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EXECUTIVE SUMMARY

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The biomass of smooth oreo in OEO 3A was estimated with Bayesian methods using a CASAL age-structured population model. Input data included research and observer-collected length data, one absolute abundance estimate from a research acoustic survey carried out in 1997 (TAN9713), and relative abundance indices from a standardised catch per unit effort analysis. Biomass estimates were made for the whole of OEO 3A. The base case used the 1997 acoustic abundance estimates, pre-GPS and early and late post-GPS standardised CPUE indices, and a depth-related selectivity. The selectivity values were estimated in a preliminary model that also included the observer length data and the 1997 acoustic survey length data. Sensitivity model cases examined the influence of using different values of natural mortality, 0.042 and 0.0945, which are close to the upper and lower 95% confidence interval values for estimates of natural mortality (0.042–0.099 yr^{-1}), and using only the left hand limb of the 1994 observer length frequency (plus the 1997 acoustic survey length frequency) with growth not estimated by the model.

For the whole of OEO 3A using the base case analysis, the smooth oreo median virgin biomass was 85 000 t (95% C.I. of 77 300–96 500 t); the median mature 2008–09 (mid-year) biomass estimate was 30 900 t or 36% of B_0 (95% C.I. of 22 400–43 000 t, or 29–45% of B_0).

The assessment contains extra sources of uncertainty that were not estimated, e.g., uncertainty in the biomass estimates because of the use of deterministic recruitment and from fixing selectivity values in the MCMC runs.

1. INTRODUCTION

1.1 Overview

This work addresses the following objectives in MFish project "Oreo stock assessment" (OEO2008/01).

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 objective

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:
   - Smooth oreo in OEO 3A
   - Black oreo in OEO 4
   - Black oreo in OEO 6 (Pukaki Rise)

This report deals only with smooth oreo in OEO 3A.

A stock assessment analysis for smooth oreo in OEO 3A (see Figure 1) was completed using the CASAL age-structured population model employing Bayesian statistical techniques. The 2005 assessment (Doonan et al. unpublished results). was updated in 2009 by including five more years of catch, CPUE and observer length data, and two new series of post-GPS standardised CPUE, one before and the second after major TACC and catch limit changes. The modelling took account of the sex and maturity status of the fish and treated OEO 3A as a single smooth oreo fishery, i.e., no subareas were recognised. The base case model used the 1997 absolute acoustic abundance estimate, pre-GPS and early and late post-GPS series of standardised CPUE indices, and the mean natural mortality estimate (0.063 yr^{-1}). Acoustic and observer length frequencies were used in a preliminary model run to estimate selectivity and the base case used these selectivity estimates but did not use the length frequencies. Other cases investigated the sensitivity of the model to data sources including: using different values of natural mortality, 0.042 and 0.0945, which are close to the upper and lower 95% confidence interval values for estimates of natural mortality (0.042–0.099 yr^{-1}); use of only the left hand limb of the 1994 observer length frequency (plus the 1997 acoustic survey length frequency) with growth not estimated by the model.

Other observation data available for the assessment included biological data from research trawl surveys (1991–93, 1995, *Tangaroa*) and relative abundance estimates from these surveys. The latter were considered unreliable in previous assessments because of catchability issues (Doonan et al. 1997a) so were not used in the current assessment. Annual observer length/catch data are available from 1990–91 on, although sampling was erratic.

Catch history data are available from the late 1970s although the early data and some subsequent data required reconstruction of species catch from known species proportions because of the use of the aggregated species code (OEO) (see Section 1.2 below). Dumping of unwanted or small fish and accidental loss of fish (lost or ripped codends) were features of oreo fisheries in the early years. These sources of mortality were probably substantial early part of the fishery, but are now thought to be relatively small. No estimate of mortality from these sources was made because of lack of data and because they now appear to be small.

Smooth oreo are caught throughout the year by bottom trawling at depths of 800–1300 m in southern New Zealand waters. The OEO 3A south Chatham Rise fishery was one of the largest oreo fisheries in the EEZ and operates between about 172° 30 and about 176° 00 E, mostly on undulating terrain (short plateaus, terraces, and "drop-offs"). Mixed catches of smooth oreo and black oreo were common although there was a higher likelihood of catching higher proportions of smooth oreo in deeper water and higher proportions of black oreo in shallower water. There is no known recreational or Maori customary catch of oreos.

Smooth oreo are thought to be slow-growing and long-lived with the larger females reaching maximum sizes of around 50 cm TL at about 80 years and males reaching 45 cm and 70 years (Doonan et al. 1997b). Age estimates for New Zealand fish are unvalidated but similar results were reported by Australian workers (D.C. Smith and B.D. Stewart, Victorian Fisheries Research Institute, unpublished). They are a schooling species and form localised aggregations to feed (all year) or to spawn (October-December).

Stock structure of Australian and New Zealand samples of smooth oreo were examined using genetic (allozyme and mitochondrial DNA) and morphological counts (fin rays, etc.). No differences between New Zealand and Australian smooth oreo samples were found using these techniques (Ward et al. 1996). A broad scale stock is suggested by these results but this seems unlikely given the large distance between New Zealand and Australia. A New Zealand pilot study examined smooth oreo stock relationships using samples from four management areas (OEO 1, OEO 3A, OEO 4, and OEO 6) of the New Zealand EEZ. Techniques used included genetic (nuclear and mitochondrial DNA), lateral line scale counts, settlement zone counts, parasites, otolith microchemistry, and otolith shape. Otolith shape from OEO 1 and OEO 6 was different to that from OEO 3A and OEO 4 samples. Weak evidence from parasite data, one gene locus, and otolith microchemistry suggested that OEO 3A samples were different from those from other areas. Lateral line scale and otolith settlement zone counts showed no differences between areas (Smith et al. 1999).

1.2 TACCs, catch, and landings data

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 1.

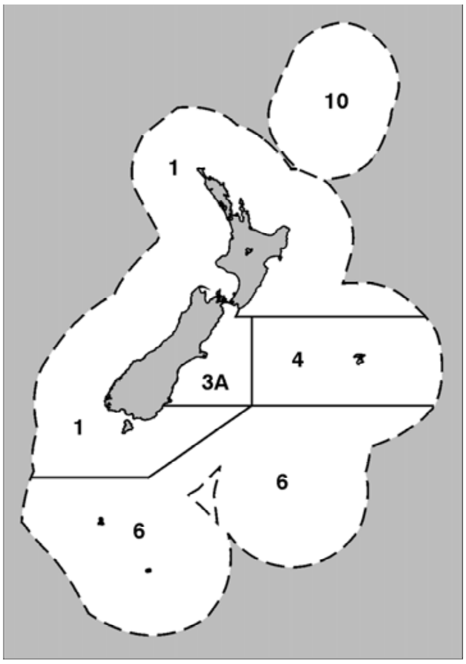


Figure 1: Oreo management areas.

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 ITQ scheme 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 (probably black oreo and smooth oreo combined, see Doonan et al. (1995)) from the New Zealand area (Table 1). Reported landings of oreos (combined species) and TACs from 1978–79 until 2007–08 are given in Table 2. The oreo catch from OEO 3A was less than the TAC from 1992–93 to 1995–96, substantially so in 1994–95 and 1995–96. 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. Subsequently the total OEO 3A TAC was reduced to 5900 t in 1999–00, 4400 in 2000–01, 4095 in 2001–02 and 3255 t in 2002–03. Reported estimated catches by species from data recorded in catch and effort logbooks (Deepwater, TCEPR, and CELR) are given in Table 2. Soviet catches from the New Zealand area from 1972 to 1977 were assumed to be black oreo and smooth oreo combined and to be from area OEO 3A (Doonan et al. 1995).

Table 1: Soviet oreo catch (t) by FAO area from 1972 to 1977 (from Fincham et al. 1991).

	†FAO area		
Year	81.4	81.5	Total
1972	121	6 879	7 000
1973	0	7 600	7 600
1974	0	10 200	10 200
1975	87	2 513	2 600
1976	242	7 758	8 000
1977	0	11 500	11 500

† The two FAO areas include waters west of N.Z. (81.4) and east of N.Z. (81.5).

Table 2: 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 2007–08. – na.

Fishing	Landings		Estimated catch	
Year	t	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	3 255	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
2007–08†	3 092	3 100	1 482	1 521

Source: Ministry of Fisheries (2009). *, 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 smooth oreo population into two sex groups, and age groups of 5–70 years, with a plus group. There was a single area.

2.1.2 Annual cycle

The nominal unit time in the model is one year during which processes (e.g., recruitment) were applied. Since these processes cannot be modelled simultaneously they were carried out in a specified sequence (Table 3). 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 3).

Table 3: Stock assessment model: timing within a year for processes and when data were fitted.

Model time step

Time	Process (in the order applied)
Oct	Increment age
Oct	Recruitment
Oct-Sep	Fishing & natural mortality

Observations fitted

Time	Description
Oct	Acoustic abundance
Oct	Acoustic length data
Mar	CPUE indices
Mar	Observer length data

2.2 Selectivities, ogives, and other assumptions

Fishing selectivity

Separate age-based selectivity ogives were estimated for males and females for the commercial fishery (catch) data. The ogives were logistic curves with parameters for the age of 50% selection and for the ages from 50 to 95% selection. The ogives also used a depth variable since smaller fish are generally found in shallower water and larger fish in deeper water so consequently the selectivity needs to be shifted according to the mean depths being fished each year. The idea for this selectivity was developed from previous work for a stock assessment of hoki (*Macruronus novaezelandiae*), (Francis 2003).

Acoustic selectivity

Separate age-based selectivity ogives were estimated for males and females for the acoustic survey abundance data. The acoustic length data did not fit a logistic curve well because of the group of small fish to the left hand side of the main length mode. Therefore, a non-parametric curve was used that covered 30 ages (ages 5 to 35 years). This used 30 estimated parameters, π_i (I=1 to 30), but the curve was constrained to be non-decreasing with a selectivity of 1 in the 30th year. The parameter, π_i, is the fraction of the gap from the selectivity of the age before it and 1, and is constrained to be between 0 and 1, i.e., the selectivity at i, O_i, is

$$O_{i-1} + \pi_i (1 - O_{i-1})$$

that ensures that the selectivity is always between 0 and 1, inclusive, and that the curve will always be constant or increasing with age.

The use of this acoustic selectivity implies that the acoustic survey "sees" only those fish to the right of the curve and since the data that the curve is estimated from are length frequencies, this assumes that the trawl net selectivity has no effect, i.e., the trawl selectivity is to the left of the acoustic curve. Although we cannot validate this, we believe that it is more or less the case since young fish (less than about 7 years old) are probably in midwater and so were not counted by the acoustic survey. At 5–6 years (16–17 cm TL) these fish settle on the bottom (based on counts out to the settlement zone on otolith samples) and are then available to the acoustic survey technique but may not be fully selected by the trawl gear. By age 8 these fish are about 20.5 cm and are almost fully selected by the trawl gear.

Maturity

The maturity ogive developed during the 2003 stock assessment of OEO 4 smooth oreo was used (Figure 2; appendix A, in Doonan et al. (2003)).

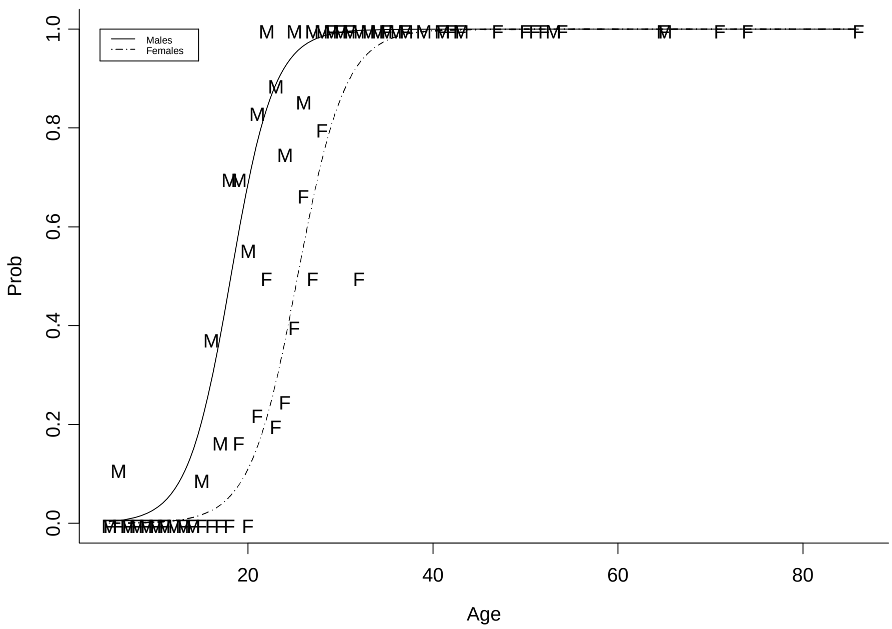


Figure 2: Plots of the observed and fitted points for male and female maturity data when using GSI thresholds of 0.4 and 1 for males and females, respectively.

2.3 Modelling methods, parameters, assumptions about parameters

The stock assessment analyses were conducted using CASAL (Bull et al. 2002). This was implemented as an age-structured population model that took account of the sex of the fish and allowed inclusion of length frequency data. The Bayesian estimator was employed. The model incorporated deterministic recruitment, life history parameters, and catch history. Data fitted in the analysis were the revised 1997 acoustic abundance estimates, and new standardised combined pre- and early and late post-GPS CPUE indices. A preliminary model also fitted the observer length data, and the 1997 acoustic survey length data from which selectivities were estimated. These estimated selectivities were then used in the final model. The model was used to estimate biomass. These procedures were conducted with the following steps.

1. Models were explored and fits assessed using maximum likelihood and the prior probabilities to estimate parameters (MPD runs).

2. From (1) above, a base case and some sensitivity cases were selected and a Bayesian analysis was performed. Samples for the posterior distribution of parameters were generated with the Markov Chain Monte Carlo procedure (MCMC) 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, 2.5, and 97.5 percentiles for parameters of interest. The median was used as the "point" estimate.

The following assumptions were made in the analyses carried out to estimate biomass.

(a) The 1997 acoustic abundance estimates were unbiased absolute values.
(b) The CPUE analyses provided a relative index of abundance for smooth oreo in the whole of OEO 3A.
(c) The ranges used for the biological values covered their true values.
(d) One assumed value (0.58) of the maximum fishing mortality (U_{max}) was used in all the analyses of smooth oreo below.
(e) Recruitment was deterministic and followed a Beverton & Holt relationship with steepness of 0.75.
(f) Catch overruns were 0% during the period of reported catch.
(g) The population of smooth oreo in OEO 3A was a discrete stock or production unit.
(h) The catch history was accurate.

3. OBSERVATIONS AND MODEL INPUTS

3.1 A single fishery

Initial analysis of OEO 3A smooth oreo catch data showed that the historical fishing pattern was not strongly influenced by area or time in contrast to the black oreo OEO 3A fishery (Hicks et al. 2002, Doonan et al. 2004) and the OEO 4 smooth oreo fishery (Doonan et al. 2003). The analyses below were therefore conducted on a single OEO 3A smooth oreo fishery.

3.2 Catch history

Catch history is presented in Table 4 and includes the yearly total catch for OEO 3A.This was derived from Tables 1 and 2 as follows.

1 Soviet catch of unspecified oreo from FAO area 81.5 from 1972 to 1977 (see Table 1) was assumed to be all from OEO 3A, to be 50:50 smooth to black oreo, and to be for fishing years rather than calendar years.
2 Catches from 1978–79 to 1982–83 (1 April to 31 March) were assumed to be for fishing years (1 October to 30 September).
3 The 1978–79 landings of unspecified oreo (1366 t, *see* Table 1) were assumed to be the same proportion of smooth oreo to black oreo estimated catch reported in 1979–80 (5075/(5075+5588) = 0.476). The estimate of the 1978–79 smooth oreo catch was 1366 t x 0.476 = 650 t.
4 The 6 month landing of smooth oreo reported as 1983–83 (713 t, see Table 2) was split and half each (356.5 t) added to the preceding and subsequent years (1982–83 and 1983–84). There was only a 3 t difference between estimated and reported landings in 1983–83 (see Table 2), so no adjustment to the reported smooth oreo catch was made.
5 From 1979–80 to 2007–08 the landings were calculated by multiplying the value by the proportion of smooth oreo to black oreo estimated catch in Table 2.
6 The last year of the catch history are assumed projected catch.

Table 4: Reconstructed catch history (t) of smooth oreo from OEO 3A. † assumed species split. ‡ projected catch.

Year	Catch	Year	Catch	Year	Catch
1972–73	†3 440	1985–86	3 142	1998–99	2 474
1973–74	†3 800	1986–87	3 190	1999–00	1 789
1974–75	†5 100	1987–88	5 905	2000–01	1 621
1975–76	†1 260	1988–89	6 963	2001–02	1 673
1976–77	†3 880	1989–90	6 459	2002–03	1 412
1977–78	†5 750	1990–91	5 054	2003–04	1 254
1978–79	650	1991–92	6 622	2004–05	1 457
1979–80	5 215	1992–93	4 334	2005–06	1 445
1980–81	2 196	1993–94	4 942	2006–07	1 306
1981–82	1 288	1994–95	4 199	2007–08	1 526
1982–83	2 495	1995–96	4 022	2008–09	‡1 526
1983–84	3 979	1996–97	3 239		
1984–85	4 351	1997–98	4 733		

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

3.3 Relative abundance estimates from CPUE analyses

The standardised CPUE analyses were described by Coburn et al. (2006) for data up to 2002–03, i.e., a pre-GPS and a post-GPS series. In 2009 three analyses were carried out; a pre-GPS analysis (unchanged from 2005) that included data from 1980–81 to 1988–89 and two new post-GPS analyses that included data from 1992–93 to 1997–98 and 2002–03 to 2007–08. The years from 1998–99 to 2001–02 were not included because a voluntary smooth oreo catch limit (1400 t) was introduced and substantial oreo TACC changes were made during that time (6600 to 3100 t). Brief details of the methods and the update using new data to 2007–08, and the indices used in the stock assessment are given below.

Method of CPUE analysis

The CPUE analysis involved regression-based methods where the zero catch tow and the positive catch tow data were analysed separately to produce positive catch and zero catch indices. The CPUE study area and the locations of all tows in OEO 3A with a reported catch of smooth oreo from 1979–80 to 2002–03are shown in Figure 3. The data include all tows that targeted or caught smooth oreo (SSO) from the study area. For target fishing, a combined index was calculated (see Coburn et al. 2006), and the year variable was forced in at the start. The predictor variables considered in the analysis included target species, depth, season, time of day, latitude, vessel (estimated for each vessel), subareas (of the CPUE study area), moon (state of lunar illumination), sun (altitude of the sun) and current (tidal current). For the post-GPS analyses, only vessels with three years' participation in the period and 10 tows per year for these years were used in the standardised index.

For the early post-GPS series, the positive catch regression selected vessel only. The zero catch regression selected subarea and vessel (target species was selected first, but it was excluded by the Deepwater Working group). For the late pre-GPS series, only a positive catch regression was used since there were very few zeros in the data. The selected predictor variables were: vessel, target species, day of year, depth, and subarea.

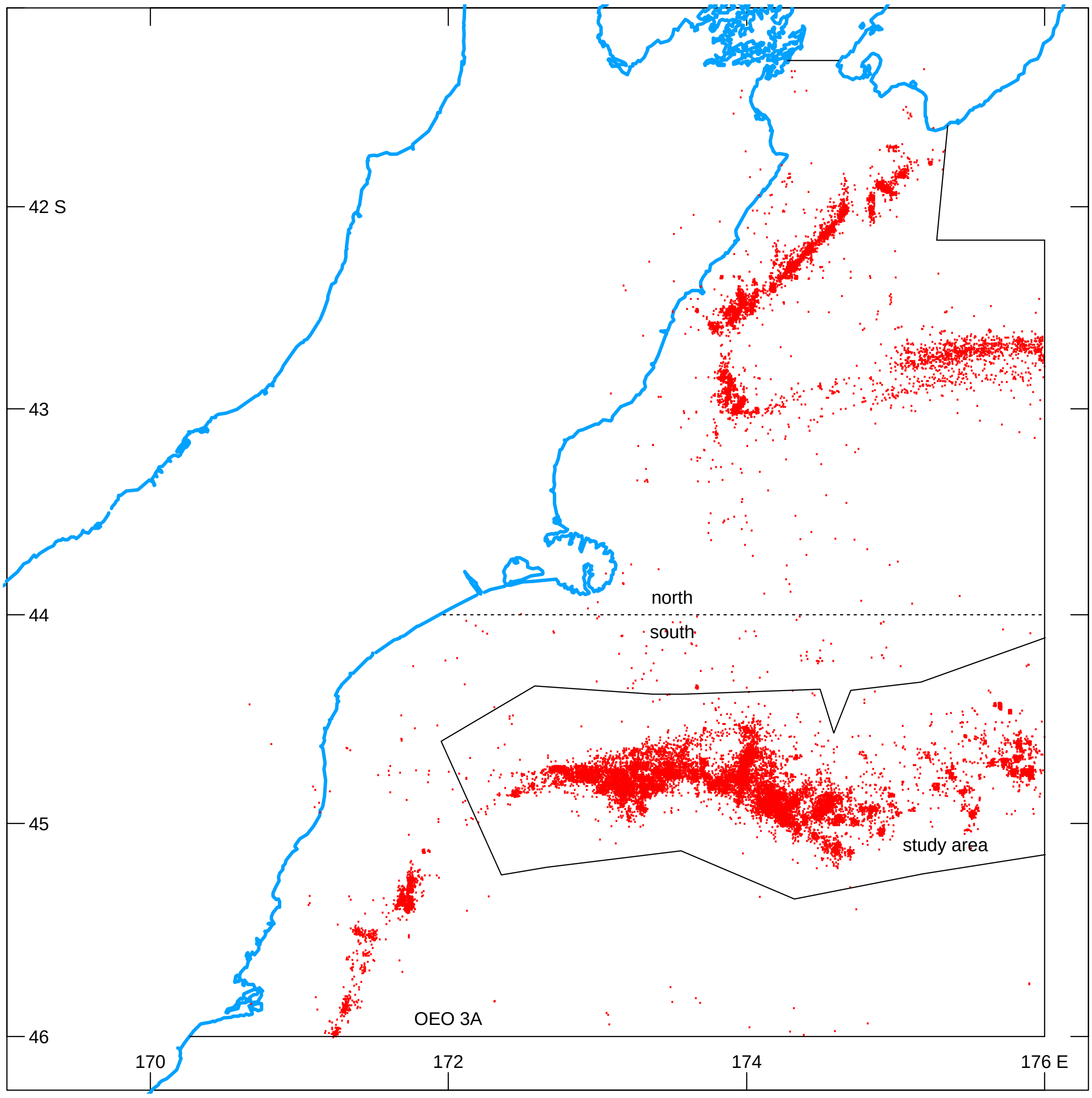


Figure 3: Locations of all tows in OEO 3A with a reported catch of smooth oreo from 1979–80 to 2002–03. The study area is shown along with the line chosen to split north from south Chatham rise catches.

Results of the CPUE analysis

The pre-GPS combined index trends down, is fairly linear, and falls to about a third of its initial level over the eight-year period. The early post-GPS trends down but the late post-GPS series trends up and flattens. The base case stock assessment analysis used all three indices (Figures 4 & 5, and Tables 5 & 6).

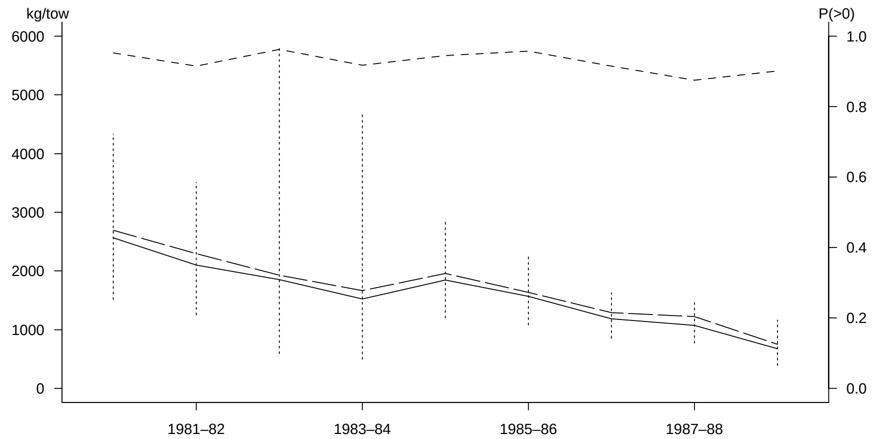


Figure 4: Positive catch (long dashes), zero catch (dashes) and combined index (solid) with 2 standard error jackknife confidence interval (dotted) from the pre-GPS analysis.

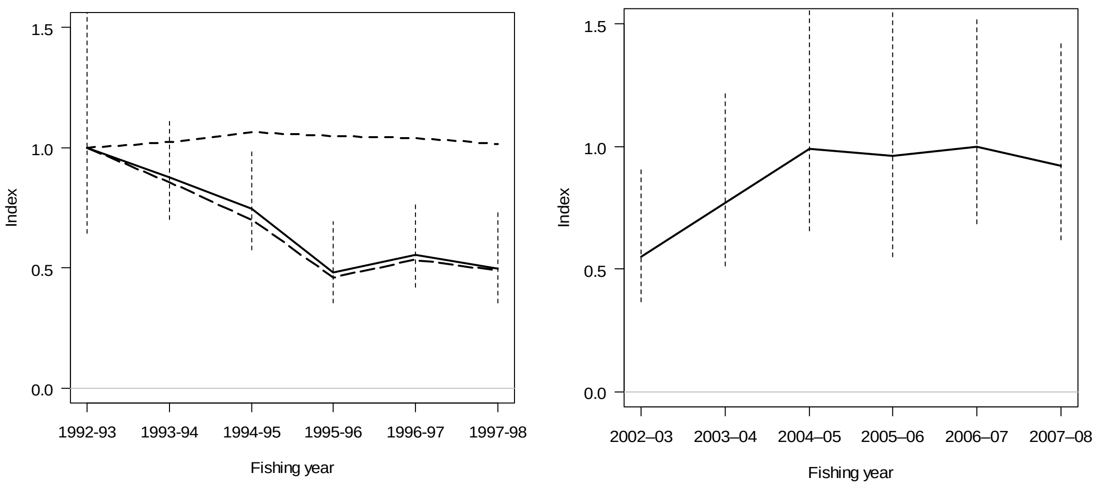


Figure 5: Left: early post-GPS series showing the positive catch (dashes), zero catch (upper solid line), and combined index (lower solid line) with 2 standard error jackknife confidence interval (dotted). Right: late post-GPS index (positive regression only).

Table 5: Positive catch, zero catch, combined index estimates by year, and jackknife c.v. estimates on the combined index from the pre-GPS analysis.

	Positive catch (kg/tow)	Zero catch	Combined	Jackknife c.v. %
1980–81	2 693	0.95	2 564	27
1981–82	2 295	0.91	2 099	26
1982–83	1 926	0.96	1 854	62
1983–84	1 663	0.92	1 525	61
1984–85	1 956	0.94	1 848	22
1985–86	1 635	0.96	1 565	19
1986–87	1 291	0.92	1 182	16
1987–88	1 224	0.87	1 070	16
1988–89	749	0.90	675	28

Table 6: Combined index estimates by year, and jackknife c.v. estimates on the combined index from the post-GPS analyses.

Early post-GPS			Late post-GPS		
Year	Index	c.v. (%)	Year	Index	c.v. (%)
1992–93	1.00	24	2002–03	0.55	23
1993–94	0.88	11	2003–04	0.77	22
1994–95	0.74	14	2004–05	0.99	22
1995–96	0.48	17	2005–06	0.96	31
1996–97	0.56	15	2006–07	1.00	20
1997–98	0.50	19	2007–08	0.92	21

3.4 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 (Table 7). The abundance estimates from the surveys before 1991 were not considered to be comparable with the *Tangaroa* series because different vessels were used. Other data from those early surveys were used, e.g., gonad stageing to determine length at maturity. The 1991–93 and 1995 "standard" (flat, undulating, and drop-off ground) surveys are comparable but were considered to be problematic because catchability estimates were inconsistent (Doonan et al. 1997a). The estimates were not included in the base case for this assessment.

Table 7: Random stratified trawl surveys (standard, i.e., flat tows only) for oreos on the south Chatham Rise (OEO 3A & OEO 4).

Year	Area (km^2)	Vessel	Survey area	No. of stations	Reference
1986	47 137	*Arrow*	South	186	Fincham et al. (1987)
1987	47 496	*Amaltal Explorer*	South	191	Fenaughty et al. (1988)
1990	56 841	*Cordella*	South, southeast	189	McMillan & Hart (1994a)
1991	56 841	*Tangaroa*	South, southeast	154	McMillan & Hart (1994b)
1992	60 503	*Tangaroa*	South, southeast	146	McMillan & Hart (1994c)
1993	60 503	*Tangaroa*	South, southeast	148	McMillan & Hart (1995)
1995	60 503	*Tangaroa*	South, southeast	172	Hart & McMillan (1998)

3.5 Absolute abundance estimates from acoustic survey

Absolute abundance estimates of smooth oreo were made from the acoustic survey carried out from 10 November to 19 December 1997 (Doonan et al. 1998, TAN9713). The abundance estimates used in the 1999 OEO 3A smooth oreo assessment (Doonan et al. 1999b) were revised for the 2005 assessment using new target strength estimates for smooth oreo, black oreo, and a number of bycatch species (Doonan et al. unpublished results). The current (2009) assessment used the same values as the 2005 analysis (Table 8).

Table 8: The acoustic abundance estimates of OEO 3A smooth oreo from the 1997 survey (TAN9713) including those from the 1999 (Doonan et al. 1999b), 2005 (Doonan et al. unpublished results), and the current assessment.

Estimated in:	1997 acoustic survey abundance (t)	c.v. (%)

1999 stock assessment	35 000	28
Current and 2005 stock assessments	25 200	23

3.6 Length data analyses

All sets of length data were fitted to the model using a log-normal likelihood with process errors.

Observer length frequencies

Observer length data were extracted from the observer database. These data represent proportional catch at length and sex. All length samples were from the CPUE study area (see Figure 3). Only samples where the catch weight was greater than zero and where a valid depth was recorded were included in the analysis. Frequencies were stratified by three depth strata: shallow, mid-depth (886 to 996 m), and deep. Data from adjacent years were pooled because of the paucity of data in some years. The pooled length frequencies were applied in the model in a year that approximated the median of the number of length samples available (Table 9).

Length frequency data from the 1997 acoustic survey

Length data collected during the 1997 survey were used to generate a population length frequency by sex using the methods described in detail by Doonan et al. (2003). A length frequency was generated from the trawls in each mark-type and also for the seamounts. These frequencies were combined using the fraction of smooth oreo abundance in each mark-type. The overall frequency was normalised over both male and female frequencies so that the sum of the frequencies over both sexes was 100%.

The c.v. for each length class was given by the regression, log(cv) = 0.86 + 8.75/log(proportion). The standard error on the estimated parameters in this regression was 0.15 on the intercept, and 0.65 for the slope. This regression was estimated from the c.v.s obtained by bootstrapping the data and provides a smoothed estimate of the c.v.s. For each bootstrap, the mark-type and seamount abundances were re-estimated from a bootstrap run using all sources of variance as outlined above. The length frequency for each mark-type and for seamounts was also re-estimated from a bootstrap run by re-sampling trawls within each category. These data were combined to give a bootstrap male and female population length frequency. C.v.s for each length class were estimated from 300 bootstraps.

The estimated length frequency is seen in Table 10. A plot of the population length frequencies is given in Figure 6.

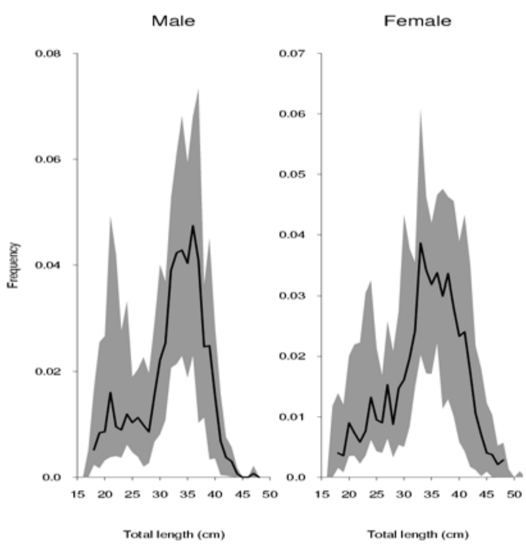


Figure 6: Population length frequency derived from the 1997 acoustic survey data. The bold line is the estimated value and the shaded area is the spread from 300 bootstraps.

Table 9: Observer length frequencies; numbers of length samples (tows sampled), number of fish measured, groups of pooled years, and the year that the length data were applied in the stock assessment model. –, not applicable.

Year	Number of length samples	Number of fish measured	Year group code	Year the grouped data were applied
1979–80	32	3 499	1	Applied
1980–81	0	0	–	–
1981–82	0	0	–	–
1982–83	0	0	–	–
1983–84	0	0	–	–
1984–85	0	0	–	–
1985–86	1	106	2	–
1986–87	4	387	2	–
1987–88	10	1 300	2	Applied
1988–89	15	1 540	2	–
1989–90	0	0	–	–
1990–91	28	3 029	3	Applied
1991–92	9	919	3	–
1992–93	0	0	–	–
1993–94	24	1 454	4	Applied
1994–95	8	778	4	–
1995–96	2	207	4	–
1996–97	3	365	5	–
1997–98	13	1 720	5	–
1998–99	5	770	5	–
1999–00	77	7 595	5	Applied
2000–01	93	9 389	6	Applied
2001–02	20	3 030	7	Applied
2002–03	14	1 427	8	Applied
2003–04	4	321	8	–
2004–05	9	840	8	–
2005–06	26	3 207	9	Applied
2006–07	2	205	9	–
2007–08	8	816	9	–

Table 10: Length frequency from the 1997 acoustic survey. The frequency covers both male and females, i.e., the sum of both the male and female frequency is 100%.

	Male		Female	
Length (cm)	Frequency (%)	c.v. (%)	Frequency (%)	c.v. (%)
18	0.5	45	0.4	49
19	0.8	38	0.4	50
20	0.9	38	0.9	37
21	1.6	28	0.7	40
22	1.0	36	0.6	43
23	0.9	37	0.8	39
24	1.2	33	1.3	31
25	1.0	35	1.0	36
26	1.1	34	0.9	37
27	1.0	36	1.5	29
28	0.9	38	0.9	37
29	1.6	29	1.5	30
30	2.2	24	1.6	28
31	2.5	22	2.0	26
32	3.9	16	2.4	23
33	4.2	15	3.9	16
34	4.3	15	3.4	18
35	4.0	16	3.2	19
36	4.8	13	3.4	18
37	4.1	15	3.0	20
38	2.5	22	3.4	18
39	2.5	22	2.8	21
40	1.5	29	2.3	23
41	0.7	41	2.4	23
42	0.4	49	1.7	27
43	0.3	52	1.1	35
44	0.1	72	0.7	40
45	0.0	80	0.4	48
46	0.0	80	0.4	49
47	0.1	71	0.2	57
48	0.0	80	0.3	53

3.7 Biological data

The fixed values for the life history parameters used in the assessment are from Doonan et al. (1997b) (Table 11). Growth was von Bertalanffy and recruitment was Beverton & Holt. In some cases growth or natural mortality (M) were estimated.

Table 11: Fixed life history parameters for smooth oreo.

Parameter	Symbol (unit)	Female	Male
Natural mortality	M (yr^{-1})	0.063	0.063
von Bertalanffy parameters	L_∞ (cm, TL)	50.8	43.6
	k (yr^{-1})	0.047	0.067
	t_0 (yr)	-2.9	-1.6
Length-at-age c.v.		0.1	0.1
Length-weight parameters	a	0.029	0.032
	b	2.90	2.87
Recruitment variability		0.65	0.65
Recruitment steepness		0.75	0.75

3.8 Base case and MPD sensitivity runs

The base case used the fixed biological parameter values (Table 11), catch history (see Table 4), pre- and post-GPS standardised CPUE combined relative abundance indices (see Tables 5 & 6), and the acoustic absolute abundance estimate (Table 8). Selectivities were estimated using a preliminary run (phase 1) of the model that included the observer and acoustic survey length data (see Tables 9 & 10). The Deepwater Working Group agreed that selectivity estimates should be made in this way and that length data would subsequently be excluded from base case model runs. Various MPD model runs are shown in Table 12, and the parameters estimated and their priors are shown in Table 13.

The base case was used to develop the Markov Chain Monte Carlo (MCMC) analysis, but MCMCs were also estimated for three values of natural mortality; 0.0420, 0.063, and 0.0945. The extreme values were calculated using a factor of 1.5 on the mean estimated value (0.063). The 95% confidence levels for the mean are 0.042–0.099 (Doonan et al. 1997b). A MCMC run was also performed for the model case that included a single length frequency (OneLF_LHS).

Table 12: CASAL MPD assessment model runs. The base case is in bold, and used selectivity estimates made from a preliminary model run (phase 1 - see text for details). –, not applicable

Code	Data changes relative to the Phase_1 case	Other	Directory and file holding results
Phase_1	–	–	R1and2.SPALLY.base.run33.noMat; R2.out.txt
OneLF	Observer length frequencies restricted to one year	1994 length frequency	R4.1.noMat; R4.1.out.txt
Base (NoLF)	**No observer or acoustic length data**	**Selectivities set to those estimated in Phase_1**	**R4.2.noMat; R4.2.out.txt**
OneLF_LHS	Observer length frequencies restricted to one year	1994 length frequency. Only the LHS fitted in model, i.e., up to & including 38 cm (males) and 39 cm (female).	R4.3.noMat; R4.3.out.txt
CPUEonly	CPUE indices only	Selectivities set to those estimated in Phase_1	R5.noMat; R5.1.out.txt
LFonly	Observer length data only	_	R5.noMat; R5.2.out.txt
ACOonly	Acoustic data only	_	R5.noMat; R5.3.out.txt

Table 13: Estimated parameters and uniform priors of the base case. The base case had two phases. In phase 1, the selectivities were estimated and this included growth and process error on the length frequency data. In phase 2, the selectivities were fixed to that estimated in phase 1 and the length frequency data excluded from the fitting.

Parameter type	Phase	Parameter	Lower Bound	Upper bound
	1+2	B_0 (t), virgin biomass, uniform-log	100	1, 000 000
Selectivity (yr)				
CPUE	1	Age at 50% selection (male + female)	1	50
	1	Ages 50–95% selection (male + female)	0.2	35
	1	Depth related length selectivity	-0.1	0.1
Acoustic	1	Increase in selectivity by age (26 parameters)	0	1
			0.2	35
Growth				
	1	L_∞ (male + female)	30	60
	1	c.v. of length-at-age (male + female)	0	0.4
Process error c.v.				
	1	Observer length frequency	0	5
Catchability				
	1+2	CPUE pre-GPS, uniform-log	1×10^{-8}	1×10^{8}
	1+2	2x CPUE post-GPS, uniform-log	1×10^{-8}	1×10^{8}

3.9 Biomass estimates

Biomass was estimated as the median of the posterior distributions.

3.10 Biomass projections

Five year projections into the future were carried out using a range of constant catches above and below the current catch limit. Projections assumed constant recruitment.

4. RESULTS

4.1 MPD results

The MPD model parameter and log-likelihood estimates are listed in Table 14 and biomass estimates in Table 15.

Table 14: MPD fits. Free parameter and log-likelihood estimates. The base case is in bold. –, not estimated or not applicable.

Estimated parameters

Parameter		Phase_1	OneLF	**Base (NoLF)**	OneLF LHS	CPUEonly	LFonly	ACOonly
B_o		84441.3	79940.4	**84052.2**	77104.9	72573.5	85407.7	69787.4
Depth related selectivity		0.016	–	**–**	–	–	0.014	–
Process error	Observer lengths	0.163	–	**–**	–	–	0.157	
Selectivity								
Males	Age at 50% selection	23.557	25.643	**–**	26.123	–	23.178	
Males	Age for 50–95% selection	6.717	9.934	**–**	7.964	–	6.687	
Females	Age at 50% selection	23.148	25.658	**–**	30.572	–	22.993	
Females	Age for 50–95% selection	5.235	9.252	**–**	14.691	–	5.306	
Acoustic selectivity		Estimated	Estimated	**–**	Estimated	–	–	Estimated
Growth								
Male L_∞		42.764	42.538	**–**	–	–	42.842	50.162
Male length-at-age c.v.		0.056	0.075	**–**	–	–	0.052	0.022
Female L_∞		50.743	50.53	**–**	–	–	50.648	57.336
Female length-at-age c.v.		0.061	0.098	**–**	–	–	0.057	0.044

Log-likelihood values for the data sets

Log likelihood component	Phase_1	OneLF	**Base (NoLF)**	OneLF LHS	CPUEonly	LFonly	ACOonly
Total	-202.92	-105.08	**-18.77**	-84.55	-17.49	-121.78	-19.32
Acoustic abundance	-1.48	-1.42	**-1.47**	-1.47	–	–	-1.31
CPUE_early_postGPS	-7.39	-7.1	**-6.81**	-7.39	-7.41	–	–
CPUE_late_postGPS	-6.65	-6.46	**-6.43**	-6.54	-6.53	–	–
CPUE_preGPS	-6.93	-7.09	**-6.75**	-7.55	-7.17	–	–
Acoustic survey lengths	-51.06	-55.45	**–**	-47.9	–	–	-29.16
Observer lengths	-132	-31.12	**–**	-18.4	–	-133.14	–
Priors							
Initial B_0	11.34	11.29	**11.34**	11.25	11.19	11.36	11.15
Depth related length selectivity	0	–	**–**	–	–	0	–
Process error, observer lengths	0	–	**–**	–	–	0	–
Male observer length selectivity	0	0	**–**	0	–	0	–
Female observer length selectivity	0	0	**–**	0	–	0	–
Acoustic length selectivity	0	0	**–**	0	–	–	0
Male L_∞	0	0	**–**	–	–	0	0
Male length-at-age c.v.	0	0	**–**	–	–	0	0
Female L_∞	0	0	**–**	–	–	0	0
Female length-at-age c.v.	0	0	**–**	–	–	0	0
q_CPUE_postGPS	-2.77	-2.39	**-2.72**	-1.92	-2.31	–	–
q_CPUE_late_postGPS	-2.62	-2.17	**-2.55**	-1.71	-2.04	–	–
q_CPUE_preGPS	-3.35	-3.17	**-3.37**	-2.93	-3.22	–	–
CatchMustBeTaken	0	0	**0**	0	0	0	0

The fits to the abundance data do not change in a material way between cases (see Table 14). However, there is a difference between the current biomasses as a percentage of the virgin biomass when each data source is used alone (CPUE.only, LFs.only, and ACO.only). The single source abundance cases have the current biomass around 20%, whereas using just the observer data makes it 37% (Table 15). Comparing the base case from the 2005 assessment with the current (2009) base case, the estimates of virgin and mature biomass for 2003–04 are similar; virgin biomass both 84 000 t, and 2003–04 biomass was 27 000 t in the 2005 analysis and 25 000 t in the 2009 analysis, Table 15.

Table 15: MPD fits. Biomass estimates (t). The base case is in bold. B_2004 is the biomass for 2003–04 (the year assessed in the 2005 assessment) and B_2009 is the biomass for 2008–09 (this assessment). Biomasses are rounded to the nearest '000 t and percentages to the nearest integer.

Case	B_0	B_2004	B_2009	B_2004 (%B_0)	B_2009 (%B_0)
Phase_1	84 000	26 000	30 000	30	36
OneLF	80 000	21 000	25 000	27	32
Base (NoLF)	**84 000**	**25 000**	**30 000**	**30**	**35**
OneLF_LHS	77 000	19 000	23 000	25	30
CPUE.only	73 000	12 000	16 000	17	22
LFs.only	85 000	27 000	31 000	31	37
ACO.only	70 000	9 200	12 000	13	18

A plot of the MPD estimates for the acoustic length selectivity parameters shows that full selectivity was not achieved until about age 26 years (Figure 7). For the fishery, 95% selectivity occurs at age 28–30 years. The acoustic abundance data and the early post-GPS CPUE index fitted the model but the pre-GPS CPUE index declined more steeply than the model trajectory and the late post-GPS CPUE series is mostly flat compared to an increasing model trajectory (Figure 8).

The acoustic survey length frequency data fits were good (Figure 9). The observer length frequency data fits were also generally good but they show a tendency to under-estimate the peaks and over-estimate the leading left hand side (Figure 10).

The Q-Q normal plots of the residuals for the observer and acoustic length frequency data and for the pre- and post-GPS CPUE (Figure 11) are approximately normal (as they are assumed to be in the model) , but the post-GPS CPUE series fit better than they should given the variance structure used in the model.

Fits to annual observer length frequencies and Q-Q normal plots for annual observer length frequencies are given in Appendix A.

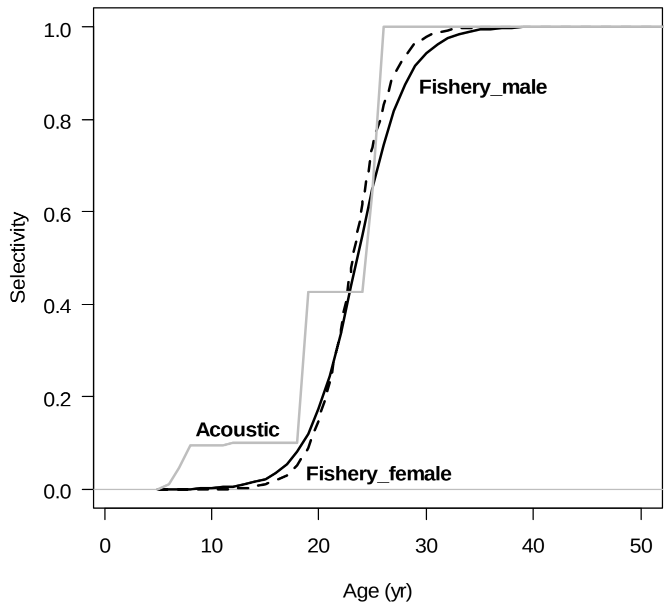


Figure 7: **Estimated selectivities for the acoustic (both sexes) and commercial fisheries by sex for the MPD fit of the Phase 1 assessment model.**

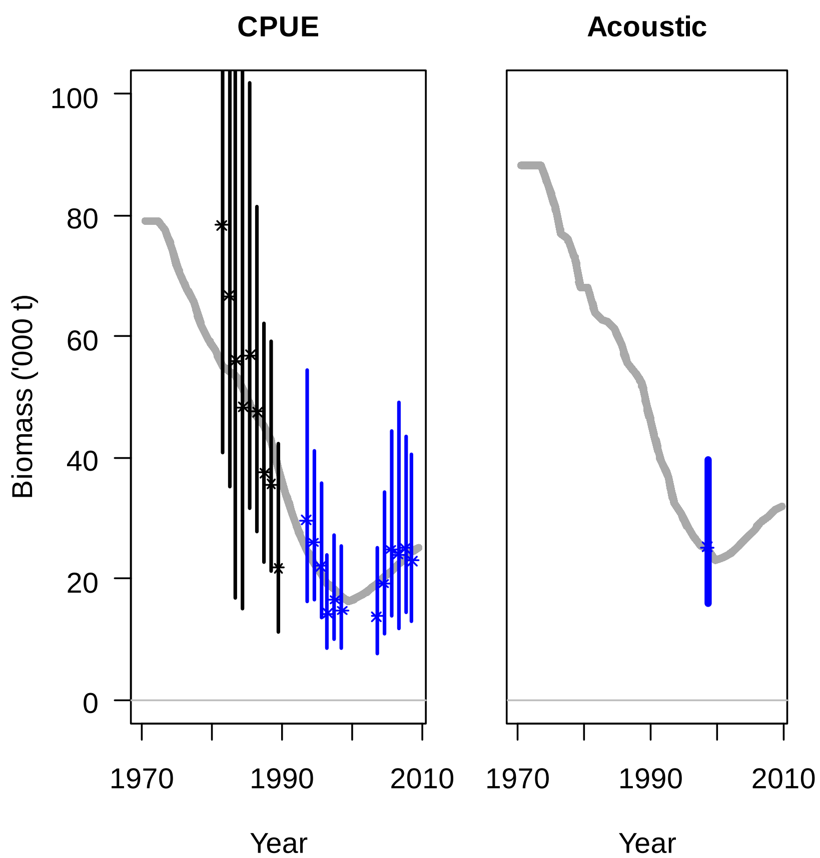


Figure 8: **Fits of the MPD base case abundance data to the biomass trajectories in the assessment model. The left hand plot is the CPUE indices for the pre-GPS (to 1989), early post-GPS (from 1993), and the late post-GPS (from 2002) scaled by their associated catchabilities to provide abundance. The trajectories are model estimates of mid-year vulnerable (i.e., selected to the fishery). The right hand plot is the acoustic (absolute) estimate and the trajectories are model estimates of mid-year acoustic (i.e., selected to the acoustic technique) biomass Vertical error bars for the acoustic and CPUE estimates are ± 2 s.d.**

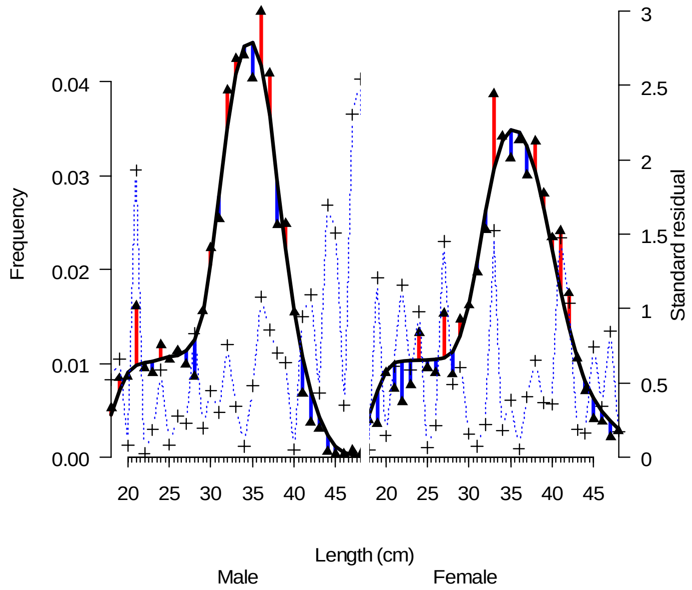


Figure 9: **Fits of the acoustic length frequency data (triangles) to the model estimates (thick solid lines) for the Phase 1 assessment model MPD fit. The right hand axis shows the scale for the absolute value of the standard residuals (thin dashed lines, small '+' symbol).**

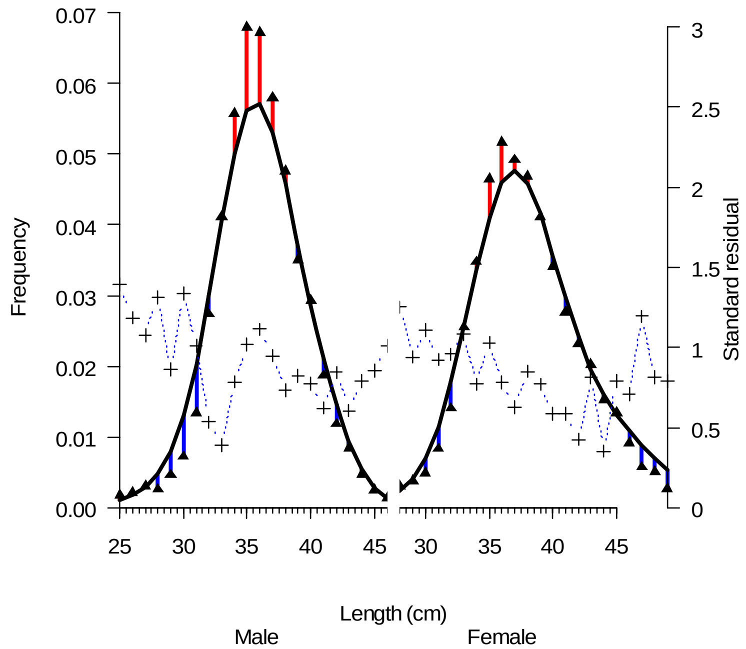


Figure 10: **Fits of the composite observer length frequency data (triangles) to the model estimates (thick solid lines) for the Phase 1 assessment model MPD fit. The composite data is calculated by averaging the data over the years in which observer length frequency data is provided to the model (1980, 1988, 1991, 1994, 2000, 2001, 2002, 2004, and 2007). The right hand axis shows the scale for the absolute value of the composite standard residuals (thin dashed lines, small '+' symbol).**

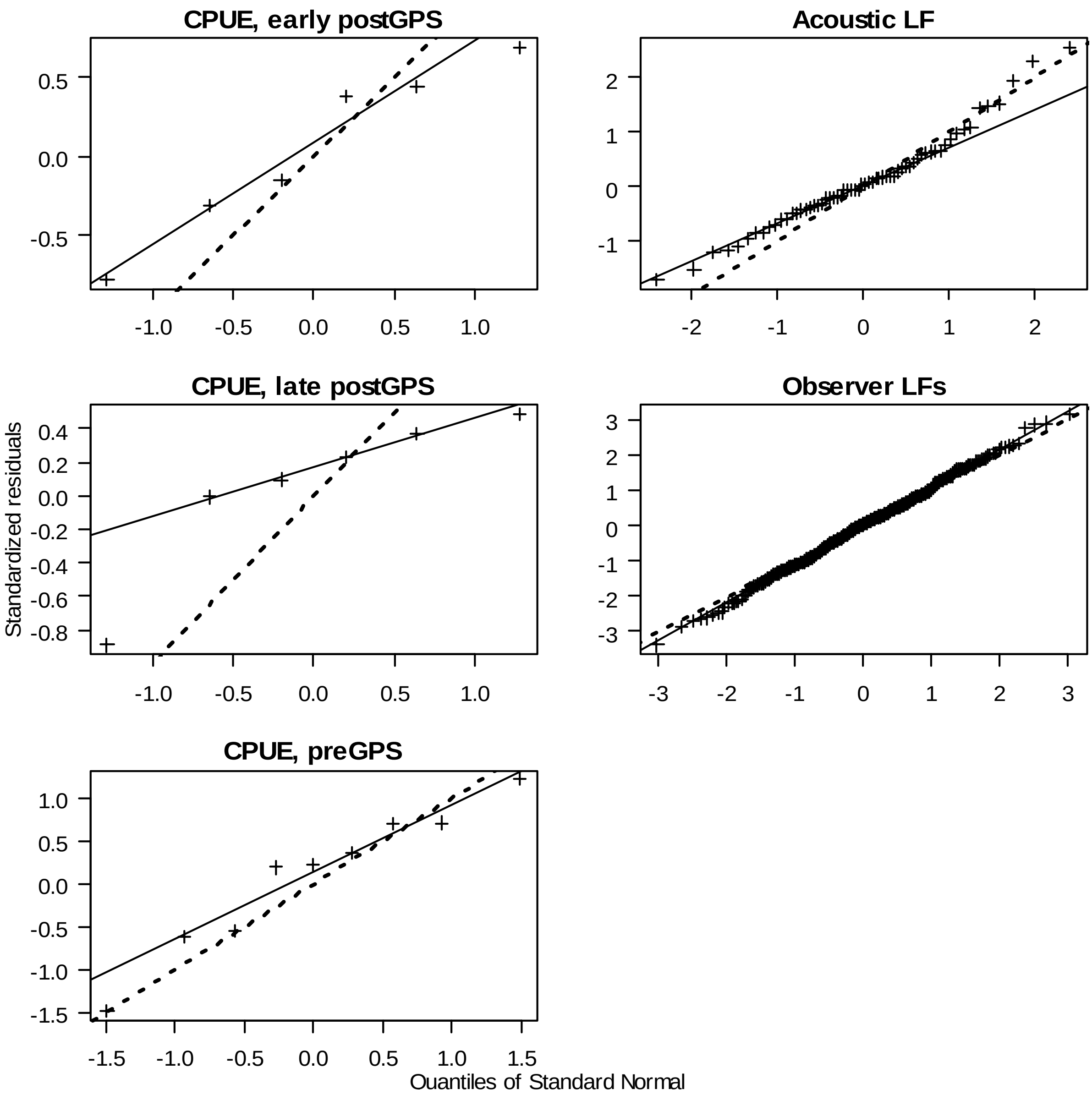


Figure 11: Q-Q normal plots for the normalised residuals from the CPUE indices, observer, and the acoustic length frequency data from the MPD fit of the Phase 1 assessment model. The solid lines are drawn through the first and third quartiles of the residuals and the corresponding quartiles of the standard normal distribution. The dotted lines are through the origin with a slope of one.

4.2 Bayesian estimates

The Markov Chain Monte Carlo analysis for each case produced a chain length of 2000 after systematically subsampling every 1000th point. No points were discarded (burn-in). Appendix B shows that the MCMC runs converged.

The summarised posterior distributions are given in Table 16 for one set of the sensitivity cases since those based on the base case had only one parameter, virgin biomass. A summary of biomass estimates can be seen in Table 17.

Table 16: Bayesian estimates: summary statistics of the posterior distributions for the sensitivity cases, left hand limb of the 1994 observer length frequency (plus the 1997 acoustic survey length frequency) with growth not estimated by the model using 3 values of natural mortality (M).

Parameter			M=0.063			M=0.042			M=0.099
Confidence interval	2.5%	Median	97.5%	2.5%	Median	97.5%	2.5%	Median	97.5%
Mature virgin	74 000	77 400	81 000	81 000	82 800	85 000	76 000	82 300	91 000
Fishery selectivity									
a50, male	23	26	28	22	24	26	25	28	31
a50.95, male	5	8	11	5	7	10	6	8	11
a50, female	27	30	35	24	26	30	29	34	40
a50.95, female	10	15	24	9	14	21	9	14	22

The distributions of the estimates of virgin and current mature biomass as a percentage of virgin biomass for the base case are shown in Figure 12 and both are approximately symmetrical.

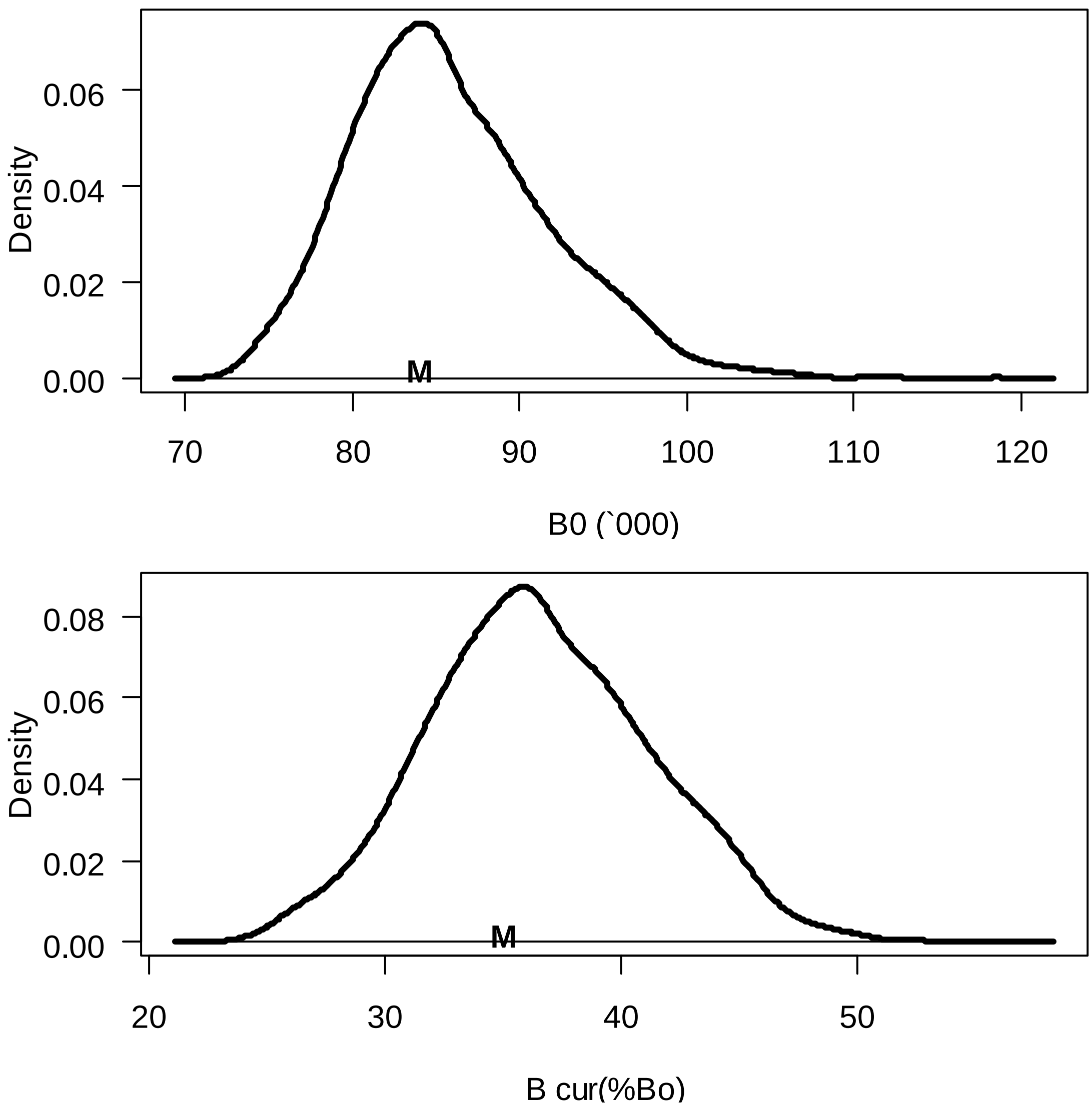


Figure 12: Posterior distributions of the virgin mature biomass (t, top frame) and the derived estimates of current mature biomass as a percentage of virgin mature biomass for the base case (bottom frame). "M" marks the MPD estimate.

4.3 Interpretation of uncertainty

Sampling error and the quantity of data are not a problem in this analysis, but there are large potential biases in the data that could shift the assessment substantially. These include: using deterministic recruitment, using a linear relationship between standardised CPUE and abundance, and treating the acoustic abundance as an absolute value.

4.4 Biomass and sensitivity estimates

A random sample of 2000 points from the MCMC was used to derive estimates of biomass from the Bayesian analysis. Results are given in Table 17. The base case posterior distributions for the virgin biomass and the mature biomass trajectories as a percentage of virgin biomass are shown in Figure 13.

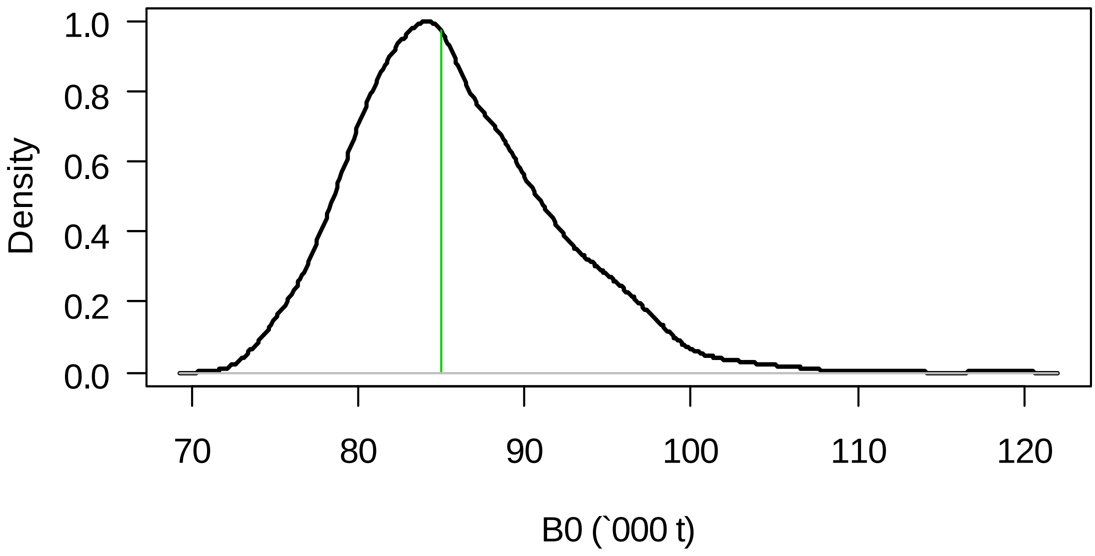
Table 17: MCMC biomass estimates: base (bold) and sensitivity (†) cases.

Base case with variations of natural mortality

	M=0.063			†M=0.042			†M=0.099		
	Median	**CI.02.5**	**CI.97.5**	Median	CI.02.5	CI.97.5	Median	CI.02.5	CI.97.5
B_0	**85 000**	**77 300**	**96 500**	97 700	90 100	110 000	68 500	60 300	79 600
B_cur	**30 900**	**22 400**	**43 000**	26 300	18 000	38 800	33 800	25 000	45 500
B_cur (%B_0)	**36**	**29**	**45**	27	20	35	49	41	57

Left hand limb of the 1994 observer length frequency (plus the 1997 acoustic survey length frequency) with growth not estimated by the model:

	†M=0.063			†M=0.042			†M=0.099		
B_0	77 400	74 800	80 200	82 800	81 600	84 200	82 300	76 700	89 200
B_cur	23 100	19 900	26 400	10 200	8 480	12 100	48 800	42 900	56 200
B_cur (%B_0)	30	27	33	12	10	14	59	56	63



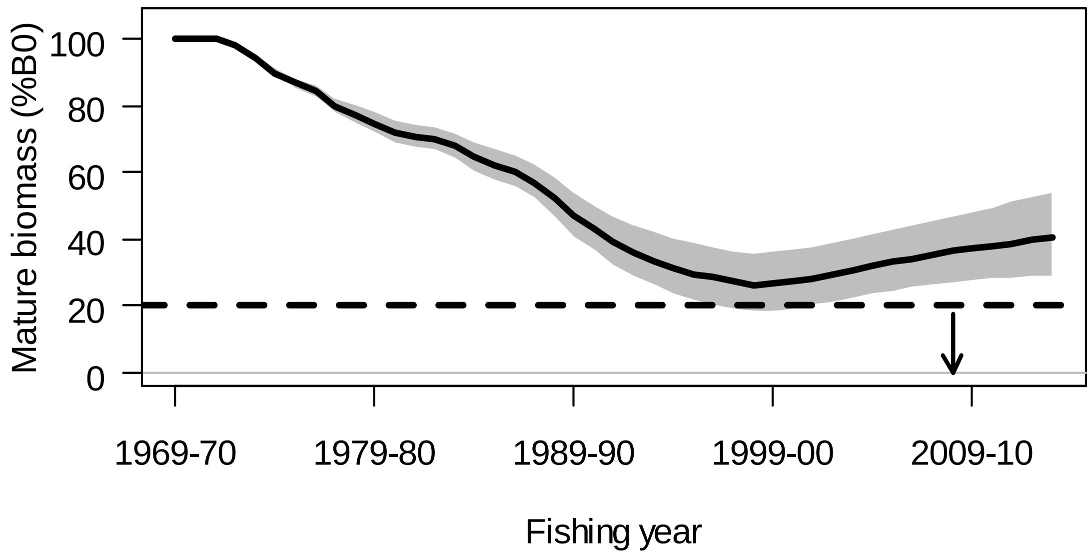


Figure13: Smooth oreo OEO 3A: posterior distribution for the virgin biomass (top) and the mature biomass trajectories as a percentage of virgin biomass (bottom) from the MCMC analysis of the "NoLF" case with M = 0.063 (base case). In the top plot, the thin vertical line is the median of the distribution. In the bottom plot, the grey area is the point-wise 95% confidence intervals of the trajectories and the solid line is the median.

4.5 Biomass projections

Forward projections over the next five years were performed to determine median biomass in five years as a $\%B_0$ under different constant catch scenarios. Recruitment variability (lognormal with σ_r = 0.67) and parameter variability were introduced (2000 random draws from the posterior distribution). The probabilities for the base case projected under different catch levels are presented in Table 18.

Table 18: Median and 95% confidence interval for mature biomass in 5 years ($B_{2013–14}$) as a $\%B_0$ under different constant catch scenarios. The 2008–09 catch limit for smooth oreo in OEO 3A was 1400 t.

Annual catch (t)	Lower 2.5%	Median	Upper 97.5%
1400	29	41	54
1550	28	40	55

1600	28	40	53
1650	28	39	55

5. DISCUSSION AND CONCLUSIONS

Males mature at a smaller size than females, i.e., the age at 50% maturity is 18–19 years for males and 25–26 years for females. Smaller mature males are less vulnerable to the fishery compared to larger males and mature females (Figure 14), and so the current (2008–09) total mature biomass has a relatively larger contribution from males. Figure 14 also shows that the fishery under constant recruitment has reduced the proportion of mature fish over 40 yr from a large proportion to almost none in 2009. This model prediction could be tested by reading otoliths from the observer samples and estimating an age frequency.

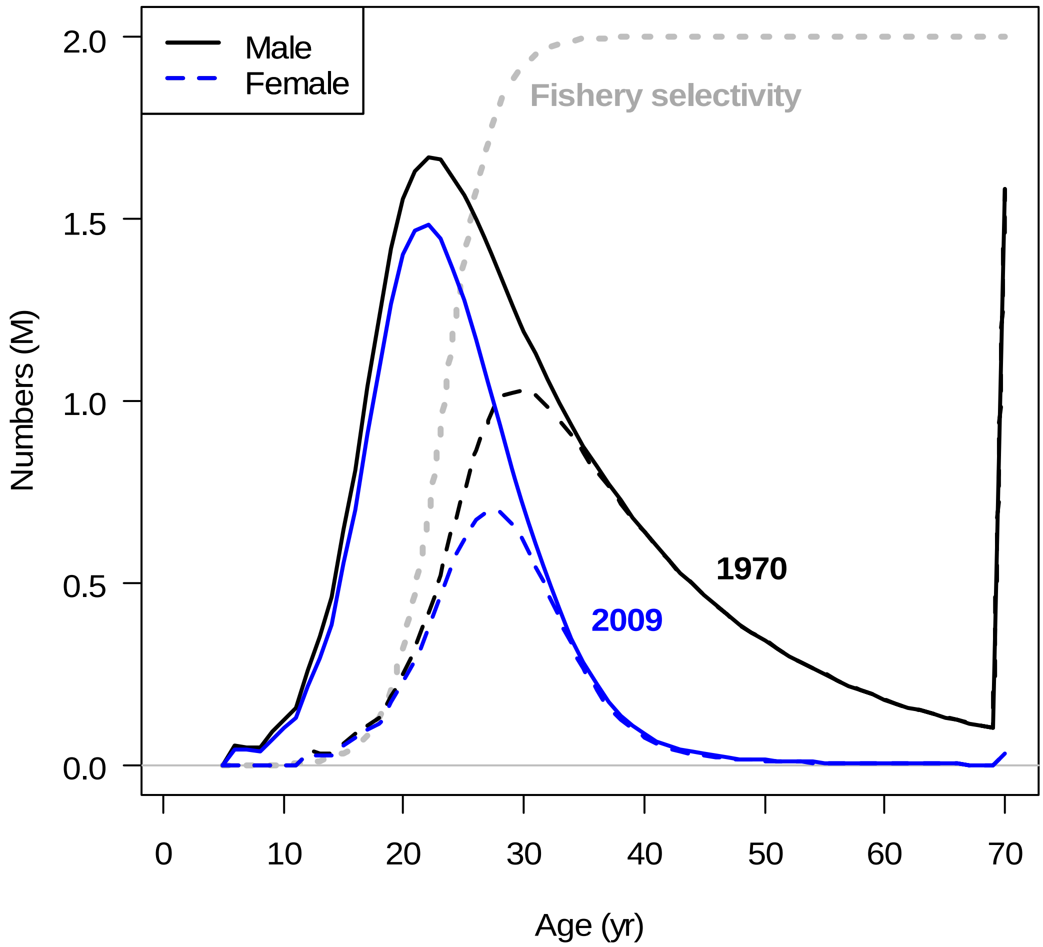


Figure 14: Base case estimated numbers-at-age for mature fish in 1969-70 (virgin, black lines) and 2008-09 (faded lines) by sex.

Model biomass estimates have extra uncertainty from a number of other factors that are outside the model and the analyses, including the use of deterministic recruitment and for the base case fixing the fishery selectivity to that estimated in the MPD fit Phase 1 model. Using the two alternative values of natural mortality, their median current biomass, as a proportion of the virgin biomass, cover the range of the confidence limits for the base case. Since the range of natural mortalities used spanned the 95% confidence interval for natural mortality, uncertainty in natural mortality is not a large problem for the base case. However, for the alternative case where the left hand side of the 1994 observer frequency is fitted, varying natural mortality gives a much wider range of median current biomass as a proportion of the virgin biomass, from 12 to 59%.

The fit of the acoustic length frequency to the model has a low shoulder at the left hand end suggesting that fish are not being steadily selected as would usually be expected. This suggests that either the acoustic length frequency data are lacking small fish (i.e., due to trawl selectivity), or that there is a problem with the acoustic technique. If young fish are lacking it could be that they recruit to the bottom over a larger area than the study area and later migrate and recruit to the study area. Comparison of the west and east OEO 4 smooth oreo stock assessment model fits to the acoustic length data shows that there is some variation at the left hand end of the curve (figure 12, Doonan et al. 2003). The west acoustic length frequency shows a steady increase of the left hand limb but starting with fish of about 25 cm TL, i.e., relatively large. In contrast, the left hand limb of the east acoustic length frequency starts with much smaller fish of about 17 cm, and climbs very steeply to an inflexion point at about 23 cm for males and females. The area south and southwest of Chatham Island is a known “nursery” ground for small smooth oreo (Annala et al. 2004) so these observations suggest that there is an areal availability effect for small smooth oreo.

6. ACKNOWLEDGMENT

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7. REFERENCES

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APPENDIX A: MPD analysis. Fits and Q-Q normal plots for each annual observer length frequency in the base case.

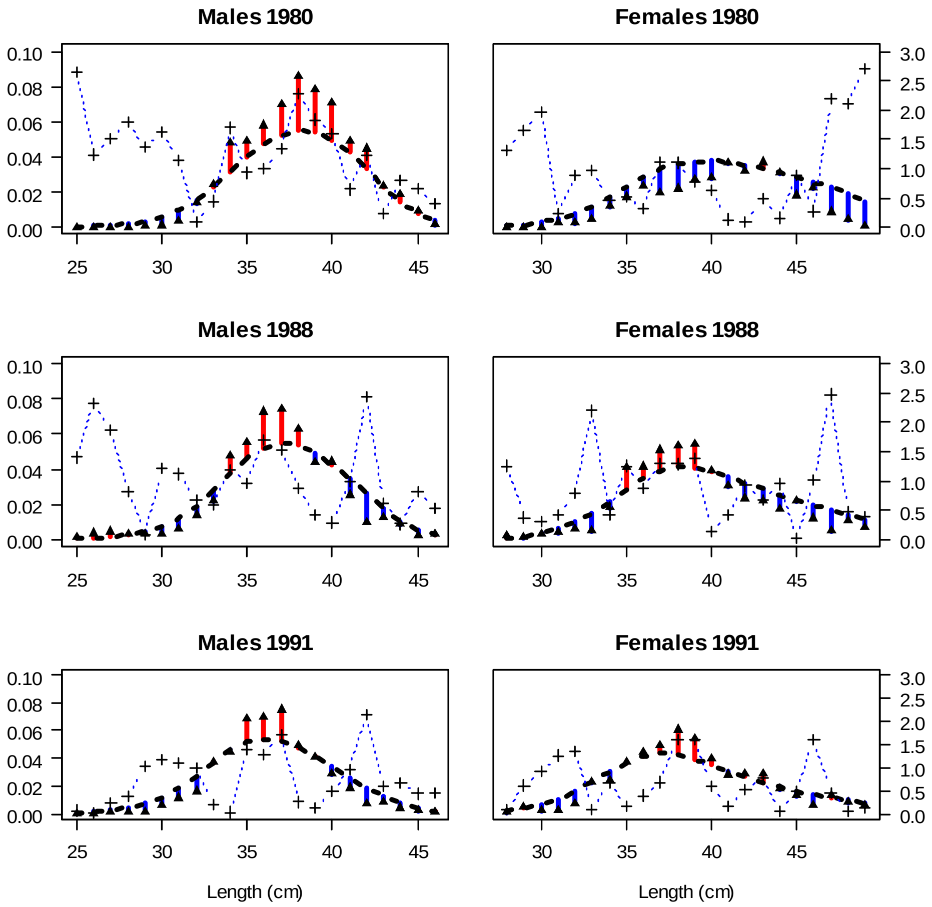

Figure A1: Fits of the annual observer length frequency data (triangles) to estimates (thick dashed lines) of these data in the MPD fit of the Phase_1 assessment model. The right hand axis shows the scale for the absolute value of the standard residuals (thin dashed lines, small '+' symbol).

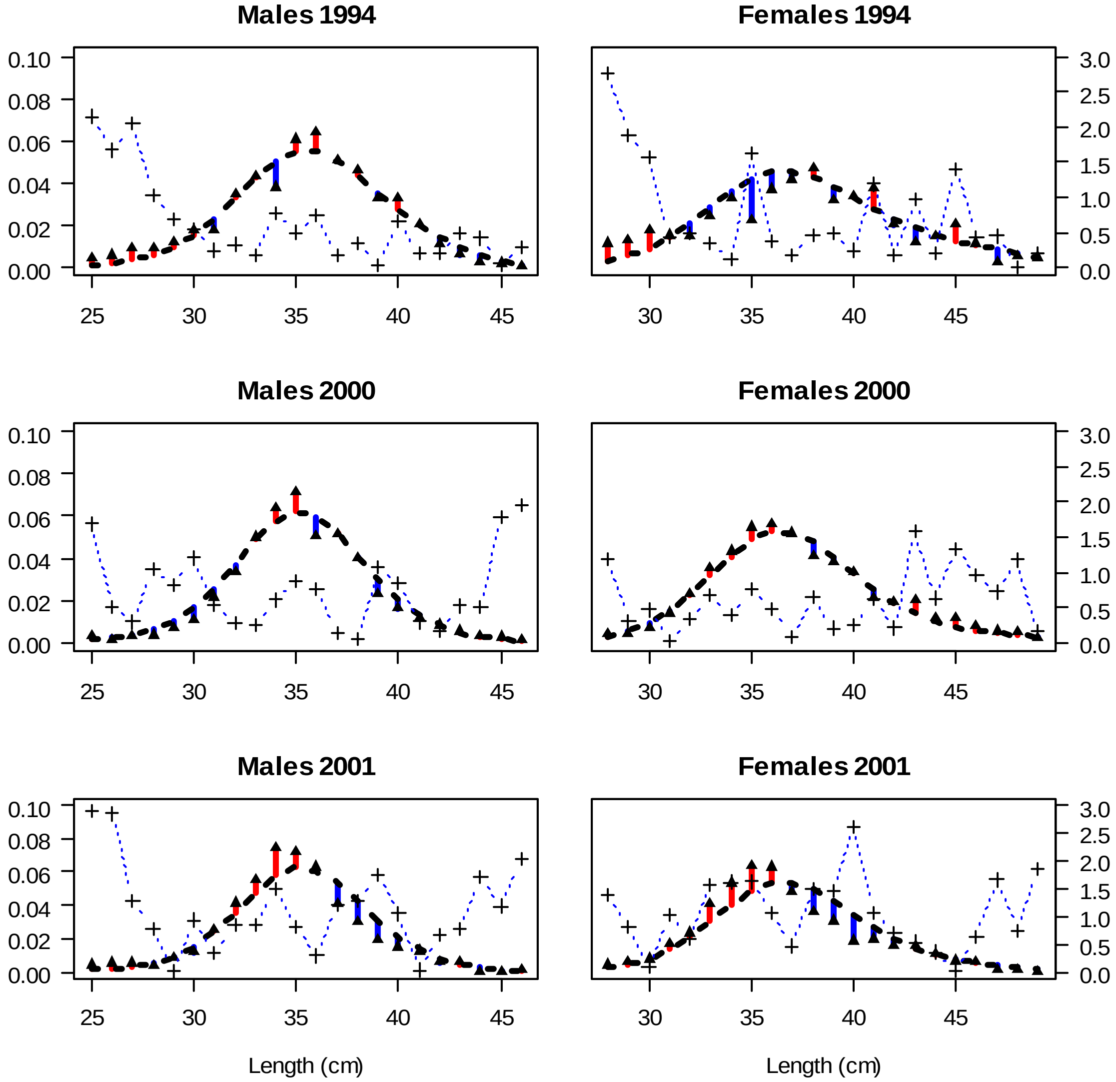

Figure A1: Ctd.

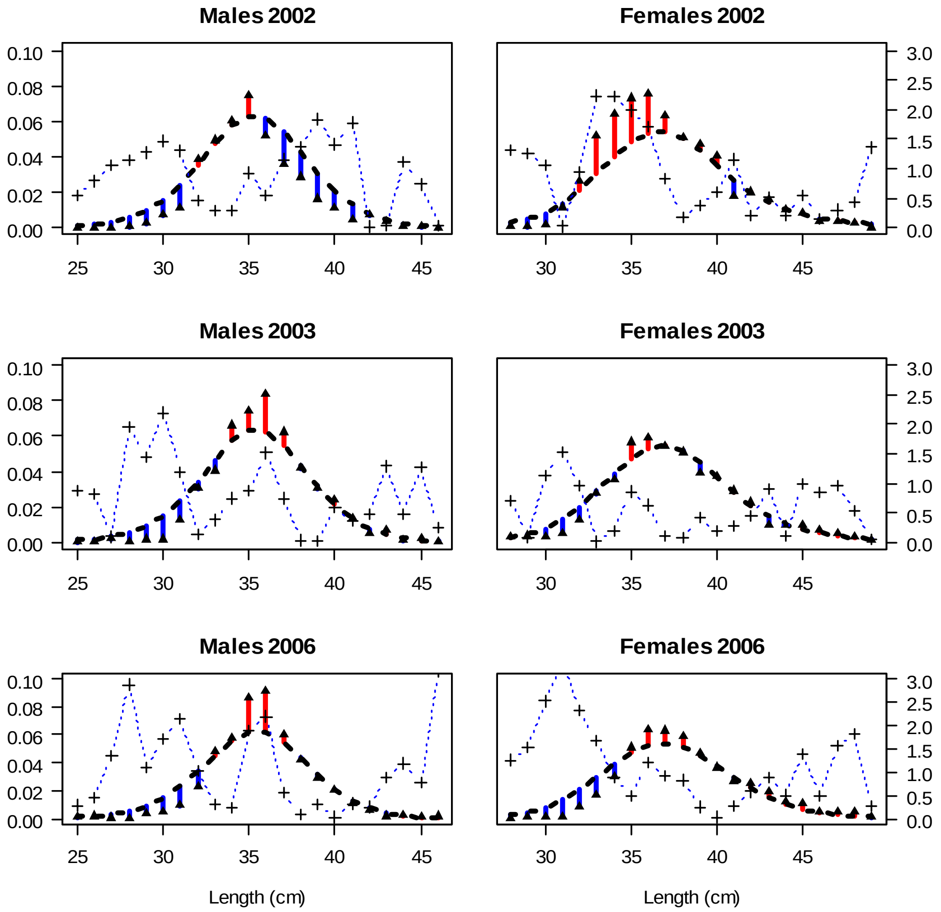

Figure A1: Ctd.

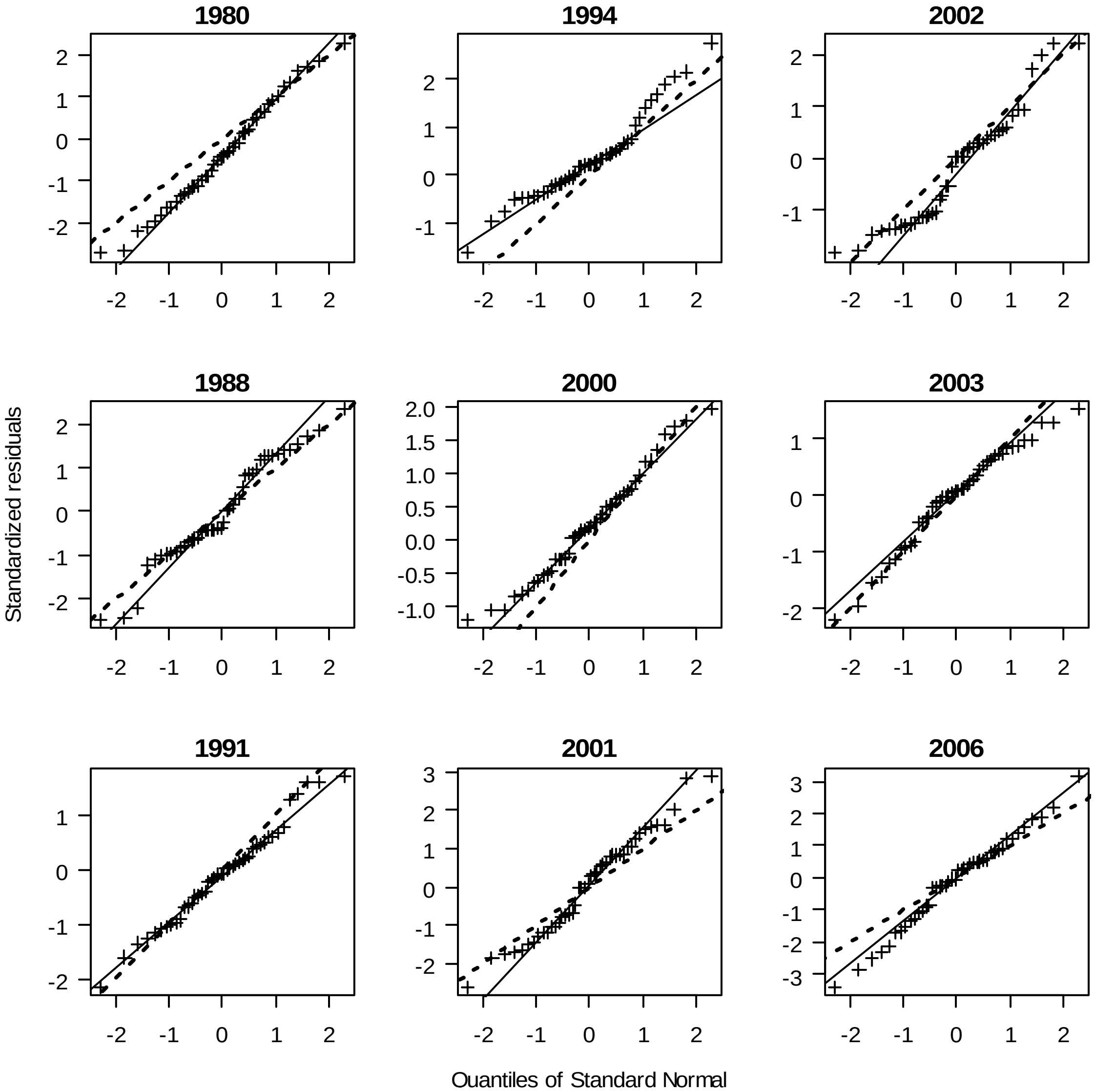

Figure A2 Q-Q normal plots for the normalised residuals from each year of the observer length frequency data. The solid line is drawn through the first and third quartiles of the residuals and the corresponding quartiles of the standard normal distribution. The dotted line is through the origin with a slope of one.

APPENDIX B: Bayesian trace plots

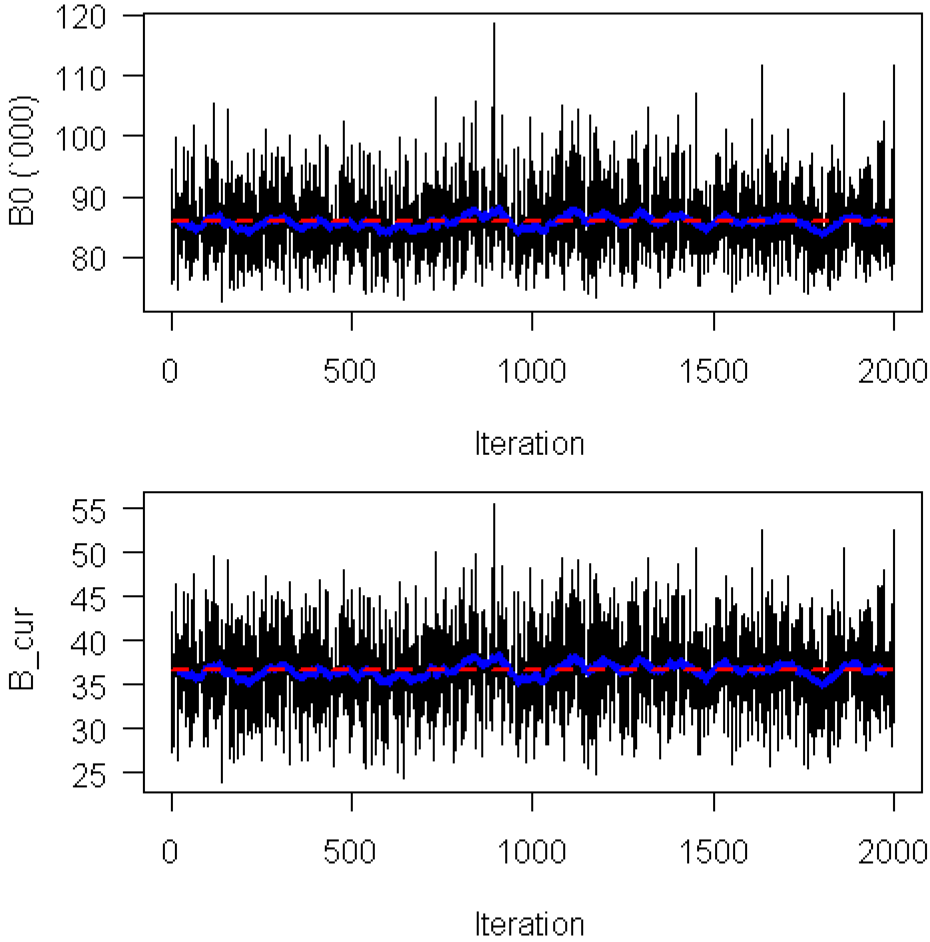

Figure B1: Time series of MCMC estimates for B_0 (top) and current mature biomass as a percentage of virgin biomass (bottom) for the base case. The continuous line is a running average of estimates using a window of 50. The dashed line is the mean over the series.

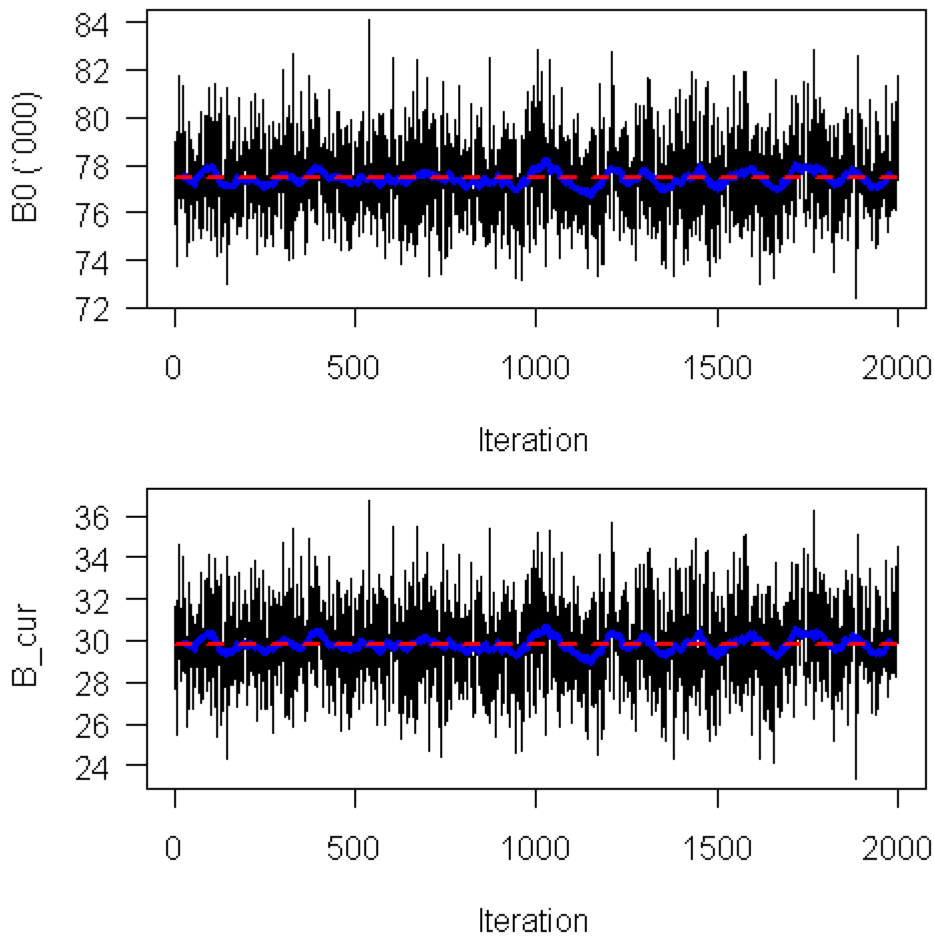

Figure B2: Time series of MCMC estimates for B_0 (top) and current mature biomass as a percentage of virgin biomass (bottom) for the OneLF_LHS (M=0.063) case. The continuous line is a running average of estimates using a window of 50. The dashed line is the mean over the series.

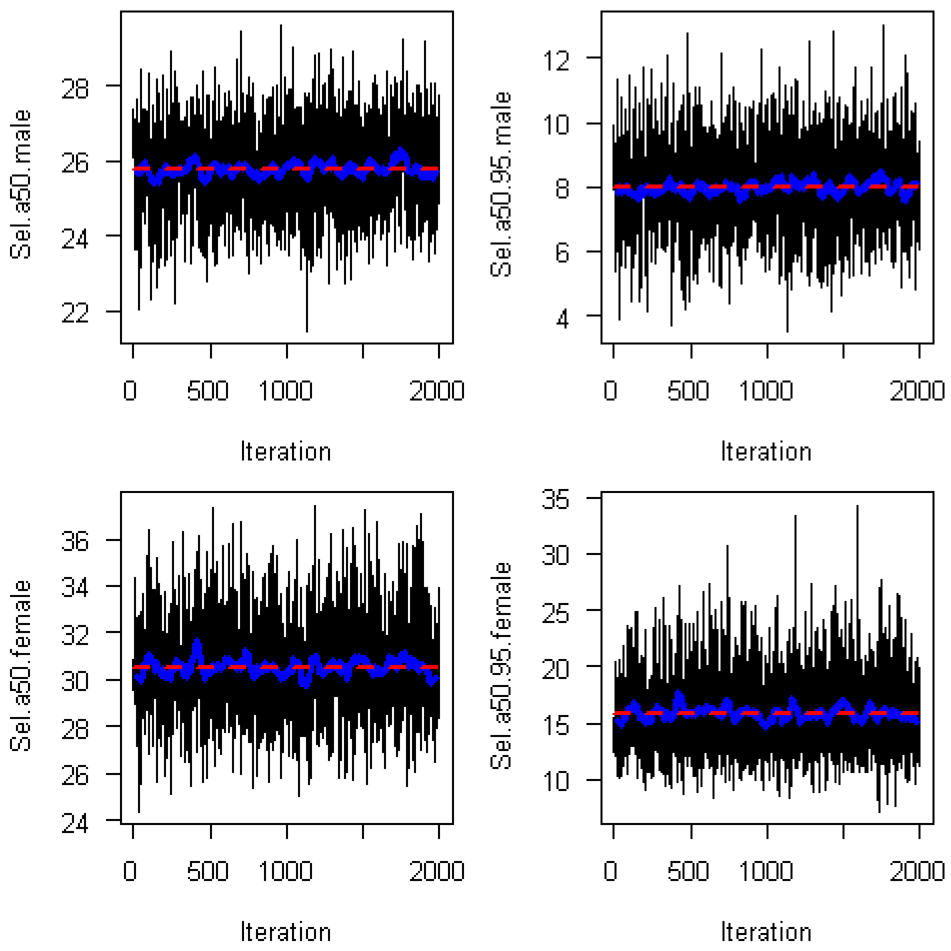

Figure B3: Time series of parameter estimates from MCMC for non-abundance parameters in the OneLF_LHS (M=0.063) case. The continuous line is a running average of estimates using a window of 100. The dashed line is the mean over the series. "Sel.a50.95.female" is the female's selectivity parameter, Age for 50–95%; "Sel.a50.female" is the female's selectivity parameter, Age for 50%; similarly for males. See Table 16 for parameter abbreviations.