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NIWA
PO Box 14 901
Wellington

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EXECUTIVE SUMMARY

Doonan, I.J., Hart, A.C., McMillan, P.J. & Coombs, R.F. 2000: Oreo abundance estimates from the October 1998 survey of the south Chatham Rise (OEO 4).
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A successful acoustic survey of area OEO 4 was carried out between 26 September and 30 October 1998 on *Tangaroa* (voyage TAN9812). Transects on flat ground were surveyed with a stratified random design and a random sample of seamounts was surveyed with either random (on large seamounts) or systematic "star" transects.

Acoustic data were collected concurrently on towed and hull-mounted transducers. The OEO 4 survey covered 59 transects on the flat and 29 on seamounts. A total of 95 trawls was carried out for target identification and to estimate target strength and species composition.

In situ and swimbladder data were collected for target strength estimation and these have yielded revised estimates of target strength for both black oreo and smooth oreo.

For OEO 4, the total estimated abundance of recruit smooth oreo from both flat and seamounts was 61 700 t with a *c.v.* of 32%. Abundance was also estimated separately for the areas west and east of a north-south line at 178° 20′ W. These were 10 600 t (52% *c.v.*) for the west and 53 300t (33% *c.v.*) for the east.

For large black oreo (33 cm total length and over) in OEO 4, the estimated abundance was 13 900 t with a *c.v.* of 55%. Black oreo abundance was also estimated separately for the western area at 6500 t (63% *c.v.*) and 2500 t (55% *c.v.*) for the east. The black oreo results are uncertain, because in addition to the estimated variance, a large scaling factor (4.3) was required to convert the flat survey abundance estimate to the much larger trawl survey area, and 59% of the total biomass was in the background mark-type.

1. INTRODUCTION

The south and east Chatham Rise (OEO 3A and OEO 4) is the main oreo fishing area in the New Zealand EEZ, with reported landings of 13 341 t in 1997–98 compared to the EEZ wide catch of 21 239 t (Annala *et al.* 1999). There is also a substantial orange roughy fishery in the area with reported 1997–98 landings of 1700 t. Oreos from seamounts have made up an increasing proportion of the total oreo catch in recent years.

For OEO 4, trawl survey data provided estimates of oreo relative abundance. Trawl surveys began in 1986 and continued until 1995 (McMillan *et al.* 1988, McMillan & Hart 1994a, 1994b, 1994c, 1995, Hart & McMillan 1998). However, both oreo species are schooling fish with the attendant difficulties that this creates in estimating abundance using fishing, particularly the high variances (e.g., table 6, p. 213 *in* Annala & Sullivan 1996). The trawl surveys yielded relative abundance estimates, and although these can be used with stock reduction to estimate absolute abundance, there are difficulties. In particular there is the requirement that there be a substantial decrease in biomass from fishing. For stock assessment, the main problem with trawl surveys in OEO 4 was the uncertainty of the relative abundance estimates associated with uncertain trawl catchability. Biomass estimates for stock assessment were derived using plausible, but wide, lower and upper bounds on catchability. Thus, alternative ways to estimate absolute abundance were assessed by the Deepwater Fishery Assessment Working Group which considered that acoustic techniques offered the possibility of fishery independent, absolute abundance estimates covering both areas of level and undulating seabed ('flat') and seamounts. A first evaluation of the approach was made using the hull-mounted Simrad EK500 echosounder on *Tangaroa* in October-November 1995 (voyage TAN9511). A trial survey on the flat, intended primarily for target strength, target identification, and acoustic equipment development was carried out in April 1997 (voyage TAN9705). The first full survey was carried out on the west end of the south Chatham Rise (OEO 3A) between 10 November and 19 December 1997 on *Tangaroa* (voyage TAN9713). We report the results of the second full survey, which used *Tangaroa* on the eastern end of the south Chatham Rise (OEO 4) from 26 September to 30 October 1998.

2. METHODS

A stratified random design was used for the acoustic part of the survey together with the standard fisheries acoustics method of echo-integration. The underlying principle of acoustic abundance estimation using the echo-integration method is to transmit a known amount of sound energy into the water and measure what is reflected back (backscattered) from the fish species to be assessed. This means that it is necessary to be able to distinguish smooth oreo and black oreo from other species or to apportion the smooth oreo and black oreo components of a complex reflection (target identification). Data on species composition were collected by targeted trawling on marks seen on the acoustic transects. To convert the reflected energy into numbers of fish, it is necessary to know the amount of energy reflected by the average smooth oreo (its target strength).

The following sections deal with:

- survey area
- estimating absolute abundance
- estimating absolute abundance for area OEO 4
- survey design
- target identification
- shadow zone correction
- tow body motion

- target strength
- correction for the absorption of sound in water
- estimating variance and bias
- acoustic system

2.1 Survey area

The survey area was defined based on the distribution of commercial oreo catch, relative abundance of black oreo and smooth oreo from past research trawl surveys, and information supplied by fishers (Figure 1).

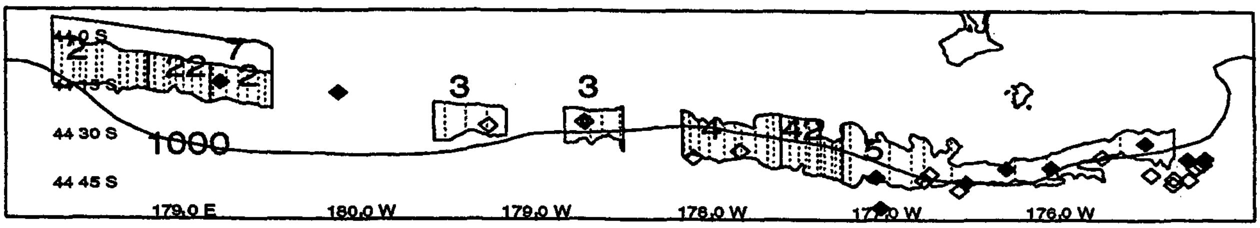

Figure 1: OEO 4 survey area showing smooth oreo (2–5, 22, & 42) and black oreo (7) flat strata (solid lines) and transects (dashed lines), seamounts selected for sampling (♦), and seamounts listed but not selected for sampling(◇).

2.2 Estimating absolute abundance

Smooth oreo

The following description deals with estimating smooth oreo abundance. The same procedure is applicable to estimating black oreo abundance.

Flat

For the flat ground, the acoustic data were classified into types of 'marks'. For stratum, *i*, the abundance of smooth oreo in mark-type *m*, is given by:

$$B_{i,m} = \frac{\text{abscf}_{i,m}}{\overline{\overline{\sigma}}_{bs,m}} \times p_{sso,m} \times \text{area}_i \times \overline{w_m}$$

where area_i is the area of the seamount or stratum, $\text{abscf}_{i,m}$ is the mean backscattering (fish.m^{-2}), $\overline{\overline{\sigma}}_{bs,m}$ is the mean tilt-averaged acoustic cross-section for the species mix, $p_{sso,m}$ is the proportion of smooth oreo, and $\overline{w_m}$ is the mean weight of a smooth oreo. 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 $\sum_l f_{sso,m,l} 10^{\frac{\langle TS \rangle_{sso}(l)}{10}}$ for smooth oreo and by $\sum_l f_{j,m,l} 10^{\frac{\langle TS \rangle_j(Ljm)}{10}}$ for other species, where $f_{sso,m,l}$ is the fraction of smooth oreo in mark-type m with length l and $f_{j,m,l}$ is a similar fraction for the j^{th} species, $\langle TS \rangle_j(l)$ 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, $\langle TS \rangle_j(l) = a_j + b_j \times \log_{10} l$ 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, $\langle TS \rangle$, is given by $10 \log_{10} \overline{\sigma}_{bs}$.

The lengths, mean weights, species composition, and proportion of smooth oreo in the population were obtained by trawling during the survey.

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

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

$B_{i,m}$ refers to recruits so two estimates of $p_{sso,m}$ must be made, one for recruits and another for pre-recruits.

Seamounts

The total abundance for all seamounts (*Hills*), B_{Hills}, is given by:

$$\sum_{h}^{Hill-classes} N_h \overline{B}_h ,$$

where $\overline{B}_h$ is the mean abundance of a seamount in the h-th seamount class, and N_h is the number of seamounts in the seamount class. Each seamount's abundance is given by $B_{i,h}$ above, where i indexes the seamount and there was only one mark class used (plumes). A 'star' transect pattern was used on most seamounts. In this case the mean backscatter, $abscf_{i,h}$ in $B_{i,h}$ was over-sampled in the centre of the star and under-sampled at the edges. As most marks are usually entered in the middle of the star with relatively large sections of the transect outside the mark, the mean is biased high in relation to the area (taken from the two ends of the transects). To compensate for this effect, the mean backscatter for each transect was a weighted mean over all segments (10 pings in length) of the transect where the weights are proportional to the distance from the fifth ping in the segment to the centre of the star.

2.3 Estimating absolute abundance for area OEO 4

Estimates from the acoustic flat survey area were scaled up to the trawl survey area and then to the OEO 4 area. Abundance was estimated by:

$$B_{Total} = f_{T2All}\left(f_{A2T}B_{Flat} + B_{Hills}\right),$$

where B_{Flat} is the estimated abundance for the flat ground in the acoustic survey, B_{Hills} is the estimated abundance for all seamounts in the trawl survey area, f_{A2T} converts the flat abundance from the acoustic survey area to the trawl survey area, and f_{T2All} converts the abundance from the trawl survey area up to the OEO 4 area.

The scaling factor f_{A2T} was calculated using data from three trawl surveys (TAN9210, TAN9309, and TAN9511) to estimate the fraction of recruit smooth oreo or black oreo in the acoustic survey area compared to the trawl survey area. A mean smooth oreo density was estimated for each trawl stratum and was applied to the sub-areas in the stratum resulting from splitting off the part, where applicable, in the acoustic survey area.

To adjust the abundance (seamount plus flat ground) up to the total OEO 4 area from the trawl survey area, f_{T2All}, the ratio of catches in the total OEO 4 area to that in the trawl survey area was used. Data from the fishing years 1986–87 to 1998–99 were analysed with 1986–87 chosen as the start because the Quota Management System was introduced in that year (Working Group decision first recorded by Annala & Sullivan (1997)). For recruit smooth oreo, this ratio was 1.07 (74 400/ 68 700). For recruit black oreo it was 1.06 (10 900/10 300).

2.4 Survey design

Flat

The basic approach taken was the same as that of Jolly & Hampton (1990). The strata created were restricted to the main areas of abundance for smooth oreo and black oreo. In each stratum, a number of randomly positioned acoustic transects was defined in the north-south direction. We assumed that all the recruit fish were in schools and randomly chosen schools in each stratum were sampled by trawl to obtain the length frequencies and proportions of smooth oreo, black oreo, and other species. Trawling also provided information for species identification.

In allocating trawl tows and acoustic transects to strata, three sources of variation were considered:

- sampling error in the acoustic data
- sampling error in the proportions of both oreo species in the species mix
- experimental error in the determination of the target strength of both oreos

Acoustic transects ran north-south across the whole stratum for the flat strata 2, 22, 3, 4, 42, and 5 (*see* Figure 1).

Trawling was targeted on marks seen on transects. For transects on the flat, marks were picked to cover the depth range, the crude mark shapes (short, plumes, layers, background, etc), and the geographic range. All trawls used the standard orange roughy bottom trawl set up for deepwater fishing (22.2 m ground rope, cut-away lower wings, 100 mm mesh in the codend).

We assumed that there had been no movements in and out of the acoustic survey area during the time of sampling. Thus, we treated all the information for the area and time of sampling as being synoptic or instantaneous. We also assumed that the distribution of oreos in and out of the acoustic survey area was relatively constant since 1992 and that it was measured by the trawl surveys carried out in OEO 4 in 1992, 1993, and 1995.

Seamounts

Each seamount was taken to be a stratum. The approach to surveying seamounts was to use randomly allocated parallel transects or systematically allocated transects in a 'star' pattern. A list of seamounts was established at a meeting between the Ministry of Fisheries, NIWA, and the Orange Roughy Management Company held on 23 September 1997 and we surveyed 11 of these. It was desirable to select seamounts from homogeneous subsets, i.e., with similar catch histories and of similar sizes. The seamounts were ranked using the following criteria.

1. Catch history, i.e., seamounts which produced large catches of smooth oreo and black oreo in the last 18 years were ranked high priority. Ranking was based on analyses of MFish smooth oreo and black oreo catch and effort data carried out by Ralph Coburn and Ian Doonan (both NIWA, Wellington).
2. Relative size and potential as oreo habitat.

The selections were as follows:

(a) Important individual seamounts (catches greater than 2500 t per year). Three of these (marked*) were selected at random for the survey but Mt. Kiso was not surveyed because of time constraints.

Trev's Pinni	44° 27.0′ S	179° 16.3′ W
Mt Kiso*	44° 25.9′ S	178° 43.2′ W
Hegerville*	44° 42.6′ S	177° 03.5′ W
Dolly Parton	44° 46.4′ S	176° 34.6′ W
Paranoia*	44° 44.3′ S	176° 32.4′ W

(b) Important seamount complex

The Big Chief complex is defined as a box bounded by 44° 35.0′ to 44° 45.0′ S and 175° 25′ to 175° 05′ W. Two individual seamounts were chosen at random from a list known to make up the complex, including Tomahawk, Hiawatha, Charlies, Flintstone, Cooks, and Teepee. The seamounts selected were:

Flintstone	44° 37.2′	175° 15.7′ W
Teepee	44° 36.9′	175° 09.8′ W

(c) Other main fishing seamounts/features. Six of these seamounts (marked *) were selected at random. Features Unnamed and Hill 94 were supplied to us as seamounts, but on inspection during the survey, we found that they did not meet the seamount criteria (features that rise steeply from a surrounding level bottom to reach a peak at least 100 m high and then fall steeply to the surrounding level bottom again) so were not sampled.

Mt Sally†	44° 38.2′ S	176° 06.1′ E
Fletcher's Pin*	44° 13.7′ S	179° 12.3′ E
Mt Nelson*	44° 16.9′ S	179° 52.3′ E
Dory Pimple	44° 36.8′ S	178° 06.1′ W
Amaltal Pimple	44° 34.8′ S	177° 50.4′ W
Chucky's*	44° 51.4′ S	177° 01.6′ W
Nielson's	44° 43.5′ S	176° 47.0′ W
Der Spriggs	44° 41.6′ S	176° 45.0′ W
Unnamed*	44° 40.0′ S	176° 18.5′ W
Featherlite*	44° 39.7′ S	176° 03.1′ W
Condom's	44° 36.4′ S	175° 45.3′ W
Hill 94*	44° 32.2′ S	175° 30.2′ W
Mangrove	44° 41.8′ S	175° 28.3′ W

† Mt Sally was selected in the initial survey design but was dropped at a planning meeting on 11 September 1998. It was not included in the list of seamounts used to scale up the absolute abundance. Featherlite was randomly selected as a replacement.

2.5 Target identification

The classification used mark length greater than an intensity threshold, and a depth to differentiate the proportion of recruit smooth oreo. This gave four generic mark-types: background, low, medium, and high (Table 1). Background marks were those which were below the intensity threshold. The cut-off in mark length between low and the medium plus high mark-types was 434 m (standard error, 79 m). The depth cut-off between medium and high mark-types was 984 m (standard error, 38 m).

Where data permitted, these generic mark-types were divided to accommodate the effect of changes in species composition along the south Chatham Rise (east-west split). This aimed to have seven or more trawls in each mark-type to provide enough data to estimate the variance contribution in the abundance estimate. However, some ended up having only five trawls. Only the low and medium mark-types could be sub-divided. Low was divided into three areas and medium into two areas (Table 1).

Table 1: Classification of echogram marks into smooth oreo mark-types and the mean percentage of recruit smooth oreo (SSOr) in catches

Mark-type	Mean SSOr (%)	Mark criteria	East-west split
Background	6	Below intensity threshold	None
Low	7	Mark length > 434 m	178° 20′ W & 179° 15′ W
Medium	29	Length ≤ 434 m & depth < 984 m	178° 20′ W
High	75	Length ≤ 434 m & depth ≥ 984 m	None

2.6 Shadow zone correction

The acoustic transducer projects a nominally conical beam down into the water with the wave-front forming part of the surface of a segment 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 any fish close to the bottom in the outer parts of the beam (shadowing). Therefore fish close to the bottom are acoustically under-sampled relative to fish that are off the bottom.

For sloping bottoms, the first reflections will come from an off-centre part of the beam and the steeper the slope the further off-centre and the worse the shadowing effect. A complex bottom contour exacerbates this even further. This effect places limitations on surveys of fish on seamounts: the feasibility of such surveys was discussed by Cordue (1996).

We calculated the height of the shadow zone by the method of Barr (NIWA, Wellington, unpublished report). For flat strata or seamounts with a grid design, the mean backscatter of each transect was corrected using the assumption that the fish density in the shadow zone of that transect was equal to that predicted by the regression of fish density in the zone 0-x m above the apparent bottom, where x is the height above the apparent bottom where density varies linearly and is determined by inspection. Shadow zones for a level bottom are about 1 m thick. The correction was applied at the stratum level and was estimated by taking a weighted mean over a sample of mark-types in each stratum. The mark-type and strata corrections for the shadow zone are listed in Table 2.

For seamount surveys using the 'star' design, the mean backscatter of each 10 ping segment was corrected using the assumption that the fish density in the shadow zone was equal to the average density in the 10 m zone above the apparent bottom. But slopes can be greater than 8° and the Barr method can be inaccurate if the masking of fish echoes is caused by an echo from a side lobe (Barr and Kloser, pers. comm.).

Table 2: Shadow zone corrections for backscatter from each stratum and mark-type. Correction is a weighted mean of the sampled marks that were on the bottom for each combination of mark-type and stratum, adjusted for the fraction of marks off the bottom (which were assumed to have a zero correction)

Mark-type	Stratum	Correction
Medium-west	2	1.08
Medium-west	22	1
Medium-west	3	1
Medium-east	4	1.01
Medium-east	42	1
Medium-east	5	1.08
High	2	1.02
High	22	1
High	3	1.08
High	4	1.02
High	42	1.06
High	5	1
Low-west	2	1.23
Low-west	22	1.13
Low-west	3	1.01
Low-east	4	1.09
Low-east	42	1.21
Low-east	5	1.12
Back	All	1.23

2.7 Tow body motion

Approximate corrections for loss of acoustic signal strength due to towbody motion were based on Stanton (1982). The increases in backscatter required were greatest at low towing speed when towed body pitching was greatest. The corrections also depend on the range from the towed body to the target, but in a periodic fashion determined by the periodicity of the pitching and the speed of sound in seawater. The percentage corrections applied to both hill and flat strata are listed in Table 3.

Table 3: Tow body motion corrections (%) applied to backscatter from each stratum and seamount

	Flat stratum						Seamount		
No./name	2	22	3	4	42	5	Chucky's	Hegerville	Paranoia
Correction	20	5	20	10	10	25	10	5	5

2.8 Target strength (TS)

For this biomass estimate the results used may be summarised as follows.

Smooth oreos

The equation of the tilt averaged target strength, <TS>, versus the logarithm of fish total length, (L, cm) for smooth oreos was estimated using swimbladder data (27 points) as:

$$\langle TS \rangle = - 89.16 + 30.42 * \log_{10}(L)$$

This has a *c.v.* due to sampling error of 9% for the cross-section of a 35 cm fish. Note that this *c.v.* does not include error from biases in the measurements. The mean TS for a 35 cm fish is -42.5, which is an increase of about 7.5 dB from the value derived from the relationship used in the 1999 stock assessment (Doonan *et al.* 1999a).

Black oreos

The equation for black oreos (22 points) was:

$\langle TS \rangle = -62.94 + 15.76 * \log_{10}(L)$, where L is total length (cm).

This has a sampling *c.v.* of 4% for the cross-section of a 35 cm fish. The mean TS for a 35 cm fish is -38.7 which is a decrease of about 1.1 dB from 1999 (Doonan *et al.* 1999b).

The relationships for both species are shown in Figure 2.

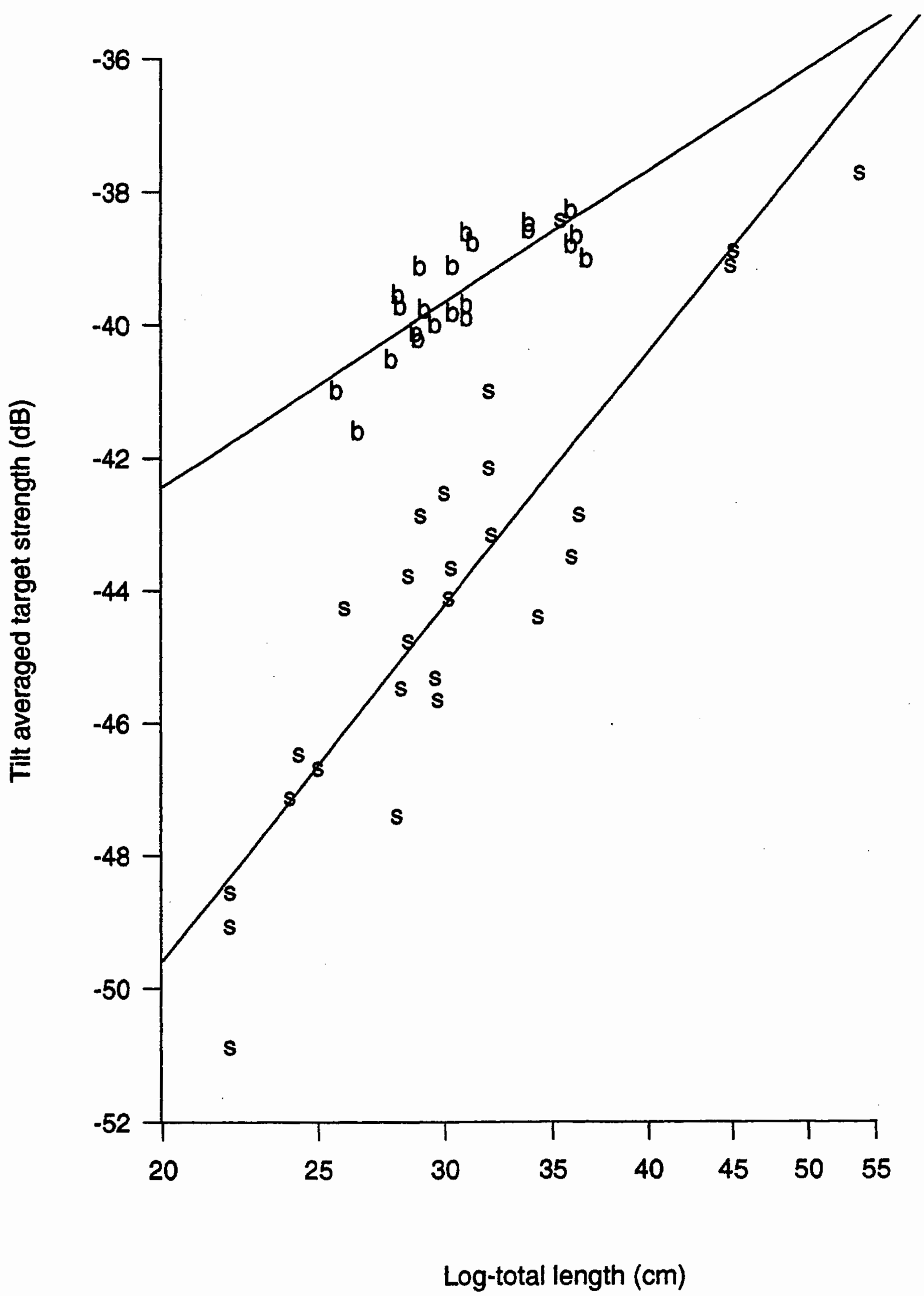

Figure 2: **Target strengths of black oreo (b) and smooth oreo (s) estimated from swimbladder model data together with the fitted regression lines.**

Orange roughy

The target strength relationship used in this analysis was from the "live" fish tank measurements of McClatchie *et al.* (1999). Scattering measurements were made on 16 "live" orange roughy in a tank (8 m long, 4 m wide, and 4 m deep). These were combined with fish orientation data and a decrease of -2 dB applied to account for lipid behaviour at the pressure and temperature found at 800–1300 m (McClatchie & Ye 2000) to yield the tilt averaged target strength-fish length relationship:

$\langle TS\rangle_{orh}(L) = -73.29 + 16.15 \log_{10}(L)$, where L is standard length (cm).

This relationship gives a <TS> of -48.4 for a standard length of 35 cm and an approximate *c.v.* of 18% in the corresponding cross-section.

Other species

Species other than orange roughy were divided into three target strength categories: non-swimbladder, cod-like, and deepwater-like (Table 4). Tilt averaged target strength for cod-like species was estimated from the <TS>-length relationship given by Foote (1987). For fish with closed swimbladders this is:

$\langle TS\rangle_j(L) = -67.5 + 20 \log_{10}(L)$

where j refers to all species with closed swimbladders, L is the mean total length (cm), and the residual standard error is 2.3 dB.

This relationship is based on in situ data from walleye pollock, Pacific whiting, cod, and five other species. Mean total lengths ranged from 15 to 82 cm. The size range for cod-like species found in association with orange roughy was 24 to 113 cm. In situ data included fish orientation and the residual standard error was made up of differences in behaviour (e.g., between day and night) and between species.

Data from Foote (1987) were re-analysed with different weightings to assess the sensitivity of the relationship to species composition and were also compared with other broad-based studies (McClatchie *et al.* 1996). Different weightings had only a small effect and the relationship generally fell within the error bounds found in the other published relationships. This relationship is therefore considered adequate for estimating the contribution made by associated species with swimbladders.

For species without a swimbladder the relationship:

$\langle TS\rangle_j(L) = -77 + 20 \log_{10}(L)$

was used where j refers to all species without swimbladders and L is the mean total length (cm). The constant, -77, was derived from the value for maximal target strength of -70 dB for two non-swimbladder species: Atlantic mackerel and silver pomfret (McClatchie *et al.* 1996). To allow for changing fish orientations in the water, this was reduced by 7 dB, the mean difference between the maximal dorsal target strength and in situ values for two of the species in Foote (1987). A residual standard deviation of 2.3 dB (the same as that for fish with closed swimbladders) was assumed. Although the relationship for fish without swimbladders is approximate, sensitivity analysis showed that the exact value had little effect on the estimated abundance.

Modelling of backscattering from swimbladder casts advanced our knowledge of the target strength of bycatch species. Current target strength data based on swimbladder modelling are presented for four-rayed rattails, serrulate rattails, hoki, smooth oreos, and black oreos. Tilt averaged target strengths of bycatch species examined to date are surprisingly low compared to other swimbladdered fish (e.g., gadoids) of comparable size. The low target strength of deepwater fish is partly explained by a swimbladder length to fish length ratio that is lower than that for gadoids (McClatchie *et al.* 1996).

For deepwater species, the swimbladder model data from four-rayed rattail (*Coryphaenoides subserrulatus*) and serrulate rattail (*C. serrulatus*) were used to set the intercept (the slope was set to 20), but the scatter about the line came from the Foote (1987) data (which were used in the bootstrap for abundance variance):

$$\langle TS \rangle_j(L) = -79.1 + 20 \log_{10}(L)$$

Table 4: Species used in the OEO 4 analysis, with the total catch of each species during the survey (flat and seamount), and the target strength-length relationship used in the analyses

Code	Common name	Catch (kg)	TS-length
BOE	Black oreo	8 938.4	BOE
BEE	Basketwork eel	630.4	Cod-like
BSL	Black slickhead	57.8	Cod-like
HAK	Hake	64.0	Cod-like
HJO	Johnson's cod	573.6	Cod-like
HOK	Hoki	626.9	Cod-like
LIN	Ling	18.4	Cod-like
RIB	Ribaldo	52.6	Cod-like
SBK	Spineback	40.1	Cod-like
SMC	Small-headed cod	17.2	Cod-like
SSM	Slickhead, smallscaled	1 077.4	Cod-like
BJA	Black javelinfish	108.2	Deepwater
CBA	Humpback rattail	27.3	Deepwater
CBO	Bollons' rattail	11.6	Deepwater
CFA	Banded rattail	48.6	Deepwater
CIN	Notable rattail	52.5	Deepwater
CKA	Kaiyomaru rattail	11.9	Deepwater
CKX	Spottyfaced rattail	12.7	Deepwater
CSE	Serrulate rattail	21.6	Deepwater
CSU	Four-rayed rattail	635.0	Deepwater
EPL	Bigeye cardinalfish	12.0	Deepwater
EPR	Robust cardinalfish	33.9	Deepwater
JAV	Javelinfish	113.7	Deepwater
LDO	Lookdown dory	13.1	Deepwater
MCA	Ridge scaled rattail	322.3	Deepwater
SBI	Slickhead, bigscaled brown	199.8	Deepwater
SOR	Spiky oreo	79.9	Deepwater
WHX	White rattail	32.0	Deepwater
CSQ	*Centrophorus squamosus*	45.3	No swimbladder
CYO	Smooth skin dogfish	25.9	No swimbladder
CYP	*Centroscymnus crepidater*	188.3	No swimbladder
ETB	Baxter's lantern dogfish	1 729.0	No swimbladder
ORH	Orange roughy	1 908.3	ORH
SSO	Smooth oreo	108 132.2	SSO

Species not used in the analyses are shown in Table 5. These were the species thought to be within 1–2 m of the bottom and therefore unlikely to show up in the backscatter.

Table 5: Species not used in the OEO 4 analysis and their total catch during the survey

Code	Common name	Catch (kg)
ACO	Tam O'Shanter urchin	10.8
APR	Catshark	80.7
JFI	Jellyfish	10.6
SCC	Sea cucumber	139.2
ANT	Anemones	15.3
ASR	Asteroid (starfish)	27.0
CHG	Chimaera, giant	110.1
DWO	Deepwater octopus	15.3
GRM	Sea urchin	285.5
MIQ	Warty squid	153.7
MRQ	Warty squid	29.7
ONG	Sponges	82.9
PZE	*Paralomis zelandica*	13.6
PLS	Plunket shark	66.4
RUD	Rudderfish	20.4
SAL	Salps	17.4
WSQ	Warty squid	10.6
CHP	Chimaera, brown	13.0
GSP	Pale ghostshark	218.2
LCH	Longnosed chimaera	171.3
PSK	Longnosed deepsea skate	67.4
RCH	Widenosed chimaera	92.3
SND	Shovelnose spiny dogfish	1 164.0
SSK	Smooth skate	39.2

2.9 Correction for the absorption of sound in water

The absorption correction depends on the distance from the towbody to the marks and the difference between the water absorption coefficient used to collect backscatter data (8 dB.km) and the value from a new regression based on a re-analysis of absorption data (Doonan, unpublished report, Deepwater Fishery Assessment Working Group Document, 99/02).

The equations for the sound attenuation in seawater ($dB.km^{-1}$) are:

$$22.19 \times S(1+0.017 \times T)e^{-1.76\times10^{-4}D}\ g(f, f_2)/c + A_w P_w f^2$$

where T (°C) is the temperature, S (ppt) is the salinity, D (m) is the depth (an alias for pressure), $g(f,f_2)$ is given by $f_2 f^2/(f_2^2+f^2)$, f (kHz) is the frequency of the sound used (which should be over 10 kHz), f_2 is the relaxation frequency for the $MgSO_4$ effect and is given by:

$f_2 = 1.80\times10^{7-1518/(T+273)}$, c is the speed of sound given by $1412 + 3.21T + 1.19S + 0.0167D$, and $A_w = 4.937\times10^{-4} - 2.59\times10^{-5}T + 9.11\times10^{-7}T^2 - 1.5\times10^{-8}T^3$, $T < 20$ °C

$P_w = 1 - 3.83 \times 10^{-5} D + 4.9 \times 10^{-10} D^2$.

2.10 Estimating variance and bias

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. This affects the estimate of p_{SSO} and p_{BOE}
- error in the target strengths of other species in the mix
- variance in the estimate of smooth oreo and black oreo target strength
- sampling error of fish lengths (negligible)
- error in the estimated length cut-off used in mark identification
- variance of the mean weight, $\overline{w}$, for oreos.

Flat

The total *c.v.* of the abundance estimate was calculated in three parts: one for the abundance in the survey area using a fixed length cut-off in mark identification, another for the error in estimating the length cut-off in the mark identification, and a third resulting from scaling up the recruit abundance in the acoustic survey area to that for the larger trawl survey area. Total *c.v.* was given by:

$$\sqrt{(cv_p^2+1)(cv_l^2+1)(cv_R^2+1)-1} \quad \text{.....................................(1)}$$

where cv_R is the *c.v.* of the recruit abundance in the acoustic survey area, cv_p is the *c.v.* of the factor to account for the proportion of abundance outside the survey area, and cv_l is the *c.v.* of the effect of error in the length cut-off in the mark identification on the abundance estimate.

To estimate cv_R, the following sources of variation were combined using simple bootstrapping.

- 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 TS-length data were re-sampled and the TS-length regression re-estimated.
- 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 TS for each species was re-sampled in three steps. First, the intercept in the <TS> versus length relationship was randomly shifted to the constant for the individual relationship of one of the component species in the Foote (1987) data (only the intercept was included because the slope was constant at 20). This intercept remained the same for a particular bootstrap run. Additionally, for each species, a difference was added to the above selected intercept and the difference was chosen randomly from those that occurred in the species in Foote's (1987) analysis. The TS was selected from the distribution of <TS> versus length (assuming this distribution to be normal with a mean equal to the above chosen constant and difference to the mean, and a standard deviation equal to the residual standard error, 1.47 dB), from the <TS> versus length regression.

To estimate cv_p for the proportion of oreo in the acoustic survey area, the sample variance from the three estimates using each of three *Tangaroa* trawl surveys (1992, 1993, 1995) were used.

To estimate cv_l for the mark length cut-off in the mark identification, the standard error in the mark length estimate was used and it was assumed that abundance, B(l), using a mark length cutoff of l was a quadratic function in l, i.e.,

$$B(l) = g(l)\ Bo$$

where $g(l) = 1 + b_1 (l-lo) + b_2 (l-lo)^2$, and Bo is the abundance using the estimated cut-off, *lo*. The constants b_1 and b_2 can be estimated from a series of $B(l)$ at different *l* values.

The expected value of $g(l)$ is 1 because the mean cut-off is *lo*, which, in turn, means that the *c.v.* of $g(l)$ is the same as its variance, $V[g(l)]$. $V[g(l)]$ is the expectation of

$$\{ b_1 (l-lo) + b_2 (l-lo)^2 \}^2$$

which can be solved if we know the distribution for the estimate of *lo*, assuming that its error outweighs that for the estimates of b_1 and b_2. We assume that the estimate of *lo* has a normal distribution, with a variance of σ_l^2, so that $V[g(l)]$ simplifies to

$$V[g(l)] = b_1^2 \sigma_l^2 + b_2^3\, 3\, \sigma_l^4 \qquad \text{.......................................(2)}$$

Thus the variance of Bo due to estimation error in *lo* is $Bo^2\, V[g(l)]$ and the *c.v.* from this source is $V[g(l)]$.

Seamounts

The equivalent recruit-abundance *c.v.* (cv_R) was calculated for each seamount. However, there was also a between-seamount variance contribution, $\sigma_B^{\ 2}$, because for each of the three seamount categories only a subsample of the seamounts was surveyed, i.e., each seamount has a different true biomass and we are sampling only a few of them. For each seamount category, the variance is given by:

$$N^2 \left\{ (1-f)\frac{\sigma_B^{\ 2}}{n} + \frac{\overline{\sigma_W^2}}{n} \right\}$$

where N is the total number of seamounts in the category, n is the number sampled, *f* is the sample fraction (n/N) of seamounts, and $\overline{\sigma_W^2}$ is the mean variance of sampling error of the surveys on the seamounts. $\overline{\sigma_W^2}$ can be estimated and $\sigma_B^{\ 2}$ can be found from the sample variance of the estimated seamount abundances which is equal to $\sigma_B^{\ 2} + \sigma_W^2$. For the total seamount abundance, the variance is the sum of the variances of the three seamount categories.

Potential sources of bias are:

- classification of marks
- differences in relative catchability of other species compared to oreos
- the species composition and species distribution in the background layer
- the proportion of oreos in the shadowed zone
- the validity of the target strength-length relationship used for estimating the target strength of associated species
- signal loss from transducer motion
- signal loss from bubbles (for the hull transducer)
- uncertainty about absorption 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 1998 and the time the distribution was measured in the trawl surveys (1992, 1993, and 1995)
- fish movements, including oreos moving to the background population from schools on both seamounts and flat
- estimating target strengths from swimbladder casts.

2.11 Acoustic system

The acoustic data were collected with NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs 1994, Coombs 2000).

The biomass estimates in this report were all made from data collected with towed transducers operating at 38 kHz. Mark type data were also collected using hull-mounted transducers at 38 and 12 kHz. Four systems were used.

1. A single channel system connected to a towed Edo model 6978 single beam transducer via 1 km of Rochester type A301301 tow cable.
2. A four channel towed system, with underwater electronics, connected to a Simrad type ES38DD split beam transducer.
3. A single channel 38 kHz system connected to a hull-mounted Simrad model 38-7 transducer.
4. A single channel 12 kHz receiver slaved to *Tangaroa*'s EK500 12 kHz channel.

All data used in the seamount analysis were drawn from system 2. For the flat strata, system 1 was mainly used.

System 4 was not calibrated; calibration data for abundance estimation for the other three systems are shown in Table 6.

Table 6: Calibration data for the three 38 kHz systems used for the biomass survey. *G* is the gain of the system at a range of 1 m. A $20\log_{10}R + 2\alpha R$ time-varied gain was used

System	1	2	3
Transducer model	Edo 6978	Simrad ES38DD	Simrad 38-7
Transducer serial no.	102	28326	23421
Nominal 3dB beamwidth (°)	6.5	6.9	7.3
Effective beam angle (sr)	0.0086	0.0081	0.0087
Operating frequency (kHz)	38.000	38.156	38.000
Transmit interval (s)	4.000	4.000	4.000
Transmitter pulse length (ms)	0.890	1.000	0.890
Effective pulse length (ms)	0.74	0.78	0.74
Filter bandwidth (kHz)	1.5	1.5	1.5
Initial sample rate (kHz)	100.000	100.000	100.000
Decimated sample rate (kHz)	4.000	4.000	4.000
SL+SRT (dB re 1 V)	47.8	61.2	51.4
Transducer depth (m)	50	500	6.5
$20 \log_{10} G$	91.45	82.60	91.55

3. RESULTS

3.1 Seamount abundance

Four acoustic transects and three trawls were completed on most seamounts. No successful tows were carried out on Teepee so catches from three tows made on a previous *Tangaroa* survey (TAN9406) were used. The abundance on individual seamounts varied widely for recruit smooth oreo, from 0 on Flintstone to 4000 t on Hegerville (Table 7). For black oreo (over 32 cm), the abundance estimate from each seamount was very low (Table 7).

Table 7: Seamounts surveyed, smooth oreo (SSO), and black oreo (BOE) abundance estimates, the sample error in the abundances, and the number of tows and number of transects carried out

				Abundance			
Seamount	Category	Number of transects	Number of tows	SSO (t)	c.v. (%)	BOE (t)	c.v. (%)
Hegerville	A	5	3	4 040	65	24	62
Paranoia	A	4	3	610	100	0	0
Flintstone	B	0	0	0	0	0	0
Teepee	B	4	3	183	92	12	90
Chuckys	C	4	3	390	30	0	97
Featherlite	C	4	2	151	62	0	0
Fletchers	C	4	3	41	48	5	69
Mt. Nelson	C	4	4	112	79	5	69

The total abundance of recruit smooth oreo on seamounts was 13 900 t (*c.v.* 53%) with the main contributor being the "A" seamounts, i.e., those that have had a mean annual catch of more than 2500 t (Table 8). For black oreo over 32 cm, the total abundance was 120 t (*c.v.* 91%).

Table 8: Smooth oreo and black oreo total seamount abundance and *c.v.* and mean abundance (t) by seamount category. –, not applicable

Category	Mean abundance		Number of seamounts		Total abundance			
	SSO	BOE	Surveyed	Total	SSO t	c.v. (%)	BOE t	c.v. (%)
A	2 330	12	2	5	11 600	63	60	83
B	91	6	2	6	550	87	35	271
C	174	2	4	10	1 740	36	24	63
Total	–	–	8	21	13 900	53	120	91

For recruit smooth oreo, the between-seamount variation in the total abundance was about the same as the sampling variation. Most of the latter was due to sampling error in the catches (Table 9).

Table 9: The *c.v.* (%) from each variation source alone and the median *c.v.* for each source over all the seamounts surveyed for smooth oreo. TS is target strength

	Seamount							
Source	Chuckys	Featherlite	Fletchers	Hegerville	Mt. Nelson	Paranoia	Tepee	Median
Catch	12	53	18	39	44	67	63	44
Backscatter	9	27	36	26	41	30	15	27
TS other species	1	1	1	8	2	1	6	1
TS SSO	11	8	6	7	6	8	7	7

3.2 Flat ground survey area abundance

The number of tows and acoustic transects carried out are shown in Table 10. One planned stratum (7) was not surveyed because of time lost due to bad weather. This was the main black oreo stratum and so black oreo was poorly surveyed.

Table 10: Numbers of flat transects and trawls completed, and the number of strata for smooth oreo (SSO) and black oreo (BOE). Tows were counted only if their performance was acceptable (code 1 or 2)

	SSO strata						BOE stratum
Stratum	2	22	3	4	42	5	7
Transects completed	17	8	6	10	10	8	0
Trawls completed	8	6	10	8	11	14	0

Smooth oreo

The abundance was adjusted up from the acoustic survey area to the trawl survey area by using the ratio of catches from the *Tangaroa* trawl surveys (1992, 1993, and 1995) for the trawl survey area versus the acoustic survey area. These surveys used the same vessel and stratification, they were close in time to each other and were also relatively close in time to the 1998 acoustic survey. The scale-up ratio was 1.98 (*c.v.* 22%) for recruit and 1.5 (16%) for pre-recruit smooth oreo.

An estimate of the *c.v.* of the length cut-off used in the mark identification analysis was made for recruit smooth oreo only. The standard error of the estimate of the length cut-off was 90 m. Therefore, the *c.v.* in the abundance due to error in the estimate of the length cut-off is given by equation 2, i.e.,

$$\sqrt{[1.256\text{x}10^{-2}\ 90]^2 + [-3.165\text{x}10^{-6}\ ]^3 * 3 * 90^4} = \sqrt{0.0128} = 8\%$$

This estimate is approximate because it assumes that, to the first order, changes in abundance due to changes in the length cut-off are proportional to the number of marks leaving or entering the high and medium mark-types. This assumption is based on the observation that the proportion of recruit smooth oreo in the medium or high mark-types is far greater than that in the low mark-types and so the contribution from the latter can be ignored. Practical considerations in the set-up of the integration of the backscatter and mark identification make using this approximation necessary.

Most of the abundance was from the eastern strata (4, 42, and 5) (Table 11). Also, most abundance was from the high and medium mark-types.

Table 11: Recruit smooth oreo (SSO) and black oreo (BOE) percentage abundance for each flat stratum and mark-type

	Stratum						Mark-type		
	2	22	3	4	42	5	High/Medium	Low	Background
SSO	2	4	5	18	22	49	49	42	8
BOE	11	4	23	11	12	38	18	24	59

Abundance for smooth oreo was 43 800 t (*c.v.* 37%), Table 12.

Table 12: Smooth oreo and black oreo abundance on flat ground

			SSO abundance		BOE
abundance		(t)	*c.v.* (%)	(t)	*c.v.* (%)
Acoustic survey area	21 900	28	3 032	51	
Trawl survey area	43 800	37	13 020	56	

Most sources of variance were important in the estimate of abundance (Table 13) with none dominating. To lower the *c.v.* markedly would require both a substantial increase in sampling resources and an increased precision in the estimates of target strength for other species. For example, doubling the sampling (acoustic transects and trawling) would decrease the *c.v.* from catches and backscatter sources by about $\sqrt{2}$ (ignoring any contribution to the precision of the trawling for estimating the length cut-off). The total *c.v.* would be reduced from 37% to about 33% (includes *c.v.* contribution from other sources). A four-fold increase in acoustic sample size and in the data used to estimate the target strength of the other species would reduce the *c.v.* to about 29%.

Table 13: The *c.v.* of the smooth oreo (SSO) and black oreo (BOE) acoustic abundance estimates for the flat ground for each variance source using that source alone. TS, target strength

	c.v.(%)	
Source	SSO	BOE
Catches	14	41
Backscatter	16	10
TS of other species	13	29
TS of oreo species	4	1
Scaling acoustic area to trawl survey area	22	20
Length cut-off in mark identification	8	3

Black oreo

For large fish (length 33 cm or more), the scale-up ratio from the acoustic to the trawl survey area was 4.3, i.e., the acoustic area has about 23% of the abundance. For small black oreo (length below 33 cm), the ratio was 11.0, i.e., the acoustic area has about 9% of the abundance. The magnitude of these ratios suggests that the size of the area surveyed was borderline for providing a reliable abundance estimate.

About 13 000 t (*c.v.* 56%) was estimated for the trawl survey area (*see* Table 12), but 59% of this came from the background mark-type (*see* Table 11). This mark-type had been thought to be trivial and little trawling effort was put into it. Commercial vessels would certainly not fish on this type of mark, where catch rates are very low and the catch mixed.

A four-fold increase in acoustic sample size and in the data used to estimate the target strength of the other species would reduce the *c.v.* from 56% to about 31%.

3.3 Total abundance for OEO 4

Smooth oreo

The survey area abundance was scaled to the rest of OEO 4 based on the ratio of commercial catch from the whole of OEO 4 to catch from the trawl survey area (*see* Section 2.3) resulting in a total estimated abundance for recruit smooth oreo of 61 700 t (*c.v.* 32%), i.e., 1.07 * (43 800 + 13 900). About 25% of the abundance was on the seamounts (0.7% of the trawl survey area) and two-thirds (seamount + flat strata) was in 14% of the trawl survey area.

Black oreo

The survey area abundance was scaled to the rest of OEO 4 based on the ratio of commercial catch from the whole of OEO 4 to catch from the trawl survey area (*see* Section 2.3) resulting in a total estimated abundance for black oreo over 32 cm of 13 900 t (*c.v.* 55%), i.e., 1.06 * (13 020+ 120).

3.4 Sensitivity

Flat

Sensitivities of the flat ground abundance estimate to changes in values of contributing parameters are presented in Table 14. Only sources of uncertainty which produced abundance changes greater than the total *c.v.* (37% for smooth oreo and 56% for black oreo) were considered as sources of potential bias.

Most sensitivities considered here did not represent potential changes, but are based on doubling and halving parameter values (e.g., a 3dB change in target strength represents a factor of two in the fish/m^2 scale) or switching all of one group into another (e.g., using cod target strength-length relationship for deepwater-like species).

For recruit smooth oreo, the largest sensitivities, at about 62% change in abundance, occurred when target-strength length relationships for all species were changed to be deepwater-like. It is unlikely, but possible, that a proportion of species could shift categories. More likely are shifts in the intercept of the target strength-length curve. The 3 dB used in the sensitivities is only a guess at the range for future revisions.

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 the other species because individual species would be expected to have a range of values. When individual species are excluded from the catch, the maximum change in abundance is 21%, but the rest combined contribute 7% or lower, i.e., the species mix acts, generally, as a sum of many species. Thus, the effect of catchability differences depends on the position of smooth oreo catchability relative to the mean of the species mix. If smooth oreo catchability is half the species mix mean, then the abundance estimate will increase by 33%.

For black oreo over 32 cm, the major potential biases are those associated with the species composition of the background mark-type where 59% of the large black oreo biomass resides, i.e., the proportions of basketwork eels, its target strength and catchability.

Table 14: Bias sources for acoustic survey abundance estimates, smooth oreo and black oreo, OEO 4, flat ground. † magnitude exceeds *c.v.* for flat abundance (smooth oreo 37%, black oreo 56%). TS, target strength

Source	Abundance change (%)	
	Smooth oreo	Black oreo
TS estimate, other species		
Use the cod TS-length curve for all deepwater-like species	-19	-12
Use the deepwater TS-length curve for all cod-like species	62†	134†
Lower intercepts by 3 dB	24	45
Increase intercepts by 3 dB	-21	-35
TS estimate of target oreo		
Lower intercept by 3 dB	47†	12
Increase intercept by 3 dB	-34	-17
Catchability of other species		
Twice that for target oreo	33	67†
Half that for target oreo	-26	-44
Species mix used		
Exclude basketwork eels (largest effect)	21	93†
Exclude small-scaled slickhead (second equal largest effect)	7	5

Seamounts

Sensitivities of the smooth oreo seamount abundance estimate to changes in values of contributing parameters are in Table 15. Only sources of uncertainty which produced abundance changes greater than the total *c.v.* (53%) were considered as sources of potential bias. The only effect worth considering is a change in the target strength of smooth oreo (Table 15).

Table 15:Bias sources for acoustic survey abundance estimates, smooth oreo, OEO 4, seamounts. † exceeds *c.v.* for total seamount abundance (53%). TS, target strength

Source	Abundance change (%)
TS estimate, other species	
Use the cod TS-length curve for all deepwater-like species	-8
Use the deepwater TS-length curve for all cod-like species	5
Lower intercepts by 3 dB	7
Increase intercepts by 3 dB	-11
TS estimate of smooth oreo	
Lower intercept by 3 dB	71†
Increase intercept by 3 dB	-45
Catchability of other species	
Twice that for smooth oreo	10
Half that for smooth oreo	-15
Species mix used	
Exclude Baxters dogfish (largest effect)	8
Exclude small-scaled slickhead (second equal largest effect)	5

3.5 East-west split

For stock assessment, the abundance was split into eastern and western parts, separated by a north-south line at 178° 20′ W. In general, the western part was fished first, mostly as a target fishery for smooth oreo with effort declining after 1991 or thereabouts. The eastern fishery began after 1989 and smooth oreo was mostly taken as a bycatch of orange roughy fishing.

The parameters used are given in Table 16 and the results are given in Table 17.

Table 16: Parameter values used in the east and west areas. SSO is smooth oreo, BOE is black oreo. * not estimated, set to 0

	Value				*c.v.* (%)			
	SSO		BOE		SSO		BOE	
	West	East	West	East	West	East	West	East
Scaling trawl area to OEO 4	1.07	1.07	1.06	1.06	*	*	*	*
Scaling acoustic area to trawl area	2.1	2.1	5.2	1.2	22	22	22	2
Length cut-off (m)	434	434	434	434	9	8	4	2

Table 17: Abundances (t) and *c.v.*s (%) for smooth oreo (SSO) and black oreo (BOE) in the western and eastern partitions by flat and seamount totals

	SSO				BOE			
	West		East		West		East	
	Abundance	*c.v.*	Abundance	*c.v.*	Abundance	*c.v.*	Abundance	*c.v.*
Flat	5 420	48	43 800	39	6 500	64	2 350	57
Seamount	5 140	93	9 520	43	36	96	96	109
Total	10 600	52	53 300	33	6 540	63	2 450	55

4. DISCUSSION

This was the first successful acoustic survey of this area and provided the first absolute abundance estimates of smooth oreo from OEO 4. The survey was complex involving two target species found on both flat ground and on seamounts. Acoustic transects were carried out with towed and hull-mounted acoustic transducers and identification of observed marks and species composition and fish size were estimated by trawling on marks on both flat and seamounts.

Abundance estimates for black oreo are based on too few data and are not reliable. The estimate is unsatisfactory because 59% of the flat estimate came from the background mark-type. Seamounts had only very small quantities of black oreo. The ground surveyed is clearly now primarily smooth oreo territory and black oreo form only a minor part of the biomass. The area is not part of the black oreo fishery. The one stratum where black oreo dominated in past commercial and research catches was not surveyed because of poor weather. Even so, this stratum is relatively small and the abundance of black oreo appeared low compared to that for smooth oreo.

Abundance estimates for smooth oreo are considered reasonable. The main uncertainties in the abundance estimates result from uncertainty in the target strength estimates for both oreos and associated species. Mark classification uncertainty appears to be small compared to the other sources. Data from the 1998 acoustic survey can be re-analysed when better estimates of target strength and mark identification are available.

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6. REFERENCES

Annala, J.H & Sullivan, K.J. (Comps) 1996: Report from the Fishery Assessment Plenary, April-May 1996: stock assessments and yield estimates. 308 p. (Unpublished report held in NIWA library, Wellington.)

Annala, J.H & Sullivan, K.J. (Comps) 1997: Report from the Fishery Assessment Plenary, May 1997: stock assessments and yield estimates. 381 p. (Unpublished report held in NIWA library, Wellington.)

Annala, J.H., Sullivan, K.J., & O'Brien, C.J. (Comps.) 1999: Report from the Fishery Assessment Plenary, April 1999: stock assessments and yield estimates. 430 p. (Unpublished report held in NIWA library, Wellington.)

Coombs, R.F. 1994: An adaptable acoustic data acquisition system for fish stock assessment. International Conference on Underwater Acoustics, Australian Acoustical Society, December 1994. 18 p.

Coombs, R.F. 2000: OEO9801 (TAN9812) acoustic equipment. Final Research Report for Ministry of Fisheries project OEO9801. (Unpublished report held by the Ministry of Fisheries, Wellington.)

Cordue, P.L. 1996: On the feasibility of using acoustic techniques to estimate orange roughy and oreo biomass on underwater hills. N.Z. Fisheries Assessment Research Document 96/22. 21 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J., McMillan, P.J., Coburn, R.P., & Hart, A.C. 1999a: Assessment of OEO 3A smooth oreo for 1999–2000. N.Z. Fisheries Assessment Research Document 99/45. 21 p. (Unpublished report held in NIWA library, Wellington.)

Doonan, I.J., McMillan, P.J., Coburn, R.P., & Hart, A.C. 1999b: Assessment of OEO 3A black oreo for 1999–2000. N.Z. Fisheries Assessment Research Document 99/52. 30 p. (Unpublished report held in NIWA library, Wellington.)

Foote, K.G. 1987: Fish target strengths for use in echo integrator surveys. *Journal of the Acoustical Society of America 82:* 981–987.

Hart, A.C. & McMillan, P.J. 1998: Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1995 (TAN9511). *NIWA Technical Report 27.* 48 p.

Jolly, G.M. & Hampton, I. 1990: A stratified random transect design for acoustic surveys of fish stocks. *Canadian Journal of Fisheries and Aquatic Sciences 47*: 1282–1291.

McClatchie, S., Alsop, J., & Coombs, R.F. 1996: A re-evaluation of relationships between fish size, acoustic frequency and target strength. *ICES Journal of Marine Science 53*: 780–791.

McClatchie, S., Macaulay, G., Coombs, R.F., Grimes, P., & Hart, A. 1999: Target strength of an oily deep-water fish, orange roughy (*Hoplostethus atlanticus*) I. Experiments. *Journal of the Acoustical Society of America 106(1)*: 131–142.

McClatchie, S. & Ye, Z. 2000: Target strength of an oily deep-water fish, orange roughy (*Hoplostethus atlanticus*) II. Modeling. *Journal of the Acoustical Society of America 107(3)*: 1280–1285.

McMillan, P.J., Hart, A.C., & Banks, D.A. 1988: Black and smooth oreos. N.Z. Fisheries Assessment Research Document 88/35. 18 p. (Unpublished report held in NIWA library, Wellington.)

McMillan, P.J. & Hart, A.C. 1994a: Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1990 (COR9004). *N.Z. Fisheries Data Report No. 49.* 46 p.

McMillan, P.J. & Hart, A.C. 1994b: Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1991 (TAN9104). *N.Z. Fisheries Data Report No. 50.* 45 p.

McMillan, P.J. & Hart, A.C. 1994c: Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1992 (TAN9210). *N.Z. Fisheries Data Report No. 51.* 45 p.

McMillan, P.J. & Hart, A.C. 1995: Trawl survey of oreos and orange roughy on the south Chatham Rise, October-November 1993 (TAN9309). *N.Z. Fisheries Data Report No. 60.* 49 p.

Stanton, T.K. 1982: Effects of transducer motion on echo-integration techniques. *Journal of the Acoustical Society of America 72(3)*: 947–949.