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EXECUTIVE SUMMARY

Hicks, A.C.; Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (2002). 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 new age-structured population model. The new model is based on a spatial model consisting of three areas: 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 included catch history, new relative abundance estimates from pre-GPS and post-GPS standardised CPUE analyses, absolute abundance estimates re-analysed from the 1997 acoustic survey, observer length frequencies, and a length frequency derived from the absolute abundance estimates. 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.

Five spatial model runs were performed.

1. Age-based migration ogive from a logistic curve; one-way migration from area 1 to 2 to 3.
2. Age-based migration ogive from a logistic curve; one-way migration from area 1 to 2 to 3 and 1 to 3.
3. Age-based migration ogive from a linear curve; one-way migration from area 1 to 2 to 3.
4. Density-dependent migration ogive from a logistic curve; one-way migration from area 1 to 2 to 3.
5. Density-dependent migration ogive from a logistic curve; one-way migration from area 1 to 2 to 3. Immature natural mortality estimated.

Density-dependent migration ogives were estimated using a logistic curve where the migration rate was dependent on the biomass of the area that the fish were moving to. Migration back into an area was not allowed.

The estimated parameters consisted of initial recruitment, migration parameters, and selectivity parameters. Run 5 estimated immature natural mortality and the others fixed the natural mortality at 0.044. All runs fixed mature natural mortality at 0.044. Bootstrapping the input data assessed variability. Yields, 5-year projections, and 10-year projections were calculated for runs 4 and 5 only.

The first three runs have very similar results with similar fits to the data. The density-dependent migration runs (4 & 5) overall fitted the data better. The estimated migration rates moved fish through the system at slow rates and the selectivities were mostly knife-edged. Run 2 was virtually identical to run 1, suggesting that fish could not migrate directly from area 1 to area 3. Run 5 estimated immature natural mortality at 0.159 resulting in a large initial recruitment.

A severe decline in the mature biomass was predicted for areas 2 and 3, but the biomass in area 1 did not decline much. The total mature biomass was predicted at 20 and 24% of B_0 for runs 4 and 5, respectively. However, in areas 2 and 3, it was less than 7% of B_0. The 95% confidence interval for the current biomass straddles B_{MAY} and is below B_{MCY}. The long-term MCY estimates (900–1800 t) are less than the 2000–01 black oreo catch in OEO 3A (about 3000 t) suggesting that the recent catch levels of black oreo from OEO 3A are higher than the long-term sustainable yield. Overall, the black oreo stock in OEO 3A is about 43–59% of B_{MCY} and 77–84% of B_{MAY}, but at the current catch levels, the biomass is likely to reduce even more. The yields and projections suggest that the catch levels should be reduced to between 1000 and 2000 t.

The results suggest that the model has not entirely dealt with the observation that smaller fish are present in area 1, and size increases across the areas. One improvement may be to allow an age-based, density-dependent migration to allow younger fish to stay in area 1 while moving older, larger fish onwards. However, significant improvements have been made over previous models, with better fits to all of the data sources.

1. INTRODUCTION

This work addresses the following objectives in the MFish project "Oreo stock assessment" (OEO2000/02).

Overall objective

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

Specific objective

1. To conduct a stock assessment for black oreo in OEO 3A, including estimating biomass and sustainable yields.

1.1 Overview

A stock assessment of black oreo in OEO 3A was carried out in 1999 (Doonan et al. 1999b) based principally on an acoustic absolute abundance estimate from the 1997 survey. That assessment identified a problem with defining recruit fish, because pre-recruit fish appeared to make up a large proportion of the total black oreo acoustic absolute abundance estimate from the 1997 survey. Observer length data provided conflicting evidence that the black oreo fishery was based on either small (mean length about 29 cm TL) or large sized fish (mean length about 34 cm TL). Research length data suggested that recruit size was at the lower end, but surveys were not considered to sample the large fish well. Research data from a lightly fished area (Puysegur, 1991–94) suggested a recruited length of 32.9 cm (McMillan et al. 1997).

The issue of recruit length/age was investigated by a preliminary analysis of the OEO 3A black oreo observer length data (Doonan et al. 1999b). This suggested that the data included samples from areas not normally fished by the oreo fleet and concluded (p. 12) that most of the small fish sampled by observers came from the shallower parts of OEO 3A and that bigger fish were from deeper water. In some years mostly small fish were sampled and in others mostly large fish. A provisional age (converted from length) selectivity ogive based on Chatham Rise research and observer length data was derived, but the data needed more careful analysis to determine the structure of the sampling and to determine the best way to estimate recruit abundance.

The 1999 NIWA assessment for OEO 3A black oreo (Annala et al. 1999, Doonan et al. 1999b) used the provisional age selectivity ogive to estimate biomass and yields. In contrast the SeaFIC assessment (Annala et al. 1999) considered 4 years of observer length data (of the 13 year observer data series), but used only 3 years of data (all with small modal size fish distributions) in their analysis. The NIWA assessment produced lower biomass and yield estimates than the SeaFIC model runs advocated by the SeaFIC staff.

A new age selectivity ogive was derived in 2001 using non-parametric methods (Doonan & McMillan 2001). This non-parametric ogive was used with the age-structured stock reduction model (PMOD, developed by NIWA) to provide a revised stock assessment for OEO 3A black oreo in 2001 (Annala et al. 2001). The 2001 assessment did not provide a complete solution to the recruit size problem and was not accepted by the Deepwater Stock Assessment Working Group.

A new stock assessment for black oreo in OEO 3A (termed the spatial analysis) is presented using a new age-structured population model (Appendix A). The new model is based on a spatial model consisting of three areas, labelled 1–3, which correspond 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 revised estimates of absolute abundance for black oreo from the 1997 research acoustic survey, and relative abundance indices from a revised and updated standardised CPUE analysis. Estimates of biomass and yields were made using the 1997 biological parameters and revised and updated catch history.

1.2 Description of the fishery

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.

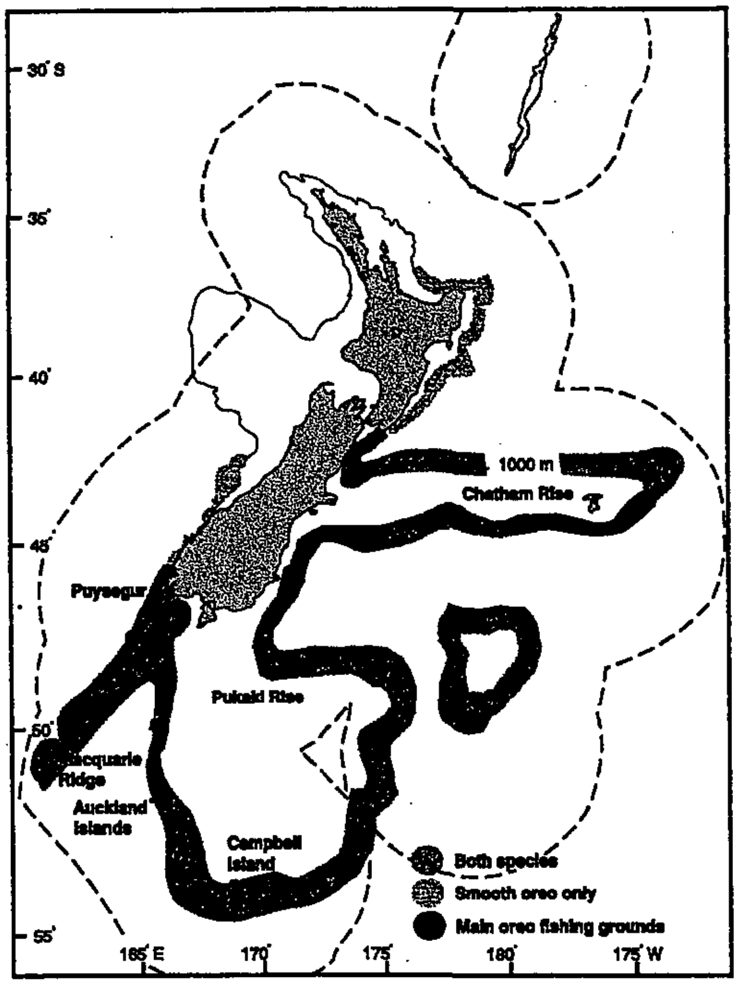

Figure 1: Approximate location of main fishing grounds and distribution of black oreo and smooth oreo. Dashed line is the EEZ boundary.

1.3 TACCs, reported and estimated catch, landings, and effort data

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

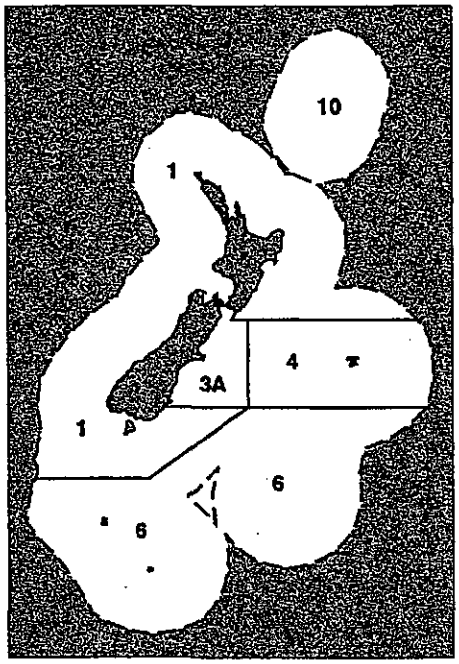

Figure 2: Oreo management areas.

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. (1995a)) from the New Zealand area. Reported landings of oreos (combined species) and TACs from 1978–79 until 2000–01 are given in Table 1. The OEO 3A oreo TAC was about 10 000 t from 1982–83 to 1995–96, but lowered to 6600 t from 1996–97 to 1998–99, 5900 t in 1999–2000 and to 4400 t in 2000–01. 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.

1.4 Other sources of fishing mortality

Dumping of unwanted or small fish and accidental loss of fish (lost or ripped codends) were features of oreo fisheries in the early years. These sources of mortality were probably substantial, but are now thought to be relatively small. No estimate of mortality from these sources has been made because of lack of data and because they now appear to be small. Estimates of discards of oreos were made for 1994–95 and 1995–96 from MFish observer data. This involved calculating the ratio of discarded oreo catch to retained oreo catch and then multiplying the annual total oreo catch from the New Zealand EEZ by this ratio. Estimates were 207 and 270 t for 1994–95 and 1995–96 respectively (Clark et al. 2000).

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 2000–01. – na.

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

Source: FSU from 1978–79 to 1987–88; QMS/MFish from 1988–89 to 2000–01.
*, 1 April to 31 March; #, 1 April to 30 September. Interim TACs applied; †, 1 October to 30 September.

1.5 Stock structure

Ward et al. (1996) compared black oreo samples from New Zealand with material from south of Tasmania, the south Tasman Rise, and Western Australia and concluded that the New Zealand samples of black oreo constituted a stock distinct from the Australian samples based on "small but significant difference in mtDNA haplotype frequencies (with no detected allozyme differences), supported by differences in pyloric caeca and lateral line counts". A New Zealand pilot study examined black oreo stock relationships using samples from four management areas (OEO 1, OEO 3A, OEO 4, and OEO 6) of the New Zealand EEZ. Techniques used included genetic (nuclear and mitochondrial DNA), lateral line scale counts, settlement zone counts, parasites, otolith microchemistry, and otolith shape. Lateral line scale and pyloric caeca counts were different between samples from OEO 6 and the other three areas. The relative abundance of three parasites differed significantly between all areas. Otolith shape from OEO 3A samples was different to that from OEO 1 and OEO 4, but OEO 1, OEO 4, and OEO 6 otolith samples were not morphologically different. Genetic, otolith microchemistry, and settlement zone analyses showed no regional differences (Smith et al. 2000).

2. SPATIAL ANALYSIS

Previous analyses (Doonan et al. 1999b) identified time, area, and depth effects on the quality of length data collected by observers from catches made by commercial fishing vessels. This section describes the analyses of the structure of the length data collected by observers and by research workers, which aimed to define areas where the available length data were relatively homogeneous, i.e., so that low sampling rates are not confused by the sample location. It also aimed to define the fishery spatially so that the spatial separation factor is removed from any age selectivity estimates used in the stock assessment, i.e., age selectivity could be estimated separately for each area. These areas were then used for the stock assessment analyses described below.

2.1 Observer length data

The observer data were selected from the obs_lf database maintained by NIWA. The length frequency distribution from each sampled tow was scaled up to the size of the catch of black oreo from that tow and the mean length calculated. There were 408 tows from 52 trips from 1979–80 to 2000–01. Data were excluded from two tows where depth was not recorded and another two tows where the mean length was extreme compared to the other mean lengths, i.e., one had a mean less than 25 cm and the other a mean length greater than 40 cm.

2.2 Research length data

The research length data were taken only from tows where the position was inside the CPUE study area (within 44° 12′ to 45° 00′ S, 172° 30′ to 175° 00′ E) and where the black oreo catch from each tow was over 100 kg. Data included came from 225 tows from 34 trips carried out between 1979 and 2001.

2.3 Commercial catch data

Commercial catch data were analysed to describe the main areas of fishing and were obtained from the Ministry of Fisheries catch and effort database for years up to the 1999–2000 fishing year for the area between 44° 12′ S to 45° 00′ S and 172° 30′ to 175° 00′ E.

2.4 Defining areas

The combined observer and research mean length data were plotted by depth and showed a strong trend of increasing mean length with increasing depth (Figure 3). This trend is especially marked at depths greater than about 900 m. There was also a weaker trend with time, with more large fish from years before 1993 (Figure 3).

The length/depth data from early years (pre-1993) and the commercial catch data suggested a split into three depth zones: small fish at shallow depths outside the fishery, a transition zone that had small and large fish, and a large fish zone at the greatest depths. The length/depth data from later years (after 1993) also showed this pattern, but it was weaker and the larger fish (about 35 cm or larger) were not as numerous. The pre-1993 length/depth data were therefore divided into three parts by choosing two depths to partition the data and calculating the sum of squares of the mean lengths from the grand means in each of the three parts.

2.5 Boundary between areas 1 and 2

Catches were summed over a grid of cells (0.025 degree latitude and 0.05 degree longitude) covering the area. A threshold value was extracted from this grid that gave the smallest set of cells that collectively contained 90% of the total catch and a contour line of this threshold was plotted. The northern boundary of this contour was established by making sure that the extracted line did not cross into area 3 (minor contour islands were ignored). The line was extended out to the edge of the study area to the west, but was kept parallel to the boundary between areas 2 and 3 in the east. This preliminary line was then smoothed by eye (Figure 4).

2.6 Boundary between areas 2 and 3

Length data were used to establish this boundary. The first step was to split the mean length data into two groups by depth to generate a depth-based sum of squares profile. The range of depths that were within 10% of the minimum sum of squares value was 920–960 m and corresponded to a mean length range of 32.0–34.7 cm (see Figure 3). A 32.5 cm length contour was chosen and the length data were also split at about 173° 42′ E into west and east subsets because the spatial correlation changed orientation at about that longitude. A Generalised Additive Model (GAM) using a 2-D lowess smooth surface ("lo" function, span=0.3 (west) or 0.2 (east), degree=2, S Statistical Language) was used to fit a mean length surface in the west and east areas separately. Kriging was investigated but was rejected because it gave very convoluted contours. A 32.5 cm contour was extracted from each surface and was joined at 173° 42′ E to produce a relatively smooth contour (Figure 5).

2.7 Confirming the defined areas

Catch and length data analyses were carried out to check the veracity of the defined areas. Figure 6 shows tow tracks with start and end positions where black oreo was caught from 1978–79 to 1999–2000 plotted on a map showing the areas. Area 1 contained mainly long tows (low catch rates), area 2 had a mixture of long and shorter tows, and area 3 had mainly short tows.

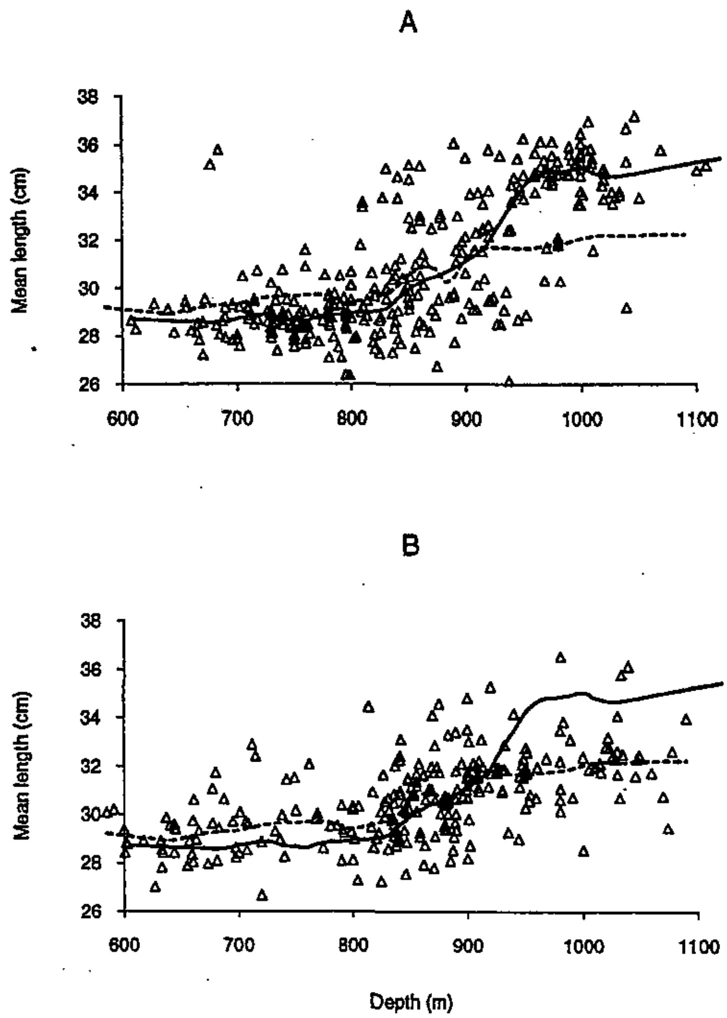

Figure 3: Black oreo mean length by depth from observer and research tow data. "A", data before 1993; "B", data after 1993. The solid line is a smooth curve (lowess) through the early data; dotted line is a smooth curve through the later data. The difference between the two lines at 1000 m is 2.9 cm.

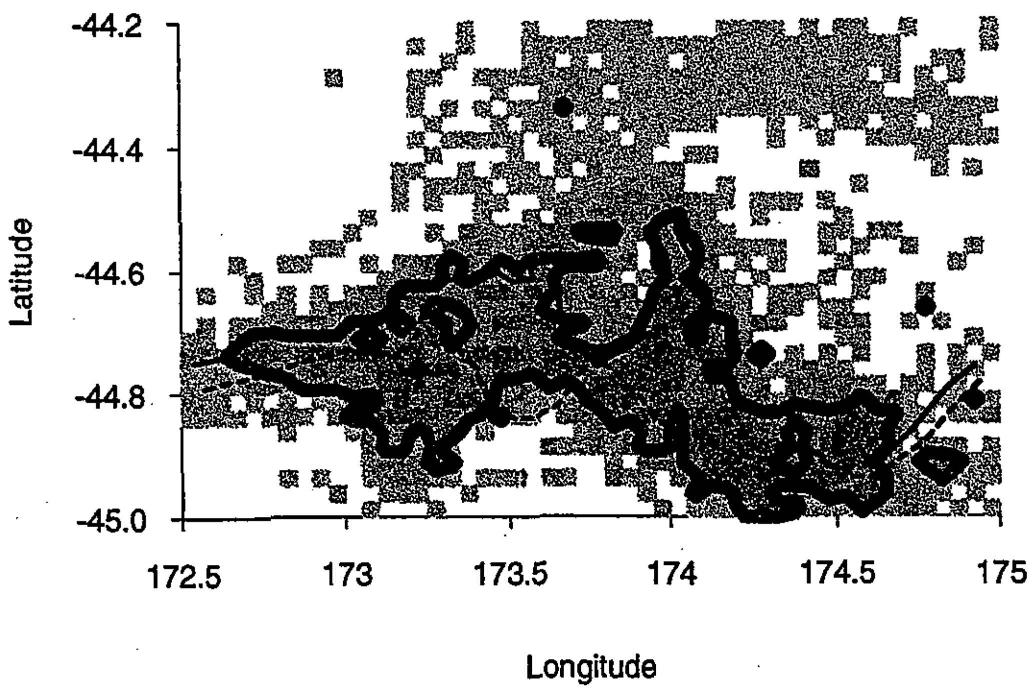

Figure 4: Area 1 and 2 boundary (solid dark line), 90% catch contour (thick grey line), areas 2 and 3 boundary (dashed dark line), and the total catch graded by a grey scale. The catches are in 0.025 degree latitude and 0.05 degree longitude cells and the break points are at 0, the median for non-zero cells, and the mean for non-zero cells, i.e., 3 grades of grey with the darkest being catches over the mean (white represents zero catches). Latitude in degrees S and longitude in degrees E.

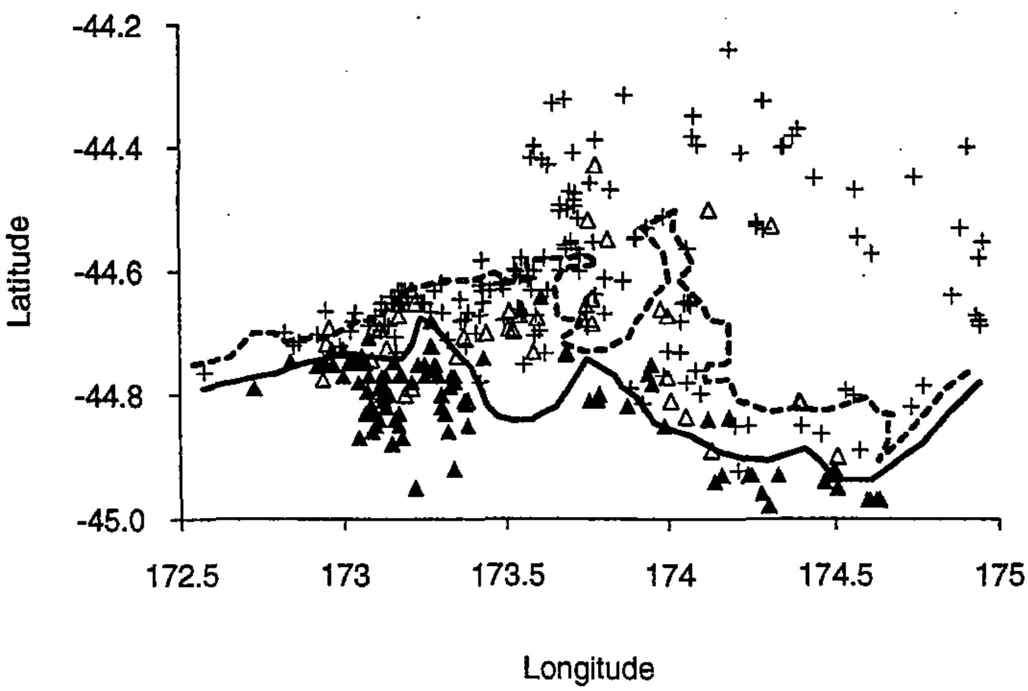

Figure 5: Areas 2 and 3 boundary (solid line) and areas 1 and 2 boundary (dotted line) with the position of tows (data up to 1993) that had mean lengths < 30 cm (cross), >=30 but < 32.5 (triangles), and >= 32.5 cm (filled triangles). Latitude in degrees S and longitude in degrees E.

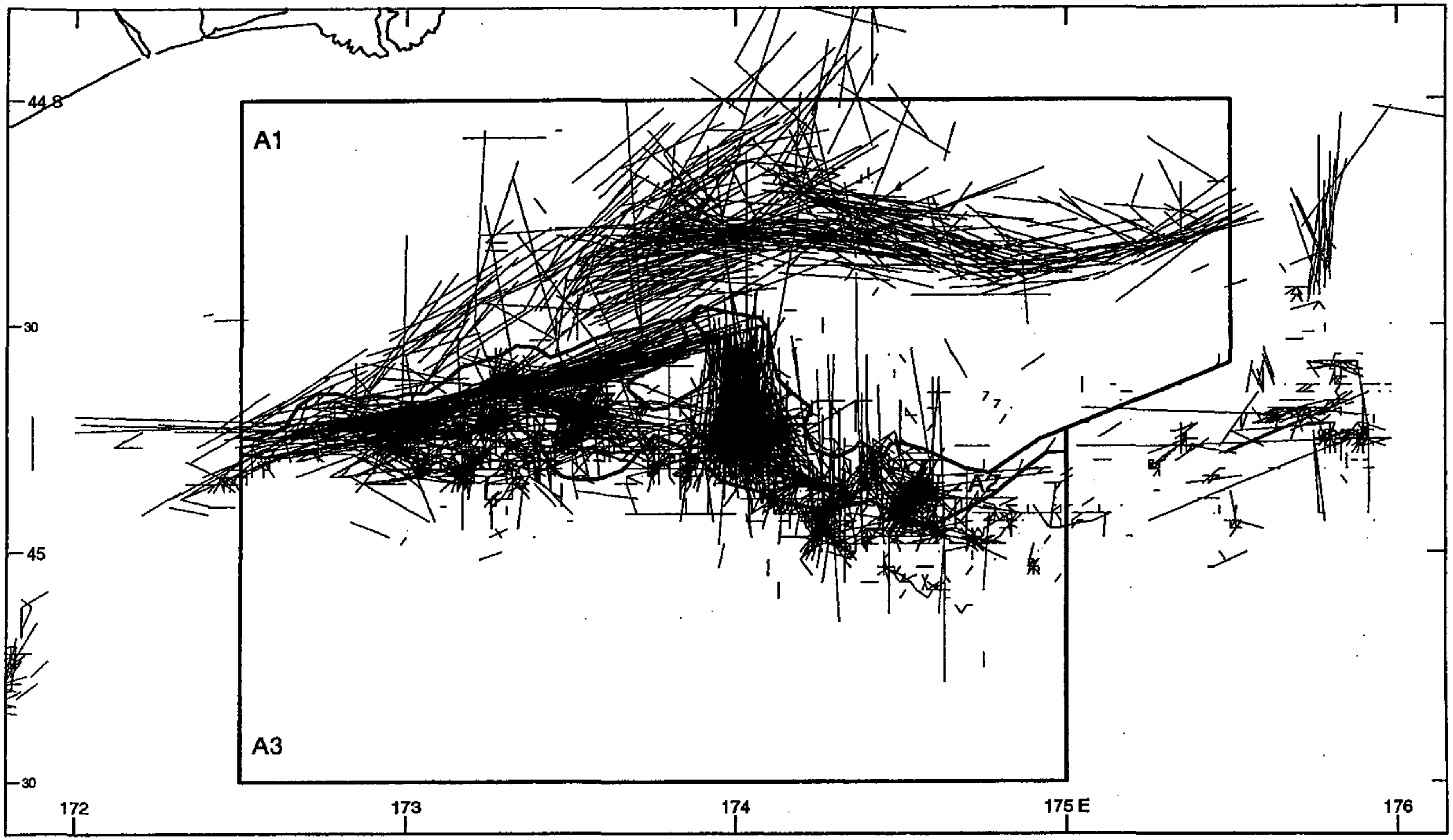

Figure 6: ***Tow tracks (black lines) where black oreo was caught. Start and end positions of the tows were jittered by plus or minus 0.5 of a minute of latitude and longitude. Heavy black lines define the areas used for the analysis. A1, shallow; A2, transition; A3, deep.***

The fraction of recorded catch of black oreo by spatial area is shown in Figure 7 and indicates that most of the catch was taken in areas 2 and 3 while on average only about 10% of the catch was from area 1. Most tows in area 1 were long tows (hours long), probably on flat ground, but most tows in area 2 were short (less than 2 hours) with a substantial number of longer tows. In contrast, most tows in area 3 were short (Figure 8).

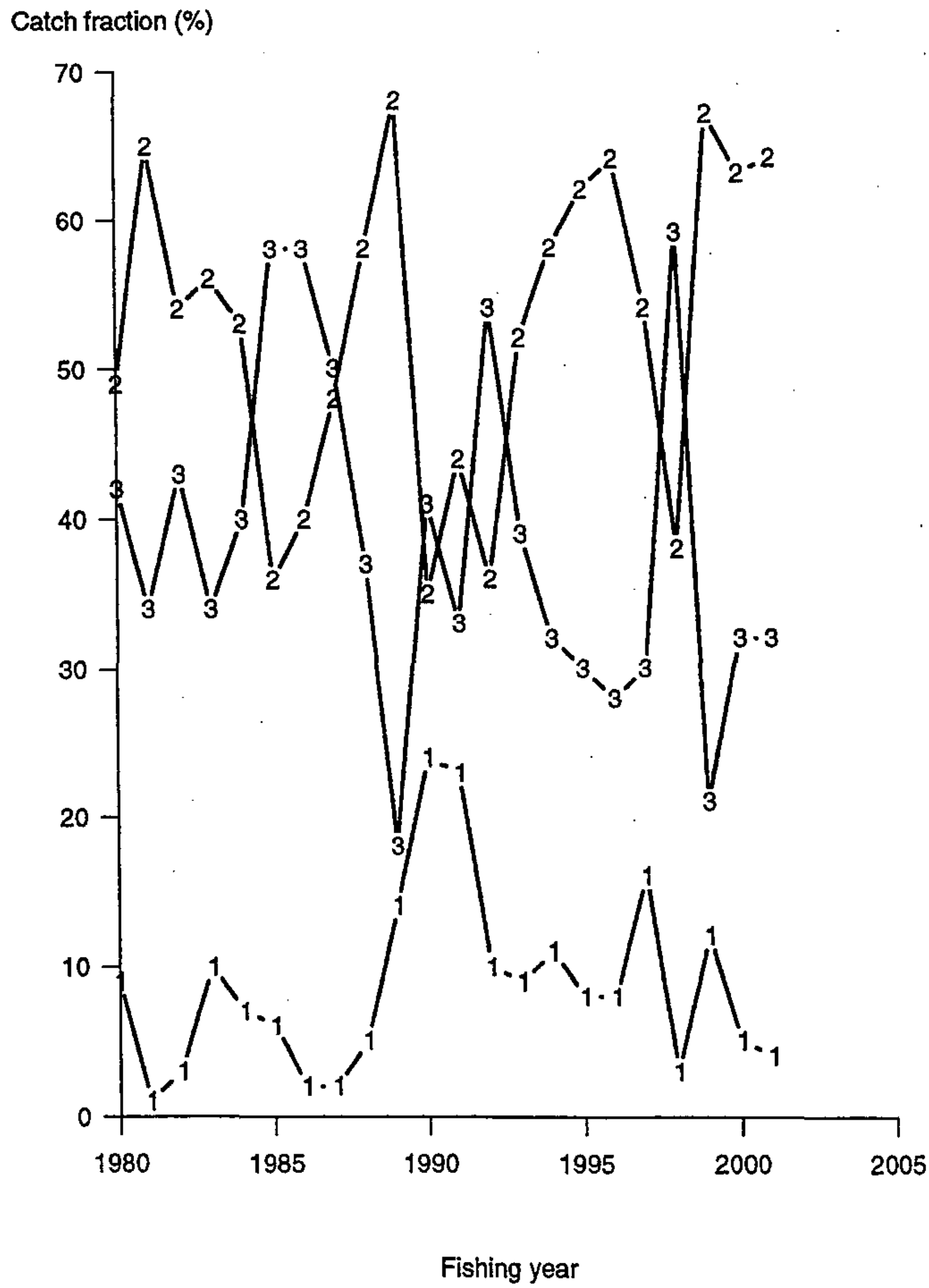

Figure 7: Fraction of recorded black oreo catch in each area for trawls that occurred in one of the three areas.

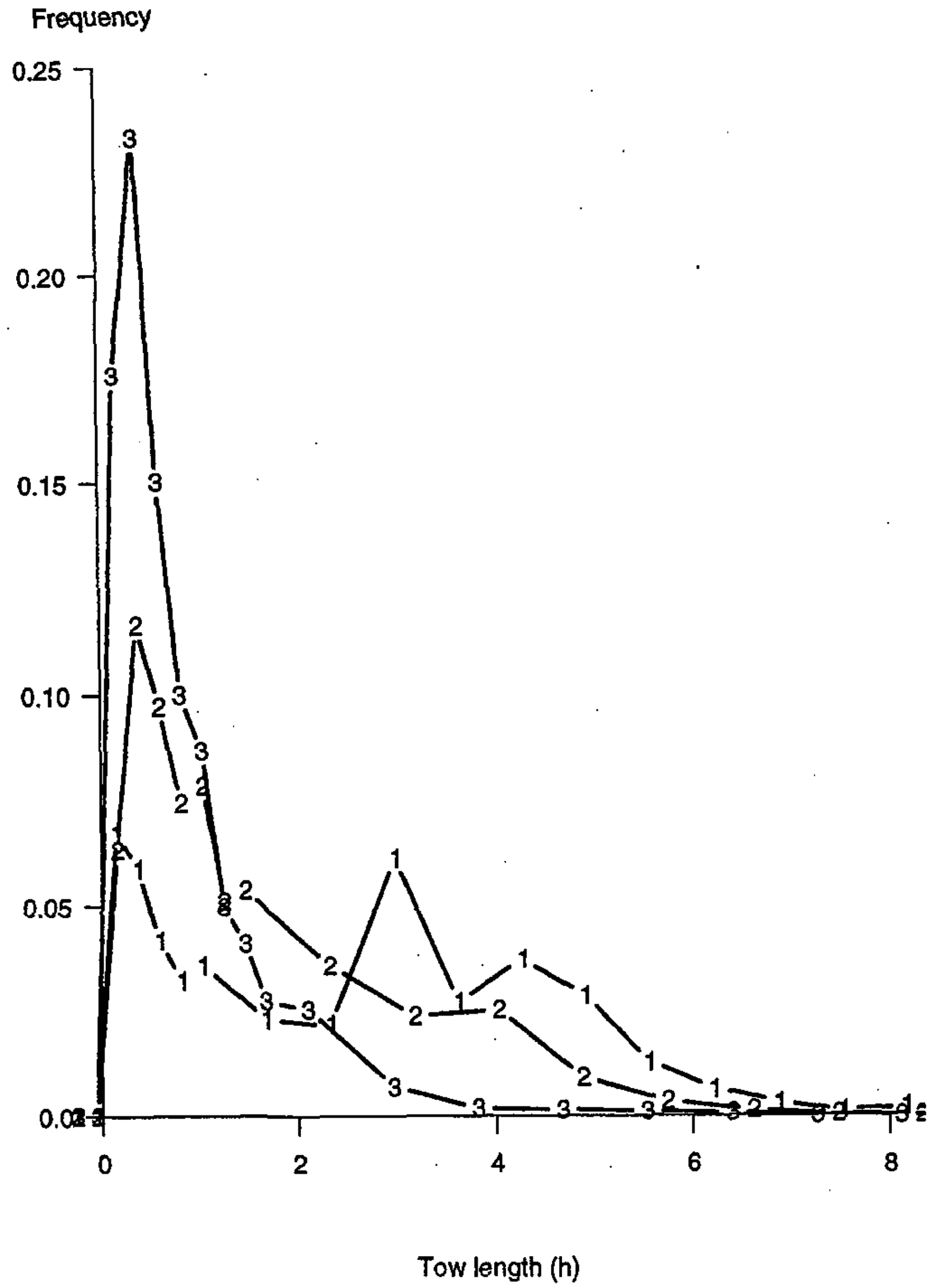

Figure 8: Distribution of length of tows in hours by area (1–3).

The distribution of mean length data collected up to 1993 and after 1993 is shown in Figure 9. Strong modes of small fish are present in the data for areas 1 and 2, while area 3 had mostly large fish for the data up to 1993. Small fish predominated in area 1, but areas 2 and 3 had more intermediate sized fish in the post 1993 data.

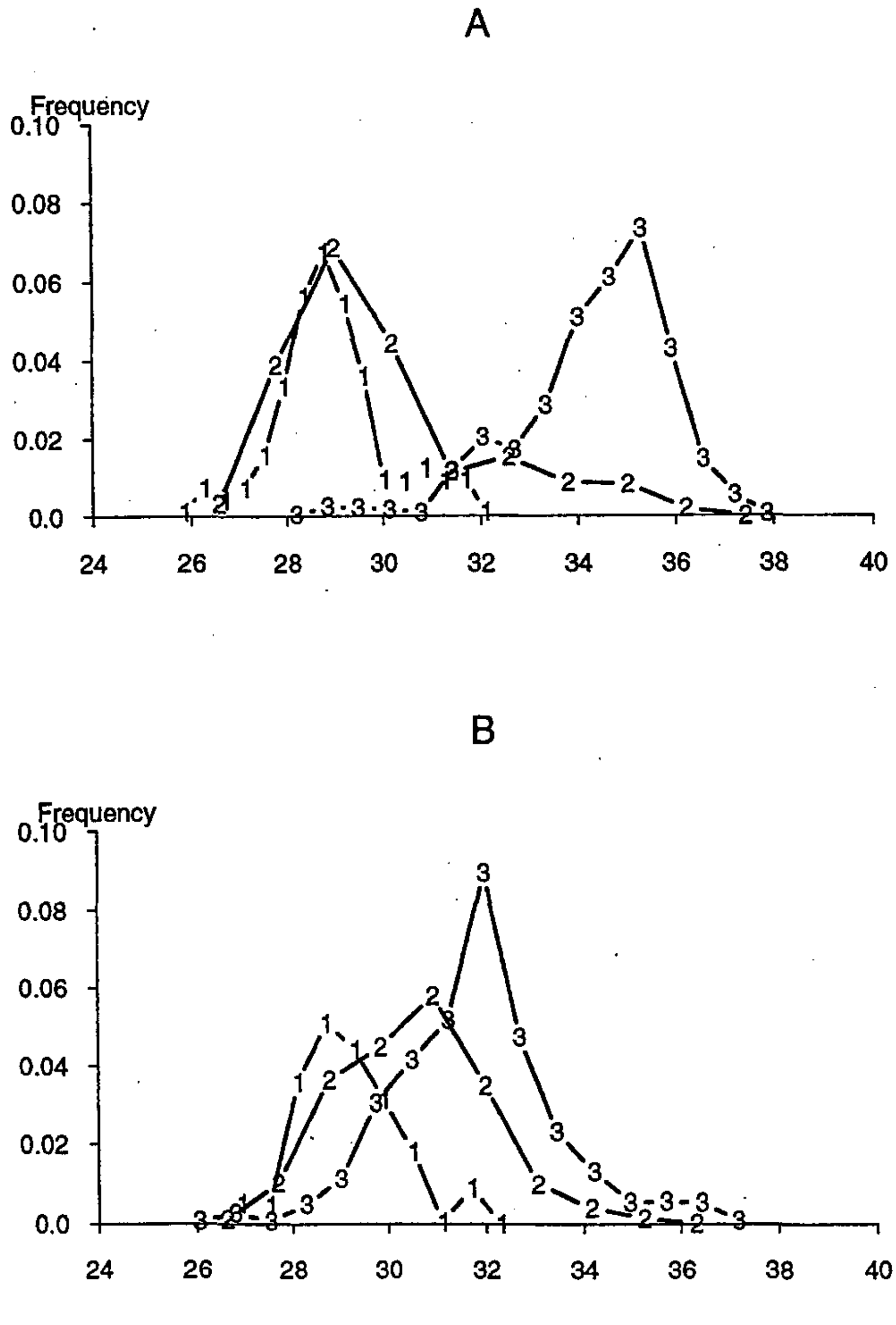

Figure 9: Distribution of relative frequency of mean lengths from observer data and research data where the catch was greater then 200 kg for each area and for data before (A) and after (B) 1993. 1 area 1, 2 area 2, 3 area 3.

Analysis of the distribution of mean length per tow by area showed a general trend for larger fish to be caught at greater depths, smaller fish at shallower depths, and a mix of small and large fish in the transition area. The area 2/3 boundary line separated most of the large fish tows although several fell into the transition area (2) (see Figure 5).

2.8 Summary

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 10). 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 relative dynamics.

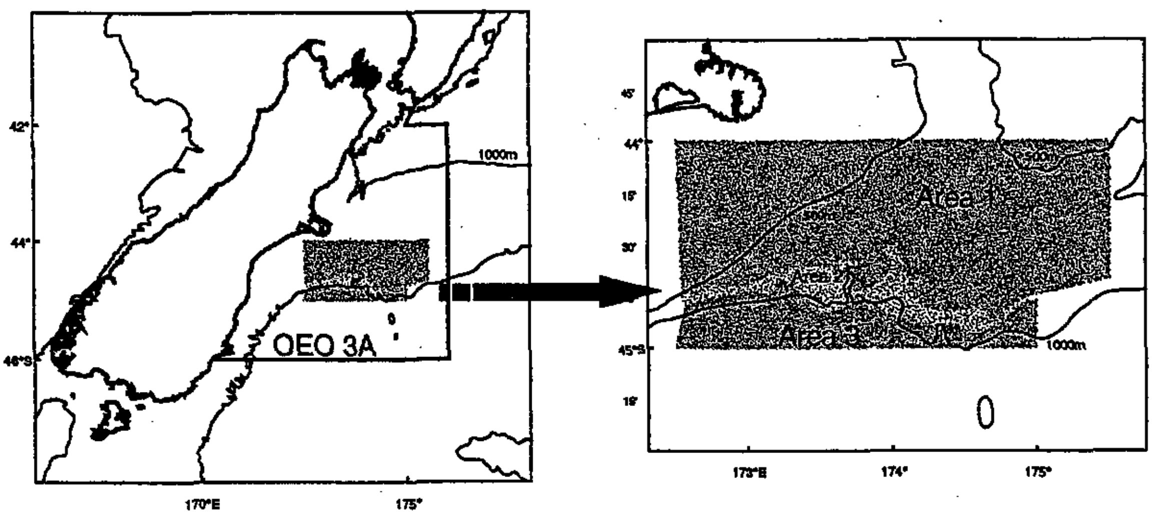

Figure 10: The three areas in the BOE spatial model for OEO 3A. The left figure shows the location of the three areas (shaded) within management area OEO 3A, and the right figure shows a zoomed view of the three areas in slightly different shades.

3. DATA INPUTS

3.1 Catch history

The total catch history of black oreo in all of OEO 3A in Table 2 was derived from the Soviet catches (see Doonan et al. 1995a) and Table 1 as follows.

1. Soviet catch of unspecified oreo from FAO area 81.5 from 1972 to 1977 was assumed to be all from OEO 3A, to be 50:50 black to smooth oreo, and to be for fishing rather than calendar years.
2. Catches from 1978–79 to 1982–83 (1 April to 31 March) were assumed to be for fishing years (1 October to 30 September).
3. The 1978–79 catch of unspecified oreo (1366 t, Table 1) was assumed to be the same proportion of black to smooth oreo catch reported in 1979–80 (5588/(5588 + 5075) = 0.524), Table 1. The estimate of the 1978–79 black oreo catch was 1366 x 0.524 = 716.
4. The 6 month OEO 3A black oreo catch reported as 1983–83 (3693 t, Table 1) was split and half each (1846.5) added to the preceding and subsequent years (1982–83 and 1983–84). Only 3 t of unspecified oreo was reported from OEO 3A in 1983–83, so no adjustment to the reported black oreo catch was required.

5. From 1979–80 to 2000–01 the catch was calculated by multiplying the landingvalue reported in Table 1 by the proportion of estimated catch of black oreo to smooth oreo in Table 1.

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 Catches by area

Catches were partitioned into the three areas by scaling up the estimated catch of black oreo from each area to the total reported catch (see Table 1) and are given in Table 2. 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 2) from 1979–80 to 1982–83.

Table 2: Black oreo catch for each fishing year in the three spatial model areas.

Year	Total	Area 1	Area 2	Area 3
1972–73	†3 440	206	1 892	1 342
1973–74	†3 800	228	2 090	1 482
1974–75	†5 100	306	2 805	1 989
1975–76	†1 260	76	693	491
1976–77	†3 880	233	2 134	1 513
1977–78	†5 750	345	3 163	2 243
1978–79	716	43	394	279
1979–80	5 743	479	2 756	2 508
1980–81	12 636	219	7 828	4 589
1981–82	11462	351	6 147	4 964
1982–83	8 285	832	4 620	2 833
1983–84	7 414	484	4 045	2 886
1984–85	3 933	229	1 440	2 265
1985–86	2 189	48	886	1 255
1986–87	4 032	91	1 919	2 022
1987–88	3 144	159	1 822	1 164
1988–89	3 228	456	2 202	571
1989–90	2 827	692	979	1 155
1990–91	4 774	1 128	2 069	1 577
1991–92	3 450	360	1 223	1 867
1992–93	4 956	466	2 572	1 918
1993–94	4 164	449	2 397	1 318
1994–95	2 401	195	1 487	719
1995–96	3 764	352	2 380	1 032
1996–97	3 752	607	2 031	1 114
1997–98	1 604	211	549	844
1998–99	3 289	438	2 171	679
1999–00	4 070	446	2 505	1 125
2000–01	2 956	225	1 913	863

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

3.4 Standardised CPUE analyses

Standardised CPUE indices for OEO 3A black oreo were developed and used as indices of abundance for the 1999–2000 stock assessment (Doonan et al. 1995b, Coburn et al. 1999). The following analyses incorporated data from 1998–99 and 1999–2000 and re-analysed the data to provide indices by spatial area. The indices were assumed to represent relative indices of abundance and were used in the spatial model stock assessment described below.

3.4.1 Data

The black oreo catch and effort data were restricted to all tows that targeted or caught black oreo in OEO 3A up to and including the 1999–2000 fishing year. The data were restricted to the spatial analysis study area defined above. Data were included in the analyses if there were at least three years with more than 50 catches of black oreo. Data were excluded if only one vessel caught 80% or more of the black oreo catch in a year. Because of the apparent changes in fishing practise attributable to the introduction of GPS, the data were split into pre- and post-GPS series. The tow data included start position, catch by species, 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. 1995a, Coburn et al. 1999).

3.4.2 Method of CPUE analysis

The basic CPUE analysis method was described by Doonan et al. (1995a) with enhancements following those described by Francis (2001). The basic 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 below (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, and vessel (Table 3). 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) used "typical" fixed values of all model predictors (p. 16) but analysis of his approach showed that the binomial indices varied depending on the fixed value used. So the method was modified to provide an initial attempt at a unique index. For the model with a fishing year-area interaction term this involved taking the means of the model predictor values at each partition of the data categorised by both fishing year and area.

The individual annual c.v. estimates for the CPUE abundance indices were estimated using a jack-knife technique (Doonan et al. 1995a) applied to the indices in their canonical form.

The following analyses were performed.

1. A modified analysis for area 1 using a single part model only (log-linear regression). No binomial model analysis was required because there were very few zero tows.
2. The modified method with year/area interaction 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.

Table 3: 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.

Variable	df	Description
Latitude	7	Latitude at start of tow.
Longitude	7	Longitude at start of tow.
Depth	7	Depth at start of tow. Bins were defined to contain about the same number of tows.
Season	7	The fishing year divided into 8 periods.
Time	7	Time of day at start of tow, blocked into 8 periods.
Target	3	Target species for the tow (BOE, SSO, OEO, OTHER).
Vessel	†	A parameter estimated for each vessel.

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

3.4.3 Results of the CPUE analyses

The annual number of tows that caught black oreo and the catch of black oreo from 1978–79 to 1999–2000 split into the spatial analysis areas are in Table 4.

Table 4: 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	93	318	745	4 356	683	3 993	6	15
1980–81	26	59	1 677	10 083	773	5 225	53	67
1981–82	14	52	514	3 154	382	2 449	40	43
1982–83	63	232	932	4 221	441	2 318	69	92
1983–84	43	125	1 010	3 129	609	2 101	54	113
1984–85	14	106	276	978	555	1 483	128	314
1985–86	4	3	230	719	328	971	353	388
1986–87	14	29	504	1 869	602	1 910	244	180
1987–88	16	29	712	1 840	517	1 098	148	75
1988–89	23	38	606	2 129	321	465	163	82
1989–90	65	293	327	954	406	863	174	252
1990–91	62	463	473	1 749	376	1 093	312	861
1991–92	32	94	182	781	169	1 032	393	1 277
1992–93	22	138	381	1 984	265	1 340	178	500
1993–94	43	168	532	2 145	373	1 074	354	611
1994–95	45	69	357	1 224	257	553	214	440
1995–96	75	87	603	1 995	456	789	278	470
1996–97	58	59	460	1 853	366	808	442	824
1997–98	212	132	144	451	412	647	397	334
1998–99	65	90	355	2 191	335	593	295	189
1999–00	130	113	392	1 822	330	732	148	75

Area 1

The analysis of area 1 had data from 1979–80, 1989–90, 1990–91 and 1995–96 to 1999–2000, but the data from years up to 1995–96 were poorly linked, so an index was provided only from 1995–96 onwards (Table 5 and Figure 11).

Table 5: Area 1 standardised CPUE indices derived from the modified log-linear model and jack-knife c.v. estimates.

Year	Index	c.v.
1995–96	0.977	19.6
1996–97	1.390	47.4
1997–98	1.040	16.4
1998–99	0.828	62.9
1999–00	0.766	48.9

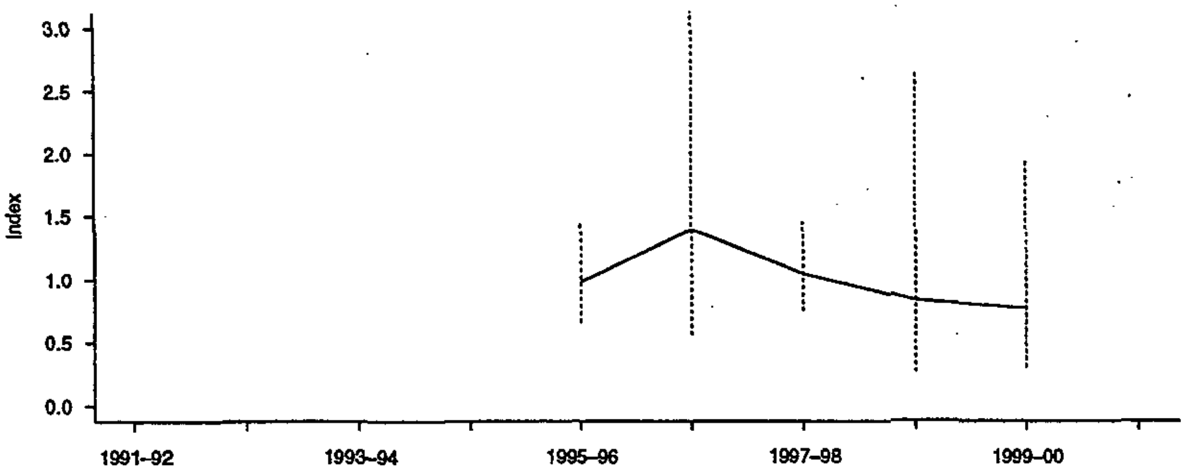

Figure 11: CPUE indices for area A1. The dotted lines show a +/- 2 s.e. confidence interval calculated by a jack-knife method. The 1996–97 upper confidence level exceeds the y-scale used.

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 6–9 and Figures 12–15.

Table 6: 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	Binomial	Combined	c.v.
1979–80	1.860	0.957	1.780	21.6
1980–81	1.500	0.965	1.440	12.8
1981–82	1.400	0.907	1.270	19.3
1982–83	1.220	0.819	0.998	11.3
1983–84	0.868	0.768	0.667	23.2
1984–85	0.836	0.822	0.687	30.3
1985–86	0.633	0.865	0.548	23.7
1986–87	0.749	0.903	0.677	13.9
1987–88	0.437	0.840	0.367	25.3
1988–89	0.494	0.974	0.481	19.9

Figure 12: CPUE indices for area A2, pre-GPS. The dotted lines show a +/- 2 s.e. confidence interval calculated by a jack-knife method.

Table 7: 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	Binomial	Combined	c.v.
1979–80	1.740	0.958	1.670	54.80
1980–81	1.800	0.953	1.720	12.50
1981–82	1.540	0.866	1.340	9.86
1982–83	1.300	0.871	1.130	12.50
1983–84	0.870	0.696	0.606	16.70
1984–85	0.810	0.699	0.566	38.60
1985–86	0.586	0.780	0.457	33.50
1986–87	0.724	0.821	0.594	30.50
1987–88	0.441	0.801	0.353	24.70
1988–89	0.178	0.950	0.169	45.60

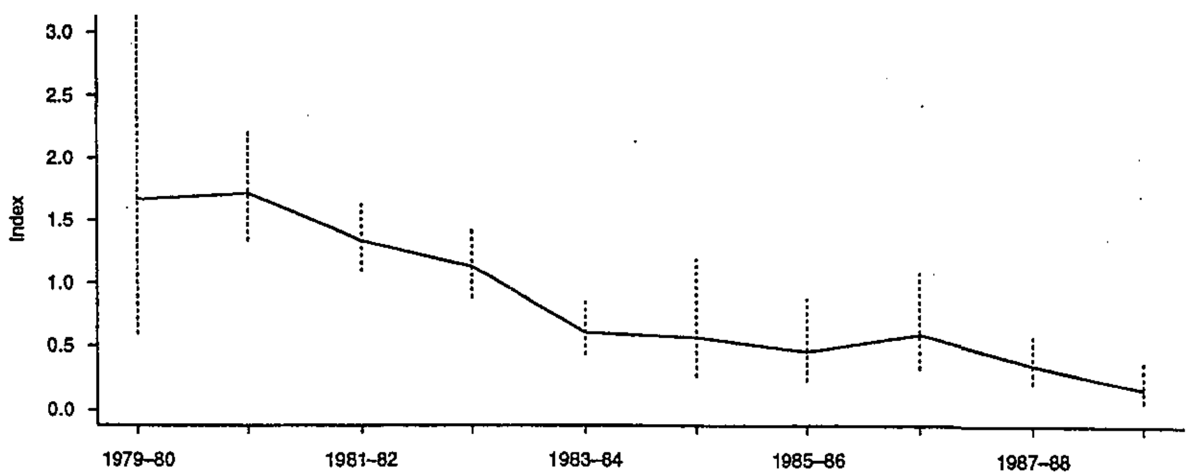

Figure 13: CPUE indices for area A3, pre-GPS. The dotted lines show a +/- 2 s.e. confidence interval calculated by a jack-knife method. The 1979–80 upper confidence level exceeds the y-scale used.

Table 8: 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	c.v.
1992–93	1.280	16.4
1993–94	0.942	21.9
1994–95	0.768	10.4
1995–96	0.776	11.2
1996–97	0.842	20.9
1997–98	0.640	22.9
1998–99	1.250	23.4
1999–00	1.510	23.2

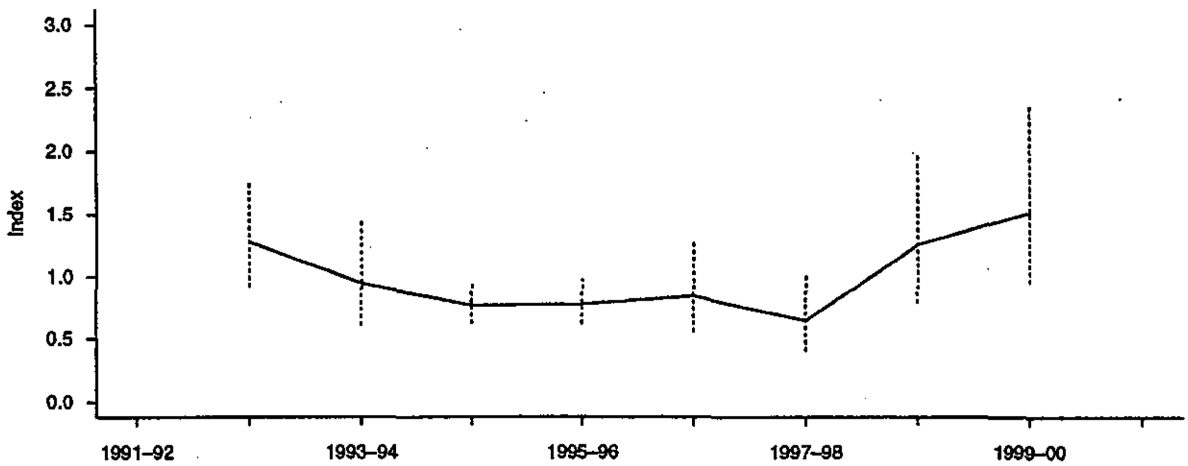

Figure 14: CPUE indices for area A2, post-GPS. The dotted lines show a +/- 2 s.e. confidence interval calculated by a jack-knife method.

Table 9: 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	c.v.
1992–93	1.650	35.4
1993–94	1.080	21.6
1994–95	0.767	16.1
1995–96	0.698	52.7
1996–97	0.989	25.4
1997–98	0.631	23.2
1998–99	0.906	17.8
1999–00	1.280	11.6

In area 1, the modified log-linear indices were used in the stock assessment model. For areas 2 and 3, the combined indices were used. The CPUE indices used for each area are summarised in Table 10.

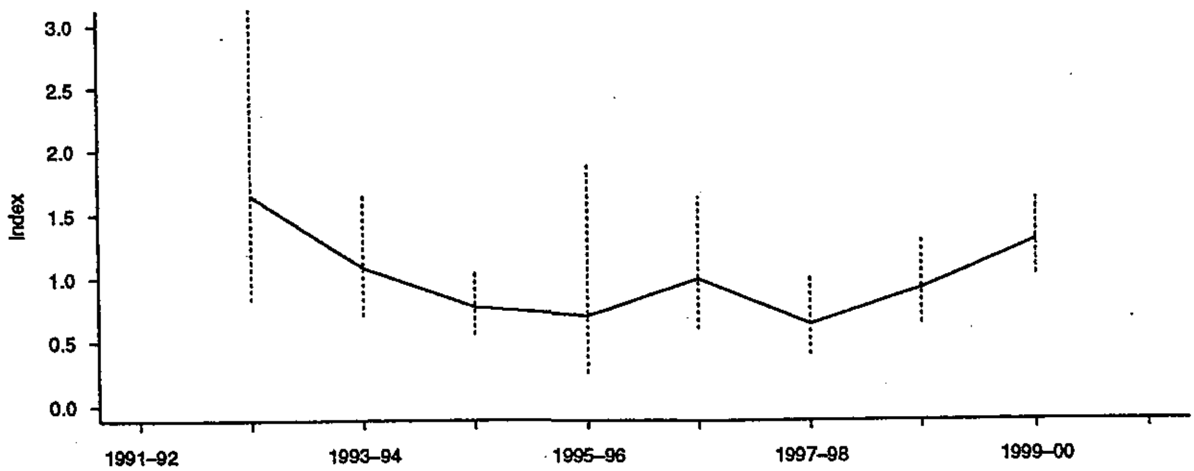

Figure 15: CPUE indices for area A3, post-GPS. The dotted lines show a +/- 2 s.e. confidence interval calculated by a jack-knife method. The 1992–93 upper confidence level exceeds the y-scale used.

Table 10: OEO 3A black oreo pre-GPS and post-GPS time series of catch per unit effort indices used in the stock assessment analysis. "–", no estimate.

Fishing	Pre-GPS			Post-GPS		
Year	Area 1	Area 2	Area 3	Area 1	Area 2	Area 3
1979–80	–	1.780	1.670	–	–	–
1980–81	–	1.440	1.720	–	–	–
1981–82	–	1.270	1.340	–	–	–
1982–83	–	0.998	1.130	–	–	–
1983–84	–	0.667	0.606	–	–	–
1984–85	–	0.687	0.566	–	–	–
1985–86	–	0.548	0.457	–	–	–
1986–87	–	0.677	0.594	–	–	–
1987–88	–	0.367	0.353	–	–	–
1988–89	–	0.481	0.169	–	–	–
1989–90	–	–		–	–	–
1990–91	–	–	–	–	–	–
1991–92	–	–	–	–	–	–
1992–93	–	–	–	–	1.280	1.650
1993–94	–	–	–	–	0.942	1.080
1994–95	–	–	–	–	0.768	0.767
1995–96	–	–	–	0.977	0.776	0.698
1996–97	–	–	–	1.390	0.842	0.989
1997–98	–	–	–	1.040	0.640	0.631
1998–99	–	–	–	0.828	1.250	0.906
1999–00	–	–	–	0.766	1.510	1.280
2000–01	–	–	–	–	–	–

3.5 Resource surveys

3.5.1 Trawl surveys

Trawl surveys of oreos on the south Chatham Rise were carried out in seven years between 1986 and 1995 (Table 11). The abundance estimates from the surveys before 1991 were not considered to be comparable with the *Tangaroa* series because different vessels were used. However, other results from these surveys were used, e.g., gonad staging to determine maturity. The 1991–93 and 1995 "standard" (flat, undulating, and drop-off ground) surveys are comparable.

Table 11: Random stratified trawl surveys (standard, i.e. flat tows only) for oreos on the south Chatham Rise (OEO 3A & OEO 4).

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

Relative abundance estimates from trawl surveys

The four *Tangaroa* trawl survey relative abundance estimates from OEO 3A (Table 12) were not used in the biomass analyses because it was assumed that catchability could be inconsistent between surveys, as reported for smooth oreo from OEO 3A by Doonan et al. (1999a).

Table 12: OEO 3A black oreo research survey abundance estimates (t). 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

3.5.2 Acoustic survey

Absolute estimates of abundance for black oreo are available from the acoustic survey on oreos carried out from 10 November to 19 December 1997 (TAN9713) (Doonan et al. 1998, 1999b). The 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 carried out on 10 marks including 2 smooth oreo, 2 black oreo, and 6 mixed oreo marks. Smooth and black oreo target strength estimates from the OEO 4 acoustic survey carried out from 26 September to 30 October 1998 were also made.

Absolute total (immature plus mature) abundance at the start of the fishing year was estimated for each of the 3 new areas. To do this, the acoustic survey was re-stratified so that each area was exactly covered by a subset of the new strata. Hills and strata 5 were ignored because they contained very little black oreo abundance in the original estimation and were outside the three black oreo areas defined from the fishery. The remaining strata (1, 2, 3, 4, and 15) were partitioned by the three black oreo areas to form 11 new strata. Transects were also partitioned by the black oreo areas so that each new stratum had its own, non-overlapping, set of transects. Apart from the re-stratification, the analysis was similar to that carried out in 1999. The estimated total abundance for each area is shown in Table 13.

Table 13: Acoustic estimates of black oreo total abundance (t) for the three areas of the main fishery.

	Area 1	Area 2	Area 3
Abundance (t)	122 000	9 100	5 100
c.v. (%)	24	24	29

3.6 Length data

3.6.1 Observer length frequencies

Catch-at-length data collected by observers in the black oreo fishery were extracted from the *obs_lfs* database administered by NIWA. The years and areas that contained 5 or more observed tows were used to compile area-specific length frequencies (Table 14) using catch-at-length software developed by NIWA (Brian Bull, pers. comm.).

Table 14: Number of observed commercial tows, that caught black oreo, used to create a length frequency (lf) for each fishing year in the three spatial model areas. "–", no length frequency created because fewer than five tows were observed.

Year	Number of tows in lf		
	Area 1	Area 2	Area 3
1972–73	–	–	–
1973–74	–	–	–
1974–75	–	–	–
1975–76	–	–	–
1976–77	–	–	–
1977–78	–	–	–
1978–79	–	–	–
1979–80	–	9	36
1980–81	–	–	–
1981–82	–	–	–
1982–83	–	–	–
1983–84	–	–	–
1984–85	–	–	–
1985–86	–	–	–
1986–87	–	–	6
1987–88	–	–	6
1988–89	12	23	7
1989–90	9	8	–
1990–91	–	5	8
1991–92	–	–	11
1992–93	–	–	–
1993–94	–	22	
1994–95	–	–	6
1995–96	–	–	–
1996–97	–	–	–
1997–98	13	–	7
1998–99	–	–	–
1999–00	–	51	58
2000–01	–	83	47

3.6.2 Trawl survey catch-at-length data

Research catch-at-length data were extracted from the *trawl* database administered by NIWA for the trawl surveys listed in Table 11. Length frequencies were compiled for each of the three areas using catch-at-length software developed by NIWA (Brian Bull, NIWA, pers. comm.).

3.6.3 Acoustic survey length data

The acoustic abundance at length data were converted to a length frequency using the fixed length-weight relationship (Table 15) to convert the abundance to numbers at length and was compared to predicted proportions at length for the total population from the start of the year. The lengths below 24 cm were pooled into the 24 cm length class, and those over 38 cm were pooled into the 38 cm length class.

3.7 Life history parameters

This model was not sex specific, thus combined sex parameters were developed. 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. 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. The combined sex von Bertalanffy parameter estimates used were averages of the male and female values, Table 15.

Table 15: Life history parameters for black oreo. The combined parameters were used in this model. Sex-specific parameters are included for comparison.

Parameter	Symbol (unit)	Combined	Female	Male
Natural mortality	M (yr^{-1})	0.044	0.044	0.044
von Bertalanffy parameters	L_∞(cm, TL)	38.2	39.9	37.2
	k (yr^{-1})	0.05	0.043	0.056
	t_0 (yr)	-17	-17.6	-16.4
Length–weight parameters	a	0.0078	0.008	0.016
	b	3.27	3.28	3.06

4. METHODS

4.1 Spatial model

The spatial model is described in detail in Appendix A. In summary, the model used the three areas described above by allowing migration between the areas. Fish recruited to the population in area 1 at age 5 (years) then migrated from area 1 to area 2 or area 2 to area 3 during one time-step. The model did not allow migration back to area 1, but an additional migration from area 1 to 3 was examined.

Biomass estimates were made using deterministic stock reduction analyses (after Francis 1990). The following assumptions were made in this analysis.

(a) The black oreo acoustic abundance estimate was an unbiased absolute value.
(b) The CPUE analysis indexed the abundance of black oreo in the whole of OEO 3A. Most of the black oreo commercial catch taken from 1978–79 to 2001–02 came from the CPUE

study area and research trawl surveys indicated that there was little habitat for, and biomass of, black oreo outside that area.

(c) The ranges used for the biological values covered their true values.

(d) Recruitment was deterministic and followed a Beverton & Holt relationship with steepness of 0.75.

(e) Catch overruns were 0% during the period of reported catch.

(f) The population of black oreo in OEO 3A was a discrete stock or production unit.

(g) The catch histories were accurate.

The extra complexity of migration was added using two different migration methodologies. An age-based migration used a linear relationship or a logistic curve to relate the probability of moving from area i to area k given age. A density-dependent migration used a logistic relationship to determine the probability that a fish would move given the current population biomass relative to the unexploited biomass of the area that the fish was moving to. Each migration ogive had two parameters to estimate. A thorough explanation of these migrations is given in Appendix A.

Five runs were performed, three using age-based migration and two using density-dependent migration. Of the age-based migration ogives, two were logistic and one used a linear ogive. Every run included migration from area 1 to 2 and migration from area 2 to 3. Run 2, which used logistic migration, also included migration from area 1 directly to area 3. One of the density-dependent runs (run 5) estimated immature mortality. A brief description of each run is given in Table 16.

Table 16: Description of the five runs. "DD" refers to density-dependent migration.

	Run 1	Run 2	Run 3	Run 4	Run 5
Migration ogive	Logistic	Logistic	Linear	DD	DD
Migration 1→3	No	Yes	No	No	No
Estimate immature M	No	No	No	No	Yes

4.2 Bootstrapping data

The input data were bootstrapped to determine the variability of the parameter estimates. Due to time constraints, only the density-dependent runs were bootstrapped, since these were the only runs approved by the 2002 Deepwater Stock Assessment Working Group. Run 4 used 510 separate bootstrapped datasets and run 5 used 503 different bootstrapped datasets. Confidence intervals were determined using the parameter estimates from the original dataset and the bootstrapped datasets.

4.2.1 Commercial length frequencies

Variability in the commercial length frequencies was determined by bootstrapping the length data using the catch-at-age software developed at NIWA (Brian Bull, pers. comm.). Tows were resampled and fish within each tow were also resampled to produce a new length frequency.

4.2.2 CPUE indices

Pre- and post-GPS CPUE indices were varied by drawing an index value from a lognormal distribution with a mean equal to that year's observed index and the c.v. associated with that year's index.

4.2.3 Acoustic total and at length abundance estimates

Acoustic absolute abundance estimates and abundance at length were also varied in the bootstraps. Absolute abundance estimates in each area were determined by drawing a value from a lognormal distribution using a mean equal to the absolute abundance and the c.v. associated with that abundance. That random abundance of a particular area was used to determine the abundance at length in that area. A sample of 2000 was taken from a multinomial distribution with the probabilities of each length class calculated from the observed abundance at length. A total sample size of 2000 was used because 200 fish are routinely measured during surveys, and an effective sample size of 10 was assumed for the length frequency. The length class probabilities from this sample were multiplied by the total abundance determined from the lognormal distribution to give the abundance at length.

4.2.4 Mortality

Mortality is a fixed parameter derived from a separate analysis, but its variability was introduced into the bootstraps. For each bootstrapped data set, a value of M was drawn from its estimated distribution (McMillan et al. 1997) and used as the fixed mortality in the model. This way, the model variability reflected the uncertainty in M. Runs 1–4 assumed equal mortality for immature and mature. Run 5 used the bootstrapped value as the mature natural mortality and estimated immature natural mortality.

4.3 Calculation of yields

The maximum constant yield, MCY, is the maximum total catch that can be taken in the long term without reducing the population below 20% B_0, 10% of the time. It was calculated using the recommendations of Francis (1992). For each parameter vector estimated from the bootstraps, the population was projected into the future with a constant catch until equilibrium was achieved (change in mature biomass in each area is less than 0.1 t). The model was projected a further $n_{discard}$ (200) simulations using stochastic recruitment to stabilize the population. Then, n_{keep} (140) simulations were done, also with stochastic recruitment, and the proportion of simulations where the mature biomass was less than 20% B_0 was recorded. This procedure was done once for each parameter vector, but it is possible to do multiple simulations with different recruitment variability and the same parameter vector. The proportion of time that the mature biomass fell below 20% B_0 is the average of the results from each parameter vector. Also recorded was the average biomass over the simulations and is reported as B_{MCY}. Different total catches were used until the catch (to the nearest 100 t) that resulted in the biomass being above 20% B_0 at least 10% of the time was found.

It was initially thought that an optimal catch split (the percentage of fish caught in each area) would be solved for when finding the MCY. However, it was decided that the status quo would be used and a catch split of 9%, 63%, and 28% for areas 1, 2, and 3, respectively, was determined based on the catches of black oreo in the three areas of OEO 3A from the last 2 fishing years (1999–2000 and 2000–01).

The Current Annual Yield, CAY, is the catch given the exploitation rate that does not reduce the population below 20% B_0, 10% of the time, E_{CAY}. The CAY was calculated using an exploitation rate relative to the entire population (i.e., all three areas) and a catch split of 9%, 63%, and 28% for areas 1, 2, and 3. For each year simulated, the total recruited biomass was calculated by summing the recruited biomasses from each area using the area specific selectivity curves. The total catch for the year being simulated was then found by multiplying the total recruited biomass of that year with the exploitation rate, and then the catches were split among the areas using the catch split. This allowed year and area specific instantaneous fishing mortalities to be calculated.

Finding E_{CAY} was done in a similar manner to the MCY calculations using parameter variability and recruitment deviates. The average biomass over all the n_{keep} simulations using E_{CAY} is B_{MAY} and the average catch is $MAY_{long-term}$.

The current surplus production, CSP, is the amount of catch that can be taken next year with no change to the total mature biomass of all three areas. Deterministic recruitment and the MLE parameter estimates were used, thus no variability was introduced. The catch split defined above was also used in this calculation.

4.4 Five-year and 10-year projections

The probabilities that the total mature biomass will increase over the next 5 years and over the next 10 years were calculated for different constant catches using the catch split defined above. Recruitment variability and parameter estimate variability were introduced using the same method as the MCY and CAY calculations. The proportion of times that the mature biomass increased over all the simulations was recorded.

Similar projections were done with the criteria being the probability that the population increased to a size greater than B_{MCY} or a criteria of B_{MAY}, where these biomasses were expressed as a percentage of B_0 and recalculated given the initial biomass that resulted from each bootstrapped parameter vector. These probabilities were calculated for the same catch levels as above.

5. MODEL RUNS AND BIOMASS ESTIMATES

Input data included the recruit acoustic absolute abundance estimates and c.v.s (see Table 13), the time series of combined abundance indices from standardised CPUE analyses and c.v.s (see Table 10), observer length frequencies, the life history parameters devised for this model (see Table 15), and the catch history (see Table 2).

Initial runs with and without the research length frequencies showed little difference in the estimated model parameters. The length frequencies also did not show much difference between the three areas possibly due to the trawl surveys missing aggregations on hills. Given this and the addition of three parameters for the survey selectivity, all trawl survey data were excluded from the model runs.

Besides the migration parameters, there were seven parameters to estimate. The initial recruitment, R_0, was the initial biomass of age 5 fish recruiting into the population. Logistic selectivity was used for the commercial fishery and required two parameters for each area. The area specific parameters were assumed to be the same for the pre-GPS and post-GPS commercial fisheries to reduce the number of selectivity parameters in light of the limited data. Catchability coefficients were assumed to be nuisance parameters and were analytically calculated in the likelihood. (See Appendix A for more detail of the parameters).

Table 17: Parameter estimates and likelihood contributions from the five model runs. Parameters are described in detail in Appendix A and data sources are described in Section 3.

		Run 1	Run 2	Run 3	Run 4	Run 5
Parameter estimates						
R_0 (t)		2556	2556	2568	2682	14379
Migration 1→2	$\theta_{12,1}$	959	959	0.057	0.32	0.26
	$\theta_{12,2}$	1 000*	1 000*	2.5×10^{-5}	0.015	0.0017
Migration 2→3	$\theta_{23,1}$	1 000*	1 000*	0.045	0.40	0.33
	$\theta_{23,2}$	940	940	5.8×10^{-6}	0.083	0.088
Migration 1→3	$\theta_{13,1}$	—	0.09	—	—	—
	$\theta_{13,2}$	—	0.53	—	—	—
Selectivity area 1	$\psi_{i,1}$	7.60	7.60	7.53	6.10	8.10
	$\psi_{i,2}$	0.20*	0.20*	0.20*	0.22	0.22
Selectivity area 2	$\psi_{i,1}$	13.37	13.37	13.26	8.89	10.00
	$\psi_{i,2}$	3.64	3.64	3.44	0.24	0.24
Selectivity area 3	$\psi_{i,1}$	13.71	13.71	13.91	20.78	18.90
	$\psi_{i,2}$	3.54	3.54	3.57	1.11	1.04
Immature natural mortality		—	—	—	—	0.159
Likelihood components						
Acoustic LFs		9.76	9.78	9.60	9.79	8.46
Commercial LFs		34.32	34.34	33.99	33.45	17.58
CPUE		46.27	46.28	46.05	23.67	23.12
Absolute abundance		14.42	14.42	13.95	8.29	2.52
TOTAL		104.78	104.82	103.59	75.19	51.68

* estimated at upper bound

The first three runs had very similar results with similar fits to the data. The density-dependent migration runs fit the data much better, overall. The migration rates were estimated at small values moving fish through the system at slow rates. Because it seemed that fish could not move into area 3 fast enough, migration from area 1 directly to area 3 was attempted. As seen in Table 17, run 2 was virtually identical to run 1. The selectivities were mostly knife-edged (small $\psi_{i,2}$ parameter), but consistently selected for larger fish in each successive area (1–3). Run 5 estimated immature natural mortality to be much larger than the fixed mature natural mortality, resulting in a large R_0.

All runs were reviewed by the 2002 Deepwater Stock Assessment Working Group but only runs 4 and 5 were approved. Therefore further results, such as confidence intervals and yields, were obtained only for those two runs. Each run is discussed in more detail in the following sections.

5.1 Age-based migration

5.1.1 Logistic migration

The first run incorporated logistic migration from area 1 to area 2, and from area 2 to area 3, resulting in four migration parameters. Mature and immature natural mortalities were set equal at 0.044.

The estimated migration parameters were large values, some at the upper bound, resulting in very small migration rates that increased slightly across the ages. The estimated logistic curves in Figure 16 show that the logistic curve may not be appropriate because only the leftmost portion of the curve (low probabilities) is being used. The cumulative distributions in Figure 16 show the probability that a fish in that area will move into the next area, given a starting age of 5 in area 1 and 15 in area 2. This is most useful for the migration from area 1 to 2 since all fish recruit into that area at age 5. Near age 16, 50% of the recruited fish in area 1 had migrated to area 2. Migration from area 2 to 3 was slower than migration from area 1 to 2.

The selectivities were estimated as steep curves (Figure 17). Areas 2 and 3 had nearly similar curves, and area 1 was nearly knife-edged between ages 7 and 8. The $\psi_{i,2}$ parameter determines the steepness of the logistic curve and was estimated at the lower bound in area 1. The lower bound was set to avoid overflow errors in the estimation program, and a smaller value would have resulted in a steeper curve. However, the curve is already so steep that the probability of selecting an age 7 fish is 1.6×10^{-4} and the probability of selecting an age 8 fish is 0.997. A steeper curve will not make a significant difference in the results since the program uses integer ages.

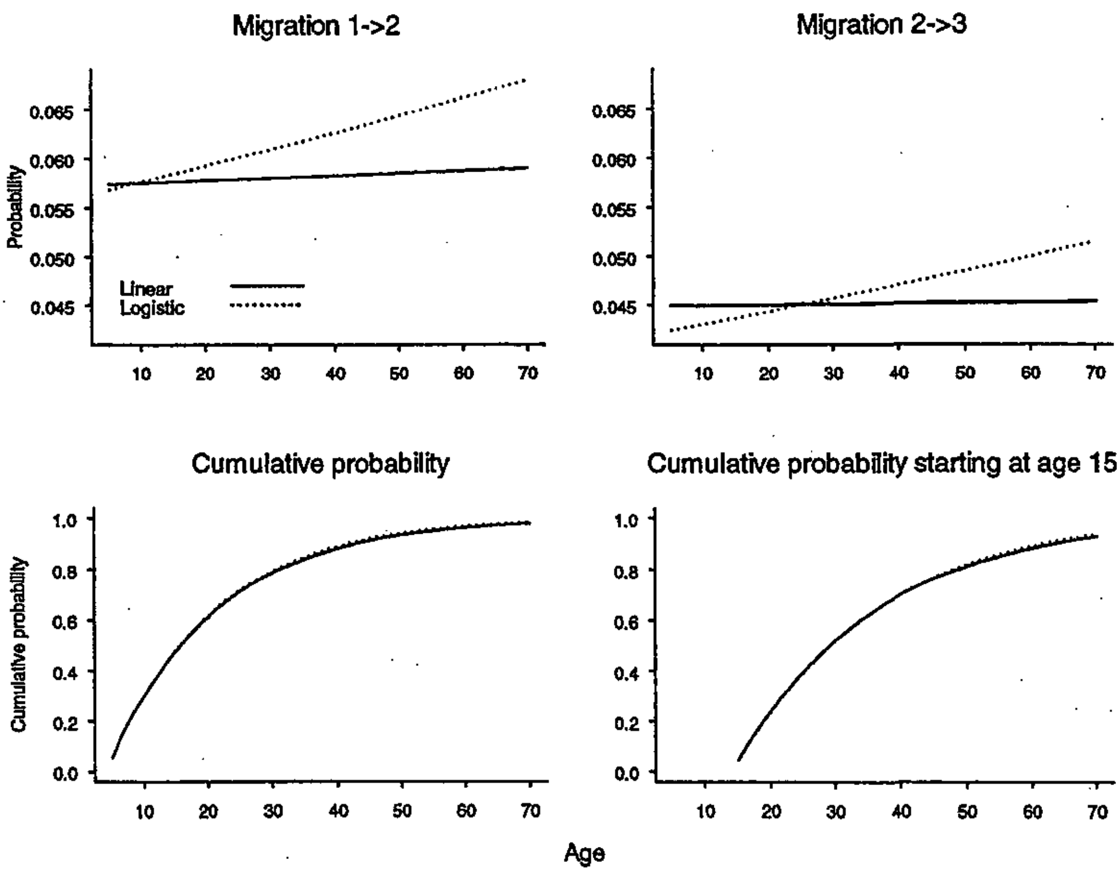

Figure 16: Estimated migration rates using logistic or linear migration ogives. The top row shows the probability that a fish will move at that age. The bottom row shows the cumulative probability that a fish will move from area 1 to 2 being recruited into area 1 at age 5, and move from area 2 to 3 given it enters area 2 at age 15. The solid line shows the linear migration ogive and the dotted line shows the logistic migration ogive.

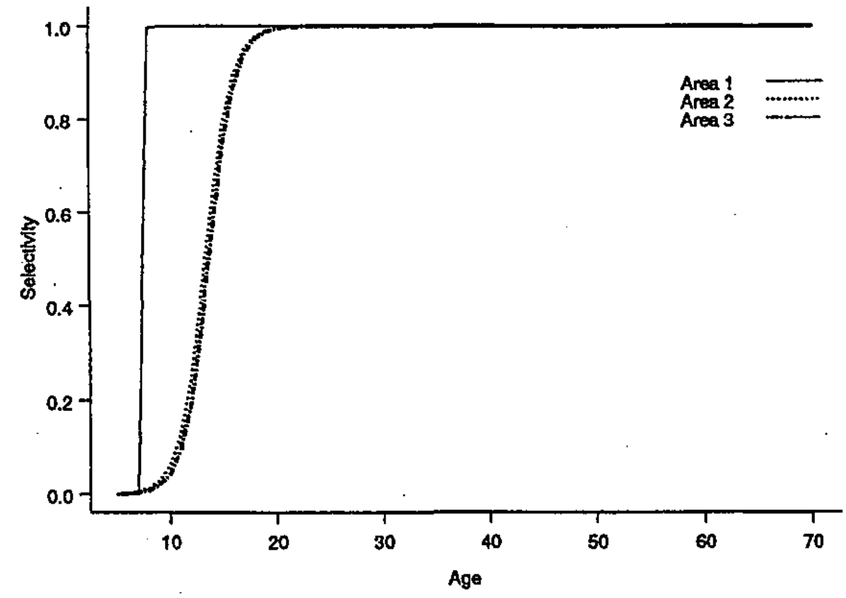

Figure 17: Estimated selectivity curves using logistic migration. The curves for areas 2 and 3 are nearly overlapping. Maximum estimated age was 70 years.

The fits to the observer length frequency data were not very good, and a pattern in the residuals was apparent where lower lengths were typically underfit and larger lengths were overfit, especially in area 1 (Figure 18). The mean lengths pictured in Figure 19 are the expected values of the length frequency distribution. Areas 1 and 2 overestimated the observed mean lengths. Area 3 fits the mean lengths in early years, but overpredicts them in the most recent years.

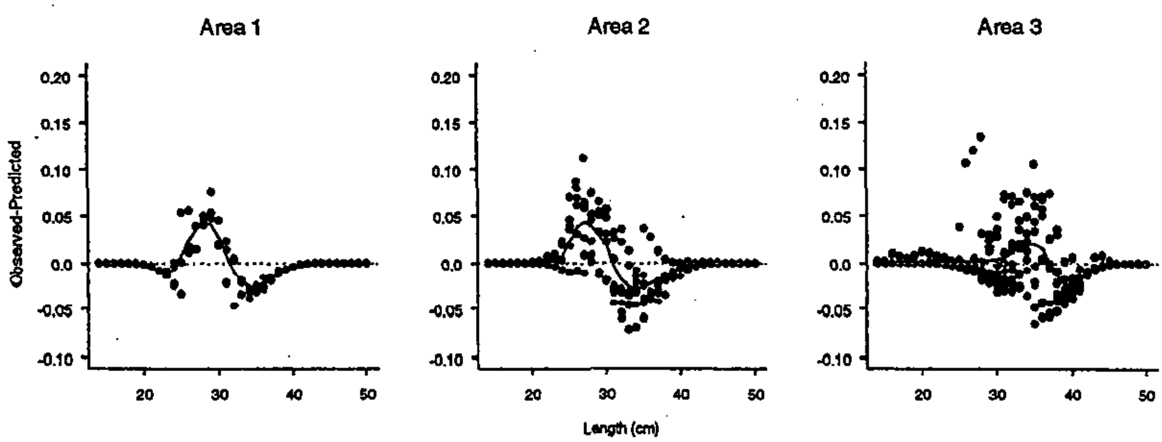

Figure 18: Residual plots of the fits to the length frequency data determined using logistic migration. A smoothed line was drawn in each plot as a guide to any pattern present and a faint dotted line indicates zero on the y-axis.

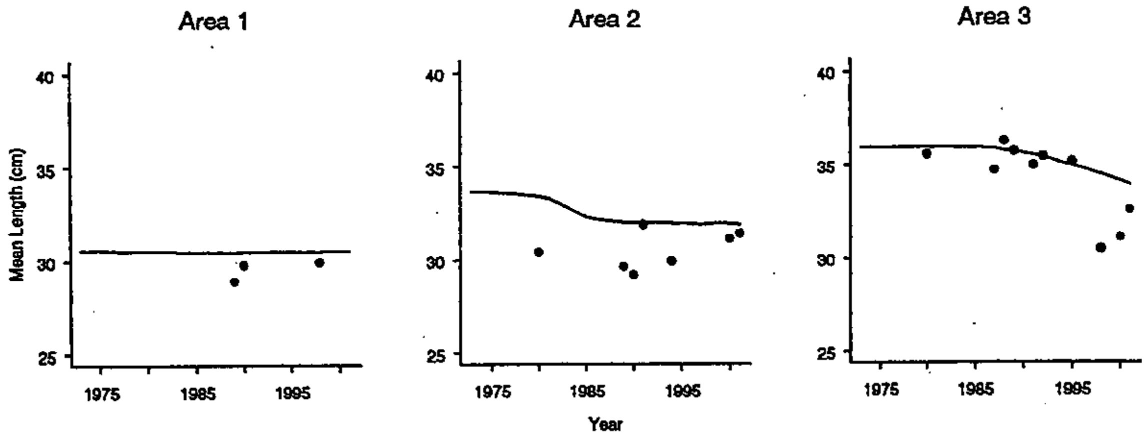

Figure 19: Fits to the mean lengths using logistic migration. Observed mean lengths were determined from the observer length frequencies for each area.

The predicted biomass trajectories are shown in Figure 20 along with the observed indices and their confidence intervals. CPUE is compared with the recruited biomass and the 1997 acoustic survey is compared with the total biomass. The large absolute abundance in area 1 is severely underpredicted, but the absolute abundance in areas 2 and 3 fit well. The biomass trajectory in area 3 is not as steep as the CPUE indicates it may be. The increase in the last two CPUE points may be a result of a change in fishing behaviour where the fishers shifted focus from smooth oreo to black oreo in those years.

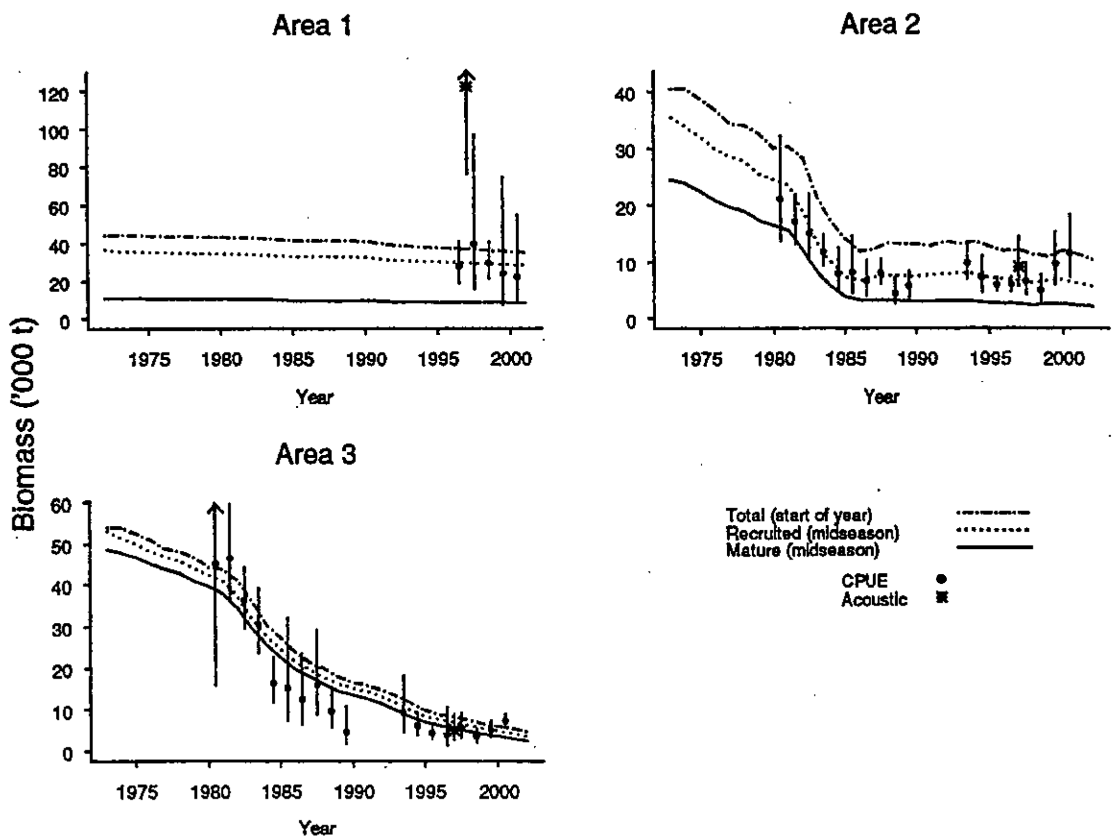

Figure 20: Biomass trajectories for each area estimated from run 1 with CPUE and absolute abundance indices and the approximate 95% confidence intervals overlayed. CPUE is compared to the recruited biomass (solid line) and the absolute abundance estimate is compared to the total biomass (dashed-dotted line). Confidence intervals that exceed the upper bound of the plot are noted with an arrow.

The Deepwater Working Group suggested that migration from area 1 to area 3 should be added because it seemed that fish were moving too slowly through area 2. Two more parameters were estimated for logistic migration from area 1 directly to area 3. Migration from area 1 to 3 was estimated near zero for all ages (see Table 17), resulting in the same parameter estimates as the logistic migration without migration from 1 to 3 (run 1).

5.1.2 Linear migration

The estimates of the logistic migration parameters resulted in a nearly linear relationship of migration rate with age and used only the leftmost portion of the logistic curve. Therefore, a simple linear relationship was used to model the migration rates since the logistic curve did not have much flexibility in the area of interest. The overall fit to the data was slightly better with linear migration, but the parameter estimates were nearly the same as the logistic migration run (see Table 17). The linear migration ogives were flatter than the logistic ogives and remained nearly constant across the ages (see Figure 16).

5.2 Density dependent migration

The logistic and linear migration ogives did not adequately capture the perceived movement of the stock, so a density dependent migration ogive was used where the probability was not dependent on age (supported by the nearly flat linear migration ogive), but was dependent on the relative biomass in the area the fish were moving to. Appendix A explains this ogive further. Four parameters are estimated for two logistic migration ogives.

Two runs were done with the density-dependent migration ogive. Run 4 (see Table 16) used fixed mature and immature natural mortalities of 0.044 and run 5 estimated immature natural mortality with mature natural mortality fixed at 0.044. These are the only two runs approved by the 2002 Deepwater Working Group, so they are explained in more detail here compared to the age based migration runs described above.

5.2.1 Parameter estimates

The parameter estimates from each run are given in Table 17. The most noticeable difference in the estimates of parameters between the two cases is that R_0 is much larger in run 5 because of the higher immature mortality. The estimate of immature mortality in run 5 was 0.16, significantly larger than the mature mortality of 0.044.

In the initial year, fish had a higher rate of movement in run 5 and more biomass was moving than in run 4. In the final year, run 5 was still moving more fish because of the larger population of immature fish, but the migration rate from area 1 to area 2 in run 4 surpassed that in run 5 (Table 18). The density-dependent migration used in these runs tended to keep large amounts of fish moving because the migration rate can increase with low densities. Since a large amount of fish were moving from area 1 to 2 in run 5, the migration rate did not increase much with the decreasing biomass in area 2.

Table 18: Migration rates and biomass (t) moving in the initial and final years for both density-dependent runs.

		Run 4		Run 5	
		Rate	Biomass	Rate	Biomass
Initial	1→2	0.030	2 190	0.038	5 200
year	2→3	0.024	1 050	0.030	1 510
Final	1→2	0.054	2 460	0.040	4 460
year	2→3	0.156	1 020	0.200	2 110

Table 17 gives the estimated selectivity parameters and Figure 21 shows the selectivity curves in each area from runs 4 and 5. The selectivity in area 3 was different from that in the other two areas, being estimated more to the right (younger ages selected less frequently). The selectivity curves were also nearly knife-edged and the age at which 50% were selected increased from area 1 to area 3. Compared to the age-based migration ogives, the selectivity curves estimated here were similar in area 1, shifted to the left in area 2, and shifted to the right in area 3. The curves in areas 2 and 3 were also more knife-edged when using the density-dependent migration.

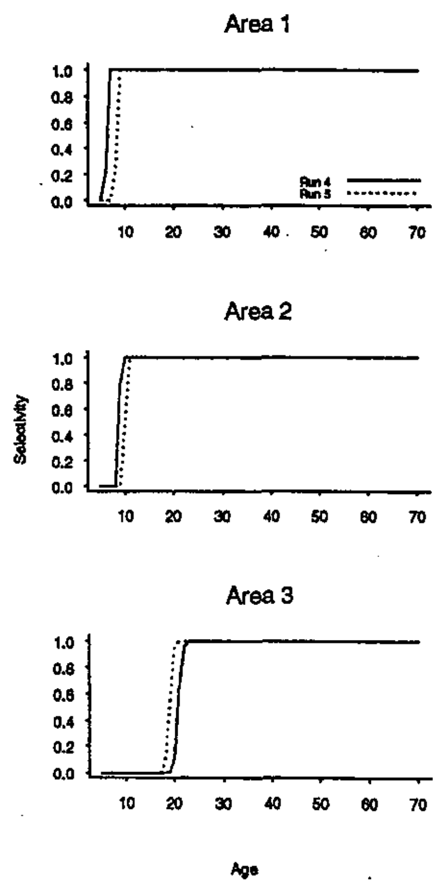

Figure 21: Selectivity curves estimated in each area for the two density-dependent migration runs (4 & 5).

5.2.2 Biomass estimates

A severe decline in the biomass was predicted for areas 2 and 3, but the biomass in area 1 did not decline much (Table 19 and Figure 22). The data driving the biomass trajectories are the catches, which removed a lot of fish in the early 1980s and early 1990s, and the CPUE which declined sharply in the early 1980s. The total mature biomass was predicted at 20 and 24% of B_0 for runs 4 and 5, respectively. However, in areas 2 and 3, the mature biomass was less than 7% of B_0, but because of migration from area 1, these areas can be replenished.

Table 19: OEO 3A black oreo mature biomass estimates and bootstrapped 95% confidence intervals from the density-dependent migration runs.

B_0	Area 1	Area 2	Area 3	Mature biomass All areas	Total biomass All areas
Run 4	28 820	32 350	27 210	88 380	142 840
	(14 110–39 340)	(19 640–42 320)	(13 610–31 040)	(64 620–99 840)	(127 700–179 700)
Run 5	18 610	25 670	27 410	71 690	206 960
	(10 530–29 680)	(17 640–31 220)	(21 530–31 340)	(60 190–80 360)	(148 700–267 500)
$B_{2000-01}$	Area 1	Area 2	Area 3	Mature biomass All areas	Total biomass All areas
Run 4	15 400	1 940	920	18 260	55 130
	(6 640–22 670)	(1 080–2 520)	(520–4 070)	(9 630–27 550)	(31 300–105 100)
Run 5	15 550	1 380	540	17 470	121 390
	(7 190–24 550)	(800–2 090)	(280–2 720)	(8 660–28 090)	(75 800–176 500)
$\%B_0$	Area 1	Area 2	Area 3	Mature biomass All areas	Total biomass All areas
Run 4	53	6	3	20	39
	(26–87)	(3–10)	(2–26)	(11–36)	(24–59)
Run 5	84	5	2	24	59
	(54–91)	(3–9)	(1–12)	(13–36)	(48–68)

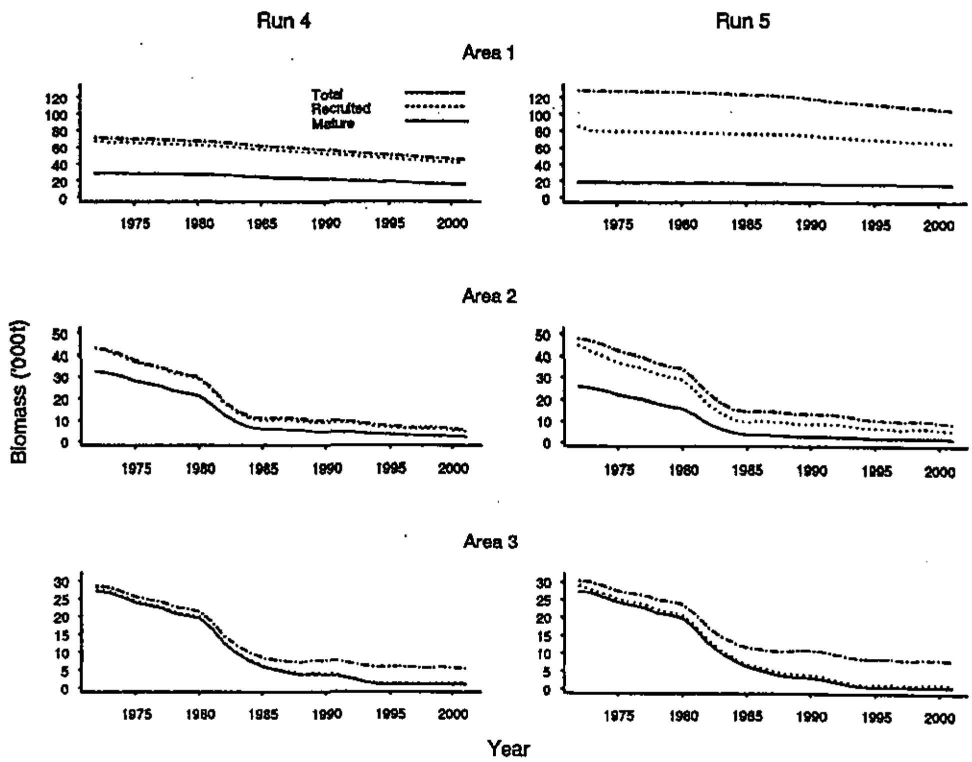

Figure 22: Mid-year biomass trajectories for runs 4 and 5. The dashed-dotted line is the total biomass (immature plus mature), the dotted line is the recruited biomass, and the solid line is mature only biomass.

5.2.3 Fits to the data

The commercial length frequencies showed some variability from year to year, even after dividing them up into the three areas. Run 5 fitted the length frequencies in areas 1 and 2 best, but run 4 fitted the length frequencies in area 3 better (Figure 23). The contribution to the log-likelihood in Table 17 shows that run 5 fitted the length frequencies better overall. In areas 1 and 2, the smaller lengths were typically under predicted and the larger lengths were over predicted. In other words, the predicted length frequency curve was shifted too much to the right. The opposite trend was observed for area 3.

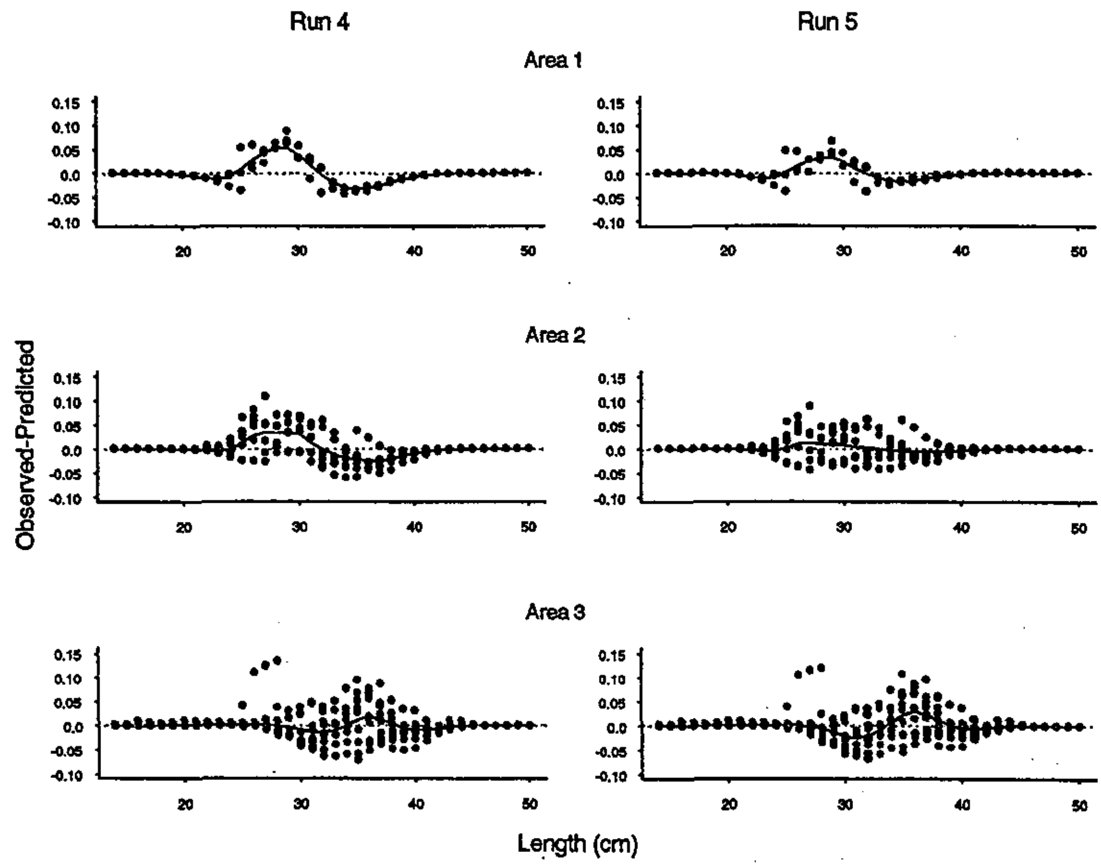

Figure 23: Residual plots from the fits to the commercial length frequencies for run 4 and 5. The solid line is a smoothed line to show possible trends.

The mean lengths from the observed commercial length frequencies were compared with the mean lengths predicted in the model (Figure 24). The mean lengths were mostly over predicted, although area 3 showed a relatively good fit except in the later years. A decreasing trend in mean length was seen in areas 2 and 3. Run 5 showed the best fit to the mean lengths over all three areas for all the runs.

The pooled length classes at each end of the acoustic length frequency were not represented very well in either run, and were over-predicted in areas 1 and 2 (Figure 25). Overall, the area 1 length frequency was predicted to be relatively flat in both runs and did not fit the peak at the smaller lengths. Areas 2 and 3 had better fits to the acoustic length frequency.

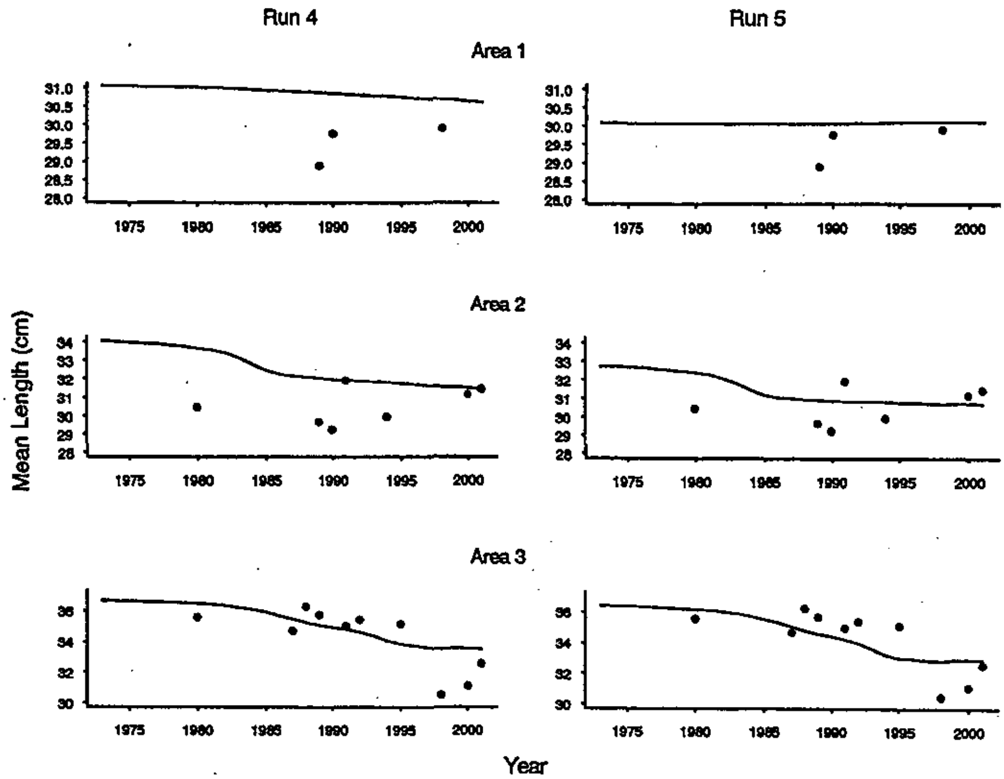

Figure 24: Mean lengths observed in the commercial length frequencies (dots) and predicted mean lengths from the spatial model (line) for the three areas and two density-dependent runs.

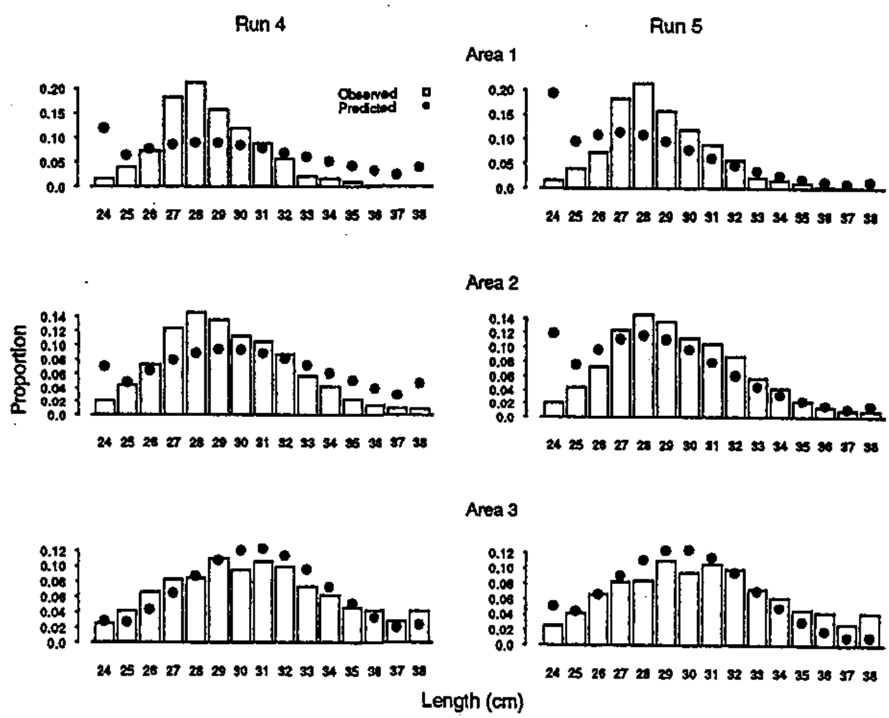

Figure 25: Fits to the acoustic length frequency data in all three areas for both density-dependent runs. Bars are the observed proportion at length (numbers of fish) and dots are the predicted proportion at length. The length class 24 cm consists of all fish less than or equal to 24 cm, and 38 cm consists of all fish greater than or equal to 38 cm.

Both CPUE series were well fitted by the model and helped to define the shape of the biomass trajectories (Figure 26). The steep decline observed in the early 1980s did not fit well in previous stock assessments, but was captured by this spatial model. An increase in the two latest CPUE indices (1999–2000 and 2000–01 fishing years) seen in areas 2 and 3 were not captured by the biomass trajectories, but they may not be representative of the post-GPS series since a different strategy was adopted by the fishery in those years, targeting black oreo more often.

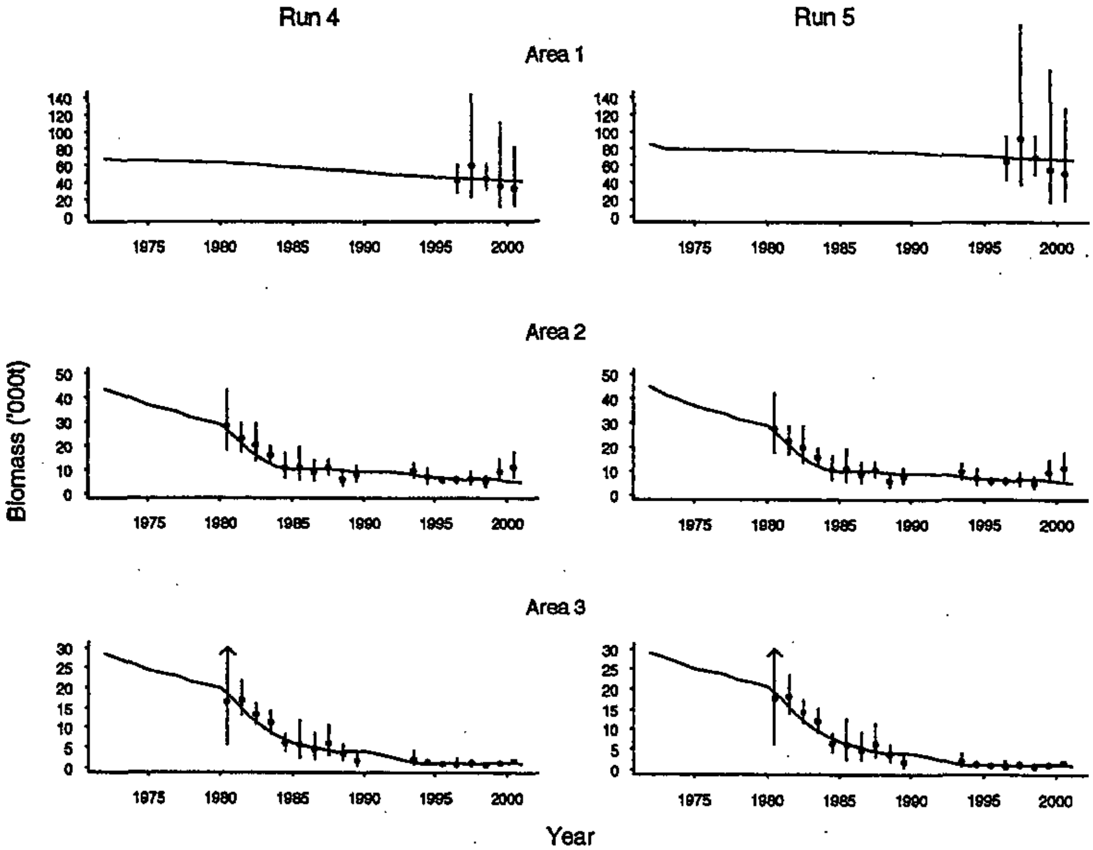

Figure 26: Recruited biomass trajectories for each area and the two density-dependent runs with CPUE indices and 95% lognormal confidence intervals overlayed. Confidence intervals that exceed the upper bound of the plot are noted with an arrow.

The spatial model was developed to mostly deal with the different mean lengths observed in different areas of OEO 3A (Doonan et al. 1999b), but a better fit to the absolute abundance estimate was also expected due to the area splits and the possibility of estimating immature mortality. The model fitted the absolute abundance in area 1 for run 5, but at the expense of overpredicting the absolute abundance in area 3 (Figure 27). Run 4 underpredicted the absolute abundance in area 1 (outside the confidence interval), but showed a better fit to the absolute abundance in area 3. Area 2 had a good fit in both runs.

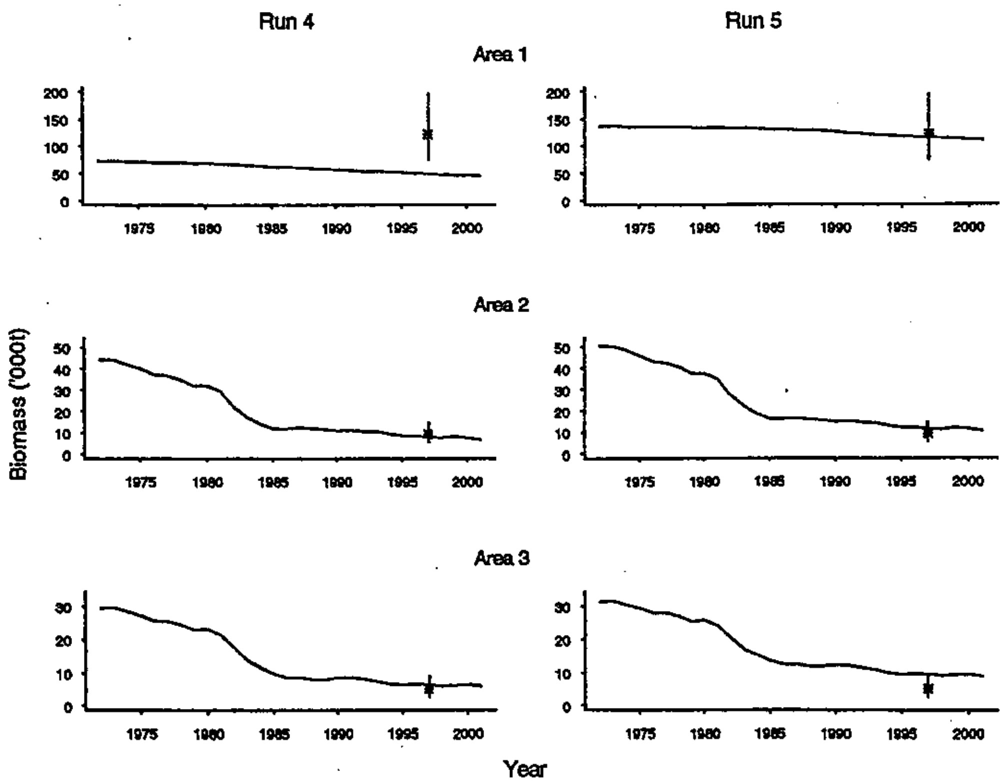

Figure 27: Total start of the year biomass trajectories for each area of runs 4 & 5 with the 1997 acoustic absolute abundance estimate and 95% confidence intervals also plotted.

5.2.4 Yields

The maximum constant yield (MCY) as reported here is the catch in all areas with reference to the recruited biomass and B_{MCY} is the average mature biomass when removing a constant catch equal to MCY. MCY was 1200 and 1600 t for runs 4 and 5 (Table 20). Under continued fishing at the MCY, B_{MCY} was 48 and 41% B_0 for runs 4 and 5.

The highest exploitation rate on the total recruited biomass, E_{CAY}, that did not reduce the mature biomass below 20% B_0, 10% of the time was 0.030 for run 4 and 0.024 for run 5. Next year's catch given E_{CAY} ($CAY_{2001-02}$) and the average catch over the forward projections ($MAY_{long-term}$) for each run are given in Table 20. The average mature biomass calculated from the projections, B_{MAY}, was 27 in run 4 and 29% B_0 in run 5.

Table 20: Estimates of MCY, CAY, and MAY (t) for the spatial model. Approximate 95% confidence bounds are given in parentheses.

	$MCY_{long-term}$	$CAY_{2001-02}$	$MAY_{long-term}$
Run 4	1 200 (900–1 400)	1 400 (1 000–1 600)	1 700 (1 200–1 900)
Run 5	1 600 (1 300–1 800)	2 100 (1 800–2 400)	2 000 (1 700–2 200)

The deterministic current surplus production (CSP) was calculated as the amount of catch in the 2001–02 fishing year (t) that can be removed with no change to the mature biomass. The same catch split as in the MCY calculations was used and no variability was introduced. Run 4 estimated a total catch of 900 t and run 5 resulted in a total catch of 2150 t (Table 21).

Table 21: Current surplus production (t) in 2001–02 as calculated in the spatial model.

	Area 1	Area 2	Area 3	All areas
Run 4	80	570	250	900
Run 5	200	1 350	600	2 150

5.2.5 Five and 10-year projections

Forward projections over the next 5 and 10 years were done to determine the probability that the projected biomass would exceed the current biomass, the probability that the projected biomass would exceed B_{MCY}, and the probability that the projected biomass would exceed B_{MAY}. A catch split of 9%, 63%, and 28% was used and recruitment variability and parameter variability were introduced, as in the MCY calculations. The probabilities for the two runs projected under different catch levels are presented in Tables 22 and 23.

Table 22: Probabilities that the mature biomass in 5 years ($B_{2005-06}$) is greater than the current biomass ($B_{2000-01}$), B_{MCY} , and B_{MAY} under different constant catch scenarios for the two cases. B_{MCY} and B_{MAY} are 48 and 27% B_0 in run 4 and 41 and 29% B_0 in run 5. The current catch limit for black oreo in OEO 3A is 2500 t (bold).

	$P(B_{2005-06}>B_{2000-01})$		$P(B_{2005-06}>B_{MCY})$		$P(B_{2005-06}>B_{MAY})$	
Annual Catch (t)	Run 4	Run 5	Run 4	Run 5	Run 4	Run 5
0	1	1	0.020	0.04	0.26	0.47
1 000	0.96	1	0.012	0.02	0.17	0.30
1 200	0.87	1	0.010	0.02	0.15	0.28
1 400	0.74	1	0.010	0.02	0.14	0.25
1 600	0.61	1	0.010	0.02	0.12	0.22
1 800	0.45	0.97	0.006	0.02	0.11	0.21
2 000	0.31	0.87	0.006	0.02	0.11	0.19
2 200	0.19	0.71	0.006	0.02	0.09	0.18
2 400	0.12	0.49	0.006	0.02	0.09	0.17
2 500	**0.08**	**0.35**	**0.006**	**0.01**	**0.08**	**0.15**
2 600	0.07	0.20	0.006	0.01	0.08	0.14
2 800	0.04	0.07	0.004	0.01	0.07	0.12
3 000	0.02	0.02	0.004	0.01	0.07	0.11

Table 23: Probabilities that the mature biomass in 10 years ($B_{2010-11}$) is greater than the current biomass ($B_{2000-01}$), B_{MCY}, and B_{MAY} under different constant catch scenarios for the two cases. B_{MCY} and B_{MAY} are 48 and 27% B_0 in run 4 and 41 and 29% B_0 in run 5. The current catch limit for black oreo in OEO 3A is 2500 t (bold).

	$P(B_{2010-11}>B_{2000-01})$		$P(B_{2010-11}>B_{MCY})$		$P(B_{2005-06}>B_{MAY})$	
Annual Catch (t)	Run 4	Run 5	Run 4	Run 5	Run 4	Run 5
0	1	1	0.041	0.25	0.61	0.85
1 000	0.99	1	0.020	0.06	0.29	0.54
1 200	0.95	1	0.016	0.04	0.24	0.48
1 400	0.82	1	0.016	0.04	0.19	0.40
1 600	0.67	1	0.016	0.03	0.17	0.34
1 800	0.48	0.97	0.014	0.02	0.14	0.29
2 000	0.31	0.84	0.010	0.02	0.11	0.23
2 200	0.18	0.59	0.006	0.02	0.10	0.20
2 400	0.09	0.32	0.006	0.01	0.09	0.17
2 500	**0.07**	**0.18**	**0.006**	**0.01**	**0.08**	**0.15**
2 600	0.05	0.09	0.006	0.01	0.07	0.13
2 800	0.02	0.02	0.004	0.01	0.06	0.09
3 000	0.01	0	0.004	0.01	0.05	0.07

6. CONCLUSIONS

This model analysed spatial complexity in the OEO 3A black oreo fishery to explain the problems observed in previous stock assessments. The steep decline in the pre-GPS standardised CPUE abundance series (approximately equivalent to the Soviet CPUE series used in previous stock assessments) now reasonably fits the model because there is a strong predicted decline in biomass in areas 2 and 3 while there is a much smaller change in biomass in area 1. The density-dependent migration fitted the data better than the age-based migrations because enough fish could move through the areas even when the stock was depressed. When using the density-dependent migration the stock was predicted to be at 20 or 24% of its initial mature biomass, depending on whether or not immature natural mortality was estimated.

Selectivity curves were estimated for each area and were found to be nearly knife-edged with a consistent increase in the age at which 50% of the fish were selected in areas 1, 2, up through 3. Doonan & McMillan (2001) calculated two non-parametric selectivity ogives for black oreo in OEO 3A, and their results suggest that the age at which 50% of the fish are selected is near 14 or 17, slightly more than the selectivities estimated in areas 2 and 3 using age-based migration, and a little less than the selectivity curve estimated in area 3 using density-dependent migration. Both of their curves were more spread out than the results here, with 95% selectivity occurring near age 35 (corresponding to a $\psi_{i,2}$ parameter approximately equal to 21 or 18).

The lack of fit to the 1999–2000 and 2000–01 CPUE data points supports the view that these years may be the start of a new CPUE time series because the recent cuts in the catch of smooth oreo have shifted the focus of fishers on to black oreo. With the addition of more fishing years, it may be advantageous to think of 1999–2000 onwards as a new CPUE series.

This model was created to deal with problems found in previous stock assessments (Annala et al. 2001) by re-specifying the model in such a way that the data differences are better explained. By allowing movement from area 1 through to area 3 and estimating separate selectivities in each area, the predicted length frequencies in each area can be different, thus allowing the model to accommodate the observed differences in mean length between the three areas. There is still some pattern in the residuals of the model fits to the data, indicating that this new model is not able to explain all the variation in the observed data, but is an improvement over previous models.

Run 5 estimated a high immature mortality, which resulted in a large biomass for area 1 and a better fit to the absolute abundance estimate in that area. However, because of the movement in the model, the large size of the biomass in area 1 flowed through to a larger predicted biomass in area 3 which exceeded the observed absolute abundance estimate in that area. This model, by predicting that small fish have a higher mortality rate than larger fish, does not entirely explain all of the acoustic observations. The high estimate of immature mortality may be trying to overcome model misspecifications, such as the possibility that the immature population in area 1 is a nursery ground for other oreo populations not included in this model. It is also possible that the absolute abundance in area 1 is biased high as a result of integrating acoustic backscatter from the midwater layer observed in that area.

The large size of the population of immature fish estimated in area 1, which is lightly fished, adds a substantial resource to the fishery. The movement assumption allowed area 1 to act as a nursery ground that can rebuild the biomass in areas 2 and 3 over time. However, because of the longevity of black oreo and the slow movement predicted in the model, it may take many years to observe an increase in mature biomass. With moderate catches, the 10 year projections (Table 23) show lower probabilities of an increase in the biomass when compared to the 5 year projections (see Table 22). This occurs because the young fish from area 1 are still migrating into areas 2 and 3 and growing older to become part of the mature biomass. An initial decline in the mature population is expected while the newly recruited fish migrate and grow to supplement the population in areas 2 and 3.

As explained in Appendix A, there was a slight misinterpretation in the maturity curve that may have actually turned out for the better. Appendix B derives an alternative maturity ogive and explores the differences seen in runs 4 and 5 when using this new ogive. In the runs where immature and mature mortalities were not estimated, but were fixed at the same values, the use of any maturity curve resulted in nearly the same fits to the data because only the spawning stock biomass was affected by the maturity ogive. Run 5 estimated immature natural mortality and kept mature natural mortality fixed, so some differences in parameter estimates occurred. However, the management implications derived from the biomass estimates did not change.

These results suggest that the model has not entirely dealt with the observation that smaller fish are present in area 1, and size increases across the areas. One improvement may be to have an age-based, density-dependent migration to allow younger fish to stay in area 1 while moving older, larger fish onwards. However, significant improvements have been made over previous models, with better fits to all of the data sources. Overall, the black oreo stock in OEO 3A is about 43–59% of B_{MCY} and 77–84% of B_{MAY}, but at the current catch levels, the biomass is likely to reduce even more. The yields and projections suggest that the catch levels should be reduced to between 1000 and 2000 t.

6.1 Management Implications

The following conclusions can be drawn from this assessment.

1. The 95% confidence interval for current biomass straddles B_{MAY} and is below B_{MCY}.

2. Yields from this stock will be low because the productivity of black oreo is low, based on unvalidated age estimates. The long-term MCY estimates of 900–1800 t are less (30–60%) than the 2000–01 black oreo catch in OEO 3A (about 3000 t; Table 2). Therefore, it seems likely that the recent catch levels of black oreo from OEO 3A are higher than the long-term sustainable yield and will not allow the stock to move towards B_{MCY}.

3. The selectivity ogives estimated in this assessment imply that the catch in areas 1 and 2 contains substantial amounts of fish that have not reached sexual maturity (Figure 22). Catches from area 3 contain mostly mature fish but the proportion of mature fish has decreased in the last 10 years of the fishery.

4. Migration from area 1 to area 2 and onward to area 3 is slow, resulting in extended periods of time to see a rebuilding in areas 2 and 3. In fact, the biomass in areas 2 and 3 may decline for a few years until fish from area 1 move into those areas. However, once the young fish move into areas 2 and 3, the biomass will increase, given low levels of fishing (see Tables 22 and 23 for projections under various catch levels).

The main sources of uncertainty for this assessment are as follows.

1. NIWA age estimates of black oreo are not validated, but the long-lived, slow-growing hypothesis is supported by two Australian age studies that used zone counts in otolith thin sections and radiometric techniques to conclude that the species reaches about 100 years.
2. Recruitment steepness. There are no data available to check the assumed value.
3. Recruitment was assumed to be deterministic, but previous stock reduction model runs suggested that either past recruitment was a lot lower than average; or that the current biomass of pre-recruits was a lot greater than average, or that natural mortality of pre-recruits was a lot higher than the recruit natural mortality; or perhaps identification of pre-recruit acoustic marks is incorrect (Doonan et al 1999b). Other interpretations are also possible. Stochastic recruitment could be considered in future assessments, but at the expense of the addition of many parameters, which was determined to not be beneficial in this assessment.

4. Stock discreteness for black oreo in areas OEO 3A and OEO 4 was assumed, based on the separation of the two fisheries by about 100 n. miles. There are no other data to help define stocks.

In spite of these uncertainties, the various model runs resulted in similar conclusions, which are stated above, suggesting that the management implications will not significantly change given slightly different assumptions.

7. ACKNOWLEDGMENTS

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APPENDIX A: SPATIAL MODEL DESCRIPTION

A full description of the black oreo spatial model is given here. First, parameters and variables are defined, next the population model is discussed, and then calculations within the model are explained. Lastly, the likelihoods used in the estimation are shown.

A.1 Parameter definitions

The model state is split into years, ages, maturity, and area. These are notated with the subscripts listed in Table A.1. Other subscripts in Table A.1 are for the different fishing gear used, and the length class used in the length frequencies.

Table A.1: Indexing subscripts used in the spatial model.

Subscript	Meaning	Definition
y	Year	The current year.
I	Initial	Denotes that the year is the initial year.
a	Age	Indexes age for age specific events; $a \geq 5$.
A	Plus age	Denotes the plus group of fish.
m	Maturity	Indexes maturity. *ma* denotes mature fish. *mi* denotes immature fish.
i or k	Area	Indexes areas 1, 2, or 3.
g	Gear	Indexes the different fishing gear.
l	Length	Indexes mid-points of length bins.

The estimated parameters consist of initial recruitment, parameters for each migration ogive, selectivity parameters for each gear and area, and juvenile (immature) natural mortality. The catchability coefficients are analytically calculated in the likelihood since the catches are assumed to be known without error. Table A.2 lists the symbols for these parameters.

Table A.2: Symbols and definitions of the estimated parameters in the spatial model.

Symbol	Meaning	Definition
R_0	Initial recruitment	Initial recruitment at the start of the model.
$\theta_{ik,n}$	Migration ogive parameters	Each of the n parameters for the migration ogive for area i to k.
$\psi_{g,i,n}$	Selectivity ogive parameters	Each of the n parameters for the selectivity ogive for gear g and area i.
M_{mi}	Natural mortality	Natural mortality rate for immature fish.
$q_{g,i}$	Catchability	The catchability for the observed indices of gear g and area a (Analytically calculated in the likelihood).

Table A.3: Symbols and definitions of fixed or calculated parameters in the spatial model.

Symbol	Meaning	Definition
$N_{y,i,a,m}$	Number of fish	Number of fish in year y, area i, of age a, and maturity state.
$\phi_{y,a,i\rightarrow k}$	Migration	Probability of moving from area i to k for an age a fish in year y.
Ω_a	Maturation	Probability of maturing for an age a fish.
M_{ma}	Natural mortality	Natural mortality rate applied to mature fish.
λ	Proportion females	Proportion of females in the population.
$\overline{w}_a$	Mean weight	Mean weight at age.
SSB_y	Spawning stock biomass	Biomass (tonnes) of mature females from all areas in year y.
h	Steepness	Steepness of the Beverton-Holt curve.
σ_R^2	Variance of recruitment	The variance of the recruitment deviates.
$C_{g,y,i}$	Catch	Catch for gear g in year y and area i.
$F_{g,y,i}$	Instantaneous fishing mortality	Instantaneous fishing mortality for gear g, in year y and area i.
$s_{g,a,i}$	Selectivity	Fishing selectivity for gear g and age a in area i.
$\overline{L}_a$	Mean length	Mean length at age from von-Bertalanffy (vB) curve.
L_∞	vB parameter	Maximum length in von-Bertalanffy curve.
K	vB parameter	von-Bertalanffy growth curve parameter.
t_0	vB parameter	von-Bertalanffy growth curve parameter.
a_{wt}	Weight paramter	Mean weight at length intercept.
b_{wt}	Weight parameter	Mean weight at length slope.
sd_a	Mean length sd	Standard deviation of the normal distribution for mean length at age.
$P_{l,y,g}$	Length frequency	Proportions of length l caught by fishery g in year y.
$E_{g,i,y}$	Predicted index	Predicted index value for gear g, area i, and year y.
$O_{g,i,y}$	Observed index	Observed index value for gear g, area i, and year y.
$c_{g,i,y}$	Index c.v.	c.v. for observed index of gear g, area i, and year y.
$B_{0,i}$	Initial biomass	Initial biomass in area i. Can be mature, total, or recruited biomass.
$B_{y,i}$	Biomass in year y	Biomass in year y. Can be mature, total, or recruited biomass.

A.2 Model assumptions

The following assumptions were made in the spatial model:

- All fish recruit into the population at age 5 and into area 1.
- Fish migrate from area 1 to area 2 and do not migrate back to area 1. The different model runs had different assumptions about migration into and out of area 3.
- A plus group was at age 70.
- There are two commercial gears. Pre-GPS is before the fishing year 1990–91, and post-GPS includes the fishing years 1990–91 and beyond.

The sequence of events in the model and the times at which predictions were calculated were:

1. Increment ages
2. Calculate age 5 fish and add to state
3. Maturation
4. Migration

5. Calculate the start of year biomasses and acoustic length frequencies for comparison to the acoustic estimates
6. Apply half mortality for midseason biomasses
7. Calculate mid-season biomasses for comparison to commercial length frequencies and CPUE indices.
8. Apply half mortality

A.3 Population model

A.3.1 Initial state

The initial state is numbers of fish at age, one year before the start of the model since the initial numbers assume no fishing mortality. Natural mortality and migration were not applied to the first age class (age 5), but were applied separately for each area and age greater than 5. The following indices are explained in Tables A.1–A.3 and refer to the initial year, area, age, and maturity. The initial numbers at age 5 are:

$$\begin{aligned} N_{I,1,5,mi} &= R_0 \quad & N_{I,1,5,ma} &= 0 \\ N_{I,2,5,mi} &= 0 \quad & N_{I,2,5,ma} &= 0 \\ N_{I,3,5,mi} &= 0 \quad & N_{I,3,5,ma} &= 0 \end{aligned}$$

The initial numbers at age greater than 5, up to 250 years beyond the age of the plus group, were calculated sequentially using the sequence of events maturation, migration, and mortality. The initial numbers in the plus groups for each area were found by summing the numbers at age greater than or equal to the plus group. The following equations, derived by reasoning that the population at age $a+1$ is the current population in area i, minus emigration, plus immigration, and multiplied by survival, were used to calculate the number in each area, maturity state, and age class.

Maturation occurred in the following way,

$$N'_{I,mi,i,a} = N_{I,mi,i,a-1}(1-\Omega_a) \qquad N'_{I,ma,i,a} = N_{I,mi,i,a-1}\Omega_a + N_{I,ma,i,a-1}$$

Then the numbers at age for mature and immature fish in each area were calculated as

$$\begin{aligned} N_{I,ma,i,a} &= e^{-M_{ma}}\left(N'_{I,ma,i,a} - N'_{I,ma,i,a}\sum_{k\neq i}^{3}\phi_{I,a,i\to k} + \sum_{k\neq i}^{3} N'_{I,ma,k,a}\phi_{I,a,k\to i}\right) \\ &= e^{-M_{ma}}\left[N'_{I,ma,i,a}\left(1-\sum_{k\neq i}^{3}\phi_{I,a,i\to k}\right) + \sum_{k\neq i}^{3} N'_{I,ma,k,a}\phi_{I,a,k\to i}\right] \\ &= e^{-M_{ma}}\left(\sum_{k=1}^{3} N'_{I,ma,k,a}\phi_{I,a,k\to i}\right) \end{aligned}$$

$$N_{I,mi,i,a} = e^{-M_{mi}}\left(\sum_{k=1}^{3} N'_{I,mi,k,a}\phi_{I,a,k\to i}\right)$$

M_{ma} and M_{mi} are the natural mortality rates for mature and immature fish, respectively, and $\phi_{y,a,k\to i}$ is the probability that in year y a fish of age a will move from area i to the current area k, in the initial time period.

To make sure that the initial numbers were at equilibrium, the population model was simulated, beginning with the above initial numbers at age, until the biomass in each area did not change by more than 0.1 tonne.

A.3.2 Recruitment

Recruitment followed a Beverton-Holt relationship parameterised with a steepness (h) of 0.75.

$$SR_y\left(SSB_{y-5}\right)=\frac{SSB_{y-5}}{SSB_0}\bigg/\left(1-\frac{5h-1}{4h}\left(1-\frac{SSB_{y-5}}{SSB_0}\right)\right)$$

The spawning stock biomass in each year (SSB_y) comes from mature female fish in all areas and was calculated immediately after aging and prior to recruitment, maturation, migration, and mortality. The biomass which contributed to the recruitment in year y was from y-5 years ago, since the age of recruitment into the population is 5.

SSB_y was calculated from the weight at age using only mature fish.

$$SSB_y=\lambda\sum_{a=5}^{A}\sum_{i=area1}^{area3}\overline{w}_a N_{y,ma,i,a}$$

where λ is the proportion of females in the population. If y-5 was less than or equal to the initial year, SSB_1 was used.

Deterministic recruitment was assumed in the model, but projections beyond the current year had recruitment deviation applied. Therefore, the number of age 5 fish in years up to and including the current year was,

$$N_{y,5}=SR(SSB_{y-5})\times R_0 .$$

When projecting beyond the current year, the number of age 5 fish was

$$N_{y,5}=SR(SSB_{y-5})\times R_0 e^{\varepsilon_{Ry}-\sigma_R^2/2} .$$

where

$$\varepsilon_{Ry}\sim N(0,\sigma_R^2).$$

A.3.3 Maturation

The probability that a fish would mature at age, given it was not mature when it reached that age (called probability of maturing or proportion maturing), was held in the vector $\mathbf{\Omega}$. This same maturity vector was applied to all areas and was estimated outside the model.

A misinterpretation in maturity resulted in maturity probabilities being used in the model other than were intended, but may have turned out for the better. The way maturation occurs in the model is to apply the probability to the number of immature fish (probability of maturing), not to apply the proportion of mature fish at age to the entire number of fish of that age (called probability mature). The use of probability of maturing occurs because maturity is a partition in the state, and thus immature fish are separate from mature fish. However, the values used in the vector $\mathbf{\Omega}$ were derived from data measuring the proportion of mature fish at age and were not translated to proportion maturing.

This proportion of mature fish at age data used to derive the vector Ω was collected from research surveys TAN9208, TAN9210, TAN9309, and TAN9406 (McMillan et al. 1997). Given 7 estimates of the proportion mature at age (Table A.4), a loess curve, with a span that had an equivalent number of 6.5 parameters, was used to obtain estimates of the proportion mature for each age. It was assumed that 100% were mature at age 70 (the plus group) and 0% were mature at the ages 17 and below. The predicted values of proportion mature at each integer age between 18 and 69 were used in the vector Ω without translating them to proportion maturing. However, one criticism of the model was that this predicted proportion of mature fish did not reach 1 soon enough, leaving a lot of old fish as immature. Because of the misinterpretation, the actual proportion mature curve is much steeper (as is seen in Figure A.1) which may be a more likely proportion mature curve. The solid line in Figure A.1 is the actual resulting proportion mature curve used in the model. The dashed-dotted line is the proportion maturing curve which was used as the vector Ω. The vertical dotted line is the knife-edged maturity used in previous stock assessments. Because the curves are actually closer to what was expected of maturity, the proportion mature is similar to the knife-edged selectivity, and using the maturity curves in the correctly interpreted manner did not result in inherent differences to the results (Appendix B), additional runs were not explicitly reported. It is recommended that in future stock assessments, the maturity is closely looked at and quality maturity probabilities are derived.

Table A.4: Estimated proportion mature from trawl survey data. Ages 17 and 70 were assumed to be 0 and 1, respectively.

Age	17.0	18.6	21.6	25.0	28.9	33.7	39.7	47.8	70.0
P(mature)	0.00	0.03	0.19	0.49	0.69	0.80	0.88	0.94	1.00

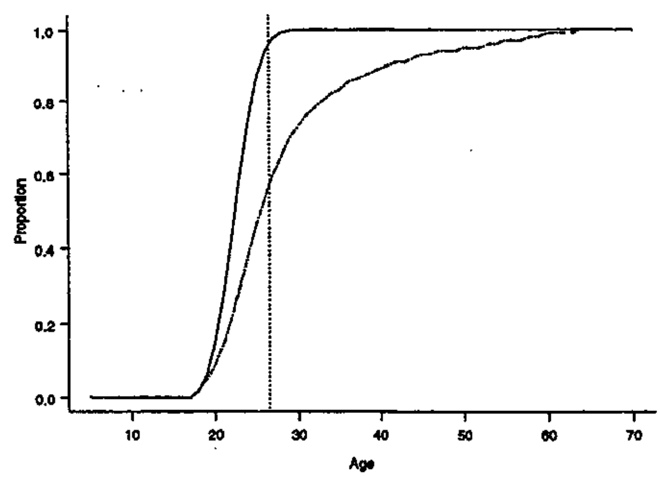

Figure A.1: The proportion of mature black oreo at age is plotted as the solid line. The dashed-dotted line represents the probability that a black oreo will mature, given it hasn't matured by that age. The vertical dotted line is the knife-edge maturity used in previous black oreo stock assessments. The dashed-dotted line was fitted to the research data in Table A.4.

After ageing at the start of the year,

$$N_{I,mi,t,a} = N_{I,mi,t,a-1} \quad a = 6,7,...A$$

maturation occurred in the following manner.

$$N'_{I,mi,i,a} = N_{I,mi,i,a}(1-\Omega_a) \qquad N'_{I,ma,i,a} = N_{I,mi,i,a}\Omega_a + N_{I,ma,i,a}$$

A.3.4 Migration

Migration occurred in one direction from area 1 to 2 to 3, and fish could move only from 1→2, 1→3, or 2→3 in one time step. Migration probabilities were calculated using different ogives to determine the probability of moving from one area to another. The probability of staying in an area is 1 minus the sum of the probabilities of moving to another area. The migration probabilities were age or year specific, depending on the ogive used, but were not specific to the maturity state.The probability of migrating from area i to k is notated as $\phi_{y,a,i\rightarrow k}$ (Table A.3). The numbers at age in each area following migration were calculated as follows.

$$N_{y,m,k,a} = \sum_{i=1}^{3} N_{y,m,i,a}\phi_{y,a,i\rightarrow k}$$

Three different ogives were used to calculate the migration probabilities in different runs. Parameters were bounded in the estimation so that probabilities remained between 0 and 1 within the range of ages, or that the exponential calculation did not cause an overflow.

Logistic ogive

A logistic curve, dependent only on age, was used in some runs where the probability of moving to the next area would increase with age. The ogive was parameterised in a way that used two easily interpretable parameters: $\theta_{ik,1}$ is the age at which a fish has a 50% probability of moving, and $\theta_{ik,2}$ is the difference, in ages between where the ogive evaluates to 95% and 50%. The curve is symmetric, thus θ_{i2} is also the difference, in ages between where the ogive evaluates to 50% and 5%.

$$\phi_{a,i\rightarrow k} = 1\Big/\left[1+19^{(\theta_{ik,1}-a)/(\theta_{ik,2})}\right]$$

A year subscript is not included because the probabilities are not year dependent.

Linear migration ogive

A linear relationship dependent only on age with a slope (θ_{i2}) and intercept (θ_{i1}) was estimated. If migration occurred only from 1→2 and 2→3, the migration probabilities would be

$$\begin{aligned} \phi_{a,1\rightarrow 2} &= \theta_{12,1} + \theta_{12,2}(age) & \phi_{a,1\rightarrow 1} &= 1-\phi_{a,1\rightarrow 2} \\ \phi_{a,2\rightarrow 3} &= \theta_{23,1} + \theta_{23,2}(age) & \phi_{a,2\rightarrow 2} &= 1-\phi_{a,2\rightarrow 3}, \end{aligned}$$

A year subscript is not included because the probabilities are not year dependent.

Density-dependent ogive

A logistic ogive was used which takes into account the biomass of the area a fish may move to. An increase in the migration rate occurs with a lower biomass, relative to the initial biomass in that area.

$$\phi_{y,l\to k} = 1/\left[1 + (100\theta_{lk,1})\exp\left(\frac{-\theta_{lk,2}}{1000}\left(B_{0,k} - B_{y,k}\right)\right)\right]$$

where $B_{0,k}$ is the initial biomass in area k, and $B_{y,k}$ is the current biomass in area k. Start of the year total biomasses are used since migration occurs before any mortality. This ogive is constant over ages, but will vary from year to year depending on the biomass that year, therefore only a year subscript is used.

A.3.5 Mortality

Natural mortality may be different for mature and immature fish in the model. Baranov mortality was used for fishery induced mortality, and assumed only one fishery operated in the areas during a specific year.

In previous stock assessments, a maximum instantaneous fishing mortality (F_{max}) was used to avoid large, unlikely catches. That idea was also adopted here, but as an exploitation rate (catch divided by recruited biomass) because the area specific selectivity curves make F_{max} difficult to interpret. If the catch in an area exceeded the maximum allowable catch determined by the maximum exploitation rate (E_{max}), the catch was reduced to the maximum allowable catch. A penalty was applied to the likelihood to keep the estimation routine from searching in parameter spaces that would exceed E_{max}.

The catches in area i for a given year were modelled as,

$$C_{g,y,l} = \sum_{\substack{a=ages\\ m=maturity}} \overline{w}_a N_{y,l,a,m} \frac{F_{g,y,l} s_{g,l,a}}{M_m + F_{g,y,l} s_{g,l,a}} \left(1 - e^{-(M_m + F_{g,y,l} s_{g,l,a})}\right).$$

The instantaneous fishing mortality, $F_{g,y,i}$, was found by iterating the following equation until successive estimates were within 0.0000001 of each other.

$$F^*_{g,y,l} = \frac{C_{g,y,l}}{\displaystyle\sum_{\substack{a=ages\\ m=maturity}} \overline{w}_{y,a} N_{y,l,a,m} \frac{s_{g,l,a}}{M_m + F_{y,l} s_{g,l,a}} \left(1 - e^{-(F_{g,y,l} s_{g,l,a} + M_m)}\right)}$$

Midseason numbers were then calculated as

$$N_{\frac{1}{2},y,l,a,m} = N_{y,l,a,m} e^{-\frac{1}{2}\left(M_m + \sum_g F_{g,y,l} s_{g,l,a}\right)}$$

and the remaining mortality was removed by applying this equation again to the midseason numbers.

A.4 Other calculations

A.4.1 Calculation of length-at-age

Length was determined from age using the von Bertalanffy curve with fixed parameters

$$\overline{L}_a = L_\infty \left(1 - e^{-K(a - t_0)}\right)$$

and assumed that the relationship was dependent only on age (i.e., same for years, areas, and maturity). The length of the plus group was set at L_∞.

A.4.2 Calculation of mean weight

The length-weight relationship was a power curve with fixed parameters,

$$\overline{W}_a = (a_{wt})(\overline{L})_a^{(b_{wt})}.$$

The parameters for combined sexes were calculated from TAN9208 survey data. This was the survey of Puysegur used by McMillan et al. (1997) to estimate natural mortality. Each observation was weighted so that the two sexes contributed equal weight to the fitting of the model, even though they had slightly different sample sizes. Log-linear least squares was used because the residuals appeared to increase with length and were stabilized by the transformation.

A.4.3 Length frequency calculations

Length frequencies from the Scientific Observer Programme were used in the model as data inputs. Expected length frequencies were calculated in the program using the distribution of mean lengths at age following an approach similar to the Coleraine model (Hilborn et al. 2000).

The von Bertalanffy curve was used to calculate mean length at age ($\overline{L}_a$) and it is assumed that the actual length at age followed a normal distribution with mean $\overline{L}_a$ and standard deviation sd_a. The standard deviation at age was assumed to be constant over all ages.

The length proportions at age were approximated using the normal distribution and size of the length bins.

$$f_{l|a} = \frac{\exp\left(\frac{(L_l - \overline{L}_a)^2}{2(sd_a^2)}\right)\Delta_l}{\sum_l \exp\left(\frac{(L_l - \overline{L}_a)^2}{2(sd_a^2)}\right)\Delta_l}$$

where L_l is the midpoint of the l^{th} length bin and Δ_l is the width of the length bin.

These proportions of length at age were used to calculate the length proportions caught in the fishery.

$$P_{l,y,g} = \frac{\sum_a \sum_m f_{l|a} s_{g,i,a} N_{y,i,a,m}}{\sum_a \sum_m s_{g,i,a} N_{y,i,a,m}}$$

A.4.4 Selectivity ogive

Selectivity was always age based. Separate selectivity curves for commercial fisheries were calculated within each area, but were assumed to be the same for pre-GPS and post-GPS fisheries. They were calculated using a logistic ogive with parameters determining at what age 50% and 95% are selected (as with the logistic migration ogive explained above).

$$s_{g,l,a} = 1/\left[1 + 19^{(\psi_{g,l,1} - a)/(\psi_{g,l,2})}\right]$$

where g indicates pre-GPS or post-GPS commercial gear.

This formulation makes the parameters easy to interpret because $\psi_{g,l1}$ is the age at which 50% of the fish are selected for and $\psi_{g,l2}$ is the distance from $\psi_{g,l1}$ in ages for 95% selectivity.

When research length frequencies were used, a double-normal selectivity curve was used to allow a declining right-hand limb (Hilborn et al. 2000). The selectivities were not area specific, thus only three parameters were estimated.

$$s_{g,l,a} = \begin{cases} \exp\left\{\dfrac{-(a - \psi_{g,l,1})^2}{\psi_{g,l,2}}\right\} & \text{for} \quad a \le \psi_{g,l,1} \\ \exp\left\{\dfrac{-(a - \psi_{g,l,1})^2}{\psi_{g,l,3}}\right\} & \text{for} \quad a > \psi_{g,l,1} \end{cases}$$

where g indicates research gear.

A.5 Estimation

Autodif (Otter Research Ltd. unpub) was used to estimate the parameters.

A.5.1 Likelihoods

Robust normal log-likelihood for proportions

The robust normal log-likelihood as proposed by Fournier et al. (1998) was used for the catch-at-size data.

$$\ln L_{1g} \propto -\tfrac{1}{2}\sum_{y}\sum_{l=1}^{N_l} \ln\left[(\xi_{l,y,g} + .1/N_l)\right] + \sum_{y}\sum_{l=1}^{N_l} \ln\left[\exp\left\{\frac{-(\tilde{P}_{l,y,g} - P_{l,y,g})^2}{2(\xi_{l,y,g} + .1/N_l)/\tau_g^2}\right\} + 0.01\right]$$

$P_{l,y,g}$ is the expected proportion of fish caught by gear g in length class l and year y, $\tilde{P}_{l,y,g}$ is the observed proportion, and $\xi_{l,y,g}$ is equal to $\tilde{P}_{l,y,g}(1 - \tilde{P}_{l,y,g})$. The observations are used to calculate $\xi_{l,y,g}$ following the results of Ernst (Ernst, B., unpublished PhD thesis, University of Washington). τ_g^2 is the assumed sample size, equal to min(N_g,1000) where N_g is the effective sample size for the proportions from gear g. Finally, N_l is the number of length classes for which proportions are calculated. Fournier et al. (1990, 1998) gave a more in-depth discussion of this likelihood.

Likelihood for biomass indices

The biomass indices were assumed to have a lognormal distribution with mean qE_y and coefficient of variation c_y. The symbol O_y will indicate an observation from year y and E_y will refer to the predicted value from the model, not corrected for the catchability of the index (q). Therefore,

$$O_y \sim LN\left(\log(qE_y) - \frac{\sigma^2}{2}, \sigma\right)$$
$$\sigma_y = \sqrt{\log(1 + c_y^{\,2})}$$

The catchability is analytically solved in the likelihood.

A.5.2 The objective function

The final objective value was the sum of all the likelihoods plus the following penalties.

A penalty on the catches is used to strongly encourage the model to stay below the maximum exploitation rate, E_{max}. Because this is a stock reduction model, the catches are assumed to be known without error. However, when E_{max} is exceeded, the observed catches will be reduced by the model. The least squares difference between the observed catches (C_O) and those predicted by the model (C_P) determines the penalty.

$$p_1 = \frac{(C_O - C_P)^2}{2[(0.01)C_O]^2}$$

A 1% coefficient of variation is used to avoid division by zero.

A selectivity penalty was used with the commercial selectivity curves to encourage the selectivity to reach 1 by age A for all areas.

$$p_2 = 100 \times \sum_g \sum_i \left(1 - s_{g,i,A}\right)$$

APPENDIX B: AN ALTERNATIVE MATURITY CURVE

This is a derivation of an alternative maturity ogive using the survey data listed in Table A.4 as proportion mature instead of proportion maturing (as explained in Appendix A). The proportion mature will be noted as α_a and the proportion maturing will be noted as Ω_a. The derivation of the proportion mature is described in Appendix A and these predicted values were used to derive the proportion maturing with the following equation.

$$\Omega_a = \frac{\alpha_a - \alpha_{a-1}}{1 - \alpha_{a-1}},$$

Proportions maturing that were undefined (due to a zero in the denominator) were set to 1. Both proportion mature and proportion maturing curves are shown in Figure B.1.

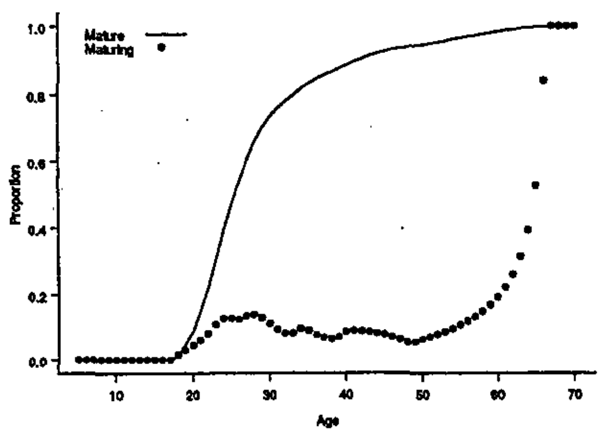

Figure B.1: Proportion mature and proportion maturing as derived from the survey data in Table A.4.

It is expected that the next age has at least the same probability of maturing as the previous age, thus the proportion maturing curve was adjusted. If a proportion maturing at age a was less than the proportion maturing at age a-1, the value at age a was set equal to the value at age a-1. This resulted in the proportion mature and proportion maturing curves shown in Figure B.2.

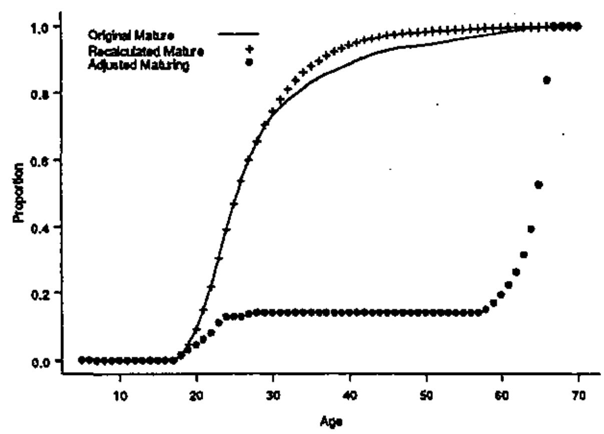

Figure B.2: Proportion mature and proportion maturing after adjusting the proportion maturing to be non-decreasing. The original proportion mature is shown as a comparison to the proportion mature as calculated from the adjusted proportion maturing.

The effect of this new maturity curve was assessed in runs 4 and 5 using the alternative adjusted maturity values. Since maturity was only a factor in determining the spawning stock biomass (SSB_y) and not to any of the fitted data, run 4 showed minor differences in the parameter estimates since immature and mature mortalities were fixed to be the same. However, run 5 estimated immature mortality and fixed mature mortality, thus differences in the parameter estimates were observed. Table B.1 shows the parameter estimates for runs 4 and 5 when using both maturity curves.

Table B.1: Parameter estimates and likelihood contributions for runs 4 and 5 when using the original maturity curve as reported in the main text, and when using the alternative maturity curve described above.

		Run 4		Run 5	
		Original	Alternative	Original	Alternative
Parameter Estimates					
R_0 (t)		2 682	2 692	14 379	11 594
Migration 1→2	$\theta_{12,1}$	0.32	0.32	0.26	0.26
	$\theta_{12,2}$	0.015	0.015	0.0017	8.07×10^{-8}
Migration 2→3	$\theta_{23,1}$	0.40	0.40	0.33	0.29
	$\theta_{23,2}$	0.083	0.082	0.088	0.076
Selectivity area 1	$\psi_{i,1}$	6.10	6.08	8.10	7.99
	$\psi_{i,2}$	0.22	0.23	0.22	0.23
Selectivity area 2	$\psi_{i,1}$	8.89	8.88	10.00	9.96
	$\psi_{i,2}$	0.24	0.24	0.24	0.27
Selectivity area 3	$\psi_{i,1}$	20.78	20.77	18.90	19.60
	$\psi_{i,2}$	1.11	1.11	1.04	1.25
Juvenile natural mortality		—	—	0.159	0.131
Likelihood Components					
Acoustic LFs		9.79	9.90	8.46	7.88
Commercial LFs		33.45	33.69	17.58	17.15
CPUE		23.67	23.81	23.12	22.81
Absolute abundance		8.29	8.22	2.52	2.25
TOTAL		75.19	75.62	51.68	50.10

With run 5, the largest difference was with the juvenile natural mortality, estimated almost 0.03 units less at 0.131. This was still enough to bring the starting total biomass in area 1 near the absolute abundance, and area 3 still overpredicted the absolute abundance outside the confidence bounds. Selectivities were relatively similar, but the migration ogives changed slightly. The migration from area 1 to 2 showed no density-dependence (small $\theta_{12,2}$ parameter) with a rate equal to the initial rate estimated using the old maturity curve. Migration from area 2 to 3 was initially higher but in the final year was nearly the same. Less biomass was moving between areas with the alternative maturity curve because less biomass was predicted overall. Table B.2 shows the migration rates and amount of biomass moving for run 5 when using the different maturity curves.

Table B.2: Migration rates and amount of biomass (t) moving in the initial and final years for run using the old and new maturity curves.

		Original		Alternative	
		Rate	Biomass	Rate	Biomass
Initial	1→2	0.038	5 200	0.038	4841
Year	2→3	0.030	1 510	0.034	1442
Final	1→2	0.040	4 460	0.038	4029
Year	2→3	0.200	2 110	0.196	1864

The biomass estimates for runs 4 and 5 using the alternative maturity curve are reported in Table B.3. The mature biomasses are considerably less because the new maturity curve leaves more old fish as immature. However, the management implications of this alternative maturity curve do not change from the results reported when using the previous maturity curve since the current area specific biomasses, as a percentage of the initial biomasses, are essentially the same (see Table 19).

Table B.3: OEO 3A black oreo mature biomass estimates from the density-dependent migration runs when using the alternative maturity ogive.

B_0				Mature biomass	Total biomass
	Area 1	Area 2	Area 3	All areas	All Areas
Run 4	23 166	27 891	25 692	76 748	143 321
Run 5	15 581	20 644	27 096	63 321	198 803

$B_{2000\text{-}01}$				Mature biomass	Total biomass
	Area 1	Area 2	Area 3	All areas	All Areas
Run 4	12 331	1 540	613	14 484	55 026
Run 5	13 814	1 119	494	15 426	116 174

$\%B_0$				Mature biomass	Total biomass
	Area 1	Area 2	Area 3	All areas	All Areas
Run 4	53	6	2	19	38
Run 5	89	5	2	24	58

Determining maturity curves in long-lived fish such as black oreos is a difficult task. There is ageing error as well as error when identifying the maturity state of an individual fish. Better defining the maturity curve for black oreo in OEO 3A is an area that needs more research and should be done before performing a new stock assessment.