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Assessment of OEO 3A black oreo for 2006–07

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EXECUTIVE SUMMARY

Doonan, I.J.; Coburn, R.P.; McMillan, P.J. (2009). Assessment of OEO 3A black oreo for 2006–07.

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An updated stock assessment for black oreo in OEO 3A is presented using a NIWA CASAL stock assessment model. The population was modelled using three spatial areas to cope with the spatial structure observed in the catch and length data. The three spatial areas included: a northern area that contained small fish and was generally shallow (Area 1), a southern area that contained large fish and was generally deeper (Area 3), and a transition area (Area 2) that lay between Areas 1 and 3. Age dependent migration was allowed in the model to move the fish between the areas.

Input data for each area included: new absolute abundance estimates and length data from the 2006 acoustic survey; a revised maturity ogive; revised and updated catch history; relative abundance estimates from an updated and a new post-GPS standardised CPUE analyses; revised observer length frequencies. Observed lengths in the commercial fishery were compiled for each area where enough data were available and the absolute abundance at length was converted to a length frequency using fixed length-weight parameters.

The base case median B_0 estimate for mature fish for OEO 3A was 87 400 t (90% confidence interval of 83 200–92 400 t). Mature mid-year biomass for OEO 3A in the current year (2006–07) was 25 200 t (21 100–30 100 t), about 29% B_0. The black oreo catch in OEO 3A in 2006–07 was about 1651 t.

Non-migration parameter estimates have low uncertainties in the Bayesian analysis with c.v. estimates less than 12%. This should be viewed with care as true variability is likely to be underestimated and some variability sources were not considered in the analyses, e.g., the use of deterministic recruitment, and the estimation error in natural mortality. The base case estimates a large reservoir of mature fish in Area 1, which is seldom fished. If Area 1 is left unfished this could mean that the current biomass could not fall below about 25% B_0 whatever the fishing effort in the other two areas. This is a consequence of using length data to estimate migration rates. One sensitivity run that excluded length data gave very few mature fish in Area 1 and fitted the CPUE and acoustic abundance data as well as the base case. The no length data case had a current mature biomass that was 17% compared to 31% B_0 for the base case (MPD results).

1. INTRODUCTION

This work addresses the following objectives in the Ministry of Fisheries project “Oreo stock assessment” (OEO2007/01).

Overall objective

1. To carry out a stock assessment of black oreo (*Allocyttus niger*) and smooth oreo (*Pseudocyttus maculatus*), including estimating biomass and sustainable yields.

Specific objectives

2. To develop both unstandardised and standardised catch per unit effort analyses with the inclusion of data up to the end of the 2005/06 fishing year for the following stocks and areas:
    - Black oreo in OEO 3A

4. To carry out a stock assessment, including reviewing and summarising historical biological data from the MFish observer programme, and estimating biomass and sustainable yields for the following areas:
    - Black oreo in OEO 3A

1.1 Overview

This report presents results of the standardised catch per unit effort analyses and the stock assessment for OEO 3A black oreo. A spatial analysis stock assessment model based on migration between three areas was first implemented in 2000 (Hicks et al. 2002). This model was converted to the NIWA CASAL software (Bull et al. 2003) with revised Areas 1–3 in the 2002 stock assessment analysis (Doonan et al. 2004). The current stock assessment is an update of the model used for the 2002 analysis. The spatial analysis model used data from Areas 1–3, which correspond to an increasing mean length of the fish caught as seen in the observer length frequency data. Area 1 contains small fish and flat ground and Area 3 contains the largest fish and many features where short tows have historically taken place. Migration was allowed in the model, and area specific selectivity curves were estimated using length frequencies derived from observed tows in the commercial fishery.

Other data fitted in the current analysis were: estimates of absolute abundance for black oreo from the 1997, 2002, and 2006 research acoustic surveys, revised catch history, relative abundance estimates from pre-GPS, relative abundance of the post-GPS standardised CPUE analyses split into two new series, and length frequencies derived from the acoustic survey absolute abundance estimates. Data were for the years up to the 2006–07 fishing year.

The stock assessment data, except catch, came from a study area that covered the main fishery on the south Chatham Rise in OEO 3A. The study area therefore did not include the fishing area in the southwest corner of OEO 3A where another fishery (Southland) takes place (Figures 1 and 2). However, the stock assessment applies to the whole of OEO 3A because the total catch from OEO 3A was used to scale up the acoustic abundance estimates to represent the catch outside the study area. Therefore, it was assumed that the population outside the study area follows the same path as the stock inside the study area.

1.2 TACCs, catch, and landings data

Black oreo are caught by trawling at depths of 600–1200 m in southern New Zealand waters (Figure 1). The OEO 3A south Chatham Rise fishery was until recently (from 2005–06 onwards the Pukaki Rise was larger) the largest black oreo fishery in the EEZ and operates between about 172 and 176° E, mostly on undulating terrain (short plateaus, terraces, and drop-offs) at the west and central parts, and mostly on hills in the east. At times, black oreo is caught as a bycatch to smooth oreo fishing.

Oreos are managed as a group that includes black oreo (*Allocyttus niger*, BOE), smooth oreo (*Pseudocyttus maculatus*, SSO), and spiky oreo (*Neocyttus rhomboidalis*, SOR). The last species is not sought by the commercial fleet and is a minor bycatch in some areas, e.g., the Ritchie Bank orange roughy fishery. The management areas used since October 1986 are shown in Figure 2.

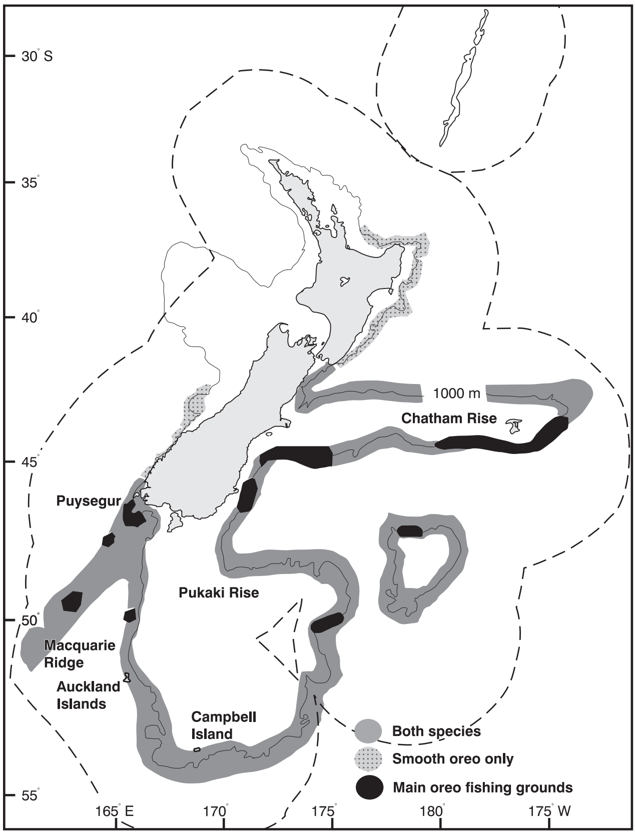

Figure 1: Approximate location of main fishing grounds and distribution of black oreo and smooth oreo. Dashed line is the EEZ boundary.

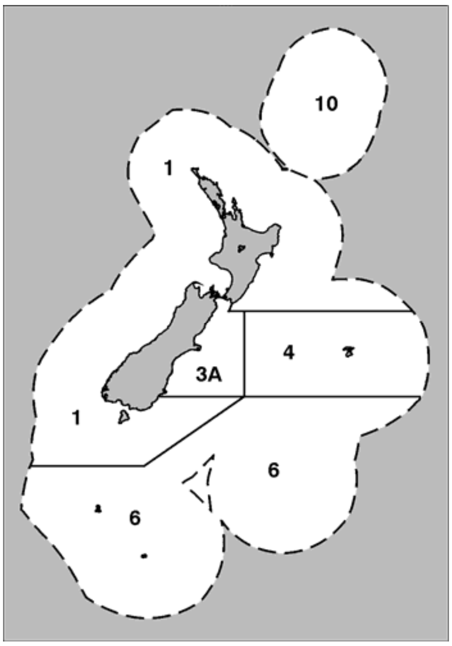

Figure 2: Oreo management areas.

Separate catch statistics for each oreo species were not requested in the version of the catch statistics logbook used when the New Zealand EEZ was formalised in April 1978, so the catch for 1978–79 was not reported by species (the generic code OEO was used instead). From 1979–80 onwards the species were listed and recorded separately. When the Quota Management System was introduced in 1986, the statutory requirement was only for the combined code (OEO) for the Quota Management Reports, and consequently some loss of separate species catch information has occurred, even though most vessels catching oreos are requested to record the species separately in the catch-effort logbooks.

The oreo fishery started in about 1972 when the Soviets reported 7000 t (assumed to be black oreo and smooth oreo combined, see Doonan et al. (1995) from the New Zealand area. Reported landings of oreos (combined species) and TACs from 1978–79 until 2001–02 are given in Table 1. The OEO 3A TAC was reduced from 10 106 to 6600 t in 1996–97. A voluntary agreement between the fishing industry and the Minister of Fisheries to limit catch of smooth oreo from OEO 3A to 1400 t of the total oreo TAC of 6600 t was implemented in 1998–99, with the balance of the TAC being black oreo by default. Subsequently the total OEO 3A TAC was reduced to 5900 t in 1999–2000, 4400 in 2000–01, 4095 in 2001–02, and 3100 t in 2002–03. Reported estimated catches by species from tow by tow data recorded in catch and effort logbooks (Deepwater, TCEPR, and CELR) are given in Table 1.

Table 1: Total reported landings and TACs (t) for all oreo species combined and total estimated catch (t) for smooth oreo (SSO) and black oreo (BOE) for OEO 3A from 1978–79 to 2006–07. –, na.

Fishing			Estimated catch	
year	Landings	TAC	SSO	BOE
1978–79*	1 366	–	0	0
1979–80*	10 958	–	5 075	5 588
1980–81*	14 832	–	1 522	8 758
1981–82*	12 750	–	1 283	11 419
1982–83*	8 576	10 000	2 138	6 438
1983–83#	4 409	#	713	3 693
1983–84†	9 190	10 000	3 594	5 524
1984–85†	8 284	10 000	4 311	3 897
1985–86†	5 331	10 000	3 135	2 184
1986–87†	7 222	10 000	3 186	4 026
1987–88†	9 049	10 000	5 897	3 140
1988–89†	10 191	10 000	5 864	2 719
1989–90†	9 286	10 106	5 355	2 344
1990–91†	9 827	10 106	4 422	4 177
1991–92†	10 072	10 106	6 096	3 176
1992–93†	9 290	10 106	3 461	3 957
1993–94†	9 106	10 106	4 767	4 016
1994–95†	6 600	10 106	3 589	2 052
1995–96†	7 786	10 106	3 591	3 361
1996–97†	6 991	6 600	3 063	3 549
1997–98†	6 336	6 600	4 790	1 623
1998–99†	5 763	6 600	2 367	3 147
1999–00†	5 859	5 900	1 733	3 943
2000–01†	4 577	4 400	1 648	3 005
2001–02†	3 923	4 095	1 769	2 378
2002–03†	3 070	3 100	1 395	1 636
2003–04†	2 856	3 100	1 244	1 590
2004–05†	3 061	3 100	1 447	1 594
2005–06†	3 333	3 100	1 354	1 770
2006–07†	3 073	3 100	1 220	1 651

Source: FSU from 1978–79 to 1987–88; QMS/MFish from 1988–89 to 2006–07.
*, 1 April to 31 March. #, 1 April to 30 September, interim TACs applied. †, 1 October to 30 September.

2. ASSESSMENT MODEL

2.1 Population dynamics

2.1.1 Partition of the population

The stock assessment model partitioned the OEO 3A black oreo population by age groups (1–70 years), with a plus group at age 70 years, and there were three areas. The data for the two sexes were combined.

Annual cycle

The nominal time unit in the model is one year during which processes such as recruitment were modelled. Because these processes cannot be modelled simultaneously, they were carried out in a specified sequence (Table 2). For convenience in the specifications, these were grouped into three time steps. Events were given a specified time within the year (month) through the specification of the percentage of natural mortality that was applied, assuming that it was applied uniformly throughout the year. Observations were fitted to model predictions specified by the time step and the time within the year (Table 2). Fishing mortality was assumed to apply throughout the year in the Baranov form.

Table 2: Stock model: timing within a year for processes and when data were fitted. Z% is the percentage of total mortality that has occurred. –, not applicable.

Model			Observations fitted		
time step	Time	Process (in the order applied)	Z%	Time	Description
1	Oct	Recruitment	0	–	
	Oct	Spawning	0	–	
	Oct	Increment age	0	–	
2	Oct	Migration (if applicable)	0	–	
3	Oct-Sep	Fishing mortality	0	Oct	Acoustic abundance
			0	Oct	Acoustic length data
			50	Mar	CPUE indices
			50	Mar	Observer length data

2.2 Selectivities, ogives, and other assumptions

Selectivities

An age-based selectivity ogive was estimated for the sexes combined for each spatial area for the commercial fishery (catch) and for the acoustic survey (abundance data). The ogives were logistic curves with parameters for the age of 50% selection and for the ages from 50 to 95% selection.

Acoustic selectivity in Area 1

Small black oreo appear in the research trawl length frequency distributions for layer and layeroff mark-types at between 21 and 27 cm TL (Figure 3). Treating the left-hand side of the research trawl length frequency distribution as a crude selectivity curve provided a 50% selection point at about 25 cm. There are two possible reasons for this high selectivity. The first is due to the selectivity of the sampling gear (gear selectivity) and the second is due to the size of fish from midwater that settle on the bottom (vertical availability). If the cause was due only to gear selectivity, we would expect to catch fish less than 21 cm because small orange roughy are also caught in the same net. Trawling in the background strata of the North West Hills survey (Chatham Rise) in 2002 caught orange roughy down to 11 cm SL (Doonan, NIWA, unpublished data).

Settlement seems more probable as a cause of high selectivity and was therefore used in the model structure as a “migration” from midwater onto the bottom in Area 1. These fish are in layers (layer and layeroff mark-types) that make up most of the acoustically estimated abundance in Area 1.

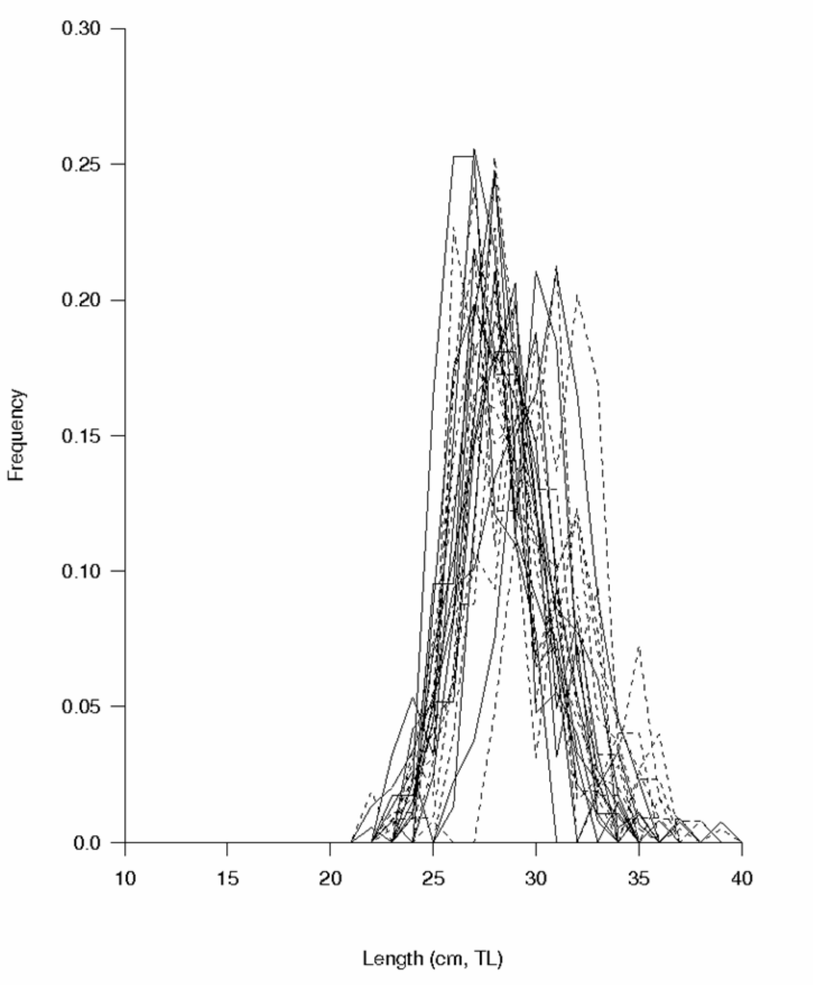

Figure 3: Male (solid line) and female (dotted line) length frequencies from research trawls in the layer and layeroff mark-types for each trawl.

Area 2 had some of the acoustic abundance derived from layer and layeroff mark types, but that was ignored because migration was modelled as a one-way process from Area 1 to 2, then from Area 2 to 3 with fish entering the model exclusively in Area 1.

Migration

Migration into Area 1 was by one-way movement of fish from midwater onto the bottom (settlement). This was modelled as an uncapped logistic function. Migration from Area 1 to Area 2 and Area 2 to Area 3 was also one-way and both of these processes were modelled as capped three parameter logistic functions.

Maturity

A revised maturity ogive was used (see Section 3.8 Biological data); it is essentially knife-edged at 38 years.

2.3 Modelling methods, parameters, assumptions about parameters

The stock assessment analyses were conducted using CASAL (Bull et al. 2003). This was implemented as an age-structured population model that combined the sexes and allowed inclusion of length frequency data. The Bayesian estimator was employed. The model incorporated deterministic recruitment, life history parameters (see Table 16), and catch history (see Table 3). Data fitted in the analysis were the 1997, 2002, and 2006 acoustic abundance estimates (see Table 12), standardised combined CPUE indices (see Tables 9–10), observer length data (see Table 13), and the 1997, 2002, and 2006 acoustic survey length data (see Table 15). The model was used to estimate biomass. These procedures were conducted with the following steps.

1. Model parameters were estimated using maximum likelihood and the prior probabilities.
2. Samples from the joint posterior distribution of parameters were generated with the Markov Chain Monte Carlo (MCMC) procedure using the Metropolis algorithm.
3. A marginal posterior distribution was found for each quantity of interest by integrating the product of the likelihood and the priors over all model parameters; the posterior distribution was described by its median, 5, and 95 percentiles for parameters of interest.

The following main assumptions were made in the analyses carried out to estimate biomasses and yields.

(a) The CPUE analyses provided a relative index of abundance for black oreo in the whole of OEO 3A.
(b) The estimated value of M is the true value.
(c) The maximum fishing mortality (F_{max}) was 0.9.
(d) Recruitment was deterministic and followed a Beverton & Holt relationship with steepness of 0.75.
(e) The population of black oreo in OEO 3A was a discrete stock or production unit.
(f) The catch history was accurate.

3. OBSERVATIONS AND MODEL INPUTS

3.1 Spatial areas

Previous analyses (Doonan et al. 1999b) identified time, area, and depth effects on the structure of length data collected by observers from catches made by commercial fishing vessels. Catch and length data analyses were carried out to check the veracity of the defined areas. Figure 4 shows tow tracks with start and end positions where black oreo were caught from 1978–79 to 1999–2000 plotted on a map showing the old (Hicks et al. 2002) areas are shown in Figure 4. The three areas used in the current assessment were revised by moving the boundary line between Areas 1 and 2 slightly to refine the area of small fish (Area 1) and are shown in Figure 5.

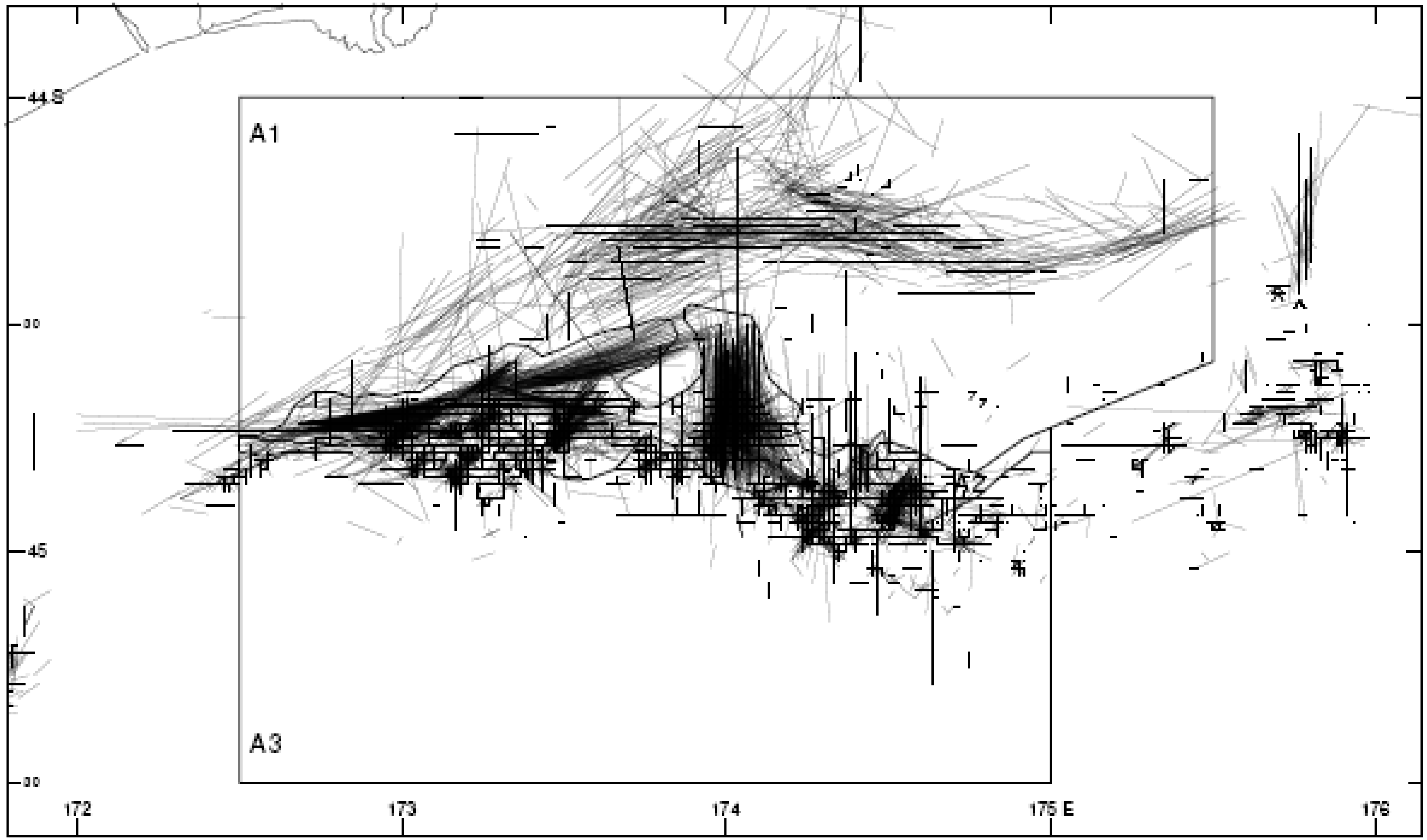

Figure 4: Tow tracks (black lines) where black oreo were caught from 1978–79 to 1999–2000, from Hicks et al. (2002). Start and end positions of the tows were jittered by plus or minus 0.5 of a minute of latitude and longitude. The heavy black lines define the Areas (A1–A3) used in the 2002 stock assessment (Hicks et al. 2002).

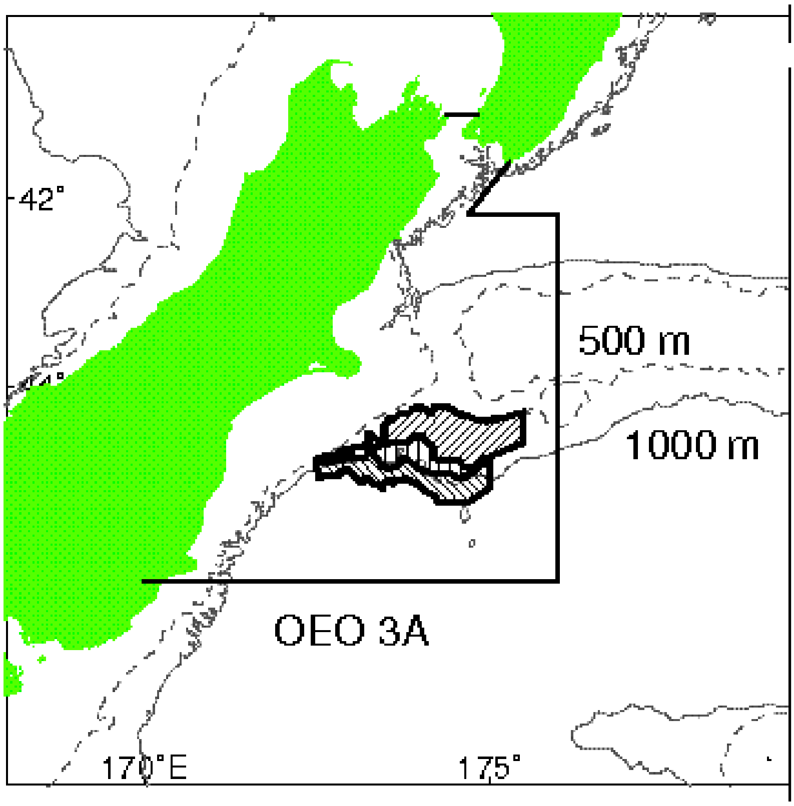

Figure 5: The three spatial areas used in the CASAL model and 2002 & 2006 acoustic abundance survey. Area 1 at the top with right sloping shading; Area 2 in the middle with v tical shading; Area 3 at the bottom with left sloping shading. The thick dark line encloses management area OEO 3A.

Summary of the three spatial areas

The main fishery area was split into three areas: a northern area that contained small fish and was generally shallow (Area 1); a southern area that contained large fish of before 1993 and which was generally deeper (Area 3); and a transition area (Area 2) that lay between Areas 1 and 3 (Figure 5). The boundary between Areas 1 and 2 was defined in terms of the northern edge of the area that enclosed 90% of the total catch from the fishery. Thus, Areas 2 and 3 contained most of the fishery and Area 1 consisted of lightly fished and unfished ground. The boundary between Areas 2 and 3 was defined by the 32.5 cm contour in mean length for data before 1993 so that the fishery is split into an area containing smaller fish and another that has larger fish. The population outside the main fishery was assumed to follow the same spatial pattern, i.e., smaller fish at shallower depths.

3.2 Scaling of estimates to OEO 3A

Estimates of catch and abundance in the following sections are all scaled up to represent estimates for the whole of area OEO 3A.

3.3 Catch history

Catches were partitioned into the three areas by scaling up (or down) the estimated catch of black oreo from each area, i.e., the proportion of black oreo to the total landed catch of oreos (combined species, see Table 1) and are given in Table 3. Soviet reported catches were assumed to be for the fishing year (1 October to 30 September) and the black oreo catch was estimated using the average estimated black oreo species proportion by spatial area (Table 3) from 1979–80 to 1982–83.

Table 3: Black oreo catch (t) for each fishing year in the three spatial model areas, rounded to the nearest 10 t.

Year	Total	Area 1	Area 2	Area 3	Year	Total	Area 1	Area 2	Area 3
1972–73	†3 440	110	2 010	1 320	1990–91	4 770	890	2 310	1 580
1973–74	†3 800	130	2 220	1 460	1991–92	3 450	300	1 290	1 870
1974–75	†5 100	170	2 970	1 960	1992–93	4 960	230	2 810	1 920
1975–76	†1 260	40	730	480	1993–94	4 160	340	2 510	1 320
1976–77	†3 880	130	2 260	1 490	1994–95	2 400	120	1 560	720
1977–78	†5 750	190	3 350	2 210	1995–96	3 760	200	2 530	1 030
1978–79	720	20	420	270	1996–97	3 750	450	2 190	1 110
1979–80	5 740	430	2 670	2 650	1997–98	1 600	170	590	840
1980–81	12 640	80	8 260	4 300	1998–99	3 290	160	2 450	680
1981–82	11 460	100	6 400	4 960	1999–00	4 070	160	2 780	1 120
1982–83	8 290	510	4 940	2 840	2000–01	2 960	100	2 010	850
1983–84	7 410	300	4 200	2 910	2001–02	2 250	60	1 530	660
1984–85	3 930	150	1 510	2 270	2002–03	1 660	100	1 260	300
1985–86	2 190	10	920	1 260	2003–04	1 600	250	840	500
1986–87	4 030	30	1 970	2 020	2004–05	1 600	80	1 040	490
1987–88	3 140	40	1 940	1 160	2005–06	1 890	60	1 480	350
1988–89	3 230	170	2 490	570	2006–07	1 770	50	970	740
1989–90	2 830	620	1 050	1 160					

† Soviet catch, assumed to be mostly from OEO 3A and to be 50:50 black oreo: smooth oreo.

3.4 Relative abundance estimates from standardised CPUE analyses

Standardised CPUE indices for OEO 3A black oreo were developed and used as indices of abundance for the first spatial stock assessment (Hicks et al. 2002). In 2002, these indices were revised to account for the revised spatial areas and also to introduce new predictors (Doonan et al. 2004). For each area, there are two series based on the introduction of GPS between 1989 and 1992. The pre-GPS series were not updated in 2008 since there were no new data or analyses.

During the post-GPS period, there was a period (1998–99 to 2001–02) when a number of reductions were made to the TAC and an industry (voluntary) cap was introduced on the amount of smooth oreo caught. This is likely to have changed the practices of the fishery so the post-GPS series was split into two. Initially, the split was in 2002–03, but the Deepwater Working Group thought that the whole period should be dropped resulting in an early series finishing in 1997–98 and a late series starting in 2002–3. Only the late series is reported in detail here since these were used in the stock assessment. The early post-GPS series were used in one sensitivity run. The late post-GPS series contains the extra data available since the last assessment (i.e., from 2002–03 to 2006–07).

3.4.1 Data

The black oreo catch and effort data were restricted to tows that targeted or caught black oreo in OEO 3A up to and including the 2006–07 fishing year. The data were restricted to the spatial analysis study area defined above. The tow data included start position, black oreo catch, target species, depth, vessel, distance towed, time of day, and date. Nationality and tonnage were recorded for each vessel. Catch-per-tow (tonnes-per-tow) was chosen as the index of abundance rather than catch-per-kilometre and follows the Deepwater Working Group’s preference in previous smooth oreo and black oreo standardised CPUE analysis (Doonan et al. 1995, Coburn et al. 1999). The length of tow was not considered to reflect effort because of the mix of flat, drop-off, and hill fishing that was carried out and because most vessels targeted marks. Technology changes, most importantly the adoption of GPS, allowed vessels to more accurately target marks and reduce tow length. Different fishing patterns and therefore tow length were observed in the three areas, e.g., more long tows in the shallows (see Figure 4) and for the two time periods (pre- and post-GPS), suggesting that tow length was not a good measure of effort across the fishery. The post-GPS series were further split into two; an early series that finished in 1997–98 and a late series that started in 2002–03.

For the late post-GPS series, only data from vessels that had 20 tows in two years or more were used. For the early post-GPS, data from vessels that that had 10 tows in two years or more were used (using 20 tows reduced the data too much in this case).

3.4.2 Method of CPUE analysis

The basic CPUE analysis method was described by Doonan et al. (1995) with enhancements following those described by Francis (2001). The generic analysis used a two-part model which separately analysed the tows that caught black oreo using a linear regression applied to log-transformed data, termed the log-linear regression (positive catch regression), and a binomial part which used a Generalised Linear Model with a logit link for the proportion of successful tows (zero catch regression). The log-linear and binomial index values for each year were multiplied together to give a combined index. When there were less than 10% of zero tows the binomial part was dropped. All area data were included into the one model and an interaction term for year and area were used to get a separate abundance index for each of the three areas. The c.v.s for the indices were estimated using a nested bootstrap procedure where vessels (and their data) were re-sampled with replacement. Selected vessels were re-named (since a vessel can appear more than once in a bootstrap set) and tow data within each vessel re-sampled with replacement: 500 bootstrap runs were made.

For the binomial analysis, Francis (2001, p. 16) used “typical” fixed values of all model predictors, but analysis of his approach showed that the binomial indices varied depending on the fixed value used. Since we have a year-area interaction term we used a different fixed value for each year-area combination and this value was set to the mean of the model’s predicted values for that year and area. For example, the index value for Area 2 in year N was the mean of the predicted CPUE when area was set to 2 and year was set to N in each row of the model data. The individual annual c.v. estimates for the CPUE abundance indices were estimated using a jack-knife technique (Doonan et al. 1995).

The variables considered in the 2002 analyses included year, latitude, longitude, depth, season, time, target species, vessel, sun altitude, and moon phase, but because of the results of that analysis only a subset was considered here (Table 4). Predictor variables in the regressions were all designated as categorical. Numeric variables, e.g., depth, were converted into categorical variables by splitting the range into eight bins. Eight bins were chosen as sufficient to model any dependencies in the data (without prejudice to the shape of any dependency) while ensuring that the resultant models were not over-parameterised. Bin widths were chosen to ensure that tow numbers in each bin were similar. One difference for the current analysis compared to that reported in 2002 was that the depth variable was nested within each area (i.e., it was estimated separately with each area).

The year effect was always included and other variables were selected on a forward stepwise selection in which a variable was accepted if it reduced R^2 by 2%.

Table 4: Summary of non-year variables that could be selected in the regression models used in the 2002 CPUE analysis and as adjusted for the 2008 analysis. All were categorical variables. "Df" was the number of parameters to be estimated for that variable. BOE, black oreo; SSO, smooth oreo; OEO, combined oreo; OTHER, any other species.

Variable	Df	Description	Considered for the post-GPS CPUE in 2008
Latitude	7	Latitude at start of tow.	Yes
Longitude	7	Longitude at start of tow.	No
Depth	7	Depth at start of tow.	Nested within area
Season	7	The fishing year.	Yes
Time	7	Time of day at start of tow.	Yes
Target	3	Target species for the tow (BOE, SSO, OEO, OTHER).	Yes
Vessel	†	A parameter estimated for each vessel.	Yes
Sun	7	Altitude of the sun above/below the horizon.	No
Moon	7	Phase of the moon.	No

† There was one degree of freedom for each of the vessels (or group of vessels) used in the analysis.

3.4.3 Results of the CPUE analyses

Given the small percentages of zero catches, only the positive catch regression was used for both the early and late post-GPS series. For the early post-GPS series, there were too few data for Area 1 so only data for Areas 2 and 3 were used. Table 5 shows the distribution of data amongst the areas and a comparison of data in the study area that was retained in the analysis. One extra factor was selected (Table 6). Indices are shown in Figures 6 & 7.

For the late post-GPS series, Table 7 shows the distribution of data amongst the areas and a comparison of data in the study area that was retained in the analysis. Three extra factors were selected (Table 8). Indices are shown in Figures 8, 9, & 10.

A summary of the indices is shown in Table 9. The alternative series used in a sensitivity run are shown in Table 10.

Table 5: Number of tows, catch, and number of vessels in the early post-GPS CPUE series.

	Number of tows					Proportion of study area catch	Number of vessels	
Fishing year	Area 1	Area 2	Area 3	Total	Catch (t)	(%)	In analysis	In study area
1993	–	302	192	494	2 870	83	9	22
1994	–	450	327	777	2 904	86	10	20
1995	–	300	224	524	1 585	86	12	25
1996	–	460	439	899	2 174	76	12	29
1997	–	344	326	670	2 022	74	12	25
1998	–	88	255	343	618	50	8	27

Table 6: R^2 for selection in the early post-GPS CPUE series.

Variable	Step 1
Vessel	18.51
Improvement in R^2	4.99

Table 7: Number of tows, catch, and number of vessels in the late post-GPS CPUE.

	Number of tows					Proportion of study area catch	Number of vessels	
Fishing year	Area 1	Area 2	Area 3	Total	Catch (t)	(%)	In analysis	In study area
2003	36	96	63	195	894	93	8	14
2004	152	89	91	332	935	96	9	17
2005	18	115	96	229	998	89	7	14
2006	24	88	41	153	1 166	97	6	11
2007	16	68	91	175	1 037	98	7	11

Table 8: Variable selection (unadjusted R^2) in the late post-GPS CPUE series. NA, not applicable.

	Step 1	Step 2	Step 3
Vessel	36.71	NA	NA
Area:Depth	35.96	41.55	NA
Target species	32.86	39.36	43.69
Improvement in R^2	6.06	4.84	2.13

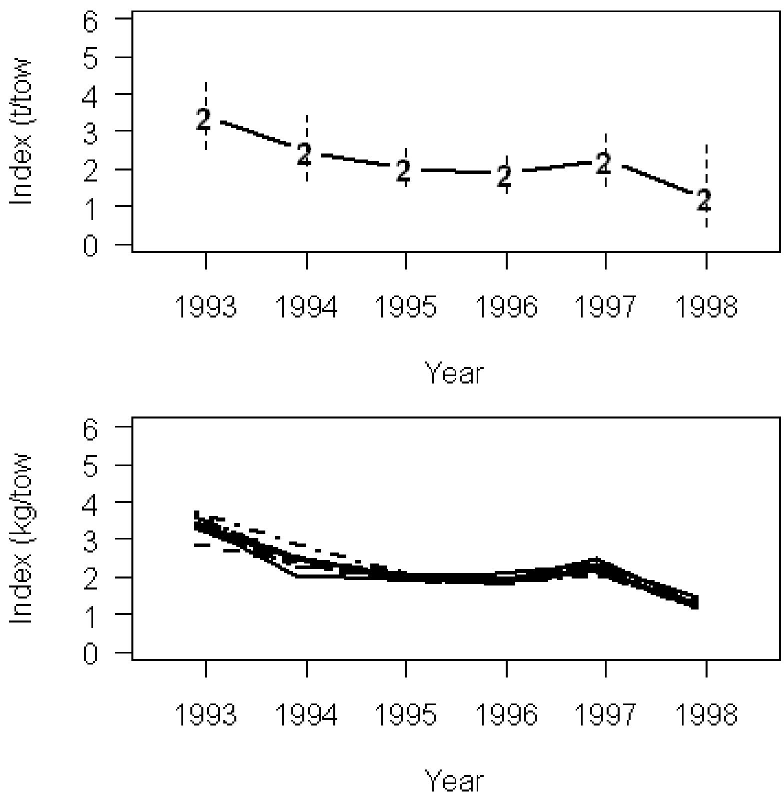

Figure 6: CPUE indexes for Area 2, early post-GPS. Top: index with the dashed vertical lines showing a confidence interval of +/- 2 s.e. Bottom: Indices resulting when each vessel is removed from the analysis one at a time.

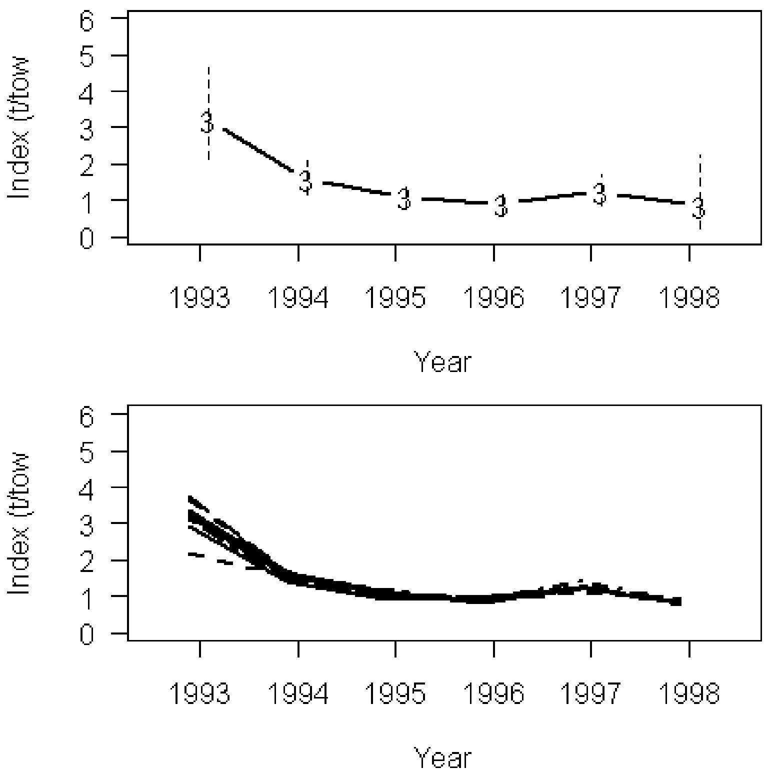

Figure 7: CPUE indices for Area 3, early post-GPS. Top: index with the dashed vertical lines showing a confidence interval of +/- 2 s.e. Bottom: Indices resulting when each vessel is removed from the analysis one at a time.

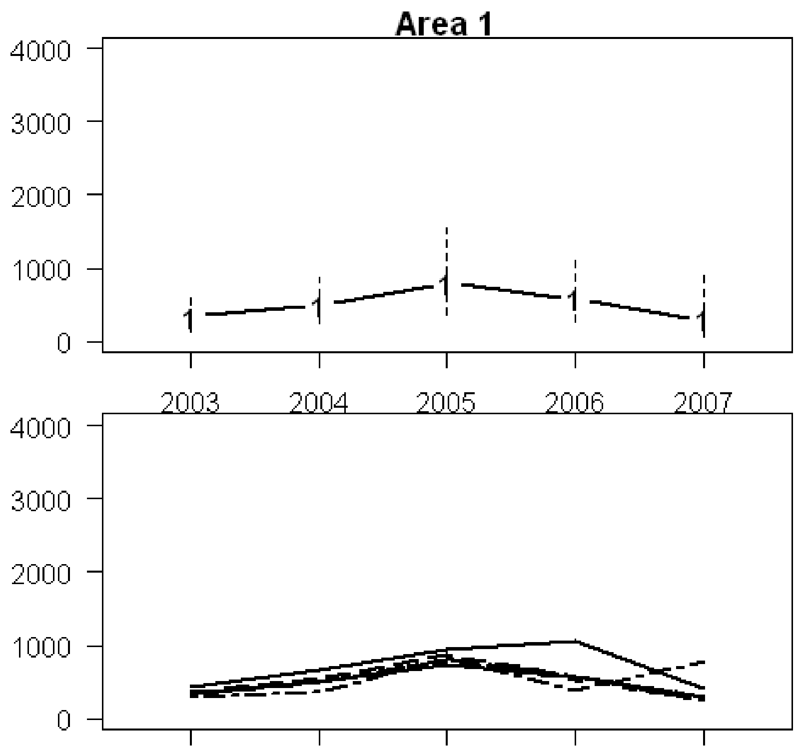

Figure 8: CPUE indices for Area 1, late post-GPS. Top: index with the dashed vertical lines showing a confidence interval of +/- 2 s.e. Bottom: Indices resulting when each vessel is removed from the analysis one at a time.

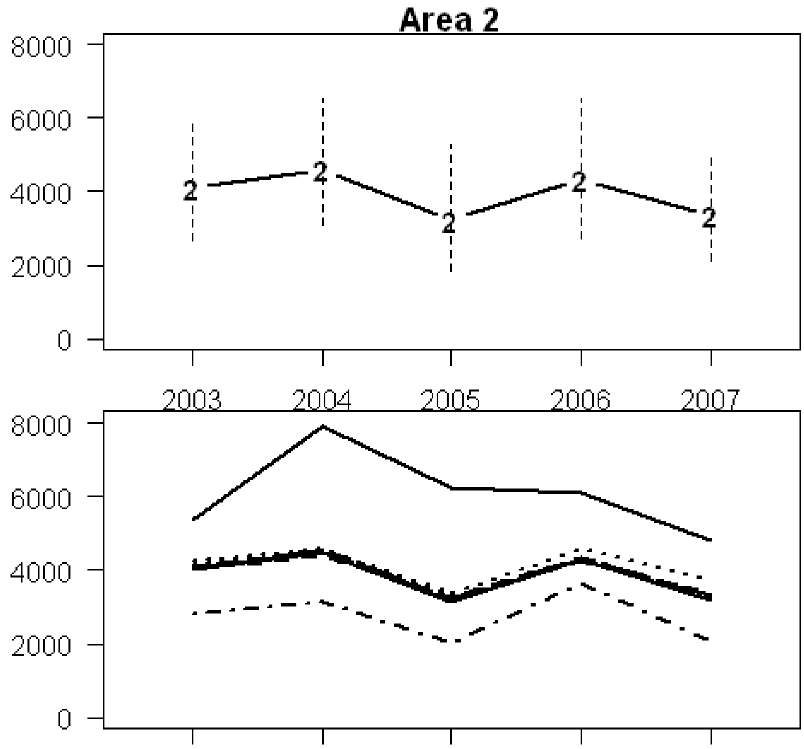

Figure 9: **CPUE log-linear indices for Area 2, late post-GPS. Top: index with the dashed vertical lines showing a confidence interval of +/- 2 s.e. Bottom: Indices resulting when each vessel is removed from the analysis one at a time.**

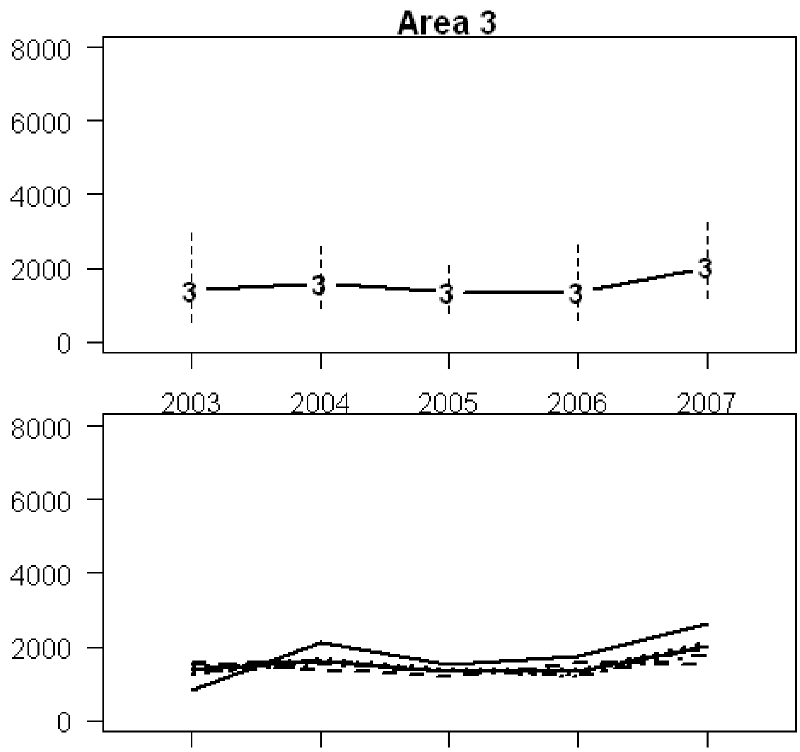

Figure 10: **CPUE log-linear indices for Area 3, late post-GPS. Top: index with the dashed vertical lines showing a confidence interval of +/- 2 s.e. Bottom: Indices resulting when each vessel is removed from the analysis one at a time.**

Table 9: Summary of the OEO 3A black oreo pre-GPS (from Doonan et al. 2004) and post-GPS time series of standardised catch per unit effort indices (geometric mean) and c.v.s (%) as used in the base case stock assessment analysis. –, no estimate.

Fishing year	Pre-GPS						Post-GPS					
	Area1		Area2		Area3		Area1		Area2		Area3	
	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.
1979–80	–	–	1.45	39	1.52	125	–	–	–	–	–	–
1980–81	–	–	1.84	17	2.55	15	–	–	–	–	–	–
1981–82	–	–	1.71	22	2.15	9	–	–	–	–	–	–
1982–83	–	–	1.41	8	1.80	14	–	–	–	–	–	–
1983–84	–	–	0.99	8	1.04	19	–	–	–	–	–	–
1984–85	–	–	0.95	27	0.99	12	–	–	–	–	–	–
1985–86	–	–	0.63	31	0.66	33	–	–	–	–	–	–
1986–87	–	–	0.81	22	0.88	36	–	–	–	–	–	–
1987–88	–	–	0.45	20	0.49	23	–	–	–	–	–	–
1988–89	–	–	0.72	21	0.23	44	–	–	–	–	–	–
1989–90	–	–	–	–	–	–	–	–	–	–	–	–
1990–91	–	–	–	–	–	–	–	–	–	–	–	–
1991–92	–	–	–	–	–	–	–	–	**Early series**			
1992–93	–	–	–	–	–	–	–	–	1.62	14	2.46	20
1993–94	–	–	–	–	–	–	–	–	1.17	17	1.20	15
1994–95	–	–	–	–	–	–	–	–	0.96	13	0.82	17
1995–96	–	–	–	–	–	–	–	–	0.89	15	0.68	22
1996–97	–	–	–	–	–	–	–	–	1.06	18	0.96	17
1997–98	–	–	–	–	–	–	–	–	0.58	47	0.64	63
1998–99	–	–	–	–	–	–	–	–	–	–	–	–
1999–0	–	–	–	–	–	–	–	–	–	–	–	–
2000–1	–	–	–	–	–	–	–	–	–	–	–	–
2001–2	–	–	–	–	–	–	**Late series**					
2002–3	–	–	–	–	–	–	0.72	42	1.05	21	0.91	44
2003–4	–	–	–	–	–	–	1.06	31	1.19	19	1.05	27
2004–5	–	–	–	–	–	–	1.71	38	0.83	27	0.88	25
2005–6	–	–	–	–	–	–	1.23	37	1.11	22	0.88	41
2006–7	–	–	–	–	–	–	0.63	83	0.86	22	1.34	25

Table 10: Summary of the OEO 3A black oreo pre-GPS (from Doonan et al. 2004) and post-GPS time series of standardised catch per unit effort indices (geometric mean) and c.v.s (%) as used in a sensitivity case stock assessment analysis. –, no estimate.

Fishing	Pre-GPS						Post-GPS					
	Area 1		Area 2		Area 3		Area 1		Area 2		Area 3	
year	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.
1979–80	–	–	1.45	39	1.52	125	–	–	–	–	–	–
1980–81	–	–	1.84	17	2.55	15	–	–	–	–	–	–
1981–82	–	–	1.71	22	2.15	9	–	–	–	–	–	–
1982–83	–	–	1.41	8	1.80	14	–	–	–	–	–	–
1983–84	–	–	0.99	8	1.04	19	–	–	–	–	–	–
1984–85	–	–	0.95	27	0.99	12	–	–	–	–	–	–
1985–86	–	–	0.63	31	0.66	33	–	–	–	–	–	–
1986–87	–	–	0.81	22	0.88	36	–	–	–	–	–	–
1987–88	–	–	0.45	20	0.49	23	–	–	–	–	–	–
1988–89	–	–	0.72	21	0.23	44	–	–	–	–	–	–
1989–90	–	–	–	–	–	–	–	–	–	–	–	–
1990–91	–	–	–	–	–	–	–	–	–	–	–	–
1991–92	–	–	–	–	–	–	–	–	–	–	–	–
							Early series					
1992–93	–	–	–	–	–	–	–	–	1.35	28	1.72	42
1993–94	–	–	–	–	–	–	–	–	0.95	39	1.15	24
1994–95	–	–	–	–	–	–	–	–	0.77	12	0.83	22
1995–96	–	–	–	–	–	–	0.94	54	0.75	19	0.73	53
1996–97	–	–	–	–	–	–	1.23	32	0.78	16	1.02	21
1997–98	–	–	–	–	–	–	0.93	32	0.56	36	0.63	21
1998–99	–	–	–	–	–	–	0.95	38	1.14	46	0.86	28
1999–00	–	–	–	–	–	–	1.19	32	1.36	52	1.17	17
2000–01	–	–	–	–	–	–	1.11	41	1.17	82	0.91	62
2001–02	–	–	–		–	–	0.73	113	1.68	27	1.42	8
							Late series					
2002–03	–	–	–		–	–	0.72	42	1.05	21	0.91	44
2003–04	–	–	–	–	–	–	1.06	31	1.19	19	1.05	27
2004–05	–	–	–	–	–	–	1.71	38	0.83	27	0.88	25
2005–06	–	–	–	–	–	–	1.23	37	1.11	22	0.88	41
2006–07	–	–	–	–	–	–	0.63	83	0.86	22	1.34	25

3.5 Relative abundance estimates from trawl surveys

Trawl surveys of oreos on the south Chatham Rise were carried out in seven years between 1986 and 1995, but the abundance estimates from the surveys before 1991 were not considered to be comparable because different vessels were used. Four comparable surveys were carried out using *Tangaroa* from 1991 on, and relative abundance estimates from those surveys are given in Table 11, but these estimates were not used in the biomass analyses because it was decided that catchability could be inconsistent between surveys, as reported for smooth oreo from OEO 3A by Doonan et al. (1999a). The *Tangaroa* trawl surveys did not sample recruited smooth oreo well because the schools of recruited smooth oreo were so small and scattered that they were very unlikely to be encountered by the trawl given the number of tows allocated. If a school was encountered, the resulting survey abundance estimate had a high c.v. because most of the trawls sampled background (low density) recruited smooth oreo. The *Tangaroa* series also spanned only five years so the index had a low weight compared to a longer time series.

Table 11: OEO 3A black oreo research survey abundance estimates (t) from *Tangaroa* surveys. N is the number of stations. Estimates were made using knife-edge recruitment set at 27 and 33 cm TL.

Year	Mean abundance		c.v. (%)	N
	27 cm	33 cm		
1991	36 299	8 999	42	44
1992	19 848	6 427	39	24
1993	16 800	4 888	40	24
1995	22 148	3 778	21	24

3.6 Absolute abundance estimates from acoustic surveys

Absolute estimates of abundance for black oreo are available from three acoustic surveys of oreos carried out from 10 November to 19 December 1997 (TAN9713) (Doonan et al. 1998, 1999b), 25 September to 7 October 2002 (TAN0213) (Smith at al. 2006), and from 17 to 30 October 2006 (TAN0615) (Doonan et al. 2008). The 1997 survey covered the flat with a series of random north-south transects over six strata at depths of 600–1200 m. Hills were also sampled using parallel and starburst transects. Targeted and some random (background) trawling was carried out to identify targets and to determine species composition. In situ target strength measurements were made on 10 marks including 2 smooth oreo, 2 black oreo, and 6 mixed oreo marks. In 2002, the survey was limited to flat ground with 77 acoustic transects and 21 mark identification trawls completed (the smooth oreo part was dropped). The 2006 survey was a repeat of the 2002 survey design and completed 78 transects and 22 trawls.

3.6.1 Acoustic abundance estimates

Absolute total (immature plus mature) acoustic abundance at the start of the fishing year was estimated for each of the three new areas. The 1997 acoustic abundance for black oreo in OEO 3A was re-estimated in 2002 using the revised estimates of target strength for smooth oreo, black oreo, and a number of bycatch species. Absolute total acoustic abundance estimates for all surveys are in Table 12.

Table 12: Total black oreo abundance estimates for the 1997, 2002, and 2006 acoustic surveys for the three model areas in OEO 3A.

	Acoustic abundance, tonnes (c.v. %)			
Survey	Area 1	Area 2	Area 3	Total
1997	148 000 (29)	10 000 (26)	5 240 (25)	163 000 (26)
2002	43 300 (31)	15 400 (27)	4 710 (38)	63 400 (26)
2006	56 400 (37)	16 400 (30)	5 880 (34)	78 700 (30)

3.7 Length data analyses

3.7.1 Observer length frequencies

Catch at length data collected by observers in Areas 1, 2, and 3 were extracted from the obs_lfs database maintained by NIWA. In the 2004 assessment, there were 516 samples. Two samples were rejected because they had extreme mean lengths, i.e., one had a mean less than 20 cm, and the second had a mean length greater than 40 cm. Thirteen samples were also excluded where fewer than 30 fish per sample were measured (all were from small catches). Three samples taken in 1979–80 from Area 3 were rejected because there was no recorded catch weight, required for the weighted combination of sample length frequencies (Table 13).

Within each area, groups of years were identified from Table 13 where each group spanned no more than five years. This procedure aimed to get adequate sample sizes to derive combined length frequencies and to use as much of the data as possible. Derived length frequencies for each group were calculated from the sample length frequencies weighted by the catch weight of each sample. For the current assessment there were an additional 77 samples which added two more length frequencies to the assessment, one for Area 1 and another for Area 2 (Table 13) and Figure 11.

For previous length data, within each group of length frequencies an estimate of the c.v. for each proportion at length class was made by bootstrap re-sampling of the length frequency data at the level of a tow, followed by fitting a regression to the proportions and bootstrap c.v. so that a resultant derived c.v. was a function of the proportion of fish in the length class and the regression coefficients. Tows were reselected with replacement for each group of length frequency data to generate 500 bootstrap sample length frequencies. The bootstrap c.v. for each length class was then calculated, i.e., the standard deviation of the bootstrap samples at each length class divided by the actual calculated proportion at each length class. The bootstrap c.v. could have been used directly but it appeared better to exploit the relationship between proportion and c.v. by fitting a simple regression model to the transformed data. Bootstrap c.v. values were transformed as log(bootstrap c.v.) and the proportion transformed as 1/log(proportion). The transformed data were then fitted with a second order linear regression of the form $y = a + b*x + c*x^2$ where y = log(bootstrap c.v.) and x = 1/log(proportion), (Figure 12, right frame). Process error was estimated within the model and it was assumed that the same value applied to all three areas. The regression coefficients for each length frequency group are given in Table 14.

Table 13: Number of observed commercial tows where black oreo were measured for length frequency. Excluded tows had fewer than 30 fish measured (13), extreme mean lengths (2) and missing catch information (3). –, no data (Area column) or length data excluded (Group no. column). New data are from 2003–04 onwards (below the bold line).

Year	Number of tows in the length frequency					
	Area 1	Group no.	Area 2	Group no.	Area 3	Group no.
1978–79	–	–	–	–	–	–
1979–80	–	–	9	1	35	1
1980–81	–	–	–	–	–	–
1981–82	–	–	–	–	–	–
1982–83	–	–	–	–	–	–
1983–84	–	–	–	–	–	–
1984–85	–	–	–	–	–	–
1985–86	–	–	–	–	1	2
1986–87	–	–	2	2	6	2
1987–88	–	–	3	2	6	2
1988–89	3	1	32	2	7	2
1989–90	8	1	9	2	2	3
1990–91	1	1	5	2	8	3
1991–92	–	–	–	–	11	3
1992–93	–	–	–	–	–	–
1993–94	–	–	22	3	4	4
1994–95	–	–	–	3	6	4
1995–96	1	–	3	3	3	4
1996–97	–	–	1	3	1	4
1997–98	13	2	–	–	7	4
1998–99	2	2	–	–	1	5
1999–00	2	2	52	4	57	5
2000–01	1	2	83	4	47	5
2001–02	–	–	18	4	14	5
2002–03	–	–	12	4	–	–
2003–04	2	3	18	–	–	–
2004–05	9	3	1	5	1	–
2005–06	1	3	7	5	–	–
2006–07	4	3	32	5	2	–

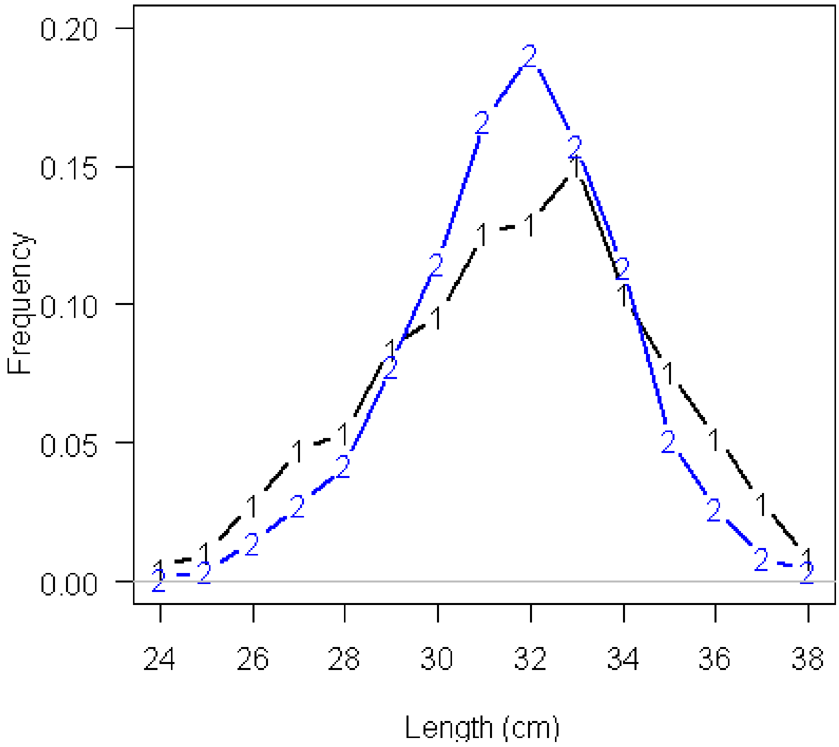

Figure 11: New combined weighted length frequencies for this assessment for Area 1 (1), and Area 2 (2) for samples identified in Table 13.

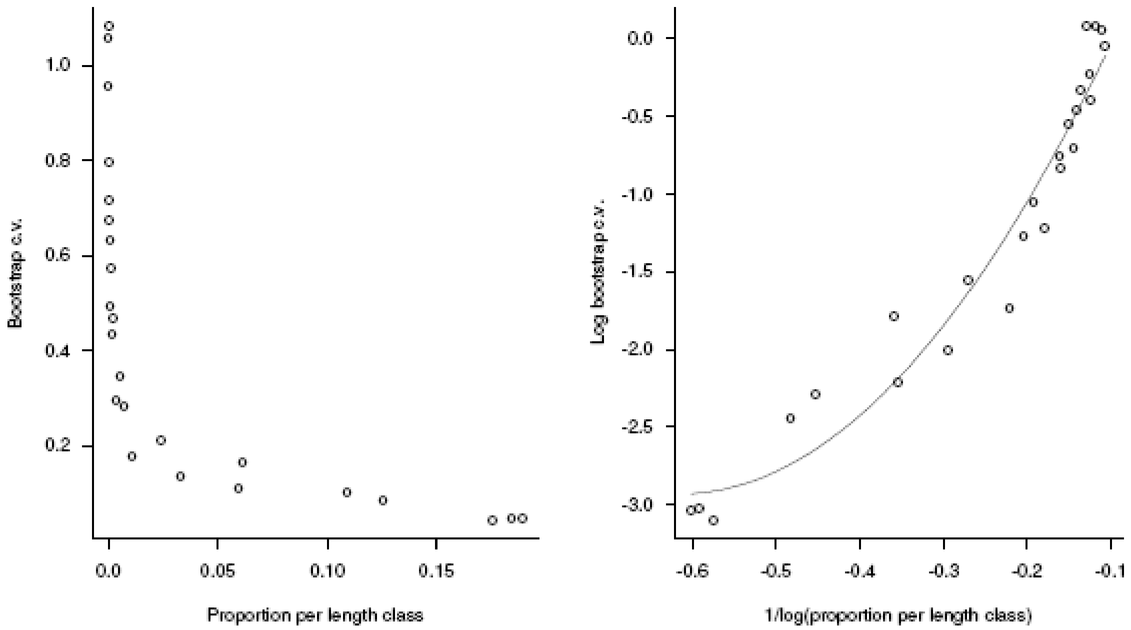

Figure 12: An example of the bootstrap c.v.s with the data from the Area 3 1979–80 length frequency group. The left-hand frame shows the raw proportions for each length class versus the bootstrap estimated c.v.s. The right-hand frame shows the data as transformed for the regression fit. The curved line is the regression fit used to calculate c.v.s.

Table 14: The regression coefficients for each group of length frequencies for the data used in the last assessment (Doonan et al. 2004).

Length frequency group	Coefficients		
	a	b	c
Area 1 1988–89 to 1990–91	1.42	12.5	11.2
Area 1 1997–98 to 2000–01	1.09	8.4	2.0
Area 2 1979–80	1.60	13.0	17.0
Area 2 1986–87 to 1990–91	1.43	15.0	13.3
Area 2 1993–94 to1996–97	0.24	4.4	-0.8
Area 2 1999–2000 to 2002–03	1.36	17.8	17.3
Area 3 1979–80	1.20	13.4	10.9
Area 3 1985–86 to 1988–89	1.13	10.6	6.5
Area 3 1989–90 to 1991–92	1.35	14.0	12.4
Area 3 1993–94 to 1997–98	1.60	14.2	15.9
Area 3 1998–99 to 2001–02	0.80	13.8	12.2

For the new length data, c.v.s for each length class were made by bootstrap re-sampling of the length frequency data at the level of a tow within the group, followed by re-sampling the data within each selected tow.

3.7.2 Acoustic research survey length data

The 1997, 2002, and the new 2006 acoustic survey abundance-at-length data were converted to numbers-at-length using a fixed length-weight relationship (see biological parameters in Table 16) (Table 15). For the 1997 and 2002 length frequencies, the relationship between proportion-at-length and c.v. established from bootstrap re-sampling of the grouped observer length frequency data were corrected for sample size and used to provide an estimate of the c.v. to apply to the acoustic survey length frequency proportions-at-length. For the 2006 sample, bootstrapping both length data within mark-type and biomass by stratum and mark-type were used to estimate the c.v.s. Process error was estimated within the model and it was assumed that the same value applied to all three areas.

Table 15: Proportions at length for each area for the revised 1997, plus the 2002 and 2006 acoustic surveys.

	1997			2002			2006		
Length (cm)	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
25	0.015	0.013	0.009	0.022	0.016	0.008	0.009	0.017	0.015
26	0.035	0.027	0.019	0.039	0.030	0.013	0.026	0.035	0.032
27	0.113	0.061	0.029	0.051	0.038	0.018	0.066	0.073	0.055
28	0.165	0.090	0.038	0.085	0.062	0.029	0.118	0.105	0.077
29	0.153	0.104	0.064	0.117	0.091	0.044	0.152	0.143	0.113
30	0.143	0.105	0.065	0.139	0.119	0.060	0.175	0.153	0.132
31	0.131	0.119	0.089	0.123	0.122	0.086	0.156	0.157	0.154
32	0.102	0.121	0.105	0.137	0.133	0.127	0.117	0.136	0.169
33	0.046	0.094	0.098	0.112	0.123	0.141	0.073	0.089	0.119
34	0.041	0.086	0.097	0.065	0.084	0.138	0.059	0.056	0.076
35	0.029	0.058	0.083	0.054	0.064	0.100	0.032	0.026	0.037
36	0.015	0.043	0.091	0.021	0.052	0.104	0.014	0.009	0.014
37	0.006	0.037	0.080	0.015	0.025	0.049	0.001	0.001	0.004
38	0.006	0.042	0.131	0.020	0.041	0.083	0.003	0.001	0.003

3.8 Biological data

This model was not sex-specific so combined sex parameters were developed (Table 16).

Table 16: Life history parameters for black oreo. The combined parameter values were used in this model and the sex-specific parameters are included in the table for comparison.

Parameter	Symbol (unit)	Combined	Female	Male
Natural mortality	M (yr^{-1})	0.044	0.044	0.044
Growth c.v.		0.077		
Length-weight parameters	a	0.0078	0.008	0.016
	b	3.27	3.28	3.06

Combined length-weight parameters were calculated from TAN9208 survey data, which surveyed the Puysegur area and were used by McMillan et al. (1997) to estimate natural mortality. Natural mortality estimates were not available from OEO 3A because there were no otolith samples for age estimation available from early in the fishery. Each observation was weighted so that the two sexes contributed equally to the fitting of the model, even though they had slightly different sample sizes. Log-linear least squares were used because the residuals seemed to increase with length and were stabilised by the transformation. Non-linear least squares did not fit as well and heteroskedastic residuals were observed.

Growth was defined by a mean length at each age class in the model (1 to 70 years), and an associated c.v. was assumed to be constant over the age classes. Hicks et al. (2002) used von Bertalanffy growth parameters, but extension of the model to include fish from age 1 year onwards made this growth form inappropriate. Growth data for black oreo split into two groups (Figure 13) at about age 5 corresponding to the pre- and post-settlement life stages and the von Bertalanffy parameters did not adequately fit the two different growth phases. Mean length-at-age was calculated separately for pre- and post-settlement fish and linear interpolation was used to join the curves.

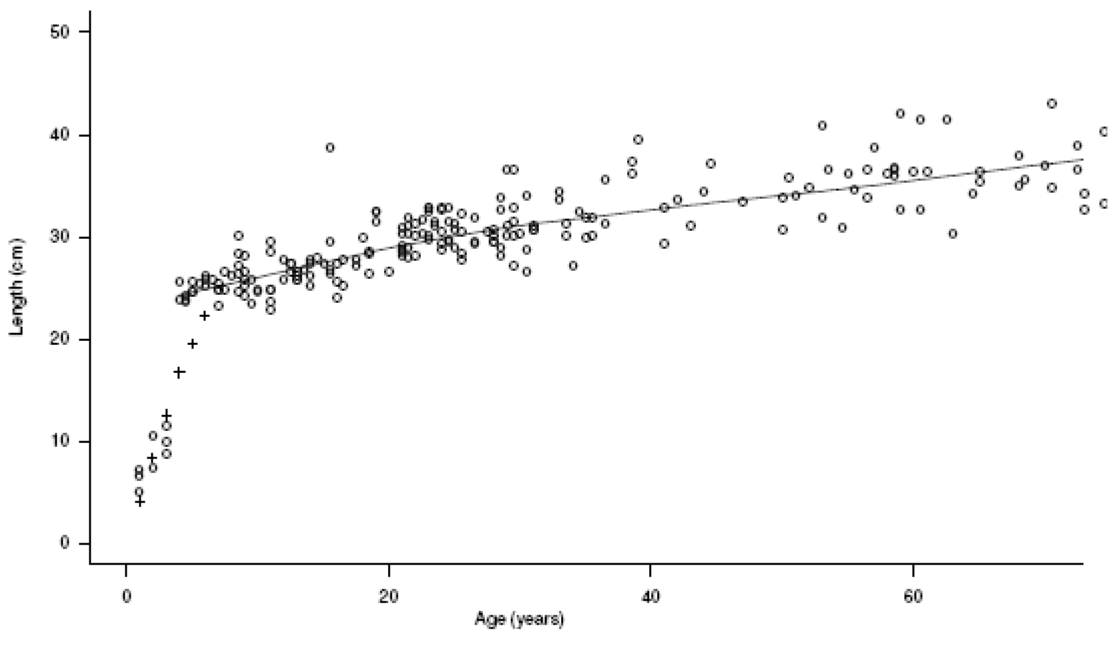

Figure 13: Growth data for black oreo from Puysegur (circles). A local regression was fitted to fish larger than 20 cm (line). Mean length for ages 1 to 6 years are shown "+". See text for more detail.

For post-settlement fish a local regression with a width spanning two-thirds of the data was fitted to all fish larger than 20 cm. Mean length at ages 7 to 70 years was calculated from this fit (Table 17). For pre-settlement fish, a straight line was taken through the origin and the mean length for fish less than 20 cm. Linear interpolation was used to calculate the mean length at ages 1 to 4 years. Finally mean length for ages 5 and 6 years was calculated by linear interpolation between those at 4 and 7 years. This three-stage method was an attempt to provide a reasonable transfer between the two growth stages. The apparent length truncation of data for the post-settlement fish suggests that settlement is length based, but also that a fit to the lowest ages of the data would be an upward biased estimate of the population mean length as an unknown fraction of fish are not selected. Otolith examination shows that at age 5 years about half the fish have a settlement check, but at age 4 few fish have the check and at age 7 nearly all have it, so 4 and 7 years were chosen as the ends of the settlement region.

The c.v. for the growth data (8%) was estimated within the model assuming that it was constant across the age classes using data from fish greater than 20 cm length (Table 17).

Table 17: Calculated mean length (cm) for ages 1 to 70 years.

Age	Mean length	Age	Mean length	Age	Mean length	Age	Mean length
1	4.2	19	28.6	37	32.2	55	34.8
2	8.4	20	28.9	38	32.3	56	34.9
3	12.6	21	29.2	39	32.5	57	35.1
4	16.8	22	29.4	40	32.7	58	35.2
5	19.6	23	29.6	41	32.8	59	35.4
6	22.4	24	29.9	42	33.0	60	35.5
7	25.2	25	30.1	43	33.1	61	35.7
8	25.5	26	30.3	44	33.3	62	35.9
9	25.8	27	30.5	45	33.4	63	36.0
10	26.1	28	30.7	46	33.5	64	36.2
11	26.3	29	30.9	47	33.7	65	36.4
12	26.6	30	31.1	48	33.8	66	36.5
13	26.9	31	31.3	49	33.9	67	36.7
14	27.2	32	31.4	50	34.1	68	36.8
15	27.5	33	31.6	51	34.2	69	37.0
16	27.8	34	31.7	52	34.3	70	37.1
17	28.1	35	31.9	53	34.5		
18	28.3	36	32.0	54	34.6		

Revised maturity

Possible causes for the large proportion of mature fish in Area 1 estimated in the previous stock assessment (Doonan et al. 2004) were examined. The previous maturity ogive was estimated by Hicks et al. (2002) using von Bertalanffy growth parameters and it did not take into account the length-at-age distribution. Maturity was therefore re-estimated using the current growth curve and the length-at-age distribution given above.

Gonad data from all of the Chatham Rise research trips were re-examined. Spawning appears to take place in October through to December and perhaps into January. The data suggested that there was some confusion with macroscopic female gonad stage 2 which was probably a mix of immature and post spawning (recovering) mature fish. There was no obvious confusion about other gonad stages. During the spawning season, none of the larger fish are stage 2 and consequently the length maturity ogive was estimated using data from fish that were gonad stage 3 and later sampled in the spawning season. There were no differences between the sexes for the length ogive and only minor differences with depth.

OEO 3A spawning season research trawl survey data from 1986 and 1987 were used to estimate the maturity rates by age by fitting the length ogive and length frequencies of mature and non-mature fish to that predicted by a simple population model (growth, constant recruitment, fixed M, and F). Maturity rates were represented by a capped logistic with parameters A_m (rates cap), a50L (age at 50% of A_m), and A50.95 (ages from 50% to 95% level). Errors were estimated by bootstrapping the trawl survey data within strata. Simulations were used to evaluate the estimation procedure when assumptions were violated. The estimated parameters were (F=0): A_m = 1, A50 = 37.7 yr, and A50.96 = 0.5 yr. The age ogive was almost knife-edge at 38 yr.

3.9 Base case and MPD sensitivity runs

The model versions tried for MPD runs are shown in Table 18. The Deepwater Working Group decided that RUN2 was the base case. The estimated model parameters and priors for RUN2 are presented in Table 19.

Table 18: CASAL model runs reported. Base case in bold. –, not applicable.

Code	Data changes relative to the base case	Other
RUN1	Used rejected post-GPS CPUE (Full CPUE set used in Table 10)	
RUN2	**–**	**Base case**
RUN3	–	Density dependent migration, 3 extra parameters
LFonly	length frequency (LF) data only	
ACO only	LF data + acoustic abundances	
Pre-GPS CPUE only	LF data + pre-GPS CPUE	
Post-GPS CPUE only	LF data + post-GPS CPUE	
OneLF	Use one year's LF data (early data)	Area 1 LF: 1988/89 to 1990/91 Area 2 LF: 1986/87 to 1990/91 Area 3 LF: 1985/86 to 1988/89 Acoustic LF: 1996/97
OneLF2	Use one year's LF data	Latest year's data
No LF	Exclude all LF data	Within area, all fish selected for fishing
FixMig	Exclude all LF data	Fix selectivity and migration rates to those estimated in RUN2
Recruits	–	Estimate YCS using 5df

Table 19: Base case: estimated parameters and uniform priors of the CASAL stock assessment model, sexes combined.

Parameter	Abbreviation	Lower bound	Upper bound
Initialisation R_0 (numbers)		3 x 10^6	1 x 10^9
Size-at-age c.v.	cv	0.01	0.50
Selectivity (yr)			
Area 1, age at 50% selection		1	50
Area 1, ages 50–95% selection		0.2	35
Area 2, age at 50% selection		1	50
Area 2, ages 50–95% selection		0.2	35
Migration (yr)			
MW to Area 1, age at 50% selection	MigMW.a50	9	17
MW to Area 1, ages 50–95% selection	MigMW.a50.95	0.2	35
Area 1 to 2, age at 50% selection, logistic ogive	Mig12.a50	1	100
Area 1 to 2, ages 50–95% selection, logistic ogive	Mig12.a50.95	0.2	70
Area 1 to 2, capped logistic ogive	Mig12.cap	0	0.2
Area 2 to 3, age at 50% selection, logistic ogive	Mig23.a50	1	100
Area 2 to 3, ages 50–95% selection, logistic ogive	Mig23.a50.95	0.2	70
Area 2 to 3, capped logistic ogive	Mig23.cap	0	0.2
Process error c.v.			
Areas 1–3 acoustic length frequency		0	5
Areas 1–3 observer length frequency		0	5
Catchability			
Area 1 CPUE post-GPS, late		1 x 10^{-8}	100
Area 2 CPUE pre-GPS		1 x 10^{-8}	100
Area 2 CPUE post-GPS, late & early		1 x 10^{-8}	100
Area 3 CPUE pre-GPS		1 x 10^{-8}	100
Area 3 CPUE post-GPS, late & early		1 x 10^{-8}	100

3.10 Biomass estimates

Biomass was estimated as the median of the posterior distributions. Yields were not estimated since there was not a sustainability issue.

In order to achieve MCMC convergence the base case model was modified in the following way.

1. Process errors for the acoustic and observer length frequency data analysis were fixed at the MPD value.
2. Selectivity for the fishery was removed so that all fish within an area were vulnerable. Removal of the latter did not change the model in a statistically significant way (in terms of an increase in log-likelihood units in the MPD).

4. RESULTS

4.1 MPD results

Parameter estimates are shown in Table 20. The fits for all series were similar where they can be compared (Table 21), except for the Area 3 acoustic abundance where runs NoLF and FixMig have the best fit, and are about 4 log-likelihood units better than the base case. The better fits can be seen in the plot of the fits (Figures 14 and 15). The NoLF case has a similar relative mature biomass for each of the three areas compared to the other cases, but the proportion of mature fish in Area 1 is very low so that the overall current mature biomass estimate is low relative to the virgin state. Apparently, fitting the acoustic LF requires more old fish in Area 1 (and therefore a greater proportion of mature fish) than in the NoLF case (Figure 16). Given that the fits to the abundance data in NoLF are as good as or better than the others, and lengths are an indirect indicator of ages, there appears to be some uncertainty about the status of mature fish on Area 1.

The revised maturity ogive (see Section 3.8 Biological data) gives substantially fewer mature fish overall mainly because the proportion of mature fish in Area 1 is lower (RUN1 results in Table 22, first and last columns).

Table 20: MPD fits. Free parameter estimates. Base case in bold. –, no estimate.

Component	RUN1	**RUN2**	RUN3	OneLF	OneLF2	NoLF	FixMig
Initialisation R_0 (numbers)	23116500	**22759600**	22496100	23227400	20082600	21360900	23803500
Migration, density dependance							
Area 1 to 2, D	–	**–**	0.072	–	–	–	–
Area 2 to 3, D	–	**–**	3.524	–	–	–	–
Area 2 to 3, S	–	**–**	-5	–	–	–	–
Process error c.v.							
Areas 1–3 acoustic length frequency	0.25	**0.248**	0.257	0	0.114	–	–
Areas 1–3 observer length frequency	0.675	**0.661**	0.62	0.521	0.661	–	–
size_at_age cv	0.071	**0.071**	0.071	0.074	0.06	0.059	0.081
Migration (yr)							
MW to Area 1, age at 50% selection	17	**17**	17	15.086	17	13.563	–
MW to Area 1, ages 50–95% selection	0.2	**0.2**	0.201	0.2	0.2	0.203	–
Area 1 to 2, age at 50% selection, logistic ogive	1	**1.016**	1.14	66.759	1.024	30.943	–
Area 1 to 2, ages 50–95% selection, logistic ogive	4.403	**22.039**	35.201	70	3.763	0.2	–
Area 1 to 2, capped logistic ogive	0.034	**0.035**	0.037	0.167	0.044	0.198	–
Area 2 to 3, age at 50% selection, logistic ogive	1.268	**11.002**	22.181	1.751	1.003	1.004	–
Area 2 to 3, ages 50–95% selection, logistic ogive	29.614	**34.267**	41.481	31.271	6.844	0.208	–
Area 2 to 3, capped logistic ogive	0.041	**0.045**	0.069	0.045	0.039	0.041	–
Selectivity (yr)							
Area 1, age at 50% selection	8.481	**8.509**	8.431	8.033	8.313	–	–
Area 1, ages 50–95% selection	0.501	**0.501**	0.5	0.5	0.501	–	–
Area 2, age at 50% selection	10.242	**10.255**	11.24	9.747	10.201	–	–
Area 2, ages 50–95% selection	0.5	**0.5**	0.498	0.499	0.5	–	–

Table 21: MPD fits. Objective function component estimates. Base case in bold. –, no estimate. †, none of the runs resulted in fishery catch limit penalty being incurred.

Component	RUN1	**RUN2**	OneLF	OneLF2	NoLF	FixMig	Recruits	LFonly	ACOonly	postCPUEonly	preCPUEonly
Total	-38.66	**-40.49**	-89.42	-32.35	-36.39	-35.8	-67.34	-11.58	-7.59	-33.41	-24.81
Acoustic abundance											
Area 1	1.21	**1.21**	1.4	2.6	0.93	1.27	-0.29	–	1.21	–	–
Area 2	-3.09	**-3.11**	-3.07	-2.89	-3.04	-3.03	-1.41	–	-2.99	–	–
Area 3	-1.51	**2.02**	-2.09	6.45	-2.29	-2.17	0.87	–	1.33	–	–
CPUE											
Area1, post-GPS, early	-5.22	**–**	–	–	–	–	–	–	–	–	–
Area1, post-GPS, late	-2.74	**-2.74**	-2.73	-2.73	-2.71	-2.74	-2.74	–	–	-2.74	–
Area2, post-GPS, early	-5.07	**-5.54**	-5.51	-5.64	-5.57	-5.5	-4.49	–	–	-5.41	–
Area2, post-GPS, late	-5.19	**-5.14**	-5.15	-5.16	-5.19	-5.21	-5.57	–	–	-4.62	–
Area2, pre-GPS	-6.66	**-6.63**	-6.39	-6.96	-6.56	-6.52	-1.72	–	–	–	-6.27
Area3, post-GPS, early	0.17	**-3.86**	-3.49	-3.99	-3.44	-3.47	-4.28	–	–	-4.09	–
Area3, post-GPS, late	-3.63	**-4.64**	-4.62	-4.61	-4.63	-4.62	-4.59	–	–	-4.66	–
Area3, pre-GPS	-4.03	**-4.47**	-3.87	-4.72	-3.87	-3.81	-5.77	–	–	–	-5.11
Acoustic survey length frequency											
Area 1	-19.55	**-19.57**	-10.33	-5.68	–	–	-16.89	-20.6	-19.74	-20.89	-19.95
Area 2	-8.29	**-8.01**	-19.73	-2	–	–	8.92	-5.74	-7.93	-5.96	-7.49
Area 3	-4.76	**-6.67**	-20.42	-1.12	–	–	2.88	-9.32	-6.64	-9.32	-7.48
Observer length frequency											
Area 1	-5.21	**-5.48**	-4.33	6.84	–	–	-20.35	-6.58	-5.4	-6.47	-5.85
Area 2	10.54	**9.92**	5.39	-0.64	–	–	-29.3	9.18	9.83	9.36	8.95
Area 3	24.39	**22.22**	-4.47	-2.08	–	–	17.39	21.49	22.74	21.39	18.39
Fishery catch limit penalty†											
Area 1	0	**0**	0	0	0	0	0	0	0	0	0
Area 2	0	**0**	0	0	0	0	0	0	0	0	0
Area 3	0	**0**	0	0	0	0	0	0	0	0	0

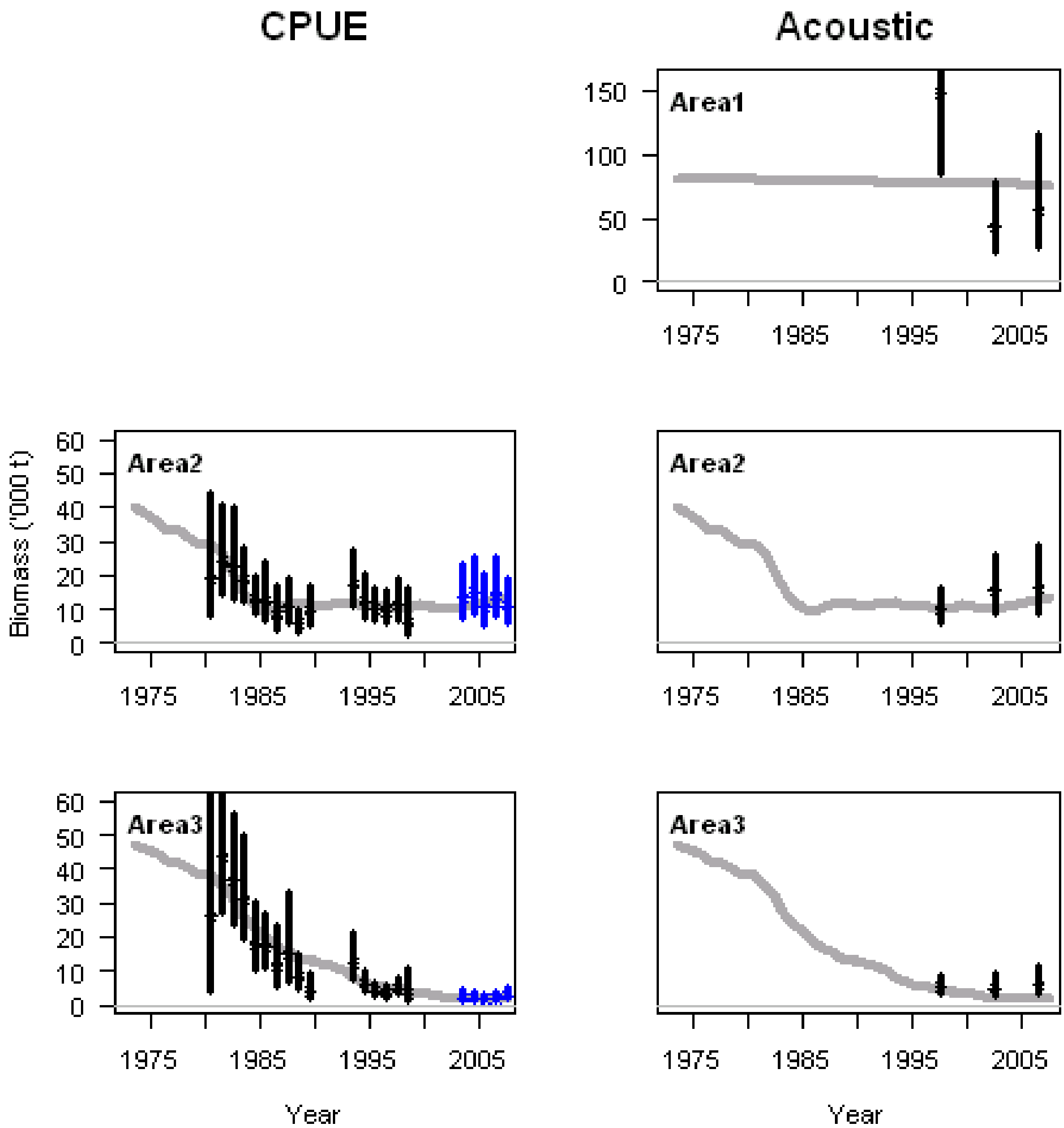

Figure 14: Base case (Run2) selected (solid line) start of year trajectories for each area with CPUE (left) and the absolute abundance (right) and the approximate 95% confidence intervals (vertical lines). Some confidence intervals exceed the axes of the plot.

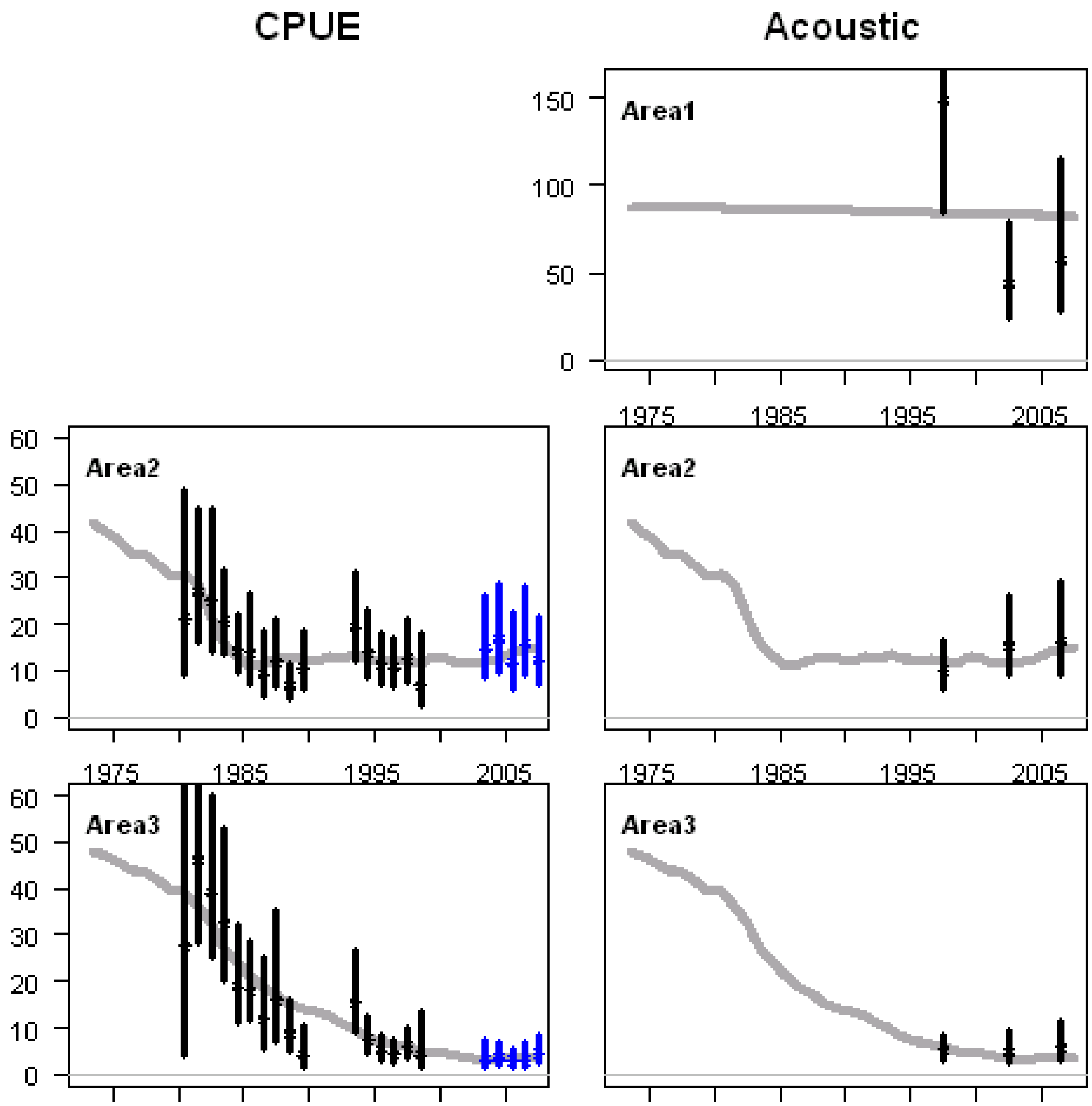

Figure 15: FixMig case selected (solid line) start of year trajectories for each area with CPUE (left) and the absolute abundance (right) and the approximate 95% confidence intervals (vertical lines). Some confidence intervals exceed the axes of the plot.

Table 22: MPD fits. Mature biomass estimates (%B_0) by area for two years, 2001-02 (as for the 2004 stock assessment) and 2006-07. Base case is in bold.

Area	RUN1	**RUN2**	RUN3	ACO.only	preCPUE.only	postCPUE.only	LFs.only	Recruits	OneLF	No LF	FixMig	RUN1 OLD MATURITY
TOTAL 2001–02	31	**30**	29	29	28	31	31	30	30	14	32	48
TOTAL 2006–07	32	**31**	30	31	29	32	32	32	31	17	34	50
Area 1 2001–02	93	**93**	89	93	93	93	93	94	93	93	93	95
Area 1 2006–07	93	**93**	88	93	92	93	93	94	93	93	93	95
Area 2 2001–02	17	**16**	18	15	14	10	10	23	18	19	18	25
Area 2 2006–07	22	**21**	23	21	20	17	17	30	25	25	23	32
Area 3 2001–02	4	**3**	3	3	1	1	1	2	5	6	5	6
Area 3 2006–07	4	**3**	4	3	1	1	1	4	5	6	5	6

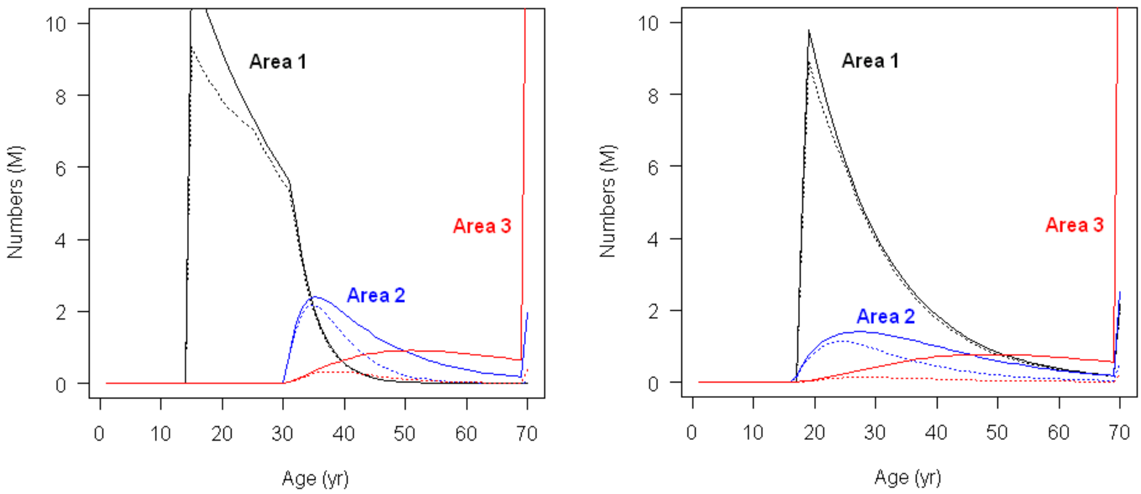

Figure 16: Predicted age frequency for each area for NoLF (left) and RUN2 (right). Solid line is for 1980 and the dotted line is 2006.

The fits of the length data are shown in Figure 17 and the QQnorm plots in Figures 18 & 19. Overall, the fits to the length data look good, except for data in Area 3. Appendices A and B show the individual plots which indicate a trend in misfits from early to late in the observer data, especially in Area 3. The run (Recruits) where year class strengths were estimated shows two major pulses early on, but this run does not fit the CPUE any better than the rest, Figure 20.

The migration rates have about 5000 t coming into Area 1 from the mid-water, and this equates to recruitment onto the ground. About 3000 t migrates from Area 1 into Area 2. Migration from Area 2 into Area 3 starts at about 2000 t and falls to about 500 t a year (Figure 21)

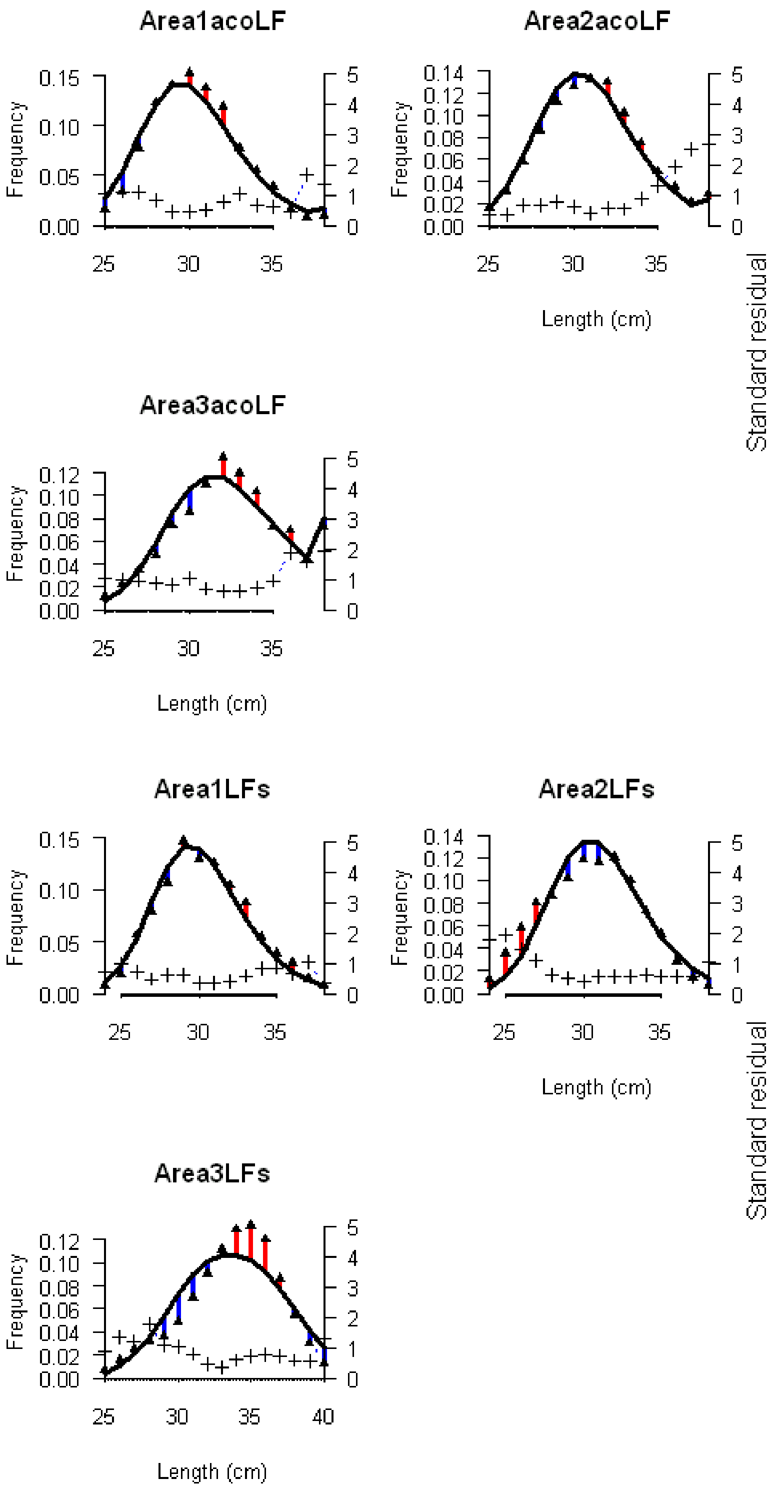

Figure 17: Base case (RUN2) overall fits to the acoustic (upper panels) and observer (lower panels) length frequency data for each area (left hand axis). The model fit is the thick dashed line and an arrowhead shows the data. Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis). Fits and residuals have been averaged across data sets in each category to show the overall fit

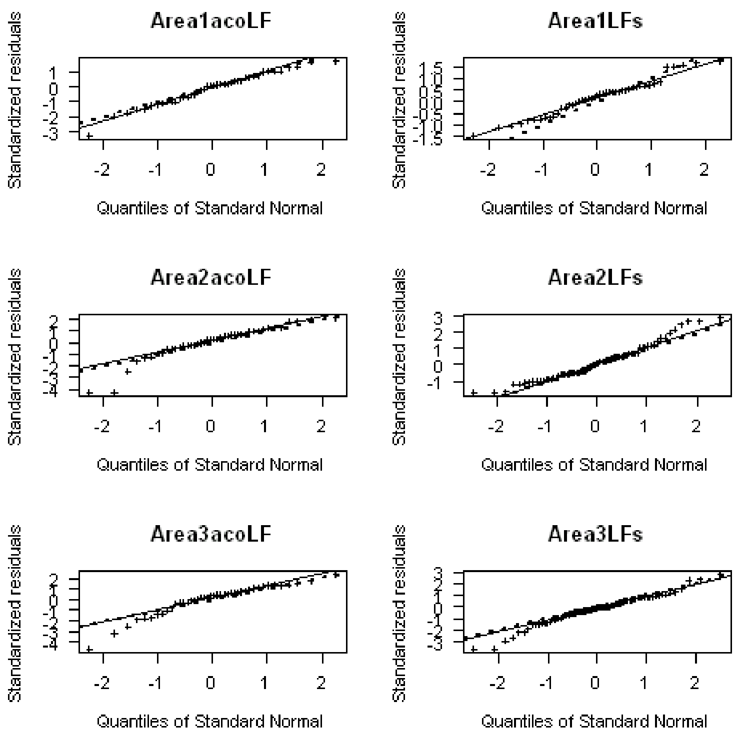

Figure 18: Base case (RUN2) QQqnorm plots for the grouped acoustic (left panels) and observer (right panels) length frequency data. The solid line passes through the first and third quartiles of the data and the standard normal distribution. The dotted line is 1:1 through the origin.

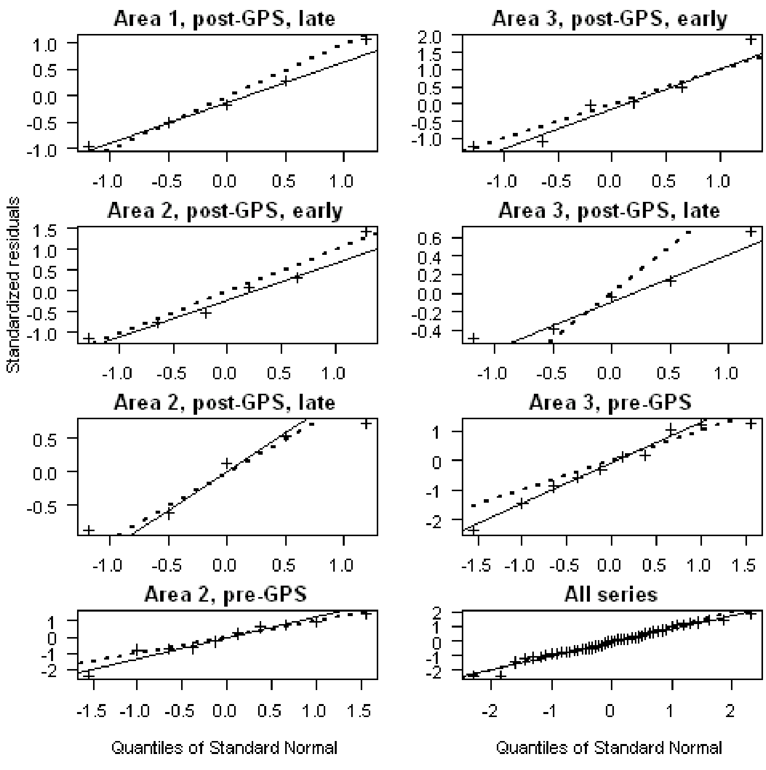

Figure 19: Base case (RUN2) QQqnorm plots for the CPUE data. The solid line passes through the first and third quartiles of the data and the standard normal distribution. The dotted line is 1:1 through the origin.

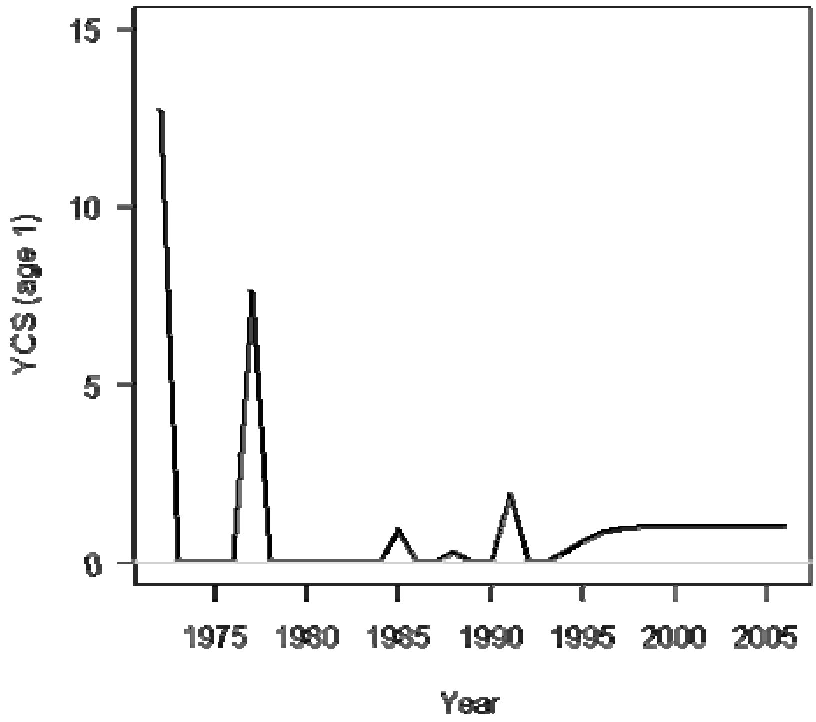

Figure 20: Estimated recruitment deviates (Recruits run).

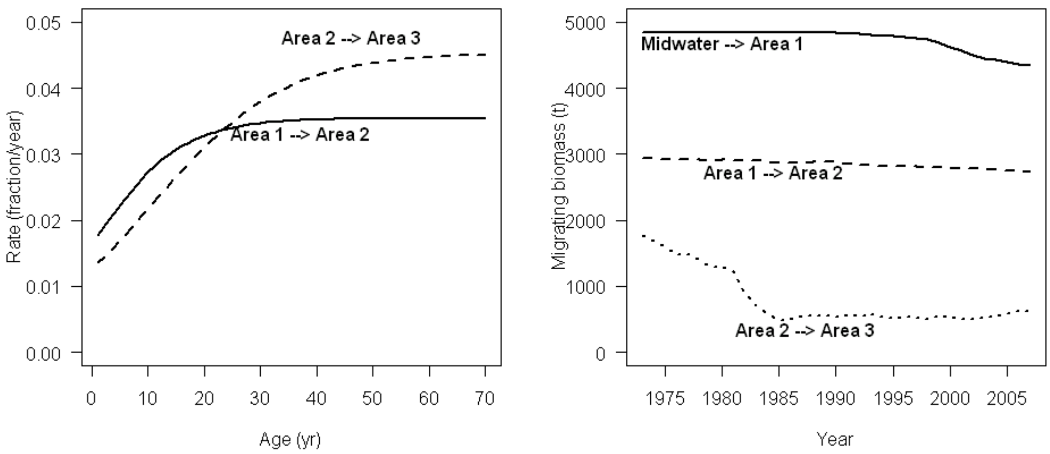

Figure 21: Base case (RUN2). Left: migration ogives for Area 1 to Area 2, and Area 2 to 3. Right: migration in terms of biomass (t). The y-axis is the proportion migrating at each age.

4.2 Bayesian results

Convergence diagnostics were run on a chain of final length 1500, after a burn-in of 500 iterations, and after systematically sub-sampling every 1000th point. Appendix C shows that the MCMC runs may have converged for some parameters. A second independent chain gave a posterior distribution for the virgin biomass that was shifted by about 3000 t. However, this difference is only about a 4% shift.

Summaries of the free parameter posteriors and biomass estimates are given in Table 23. The c.v. estimates for recruitment are very low, whilst those for the migration parameters are high. Posterior plots of virgin and current biomass are given in Figure 22 and other parameter plots are given in Appendix D.

Table 23: Base case (RUN2) MCMC summary statistics for the posterior distributions.

Parameter	Abbreviation	Median	c.v. (%)	CI.5%	CI.95%	MPD
Mature virgin	B_0	87 400	3	83 200	92 400	89 300
Mature 2006–07 mid-year (t)	B_cur	25 200	11	21 100	30 100	27 500
Mature 2006–07 mid-year (%B_0)	B_cur(%B_0)	28.766	8	25.28	32.599	30.8
Size-at-age, c.v.	cv	0.072	3	0.069	0.075	0.071
Migration						
MW to Area 1, ages 50% selection	MigMW.a50	16.775	2	16.181	16.985	17
MW to Area 1, ages 50–95% selection	MigMW.a50.95	0.561	33	0.266	0.839	0.2
Area 1 to 2, age at 50% selection, logistic ogive	Mig12.a50	18.116	14	14.661	22.502	1
Area 1 to 2, age at 50–95% selection, logistic ogive	Mig12.a50.95	55.336	39	6.418	68.881	11
Area 1 to 2, capped logistic ogive	Mig12.cap	0.053	15	0.037	0.064	0.035
Area 2 to 3, age at 50% selection, logistic ogive	Mig23.a50	10.161	63	1.832	23.695	11
Area 2 to 3, ages 50–95% selection, logistic ogive	Mig23.a50.95	35.112	54	4.399	64.567	34
Area 2 to 3, capped logistic ogive	Mig23.cap	0.047	14	0.04	0.061	0.045

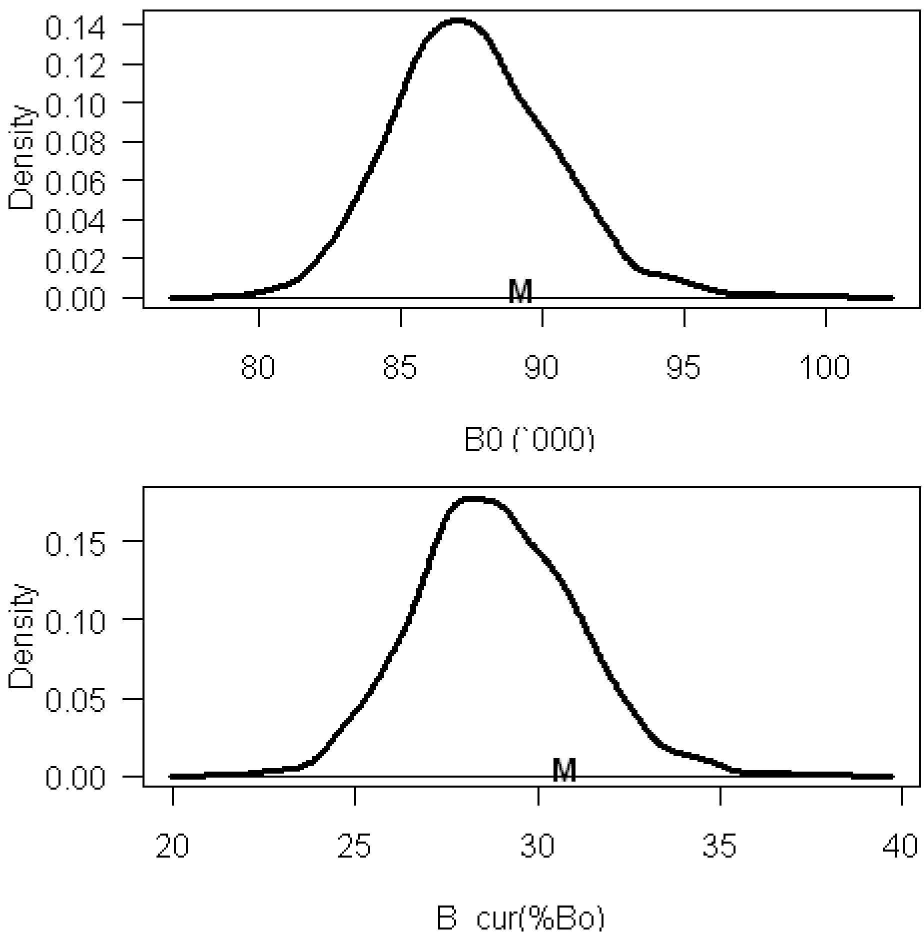

Figure 22: Posterior distribution of mid-year mature B_0 in tonnes (top panel) and current (2006–07) biomass as a percentage of mid-year mature B_0 (bottom). The M marks the MPD estimate.

5. DISCUSSION AND CONCLUSIONS

Parameter uncertainty

The non-migration parameters were well determined by the model (See Table 23), i.e., less than 12% c.v. for their posterior distributions, probably because the acoustic abundance estimates were used as absolute values and also because there is a long time-series of observer length data. Model variance estimates probably don't represent the true levels of uncertainty associated with these parameters.

Deterministic recruitment was assumed and so variability in the analysis from this source is not estimated although recruitment variability is expected. Recruitment can only be indirectly inferred because length data are used to infer age distributions. Age estimates should be considered for future stock assessments to enable estimates of recruitment and variability to be made. Another source of uncertainty not included in this assessment is that due to the estimation error in M.

Model problems

There is a trend in the residuals in the Area 3 observer length frequency that could signify a change in selectivity over time (at around 1996) or recent good recruitment, and the settlement ogive needs investigating and seems to be in conflict with age at the settlement zone. The Area 1 acoustic abundance estimates rely on mixed species in layers and so are much more uncertain compared to the acoustic abundance estimates from Areas 2 and 3.

The estimated migrations were inferred and were not based on direct observations, i.e., the model needed to shift sufficient biomass into Areas 2 and 3 to maintain the catches in each area and also to explain the observed length frequencies. The best observation data to improve the assessment would be that provided by tagged and re-captured fish, but such data are impractical to collect with current methods, i.e., deepwater species would have to be tagged in situ. The inferred nature of the migrations meant that there were two different age structures for each area that could fit the CPUE and acoustic abundance data equally well (Figure 16). These included the base case (RUN2) which was preferred because length data were used and consequently length is used as a proxy for age. The other case that fits the CPUE and acoustic abundance data used no length data (NoLF). These two different age structures resulted in a current mature biomass estimate that was 31% in the base case and 17% in the NoLF case. In the NoLF case there were fewer old, mature fish in Area 1 compared to the base case. The large biomass of mature fish in Area 1 in the base case can not fall below about 25% of virgin levels if it is left unfished. These conflicting results have implications for management and need to be verified by further study.

Conclusions

The assessment suggests that, since the last quota adjustments in 2002–03, the stock is slightly rebuilding or has been constant and this matches the trends in the CPUE and acoustic abundances.

The hypothesis of a large reservoir of mature fish in Area 1 should be tested by estimating the age structure of the population using age estimates obtained from otoliths. Future research surveys should incorporate a design that ensures that fish otoliths are sampled to provide age estimates that represent the sampled population.

Some caution is advised in accepting the stock assessment model base case because if the length induced migration rates are wrong, or the area structure is wrong, then the current mature biomass could be below 20% B_0.

6. ACKNOWLEDGMENTS

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A.1 Appendix A: Observer length frequency fits.

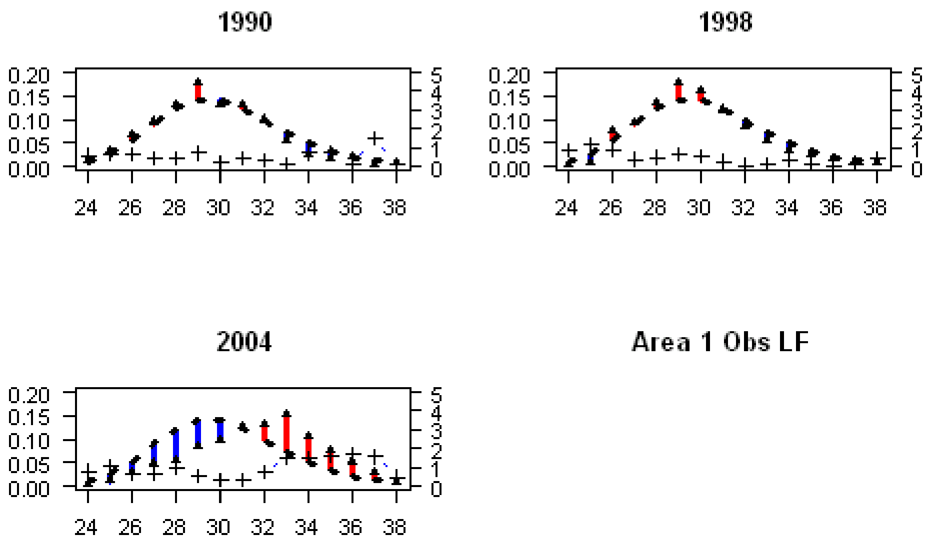

Figure A1: Base case (Run2) observer length frequency distributions for Area 1. The model fit is the thick dashed line and arrowhead shows the data (left hand axis). Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).

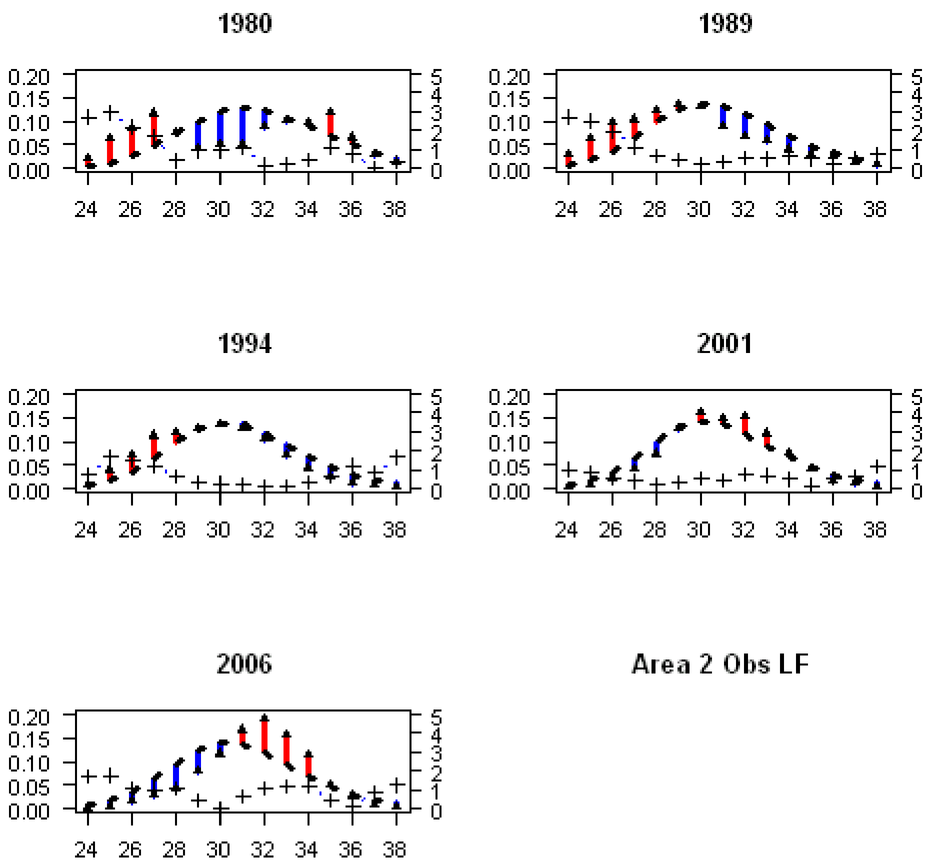

Figure A2: Base case (Run2) observer length frequency distributions for Area 2. The model fit is the thick dashed line and arrowhead shows the data (left hand axis). Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).

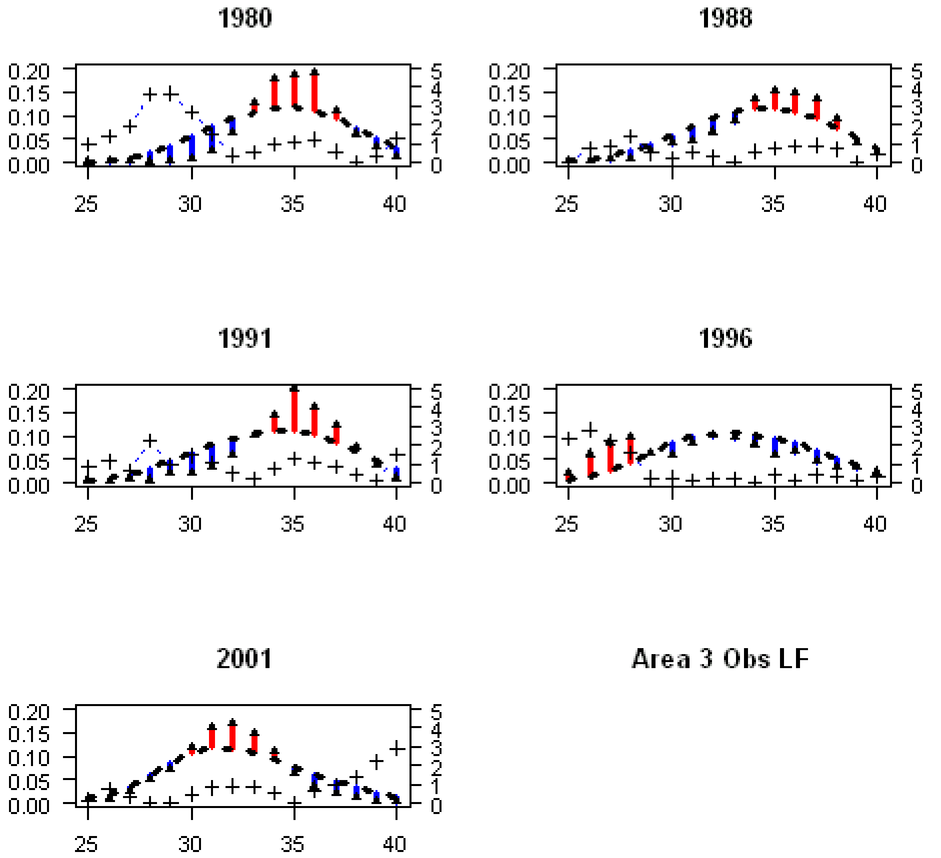

Figure A3: Base case (Run2) observer length frequency distributions for Area 3. The model fit is the thick dashed line and arrowhead shows the data (left hand axis). Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).

A.2 Appendix B: Fits of the acoustic length data.

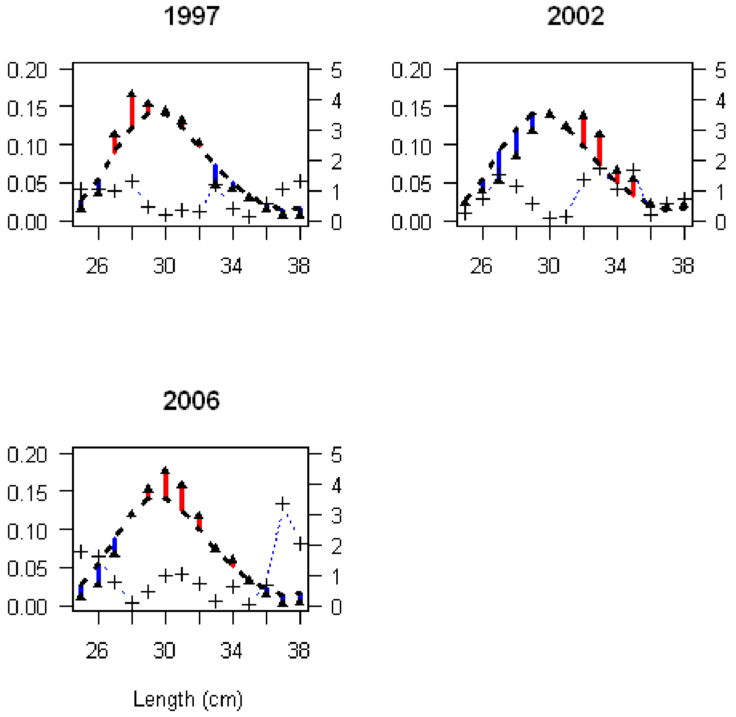

Figure B1: Base case (RUN2) acoustic survey length frequency distributions for Area 1. The model fit is the thick dashed line and arrowhead shows the data (left hand axis). Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).

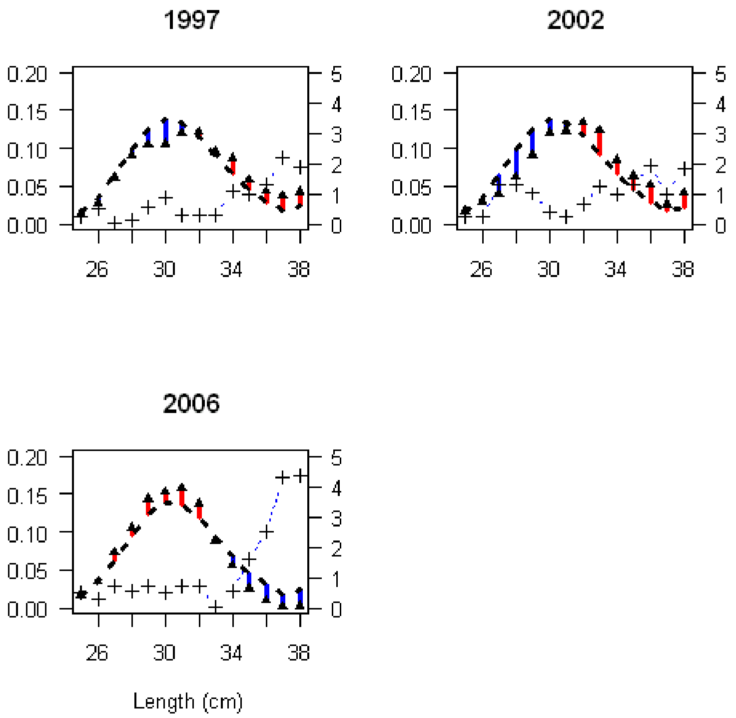

Figure B2: Base case (RUN2) acoustic survey length frequency distributions for Area 2. The model fit is the thick dashed line and arrowhead shows the data (left hand axis). Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).

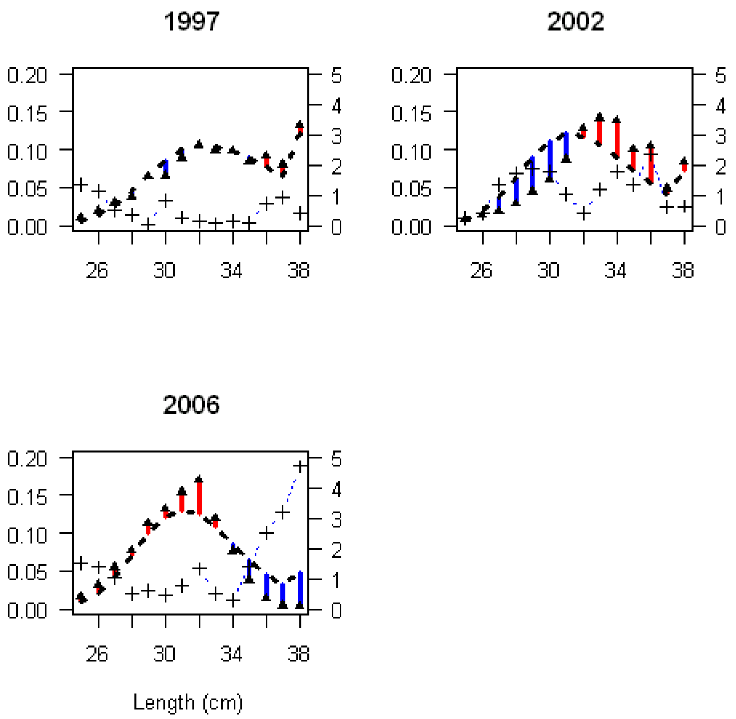

Figure B3: Base case (RUN2) acoustic survey length frequency distributions for Area 3. The model fit is the thick dashed line and arrowhead shows the data (left hand axis). Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).

A.3 Appendix C: Bayesian trace plots.

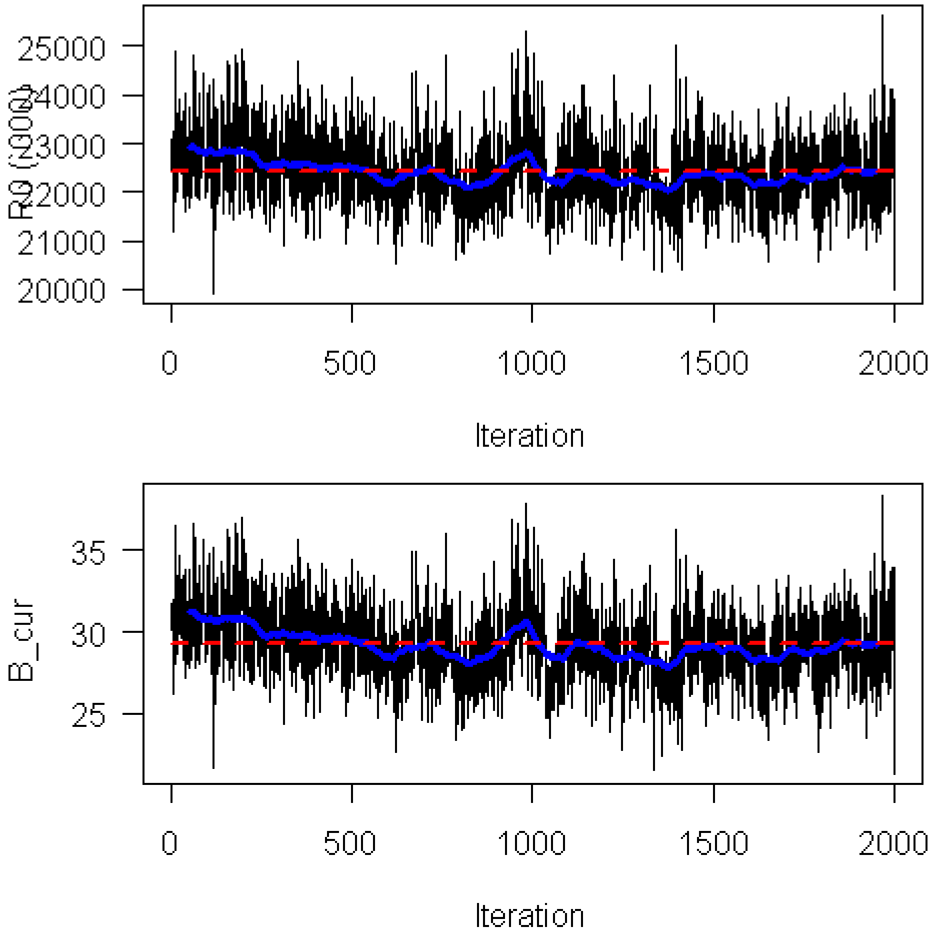

Figure C1: Time series of MCMC estimates for R_0 (top) and current mature biomass as a percentage of virgin biomass (bottom) for the base case. The continuous line is a running average of estimates using a window of 100. The dashed line is the mean over the series.

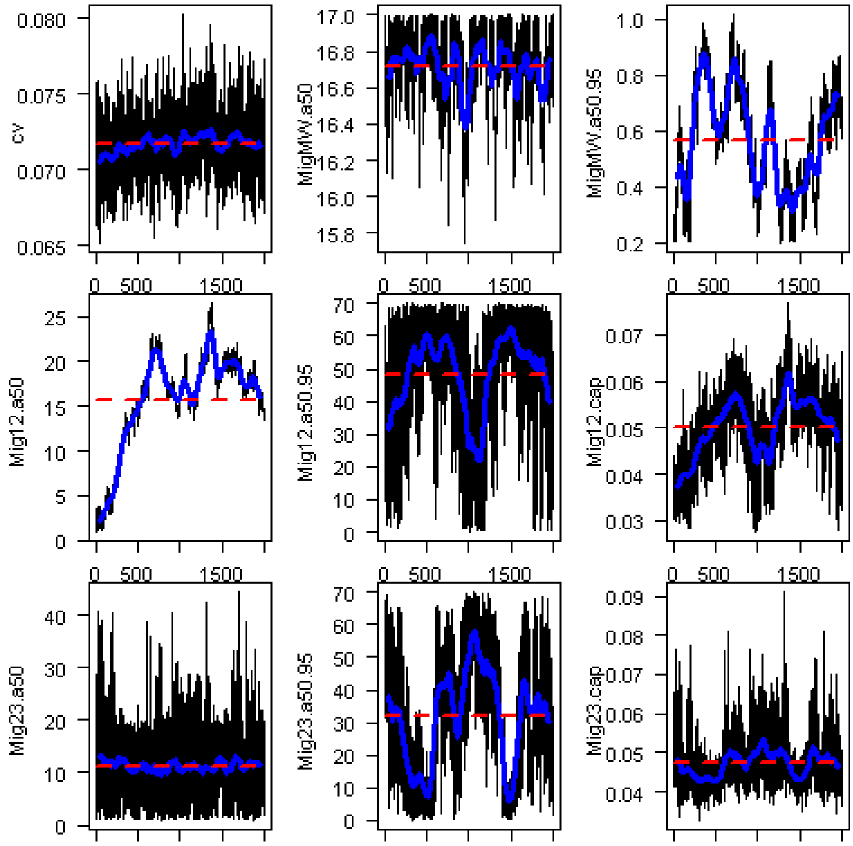

Figure C2: Time series of parameter estimates from MCMC for non-abundance parameters in the base case. The continuous line is a running average of estimates using a window of 100. The dashed line is the mean over the series. See Table 19 for parameter abbreviations.

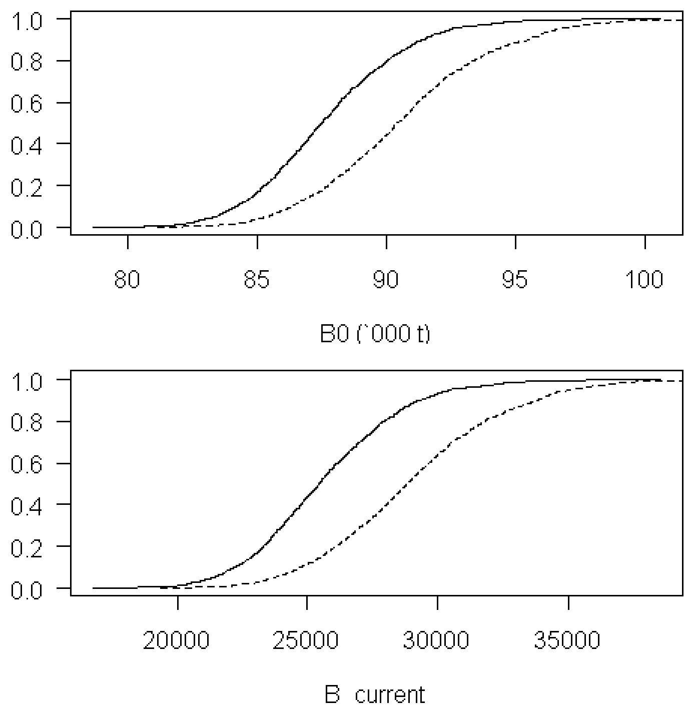

Figure C3: Cumulative density plots from two independent MCMC chains for virgin biomass (top) and current mature biomass (bottom) for the base case

A.4 Appendix D: MCMC free parameter density plots.

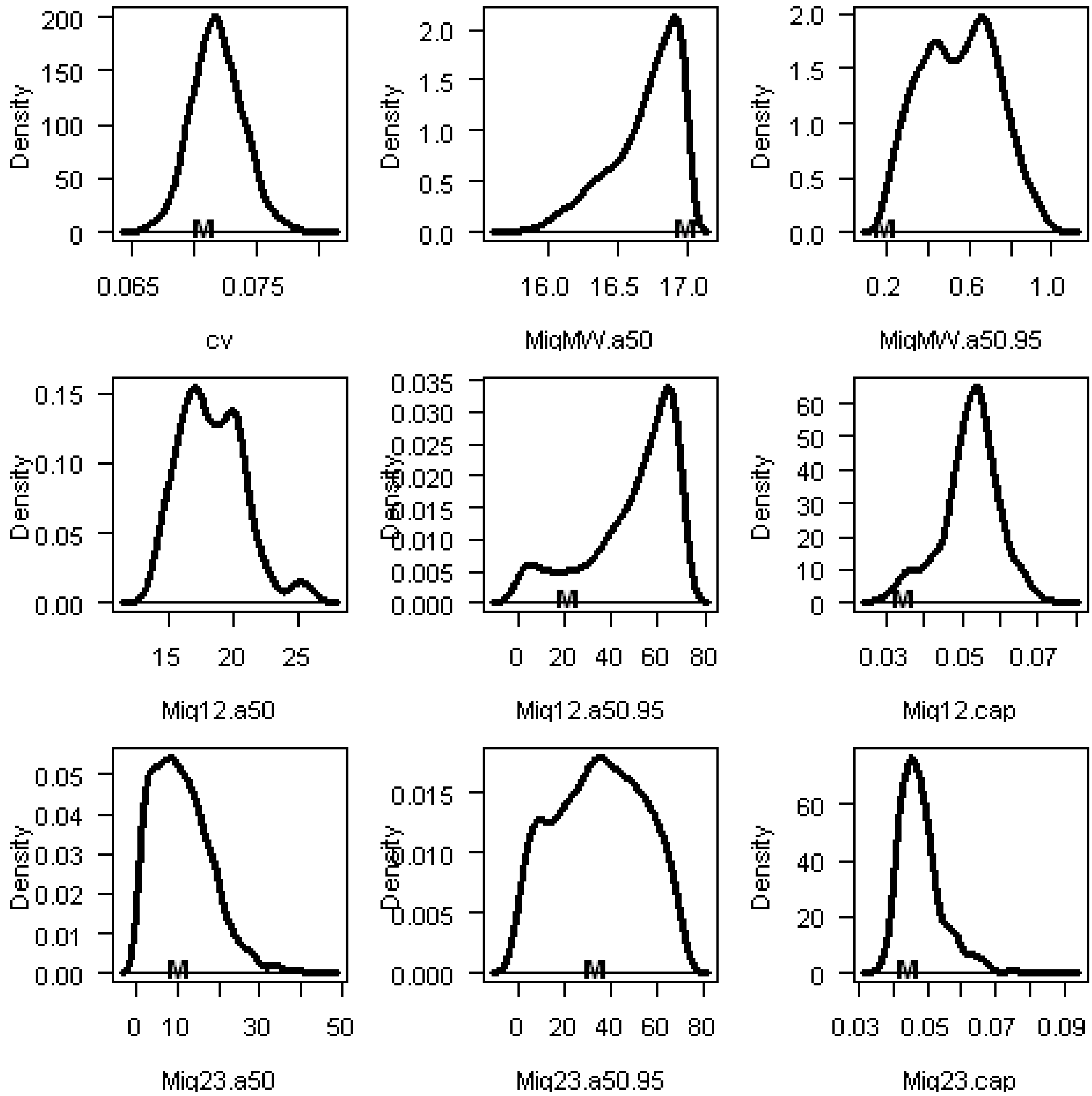

Figure D1: Base case (RUN2) MCMC free parameter density plots. See parameter definitions and abbreviations in Table 19.