ISSN 1175-1584

MINISTRY OF FISHERIES
Te Tautiaki i nga tini a Tangaroa

Assessment of OEO 4 smooth oreo for 2000–01

I. J. Doonan
P. J. McMillan
R. P. Coburn
A. C. Hart

New Zealand Fisheries Assessment Report 2001/21
May 2001

Assessment of OEO 4 smooth oreo for 2000–01

I. J. Doonan
P. J. McMillan
R. P. Coburn
A. C. Hart

NIWA
PO Box 14 901
Wellington

New Zealand Fisheries Assessment Report 2001/21
May 2001

Published by Ministry of Fisheries
Wellington
2001

ISSN 1175-1584

Citation:
Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (2001).
Assessment of OEO 4 smooth oreo for 2000–01.
New Zealand Fisheries Assessment Report 2001/21. 37 p.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (2001): Assessment of OEO 4 smooth oreo for 2000–2001.

New Zealand Fisheries Assessment Report 2001/21. 37 p.

The biomass of smooth oreo in OEO 4 was estimated from deterministic stock reduction analysis using an absolute abundance estimate from a research acoustic and trawl survey carried out in 1998 (TAN9812), relative abundance indices from standardised catch per unit effort analyses, and relative abundance indices from *Tangaroa* trawl surveys (1991–93, 1995). Biomass estimates were made for the whole of OEO 4 and also separately for the west and east parts of OEO 4 divided at 178° 20′ W. This separation was based on analysis of commercial catch, standardised CPUE, and research trawl and acoustic results which suggested distinct fisheries and fish distribution patterns for the west and east parts of OEO 4. Yields from the west and east "stocks" were moderate because the productivity of smooth oreo, based on unvalidated age estimates, is low. For the OEO 4 base case analysis (acoustic absolute abundance plus standardised CPUE relative abundance), the 95% confidence interval for B_0 was between 100 000 and 148 000 t and the 95% confidence interval for long-term MCY was 1600–2400 t. Smooth oreo mean catch per year between 1989–90 and 1998–99 from OEO 4 (about 6200 t) was higher than the range of long-term MCY. Summed biomasses and yield estimates from the separate west and east base case analyses were similar to the values for the OEO 4 base case. The west and east analyses indicated that fish from the west had been more heavily exploited than fish in the east.

1. INTRODUCTION

1.1 Overview

This work addresses the following objectives in MFish project "Oreo stock assessment" (OEO1999/02).

Overall objective

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

Specific objectives

2. To analyse length frequency, sex ratio, and reproductive condition data for black oreo and smooth oreo collected by the Scientific Observer Programme and other sources and from research projects OEO9801 and ORH9801 during the 1998/99 fishing year for input into stock assessment models.
3. To conduct a stock assessment for black oreo and smooth oreo in OEO 4, including estimating biomass and sustainable yields.

A new stock assessment for smooth oreo in OEO 4 is presented based on the first estimates of absolute abundance for smooth oreo from research acoustic survey data, abundance indices from a new standardised CPUE analysis, and past relative abundance estimates from trawl surveys. The last major assessment was that of Doonan et al. (1997a). Estimates of biomass and yields were modelled using deterministic recruitment (knife-edge at 34 cm TL), and incorporated the 1997 biological parameters and an updated catch history.

1.2 Description of the fishery

Smooth oreo are caught by trawling at depths of 800–1300 m in southern New Zealand waters (Figure 1). The OEO 4 south Chatham Rise fishery is the largest oreo fishery in the EEZ (see Table 2) and operates between 176° E and about 172° W mostly on undulating terrain (short plateaus, terraces, and "drop-offs") at the west end, and mostly on seamounts in the east. Most smooth oreo is caught as a bycatch to orange roughy fishing. Black oreo is the other main species caught and has been a small bycatch from 1994–95 to 1998–99.

1.3 Literature review

The literature was summarised by McMillan et al. (1988), McMillan & Hart (1991), and Doonan et al. (1995a, 1996, 1997a). Age estimates for Chatham Rise smooth oreo were given by Doonan et al. (1995b, 1997b). The 2000 stock assessment was summarised by Annala et al. (2000). Fincham et al. (1991) summarised oreo catches from 1972 to 1988, and McMillan & Hart (1994a, 1994b, 1994c, 1995) and Hart & McMillan (1998) reported on annual south Chatham Rise relative abundance trawl surveys from 1990 to 1995.

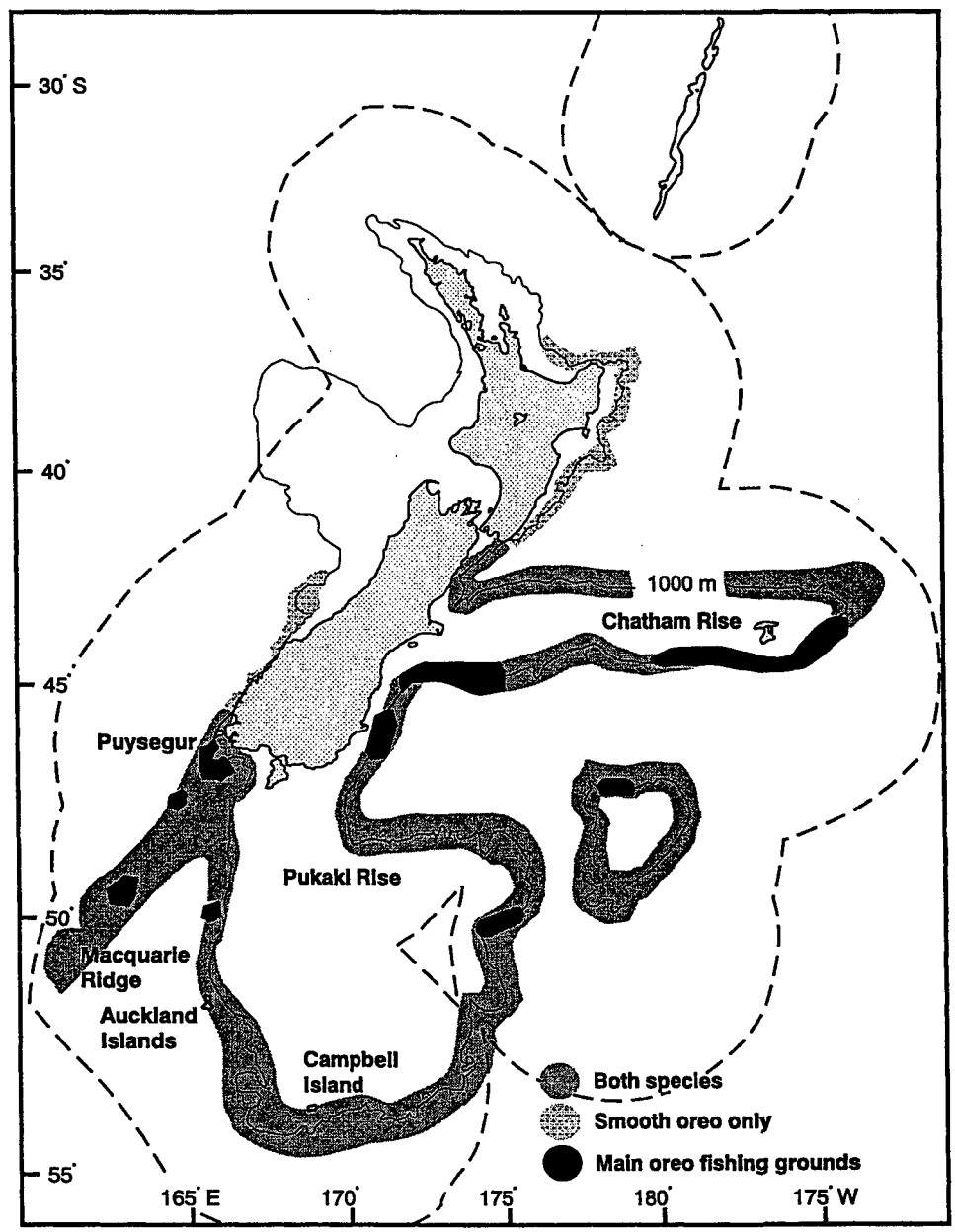


Figure 1: Approximate location of main fishing grounds and distribution of black oreo and smooth oreo. Dashed line is the EEZ boundary.

2. REVIEW OF THE FISHERY

2.1 TACCs, 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.

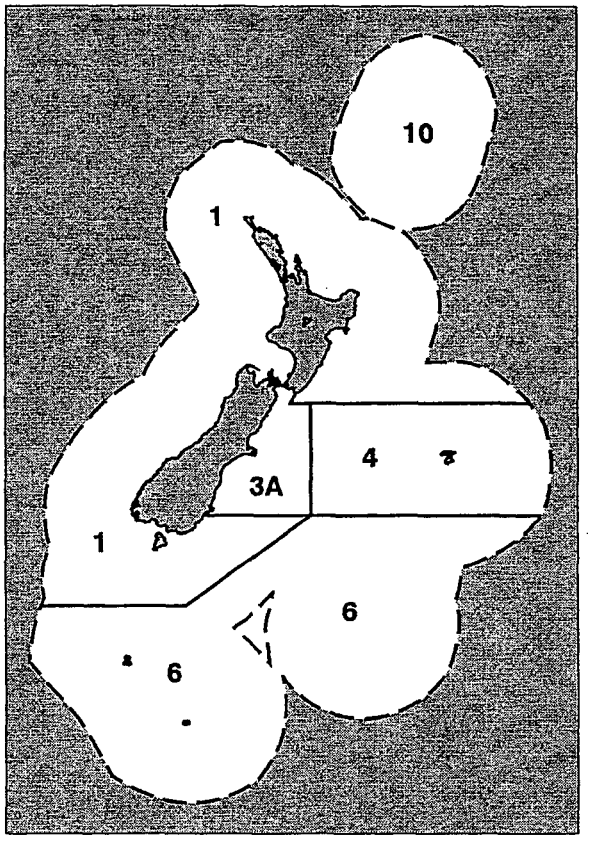


Figure 2: Oreo management areas.

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 ITQ scheme was introduced in 1986, the statutory requirement was only for the combined code (OEO) for the Quota Management Reports, and consequently some loss of separate species catch information has occurred even though most vessels catching oreos are requested to record the species separately in the catch-effort logbooks.

Reported landings of oreos (combined species) and TACs from 1978–79 until 1998–99 are given in Table 1. The OEO 4 TAC has been about 7000 t from 1982–83 to 1999–2000. Reported estimated catches by species from tow by tow data recorded in catch and effort logbooks (Deepwater, TCEPR, and CELR) are given in Table 2. Soviet catches from the New Zealand area from 1972 to 1977 were assumed to be black oreo and smooth oreo combined and to be from area OEO 3A (Doonan et al. 1995a).

Table 1: Total reported landings (t) for all oreo species combined by Fishstock from 1978–79 to 1998–99 and TACs (t) from 1982–83 to 1998–99.

Fishing	OEO 1		OEO 3A		OEO 4		OEO 6		Totals	
year	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC
1978–79*	2 808	–	1 366	–	8 041	–	17	–	12 231	–
1979–80*	143	–	10 958	–	680	–	18	–	11 791	–
1980–81*	467	–	14 832	–	10 269	–	283	–	25 851	–
1981–82*	21	–	12 750	–	9 296	–	4 380	–	26 514	–
1982–83*	162	–	8 576	10 000	3 927	6 750	765	–	13 680	17 000
1983–83#	39	–	4 409	#	3 209	#	354	–	8 015	#
1983–84†	3 241	–	9 190	10 000	6 104	6 750	3 568	–	22 111	17 000
1984–85†	1 480	–	8 284	10 000	6 390	6 750	2 044	–	18 204	17 000
1985–86†	5 390	–	5 331	10 000	5 883	6 750	126	–	16 820	17 000
1986–87†	532	4 000	7 222	10 000	6 830	6 750	0	3 000	15 093	24 000
1987–88†	1 193	4 000	9 049	10 000	8 674	7 000	197	3 000	19 159	24 000
1988–89†	432	4 233	10 191	10 000	8 447	7 000	7	3 000	19 077	24 233
1989–90†	2 069	5 033	9 286	10 106	7 348	7 000	0	3 000	18 703	25 139
1990–91†	4 563	5 033	9 827	10 106	6 936	7 000	288	3 000	21 614	25 139
1991–92†	4 156	5 033	10 072	10 106	7 457	7 000	33	3 000	21 718	25 139
1992–93†	5 739	6 044	9 290	10 106	7 976	7 000	815	3 000	23 820	26 160
1993–94†	4 910	6 044	9 106	10 106	8 319	7 000	983	3 000	23 318	26 160
1994–95†	1 483	6 044	6 600	10 106	7 680	7 000	2 528	3 000	18 291	26 160
1995–96†	4 783	6 044	7 786	10 106	6 806	7 000	4 435	3 000	23 810	26 160
1996–97†	5 181	6 044	6 991	6 600	6 962	7 000	5 645	6 000	24 779	25 644
1997–98†	2 681	6 044	6 336	6 600	7 010	7 000	5 222	6 000	21 249	25 644
1998–99†	4 102	5 033	5 501	6 600	6 931	7 000	5 287	6 000	21 821	24 633

Source: FSU from 1978–79 to 1987–88; QMS/MFish from 1988–89 to 1998–99. * 1 April to 31 March. # 1 April to 30 September. Interim TACs applied. † 1 October to 30 September.

Table 2: Reported estimated catch (t) by species (smooth oreo (SSO), black oreo (BOE), by Fishstock from 1978–79 to 1998–99 and the ratio (percentage) of the total estimated SSO plus BOE, to the total reported landings (from Table 1). –, less than 1.

	SSO				BOE					
Year	OEO 1	OEO 3A	OEO 4	OEO 6	OEO 1	OEO 3A	OEO 4	OEO 6	Total estimated	Estimated:landings (%)
1978–79*	0	0	0	0	9	0	0	0	9	–
1979–80*	16	5 075	114	0	118	5 588	566	18	11 495	98
1980–81*	1	1 522	849	2	66	8 758	5 224	215	16 637	64
1981–82*	21	1 283	3 352	2	0	11 419	5 641	4 378	26 096	98
1982–83*	28	2 138	2 796	60	6	6 438	1 088	705	13 259	97
1983–83#	9	713	1 861	0	1	3 693	1 340	354	7 971	100
1983–84†	1 246	3 594	4 871	1 315	1 751	5 524	1 214	2 254	21 769	99
1984–85†	828	4 311	4 729	472	544	3 897	1 651	1 572	18 004	99
1985–86†	4 257	3 135	4 921	72	1 060	2 184	961	54	16 644	99
1986–87†	326	3 186	5 670	0	163	4 026	1 160	0	14 531	96
1987–88†	1 050	5 897	7 771	197	114	3 140	903	0	19 072	100
1988–89†	261	5 864	6 427	–	86	2 719	1 087	0	16 444	86
1989–90†	1 141	5 355	5 320	–	872	2 344	439	–	15 471	83
1990–91†	1 437	4 422	5 262	81	2 314	4 177	793	222	18 708	87
1991–92†	1 008	6 096	4 797	2	2 384	3 176	1 702	15	19 180	88
1992–93†	1 716	3 461	3 814	529	3 768	3 957	1 326	69	18 640	78
1993–94†	2 000	4 767	4 805	808	2 615	4 016	1 553	35	20 599	88
1994–95†	835	3 589	5 272	1 811	385	2 052	545	230	14 719	81
1995–96†	2 517	3 591	5 236	2 562	1 296	3 361	364	1 166	20 093	84
1996–97†	2 203	3 063	5 390	2 492	2 578	3 549	530	1 950	21 755	88
1997–98†	1 510	4 790	5 868	2 531	1 027	1 623	811	1 982	20 142	95
1998–99†	2 904	2 363	5 638	3 344	782	2 716	840	1 211	19 798	91

Source: FSU from 1978–79 to 1987–88 and MFish from 1988–89 to 1998–99
*, 1 April to 31 March..# ,1 April to 30 September. † ,1 October to 30 September.

2.1.1 CPUE analysis

The following is a summary of the analysis described by Coburn et al. (2001).

Data

The catch and effort data were restricted to that area within OEO 4 (the "study area") where the main smooth oreo fishery occurred from 1978–79 to 1998–99 (see Figure 1 in Coburn et al. 2001). Data from OEO 4 were divided into target smooth oreo and bycatch smooth oreo and into pre- and post-global positioning system (GPS) with a further subdivision into west and east of 178° 12.6′ W.

East and west analyses

Initial analysis of OEO 4 oreo catch data showed marked changes in fishing patterns over time. This involved a progression of high catches over time starting in the west and moving east and appeared to represent successive exploitation of new areas (Figure 3). Areas in the west previously exploited did not later return to sustained high catches. The target species and the type of fishing changed over time with smooth oreo the target species in the west on flat, dropoff, and seamounts from the late 1970s, with a gradual change to target fishing for orange roughy on seamounts in the east in the late 1980s (Figure 4). To achieve a consistent CPUE series, the catch data were therefore split at 178° 12.6′ W into a west series from 1979–80 to 1988–89 and an east series from 1992–93 to 1998–99 (Coburn et al. 2001). The intermediate years (1989–90 to 1991–92) represented a period of rapid improvement of fishing ability due largely to the introduction of GPS which gave continuous update of vessel position and allowed seamounts to be fished at any time of the day. Previous positioning systems gave only irregular single estimates of position (fixes) and position estimates were calculated by dead reckoning (based on vessel speed, direction, etc.) in the interval between fixes.

Method of CPUE analysis

The CPUE analysis method was described by Doonan *et al.* (1995a, 1996, 1997a) and involved regression based methods where the zero catch tow and the positive catch tow data were analysed separately to produce positive catch and zero catch indices. For target fishing, a combined index was calculated (see Coburn et al. 2001). The predictor variables considered in the analysis included axis-position (position along a line drawn west to east through the fished band along the continental slope of the south Chatham Rise), depth, season, time, seamount (indicates if a tow starts within 5 km of a known seamount), and vessel. The reference year can be any year but was arbitrarily assigned to a year near the middle of the time series. Annual c.v.s for the combined indices were estimated using a jackknife technique (Doonan et al. 1995a). The mean c.v. for the series was then calculated by dividing the square root of the mean of the squared annual c.v.s. (excluding the reference year c.v. = 0) by the square root of 2. This approximately estimates c.v. for the target year by converting the variability in the reference and target years into a single year estimate.

For the smooth oreo (SSO) and unspecified oreo (OEO) target fisheries combined indices were used in the stock reduction, but for bycatch fisheries (orange roughy target fishing) only the positive catch indices were used in the stock reduction analyses.

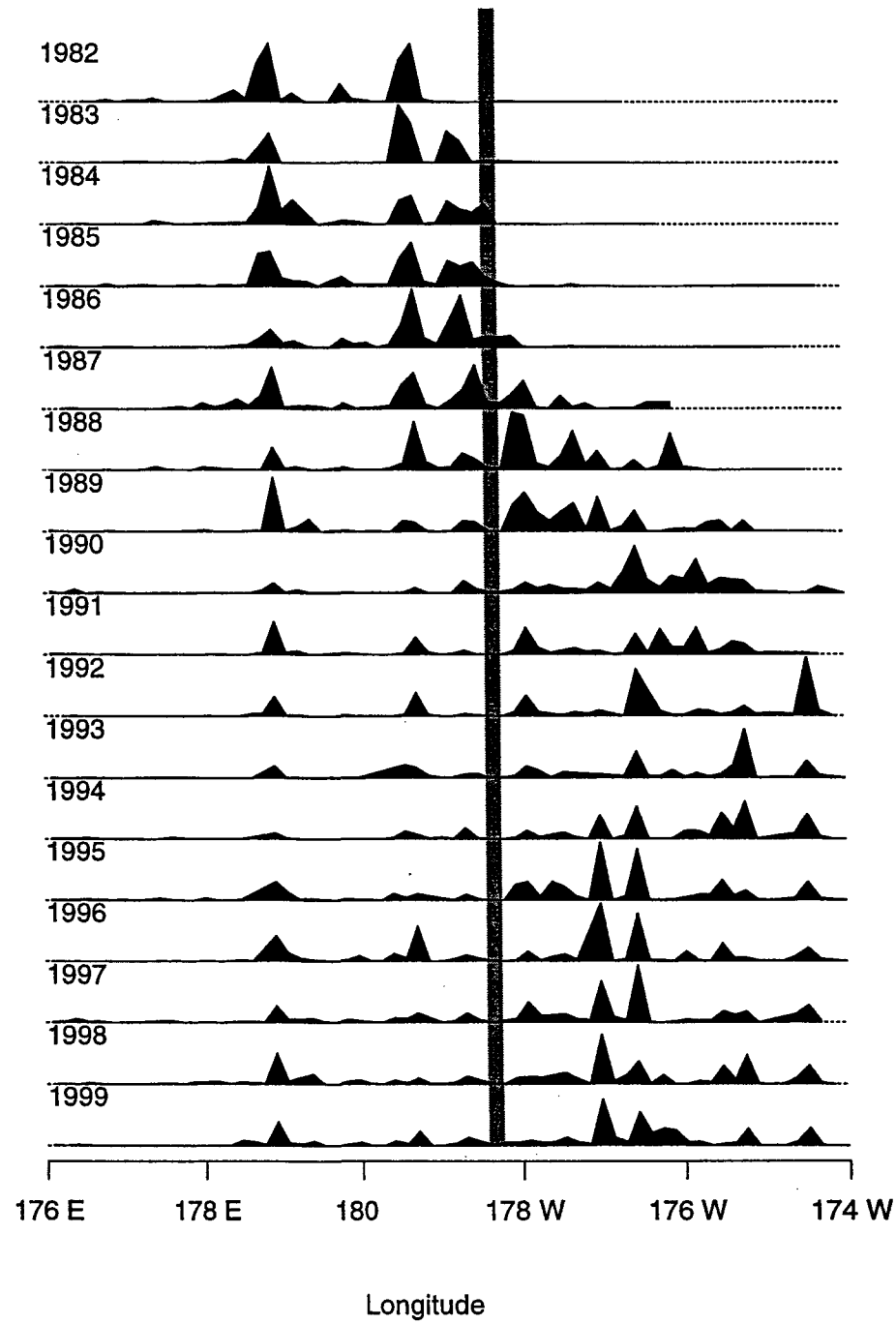


Figure 3: All estimated reported catches of smooth oreo (black shading, t) by longitude over time from OEO 4 on the south Chatham Rise between 176° E and 174° W, south of 44° S. Years are fishing years, e.g., 1982 is 1981–82. There were low reported catches of smooth oreo before 1981–82 so 1982 includes that year plus prior catches. Vertical scale is 1000 t between years (horizontal lines). The vertical line at 178° 20' W marks the split between west and east parts of OEO 4.

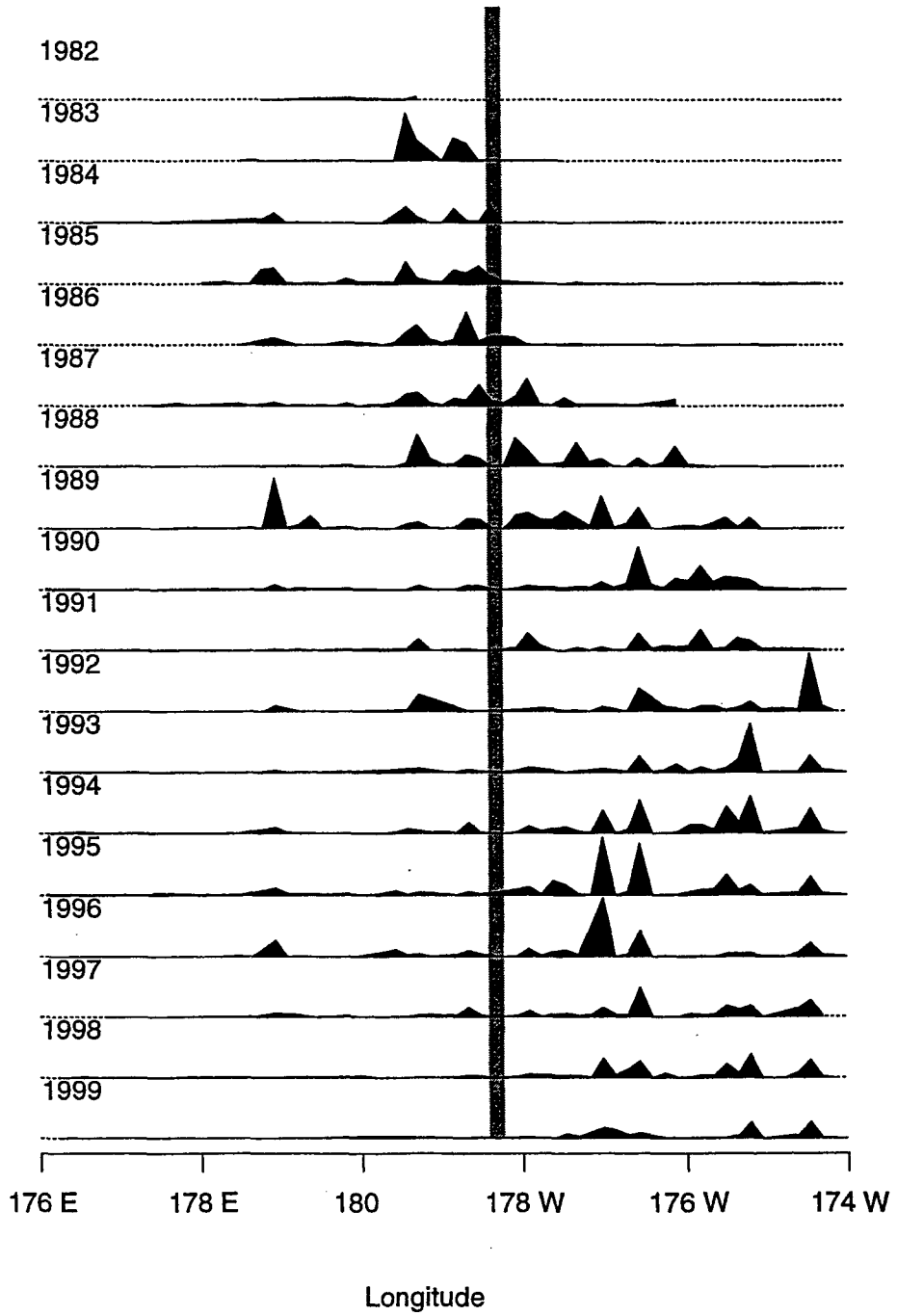


Figure 4: **Estimated reported catches of smooth oreo (black shading, t) where target species was orange roughy, by longitude over time from OEO 4 on the south Chatham Rise between 176° E and 174° W, south of 44° S. Years are fishing years, e.g., 1982 is 1981–82. There were low reported catches of smooth oreo before 1981–82 so 1982 includes that year plus prior catches. Vertical scale is 1000 t between years (horizontal lines). The vertical line at 178° 20' W marks the split between west and east parts of OEO 4.**

Results of CPUE analysis

Six analyses were carried out: target smooth oreo or unspecified oreo pre-GPS, target smooth oreo or unspecified oreo post-GPS, bycatch smooth oreo (target orange roughy) pre-GPS, bycatch smooth oreo (target orange roughy) post-GPS, target smooth oreo or unspecified oreo post-GPS west, target smooth oreo or unspecified oreo post-GPS east (Coburn et al. 2001), but only four were chosen for use in the stock reduction model analyses. Three satisfied the criteria of preferring the target smooth oreo or unspecified oreo analyses to bycatch analyses, but the bycatch post-GPS series (7 years) was used instead of the target smooth oreo or unspecified oreo post-GPS east series because the latter had only 4 years in the series including one where the jacknife c.v. was 236%.

a Target SSO, pre-GPS series. Data used were from 1981–82 to 1988–89 and were mainly from the west. The final model for positive catch used vessel, season, and axis-position and that for zero catch used vessel, axis-position, and season. The combined index from the final year was approximately half that of the first year (Table 3a). The overall mean c.v. (applied across the series including the reference year) was 29%.

b Target SSO or OEO, post-GPS series. Data used were from 1992–93 and 1994–95 to 1998–99 and were from east and west. The final model for positive catch used season, depth, vessel, and axis-position and that for zero catch used vessel, axis-position, year, depth, and season. The combined index changed little over time (Table 3b). The overall mean c.v. (applied across the series including the reference year) was 38%.

c Target SSO or OEO, post-GPS west series. Data used were from 1992–93 and 1995–96 to 1998–99. The final model for positive catch used depth, season, axis-position, vessel, and year and that for zero catch used axis-position, vessel, year, time, depth, and season. The final combined index was approximately twice that of the first year index (Table 3c). The overall mean c.v. (applied across the series including the reference year) was 60%.

d Bycatch post-GPS series. Data used were from 1992–93 to 1998–99 and were mainly from the east. The final model for positive catch used axis-position, vessel, season, and depth. The positive catch index in the last year was about two-thirds that of the first year (Table 3d). The overall mean c.v. (applied across the series including the reference year) was 25%.

2.2 Other information

Descriptive length distribution and mean length

Data collected from the commercial fishery by observers are described. A separate analysis of the potential use of length data (observer and research survey) for stock assessment modelling was carried out. Mean total length (TL) per year was estimated for males and females from all observer length data collected from commercial vessels fishing in OEO 4. Data from the observer database (Obs_lf) from the south Chatham Rise between 176° E and 174° W south of 44° S from 1979 to 1999 (calendar year) were extracted for tows where target species was smooth oreo, black oreo, unspecified oreo, or orange roughy only (oreo samples from tows where the target was hoki were excluded as they do not represent the fish at depths exploited in the target oreo or orange roughy fisheries). Mean lengths for the data from OEO 4 (as defined above) are in given Table 4, numbers of tows sampled are shown in Table 5, and numbers of fish measured are given in Table 6. Annual length distributions scaled by catch size for OEO 4 data are shown in Appendix 1. The data suggest a decline in mean length over time from 1988 to 1999 (years when there were at least 1000 fish measured) for males, females and sexes combined (Table 4).

Table 3: Smooth oreo time series of combined and positive catch abundance indices from standardised CPUE analyses.

Year	Combined index	Jackknife c.v.
(a) Target SSO pre-GPS		
1981–82	1.66	27.4
1982–83	1.61	22.9
1983–84	1.24	40.0
1984–85	1.00	0.0
1985–86	1.19	34.8
1986–87	1.17	55.2
1987–88	1.05	59.8
1988–89	0.81	28.5
(b) Target OEO/SSO post-GPS		
1992–93	0.82	37.1
1994–95	1.12	45.5
1995–96	0.66	80.3
1996–97	1.00	0.0
1997–98	0.80	59.6
1998–99	0.80	28.4
(c) Target OEO/SSO post-GPS, west		
1992–93	0.41	144.0
1995–96	0.56	67.6
1996–97	1.00	0.0
1997–98	0.81	26.7
1998–99	0.86	52.4
(d) Bycatch post-GPS		
1992–93	1.22	35.9
1993–94	1.01	15.2
1994–95	1.00	0.0
1995–96	0.83	68.0
1996–97	1.28	12.4
1997–98	0.82	18.1
1998–99	0.81	26.1

Table 4: Smooth oreo mean length (cm) for males, females and both sexes combined (Total) from samples taken by observers in OEO 4 from 1979 to 1999 from all vessels, scaled to catch. See Table 5 for numbers of tows, and Table 6 for numbers of fish sampled.

Year	Total	Males	Females
1986	38.4	37.6	39.5
1987	36.7	35.2	38.8
1988	39.0	37.3	40.7
1989	39.2	37.5	40.4
1990	37.6	36.4	38.7
1991	36.8	35.7	37.9
1992	35.9	34.5	37.3
1993	37.4	36.3	38.5
1994	35.3	34.6	36.2
1995	37.5	36.5	38.6
1996	36.4	35.8	37.1
1997	38.0	36.9	39.2
1998	35.2	34.2	35.9
1999	37.5	36.3	38.6

Data were also split into five major fishing areas plus the remaining area within OEO 4 because of known spatial and temporal fishing patterns for oreos in OEO 4 (Coburn et al. 2001):

Area 1 178° E to 177° 08' W. Flat ground and dropoffs excluding seamounts (includes Bobbin Tow and Urk).

Area 2 177° 08' W to 176° 16' W. Includes seamounts such as Hegerville and Paranoia.

Area 3 176° 16' W to 175° W. Includes seamounts such as Condoms and Big Chief.

Area 4 175° to 174° W. Includes the Andes.

Area 5 178° E to 177° 08' W. Seamounts only including Trev's and Mt Kiso.

Rest The remainder of OEO 4 south of 44° S.

The number of tows sampled and the number of fish measured for these areas are given in Tables 5 and 6. The length distributions scaled to catch for these areas by year are plotted in Appendices 2–6. The estimated mean lengths for males and females by area by year scaled to catch (Tables 7 and 8) suggest a decline in mean length over time (years when there were at least 1000 fish measured) for areas 1 and 4 (males and females), with no change in areas 2 and 3 over time. Other areas had too few data (Tables 7 and 8).

Table 5: Numbers of tows where smooth oreo length/sex samples were taken by observers in OEO 4 from 1979 to 1999 from all vessels. Area 1 - 178° E to 177° 08' W, flat ground and dropoffs excluding seamounts. Area 2 - 177° 08' W to 176° 16' W. Area 3 - 176° 16' W to 175° W. Area 4 - 175° to 174° W. Area 5 - 178° E to 177° 08' W, seamounts only. Rest - the remainder of OEO 4 south of 44° S.

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Rest of OEO 4	Total
1986	2	0	0	0	0	0	2
1987	5	0	0	0	0	0	5
1988	9	0	0	0	0	0	9
1989	7	0	0	0	0	1	8
1990	8	2	18	0	5	0	33
1991	18	5	4	46	7	1	81
1992	0	0	3	9	0	0	12
1993	2	8	28	33	0	0	71
1994	6	29	17	39	0	0	91
1995	10	13	8	5	4	0	40
1996	13	16	2	1	3	0	35
1997	7	19	8	4	1	2	41
1998	12	29	0	0	2	0	43
1999	4	12	6	0	3	1	26

Table 6: **Numbers of fish measured for smooth oreo length/sex samples taken by observers in OEO 4 from 1979 to 1999 from all vessels. See Table 5 for explanation of areas.**

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Rest of OEO 4	Total
1986	307	0	0	0	0	0	307
1987	685	0	0	0	0	0	685
1988	1 207	0	0	0	0	0	1 207
1989	1 024	0	0	0	0	105	1 129
1990	1 376	210	2 070	0	779	0	4 435
1991	2 141	495	684	4 132	631	102	8 185
1992	0	0	328	986	0	0	1 314
1993	147	853	2 680	3 372	0	0	7 052
1994	616	3 154	1 544	4 325	0	0	9 639
1995	1 085	1 460	952	528	330	0	4 355
1996	1 653	2 027	205	196	353	0	4 434
1997	774	2 230	793	398	111	195	4 501
1998	1 279	4 530	0	0	202	0	6 011
1999	480	1 509	572	0	414	107	3 082

Table 7: **Mean length (cm TL) of male smooth oreo from samples taken by observers in OEO 4 scaled to catch from 1979 to 1999 from all vessels. See Table 5 for explanation of areas. –, no data.**

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Rest of OEO 4
1986	37.6	–	–	–	–	–
1987	35.2	–	–	–	–	–
1988	37.3	–	–	–	–	–
1989	37.7	–	–	–	–	32.7
1990	36.7	36.1	36.8	–	35.1	–
1991	34.3	34.8	35.5	37.3	34.8	36.0
1992	–	–	34.1	34.8	–	–
1993	35.2	35.0	36.3	36.9	–	–
1994	34.9	33.0	36.6	36.4	–	–
1995	35.5	37.4	37.0	35.5	35.5	–
1996	35.1	36.3	39.2	36.3	34.8	–
1997	35.2	38.0	37.2	35.9	34.2	33.9
1998	33.2	34.5	–	–	32.8	–
1999	33.1	37.5	36.7	–	35.7	36.9

Table 8: **Mean length (cm TL) of female smooth oreo from samples taken by observers in OEO 4 scaled to catch from 1979 to 1999 from all vessels. See Table 5 for explanation of areas. –, no data.**

Year	Area 1	Area 2	Area 3	Area 4	Area 5	Rest of OEO 4
1986	39.5	–	–	–	–	–
1987	38.8	–	–	–	–	–
1988	40.7	–	–	–	–	–
1989	40.8	–	–	–	–	32.4
1990	38.0	37.5	39.7	–	36.6	–
1991	35.8	35.9	37.3	40.6	36.1	37.2
1992	–	–	34.5	38.4	–	–
1993	36.4	37.2	38.1	39.7	–	–
1994	36.7	33.7	38.2	39.2	–	–
1995	37.6	39.5	38.9	36.8	37.0	–
1996	36.6	37.5	42.4	37.7	35.4	–
1997	37.2	40.6	40.0	37.8	33.8	34.0
1998	33.7	36.3	–	–	32.6	–
1999	34.2	39.8	39.2	–	38.5	39.7

Descriptive female gonad stage data

Gonad stage data from females sampled by observers on commercial vessels fishing in OEO 4 were selected from the observer database (Obs_lf) from the south Chatham Rise between 176° E and 174° W south of 44° S from 1979 to 1999 from all tows where smooth oreo gonad stage data were collected (Table 9). The staging definitions used for these data are uncertain and may be a mixture of the four stage oreo scale and the five stage orange roughy scale provided in the observer manual. In the five stage scale stages 3 and 4 are equivalent to stage 3 in the four stage scale. The data suggest that smooth oreo spawn from October to December and this is consistent with research results (Annala et al. 2000).

Table 9: Percentage female gonad stages by month for smooth oreo from observed trawls in OEO 4, from 1990–91 to 1999–00, all years combined. n, number of fish sampled. –, less than 1 %.

	Gonad stage					
Month	1	2	3	4	5	n
Jan	48	43	9	0	0	303
Feb	29	67	4	0	0	576
Mar	67	33	1	0	0	462
Apr	53	45	1	0	0	1 142
May	61	36	3	0	0	3 228
Jun	44	45	11	0	0	940
Jul	17	83	0	0	0	72
Aug	6	87	3	0	4	839
Sep	64	29	7	–	0	2 873
Oct	57	24	16	2	–	3 798
Nov	49	28	22	1	0	2 023
Dec	65	23	8	5	0	1 092

2.3 Recreational and Maori customary fisheries

There is no known recreational or Maori customary catch of oreos.

2.4 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).

3. RESEARCH

3.1 Stock structure

Stock structure of Australian and New Zealand samples of smooth oreo were examined using genetic (allozyme and mitochondrial DNA) and morphological counts (fin rays, etc.). No differences between New Zealand and Australian smooth oreo samples were found using these techniques (Ward et al. 1996). A broad scale stock is suggested by these results but this seems unlikely given the large

distances between New Zealand and Australia. A New Zealand pilot study examined smooth oreo stock relationships using samples from four management areas (OEO 1, OEO 3A, OEO 4, and OEO 6) of the New Zealand EEZ. Techniques used included genetic (nuclear and mitochondrial DNA), lateral line scale counts, settlement zone counts, parasites, otolith microchemistry, and otolith shape. Otolith shape from OEO 1 and OEO 6 was different to that from OEO 3A and OEO 4 samples. Weak evidence from parasite data, one gene locus, and otolith microchemistry suggested that OEO 3A samples were different from those from other areas. Lateral line scale and otolith settlement zone counts showed no differences between areas (Smith et al. 1999).

3.2 Resource surveys

Trawl surveys

Trawl surveys of oreos on the south Chatham Rise were carried out in seven years between 1986 and 1995 (Table 10). The abundance estimates from the surveys before 1991 were not considered to be comparable with the *Tangaroa* series because different vessels were used. Other data from those early surveys were used, e.g., gonad staging to determine length at maturity. The 1991–93 and 1995 "standard" (flat, undulating, and drop-off ground) surveys are comparable.

Table 10: 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

Abundance estimates were made, using knife-edge recruitment at 34 cm TL, for the whole of the trawl survey area, but also for west and east parts split at 178° 20′ W (a stratum boundary) (Table 11). The east/west estimates were made to correspond to the standardised CPUE abundance estimates (see Section 2.1.1), but there are changes in fish distribution along the west/east axis of OEO 4 suggested by research trawl survey data, e.g., recruit black oreo were abundant on the flat in the west but at low abundance on the flat in the east and orange roughy were more abundant on the flat in the east than the west (Hart & McMillan 1998).

Table 11: Research survey recruit abundance estimates for smooth oreo (t) from the south Chatham Rise, OEO 4. N is the number of stations. Estimates were made based on a recruited length of 34 cm TL using the distance between the wings of the net.

	Mean abundance	c.v. (%)	N
OEO 4			
1991	133 492	30	110
1992	83 550	33	122
1993	71 982	23	124
1995	27 984	37	153
West			
1991	66 448	46	59
1992	4 163	55	38
1993	21 262	38	54
1995	3 654	55	45
East			
1991	78 645	44	47
1992	79 387	35	84
1993	50 720	29	70
1995	24 330	41	108

Acoustic survey

Absolute estimates of abundance were available from the acoustic survey on oreos which was carried out from 26 September to 30 October 1998 on *Tangaroa* (voyage TAN9812) Doonan (et al. 2000). Transects on flat ground were surveyed to a stratified random design and a random sample of seamounts surveyed with either a random transect (large seamounts) or a systematic "star" transect design (Figure 5). For some seamounts the flat ground nearby was also surveyed to compare the abundance of fish on and near the seamount either by extending the length of the star transects or by extra parallel transects. Acoustic data were collected concurrently for flat and seamounts on both towed and hull mounted transducers. The OEO 4 survey covered 59 transects on the flat and 29 on seamounts. A total of 95 tows was carried out for target identification and to estimate target strength and species composition (Tables 12 and 13). In situ and swimbladder samples for target strength data were collected and these have yielded revised estimates of target strength for both black and smooth oreos.

Table 12: Numbers of flat transects and tows completed, and the number of strata for smooth oreo (SSO) and black (BOE) oreo. Tows were counted only if their performance was acceptable (code 1 or 2).

	SSO strata						BOE stratum
Stratum	2	22	3	4	42	5	7
Transects completed	17	8	6	10	10	8	0
Tows completed	8	6	10	8	11	14	0

Table 13: List of seamounts surveyed, the number of tows and number of transects carried out. Categories A to C rank seamounts in the order of descending importance based on oreo catch history.

Seamount	Category	Number of transects	Number of tows
Hegerville	A	5	3
Paranoia	A	4	3
Flintstone	B	0	0
Teepee	B	4	3
Chuckys	C	4	3
Featherlite	C	4	2
Fletchers	C	4	3
Mt. Nelson	C	4	4

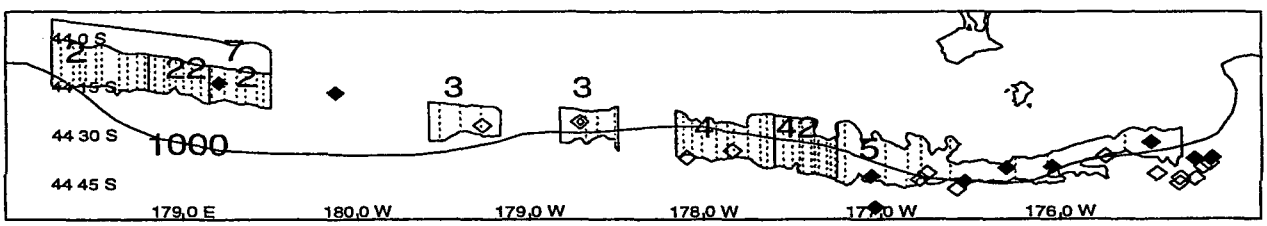


Figure 5: OEO 4 survey area showing smooth oreo (2–5, 22 & 42) and black oreo (7) flat strata (dark lines) and transects (dashed lines). Seamounts selected for sampling (♦) plus seamounts listed but not selected for sampling(◇).

Acoustic absolute abundance estimates

Estimates were made for recruit fish using the following parameter values. The mean absorption coefficient of sound in seawater used was 8.9 $dB.km^{-1}$ (Doonan, unpublished results). Shadow zone corrections were made (R. Barr. NIWA, unpublished results). Approximate corrections for loss of acoustic signal strength due to towbody motion were based on the method of Stanton (1982).

The equation for the tilt averaged target strength, <TS>, versus the logarithm of fish total length, (L, cm) for smooth oreo was

$<TS> = - 89.16 + 30.42 * \log_{10}(L)$.

The mean TS for a 35 cm fish is -42.5 which is an increase of about 7.5 dB from the value derived from the relationship used in the 1999 stock assessment (Doonan et al. 1999a). The equation for black oreo was

$<TS> = -62.94 + 15.76 * \log_{10}(L)$, where L is total length (cm).

The mean TS for a 35 cm fish is -38.7 which is a decrease of about 1.1 dB from 1999 (Doonan et al. 1999b).The target strength estimate for black oreo is the largest potential source of bias for the acoustic survey abundance estimates for smooth oreo.

The target strength-length (L) relationship used for species other than black and smooth oreo was divided into three target strength categories: non-swimbladder ($-77 + 20\log_{10} L$), cod-like ($-67.5 + 20\log_{10} L$), and deepwater-like ($-79.4 + 20\log_{10} L$). Target strength for cod-like species was estimated from the TS-length relationship given by Foote (1987) and that for deepwater species used the swimbladder model data from the rattails *Caelorinchus innotabilis* and *Coryphaenoides subserrulatus* and smooth oreo to set the general level, but used the scatter of data from Foote (1987) to estimate target strength using bootstrap techniques.

Scaling estimates to OEO 4

Estimates from the acoustic flat survey area were scaled up to the trawl survey area and then to the OEO 4 area. Abundance was estimated by:

$$B_{Total} = f_{T2All}\left(f_{A2T}B_{Flat} + B_{Hills}\right),$$

where B_{Flat} is the estimated abundance for the flat ground in the acoustic survey, B_{Hills} is the estimated abundance for all seamounts in the trawl survey area, f_{A2T} converts the flat abundance from the acoustic survey area to the trawl survey area and f_{T2All} converts the abundance from the trawl survey area up to the OEO 4 area.

The scaling factor f_{A2T} was calculated using data from three trawl surveys (TAN9210, TAN9309, and TAN9511) to estimate the fraction of recruit smooth oreo in the acoustic survey area compared to the trawl survey area. A mean smooth oreo density was estimated for each trawl stratum and this density was applied to the sub-areas in the stratum resulting from splitting off the part, where applicable, in the acoustic survey area. For recruit smooth oreo this factor was 2.0 for the whole of OEO 4, and 2.1 for the west and east parts of OEO 4.

For the scaling factor f_{T2All}, the ratio of catches in the total OEO 4 area to that in the trawl survey area was used to adjust the abundance (seamount plus flat ground) up to the total OEO 4 area from the trawl survey area. Data from the fishing years 1986–87 to 1998–99 were analysed with 1986–87 chosen as the start because the Quota Management System was introduced in that year (Working Group decision first recorded by Annala & Sullivan (1997)). For recruit smooth oreo, this ratio was 1.07 (74 400/ 68 700). All estimates presented below are scaled up to the total OEO 4 area including the estimates from the west and east parts of OEO 4.

Mark categorisation methods to assign acoustic backscatter to marks recorded on transects were developed and involved using supervised statistical classification techniques (Doonan & McMillan 2000). Acoustic abundance estimates for recruit smooth oreo from seamounts and flat for the whole of OEO 4 are given in Table 14 and split into the west and east parts of OEO 4 to correspond to the standardised CPUE abundance estimates (Section 2.1.1) in Table 15.

Table 14: OEO 4 recruit smooth oreo seamount, flat, and total acoustic abundance estimates and recruit c.v. based on knife-edge recruitment (21 years).

	Abundance (t)	c.v. (%)
Seamount	14 873	53
Flat	46 866	37
Total	61 700	32

Table 15: West and east OEO 4 (split at 178° 20′ W) recruit smooth oreo seamount, flat, and total acoustic abundance estimates and recruit c.v. based on knife-edge recruitment (21 years).

	West		East	
	Abundance (t)	c.v. (%)	Abundance (t)	c.v. (%)
Seamount	5 140	93	9 520	43
Flat	5 420	48	43 800	39
Total	10 600	52	53 300	33

3.3 Other studies

Catchability (q) of smooth oreo from the trawl surveys

Doonan et al. (1997a) reported an analysis of smooth oreo trawl survey catchability for OEO 3A and concluded that the *Tangaroa* surveys in OEO 3A probably did not sample recruit smooth oreo very well. They estimated a range of plausible q values for the *Tangaroa* surveys. The OEO 4 trawl survey abundance estimates used in the stock reduction analysis had associated unknown q values.

3.4 Biomass estimates

Stock reduction analysis

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

(a) The smooth oreo acoustic abundance estimate was an unbiased absolute value.
(b) The CPUE analysis indexed the abundance of smooth oreo in the whole of OEO 4. Most of the smooth oreo commercial catch taken from 1978–79 to 1998–99 came from the CPUE study area and research trawl surveys indicated that there was little habitat for, and biomass of, smooth oreo outside that area.
(c) The ranges used for the biological values covered their true values.
(d) Varying the maximum fishing mortality (F_{max}) from 0.5 to 3.5 altered B_0 for smooth oreo in OEO 3A by only about 6% in the 1996 assessment, so only one assumed value (0.9) was used in all the analyses below.
(e) Recruitment was deterministic and followed a Beverton & Holt relationship with steepness of 0.75.
(f) Catch overruns were 0% during the period of reported catch.
(g) The population of smooth oreo in OEO 4 was a discrete stock or production unit.
(h) The catch histories were accurate.

Input data

Input data included the recruit absolute acoustic abundance estimates and c.v.s (see Tables 14 and 15), the time series of combined abundance indices from standardised CPUE analyses and c.v.s (see Table 3), the relative abundance estimates from the trawl surveys (1991–93, 1995, see Table 11), the life history parameters from Doonan et al. 1997b (Table 16), and the catch history (Table 17).

Table 16: Life history parameters for smooth oreo. –, not estimated.

Parameter	Symbol (unit)	Female	Male
Natural mortality	M (yr^{-1})	0.063	0.063
Age at recruitment	A_r (yr)	21	21
Age at maturity	A_m (yr)	31	–
von Bertalanffy parameters	L_∞ (cm, TL)	50.8	43.6
	k (yr^{-1})	0.047	0.067
	t_0 (yr)	-2.9	-1.6
Length-weight parameters	a	0.029	0.032
	b	2.90	2.87
Recruitment variability		0.65	0.65
Recruitment steepness		0.75	0.75
Length at recruitment	(cm, TL)	34	–
Length at maturity	(cm, TL)	40	–

Catch history (Table 17)

This was derived from Tables 1 and 2 and included the yearly total catch for OEO 4 and catches from west and east (split at 178° 20′ W) to correspond to the standardised CPUE abundance estimates (section 2.1.1).

1 Catches from 1978–79 to 1982–83 (1 April to 31 March) were assumed to be for fishing years (1 October to 30 September).
2 The 1978–79 catch of unspecified oreo (8041 t, Table 1) was assumed to be the same proportion of smooth to black oreo catch reported in 1979–80 (114/(114+566) = 0.168) (Table 2). The estimate of the 1978–79 smooth oreo catch was 8041 t x 0.168 = 1351 t.
3 The 6 month catch of smooth oreo reported as 1983–83 (1861 t, Table 2) was split and half each (930.5 t) added to the preceding and subsequent years (1982–83 and 1983–84). There was only an 8 t difference between estimated and reported catch in 1983–83 (Tables 1 and 2), so no adjustment to the reported smooth oreo catch was made.
4 From 1979–80 to 1998–99 the catch was calculated by multiplying the value reported in Table 1 by the proportion of smooth oreo to black oreo in Table 2.
5 The last two years of the catch history are assumed projected catch.

Table 17: Reconstructed catch history (t) of smooth oreo from OEO 4 used in the 2000 stock reduction analysis. OEO 4 is the catch from the whole area. "West" is the proportion of the total taken west and "East" is the catch taken to the east of 178° 20′ W. ‡ indicates assumed catch.

Year	OEO 4	West	East
1978–79	1 351	1 351	0
1979–80	114	114	0
1980–81	1 436	1 436	0
1981–82	3 465	3 430	35
1982–83	3 757	3 757	0
1983–84	5 817	5 759	58
1984–85	4 736	4 547	189
1985–86	4 921	4 380	541
1986–87	5 670	4 196	1 474
1987–88	7 771	2 642	5 129
1988–89	7 225	2 457	4 769
1989–90	6 788	1 154	5 634
1990–91	6 028	1 808	4 220
1991–92	5 504	1 211	4 293
1992–93	5 918	1 420	4 498
1993–94	6 287	1 069	5 218
1994–95	6 960	1 392	5 568
1995–96	6 364	2 227	4 137
1996–97	6 339	1 712	4 627
1997–98	6 159	1 848	4 311
1998–99	6 032	1 749	4 283
1999–00	‡6 000	‡1 800	‡4 200
2000–01	‡6 000	‡1 800	‡4 200

Results of several different stock reduction model runs (referred to as "cases") with different abundance inputs are presented below. The "base" case for the whole of OEO 4 used the acoustic abundance estimate, the target pre-GPS and target post-GPS standardised combined CPUE indices (Figure 6). The trawl survey indices were not used in the base case because they had a poor fit to the trajectory, had wide 95% confidence intervals (C.I.), and showed a very steep (probably unrealistic) declining trend with time. The target pre-GPS and target post-GPS standardised combined CPUE

abundance indices were all within one standard error of the trajectory line and the absolute acoustic abundance (adjusted to a mid-year value) falls just above the line. The base case for west of 178° 20′ W used the west acoustic abundance estimate and the target pre-GPS and west target post-GPS standardised combined CPUE indices (Figure 7). The base case for east of 178° 20′ W used the east acoustic abundance estimate and the bycatch post-GPS positive CPUE abundance indices (Figure 8). For OEO 4 combined the estimates of B_0 from the CPUE-only and trawl-only cases have very high upper 95% confidence intervals. Cases that include the acoustic abundance estimate had smaller 95% confidence intervals for B_0 illustrating the importance of the acoustic estimate.

Biomass estimates by case, including the maximum likelihood value and the 95% confidence intervals (in parentheses), are given in Table 18. The 95% confidence interval estimates of B_0 for the OEO 4 base case from this analysis were 100 000–148 000 t, based on bootstrap simulation that used the c.v. from the CPUE indices, the c.v. from the acoustic abundance estimates, and assumed deterministic recruitment.

Table 18: Recruit smooth oreo biomass estimates (t) from the stock reduction model. The 95% confidence intervals are in parentheses. Base cases marked in bold. "East" is to the east of 178° 20′ W. "West" is west of 178° 20′ W.

	B_0		Mid-year $B_{1999-00}$			
OEO 4	(t)		(t)			(%B_0)
Abs.+ target pre- & post-GPS CPUE	**126 000**	**(100 000–148 000)**	**50 600**	**(24 200–72 300)**	**40**	**(24–49)**
Abs.+ Tar. pre- & post-GPS CPUE + Tr.	124 000	(98 500–144 000)	48 600	(22 700–68 800)	39	(23–48)
Absolute (Abs.)	127 000	(96 000–149 000)	51 600	(20 100–73 800)	41	(21–50)
Target (Tar.) pre- & post-GPS CPUE	114 000	(86 000–1 000 000)	38 500	(9 590–925 000)	34	(11–93)
Trawl (Tr.)	86 000	(86 000–1 000 000)	9 590	(9 590–925 000)	11	(11–93)
West						
Abs.+ target pre- & west post-GPS CPUE	**47 000**	**(38 000–57 000)**	**16 100**	**(6 740–26 300)**	**34**	**(18–46)**
Abs.+ Tar. pre- & west post-GPS CPUE + Tr.	47 000	(37 000–57 000)	16 100	(5 670–26 300)	34	(15–46)
West absolute abundance (Abs.)	39 000	(34 500–43 500)	7 800	(2 910–12 500)	20	(8–29)
Target (Tar.) pre-& west post-GPS CPUE	61 000	(39 000–202 000)	30 300	(7 800–171 000)	50	(20–85)
West trawl abundance (Tr.)	34 500	(34 500–1 000 000)	2 910	(2 910–970 000)	8	(8–97)
East						
Abs.+ Bc. Post-GPS CPUE	**91 000**	**(68 500–110 000)**	**46 500**	**(23 900–65 000)**	**51**	**(35–59)**
Abs.+ Bc. Post-GPS CPUE + Tr.	85 000	(64 000–104 000)	40 500	(19 300–59 000)	48	(30–57)
East absolute abundance (Abs.)	89 000	(60 500–109 000)	44 500	(15 800–64 000)	50	(26–59)
Bycatch (Bc.) post-GPS CPUE	107 000	(63 000–1 000 000)	62 500	(18 300–956 000)	58	(29–96)
East trawl abundance (Tr.)	52 500	(52 500–1 000 000)	7 510	(7 510–956 000)	14	(14–96)

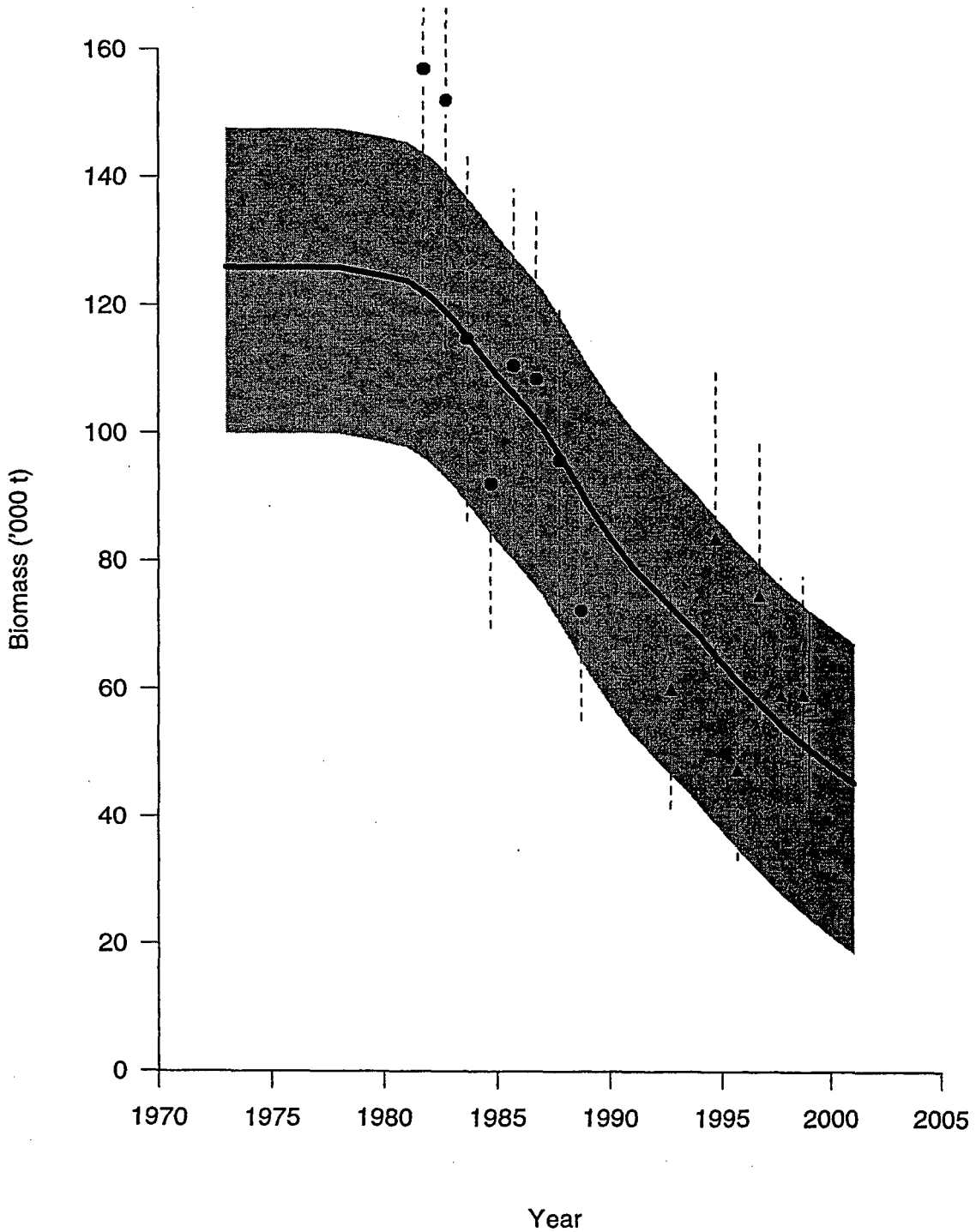


Figure 6: **Biomass trajectory for OEO 4 from stock reduction analysis for the base case (acoustic absolute abundance, plus the target pre-GPS and target post-GPS standardised combined CPUE indices). ●target pre-GPS CPUE, ▲ target post-GPS CPUE, □ acoustic absolute abundance estimate. Dashed vertical lines are one standard deviation. The grey area is bounded by the trajectories from B_0 that make up the 95% C.I. for B_0.**

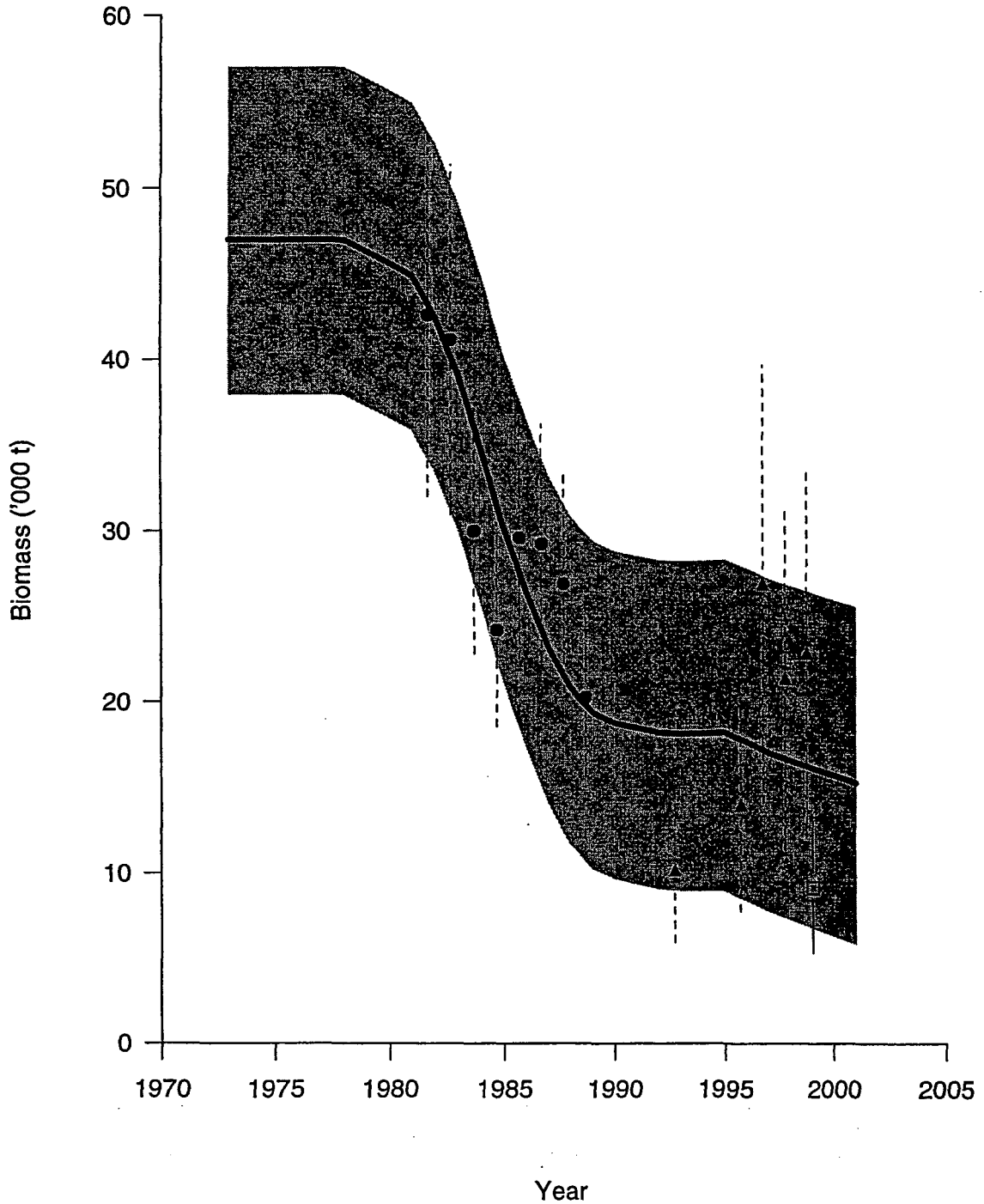


Figure 7: **Biomass trajectory for west (OEO 4 west of 178° 20′ W) from stock reduction analysis for the base case (west acoustic absolute abundance, plus the target pre-GPS and west target post-GPS standardised combined CPUE indices). ●target pre-GPS CPUE, ▲ west target post-GPS CPUE, □ acoustic absolute abundance estimate. Dashed vertical lines are one standard deviation. The grey area is bounded by the trajectories from B_0 that make up the 95% C.I. for B_0.**

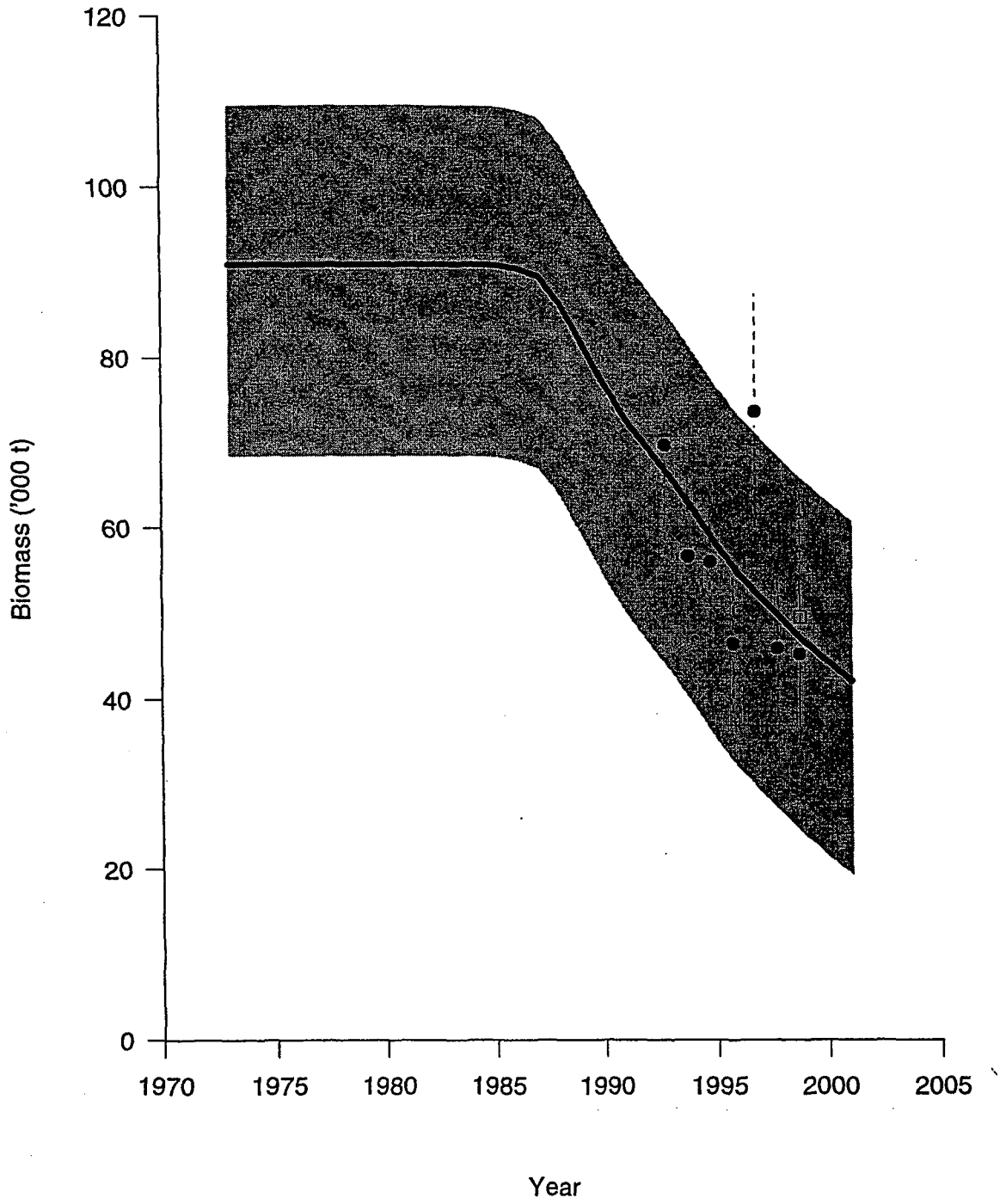


Figure 8: **Biomass trajectory for east (OEO 4 east of 178° 20′ W) from stock reduction analysis for the base case (east acoustic absolute abundance, plus the bycatch post-GPS standardised positive CPUE index). ● bycatch post-GPS CPUE, □ acoustic absolute abundance estimate. Dashed vertical lines are one standard deviation. The grey area is bounded by the trajectories from B_0 that make up the 95% C.I. for B_0.**

3.4.1 Sensitivity of biomass estimates, OEO 4 base case

Virgin biomass estimates were sensitive to changes in the M values because increasing M by 2 standard errors resulted in a 13% reduction in B_0, but reducing M by 2 standard errors resulted in a 9% increase (Table 19). Catch history was also important and increased B_0 by 6% when it was 10% higher and reduced B_0 by 6% when it was 10% lower. The ratio of $B_{1990-00}$ to B_0 was not sensitive to M or catch history. Decreasing the target strength estimate for smooth oreo by 3 dB increased the B_0 estimate by 21% and increasing the target strength 3 dB decreased B_0 by 14%.

Table 19: Sensitivity of virgin (B_0) and mid-year ($B_{1999-00}$) biomass estimates (t) to changes in the CPUE index, natural mortality (M), and catch history for the base case. s.e. is standard error. Only relatively large sensitivity effects are presented.

Change in parameters	B_0 (t)	$B_{1999-00}$ (t)	$B_{1999-00}$ (% B_0)
Base case	126 000	51 000	40
M + 2 s.e. (0.099)	110 000	49 000	45
M - 2 s.e. (0.042)	137 000	52 000	38
Catch + 10%	134 000	51 000	38
Catch - 10%	118 000	50 000	43
TS_{SSO} - 3 dB	153 000	78 000	51
TS_{SSO} + 3 dB	108 000	32 000	30

3.5 Yield estimates

Estimation of Maximum Constant Yield (MCY)

Using the method of Francis (1992), the maximum constant catch that can be taken indefinitely (without reducing the population below 20% B_0 more than 10% of the time) from a population with life history parameters as in Table 16 was 1.6% B_0. Under continued fishing at this level the mean biomass was 44% B_0 (B_{MCY}).

Yield estimates (Table 20) were calculated from the results of the stock reduction analyses reported above, using the "Depressed stocks" methods of Francis (1992). Where stocks are depressed (below 20% B_0), the MCY for 1999–00 was scaled down.

The level of risk to the stocks by harvesting the populations at the estimated MCY values cannot be determined.

Estimation of Current Annual Yield (CAY)

CAY was estimated using the methods given by Francis (1992). F_{CAY}, the maximum constant fishing mortality (F) that can be applied (without reducing the population below 20% B_0 more than 10% of the time) to a population with the life history parameters as in Table 16 is 0.0497. The mean catch when fishing at F = 0.0497 is 1.93% B_0, and the mean biomass (B_{MAY}) is 25% B_0. Yield estimates are shown in Table 20.

Table 20: Yield estimates (t). The 95% confidence limits are in parentheses. Base cases marked in bold. "East" is to the east of 178° 20′ W. "West" is west of 178° 20′ W.

OEO 4	$MCY_{2000-01}$		$MCY_{long-term}$		$CAY_{2000-01}$	
Abs.+ target pre-& post-GPS CPUE	**2 000**	**(1 600–2 400)**	**2 000**	**(1 600–2 400)**	**2 300**	**(1 100–3 400)**
Abs.+ Tar. pre- & post-GPS CPUE + Tr.	2 000	(1 600–2 300)	2 000	(1 600–2 300)	2 200	(990–3 200)
Absolute (Abs.)	2 000	(1 500–2 400)	2 000	(1 500–2 400)	2 400	(860–3 500)
Target (Tar.) pre-& post-GPS CPUE	1 800	(770–16 000)	1 800	(1 400–16 000)	1 800	(360–45 000)
Trawl (Tr.)	770	(770–16 000)	1 400	(1 400–16 000)	360	(360–45 000)
West						
Abs.+ target pre- & west post-GPS CPUE	**750**	**(540–910)**	**750**	**(610–910)**	**790**	**(330–1 300)**
Abs.+ Tar. pre- & west post-GPS CPUE + Tr.	750	(450–910)	750	(590–910)	790	(280–1 300)
West absolute abundance (Abs.)	620	(230–700)	620	(550–700)	380	(140–610)
Target (Tar.) pre- & west post-GPS CPUE	970	(620–3 200)	970	(620–3 200)	1 500	(380–8 300)
West trawl abundance (Tr.)	230	(230–16 000)	550	(550–16 000)	140	(140–47 000)
East						
Abs.+ Bc. post-GPS CPUE	**1 500**	**(1 100–1 700)**	**1 500**	**(1 100–1 700)**	**2 100**	**(1 000–3 000)**
Abs.+ Bc. post-GPS CPUE + Tr.	1 400	(1 000–1 700)	1 400	(1 000–1 700)	1 900	(820–2 800)
East absolute abundance (Abs.)	1 400	(970–1 700)	1 400	(970–1 700)	2 000	(650–3 000)
Bycatch (Bc.) post-GPS CPUE	1 700	(1 000–16 000)	1 700	(1 000–16 000)	2 900	(770–46 000)
East trawl abundance (Tr.)	600	(600–16 000)	840	(840–16 000)	250	(250–46 000)

Sensitivity of MCY to M, steepness, and smooth oreo target strength, OEO 4 base case

M was varied by plus or minus 2 standard errors, and steepness values were changed to 0.5 and 0.95 from the 0.75 used in the yield estimates above. Long-term MCY, as a percentage of virgin biomass, varied widely with changes in M and steepness (Table 21). For the base case, this resulted in a range of long-term MCY estimates from 1400 to 2500 t (Table 22). Lowering the target strength of smooth oreo by 3 dB increased $MCY_{long-term}$ to 2400 t while raising it by 3 dB decreased $MCY_{long-term}$ to 1700 t.

Table 21: Sensitivity of OEO 4 base case long-term MCY (% virgin biomass) to M and "steepness". –, not estimated.

	Steepness		
M	0.50	0.75	0.95
0.042	–	1.14	–
0.063	1.12	1.60	1.94
0.099	–	2.30	–

Table 22: Sensitivity of OEO 4 base case long-term MCY (t) to M and "steepness". –, not estimated.

	Steepness		
M	0.50	0.75	0.95
0.042	–	1 600	–
0.063	1 400	2 000	2 400
0.099	–	2 500	–

4. MANAGEMENT IMPLICATIONS

This stock assessment of OEO 4 smooth oreo is based on deterministic recruitment incorporated into a stock reduction analysis using an absolute acoustic abundance estimate and relative abundance indices from new standardised CPUE analyses and research trawl surveys. OEO 4 was assessed as a combined fishery but also as two fisheries, one at the west end and another at the east end of OEO 4.

The separate west and east analyses were carried out because substantial temporal and spatial changes in fishing took place between 1978–79 and 1998–99. These changes appear to be largely driven by the quest for orange roughy and involved a progressive shift of effort from the west, where mainly flat and seamounts were fished, to the east, where fishing was mainly on seamounts. These changes in the fishery are reflected in the CPUE abundance indices only and do not affect the acoustic abundance estimate, i.e., the OEO 4 total acoustic absolute biomass estimate is close to the sum of the east plus west absolute biomass estimates. The base case stock reduction analysis biomass and yield results are dominated by the absolute abundance estimates.

The following conclusions can be drawn from this assessment.

Base case, whole of OEO 4

1. The biomass at the start of 1999–2000 (50 600t) was likely to be close to 40% of B_0 and about the same as B_{MCY} (44% B_0).
2. Yields from this stock will be low because the productivity of smooth oreo is low, based on unvalidated age estimates. The long-term MCY estimates from a stock of between 100 000 and 148 000 t are 1600–2400 t, 26–39% of the mean annual reported (partly reconstructed) smooth oreo catch in OEO 4 from the last 10 years (about 6200 t per year, 1989–90 to 1998–99), from Table 17). Therefore, it seems likely that the recent catch levels of smooth oreo from OEO 4 are higher than the long-term sustainable yield and will not allow the stock to remain near B_{MCY}.

Base case, west OEO 4

1. The biomass at the start of 1999–2000 (16 100 t) was likely to be close to 34% of B_0, and less than B_{MCY} (44% B_0), but greater than B_{CAY} (25% B_0).
2. The long-term MCY estimates from a stock of between 38 000 and 57 000 t are 610–910 t, 39–58% of the mean annual reported (partly reconstructed) smooth oreo catch in west OEO 4 from the last 10 years (about 1600 t per year, 1989–90 to 1998–99), from Table 17). Therefore, it seems likely that the recent catch levels of smooth oreo from west OEO 4 are higher than the long-term sustainable yield and will not allow the stock to remain near B_{MCY}.

Base case, east OEO 4

1. The biomass at the start of 1999–2000 (46 500 t) was likely to be close to 51% of B_0 and more than B_{MCY} (44% B_0).
2. The long-term MCY estimates from a stock of between 68 500 and 110 000 t are 1100–1700 t, 24–36% of the mean annual reported (partly reconstructed) smooth oreo catch in east OEO 4 from the last 10 years (about 4700 t per year, 1989–90 to 1998–99), from Table 17). Therefore, it seems likely that the recent catch levels of smooth oreo from west OEO 4 are higher than the long-term sustainable yield.

The sum of the base case mean biomasses and yields from the west and east analyses fall within the 95% C.I. for the whole of OEO 4 analyses, i.e., B_0 of 138 000 cf. 100 00–148 000 and $MCY_{long\text{-}term}$ of 2250 cf. 1600–2400 t respectively. This suggests that the separate area assessments are consistent with the whole area assessment, but the separate area assessment indicates that exploitation in the west has been relatively greater than in the east.

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

1. Age estimates. Smooth oreo age estimates are not validated, although Australian workers using the same method achieved similar results. Small smooth oreo are not available to known sampling methods and other ageing methods are needed to validate age estimates from otolith sections.
2. Stock discreteness for smooth 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.
3. The east-west split assumes that these areas have discrete stocks or that fish stay at or near the same place once they reach maturity. The latter also assumes that the recruitment split between areas is proportional to the east-west virgin biomasses.
4. Target strength of smooth oreo. Virgin and current biomass estimates are sensitive to the value of smooth oreo target strength. A 3 dB decrease in target strength increased the virgin biomass estimate (153 000 t) to just outside the OEO 4 base case 95% C.I. (100 000–148 000 t).
5. Recruitment steepness. Yields are sensitive to the uncertainties in the estimate of the value of recruitment steepness but there are no data available to check the assumed value of recruitment steepness. Reducing steepness to 0.5 decreased the OEO 4 base case long-term MCY estimate (1400 t) to below the 95% C.I. (1600–2400 t).
6. Natural mortality estimate. Increasing M to 0.099 increased the OEO 4 base case long-term MCY (2500 t) estimate to a value greater than the 95% C.I. (1600–2400 t).

5. ACKNOWLEDGMENTS

This work was carried out for the Ministry of Fisheries under project OEO199902. We thank Malcolm Clark (NIWA, Wellington) for providing comments on the manuscript.

6. REFERENCES

Annala, J.H.; Sullivan, K.J. (Comps.) (1997). Report from the Fishery Assessment Plenary, May 1997: stock assessments and yield estimates. 381 p. (Unpublished report held in NIWA library, Wellington.)

Annala, J.H.; Sullivan, K.J.; O'Brien, C.J. (Comps.) (2000). Report from the Fishery Assessment Plenary, May 2000: stock assessments and yield estimates. 495 p. (Unpublished report held in NIWA library, Wellington.)

Clark, M.R.; Anderson. O.F.; Gilbert, D.J. (2000). Discards in trawl fisheries for southern blue whiting, orange roughy, hoki, and oreos in waters around New Zealand. *NIWA Technical Report 71*. 73 p.

Coburn, R.P.; Doonan, I.J.; McMillan, P.J. (2001). Smooth oreo abundance indices from standardised catch per unit of effort data for OEO 4. *New Zealand Fisheries Assessment Report 2001/11*. 39 p.

Doonan, I.J.; McMillan, P.J. 2000: Objective classification of acoustic fish marks for the 1998 south Chatham Rise (OEO 4) oreo survey (TAN9812). In Coombs, R.F. Final Research Report for Ministry of Fisheries Project OEO9801. (Unpublished report held by Ministry of Fisheries, Wellington.)

Doonan, I.J.; Hart, A.C.; McMillan, P.J.; Coombs, R.F. (2000). Oreo abundance estimates from the October 1998 survey of the south Chatham Rise (OEO 4). New Zealand Fisheries Assessment Report 2000/52. 26 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C.; Cordue, P.L. (1995a). Assessment of smooth oreo for 1995. New Zealand Fisheries Assessment Research Document 95/12. 31 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (1996). Assessment of Chatham Rise smooth oreo (OEO 3A and OEO 4) for 1996. New Zealand Fisheries Assessment Research Document 96/17. 21 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (1997a). Assessment of Chatham Rise smooth oreo (OEO 3A and OEO 4) for 1997. New Zealand Fisheries Assessment Research Document 97/21. 26 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (1999a). Assessment of OEO 3A smooth oreo for 1999–2000. New Zealand Fisheries Assessment Research Document 99/45. 21 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (1999b). Assessment of OEO 3A black oreo for 1999–2000. New Zealand Fisheries Assessment Research Document 99/52. 30 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Hart, A.C. (1997b). Revision of smooth oreo life history parameters. New Zealand Fisheries Assessment Research Document. 97/9. 11 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J.; McMillan, P.J.; Kalish, J.M.; Hart, A.C. (1995b). Age estimates for black oreo and smooth oreo. New Zealand Fisheries Assessment Research Document 95/14. 26 p. (Unpublished report held in NIWA library, Wellington.)

Fenaughty, J.M.; Banks, D.A.; Hart, A.C.; McMillan, P.J. (1988). Cruise report: the second stratified random bottom trawl survey of the south Chatham Rise, November 1987. Fisheries Research Centre Internal Report No. 99. 73 p. (Unpublished report held in NIWA library, Wellington.)

Fincham, D.J.; Banks, D.A.; McMillan, P.J. (1987). Cruise report - stratified random bottom trawl survey of the southern Chatham Rise, 600 1200 m, 31 October-7 December 1986. Fisheries Research Division Internal Report No. 74. 63 p. (Unpublished report held in NIWA library, Wellington.)

Fincham, D.J.; McMillan, P.J.; Hart, A.C. (1991). Catches of oreos (Family Oreosomatidae) in New Zealand waters, 1972–88. *New Zealand Fisheries Data Report No. 38.* 58 p.

Foote, K.G. (1987). Fish target strengths for use in echo integrator surveys. *Journal of the Acoustical Society of America 82:* 981–987.

Francis, R.I.C.C. (1990). A maximum likelihood stock reduction method. New Zealand Fisheries Assessment Research Document 90/4. 11 p. (Unpublished report held in NIWA library, Wellington.)

Francis, R.I.C.C. (1992). Recommendations concerning the calculation of maximum constant yield (MCY) and current annual yield (CAY). New Zealand Fisheries Assessment Research Document 92/8. 27 p. (Unpublished report held in NIWA library, Wellington.)

Hart, A.C.; McMillan, P.J. (1998). Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1995 (TAN9511). *NIWA Technical Report 27.* 48 p.

McMillan, P.J.; Hart, A.C. (1991). Assessment of black and smooth oreos for the 1991–92 fishing year. New Zealand Fisheries Assessment Research Document 91/10. 29 p. (Unpublished report held in NIWA library, Wellington.)

McMillan, P.J.; Hart, A.C. (1994a). Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1990 (COR9004). *New Zealand Fisheries Data Report No. 49.* 46 p.

McMillan, P.J.; Hart, A.C. (1994b). Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1991 (TAN9104). *New Zealand Fisheries Data Report No. 50.* 45 p.

McMillan, P.J.; Hart, A.C. (1994c). Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1992 (TAN9210). *New Zealand Fisheries Data Report No. 51.* 45 p.

McMillan, P.J.; Hart, A.C. (1995). Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1993 (TAN9309). *New Zealand Fisheries Data Report No. 60.* 49 p.

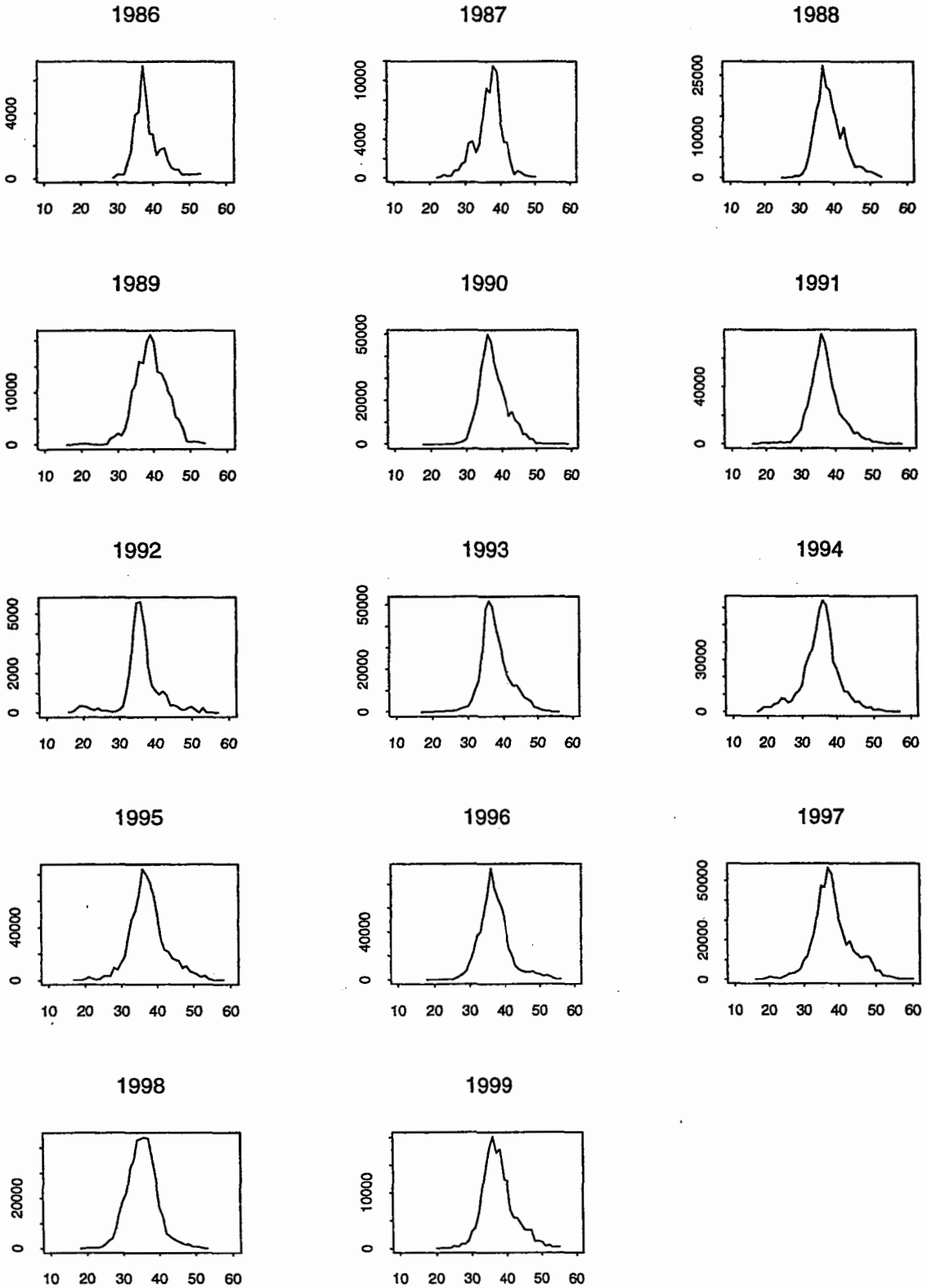
McMillan, P.J.; Hart, A.C.; Banks, D.A. (1988). Black and smooth oreos. New Zealand Fisheries Assessment Research Document 88/35. 18 p. (Unpublished report held in NIWA library, Wellington.)

Smith, P.; McMillan, P.; Proctor, C.; Robertson, S.; Knuckey, I.; Diggles, B.; Bull, B. (1999). Stock relationships of smooth oreo in New Zealand waters. Final Research Report for Ministry of Fisheries Research Project DEE9801. 76 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

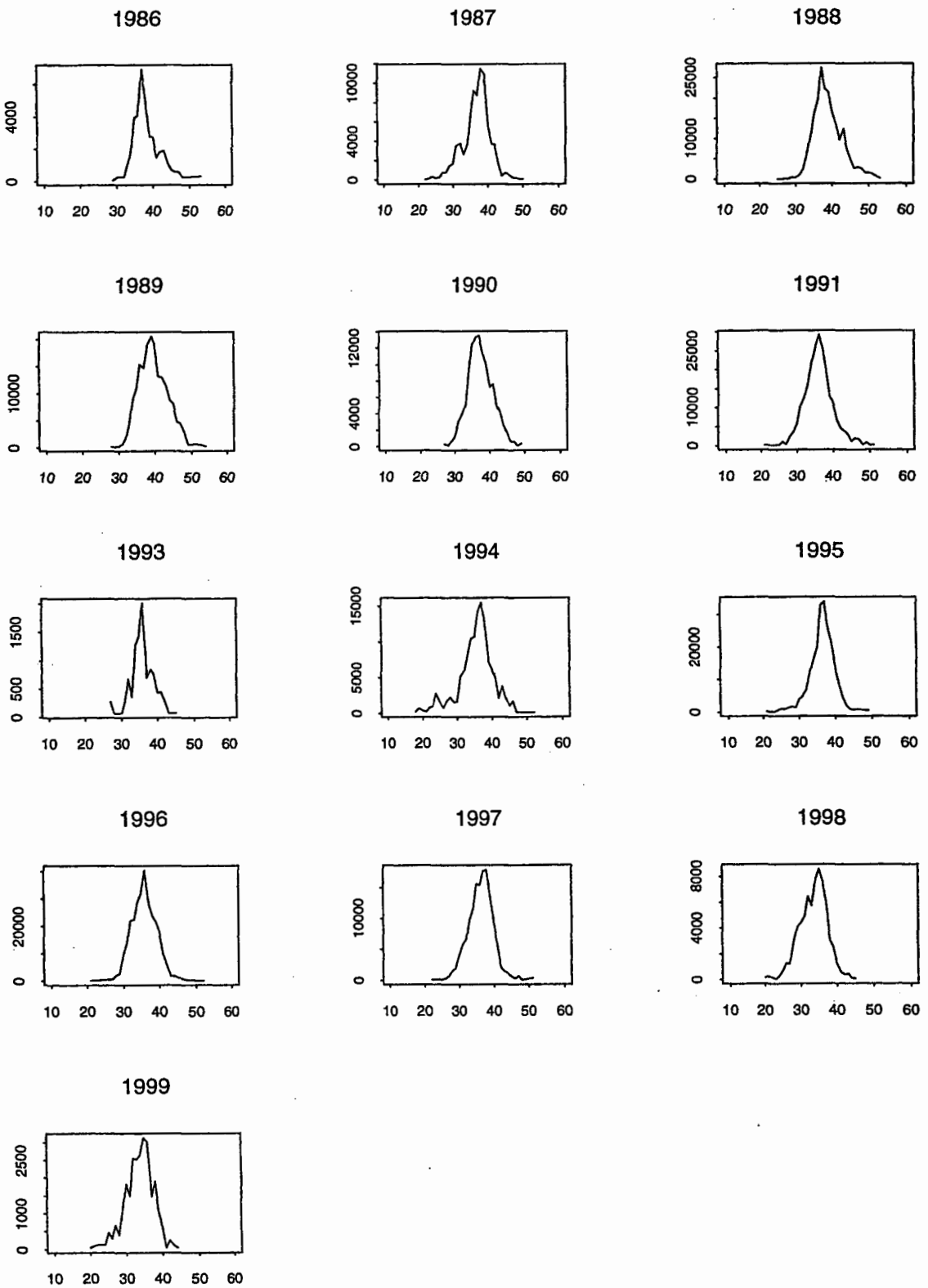
Stanton, T.K. (1982). Effects of transducer motion on echo-integration techniques. *Journal of the Acoustical Society of America 72(3)*: 947–949.

Ward, R.D.; Elliot, N.G.; Yearsley, G.K.; Last P.R. (1996). Species and stock delineation in Australasian oreos (Oreosomatidae). Final Report to Fisheries Research and Development Corporation. CSIRO, Hobart. 144 p. (Unpublished report held by CSIRO library, Hobart).

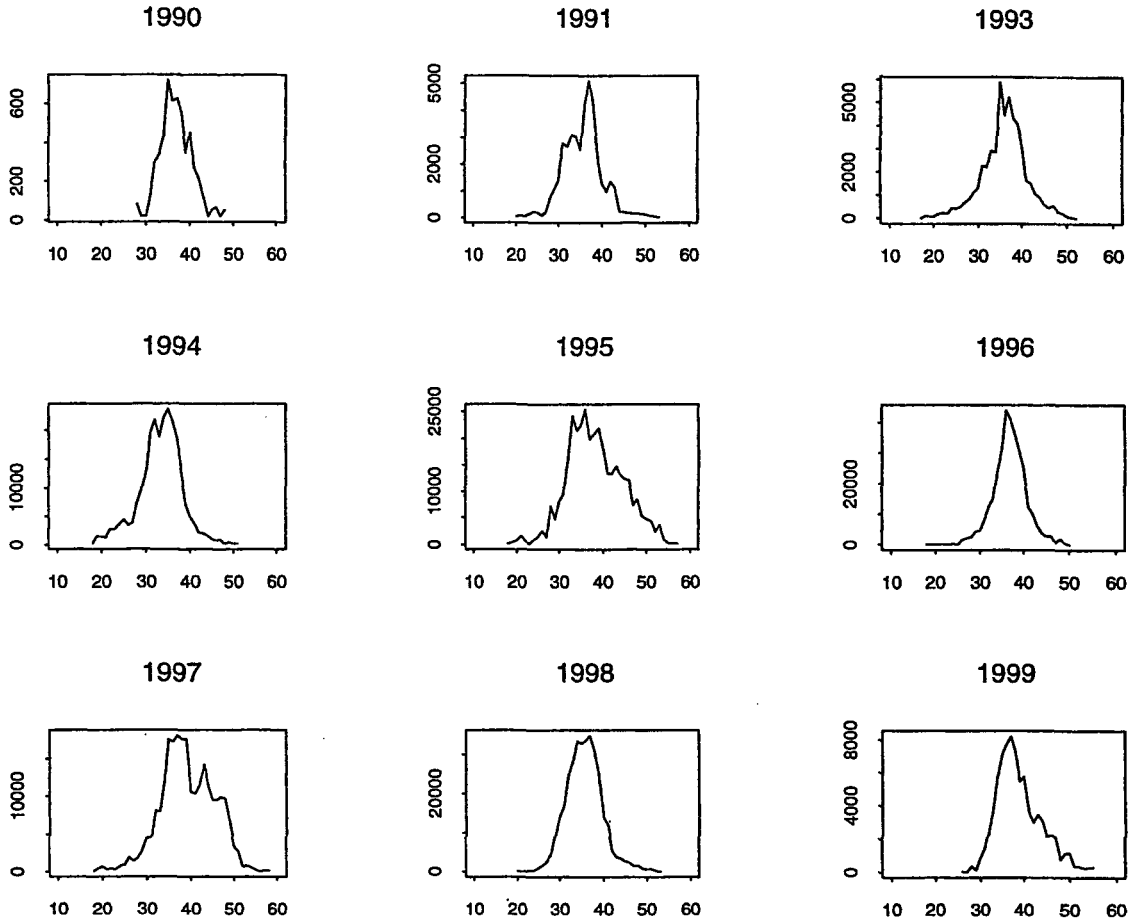
Appendix 1: ***Smooth oreo observer-collected length distributions by calendar year from the whole of OEO 4 (176° E to 174° W, south of 44° S). Data from all nations scaled by catch weight. Horizontal (x) axis is total length (cm) and vertical (y) axis is numbers of fish. See Table 5 for numbers of tows sampled and Table 6 for numbers of fish measured.***



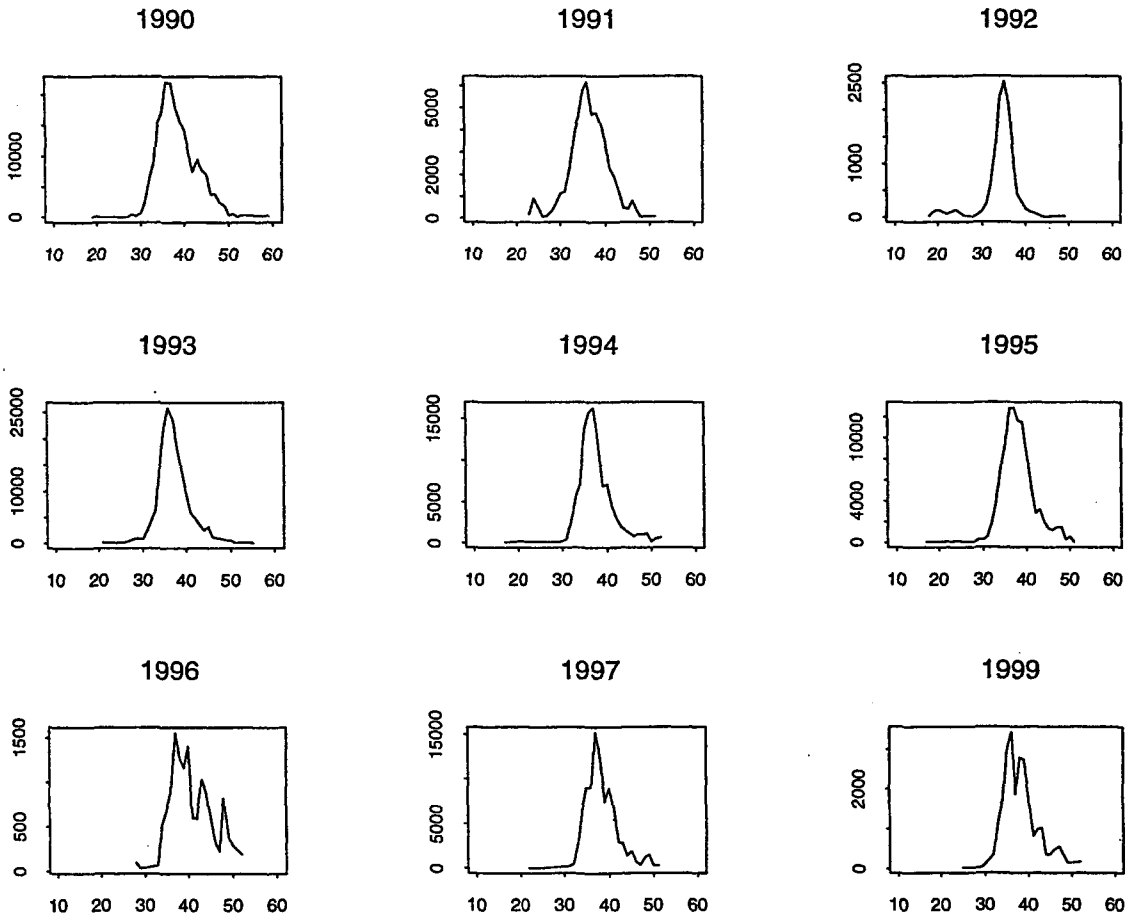
Appendix 2: **Smooth oreo observer-collected length distributions by calendar year from area 1 (178° E to 177° 08'W, south of 44° S, excludes hills). Data from all nations scaled by catch weight. Horizontal (x) axis is total length (cm) and vertical (y) axis is numbers of fish. See Table 5 for numbers of tows sampled and Table 6 for numbers of fish measured.**



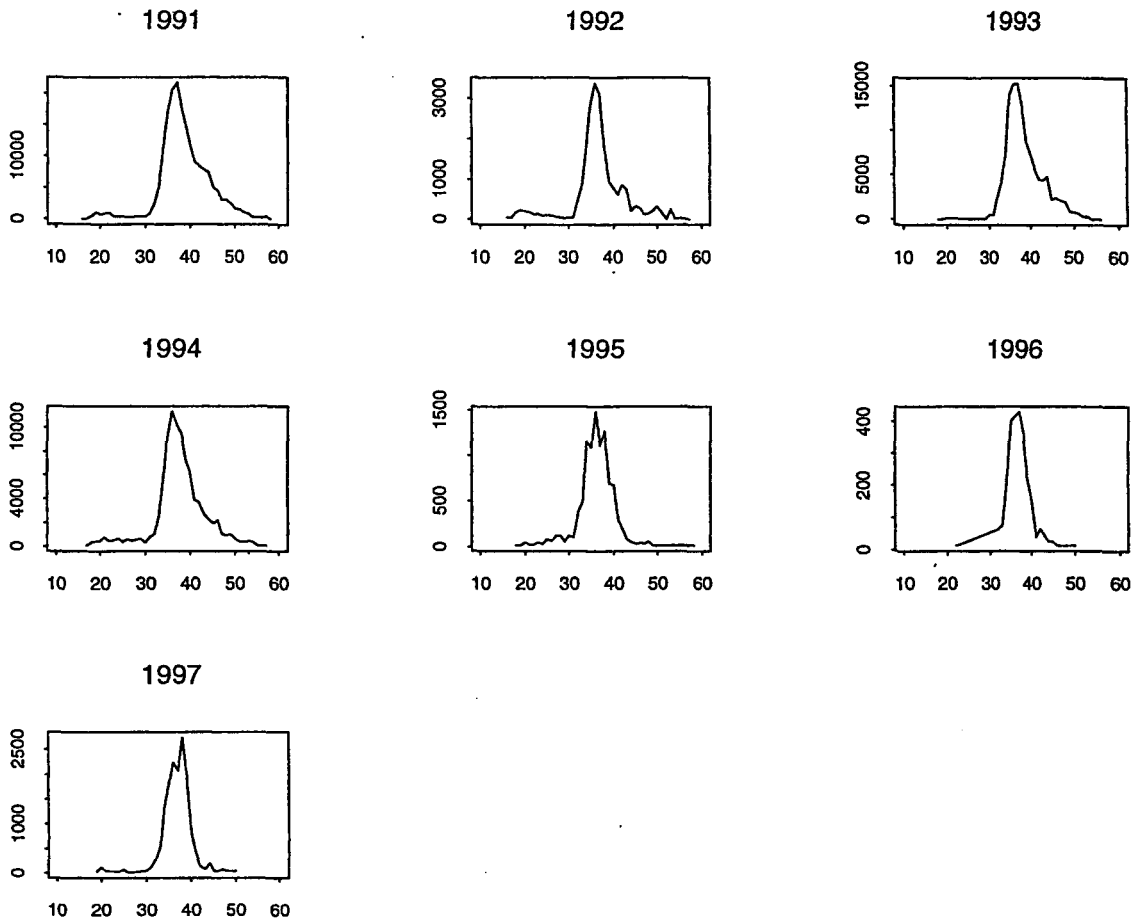
Appendix 3: **Smooth oreo observer-collected length distributions by calendar year from area 2 (177° 08' W to 176° 16' W, south of 44° S, includes hills). Data from all nations scaled by catch weight. Horizontal (x) axis is total length (cm) and vertical (y) axis is numbers of fish. See Table 5 for numbers of tows sampled and Table 6 for numbers of fish measured.**



Appendix 4: **Smooth oreo observer-collected length distributions by calendar year from area 3 (176° 16' W to 175° W, south of 44° S, includes hills). Data from all nations scaled by catch weight. Horizontal (x) axis is total length (cm) and vertical (y) axis is numbers of fish. See Table 5 for number of tows sampled and Table 6 for number of fish measured.**



Appendix 5: **Smooth oreo observer-collected length distributions by calendar year from area 4 (175° W to 174° W, south of 44° S, includes hills). Data from all nations scaled by catch weight. Horizontal (x) axis is total length (cm) and vertical (y) axis is numbers of fish. See Table 5 for number of tows sampled and Table 6 for number of fish measured.**



Appendix 6: **Smooth oreo observer-collected length distributions by calendar year from area 5 (178° E to 177° 08' W, south of 44° S, hills only). Data from all nations scaled by catch weight. Horizontal (x) axis is total length (cm) and vertical (y) axis is numbers of fish. See Table 5 for number of tows sampled and Table 6 for number of fish measured.**