The 2007 age-structured production model assessments and projections for the South Coast rock lobster resource – routine update using Pope's approximation model fitting to catch-at-age data including scenarios for time-varying selectivity

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Executive Summary

The assessment conducted in 2006 (WG/06/06/WCRL3) has been routinely extended (except that the Baranov equation has been replaced by Pope's approximation), taking account of a further year's catch, CPUE and catch-at-age data.

The observed CPUE shows a slight decrease for 2005 (2005/06 season). The sustainable yield estimates are generally very similar to those for the 2006 assessment, although estimates of current biomass levels relative to *K* increase. The Reference Case (RC) scenario suggests that a TAC of a little less than 330 MT or less would be appropriate to prevent biomass decline in the future. The other four scenarios reported suggest higher values than this, ranging from 350 MT to 405 MT. Spawning biomass trends over the last 10 years are downward for all the models considered.

Introduction

The age-structured production model which fits to catch-at-age data, and which has been applied previously to South Coast rock lobster, has been used to update the assessment of the resource and to provide a range of projections into the future for a number of harvesting policies. The age-structured production model is essentially unchanged from that initially described by Geromont (2000a) and used for the 2001-2006 assessments (Johnston and Butterworth 2001; 2002a; 2003a; 2003b, 2004, 2005, 2006). The age-structured model is reported in detail here in the Appendix. Note that his model is sex- and area-aggregated.

The Reference Case (RC) "Bayesian" ASPM assessment as considered for 2007 involves the following choices (essentially unchanged from 2003-2006 except for taking the extra year into account).

1. Standard priors for P, h[1], M, a_{50}, a_{95}.

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[1] The prior for h is a truncated (at 1.0) normal distribution with mean of 0.95 and σ =0.2

2. Use of GLM-standardised CPUE for 1977-2005[2].
3. Use of scientific-sample-based catch-at-age data for 1994-2005, with an 8- and 20+ grouping. Note that the Working Group agreed that the 1999 scientific catch-at-age data should not be included in the RC assessment due to poor spatio-temporal coverage for that season that may render them unrepresentative.
4. A Beverton-Holt stock recruit relationship.
5. Deterministic recruitment, except for estimation of recruitment residuals from 1974-1997 (i.e. one more year included than last year) with zero serial correlation ($\rho = 0$) and CV (σ_R) of 0.4.

The ASPM has been modified to use Pope's approximation as instead of Baranov's equations for speedier and more reliable estimation. Tests showed that this had minimal effects on results.

Data

The annual total catch (by mass) (C_y) and relative abundance index ($CPUE_y$) data used are reported in Table 1a. The relative abundance index corresponds to the standardised CPUE time series provided by Glazer (pers. commn). The commercial catches-at-age ($C_{y,a}$) derived from the updated scientific length data are given in Table 2 (Bergh pers. commn). Table 3 summarises the somatic growth curve parameter values (Glazer and Groeneveld 1999) used in this process.

Sensitivity analyses

In addition to the RC, results for the following sensitivity analyses are also reported in Table 4a.

1) Effort Saturation (ES)

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 (see the appendix equations 15 and 16 for details). This analysis also includes fitting to the 1998 Effort Saturation Experiment data (Groeneveld *et al.* 1999). For this application, parameters E' and n^* are fixed at 2500 and 1.0 respectively (see Model 5c of Geromont 2000b). Thus the extent of effort saturation is determined by the parameter E^* alone. In previous stock assessment scenarios that have taken effort saturation into account, the approach was formulated slightly differently (the observed CPUE series was "detrended" to take account of effort saturation), but the resultant computations are mathematically identical so yield the same results.

2) Catch-at-age down-weight (CDW)

The catch-at-age data is down-weighted by a multiplicative factor of 0.10 in the likelihood function as an *ad hoc* approach to allow for positive correlations in these data.

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[2] In this report the year "2000", for example, refers to the 2000/01 season

3a) Time-varying selectivity - MARAM method (TVS-MARAM)

This scenario is identical to the RC model, except that the selectivity function (which depends on age) is allowed to vary over the time period for which catch-at-age data are available (1994-2003). To effect this, the form of the selectivity function is generalised to:

$$S_{y,a} = \frac{1}{1+e^{-K(a-(a50+\delta_y))}} \text{ where } K = \frac{\ln 19}{\Delta} \qquad (1)$$

The estimable parameters are thus: $a50$ (the expected age at 50% selectivity), Δ and δ_y for y = 1994-2005 (excluding 1999 as there are no catch-at-age data for 1999). Note that the expected age at 95% selectivity ($a95$) is given by $a50+\Delta$.

It is also assumed that for y<1994 and 2006+ the δ_y = 0, while for y=1999, the average of the δ_y for 1998 and 2000 is used. When calculating MSY, it is assumed that the 2006 selectivity (with δ_y =0) function applies.

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

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

where the σ_{sel} is input (a value of 0.75 was found to provide reasonable performance). It may appear from the form of equation (1) that there is a confounding between $a50$ and δ_y as δ_y is estimated for every year for which there are catch-at-age data input to the model. This is however not the case (otherwise the term added in expression (2) would secure a mean at the estimated δ_y's of zero). The reason is that δ_y is set to zero for other years, to which $a50$ then applies, and this then influences the model estimated CPUE (equation (3) below) for those years, which in turn impacts the overall value of the likelihood.

Another issue is that for equation (1), if δ_y decreases, this means that selectivity is increasing on younger lobsters, while given that the model fitting procedure assumes that

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

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:

$$S_{y,a} \rightarrow S^*_{y,a} = S_{y,a} / X_y \qquad (4)$$

where here as a simple initial approach we have chosen:

$$X_y = \sum_{a1}^{a2} \frac{S_{y,a}}{a2 - a1 + 1} \qquad (5)$$

i.e., normalising selectivity by its average over a certain age range, so that now if δ_y decreases, the $S^*_{y,a}$ will decrease for large *a* to compensate for the effort spread to locations where younger animals are found associated with the increase for smaller *a*.

The authors experimented with choices for *a*1 and *a*2. A choice of *a*1=8 and *a*2=12 as a standard gave reasonable performance and are used for the results reported here.

3b) Time-varying selectivity - OLRAC method (TVS-OLRAC)

This scenario is identical to the RC model, except that the selectivity function (which depends on age) is allowed to vary over time.

The time-invariant selectivity

$S_a = \frac{1}{1+e^{-K(a-a50)(a95-a50)}}$ where $K = \frac{\ln 19}{\Delta}$ is modified to be time-varying as follows:

$$S_{y,a} = S_a \alpha_{y,a} \qquad (6)$$

where

$$\alpha_{y,a} = \frac{x_y}{X_y} \qquad a \le 6$$

$$\alpha_{y,a} = \frac{x_{y+(a-6)(1-x_y)/(a_{kink}-6)}}{X_y} \qquad 6 \le a \le a_{kink} \qquad (7)$$

$$\alpha_{y,a} = \frac{1}{X_y} \qquad a > a_{kink}$$

and where

$$X_y = \left\{ \sum_{a=a1}^{6} x_y + \sum_{a=7}^{a_{kink}} \left[x_y + \frac{(a-6)(1-x_y)}{a_{kink}-6} \right] + \sum_{a=a_{kink}}^{a2} a \right\} / (a2 - a1 + 1) \qquad (8)$$

- see Figure 7.

The estimable parameters are thus: $a50$, $a95$, and x_y for y=1973-2005 where $x_y \ge 0$. It is assumed that for 2006+ the average of the 1973-2005 x_y values applies. When calculating MSY, it is assumed that the 2006 selectivity function applies.

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

$$-\ln L \rightarrow -\ln L + w_{pen} \sum_{y=1973}^{2004} (x_y - x_{y+1})^2 \qquad (9)$$

A number of fixed values of $a1, a2$ and a_{kink} were tested (see Table 4b). The selected values for sensitivity 3b are $a1 = 5, a2 = 20$ and a_{kink} =9. A selectivity penalty weighting value of $w_{pen} = 5$ was also selected, for reasonable estimation performance.

Projections

The resource is projected ahead from 2007 to 2016 under a number of constant catch (CC) levels: 330 MT, 360 MT, 390 MT, 420 MT and 450 MT.

Results

Assessment results

The assessment results for the RC model and the three sensitivity analyses are presented in Table 4a, and correspond to Bayesian posterior modes. Table 4b reports results for a number of sensitivity 3b variants. Fits to CPUE data and catch-at-age data are illustrated in Figures 1 and 2 respectively. The RC and effort saturation (ES) fits to the CPUE data are shown in Figure 1a, those for the catch-at-age down-weight (CDW) scenarios in Figure 1b, for the time varying selectivity (TVS – MARAM method) in Figure 2c and for the TVS-OLRAC method in Figure 2d. Figures 3a-d show the estimated exploitable biomass and spawning biomass trends. Note that the spawning biomass trends show decreases over the last 10 years for all models considered.

The estimated stock-recruit residuals for the RC and the four sensitivities are illustrated in Figures 4a and b.

Projections

Table 5a presents results of projected spawning biomass trends for the RC and the four sensitivity analyses for a range of future constant catches. Table 5b reports similar statistics for variants of the TVS-OLRAC method (sensitivity 3b).

Discussion

The 2006 RC assessment of the south coast rock lobster resource estimated the resource at the start of 2005 to be 31% of carrying capacity for the exploitable portion of the stock, and 33% of capacity for the spawning biomass. The updated 2007 RC assessment estimates these values (for 2006) to now be 30% and 33% respectively (see Table 4a). Whilst these values are similar to the (Baranov based) estimates for the 2006 assessment, both the spawning biomass and exploitable biomass are now estimated to have declined slightly between the years 2005 and 2006. The MSY for the resource is estimated to be 359 MT for the RC model, and between 371 and 440 for the four sensitivity analyses reported here.

The effort saturation scenario results are more positive than those for the RC model. The ES model estimated CPUE is able to reproduce the observed CPUE trends, particularly in more recent years, to a better extent that the RC (Figure 1a).

Down-weighting the catch-at-age data once again results in a more optimistic appraisal of the resource. Through this down-weighting, this model is able to fit better the CPUE data (Figure 1b), in particular the recent upturn in CPUE. The fits to the catch-at-age data do however deteriorate substantially (see Figure 2), particularly for more recent years such as the 2000-2005 seasons for which there is appreciable overestimation of the proportion of small and underestimation of that of large lobsters. This once again points to the incompatibility of the CPUE and catch-at-age data within this model structure.

The MARAM approach time-varying selectivity scenario produces a relatively optimistic appraisal of the resource with respect to future productivity. The fit to CPUE (Figure 1c) is much better than for the RC, while that to the catch-at-age data deteriorates to a much lesser extent (Table 4a).

The implication of the OLRAC approach to time-varying selectivity produces a better still fit to the CPUE data (essentially the x_y parameter is allowed to vary pre-1994, unlike for δ_y for the MARAM approach), but does not fit the catch-at-age data as well as the MARAM approach. It produces relatively low estimates of resource productivity.

The projected spawning biomass trends estimated for the different future constant catch harvesting strategies, are rather different across the various scenarios (see Table 5a for the RC and four sensitivity scenarios). The RC predicts that catches of a little less than 330 MT will result in the spawning biomass remaining at its current (2006) level. Sensitivities 2 and 3a produce slightly more optimistic results indicating an appropriate TAC of around 380 MT and 405 MT respectively. The other two sensitivities (1 and 3b) produce less optimistic results suggesting TACs of about 350 and 330 MT respectively. This last figure (for the OLRAC-TVS approach) is relatively insensitive to variations in parameters of that model (Table 5b).

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Table 1: Total annual catch (data from WG/06/04/SCRL1) and GLM standardised CPUE (Glazer 2007) data for the South Coast rock lobster fishery.

Year	**Total Catch (MT tails)**	**CPUE (kg tails/trap)**
1973	372	
1974	973	
1975	551	
1976	712	
1977	667	0.2187
1978	461	0.2059
1979	122	0.1607
1980	176	0.2041
1981	348	0.1930
1982	407	0.1657
1983	524	0.1958
1984	450	0.1625
1985	450	0.1589
1986	450	0.2074
1987	452	0.1864
1988	452	0.2211
1989	452	0.2050
1990	477	0.1737
1991	524.54	0.1428
1992	529.96	0.1393
1993	524.27	0.1271
1994	507.89	0.1161
1995	504.89	0.1077
1996	442.69	0.0900
1997	416.39	0.0823
1998	516.03	0.0786
1999	512.16	0.0800
2000	423.4	0.0896
2001	288	0.0998
2002	340	0.1107
2003	350	0.1154
2004	382	0.1298
2005	382	0.1136
2006	382	

Table 2: Scientific sampling-based catches at-age (proportions) for the South Coast rock lobster. [Note that the 1999 values are omitted from the assessment because of poor sampling levels that season.]

AGE	1994	1995	1996	1997	1998	2000	2001	2002	2003	2004	2005
0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
6	0.0000	0.0000	0.0039	0.0000	0.0056	0.0000	0.0000	0.0000	0.0000	0.0001	0.0000
7	0.0003	0.0006	0.0140	0.0003	0.0201	0.0012	0.0001	0.0011	0.0009	0.0004	0.0004
8	0.0029	0.0093	0.0266	0.0066	0.0484	0.0069	0.0010	0.0190	0.0092	0.0075	0.0059
9	0.0215	0.0554	0.0478	0.0609	0.0834	0.0389	0.0105	0.0510	0.0218	0.0379	0.0223
10	0.0709	0.1265	0.0819	0.1467	0.1233	0.1166	0.0451	0.0767	0.0446	0.0690	0.0540
11	0.1441	0.1838	0.1202	0.2080	0.1429	0.2099	0.1119	0.0930	0.0816	0.0924	0.0989
12	0.1537	0.1369	0.1256	0.1373	0.0939	0.1648	0.1548	0.0986	0.1033	0.1106	0.1108
13	0.1493	0.1110	0.1184	0.1079	0.0844	0.1224	0.1552	0.1143	0.1278	0.1180	0.1186
14	0.1343	0.0829	0.1054	0.0775	0.0744	0.0782	0.1437	0.1242	0.1453	0.1196	0.1203
15	0.0677	0.0440	0.0603	0.0412	0.0462	0.0397	0.0762	0.0708	0.0868	0.0734	0.0733
16	0.0786	0.0548	0.0782	0.0498	0.0637	0.0461	0.0924	0.0927	0.1155	0.1003	0.1003
17	0.0386	0.0342	0.0419	0.0262	0.0361	0.0252	0.0459	0.0510	0.0564	0.0534	0.0557
18	0.0293	0.0319	0.0349	0.0215	0.0315	0.0213	0.0354	0.0434	0.0433	0.0443	0.0479
19	0.0238	0.0274	0.0296	0.0192	0.0271	0.0195	0.0290	0.0368	0.0372	0.03880	0.0419
20+	0.0849	0.1013	0.1113	0.0968	0.1192	0.1094	0.0990	0.1275	0.1266	0.1350	0.1498

Table 3: Somatic growth parameters as detailed in Glazer and Groeneveld (1999).

α (w in gm)	0.0007
β	2.846
l_∞ (mm CL)	111.9
κ (year^{-1})	0.08
t_0 (years)	0.0

Table 4a: Stock assessment results (Bayesian posterior modes) for the Reference Case and three sensitivity analyses. Units of mass-related quantities (e.g. *MSY*) are tons. Note that recruitment residuals from 1974 to 1997 are estimated in all instances.

	Reference Case	**Sensitivity 1: Effort saturation**	**Sensitivity 2: Catch-at-age log-likelihood down-weighted by 0.10 multiplier**	**Sensitivity 3a: Time varying selectivity – MARAM method**	**Sensitivity 3b: Time varying selectivity – OLRAC method**
K^{sp}	8465	7917	7344	8270	8203
h	0.877	0.866	0.920	0.877	0.913
M	0.098	0.122	0.134	0.122	0.101
a_{50}	10.04	10.03	11.19	10.80	10.01
a_{95}	12.46	12.38	13.75	12.76	12.12
$n*$	-	1.0 fixed	-	-	-
E'	-	2500 fixed	-	-	-
$E*$	-	6826	-	-	-
σ	0.202	0.113	0.076	0.126	0.054
σ_{age}	0.067	0.066	0.137	0.054	0.065
-*lnL* CPUE	-31.82	-48.81	-60.36	-45.48	-69.97
-*lnL* CAA	-115.82	-116.40	-12.68	-144.65	-119.79
-*lnL* S-R	4.57	6.32	5.65	1.96	4.47
-*lnL* effort expt	**-**	1.16		**-**	**-**
Selectivity pen				8.84	5*3.73
-lnL CPUE+CAA+SR	**-143.08**	**-158.89**	**-67.39**	**-188.17**	**-185.28**
-*lnL*(total)	**-143.70**	**-160.66**	**-56.66**	**-179.95**	**-167.26**
MSY	359	402	440	433	371
$MSYL^{exp}/K$	0.214	0.207	0.146	0.183	0.196
$B_{2006}^{\exp}/K^{\exp}$	0.307	0.349	0.358	0.329	0.316
$B_{2006}^{\exp}/B_{msy}^{\exp}$	1.440	1.679	2.448	1.795	1.612
B_{2006}^{sp}/K^{sp}	0.331	0.372	0.438	0.373	0.342
B_{2016}^{sp}/K^{sp} **CC=330 MT**	0.327	0.397	0.486	0.441	0.345
$B_{2016}^{sp}/B_{06}^{sp}$ **CC=330 MT**	0.989	1.067	1.108	1.182	1.001

Table 4b: Time-varying selectivity – ORLAC method sensitivities.

	3b	**3b1**	**3b2**	**3b3**
a_1	5	5	5	5
a_2	20	20	20	**16**
a_{kink}	**9**	7	**11**	9
Selectivity penalty multiplier	**5**	2	**10**	**5**
-lnL CPUE	-70	-69	-64	-73
-lnL CAA	-120	-116	-124	-120
SR pen	4.47	4.11	2.86	4.40
Selectivity penalty	3.74	8.9	1.60	2.1
-lnL Total	-167.21	-163.76	-169.96	-168.21
-lnL (CPUE+CAA+SR)	-185.28	-180.86	-185.22	-188.33

Table 5a: Projected spawning biomass estimates for various harvesting strategies and models. Units of mass-related quantities (e.g. *RY*) are tons. [Shaded cells show a biomass reduction relative to 2006.]

Statistic	**Strategy**	**Reference Case**	**Sensitivity 1: Effort saturation**	**Sensitivity 2: Catch-at-age log-likelihood down-weighted by 0.10 multiplier**	**Sensitivity 3a: Time varying selectivity – MARAM method**	**Sensitivity 3b: Time varying selectivity – OLRAC method**
B_{2006}^{sp}/K^{sp}	**ALL**	0.331	0.372	0.438	0.373	0.342
B_{2016}^{sp}/K^{sp}						
	CC=450	0.213	0.284	0.373	0.333	0.228
	CC=420	0.242	0.313	0.401	0.361	0.257
	CC=390	0.270	0.341	0.429	0.387	0.287
	CC=360	0.299	0.369	0.457	0.414	0.316
	CC=330	0.327	0.397	0.486	0.441	0.345
$B_{2016}^{sp}/B_{2006}^{sp}$						
	CC=450	0.642	0.766	0.851	0.894	0.665
	CC=420	0.730	0.842	0.915	0.967	0.751
	CC=390	0.817	0.918	0.980	1.039	0.837
	CC=360	0.903	0.993	1.044	1.110	0.922
	CC=330	0.989	1.067	1.108	1.182	1.001
	MSY					

Table 5b: Projected spawning biomass estimates for four variants of the TVS-OLRAC method model. Units of mass-related quantities (e.g. *RY*) are tons. [Shaded cells show a biomass reduction relative to 2006.]

Statistic	Strategy	3b	3b1	3b2	3b3
B^{sp}_{2006}/K^{sp}	**ALL**	0.342	0.400	0.374	0.363
B^{sp}_{2016}/K^{sp}					
	CC=450	0.228	0.286	0.275	0.251
	CC=420	0.257	0.314	0.304	0.280
	CC=390	0.287	0.342	0.332	0.309
	CC=360	0.316	0.370	0.360	0.338
	CC=330	0.345	0.398	0.388	0.366
$B^{sp}_{2016}/B^{sp}_{2006}$					
	CC=450	0.665	0.714	0.735	0.692
	CC=420	0.751	0.785	0.811	0.772
	CC=390	0.837	0.856	0.888	0.852
	CC=360	0.922	0.925	0.963	0.931
	CC=330	1.001	0.995	1.037	1.010
	MSY	371	399	396	382

Figure 1a: Observed and estimated CPUE for the Reference Case (RC) and effort saturation (ES – Sensitivity 1) scenarios.

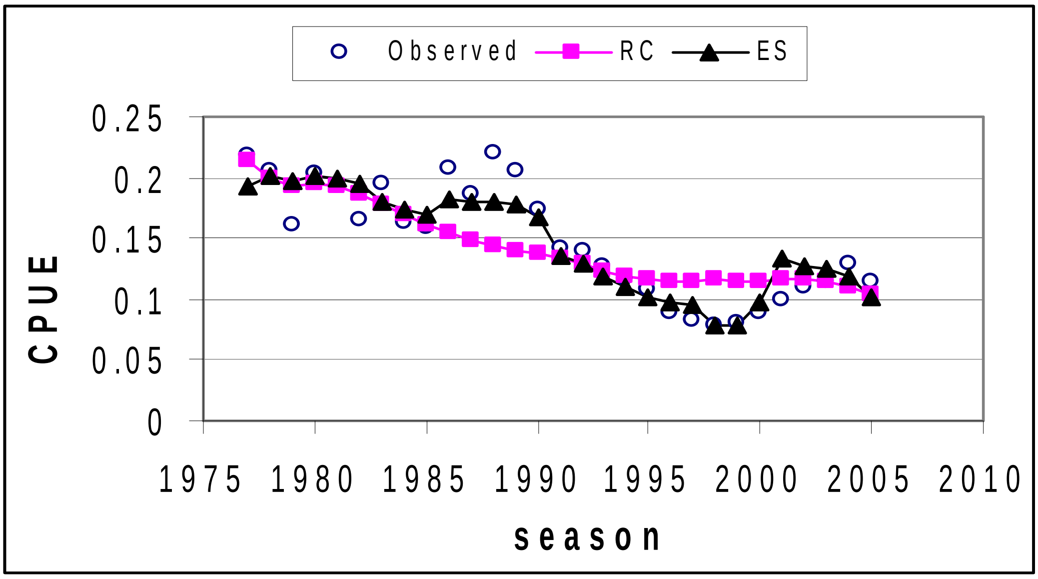


Figure 1b: Observed and estimated CPUE for the catch-at-age down-weight (CDW – Sensitivity 2) scenario.

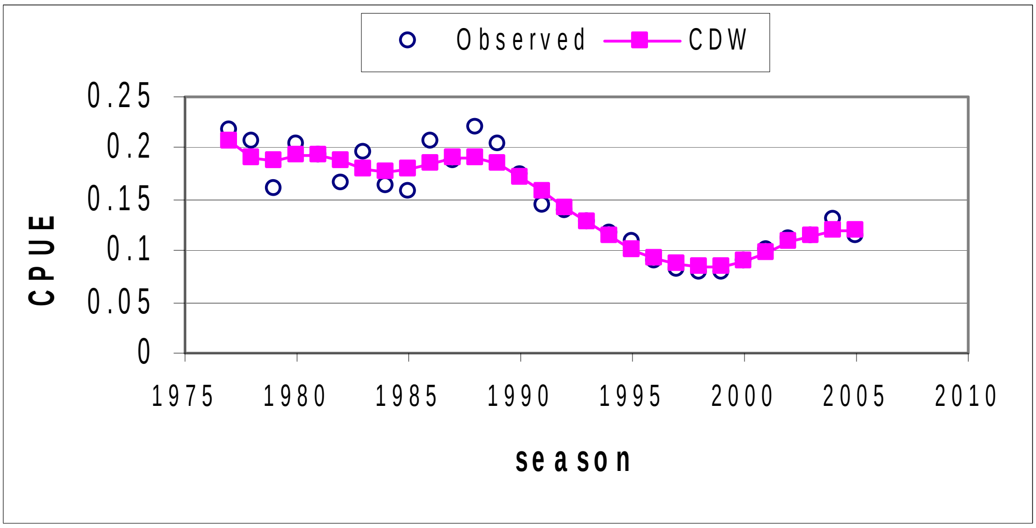


Figure 1c: Observed and estimated CPUE for the time varying selectivity- MARAM method – (TVS – Sensitivity 3a) scenario.

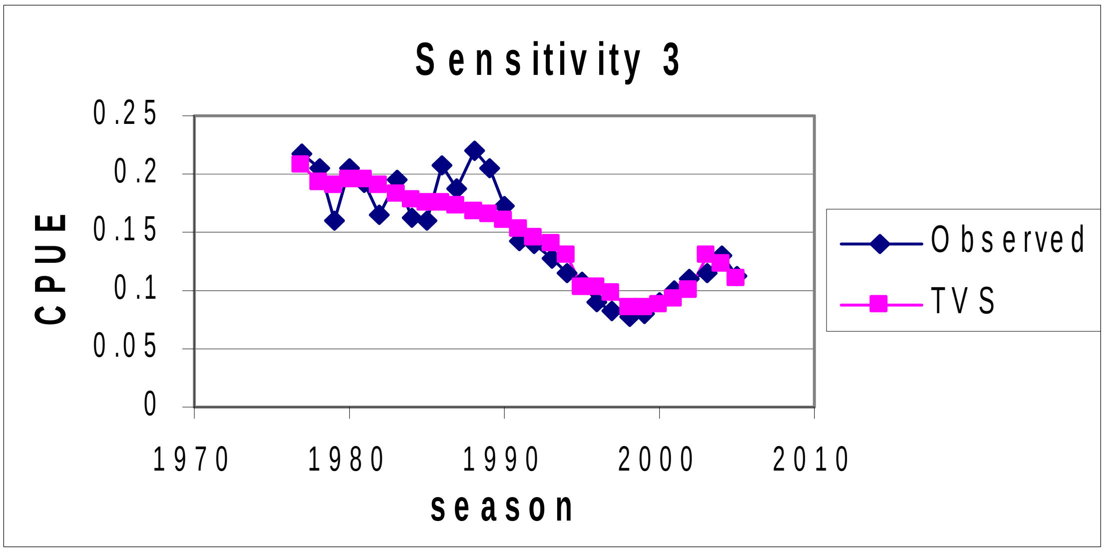


Figure 1d: Observed and estimated CPUE for the time varying selectivity- OLRAC method – (TVS – Sensitivity 3b) scenario.

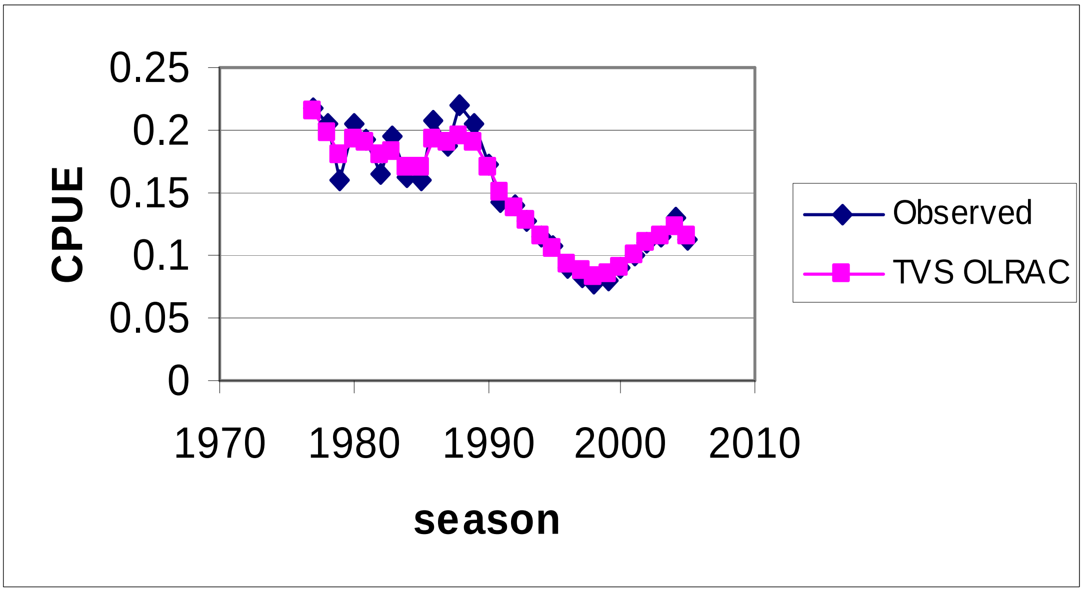


Figure 2: Observed and estimated catch-at-age proportions for the Reference Case (RC) and catch-at-age down-weight (CDW – Sensitivity 2) scenarios.

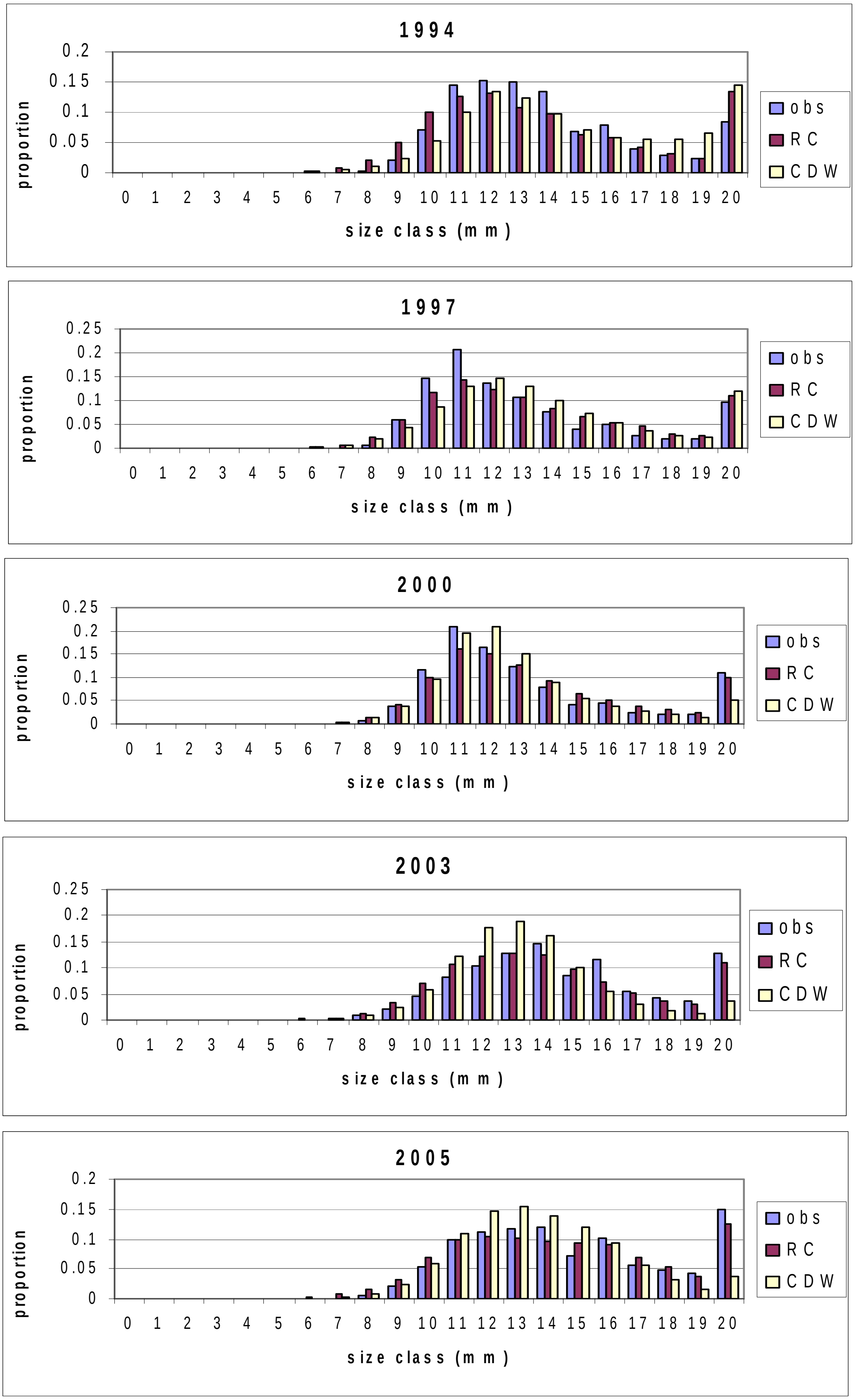


Figure 3a: Exploitable biomass trends for the Reference Case and effort saturation (Sensitivity 1) scenarios.

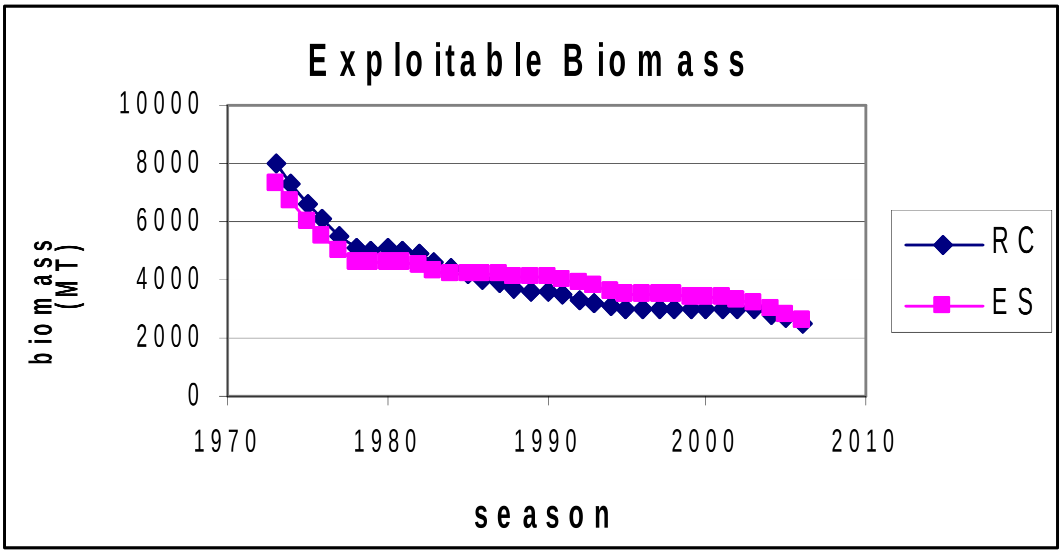


Figure 3b: Spawning biomass trends for the Reference Case and effort saturation (Sensitivity 1) scenario.

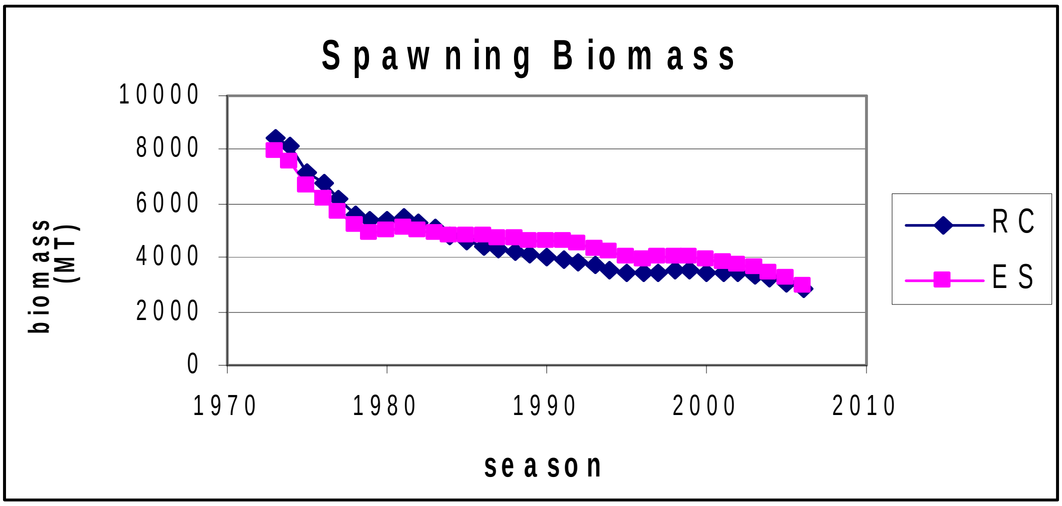


Figure 3c: Spawning biomass trends for the time-varying selectivity MARAM method scenario.

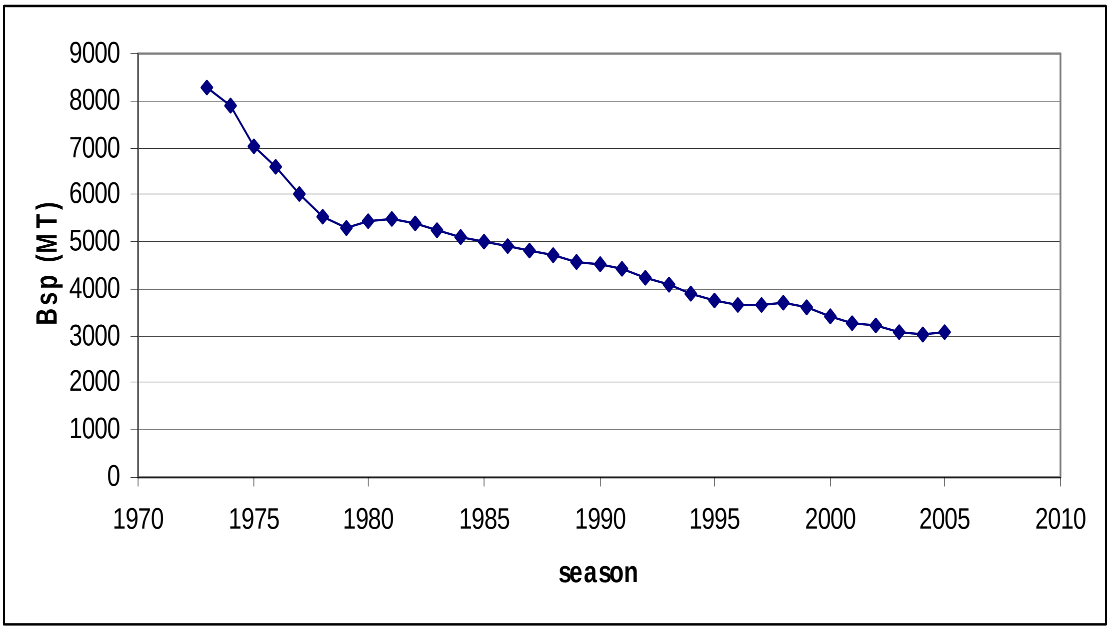


Figure 3d: Spawning biomass trends for the time-varying selectivity OLRAC method (3b) scenario.

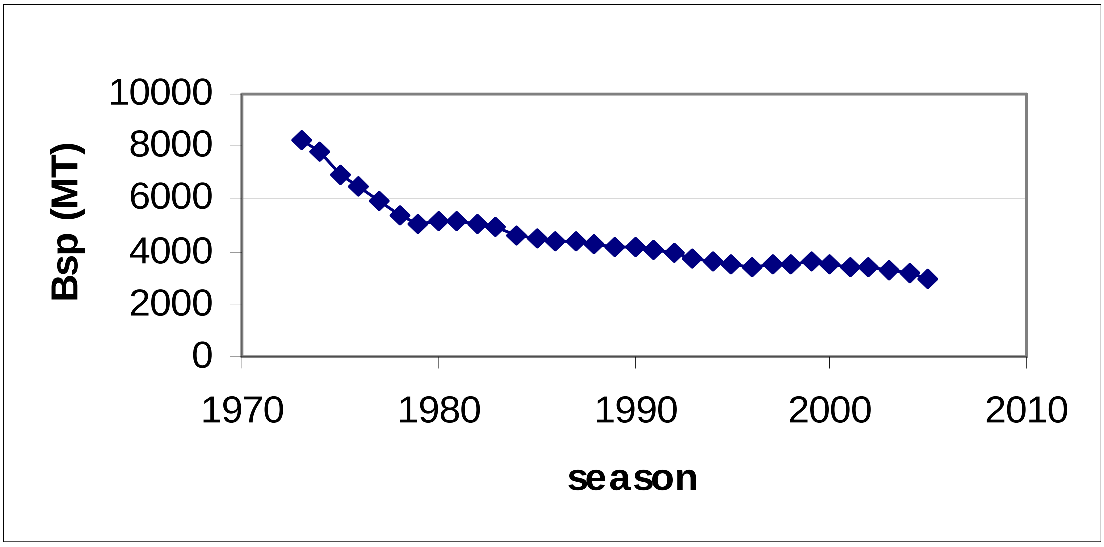


Figure 4a: Stock-recruitment residuals for the Reference Case, effort saturation (Sensitivity 1), catch-at-age down-weighting (Sensitivity 2) and time-varying selectivity – MARAM method (Sensitivity 3a) scenarios.

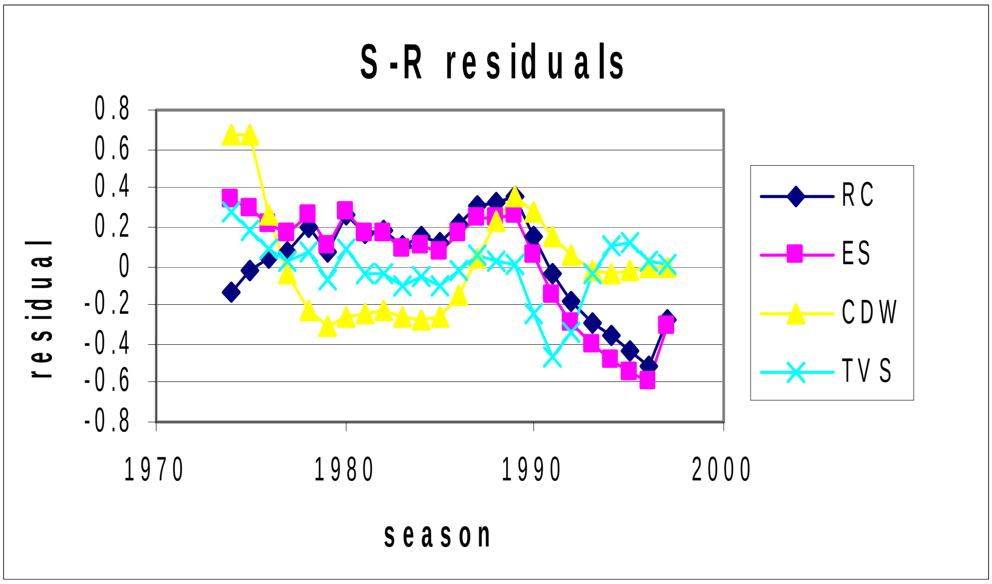


Figure 4b: Comparison of the stock-recruitment residuals for the two time-varying selectivity scenarios – MARAM method (sensitivity 3a) and OLRAC method (Sensitivity 3b).

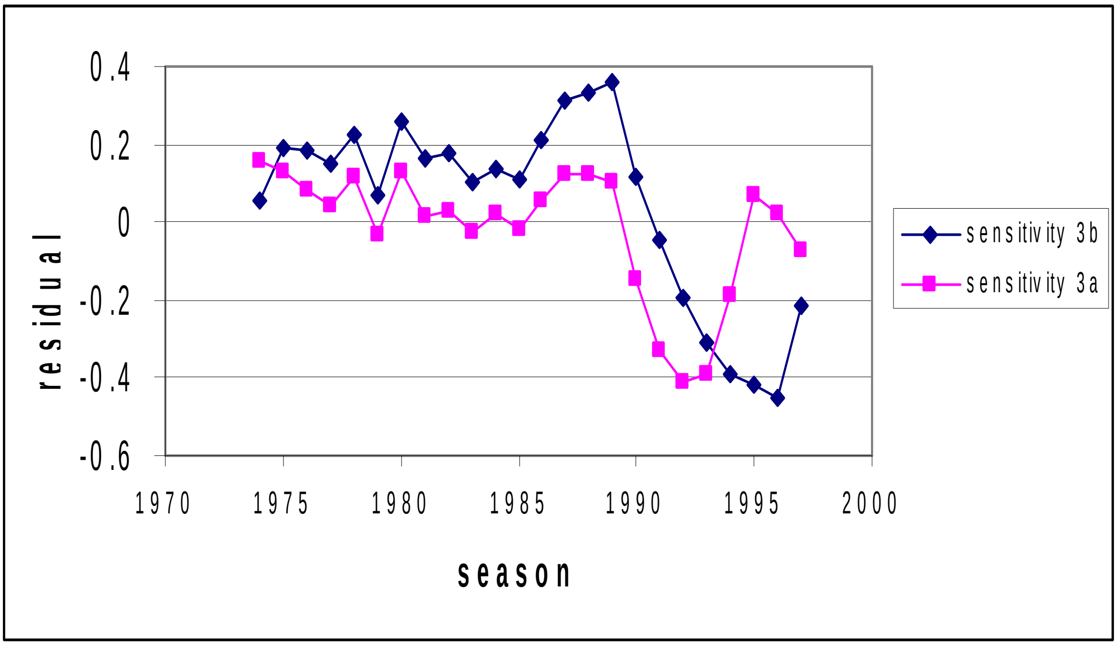


Figure 5a: The selectivity time-varying parameter δ_y values for sensitivity 3a (TVS - MARAM method).

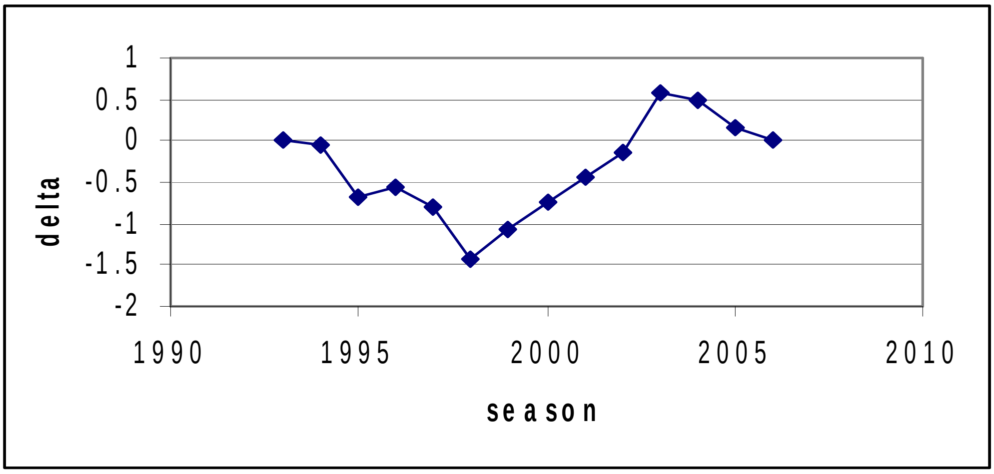


Figure 5b: The selectivity time-varying parameter x_y values for sensitivity 3b (TVS - OLRAC method).

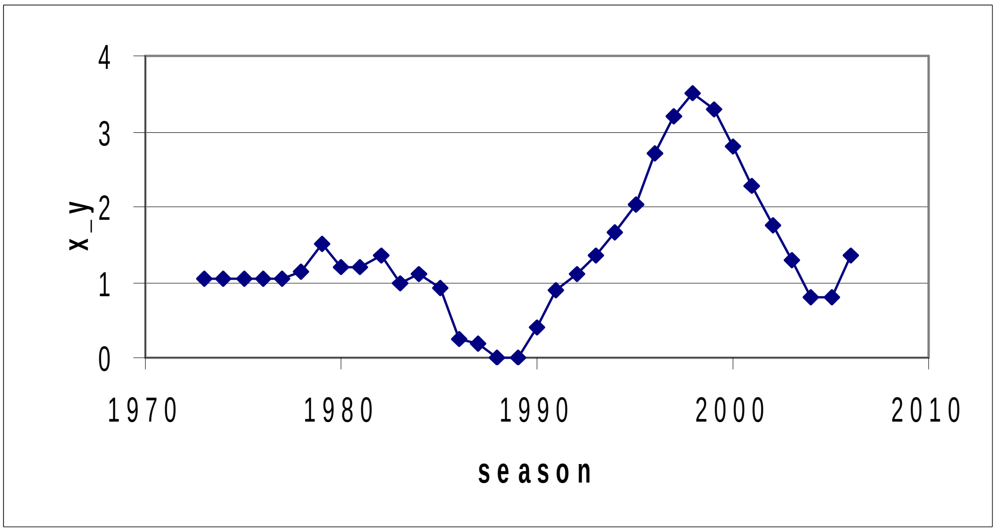


Figure 6a: Selectivity functions for sensitivity 3a (TVS - MARAM method).[Note that these values have been scaled so that the selectivity for age=20 when δ_y =0 (pre-1994 and post-2005) is equal to 1.0]

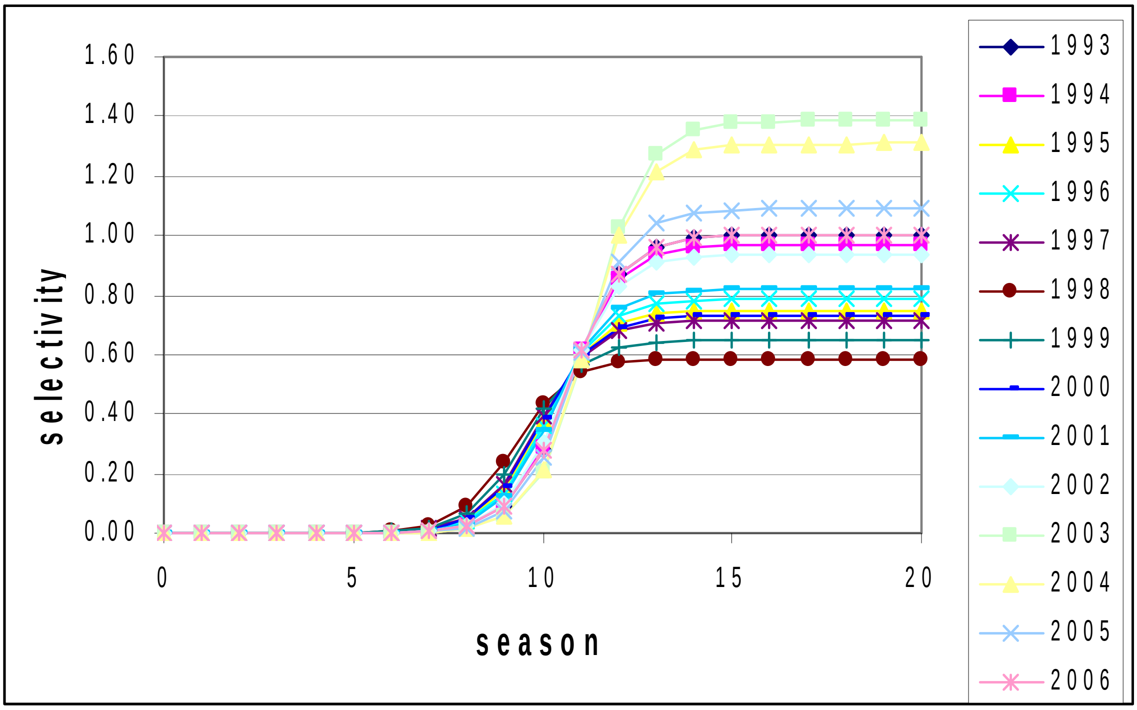


Figure 6a: Selectivity functions for sensitivity 3b (TVS - OLRAC method. Only years 1993-2006 shown.

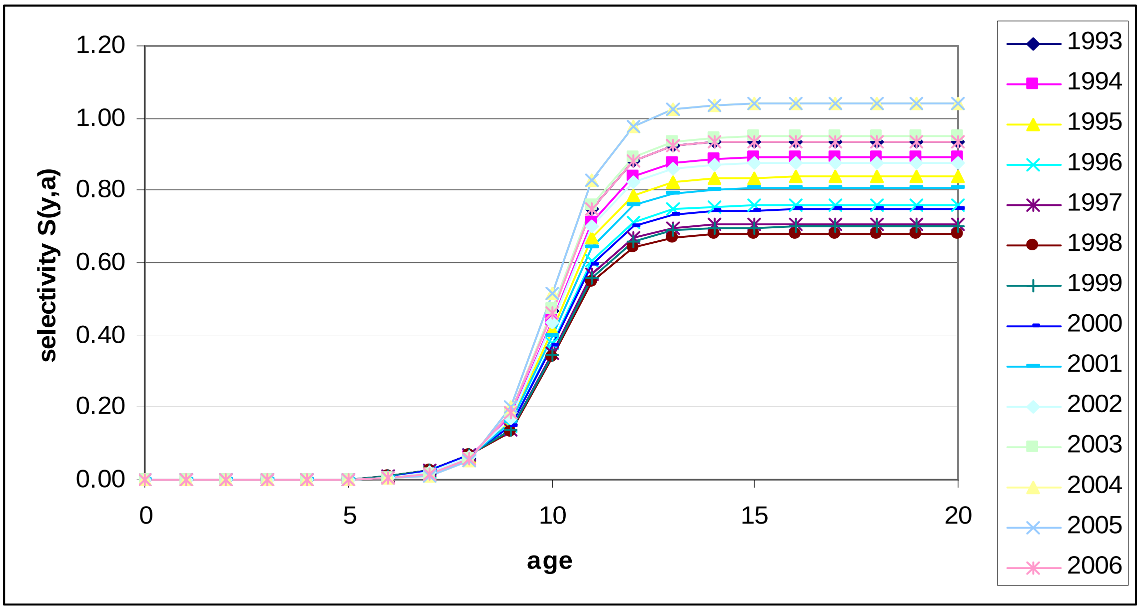
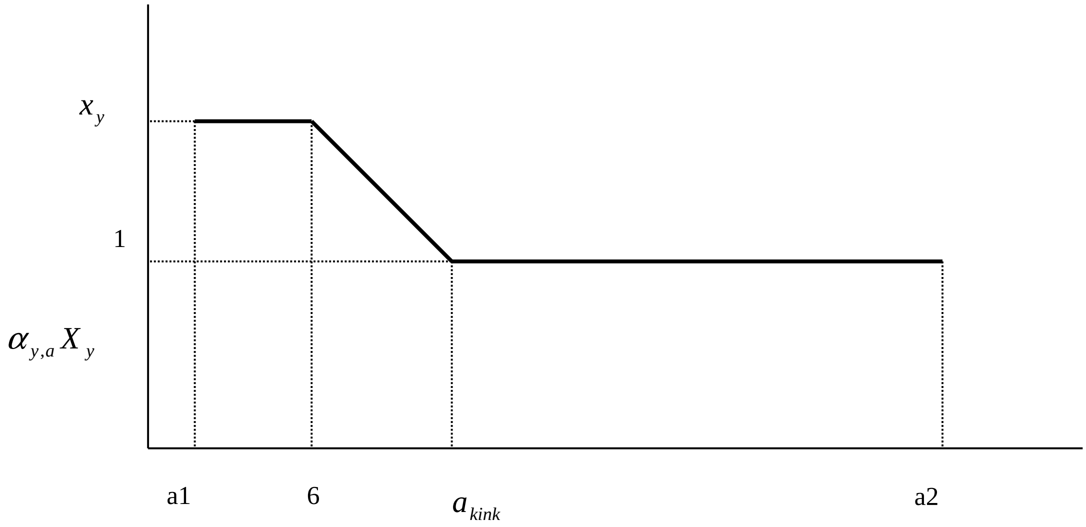


Figure 7: Shape of the $\alpha_{y,a}$ function; $x_y \geq 0$ is estimated for each year and can be either ≤ 1 or ≥ 1.



Appendix: The Age-structured production model for the South Coast rock lobster resource.

1. The population model:

The resource dynamics are modeled by the equations:

$$N_{y+1,0} = R_{y+1} \tag{1}$$

$$N_{y+1,a+1} = N_{y,a} e^{-M_a} (1 - S_a F_y) \tag{2}$$

$$N_{y+1,m} = N_{y,m-1} e^{-M_{m-1}} (1 - S_{m-1} F_y) + N_{y,m} e^{-M_m} (1 - S_m F_y) \tag{3}$$

where

$N_{y,a}$ is the number of lobsters of age *a* at the start of year *y*,

M_a denotes the natural mortality rate on lobsters of age *a*,

S_a is the age-specific selectivity,

F_y is the fully selected fishing mortality in year *y*, and

m is the maximum age considered (taken to be a plus-group).

The number of recruits at the start of year *y* is related to the spawner stock size by a stock-recruitment relationship:

$$R_y = \frac{\alpha B_y^{sp}}{\beta + (B_y^{sp})^{\gamma}} e^{\varsigma_y} \tag{4}$$

where

α, β and γ are spawner biomass-recruitment parameters (γ=1 for a Beverton-Holt relationship),

ς_y reflects fluctuation about the expected recruitment for year *y*, and

B_y^{sp} is the spawner biomass at the start of year *y*, given by:

$$B_y^{sp} = \sum_{a=1}^{m} f_a w_a N_{y,a} \tag{5}$$

where w_a is the begin-year mass of fish at age *a* and f_a is the proportion of fish of age *a* that are mature.

In order to work with estimable parameters that are more meaningful biologically, the stock-recruit relationship is re-parameterised in terms of the pre-exploitation equilibrium spawning biomass, K^{sp}, and the "steepness" of the stock-recruit relationship (recruitment at $B^{sp} = 0.2K^{sp}$ as a fraction of recruitment at $B^{sp} = K^{sp}$):

$$\alpha = \frac{\left(5 - 0.2^{\gamma-1}\right) h R_1 \left(K^{sp}\right)^{\gamma-1}}{5h - 1} \tag{6}$$

and

$$\beta = \frac{\left(K^{sp}\right)^{\gamma} \left(1 - 0.2h\right)^{\gamma-1}}{5h - 1} \tag{7}$$

where

$$R_1 = K^{sp} \Bigg/ \left[\sum_{a=1}^{m-1} f_a w_a e^{-\sum_{a'=0}^{a-1} M_{a'}} + f_m w_m \frac{e^{-\sum_{a'=0}^{m-1} M_{a'}}}{1-e^{-M_m}} \right] \tag{8}$$

The total catch by mass in year *y* is given by:

$$C_y = \sum_{a=0}^{m} w_{a+\frac{1}{2}} N_{y,a} e^{-M_a/2} S_a F_y \tag{9}$$

where $w_{a+\frac{1}{2}}$ denotes the mid-year mass of a lobster at age *a*.

The model estimate of mid-year exploitable biomass is given by:

$$\hat{B}_y = \sum_{a=0}^{m} w_{a+\frac{1}{2}} S_a N_{y,a} e^{-M_a/2} (1 - S_a F_y / 2) \tag{10}$$

where

$\hat{B}_y$ is the model estimate of exploitable biomass for year *y*, and

S_a is the fishing selectivity-at-age for age *a*.

Models that do not allow for the possibility of fluctuations about the stock-recruitment relationship (i.e. those which set $\varsigma_y = 0$ in equation 4) assume that the resource is at the deterministic equilibrium that corresponds to an absence of harvesting at the start of the initial year ($B^{sp}_{1973} = K^{sp}$). For models that allow for that possibility, this assumption together with that of the associated equilibrium age-structure is made for 1973, with the biomass and age-structure thereafter potentially impacted by such fluctuations.

2. The likelihood function

The model is fitted to CPUE and catch-at-age data to estimate model parameters. Contributions by each of these to the negative log-likelihood (-ln*L*) are as follows:

2.1 Relative abundance data (CPUE):

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

$$CPUE_y = qB_y e^{\varepsilon_y} \text{ or } \varepsilon_y = \ln(CPUE_y) - \ln(qB_y) \tag{11}$$

where

$CPUE_y$ is the CPUE abundance index for year *y*,

B_y is the model estimate of mid-year exploitable biomass for year *y* given by equation 10,

q is the constant of proportionality (catchability coefficient), and

ε_y from $N(0,\sigma^2)$.

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

$$-\ln L = \sum_y \left[(\varepsilon_y)^2 / 2\sigma^2 + \ln \sigma \right] \qquad (12)$$

where

σ is the residual standard deviation estimated in the fitting procedure by its maximum likelihood value:

$$\hat{\sigma} = \sqrt{1/n \sum_y \left(\ln CPUE_y - \ln \hat{q}\hat{B}_y \right)^2} \qquad (13)$$

where

n is the number of data points in the CPUE series, and

q is the catchability coefficient, estimated by its maximum likelihood value:

$$\ln \hat{q} = 1/n \sum_y \left(\ln CPUE_y - \ln \hat{B}_y \right) \qquad (14)$$

2.2 "Effort saturation"

When the possibility of "effort saturation" is taken into account, the CPUE abundance relationship of equation 11 is modified as follows:

$$CPUE_y = q_y B_y e^{\varepsilon_y} \text{ or } \varepsilon_y = \ln(CPUE_y) - \ln(q_y B_y) \qquad (15)$$

where

$$q_y = q' / \left[1 + \left(\frac{E_y - E'}{E^* - E'} \right)^{n^*} \right] \qquad \text{if } E_y > E' \qquad (16)$$

$$q_y = q' \qquad \text{if } E_y \leq E'$$

where

$CPUE_y$ is the GLM standardised CPUE data given in Table 1,

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

$$q' = e^{\left(\sum_{y, E_y < E'} \left(\ln(CPUE_y) - \ln B_y \right) + \sum_{y, E_y \geq E'} \left(\ln(CPUE_y \left[1 + \left(\frac{E_y - E'}{E^* - E'} \right)^{n^*} \right]) - \ln B_y \right) \right) / n}$$

E^* quantifies the extent of "effort saturation",

E' is the threshold effort above which "effort saturation" sets in, and

n^* allows for flexibility in the "effort saturation" relationship.

For this scenario, equation 13 is modified by replacing q with the q_y as defined above.

2.3 Catches-at-age

The contribution of the catch-at-age data to the negative of the log-likelihood function when assuming a log-normal error distribution and when making an adjustment to effectively weight in proportion to sample size is given by:

$$-\ln L = \sum_y \sum_a \left[\ln(\sigma_{age} / \sqrt{p_{y,a}}) + p_{y,a} \left(\ln p_{y,a} - \ln \hat{p}_{y,a} \right)^2 / 2(\sigma_{age})^2 \right] \qquad (17)$$

where

$p_{y,a} = C_{y,a} / \sum_{a'} C_{y,a'}$ is the observed proportion of fish caught in year y that are of age a,

$\hat{p}_{y,a} = \hat{C}_{y,a} / \sum_{a'} \hat{C}_{y,a'}$ is the model predicted proportion of fish caught in year *y* that are of age *a*, where:

$$\hat{C}_{y,a} = N_{y,a} e^{-M_a/2} S_a F_y \tag{18}$$

and σ_{age} is the standard deviation associated with the catch-at-age data, estimated in the fitting procedure by:

$$\hat{\sigma}_{age} = \sqrt{\left[\sum_y \sum_a p_{y,a} (\ln p_{y,a} - \ln \hat{p}_{y,a})^2 / \sum_y \sum_a 1 \right]} \tag{19}$$

Note that allowance is made for a "minus" group (lobsters age 8 and younger) in the catch-at-age contribution to the likelihood function, as well as for a "plus" group (lobsters aged 20 and over).

2.4 Stock-recruitment function residuals:
The assumption that these residuals are log-normally distributed and could be serially correlated defines a corresponding joint prior distribution. This can be equivalently regarded as a penalty function added to the log-likelihood, which for fixed ρ is given by:

$$-\ln L = \sum_{y=y1}^{y2} \left[\frac{\varsigma_y - \rho \varsigma_{y-1}}{\sqrt{1-\rho^2}} \right]^2 / 2\sigma_R^2 \tag{20}$$

where

$\varsigma_y = \rho \tau_{y-1} + \sqrt{1-\rho^2} \varepsilon_y$ is the recruitment residual for year *y* (see equation 4), which is estimated for years *y1* to *y2* if $\rho = 0$, or *y1*+1 to *y2* if $\rho > 0$,

$\varepsilon_y \sim N(0, \sigma_R^2)$,

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

ρ is their serial correlation coefficient, which is input.

Note that for the Reference Case assessment, ρ is set equal to zero, i.e. the recruitment residuals are assumed uncorrelated, and σ_R is set equal to 0.4. Because of the absence of informative age data for a wider period, recruitment residuals are estimated for years 1974 to 1997 only for the 2007 assessment.

3 Model parameters

Natural mortality: Natural mortality, M_a, is assumed to be the same (*M*) for all age classes.

Commercial selectivity-at-age: The following time-invariant logistic curve is assumed for the commercial selectivity:

$$S_a = \frac{1}{1 + e^{(-\ln(19)(a-a_{50})/(a_{95}-a_{50}))}} \tag{21}$$

where

a_{50} years is the age-at-50% selectivity which is estimated, and

a_{95} years is the age-at-95% selectivity which is estimated.

Age-at-maturity: The proportion of lobsters of age *a* that are mature is approximated by $f_a = 1$ for *a* > 9 years (i.e. $f_a = 0$ for a = 0, …,9).

Minimum age: Age 8 it taken to be a minus group.

Maximum age: *m* = 20, and is taken as a plus-group.

Mass-at-age: The mass *w* of a lobster at age *a* is given by:

$$w = \alpha\left[l_\infty\left(1 - e^{-\kappa(a-t_0)}\right)\right]^\beta \qquad (22)$$

where the values assumed for the growth parameters are shown in Table 3.

Stock-recruitment relationship: The shape parameter, γ, is fixed to 1, corresponding to a Beverton-Holt form.

4. The Bayesian approach

The Bayesian method entails updating prior distributions for model parameters according to the respective likelihoods of the associated population model fits to the CPUE, catch-at-age and tag-recapture data, to provide posterior distribution for these parameters and other model quantities.

In the case of an age-structured production model, the Bayesian computations require integration over the following priors:

- The “steepness” of the stock-recruit relationship (*h*), and
- Natural mortality (M_a), assumed independent of age.
- In addition, we integrate over the two parameters defining the shape of the selectivity-at-age curve (a_{50} and a_{95}).

Furthermore, priors for the parameters characterising the postulated “effort saturation” effects (E^*, E' and *n**) of equation 16 are also required. In applications considered thus far, E' and *n** have been taken as fixed. An effective prior based on the effort saturation experiment leads to the following term:

$$-\ln L = 4\ln\sigma_E + 2 \qquad (23)$$

where σ_E is estimated from the data such that:

$$\sigma_E = \sqrt{SS(E^*)/4} \qquad (24)$$

where σ_E is the standard deviation of the residuals.

The *SS*(*E**) term is developed as follows (Butterworth 2000): Considering the “full effort” exerted in Dec-Jan of the 1998/99 experiment as the standard, the extent of effort reduction (λ) and the associated relative change in CPUE (GLM-standardised to adjust for normal monthly trends), $f^{obs}(\lambda)$, were as follows for the four area-period combinations considered in the experiment:

Area-period	λ	$f^{obs}(\lambda)$
East – Feb/Mar	0.93	1.25
East – Apr/May	1.24	1.30
Agulhas – Feb/Mar	1.15	1.04
Agulhas – Apr/May	0.60	0.71

The effort "reduction" factors, λ, above are taken from Groeneveld *et al*. (1999), (specifically Table 2c) for effective effort. The $f^{obs}(\lambda)$ values follow from Tables 1 and 2 of an update of a section of that paper (WG/07/99/SCL16a), by dividing CPUE ratios (in relation to the Dec-Jan values taken as the standard) from the 1998/99 experiment by average values over the preceding 1991/92 to 1997/98 seasons.

To relate this "observed" information to a model for the extent of effort saturation, the formulation of Geromont (2000a), equation 16, is used:

$$\hat{f}(\lambda) = \frac{1+\left[\left(E_{98/99} - E'\right)/\left(E^* - E'\right)\right]^{n^*}}{1+\left[\left(\lambda E_{98/99} - E'\right)/\left(E^* - E'\right)\right]^{n^*}} \qquad (25)$$

Taking the effort for 1998/99, given by $C_{98/99}/CPUE_{98/99}$, (see Geromont 2000a, equation 16 and Table 1) to be reflective of the full effort Dec-Jan period of the experiment, sets $E_{98/99}$ above to equal 5255. Geromont (pers. commn) advised values of E'=2500 and n^* = 1 to be typical of those obtained in her fits of the ASPM model with effort saturation. This leaves only the key E^* parameter unspecified, and this is estimated by minimizing the sums of squared differences between the observed $f(\lambda)$ values and those predicted by equation 25 above:

$$SS(E^*) = \sum_{i=1}^{4}\left[f^{obs}(\lambda_i) - \hat{f}(\lambda_i, E^*)\right]^2 \qquad (26)$$

The catchability coefficient (q) and the standard deviations associated with the CPUE and catch-at-age data (σ and σ_{age}) are estimated in the fitting procedure by their maximum likelihood values, rather than integrating over these three parameters as well. This is adequately accurate given reasonable large sample sizes (Walters and Ludwig 1994, Geromont and Butterworth 1995).

Modes of posteriors, obtained by finding the maximum of the product of the likelihood and the priors, are then estimated rather than performing a full Bayesian integration, due to the time intensiveness of the latter.

4.1 Priors

The following prior distribution for *h* is assumed, as previously agreed to by the Working Group (see also Butterworth 1997 and Groeneveld *et al*. 1997).

h: N(0.95,SD) with SD=0.2, where the normal distribution is truncated at $h = 1$.