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Black oreo abundance estimates from the October 2014 acoustic survey of the south Chatham Rise (OEO 3A)

New Zealand Fisheries Assessment Report 2016/18

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The abundance of the black oreo (*Allocyttus niger*) population in area OEO 3A was estimated from an acoustic survey carried out between 16 to 29 October 2014 using *San Waitaki* (voyage SWA1402). The survey covered the southern slope of the west end of the Chatham Rise and was the fifth in a series of acoustic surveys of the area, with earlier surveys carried out in 1997, 2002, 2006, and 2011. From 2002 onward, the surveys covered only the main "flat" area (i.e., they 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). The survey used a stratified design with randomly allocated transects, and collected data with a hull-mounted acoustic system. The survey included 72 transects and 34 trawl tows over 8 flat area strata (15 110 km^2 total area).

The total (immature plus mature) estimated abundance of black oreo for OEO 3A was 200 700 t with a CV of 27%, which is within the specified target CV of the project (20–30%). 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 occurring there 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 are commercially fished, and most mark-types observed were discrete school and layer marks. Total abundance estimates were: Area 1, 129 100 t (CV 32%); Area 2, 48 600 t (24%); Area 3, 23 000 t (28%).

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 1649 t from 2007–08 to 2011–12 and a maximum of 12 700 t in 1980–81 (Ministry for Primary Industries 2015). There is also a substantial smooth oreo (*Pseudocyttus maculatus*) fishery in the area with estimated mean annual catches of 1566 t from 1998–99 to 2007–08 (Ministry for Primary Industries 2015). 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). 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) and 2011 (Doonan et al. 2014). The same survey was repeated in 2014 and is the subject of this report. It was carried out to meet the objective of the Ministry of Fisheries project OEO201004B: "To estimate the abundance of black oreo (*Allocyttus niger*) in OEO 3A on the Chatham Rise using an acoustic survey".

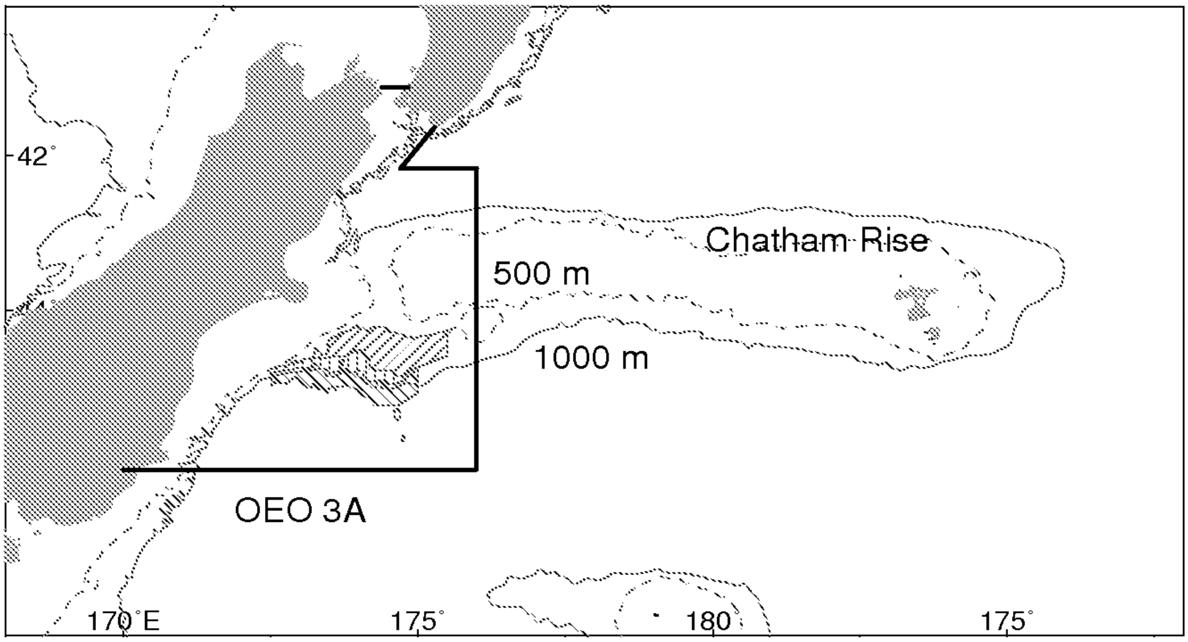

Figure 1: Oreo management area OEO 3A bounded by thick dark lines with the 2014 acoustic survey region shown divided into three areas (shaded), i.e., Area 1 at the top with right sloping shading, Area 2 in the middle with vertical shading, and Area 3 at the bottom with left sloping shading.

The 2014 survey took place between 16 and 29 October. 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. As in 2011, this survey used a hull transducer on a fishing industry vessel, the *San Waitaki*, operated by Sanford Ltd. The first three 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). New work by Shabangu et al. (2014) compared the sea floor backscatter from a hull mounted transducer with that from a transducer mounted on a keel (i.e., about another 2.5 m deeper) and found that bubble attenuation had a similar form as expected from theoretical expectations (i.e., that the attenuation increases exponentially with increased wind speeds), but only up to 15 m s^{-1} (29 knots). At wind speeds over 15 m s^{-1}, bubbles were present below the keel transducers and so the comparison was biased. Shabangu et al. (2014) reported that their correction factors are much lower than previous experimental values (Berg et al. 1983, Dalen & Løvik, 1981), but well within the expected range for 38 kHz transducers that were at 5.5 and 8 m depth (Novarini & Bruno, 1982). The experimental work used different vessels so there may be strong vessel effects in the results, otherwise it is difficult to see why the differences are so great. Note that the transducer depth for Dalen & Løvik, (1981) was 5 m, so transducer depth is not a factor, and that Shabangu et al. (2014) report that the depth to the sea floor is not enough to affect results from timing of send and receiving signals due to the pitch and roll of the vessel. 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, obtained by trawling, on the size structure of the black oreo samples and the mix of species present in acoustic marks. Data on the species mix for the Back and Backdeep mark-types from the 1997 survey trawl results (Doonan et al. 1998) 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, 2006, and 2011 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 2014 survey used the results of the 2011 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, 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 (estimated from trawl tows) 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 that 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 can be made using the method of Dunford (2005). The final abundance estimate does not use this method since motion correction is included in the bubble layer correction (see Section 2.3 below).

The absorption of sound by seawater is not well known at 38 kHz (Doonan et al. 2003a), 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° 54.60' S, 172° 54.07' E) on 17 October 2014. Water depth was about 35 m (below the transducer). Detailed results 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 (i.e., for loss of signal due to 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 estimated to be a factor of 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 2014 acoustic survey region was the same as that surveyed in 2002, 2006, and 2011, 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. Hills have been excluded since the 2002 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) and the survey then was designated to be only a black oreo survey.

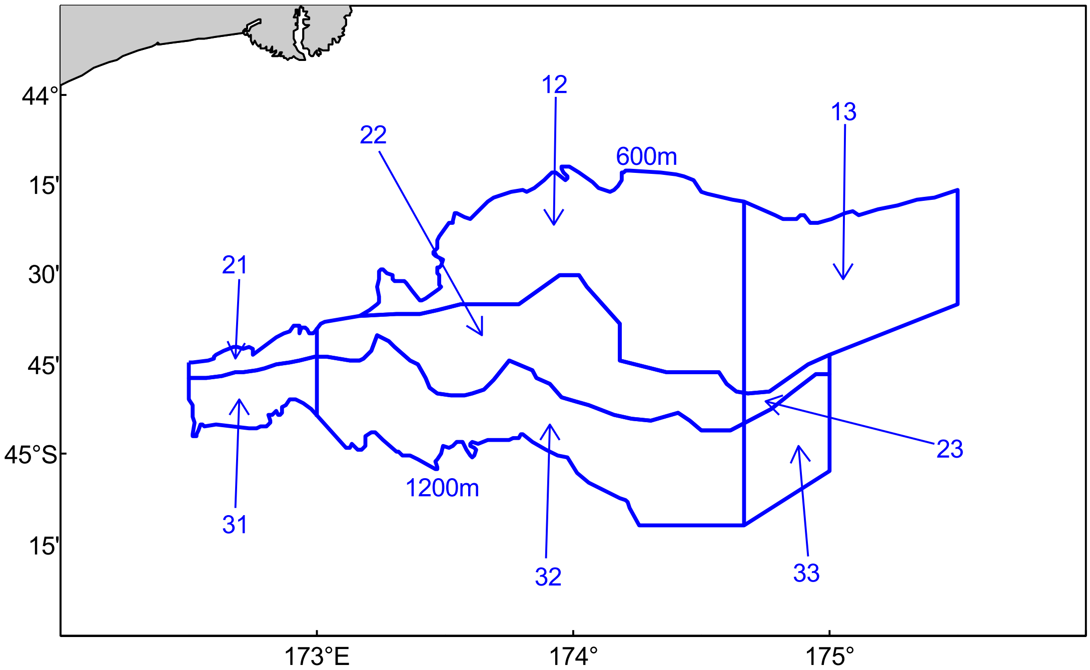

Figure 2: The 2014 acoustic abundance survey region with stratum boundaries and labels (i.e., numbers from 12 to 33).

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, 2006, and 2011. 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 produces 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 survey region since the 2002 survey is 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 2011 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. For low density distributions, the rat-catcher gear was used to gain more data on the species composition of these mark-types. For higher density aggregations, the rough bottom net was used which is similar to that used for commercial trawling. 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, 2011 and 2014 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 catch data from the 2014 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 (estimated from trawl tows). 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), over 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

The acoustic data were classified into six different kinds of mark-types, which 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, 2011, and 2014 surveys on each mark-type.

						Number of tows
Mark-type	Description	1997	2002	2006	2011	2014
SHORT	Discrete marks < 500 m long	6	5	4	4	13
LONG	Discrete marks > 500 m long	4	3	3	3	5
LAYEROFF	Layers off the bottom	3	4	6	7	5
LAYER	Layers on the bottom	6	1	8	6	3
BACK	Background < 1000 m deep	11	2	0	2	7
BACKDEEP	Background > 1000 m deep	7	0	1	2	1

Table 3 shows how species composition and catch rates differed between mark-types for 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 2014 survey tows were used in the main analysis. To check whether catch or acoustic signal drives the 2014 estimate, we calculate an alternative estimate using the 2006 catches in place of 2014 catches. In 2014, as in earlier surveys, catch rates from SHORT and LONG marks were dominated by a mixture of smooth oreo and black oreo, and its ratio were similar to that in 2002 and 2006. However, in 2011, black oreo dominated smooth oreo in the Short mark, the reverse of the results in 2002, 2006, and 2014. (Table 3).

Table 3: Surveymean tow catch rates (kg/n.mile) for black oreo, smooth oreo, and all other species combined for each mark-type from 2002 to 2014, and the number of unique species in the catch data by mark-type (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 2014 survey				
SHORT	21	13	2 080	4 718	141	ETB	67	HJO	18
LONG	18	5	9 212	2 098	242	ETB	149	HOK	43
LAYEROFF	16	5	189	0	229	JAV	60	GSP	59
LAYER	15	3	74	0	303	JAV	105	HOK	77
BACK	24	7	320	3	144	GSP	30	JAV	22
BACKDEEP	8	1	0	0	181	SSM	81	MCA	66
					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 2014 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.

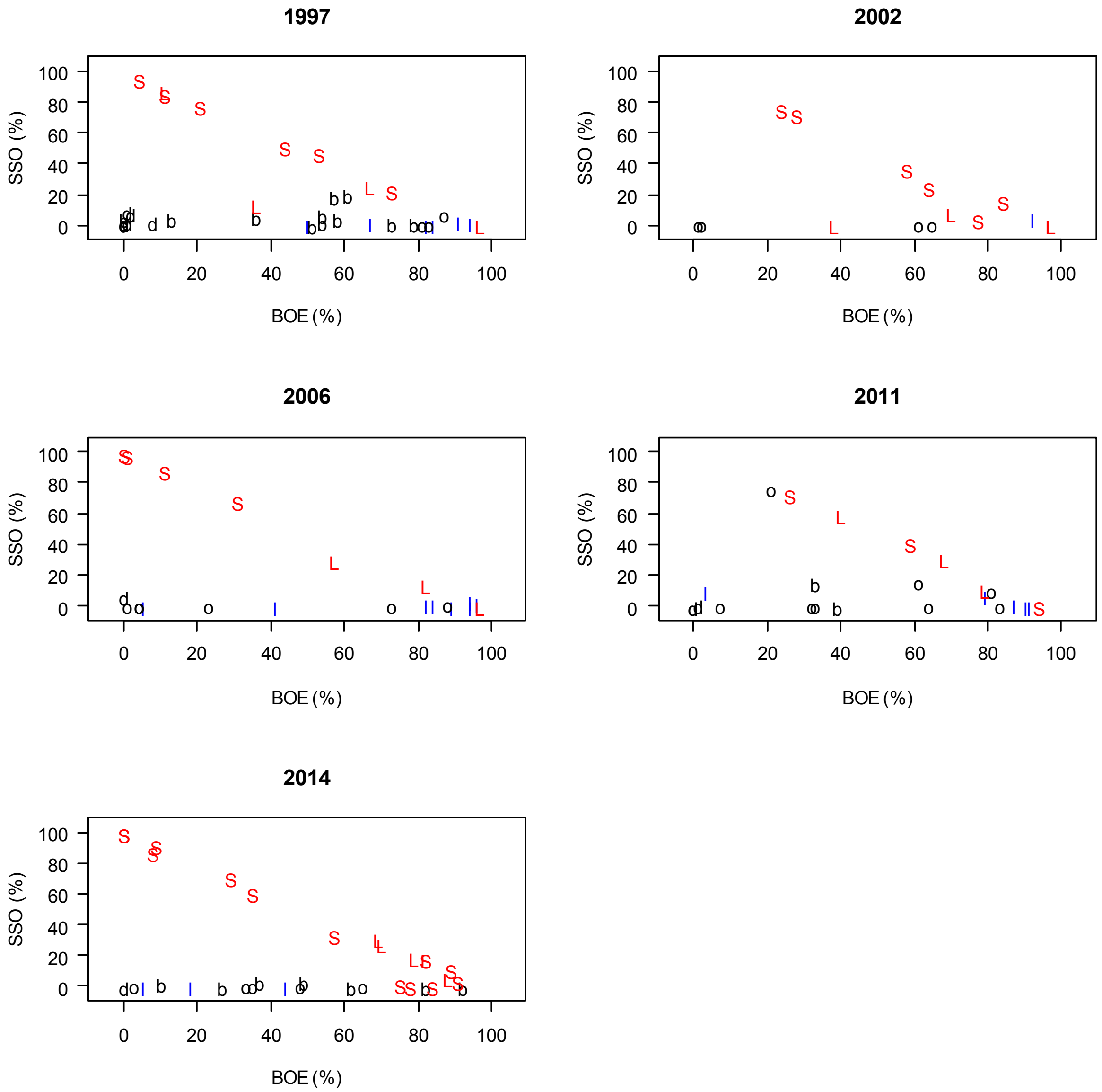

Figure 3: Percent (by weight) of black oreo (BOE), and smooth oreo (SSO) in tows for the 1997, 2002, 2006, 2011, and 2014 surveys. Mark-types are coded: "S" SHORT, "L" LONG, "l" Layer, "o" LAYEROFF, "b" BACK, "d" BACKDEEP.

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:

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

and

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

for smooth oreo and black oreo respectively, where *TS* is the target strength and *L* is the total fish 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., $TS = a + b\log_{10}(L)$ with parameters from Table 4, 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	-74.0	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	-76.71	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 with swimbladder		-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 (n = 200) and also using 200 bootstrapped B_j values.

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 trawl 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 the 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 by stratum and tows by mark-type are listed 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 2014.

Stratum	Area (km^2)	Number of transects	
		Planned	Actual
12	4 290	11	11
13	2 880	9	9
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 2014.

Mark-type	Description	Number of tows	
		Planned	Completed
Short	Discrete marks < 500m long	3	13
Long	Discrete marks > 500m long	4	5
Layeroff	Layers off the bottom	8	5
Layer	Layers on the bottom	7	3
Back	Background < 1000m deep	2	7
Backdeep	Background > 1000m deep	1	1
Total		25	34

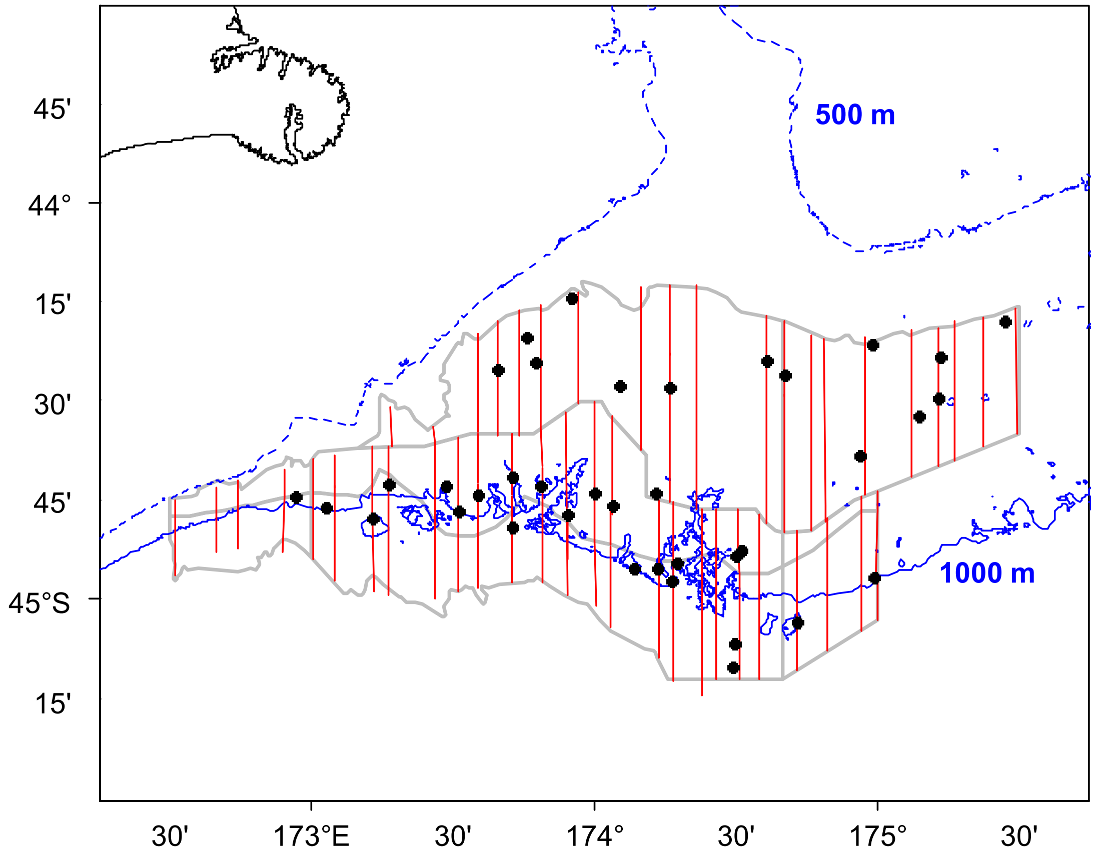

Figure 4: Strata (thick grey lines), acoustic transects completed (vertical red lines), and tows (dots) for the 2014 survey.

3.2 Abundance and variance estimates for area OEO 3A

The total estimated abundance of 132 442 t from the survey area (Table 7) was scaled up to the overall OEO 3A area (see Section 2.6.1) and a factor of 1.33 applied for bubble and motion corrections to give an estimate of the abundance of black oreo of 200 700 t with a CV of 27%. When catch data from the 2006 survey was used instead of the 2014 catch data this gave an estimated abundance of 240 800 t, i.e., a modest different, so that the ratio of black oreo in mark-type 2014 catches is not that much different from that in 2006. For stock assessment, the overall abundance was also split into the three spatial areas giving the following abundances: Area 1, 129 100 t (CV 32%); Area 2, 48 600 t (24%); Area 3, 23 000 t (28%).

Estimated black oreo abundance by mark-type for the total survey area and for the spatial areas within the 2014 survey region are given in Table 7. Of the total abundance, only 16% 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 34% of the abundance.

Table 7: Estimated black oreo abundance (t) in the 2014 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							
Name	Area 1		Area 2		Area 3		Total	
BACK	19 600	(15%)	17 000	(13%)	7 950	(6%)	44 600	(34%)
BACKDEEP	-		1	(0%)	20	(0%)	22	(0%)
LAYER	2 950	(2%)	2 770	(2%)	1 300	(1%)	7 010	(5%)
LAYEROFF	60 000	(45%)	359	(0%)	-		60 400	(46%)
LONG	2 060	(2%)	9 450	(7%)	2 880	(2%)	14 400	(11%)
SHORT	565	(0%)	2 520	(2%)	2 930	(2%)	6 010	(5%)
	85 175	(64%)	32 100	(24%)	15 080	(11%)	132 442	(100%)

Coefficients of variation for the individual components contributing to the estimate of total black oreo abundance in the survey region are given in Table 8. The largest CV (16%) is associated with the estimate of the target strength of species other than black oreo.

Table 8: 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	11
Backscatter	7
Target strength of other species	16
Target strength of black oreo	12

Length frequency distributions from trawl tows in each spatial area and the total survey area, by length class, are given in Table 9. Modal lengths in all areas were 30–31 cm and the mark-types LONG and SHORT have larger fish than the other mark-types (Figure 5).

Table 9: Length frequency distributions (proportions by length class) and associated CV (%, in parentheses) 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	(87)	0.002	(122)	0.002	(104)	0.001	(52)
23	0.010	(28)	0.007	(78)	0.007	(69)	0.009	(19)
24	0.038	(24)	0.023	(73)	0.023	(63)	0.033	(16)
25	0.073	(14)	0.053	(30)	0.055	(26)	0.066	(8)
26	0.070	(19)	0.048	(27)	0.048	(27)	0.063	(11)
27	0.085	(13)	0.055	(18)	0.054	(21)	0.075	(8)
28	0.097	(18)	0.066	(17)	0.064	(20)	0.087	(10)
29	0.140	(7)	0.087	(13)	0.085	(15)	0.122	(6)
30	0.136	(13)	0.140	(13)	0.136	(15)	0.137	(5)
31	0.136	(14)	0.129	(11)	0.124	(10)	0.133	(5)
32	0.097	(13)	0.123	(12)	0.122	(13)	0.105	(7)
33	0.072	(27)	0.107	(15)	0.107	(18)	0.083	(11)
34	0.023	(20)	0.074	(21)	0.075	(24)	0.040	(17)
35	0.011	(25)	0.050	(22)	0.054	(25)	0.024	(21)
36	0.005	(46)	0.021	(29)	0.024	(31)	0.010	(24)
37	0.003	(30)	0.010	(32)	0.013	(43)	0.006	(22)
38	0.000	(70)	0.002	(38)	0.004	(48)	0.001	(37)
39	0.002	(70)	0.000	(59)	0.001	(69)	0.001	(31)
40	0.000	(170)	0.000	(138)	0.000	(143)	0.000	(79)
41	0.000	(205)	0.000	(146)	0.000	(125)	0.000	(72)
42	0.000	(0)	0.000	(0)	0.000	(0)	0.000	(0)

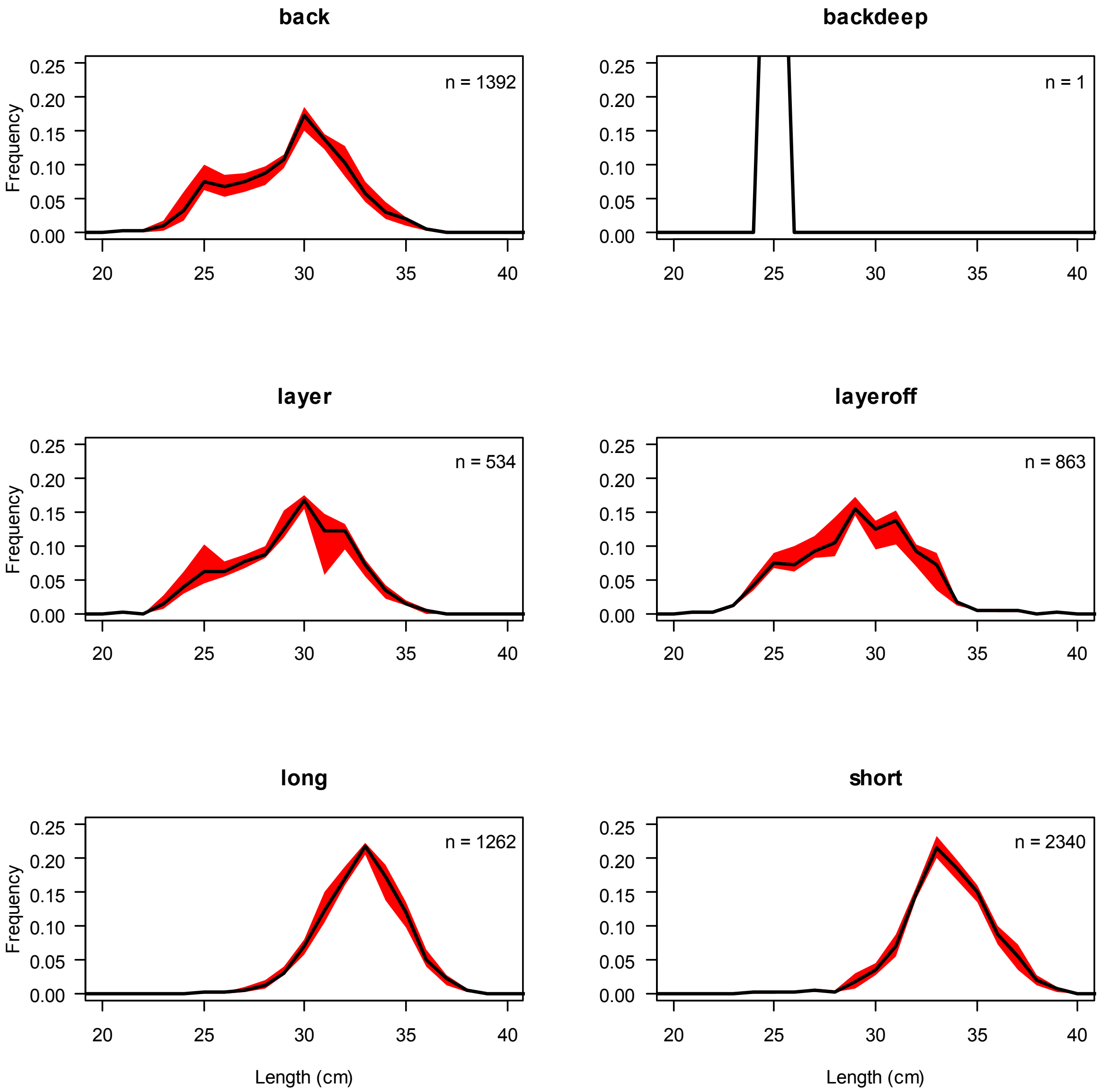

Figure 5: Length frequency distributions of black oreo by mark-type. Shaded red areas are the 95% confidence intervals.

3.3 Bias and sensitivity

The sensitivity of the abundance estimates to changes in values of contributing parameters is shown in Table 10. Most sensitivities considered here are arbitrary and 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 2014 survey produced abundance changes greater than the total CV (27%) and therefore have to be considered as possible sources of significant bias.

Shifts in the intercept of the target strength-length curves produced large changes in the abundance. The sensitivity tests produced a decrease (factor of 0.69) and an increase (factor of 1.32) (Table 10). The trawl catchabilities of other species are unknown, and it is also not known if oreos are more or less catchable than other species. The sensitivity values 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 1.29, and it will decrease by a factor of 0.72 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 javelinfish (1.30). This sensitivity analysis gives an indication of how much of the acoustic backscatter was apportioned to the excluded species.

Table 10: Sources of bias in the 2014 acoustic survey abundance estimates, black oreo, OEO 3A. †, magnitude of change exceeds CV for abundance estimate (27%). TS, target strength.

Source	Abundance multiple factor
TS estimate of black oreo	
Decrease intercept by 2 dB	1.25
Increase intercept by 2 dB	0.77
TS estimates of other species	
Decrease intercept by 3 dB	1.32†
Increase intercept by 3 dB	0.69†
Trawl catchability of other species	
Double that for black oreo	1.29†
Half that for black oreo	0.72†
Exclusion of species from species mix (ordered by effect size)	
Exclude javelinfish	1.30†
Exclude smooth oreo	1.03
Exclude basketwork eel	1.03
Exclude Johnson's cod	1.02
Exclude ribald	1.02
Exclude ridge scaled rattail	1.02
Exclude notable rattail	1.02
Alternative trawl data	
Use 2006+1997 catch data	1.21

4. DISCUSSION

The 2014 survey was the fifth acoustic survey of OEO 3A and the second acoustic survey that used a hull-mounted echosounder on a fishing industry vessel; the first 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 onwards, 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, and 2014). The current survey area covers where most of the historical 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 2014 abundance estimate, as measured by the CV (25%), is within the target range for the series (20 to 30%).

Abundance estimates for the whole of OEO 3A scaled up (by 1.14) to the management area and including an estimate where corrections for probable micro-aeration (bubble layer) for all surveys are shown in Table 11 (from Doonan et al. 2008, Doonan et al. 2014).

Table 11: Comparison of abundance estimates for black oreo in OEO 3A from the acoustic survey series. Total (immature plus mature) black oreo abundance estimates (t), as used in the assessment model, for the 1997 (using revised target strength estimates from those used in the 2002 assessment), 2002, 2006, 2011, and 2014 acoustic surveys, and CV estimates (%, in parentheses), for the three spatial (model) areas in OEO 3A. †, bubble layer correction applied. Rounded to nearest 100 t.

Survey	Area 1	Area 2	Area 3	Total
1997	148 000 (29)	10 000 (26)	5 200 (25)	163 000 (26)
2002	43 300 (31)	15 400 (27)	4 700 (38)	63 400 (26)
2006	56 400 (37)	16 400 (30)	5 900 (34)	78 700 (30)
2011†	183 700 (27)	48 900 (30)	9 800 (34)	242 500 (25)
2014†	129 100 (32)	48 600 (24)	23 000 (28)	200 700 (27)

The percentage of the abundance by stratum for the 2014, 2011, and 2006 surveys (Table 12) shows that the largest contribution to the 2014 survey abundance estimate (37%) was from stratum 12. In Areas 2 and 3, where most of the fishery occurred, stratum 22 had 22% of the abundance followed by stratum 32 with 6%. Percentage abundance estimates by stratum from the 2006, 2011, and 2014 surveys are similar (Table 12) but the absolute estimates were generally higher in 2011 and 2014 (Table 11).

Table 12: Estimated black oreo abundance in the survey strata expressed as a percentage (rounded) of the total abundance for the survey region for the 2014, 2011 and 2006 surveys. No bubble layer correction applied.

Area	Stratum	2014 %	2011 %	2006 %
Area 1	12	36.9	49.5	39.1
	13	27.4	26.2	32.6
	Total	64.3	75.7	71.7
Area 2	21	1.3	1.7	2.1
	22	21.7	17.9	16.8
	23	1.2	0.5	1.9
	Total	24.2	20.2	20.8
Area 3	31	1.1	0.5	0.4
	32	6.2	2.6	4.4
	33	4.3	1	2.6
	Total	11.6	4.1	7.5
Total		100	100	100

An alternative abundance estimate was calculated by including only SHORT and LONG discrete mark-types (i.e., 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 (i.e., mixed species marks less likely to be fished). Comparable estimates were also made for the previous three surveys (Table 13). The 2014 estimates were substantially higher than any of the previous survey estimates in Area 2. This abundance version was used in the smooth oreo assessment for management area OEO 4.

Table 13: 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 and 2014 estimates were corrected for bubble layer; all estimates were scaled to OEO 3A, i.e., values that would be used in an assessment (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)
2014	4 000 (44)	18 100 (30)	8 800 (30)	31 000 (23)

The high values of the abundance estimates from the 2011 and 2014 surveys is driven by high backscatter estimates from these surveys compared to earlier surveys. An example of a comparison of mean backscatter estimates from stratum 22 for the 2014, 2011, and 2006 surveys is in Table 14. Note that when alternative catches from other years are used instead of those from the survey itself, abundance changed very little, the largest being for 2014 backscatter using the 2006 catches (factor 1.2), so the interpretation is that the differences are caused by more backscatter being present, not a change in the ratio of black oreo to other species in the catches.

Table 14: Comparison of mean backscatter (1.0×10^{-7} fish per m^2) estimates for stratum 22 by mark-type from the 2014, 2011 and 2006 surveys. Data are for the survey area only, i.e., not scaled up to OEO 3A.

Mark-type	2014	2011	2006	Ratio		Ratio with bubble layer correction	
				2014/2006	2011/2006	2014/2006	2011/2006
BACK	18.5	9.8	4.8	3.9	2.1	5.1	2.8
LAYER	6.9	9.5	4	1.7	2.4	2.3	3.2
LAYEROFF	0.5	6.2	0.8	0.6	7.4	0.8	9.8
SHORT	6.5	1.1	0.5	13.0	2.2	17.3	2.9
LONG	2.2	2.2	2	1.1	1.1	1.5	1.5

The abundance series appears to be driven by changes in backscatter seen, but it is unfortunate that most of the backscatter comes from mark-types such as LAYEROFF and BACK since the analysis method can only indirectly estimate any black oreo in them. These mark-types contain a mixture of species of which it is difficult to estimate the species composition as it is necessary to assume both that species catchability is the same for other species as for black oreo and that all sizes of fish are caught. Both assumptions are known to be violated, but it is hoped that the violations are not too serious and this would apply when the abundance from such marks do not dominate the total abundance. In contrast, estimates from marks composed mostly of black oreo and smooth oreo are far more reliable. Here, we have 80% of the abundance coming from LAYEROFF and BACK in 2014 (Table 7), and a very large total abundance of 200 000 t, which is much larger than any other deepwater stocks and even greater than virgin biomasses of some stocks, e.g., orange roughy in MEC and 7A. Only east and south Chatham Rise orange roughy has a virgin biomass that is larger. The LAYEROFF mark is especially troublesome, since in the shallow area it can sometimes be seen to be a tail from layers that come from much shallower ground. Trawling on LAYEROFF will inevitably pick up species composition from BACK since this resides beneath it and this feature is unaccounted for in the species compositional analysis. These aspects have made the Deepwater Working Group nervous of the results and new work is being commissioned to look more closely at the data with the aim of getting an abundance series that can be confidently used in a stock assessment.

5. ACKNOWLEDGMENTS

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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 according to the procedures in (Demer et al. 2015). The ES60 was configured to recommended settings (2000 W power and 1.024 ms pulse). The three lines were clipped together, the weight and sphere attached and this was lowered down to vessel crew in the workboat and released. 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 centred in the beam to obtain data for the on-axis calibration, and was then moved around the beam to obtain data for the beam shape calibration.

The weather was moderate with a 20–25 knot breeze, and some chop. Because of the conditions the vessel was anchored off the port anchor. The sphere was located in the beam at 08:18 NZDT. Calibration data were recorded into a single ES60 raw format file (L0001-D20141016-T191801-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 1.

Table 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	31135
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 (°) alongship/athwartship	7.10/7.10
Angle offset (°) alongship/athwartship	0.0/0.0

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. (2003) and an estimate of sound speed was calculated using the formulae of Fofonoff & Millard (1983).

The data in the ES60 file 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 Sa 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 2.

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

Parameter	Value
Mean sphere range (m)	19.3
S.D. of sphere range (m)	0.2
Mean sound speed (m/s)	1494.4
Mean absorption (dB/km)	9.25
Sphere TS (dB re 1m2)	–42.41

The calibration results are given in Table 3. The estimated beam pattern and sphere coverage are given in Figure 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 fits between the theoretical beam pattern and the sphere echoes is shown in Figure 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 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 October 2014 was of the same order of magnitude as those measured previously (Table 3) and about 0.03 dB lower. Other long-term time series of echosounder calibrations have also observed gradual declines in peak gain, possibly as a function of transducer ageing (Knudsen 2009).

Table 3: Calculated echosounder calibration parameters for *San Waitaki*. July 2012 values are from Mike Soule (pers comm.).

Parameter	Oct 2014			Jul 2012	Dec 2011
Calibration analysis method	ExCal	Lobe	Echoview	Graphical	ExCal
Mean TS within 0.2° of centre	-42.7518				-43.1022
Std dev of TS within 0.2° of centre	0.39566				0.38422
Max TS within 0.2° of centre	-42.1238				-42.2851
No. of echoes within 0.2° of centre	105				107
On axis TS from beam-fitting	-42.7712				-42.8697
Transducer peak gain (dB)	26.3268	26.68	26.48	26.47	26.57
Sa correction (dB)	-0.63	-0.70	-0.70		-0.64
Beamwidth alongship (º)	7.0	6.81		7.14	6.9
Beam offset alongship (º)	0.00	-0.03		-0.02	-0.08
Beamwidth athwarthship (º)	6.9	6.76		7.06	6.9
Beam offset athwarthship (º)	0.00	0.06		0.06	+0.10
RMS deviation	0.20	0.18			0.21
Number of echoes	19929				23585

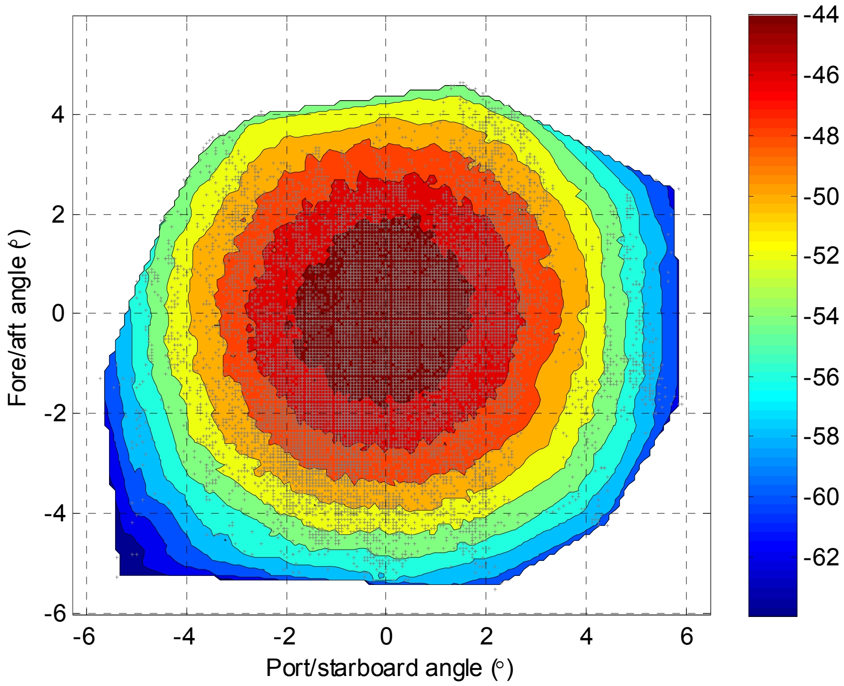

Figure 1. The estimated beam pattern from the sphere echo strength and position for the October 2014 calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

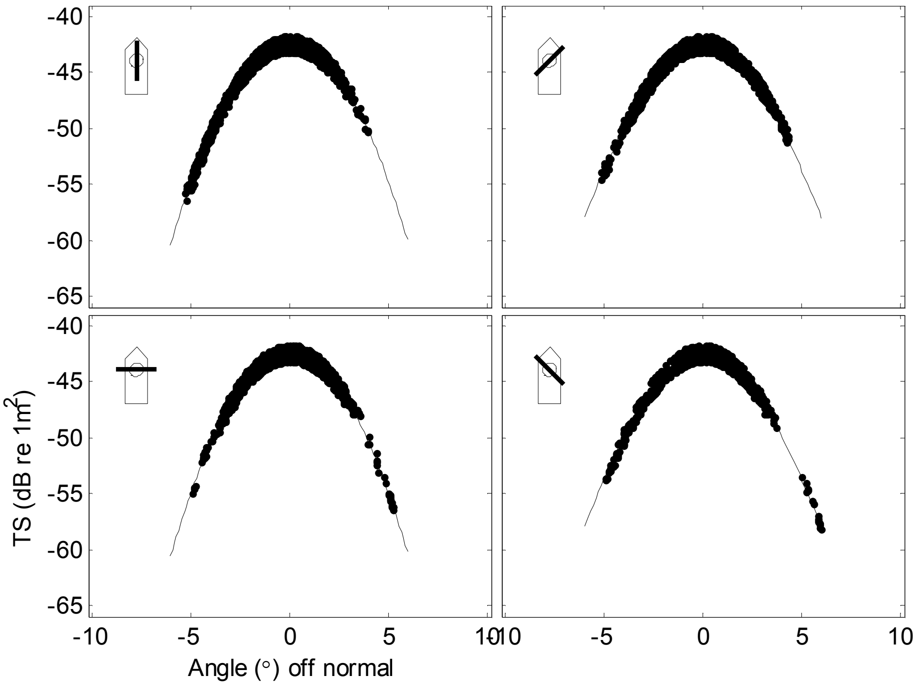

Figure 2. Beam pattern results from the calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

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