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EXECUTIVE SUMMARY

Doonan, I.J.; Smith, M.H.; McMillan, P.J.; Hart, A.C.; Dunford, A. (2008). Black oreo abundance estimates from the October 2006 acoustic survey of the south Chatham Rise (OEO 3A).

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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 and 30 October 2006 using *Tangaroa* (voyage TAN0615). The survey covered the south slope of the west end of the Chatham Rise and is the third in a series of acoustic surveys of the area which were carried out in 1997 and 2002. The 2006 and 2002 surveys covered only the main "flat" area, i.e., did not specifically survey hills, because only 0.013% of the recruited black oreo biomass was observed on hills in the 1997 survey,.

A stratified design using randomly allocated transects was used and data were collected concurrently on both towed and hull-mounted acoustic systems. The survey included 78 transects and 22 trawls over 8 flat area strata (15 000 km^2 in total area). Trawls from the 1997 survey were also used to estimate species proportions in background mark types.

The total estimated abundance (immature plus mature) of black oreo for OEO 3A was 78 700 t with a c.v. of 30%, which is at the high end of the specified target c.v. of the project (20–30%). Total abundances were also estimated separately for the three spatial areas used in the stock assessment: Areas 2 and 3 cover the main fishery and Area 1 is not generally fished as most black oreo there are immature fish that appear in the low-density background and layer acoustic mark-types. Estimates were 56 400 t with a c.v. of 37% for Area 1, 16 400 t with a c.v. of 30% for Area 2, and 5880 t with a c.v. 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 (19% c.v.) and the target strength of black oreo (15% c.v.). A potential source of bias was that 17% of the black oreo abundance came from the background mark-types, where the acoustic method performs poorly, whereas 15% came from the short plus long mark-types, where the acoustic method performs well.

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 2583 t from 1995–96 to 2004–05 (Ministry of Fisheries, Science Group, 2006). There is also a substantial smooth oreo fishery in the area with estimated mean annual catches of 2305 t from 1995–96 to 2004–05 (Ministry of Fisheries, Science Group, 2006). 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 oreos and smooth oreos are widespread and abundant throughout OEO 3A between depths of about 600 and 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 surveys was made in 1997 (Doonan et al. 1998, 2000). Acoustic surveys covering all of OEO 3A were carried out in 1997 (Doonan et al. 1998), and a reduced survey was conducted in 2002 (Smith et al. 2006). The reduced survey was repeated in 2006 and is the subject of this report. It was carried out to meet the objective of the Ministry of Fisheries project OEO200601: "To estimate the abundance with a target coefficient of variation (c.v.) less than or equal to 20–30% for black oreo in OEO 3A on the Chatham Rise."

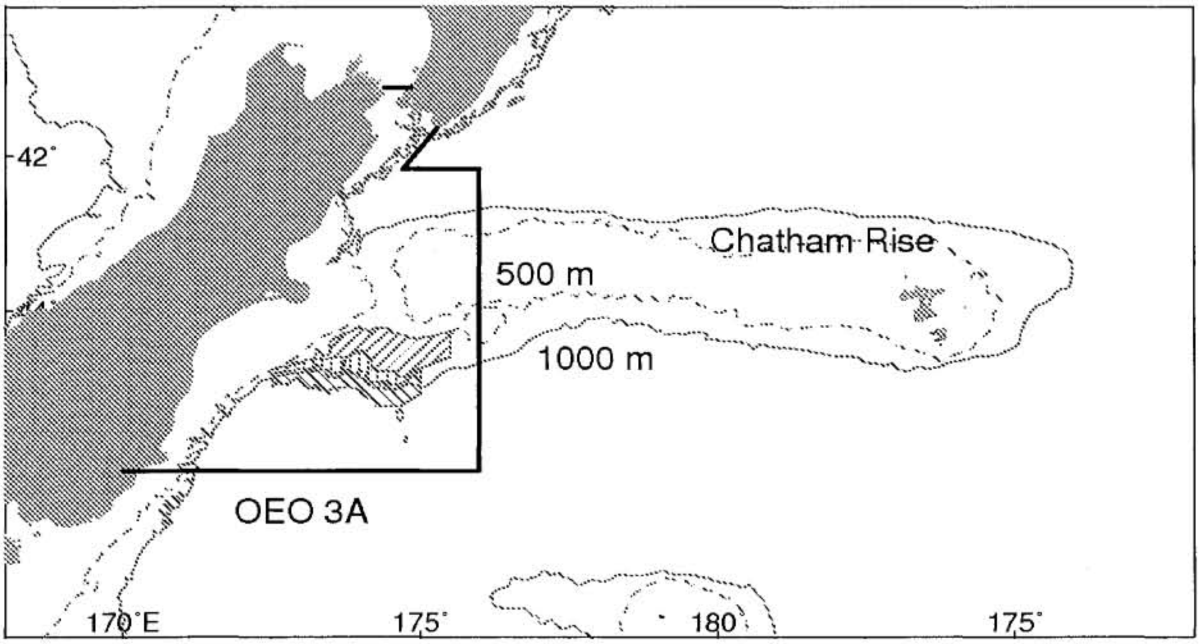

Figure 1: Oreo management area OEO 3A bounded by thick dark lines with the 2006 acoustic survey region shown divided into three areas (shaded) including Area 1 at the top with right sloping shading; Area 2 in the middle with vertical shading; Area 3 at the bottom with left sloping shading.

The 2006 survey took place between 17 and 30 October 2006. The approach to both survey design and analysis was similar to that used in the 2002 survey (Smith et al. 2006). The survey region is 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) include more than 90% of the catch in the South Chatham Rise black oreo fishery.

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 mixes for the Back and, Backdeep mark-types from the 1997 survey trawl results were also included in the analysis. A stratified random approach was used for the survey (Jolly & Hampton 1990). The strata are very similar to the spatial areas (modified following analysis of recent commercial catch data) used in the 2002 stock assessment analysis (Hicks et. al. 2002). NIWA's 70 m research vessel *Tangaroa* was used to carry out all the acoustic work and the trawl sampling. The current survey used the results of the 2002 survey to optimise allocations of transect within 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 its 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 seafloors. 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 sea bottom, then the sea bottom reflection from the central part of the beam swamps the reflections from fish close to the bottom in the outer parts of the beam. There is thus a volume close to the sea bottom, which is not visible to the acoustic gear, called the 'shadow zone'. The shadow zone is reported as the thickness of an an equivalent layer just above the bottom and this thickness depends on the distance of the transducer from the bottom and particularly on the steepness of the nominal bottom. For the transducers used in this survey, on a flat seafloor it 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 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 includes motion correction.

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

The acoustic data were collected with NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs et al. 2003) and the configuration used was the same as that described by Doonan et al. (2001). The backscatter data were collected with a split-beam system towed at 100–300 m. The towbody was calibrated on the south Chatham rise during the survey (Gauthier, pers. Comm.). The calibration broadly followed the approach described by Foote et al. (1987). A 38.1 mm ± 2.5 µm diameter tungsten carbide sphere with nominal target strength of –42.4 dB was used as a calibration standard. The system was operated at 38.156 kHz and transmitted at 4 s intervals. Calibration data are summarised in Table 1.

Data for mark identification were collected for each trawl using single-beam hull-mounted transducers on *Tangaroa*, where a dual-frequency *CREST* system operating at 12 and 38 kHz was used with a 1 ms pulse length and time between transmits of 4 s. The hull-mounted transducer was calibrated at 38 kHz during the preceding southern blue whiting survey (Gauthier, pers. Comm.) and those data are also shown in Table 1.

Table 1: Calibration data for the 38 kHz systems used for the abundance survey. V_T is the in-circuit voltage at the transducer terminals for a target of unit backscattering cross-section at unit range. G is the voltage gain of the receiver at a range of 1 m with the system configured for echo-integration.

System	Towed body 2	*Tangaroa* hull
Transducer serial no.	28327	23421
Nominal 3dB beam-width (°)	7.0x6.9	7.2x7.3
Effective beam angle (sr)	0.0083	0.0091
Effective pulse length (ms)	0.78	0.78
V_T (V)	1 279	292
Transducer depth (m)	100–300	6.5
G	14 491	36 690

2.3 Trawl gear

Tangaroa used the standard orange roughy bottom trawl set up for deepwater fishing (22 m ground rope, cut-away lower wings, 60 mm codend mesh) and also the full wing trawl, nicknamed the ratcatcher (50 m groundrope and 40 mm codend mesh) with 50 m bridles, 50 m sweeps, and 6.1 m^2 Morgere super-vee doors.

2.4 Survey design

The 2006 acoustic survey region is the same as that used in 2002 and is also approximately the same as that used in 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 (see 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 determined by straight line approximations to the southern boundaries of the earlier trawl and acoustic survey regions. No seamounts were included in the 2006 survey because they contributed only 5.4 t of the 18 800 t recruited biomass in the 1997 black oreo abundance estimate (Doonan et al. 1998).

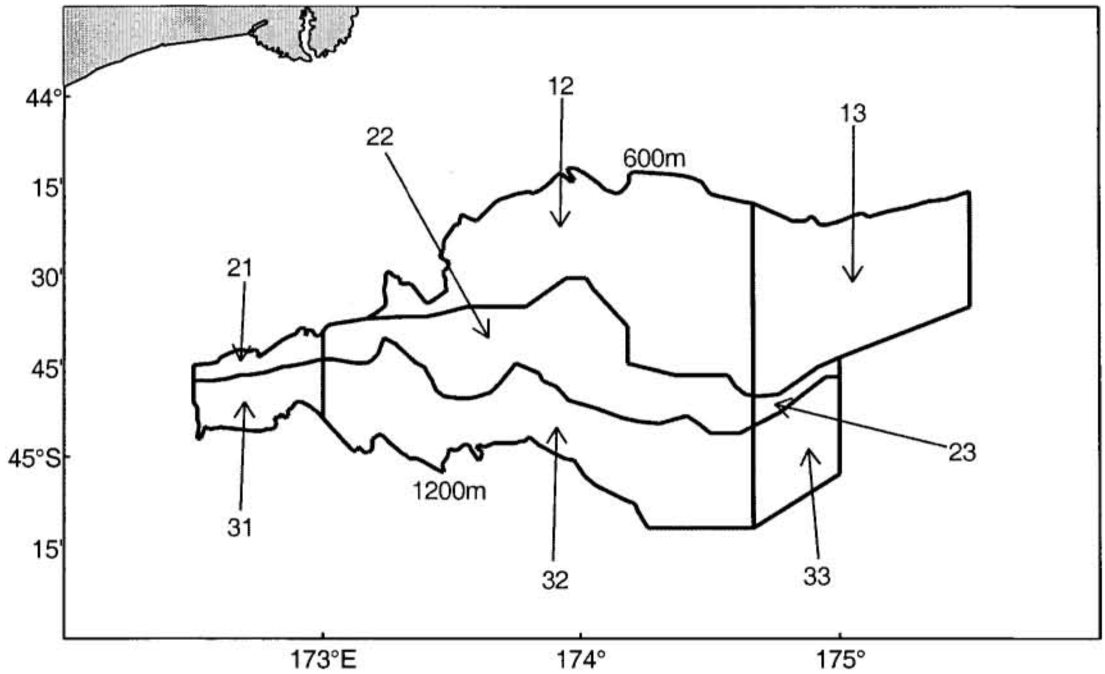

Figure 2: The 2006 acoustic abundance survey region with strata boundaries.

A conventional stratified random approach was used (Jolly & Hampton 1990) and eight strata were chosen to cover the survey region (Figure 2 and Table 2). The strata are the same as those used in 2002, but they differ from those used in the 1997 acoustic survey. Each stratum lies entirely in 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). Thus, 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 MFish 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 2006 survey region is the 600 m contour and this differs slightly from the northern boundary of the 1997 survey because more recent bathymetry is used to define it.

The assignment of transects to strata was made using the criteria of attaining the target c.v. 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 would enable transects to be sailed contiguously across spatial areas 2 and 3 without repositioning the vessel. The 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 2002 survey.

Table 2: 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 various strata were sampled by trawl to obtain species composition and length-frequencies of 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 spatial areas (2 & 3) and that the trawls should concentrate on discrete mark-types rather than layer and background mark-types. For spatial 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. Thus, we treated all the information for the survey region as being effectively at the same instant of time. We also assumed that the species composition for the Back and Backdeep mark types had changed little between the 1997 (within OEO 3A) and the 2006 surveys.

2.5 Estimating absolute 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 and 2006 surveys were specifically a survey of black oreo and because additional trawl data were gathered in 2002. 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), 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). Trawl data from the 2006 survey as well as data from trawls in OEO 3A from the 1997 survey on Back and Backdeep mark-types were used in the abundance calculations. 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.

2.5.1 Abundance scaling factor

One scaling factor was used to multiply the flat acoustic survey area abundance up to the OEO 3A area for the 2004 stock assessment. The scaling factor was calculated as the total black oreo catch from the whole of OEO 3A, excluding the Waitaki fishery, relative to the ratio of the total catch from the survey area for the 10 fishing years from 1992–03 to 2001–02. The multiplying factor was 1.14.

2.5.2 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 scheme is described in Table 3.

Table 3: Classification of echogram marks into black oreo mark-types, the number of occurrences of mark-types observed in transects from the 2006 survey and the numbers of trawl catches in the 1997, 2002, and 2006 surveys on each mark-type. NA, not applicable since all transects include the background.

Mark-type	Description		Number of occurrences		
		Transects	'97 trawls	'02 trawls	'06 trawls
Short	Discrete marks < 500 m long	30	6	5	4
Long	Discrete marks > 500 m long	10	4	3	3
Layeroff	Layers off the bottom	3	3	4	6
Layer	Layers on the bottom	13	6	1	8
Back	Background < 1000 m deep	NA	11	2	0
Backdeep	Background > 1000 m deep	NA	7	0	1

Table 4 shows how catch rates differed between mark-types for the two main species, black oreo (BOE) and smooth oreo (SSO), and the other species combined for trawls targeting each mark-type. Catch rates are in kg per n.mile and the trawl data are from the 1997 and 2002 surveys for the 2002 analysis, and from the 2006 survey augmented by the 1997 data on the Back and Backdeep mark-types. Note the higher catch rates for BOE over SSO for the long, layer, and shallower background mark-types.

The species composition for the Long and Short mark-types are nearly 100% smooth and 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 applies to each survey's data, although details differ between years.

Table 4: Catch rates (kg/n.mile) for BOE, SSO, and all other species combined for trawls targeting each mark type.

Mark-type	Number of species	Number of trawls	Catch rates (kg/n.mile) BOE	SSO	All others Total	Highest species		Next highest	
Catch data used for the 2006 survey									
Short	12	4	581	4021	54	ETB	24	MCA	12
Long	13	3	2648	307	131	ETB	88	MCA	12
Layeroff	24	6	328	2	200	HOK	84	JAV	46
Layer	25	8	1336	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 used for the 2002 survey									
Short	14	11	1890	2919	82	ETB	54	MCA	14
Long	18	7	1786	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

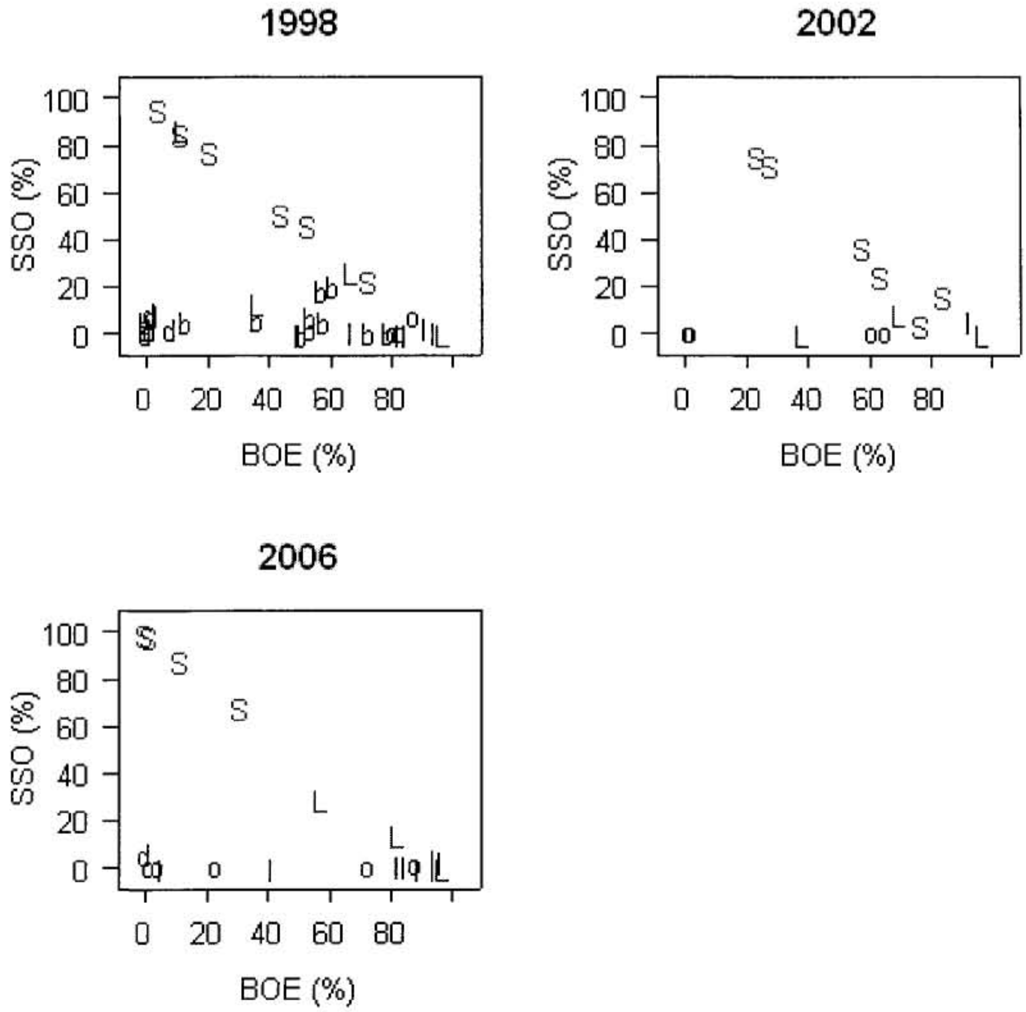

Figure 3: Percent (by weight) of \black oreo (BOE), and smooth oreo (SSO) in trawls for the 1997, 2002, and 2006 surveys. Mark-types are coded: "S" Short, "L" Long, "l" Layer, "o" Layeroff, "b" Back, "d" Backdeep.

2.5.3 Target strength

The target strength relationships used in this assessment were the same as those used by Doonan et al. (2003b), apart from the two oreo species. The latter were derived from a Monte-Carlo analysis of in situ and swimbladder data (Macaulay et al. 2001, Coombs & Barr unpublished results) and the relationships used 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 and where TS is the target strength and L the fish length.

The relationship used for orange roughy is based on measurements of live fish in a tank (McClatchie et al. 1999) combined with in situ results from Barr & Coombs (2001). For other common species we used relationships based on swimbladder modelling (Macaulay et al. 2001). Generic relationships were used for species for which no specific relationships are available as detailed by Doonan et al. (1999). A more conventional formulation of the form $TS = a + b\log_{10}(L)$ was used for all species other than oreos and these are shown in Table 5.

Table 5: 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	-74.34	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

2.5.4 Acoustic length frequency

A length frequency (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 was estimated by combining individual trawl length frequencies weighted by catch size. Biomass by length for each mark-type was then found by applying the mark-type biomass to the weight by length frequency, and then these were summed over all mark-types to give the total biomass by length, i.e., the biomass for length class, l, was

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

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

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

2.6 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 c.v. 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 oreos 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 oreos moving to the background population from schools on the flat
- estimation of target strengths 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 trawls are shown in Tables 6 and 7. Table 6 shows that some extra transects were steamed in strata 22 and 32 since some of the earlier ones were found to be too noisy to be used in any subsequent analysis, i.e., only 72 transects were used in the analysis. Transects surveyed and trawl stations are shown in Figure 4.

Table 6: Strata, stratum areas, transects planned and carried out.

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	21
23	160	4	4
31	610	4	4
32	3 340	18	21
33	830	4	4
Totals	15 110	72	78

The transects were carried out in the order:

4 transects each in strata 12 and 13
18 transects in each of strata 22 and 32
4 transects in each of strata 23 and 33
11 transects in stratum 13
9 transects in stratum 12
4 replacement transects for stratum 32 and 3 for stratum 22.

Table 7: Trawls planned and carried out.

Strata	Trawls	
	Planned	Actual
12–13	6–8	13
21–23	6–8	5
31–33	6–8	4
Total	18-24	21

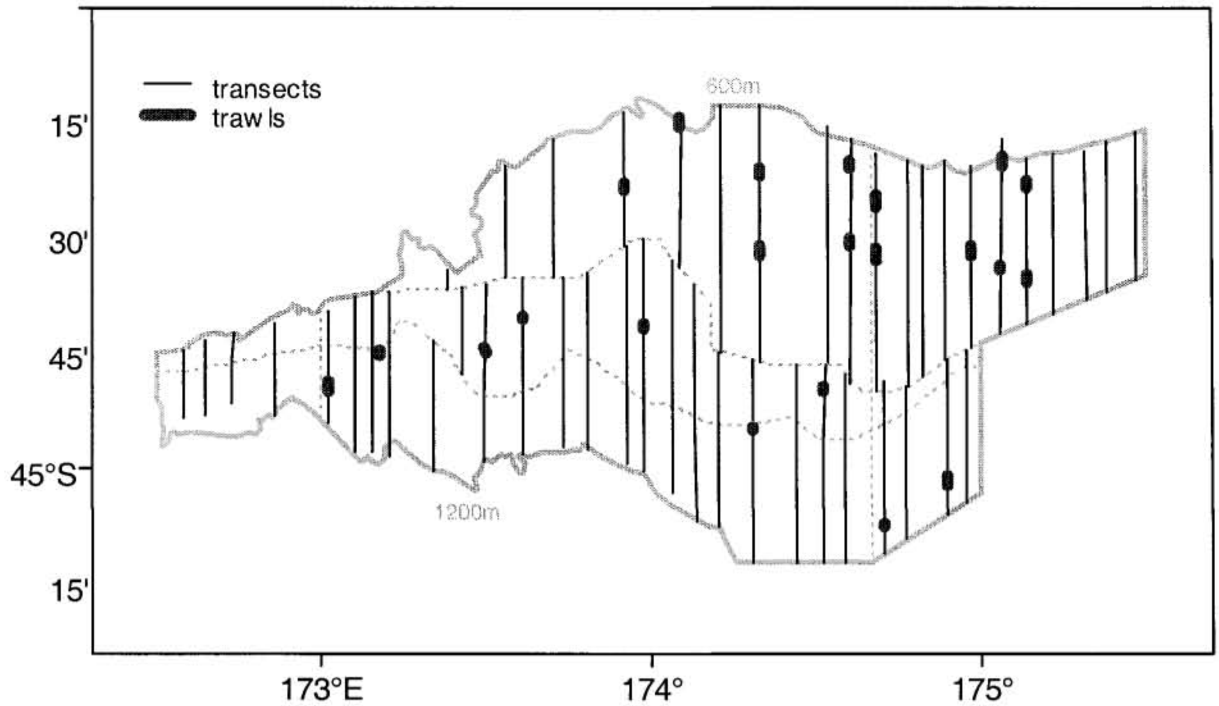

Figure 4: Strata, acoustic transects completed, and trawl stations for the 2006 survey.

3.2 Abundance estimates for area OEO 3A and variances

The abundance from the survey area was scaled up to the overall OEO 3A area giving an estimate of the abundance of black oreo of 78 700 t with a c.v. of 30%. For stock assessment, the overall abundance was also split into three spatial areas. Abundance estimates for the whole of OEO 3A scaled up (by 1.14) from the 2006 survey region are presented in Table 8 along with those for the 1997 and 2002 surveys (Smith et al. 2006).

Table 8: 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, and 2006 acoustic surveys and c.v. estimates (%), in parentheses, for the three spatial (model) areas in OEO 3A.

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)

A breakdown of the percentage of the abundance by stratum is shown in Table 9 from which it can be seen that the largest contribution is in stratum 12, with 39% of the biomass. In spatial areas 1 and 2, where most of the fishery occurs, stratum 22 has 17% of the biomass followed by stratum 32 with 4%.

Table 9: Estimated black oreo abundance in the survey strata expressed as biomass (t) and by percentage of the total biomass for the survey region.

Area	Stratum	Estimated Abundance	%
Area 1	12	31 000	39.1
	13	26 000	32.6
	Total	56 000	71.7
Area 2	21	1 600	2.1
	22	13 000	16.8
	23	1 500	1.9
	Total	16 000	20.8
Area 3	31	330	0.4
	32	3 500	4.4
	33	2 100	2.6
	Total	5 900	7.5
Total		79 000	100

Estimated black oreo biomass by mark type in total and for the spatial areas within the 2006 survey region is given in Table 10. Of the total biomass, 17% was in the background mark types, 69% was in the layer mark-types, and 15% was in the short and long mark-types.

Table 10: Estimated black oreo abundance (t) in the 2002 survey region by mark type and spatial area with percentages of the total.

Mark-type	Spatial area						Total	
	Area 1		Area 2		Area 3			
Back	4 980	(7%)	4 010	(6%)	2 430	(4%)	11 400	(17%)
Backdeep	-		9	(0%)	108	(0%)	117	(0%)
Layer	8 300	(12%)	4 980	(7%)	300	(0%)	13 600	(20%)
Layeroff	33 100	(48%)	736	(1%)	-		33 900	(49%)
Long	2 540	(4%)	4 410	(6%)	1 920	(3%)	8 870	(13%)
Short	550	(1%)	226	(0%)	396	(1%)	1 170	(2%)

Coefficients of variation for the individual components of variation in the estimate of total black oreo biomass in the survey region are given in Table 11.

Table 11: The c.v. 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, trawls were re-sampled within each mark-type.

Source	c.v. (%)
Catches	19
Backscatter	8
Target strength of other species	11
Target strength of black oreo species	15

Length frequency distributions for each spatial area within the survey region and the total for the region are given in Table 12. The length frequency distributions by mark-types are shown in Figure 5.

Table 12: Length frequency distributions (c.v. (%)) of black oreo in the survey region by spatial area. A length class of 24 means the length is greater than or equal to 24 cm and less than 25 cm.

Length	Area 1		Area2		Area3		Survey	
22	0.000	(169)	0.000	(125)	0.000	(151)	0.000	(86)
23	0.001	(137)	0.001	(60)	0.001	(106)	0.001	(42)
24	0.004	(99)	0.004	(47)	0.006	(55)	0.004	(17)
25	0.009	(67)	0.017	(25)	0.015	(43)	0.011	(28)
26	0.026	(56)	0.035	(26)	0.032	(43)	0.028	(21)
27	0.066	(34)	0.072	(17)	0.055	(35)	0.066	(15)
28	0.118	(16)	0.105	(14)	0.076	(22)	0.113	(7)
29	0.151	(9)	0.142	(8)	0.112	(13)	0.147	(4)
30	0.174	(8)	0.152	(6)	0.131	(8)	0.168	(5)
31	0.156	(13)	0.156	(9)	0.153	(13)	0.156	(3)
32	0.116	(20)	0.136	(13)	0.168	(16)	0.123	(7)
33	0.073	(27)	0.088	(14)	0.118	(17)	0.078	(11)
34	0.058	(20)	0.055	(16)	0.075	(14)	0.059	(9)
35	0.031	(29)	0.025	(15)	0.037	(23)	0.031	(11)
36	0.014	(57)	0.009	(22)	0.014	(42)	0.013	(19)
37	0.000	(112)	0.001	(77)	0.004	(75)	0.001	(64)
38	0.003	(73)	0.001	(52)	0.002	(60)	0.003	(31)
39	0.000	(218)	0.000	(174)	0.000	(116)	0.000	(99)
40	0.000	(121)	0.000	(96)	0.001	(71)	0.000	(64)
41	0.000	(0)	0.000	(172)	0.000	(181)	0.000	(126)
42	0.000	(0)	0.000	(172)	0.000	(181)	0.000	(126)

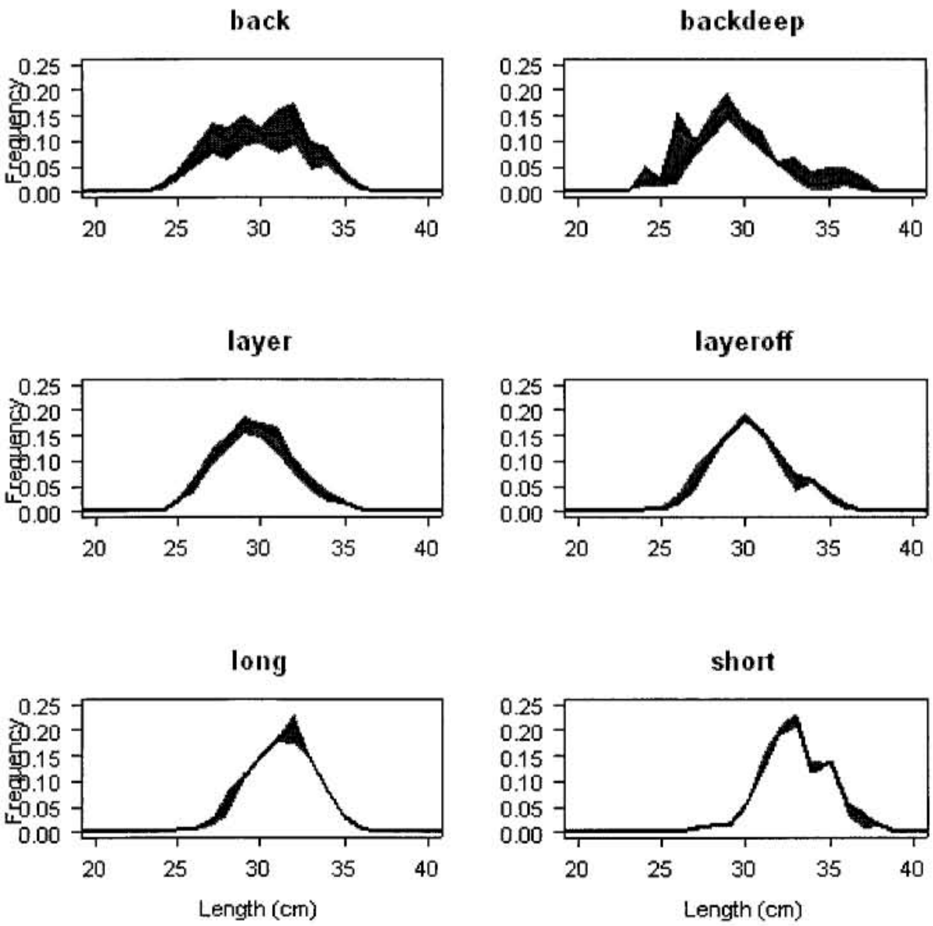

Figure 5: Length frequency distributions of black oreo by mark-type. Shaded areas are the 95% confidence intervals.

3.3 Bias and sensitivity

The sensitivity of the abundance estimates to changes in values of contributing parameters is shown in Table 13. 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 2006 survey produced abundance changes greater than the total c.v. (30%) and therefore have to be considered as possible sources of significant bias.

The most important group of sensitivities was shifts in the intercept of the target strength-length curve for black oreo followed by shifts in the target strengths of other species. The changes ranged in magnitude between 20% and 35%. The 2–3 dB used in the sensitivities was perhaps extreme and intended to capture the maximum possible error in our current target strength estimates.

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 18%, and it will decrease by 20% 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 (+16%). Such a sensitivity analysis gives an indication of how much of the acoustic backscatter was apportioned to the excluded species. The maximum change in abundance was an increase by 75% when smooth oreo was excluded. Using the trawl data used in the 2002 analysis instead of that used here resulted in a small increase of 8%.

Table 13: Bias sources for acoustic survey abundance estimates, black oreo, OEO 3A. † magnitude of change exceeds c.v. for abundance estimate (30%), *TS* target strength.

Source	Abundance change (%)
***TS* estimate, other species**	
Decrease all intercepts by 3 dB	+24
Increase all intercepts by 3 dB	-25
***TS* estimate of black oreo**	
Decrease intercept by 2 dB	+32†
Increase intercept by 2 dB	-27
Catchability of other species	
Double that for black oreo	+18
Half that for black oreo	-20
Exclusion of species from species mix (ordered by effect size)	
Exclude javelinfish	16
Exclude hoki	4
Exclude ridge scaled rattail	4
Exclude smooth oreo	3
Exclude Johnson's cod	3
Exclude notable rattail	1
Alternative trawl data	
Use 2002+1997 catch data	8

4. DISCUSSION

The 2006 survey was the third acoustic survey of OEO 3A and provided the third set of absolute abundance estimates of black oreo only (the 1997 survey also produced smooth oreo abundance estimates). While acoustic abundance estimates are usually taken as absolute estimates, catchability is still an issue in obtaining the species mixes used in the estimates. The 2002 and 2006 surveys have a reduced coverage compared with the 1997 survey and sampled only areas of flat ground where most of the abundance from the previous survey was observed and where, historically, most of the commercial catch has been taken. However, the 2002 and 2006 surveys covered exactly the study area used in the 2004 stock assessment. Overall variability of the abundance estimate, as measured by the c.v., was a little higher than in 1997 and 2002. The contribution of abundance from Area 1 was much higher in the 1997 survey because there were more layer marks observed in 1997 than in either the 2002 or 2006 surveys. Bottom trawls on some of the layer marks in Area 1 produced catches of hoki (*Macruronus novaezelandiae*), javelinfish (*Lepidorhynchus denticulatus*), spineback eel (*Notacanthus sexspinnis*), and other associated species in addition to black oreo. The layer marks appeared to originate from depths shallower than 600 m and declined in density as depth increased. The depth range of black oreo on the bottom is 600–1150 m, so species living shallower than 600 m are more likely to be associated with shallower-living species such as hoki instead of black oreo. Allocating backscatter contributed by numerous swim-bladder fish species including black oreo in these shallow water layers is difficult and may be a potential source of bias for the abundance estimates, particularly in Area 1.

A large decrease in estimated black oreo abundance for Area 1 from 1997 to 2002 and 2006 is shown in Table 8, i.e., the 2002 and 2006 Area 1 estimates are only 29 and 38% of the 1997 estimates. Smith et al. (2006) showed that the different mark identification used for the 2002 survey had little effect on abundance, and that the 2002 catch data resulted in only a 10% decrease in Area 1 abundance. The reason for the substantial difference between the 1997 and later surveys is unknown. Intense layer marks observed in the 1997 survey were not encountered in the later surveys. These marks were interpreted as a mix of black oreo and other species. A re-analysis of the acoustic data from the 1997 survey should be carried out at a future date to re-examine this issue.

The survey analysis differed from that originally used in 1997 (Doonan et al. 1998) in that abundance of all black oreo was estimated rather than that of recruited fish only. This change is necessary because the fishing ogive for the vulnerable biomass is now estimated within the stock assessment model, requiring the total biomass rather than the vulnerable biomass. In the previous stock assessments, the vulnerable biomass was estimated outside the model and used as an input (Annala et al. 2002). The change in emphasis also meant that the survey design was slightly different since the target c.v. now applies to the total biomass and not just to the vulnerable biomass. The change also gives rise to another problem: the relatively high proportions of total black oreo abundance in the background mark-types (17%) and in the layer mark-types (69%). The black oreo that are in these mark-types are mostly pre-recruits. Consequently the acoustic method is less accurate for estimating the abundance of non-vulnerable black oreo since it is less suited to these mark types than to the short and long mark-types. When vulnerable biomass was estimated in 1997 (fish over 32 cm), most of the black oreo abundance (49%) was in the short and long mark-types. Thus, there are extra (unknown) non-sampling uncertainties in the parts of the biomass estimates from background, and to a lesser extent, layer mark-types.

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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:

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