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EXECUTIVE SUMMARY

Doonan, I.J.; Coburn, R.P.; McMillan, P.J.; Hart, A.C. (2004). Assessment of OEO 3A black oreo for 2002–03.

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A new stock assessment for black oreo in OEO 3A is presented using a NIWA CASAL stock assessment model employing Bayesian statistical methods. This modelled the population using data from three new 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. Migration was allowed in the model to move the fish between the areas.

Input data for each area for the new base case stock assessment included: new absolute abundance estimates and length data from the 2002 acoustic survey and revised estimates from the 1997 acoustic survey; revised and updated catch history; revised and updated relative abundance estimates from pre-GPS and post-GPS standardised CPUE analyses; revised observer length frequencies; some revised growth parameter estimates; and age dependent migration. 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 161 000 t (90% confidence interval of 151 000–176 000 t), but for the fished part of OEO 3A (Areas 2 & 3) it was 88 000 t (85 000–91 000 t). Mature mid-year biomass for OEO 3A in the current year (2001–02) was 84 000 t (74 000–100 000 t), about 52% B_0. But mature mid-year biomass for the fished part of OEO 3A (Areas 2 & 3) in the current year (2001–02) was 15 000 t (12 000–18 000 t), about 17% of B_0. Current surplus production was estimated to be 2330 t. The black oreo catch in OEO 3A in 2001–02 was 2250 t. The vulnerable stock size was approximated by the total biomass in Areas 2 and 3. The estimate of current mid-year vulnerable biomass was 18% B_0.

Five sensitivity model runs on the base case were also carried out where natural mortality was estimated for mature or immature fish, catchability of fish in Area 1 was varied, where restrictions on recruitment deviates were removed, and recruitment deviates were restricted to six degrees-of-freedom. Restricting the recruitment deviates to six degrees-of-freedom gave the same fits as if they were unrestricted and using them gave improved fits of the observer and length frequency data to the model in Area 2. The run that made the largest differences to the estimated current biomasses relative to B_0 was when recruitment deviates were estimated. For Areas 1, 2, and 3, the latter case estimated current biomass at 81% B_0, 38% B_0, and 7% B_0, compared to 96%, 30% and 7% for the base case respectively. Four additional runs were made at the request of the Deepwater Stock Assessment Working Group to determine the sensitivity of the results of the base case to: the Area 1 acoustic absolute abundance estimate treated as a relative value; the two pre-GPS CPUE abundance indices (excluded); the three post-GPS CPUE abundance indices (excluded); and Area 1 research trawl survey length frequency data. None of these runs gave a substantially different result to that from the base case.

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1. INTRODUCTION

This work addresses the following objectives in the MFish project "Oreo stock assessment" (OEO2002/02).

Overall objective

1. To carry out a stock assessment of black oreo and smooth oreo, including estimating biomass and sustainable yields.

Specific objectives

2. To update the standardised and unstandardised catch per unit effort analyses for black oreo and smooth oreo in OEO 3A on the Chatham Rise with the inclusion of data up to the end of the 2001/02 fishing year.

4. To update the stock assessment for black oreo and smooth oreo in OEO 3A, including estimating biomass and sustainable yields.

1.1 Overview

This report presents results of the standardised catch per unit effort analyses and the stock assessment for OEO 3A black oreo only. The last stock assessment for black oreo in OEO 3A (a spatial analysis) used an age-structured population model (Hicks et al. 2002). The spatial analysis model used data from three areas, labelled 1–3, which corresponded to an increasing mean length of the catch as seen in the observer length frequency data. Area 1 contained small fish and flat ground and Area 3 contained 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. Abundance estimates used included estimates of absolute abundance for black oreo from the 1997 research acoustic survey, and relative abundance indices from standardised CPUE analysis. Estimates of biomass and yields were made using the 1997 biological parameters and catch history.

The new stock assessment presented here implemented a spatial analysis using the NIWA CASAL software (Bull et al. 2003). It used revised spatial areas, new absolute abundance estimates from the 2002 and revised estimates from the 1997 acoustic surveys; revised catch history; new relative abundance estimates from pre-GPS and post-GPS standardised CPUE analyses; revised observer length frequencies; and length frequencies derived from the absolute abundance estimates.

The 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). But the assessment applies to the whole of OEO 3A because the total catch from OEO 3A was used to scale up the the acoustic 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 is 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 seamounts 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.

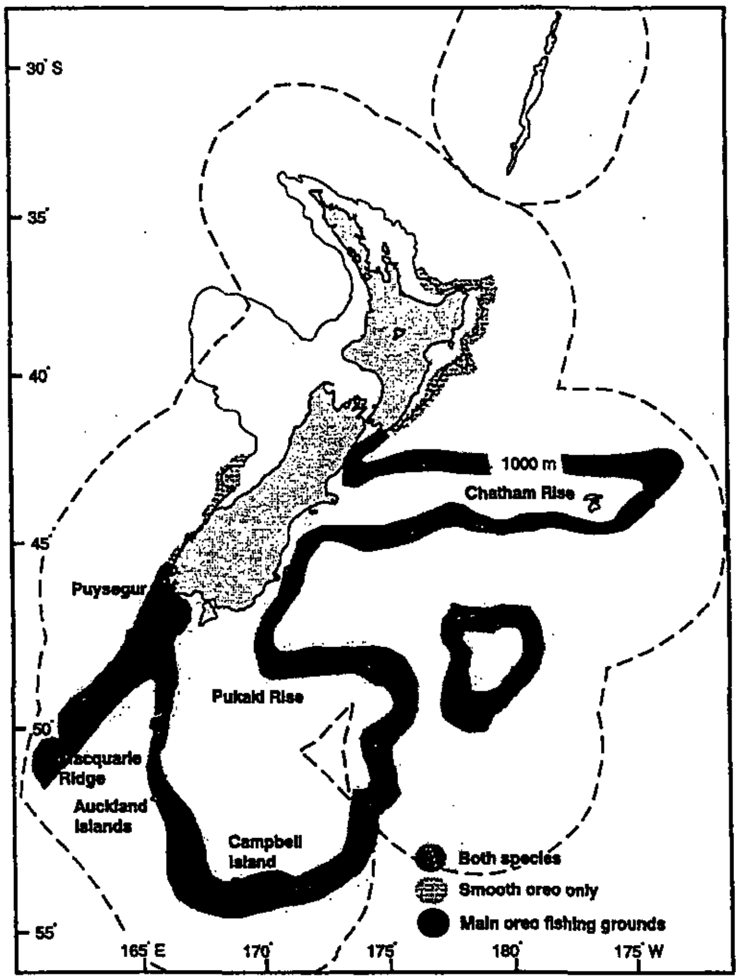

Figure 1: Approximate location of main fishing grounds and distribution of black oreo and smooth oreo. Dashed line is the EEZ boundary.

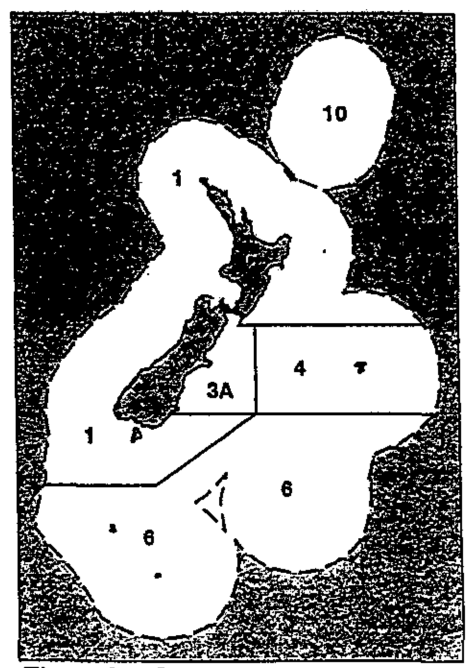

Figure 2: Oreo management areas.

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. Subsequently the total OEO 3A TAC was reduced to 5900 t in 1999–2000, 4400 in 2000–01, 4095 in 2001–02, and 3255 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 2001–02. –, na.

Fishing year	Landings	TAC	Estimated catch SSO	Estimated catch 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

Source: FSU from 1978–79 to 1987–88; QMS/MFish from 1988–89 to 2001–02.
*, 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, and there were three areas. The data for the sexes were combined.

2.1.2 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 only due 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 (I. 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.

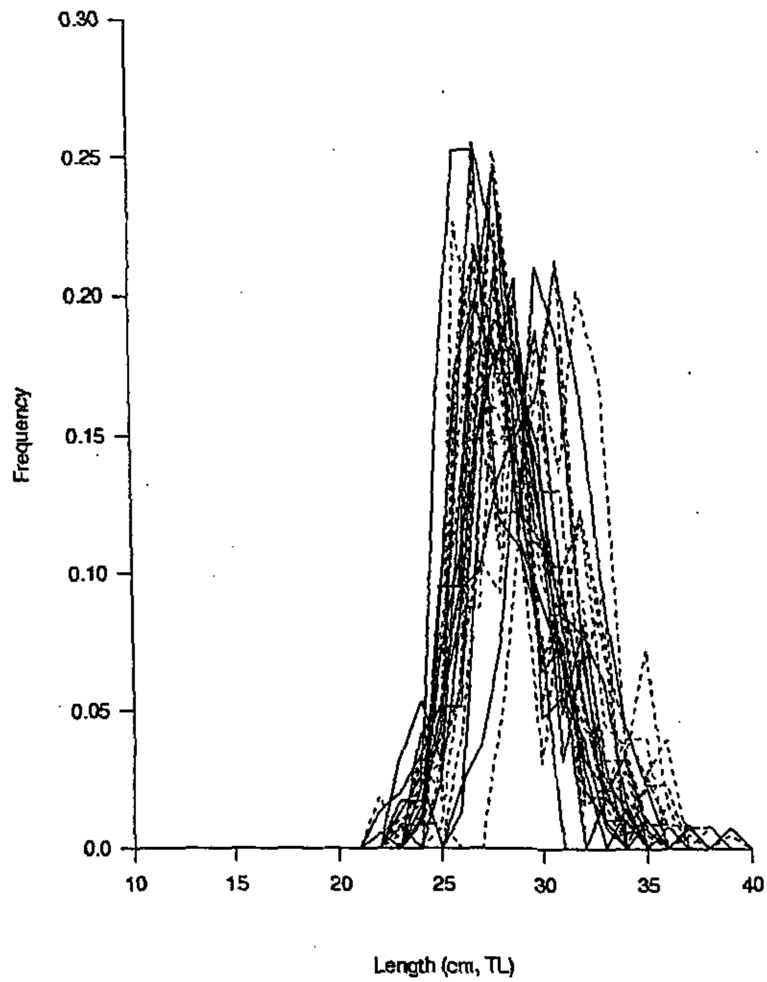

Figure 3: Male (solid line) and female (dotted line) length frequencies from research trawls in the layer and layeroff mark-types for each trawl.

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

The maturity ogive was estimated by Hicks et al. (2002) from age and maturity data and started at age 18, with a mid-point at 25, and a 95% point at 50 years. In terms of total fish, most black oreo are mature by age 27 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, and catch history (see Table 3). Data fitted in the analysis were the 1997 and 2002 acoustic abundance estimates (see Table 14), standardised combined CPUE indices (see Tables 6–10 summary, Table 11), observer length data (Table 15), and the 1997 and 2002 acoustic survey length data (see Table 17). The model was used to estimate biomass and generate projected biomass estimates. 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 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, 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.

2.4 Vulnerable abundance

In the current (three-area) model, the vulnerable stock definition needed further qualification to make it comparable with a one-area model. For the one-area model, vulnerable abundance is standardised to the age group with the largest fishing mortality so that a particular fishing mortality can be applied to the vulnerable abundance to get the right catch size without having to know selectivities or having to provide a vector of fishing mortalities, one for each age class. This makes interpretation simpler.

When multiple areas are involved and these are fished at different rates, the standardisation needs to take place over all age classes within each area. For the present analysis, this was approximated by taking the sum of the total abundance in Areas 2 and 3, since about 90% of the total historical catch came from Areas 2 and 3 (i.e., the fishery was based on these areas, as a first approximation) and because the fishing selectivities are based on selecting area (i.e., all the fish in an area are equally vulnerable). The latter is based on results presented later.

There is potential confusion when looking at vulnerable abundance within one area as opposed to the vulnerable abundance for the whole stock. The vulnerable abundance within one area is the same as in a one-area model, and so it has been standardised internally and does take into account fishing mortalities in the other areas. This is called selected abundance in this document to differentiate it from the vulnerable abundance for the whole stock.

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. 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.

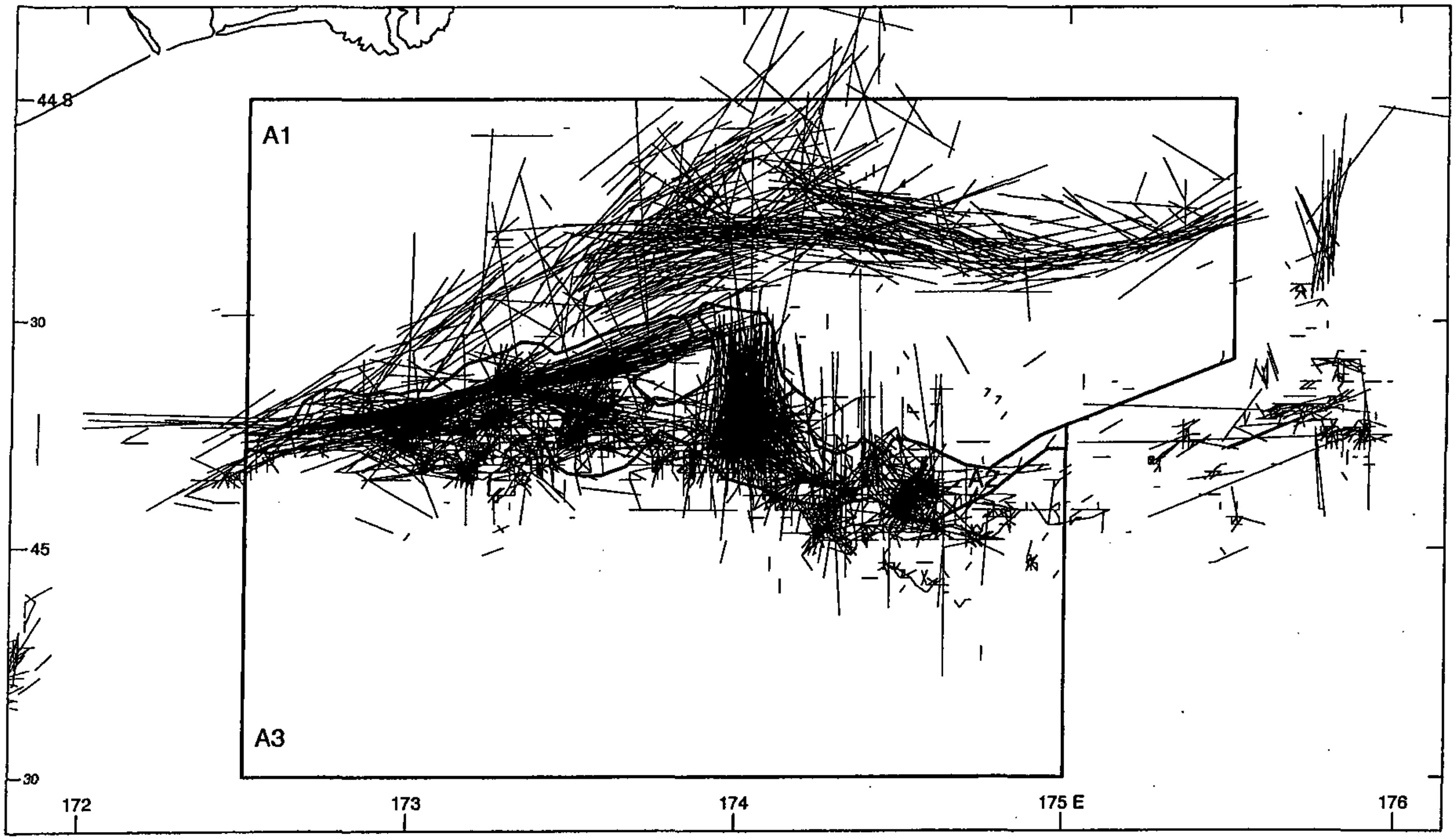

Figure 4: Tow tracks (black lines) where black oreo were caught from 1978–79 to 1999–2000, from Hicks et al. (2002). Start and end positions of the tows were jittered by plus or minus 0.5 of a minute of latitude and longitude. The heavy black lines define the Areas (A1–A3) used in the 2002 stock assessment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

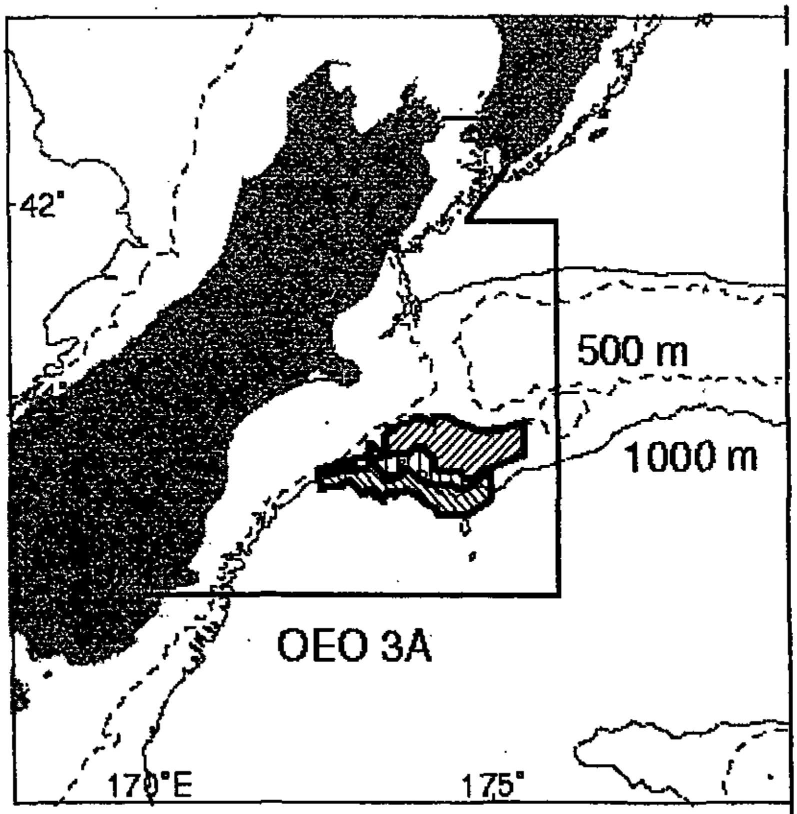

Figure 5: The three spatial areas used in the CASAL model and 2002 acoustic abundance survey. Area 1 at the top with right sloping shading; Area 2 in the middle with vertical ading; Area 3 at the bottom with left sloping shading. The thick dark line encloses management area OEO 3A.

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

† 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 previous stock assessment (Hicks et al. 2002). The following analyses used revised spatial areas and incorporated two more years of data (2000–01 and 2001–02). New derived parameters, altitude of the sun and phase of the moon, were introduced as predictors in the regression model selection.

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 2001–02 fishing year. The data were restricted to the spatial analysis study area defined above. Because of the apparent changes in fishing practice attributable to the introduction of GPS, the data were split into pre- and post-GPS series. Years were included in the time series provided that they had at least 50 catches of black oreo and that the records were not dominated by a single vessel, defined as greater than 80% of the records for the year. 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 seamount 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) and suggesting that tow length was not a good measure of effort across the fishery.

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 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. The variables considered in the analyses included year, latitude, longitude, depth, season, time, target species, vessel, sun altitude, and moon phase (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 as 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. The modified model incorporated an interaction term for year and area that enabled the CPUE from each of the three areas defined in the spatial analysis to be analysed. 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. So the method was modified to provide a unique index. For the model with a fishing year-area interaction term this involved taking the means of the model predicted values for each combination of 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).

Table 4: Summary of non-year variables that could be selected in the regression models used in the CPUE 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
Latitude	7	Latitude at start of tow.
Longitude	7	Longitude at start of tow.
Depth	7	Depth at start of tow.
Season	7	The fishing year.
Time	7	Time of day at start of tow.
Target	3	Target species for the tow (BOE, SSO, OEO, OTHER).
Vessel	†	A parameter estimated for each vessel.
Sun	7	Altitude of the sun above/below the horizon.
Moon	7	Phase of the moon.

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

The following analyses were performed.

1. Analysis for Area 1 used a single part model only (log-linear regression). No binomial model analysis was required because there were very few zero tows.
2. Analysis with year/area interaction was applied to Areas 2 and 3 for pre- and post-GPS data separately. Two part (log-linear and binomial) models were employed for the pre-GPS series.

The single part (log-linear) model was used for the post-GPS series because there was very little post-GPS target fishing for black oreo and therefore very few zero catch tows.

3.4.3 Results of the CPUE analyses

The annual number of tows that caught black oreo and the catch of black oreo from 1978–79 to 2001–02 split by area are in Table 5.

Table 5: The number of tows that caught black oreo and the catch (t) for those tows by area and fishing year from OEO 3A *split into the three spatial analysis area.* Rest: remainder of OEO 3A.

Year	Area 1		Area 2		Area 3		Rest	
	Tows	Catch	Tows	Catch	Tows	Catch	Tows	Catch
1978–79	0	0	0	0	0	0	3	0
1979–80	182	645	656	4 030	683	3 993	6	15
1980–81	39	98	1 664	10 045	773	5 225	53	67
1981–82	15	50	513	3 156	382	2 449	40	43
1982–83	118	419	877	4 033	441	2 318	69	92
1983–84	77	219	975	3 035	610	2 101	54	113
1984–85	16	99	274	985	555	1 483	128	314
1985–86	9	11	225	711	328	971	353	388
1986–87	14	33	504	1 865	602	1 910	244	180
1987–88	17	38	711	1 830	517	1 098	148	75
1988–89	46	140	583	2 027	321	465	163	82
1989–90	91	466	301	780	406	863	174	252
1990–91	74	613	461	1 599	376	1 093	312	861
1991–92	44	164	170	710	169	1 032	393	1 277
1992–93	25	159	378	1 962	265	1 340	178	500
1993–94	65	273	510	2 040	373	1 074	354	611
1994–95	50	90	352	1 203	257	553	214	440
1995–96	94	155	584	1 927	456	789	278	470
1996–97	101	323	417	1 588	366	808	442	824
1997–98	212	133	144	451	412	647	397	334
1998–99	72	144	348	2 137	335	593	295	189
1999–00	124	107	394	1 841	329	743	148	75
2000–01	95	78	327	1 584	314	671	109	89
2001–02	83	50	228	1 259	184	540	110	57

Area 1

The analysis of Area 1 had data from 1979–80, 1989–90, 1990–91 and 1995–96 to 2001–02, but the data from years up to 1995–96 were poorly linked, so an index was provided only from 1995–96 onwards (Table 6 and Figure 6).

Table 6: Area 1 standardised CPUE index derived from the log-linear model and jack-knife c.v. estimates.

Year	Log-linear (kg/tow)	Jacknife c.v. (%)
1995–96	127	54
1996–97	164	32
1997–98	124	32
1998–99	127	38
1999–00	159	32
2000–01	148	41
2001–02	98	113

Figure 6: CPUE indices for Area 1. The dotted lines show a +/- 2 s.e. confidence interval calculated by a jack-knife method.

Areas 2 and 3

The pre-GPS combined indices (log-linear and binomial) and jack-knife c.v.s and the post-GPS log-linear model indices and jack-knife c.v.s for each area using the modified model with year-area interaction are in Tables 7–10 and Figures 7–10.

Table 7: Area 2 pre-GPS standardised CPUE indices derived from the modified model with year-area interaction and jack-knife c.v. estimates.

Year	Log-linear (kg/tow)	Binomial	Combined (kg/tow)	Jack-knife c.v. (%)
1979–80	5 700	0.65	3 700	39
1980–81	4 800	0.97	4 700	17
1981–82	4 600	0.94	4 400	22
1982–83	4 100	0.88	3 600	8
1983–84	2 900	0.87	2 500	8
1984–85	2 800	0.86	2 400	27
1985–86	2 100	0.76	1 600	31
1986–87	2 500	0.83	2 100	22
1987–88	1 500	0.77	1 200	20
1988–89	1 900	0.94	1 800	21

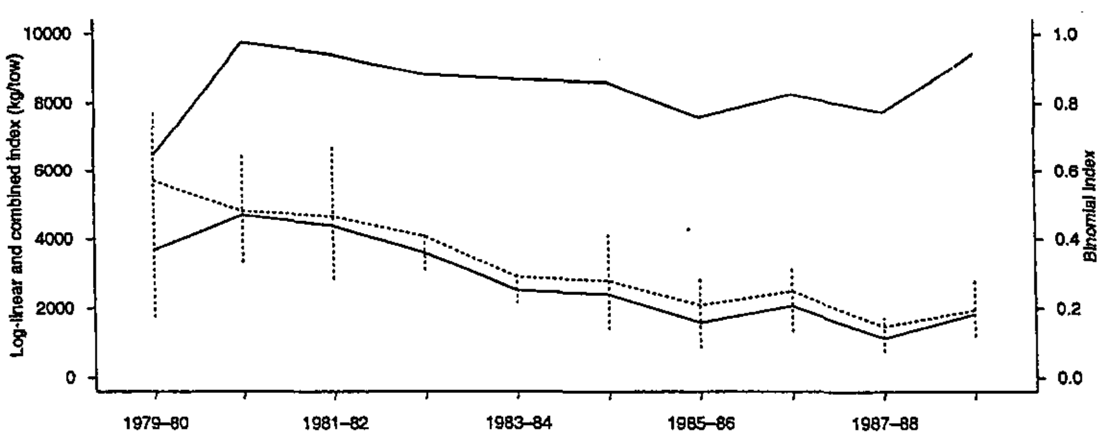

Figure 7: CPUE indices for Area 2, pre-GPS. The upper line shows the binomial index (right hand axis); the dotted line shows the log-linear index (left hand axis); the lowest line is the combined index (left hand axis) with dotted vertical lines showing a +/- 2 s.e. confidence interval calculated by a jack-knife method.

Table 8: **Area 3 pre-GPS standardised CPUE indices derived from the modified model with year-area interaction and jack-knife c.v. estimates.**

Year	Log-linear (kg/tow)	Binomial	Combined (kg/tow)	Jack-knife c.v. (%)
1979–80	5 200	0.61	3 100	125
1980–81	5 500	0.95	5 200	15
1981–82	4 800	0.92	4 400	9
1982–83	4 100	0.90	3 700	14
1983–84	2 700	0.78	2 100	19
1984–85	2 500	0.80	2 000	12
1985–86	1 900	0.73	1 400	33
1986–87	2 300	0.78	1 800	36
1987–88	1 400	0.69	1 000	23
1988–89	600	0.77	500	44

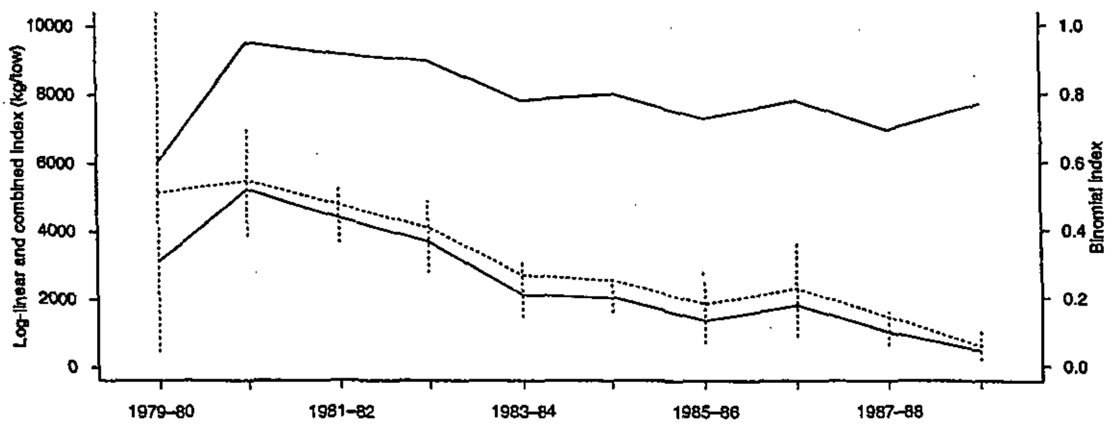

Figure 8: **CPUE indices for Area 3, pre-GPS. The upper line shows the binomial index (right hand axis); the dotted line shows the log-linear index (left hand axis); the lowest line is the combined index (left hand axis) with dotted vertical lines showing a +/- 2 s.e. confidence interval calculated by a jack-knife method.**

Table 9: **Area 2 post-GPS standardised CPUE indices derived from the modified model with year-area interaction and jack-knife c.v. estimates.**

Year	Log-linear (kg/tow)	Jack-knife c.v. (%)
1992–93	2 800	28
1993–94	1 900	39
1994–95	1 600	12
1995–96	1 500	19
1996–97	1 600	16
1997–98	1 200	36
1998–99	2 300	46
1999–00	2 800	52
2000–01	2 400	82
2001–02	3 400	27

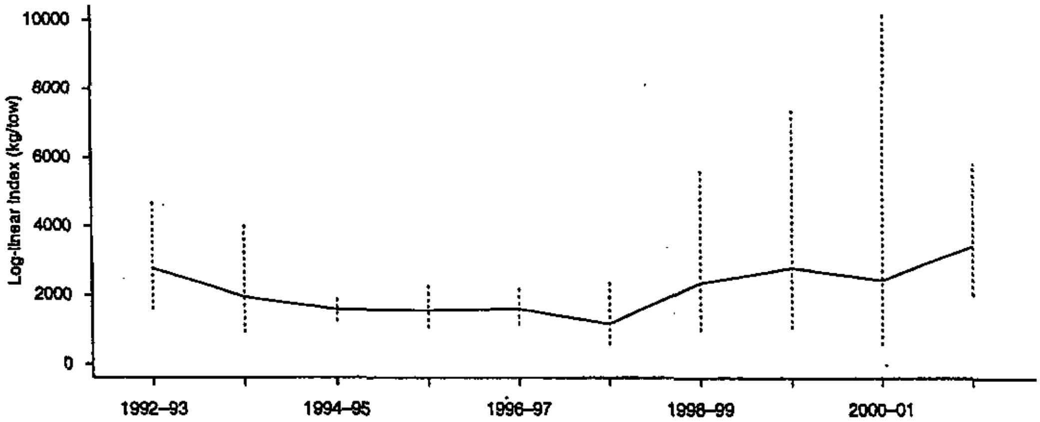

Figure 9: CPUE log-linear indices for Area 2, post-GPS. The dotted lines show a +/- 2 s.e. confidence interval calculated by a jack-knife method.

Table 10: Area 3 post-GPS standardised CPUE indices derived from the modified model with year-area interaction and jack-knife c.v. estimates.

Year	Log-linear (kg/tow)	Jack-knife c.v. (%)
1992–93	2 300	42
1993–94	1 500	24
1994–95	1 100	22
1995–96	900	53
1996–97	1 300	21
1997–98	800	21
1998–99	1 200	29
1999–00	1 600	17
2000–01	1 200	62
2001–02	1 800	8

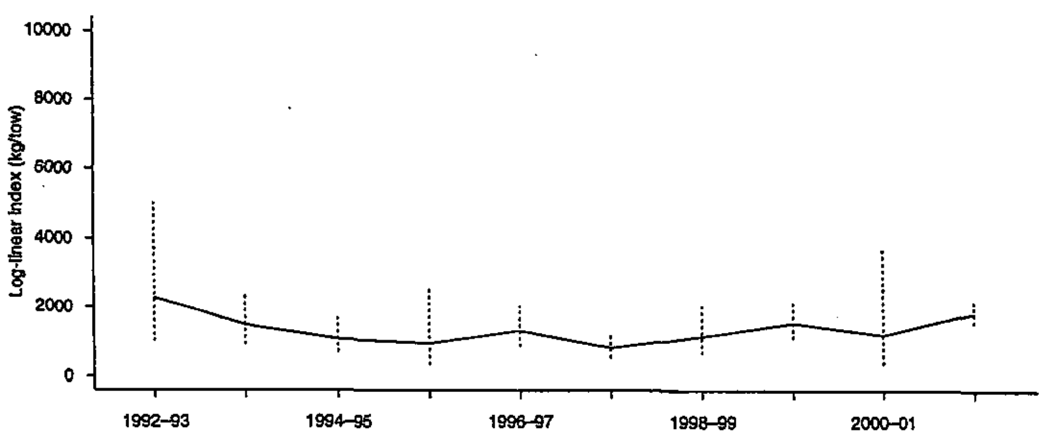

Figure 10: CPUE log-linear indices for Area 3, post-GPS. The dotted lines show a +/- 2 s.e. confidence interval calculated by a jack-knife method.

For Areas 2 and 3, pre-GPS the combined indices were used. For Areas 2 and 3, post-GPS the log linear indices were used. The CPUE indices developed for each area and used in the assessments are summarised in Table 11.

Table 11: Summary of the OEO 3A black oreo pre-GPS and post-GPS time series of standardised catch per unit effort indices (kg/tow) used in the *stock assessment analysis*. –, *no estimate*.

Year	Pre-GPS			Post-GPS		
	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
1979–80	–	3 700	3 100	–	–	–
1980–81	–	4 700	5 200	–	–	–
1981–82	–	4 400	4 400	–	–	–
1982–83	–	3 600	3 700	–	–	–
1983–84	–	2 500	2 100	–	–	–
1984–85	–	2 400	2 000	–	–	–
1985–86	–	1 600	1 400	–	–	–
1986–87	–	2 100	1 800	–	–	–
1987–88	–	1 200	1 000	–	–	–
1988–89	–	1 800	500	–	–	–
1989–90	–	–		–	–	–
1990–91	–	–	–	–	–	–
1991–92	–	–	–	–	–	–
1992–93	–	–	–	–	2 800	2 300
1993–94	–	–	–	–	1 900	1 500
1994–95	–	–	–	–	1 600	1 100
1995–96	–	–	–	127	1 500	900
1996–97	–	–	–	164	1 600	1 300
1997–98	–	–	–	124	1 200	800
1998–99	–	–	–	127	2 300	1 200
1999–00	–	–	–	159	2 800	1 600
2000–01	–	–	–	148	2 400	1 200
2001–02	–	–	–	98	3 400	1 800

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 12, 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. 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 only spanned five years so the index had a low weight compared to a longer time series.

Table 12: 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 two acoustic surveys of oreos carried out from 10 November to 19 December 1997 (TAN9713) (Doonan et al. 1998, 1999b) and 25 September to 7 October 2002 (TAN0213). The 1997 survey covered the flat with a series of random north-south transects over six strata at depths of 600–1200 m. Seamounts 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. The 2002 survey was limited to flat ground with 77 acoustic transects and 21 mark identification trawls completed.

3.6.1 Acoustic abundance estimates

Target strength

The target strength relationships used in this assessment were the same as used by Doonan et al. (2003b). Since the 1997 estimate (Doonan et al. 1998, 1999b), the target strengths for black oreo and smooth oreo were re-estimated using a Monte-Carlo analysis of in situ and swimbladder data (Macaulay et al. 2002, Coombs & Barr unpublished results) to give the following relationships:

$TS_{SSO} = -82.16+24.63\log_{10}(L)+1.0275\sin(0.1165L-1.765)$

for smooth oreos and

$TS_{BOE} = -78.05+25.3\log_{10}(L)+1.62\sin(0.0815L+0.238)$

for black oreos, where TS is the target strength and L the fish length.

For other common species, we used the relationships based on swimbladder modelling (Macaulay et al. 2001) as expressed in the more conventional formulation TS = a+b log10(L) (Table 13). Generic relationships were used for species for which no specific relationships are available as detailed by Doonan et al. (1999b).

Table 13: Length-target strength relationships used where relationships are of the form $TS=a + b \log_{10}(L)$.

Species name	Code	Intercept (a)	Slope (b)
Basketwork eel (*Diastobranchus capensis*)	BEE	-76.7	23.3
Black javelinfish (*Mesobius antipodum*)	BJA	-70.6	17.8
Four-rayed rattail (*Coryphaenoides subserrulatus*)	CSU	-92.5	31.8
Hoki (*Macruronus novaezelandiae*)	HOK	-74	18.0
Javelinfish (*Lepidorhyncus denticulatus*)	JAV	-73.5	20.0
Johnson's cod (*Halargyreus johnsonii*)	HJO	-74.0	24.7
Notable rattail (*Caelorinchus innotabilis*)	CIN	-107.8	44.9
Orange roughy (*Hoplostethus atlanticus*)	ORH	-74.34	16.15
Ribaldo (*Mora moro*)	RIB	-66.7	21.7
Ridge scaled rattail (*Macrourus carinatus*)	MCA	-95.5	35.6
Robust cardinalfish (*Epigonus robustus*)	EPR	-70.0	23.2
Serrulate rattail (*Coryphaenoides serrulatus*)	CSE	-135.0	59.7
White rattail (*Trachyrincus aphyodes*)	WHX	-62.1	18.1
Cod-like		-67.5	20.0
Deep water swimbladdered		-79.4	20.0
No swimbladder		-77.0	20.0

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 using the revised estimates of target strength for smooth oreo, black oreo, and a number of bycatch species. The revised estimates presented here change by 21% for Area 1, 10% for

Area 2, and 2% for Area 3 (Table 14). Absolute total acoustic abundance estimates for the 2002 survey are also in Table 14.

Table 14: Total black oreo abundance estimates for the 1997 and 2002 acoustic surveys for the three model areas in OEO 3A.

Year estimated	Acoustic abundance, tonnes (c.v. %) Area 1	Area 2	Area 3
(a) 1997 survey			
Hicks et al. (2002)	122 000 (24)	9 100 (24)	5 100 (27)
Revised (this study)	148 000 (29)	10 000 (26)	5 240 (25)
(b) 2002 survey			
This study	43 300 (31)	15 400 (27)	4 710 (38)

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 on 17 April 2003. 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 15).

Table 15: Number of observed commercial tows where black oreo were measured for length frequency. Excluded tows had less than 30 fish measured (13), extreme mean lengths (2) and missing catch information (3). –, no data (Area column) or that the length data were excluded (Group no. column).

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	–	

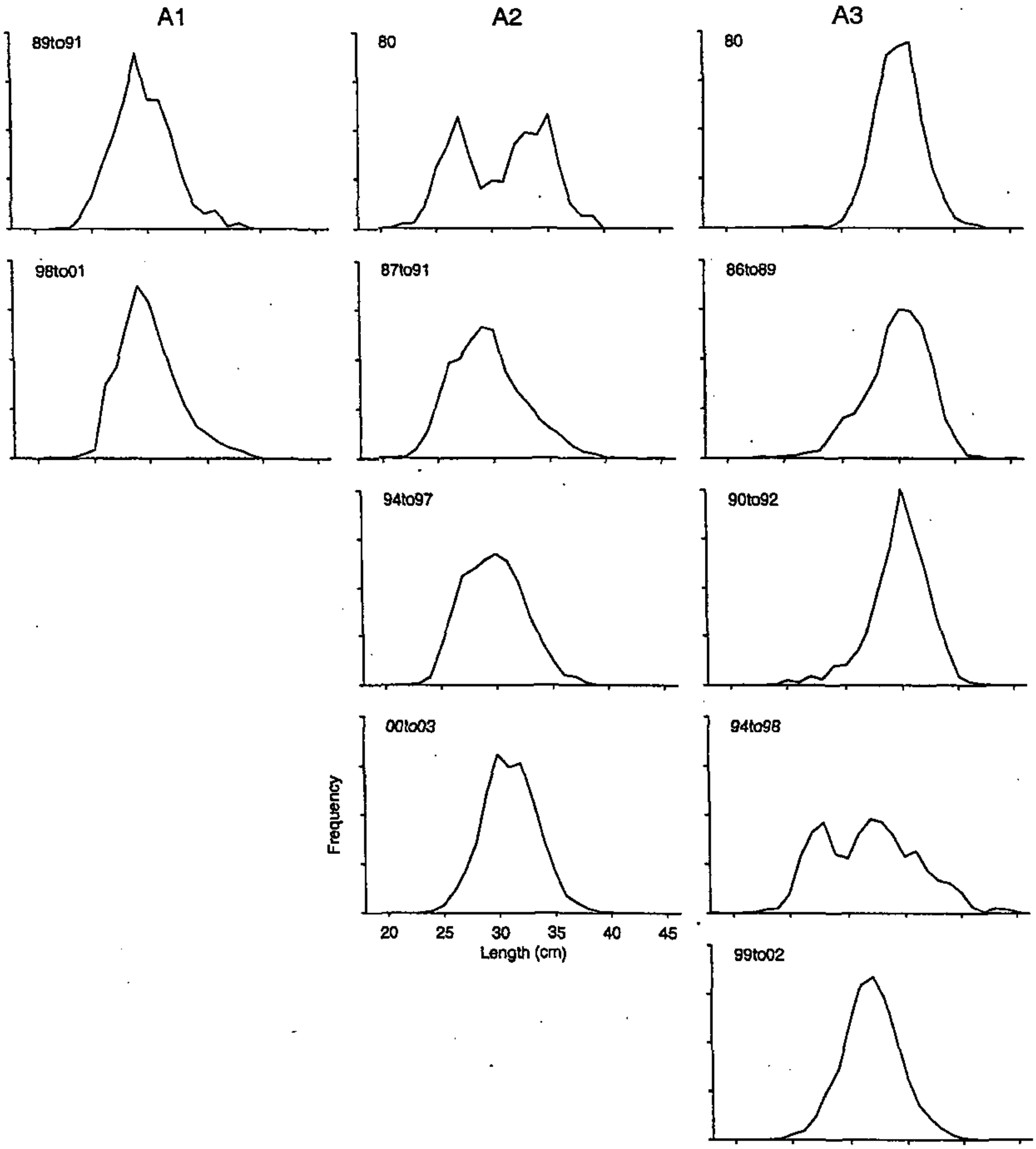

Figure 11: Distributions for the combined weighted length frequencies for the areas and periods identified in Table 15. The sum of the length frequencies across the length classes is one in each case and each frame shares common x- and y-axes.

Within each area, groups of years were identified from Table 15 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. Only one sample, from Area 1 in 1995–96, was not included.

Derived length frequencies for each group were calculated from the sample length frequencies weighted by the catch weight of each sample (Figure 11).

Within each group of length frequencies an estimate of the c.v. for each proportion at length class was made by bootstrap resampling 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. Table 16 lists the regression coefficients for each length frequency group.

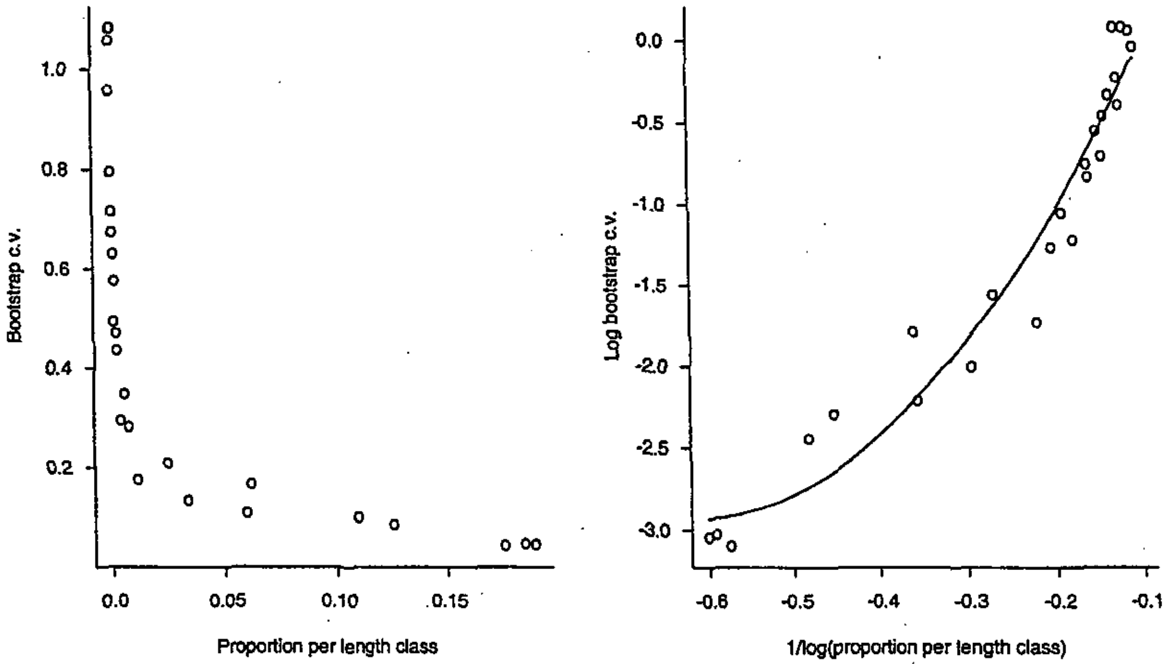

Figure 12: An example of the bootstrap c.v.s with the data from the Area 3, 1979–80 length frequency grouping. The left-hand frame shows the raw proportions for each length class versus the bootstrap estimated c.v.s. The right-hand frame shows the data as transformed for the regression fit. The curved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

Table 16: The regression coefficients for each group of length frequencies.

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

3.7.2 Acoustic research survey length data

The revised 1997, and the new 2002 acoustic survey abundance-at-length data were converted to numbers-at-length using a fixed length-weight relationship (see Table 18). Lengths below 25 and greater than 38 cm were pooled (see Table 17). The relationship between proportion-at-length and c.v. established from bootstrap resampling of the grouped observer length frequency data was 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. Process error was estimated within the model and it was assumed that the same value applied to all three areas.

Table 17: Proportions at length for each area for the revised 1997 and 2002 acoustic surveys.

	1997			2002		
Length (cm)	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
1–25	0.015	0.013	0.009	0.022	0.016	0.008
26	0.035	0.027	0.019	0.039	0.030	0.013
27	0.113	0.061	0.029	0.051	0.038	0.018
28	0.165	0.090	0.038	0.085	0.062	0.029
29	0.153	0.104	0.064	0.117	0.091	0.044
30	0.143	0.105	0.065	0.139	0.119	0.060
31	0.131	0.119	0.089	0.123	0.122	0.086
32	0.102	0.121	0.105	0.137	0.133	0.127
33	0.046	0.094	0.098	0.112	0.123	0.141
34	0.041	0.086	0.097	0.065	0.084	0.138
35	0.029	0.058	0.083	0.054	0.064	0.100
36	0.015	0.043	0.091	0.021	0.052	0.104
37	0.006	0.037	0.080	0.015	0.025	0.049
38–50	0.006	0.042	0.131	0.020	0.041	0.083

3.8 Biological data

This model was not sex-specific so combined sex parameters were developed (Table 18). The 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 stabilized by the transformation. Non-linear least squares did not fit as well and heteroskedastic residuals were observed.

Table 18: Life history parameters for black oreo. The combined parameters 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

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 parameters, but extension of the model to include fish from age one year onwards made this form inappropriate. Growth data for black oreo splits 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.

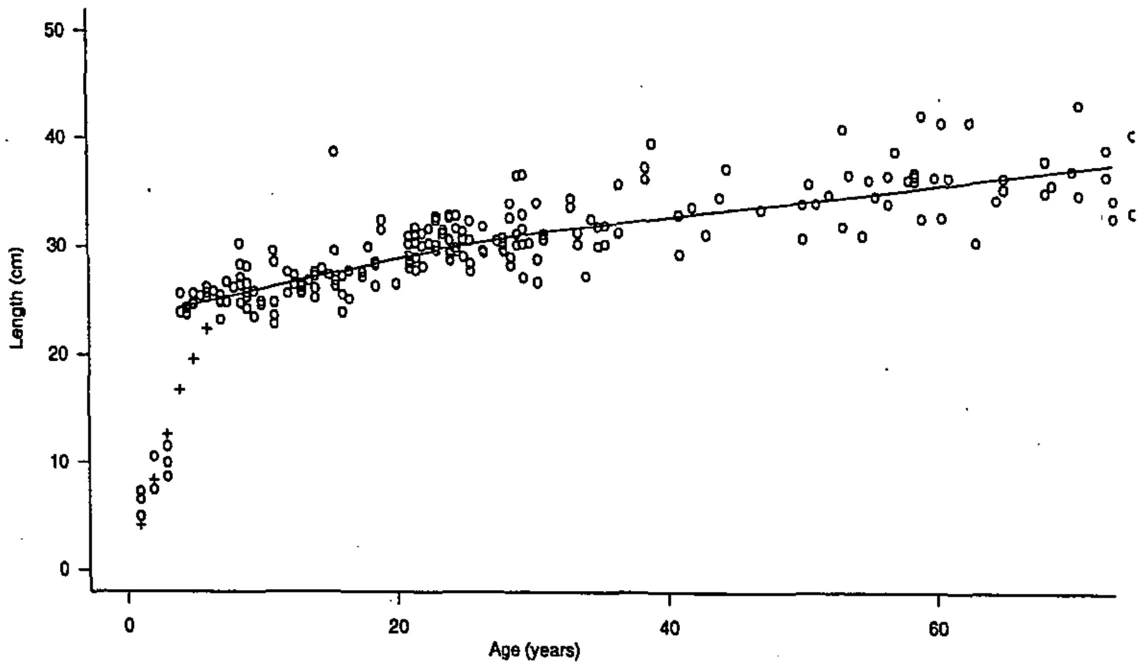

Figure 13: Growth data for black oreo from Puysegur (circles). A local regression was fitted to fish greater than 20 cm length (line). Mean length for ages 1 to 6 years are shown "+". See text for more detail.

For post-settlement fish a local regression with a width spanning 2/3 of the data was fitted to all fish greater than 20 cm. Mean length at ages 7 to 70 years was calculated from this fit (Table 19). For pre-settlement fish, a straight line was taken through the origin and the mean length for fish less than 20 cm length. 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 19).

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

3.9 Development of a base case model

A CASAL model (termed the H&D model below) that emulated the Hicks et al. (2002) spatial analysis model was developed first. New and updated data sets were then applied to the H&D model and new parameters were examined to establish better fits to the data. The differences between the H&D model and the base case model are summarised in Table 20. More detail on the stages of model development are shown in Figure 14 and summarised in Tables 21–23. The base case chosen was the model that showed the best fit to the data without overfitting, in our opinion.

Four series of model fits are reported (Table 23). Series 1 evolved the D2000 model with the data and model structure changes detailed in Table 22. The series 2 models used the developed series 1 model to develop the base case by changing the migration parameters. Series 3 models investigated the sensitivity of the base case model to changes in some of the key parameters. Series 4 models investigated the effects of changes to input data suggested by the Deepwater Stock Assessment Working Group including treating the Area 1 acoustic absolute abundance estimate as a relative value, excluding the two pre-GPS CPUE abundance indices, excluding the three post-GPS CPUE abundance indices, and including Area 1 trawl survey length frequency data.

Estimated model parameters and priors are presented in Table 24.

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

1. Process error for the acoustic and observer length frequency data analysis were fixed at the MPD value.
2. The b value for the migration from midwater to Area 1 parameter was fixed at the MPD value. This value was at or close to a limit.
3. The b value for the migration from Area 1 to Area 2 parameter was fixed at the MPD value. This value was at or close to a limit.

Table 20: Differences between the initial CASAL model (H&D) and the base case model used in this assessment.

Parameter	H&D	Base case
1 CPUE	Up to 1999–2000, old standard errors.	Up to 2001–02, new standard errors, 20% process error.
2 Abundance	1997 acoustic survey.	1997 & 2002 surveys, corrected for TS & area outside study area.
3 Acoustic LF	1997 acoustic survey, Coleraine distribution.	1997 & 2002, lognormal, new c.v., process error estimated.
4 Observer LF	Up to 2000–01, Coleraine distribution. Annual length frequencies.	Up to 2002–03, grouped (5 yr), lognormal distribution. Process error estimated.
5 Recruitment	At age of 5 years into Area 1.	At age 1 year into new midwater layer "area". Fish settle on bottom in Area 1 via a migration ogive.
6 Selectivity	One per area.	All free selectivity parameters were dropped, but when used for Area 1 was made linear and Area 2 kept the same as Area 3.
7 Growth	von Bertalanffy, fixed c.v.	Three phases. Estimated c.v. of the length spread.
8 Migration	Constant proportional. Density dependent Area 2 to 3.	Age dependent. No density effects.
9 Catch	To 2000–01.	To 2001–02.

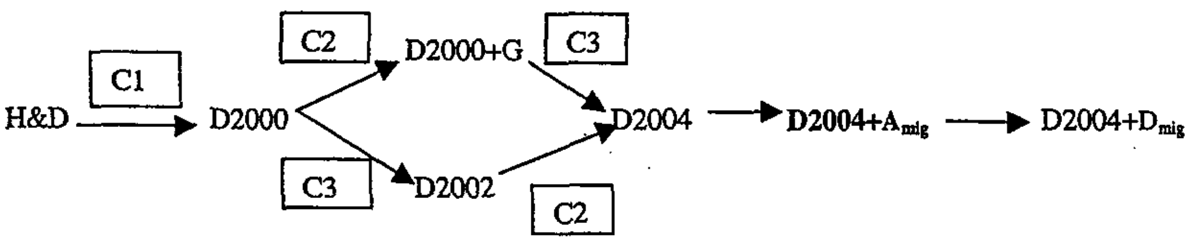

Figure 14: Flowchart of the development of the CASAL stock assessment models presented in this report. Base case in bold. Arrows link the model runs and the boxes denote groups of data and method changes. See Tables 21–22 for details and Table 23 for run name abbreviations.

Table 21: Parameter codes and descriptions used in Figure 14 and Table 22.

Code	Description
A_{mig}	Age dependent migration
D_{mig}	Age and density dependent migration
M_{ad}	Natural mortality of mature fish
M_{juv}	Natural mortality of immature fish
$Q_{aco.A1}$	Catchability for acoustic Area 1
R_{dev}	No restriction on recruitment deviates.
R_{dev6}	Recruitment deviates restricted to 6.

Table 22: CASAL model data inputs and method changes compared to the Hicks et al. (2002) spatial model. Changes were applied together in three groups, C1, C2, and C3.

Group	Data source	Description of use and estimates made
C1	Observer length frequency	Data to 2000–01. Lognormal error structure, grouped over years. Process error estimated.
C1	Acoustic length frequency	1997 survey data only. Lognormal error structure. Process error estimated.
C1	CPUE abundance	Data to 1999–2000. New standard errors. 20% process error assumed.
C1	Acoustic abundance	1997 survey only. Corrected for catches outside study area. Revised target strength.
C1	Midwater layers	Assumed recruitment to midwater and then into Area 1. 1–70 years.
C1	Fishing selectivities	Area 3 assumed same as Area 2.
C2	Growth	New growth (Section 3.8), pre- and post-settlement. Length-at-age c.v.s estimated
C3	CPUE abundance	Updated with 2000–01 and 2001–02.
C3	Acoustic abundance	1997 plus 2002 surveys.
C3	Acoustic length frequency	1997 plus 2002 survey data.
C3	Observer length frequency	Updated with 2001–02 and 2002–03.
C3	Catch history	Updated with 2000–01 and 2001–02.

Table 23: CASAL model runs reported. Base case in bold. –, not applicable.

Code	Run numbers	Series	Changes (Table 22)	Extra parameters (Table 21)	Description
H&D	1.2	1	–	–	Emulated the 2002 analysis.
D2000	138, 138x, 138xx	1	C1	–	Added revised data and "old" growth.
D2000+G	141, 142, 143	1	C1+C2	–	Added "new" growth.
D2002	134, 139, 139.1	1	C1+C3	–	Added 2002 survey and updated data.
D2004	151	2	C1+C2+C3	–	Simple model, constant proportional migration
D2004+A_{mig}	**152**	**2**	**C1+C2+C3**	**A_{mig}**	**Plus age dependent migration**
D2004+D_{mig}	155	2	C1+C2+C3	D_{mig}	Plus age and density dependent migration.
D2004+M_{ad}	160	3	C1+C2+C3	A_{mig}+M_{ad}	Sensitivity to mature fish M.
D2004+M_{juv}	156	3	C1+C2+C3	A_{mig}+M_{juv}	Sensitivity to immature fish M.
D2004+$Q_{aco.A1}$	163	3	C1+C2+C3	A_{mig}+$Q_{aco.A1}$	Sensitivity to catchability in Area 1.
D2004+R_{dev}	161	3	C1+C2+C3	A_{mig}+R_{dev}	Sensitivity to recruitment effects.
D2004+R_{dev6}	164	3	C1+C2+C3	A_{mig}+R_{dev6}	Sensitivity to recruitment effects.
Base	152	4	C1+C2+C3		Base case as above.
A1.aco.rel	163	4	C1+C2+C3		Make Area 1 acoustic abundance relative.
Drop.pre.GPS	170	4	C1+C2+C3		Exclude pre-GPS CPUE.
Drop.post.GPS	171	4	C1+C2+C3		Exclude post-GPS CPUE.
A1.res.LF	190	4	C1+C2+C3		Include Area 1 trawl survey length data.

Table 24: Estimated parameters and uniform priors of the CASAL stock assessment model, sexes combined.

Parameter	Lower bound	Upper bound
Initialisation R_0 (numbers)	3×10^6	1×10^8
Size-at-age c.v.	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	9	17
MW to Area 1, ages 50–95% selection	0.2	35
Area 1 to 2, age at 50% selection, logistic ogive	1	100
Area 1 to 2, ages 50–95% selection, logistic ogive	0.2	70
Area 1 to 2, capped logistic ogive	0	0.2
Area 2 to 3, age at 50% selection, logistic ogive	1	100
Area 2 to 3, ages 50–95% selection, logistic ogive	0.2	70
Area 2 to 3, capped logistic ogive	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	1×10^{-8}	100
Area 2 CPUE pre-GPS	1×10^{-8}	100
Area 2 CPUE post-GPS	1×10^{-8}	100
Area 3 CPUE pre-GPS	1×10^{-8}	100
Area 3 CPUE post-GPS	1×10^{-8}	100

4. RESULTS

4.1 MPD results

The MPD parameter estimates and run details are listed in Tables 25–37 (see Tables 21–23 for run descriptions). The results showed that the CASAL emulation of the Hicks et al. (2002) spatial analysis (H&D, Series 1) gave similar results to the Hicks et al. (2002) results (Table 28). The series 1 model and the revised data gave improved model fits (Figures 15–18). However, the CASAL Series 1 models also gave more optimistic current biomass results compared to Hicks et al. (2002) because of the different parameter estimates. When the new data sources (see Table 22, C1) were added to the H&D model to create the D2000 model run, the selectivities in Areas 2 and 3 moved to the left of the those from the H&D model run, so that effectively all fish in the area were selected. In contrast to the H&D model, age-dependent migration significantly improved the fit (Table 27), but estimating M_{juv} did not. These changes may reflect the fact that the observer length frequencies were down-weighted relative to the acoustic length frequencies since the estimated process error on the observer length frequencies is about 60% compared to 30% on the acoustic length frequencies.

In the series 2 model runs (see Table 23) the new growth form and the new data (2002 acoustic abundance, CPUE, etc) were used (Tables 29–31) and a base case was developed for MCMC runs (Figures 19–24). Age based migration was needed mainly to help fit the acoustic length frequency data from Areas 1 and 2. Density dependent migration is also statistically significant through better fits to the observer and acoustic length frequency and CPUE data in Area 3. But the better fits are not visually apparent and so age dependent migration alone (no density dependent migration) was chosen for the base case (See Table 23). Fits of the observer and acoustic length data by grouped year and area and QQnorm plots are in Appendices A-D.

The series 3 model runs (see Table 23) are sensitivities of the base case to various key parameters and results show significantly better fits when adult M was estimated and recruitment deviates were used (See Tables 32–34, Figures 25 & 26). The fits to the observer and acoustic length frequency data in Area 2 are improved by the recruitment deviate effect (Figure 27).

The series 4 model runs (see Table 23) were extra runs requested by the Deepwater Working Group and produced results that were not significantly different to those from the base case (Tables 35–37).

Series 1

Table 25: MPD fits. Free parameter estimates for series 1 model runs. –, not estimated.

	H&D	D2000	D2000+G	D2002
Initialisation R_0	8 059 000	12 127 500	30 531 400	14 007 900
Size-at-age L_{inf} (cm)	–	37.7	–	37.6
Size-at-age c.v.	–	0.05	0.06	0.05
Selectivity (yr)				
Area 1, age at 50% selection	6.59	7.54	8.22	7.18
Area 1, ages 50–95% selection	0.20	1.29	0.50	0.20
Area 2, age at 50% selection	10.59	4.27	8.62	4.34
Area 2, ages 50–95% selection	0.48	0.20	0.48	0.20
Area 3, age at 50% selection	19.34	–	–	–
Area 3, ages 50–95% selection	1.16	–	–	–
Migration (yr)				
MW to Area 1, age at 50% selection	–	5.00	14.00	5.00
MW to Area 1, ages 50–95% selection	–	0.20	0.20	0.20
Area 1 to 2 proportion	0.03	0.04	0.02	0.03
Area 1 to 2, density dependent	0.69	–	–	–
Area 2 to 3 proportion	0.03	0.04	0.04	0.03
Area 2 to 3, density dependent	2.11	–	–	–
Process error c.v.				
Areas 1–3 acoustic length frequency	–	0.28	0.14	0.29
Areas 1–3 observer length frequency	–	0.57	0.66	0.63

Table 26: MPD fits. Objective function component estimates for series 1 model runs.

	H&D	D2000	D2000+G	D2002
Acoustic abundance				
Area 1	9.5	5.1	-1.3	2.1
Area 2	-1.2	-0.9	-1.2	-0.9
Area 3	-1.2	-1.3	-1.4	-1.9
CPUE				
Area 1, post-GPS	-5.1	-5.1	-5.1	-5.2
Area 2, post-GPS	-2.3	-6.0	-6.1	-4.7
Area 2, pre-GPS	-12.1	-7.4	-6.4	-6.9
Area 3, post-GPS	-6.4	-3.5	-5.3	-1.5
Area 3, pre-GPS	-10.8	-4.6	-4.4	-3.7
Acoustic survey length frequency				
Area 1	-21.2	2.7	-7.3	4.6
Area 2	-21.6	-7.3	-10.5	-19.0
Area 3	-20.6	-13.0	-15.5	-22.0
Observer length frequency				
Area 1	-260.6	-7.1	-6.8	-4.4
Area 2	-577.7	2.2	6.7	7.5
Area 3	-847.6	6.5	23.0	9.9
Fishery catch limit penalty				
Area 1	0.0	0.0	0.0	0.0
Area 2	0.0	0.0	0.0	0.0
Area 3	0.0	0.0	0.0	0.0
Total	-1 779.0	-39.6	-41.5	-46.0

Table 27: MPD fits. Log-likelihood estimates and data drivers for series 1 model runs. Delta L A_{mig} is the change in log-likelihood when age-dependent migration was included in the model. Delta A_{mig} + M_{juv} is the change in log-likelihood when age-dependent migration and M of immature fish were included in the model. Data drivers are the few data sources that produce the largest changes in the log-likelihood estimates.

	D2000	D2000+G	D2002
Delta L A_{mig}	-8.2	-13.9	-5.4
Delta L A_{mig} + M_{juv}	-9.4	-15.3	-6.3
M_{juv} estimate	0.073	0.021	0.018
A_{mig} drivers	Area 3 obs.LF	Area 2 aco.LF	Area 2 aco.LF
	Area 2 obs.LF	Area 3 obs.LF	Area 1 obs.LF
M_{juv} drivers	Area 1 aco.abund	Area 3 obs.LF	Area 2 aco.LF
	Area 2 obs.LF	Area 2 obs.LF	Area 1 aco.LF

Table 28: MPD fits. Biomass estimates (t) for series 1 model runs. –, no data. The reference year for the Hicks et al. (2002) biomass estimates (†) was 2000–01.

	Hicks et al. (2002)	H&D	D2000	D2000+G	D2002
Mid-year, selected					
Area 1					
B_0	–	59 500	54 500	160 000	70 200
B_{2003}	–	35 000	46 500	153 000	63 800
B_{2003}/B_0	–	59	85	96	91
Area 2					
B_0	–	38 700	42 600	36 300	47 400
B_{2003}	–	3 960	11 100	10 800	14 900
B_{2003}/B_0	–	10	26	30	31
Area 3					
B_0	–	28 700	45 800	47 500	46 800
B_{2003}	–	988	2 010	3 030	3 430
B_{2003}/B_0	–	3	4	6	7
Areas 1–3 combined					
B_0	–	127 000	143 000	244 000	164 000
B_{2003}	–	39 900	59 700	167 000	82 100
B_{2003}/B_0	–	31	42	68	50
Total biomass, Areas 1–3 combined					
B_0	143 000	132 000	150 000	244 000	173 000
B_{2003}	55 000†	47 300	65 900	167 000	89 300
B_{2003}/B_0	39†	36	44	68	52

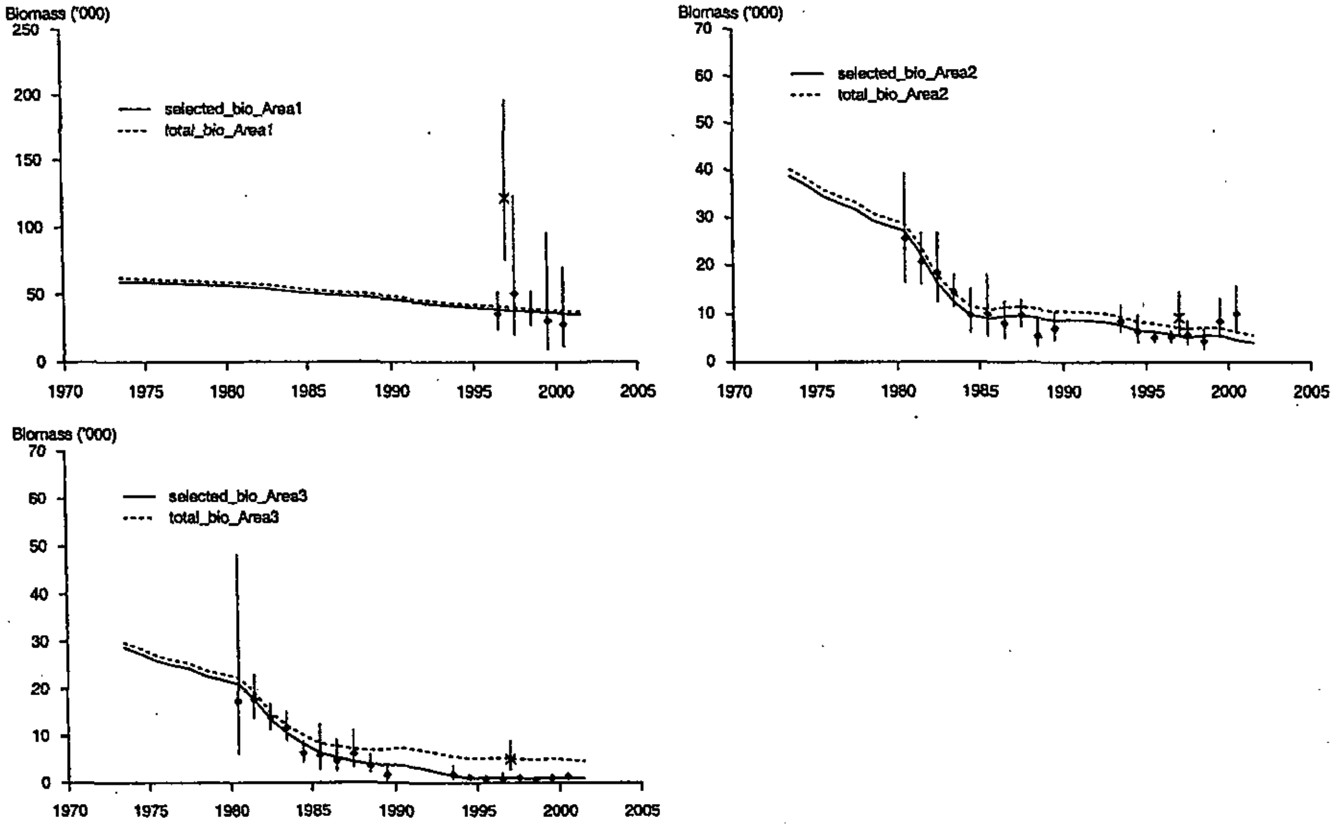

Figure 15: Run 1.2 (H&D) selected (solid line) and total (dashed line, may be obscured) biomass (start of year) trajectories for each area with CPUE (diamonds) and the 1997 absolute abundance (cross) indices and the approximate 95% confidence intervals (two upper and lower left panels). Some confidence intervals exceed the axes of the plot.

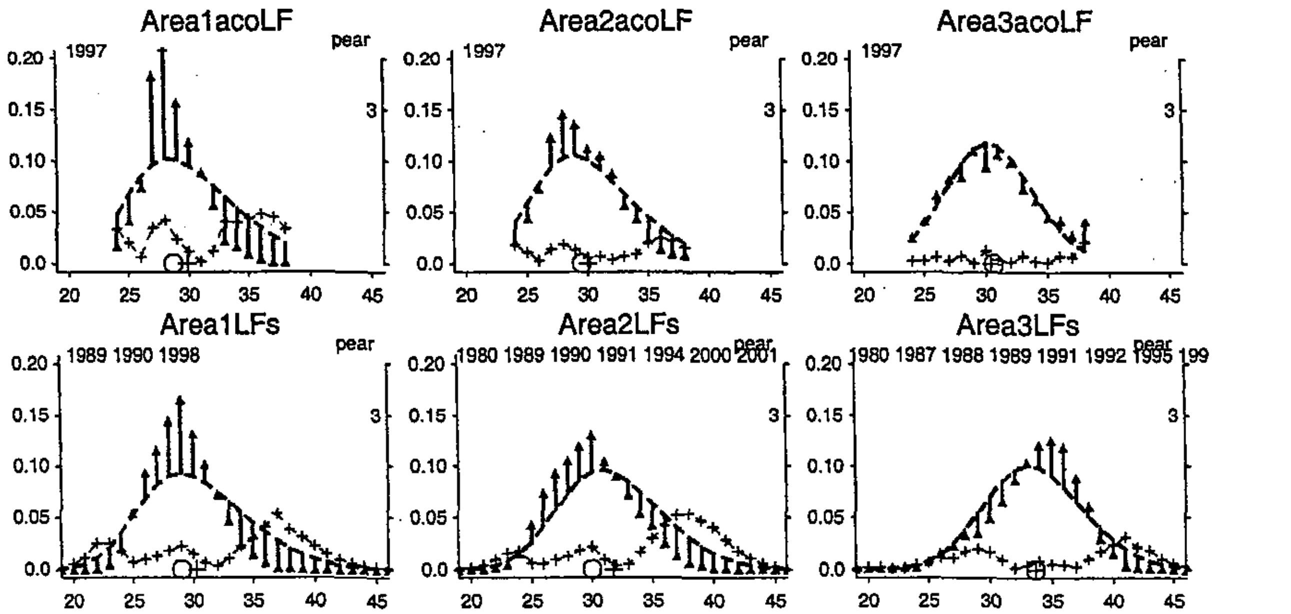

Figure 16: Run 1.2 (H&D) fits to the acoustic (upper panels) and observer (lower panels) length frequency data for each area (left hand axis). The model fit is the thick dashed line and arrowhead shows the data. The large cross near the x-axis is the mean of the model fit and the circle is the mean of the data. Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).

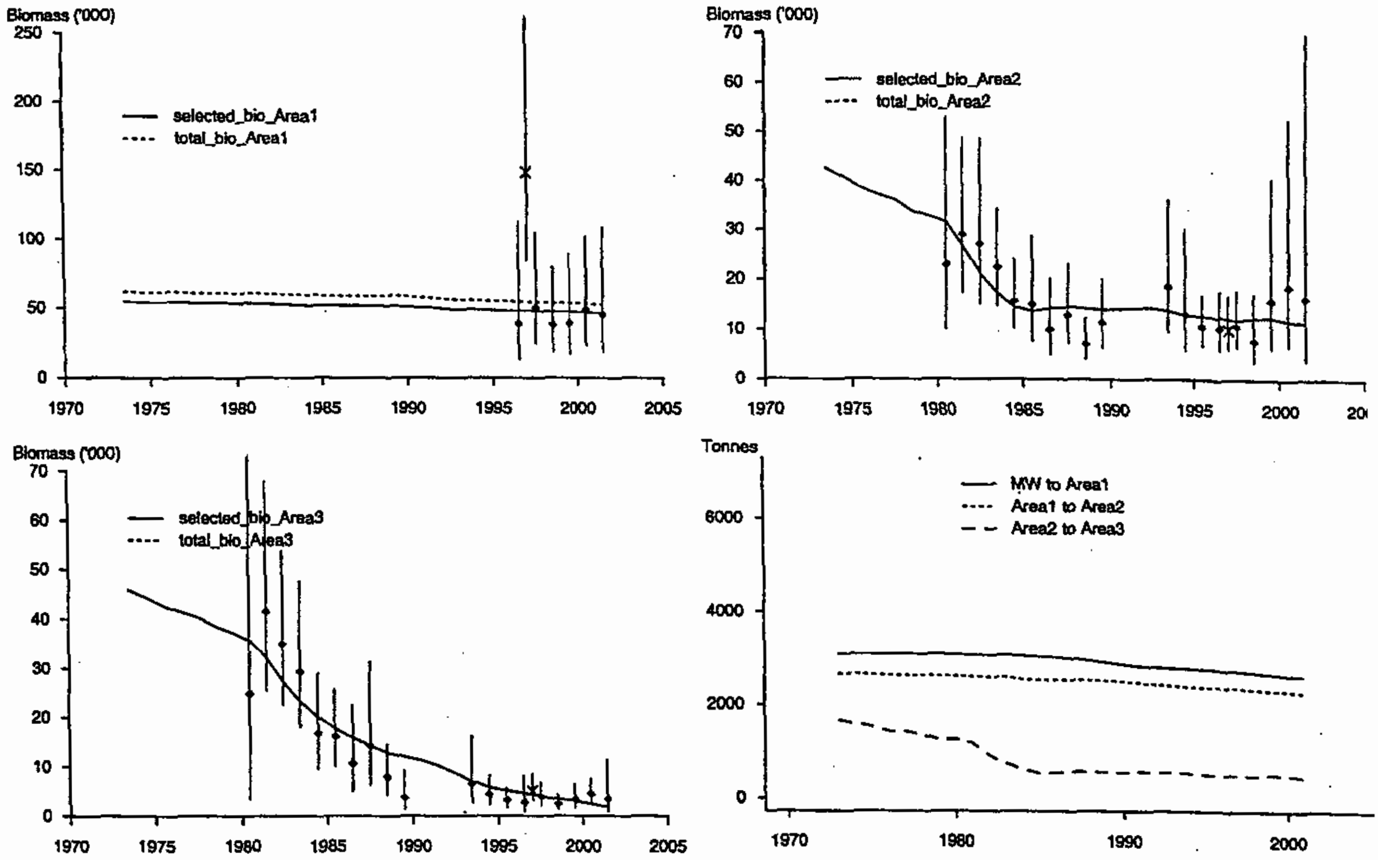

Figure 17: **Run 138 (D2000) selected (solid line) and total (dashed line, which may be obscured) biomass (start of year) trajectories for each area with CPUE (diamonds) and the 1997 absolute abundance indices (cross) and the approximate 95% confidence intervals (two upper and lower left panels). Some confidence intervals exceed the axes of the plot. The lower right panel shows the migration of fish for each area used in this run.**

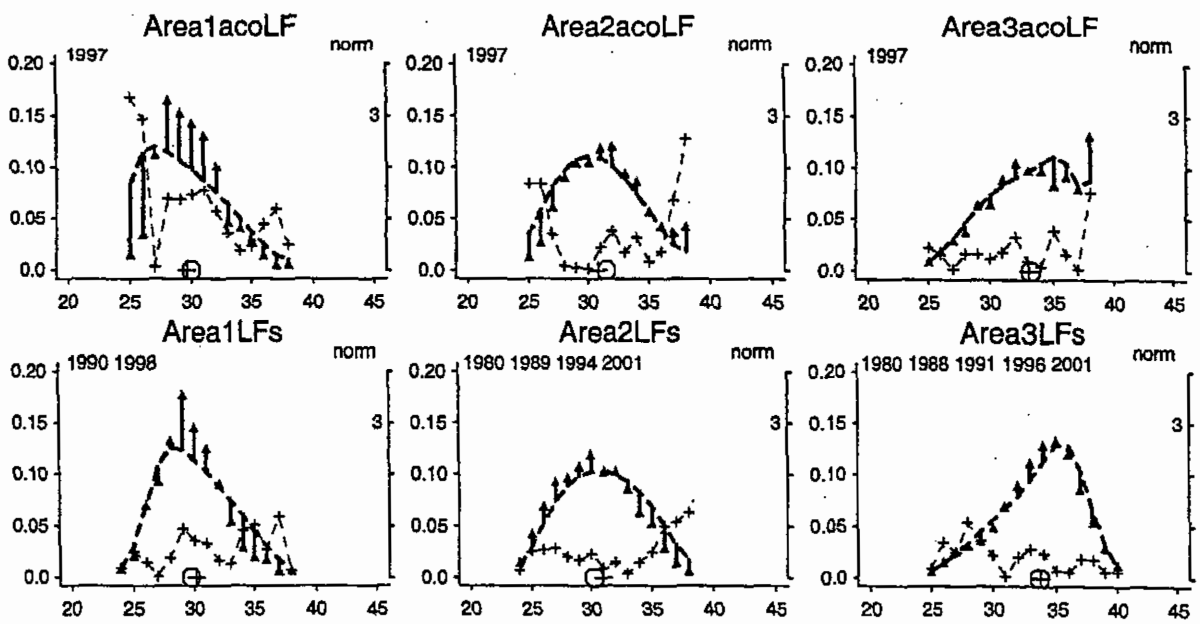

Figure 18: **Run 138 (D2000) fits to the acoustic (upper panels) and observer (lower panels) length frequency data for each area (left hand axis). The model fit is the thick dashed line and arrowhead sho+- the data. The large cross near the x-axis is the mean of the model fit and the circle is the mean of the data. Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).**

Series 2

Table 29: MPD fits. Free parameter estimates for series 2 model runs. Base case in bold. –, not estimated.

	D2004	**D2004+ A_{mig}**	D2004+ D_{mig}
Initialisation R_0	26 663 100	**24 517 700**	23 808 400
Size-at-age c.v.	0.07	**0.08**	0.08
Selectivity (yr)			
Area 1, age at 50% selection	11.22	**8.47**[†]	8.47
Area 1, ages 50–95% selection	0.20	**0.50**[‡]	0.50
Area 2, age at 50% selection	1.01	**10.11**[†]	10.14
Area 2, ages 50–95% selection	0.31	**0.50**[‡]	0.50
Migration (yr)			
MW to Area 1, age at 50% selection	17	**17**	17
MW to Area 1, ages 50–95% selection	0.30	**0.20**	0.31
Area 1 to 2 proportion	0.03	**–**	–
Area 1 to 2, age at 50% selection, logistic ogive	–	**35.12**	56.27
Area 1 to 2, ages 50–95% selection, logistic ogive	–	**70.00**	70.00
Area 1 to 2, capped logistic ogive	–	**0.07**	0.12
Area 2 to 3 proportion	0.04	**–**	–
Area 2 to 3, age at 50% selection, logistic ogive	–	**17.67**	81.83
Area 2 to 3, ages 50–95% selection, logistic ogive	–	**23.32**	64.61
Area 2 to 3, capped logistic ogive	–	**0.04**	0.20
Area 2 to 3. Density dependent source	–	**–**	-6.64
Area 2 to 3. Density dependent destination	–	**–**	6.19
Process error c.v.			
Area 1–3 acoustic length frequency	0.16	**0.13**	0.12
Area 1–3 observer length frequency	0.74	**0.74**	0.71

[†] Set to 1 in final model, [‡] set to 0 in final model; for no change in parameters or likelihood.

Table 30: MPD fits. Objective function component estimates for series 2 model runs. Base case in bold.

	D2004	**D2004+ A_{mig}**	D2004+ D_{mig}
Acoustic abundance			
Area 1	2.3	**1.9**	1.9
Area 2	-1.2	**-1.7**	-1.6
Area 3	-1.4	**-2.0**	-1.9
CPUE			
Area 1, post-GPS	-5.2	**-5.2**	-5.2
Area 2 post-GPS	-5.1	**-5.1**	-4.3
Area 2 pre-GPS	-6.5	**-6.4**	-7.3
Area 3 post-GPS	-3.4	**-1.3**	-4.3
Area 3 pre-GPS	-3.3	**-3.9**	-5.9
Acoustic length frequency			
Area 1	-17.3	**-16.4**	-15.7
Area 2	-28.7	**-34.1**	-33.2
Area 3	-21.6	**-24.4**	-27.5
Observer length frequency			
Area 1	-4.7	**-5.4**	-5.8
Area 2	12.2	**14.0**	15.8
Area 3	27.1	**25.7**	18.7
Fishery catch limit penalty			
Area 1	0.0	**0.0**	0.0
Area 2	0.0	**0.0**	0.0
Area 3	0.0	**0.0**	0.0
Total	-56.8	**-64.2**	-76.4

Table 31: MPD fits. Biomass estimates (t) for series 2 model runs. Base case in bold.

	D2004	D2004+ A_{mig}	D2004+ D_{mig}
Mid-year, selected			
Area 1			
B_0	105 000	**92 100**	90 700
B_{2003}	101 000	**88 200**	86 900
B_{2003}/B_0	96	**96**	96
Area 2			
B_0	43 800	**42 000**	44 600
B_{2003}	13 800	**12 600**	9 600
B_{2003}/B_0	31	**30**	22
Area 3			
B_0	48 400	**47 800**	41 400
B_{2003}	4 510	**3 200**	2 830
B_{2003}/B_0	9	**7**	7
Areas 1–3 combined			
B_0	197 000	**182 000**	177 000
B_{2003}	119 000	**104 000**	99 300
B_{2003}/B_0	61	**57**	56
Total biomass, Areas 1–3 combined			
B_0	197 000	**182 000**	177 000
B_{2003}	119 000	**104 000**	99 300
B_{2003}/B_0	61	**57**	56

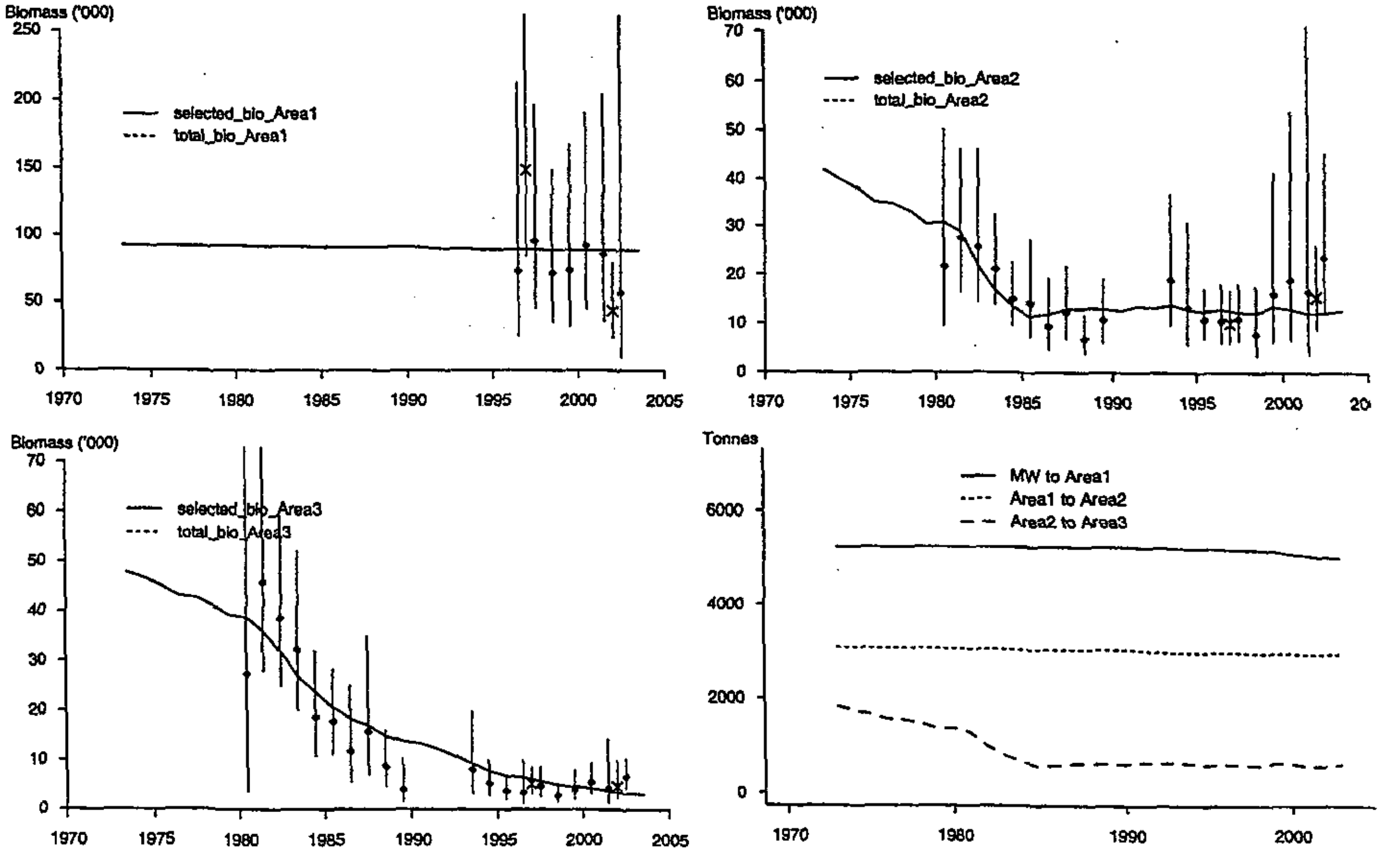

Figure 19: Base case (run 152) selected (solid line) and total (dashed line, may be obscured) biomass (start of year) trajectories for each area with CPUE (diamonds) and the 1997 and 2002 absolute abundance (crosses) indices and the approximate 95% confidence intervals (two upper and lower left panels). ***Some confidence intervals exceed the axes of the plot.*** **The lower right panel shows the migration of fish for each area used in this run.**

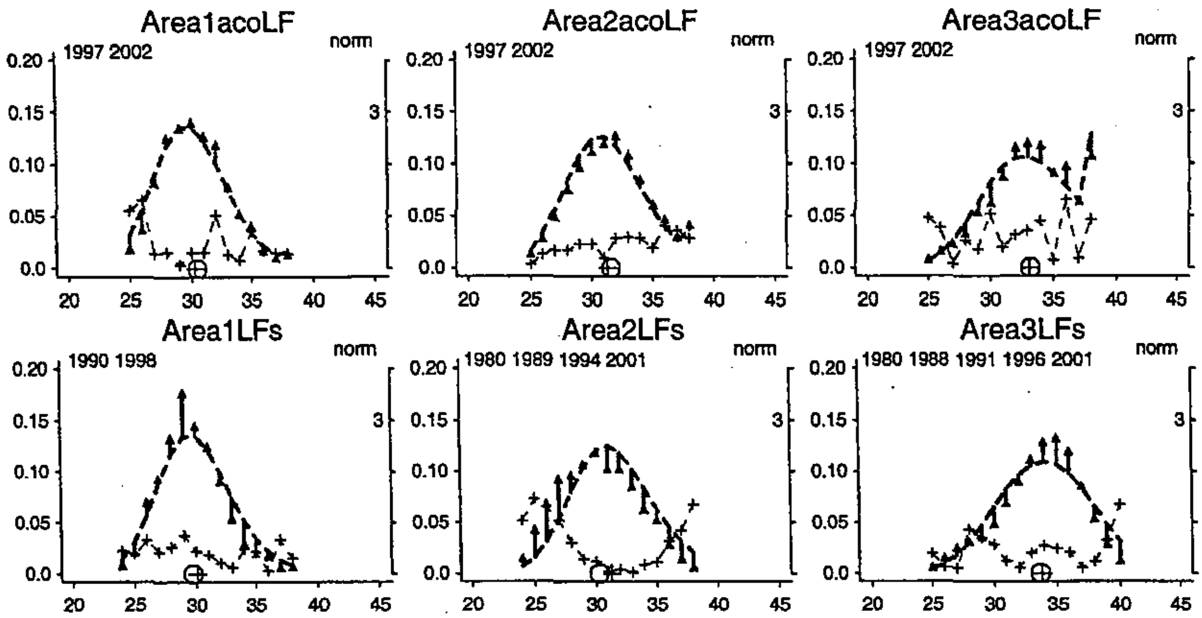

Figure 20: Base case (run 152) overall fits to the acoustic (upper panels) and observer (lower panels) length frequency data for each area (left hand axis). The model fit is the thick dashed line and arrowhead shows the data. The large cross near the x-axis is the mean of the model fit and the circle is the mean of 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

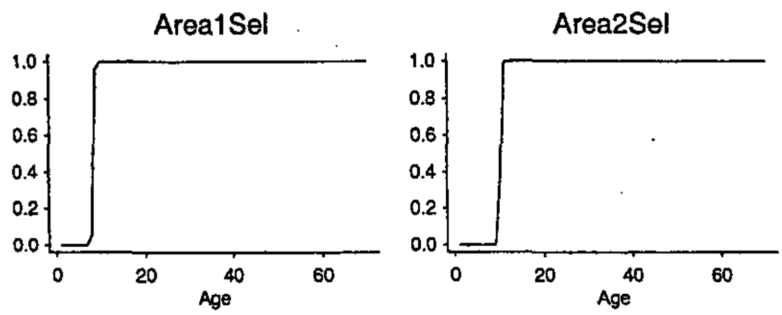

Figure 21: Base case (run 152) selectivity ogives for Areas 1 and 2. The y-axis is the proportion selected.

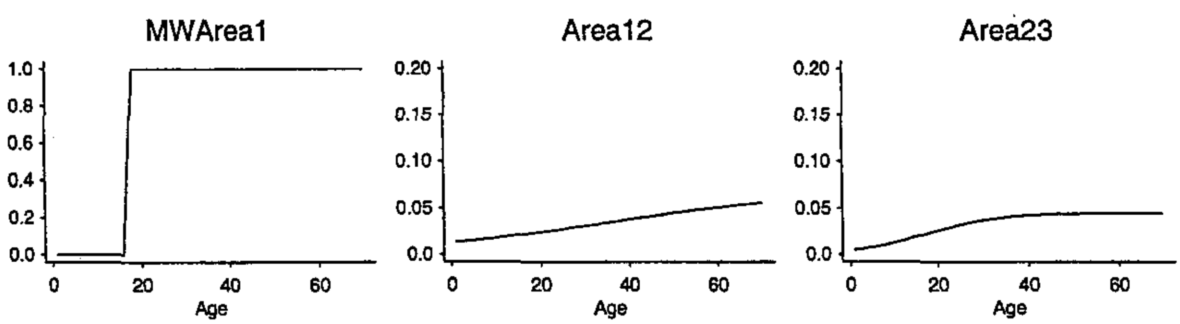

Figure 22: Base case (run 152) migration ogives for the midwater to Area 1, Area 1 to two, and Area 2 to 3. The y-axis is the proportion migrating at each age.

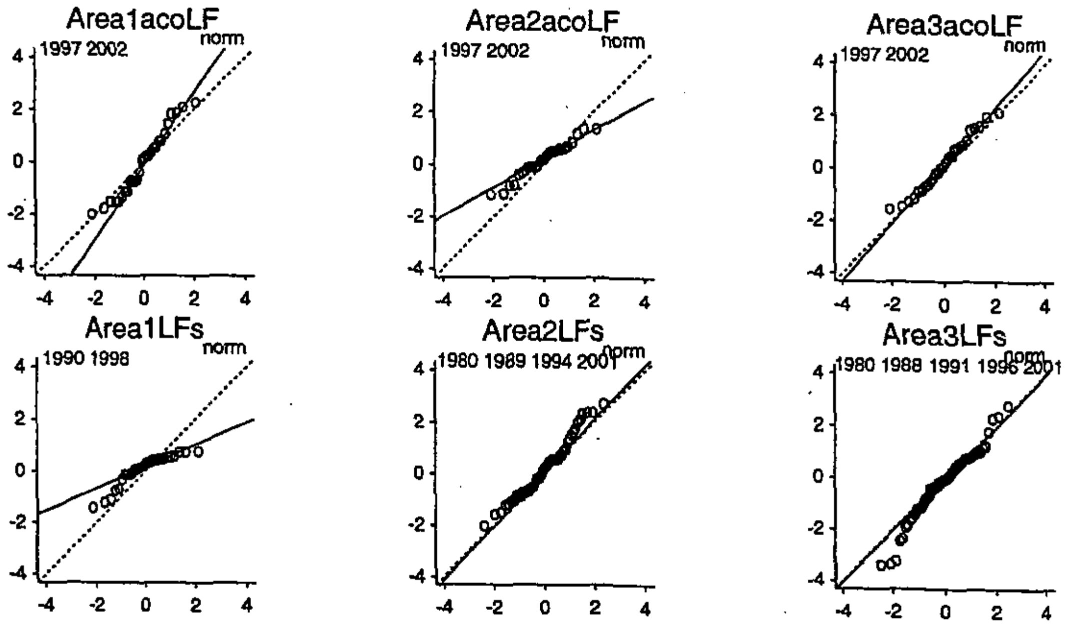

Figure 23: Base case (run 152) QQqnorm plots for the grouped acoustic (upper panels) and observer (lower panels) length frequency data. The solid line passes through the first and third quartiles of the data and the standard normal distribution. The dotted line is 1:1 through the origin.

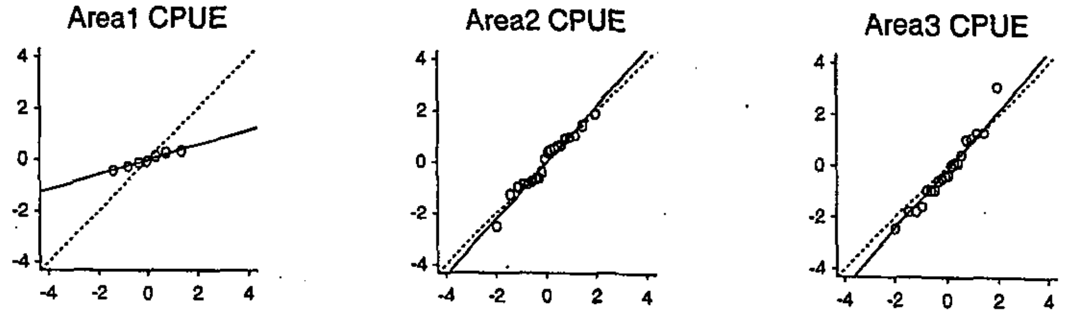

Figure 24: Base case (run 152) QQqnorm plots for the CPUE data. The solid line passes through the first and third quartiles of the data and the standard normal distribution. The dotted line is 1:1 through the origin.

Series 3

Table 32: MPD fits. Free parameter estimates for series 3 model runs. –, not estimated.

	D2004+M_{ad}	D2004+M_{juv}	D2004+$Q_{aco.A1}$	D2004+R_{dev}	D2004+R_{dev6}
Initialisation R_0	37 780 300	14 236 200	24 904 400	24 230 200	23 667 900
Mature natural mortality	0.057	–	–	–	–
Immature natural mortality	–	0.020	–	–	–
Area 1 acoustic abundance q	–	–	0.92	–	–
Recruitment YCS	–	–	–	Fig. 27	Fig. 27
Size-at-age c.v.	0.08	0.08	0.08	0.08	0.08
Selectivity (yr)					
Area 1, age at 50% selection	8.05	8.47	8.45	8.22	8.22
Area 1, ages 50–95% selection	0.50	0.50	0.50	0.50	0.50
Area 2, age at 50% selection	9.91	10.11	10.10	10.04	8.63
Area 2, ages 50–95% selection	0.50	0.50	0.50	0.50	0.47
Migration (yr)					
MW to Area 1, age at 50% selection	17.00	17.00	17.00	11.35	9.59
MW to Area 1, ages 50–95% selection	0.21	0.20	0.20	0.20	0.20
Area 1 to 2, age at 50% selection, logistic ogive	74.26	35.59	33.11	55.94	56.77
Area 1 to 2, ages 50–95% selection, logistic ogive	62.88	70.00	65.77	49.93	48.45
Area 1 to 2, capped logistic ogive	0.20	0.07	0.06	0.12	0.13
Area 2 to 3, age at 50% selection, logistic ogive	40.06	18.22	1.00	26.00	24.86
Area 2 to 3, ages 50–95% selection, logistic ogive	32.08	21.89	60.23	17.01	11.70
Area 2 to 3, capped logistic ogive	0.11	0.04	0.05	0.05	0.05
Process error c.v.					
Area 1–3 acoustic length frequency	0.12	0.13	0.13	0.08	0.09
Area 1–3 observer length frequency	0.70	0.74	0.74	0.57	0.56

Table 33: MPD fits. Objective function component estimates for series 3 model runs. NA, not applicable.

	D2004+M_{ad}	D2004+M_{juv}	D2004+$Q_{aco.A1}$	D2004+R_{dev}	D2004+R_{dev6}
Acoustic abundance					
Area 1	4.6	1.9	1.9	2.1	1.9
Area 2	-1.6	-1.6	-1.8	-0.7	-1.0
Area 3	-1.6	-1.9	-1.9	-2.0	-2.1
CPUE					
Area 1 post-GPS	-5.2	-5.2	-5.2	-5.1	-5.1
Area 2 post-GPS	-5.4	-5.1	-5.1	-4.9	-4.7
Area 2 pre-GPS	-3.3	-6.5	-6.4	-2.5	-2.6
Area 3 post-GPS	-4.7	-1.3	-1.7	-3.5	-4.2
Area 3 pre-GPS	-5.8	-3.8	-3.8	-5.0	-5.0
Acoustic length frequency					
Area 1	-14.4	-16.8	-16.9	-29.0	-28.4
Area 2	-34.3	-34.3	-34.5	-35.0	-35.1
Area 3	-27.8	-24.4	-24.1	-24.8	-23.5
Observer length frequency					
Area 1	-6.2	-5.2	-5.2	-9.4	-7.8
Area 2	8.8	14.2	15.3	-8.1	-11.1
Area 3	24.8	25.9	25.6	21.2	21.4
Fishery catch limit penalty					
Area 1	0.0	0.0	0.0	0.0	0.0
Area 2	0.0	0.0	0.0	0.0	0.0
Area 3	0.0	0.0	0.0	0.0	0.0
YCS average penalty	NA	NA	NA	0.0	0.1
YCS smoothing penalty	NA	NA	NA	NA	0.1
Total	-72.2	-64.3	-63.9	-106.9	-107.1

Table 34: **MPD fits. Biomass estimates (t) for series 3 model runs.**

	D2004+M_{ad}	D2004+M_{juv}	D2004+$Q_{aco.A1}$	D2004+R_{dev}	D2004+R_{dev6}
Mid-year, selected					
Area 1					
B_0	138 000	87 900	95 300	125 000	131 000
B_{2003}	134 000	84 100	91 400	108 000	106 000
B_{2003}/B_0	97	96	96	86	81
Area 2					
B_0	34 600	42 500	40 900	37 200	36 500
B_{2003}	13 400	12 700	12 000	14 800	13 900
B_{2003}/B_0	39	30	29	40	38
Area 3					
B_0	44 700	47 800	48 300	46 400	46 500
B_{2003}	2 640	3 220	3 460	2 830	3 050
B_{2003}/B_0	6	7	7	6	7
Areas 1–3 combined					
B_0	218 000	178 000	185 000	208 000	214 000
B_{2003}	151 000	100 000	107 000	125 000	123 000
B_{2003}/B_0	69	56	58	60	57
Total biomass, Areas 1–3 combined					
B_0	218 000	178 000	185 000	208 000	214 000
B_{2003}	151 000	100 000	107 000	125 000	123 000
B_{2003}/B_0	69	56	58	60	57

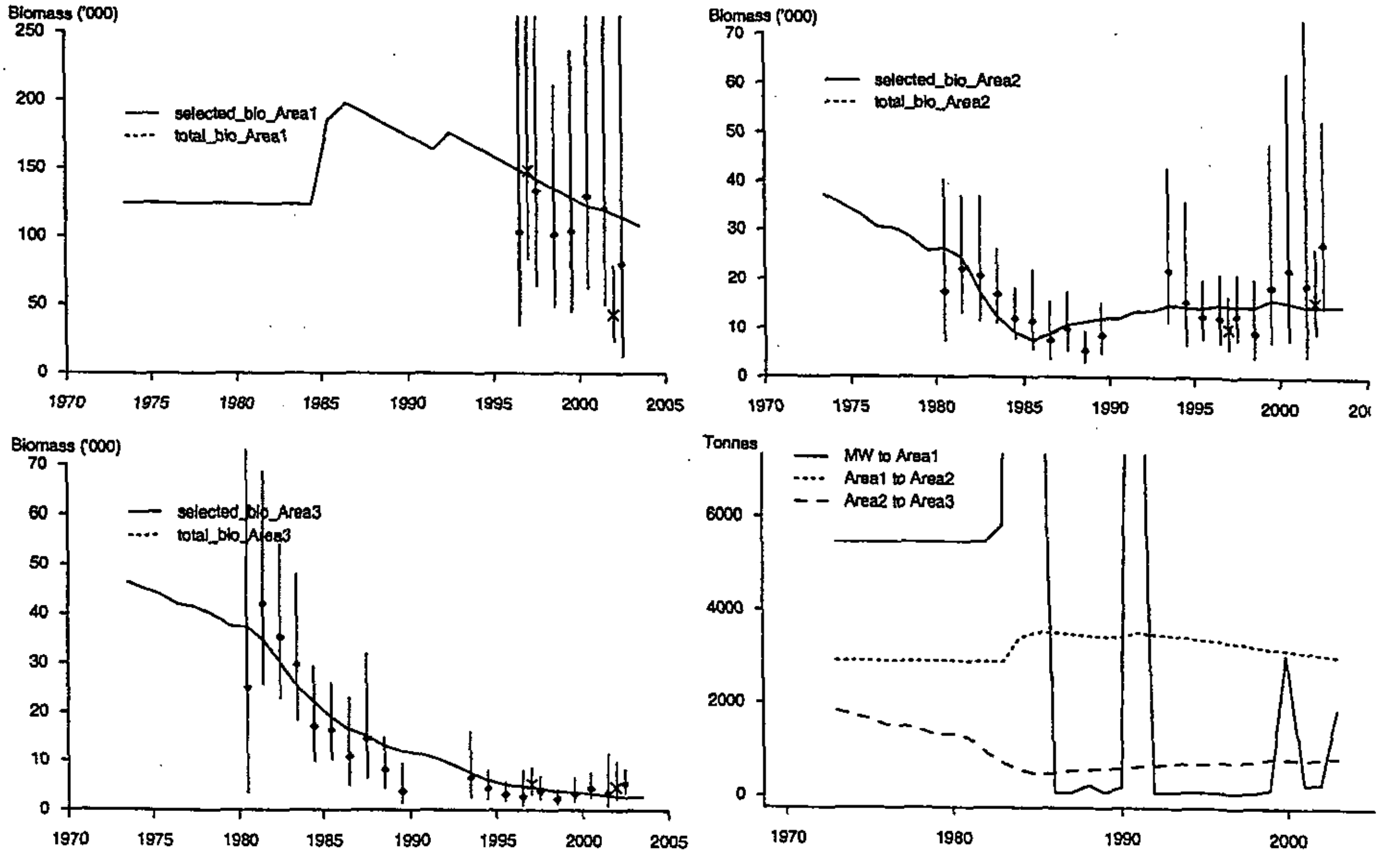

Figure 25: Run 161 (sensitivity) selected (solid line) and total (dashed line, may be obscured) biomass (start of year) trajectories for each area with CPUE (diamonds) and the 1997 and 2002 absolute abundance (crosses) indices and the approximate 95% confidence intervals (two upper and lower left panels). Some confidence intervals exceed the axes of the plot. The lower right panel shows the migration of fish for each area used in this run.

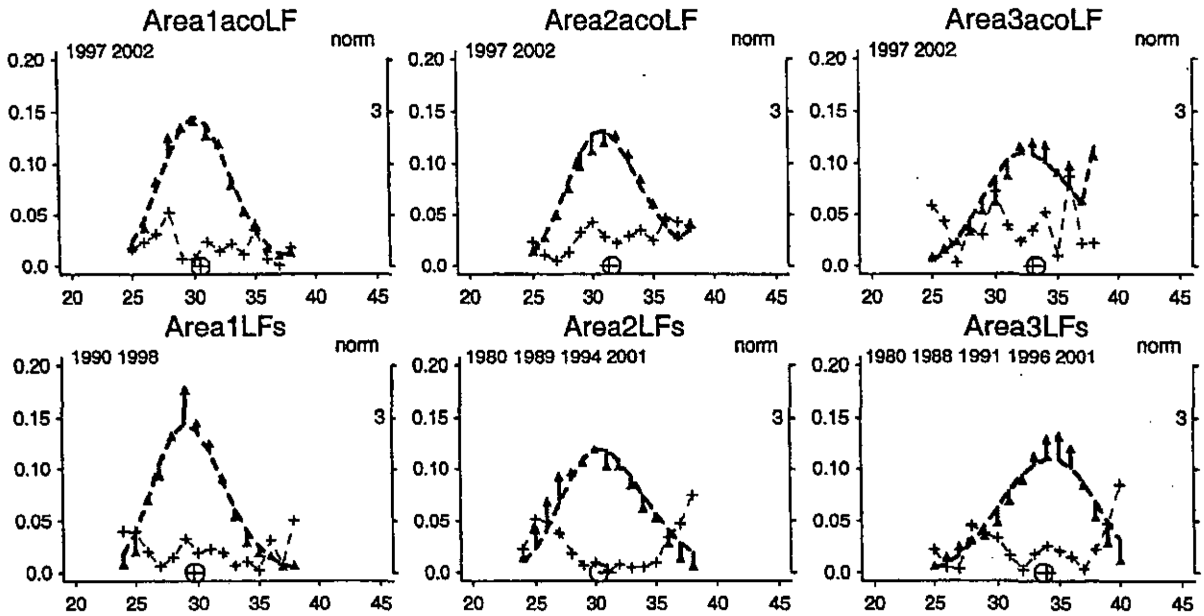

Figure 26: Run 161 (sensitivity) overall fits to the acoustic (upper panels) and observer (lower panels) length frequency data for each area (left hand axis). The model fit is the thick dashed line and arrowhead shows the data. The large cross near the x-axis is the mean of the model fit and the circle is the mean of the data. Absolute normalised residuals are shown as crosses joined with thin dashed line (right hand axis). Fits and residuals have been averaged across data sets in each category to show the overall fit.

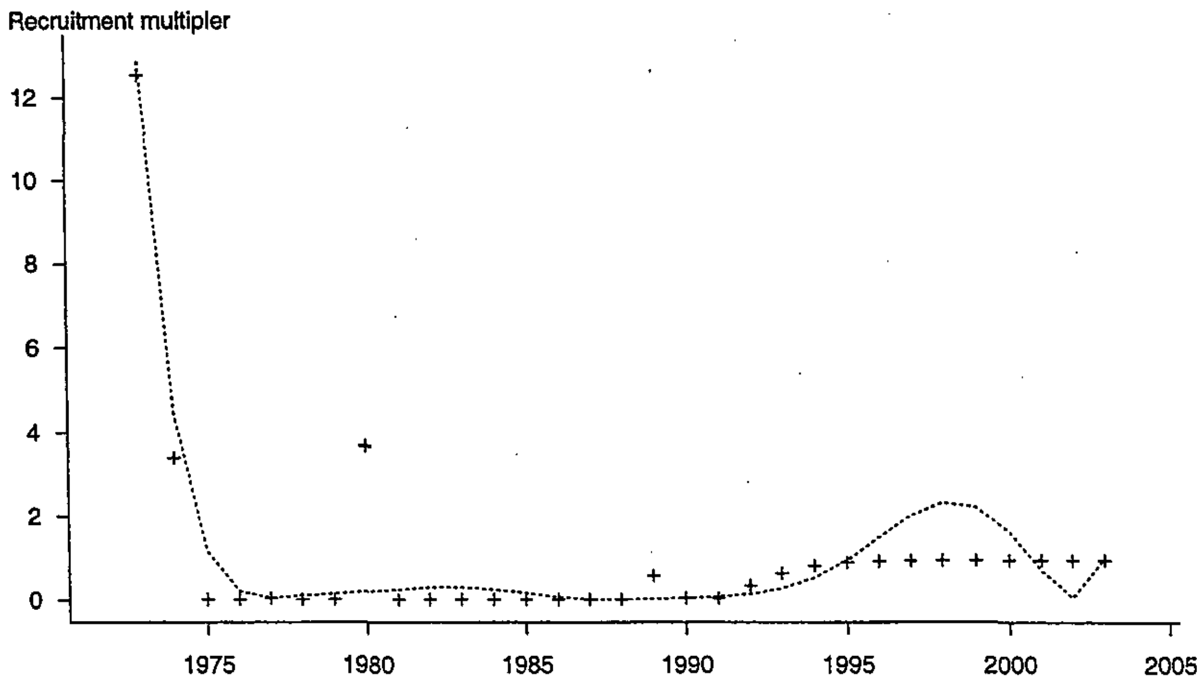

Figure 27: Run 161 (crosses) and run 164 (dashed line) recruitment deviates.

Series 4

Table 35: MPD fits. Free parameter estimates for series 4 model runs with the base case included for comparison. See model run details and abbreviations in Table 23. –, not estimated.

	Base	A1.aco.rel	Drop.pre.gps	Drop.post.gps	A1.res.LF
Initialisation R_0	24 517 700	24 904 400	24 583 800	23 966 800	24 109 900
Size-at-age c.v.	0.08	0.08	0.08	0.08	0.08
Selectivity (yr)					
Area 1, age at 50% selection	8.47	8.45	8.47	8.47	8.47
Area 1, ages 50–95% selection	0.50	0.50	0.50	0.50	0.50
Area 2, age at 50% selection	10.11	10.10	10.11	10.11	10.11
Area 2, ages 50–95% selection	0.50	0.50	0.50	0.50	0.50
Migration (yr)					
MW to Area 1, age at 50% selection	17.00	17.00	17.00	17.00	15.01
MW to Area 1, ages 50–95% selection	0.20	0.20	0.20	0.20	0.20
Area 1 to 2, age at 50% selection, logistic ogive	35.12	33.11	35.19	39.57	56.36
Area 1 to 2, ages 50–95% selection, logistic ogive	70.00	65.77	70.00	70.00	70.00
Area 1 to 2, capped logistic ogive	0.07	0.06	0.07	0.08	0.12
Area 2 to 3, age at 50% selection, logistic ogive	17.67	1.00	16.59	22.78	20.14
Area 2 to 3, ages 50–95% selection, logistic ogive	23.32	60.23	23.21	27.68	23.40
Area 2 to 3, capped logistic ogive	0.04	0.05	0.05	0.05	0.04
Process error c.v.					
Area 1–3 acoustic length frequency	0.13	0.13	0.13	0.13	0.16
Area 1 trawl survey length frequency	–	–	–	–	0.59
Area 1–3 observer length frequency	0.74	0.74	0.74	0.72	0.72

Table 36: MPD fits. Objective function component estimates for series 4 model runs with the base case included for comparison. See model run details and abbreviations in Table 23. NA, not applicable.

	Base	A1.aco.rel	Drop.pre.gps	Drop.post.gps	A1.res.LF
Acoustic abundance					
Area 1	1.9	1.9	1.9	1.9	2.0
Area 2	-1.7	-1.8	-1.8	-1.8	-1.4
Area 3	-2.0	-1.9	-1.9	-0.8	-2.0
CPUE					
Area 1 post-GPS	-5.2	-5.2	-5.2	NA	-5.2
Area 2 post-GPS	-5.1	-5.1	-5.1	NA	-5.1
Area 2 pre-GPS	-6.4	-6.4	NA	-6.5	-6.4
Area 3 post-GPS	-1.3	-1.7	-1.8	NA	-1.0
Area 3 pre-GPS	-3.9	-3.8	NA	-4.5	-3.9
Acoustic length frequency					
Area 1	-16.4	-16.9	-16.5	-16.3	-8.9
Area 2	-34.1	-34.5	-34.0	-33.8	-31.7
Area 3	-24.4	-24.1	-24.4	-23.8	-25.0
Observer length frequency					
Area 1	-5.4	-5.2	-5.3	-5.7	-5.1
Area 2	14.0	15.3	13.8	13.2	10.1
Area 3	25.7	25.6	26.2	24.0	26.4
Fishery catch limit penalty					
Area 1	0.0	0.0	0.0	0.0	0.0
Area 2	0.0	0.0	0.0	0.0	0.0
Area 3	0.0	0.0	0.0	0.0	0.0
Area 1 trawl survey length frequency	NA	NA	NA	NA	3.3
Total	-64.2	-63.9	-54.0	-54.2	-54.0

Table 37: MPD fits. Biomass estimates (t) for series 4 model runs with the base case included for comparison. See model run details and abbreviations in Table 23.

	Base	A1.aco.rel	Drop.pre.gps	Drop.post.gps	A1.res.LF
Mid-year, selected					
Area 1					
B_0	92 100	95 300	92 500	90 000	98 500
B_{2003}	88 200	91 400	88 600	86 100	94 000
B_{2003}/B_0	96	96	96	96	95
Area 2					
B_0	42 000	40 900	41 400	41 100	42 600
B_{2003}	12 600	12 000	12 400	11 900	14 600
B_{2003}/B_0	30	29	30	29	34
Area 3					
B_0	47 800	48 300	48 300	46 600	47 300
B_{2003}	3 200	3 460	3 500	1 910	3 190
B_{2003}/B_0	7	7	7	4	7
Areas 1–3 combined					
B_0	182 000	185 000	182 000	178 000	188 000
B_{2003}	104 000	107 000	104 000	100 000	112 000
B_{2003}/B_0	57	58	57	56	59
Total biomass, Areas 1–3 combined					
B_0	182 000	185 000	182 000	178 000	188 000
B_{2003}	104 000	107 000	104 000	100 000	112 000
B_{2003}/B_0	57	58	57	56	59

4.2 Bayesian results

Convergence diagnostics were run on a chain of final length 8 x 10^3, after a burn-in of 860 iterations, and after systematically subsampling every 1000th point. Autocorrelations and single chain convergence tests of Geweke (1992) and Heidelberger & Welch (1983) were applied to the resulting chain to determine non-convergence. The tests used a significance level of 0.05 and the diagnostics were calculated using the Bayesian Analysis Output software (Smith, B.J., 2001. Bayesian output analysis program. Version 1.00 user's manual. Unpublished manuscript. 45 p. University of Iowa College of Public Health. http://www.public-health.uiowa.edu/boa). Appendix E shows that the MCMC runs converged.

4.2.1 Biomass, yields, current surplus production estimates

Bayesian estimates were therefore based on the median of an 8 x 10^3 long MCMC, Table 38. The MCMC runs did not estimate the process error of the length data so these were fixed at the MPD estimates.

Table 38: Base case (run152) MCMC summary statistics of the posterior distributions.

	Abbrev.	5% quantile	Median	Mean	95% quantile	c.v.(%).
Initialisation R_0	intlztR0	23 160 000	24 670 000	24 820 000	26 980 000	5
Size-at-age c.v.	sz.t.g.c	0.07	0.08	0.08	0.08	4
Migration						
MW to Area 1, ages 50–95% selection	mgrMWA12	0.33	1.46	1.64	3.60	62
Area 1 to 2, age at 50% selection, logistic ogive	mgrtA121	12.58	42.16	41.56	67.24	40
Area 1 to 2, capped logistic ogive	mgrtA123	0.04	0.08	0.09	0.18	46
Area 2 to 3, age at 50% selection, logistic ogive	mgrtA231	2.78	15.34	16.21	33.60	59
Area 2 to 3, ages 50–95% selection, logistic ogive	mgrtA232	10.59	46.00	43.56	67.96	41
Area 2 to 3, capped logistic ogive	mgrtA233	0.04	0.05	0.05	0.07	18

The estimates of biomass and yield from the base case analysis were dominated by the acoustic absolute abundance estimates and observer length data. The biomass estimates are given in Table 39.

The CSP estimate was 2330 t (Table 39) and was the catch that ensured that the total biomass at the end of the 2002–03 fishing year was the same as the total biomass at the end of 2001–02.

Table 39: Biomass, and Current Surplus Production (CSP) estimates (t). –, not estimated or na.

(a) Biomass estimates

OEO 3A	Median	90% C.I. mid-year	$\%B_0$
Mature virgin	161 000	151 000–176 000	–
Mature 2001–02 mid-year	84 000	74 000–100 000	52
Selected virgin	185 000	172 000–206 000	–
Selected 2001–02 mid-year	107 000	94 000–128 000	58
Areas 2 & 3 only			
Mature virgin	88 000	85 000–91 000	–
Mature 2001–02 mid-year	15 000	12 000–18 000	17
Vulnerable virgin	90 000	86 000–93 000	–
Vulnerable 2001–02 mid-year	16 000	13 000–19 000	18

(b) CSP estimate

OEO 3A	2 330

Paired plots of free parameters to check for correlations for the base case are shown in Appendix F. The plots used a subsample of 400 points from the posterior sample from the MCMC. The posterior distributions for estimates of mid-year mature virgin biomass (B_0) for all areas combined, mid-year mature current (2002–03) biomass as a percentage of B_0 for all areas, mid-year selected current (2002–03) biomass as a percentage of B_0 for all areas, and mid-year selected current (2002–03) biomass as a percentage of B_0 for Areas 2 and 3 only are shown in Figures 28–29. Plots of the posterior distributions for estimates of virgin recruitment, free parameters, and migration are in Appendix G.

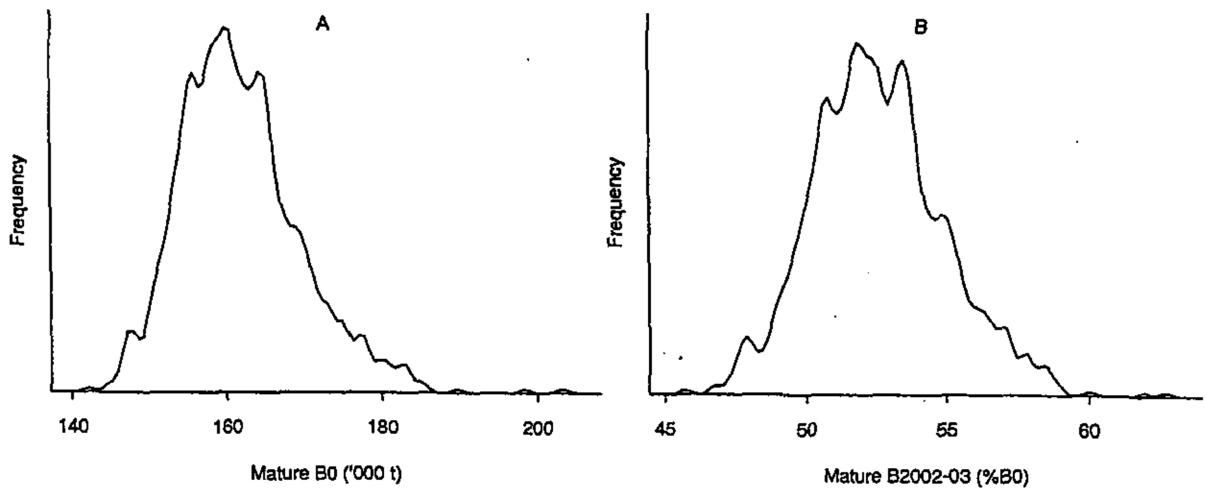

Figure 28: Posterior distribution of mid-year mature (a) B_0 (t) and (b) current (2002–03) biomass as a percentage of mid-year mature B_0, for Areas 1, 2, and 3, i.e., excluding the mid-water population.

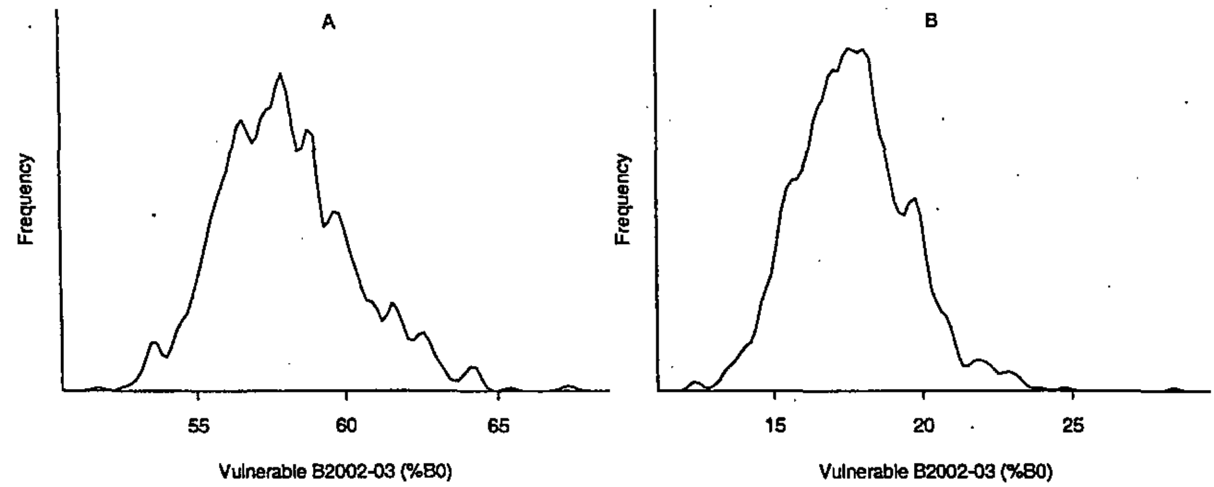

Figure 29: Posterior distribution of mid-year selected current (2002–03) biomass as a percentage of mid-year selected B_0 for (a) Areas 1, 2, and 3 and (b) Areas 2 and 3 only.

4.2.2 Projections

Forward projections over the next five years were performed to determine the probability that the projected biomass would exceed the current biomass, the probability that the projected biomass would exceed 20%B_0, and the probability that the projected biomass would exceed B_{MSY} (which was interpreted as being 27%B_0). A catch split of 5%, 68%, and 27% was used for Areas 1–3 respectively and recruitment variability (lognormal with $\sigma_r = 0.67$) and parameter variability were introduced. The probabilities for the base case projected under different catch levels are presented in Table 40.

Table 40: Probability that biomass in 5 years ($B_{2007-08}$) is greater than the reference biomass (20% and 27%B_0) and the median biomass in 5 years as a %B_0 ($Bmed_{2007-08}$) under different constant catch scenarios. The 2002–03 catch limit for black oreo in OEO 3A was 1855 t.

Annual catch (t)	$P(B_{2007-2008}>20\%B_0)$	$P(B_{2007-2008}>27\%B_0)$	$Bmed_{2007-08}$ (%)
(a) Mature biomass Areas 1–3			
1000	1.0	1.0	56
1500	1.0	1.0	55
1855	1.0	1.0	54
2000	1.0	1.0	54
2500	1.0	1.0	52
3000	1.0	1.0	51
(b) Vulnerable biomass (Areas 2 & 3)			
1000	1.0	0.06	24
1500	0.88	0.01	22
1855	0.65	0	21
2000	0.51	0	20
2500	0.15	0	18
3000	0.03	0	16

5. DISCUSSION AND CONCLUSIONS

Parameter uncertainty

The non-migration parameters were well determined by the model (See Table 35), i.e., about 5% c.v. for their posterior distributions, probably because there are some good time-series of observed data, e.g., two pre-GPS and two post-GPS CPUE series of 10 years each; 17 years of observer length data; 31 years of catches; and two acoustic abundance estimates. Presumably, the low uncertainty on the estimated R_0 caused low c.v.s (less than 20%) on current biomass (See Figure 29) despite some migration parameters having large uncertainties.

The migration from Area 1 to 2 had large uncertainties in the two parameters estimated, but these were highly positively correlated (Appendix F) so that a linear combination of these parameters was well determined, i.e., the data are such that only one aspect of the migration was able to be estimated and so it is over-parameterised. There were large uncertainties in the Area 2 to 3 migration in the 50% selection and 50–95% parameters (the cap parameter was reasonably well determined), and the correlation between these two parameters was low (Appendix F). The problem is partly that the 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 and also to explain the observed length frequencies. The uncertainties may also reflect the pattern in misfits in the length frequencies (Appendix A), especially for Area 3, created by using a constant ogive over time. Improvements in modelling would involve the use of age data and make allowance for time shifts in the migration ogive (or in fishing selectivity). The best data would be tag data, but such data are impractical to collect with current methods.

Deterministic recruitment was assumed and so variability in the analysis from this source is not included. Recruitment variability can reasonably be expected so there is some extra uncertainty not accounted for. Given that length data are used to infer age distributions, recruitment can only be indirectly inferred. Only age data can help here. Another source of uncertainty not included is that due to the estimation error in M.

Comparison of the CASAL spatial model with previous stock assessments

The 1999 OEO 3A black oreo stock assessment used a single area, but both the SeaFIC and NIWA models were unable to explain some of the data (Table 41) and also produced conflicting assessment results (Annala et al. 1999, Doonan et al. 1999b). When stock assessment models cannot satisfactorily predict what appear to be valid observations for fish populations, it may be that the model is miss-specified, the observations are incorrect, or both. In response to these problems, a spatial model based on splitting the population into three areas was produced in 2002 (Hicks et al. 2002). This solved most of the problems with the 1999 assessment (Table 41). The 2004 model built on the 2002 model and solved more of the problems (Table 41) as well as using methods employed by NIWA for other recent oreo assessments, e.g., the 2003 OEO 4 smooth oreo stock assessment (Doonan et al. 2003a).

Table 41: The main problems with OEO 3A black oreo stock assessment models (1999, 2002, 2004). Yes - explained the data to an acceptable level. No - unable to explain the data to an acceptable level. NA, not applicable or not used.

Observation	1999 NIWA	1999 SeaFIC	2002	2004
Whole area				
Soviet CPUE declined steeper than the predicted biomass trajectory.	No	NA	Yes	Yes
Annual length frequency switched from large to small fish and vice versa.	No	No	Yes	Yes
Large acoustic abundance of small fish in Area 1.	No	No	Yes†	Yes
Spatial Areas (1–3)				
Area 1 acoustic and observer length frequencies.	NA	NA	No	Yes
Area 2 observer length frequencies.	NA	NA	No	Yes
Area 3 observer length frequencies.	NA	NA	No	Yes

† only when immature natural morality was estimated.

The new assessment is more optimistic than the previous one (Hicks et al. 2002) and fits the data better.

Model problems

The assessment still has problems, including the fact that the CPUE does not fit to the last few years, i.e., the CPUE levels out in contrast to biomass that continues to decline slowly. 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 estimates rely on mixed species in layers and so are much more uncertain compared to the acoustic estimates from Areas 2 and 3. However, the assessment is not reliant on the Area 1 acoustic abundance value, because the estimate of catchability for the model run where the Area 1 acoustic abundance estimates were made relative was similar to the runs where the acoustic abundance estimates were absolute, i.e., catchability of about 0.9 compared to the assumed value of 1 for the other runs.

In addition to biases, one known source of uncertainty was not included in the overall uncertainties in the estimate of M. The model could be improved by using age frequencies that are separated by about 10 years. Otolith samples for age frequencies are available from research surveys collected early on in the fishery and also from the most recent (2002) survey. This would enable changes in the age structure of the population over time to be modelled and may enable better estimates of the recruitment variation and the migration effects to be made (since these are based on age ogives). Using observer length data requires age to be approximated from length and may not be the best estimate of the population age structure.

In the new model, fishing selectivity is a result of area selection, with older fish preferentially moving deeper. About 3000 t migrates from Area 1 into Area 2 in the base case and this is constant over the years assessed. About 750 t migrates from Area 2 to Area 3 and that is over half the amount in the virgin state. Given the above and because 90% of the total historical catch has been caught in Areas 2 and 3, it is possible that a model based on a single area covering Areas 2 and 3 could give similar results as obtained here, but with a great simplification in analysis and, perhaps, interpretation. Such a move would also mean dropping the acoustic data from Area 1, which is based on estimates from layers containing a mix of species. Acoustic abundance estimates from the layers have biases that cannot be quantified, so the Area 1 acoustic estimate has an unknown uncertainty. It would also mean implicitly assigning fish in Area 1 as being immature, in contrast to the current model which has 72 000 t of mature fish out of a total of 92 000 t (See Table 37; note that mature fish not reported by area) in Area 1.

6. ACKNOWLEDGMENTS

This work was carried out for the Ministry of Fisheries under Project OEO2002/02. We thank members of the 2003–04 Deepwater Stock Assessment Working Group for advice during the building and testing of the model, and Stuart Hanchet (NIWA, Nelson) for constructive comments on the manuscript.

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Appendix A

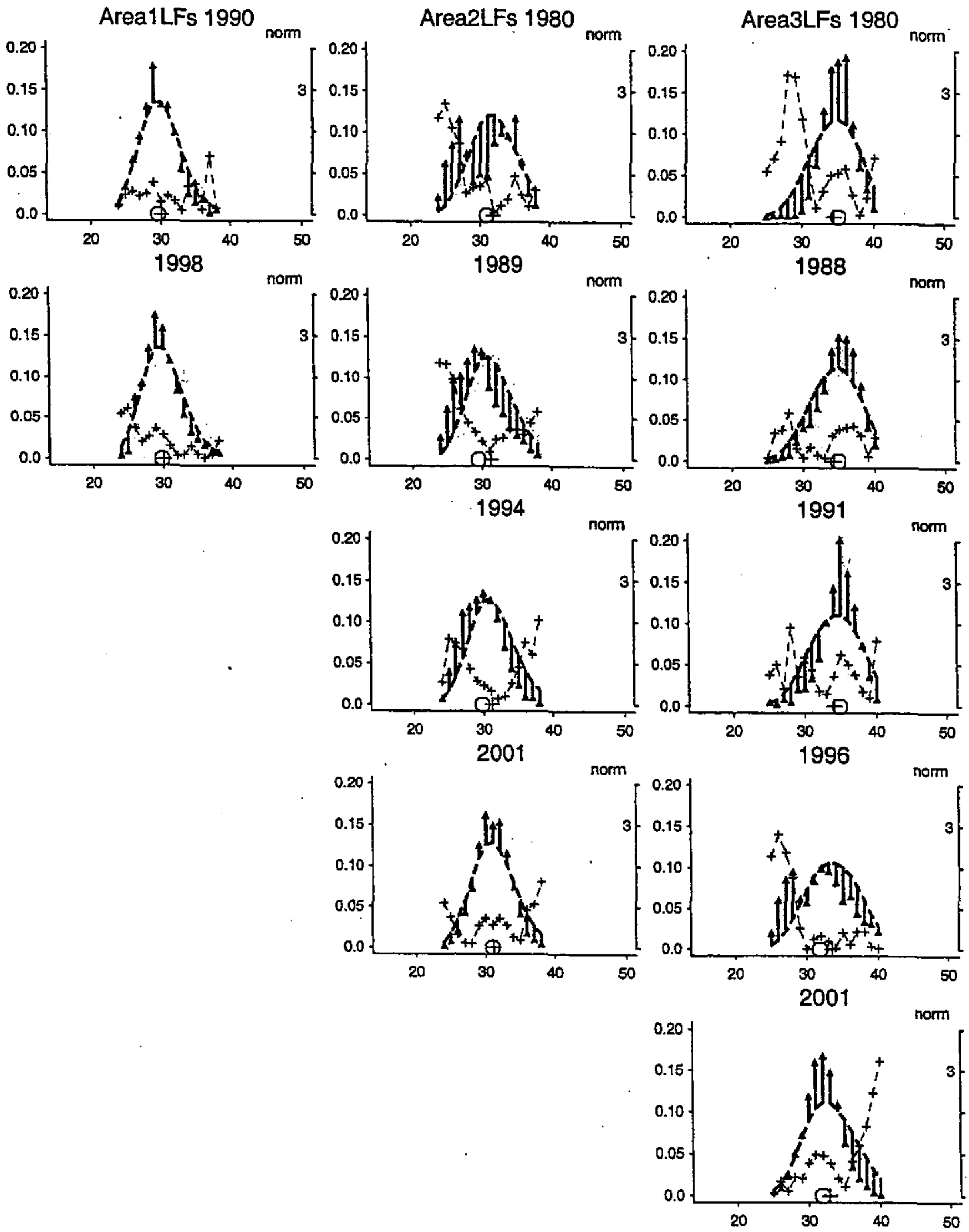

Figure A1: **Base case (run 152) grouped observer length frequency distributions by area. The model fit is the thick dashed line and arrowhead shows the data (left hand axis). The large cross near the x-axis is the mean of the model fit and the circle is the mean of the data. Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).**

Appendix B

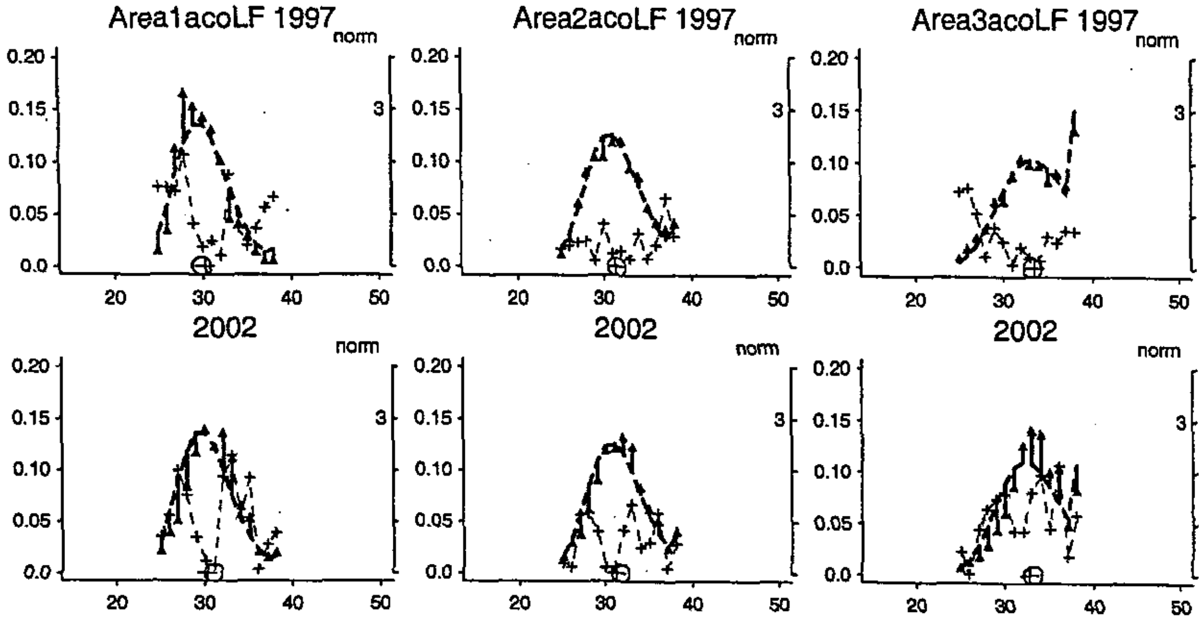

Figure B1: . **Base case (run 152) acoustic survey length frequency distributions by area. The model fit is the thick dashed line and arrowhead shows the data (left hand axis). The large cross near the x-axis is the mean of the model fit and the circle is the mean of the data. Absolute normalised residuals are shown as crosses joined with a thin dashed line (right hand axis).**

Appendix C

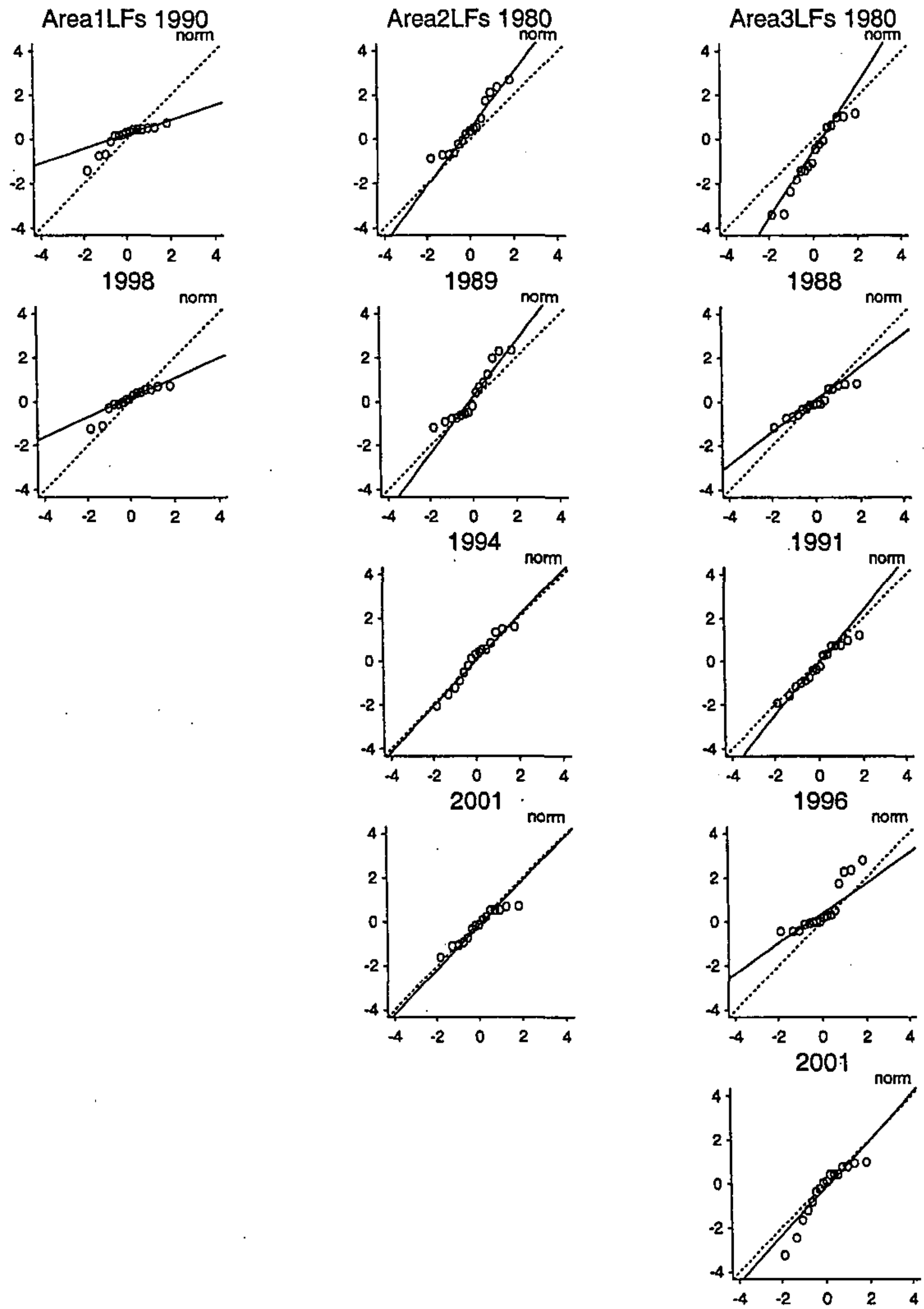

Figure C1: Base case (run 152) grouped observer length frequency QQnorm plots by area. The solid line passes through the first and third quartiles of the data and the standard normal distribution. *The dotted line is 1:1 through the origin.*

Appendix D

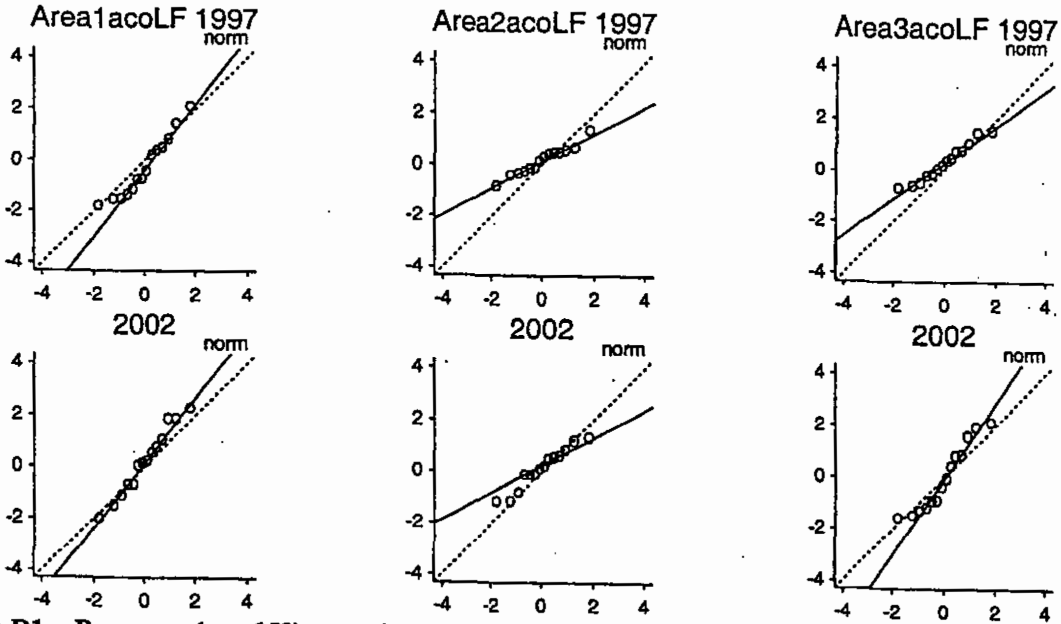

Figure D1: Base case (run 152) acoustic survey length frequency QQnorm plots by area. The solid line passes through the first and third quartiles of the data and the standard normal distribution. The dotted line is 1:1 through the origin.

Appendix E

Convergence tests performed on the final MCMC chain of 8 000 points. See Table 38 for parameter definitions and abbreviations.

	Heidleberger and Welch tests		Geweke convergence diagnostic test
Parameter	Stationarity	Interval halfwidth	P value
intlztR0	Passed	Passed	0.47
mgrMWA12	Passed	Passed	0.81
mgrtA121	Passed	Passed	0.10
mgrtA123	Passed	Passed	0.03
mgrtA231	Passed	Passed	0.68
mgrtA232	Passed	Passed	0.31
mgrtA233	Passed	Passed	0.52
sz.t.g.c	Passed	Passed	0.31

Appendix F

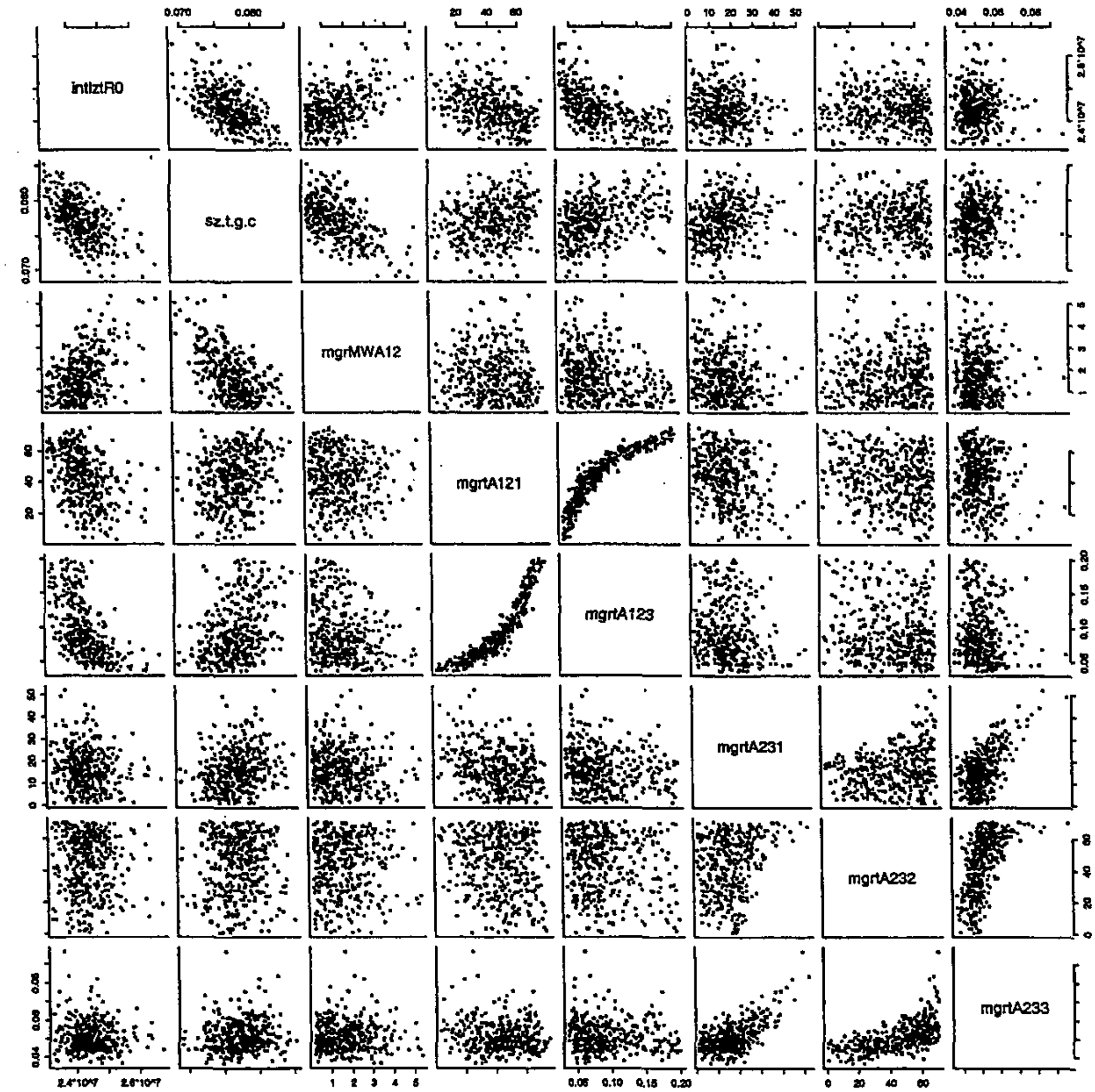

Figure F1: Pairwise plots of MCMC free parameter estimates using a sub-sample of 400 points from the base case posterior distribution. See parameter definitions and abbreviations in Table 38.

Appendix G

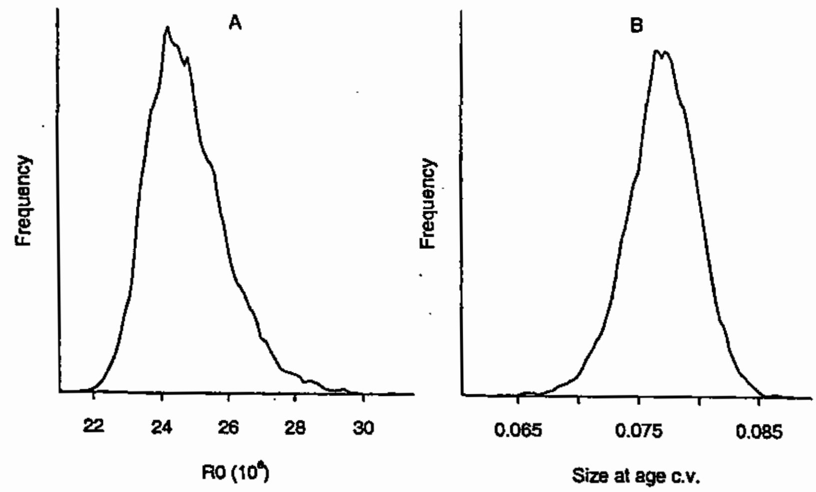

Figure G1: (a) Virgin recruitment in numbers of fish ("Initialisation R_0"). Shown on a log scale. (b) Base case (run 152) MCMC free parameter density plots. See parameter definitions and abbreviations in Table 38.

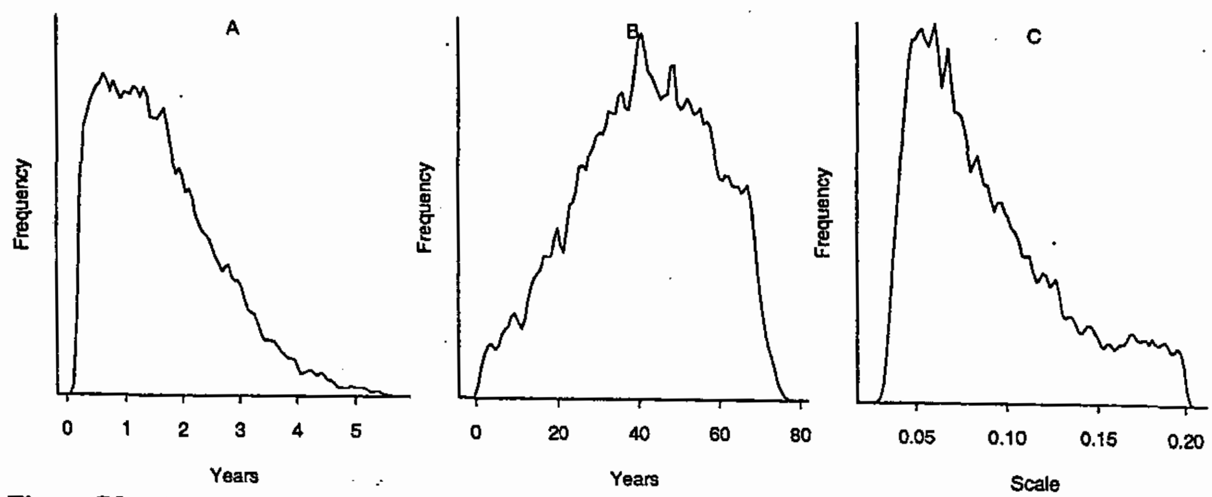

Figure G2: Base case (run 152) migration distribution plots, midwater layer to Area 1 and Area 1 to Area 2. See parameter definition in Table 38.

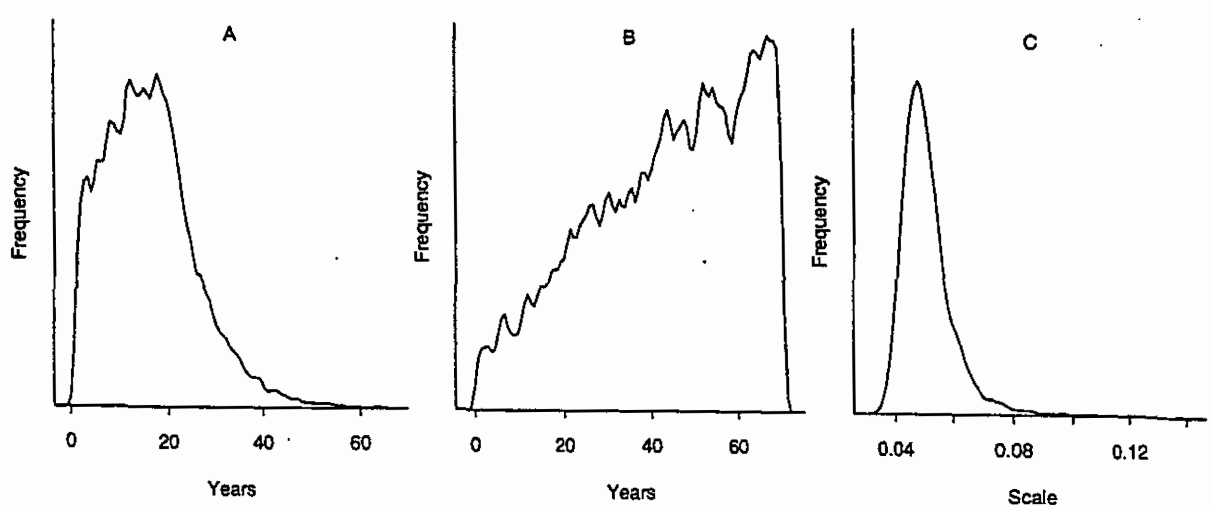

Figure G3: Base case (run 152) migration distribution plots, Area 2 to 3. See parameter definition in Table 38.