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EXECUTIVE SUMMARY

Smith, M.H.; Doonan, I.J.; McMillan, P.J.; Hart, A.C. (2006). Black oreo abundance estimates from the September-October 2002 acoustic survey of the south Chatham Rise (OEO 3A).

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An acoustic survey to measure the absolute abundance of the black oreo (*Allocyttus niger*) population in area OEO 3A was carried out between 25 September and 7 October 2002 using *Tangaroa* (voyage TAN0213). The survey covered the south slope of the west end of the Chatham Rise and was the second major acoustic survey of the area. Because only 0.013% of the recruited black oreo biomass was observed on seamounts in the 1997 survey, this survey covered only the main flat area. However, the survey region is the study area used in the 2004 black oreo OEO 3A stock assessment.

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 77 transects and 21 trawls over 8 flat area strata (15 000 km^2 in total area). For estimating species proportions in the various mark types, trawls from the 1997 survey were also included.

The total estimated abundance (immature plus mature) of black oreo for OEO 3A was 64 000 t with a c.v. of 26%, which is well below the specified target c.v. of the project (35–40%). 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 43 300 t with a c.v. of 31% for Area 1, 15 400 t with a c.v. of 27% for Area 2, and 4710 t with a c.v. of 38% for Area 3.

The main sources of variability in the abundance estimates were the target strength of black oreo (15% c.v.) and the variability in the species proportions in the trawl catches (14% c.v.). A potential source of bias was that 24% of the black oreo abundance came from the background mark-types, where the acoustic method performs poorly, whereas 21% 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 2991 t from 1993–94 to 2002–03 (Annala et al. 2004). There is also a substantial smooth oreo fishery in the area with estimated mean annual catches of 3011 t from 1993–94 to 2002–03 (Annala et al. 2004). 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 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. The latter is the subject of this report, and was carried out to meet the objective of the Ministry of Fisheries project OEO200201: *to estimate, with a target coefficient of variation of 35-40%, the abundance of black oreo in OEO 3A on the Chatham Rise.*

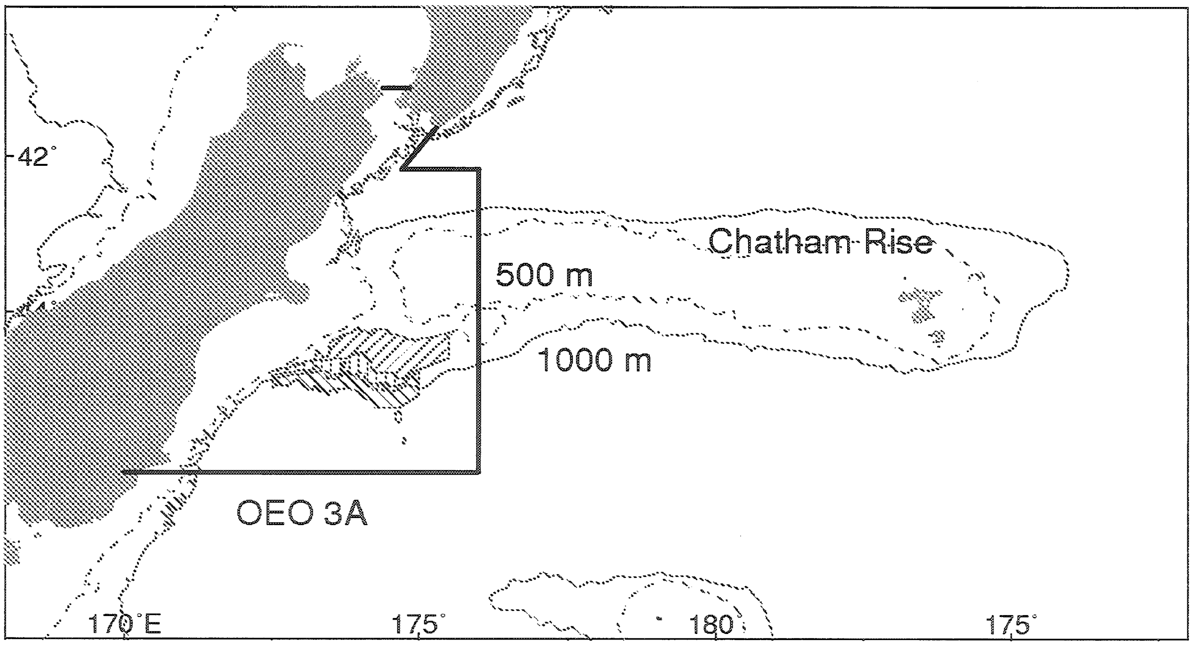

Figure 1: Oreo management area OEO 3A bounded by thick dark lines with the 2002 acoustic survey region shown divided into three areas (shaded) including Area 1 at the top with right sloping shading; Area 2 in the middle with vertical shading; Area 3 at the bottom with left sloping shading.

The 2002 survey took place between 25 September and 7 October 2002. The approach to both survey design and analysis was similar to that for the flat area part of the 1997 survey (Doonan et al. 1998).

The survey region is the study area used in the 2004 black oreo stock assessment (Doonan et al. 2004). Areas 2 & 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 from the 1997 survey trawl results were also included in the analysis. A stratified random approach was used for the survey (Jolly & Hampton 1990) and the strata are those used in the 2004 black oreo stock assessment (Doonan et al. 2004). The strata are very similar to the spatial areas (modified in the light 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 of the acoustic work and the trawl sampling. Advice and information from skippers engaged in the fishery at the time (Stephen Potter (*Galatea*), Darryle Saunders (*Amaltal Voyager*), and Robert Hart/Guy Duggan (*Ocean Ranger*)) was provided through the Orange Roughy Management Company Limited and was used to check and modify the survey area and approach.

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 seamounts 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 size of the shadow zone 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 (unpublished results). 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 1994) and the configuration used was the same as that described by Doonan et al. (2001). The backscatter data were collected with one split-beam system towed at 52–193 m with a mean depth of 91 m. The towbody was calibrated in the deep tank at Greta Point before the voyage. 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 3 or 4 s intervals. Calibration data are summarised in Table 1.

Data for mark identification were collected for each trawl using 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. Decimation rates and filter specifications were the same as for the towed system. Calibration data for the 38 kHz channels 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 3	*Tangaroa* hull
Transducer serial no.	28332B	23421
Nominal 3dB beam-width (°)	7.3x7.4	7.2x7.3
Effective beam angle (sr)	0.0093	0.0091
Effective pulse length (ms)	0.78	0.78
V_T (V)	1 013	331
Transducer depth (m)	50–200	6.5
G	12 866	38 459

Some difficulties were experienced with the towed system during the survey. Only one long (about 1500 m) tow-cable and one short tow-cable (about 300 m) were available. The long tow-cable was preferred but the short cable was used when a re-termination of the long cable was required. The data recorded using the short cable were found to be very noisy – presumably because the towbody was relatively close behind the ship and was affected by the surface bubble layer – and the data were almost unusable. In addition, the towbody was subsequently found to have been operating at reduced output power throughout the entire survey. The output power problem was identified after the survey and compensatory corrections were applied from a calibration done in the tank located at NIWA, Greta Point.

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, 100 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 2002 acoustic survey region is a subset of the earlier trawl survey area (McMillan & Hart 1994a, 1994b, 1994c, 1995, 1998), approximates the 1997 acoustic survey region flat strata and covers 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 1200m 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 2002 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).

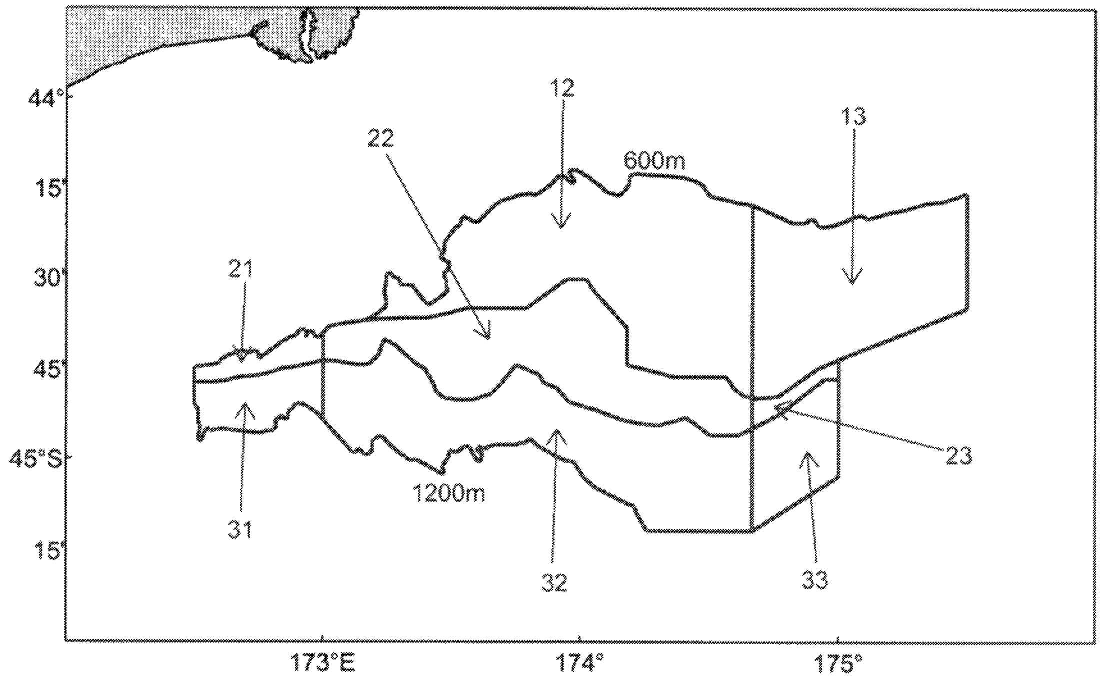

Figure 2: The 2002 acoustic abundance survey region with strata boundaries.

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 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 earlier 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 32.5cm) separates strata 21, 22, and 23 from strata 31, 32, and 33. The northern boundary of the 2002 survey region is the 600 m contour and this differs in a small way from the northern boundary of the 1997 survey because more recent bathymetry is used to define it.

Budget constraints limited the time that the vessel could spend in the survey region. 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. Three sources of variation were considered when allocating the numbers of acoustic transects and trawls in each stratum:

- sampling error in the acoustic data
- sampling error in the proportions of black oreo species in the species mix
- experimental error in the determination of the target strengths of oreos species and other species; estimates of these were taken from the 1997 acoustic 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 six to eight trawls in each of the three spatial areas and that the trawls should concentrate on discrete mark-types rather than layer mark-types. However 2-3 trawls of the trawls in spatial area 1 were to be made on layer mark-types using the ratcatcher gear to gain more data on the species composition of these mark-types. Additional transects through strata 22 and 32 were drawn at random before departure, to be used to search for further marks to trawl, in the event that the required number of trawls for the survey was not met.

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 assume that the species composition for the same mark types has changed little between the 1997 survey (within OEO 3A) and the 2002 survey.

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 puposes.

Abundance was estimated by classifying the acoustic data into mark-types where marks equate approximately to images on echograms. The mark classification scheme was an updated version of that used for the 1997 survey (Doonan et al. 1998) because the 2002 survey was specifically a survey of black oreo and because additional trawl data were gathered. 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 2002 survey as well as data from trawls in OEO 3A from the 1997 survey was 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 2002 survey and the numbers of trawl catches in the 1997 and 2002 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
Short	Discrete marks < 500 m long	30	6	5
Long	Discrete marks > 500 m long	10	4	3
Layeroff	Layers off the bottom	3	3	4
Layer	Layers on the bottom	13	6	1
Back	Background < 1000 m deep	NA	11	2
Backdeep	Background > 1000 m deep	NA	7	0

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 trawl and the trawl data are from the 1997 and 2002 surveys. Note the higher catch rates for BOE over SSO for the long, layer, and shallower background mark-types.

Table 4: Catch rates (kg/trawl) 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/trawl) BOE	SSO	All others
Short	14	11	1 328	1 443	39
Long	18	7	985	258	76
Layeroff	21	7	367	14	133
Layer	19	7	708	15	80
Back	21	13	105	7	72
Backdeep	12	7	2	4	93

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:

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

and

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

for smooth and black oreos 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) corrected for depth (McClatchie & Ye 2000) and 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 (*Caelorinchus 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 Estimating biomass by length class

Biomass was estimated by 1 cm length classes 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, and then converted into a weight by length frequency using the length weight relationship $w = al^b$, where l is the length and a and b are constants. Biomass by length for each mark-type was than 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

$$b_l = \sum_j B_j f_{w,j,l},$$

where B_j is the biomass of the j^{th} mark-type and $f_{w,j,l}$ is the weight by length frequency for mark-type j and length class l which is given by

$$\frac{w_{j,l}}{\sum_k w_{j,k}}, \text{ where } w_{j,l} \text{ is given by } f_l \, al^b.$$

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
- a change in the distribution of oreos on flat ground between the acoustic survey area and the rest of the area between the time the distribution was measured in the trawl surveys (1992, 1993, 1995 and 1998)
- 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 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 carried out are shown in Tables 6 and 7. To obtain the required trawl data, eight transects, additional to the original plan, were made in each of strata 22 and 32 and one additional positioning transect was made in stratum 12. Acoustic data collected from the additional transects were used in the abundance estimates.

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

Stratum	Area (km^2)	Number of transects	
		Planned	Actual
12	4 290	11	12
13	2 880	5	5
21	300	4	4
22	2 700	14	22
23	160	4	4
31	610	4	4
32	3 340	14	22
33	830	4	4
Totals	15 110	60	77

The transects were carried out in the order:

3 transects in stratum 13
5 transects in each of strata 23 and 33
14 transects in each of strata 22 and 23
4 transects in each of strata 21 and 31
8 additional transects in each of strata 22 and 23
2 transects in stratum 13
12 transects (including 1 additional) in stratum 12.

Table 7: Trawls planned and carried out.

Strata	Trawls	
	Planned	Actual
12–13	6–8	4
21–23	6–8	11
31–33	6–8	6
Total	18-24	21

Transects surveyed and trawl stations are shown in Figure 3.

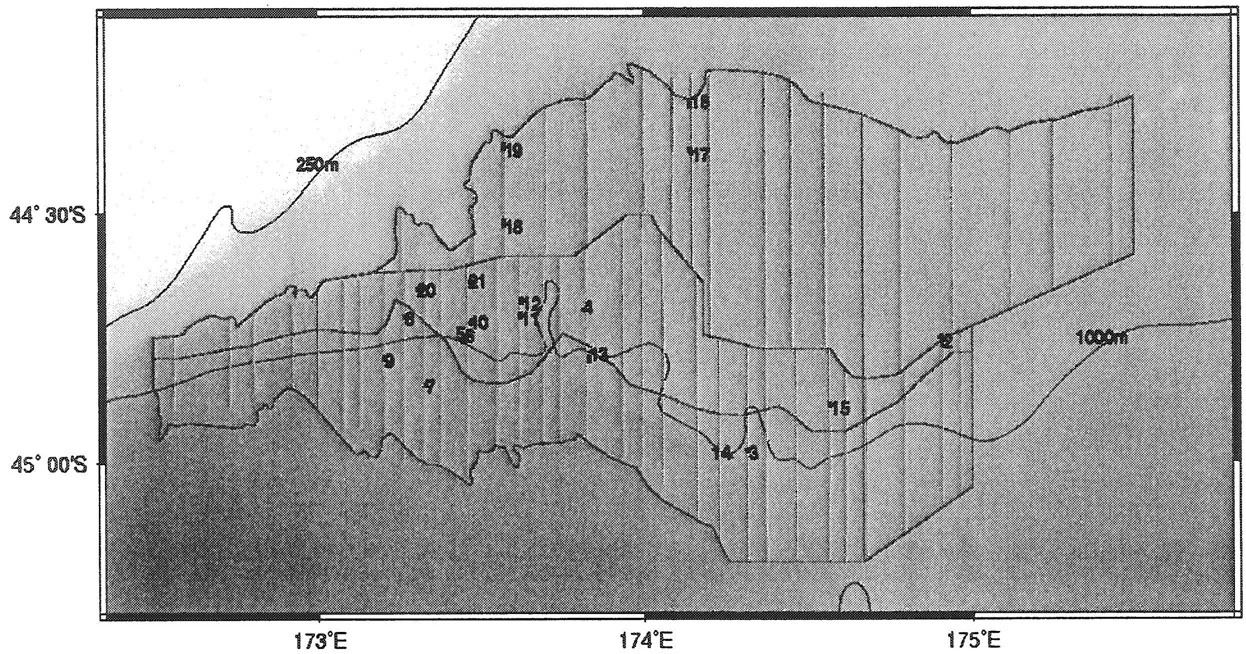

Figure 3: Strata, acoustic transects completed, and numbered trawl stations for the 2002 survey.

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 oreos of 63 400 t with a c.v. of 26%. For stock assessment purposes, 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 2002 survey region are presented in Table 8 along with the re-estimated values for the 1997 survey, using the latest target strength estimates.

The 1997 abundances for the spatial areas and the total 2002 survey region were calculated from the 1997 survey echograms and just the 1997 trawl catch data within the 1997 mark-types, and using the same target strengths and water absorption relationships as in the 2002 result. Strata were split along spatial area boundaries where the original 1997 strata straddled such a boundary and the echograms in these original strata were divided between the new strata. Thus, in the new stratification, each spatial area was covered by a mutually exclusive set of strata. Shadow zone corrections were conducted as in 1997, which is different to that applied to the 2002 result, but the significant differences apply only to the hill corrections where the slope is greater than 6 degrees and does not affect between year comparisons. No motion corrections were applied to the 1997 result since that survey was carried out before such data were collected.

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) and 2002 acoustic surveys and c.v. estimates (%), in parentheses, for the three 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)

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 13, with 46% of the biomass. In spatial areas 1 and 2, where most of the fishery occurs, stratum 22 has 20% of the biomass followed by stratum 32 with 6%.

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	12 500	22.5
	13	25 400	45.7
	Total	38 000	68.2
Area 2	21	896	1.6
	22	11 400	20.5
	23	1 260	2.3
	Total	13 500	24.3
Area 3	31	30	0.1
	32	3 340	6.0
	33	760	1.4
	Total	4 130	7.4
Total		55 600	100.0

Estimated black oreo biomass by mark type in total and for the spatial areas within the 2002 survey region is given in Table 10. Of the total biomass, 24% was in the background mark types, 55% was in the layer mark-types, and 21% 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	9 282 (17%)	3 612 (6%)	528 (1%)	13 422 (24%)
backdeep		12 (0%)	48 (0%)	60 (0%)
layer	10 011 (18%)	1 760 (3%)		11 771 (21%)
layeroff	17 031 (31%)	1 255 (2%)	540 (1%)	18 826 (34%)
long	502 (1%)	3 655 (7%)	344 (1%)	4 501 (8%)
short	1 141 (2%)	3 246 (6%)	2 673 (5%)	7 060 (13%)

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 2.6.1), e.g., in the catches source, trawls were re-sampled within each mark-type.

Source	c.v. (%)
Catches	8
Backscatter	14
Target strength of other species	9
Target strength of black oreo species	15

Biomasses by length class for each spatial area within the survey region and the total for the region are given in Table 12.

Table 12: Estimated biomass (t) of black oreo by length class 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 (cm)	Area 1	Area 2	Area 3	Total
22	70	21	4	95
23	165	45	8	218
24	412	152	23	587
25	1 445	465	76	1 986
26	2 306	752	119	3 177
27	2 663	856	142	3 661
28	3 917	1 231	202	5 351
29	4 841	1 606	279	6 726
30	5 167	1 901	338	7 405
31	4 118	1 741	437	6 295
32	4 112	1 720	581	6 413
33	3 065	1 445	586	5 096
34	1 616	892	518	3 026
35	1 208	615	344	2 166
36	423	456	326	1 206
37	286	203	140	629
38	131	115	77	323
39	117	64	41	221
40	20	57	47	125
41	37	29	23	88
42	2	6	5	12

3.3 Bias and sensitivity

The sensitivity of the abundance estimate 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 2002 survey produced abundance changes greater than the total c.v. (26%) and therefore have to be considered as possible sources of bias.

The largest sensitivities in the abundance estimate were due to the effects of excluding various species, one at a time, from the species mix. 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. Exclusion of any one of the seven species: smallscaled brown slickhead, spineback, small-headed cod, bigscaled slickhead, ribaldo, rudderfish, or ridge scaled rattail from the mix resulted in increases in the abundance estimate that ranged between 34% and 44%, while the exclusion of either hoki or Johnson's cod resulted in increases of about 10%. For every other species considered in the species mix the change in the abundance estimate from excluding the species was 4% or less.

The next most important group of sensitivities was shifts in the intercept of the target strength-length curve for black oreos followed by shifts in the target strengths of other species. The changes ranged in magnitude between 20% and 35%. The 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 17%, and it will decrease by 19% if the catchability of black oreo is double that of the mean of the species mix.

Table 13: Bias sources for acoustic survey abundance estimates, black oreo, OEO 3A. † magnitude of change exceeds c.v. for abundance estimate (26%), *TS* target strength.

Source	Abundance change (%)
***TS* estimate, other species**	
Decrease all intercepts by 3 dB	+20
Increase all intercepts by 3 dB	-23
***TS* estimate of black oreo**	
Decrease intercept by 3 dB	+35†
Increase intercept by 3 dB	-28†
Catchability of other species	
Double that for black oreo	+17
Half that for black oreo	-19
Exclusion of species from species mix (ordered by effect size)	
Exclude smooth oreo	+75†
Exclude smallscaled brown slickhead	+46†
Exclude spineback or small-headed cod	+39†
Exclude bigscaled slickhead	+38†
Exclude ribaldo or rudderfish	+36†
Exclude ridge scaled rattail	+34†
Exclude javelinfish or ling	+17
Exclude hoki	+11
Exclude Johnson's cod	+10

4. DISCUSSION

The 2002 survey was the second acoustic survey of OEO 3A and provided the second 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 survey had 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 survey covered exactly the study area used in the 2004 stock assessment. Overall variability of the abundance estimate, as measured by the c.v., was the same as in 1997. The contribution of abundance from area 1 was much lower in the 2002 survey than the 1997 survey because there were fewer layer marks observed in 2002. Bottom trawls on some of the layers 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 is shown in Table 8 and it is possible that some of the difference was due to the different mark identification scheme used in 2002 or due to the different species mix that results from the extra catch data from the 2002 trawls. To check for these effects, two further sets of abundance estimates in OEO 3A for the 2002 survey were made. Both used the 1997 mark identification scheme and one used only the 1997 trawl catch data. The results are given in Table 14.

Table 14: Comparison of black oreo abundance estimates for OEO 3A. The table includes the 1997 estimate using the 1997 mark identification scheme and the 1997 trawl catch data only, the 2002 estimate for the fishery, the 2002 estimate using the 2002 mark identification scheme and the 1997 trawl catch data only and the 2002 estimate using the 1997 mark identification scheme and the 1997 trawl data only.

Survey	Using	Area 1	Area 2	Area 3	Total
1997	'97 mark ID, '97 trawl data	148 000	10 000	5 240	163 000
2002	'02 mark ID, '97 + '02 trawl data	43 300	15 400	4 710	63 400
2002	'02 mark ID,'97 trawl data	47 900	14 900	4 500	67 300
2002	'97 mark ID,'97 trawl data	47 500	14 700	4 240	66 400

It thus appears that the new mark identification scheme has little effect on the estimates compared with the older scheme, but the extra catch data obtained in the 2002 survey does result in a 10% decrease in the abundance in Area 1 and increases of between 5% and 10% in the abundance for Areas 2 and 3. The layer mark-types in the 2002 survey were less dense and occurred much less frequently compared with the 1997 survey and this is the most likely explanation for the substantial change in abundance estimates for a Area 1 between the 2 surveys. The 2002 survey was carried out a month earlier in the year than the 1997 survey and this may explain some of the difference in the frequency of occurrence of the layer mark-types.

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 (24%) and in the layer mark-types (55%). 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.

This survey used a new oreo target strength relationship fitted explicitly to the data (Macaulay et al. 2001, Barr & Coombs unpublished results) rather than the usual log-linear relationship (Doonan et al. 2000). In this, the target strength of large fish is a little lower than in the previous relationship, but much the same for small and medium sized fish. The effect is to increase the abundance relative to the old relationship by a few percent overall depending on the size distribution.

The larger sources of uncertainty in the estimates resulted from uncertainty in target strength of oreos and in the backscatter (see Table 11). For the former, the c.v. was 15% and for the latter it was 14%. The success of reducing abundance estimate variability achieved by redesigning the survey in 2002 means that sources of variability not related to survey design are now relatively more important to improving accuracy. These variability sources, and also potential bias sources (see Table 13), should be the focus for improvements to possible future surveys.

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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:

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

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:

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