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Assessment of OEO 4 smooth oreo for 2012–13

New Zealand Fisheries Assessment Report 2015/7

D. Fu
I. J. Doonan

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EXECUTIVE SUMMARY

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The biomass of smooth oreo in OEO 4 was estimated using a Bayesian CASAL age-structured population model. As CPUE was not considered a reliable index of abundance due to changes in fishing patterns over time and across the stock area, assessments since 2012 have used a single area model using observations of vulnerable abundance from acoustic surveys as the only index of abundance. In this assessment, we update the model with new information collected since 2012, including an additional abundance estimate from the acoustic survey carried out in 2012.

The 2014 model was fitted to biomass estimates from acoustic surveys carried out in 1998 (trip code TAN9812), 2001 (TAN0117, AEX0101), 2005 (TAN0514, SWA0501), 2009 (TAN0910, SWA0901), and 2012 (TAN1214, SWA1201). The assessment also included age frequency data collected from the 1998 and 2005 acoustic surveys. These biomass estimates were fitted in the assessment model as relative biomass indices using an informed lognormal prior of the survey catchability coefficient *q*.

The base case assessment model estimated that the current mature biomass was 27% B_0 (90% CI of 16–41%). Sensitivity trials were carried out to assess some of the key model assumptions including alternative values for prior on *q* and the rate of natural mortality *M*. Model results were strongly influenced by the assumed mean of the prior for the catchability coefficient *q*, suggesting that the signal in the acoustic estimates is not strong enough to determine *q* well. For example, when the mean of the prior for *q* was 20% higher and *M* was 20% lower than for the base case, the current spawning stock biomass was estimated to be 18% B_0; and when the mean of the prior for *q* was 20% lower and *M* was 20% higher, the current spawning stock biomass was estimated to be 36% B_0.

There was additional uncertainty in the input data and assumptions that was not fully captured in this analysis. Additional unmeasured uncertainty in the mixture of species from LAYER denoted marks could have resulted in an overestimate of the smooth oreo biomass from the acoustic survey. Further, acoustic biomass estimates using the length cut-off were much higher than those based on fished marks, and sensitivity analyses using biomass estimates from the length cut-off resulted in a higher estimate of current biomass.

There is an additional uncertainty in the 2012 survey observation where about 25% of the estimated acoustic biomass was from a mark that was highly uncertain, but was assumed to be smooth oreo. The species composition for this mark was not able to be verified at the time by trawling. Sensitivity analyses that excluded this mark reduced the 2012 observed abundance by about 45%, and as a result, reduced the models estimate of current spawning stock biomass from 27% B_0 to about 20% B_0.

1. INTRODUCTION

1.1 Overview

This work addresses Ministry for Primary Industries (MPI) project DEE201002OEO C, “to carry out a stock assessment of black oreo (*Allocyttus niger*) and smooth oreo (*Pseudocyttus maculatus*), including estimating biomass and sustainable yields, and specifically, to carry out a stock assessment, including reviewing and summarising historical biological data from the MPI observer programme, and estimating biomass and sustainable yields for the following areas: smooth oreo in OEO 4”.

This report provides an updated stock assessment for smooth oreo in OEO 4 (see Figure 1) based on a new abundance estimate derived from a research acoustic survey carried out in 2012 (trip codes TAN1214, SWA1201), plus four previous abundance estimates from 1998 (TAN9812), 2001 (TAN0117, AEX0101), 2005 (TAN0514, SWA0501), and 2009 (TAN0910, SWA0901).

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. It operates between 176° E and about 172° W, mostly on undulating terrain (short plateaus, terraces, and "drop-offs") at the western end and 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 since 1994–95. There is no recreational or Maori customary catch of oreo.

Smooth oreo are 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 at about 70 years (Doonan et al. 1997b). Age estimates for New Zealand fish have not been validated, but similar ages were reported by D.C. Smith and B.D. Stewart (Victorian Fisheries Research Institute, unpublished) for Australian smooth oreo. Smooth oreo are a schooling species and form localised aggregations to feed (throughout the year) and to spawn (typically October–December).

Stock structure of Australian and New Zealand samples of smooth oreo were examined using genetic analyses (allozyme and mitochondrial DNA) and morphological counts (fin rays, etc.), but no differences between New Zealand and Australian smooth oreo samples were found (Ward et al. 1996). While this suggests a broad scale homogenous stock, it would seem to be unlikely given the large distance between New Zealand and Australia. A small 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. The study found some evidence that the 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 that OEO 3A samples were different to those from other areas; but lateral line scale and otolith settlement zone counts showed no differences between areas (Smith et al. 1999).

Observations available for assessment include biological data from research trawl surveys (1991–93, 1995, *Tangaroa*), but relative biomass estimates from these surveys were considered unreliable because of catchability issues (Doonan et al. 1997a). Biomass estimates from acoustic surveys were available in 1998, 2001, 2005, 2009, and 2012. Annual observer length-frequency and catch composition 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 Section 1.2 below). Dumping of unwanted or small fish and accidental loss of fish (from either 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 are likely to be relatively small in more recent years. No estimate of the mortality from these sources has been made due to lack of data. Estimates of discards of oreo 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 t and 270 t for 1994–95 and 1995–96 respectively (Clark et al. 2000).

1.2 Previous assessments

Stock assessments in 1997 and 2001 aimed to estimate virgin and current biomass using the stock reduction analysis package PMOD (Doonan et al. 1997a, 2001). The 1997 assessment used relative abundance estimates from standardised CPUE, and relative abundance estimates from past trawl surveys (1991–1993, 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 t 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 frequency distribution (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).

In 2012, the Deepwater Working Group decided that using CPUE to index abundance should be discontinued, due to changes in fishing patterns over time within the stock area. With no CPUE indices, the 2012 assessment was simplified to a single area model using only the observations of vulnerable biomass from acoustic surveys carried out in 1998, 2001, 2005, and 2009. The biomass indices were fitted in the assessment model as relative abundance indices and used informed lognormal priors for the survey catchability coefficient q. The indices were calculated either using the ratio of vulnerable to total abundance assuming a length cut-off value of 33 cm (or 34 cm in one sensitivity analysis) for the vulnerable fish, or based on acoustic mark-types that are commercially fished for smooth oreo.

The 2014 stock assessment updated the 2012 assessment model using the same single area model structure. This assessment used an additional observation of abundance derived from the research acoustic survey carried out in 2012. The assessment also revised the previous assessments by including the age frequency estimates from the 1998 and 2005 acoustic surveys and by estimating relative year class strengths.

1.3 TACCs, catch, and landings data

Oreo 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.

Separate catch statistics for each oreo species were not recorded in 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 oreo were requested to record the species separately in the catch-effort logbooks. Reported landings of oreo (combined species) and TACs from 1978–79 to 2012–13 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 below the TACC in the last two 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 assumed to be from area OEO 3A (Doonan et al. 1995).

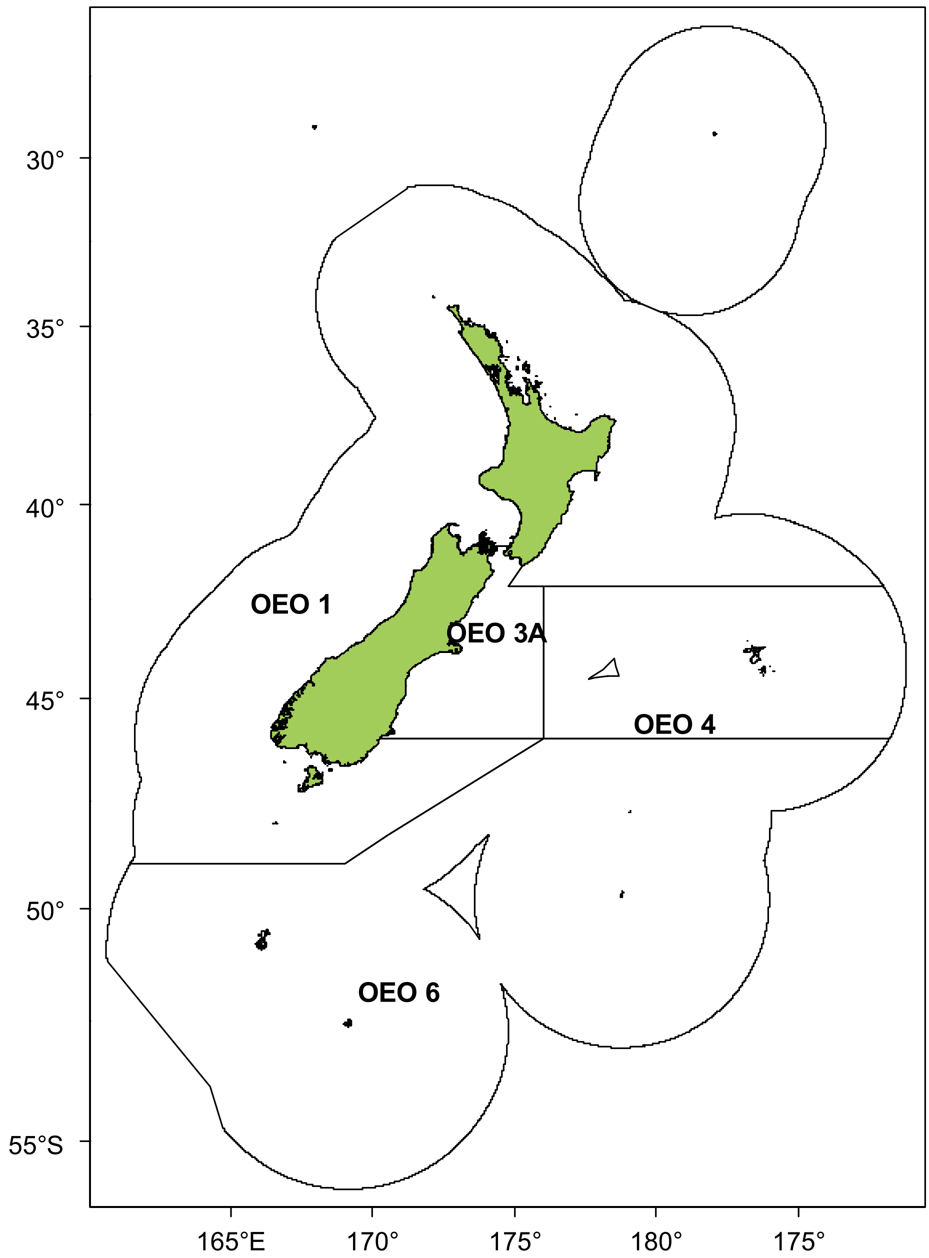

Figure 1: Oreo management areas.

Table 1: Total reported landings and TACCs (t) for all oreo species by QMA from 1978–79 to 2012–13 (– not applicable).

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	3 550	3 350	7 047	7 000	5 730	6 000	16 792	21 133
2010–11†	381	2 500	3 370	3 350	7 061	7 000	3 610	6 000	14 422	21 133
2011–12†	581	2 500	3 324	3 350	6 858	7 000	2 325	6 000	13 088	18 850
2012–13†	652	2 500	3 245	3 350	6 944	7 000	1 364	6 000	10 978	18 860

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 2012–13.

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
2010–11†	6 472	539	0	7 011
2011–12†	6 183	487	0	6 670
2012–13†	5 920	973	0	6 893

*, 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

The stock assessment model partitioned the OEO 4 smooth oreo population into a single area, two sex groups, and age groups 1–70 years with the last age a plus group.

The models were run for the years 1955–2013. The nominal unit time in the model is one year during which population processes (e.g., recruitment, spawning, and ageing) 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-Sep	Fishing mortality	Oct	Acoustic abundance
			Oct	Acoustic age data

2.2 Selectivities, ogives, and other assumptions

2.2.1 Selectivities

Length frequency data from both the commercial catch sampling and from the acoustic survey were not used in this assessment, and the selectivities for the commercial fishery and the acoustic survey (vulnerable biomass) were assumed known and fixed. They were both assumed to be length-based and knife-edged at 33 cm. The choice of the selectivity was determined by the left-hand side of the commercial catch length frequency from observers, using a point halfway to the mode. A separate selectivity was used for fitting the age frequency data from the acoustic surveys. This selectivity was assumed to be logistic and was estimated within the model.

2.2.2 Migration

No migration factors were used.

2.2.3 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 and used Bayesian estimation. The model incorporated deterministic recruitment, life history parameters, and catch history. Data fitted in the analysis were the vulnerable acoustic abundances estimated from the 1998, 2001, 2005, 2009, and 2012 acoustic surveys, and the age frequencies derived from the 1998 and 2005 acoustic surveys. 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-Hastings 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 this assessment were the acoustic abundance estimates and age frequency data from acoustic surveys. Earlier assessments (Doonan et al. 2008a, 2003a) included standardised CPUE indices, observer length frequencies, and the acoustic survey length frequencies. The acoustic abundance estimates, observer length frequencies, and the acoustic survey length data were updated in the preliminary analysis of the 2014 assessment, following the same methodology as in the 2012 assessment (Fu & Doonan 2013). The Deepwater Working Group decided that using CPUE to index abundance should be discontinued and CPUE indices were not used in the 2012 assessment (Fu & Doonan 2013), so no update on the standardised CPUE indices was made for the 2014 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 addition, the following assumptions were made:

1. The catches before 1977–78 were assumed to be zero (i.e., Soviet catches from 1972 to 1977 were assumed to be black oreo from area OEO 3A).
2. The catches from 1978–79 to 1982–83 were assumed to be for fishing years (1 October to 30 September).
3. The 1978–79 landings of unspecified oreo (8041 t, see Table 1) were assumed to be in the same proportions of smooth oreo to black oreo estimated catch in 1979–80.
4. The 6 month estimated catch of smooth oreo reported as 1983–83 (1854 t, Table 2) was 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 (compare Tables 1 and 2), so no adjustment to the reported smooth oreo catch was made.
5. From 1979–80 to 2009–13 the catches were calculated by multiplying the total reported OEO 4 landings by the proportion of smooth oreo to black oreo estimated catches 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	1996–97	6 359
1979–80	112	1997–98	6 248
1980–81	1 435	1998–99	6 030
1981–82	3 461	1999–2000	6 357
1982–83	3 764	2000–01	6 491
1983–84	5 759	2001–02	4 291
1984–85	4 741	2002–03	4 462
1985–86	4 895	2003–04	5 656
1986–87	5 672	2004–05	6 473
1987–88	7 764	2005–06	5 955
1988–89	7 223	2006–07	6 363
1989–90	6 789	2007–08	6 422
1990–91	6 019	2008–09	6 090
1991–92	5 508	2009–10	6 118
1992–93	5 911	2010–11	6 518
1993–94	6 283	2011–12	6 357
1994–95	6 936	2012–13	5 964
1995–96	6 378		

3.2 Descriptive analysis of catch and effort data

This section provides a brief description of the fishery using commercial catch and effort data up to 2012–13. No updates to the standardised CPUE indices were made. The analysis was based on TCEPR tow-by-tow data from all tows that either targeted or caught unspecified oreo, black oreo, or smooth oreo within OEO 4. Following Anderson (2011), raw catch weights by species were modified by (i) adding a proportion of the catch of unspecified oreos according to the ratio of species catch weights in the relevant fishing year, and (ii) applying a scaling factor based on the ratio of estimated catch to landed catch for the relevant fishing year and QMA.

Figure 2 shows the distribution of smooth oreo catch by target species in OEO 4. The main smooth oreo fishery has occurred in the area south of 43º 30' S and west of 174º 20' W (referred to as the "study area" in previous CPUE standardisation analyses). This area accounted for about 75% of the smooth oreo taken as bycatch and most of the target smooth oreo catch within OEO 4 since 1978–79. In the last two years, over 99% of smooth oreo catches have been taken from the southern Chatham Rise.

Nearly all the smooth oreo taken as bycatch in the orange roughy target fishery were from the northern Chatham Rise (Figure 2). The proportion of the total smooth oreo catch taken as a bycatch progressively decreased as the orange roughy catch diminished following the quota reductions on the Chatham Rise in recent years (Ministry for Primary Industries 2013). Over 50% of the annual catch of smooth oreo was taken as bycatch between 1992–93 and 1997–98 and between 2001–02 and 2003–04 (Figure 3). Immediately after 2004–05 the proportion of smooth oreo bycatch was about 30–40% and had dropped markedly to 15% in 2009–10, 3% in 2011–12 and 4% in 2012–13. The remaining catches were mainly from tows that targeted either smooth oreo or used the unspecified oreo code OEO. The reason to consider OEO target tows as part of the target fishery for smooth oreo (SSO) is that there was very little targeting of black oreo (BOE) in this period and almost none that targeted black oreo caught smooth oreo. Therefore it is likely that tows that used the target code OEO were in reality targeting smooth oreo. In early years, some fishers had thought that it was compulsory to use the code OEO for all oreo (Coburn et al. 2001). There have been no target tows using the code OEO since 2008–09.

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 for smooth oreo and orange roughy was close to being fully caught towards the end of the fishing year.

The distribution of smooth oreo catch along the south Chatham Rise shows that the catch has predominantly been taken from the east area since 1993–94 (Figure 5). The eastern fishery was predominantly an orange roughy target fishery before 1997–98, but target fishing for smooth oreo increased after 1997–98, and it is now predominantly a smooth oreo target fishery. The western fishery has mainly been a target oreo fishery throughout the entire time period.

Unstandardised catch rates of smooth oreo since 1999–2000 are summarised in Table 5 (SSO or OEO target) and Table 6 (ORH target) respectively. The smooth oreo target catch had a lower percentage of zero tows and much higher catch rates than the bycatch. The catch rates from the ORH target tows appears to have dropped in recent years compared to the early 1990s.

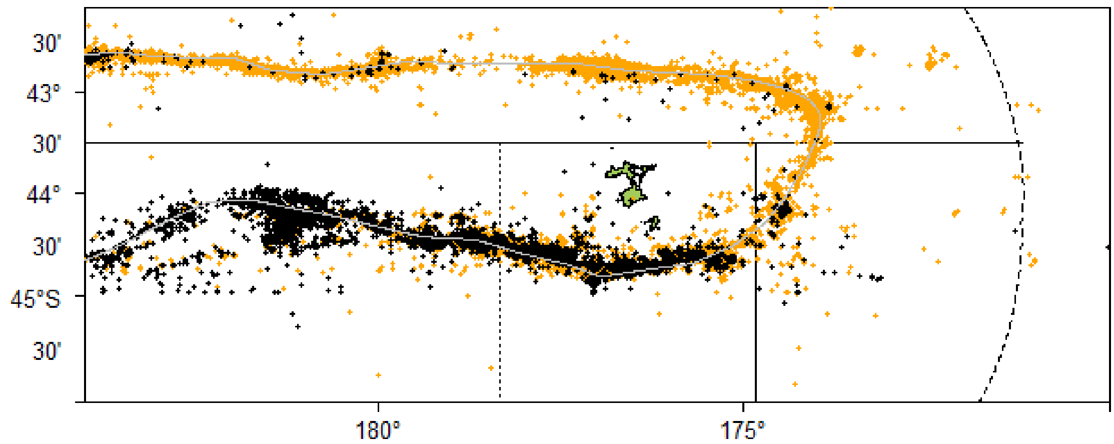

Figure 2: Start position (dots) of all trawls that targeted or caught smooth oreo in OEO 4 from 1978–79 to 2012–13. Black dots are trawls that targeted smooth oreo; orange dots are trawls that targeted orange roughy and caught smooth oreo. The western end of the study area is the boundary of OEO 4 at 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.

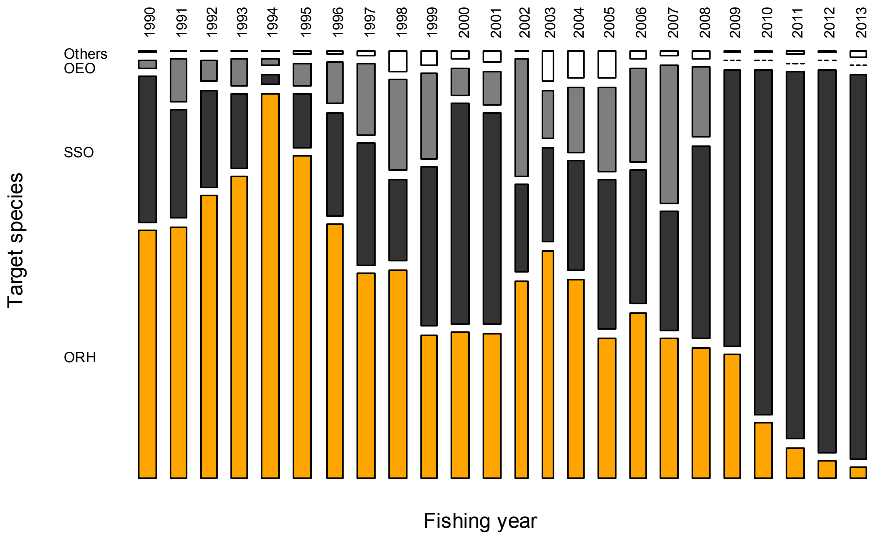

Figure 3: Distribution of smooth oreo catch from OEO 4 by target species, 1992–93 to 2012–13. Years are fishing years, e.g., 1993 is 1992–93. Only the top three target species are shown: ORH, orange roughy (yellow); SSO, smooth oreo (black); OEO, unspecified oreo (grey). The length of the bar is proportional to the catch by target species within each year; the width is proportional to the total catch of the year.

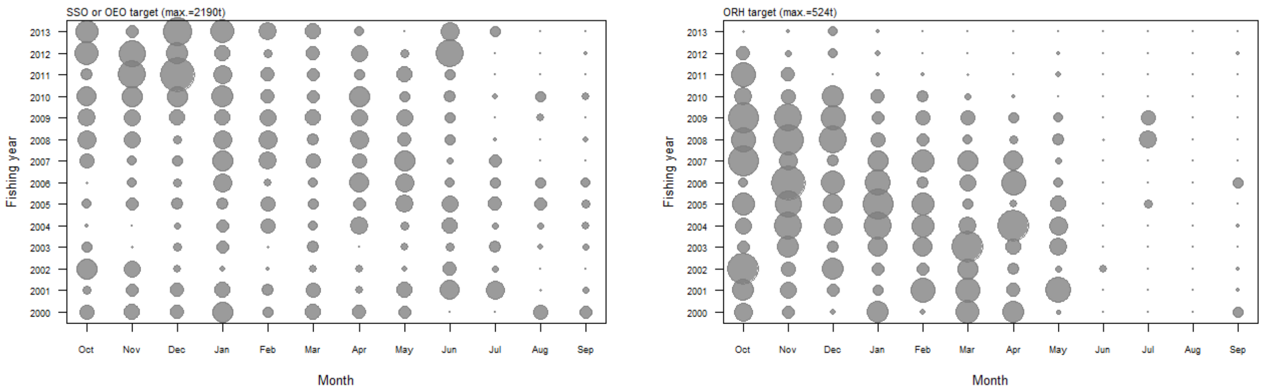

Figure 4: Distribution of smooth oreo catch from OEO 4 by month from 1992–93 to 2012–13 for trawls that targeted smooth oreo or unspecified oreo (left) and for trawls that targeted orange roughly (right).

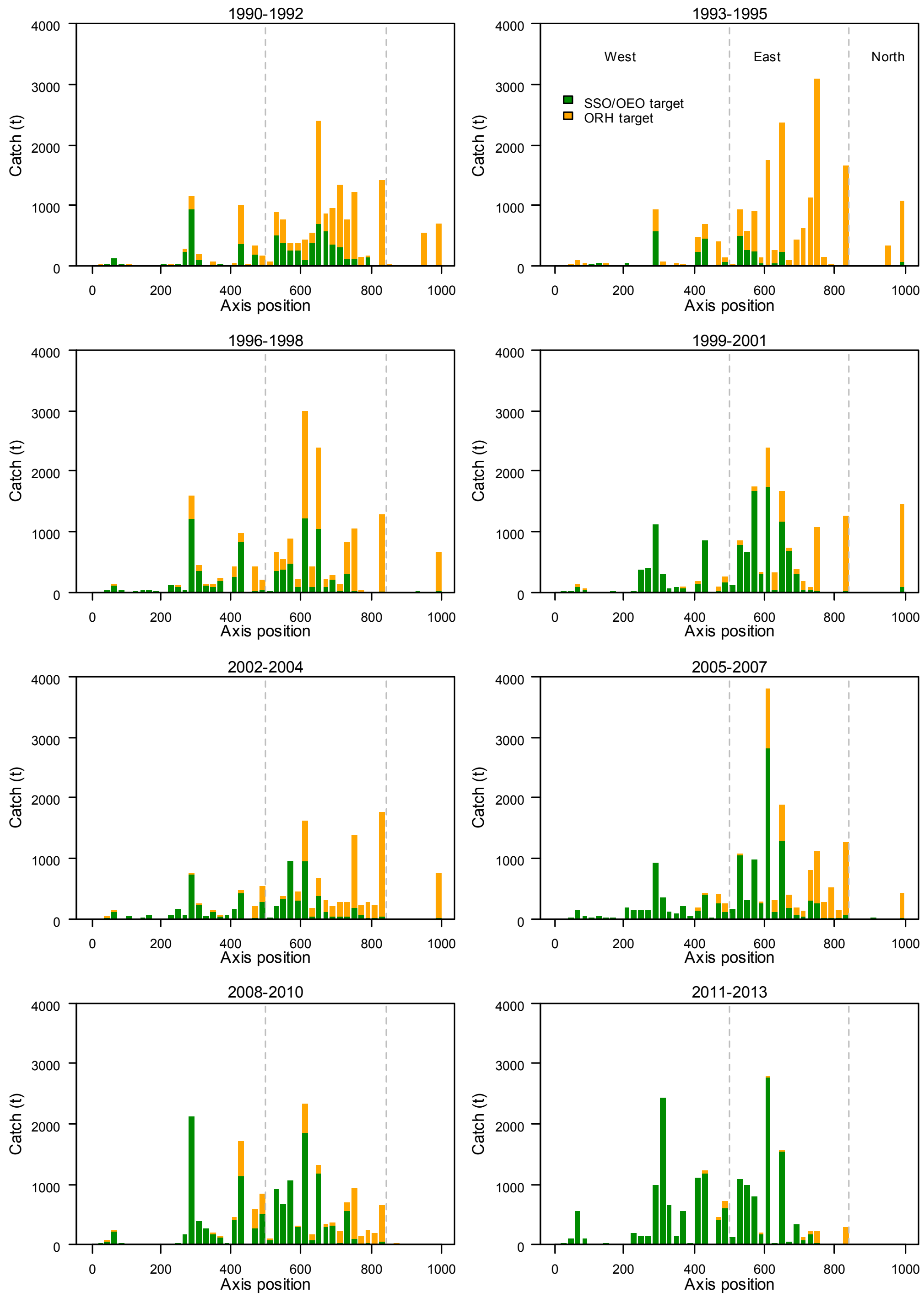

Figure 5: Distribution of smooth oreo catch along the axis position for every 20 km bin. Green, catch from SSO and OEO target tows; orange, bycatch from ORH target tows. The grey dashed lines (from left to right) represent the west/east split used in previous stock assessments and the south/north split along the axis-line (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 2012–13. 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
1999–2000	3833	442	426	0.04	9.00	8
2000–01	3941	385	371	0.04	10.62	9
2001–02	2178	233	210	0.10	10.37	5
2002–03	1588	138	133	0.04	11.94	6
2003–04	2417	263	255	0.03	9.48	8
2004–05	3705	353	343	0.03	10.80	11
2005–06	3358	322	307	0.05	10.94	9
2006–07	4053	454	436	0.04	9.29	8
2007–08	4111	416	404	0.03	10.18	5
2008–09	4184	397	390	0.02	10.73	3
2009–10	5228	515	500	0.03	10.46	5
2010–11	5940	470	459	0.02	12.94	4
2011–12	6044	575	568	0.01	10.64	6
2012–13	5700	704	687	0.02	8.30	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 2012–13. 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
1999–2000	991	302	247	0.18	4.01	10
2000–01	1344	454	372	0.18	3.61	10
2001–02	1177	466	383	0.18	3.07	9
2002–03	1357	584	525	0.10	2.58	11
2003–04	1884	736	679	0.08	2.77	8
2004–05	1545	771	679	0.12	2.28	7
2005–06	1634	769	654	0.15	2.50	7
2006–07	1389	592	522	0.12	2.66	6
2007–08	1443	642	550	0.14	2.62	3
2008–09	1442	675	593	0.12	2.43	3
2009–10	623	327	272	0.17	2.29	4
2010–11	367	128	106	0.17	3.46	3
2011–12	166	119	95	0.20	1.75	3
2012–13	63	70	51	0.27	1.23	4

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 7). The abundance estimates from the surveys before 1991 were not considered to be comparable with the R.V. *Tangaroa* series because different vessels had been 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 7: Random stratified trawl surveys (standard, i.e., flat tows only) for oreos on the south Chatham Rise (OEO3A 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 abundance estimates from acoustic surveys

Acoustic surveys to determine the absolute abundance of smooth oreo in area OEO 4 were carried out in 1998, 2001, 2005, 2009, and 2012 (). In early assessments, the acoustic abundance estimates for the east and west areas were included in the model as absolute abundance indices (Doonan et al. 2008a). The 2012 assessment included the abundance estimates from the 1998, 2001, 2005, and 2009 surveys (Fu & Doonan 2013). As the assessment model was simplified into a one-area model, the abundance estimates for the whole OEO 4 were used (instead of splitting into the east and west component). In addition, only the vulnerable portion of the abundance estimates were used, and were included as relative abundances indices. The 2014 assessment used the same approach as the 2012 assessment and incorporated the vulnerable acoustic abundance estimates from the five acoustic surveys as relative abundance indices

3.4.1 1998 survey

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 6). 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. (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. 2008c). The revised abundance estimates are shown in Table 8.

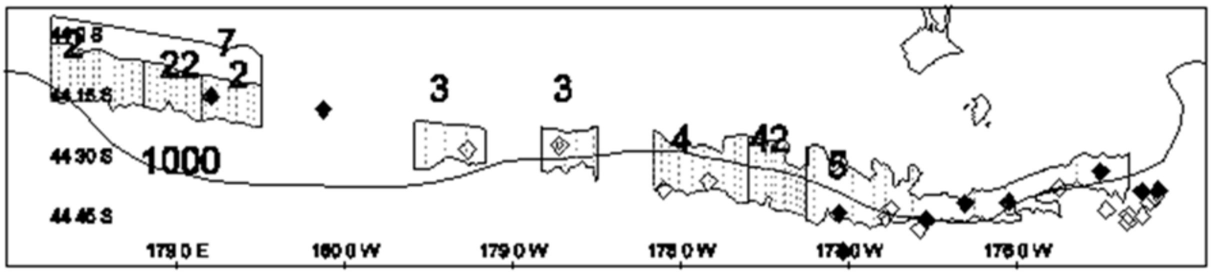

Figure 6: 1998 OEO 4 acoustic survey area showing smooth oreo (2–5, 22 and 42) and black oreo (7) flat strata (solid lines) and transects (dashed lines). Hills selected for sampling (♦); hills listed but not selected for sampling (◊).

3.4.2 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 7). The estimate was revised to align the net catchability with that used in the 2005 survey (Doonan et al. unpublished results). The revised abundance estimates are shown in Table 8.

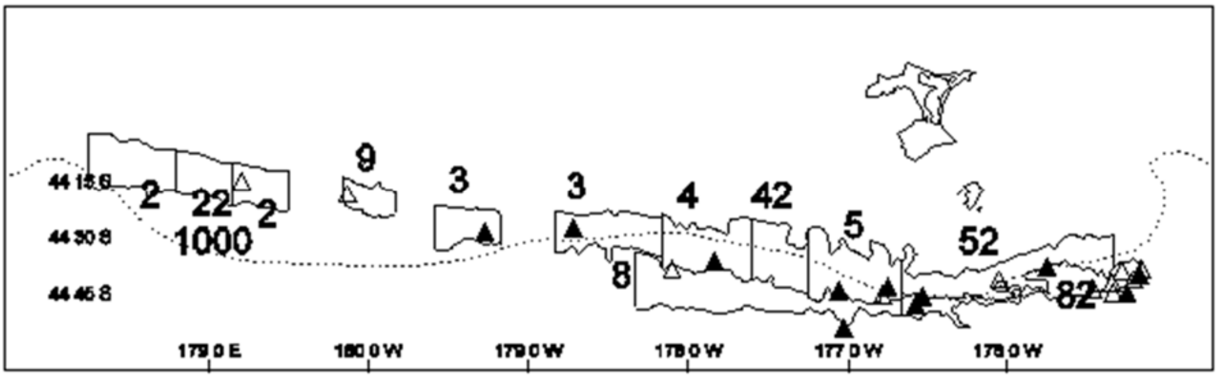

Figure 7: 2001 OEO 4 smooth oreo acoustic survey area showing flat strata and hills surveyed (filled triangles). Hills not surveyed are empty triangles. The dotted line is the 1000 m depth contour.

3.4.3 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. 2008c). 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 8). Abundance estimates are shown in Table 8.

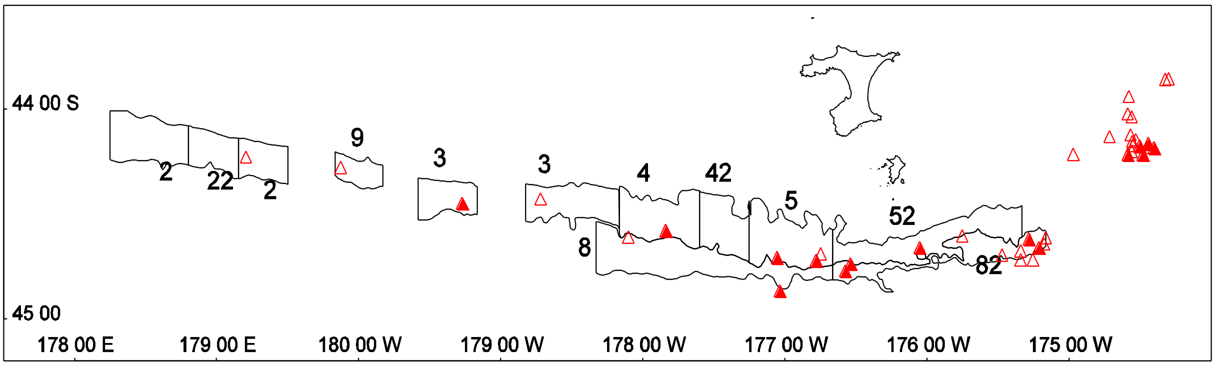

Figure 8: 2005 OEO 4 smooth oreo acoustic survey area showing flat strata and hills surveyed (filled triangles). Hills not surveyed are empty triangles.

3.4.4 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 9). Abundance estimates are shown in Table 8.

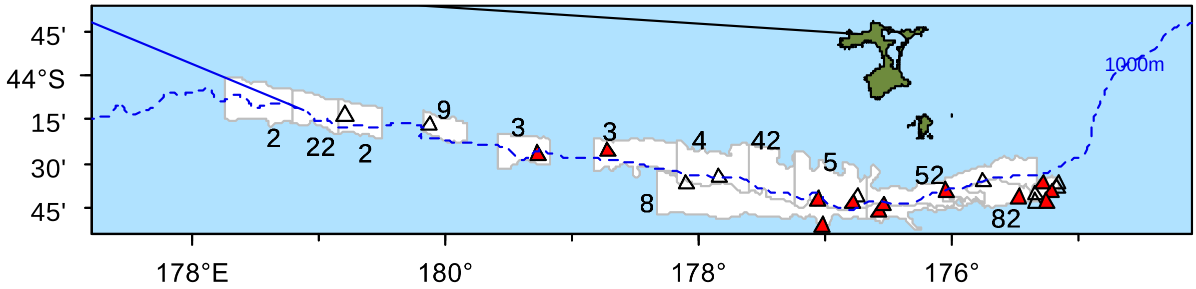

Figure 9: 2009 OEO 4 smooth oreo acoustic survey area showing flat strata and hills surveyed (filled triangles). Hills not surveyed are open triangles.

3.4.5 2012 survey

Absolute estimates of abundance were available from the acoustic survey of oreos carried out beween 8 and 26 November 2012 using *Tangaroa* (TAN1214) for acoustic work and *San Waitaki* (SWA1201) for trawling (Doonan et al. 2014). The flat survey included 95 transects and 85 trawls over 10 flat area strata whilst the hill survey included 37 transects and 17 trawls over 11 hills (Figure 10). Abundance estimates are in Table 8.

One major source of uncertainty in the 2012 estimates was that about 25% of the total estimate came from one school mark on the flat. The species composition of this mark was not able to be verified by trawling. Excluding this mark, i.e., assuming they are not smooth oreo, reduced the abundance for the total abundance for OEO 4 to 64 860 t with a reduced CV of 31%.

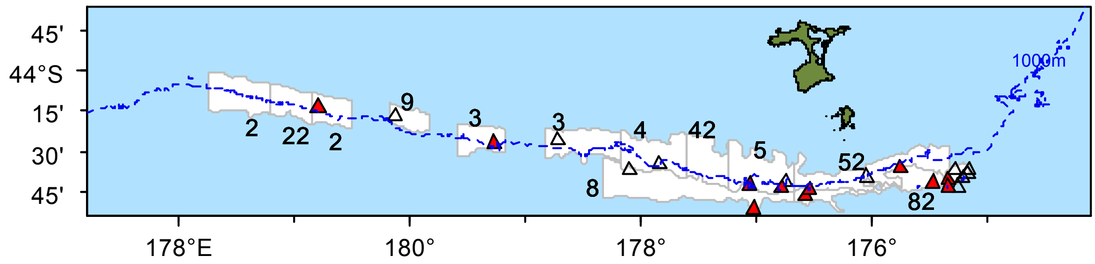

Figure 10: 2012 OEO 4 smooth oreo acoustic survey area showing flat strata and hills surveyed (filled triangles). Hills not surveyed are open triangles.

3.4.6 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 (72% of the total abundance for the 1998 survey, 47% for the 2001 survey, 45% for the 2005 survey, 61% for the 2009 survey, 49% for the 2012 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 may be biased due to mis-specification of the contribution made by other fish species present in the layers, 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 of vulnerable smooth oreo was estimated using two different methods. The first 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. The second 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 a length cut-off of 33 cm (the 2012 assessment also considered a length cut-off of 34 cm as a sensitivity analysis). These estimates were made for the whole of OEO 4 (Table 8).

Table 8: Estimated smooth oreo abundance (t) and CV (in brackets, %) from acoustic surveys in 1998, 2001, 2005, and 2009, and 2012 for OEO 4, including estimates for total abundance and vulnerable abundance. The vulnerable abundance estimates were based either on vulnerable acoustic marks (shallow and deep schools), or a length cut-off of 33 cm.

	Total		Adult (school mark)		Adult (>33cm)	
Year	Abundance (t)	c.v. (%)	Abundance (t)	c.v. (%)	Abundance (t)	c.v. (%)
1998	146 000	33	65 679	26	99619	33
2001	218 200	22	81 633	26	142348	19
2005	115 500	28	63 237	25	90316	22
2009	66 500	36	26 953	26	63471	30
2012	88558	42	58 603	30	69 925	42

3.5 Smooth oreo age frequencies from acoustic surveys

Population age frequency distributions for smooth oreo in OEO 4 were determined by estimating ages from otoliths and data collected on two acoustic surveys carried out in 1998 and 2005 (Doonan 2008b). All of the sampled otoliths (n = 546) from the 1998 survey and randomly selected otoliths (n = 500) from the 1800 otoliths collected during the 2005 survey were read.

The age frequency distribution was estimated using the aged otoliths from tows in each mark-type weighted by the catch rates and the proportion of abundance in the mark-type. Age frequencies were estimated by sex and combined over sexes (Figure 11). The variance was estimated by bootstrapping the tows within mark-types for the 1998 survey and within mark-type and stratum for the 2005 survey (Doonan 2008b). The ageing error was estimated by comparing age estimates from two readers and also by using repeated readings from the same reader. The age frequencies had a mean weighted CV of 36% (1998) and 45% (2005). The ageing error was estimated to be about 8.5%. The age frequencies data (male and female combined) were included in order to estimate year class strength.

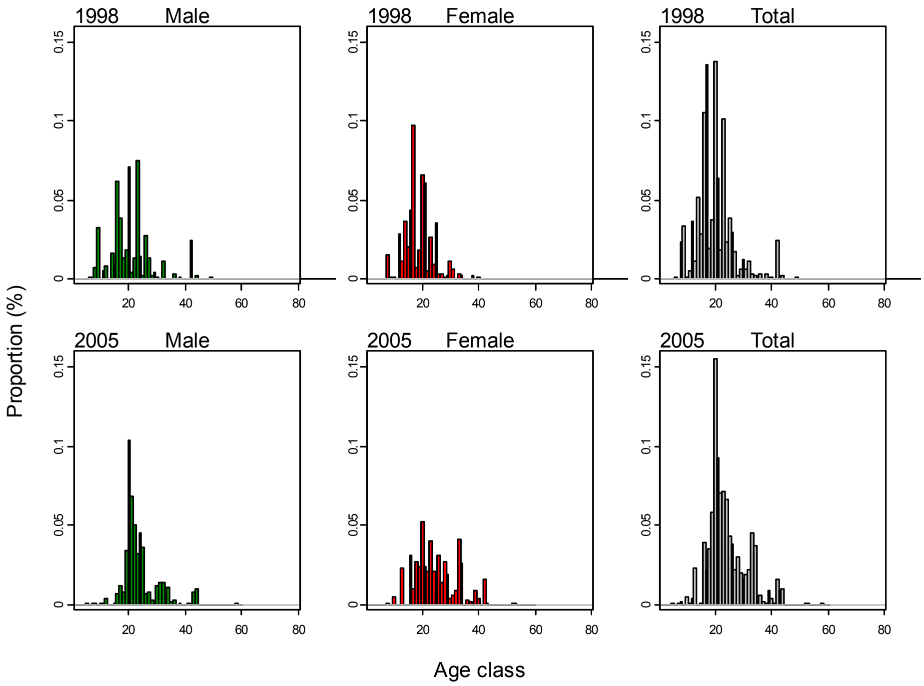

Figure 11: Smooth oreo scaled age frequency distributions from the 1998 and 2005 acoustic surveys.

3.6 Smooth oreo length frequencies from acoustic surveys

Population length frequencies were generated from the 2001, 2005, 2009, and 2012 surveys. 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 tow 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 frequency distributions for the 2001, 2005, 2009, and 2012 acoustic surveys are shown in Figure 12.

While length frequency data were used in previous assessments in order to estimate survey selectivities for the east and west areas (Doonan et al 2008a), they were not included in this assessment and the survey selectivity was assumed to be fixed.

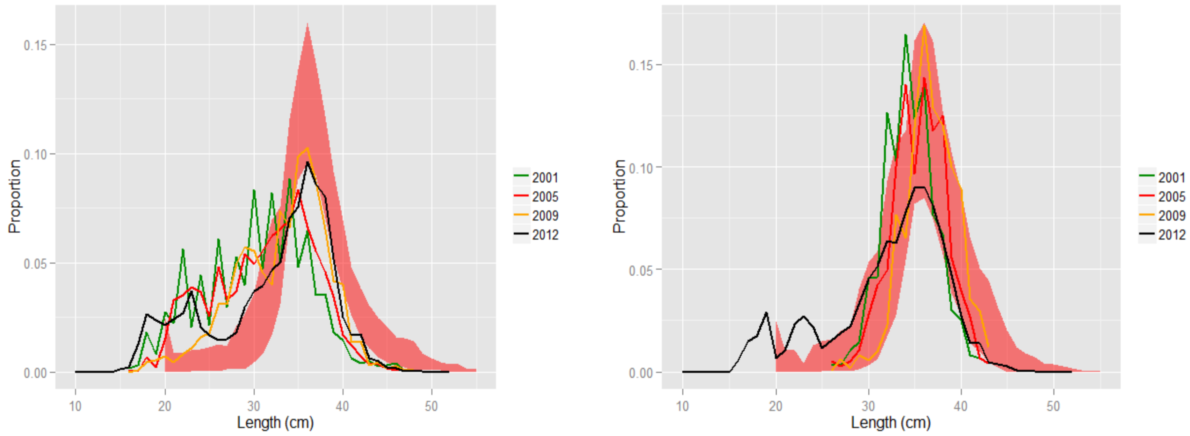

Figure 12: 2001, 2005, 2009, 2012 acoustic survey smooth oreo length frequency distributions (males and females combined) for east (left) and west (right). Shaded area represents an approximate inter-quartile region for available annual observer length frequency data.

Doonan et.al (2008c) suggested that there was close correspondence between the observer length data and the length frequencies from SCHOOL mark-types, although there appears to be some selectivity within the school mark-types (see figures 10C and 11B in Doonan et al. 2008c). Observations of fishing during the survey and anecdotal evidence from fishers corroborate this correspondence. 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.

3.7 Smooth oreo length frequencies from commercial observer programme

Observer length data were extracted from the MPI observer database. P. Starr (pers. comm.) found that the observer data should be stratified using a west-east split at 178º 20' W with a seasonal split to distinguish the October–March and April–September periods. This resulted in a total of four strata. We use these strata to scale the length frequency data using the proportion of catch in each stratum. However, many years did not have length data in every stratum (Table 9). Hence, we applied the following rules:

- 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;
- there must be at least five sampled tows for the year (for each stratum);
- tows were excluded where there were 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 19 years of data for the east, and 11 years of data for the west (Table 9). The length frequency distributions are shown in Figure 13.

Table 9: 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 indicate years where data were combined and the "Y" shows the year it was assigned to. Numbers of tows and fish sampled each year are also included.

	West			East					
Year	Oct–Mar	Apr–Sep	Used	Oct–Mar	Apr–Sep	Used	no of tows	no of fish	% catch
1987	2	2					4	508	0.01
1989	10	5	Y	1	0		16	2277	0.06
1990	4	0		0	1		5	451	0.01
1991	16	0		26	4	Y	46	6531	0.10
1992	6	0		45	8	Y	59	5678	0.08
1993	0	0		22	16	Y	38	4211	0.05
1994	1	0		64	33	Y	98	10078	0.10
1995	1	0		42	30	Y	73	7812	0.13
1996	9	10	Y	6	6	Y	31	3997	0.12
1997	11	0		28	3	Y	42	4837	0.12
1998	2	10	Y	20	8	Y	40	4042	0.06
1999	0	7		30	21	Y	58	7981	0.09
2000	3	15	Y	14	0		32	3505	0.09
2001	8	15	Y	44	4	Y	71	6513	0.08
2002	0	3		24	16	Y	43	4363	0.08
2003	4	4	Y	28	6	Y	42	4802	0.07
2004	1	6		27	3	Y	37	4520	0.07
2005	3	3		18	46	Y	70	8528	0.13
2006	3	14	Y	3	14	Y	34	4516	0.10
2007	6	21	Y	28	3	Y	58	6767	0.14
2008	7	15	Y	23	26	Y	71	7944	0.15
2009	16	19		53	12		100	10960	0.25
2010	33	0	Y	50	0	Y	83	11198	0.20
2011	44	11		6	4		65	8906	0.26
2012	25	1	Y	21	1	Y	48	6154	0.13
2013	13	0		7	0		20	2462	0.08

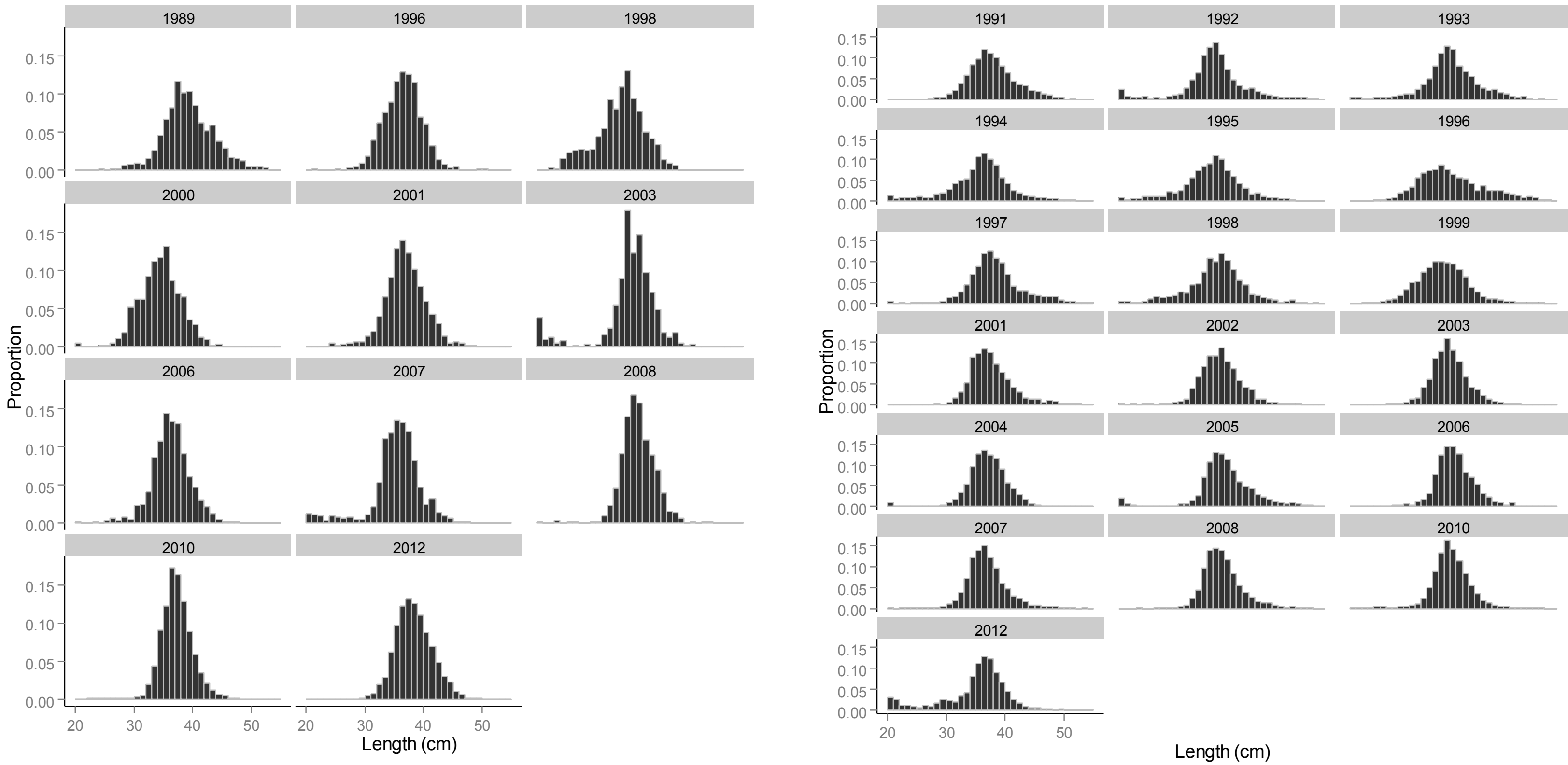

Figure 13: Smooth oreo scaled length frequency distributions by fishing year from observer data for the west area (left) and the east area (right) in OEO 4.

3.8 Biological data

The fixed values for the life history parameters used in the assessment are from Doonan et al. (1997b) (Table 10). Growth was von Bertalanffy and recruitment was assumed to follow a Beverton-Holt relationship.

Table 10: 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

3.9 Stock assessment base case and sensitivity models

Oreo catch data showed marked changes in fishing patterns over time. Large catches started in the west and then progressed east 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 changes described above, using CPUE to index abundance was discontinued in the 2012 assessment and the assessment was simplified into a one area model using the acoustic abundance estimates.

The 2014 assessment was based on the same model structure as the 2012 assessment, and was fitted to vulnerable abundance estimates from the 1995, 1998, 2001, 2005, 2009, and 2012 acoustic surveys, and the age frequency data from the 1998 and 2005 acoustic surveys. The biomass estimates from the fished marks were used in the base case, and the estimates using the length cut-off method were used as a sensitivity analysis.

Acoustic abundance data were fitted as relative indices of vulnerable abundance using a log-normal likelihood with no additional process error. Age frequency data were fitted using a multinomial distribution assuming an effective sample size of 50. Alternative sample sizes of 10, 100, and 200 were investigated in preliminary analyses, and diagnostics based on residual patterns suggested that N=50 was appropriate. Doonan et al. (2008b) estimated an ageing error with a CV of 0.085 for the age estimates, and this was applied to the age frequency data when fitted in the model.

Year class strengths (YCS) were estimated for 1955–2000 (based on the range of age estimates in the age frequency data). YCS were assumed to be fixed at 1 in previous assessments as no age data were used. A number of prior distributions on YCS were investigated. The base case used a non-informative prior that is close to being uniform (parameterised as a lognormal distribution with a mode of 1 and sigma of 4), which places minimum constraint on the YCS. An informative prior (parameterised as a lognormal distribution with a mean of 1 and sigma of 1.1) was used in a sensitivity analysis.

Informed priors were assumed for the survey catchability coefficient q. For the time series based on fished marks, a lognormal prior with mean of 0.83 and CV of 0.3 was used. For the time series based on the length cut-offs, a lognormal prior with mean of 1 and a CV of 0.3 was used. The choice of the priors was based on limited information on target strength, the QMA scaling-factor, and the proportion of vulnerable biomass in the vulnerable acoustic marks (Fu & Doonan 2013). Estimated parameters and their assumed priors for the base case are summarised in Table 11.

Sensitivity trials were carried out to investigate impacts of key model assumptions on assessment results. Model 5.0a assumed an informative prior on YCS; model 5.1 used a prior mean for the survey q which was 20% higher than the base case, and also assumed that the value of M was 20% lower; model 5.2 used a prior mean for q 20% lower and an M 20% higher than the base case; Model 5.3 assumed a dome-shaped selectivity (double normal) for the age frequency; model 5.4 excluded the uncertain school mark in stratum 52 from the 2014 acoustic biomass estimate; model 6.0 was fitted to the alternative vulnerable abundance indices which was calculated using the length-cut off method (see Table 8). A brief description of the base case and sensitivity runs are summarised in Table 12.

The Deepwater Working Group recommended that MCMC runs be carried out for the base case and models 5.1, 5.2 and 5.4 to address the uncertainty in survey q and acoustic abundance estimates.

Table 11: Estimated model parameters and their prior, as used in the base case. U, uniform; LN, lognormal.

Parameter	Number	Prior
Virgin biomass	1	ln B_0 ~U[0, ln (500 000)]
Age-based selectivity - age frequency		
Age at 50% selected	1	U[1, 50]
Extra years to 95% selected	1	U[0,1]
Acoustic catchability *q*	1	LN (mean=0.83 CV=0.3)
Year class strength (1955-2000)	46	LN (mode=1, sigma=0.3)

Table 12: Descriptions of the base case and sensitivity model runs presented for the 2014 smooth oreo stock assessment. LN, the lognormal distribution with mean and standard deviation (log space) are given in brackets.

Model run	Description
5.0 (base case)	estimated q with a LN (0, 0.3) prior, uninformative prior on YCS, fixed M at 0.063
5.0a	5.0, but an informative prior on YCS (lognormal with mean of 1 and sigma of 4)
5.1	5.0, but estimated q with a LN(1, 0.3) prior , M fixed at 0.05
5.2	5.0, but estimated q with a LN(0.6, 0.3) prior , M fixed at 0.07
5.3	5.0, but assumed a domed-shaped selectivity on for age frequency data
5.4	5.0, but excluded the 2012 large school mark in stratum 52 in the acoustic abundance
6.0	5.0, but alternative acoustic abundance estimates (length cut off method)

4. RESULTS

4.1 MPD results

The MPD parameter estimates and likelihood details for base case and sensitivity runs are summarised in Table 13. For the base case, B_0 was estimated to be about 121 000 t and the current spawning stock biomass (B_{2013}) was 30% B_0. The catchability coefficient q was estimated to be 0.84, close to the median value of the assumed prior distribution.

For the base case, fits to the abundance indices of vulnerable biomass are within two standard errors of the observations except for the 2009 survey. The estimated vulnerable biomass showed an overall flat trend between 1990 and 2005 and a marked decline after 2005 (Figure 14). The fits to the acoustic age frequencies appear to be reasonably good (Figure 15) and the residuals are mostly within two standard errors from the mean across all age classes (Figure 16). There is a lack of observed data for ages 50+.

The profile likelihood on B_0 suggested that model fits to abundance data were sensitive to smaller values of B_0, and fits to age data were sensitive to both small and large values of B_0 (Figure 17–left panel). Estimated B_0 was close to the value that attained the optimal fits to the abundance and age data. The prior on YCS had little influence on profile likelihood of B_0 (Figure 17–right panel).

The base case estimated a few very strong year classes (i.e. the 1972, 1973, 1978, 1982, and 1985 year classes, see Figure A1, Appendix A). This was generally consistent with the strong age classes observed in the age distributions. When an informative prior (lognormal with a sigma 1.1) was assumed (MPD 5.0a), the model estimated a period of good recruitment through the 1970s and early 1980s, followed a period of relatively low recruitment in the 1990s (see Figure A1, Appendix A). Despite the differences in the estimated values, the overall pattern in the estimated YCS was similar between the two models. The use of an informative prior effectively placed more constraints on the YCS and this led to slightly poorer fits to the age data (an increase of 4 in the likelihood value) although the difference was marginal (Figure A2, Appendix A). For model 5.0a, estimated B_0 was slightly higher than the base case (Figure A3, Appendix A), and current stock size was estimated to be 28% B_0 (see Table 13).

Model 5.1 increased the prior mean of survey q by 20% (assumed to be 1.00), and reduced M by 20% (assumed to be 0.0504). These changes were expected to result in more pessimistic estimates of stock sizes (Figure A4, Appendix A). Model 5.2 reduced the prior mean of survey q by 20% (assumed to be 0.67), and increased M by 20% (assumed to be 0.0756). These changes were expected to lead to more optimistic results (Figure A4, Appendix A). The estimate of B_{2013} was about 18% B_0 for model 5.1 and 40% B_0 for model 5.2 (see Table 13). For both models, the fit to the acoustic abundance indices was neither worse nor better than the base case (Figure A5, Appendix A).

Model 5.3 used a dome-shape selectivity (parameterized as a double-normal ogive) for the acoustic age frequencies. This was investigated because the 1998 survey did not survey one of the deep strata where the old smooth oreo were typically caught. The left-hand limb of the estimated ogive was similar to the logistic ogive estimated in the base case, and the mid-point of the right hand limb was estimated to be at about age 40 (Figure A6, Appendix A). The fits to the age frequency data were very similar to the base case (Figure A7, Appendix A). The estimated recruitment pattern was different to the base case, especially for the early years (Figure A8, Appendix A), which could be explained by the possible confounding between YCS and the dome-shaped selectivity. Estimated current stock status was close to the base case (Table 13).

Model 5.4 excluded the large mark in stratum 52 from the 2012 survey (as a result, vulnerable abundance in 2012 was 38% less than that used in the base case). This led to a much steeper decline in the estimated biomass trend for recent years and more pessimistic stock status (Figure A9, Appendix A), with B_{2013} estimated to be about 21% B_0 (see Table 13).

Model 6.0 fitted to the abundance indices estimated using the length cut-off method (assuming a length cut-off at 33 cm). These alternative abundance indices were about 20% to 120% higher than those obtained from fished marks. The assumed prior for the survey *q* has a mean of 1. Estimated B_0 was about 126 000 t, and estimated B_{2013} was about 34% B_0 (see Table 13, also Figure A10, Appendix A).

Table 13: MPD parameter and biomass estimates, and log-likelihood values for base case (5.0) and sensitivity analyses (5.0a, 5.1, 5.2, 5.3, 5.4, 6.0).

(a) Estimated parameter	5.0	5.0a	5.1	5.2	5.3	5.4	6.0
Acoustic *q*	0.84	0.94	1.00	0.67	0.74	0.88	1.24
a_{50}	14.5	15.9	14.2	14.8	–	10.0	13.6
a_{to95}	8.4	6.9	8.6	8.0	–	8.5	8.5
a_1	–	–	–	–	22.7	–	–
s_L	–	–	–	–	7.7	–	–
s_R	–	–	–	–	18.4	–	–
(b) Biomass							
B_0	121 000	129 000	126 000	123 000	135 000	112 000	126 000
B_{2013}	35 000	34 000	27 000	47 000	43 000	23 000	42 000
B_{2013}/B_0	0.30	0.28	0.22	0.40	0.33	0.21	0.34
(c) Log-likelihoods							
Acoustic abundance	-1.9	-2.2	-1.8	-1.9	-2.2	-4.0	-4.5
Acoustic AF	83.3	87.2	84.8	82.6	81.7	83.6	83.4
prior on *B0*	11.7	11.8	11.7	11.7	11.8	11.6	11.7
prior on YCS	473.4	38.3	473.4	473.4	473.0	474.2	473.6
prior on acoustic *q*	-0.2	0.1	0.0	-0.4	-0.3	-0.1	0.5
Total	566.4	135.1	568.2	565.5	564.1	565.3	564.8

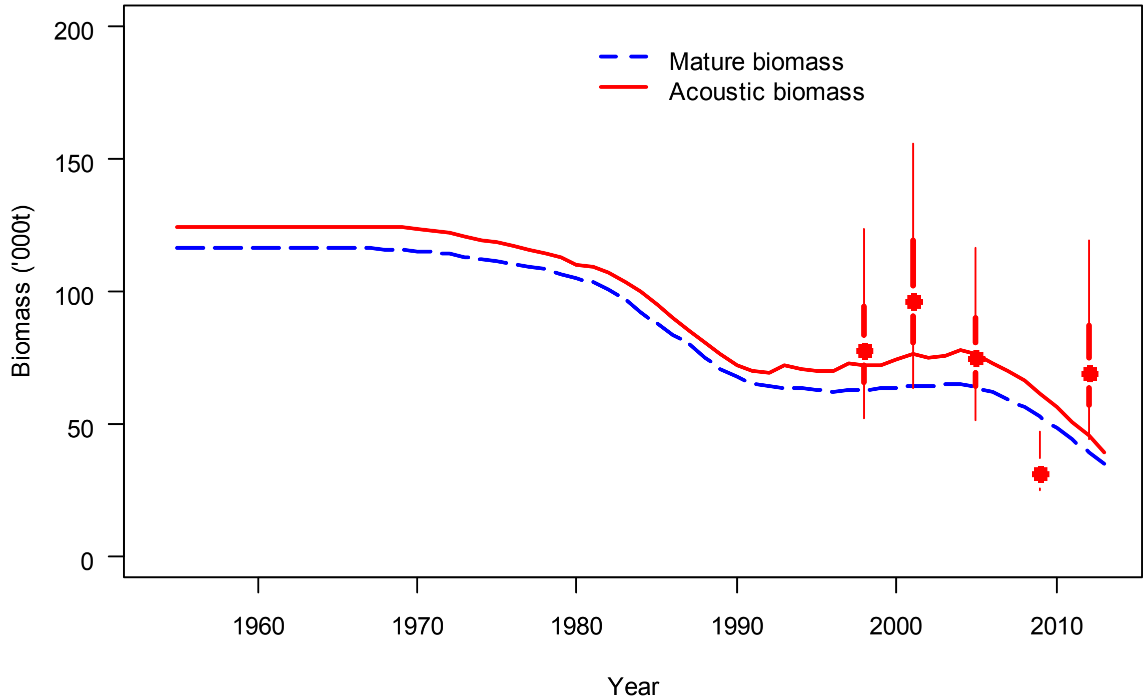

Figure 14: MPD fits to the time series of vulnerable abundance for the base case (model 5.0). Points are the acoustic estimates scaled by catchability coefficient to produce abundance indices. Curved lines are the model estimates of biomass (t): solid top line is the abundance that the acoustics measures and dashed line is the mature abundance. Vertical error bars for the indices are plus or minus 2 standard error (thin), and plus or minus 1 standard error (thick).

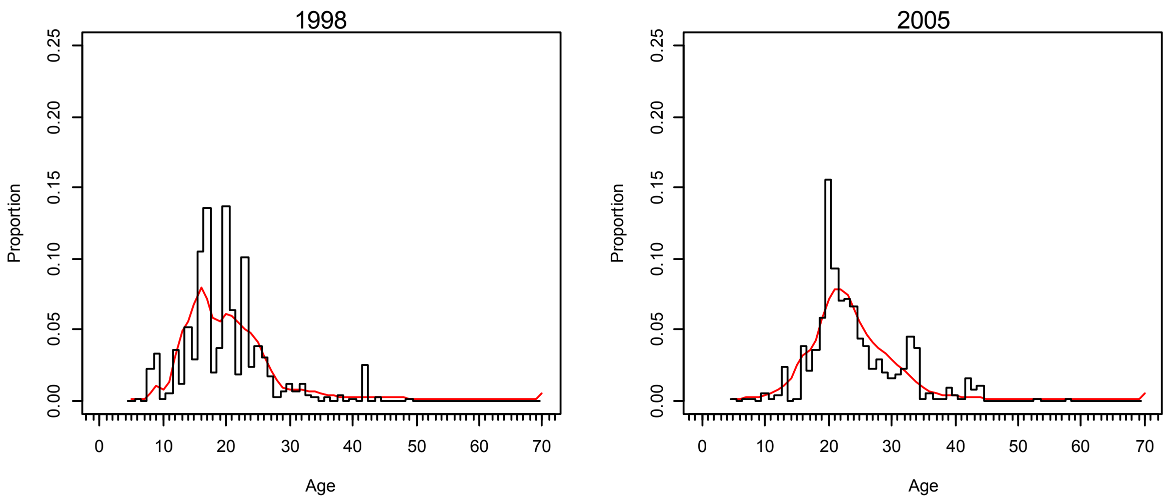

Figure 15: MPD fits to the age frequency distributions from the 1998 and 2005 acoustic surveys for the base case (model 5.0). Black lines are observed age frequency distributions and red lines are predicted age frequency distributions from the model.

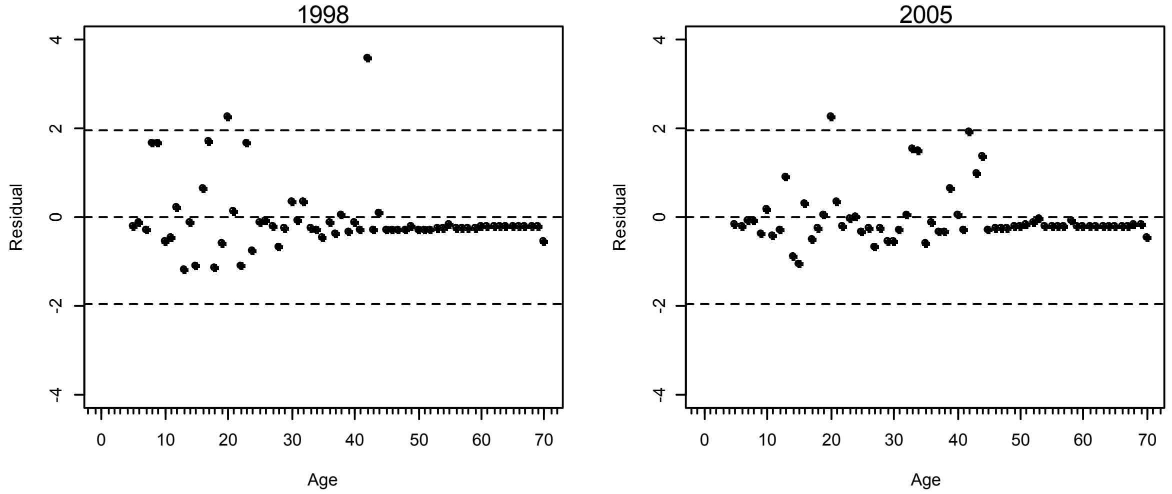

Figure 16: Pearson residuals from the fits to the age frequency data for the 1998 and 2005 acoustic surveys for the base case (model 5.0).

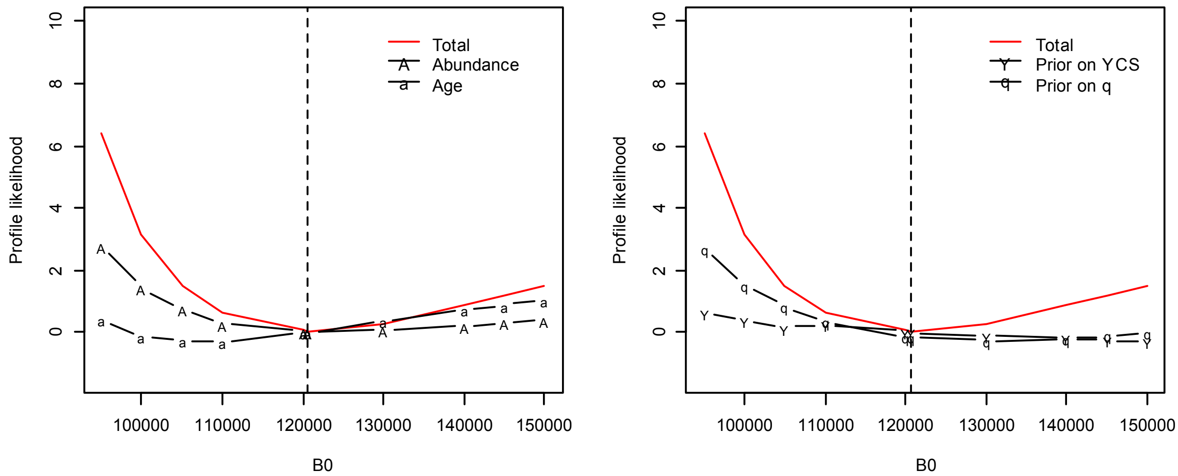

Figure 17: Likelihood profile of B_0 for the base case (model 5.0). Both total likelihood and component likelihood values are shown (contributions from observational data are shown on the left and prior function values are shown on the right). The dashed line represents the MPD estimate of B_0.

4.2 MCMC results

MCMC analyses were conducted for the base case (5.0) and models 5.1, 5.2, and 5.4. When carrying out MCMC simulations to obtain posterior samples, the survey q was estimated as a free parameter (it was estimated as a nuisance parameter in the MPD). This allowed the uncertainly associated with q to be incorporated into model results because estimates of stock sizes were integrated over possible values of q. Because of the strong correlation between B_0 and q, the MCMC chain converged very slowly. A number of methods were investigated to improve the performance of MCMC simulations, including running a longer chain and using a fixed step size for the simulations. As a comparison, simulations where q was estimated as a nuisance parameter were also carried out but only the main results were summarised.

For each model, three separate chains were generated and each consisted of 30 million iterations. Samples were saved for every 1000 iterations, producing 30 000 samples for each chain. The first 25 000 iterations were discarded as the burn in period, and the last 5000 samples from each chain were combined to generate the final posterior samples for the model.

The traces of the posterior objective function values for the base case showed that the MCMC chains generally stabilised after 25 million iterations (Figure 18). Other diagnostic tools included the comparison of the accumulative median of the posterior samples (for B_0) for individual chains as well as for the combined chain (Figure 19–left panel), and the posterior density for each for the three chains (Figure 19–right panel). These plots suggested that the posterior distributions of B_0 from each of the three chains were very comparable and there was no evidence of non-convergence.

The estimates of biomass for base case and sensitivity models are summarised in Table 14. For the base case, the median of B_0 was estimated to be 131 000 t, with a 90% credible interval between 115 000 and 156 000 t. The median estimate of current mature biomass was 27%, with a 90% confidence interval between 16 and 41%. The biomass trend showed a steeper decline after the mid 2000s and most of the distribution of current biomass was above the soft limit of 20% (Figure 20).

Biomass estimates were sensitive to the assumed q and M. If the assumed prior mean of q was 20% higher, and M was 20% lower than in the base case (model 5.1), B_{2013} was estimated to be 18% B_0, with a 90% confidence interval between 11 and 29%; if the prior mean of q was 20% lower, and M was 20% higher than the base case (model 5.2), B_{2013} was estimated to be 36% B_0, with a 90% confidence interval between 21 and 56% (Table 14). The location and shape of the posterior distribution of survey q appeared to be strongly driven by the assumed prior (Figure 21), suggesting that the signal in the acoustic estimates is not strong enough to determine q.

Excluding the uncertain large mark in stratum 52 from the 2012 survey led to much more pessimistic estimates of stock status (Model 5.4), with B_{2013} estimated to be 20% B_0 (90% CI of 12–36%).

For the base case, estimated YCS appeared noisy with associated large variability. Overall they suggested that there was a period of relatively low recruitment before 1970, relatively high recruitment between 1970 and 1985, and the recruitment in more recent years was below the long term average (Figure 22–left panel). Estimated exploitation rates were low but appeared to have steadily increased over time, especially after 2000 (Figure 22–right panel). The current exploitation rate was estimated to be 13%.

For the base case and sensitivity models, biomass estimates with survey q being estimated as a nuisance parameter were similar to those when q was estimated as a free parameter (Table 14).

Table 14: Estimates of Mature biomass for OEO 4 smooth oreo for MCMC models 5.0 (base case), 5.1, 5.2, and 5.4. AcAq, catchability coefficient for relative indices of vulnerable biomass; U_{2013}, current exploitation rate.

			Free q			Nuisance q
MCMC 5.0	5%	Median	95%	5%	Median	95%
B_0	115 000	131 000	156 000	118 000	136 000	165 000
B_{2013}	18 000	35 000	62 000	20 000	37 000	67 000
B_{2013} (%B_0)	0.16	0.27	0.41	0.17	0.28	0.42
ACAq	0.65	0.94	1.36	0.63	0.91	1.26
U_{2013}	0.09	0.16	0.29	0.08	0.15	0.27
MCMC 5.1	5%	Median	95%	5%	Median	95%
B_0	126 000	138 000	159 000	125000	139 000	162 000
B_{2013}	13 000	25 000	45 000	14000	28 000	51 000
B_{2013} (%B_0)	0.11	0.18	0.29	0.12	0.20	0.33
ACAq	0.79	1.11	1.55	0.76	1.06	1.41
U_{2013}	0.12	0.21	0.38	0.11	0.19	0.35
MCMC 5.2	5%	Median	95%	5%	Median	95%
B_0	112 000	132 000	185 000	115000	140 000	180 000
B_{2013}	23 000	43 000	99 050	27000	51 000	93 000
B_{2013} (%B_0)	0.21	0.34	0.56	0.24	0.38	0.54
ACAq	0.44	0.75	1.10	0.49	0.74	1.07
U_{2013}	0.06	0.13	0.24	0.06	0.11	0.20
MCMC 5.4	5%	Median	95%	5%	Median	95%
B_0	113 950	127 000	152 000	114000	128 000	152 000
B_{2013}	13 000	27 000	53 000	14000	27 000	52 000
B_{2013} (%B_0)	0.12	0.22	0.36	0.12	0.22	0.35
ACAq	0.64	0.95	1.33	0.70	1.00	1.36
U_{2013}	0.10	0.20	0.39	0.11	0.20	0.38

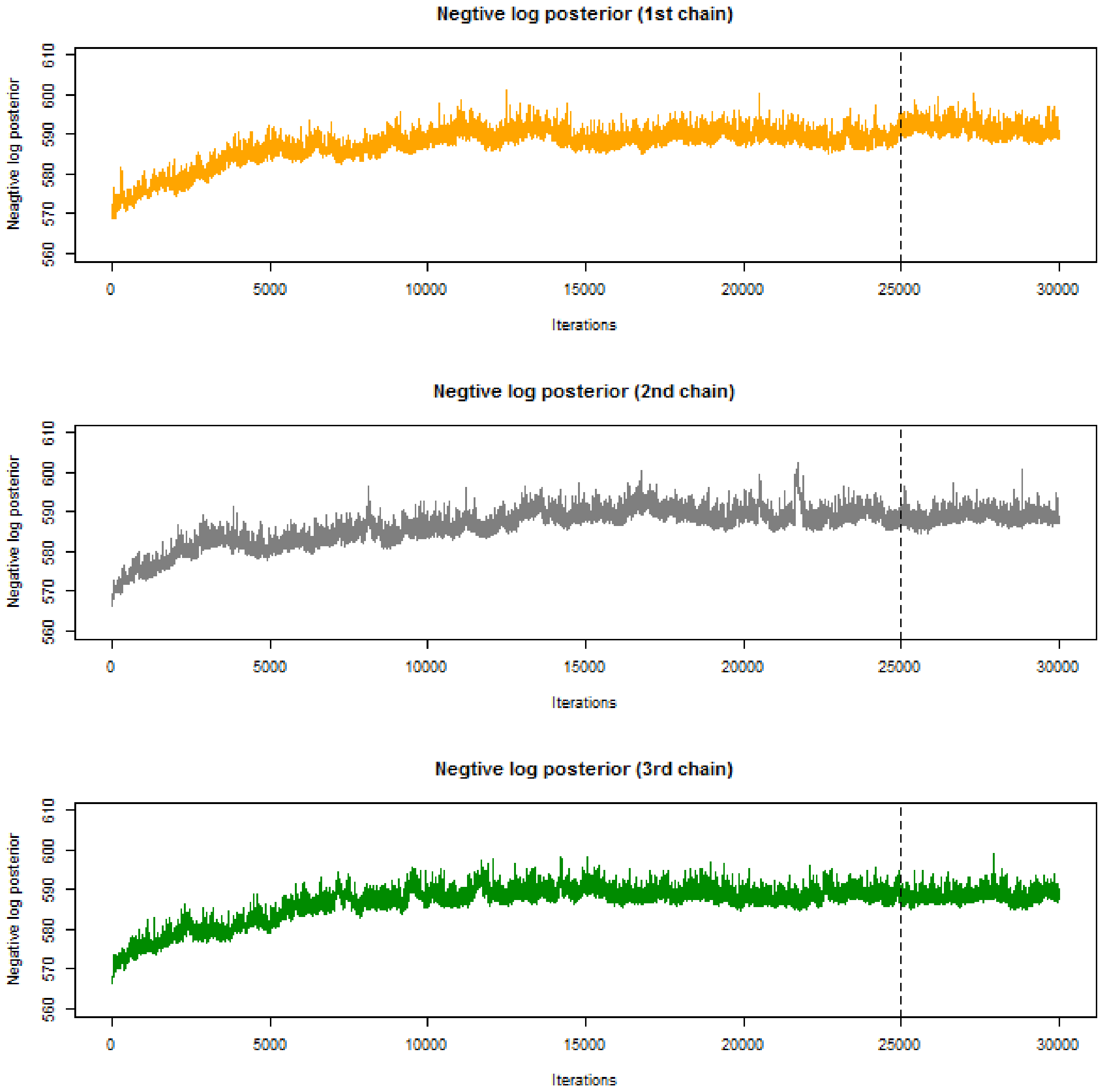

Figure 18: Traces of objective function values for each of the three MCMC chains for the base case model. The dashed line at 25 000 iterations indicates the burn in period.

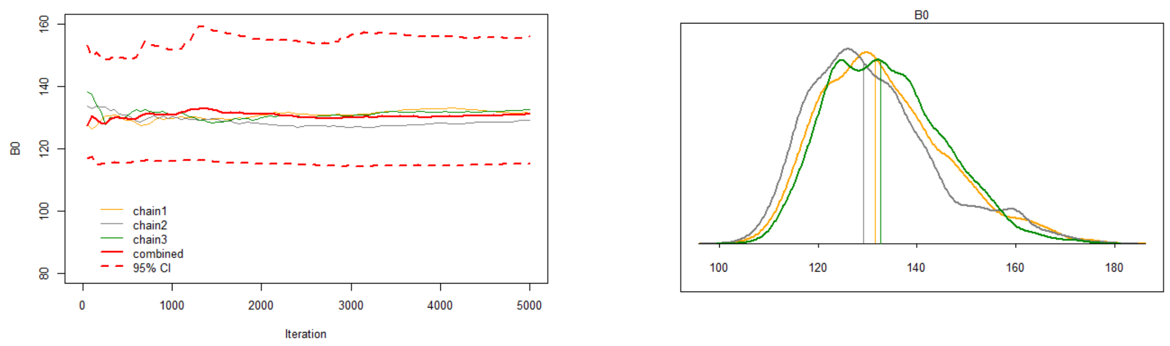

Figure 19: A comparison of the B_0 posterior samples of three MCMC chains for the base case (using the 5000 samples after the burn in period). Left, the accumulative median (up to the 50th, 100th, 150th, etc. samples) for each chain as well as for the combined chain, and the accumulative 5% and 95% percentile for the combined chain. Right, the posterior distribution for each of the three MCMC chains (vertical lines indicate the median).

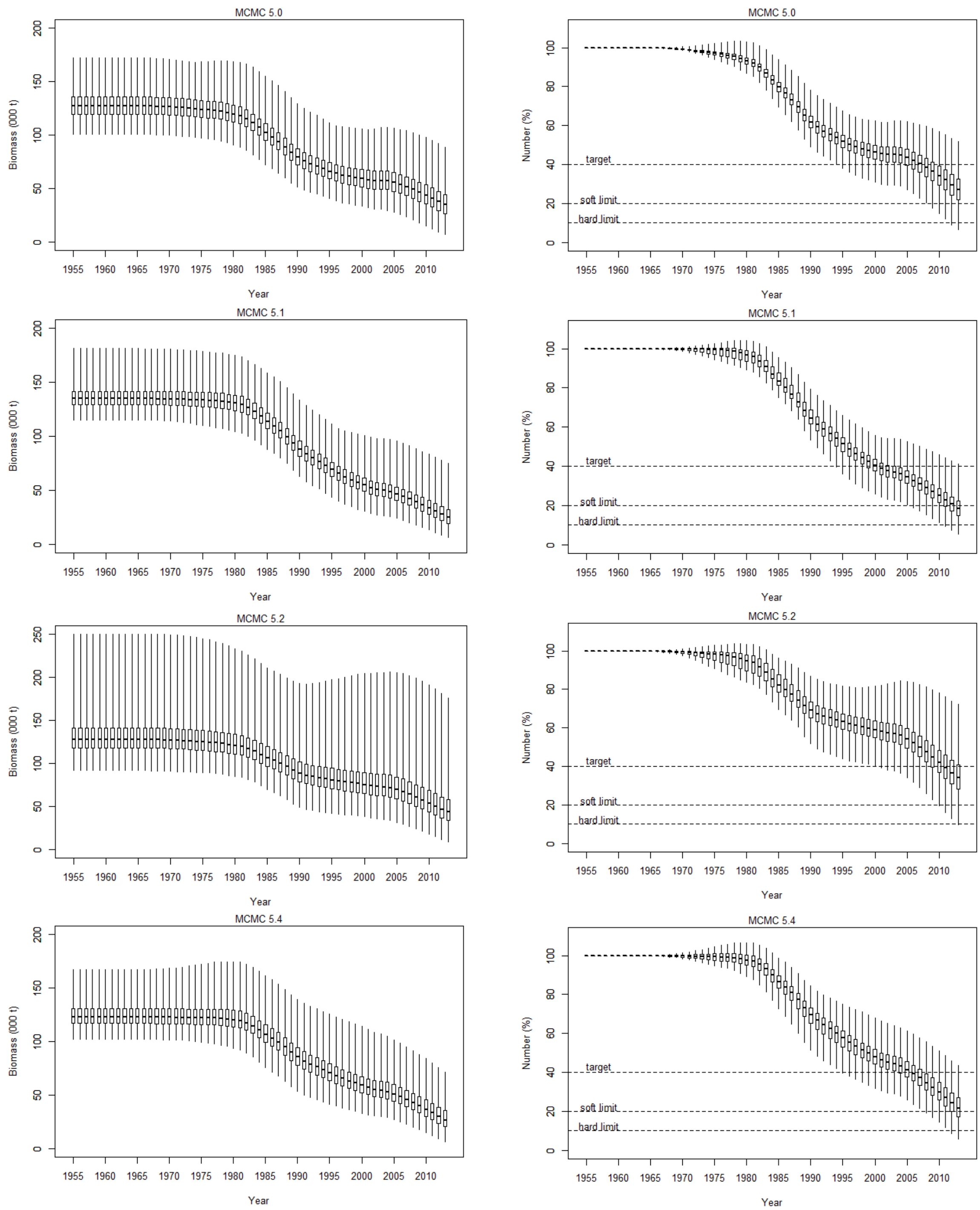

Figure 20: Bayesian posterior distribution of mature biomass (left) and mature biomass as a percentage of B_0 (right) for models 5.0, 5.1, 5.2, and 5.4. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution.

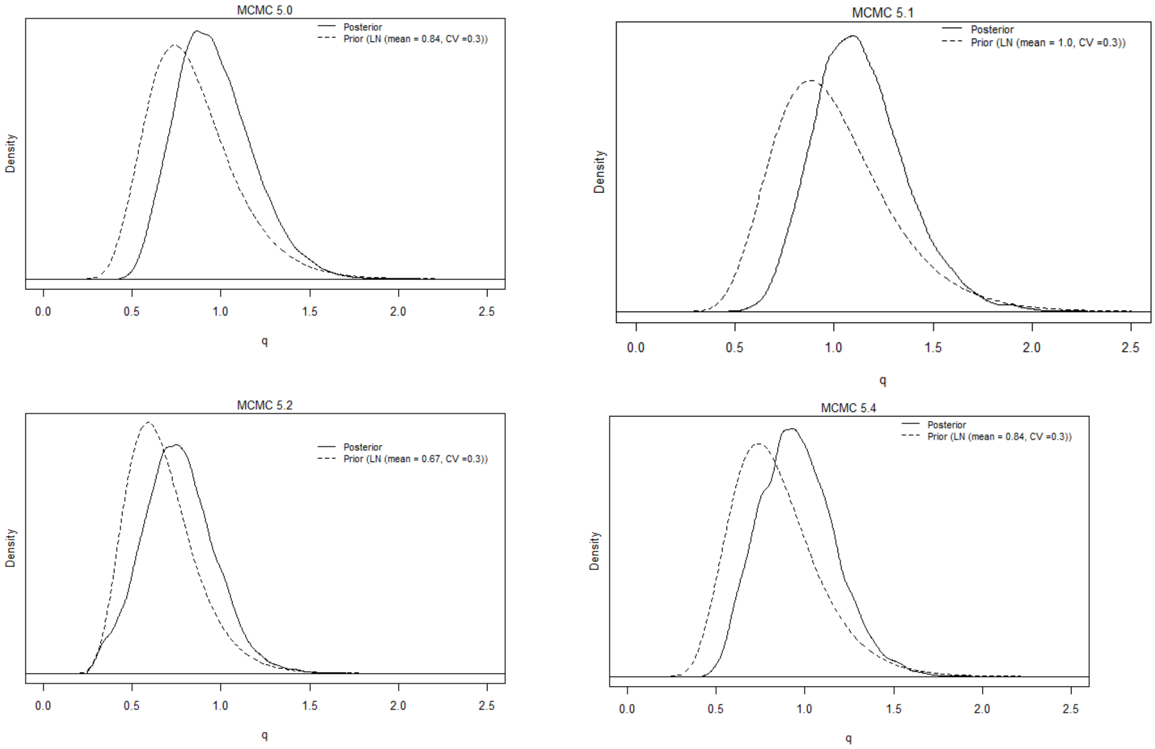

Figure 21: Estimated Bayesian posterior distribution and the assumed prior distribution for survey *q* for models 5.0, 5.1, 5.2, and 5.4.

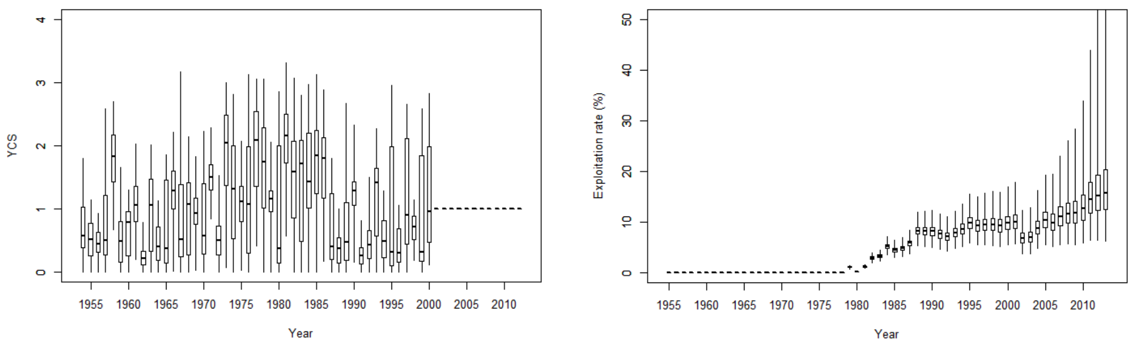

Figure 22: Estimated Bayesian posterior distributions of year class strength (left) and exploitation rates (right) for the base case. The box shows the median of the posterior distribution (horizontal bar), the 25th and 75th percentiles (box), with the whiskers representing the full range of the distribution. YCS were estimated for 1955–2000, and fixed at 1 for other years.

4.3 Projections

Estimates of mature biomass and biomass status (%B_0) over 5-year projections (2014–2018) were carried out, with future catch scenarios: (1) zero catch, (2) 6000 tonnes per annum, and (3) an annual catch that would keep the stock above the soft limit (20% B_0) with a probability of 50%. The projection runs were conducted using the MCMC samples generated with the base case model (5.0).

The results are summarised in Table 15. When assuming zero catch, the median estimate of spawning stock biomass increased from 34 611 t in 2013 to 42 466 t in 2018, or 33.4 $\%B_0$. Assuming a future catch of 6000 t led to a reduction in the median estimate of spawning stock biomass to 22 400 t, or 17.6 $\%B_0$ in 2018. The future catch that led to a spawning stock biomass of 20$\%B_0$ in 2018 with 50% probability was 5060t (B_{2018} of 25 435t, with 95%CI of 6.8–37.1 $\%B_0$).

Table 15: Projected spawning stock biomass in 2018 and $\%B_0$ in OEO 4 with different projected annual catch

Projection	Projected annual catch (tonnes)	B_{2018} (95% CI)	$\%B_0$ in 2018 (95% CI*)
1	0	42 466t (22 339–76 022)	33.4 (20.4–48.8)
2	6 000	22 400t (5 832–54 518)	17.6 (5.3–35.0)
3	5 060	25 435t (7 442–57 878)	20.0 (6.8–37.1)

5. DISCUSSION

The 2014 assessment of smooth oreo in OEO 4 updated the 2012 assessment. This was a one-area model that used just the acoustic abundance indices as relative indices with the addition of the abundance estimate from the 2012 acoustic survey. The 2014 assessment also included age frequency data from two acoustic surveys and allowed the recruitment variability to be estimated within the model (the 2012 assessment assumed that there was no variability in recruitment).

Similar to the 2012 assessment, to limit the extra uncertainty in LAYER marks which contained the pre-recruit fish, the abundances estimates were re-calculated using just the vulnerable portion of the biomass 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 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 27% (90% CI of 16–41%) of initial levels for the base case model. 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. Another major source of uncertainty was in the 2012 survey estimates in which a significant proportion of the biomass was from a mark which was dubiously identified as smooth oreo. The species composition of this mark was not able to be verified by trawling. Excluding this mark would reduce the 2012 abundance estimates by 45%, and as a result, reduce the estimate of current spawning stock biomass to 20% B_0.

This assessment suggests that while the current biomass of OEO 4 smooth oreo is at or near management targets, the large decline in the 2009 acoustic abundance estimate and the subsequent rapid increase in the 2012 estimate suggests that continued monitoring of the stock would be useful to detect future changes. 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).

The 2001 and 2003 stock assessments of OEO 4 smooth oreo incorporated observer and research length data into the model as a proxy for population age estimates. In the 2003 assessment the observer length data and acoustic absolute abundance estimates dominated the model fits and drove the analysis. The assessment suggested that the previously observed estimates of natural mortality (*M*) and growth (Doonan et al. 1995, 1997a) were inconsistent with the observer length data. The length data do not provide good contrast in any signal that is present. The 2014 stock assessment used direct age estimates from otolith readings of research samples collected in 1998 and 2005, and these data provide information on relative levels of recruitment over time.

The assessment model estimated a period of relatively high recruitment through the 1970s to the early 1980s. This was consistent with the age frequencies that showed that in 1998 there was a pulse of fish younger than 16 years and that this pulse progressed into the main body of the age frequency in 2005. Doonan et al. 2008b suggested that a block of good recruitment was required in the model to achieve a reasonable correspondence to the age frequency data and assuming constant recruitment might induce bias on model estimates of stock status and total mortality.

There was variability associated with the two age frequency samples derived from otolith sections. Doonan et el. 2008b concluded that these data are useful to detect blocks of poor or good recruitment of young fish into the OEO 4 smooth oreo fishery, but it is not possible to detect individual year class strength. The spikes in the estimated age frequency distribution are most likely due to the difficulty in interpreting the otolith growth zones (Doonan et al. 2008b). He suggested that intervals of 3–5 years between surveys of OEO 4 smooth oreo would give a better chance of detecting blocks of recruitment. In addition, the 1998 survey did not sample some deep strata, and therefore could have missed some old fish, adding extra error in the estimates of age distribution. More otolith samples need to be aged from future surveys to verify the recruitment pattern.

There were some discussions on the choice of prior functions for estimating the YCS. The preference of the Deepwater Working Group was to use a non-informative prior (as used in the base case) although no definitive conclusion was made. A non-informative prior places less constraint on the YCS therefore obtaining better fits to the age distributions, and it also has little influence on the overall likelihood function value (therefore little effect on the estimate of B_0). However, preliminary investigations suggested that in some instances the model could produce very large values of YCS to support the catch history, and this is likely to occur when the catches were variable and when there was little constraint on the YCS. Therefore, some form of informative prior could help prevent the model producing implausible values of recruitment.

6. ACKNOWLEDGMENTS

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APPENDIX A: MODEL FITS AND DIAGNOSTICS OF MPD SENSITIVITY RUNS

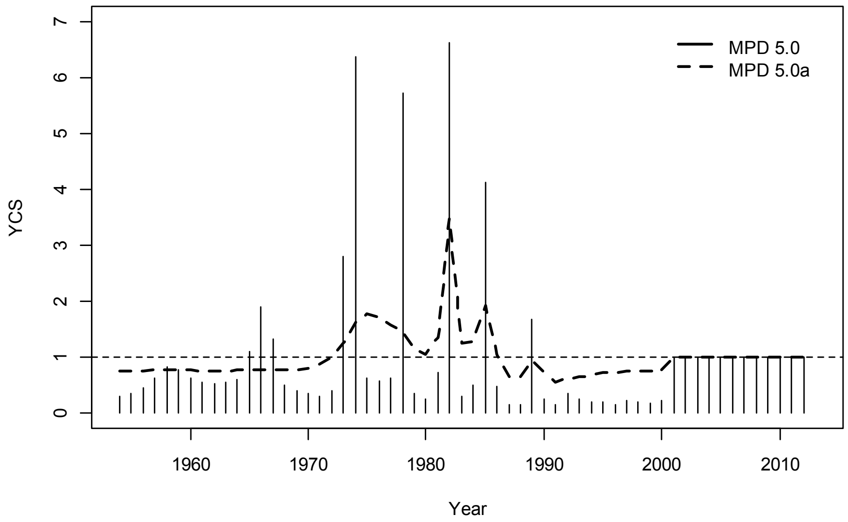

Figure A1: A comparison of estimated YCS in the base case (5.0) and model 5.0a.

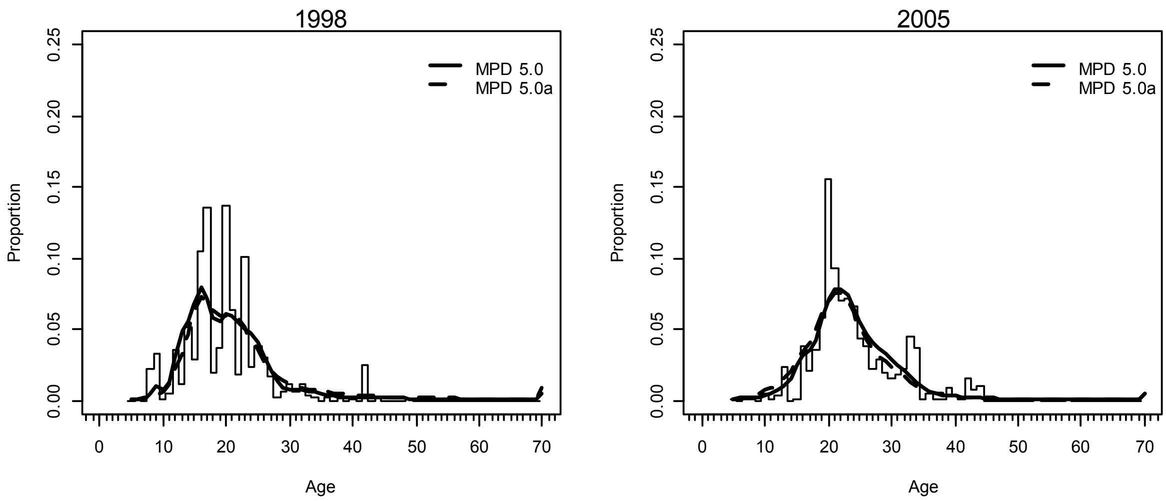

Figure A2: A comparison of fits to the age data between the base case and model 5.0a.

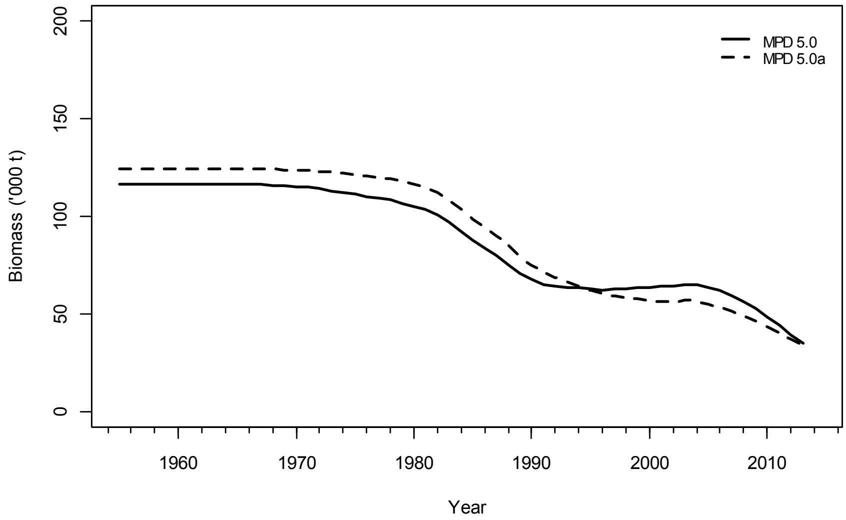

Figure A3: A comparison of estimated spawning stock biomass between the base case and model 5.0a.

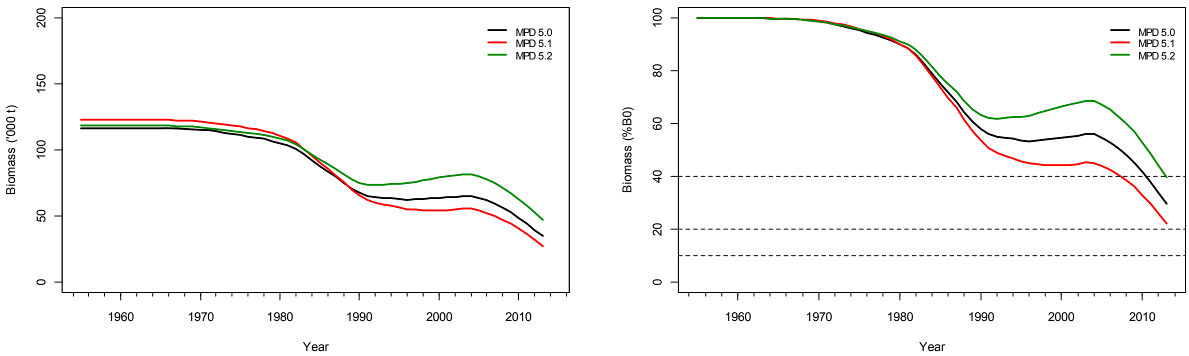

Figure A4: A comparison of estimated SSB (left) and SSB as a percent of B_0 (right) from model 5.0 (base case), and sensitivity models 5.1, and 5.2.

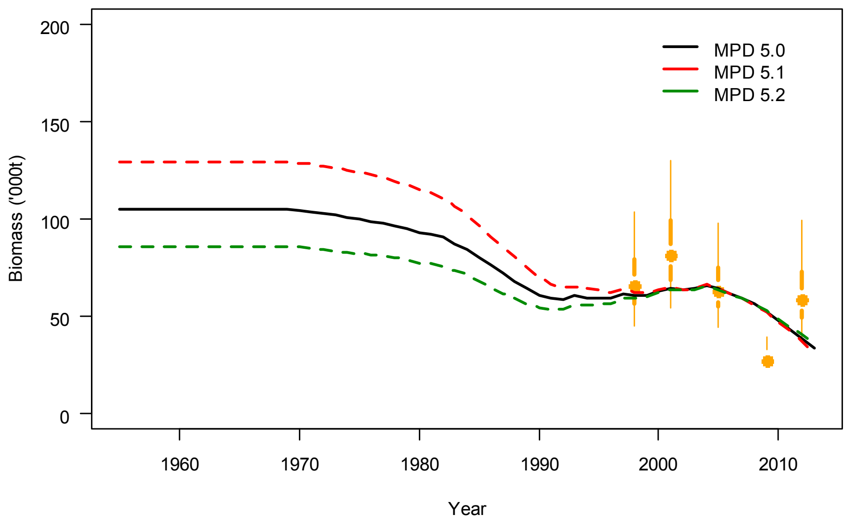

Figure A5: A comparison of MPD fits to acoustic abundance estimates from model 5.0 (base case), and sensitivity models 5.1, and 5.2.

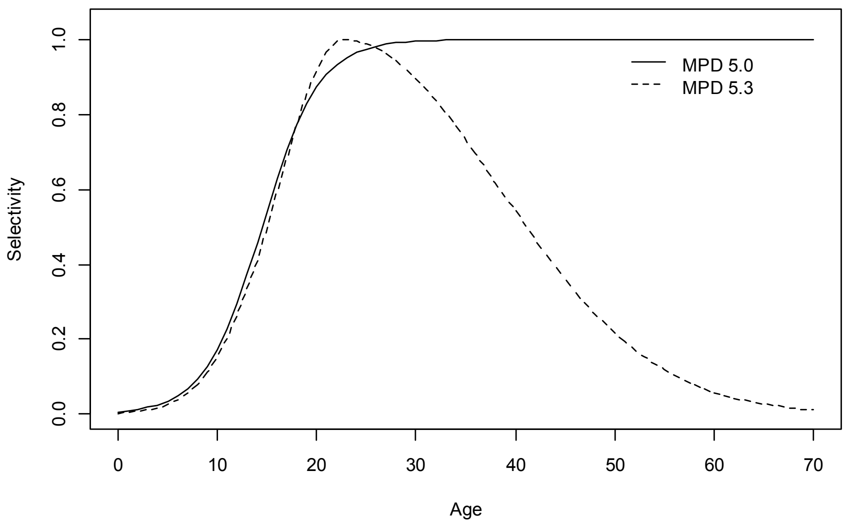

Figure A6: Estimated selectivity for acoustic age frequency data: logistic for the base case and double normal for model 5.3.

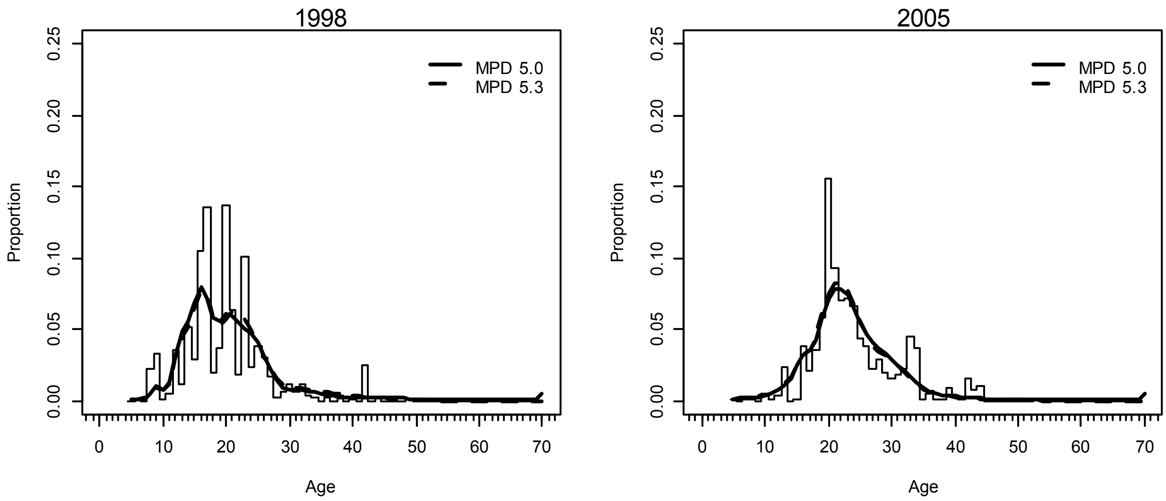

Figure A7: A comparison of fits to the age data between base case and model 5.3.

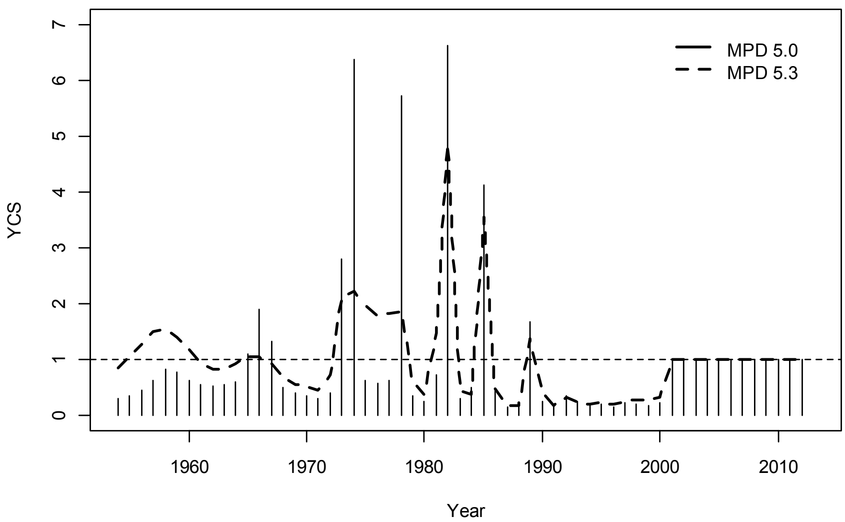

Figure A8: A comparison of estimated YCS for the base case and model 5.3.

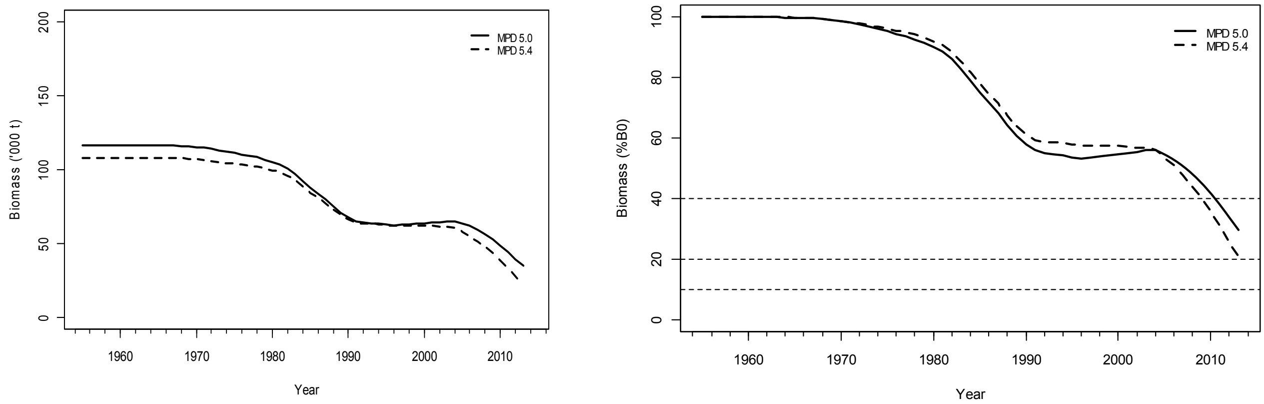

Figure A9: A comparison of estimated SSB (left) and SSB as a percent of B_0 (right) from model 5.0 (base case) and sensitivity model 5.4.

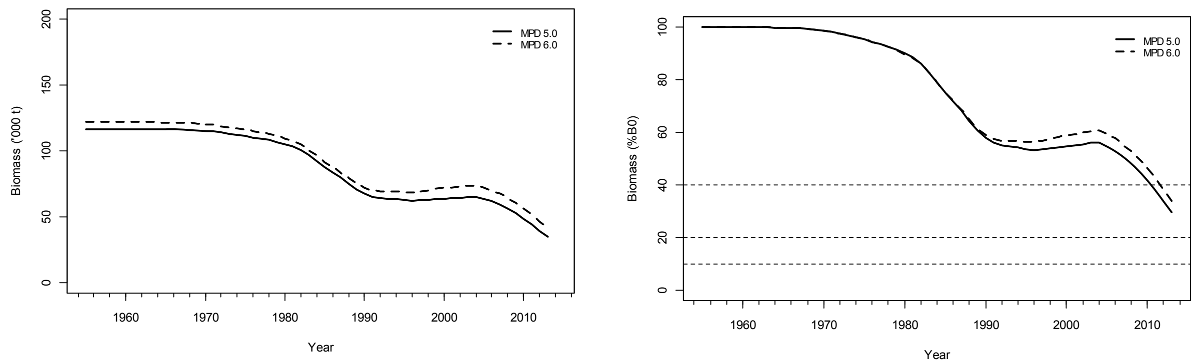

Figure A10: A comparison of estimated SSB (left) and SSB as a percent of B_0 (right) from model 5.0 (base case) and sensitivity model 6.0.