Ministry for Primary Industries
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Black oreo abundance estimates from the November–December 2011 acoustic survey of the south Chatham Rise (OEO 3A)

New Zealand Fisheries Assessment Report 2014/01

I. J. Doonan
P. J. McMillan
A. C. Hart
A. Dunford

ISSN 1179-5352 (online)
ISBN 978-0-478-42332-7 (online)

January 2014

New Zealand Government

Growing and Protecting New Zealand

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The absolute abundance of the black oreo (*Allocyttus niger*) population in area OEO 3A was estimated from an acoustic survey carried out between 17 November and 1 December 2011 using *San Waitaki* (voyage SWA1102). The survey covered the south slope of the west end of the Chatham Rise and was the fourth in a series of acoustic surveys of the area with earlier surveys carried out in 1997, 2002, and 2006. From 2002 onward, the surveys covered only the main "flat" area, i.e., did not specifically survey hills, because the estimate of recruited black oreo abundance observed on hills in the 1997 survey was very low, i.e., less than 1% of the total survey abundance estimate. A stratified design using randomly allocated transects was used in 2011 and data were collected from a hull-mounted acoustic system. The survey included 72 transects and 25 tows over 8 flat area strata (15 110 km^2 in total area). Tows from the 1997 survey were also used to estimate species proportions for background mark-types.

The total (immature plus mature) estimated abundance of black oreo for OEO 3A was 182 300 t (no bubble layer correction) with a CV of 25%, which is within the specified target CV of the project (20–30%), or 242 500 t (corrected for the bubble layer) with a CV of 25%. Total abundance was also estimated separately for the three spatial areas used in the stock assessment. Area 1 included the shallow part of the survey area and was generally not fished commercially because most black oreo sampled were smaller fish. Area 1 was large, nearly 50% of the total survey area and was dominated by low-density background and layer acoustic mark-types. Areas 2 and 3 covered most of the area that was commercially fished and most mark-types observed were discrete school and layer marks. Total abundance estimates (all with no bubble layer correction) were 138 100 t with a CV of 27% for Area 1, 36 800 t with a CV of 30% for Area 2, and 7400 t with a CV of 34% for Area 3.

The main sources of variability in the abundance estimates were the variability in the species proportions in the trawl catches (10% CV), and the target strength of black oreo (14% CV).

The black oreo total abundance estimate from the 2011 acoustic survey was substantially larger than the 2002 and 2006 survey estimates but was similar to the 1997 value. The reasons for the large increase in 2011 are unclear, but it seems unlikely to be real given the low productivity of black oreo. The results indicate that unaccounted variability is much larger than the estimated survey CV.

1. INTRODUCTION

The southwest Chatham Rise (OEO 3A) is the main black oreo (*Allocyttus niger*) fishing area in the New Zealand EEZ (Figure 1), with estimated mean annual catches of 2224 t from 1998–99 to 2007–08 (Ministry for Primary Industries 2012). There is also a substantial smooth oreo fishery in the area with estimated mean annual catches of 1566 t from 1998–99 to 2007–08 (Ministry for Primary Industries 2012). Most of the black oreo catch from the area appears to be taken from drop-offs and ridge tops where oreos form small aggregations to feed or spawn.

Black oreo and smooth oreo are widespread and abundant throughout OEO 3A at depths of 600–1200 m, and adult fish typically form aggregations, particularly when spawning. These show on echosounder traces as 'pyramid' or 'ball' marks. Both oreo species also occur in lower densities in background layers that, for black oreo at depths of 600–800 m, may be extensive. In the early years of the fishery (1986–95), trawl surveys were used to give fishery-independent estimates of abundance. However, the clumped nature of the oreo populations and the low probability of encountering an aggregation led to very high estimated variances (McMillan et al. 1996) and these, together with other problems, meant that the abundance estimates were very uncertain. While the aggregated nature of oreo distributions is a problem for trawl surveys, it is much better suited to acoustic techniques, particularly since the aggregations are largely composed of either black oreo or smooth oreo or a mixture of both species. Some initial investigations of acoustics were carried out during the trawl survey in 1995 (Hart & McMillan 1998) and a move to acoustic methods was made in 1997 with an acoustic survey that covered all of OEO 3A (Doonan et al. 1998, 1999). A reduced survey of the main oreo fishing area of OEO 3A was conducted in 2002 (Smith et al. 2006) and was repeated in 2006 (Doonan et al. 2008). The reduced survey was repeated in 2011 and is the subject of this report. It was carried out to meet the objective of the Ministry of Fisheries project OEO201004: "To estimate the abundance of black oreo (*Allocyttus niger*) in OEO 3A on the Chatham Rise using acoustic survey".

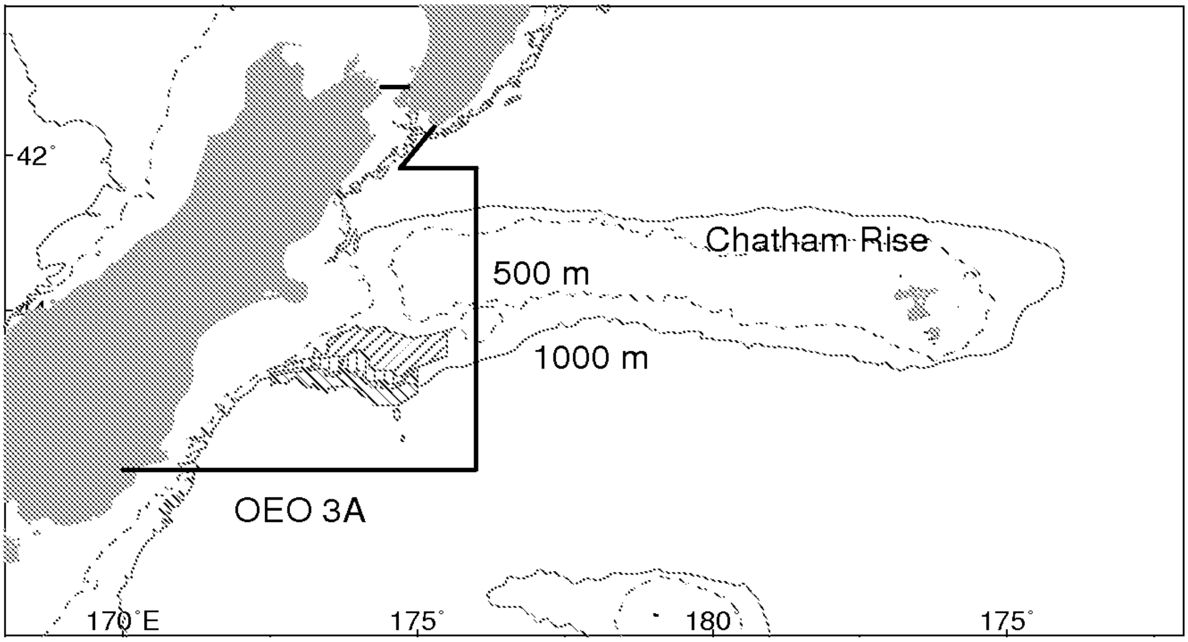

Figure 1: Oreo management area OEO 3A bounded by thick dark lines with the 2011 acoustic survey region shown divided into three areas (shaded) including Area 1 at the top with right sloping shading; Area 2 in the middle with vertical shading; Area 3 at the bottom with left sloping shading.

The 2011 survey took place between 17 November and 1 December 2011. The approach to both survey design and analysis was similar to that used in the 2006 survey (Doonan et al. 2008). The survey region was the same as the study area used in the 2004 black oreo stock assessment (Doonan et al. 2004), and Areas 2 and 3 in particular (see Figure 1) included more than 90% of the catch in the OEO 3A black oreo fishery. However, for this survey a hull transducer was used on a fishing industry vessel, the *San Waitaki*, operated by Sanford Ltd. The three earlier surveys all used a towed echosounder system which allowed surveying to continue at wind speeds of up to at least 40 knots. In contrast the hull echosounder survey work was limited to wind speeds of less than 20 knots due to the formation of unacceptable micro-aeration in the water column at higher wind speeds (Novarini & Bruno 1982). Analysis of wind speed records from the three earlier surveys showed that wind speeds were at least 20 knots for half of the survey time, so in order to achieve a repeat survey, the planned total voyage length was approximately doubled. Commercial fishing operations were planned for the non-survey time.

2. METHODS

The survey design and analysis were similar to those of Doonan et al. (1998). The overall approach to the survey was to measure acoustic backscatter together with information on the size structure of the black oreo samples and the mix of species present in acoustic marks obtained by trawling. Data on the species mix for the Back and Backdeep mark-types from the 1997 survey trawl results (Doonan et al. 1998, 1999) were also included in the analysis. A stratified random approach was used for the survey (Jolly & Hampton 1990). The strata were the same as those used in the 2002 and 2006 surveys. In 2002, the 1997 strata were modified slightly to make the survey easier to manage.. The Sanford Ltd fishing vessel *San Waitaki* (64 m, 1899 GRT) was used for the acoustic survey and all trawling. The 2011 survey used the results of the 2006 survey to optimise allocations of transects within the strata.

2.1 Acoustic principles

The conventional approach of echo-integration was used to estimate areal backscatter of acoustic energy by fish (Burczynski 1982, Do & Coombs 1989, Doonan et al. 2000), which was then divided into mark-types using a mark classification scheme based on matched trawl and acoustic data, primarily from the 1997 survey (Doonan et al. 1998), but also from research work carried out in OEO 4 (Barr et al. 2002). Areal backscatter by mark-type was converted into total fish numbers by using a composite target strength derived from the proportion of species within the mark-type and the individual target strengths of each species. The total number of black oreo was obtained from the fraction (by number) in the species composition and this was converted into abundance by multiplying by the average weight.

The detailed mathematical analysis used to estimate abundance from the survey results is the same as that used by Doonan et al. (1999) and a generic derivation is given in Appendix 1. This derivation is more complicated than used here since data for mark-types are split into mark-type and stratum categories whereas, here, all data for a mark-type are applied to each stratum.

There are a number of physical factors that affect the accuracy of the estimates of backscatter. The most important for oreo surveys are shadowing, towed body motion, and absorption of sound by seawater.

Shadowing is a problem when the fish are on the sides of hills or on sloping seafloor. The acoustic transducer projects a conical beam down through the water column with the wave-front forming part of the surface of a sphere. If the axis of the beam is perpendicular to a flat seafloor, then the seafloor reflection from the central part of the beam swamps the reflections from fish close to the seafloor in the outer parts of the beam. There is thus a volume close to the seafloor, which is not visible to the acoustic gear, called the ‘shadow zone’. The shadow zone is reported as the thickness of an equivalent layer just above the seafloor and this thickness depends on the distance of the transducer from the seafloor and particularly on the steepness of the nominal seafloor. For the transducers used in this survey, on a flat seafloor the shadow zone is typically about 1 m, but on steep hillsides it can be over 30 m. We estimated the thickness of the shadow zone using the method of Barr (in Doonan et al. 1999) and assumed that the black oreo density in the shadow zone was the same as that in the 10 m immediately above. Corrections were calculated for groups of 10 pings and reported as the mean of these corrections for a stratum and snapshot. The final abundance estimate includes shadow zone correction.

Transducer motion during a transmit results in the transducer pointing in different directions when transmitting and receiving. Corrections for the decrease in acoustic signal strength due to this motion were made using the method of Dunford (2005). Transducer movement data were collected synchronously with the acoustic data at 50 ms intervals. These data were interpolated to match the acoustic data that were then corrected on a sample-by-sample basis. The corrections required are a function of the difference in pointing angle between transmission and reception and are therefore greatest at longer ranges and when transducer motion is most pronounced. Backscatter was calculated both with and without motion correction for each stratum and snapshot. The final abundance estimate does not use this method since motion correction is included in the bubble layer correction (see below).

The absorption of sound by seawater is not well known at 38 kHz (Do & Coombs 1989, Doonan et al. 1999), and this uncertainty is a significant factor where long ranges are involved (e.g., flat background strata). The absorption coefficient was estimated from temperature and salinity data collected during the survey using the relationship derived by Doonan et al. (2003a).

2.2 Acoustic system

Acoustic data were collected along the survey transects and during trawling with a 38 kHz Simrad ES60 split-beam hull mounted echosounder. Calibration of the sounder on *San Waitaki* took place near Banks Peninsula (43° 54.98 S 172° 51.53 E) on 1 December 2011. Water depth was about 35 m (below the transducer). Prior to this the vessel had a new transducer (model no. ES38B) fitted and this was the first calibration of the new transducer. Results of this and previous calibrations of the ES60 system with the old transducer by both NIWA and other researchers are in Appendix 2.

2.3 Bubble layer correction

Corrections for probable micro-aeration (bubble layer) in the upper part of the water column during each acoustic transect should be applied according to recorded wind speeds. Doonan et al. (2012) calculated that the mean weather correction (bubbles and motion) for the *San Waitaki* hull acoustic system during the June/July 2002 to 2009 surveys of the north Chatham Rise orange roughy Spawning Plume was 1.33 with a CV of 5%. This result was used for the abundance estimates made in this report.

2.4 Trawl gear

Tows on dense marks were carried out using the *San Waitaki* Champion net with an 18.3 m rockhopper ground-rope, 45 m sweeps and 60 mm mesh codend, while the NIWA rat-catcher net with light rubber ground-rope, 45 m sweeps and a 40 mm mesh codend was used for layer and more diffuse marks.

2.5 Survey design

The 2011 acoustic survey region was the same as that surveyed in 2002 and 2006, and it is approximately the same as the area of the 1997 acoustic survey region flat strata. These areas are a subset of the earlier trawl survey area (McMillan & Hart 1994a, 1994b, 1994c, 1995, 1998) and cover only part of the overall OEO 3A area (Figure 1). The region comprises flat and undulating ground bounded by the longitude parallels 172°30’ E and 175°30’ E and by the 600 m depth contour in the north (Figure 2). The southern boundary of the survey region between 172°30’ E and 174°15.51’ E, is the 1200 m depth contour, and between 174°15.51’ E and 175°30’ E it is three straight line approximations to the southern boundaries of the earlier trawl and acoustic survey regions. No hills were included in the 2011 survey because they contributed only 5.4 t of the 18 800 t recruited abundance in the 1997 black oreo acoustic abundance estimate (Doonan et al. 1998).

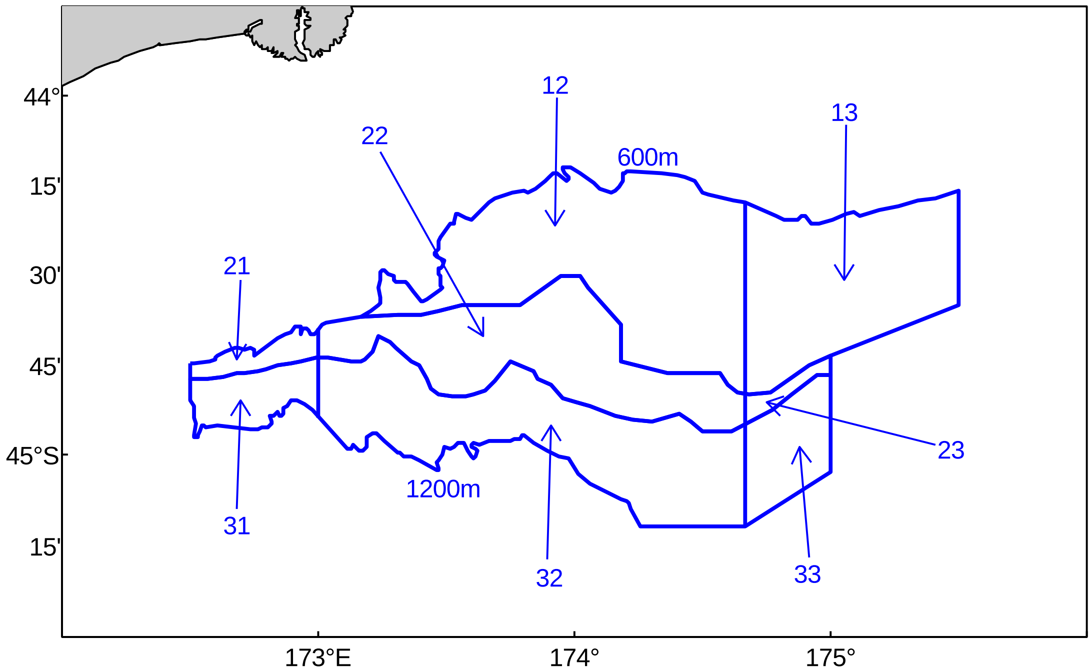

Figure 2: The 2011 acoustic abundance survey region with stratum boundaries.

A conventional stratified random approach was used (Jolly & Hampton 1990) and the eight strata (Figure 2 and Table 1) were the same as those used in 2002 and 2006. Each stratum lies entirely within one of the three spatial areas used in the 2002 stock assessment (Hicks et al. 2002) while at the same time approximating as closely as possible the flat strata of the 1997 acoustic and trawl surveys. For ease of identification, the first digit of the stratum number gives the spatial area to which the stratum belongs (i.e., Areas 1, 2, or 3). The boundary line between spatial Areas 1 and 2 (the northern boundary for an area that encloses 90% of the commercial catch) separates strata 12 and 13 from strata 22 and 23. The boundary between spatial Areas 2 and 3 (the smoothed contour line south of which the mean length of black oreo sampled in the Ministry of Fisheries (now Ministry for Primary Industries) scientific observer programme is greater than 32.5 cm) separates strata 21, 22, and 23 from strata 31, 32, and 33. The northern boundary of the 2011 survey region was the 600 m contour and this differs slightly from the northern boundary of the 1997 survey because more recent bathymetry was used to define the line.

The assignment of transects to strata was made using the criteria of attaining the target CV for the overall abundance while minimising the total length of the transects (i.e., time steaming) and requiring a minimum of four transects per stratum. Because the initial allocations were very similar, further savings of vessel time came from assigning the same number of transects to each stratum in the pairs

(21, 31), (22, 32) and (23, 33) since this enabled transects to be sailed contiguously across spatial Areas 2 and 3 without repositioning the vessel. Transects for each stratum of the survey ran north-south across the whole of the stratum and their lines of longitude were chosen at random across the stratum with the restriction that all transects were at least 2 n. miles apart. The allocation was based on the variability by stratum from the 2006 survey.

Table 1: Spatial areas, stratum labels and areas.

Spatial area	Stratum	Area (km^2)
Area 1	12	4 290
	13	2 880
Area 2	21	300
	22	2 700
	23	160
Area 3	31	610
	32	3 340
	33	830
Total		15 110

We assumed that fish occurred over the survey region either in diffuse low-density distributions or in aggregations or schools of higher density, and that these characteristics are identifiable with the variety of image mark-types that appear on echograms. Acoustic mark-types in each stratum were sampled by trawl to obtain species composition and length-frequency distributions for black oreo, smooth oreo, and other species in the catch. With the limited time available it was also decided to carry out about five trawls in each of the two deeper Areas (2 and 3) and that the trawls should concentrate on discrete mark-types rather than layer and background mark-types. For Area 1, 10–13 trawls were planned concentrating on layer mark-types. The latter also used the ratcatcher gear to gain more data on the species composition of these mark-types. We assumed that there was no movement in and out of the acoustic survey area during the time of sampling. We treated all the information for the survey region as being effectively at the same instant of time.

2.6 Estimating acoustic abundance

The procedure for estimating abundance was essentially the same as in previous oreo surveys (Doonan et al. 1998, 2000). The total abundance of the stock (immature and mature fish combined) is required for stock assessment. Abundance was estimated by classifying the acoustic data into mark-types where marks equate approximately to images on echograms. The mark classification scheme was the same as that used in 2002, which itself was an updated version of that used for the 1997 survey (Doonan et al. 1998), because the 2002, 2006 and 2011 surveys were specifically designed for black oreo. The abundance of black oreo in each mark-type was estimated from the backscatter assigned to the mark-type, the proportion of black oreo in the mark-type (estimated by trawling, including catch data from the 2011 survey), the mean acoustic cross-section (related to target strength) for the mix of species in the mark-type, and the mean weight of the black oreo in the mark-type. These were then summed over each transect, scaled up by the stratum area, and the results summed over all strata (Doonan et al. 2000). The black oreo abundance for the whole of OEO 3A was estimated by scaling up the abundance from the acoustic survey area to the whole of OEO 3A as detailed immediately below.

2.6.1 Abundance scaling factor

A scaling factor was used to multiply the flat acoustic survey area abundance up to the entire OEO 3A area for stock assessment purposes. The scaling factor was calculated as the total black oreo catch from the whole of OEO 3A, (excluding that part of OEO 3A that falls within the Southland fishery as defined in Anderson 2011), relative to the total catch from the survey area for the 10 fishing years 1992–03 to 2001–02. The multiplying factor was 1.14.

2.6.2 Species composition and mark-types

As noted above, the acoustic data were classified into six different kinds of mark-types that differed from the four mark-types used in the initial analysis of the 1997 survey (Doonan et al. 1998). The mark-type scheme is described in Table 2.

Table 2: Classification of echogram marks into black oreo mark-types, and the numbers of tows in the 1997, 2002, 2006, and 2011 surveys on each mark-type.

		Number of occurrences			
Mark-type	Description	1997 tows	2002 tows	2006 tows	2011 tows
Short	Discrete marks < 500 m long	6	5	4	4
Long	Discrete marks > 500 m long	4	3	3	3
Layeroff	Layers off the bottom	3	4	6	7
Layer	Layers on the bottom	6	1	8	6
Back	Background < 1000 m deep	11	2	0	2
Backdeep	Background > 1000 m deep	7	0	1	2

Table 3 shows how species composition and catch rates differed between mark-types for the two main species, black oreo (BOE) and smooth oreo (SSO), and for the other species combined, for tows targeting each mark-type. Catch rates are in kilograms per nautical mile and only the data from the 2011 survey tows were used in the analysis. In 2011, as in earlier surveys, catch rates from Short and Long marks were dominated by a mixture of smooth oreo and black oreo, but the catch rate for black oreo relative to smooth oreo changed. In 2011, black oreo dominated smooth oreo in the Short mark, the reverse of the results in 2002 and 2006. The 2011 black oreo catch rate was similar to smooth oreo in Long and Layeroff marks, but black oreo dominated smooth oreo in the earlier surveys (Table 3).

Table 3: Survey tow catch rates (kg/n.mile) for black oreo, smooth oreo, and all other species combined for each mark-type from 2002 to 2011 (see http://marlin.niwa.co.nz **for species code definitions).**

Mark-type	Number of species	Number of tows	Catch rates (kg/n.mile) BOE	SSO	All others Total	Highest species		Next highest	
						Catch data from the 2011 survey			
Short	15	3	2 853	1 941	126	ETB	65	HJO	30
Long	18	3	4 585	4 517	161	ETB	98	HOK	21
Layeroff	21	7	205	155	73	HOK	21	JAV	14
Layer	24	6	466	15	147	HJO	25	BJA	23
Back	21	2	90	25	140	HOK	63	ETB	35
Backdeep	14	2	0	0	113	SSM	46	MCA	28
						Catch data from the 2006 survey			
Short	12	4	581	4 021	54	ETB	24	MCA	12
Long	13	3	2 648	307	131	ETB	88	MCA	12
Layeroff	24	6	328	2	200	HOK	84	JAV	46
Layer	25	8	1 336	27	114	HOK	41	ETB	16
Back	13	11	66	7	41	ETB	19	MCA	9
Backdeep	15	8	2	4	84	SSM	24	MCA	21
						Catch data from the 2002 survey			
Short	14	11	1 890	2 919	82	ETB	54	MCA	14
Long	18	7	1 786	509	109	ETB	62	MCA	11
Layeroff	21	7	296	11	126	JAV	34	HOK	24
Layer	19	7	714	16	71	ETB	29	GSP	19
Back	21	13	95	6	69	JAV	25	ETB	15
Backdeep	12	7	2	3	73	SSM	21	MCA	21

The 2011 survey species composition for the Long and Short mark-types are nearly 100% smooth oreo plus black oreo (Figure 3), whilst the composition for the other mark-types contains some black oreo with a mixture of other species and very little smooth oreo. This broad pattern was also observed in previous surveys, although details differ between years.

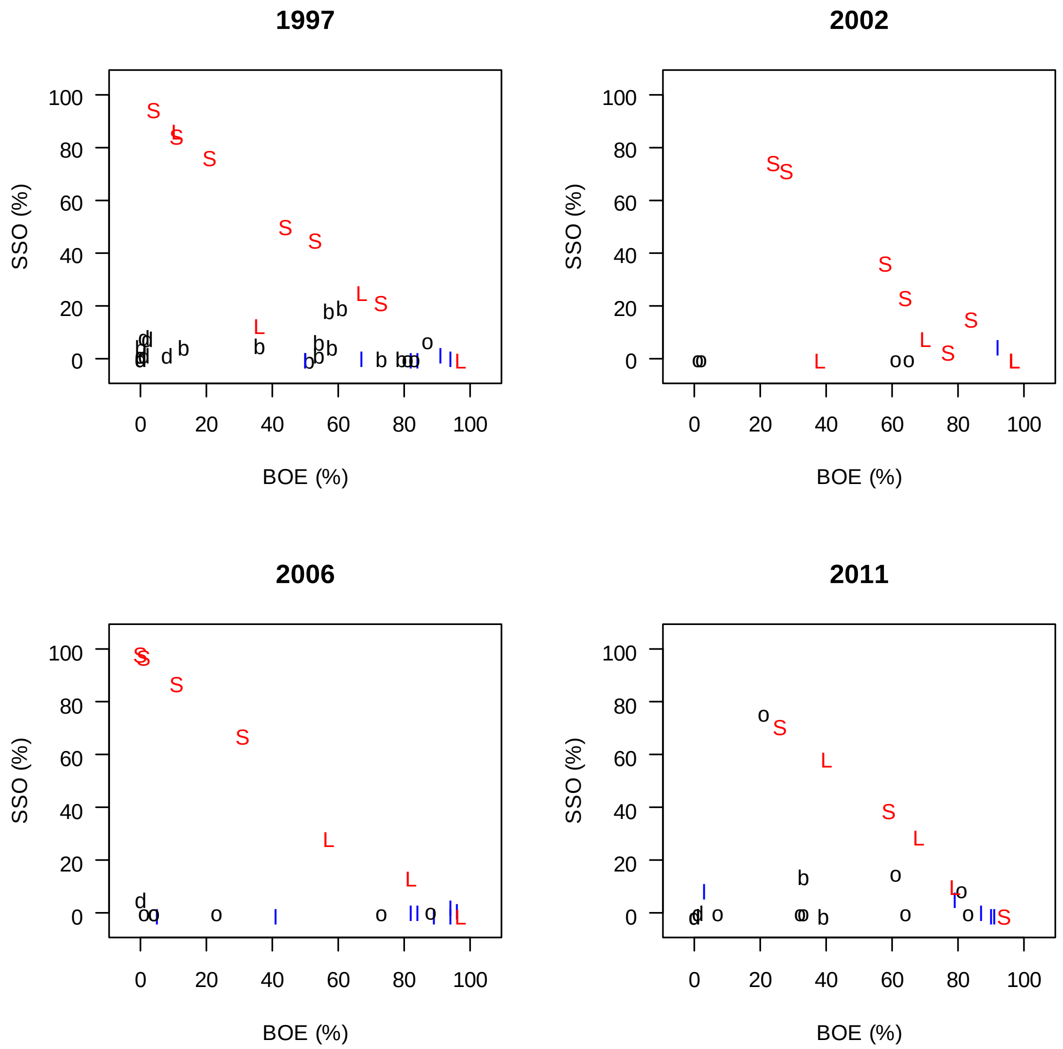

Figure 3: Percent (by weight) of black oreo (BOE), and smooth oreo (SSO) in tows for the 1997, 2002, 2006, and 2011 surveys. Mark-types are coded: "S" Short, "L" Long, "l" Layer, "o" Layeroff, "b" Back, "d" Backdeep.

2.6.3 Target strength

The target strength relationships for black oreo and smooth oreo used in these analyses were derived from a Monte-Carlo analysis of in situ and swimbladder data (Macaulay et al. 2001, Coombs & Barr, 2004 and were:

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

and

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

for smooth oreo and black oreo respectively and where TS is the target strength and L the fish total length.

Estimates for orange roughy and hoki were those used by Doonan et al. (2003b), and for other common species we used relationships based on swimbladder modelling (Macaulay et al. 2001),

Table 4. A generic relationship, i.e., $TS = a + b\log_{10}(L)$, was used for species for which no specific relationship was available as detailed by Doonan et al. (1999).

Table 4: Fish length-target strength relationships used where relationships are of the form TS = $a + b\log_{10}(L)$.

Species	Code	Intercept (*a*)	Slope (*b*)
Basketwork eel (*Diastobranchus capensis*)	BEE	-76.7	23.3
Black javelinfish (*Mesobius antipodum*)	BJA	-70.6	17.8
Four-rayed rattail (*Coryphaenoides subserrulatus*)	CSU	-92.5	31.8
Hoki (*Macruronus novaezelandiae*)	HOK	-74	18.0
Javelinfish (*Lepidorhyncus denticulatus*)	JAV	-73.5	20.0
Johnson's cod (*Halargyreus johnsonii*)	HJO	-74.0	24.7
Notable rattail (*Coelorinchus innotabilis*)	CIN	-107.8	44.9
Orange roughy (*Hoplostethus atlanticus*)	ORH	-76.81	16.15
Ribaldo (*Mora moro*)	RIB	-66.7	21.7
Ridge scaled rattail (*Macrourus carinatus*)	MCA	-95.5	35.6
Robust cardinalfish (*Epigonus robustus*)	EPR	-70.0	23.2
Serrulate rattail (*Coryphaenoides serrulatus*)	CSE	-135.0	59.7
White rattail (*Trachyrincus aphyodes*)	WHX	-62.1	18.1
Cod-like		-67.5	20.0
Deepwater swimbladdered		-79.4	20.0
No swimbladder		-77.0	20.0

2.6.4 Black oreo acoustic length frequency

A length frequency distribution (1 cm length classes) was estimated for each of the spatial areas and also for the total area. For each mark-type, j, an overall length frequency distribution was estimated by combining individual tow length frequency distributions weighted by catch size. Abundance by length for each mark-type was then found by applying the mark-type abundance to the weight by length frequency, and then these were summed over all the mark-types to give the total abundance by length, i.e., the abundance for length class, l, was

$$f_l = \sum_j B_j f_{j,l} \Big/ \sum_j B_j \ ,$$

where B_j is the abundance of the j^{th} mark-type and $f_{j,l}$ is the length frequency for mark-type j and length class l .

The CV for each length interval was found by bootstrapping the tow data within mark-types (m = 200) and also using 200 bootstrapped B_js.

2.7 Estimating variance and bias

Methods used to estimate variance and bias were the same as those used in previous oreo surveys (Doonan et al. 2003b). Sources of variance are:

- sampling error in the mean backscatter;
- the proportion of smooth oreo and black oreo in the acoustic survey area;
- sampling error in catches which affects the estimate of the proportion of black oreo;
- error in the target strengths of other species in the mix;
- variance in the estimate of black oreo target strength;
- sampling error of fish lengths (negligible);
- variance of the mean weight, $\overline{w}$, for black oreo (negligible).

The CV of the abundance estimate was obtained using simple bootstrapping that allows for the following sources of variation:

- For acoustic sampling, acoustic transects were re-sampled from those within a stratum.
- For trawl sampling, the stations were re-sampled from those within the same mark-types.
- For target strength of oreos (TS_{SSO} and TS_{BOE}), the intercept of the target strength-length relationship was randomly shifted using a normal distribution with a zero mean and a standard deviation of 1.0 dB.
- For species with a target strength determined by swimbladder modelling, a in the relationship $TS = a + b\log_{10}(L)$ had a random value added to it from a normal distribution that had a zero mean and a standard deviation of 3 dB.
- For target strength of other species, bootstrapping was carried out in two independent parts: one for cod-like species and another for deepwater species. The target strength for each species was re-sampled as described by Doonan et al. (2000) and involved random shifts in the intercepts of the target strength-length relationships (the slope was constant at 20).

Potential sources of bias in the abundance estimates are:

- classification of marks;
- differences in relative catchability of other species compared with oreos;
- the species composition and species distribution in the background layer;
- the proportion of black oreo and smooth oreo in the shadow zone;
- the validity of the target strength-length relationship used for estimating the target strength of associated species;
- error in the method used to correct for signal loss from transducer motion;
- signal loss from bubbles (for the hull transducer);
- estimation of absorption rate of sound in water;
- fish movements, including black oreo and smooth oreo moving to the background population from schools on the flat;
- estimates of target strength from swimbladder casts.

Analyses were carried out to assess the sensitivity of the abundance estimates to changes in target strengths, catchability, and species mix.

3. RESULTS

3.1 Survey details

The numbers of acoustic transects and tows are in Tables 5 and 6 and are shown in Figure 4. There were 72 transects used in the analysis.

Table 5: Strata, stratum areas, transects planned and carried out in 2011.

Stratum	Area (km^2)	Number of transects	
		Planned	Actual
12	4 290	9	9
13	2 880	11	11
21	300	4	4
22	2 700	18	18
23	160	4	4
31	610	4	4
32	3 340	18	18
33	830	4	4
Totals	15 110	72	72

Table 6: Tows planned and carried out in 2011.

Mark type	Description	Number of tows	
		Planned	Completed
Short	Discrete marks < 500m long	3	4
Long	Discrete marks > 500m long	4	3
Layeroff	Layers off the bottom	8	7
Layer	Layers on the bottom	7	6
Back	Background < 1000m deep	2	2
Backdeep	Background > 1000m deep	1	2
Total		25	24

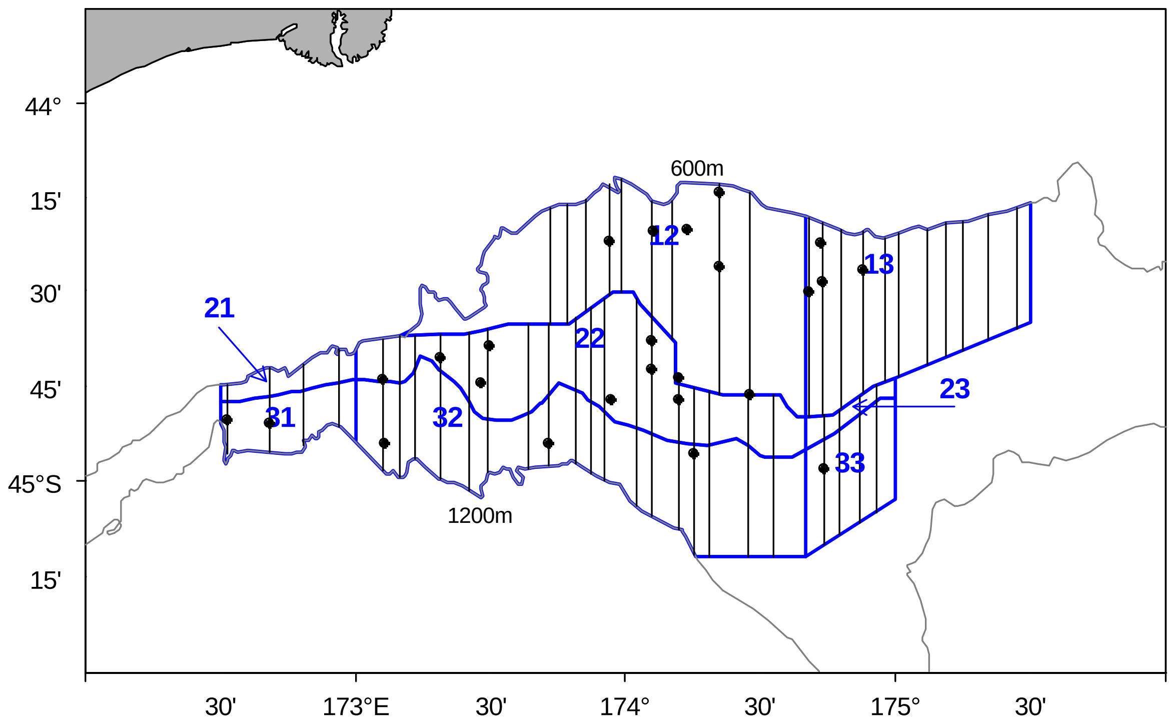

Figure 4: Strata (thick blue lines), acoustic transects completed (vertical black lines), and tows (dots) for the 2011 survey.

3.2 Abundance and variance estimates for area OEO 3A

The abundance from the survey area was scaled up to the overall OEO 3A area (see Section 2.6.1) giving an estimate of the abundance of black oreo of 182 300 t with a CV of 25%. When catch data from the 2006 survey was used instead of the 2011 catch data to test the effect of the 2011 catches this gave an estimated abundance of 172 600 t, i.e., not substantially different. For stock assessment, the overall abundance was also split into the three spatial areas. Abundance estimates for the whole of OEO 3A scaled up (by 1.14) from the 2011 survey region included an estimate where corrections for probable micro-aeration (bubble layer) were made, along with the estimates for comparison from the 1997, 2002, and 2006 surveys (from Doonan et al. 2008), Table 7.

Table 7: Comparison of abundance estimates from the OEO 3A black oreo acoustic survey series. Total (immature plus mature) black oreo abundance estimates (t) for the 1997 (using revised target strength estimates from those used in the 2002 assessment), 2002, 2006, and 2011 acoustic surveys and CV estimates (%), in parentheses, for the three spatial (model) areas in OEO 3A. † bubble layer correction applied.

Survey	Area 1	Area 2	Area 3	Total
1997	148 000 (29)	10 000 (26)	5 240 (25)	163 000 (26)
2002	43 300 (31)	15 400 (27)	4 710 (38)	63 400 (26)
2006	56 400 (37)	16 400 (30)	5 880 (34)	78 700 (30)
2011	138 100 (27)	36 800 (30)	7 400 (34)	182 300 (25)
2011†	183 700 (27)	48 900 (30)	9 800 (34)	242 500 (25)

The percentage of the abundance by stratum is shown in Table 8 for the 2011 compared to the 2006 survey showing that the largest contribution to the 2011 survey abundance estimate was from stratum 12, with 50% of the abundance. The contribution from several Short mark-types in one transect in stratum 12 was 14% (8% for total survey area), and there was also 18% (9% for the total area) contributed by Layeroff marks in another transect in stratum 12. In spatial Areas 2 and 3, where most of the fishery occurred, stratum 22 had 18% of the abundance followed by stratum 32 with 3%. Percentage abundance estimates by stratum from the 2006 and 2011 surveys are similar but the magnitude of the estimates were generally higher in 2011.

Table 8: Estimated black oreo abundance in the survey strata expressed as a percentage (rounded) of the total abundance for the survey region for the 2011 and 2006 surveys. No bubble layer correction applied.

Area	Stratum	2011 %	2006 %
Area 1	12	49.5	39.1
	13	26.2	32.6
	Total	75.7	71.7
Area 2	21	1.7	2.1
	22	17.9	16.8
	23	0.5	1.9
	Total	20.2	20.8
Area 3	31	0.5	0.4
	32	2.6	4.4
	33	1	2.6
	Total	4.1	7.5
Total		100	100

Estimated black oreo abundance by mark type in total and for the spatial areas within the 2011 survey region are given in Table 9. Of the total abundance, only 15% was in the Short and Long mark-types, which are the discrete school marks most likely to be fished by commercial vessels. About half of the abundance came from layer marks off the bottom (Layeroff). The shallow background mark-type (Back) provided 18% of the abundance, with two-thirds coming from Area 1.

Table 9: Estimated black oreo abundance (t) in the 2011 survey region by mark type and spatial area with percentages of the total. No bubble correction was applied. –, less than 1 t, NA, not applicable.

Mark-type	Spatial area						Total	
Name	Area 1		Area 2		Area 3		Total	
Back	19 900	(12%)	8 680	(5%)	0	(0%)	28 600	(18%)
Backdeep	NA		0	(0%)	48	(0%)	48	(0%)
Layer	15 400	(10%)	8 040	(5%)	2 150	(1%)	25 500	(16%)
Layeroff	72 400	(45%)	9 380	(6%)	–	(0%)	82 000	(51%)
Long	379	(0%)	4 290	(3%)	305	(0%)	4 980	(3%)
Short	13 100	(8%)	1 910	(1%)	3 840	(2%)	18 800	(12%)

An alternative abundance estimate was calculated by including only Short and Long discrete mark-types which are more likely to contain mostly black oreo and smooth oreo, and to be fished by commercial fishing vessels, and by excluding the layer and background mark-types which are less likely to be fished, i.e., mixed species marks were excluded. These estimates were also made for the previous three surveys (Table 10) to enable comparison. The 2011 estimates were substantially higher than any of the previous survey estimates in Area 1 but had a large CV of 93%, due to one large mark. The 2011 estimates are also the second highest estimates for Area 2 (after 2002), and are the largest estimates in Area 3 of the survey series.

Table 10: Comparison of abundance (t) and CV (%) estimates for the Long plus Short mark-types only from the 1997, 2002, 2006 and 2011 acoustic surveys. The 2011 estimate was corrected for bubble layer, all estimates were scaled to OEO 3A (see Section 2.6.1).

Year	Area 1	Area 2	Area 3	Total
1997	3 140 (41)	1 880 (36)	2 270 (30)	7 290 (28)
2002	1 870 (55)	7 870 (34)	3 440 (48)	13 200 (28)
2006	3 520 (55)	5 290 (44)	2 650 (55)	11 500 (33)
2011	20 400 (93)	9 400 (37)	6 300 (37)	36 000 (54)

The high values of the abundance estimates from the 2011 survey is reflected by high backscatter estimates from the 2011 survey compared to earlier surveys. An example of a comparison of mean backscatter estimates from stratum 22 for the 2011 and 2006 surveys is in Table 11. Reasons why the backscatter estimates are high in 2011 are uncertain, and are considered in the Discussion.

Table 11: Comparison of mean backscatter (scaled up by x 10^7 fish, per m^2) estimates for stratum 22 by mark-type from the 2011 and 2006 surveys. Survey area only, i.e., not scaled up to OEO 3A.

Mark-type	2011	2006	Ratio	Ratio with bubble layer correction
Back	9.8	4.8	2.1	2.8
Layer	9.5	4	2.4	3.2
Layeroff	6.2	0.8	7.4	9.8
Short	1.1	0.5	2.2	2.9
Long	2.2	2	1.1	1.5

Coefficients of variation for the individual components contributing to the estimate of total black oreo abundance in the survey region are given in Table 12. The largest CV (14%) is associated with the estimate of the target strength of black oreo.

Table 12: The CV of the total black oreo acoustic abundance estimates for the survey region for each variance source using that source alone (see Section 2.6), e.g., in the Catches source, tows were re-sampled within each mark-type.

Source	CV (%)
Catches	10
Backscatter	10
Target strength of other species	10
Target strength of black oreo	14

Acoustic survey length frequency distributions for each spatial area within the survey area and the totals by length class are given in Table 13. Modal lengths in Areas 1 and 2 were 30–31 cm but 32–33 cm TL in Area 3. The acoustic survey length frequency distributions by mark-types are shown in Figure 5.

Table 13: Length frequency distributions and associated CV (%) of black oreo in the survey region by spatial area. A length class of 24 means the total length is greater than or equal to 24 cm and less than 25 cm.

Length	Area 1		Area 2		Area 3		Survey area	
22	0.001	(63)	0.001	(60)	0.000	(170)	0.001	(35)
23	0.007	(60)	0.008	(35)	0.002	(62)	0.007	(24)
24	0.021	(43)	0.019	(35)	0.007	(56)	0.020	(22)
25	0.031	(43)	0.029	(29)	0.010	(61)	0.030	(22)
26	0.027	(37)	0.027	(28)	0.019	(56)	0.027	(21)
27	0.044	(34)	0.047	(26)	0.032	(54)	0.044	(17)
28	0.083	(28)	0.086	(18)	0.055	(46)	0.083	(15)
29	0.112	(23)	0.114	(14)	0.072	(33)	0.111	(13)
30	0.153	(9)	0.154	(7)	0.107	(17)	0.152	(5)
31	0.159	(14)	0.157	(9)	0.125	(10)	0.158	(7)
32	0.121	(18)	0.119	(12)	0.153	(14)	0.122	(9)
33	0.121	(30)	0.118	(18)	0.175	(17)	0.122	(15)
34	0.069	(38)	0.067	(23)	0.126	(20)	0.070	(19)
35	0.026	(31)	0.029	(22)	0.057	(40)	0.027	(16)
36	0.018	(29)	0.018	(21)	0.034	(29)	0.018	(16)
37	0.005	(54)	0.005	(40)	0.018	(52)	0.006	(33)
38	0.002	(41)	0.002	(45)	0.005	(32)	0.002	(27)
39	0.000	(102)	0.000	(69)	0.002	(54)	0.000	(59)
40	0.000	(0)	0.000	(0)	0.000	(0)	0.000	(0)
41	0.000	(0)	0.000	(0)	0.000	(0)	0.000	(0)
42	0.000	(147)	0.000	(150)	0.000	(158)	0.000	(68)

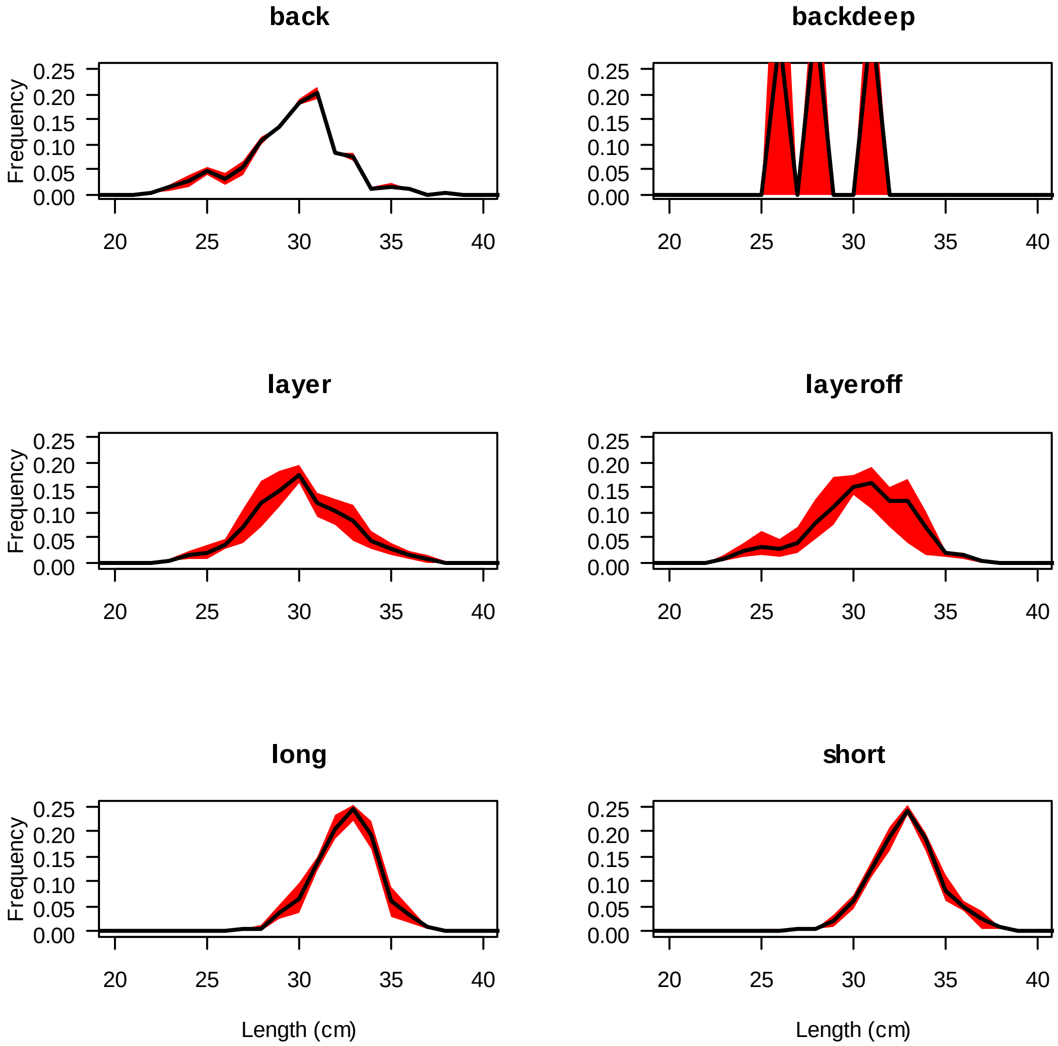

Figure 5: Length frequency distributions of black oreo by mark-type. Shaded red areas are the 95% confidence intervals.

3.3 Bias and sensitivity

The sensitivity of the abundance estimates to changes in values of contributing parameters is shown in Table 14. Most sensitivities considered here do not represent likely changes, but are based on doubling and halving parameter values (e.g., a 3 dB change in target strength represents a factor of two in the fish per m^2 scale) or excluding one species completely from the species mix. However, a number of sources of uncertainty in the 2011 survey produced abundance changes greater than the total CV (25%) and therefore have to be considered as possible sources of significant bias.

Shifts in the intercept of the target strength-length curves gave large changes in the abundance. The sensitivity estimates ranged from a decrease by 74% to an increase of 129% (Table 14). The catchabilities of other species are unknown, and it is also not known if oreos are more or less catchable than other species. The sensitivities used should be viewed as a mean change for all of the other species because there would be a range of values over all the species. The effect of catchability differences depends on the position of black oreo catchability relative to the mean of the species mix. If black oreo catchability is half the species mix mean, then the abundance estimate will increase by 122%, and it will decrease by 75% if the catchability of black oreo is double that of the mean of the species mix.

The effect of excluding various species, one at a time, from the species mix is low for all species except smooth oreo (+11%) and javelinfish (+10%). This sensitivity analysis gives an indication of how much of the acoustic backscatter was apportioned to the excluded species.

Using the 1997 plus 2006 trawl catch data instead of the 2011 trawl data resulted in a small decrease in abundance (-6%).

Table 14: Bias sources for the 2011 acoustic survey abundance estimates, black oreo, OEO 3A. †, magnitude of change exceeds CV for abundance estimate (25%). TS, target strength.

Source	Abundance change (%)
TS estimate of black oreo	
Decrease intercept by 2 dB	+129†
Increase intercept by 2 dB	-74†
TS estimates of other species	
Decrease intercept by 3 dB	**+125**†
Increase intercept by 3 dB	**-72**†
Catchability of other species	
Double that for black oreo	+122†
Half that for black oreo	-75†
Exclusion of species from species mix (ordered by effect size)	
Exclude smooth oreo	11
Exclude javelinfish	10
Exclude hoki	5
Exclude basketwork eel	4
Exclude Johnson's cod	3
Exclude ridge scaled rattail	2
Alternative trawl data	
Use 2006+1997 catch data	-6

4. DISCUSSION

The 2011 survey was the fourth acoustic survey of OEO 3A and provided the fourth set of abundance estimates of black oreo. The 2011 survey was also the first acoustic survey of black oreo that used a hull-mounted echosounder on a fishing industry vessel; the previous three surveys (1997, 2002, and 2006) used towed echosounders deployed from *Tangaroa* to avoid the issue of micro-aeration of the upper layer of the ocean. The 1997 survey covered more ground than the surveys from 2002 onwards but the 1997 survey was designed to survey both black oreo and smooth oreo. From 2002 on the surveys were re-designed for black oreo specifically and also excluded hills. The 1997 estimate was re-analysed to provide abundance estimates that were comparable to the later reduced-area surveys (2002, 2006, 2011). The 2011 survey covered the area where, historically, most of the commercial black oreo catch was taken. All the surveys were designed to cover the study area used in the stock assessments. The total assessed variability of the 2011 abundance estimate, as measured by the CV (25%), was the lowest in the survey series.

The total black oreo abundance estimate (no bubble layer correction) from the 2011 survey was larger than the 2006 and 2002 survey abundance estimates and similar to the 1997 value. The 2011 Area 1 abundance estimates were the second largest in the abundance survey series after the 1997 values but the 2011 survey estimates for Area 2 and Area 3 were both the largest in the series. The reason for this result is uncertain and could be due to a number of possibilities including:

- A real increase in abundance. This seems highly unlikely given the slow growth of black oreo (Ministry for Primary Industries 2012). A real change in abundance is only likely to be detected by another survey.
- An increase in availability within the survey area at the time of the survey, e.g., perhaps due to high food availability. Migration of fish into the area also seems unlikely given that populations of black oreo to the east (OEO 4) and to the southwest (Southland) have a long history of exploitation and are probably fully fished (Ministry for Primary Industries 2012, Anderson 2011).
- A technical issue related to the change in survey equipment from a towed echosounder to a hull mounted echosounder system on another vessel. The equipment change should not be an issue in theory but the large increase in abundance suggests the possibility that there is some technical factor that was overlooked in the complex analysis. The mean backscatter estimates from 2011 were about twice the 2006 survey estimates in stratum 22 for Back, Layer, and Short, about seven times greater for Layeroff, and about the same for the Long mark-types, suggesting that if there is an issue it is with the calculation of the acoustic backscatter rather than with the calculation of abundance by mark-type, strata, and area. Using catches from previous surveys instead of the 2011 ones gave a small decrease in abundance, suggesting a greater density of backscatter in 2011.
- A seasonal influx of small fish with air-filled swimbladders which create a large increase in backscatter. Being small, they are not well represented (caught) in the trawl catches and so their backscatter is assigned to black oreo. Survey series dates were:

1997	10 November to 18 December
2002	25 September to 7 October
2006	17–30 October
2011	17 November to 1 December

The 2011 survey was later than in 2002 and 2006, but similar to that in 1997. The1997 survey also had high backscatter, especially in Area 1. Total abundance for the surveys were 163 000 t, 63 400 t, 78 700 t, and 182 300 t (not bubble layer corrected).

5. ACKNOWLEDGMENTS

This work was carried out for the Ministry for Primary Industries under project OEO2010/04. We thank all the vessel staff of F. V. *San Waitaki*, particularly the skipper Tony Barnett, first mate Gavin Virtue, and factory manager Peter Thornton. The Sanford Ltd vessel manager Steve Collier was especially helpful and provided vital communication, logistical support and other help. Ben Lennard (NIWA acoustics) organised the mobile wetlab and other electronic gear required. The biological staff included Alan Hart (shift leader) Brent Wood, Michael Stevenson, Mark Fenwick, and Peter Notman. Thanks to Peter Horn (NIWA) who reviewed the draft report and provided constructive comments.

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APPENDIX 1: Generic mark-stratum analysis for acoustic surveys

The following gives an account of the estimation of abundance when using mark-classes and strata for a generic deepwater species, called DEEPWATER in what follows, with code XXX. For flat ground, the acoustic data are classified into mark-types where marks equate approximately to echogram images. The mark classification schemes are a result of analyses of concurrent data collection from trawling and the echogram of the mark trawled on. The biomass of DEEPWATER in each mark-type is estimated from the backscatter for each mark, the proportion by number of DEEPWATER in that type (estimated by trawling), the mean acoustic cross-section (target strength) for the mix of species in that mark-type, and the mean weight of the DEEPWATER in that mark-type. These were then summed over each stratum, scaled up by the stratum area, and the results summed over all strata.

The acoustic data were classified into types of 'marks' (mark-type). For stratum, *i*, the abundance of DEEPWATER in mark-type *m*, is given by:

$$B_{i,m} = \frac{abscf_{i,m}}{\overline{\overline{\sigma}}_{bs,m}} \times p_{XXX,m} \times area_i \times \overline{w_m} \ ,$$

where $area_i$ is the area of the stratum, $abscf_{i,m}$ is the mean backscattering (fish.m^{-2}), $\overline{\overline{\sigma}}_{bs,m}$ is the mean tilt-averaged acoustic cross-section for the species mix, $p_{XXX,m}$ is the proportion of DEEPWATER by number, and $\overline{w_m}$ is the mean weight of a DEEPWATER. The mean tilt-averaged acoustic cross-section for the species mix is given by:

$$\overline{\overline{\sigma}}_{bs,m} = \sum_j^{species} p_{jm} \overline{\overline{\sigma}}_{bs,jm}$$

where j indexes each species, p_{jm} is the proportion in numbers of species j in the mix, and $\overline{\overline{\sigma}}_{bs,jm}$ is the mean tilt-averaged cross-section for species j (which depends on the length distribution of that species in mark-type m).

Mean cross-section, $\overline{\overline{\sigma}}_{bs,jm}$, is given by $\sum_l f_{XXX,m,l} 10^{\frac{\langle \mathrm{TS} \rangle_{sso}(l)}{10}}$ for DEEPWATER and by $\sum_l f_{j,m,l} 10^{\frac{\langle \mathrm{TS} \rangle_j (Ljm)}{10}}$ for other species, where $f_{XXX,m,l}$ is the fraction of DEEPWATER in mark-type m with length l and $f_{j,m,l}$ is a similar fraction for the j^{th} species, $\langle \mathrm{TS} \rangle_j(l)$ is the tilt-averaged or *in situ* target strength-to-length function for species j, L_{jm} is the mean length of species j in mark-type m, $\langle \mathrm{TS} \rangle_j(l) = a_j + b_j \times \log_{10} l$ and a_j and b_j are constants.

The mean tilt-averaged acoustic cross-section is given by:

$$\overline{\sigma}_{bs} = \int \sigma_{bs}(\theta) g(\theta) d\theta,$$

where θ is the tilt angle (in the pitch plane only), $\sigma_{bs}(\theta)$ is the acoustic cross-section as a function of θ, and $g(\theta)$ is the probability of a fish being at an angle θ. Tilt-averaged target strength, $\langle \mathrm{TS} \rangle$, is given by $10 \log_{10} \overline{\sigma}_{bs}$.

For several strata (*strata*) and mark-types (*marks*) the total abundance, B_{Flat}, is given by:

$$B_{Flat} = \sum_{i}^{strata} \sum_{m}^{marks} B_{i,m} \ .$$

APPENDIX 2: Acoustic calibration

The calibration was conducted broadly as per the procedures in MacLennan & Simmonds (1992). The ES60 was configured to recommended settings (2000 W power and 1.024 ms pulse). Long (3.8 m) fibreglass calibration poles were used to help keep the calibration lines clear of the hull and to allow the rods to point forward. The sphere and associated lines were immersed in a soap solution prior to entering the water. A lead weight was also deployed about 2 m below the sphere to steady the arrangement of lines. The sphere was centered in the beam to obtain data for on-axis calibration, and then moved around the beam to obtain data for beam shape calibration.

The weather was moderate with a 20–25 knot northeast breeze, 1–2 m swell and some chop. The vessel was allowed to drift, and the drift speed was about 0.9 knots. The sphere was located in the beam at 13:35 NZDT. Calibration data were recorded into a single ES60 raw format file (L0203-D20111201-T133651-ES60.raw). Raw data are stored in the NIWA Fisheries Acoustics Database. The ES60 transceiver settings in effect during the calibration are given in Table A2.1.

A temperature/salinity/depth profile was taken using a Seabird SBE21 conductivity, temperature, and depth probe (CTD). An estimate of acoustic absorption was calculated using the formulae in Doonan et al. (2003a) and an estimate of sound speed was calculated using the formulae of Fofonoff & Millard (1983).

The data in the ES60 files were extracted using custom-written software. The amplitude of the sphere echoes was obtained by filtering on range, and choosing the sample with the highest amplitude. Instances where the sphere echo was disturbed by fish echoes were discarded. The alongship and athwartship beam widths and offsets were calculated by fitting the sphere echo amplitudes to the Simrad theoretical beam pattern:

$$compensation = 6.0206\left(\left(\frac{2\theta_{fa}}{BW_{fa}}\right)^2 + \left(\frac{2\theta_{ps}}{BW_{ps}}\right)^2 - 0.18\left(\frac{2\theta_{fa}}{BW_{fa}}\right)^2\left(\frac{2\theta_{ps}}{BW_{ps}}\right)^2\right),$$

where θ_{ps} is the port/starboard echo angle, θ_{fa} the fore/aft echo angle, BW_{ps} the port/starboard beamwidth, BW_{fa} the fore/aft beamwidth, and *compensation* the value, in dB, to add to an uncompensated echo to yield the compensated echo value. The fitting was done using an unconstrained nonlinear optimisation (as implemented by the Matlab fminsearch function). The S_a correction was calculated from:

$$S_{a,corr} = 5\log_{10}\left(\frac{\sum P_i}{4P_{max}}\right),$$

where P_i is the sphere echo power measurement and P_{max} the maximum sphere echo power measurement. A value for $S_{a,corr}$ is calculated for all valid sphere echoes and the mean over all sphere echoes is used to determine the final $S_{a,corr}$.

A correction for the triangle wave error in ES60 data (Ryan & Kloser 2004) was also applied as part of the analysis.

Analysis

The mean range of the sphere and the sound speed and acoustic absorption between the transducer (about 4 m deep) and the sphere are given in Table A2.2.

The calibration results are given in Table A2.3. The estimated beam pattern and sphere coverage are given in Figure A2.1. The symmetrical nature of the pattern and the zero centre of the beam pattern indicate that the transducer and ES60 transceiver were operating correctly. The fit between the theoretical beam pattern and the sphere echoes is shown in Figure A2.2 and confirms that the transducer beam pattern is correct. The RMS of the difference between the Simrad beam model and the sphere echoes out to 3.4° off axis was 0.20 dB (Table A2.3), indicating that the calibration was of acceptable quality (<0.4 dB is poor, <0.3 dB good, and <0.2 dB excellent).

The estimated peak gain (G_0) in December 2011 was of the same order of magnitude as those measured previously c.f (Table A2.3) despite the fact that these were with a different transducer. It was also comparable with the July 2012 calibration. As the non-NIWA calibrations were performed using a copper sphere and different analysis methods they are primarily useful for qualitative comparison purposes only.

Table A2.1: ES60 transceiver settings and other relevant parameters during the calibration.

Parameter	Value
Echosounder	ES60
ES60 software version	1.5.2.77
Transducer model	ES38B
Transducer serial number	To be confirmed by Sanford Ltd
ES60 GPT serial number	Not recorded
GPT software version	Not recorded
Sphere type/size	Tungsten carbide/38.1 mm diameter
Operating frequency (kHz)	38
Transducer draft setting (m)	4
Transmit power (W)	2000
Pulse length (ms)	1.024
Transducer peak gain (dB)	26.5
Sa correction (dB)	0.0
Bandwidth (Hz)	2425
Sample interval (m)	0.192
Two-way beam angle (dB)	–20.60
Absorption coefficient (dB/km)	9.75
Speed of sound (m/s)	1500
Angle sensitivity (dB) alongship/athwartship	21.90/21.90
3 dB beamwidth (º) alongship/athwartship	7.10/7.10
Angle offset (º) alongship/athwartship	0.0/0.0

Table A2.2: Auxiliary calibration parameters derived from depth/temperature measurements.

Parameter	Value
Mean sphere range (m)	10.1
S.D. of sphere range (m)	1.1
Mean sound speed (m/s0	1 499.6
Mean absorption (dB/km)	9.01
Sphere TS (dB re 1m2)	–42.4

Table A2.3: Calculated echosounder calibration parameters for *San Waitaki*. All values prior to December 2011 are from a different transducer (Ian Hampton pers. comm.). July 2012 values are from Mike Soule (pers. comm.).

Parameter	Jul 2012			Dec 2011	Jun 2011	2010	2009	2008	2007	2006	2005	2004
	Lobe	Echoview	Graphical									
Mean TS within 0.2° of centre				-43.1022	-43.6644							
Std dev of TS within 0.2° of centre				0.38422	0.36015							
Max TS within 0.2° of centre				-42.2851	-42.9677							
No. of echoes within 0.2° of centre				107	93							
On axis TS from beam-fitting				-42.8697	-43.5551							
Transducer peak gain (dB)	26.68	26.48	26.47	26.57	26.22	25.87	26.05	25.97	25.47	26.29	26.28	26.28
Sa correction (dB)	-0.70	-0.70		-0.64	-0.69	-0.64	-0.76	-0.74	-0.85	-0.80	-0.84	-0.9
Beamwidth alongship (º)	6.81		7.14	6.9	6.5	7.13	6.80	6.81	6.90	7.22	7.03	7.1
Beam offset alongship (º)	-0.03		-0.02	-0.08	0.00	+0.02	-0.14	-0.08	-0.07	-0.16	-0.02	-0.18
Beamwidth athwarthship (º)	6.76		7.06	6.9	6.9	7.04	6.98	6.98	6.90	7.08	7.03	7.3
Beam offset athwarthship (º)	0.06		0.06	+0.10	0.00	+0.06	+0.04	+0.21	+0.14	-0.16	+0.03	+0.13
RMS deviation	0.18			0.21	0.20							
Number of echoes				23585	21471							

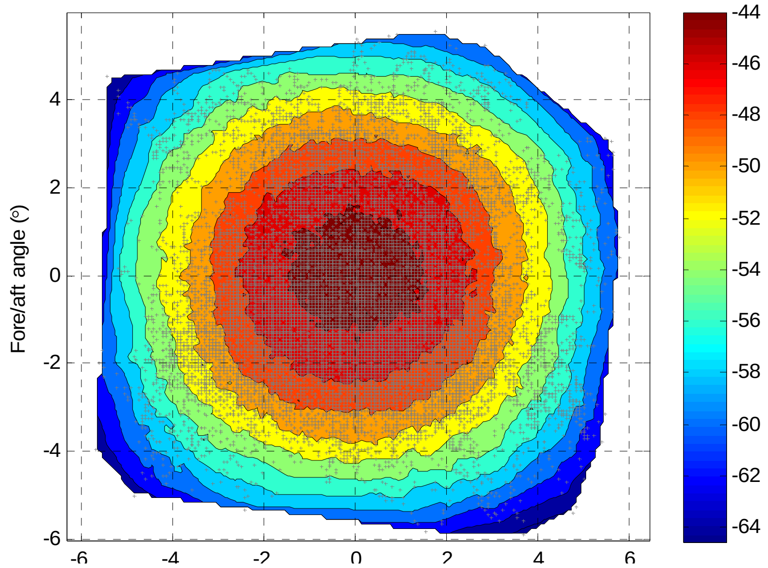

Figure A2.1: The estimated beam pattern from the sphere echo strength and position for the December 2011 calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

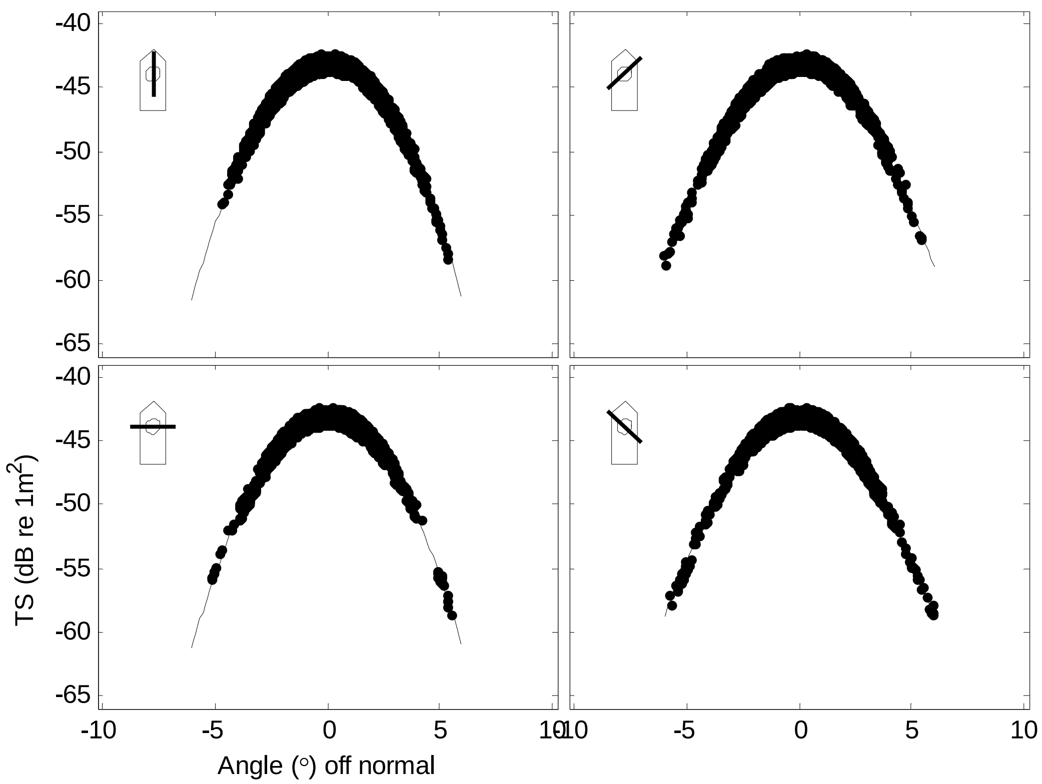

Figure A2.2: Beam pattern results from the calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.