possibly $B_{2006}^{sp} = \hat{B}_{2006}^{sp} * 1.2$)
R4: RC A with $B_{2006}^{sp} = \hat{B}_{2006}^{sp} * 0.95$

For further tests related to productivity levels, alternative values to the current assumption that *M*=0.1 yr^{-1} are required. Initial suggestions to add to the set above for RC A:

R5: RC A with *M* = 0.07
R6: RC A with *M* = 0.15.

Results and Discussion

Tables 1-4:	report the results for the following models:
Table 1:	Model 1 (no time varying selectivity or effort saturation– two selectivity functional forms for Area 3),
Table 2:	Model 2 (time varying selectivity MARAM method – two selectivity functional forms for Area 3)
Table 3:	Model 3 (time varying selectivity OLRAC method - – two selectivity functional forms for Area 3)
Table 4:	Model 4 (Model 2 with effort saturation).
Table 5:	provides comparisons between models 1-4 for quantities of key interest.
Table 6:	provides results (in form of –*ln*L values) for fits of some suggested robustness tests.

Figure 1a compares the fit to observed CPUE trends for Model 1 (which has no time varying selectivity or effort saturation) and the two time varying selectivity models, while Figure 1b provides similar plots comparing Model 1 with Model 4 (effort saturation). Figure 2a compares Model 1-3 fits to observed catch-at-length data which have been averaged over the data period. Figure 2b provides similar plots for Model 4.

[Note: An error was detected at the last moment in the coding for Model 3 – corrected results will be circulated shortly.]

From the results for Model 4 in Table 4 and Figures 1b and 2b, it is clear that the effort saturation effect is not (as yet) able to adequately capture patterns in the data. Further exploration with this model will be pursued, but if no success is obtained it will be dropped from the RS.

The effort saturation hypothesis looks plausible when the fishing as a whole is considered (Figure A1.2) with CPUE decreasing in the late 1990s as effort increased. However, when this is considered on a per area basis (Figure A1.1) it seems that most of the CPUE drop occurred in Area 2 at a time when effort also decreased – the increase in effort in fact amounted to a transfer of effort to Area 3 at this time. This may be the reason why the effort saturation Model 4 is having difficulty fitting the data.

Assumptions required for future projections for OMP testing

When projecting the population forwards for simulation testing of various OMP candidates, a number of assumptions need to be made for the operating models to be used. Here the authors provide a suggested framework.

1. Stock-Recruit residuals

For 1998+ $$R_y = \frac{\alpha B_y^{sp}}{\beta + (B_y^{sp})} e^{\varepsilon_y} \qquad \varepsilon_y \sim N(0, \sigma_R^2) \qquad (6)$$

where σ_R =0.4
[see Johnston and Butterworth (2008a) – Equations 7 and 37].

2. Proportional split of recruitment R_y by Area

For each Area A we have estimated λ_y^A for 1973 to 2000 (see Johnston and Butterworth (2008a) Equations 28 and 29 reproduced below as Equations 7 and 8).

$$R_y^A = \lambda_y^{*,A} R_y \tag{7}$$

where

$$\lambda_y^{*,A} = \frac{\lambda^A e^{\varepsilon_{A,y}}}{\sum_A \lambda^A e^{\varepsilon_{A,y}}} \tag{8}$$

and

$$\varepsilon_{A,y} \sim N(0, \sigma_\varepsilon^2)\,; \qquad \sigma_\varepsilon = 0.05.$$

The $\varepsilon_{A,y}$ are thus further estimable parameters. From these estimated values we can thus calculate $\bar{\lambda}^A$ and σ_λ^A (the mean and standard deviation).

Then for future years, 2001+

$$\lambda_y^{A,S} = \bar{\lambda}^A e^{\varepsilon_y^{A,S}} \quad \text{where } \varepsilon_y^{A,S} \sim N(0, \sigma_\lambda^{A^2}) \tag{9}$$

and for each year, $\lambda_y^{A,S} \rightarrow \frac{\lambda_y^{A,S}}{\sum_{A=1}^{3} \lambda_y^{A,S}}$ (10)

where S is the simulation index.

3 Selectivity

<u>MARAM selectivity model (Model 2)</u>

Model 2 estimates $\delta_y^{m/f,A}$ for 1994 to 2004 (see Johnston and Butterworth (2008a) Equation 24 reproduced below as Equation 11).

$$S_{y,l}^{m/f,A} = \frac{1}{1 + e^{-\ln 19(l - (l_{50}^{m/f,A} + \delta_y^{m/f,A}))/\Delta^{m/f,A}}} \tag{11}$$

These δ values appear to change fairly randomly from year to year. Hence we suggest:

For 2005+ $\quad \delta_y^{m/f,A,S} = \bar{\delta}^{m/f,A} + \eta_y^{m/f,A,S}$ (12)

where $\quad \eta_{y\leq}^{m/f,A,S} \sim N(0, \sigma_\delta^{m/f,A^2})$ (13)

where $\bar{\delta}^{f/m,A}$ and $\sigma_{\delta}^{m/f,A}$ are calculated as the mean and standard deviation of the 1994 to 2004 estimates.

Note that for Area 3 where there are two selectivity functions (see Johnston and Butterworth (2008b),

$$S_{y,l}^{m/f,3} = (1-\mu)S1_{y,l}^{m/f,3} + \lambda\mu S2_{l}^{m/f,3} \qquad (14)$$

where

$S1_{y,l}^{m/f,3}$ is the original selectivity function (as used for other Areas) and simulated for the future by Equation 12,

$S2_{l}^{m/f,3} = e^{-\left(l-l^{*}_{m/f}\right)^2/\omega^2}$ (the second normal-shaped selectivity function which remains fixed over time), and

the μ remains constant in the future at the estimated value.

<u>OLRAC selectivity model (Model 3)</u>

See Johnston and Butterworth (2008b) Equations 8-13 reproduced below as Equations 15-20:

$$\bar{S}_{l}^{m/f,A} = \frac{1}{1+e^{-\ln 19(l-l_{50}^{m/f,A})/\Delta^{m/f,A}}} \qquad (15)$$

$$S_{y,l}^{m/f,A} = \bar{S}_{l}^{m/f,A}\alpha_{y,l}^{m/f,A} \qquad (16)$$

where

$$\alpha_{y,l}^{m/f,A} = \frac{x_{y}^{m/f,A}}{X_{y}^{m/f,A}} \qquad l \le 50 \qquad (17)$$

$$\alpha_{y,l}^{m/f,A} = \frac{x_{y}^{m/f,A} + (l-50)(1-x_{y}^{m/f,A})(l_{kink}-50)}{X_{y}^{m/f,A}} \qquad 50 \le l \le l_{kink} \qquad (18)$$

$$\alpha_{y,l}^{m/f,A} = \frac{1}{X_{y}^{m/f,A}} \qquad l > l_{kink} \qquad (19)$$

and where

$$X_{y}^{m/f,A} = \left\{\sum_{l=l1}^{50} x_{y}^{m/f,A} + \sum_{l=51}^{l_{kink}}\left[x_{y}^{m/f,A} + \frac{(l-50)(1-x_{y}^{m/f,A})}{l_{kink}-51}\right] + \sum_{l=l_{kink}}^{l2} l\right\} / (l2-l1+1) \qquad (20)$$

The $x_{y}^{m/f,A}$ are the key time dependent parameters. We thus plan to consider the $x_{y}^{m/f,A}$ estimates for years 1973 to 2006, and likely generate future values based on their distribution.

<u>Effort Saturation (Model 4)</u>

Here as there is no time dependency in selectivity for this model, no further specifications for future selectivity are required.

4. Future data generation

We will need to generate future CPUE values. Whichever model is fit, there is a model estimate for $CPUE_y^A$ for past years. Projected into the future, the model provides expected $CP\hat{U}E_y^A$ values for each year and Area. Future CPUE values will be generated for each area A from:

$$CPUE_y^{A,S} = CP\hat{U}E_y^{A,S} \exp(\varepsilon_y^{A,S}) \qquad \varepsilon_y^{A,S} \sim N(0, \sigma_{CPUE}^{A^2}) \tag{21}$$

At a later stage, future catch-at-length data may also be generated to allow for testing of the possible use of such data inputs to the OMP as well.

Suggested TAC rule for initial OMP testing

Plans are to start off with a simple rule based on recent CPUE trends, *viz*

$$TAC_{y+1} = TAC_y(1 + \lambda S_y^A) \tag{17}$$

where

S_y^A is the slope parameter from a regression of $\ln CPUE_y^A$ versus *y* over the last five years for each area A, and

$$S_y = \sum_{A=1}^{3} w^A S_y^A \tag{18}$$

where $w^A = \dfrac{\dfrac{1}{\sigma_S^{A^2}}}{\sum_{A'=1}^{3}(\dfrac{1}{\sigma_S^{A'^2}})}$

and σ_S^A is the standard error of the regression estimate of S_y^A.

A rule to control the inter-annual TAC variation would also be applied e.g. no more that 10% up or down from year to year.

How should the future catch be divided by Area? We suggest for a start to take the average areal split over the last five years and use that for each year in the future.

References

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Table1: Model 1 (no time varying selectivity or effort saturation effects, but **two** selectivity functional forms for Area 3) estimated parameters and quantities of management interest. Biomass quantities are in MT. The number of parameters estimated is 140.

Parameter/quantity		**Global**	**Area 1**	**Area 2**	**Area 3**
Total number of estimable parameters		140			
K^{sp}	total female spawning biomass	794			
h	S/R steepness parameter	0.705			
λ^A	proportion R to Area A		0.38	0.40	0.22
μ^A	rel. female scaling parameter for Area A		1.25	1.23	1.20
$l_{50}^{m,A}$	length at 50% selectivity for male lobsters in Area A (mm)		66.94	61.98	59.99
$l_{95}^{m,A}$	length at 95% selectivity for male lobsters in Area A (mm)		76.61	61.98	59.99
$l_{50}^{f,A}$	length at 50% selectivity for female lobsters in Area A (mm)		64.80	61.19	73.16
$l_{95}^{f,A}$	length at 95% selectivity for male lobsters in Area A (mm)		71.61	68.56	79.96
β^*	growth function parameter	0.104			
$L_\infty^{m,A}$	L_∞ for male lobsters in Area A (mm)		104.94	107.04	112.58
$L_\infty^{f,A}$	L_∞ for female lobsters in Area A (mm)		101.05	100.39	110.22
κ	growth curve parameter (yr^{-1})	0.089			
t_0	growth curve parameter (yr^{-1})	-1.94			
l_m^*		63.22			
l_f^*		63.21			
ϖ		7.23			
λ		0.76			
-ln L (CPUE)		-79.86	-35.80	-22.63	-21.43
CPUE σ			0.176	0.278	0.290
-ln L (CAL)		-171.91	-73.04	-22.68	-76.19
CAL σ			0.062	0.095	0.062
SR residual penalty (Eqn 37)		7.65			
Time varying selectivity penalty (Eqn 39)		-			
Growth parameters penalty (Eqn 36)		2.35			
Time varying recruitment penalty (Eqn 38)		17.42			
Total –ln$L$ value		-222.65			
B_{06}^{sp} / K^{sp}		0.35			
$B_{06}^{\exp,A} / K_{1973}^{\exp,A}$		0.28	0.32	0.31	0.32
$B_{06}^{\exp,A}$		528	174	194	161
$B_{2015}^{sp} / B_{2006}^{sp}$ *		0.89			

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

Table 2: 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. The number of parameters estimated is 206.

Parameter/quantity		**Global**	**Area 1**	**Area 2**	**Area 3**
Total number of estimable parameters		206			
K^{sp}	total female spawning biomass	796			
h	S/R steepness parameter	0.705			
λ^A	proportion *R* to Area *A*		0.38	0.40	0.22
μ^A	rel. female scaling parameter for Area *A*		1.25	1.25	1.20
$l_{50}^{m,A}$	length at 50% selectivity for male lobsters in Area *A* (mm)		67.90	62.00	60.00
$l_{95}^{m,A}$	length at 95% selectivity for male lobsters in Area *A* (mm)		77.32	62.00	60.00
$l_{50}^{f,A}$	length at 50% selectivity for female lobsters in Area *A* (mm)		65.82	62.29	74.29
$l_{95}^{f,A}$	length at 95% selectivity for male lobsters in Area *A* (mm)		72.45	69.24	81.06
β^*	growth function parameter	0.104			
$L_\infty^{m,A}$	L_∞ for male lobsters in Area *A* (mm)		104.94	107.04	112.58
$L_\infty^{f,A}$	L_∞ for female lobsters in Area *A* (mm)		101.05	100.39	110.22
κ	growth curve parameter (yr^{-1})	0.089			
t_0	growth curve parameter (yr^{-1})	-1.94			
l_m^*		63.22			
l_f^*		63.22			
ϖ		7.25			
λ		0.77			
-ln *L* (CPUE)		-80.07	-36.40	-22.30	-21.36
CPUE σ			0.173	0.281	0.290
-ln *L* (CAL)		-183.67	-77.01	-29.23	-77.45
CAL σ			0.061	0.092	0.061
SR residual penalty (Eqn 37)		7.53			
Time varying selectivity penalty (Eqn 39)		3.26			
Growth parameters penalty (Eqn 36)		2.34			
Time varying recruitment penalty (Eqn 38)		17.50			
Total –ln*L* value		-231.66			
B_{06}^{sp} / K^{sp}		0.35			
$B_{06}^{\exp,A} / K_{1973}^{\exp,A}$		0.30	0.33	0.28	0.32
$B_{06}^{\exp,A}$		529	176	191	162
$B_{2015}^{sp} / B_{2006}^{sp}$ *		0.89			

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

Table 3: Model 3 (time varying selectivity OLRAC method – variant 3e) estimated parameters and quantities of management interest. Biomass quantities are in MT. The number of parameters estimated is 322.

Parameter/quantity		**Global**	**Area 1**	**Area 2**	**Area 3**
Total number of estimable parameters		322			
K^{sp}	total female spawning biomass	1084			
h	S/R steepness parameter	0.753			
λ^A	proportion R to Area A		0.35	0.32	0.33
μ^A	rel. female scaling parameter for Area A		1.28	1.67	1.47
$l_{50}^{m,A}$	length at 50% selectivity for male lobsters in Area A (mm)		64.58	61.26	50.45
$l_{95}^{m,A}$	length at 95% selectivity for male lobsters in Area A (mm)		74.48	64.05	50.64
$l_{50}^{f,A}$	length at 50% selectivity for female lobsters in Area A (mm)		63.97	60.70	66.65
$l_{95}^{f,A}$	length at 95% selectivity for male lobsters in Area A (mm)		70.04	68.07	77.45
β^*	growth function parameter	0.130			
$L_\infty^{m,A}$	L_∞ for male lobsters in Area A (mm)		104.83	107.34	111.36
$L_\infty^{f,A}$	L_∞ for female lobsters in Area A (mm)		98.32	101.33	108.07
κ	growth curve parameter (yr^{-1})	0.079			
t_0	growth curve parameter (yr^{-1})	-1.77			
l_m^*		63.82			
l_f^*		61.80			
ϖ		6.63			
λ		0.871			
-ln L (CPUE)		-93.73	-43.80	-32.37	-17.56
CPUE σ			0.134	0.199	0.331
-ln L (CAL)		-269.08	-61.52	-54.81	-152.75
CAL σ			0.066	0.081	0.045
SR residual penalty (Eqn 37)		4.38			
Time varying selectivity penalty (Eqn 39)		8.14			
Growth parameters penalty (Eqn 36)		6.54			
Time varying recruitment penalty (Eqn 38)		12.94			
Total –ln$L$ value		-298.09			
B_{06}^{sp}/K^{sp}		0.47			
$B_{06}^{\exp,A}/K_{1973}^{\exp,A}$		0.34	0.38	0.29	0.38
$B_{06}^{\exp,A}$		569	221	210	138
$B_{2015}^{sp}/B_{2006}^{sp}$ *		0.97			

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

Table 4: Model 4 (effort saturation in Areas 1, 2 and 3, no time-varying selectivity) estimated parameters and quantities of management interest. Biomass quantities are in MT. The number of parameters estimated is 146.

Parameter/quantity		**Global**	**Area 1**	**Area 2**	**Area 3**
Total number of estimable parameters		146			
K^{sp}	total female spawning biomass	795			
h	S/R steepness parameter	0.705			
λ^A	proportion R to Area A		0.38	0.40	0.22
μ^A	rel. female scaling parameter for Area A		1.25	1.25	1.20
$l_{50}^{m,A}$	length at 50% selectivity for male lobsters in Area A (mm)		67.95	62.00	60.00
$l_{95}^{m,A}$	length at 95% selectivity for male lobsters in Area A (mm)		77.61	62.01	60.00
$l_{50}^{f,A}$	length at 50% selectivity for female lobsters in Area A (mm)		65.80	62.16	74.30
$l_{95}^{f,A}$	length at 95% selectivity for male lobsters in Area A (mm)		72.59	69.57	81.13
β^*	growth function parameter	0.104			
$L_\infty^{m,A}$	L_∞ for male lobsters in Area A (mm)		104.94	107.04	112.58
$L_\infty^{f,A}$	L_∞ for female lobsters in Area A (mm)		101.05	100.39	110.22
κ	growth curve parameter (yr^{-1})	0.089			
t_0	growth curve parameter (yr^{-1})	-1.94			
l_m^*		63.24			
l_f^*		63.22			
ϖ		7.27			
λ		0.76			
E'			182	210*	199
-ln *L* (CPUE)		-80.06	-36.38	-22.01	-21.66
CPUE σ			0.173	0.281	0.290
-ln *L* (CAL)		-172.78	-72.86	-23.55	-76.37
CAL σ			0.062	0.094	0.061
SR residual penalty (Eqn 37)		7.53			
Growth parameters penalty (Eqn 36)		2.34			
Time varying recruitment penalty (Eqn 38)		17.33			
Total –ln*L* value		-224.13			
B_{06}^{sp} / K^{sp}		0.35			
$B_{06}^{\exp,A} / K_{1973}^{\exp,A}$		0.30	0.33	0.28	0.32
$B_{06}^{\exp,A}$		532	176	193	162
$B_{2015}^{sp} / B_{2006}^{sp}$ *		0.89			

* bounded by maximum observed value in Area

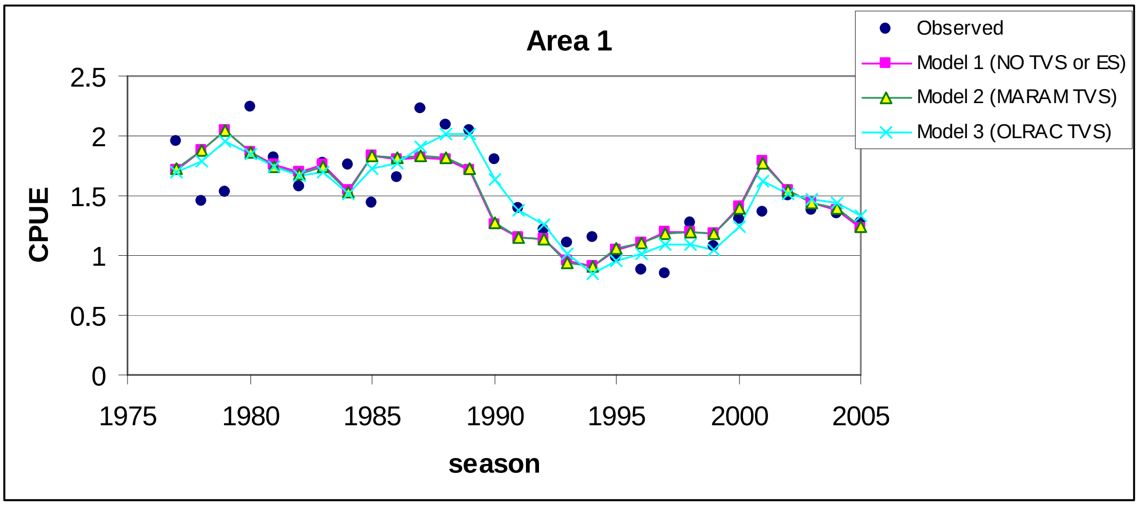
Table 5: Comparisons between Models 1-4 of key parameters and management quantities.

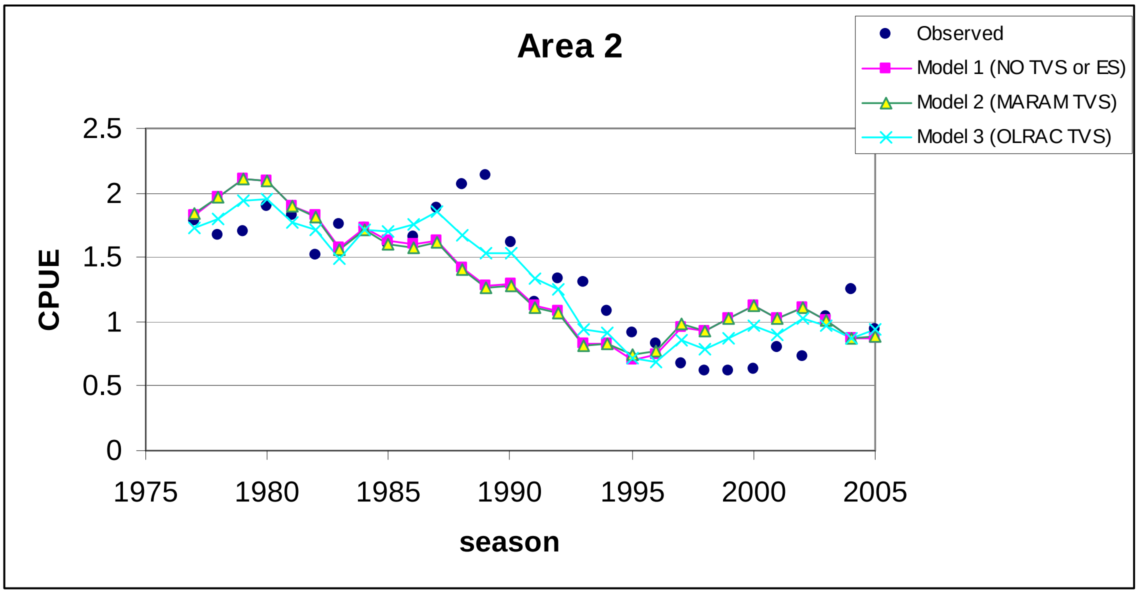
Parameter/quantity	**Model 1**	**Model 2**	**Model 3**	**Model 4**
	No TVS or effort saturation	TVS – MARAM method	TVS- OLRAC method	Effort saturation (3 Areas)
K^{sp} (total female spawning biomass)	794	796	1084	796
h (S/R steepness parameter)	0.705	0.705	0.753	0.705
-ln L (CPUE)	-79.86	-80.07	-93.73	-80.06
-ln L (CAL)	-171.91	-183.67	-269.08	-172.77
Total –ln$L$ values	-222.65	-231.66	-298.09	-224.13
# estimable parameters	140	206	322	146
AIC	-165.30	-51.32	47.82	-156.3
B^{sp}_{06} / K^{sp}	0.35	0.35	0.47	0.35
$B^{\exp}_{06} / K^{\exp}$	0.28	0.30	0.34	0.30
$B^{\exp}_{06}$	528	529	569	532
$B^{sp}_{2015} / B^{sp}_{2006}$	0.89	0.89	0.97	0.89

Table 6: Model 2 potential robustness test statistics.

Model 2		**-*ln*L**	$B^{sp}_{2015} / B^{sp}_{2006}$
RC [$\hat{h} = 0.705; \hat{B}^{sp}_{2006} = 276{,}8$]		-231.659	0.89
$h = \hat{h} + 0.1$	$\hat{h}$ =0.705	-231.129	0.93
$h = \hat{h} - 0.1$		-229.723	0.83
$h = \hat{h} - 0.2$		to come	to come
$B^{sp}_{2006} = \hat{B}^{sp}_{2006} + 20\%$	$\hat{B}^{so}_{2006} = 276.8$	to come	to come
$B^{sp}_{2006} = \hat{B}^{sp}_{2006} + 10\%$		-229.401	0.90
$B^{sp}_{2006} = \hat{B}^{sp}_{2006} - 5\%$		-196.037	0.88

Figure 1a: Comparison of model fits to observed CPUE trends for Models 1 to 3.





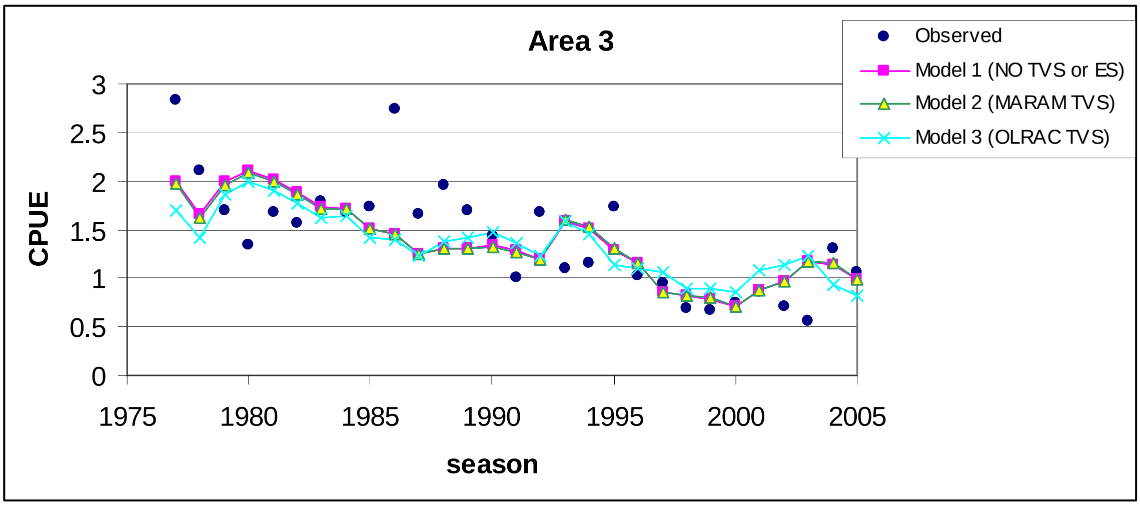


Figure 2a: Comparison of model fits to observed CPUE trends for Models 1 and 4.

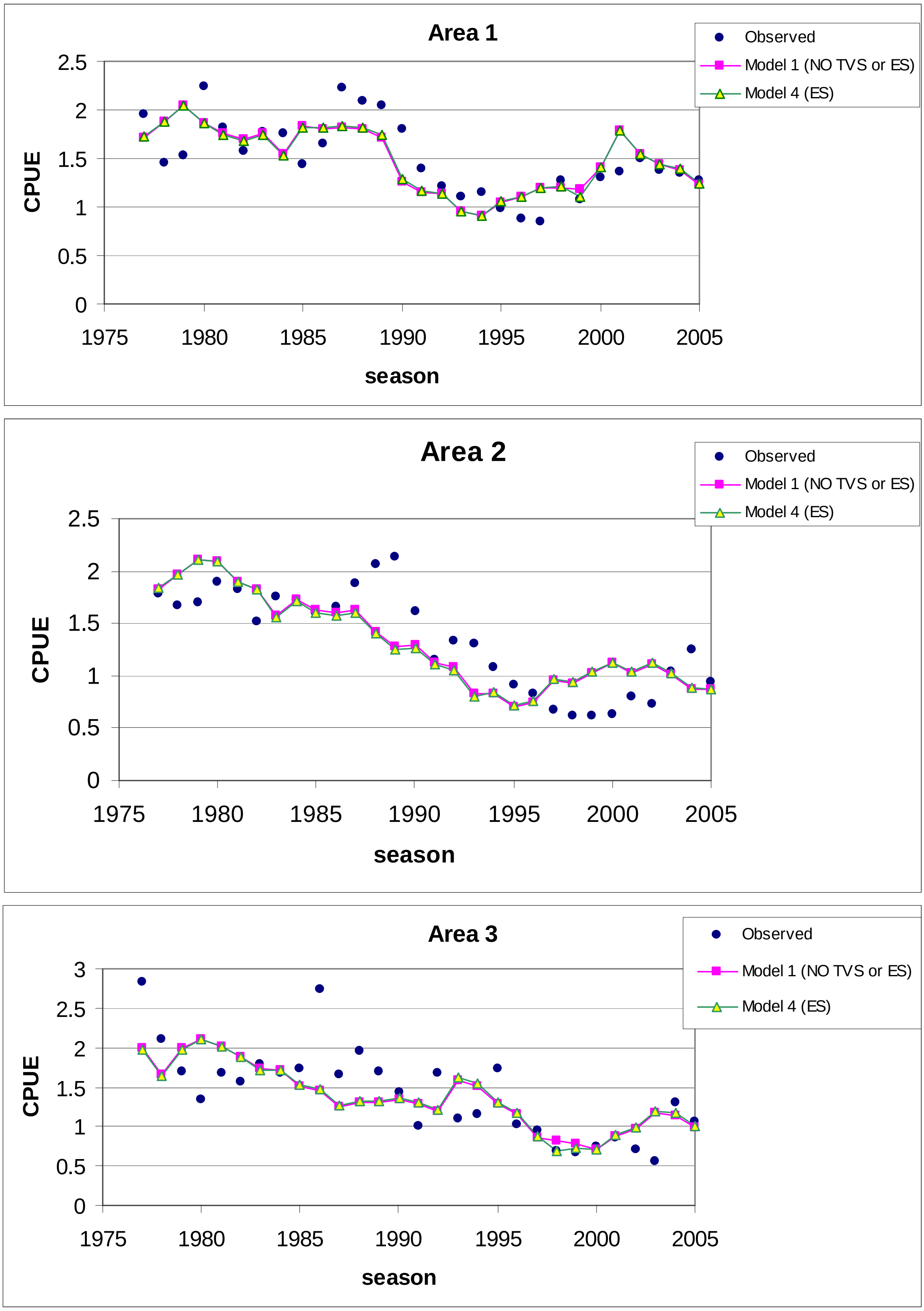


Figure 1a: Comparison of model fits to observed catch-at-length (CAL) trends for Models 1 to 3.

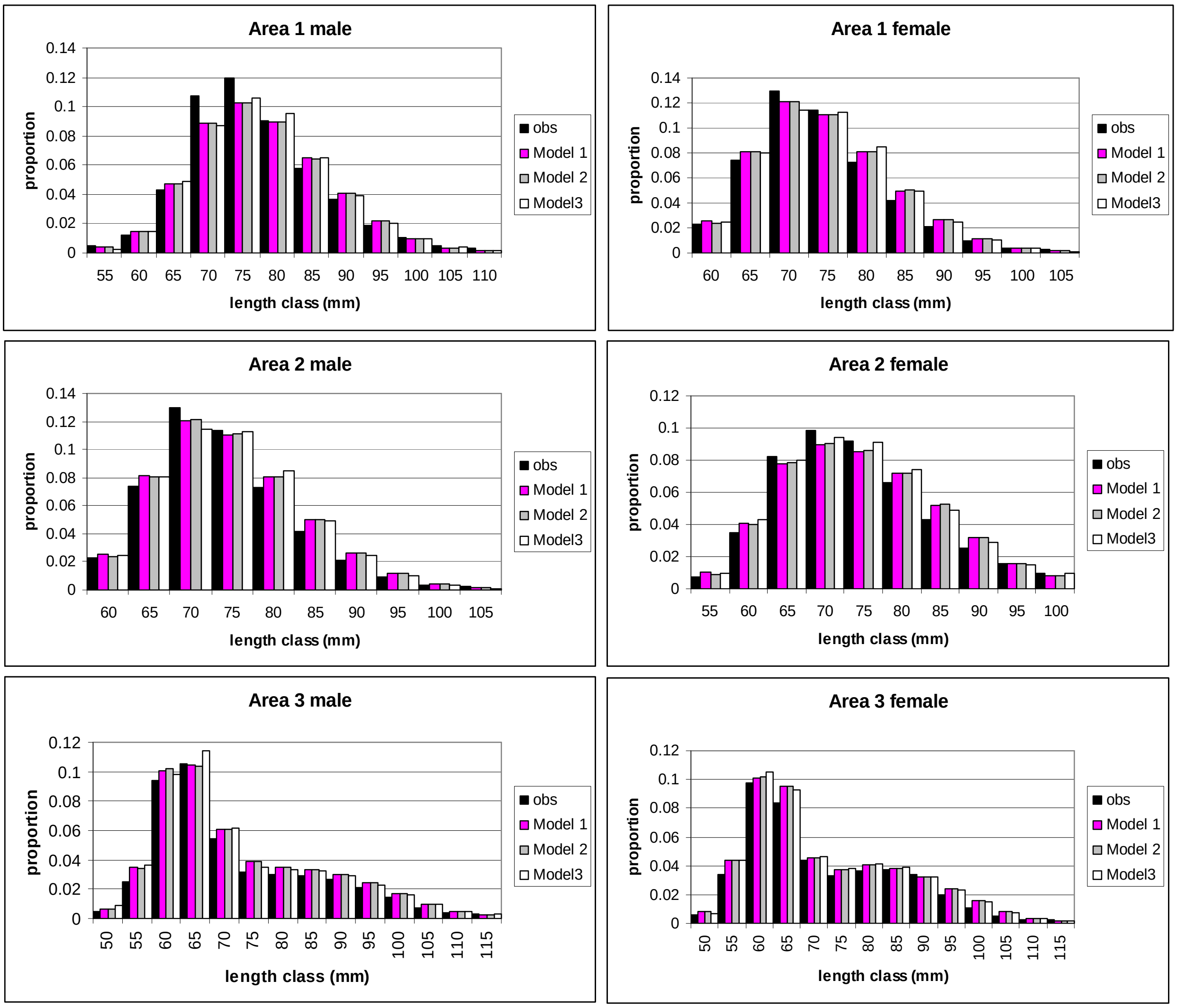
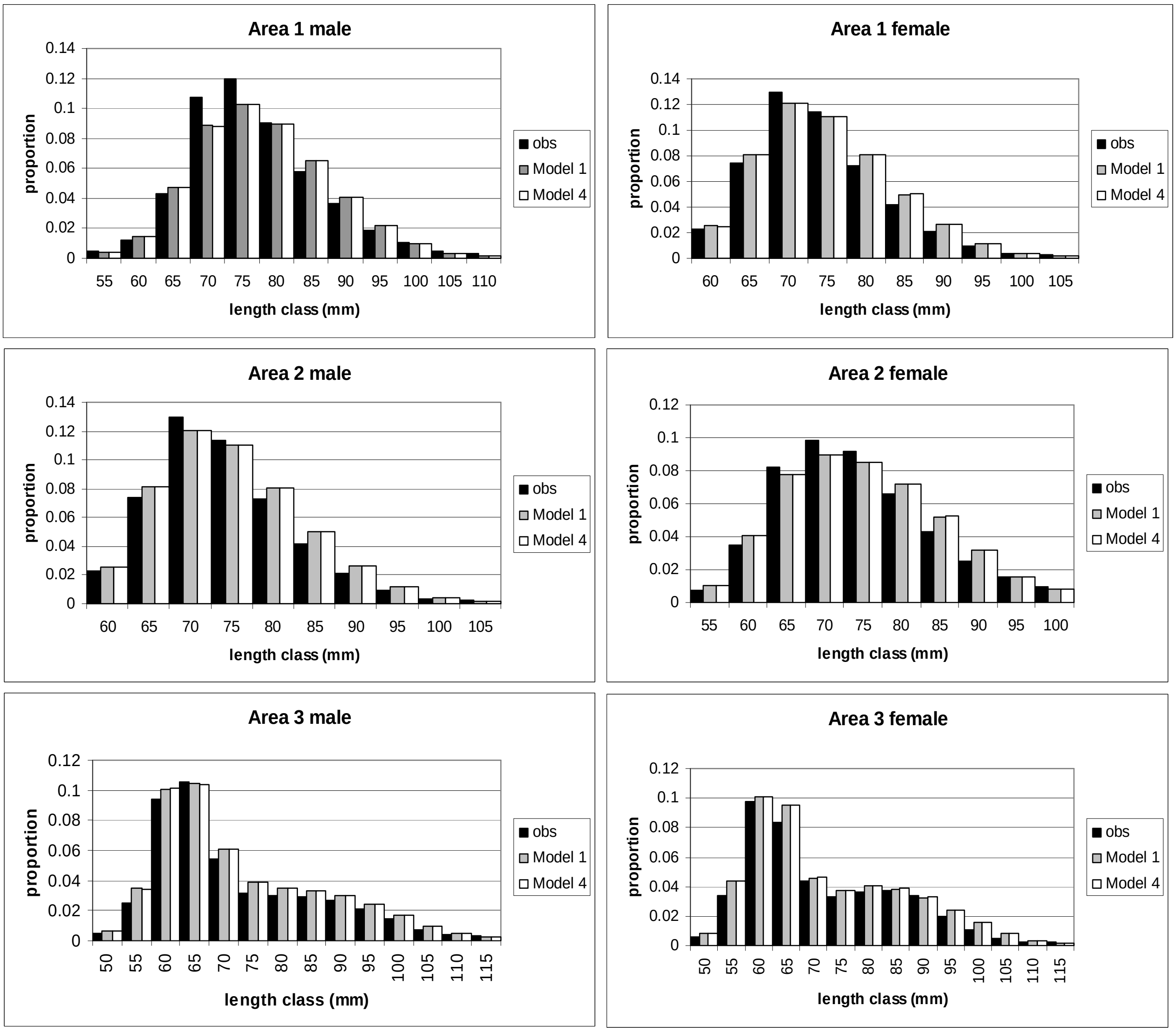


Figure 1b: Comparison of model fits to observed catch-at-length (CAL) trends for Models 1 and 4.



Appendix 1: Catch, CPUE and Effort trends in the SCRL resource

Figure A1.1: Catch, CPUE and Effort trends for the three fishing Areas for the SCRL fishery.

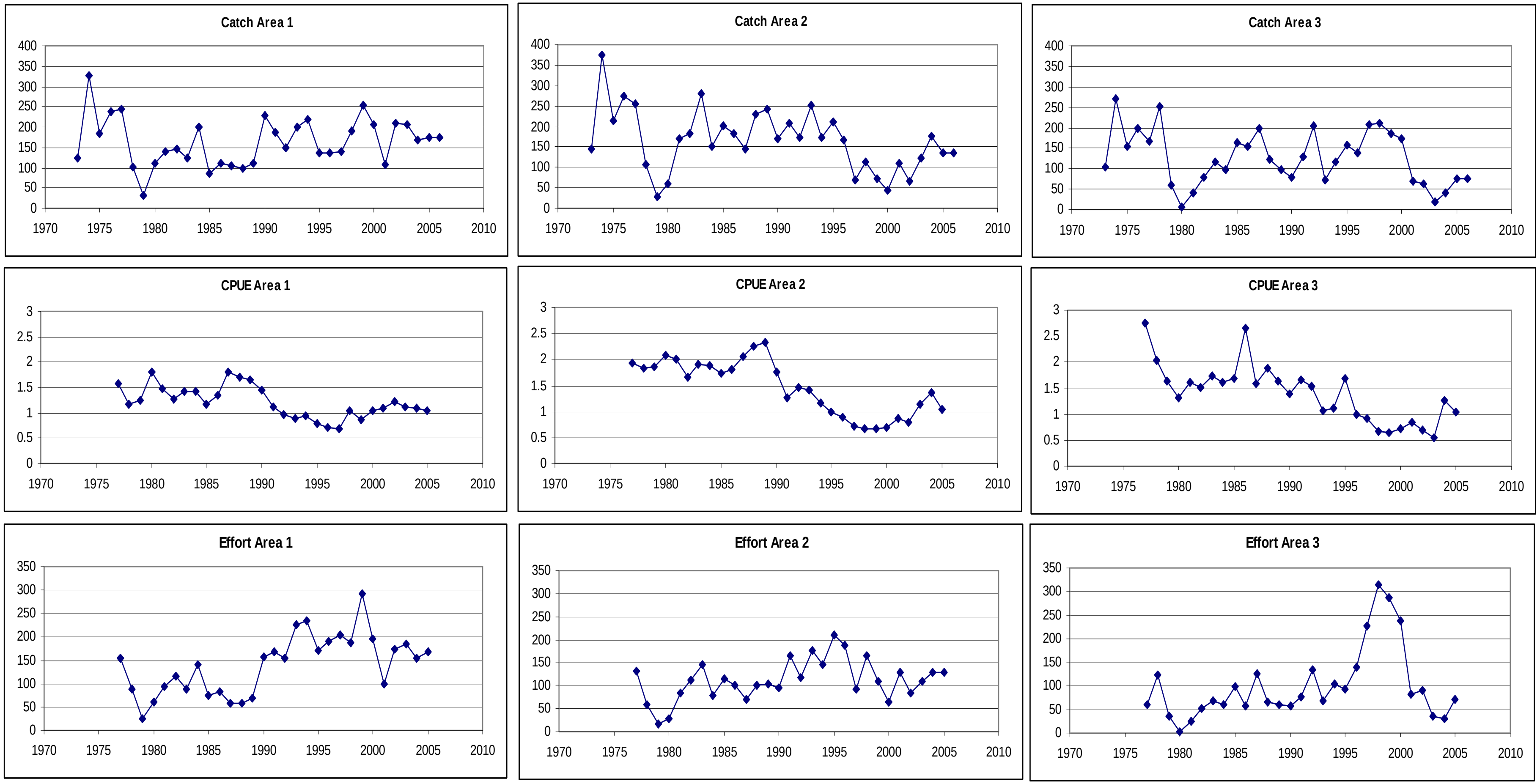


Figure A1.2: Catch, CPUE and Effort trends for the SCRL fishery as a whole.