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Assessment of OEO 4 smooth oreo for 2009–10

New Zealand Fisheries Assessment Report 2013/22

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EXECUTIVE SUMMARY

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The biomass of smooth oreo in OEO 4 was estimated with Bayesian methods using a CASAL age-structured population model. In the previous assessment, the stock area in OEO 4 was split at 178° 20′ W into a west and an east fishery, and data fitted in the model included acoustic survey abundance estimates, standardised CPUE indices, observer length data, and the acoustic survey length data. Based on changes in fishing patterns over time within the stock area, the Deepwater Working Group decided that using CPUE to index abundance should be discontinued.

With no CPUE indices, the 2012 assessment was simplified into a one area model using only the vulnerable abundances from acoustic surveys carried out in 1998 (TAN9812), 2001 (TAN0117, AEX0101), 2005 (TAN0514, SWA0501), and 2009 (TAN0910, SWA0901). The vulnerable abundances were fitted in the assessment model as relative abundance indices and informed priors were developed for the survey catchability coefficient (q). Vulnerable abundance indices were calculated either using the ratio of vulnerable to total abundance assuming a length cut-off value (33 or 34 cm) for the vulnerable fish, or based on acoustic mark-types that are commercially fished for smooth oreo. Two model runs are reported: one using the vulnerable acoustic abundances calculated using a length cut-off of 33 cm and another using abundances calculated from the fished marks.

For the model fitted to the abundance indices based on the length cut-off of 33 cm, the estimate of current mature biomass was about 41% B_0 (95% confidence interval, 26–55%); for the model fitted to the abundance indices based on fished marks, the estimate was about 33% B_0 (18–49%). These results suggest that there are no immediate sustainability issues for OEO 4 smooth oreo.

In this assessment one major source of uncertainly is that the model results appear to be strongly driven by the assumed prior for the catchability coefficient q, i.e., the signal in the acoustic estimates is not strong enough to determine q. There is also additional uncertainty that is not fully captured in the error analysis with the inputs to the assessment analysis. In previous assessments, the main concern was the use of the acoustic survey abundance estimates as absolute values. In particular, a large proportion of the smooth oreo acoustic abundance from all surveys came from the LAYER and BACKGROUND mark-types. Determining the exact mixture of species in the LAYER marks had unmeasured uncertainty that may have resulted in an overestimate of the smooth oreo abundance. When the vulnerable abundance estimates above were estimated, the version based on school marks were similar to those using the length cut-offs for the 1998, 2001, and 2005 surveys, but it was much lower for the 2009 survey. As a result, current biomass estimates for the model based on fished marks were less optimistic.

1. INTRODUCTION

1.1 Overview

This work addresses the following objectives in MFish project "DEE201002OEOA".

Overall objective

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

Specific objective

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

A new stock assessment for smooth oreo in OEO 4 (Figure 1) is presented based on a new abundance estimate derived from a research acoustic survey carried out in 2009 (TAN0910, SWA0901), plus three previous abundance estimates from 1998 (TAN9812), 2001 (TAN0117, AEX0101), and 2005 (TAN0514, SWA0501).

Early stock assessments in 1997 and 2001 aimed to estimate virgin and current biomass (Doonan et al. 1997a, 2001) using a stock reduction analysis (PMOD). The 1997 assessment used relative abundance estimates from standardised CPUE, and relative abundance estimates from past trawl surveys (1991–93, 1995) with q values constrained. The 1997 assessment was considered uncertain because of the problems with the trawl survey catchabilities (Doonan et al. 1997a). The 2001 assessment used the single 1998 acoustic absolute abundance estimate as well as the relative abundance estimates from standardised CPUE (base case) and estimated a 95% confidence interval of 100 000 to 148 000 t for B_0.

In 2003, the stock assessment was updated using a CASAL age-structured population model (Bull et al. 2002). This took account of the sex and maturity status of the fish and allowed inclusion of length frequency data. The assessment modelled separate west and east fisheries as well as a combined area fishery (OEO 4). Initial model runs gave poor fits to the data and indicated that there were major conflicts between the absolute abundance estimates, the observer collected length data, and previous estimates (Doonan et al. 1997b) of growth and natural mortality (M) (Doonan et al. 2003a). For the 2003 base case, the median estimate for the mature fish B_0 for OEO 4 was 172 000 t (90% confidence interval of 147 000–209 000 t).

In 2005, the stock assessment was updated using a similar model structure as the 2003 assessment. The stock-area was split at 178° 20′ W into a west and an east fishery with no migration. Data fitted in that model included absolute abundance estimates from past acoustic surveys (1998, 2001, and 2005), relative abundance indices from standardised CPUE analyses, observer length data, and the acoustic survey length data. To resolve major conflicts between the absolute abundance estimates and the observer collected length data, the base case model fitted only the left-hand side (up to the peak) of the observer length frequencies (Doonan et.al 2008a). For the 2005 base case, the median estimate of B_0 for the mature fish for OEO 4 was 202 000 t (90% confidence interval of 178 000–231 000 t).

Smooth oreo are caught throughout the year by bottom trawling at depths of 800–1300 m in southern New Zealand waters. The OEO 4 south Chatham Rise fishery is the largest oreo fishery in the EEZ 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 hills 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. There is no known recreational or Maori customary catch of oreos.

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

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

Observations available for stock assessment analysis include biological data from research trawl surveys (1991–93, 1995, *Tangaroa*) but relative abundance estimates from these surveys are considered unreliable because of catchability issues (Doonan et al. 1997a). Absolute abundance estimates were made using acoustic methods in 1998, 2001, and 2005. Annual observer length/catch data are available from 1990–91 on, although sampling was erratic and was influenced by the progression of fishing from west to east with time and possibly by a trend from flat to hill fishing in the east.

Catch history data are available from the late 1970s although the early data and some subsequent data required reconstruction of species catch from known species proportions because of the use of the aggregated species code (OEO) (see 1.2 below). Dumping of unwanted or small fish and accidental loss of fish (lost or ripped codends) were features of oreo fisheries in the early years. These sources of mortality were likely to have been substantial in the early years, but they 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 Ministry of Fisheries (now Ministry for Primary Industries) 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).

1.2 TACCs, catch, and landings data

Oreos are managed as a group that includes black oreo (*Allocyttus niger*, BOE), smooth oreo (*Pseudocyttus maculatus*, SSO), and spiky oreo (*Neocyttus rhomboidalis*, SOR). The last species is not sought by the commercial fleet and is a minor bycatch in some areas, e.g., the Ritchie Bank orange roughy fishery. The management areas used since October 1986 are shown in Figure 1.

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 2009–10 are given in Table 1.

The OEO 4 TACC was about 7000 t from 1982–83 to 2000–01, but was reduced to 5460 t in 2001–02, and then increased again to 7000 t in 2003–04. The OEO 4 landings were slightly above the TACC in three of the last four years (Table 1). Reported estimated catches by species from data recorded in catch and effort logbooks (Deepwater, TCEPR, and CELR) for OEO 4 are given in Table 2. Soviet catches from the New Zealand area from 1972 to 1977 were assumed to be black oreo and smooth oreo combined and to be from area OEO 3A (Doonan et al. 1995).

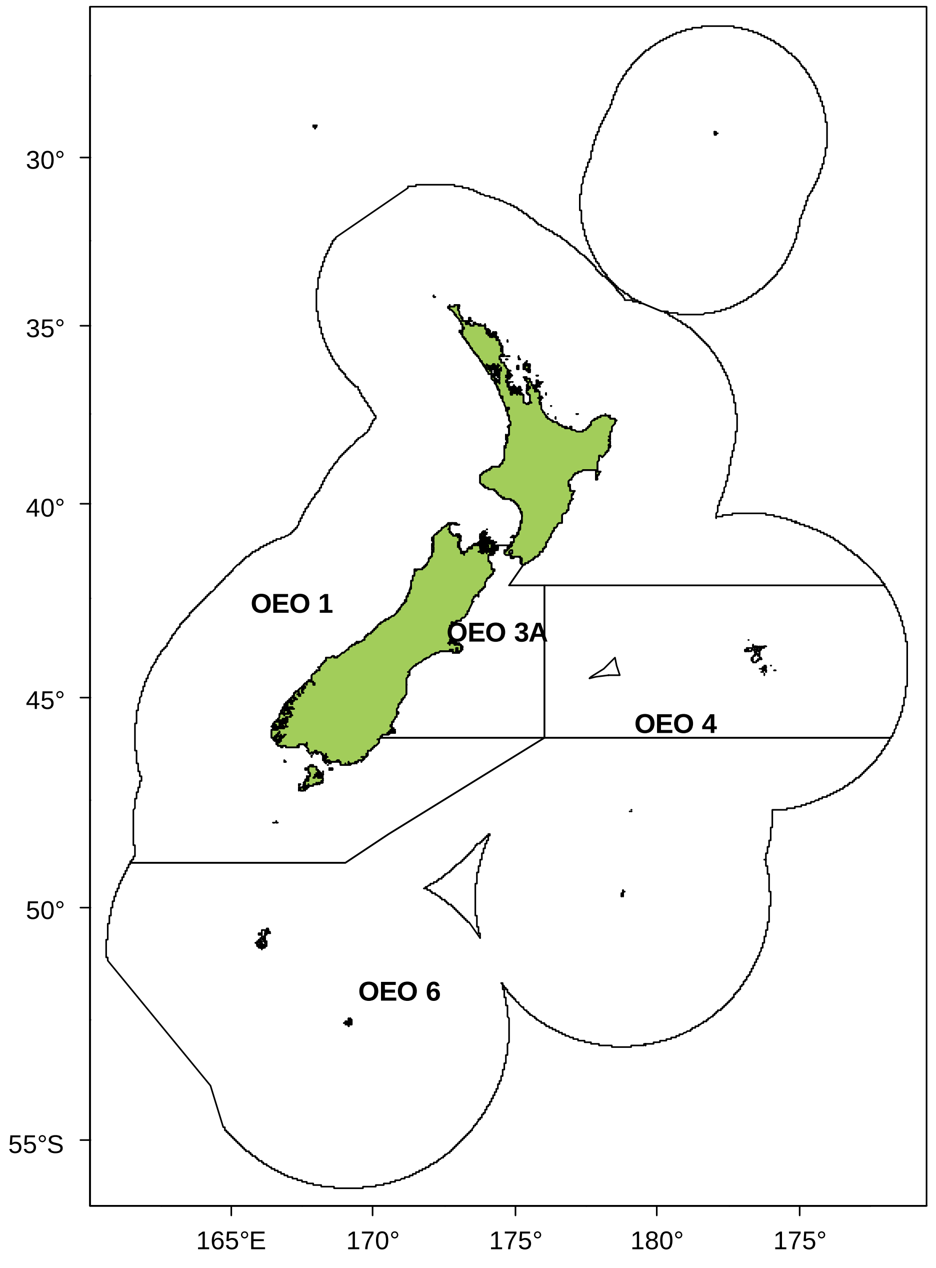


Figure 1: Oreo management areas.

Table 1: Total reported landings and TACCs (t) for all oreo species by QMA from 1978–79 to 2009–10. – na.

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†	1480	–	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	5 763	6 600	6 931	7 000	5 287	6 000	22 083	24 633
1999–00†	3 711	5 033	5 859	5 900	7 034	7 000	5 914	6 000	22 518	23 933
2000–01†	4 852	5 033	4 577	4 400	7 358	7 000	5 932	6 000	22 719	22 433
2001–02†	4 197	5 033	3 923	4 095	4 864	5 460	5 737	6 000	18 721	20 588
2002–03†	3 034	5 033	3 070	3 100	5 402	5 460	6 115	6 000	17 621	19 593
2003–04†	1 703	5 033	2 856	3 100	6 735	7 000	5 811	6 000	17 105	21 133
2004–05†	1 025	5 033	3 061	3 100	7 390	7 000	5 744	6 000	17 220	21 133
2005–06†	850	5 033	3 333	3 100	6 829	7 000	6 463	6 000	17 475	21 133
2006–07†	903	5 033	3 073	3 100	7 211	7 000	5 926	6 000	17 113	21 133
2007–08†	947	2 500	3 092	3 100	7 038	7 000	5 902	6 000	16 979	18 600
2008–09†	582	2 500	2 848	3 100	6 907	7 000	5 540	6 000	15 877	18 600
2009–10†	464	2 500	3551	3 100	7 047	7 000	5 730	6 000	16 792	18 600

Source: FSU from 1978–79 to 1987–88; QMS/MFish from 1988–89 to 2009–10. *, 1 April to 31 March. #, 1 April to 30 September. Interim TACs applied. †, 1 October to 30 September. Data prior to 1983 were adjusted up due to a conversion factor change.

Table 2: Reported estimated catch (t) for smooth oreo (SSO) and black oreo (BOE), and unspecified oreo (OEO) for OEO 4 from 1978–79 to 2009–10.

Fishing year	SSO	BOE	OEO	Total
1978–79*	0	0	8 150	8 150
1979–80*	114	580	0	694
1980–81*	870	5 356	4 250	10 476
1981–82*	3 428	5 780	9	9 217
1982–83*	2 851	1 095	54	4 001
1983–83#	1 854	1 340	6	3 200
1983–84†	4 863	1 280	15	6 158
1984–85†	4 757	1 654	8	6 419
1985–86†	4 858	980	0	5 838
1986–87†	5 662	1 156	0	6 818
1987–88†	7 638	895	0	8 533
1988–89†	6 431	1 090	0	7 521
1989–90†	5 339	439	26	5 804
1990–91†	5 260	802	65	6 127
1991–92†	4 793	1 696	7	6 496
1992–93†	3 845	1 343	1 053	6 240
1993–94†	4 806	1 558	548	6 912
1994–95†	5 780	620	109	6 509
1995–96†	5 428	364	42	5 834
1996–97†	5 606	531	1	6 138
1997–98†	5 688	694	3	6 385
1998–99†	5 652	845	7	6 503
1999–00†	5 877	626	19	6 522
2000–01†	6 008	803	43	6 854
2001–02†	3 860	515	3	4 378
2002–03†	4 090	862	26	4 978
2003–04†	5 098	973	260	6 331
2004–05†	6 014	852	5	6 871
2005–06†	5 202	763	303	6 268
2006–07†	5 978	796	5	6 779
2007–08†	6 171	592	0	6 762
2008–09†	5 703	766	0	6 469
2009–10†	6 204	942	0	7 146

*, 1 April to 31 March; #, 1 April to 30 September, interim TACs applied. †, 1 October to 30 September.

2. ASSESSMENT MODEL

2.1 Population dynamics

2.1.1 Partition of the population

The stock assessment model partitioned the OEO 4 smooth oreo population into two sex groups, and age groups 1–70 years, with a plus group. In the 2007 assessment, there were two area partitions (west and east) which were treated as two stocks. In this assessment, there is no area partition, and east and west were treated as a single stock.

2.1.2 Annual cycle

The nominal unit time in the model is one year during which processes (e.g., recruitment) were applied. Since these processes cannot be modelled simultaneously they were carried out in a specified sequence (Table 3). For convenience in the specifications, these were grouped into three time steps. Events were given a specified time within the year (month) through the specification of the percentage of natural mortality that was applied, assuming that it was applied uniformly throughout the year. Observations were fitted to model predictions specified by the time step and the time within the year (Table 3).

Table 3: Stock model: timing within a year for processes and when data were fitted. –, not applicable.

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

2.2 Selectivities, ogives, and other assumptions

Selectivities

No length frequency data were fitted in this assessment, so selectivities were assumed to be fixed. There were two versions: selectivities for both the commercial fishery and acoustic survey were assumed to be length-based and knife-edged at 33 cm. Another version used 34 cm. Both were based on the left-hand side of the observer length frequency at a point halfway to the mode.

Migration

No migration factors were used.

Maturity

The maturity ogive developed during the 2002 stock assessment was used (see appendix A in Doonan et al. 2003a).

2.3 Modelling methods, parameters, assumptions about parameters

The stock assessment analyses were conducted using CASAL (Bull et al. 2002). This was implemented as an age-structured population model that took account of the sex and maturity status of the fish. The Bayesian estimator was employed. The model incorporated deterministic recruitment, life history parameters, and catch history. Data fitted in the analysis were just the vulnerable acoustic abundances estimated from the 1998, 2001, 2005, and 2009 acoustic surveys. The model was used to estimate biomass. These procedures were conducted with the following steps.

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

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

(a) Recruitment was deterministic and followed a Beverton and Holt relationship with steepness of 0.75.
(b) Catch overruns were 0% during the period of reported catch.
(c) The population of smooth oreo in OEO 4 was a discrete stock or production unit.
(d) The catch history was accurate.

3. OBSERVATIONS AND MODEL INPUTS

Data fitted in previous assessments were the acoustic abundance estimates, standardised CPUE indices, observer length data, and the acoustic survey length data, for the east and west fisheries separately. These data series were updated in the preliminary analysis of the 2012 assessment, following the same methodology as in the previous assessment (Doonan et al. 2008a), although only the acoustic abundance estimates were used in the final model of this assessment.

3.1 Catch history

Catch history of smooth oreo is presented in Table 4 and includes the yearly total catch for OEO 4. Total catch of smooth oreo is derived using the total landings and the species proportions from the estimated catches. In the 2007 assessment, total catch of smooth oreo in OEO 4 was also split between west and east using the ratio of SSO estimated catch between the two areas. In addition, the following assumptions were made:

1 The Catches from 1978–79 to 1982–83 were assumed to be for fishing years (1 October to 30 September).
2 The 1978–79 landings of unspecified oreo (8041 t, see Table 1) were assumed to be the same proportion of smooth oreo to black oreo estimated catch reported in 1979–80.
3 The 6 month estimated catch of smooth oreo reported as 1983–83 (1854 t, Table 1) were split and half each (927 t) added to the preceding and subsequent years (1982–83 and 1983–84). There was only an 8 t difference between estimated and reported landings in 1983–83 (see Table 1, Table 2), so no adjustment to the reported smooth oreo catch was made.
4 From 1979–80 to 2009–10 the catches were calculated by multiplying the landings by the proportion of smooth oreo to black oreo estimated catch in Table 2.

Table 4: Reconstructed catch history (t) of smooth oreo from OEO 4. "OEO 4" is the catch from the whole area.

Year	OEO 4	Year	OEO 4
1978–79	1 321	1994–95	6 936
1979–80	112	1995–96	6 378
1980–81	1 435	1996–97	6 359
1981–82	3 461	1997–98	6 248
1982–83	3 764	1998–99	6 030
1983–84	5 759	1999–2000	6 357
1984–85	4 741	2000–01	6 491
1985–86	4 895	2001–02	4 291
1986–87	5 672	2002–03	4 462
1987–88	7 764	2003–04	5 656
1988–89	7 223	2004–05	6 473
1989–90	6 789	2005–06	5 955
1990–91	6 019	2006–07	6 363
1991–92	5 508	2007–08	6 422
1992–93	5 911	2008–09	6 090
1993–94	6 283	2009–10	6 118

3.2 Relative abundance estimates from CPUE analyses

The analyses were updated from those described by Doonan et al. (2008a) by including data from 2006–07 to 2009–10.

3.2.1 Data

Commercial tow-by-tow catch and effort data (from TCEPR forms) for all tows that targeted or caught unspecified oreo (OEO), black oreo (BOE), or smooth oreo (SSO) within OEO 4 were used to provide a simple descriptive analysis of the fishery. However, the standardised CPUE analysis was restricted to the area south of 43º 30' S and west of 174º 20' W (the 'study area') where the main smooth oreo fishery has occurred since 1978–79 (Figure 2). The study area accounted for about 75% of the smooth oreo taken as bycatch and nearly all of the target smooth oreo catch within OEO 4.

Methods used to conduct a descriptive analysis followed those of Anderson (2011). Raw catch weights by species were modified by adding a fraction of the catch of unspecified oreos according to the ratio of species catch weights in the relevant fishing year, and then by applying a scaling factor based on the ratio of estimated catch to landed catch for the relevant fishing year and QMA. However, the CPUE standardisation was still based on the raw, unmodified estimated catch of smooth oreo.

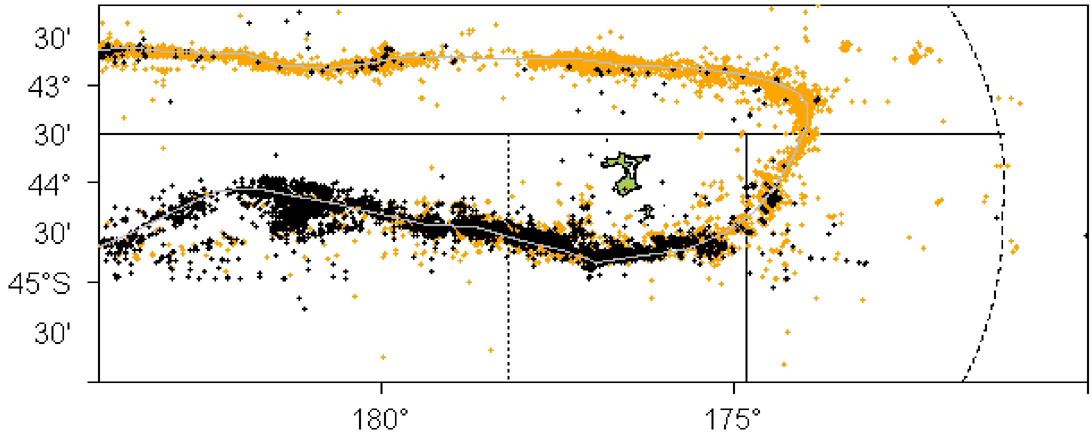


Figure 2: Start position (dots) of all trawls that targeted or caught smooth oreo in OEO 4 from 1978–79 to 2009–10. Black dots are trawls that targeted smooth oreo; orange dots are trawls that targeted orange roughy and caught smooth oreo. The western end of the study area is the boundary of OEO 4 at 176º E. The eastern boundary of 174º 50' W is shown with a vertical line. The northern boundary of 43º 30' S is shown with a horizontal line. The dashed line shows the position of the west/east split at 178º 20' W used in previous assessments. The axis-line (curved grey line) onto which positions were projected is also shown.

3.2.2 Descriptive analysis

The proportion of smooth oreo caught as a bycatch progressively decreased as the distribution of orange roughy catch diminished. Over 50% of the annual catch of smooth oreo was taken as bycatch (target orange roughy) between 1992–93 and 1997–98 and between 2001–02 and 2003–04 (Figure 3). After 2004–05 the proportion of smooth oreo taken as bycatch was about 30–40% and it dropped to 15% in 2009–10. This was mainly due to the quota cut of orange roughy in ORH 4 for the 2009–10 fishing year. The remaining catches were mainly from tows that targeted either smooth oreo (SSO) or unspecified oreo (OEO). The reason to consider OEO target tows as part of the target fishery for SSO is that there was very little targeting of black oreo (BOE) in this period and almost none that targeted BOE and caught SSO, so it is likely that OEO target tows were in reality targeting SSO. Some fishers thought that it was compulsory to use OEO as the formal quota code (Coburn et al. 2001). In 2008–09 and 2009–10, there were no OEO target tows.

Smooth oreo were generally caught throughout the fishing year but between July and September there was less catch for the target fishery and very little catch for the bycatch fishery (Figure 4). This might be because the quota was close to being fully caught towards the end of fishing year.

The distribution of smooth oreo catch along the south Chatham Rise showed that the catch was predominantly taken from the east area since 1993–94 (Figure 5). The east fishery was predominantly an orange roughy target fishery before 1997–98, but target fishing for smooth oreo increased after 1997–98. The west fishery was mainly a target oreo fishery throughout the time period.

Catch rates of smooth oreo from both the target and bycatch fisheries are summarised in Tables 5 and 6 respectively. The target catch generally has a lower percentage of zero tows and much higher catch rates than the bycatch fishery. For the bycatch fishery, the proportion of zero tows has dropped in more recent years, and the catch rate also dropped compared to the early 1990s.

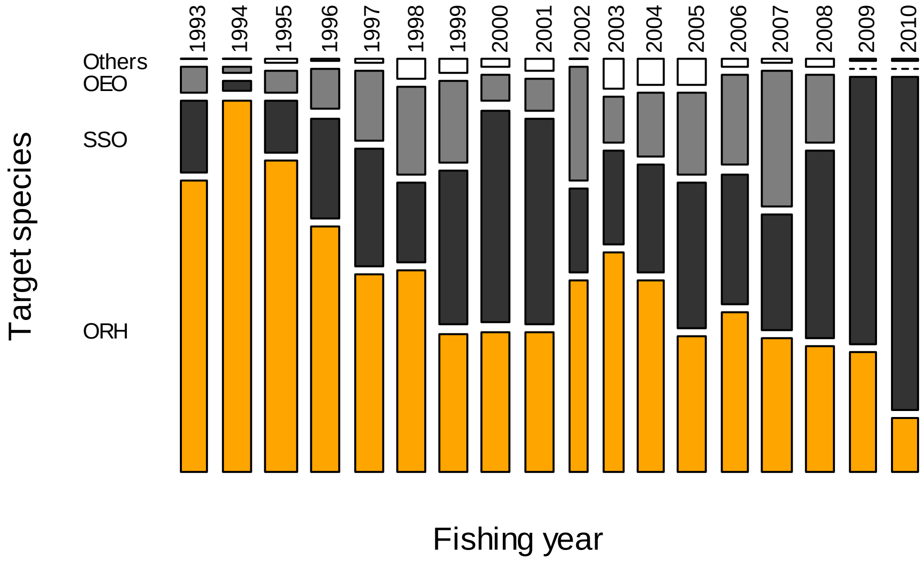


Figure 3: Distribution of smooth oreo catch from OEO 4 by target species, 1992–93 to 2009–10. Years are fishing years, e.g., 1993 is 1992–93. Only the top three target species are shown: ORH, orange roughy (yellow); SSO, smooth oreo (black); OEO, unspecified oreo (grey). The length of the bar is proportional to the catch by target species within each year; the width is proportional to the total catch of the year.

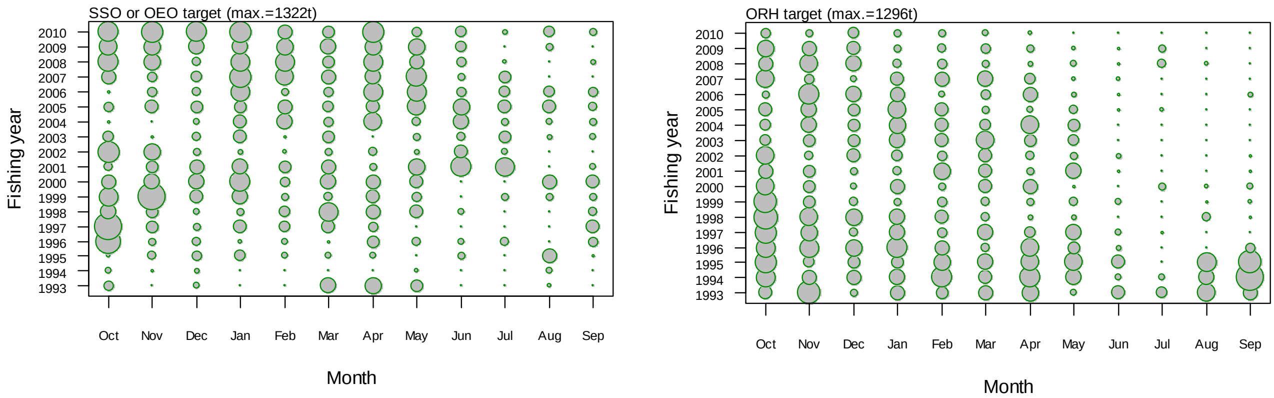


Figure 4: Distribution of smooth oreo catch from OEO 4 by month from 1992–93 to 2009–10 for trawls that targeted smooth oreo or unspecified oreo (left) and for trawls that targeted orange roughly (right).

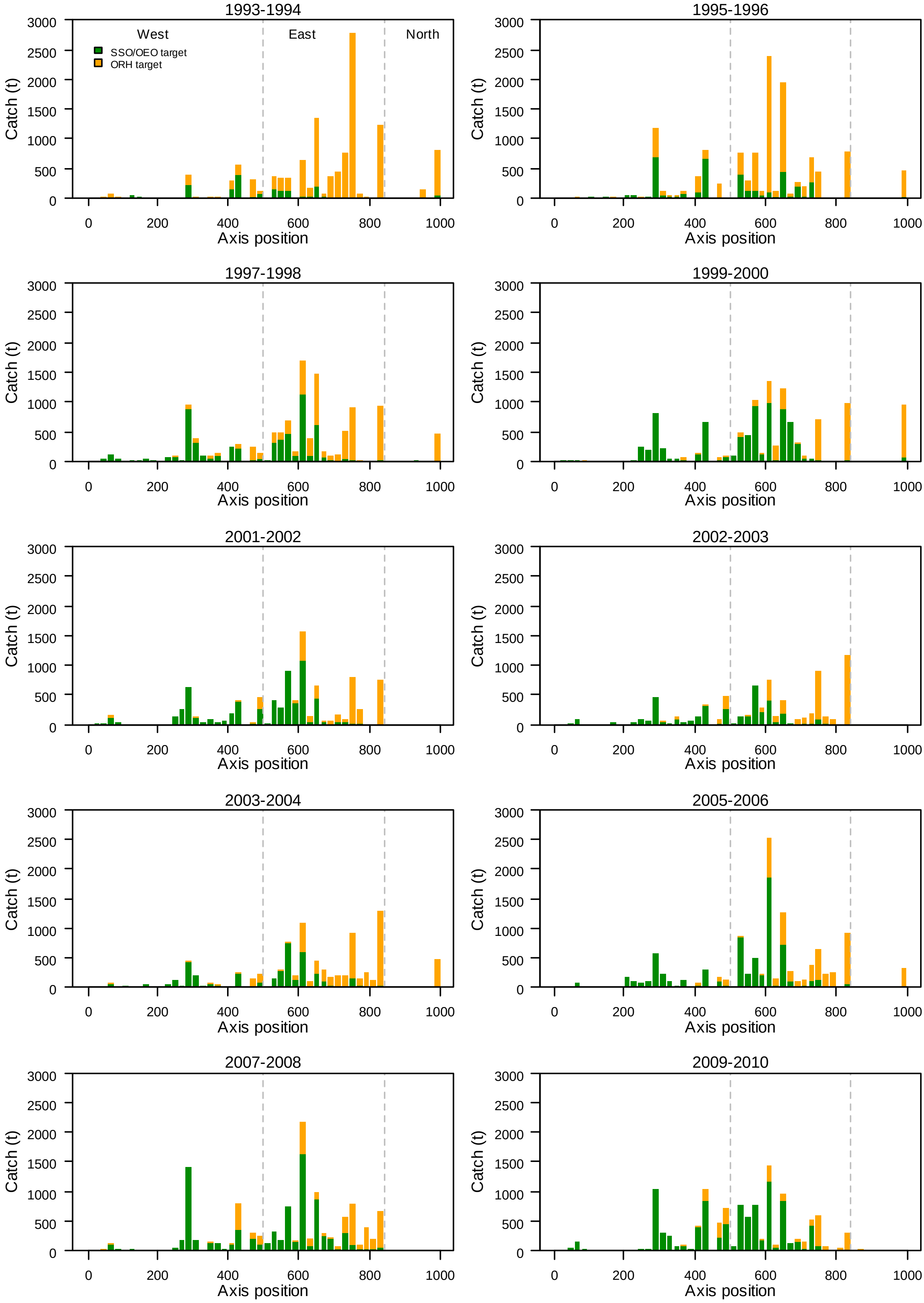


Figure 5: Distribution of smooth oreo catch along the axis position for every 20 km bin. Green, catch from SSO and OEO target tows; orange, bycatch from ORH target tows. The grey dashed lines (from left to right) represent the west/east split used in previous stock assessments and the south/north split along the axis position (see Figure 2).

Table 5: Unstandardised CPUE of smooth oreo for trawls that targeted smooth oreo and unspecified oreo from the study area within OEO 4 from 1992–93 to 2009–10. Total catch is scaled up to landings and includes a fraction of the unspecified oreo catch based on the ratio of SSO and BOE catches in that year.

Year	Catch (t)	Tows	Nonzero tows	Zero tows (%)	CPUE (t/tow)	Vessels
1992–93	1 148	161	144	0.11	8.0	8
1993–94	173	42	39	0.07	4.5	8
1994–95	1 071	131	121	0.08	8.9	6
1995–96	1 922	220	201	0.09	9.6	9
1996–97	2 672	440	378	0.14	7.1	9
1997–98	2 435	397	373	0.06	6.5	9
1998–99	3 409	564	535	0.05	6.4	16
1999–2000	3 554	442	426	0.04	8.3	8
2000–01	3 644	385	370	0.04	9.9	9
2001–02	1 960	233	210	0.1	9.3	5
2002–03	1 464	138	133	0.04	11.0	6
2003–04	2 057	263	218	0.17	9.4	8
2004–05	3 445	353	343	0.03	10.0	11
2005–06	2 846	322	288	0.11	9.9	9
2006–07	3 808	454	435	0.04	8.8	8
2007–08	3 950	416	404	0.03	9.8	5
2008–09	3 918	397	390	0.02	10.1	3
2009–10	5 302	515	500	0.03	10.6	4

Table 6: Unstandardised CPUE of smooth oreo for trawls that targeted orange roughy but caught smooth oreo as bycatch from the study area within OEO 4 from 1992–93 to 2009–10. Total catch is scaled up to landings and includes a fraction of the unspecified oreo (OEO) catch based on the ratio of known SSO and BOE catches in that year.

Year	Catch (t)	Tows	Nonzero tows	Zero tows (%)	CPUE (t/tow)	Vessels
1992–93	2 086	1 128	619	0.45	3.4	9
1993–94	3 561	1 826	1 060	0.42	3.4	13
1994–95	3 884	1 189	879	0.26	4.4	14
1995–96	2 857	742	544	0.27	5.3	9
1996–97	2 030	550	461	0.16	4.4	7
1997–98	2 104	826	643	0.22	3.3	10
1998–99	1 135	480	359	0.25	3.2	12
1999–2000	918	302	246	0.19	3.7	10
2000–01	1 252	454	372	0.18	3.4	10
2001–02	1 059	466	383	0.18	2.8	9
2002–03	1 251	584	525	0.1	2.4	11
2003–04	1 771	736	679	0.08	2.6	8
2004–05	1 437	771	679	0.12	2.1	7
2005–06	1 500	769	654	0.15	2.3	7
2006–07	1 305	592	522	0.12	2.5	6
2007–08	1 386	642	550	0.14	2.5	3
2008–09	1 351	675	593	0.12	2.3	3
2009–10	632	327	272	0.17	2.3	3

3.2.3 CPUE analysis

The CPUE analysis method was described by Doonan et al. (1995, 1996, 1997a) and involved regression-based methods where the zero catch tow and the positive catch tow data were analysed using a binomial and a lognormal model respectively to produce positive catch and zero catch indices, which were combined to produce final indices.

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 a west series from 1979–80 to 1988–89 and an east series from 1992–93 to 2009–10). The intermediate years (1989–90 to 1991–92) represented a period of rapid improvement of fishing ability due largely to the introduction of GPS and therefore those data were omitted from the analysis. Coburn et al. (2001) developed six sets of indices:

1. Target smooth oreo pre-GPS
2. Target smooth oreo or unspecified oreo post-GPS
3. Bycatch smooth oreo (target orange roughy) pre-GPS
4. Bycatch smooth oreo (target orange roughy) post-GPS
5. Target smooth oreo or unspecified oreo post-GPS west
6. Target smooth oreo or unspecified oreo post-GPS east.

Indices from 1, 2, 4, and 5 were chosen for use in the 2003 assessment model analyses since they satisfied the criteria of preferring the target smooth oreo or unspecified oreo analyses to bycatch analyses, but the bycatch post-GPS series (seven years) was used instead of the target smooth oreo or unspecified oreo post -GPS east series because the latter had only four years in the series including one in which the jack-knife c.v. was 236%. In the 2003 and 2007 stock assessments (Doonan et al. 2003a, 2008a), indices for 1, 4, and 5 were used in the base case (1 and 5 were for the west and 4 was for the east). Only index series 4 and 5 were updated because series 1 was unchanged.

Data were not used in the standardised analyses from any year when there were fewer than 50 tows or where a single vessel dominated the year's tows (greater than 80% of tows). Vessels with fewer than 50 tows over the whole time period were all lumped into the same category. Catch-per-tow (tonnes-per-tow) was chosen as the index of abundance rather than catch-per-kilometre or catch-per-hour following the Deepwater Working Group's preference in previous smooth oreo standardised CPUE analyses (Doonan et al. 1995).

For the smooth oreo (SSO) and unspecified oreo (OEO) target fisheries, a combined index was calculated. For bycatch fisheries (orange roughy target fishing) only the positive catch indices were used 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, see Figure 2), depth, season, time, hill (indicated if a tow started within 5 km of a known hill), and vessel. The reference year was arbitrarily assigned to a year near the middle of the time series. A revised method was introduced in the 2003 stock assessment to convert the index values to a canonical form by dividing each value by the geometric mean of the index series following the suggestion of Francis (1999) and resulted in the index value for the reference year being a value other than 1. Annual c.v.s for the combined indices were estimated using a jack-knife technique (Doonan et al. 1995), but the method was revised by using the canonical index values to calculate the jack-knife c.v. values and resulted in the reference year c.v. having a value other than 0.

Standardised CPUE indices for the updated series 4 and 5 are given in Table 7 and model diagnostic values are presented in Appendix A. For the bycatch ORH target post GPS series (series 4), the lognormal model included the variables fishing year, axis, day, vessel and depth, and the model explained 25% of the deviance in the data. The index showed an overall decline for 1992–93 to 2005–06, increased in 2006–07, and declined in the last three years. For the target smooth oreo or unspecified oreo post west series (series 5), the binomial model included variables fishing year, vessel, and axis position, and the lognormal model and fishing year, day, depth, vessel, and axis position. These models explained 17% and 13% of deviance in the data respectively. The updated final indices showed similar trends from 1992–93 to 2005–06 to the indices used in the previous assessment (Figure 6). The indices between 2006–07 and 2009–10 showed some fluctuations but overall remained flat.

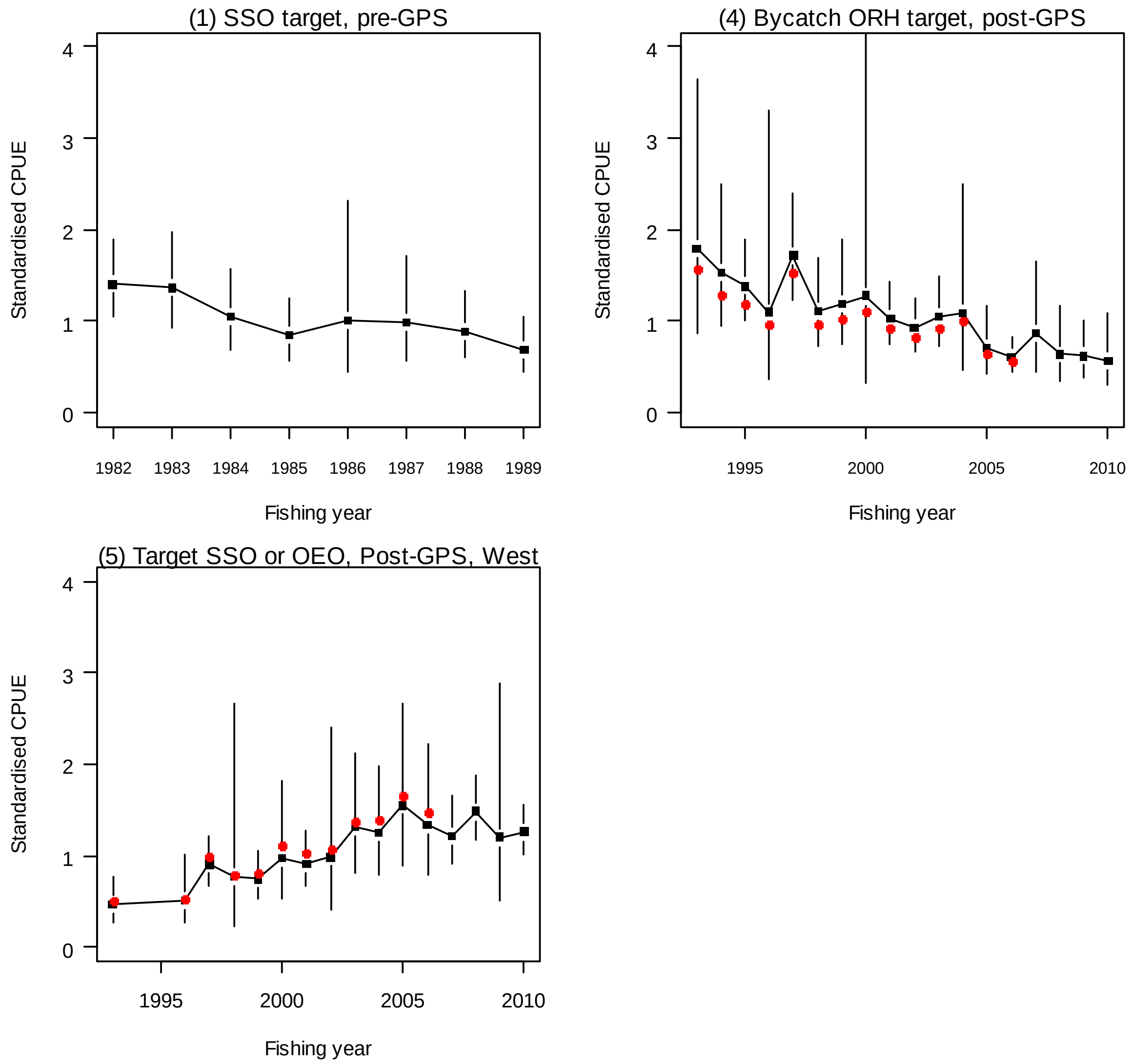


Figure 6: Standardised CPUE indices (lines with square dots) for (1) target SSO, pre-GPS series (upper left), (4) bycatch post-GPS series (upper right), and (5) target SSO or OEO, post-GPS west series (lower). The vertical lines are plus or minus two standard errors. The red dots are the indices used in the last stock assessment (Doonan et al. 2008a).

Table 7: Smooth oreo time series of abundance indices from standardised CPUE analyses for target SSO, pre-GPS series (1), bycatch post-GPS series (4), and target SSO or OEO, post-GPS west series (5). – , no data.

(1) SSO target pre-GPS			(4) Bycatch post-GPS			(5) Target post-GPS west		
Year	Index	c.v.	Year	Index	c.v.	Year	Index	c.v.
1981–82	1.4	15	1992–93	1.79	37	1992–93	0.46	27
1982–83	1.36	19	1993–94	1.53	25	1993–94	–	–
1983–84	1.04	21	1994–95	1.38	16	1994–95	–	–
1984–85	0.84	20	1995–96	1.09	60	1995–96	0.50	36
1985–86	1	44	1996–97	1.72	17	1996–97	0.90	15
1986–87	0.99	28	1997–98	1.10	22	1997–98	0.76	70
1987–88	0.89	20	1998–99	1.19	24	1998–99	0.74	18
1988–89	0.68	22	1999–2000	1.28	76	1999–2000	0.98	32
			2000–01	1.03	17	2000–01	0.92	16
			2001–02	0.92	16	2001–02	0.99	47
			2002–03	1.05	18	2002–03	1.32	24
			2003–04	1.09	44	2003–04	1.25	23
			2004–05	0.71	26	2004–05	1.55	28
			2005–06	0.60	16	2005–06	1.33	26
			2006–07	0.86	33	2006–07	1.22	15
			2007–08	0.63	31	2007–08	1.49	12
			2008–09	0.61	25	2008–09	1.20	46
			2009–10	0.56	33	2009–10	1.27	10

3.3 Relative abundance estimates from trawl surveys

Trawl surveys of oreos on the south Chatham Rise were carried out in seven years between 1986 and 1995 (Table 8). 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 but were considered to be problematic because catchability estimates were inconsistent (Doonan et al. 1997a). The estimates were not included in the base case for the 2001 stock assessment (Doonan et al. 2001) and are not included in this assessment.

Table 8: Random stratified trawl surveys (standard, i.e., flat tows only) for oreos on the south Chatham Rise (OEO 3A and OEO 4).

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

3.4 Smooth oreo relative abundance estimates from acoustic surveys

The 1998, 2001, and 2005 acoustic abundance estimates for the east and west areas were included in the 2007 assessment model as absolute abundance indices (Doonan et al. 2008a). A new acoustic survey was carried out in 2009. The 2012 assessment incorporated the vulnerable acoustic abundance estimates from the four acoustic surveys as relative abundance indices.

1998 survey

Relative estimates of abundance were available from the acoustic survey of oreos that was carried out from 26 September to 30 October 1998 on *Tangaroa* (voyage TAN9812) (Doonan et al. 2000). The survey covered 59 transects over 6 strata on the flat and 29 transects on 8 hills (Figure 7). A total of 95 tows were carried out for target identification and to estimate target strength and species composition. The 1998 survey abundance was re-estimated for total smooth oreo, instead of just recruited fish as reported by Doonan et al. (2000, 2001). The scale-up factor to take the flat survey abundance to the trawl survey area was also re-estimated for total (versus recruited) smooth oreo. The latter value became 1.75 (2.0 for recruited fish) for the abundance as a single area and also for the east area, and 2.21 for the west area. The scale-up factor to take the trawl survey area abundance to the whole of OEO 4 was also revised upwards from 1.07 to 1.11. The same values were used when the abundance was split into LAYER (unfished) and SCHOOL (fished) mark-types. The estimate was further revised to use the square-root weighting for the trawl data and to align the net catchability with that used in the 2005 survey (Doonan et al.2008b). The revised abundance estimates are in Table 9.

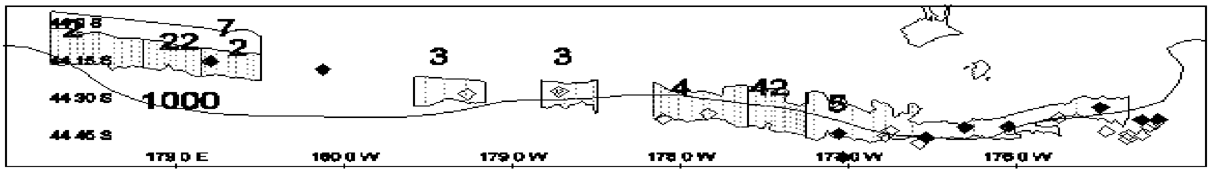


Figure 7: 1998 OEO 4 acoustic survey area showing smooth oreo (2–5, 22 and 42) and black oreo (7) flat strata (solid lines) and transects (dashed lines). Hills selected for sampling (♦); hills listed but not selected for sampling(◊).

2001 survey

Estimates of abundance were available from the acoustic survey of oreos carried out between 16 October and 14 November 2001 using *Tangaroa* for acoustic work and *Amaltal Explorer* for trawling (Doonan et al. 2003b). The flat survey included 138 transects and 84 trawls over 10 flat area strata whilst the hill survey included 46 transects and 36 trawls over 14 hills (Figure 8). The estimate was revised to align the net catchability with that used in 2005 survey (Doonan et al. unpublished results). The revised abundance estimates are in Table 9.

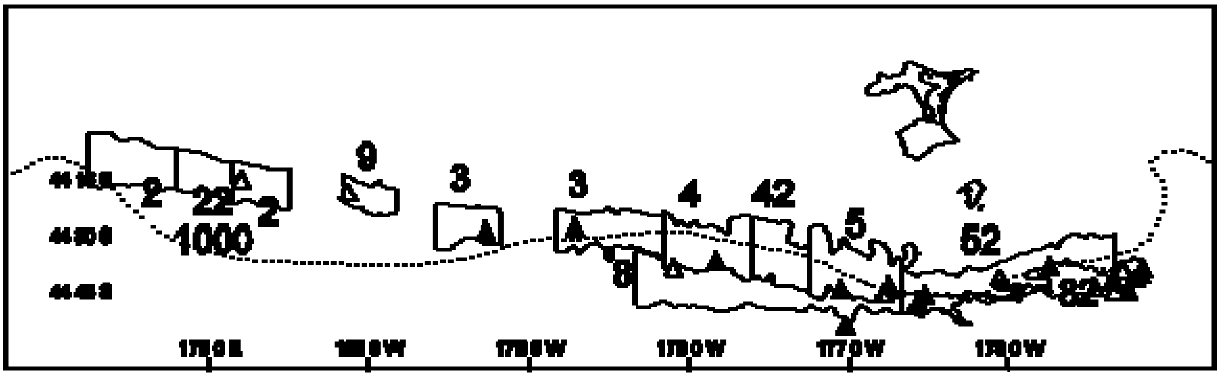


Figure 8: 2001 OEO 4 smooth oreo acoustic survey area showing flat strata and hills surveyed (filled triangles). Hills not surveyed are the empty triangles. The dotted line is the 1000 m depth contour.

2005 survey

Absolute estimates of abundance were available from the acoustic survey of oreos carried out between 3 and 22 November 2005 using *Tangaroa* for acoustic work and *San Waitaki* for trawling (Doonan et al. 2008b). The flat survey included 116 transects and 67 trawls over 10 flat area strata whilst the hill survey included 49 transects and 29 trawls over 15 hills (Figure 9). Abundance estimates are in Table 9.

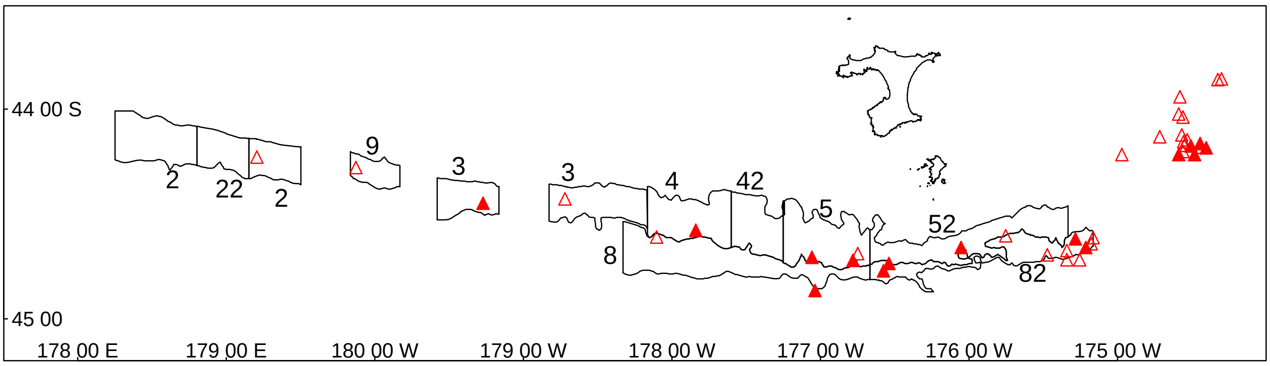


Figure 9: 2005 OEO 4 smooth oreo acoustic survey area showing flat strata and hills surveyed (filled triangles). Hills not surveyed are the empty triangles.

2009 survey

Absolute estimates of abundance were available from the acoustic survey of oreos carried out between 2 and 18 November 2009 using *Tangaroa* for acoustic work and *San Waitaki* for trawling (Doonan et al. 2011). The flat survey included 118 transects and 62 trawls over 10 flat area strata whilst the hill survey included 40 transects and 13 trawls over 12 hills (Figure 10). Abundance estimates are in Table 9.

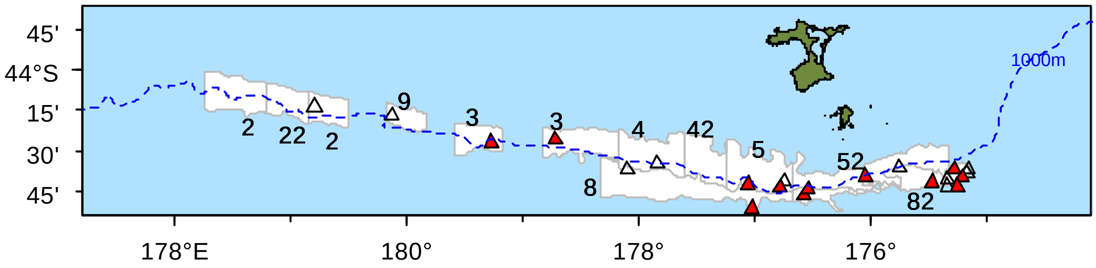


Figure 10: 2009 OEO 4 smooth oreo acoustic survey area showing flat strata and hills surveyed (filled triangles). Hills not surveyed are the open triangles.

Table 9: Estimated smooth oreo relative abundance (t) and c.v.s from acoustic surveys in 1998, 2001, 2005, and 2009 by east, west, and for the combined area.

	West		East		Total	
Survey year	Abundance (t)	c.v. (%)	Abundance (t)	c.v. (%)	Abundance (t)	c.v. (%)
1998	22 600	52	127 000	37	146 000	33
2001	43 000	35	183 200	22	218 200	22
2005	32 200	31	91 800	30	115 500	28
2009	28 100	51	46 900	35	66 500	36

Smooth oreo vulnerable abundance estimates

One of the major uncertainties in the assessment is from the large contribution to the total acoustic abundance estimate from smooth oreo estimated to be in the LAYER mark-type (about 72% of the total abundance for the 1998 survey, 47% for the 2001 survey, 45% for the 2005 survey, and 61% for the 2009 survey). The contribution of large (greater than 31 cm) smooth oreo to the total backscatter in these LAYER marks was typically less than 10% of the total LAYER abundance, with the remainder composed of a number of associated bycatch species and smaller smooth oreo in 1998 and 2001. The layer acoustic abundance could be biased because the contribution made by the suite of other fish species present in the layers may be mis-specified, thus adding to the overall uncertainty in the biomass estimates from the assessment. The contribution of large smooth oreo to the total backscatter in the SCHOOL mark-types was typically greater than 75% in 1998 and 2001. Therefore, the acoustic smooth oreo abundance estimates from the schools were considered to be better estimated than the equivalent acoustic estimates from the layers.

Abundance for vulnerable smooth oreo was estimated using two different methods. The first method was based on the length cut-offs on the total biomass, where the ratio of vulnerable to total biomass was calculated from the length data collected from the surveys using a vulnerable cut-off length determined from a mid-point on the left hand limb of the commercial length distribution. Estimates were therefore produced for length cut-offs of both 33 and 34 cm. The second method was based on the acoustic mark types where vulnerable biomass was the sum over two flat mark types: DEEP SCHOOLS and SHALLOW SCHOOLS, with the hill biomass added on. These estimates were made for the whole of OEO 4 (Table 10).

Table 10: Smooth oreo vulnerable acoustic abundance estimates (t) for OEO 4 based on a length cut-off of 33 or 34 cm, or on the vulnerable acoustic marks from acoustic surveys in 1998, 2001, 2005, and 2009. C.v.s are in brackets (%).

Year	Vulnerable (>33 cm)	Vulnerable (>34 cm)	Vulnerable marks
1998	69 673 (33)	59 855 (33)	65 679 (26)
2001	102 017 (19)	88 417 (19)	81 633 (26)
2005	70 304 (22)	61 056 (22)	63 237 (25)
2009	55 441 (30)	49 760 (31)	26 953 (26)

Abundance scaling factors

The smooth oreo abundance for the whole of OEO 4 was estimated by scaling up the flat abundance to the trawl survey area, adding the hill abundance estimates and scaling the sum up to OEO 4.

Two abundance scaling factors were used, the first to multiply the flat acoustic survey area up to the trawl survey area and the second to multiply the trawl area up to the overall OEO 4 area. The first factor was calculated using data from early trawl surveys to estimate the fraction of smooth oreo in the acoustic survey area compared to the trawl survey area (McMillan & Hart 1994c, 1995). The factor was 1.23 (c.v. 6%) for the total acoustic area. The second factor was estimated from the ratio of catches in the total OEO 4 area to that in the trawl survey area. The ratio used was 1.11 with a c.v. of 2%, calculated from data for the fishing years 1986–87 to 2000–01. The total combined scaling factor was 1.36 for the total acoustic area. Over 50% (mean of 72%) of the annual OEO 4 commercial catch of smooth oreo was taken in areas covered by the acoustic survey (Table 11).

Table 11: Proportion of smooth oreo catch in OEO 4 taken from inside and outside the 2005 acoustic survey area from 1986–87 to 2009–10. North is the area north of 43º 30' S; West is the area south of 43º 30' S and west of 174º 20' W; East is the area south of 43º 30' S and east of 174º 20' W. Total catch is scaled up to landings and includes a fraction of the unspecified oreo (OEO) catch based on the ratio of known SSO and BOE catches in that year.

		North	West		East		West/East
Fishing year	Total catch (t)		Inside survey	Outside survey	Inside survey	Outside survey	Inside survey
1987	5 672	0.02	0.51	0.22	0.21	0.04	0.72
1988	7 764	0.01	0.18	0.15	0.59	0.06	0.77
1989	7 223	0.02	0.19	0.14	0.61	0.04	0.8
1990	6 789	0.02	0.13	0.04	0.68	0.13	0.81
1991	6 019	0.18	0.2	0.04	0.54	0.04	0.74
1992	5 508	0.03	0.18	0.03	0.4	0.36	0.58
1993	5 911	0.05	0.16	0.03	0.62	0.14	0.78
1994	6 283	0.11	0.11	0.03	0.58	0.17	0.69
1995	6 936	0.07	0.15	0.04	0.59	0.15	0.74
1996	6 378	0.05	0.29	0.04	0.45	0.17	0.74
1997	6 359	0.07	0.2	0.06	0.52	0.16	0.72
1998	6 248	0.07	0.24	0.03	0.47	0.18	0.71
1999	6 030	0.09	0.23	0.03	0.51	0.13	0.74
2000	6 357	0.12	0.21	0.02	0.49	0.16	0.7
2001	6 491	0.09	0.2	0.04	0.52	0.14	0.72
2002	4 291	0.08	0.26	0.05	0.33	0.28	0.59

		North	West		East		West/East
Fishin g year	Total catch (t)		Inside survey	Outsid e survey	Inside survey	Outsid e survey	Inside survey
2003	4 462	0.07	0.21	0.07	0.39	0.27	0.6
2004	5 656	0.06	0.22	0.03	0.46	0.24	0.68
2005	6 473	0.04	0.2	0.07	0.44	0.25	0.64
2006	5 955	0.04	0.19	0.01	0.48	0.29	0.67
2007	6 363	0.02	0.19	0.03	0.52	0.24	0.71
2008	6 422	0.01	0.38	0.04	0.39	0.18	0.77
2009	6 090	0.02	0.36	0.04	0.42	0.16	0.78
2010	6 118	0.01	0.34	0.06	0.5	0.09	0.84
Total	173 296	0.06	0.23	0.06	0.5	0.16	0.73

3.5 Length data analyses

Observer length frequencies

Observer length data were extracted from the observer database. These data represent proportional catch at length and sex. Starr (unpublished data) found that the observer data needed stratifying on the basis of an west-east split at 178º 20' W and also on a 6 month seasonal split. The working group settled on October-March and April-September periods resulting in a total of four strata for OEO 4 with two in each of the west and east parts. The length frequencies were combined over strata by the proportion of catch in each stratum. Using seasonal strata meant that many years did not have data for each stratum (Table 12). The rules used to form length frequencies were:

- there must be data in each stratum, except when the proportion of catch in a stratum was lower than 10% for the east or west area;
- a total of at least five sampled tows for the year;
- tows were excluded where there was not more than 30 fish measured or if there were no data on either females or males;
- tows were restricted to the area south of 43º 30' S.

This resulted in 18 years of data for the east, and 12 years of data for the west (Table 12). The new length frequencies for this analysis are shown in Figures 11 and 12. The observer length frequency data were not included in this assessment.

Table 12: Observer smooth oreo tows sampled for length frequency from for the west and east areas and by season, plus whether a scaled length frequency was calculated ("Y"). Boxes for the west data indicate years where data were combined and the "Y" shows the year it was assigned to.

	West			East		
Year	Oct–Mar	Apr–Sep	Used	Oct–Mar	Apr–Sep	Used
1987	2	2				
1989	10	5	Y	1	0	
1990	4	0		0	1	
1991	16	0		26	4	Y
1992	6	0		45	8	Y
1993	0	0		22	16	Y
1994	1	0		64	33	Y
1995	1	0		42	30	Y
1996	9	10	Y	6	6	Y
1997	11	0		28	3	Y
1998	2	10	Y	20	8	Y
1999	0	7		30	21	Y
2000	3	15	Y	14	0	
2001	8	15	Y	44	4	Y
2002	0	3		24	16	Y
2003	4	4	Y	28	6	Y
2004	1	6		27	3	Y
2005	3	3		18	46	Y
2006	3	14	Y	3	14	Y
2007	6	21	Y	28	3	Y
2008	7	15	Y	23	26	Y
2009	16	19	Y	53	12	Y
2010	34	0		50	0	

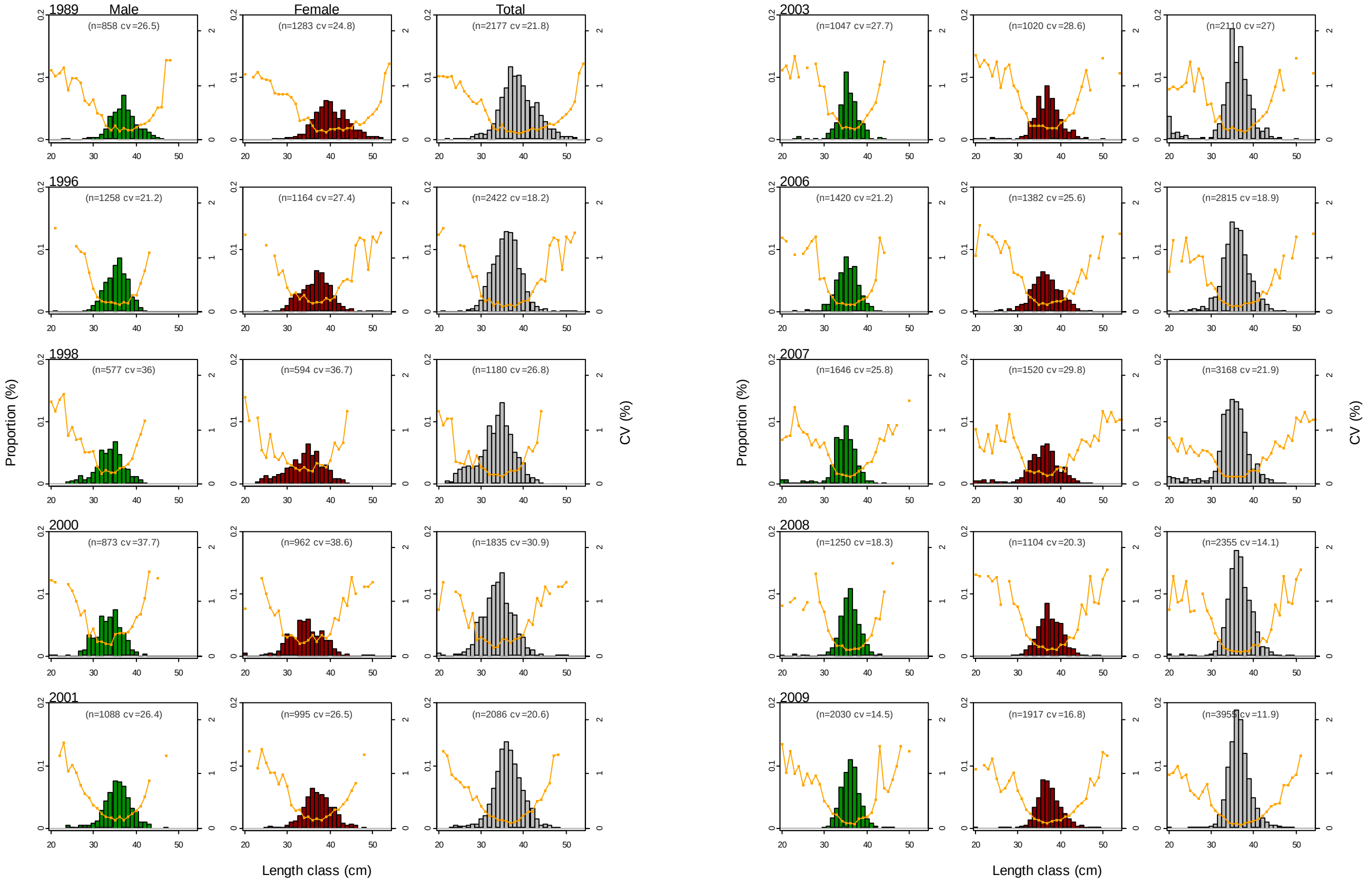


Figure 11: Smooth oreo scaled length frequencies by fishing year from observer data for the west area in OEO 4. 2003 are for 2002, 2003, and 2004 data combined; 2006 are for 2005 and 2006 data combined.

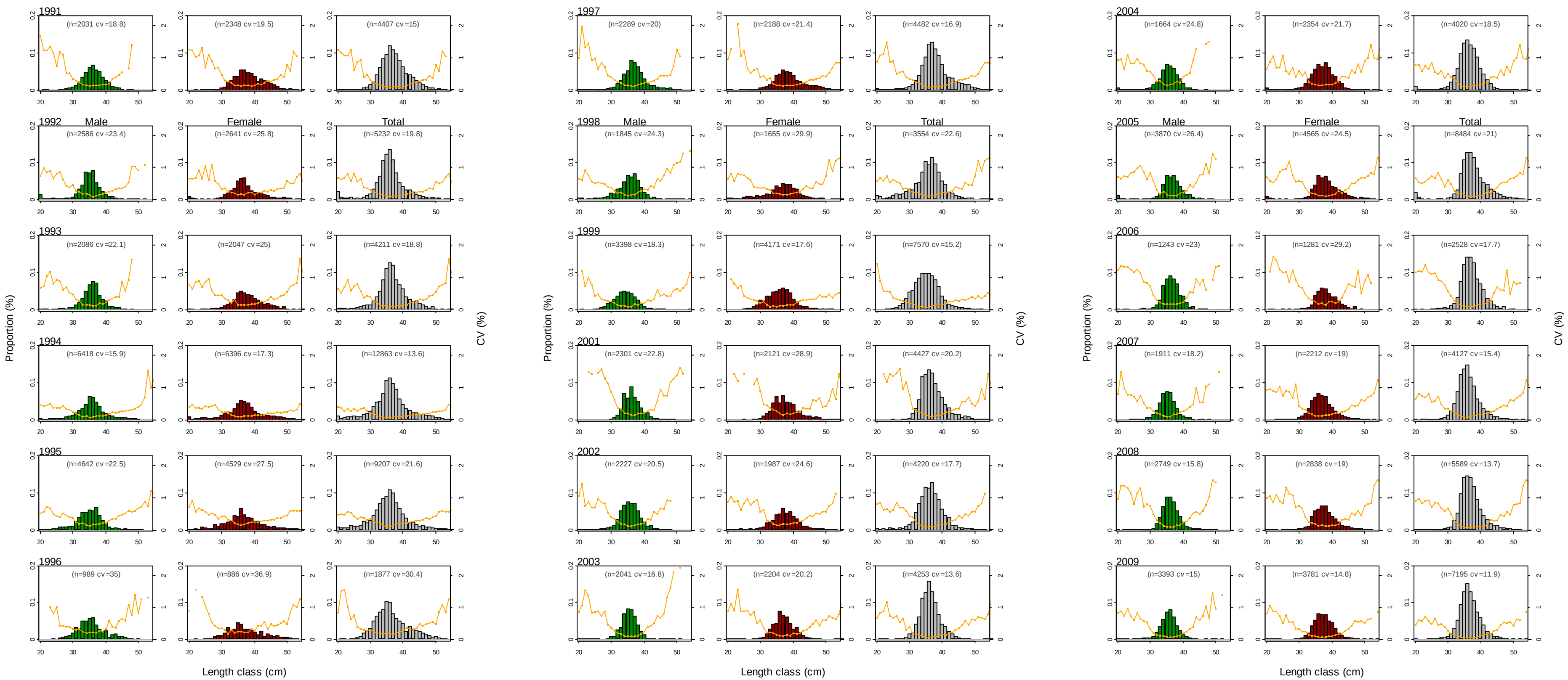


Figure 12: Smooth oreo scaled length frequencies by fishing year from observer data for the east areas in OEO 4.

Smooth oreo length frequency data from the 2001, 2005, and 2009 acoustic surveys

Population length frequencies were generated for the whole area, the east, and the west areas. These frequencies were in the CASAL form that included an implicit sex ratio, i.e., the normalisation was over both male and female frequencies so that the sum of the frequencies over both summed to 1. Each frequency was estimated using the length data from tows in each mark-type weighted by the catch rates and the proportion of abundance in the mark-type. For the flat strata, the method was:

$$f_{l,s} = \sum_{i,j} \frac{N_{i,j}}{\sum_{i2,j2} N_{i2,j2}} \sum_{k} \frac{cr_{i,j,k,s}}{\sum_{k2} \left(cr_{i,j,k2,male} + cr_{i,j,k2,female} \right)} f_{i,j,k,s,l}$$

where f is the length frequency, l is the length class, s is sex, i is stratum, j is mark-type, k is tows within mark j and stratum i, cr is catch rate, and N is abundance by numbers. N was estimated as the abundance by weight divided by the mean weight, where the mean weight was a mean weighted bycatch rate. The denominator for the catch rate part was over both males and females to account for the sex ratio. For hills, the same form was used, but some changes were needed to account for subsampling of hills within each of the three groups of hills. Scaled length frequencies for the 2001, 2005, and 2009 acoustic surveys are shown in Figure 13. The length frequency data from the acoustic surveys were not included in this assessment.

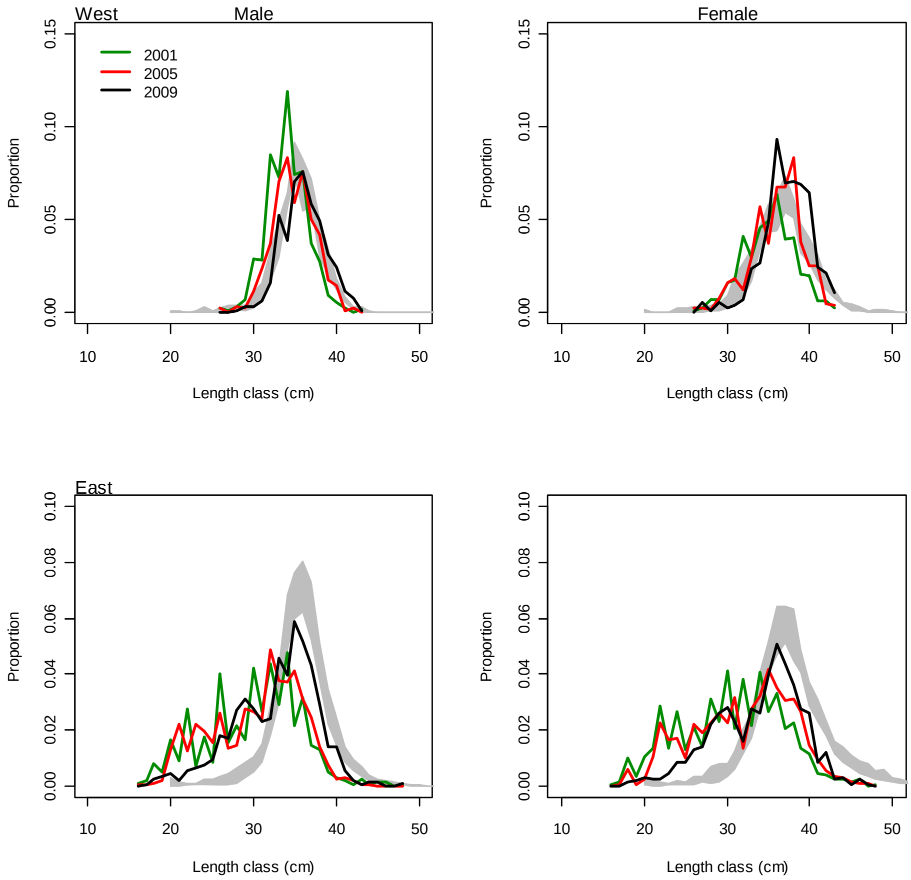


Figure 13: 2001, 2005, and 2009 acoustic survey smooth oreo length frequencies for male and female and for east and west. Shaded area represents an approximate inter-quartile region for available annual observer length frequencies.

Doonan et.al (2008b) suggested that there was close correspondence between the observer length data and the length frequencies from SCHOOL mark-types (see figures 10C and 11B in Doonan et.al 2008b). The observer data relate well to the SCHOOL mark-types length frequency, but not to the LAYER mark-type length frequency, although there appears to be some selectivity within the school mark-types since the observer data is shifted to larger values by about 1.5 cm in the case shown (female, east area). Similar patterns occur for the length frequencies of males in the east and length frequencies from the west area.

Observations of fishing during the survey and anecdotal evidence from fishers corroborate this correspondence. Further, catch rates in the LAYER mark-types were too low to be economic. Also, remarks from the skipper of the catcher vessel indicated that some marks in the SCHOOL mark-types would not be fished as they were too small and shallow, so some selectivity is practised and this may be the cause of the shifts in length frequencies between the SCHOOL mark-types and the observer data.

3.6 Biological data

The fixed values for the life history parameters used in the assessment are from Doonan et al. (1997b) (Table 13). Growth was von Bertalanffy and recruitment was assumed to follow a Beverton Holt relationship. In some cases growth or natural mortality (M) were estimated.

Table 13: Fixed life history parameters for smooth oreo.

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

3.7 Previous stock assessments

Model runs in early assessments showed that the likelihood values were dominated by the fits to the observer length frequency data and that there were poor model fits for the right-hand limb of the length frequency distributions. In the 2003 assessment, in order to fit the length frequency data, either growth or M was estimated in the model (Doonan et al. 2003a). When M was estimated the value doubled from 0.063 to about 0.12, which appears to be at variance with the age data containing fish with ages over 50 years. It was therefore considered better to estimate growth. However, it is acknowledged that allowing the model to estimate growth shows that there is a conflict between the data used to estimate the fixed parameter values of growth, the M estimate, and the length frequency data, and therefore that this makes this assessment more uncertain. In the 2003 assessment, length data had a log-normal likelihood with process errors.

In the 2007 assessment, two alternative approaches were tried: changing the observer length frequency distribution to the robustified multinomial and just fitting to the LHS (up to the peak) of the length frequencies (Doonan et.al 2008a). The latter was used to stop the influence of the RHS of these length frequencies on the estimate of virgin biomass which was outweighing that from the abundance data. The main purpose of the length data is to define the selectivities which are determined by the

LHS of the length distributions. Using both the robustifed multinomial and fitting to the LHS of the length frequencies gave the best fit to the abundance data and the Working Group chose this to be the base case. The model was also simplified by making it a two stock model, rather than use migration or a partition of the recruitment into the east and west area as in the 2003 assessment. These changes did not alter the results very much.

3.8 2012 stock assessment model

The 2012 assessment initially updated the base case of the 2007 assessment with recent catch data, a new acoustic absolute abundance estimate from the survey carried in 2009, updated observer length data, standardised CPUE, and length data from the acoustic survey. The updated model had similar results to the previous assessment, with current spawning biomass estimated to be about 46% of the virgin level. However, some of the issues seen in previous assessments remained: the length frequency data seemed to be in conflict with the abundance data; the west post-GPS standardised CPUE showed an opposite trend to the east CPUE and was inconsistent with the acoustic abundance indices.

Oreo catch data showed marked changes in fishing patterns over time. Large catches first started in the west and then progressed east over time and appeared to represent successive exploitation of new areas. Previously exploited areas in the west did not later sustain high catches. The target species and the type of fishing also 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 from the late 1980s. Since the late 1990s, there has been an increase in target fishing for smooth oreo in the east, with more fish being caught as a target species than as bycatch. Given the above, the Deepwater Working Group decided that using CPUE to index abundance should be discontinued.

With no CPUE indices, the 2012 assessment was simplified into a one area model using just the acoustic abundance estimates. Acoustic abundance data were fitted as relative indices of vulnerable abundance using a log-normal likelihood with no additional process error. The model assumed a fixed M (0.063).

Two model runs were reported: model 3.2 was fitted to the vulnerable abundance estimates from the acoustic surveys based on the length cut-off of 33 cm (an alternative model using the length cut-off of 34 cm produced similar results and therefore was not reported) and model 5.2 was fitted to the estimates based on the fished marks (Table 14).

Informed priors were assumed for the survey catchability coefficient (q). For the time series based on fished marks, a lognormal prior LN(-0.22, 0.3) was assumed. For the time series based on the length cut-offs, a lognormal prior LN(0, 0.3) was assumed. The same c.v. was used because the additional variance associated with target strength bias in the layers is similar to the variance from the adult-proportion uncertainty. See Appendix B for details.

Table 14: Descriptions of the two model runs presented for the 2012 smooth oreo stock assessment: LN, the lognormal distribution with mean and standard deviation (log space) are given in the bracket.

Model run	Description
3.2	Adult acoustic estimates using a length cut-off at 33 cm, estimating q with a LN(0, 0.3) prior
5.2	Adult acoustic estimates using the fished marks, estimating q with a LN(-0.22, 0.3) prior

3.9 Stock assessment projections

No projections were performed because the immediate sustainability of the stock was not considered to be an issue.

4. RESULTS

4.1 MPD results

The MPD parameter estimates and likelihood details for model runs 3.2 and 5.2 are listed in Table 15. B_0 was estimated to be about 157 200 t for the model using the vulnerable abundance estimates based on the length cut-off of 33 cm, and about 137 500 t for the model based on fished marks. Current stock status was estimated to be about 39% and 30% B_0 for the two models respectively. For model run 3.2, the catchability coefficient q was estimated to be about 1, close to the median value of the assumed prior distribution; for model run 5.2, q was estimated to be 0.92, slightly higher than the median of the prior.

For both models, fits to the vulnerable abundance indices are within two standard errors of the observations and are generally in line with the overall declining trend, although neither model predicted the increase of abundance between 1998 and 2001 (Figure 14).

Effects of the assumed prior of q on model results were investigated by the use of alternative log-normal priors with different mean or median values. For both models when the prior mean was doubled or halved, the estimate of q changed by a similar magnitude, and biomass estimates also changed significantly. The likelihood profile on B_0 suggested that the change of the likelihood appeared to be strongly driven by the prior distribution of q for both models (Figure 15).

Table15: MPD parameter and biomass estimates, and log-likelihood values for model runs 3.2 and 5.2.

	3.2	5.2
(a) Estimated parameter		
B_0	157 200	137 500
q	0.988	0.916
(b) Biomass estimates		
Mid-year, mature		
B_0	152 000	133 000
B_{2010}	59 000	40 000
B_{2010}/B_0	0.39	0.30
(b) Log-likelihoods		
Acoustic abundance	-4.45	-2.53
Prior on B_0	11.97	11.83
Total	7.51	9.31

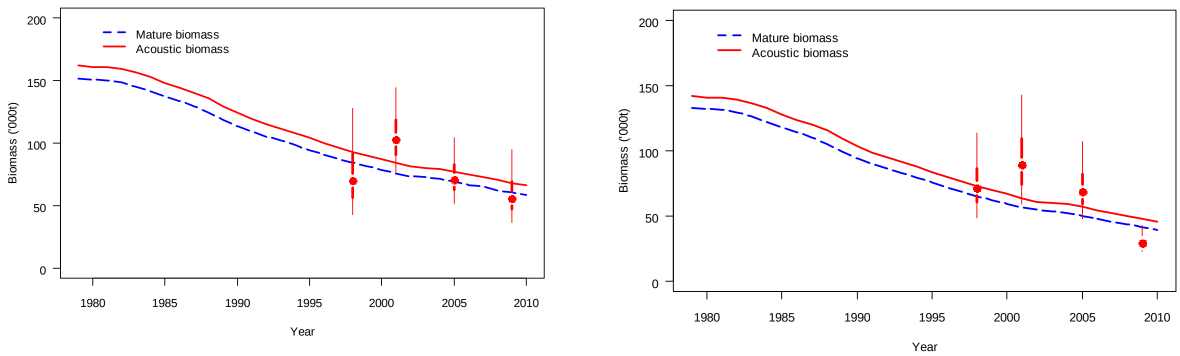


Figure14: MPD fits of the vulnerable abundance time series for models 3.2 (left) and 5.2 (right). Points are the acoustic estimates scaled by catchability coefficient to abundance. Curved lines are the model estimates of biomass (t): solid top line is the abundance that the acoustics measures and dashed line is the mature abundance. Vertical thinner error bars for acoustic are plus or minus 2 S.D., the thicker bars are plus or minus 1 S.D.

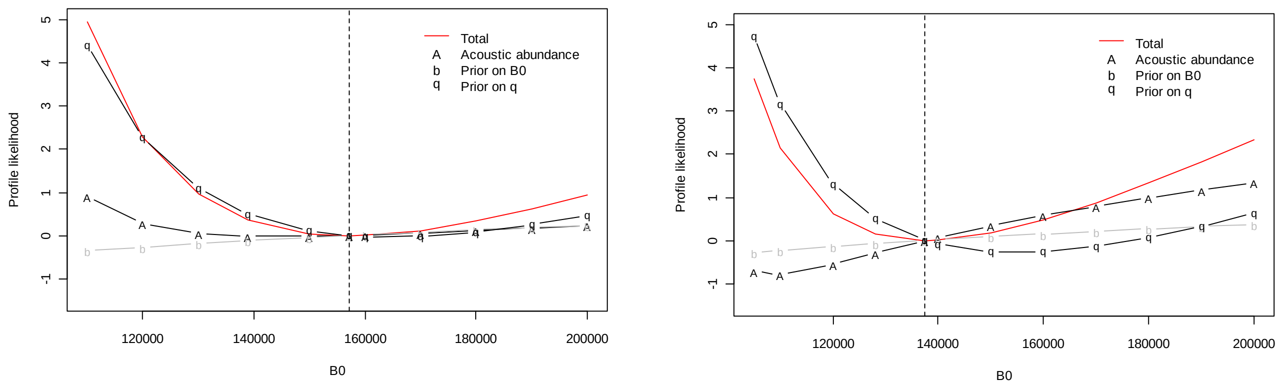


Figure 15: Likelihood profile of B_0 for model 3.2 (left) and 5.2 (right). Both total likelihood and component likelihood values are shown. The dashed line represents the MPD estimate of B_0.

4.2 MCMC results

MCMC analyses were conducted for both models. A single chain of 5 million simulations was run, starting at the MPD estimates, and samples were saved regularly, spaced by 5000. The main diagnostic used was the trace plots of the posterior samples. The MCMC traces for B_0 and $B_{current}$ are very stable and there is no evidence of non-convergence for either model run (Figure 16). For both models 3.2 and 5.2, the posterior distributions of q were similar to their prior distributions (Figure17).

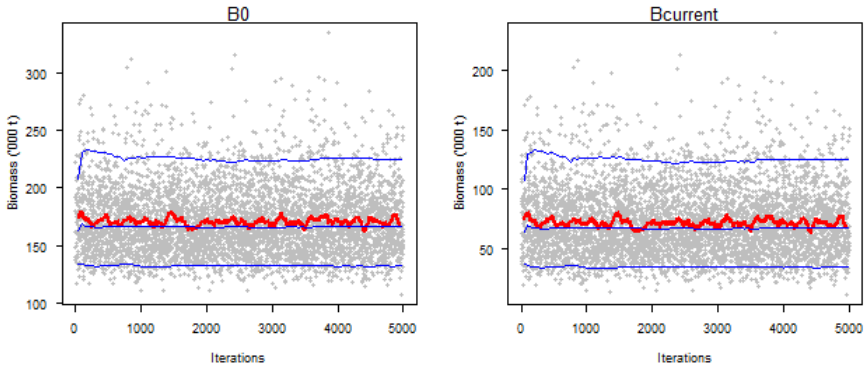
The estimates of biomass are summarised in Table 16. The median estimate of current mature biomass was 41% for the model using the abundance estimates based on the 33 cm length cut off, and was 33% B_0 for the model based on fished marks. The biomass estimates generally have wide 90% confidence bounds (Figure 18).

Estimated exploitation rates were low but appeared to have steadily increased over recent years (Figure 19). The median of current exploitation rate was estimated to be about 8% for model 3.2 and about 12% for model 4.2.

Table 16: Estimates of Mature biomass for OEO 4 smooth oreo for MCMC model runs 3.2 and 5.2.

	Model 3.2			Model 5.2		
	5%	Median	95%	5%	Median	95%
B_0	132 000	166 000	225 000	118 000	146 000	193 000
$B_{current}$	34 000	67 000	125 000	22 000	48 000	94 000
$B_{current}$ $(\%B_0)$	0.26	0.41	0.55	0.18	0.33	0.49

Model 3.2



Model 5.2

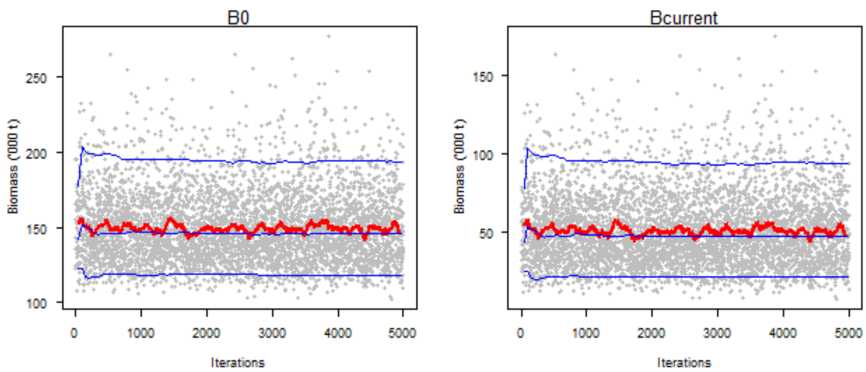


Figure 16: Traces of MCMC estimates of B_0 and $B_{current}$ for models 3.2 and 5.2. The blue lines are the running 5%, 50%, 95% quantiles, and the red line is the moving average of the posterior samples.

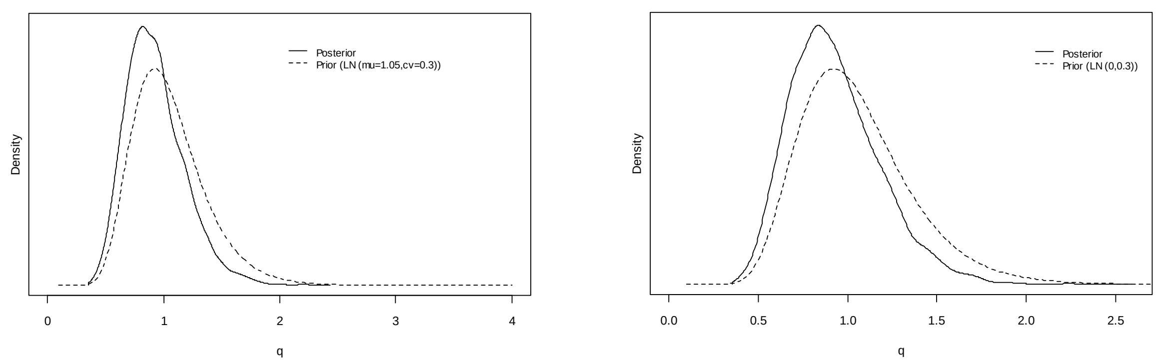


Figure 17: Bayesian posterior distribution of survey catchability q and the prior for model 3.2 (left) and 5.2 (right).

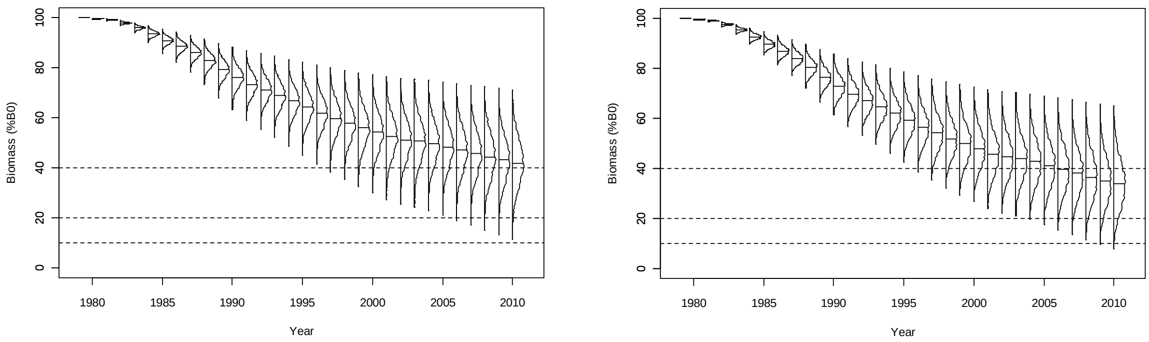


Figure 18: Bayesian posterior distribution of mature biomass as a percentage of B_0 for model 3.2 (left) and 5.2 (right). Dashed lines represent the target (40% B_0), soft limit (20% B_0), and hard limit (10%B_0) respectively.

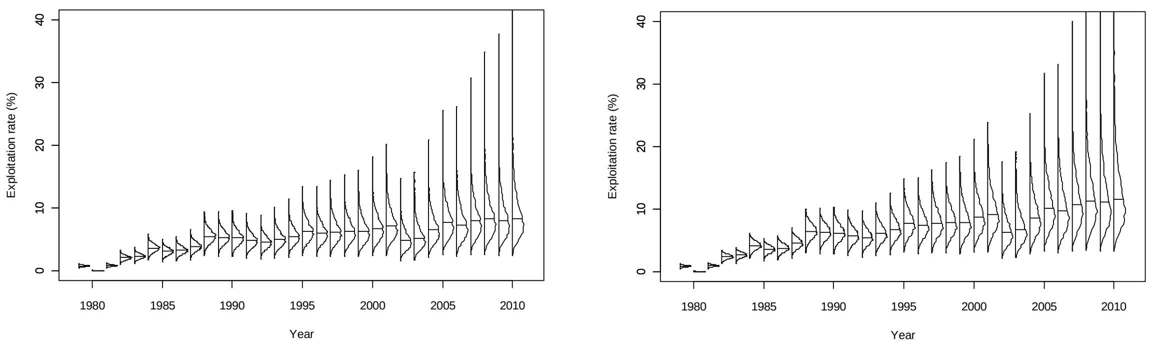


Figure 19: Bayesian posterior distribution of exploitation rate for models 3.2 (left) and 5.2 (right).

5. DISCUSSION

The 2012 assessment of smooth oreo in OEO 4 was simplified into a one-area model that used just the acoustic abundance indices as relative indices. To limit the extra uncertainty in "layer" marks which contained the pre-recruit fish, the abundances estimates were re-calculated and were included as relative abundance estimates. Model results were strongly driven by the assumed prior for the relative catchability coefficient (q), and estimates of q were sensitive to the median of the assumed lognormal prior. The range estimates for q were based on limited information on target strength, the QMA scaling-factor, and the proportion of vulnerable biomass in the vulnerable acoustic marks.

The current stock size was estimated to be 26–55% of virgin levels for the model in which the vulnerable acoustic abundances were based on the ratio of adult to total biomass assuming a length cut-off of 33 cm, and 18–49% of virgin biomass for the model based on fished marks. The difference is mainly due to the much lower estimate of vulnerable abundance in 2009 for fished marks. The acoustic smooth oreo abundance estimates from the schools were considered to be better estimated than the equivalent acoustic estimates from the layers.

The estimated bounds of stock size may not represent the true level of uncertainty in the stock assessment. There are a number of structural assumptions in the model that result in the true uncertainty of the model biomass estimates being underestimated. These include the assumption that there was no variability in recruitment (deterministic recruitment was used).

This assessment suggests that there is no immediate sustainability issue for OEO 4 smooth oreo, but the large decline in the 2009 acoustic abundance estimate suggests that future monitoring of the stock would be wise. Age frequencies estimated from the 1998 and 2005 acoustic surveys suggest the possibility of poor recruitment to 1 year olds from 1986 up to 1995, the youngest cohort that would be seen in the 2005 acoustic data (Doonan & McMillan 2011). These cohorts would enter the fishery (at about age 23 years) from 2009 to 2018. However, age data from the 1993 and 1994 trawl surveys on the eastern end of the south Chatham Rise were ambiguous (Doonan & McMillan 2011).

6. ACKNOWLEDGMENTS

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APPENDIX A: CPUE model diagnostics

Table A1: Predictor variables and R^2 values from GLM stepwise regression analysis for selected models. Variables are shown in order of acceptance by the model with associated cumulative R^2 value. Only variables entered into the model are shown.

Model 4 (Bycatch ORH target post GPS)		Model 5 (Target SSO or OEO post GPS West)			
	Lognormal		Binomial		Lognormal
Variable	R^2	Variable	R^2	Variable	R^2
fishing year	0.060	*fishing year*	0.069	*fishing year*	0.035
Axis	0.173	vessel	0.150	*depth*	0.074
vessel	0.221	axis	0.176	*fishing day*	0.095
fishing day	0.236			*vessel*	0.115
Depth	0.252			*axis*	0.130

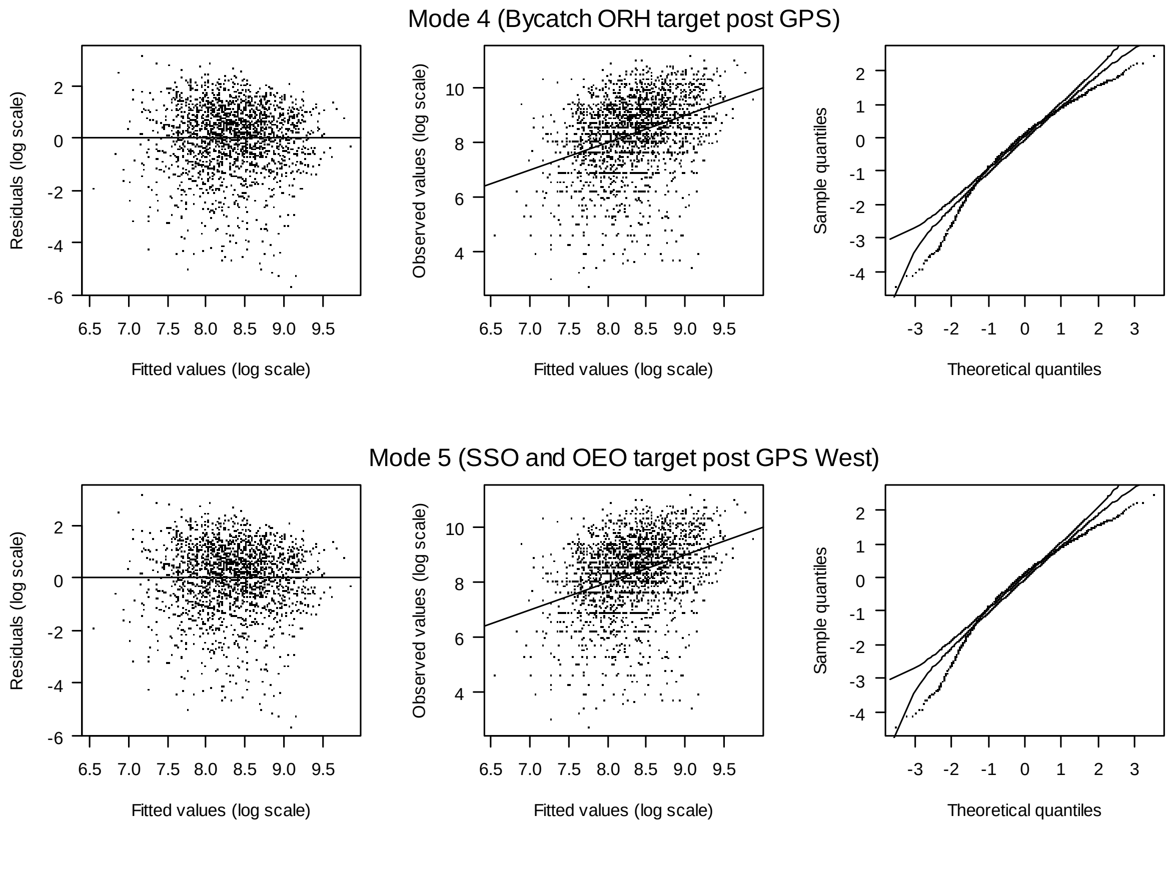

Figure A1: Residual diagnostic plots for updated CPUE model 4 (Bycatch ORH target post GPS) and Model 5 (SSO and OEO target post GPS west).

APPENDIX B: Informed prior on the acoustic catchability (*q*) (P Cordue, pers. comm.)

The acoustic survey covers only part of the trawl survey area, which is not all of the QMA so acoustic estimates must be scaled up to be absolute estimates for the whole QMA (*Y*):

Y = $S\ (T\ X_{flat} + X_{hill}\ )$, where:

X_{flat} = acoustic estimate from the flat,

X_{hill} = acoustic estimate from the hills,

T = factor to scale up to trawl survey area, and

S = factor to scale up to QMA.

For 1998, T was estimated to be 1.75, and for 2001–2009 it was estimated to be 1.23) using trawl survey results from 1992, 1993, and 1995. S was estimated from ratio of catches in trawl-survey area compared to whole QMA (value used = 1.11). There was a temporal trend in S for individual years from 1.03 in late 1980s to 1.25 in 2000.

Assuming that the procedure for scaling up to the trawl survey area is unbiased, the q for the time series from smooth oreo adult marks is given by

$$q = \mathrm{E}[\ t_{true} / t\ ]\ \mathrm{E}[\ S / S_{true}\ ]\ p,$$

where t is the mean areal backscattering coefficient, and p is the proportion of recruited smooth oreo in the adult marks

The method to arriving at a prior is to find the "best guess" for each factor and its range. These are then fitted to a (usually) lognormal distribution by setting the median to the best guess and the 99% coverage to the range.

The best guess for S / S_{true} is 1.0 with a range over individual years from 1.11/1.25 = 0.89 to 1.11/1.03 = 1.08.

For the proportion in adult marks (p) we use the adult estimates based in fish lengths greater than or equal to 32 cm from the 4 surveys which had a mean proportion 0.78 with 95% confidence level that was 0.78 ± 0.2. We chose the best guess as 0.8 with a range from 0.6 to 1.0.

The range of the ratio, t_{true} / t, was evaluated from the target strength reported estimates. The best guess was taken as 1.0. Difference indicated a range of ± 2 dB, which is a factor of 1.58 in the biomass scale.

Putting the three factors together for q gives best guess of 0.8 and a range from 0.34 to 1.71, which gives a lognormal distribution of LN(-0.22, 0.3).

For the acoustic time series based on using a length cutoff of 32 cm, we use a similar procedure and assume the same c.v. as the prior above, but we have changed the best guess for q equal to be 1.0, which results in a prior LN(0, 0.3).