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EXECUTIVE SUMMARY

Doonan, I.J.; McMillan, P.J.; Macaulay, G.; Hart, A.C. (2008). Smooth oreo abundance estimates from the November 2005 acoustic survey of the south Chatham Rise (OEO 4).

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An acoustic survey to determine the absolute abundance of the smooth oreo (*Pseudocyttus maculatus*) population in area OEO 4 was carried out between 3 and 22 November 2005 using *Tangaroa* (TAN0514) for acoustic work and *San Waitaki* (SWA0501) for trawling. The survey covered the south slope of the eastern half of the Chatham Rise and was the third full acoustic survey of the area; previous surveys were in 1998 and 2001. The area covered was the same as that in the 2001 survey, which had been increased slightly over that in 1998. In 2005, the hills covered included the Andes for the first time. A stratified design using randomly allocated transects was used for flat ground strata and a random sample of hills was surveyed with either random or systematic 'star' transects. Data were collected concurrently on both towed and hull-mounted acoustic systems. The flat survey included 116 transects and 67 tows over 10 flat area strata (6 strata in 1998, 10 in 2001) and the hill survey included 49 transects and 29 tows over 15 hills (8 hills in 1998, 14 in 2001).

The total estimated abundance of smooth oreo for OEO 4 was 115 500 t with a c.v. of 28%. Abundance estimates were also made separately for the areas west and east of a north-south line at 178° 20′ W. These were 32 200 t with a c.v. of 31% for the west and 91 800 t with a c.v. of 30% for the east.

For the flat, the main sources of variability in the abundance estimates were the variability in the species proportions in the tow catches (14%) and the target strength of species other than oreos (13% c.v. contribution). For the hills, the main source of variability was the backscatter (31%). A potential source of bias was that 45% of the smooth oreo abundance came from the Layer mark-type which contains mixed species on which the acoustic method has problems.

1. INTRODUCTION

The south and east Chatham Rise (OEO 4) is the main smooth oreo (*Pseudocyttus maculatus*) fishing area in the New Zealand EEZ (Figure 1), with estimated median annual catches of 5290 t from 1995–96 to 2004–05 (Ministry of Fisheries Science Group, 2006). There is also a substantial orange roughy fishery in the area with reported 2004–05 landings of 1700 t (Ministry of Fisheries Science Group, 2006). Oreos from hills have made up an increasing proportion of the total oreo catch in recent years.

Both smooth oreo and black oreo are widely spread throughout OEO 4 between depths of about 600 and 1200 m and typically form aggregations, particularly when spawning. These show on echosounder traces as 'pyramid' or 'ball' marks. Oreos of both species also occur in low densities in background layers which may be very 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 population and the low probability of encountering an aggregation led to very high variances and these, together with other problems, meant that the abundance estimates were very uncertain. Although the aggregated nature of oreo distribution is a problem for trawl surveys, it is much better suited to acoustic techniques, particularly since the aggregations are largely monospecific. 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 some or all of OEO 4 were carried out in 1997 (Doonan et al. 1998), 1998 (Doonan et al. 2000), 2001 (Doonan et al. 2003c), and 2005. The last is the subject of this report.

The 2005 survey took place from 3 to 22 November 2005 and used *Tangaroa* for the acoustic work and *San Waitaki* for mark identification trawling. The approach to both survey design and analysis was closely similar to that for the 1998 (Doonan et al. 2000) and 2001 surveys (Doonan et al. 2003c).

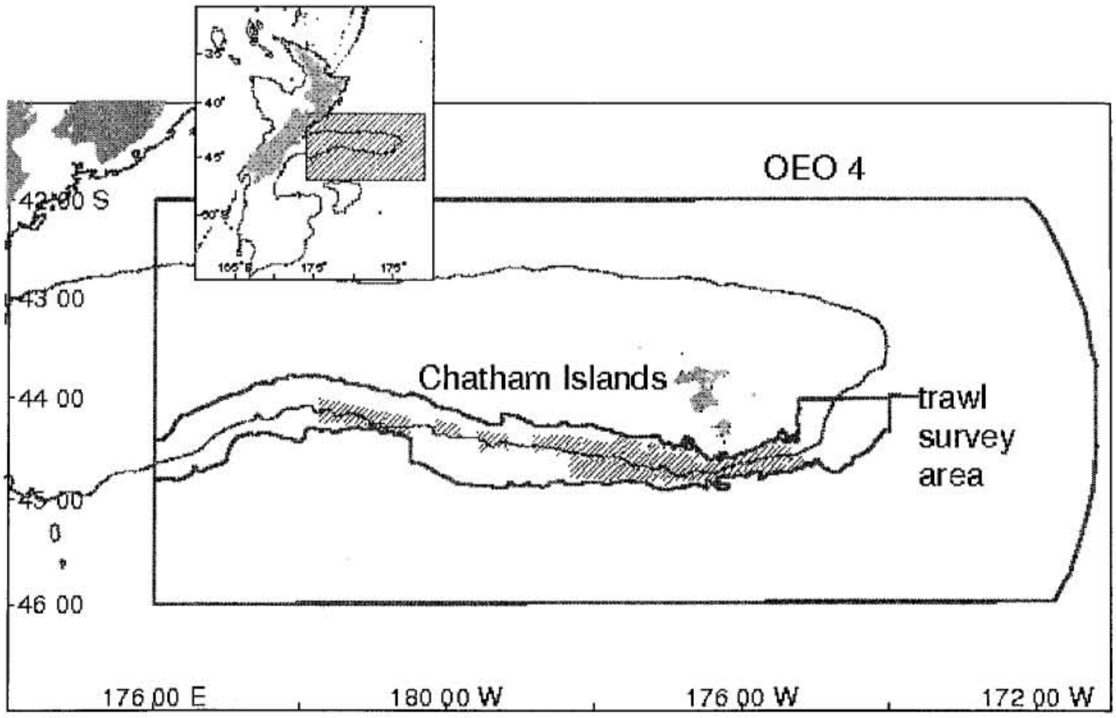

Figure 1: OEO 4 with boundaries of the previous trawl survey area and the 2005 acoustic survey area (shaded area).

2. METHODS

The overall approach to the survey was to measure acoustic backscatter together with information on the size and age structure of the smooth oreos and the mix of species present in acoustic marks obtained by trawling. A stratified random approach was used (Jolly & Hampton 1990) and the strata were those used in the trawl surveys modified in the light of the 1998 survey results and recent commercial catch data. Two vessels were used, NIWA's research vessel *Tangaroa*, which carried out all the acoustic work, and *San Waitaki*, a factory trawler owned by Sanford Limited, which carried out all the trawling.

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 apportioned using a mark classification scheme based on extensive matched tow and acoustic data, primarily from the 1998 survey (Doonan & McMillan 2000, Doonan et al. 2000, Barr et al. 2002). Areal backscatter apportioned to different species was converted to numbers of that species by dividing by its target strength and to abundance by multiplying by its 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).

There are a number of physical factors that affect the accuracy of the estimates of backscatter and the most important for oreo surveys are shadowing, towed body motion, and absorption of sound by seawater. Shadowing is a problem when the fish are on the sides of hills or on sloping seafloors. The acoustic transducer projects a conical beam down through the water column with the wave-front forming part of the surface of a sphere. If the axis of the beam is perpendicular to a flat sea bottom, then the sea bottom reflection from the central part of the beam swamps the reflections from fish close to the bottom in the outer parts of the beam. There is thus a volume close to the sea bottom which is not visible to the acoustic gear, called the 'shadow zone'. The 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 smooth oreo density in the shadow zone was the same as that in the 10 m immediately above. Corrections were calculated for groups of 10 pings and reported as the mean of these for a stratum and snapshot. The final abundance estimate includes shadow zone correction.

Transducer motion during a transmit results in the transducer pointing in different directions when transmitting and receiving. Corrections for the decrease in acoustic signal strength due to this motion were made using the method of Dunford (2005). Transducer movement data were collected synchronously with the acoustic data at 50 ms intervals. These data were interpolated to match the acoustic data which 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 using the relationship derived by Doonan et al. (2003a) and this was used to correct the data from the nominal absorption coefficient (8 $dB.km^{-1}$) applied by the receiver.

2.2 Acoustic system

The acoustic data were collected with NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs et al. 2003) and the configuration used was the same as that described by Doonan et al. (2001). The backscatter data were collected with a split-beam system towed at 160–220 m on flat ground and 250–360 m over the hills. The towbody was calibrated during the survey (Dunford & Macaulay, unpublished report, 2005). The calibration broadly followed the approach described by Foote et al. (1987). A 38.1 mm ± 2.5 μm diameter tungsten carbide sphere with nominal target strength of -42.4 dB was used as a calibration standard. The system was operated at 38.156 kHz and transmitted at 4 s intervals. Calibration data are summarised in Table 1.

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

System	Towed body 2 – Flat	Towed body 2 - Hills
Transducer serial no.	28327	28327
Nominal 3dB beam-width (°)	7.0 x 6.9	7.0 x 6.9
Effective beam angle (sr)	0.0083	0.0083
Effective pulse length (ms)	0.78	0.78
V_T (V)	1 323	1 339
Transducer depth (m)	160 – 220	250 – 360
G	14 491	14 491

2.3 Trawling gear

The *San Waitaki* used a two-panel Champion 74.4 m net with rockhopper groundrope for most of the tows. This had a total footrope of 69.3 m, and the net was fished with 45 m sweeps and 45 m bridles and used a 60 mm mesh codend. Doorspread was 120–155 m (mean 142 m) measured on 20 of the 83 tows with this net, and headline height was 4–8 m (mean 5 m) measured on 81 tows. Tows on layer marks were made with the NIWA 6 panel wing net (rat catcher) which has a groundrope of 49.8 m and used the same 45 m sweeps and bridles but has a 40 mm mesh codend. Doorspread was 133–154 m (mean 145 m) measured on 9 of the 11 tows with this net, and headline height was 2.5–4.0 m (mean 3.1 m) measured on 11 tows. Layers off the bottom were also sampled with a Motueka Nets Rover 119 midwater net which had a 119 m headrope and 103 m groundrope. Headline height was 18–19 m measured on the two tows with this net.

2.4 Survey design

The survey area was a subset of the earlier trawl survey area (McMillan & Hart, 1994a, 1994b, 1994c, 1995, 1998) which in turn covered only part of the overall OEO 4 area (see Figure 1). The area includes both flat and undulating ground ('flat') and hills. The survey area was chosen to yield a target c.v. of 30% or less while minimising the time taken to complete the work. The 2005 survey area was the same as that used in 2001. The latter was increased after the 1998 survey. The flat strata were separated into areas west and east of 178° 20′ W.

After the re-design for the 2001 survey, analysis showed that increases in sampling would bring only minor improvements and that more data on target strength were needed to make further gains in precision (Doonan et al. 2003c). Consequently, the 2005 survey had a similar level of sampling to that used in 2001, but with a shift in effort into strata 82 and 52 from other parts of the survey area since these strata had most of the total abundance in 2001. Up to 12% of the reported smooth oreo commercial catch came from the Andes hill complex during the 1990s, so the Andes hills were added to the 2005 survey. However, the overall survey effort in 2005 on hills stayed the same as in 2001 because the total hill abundance was not a large proportion of the total abundance and in a strictly statistical sense is over-sampled. The flat area and hills surveyed are shown in Figure 2.

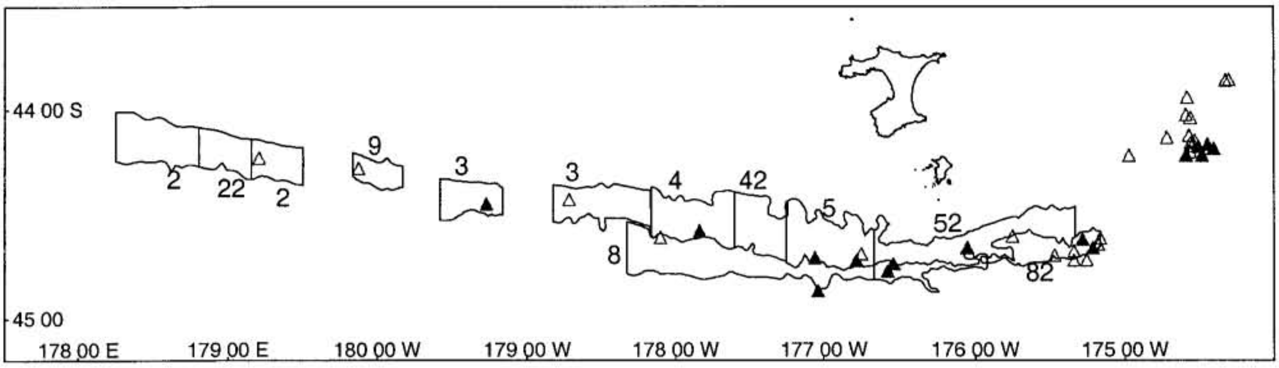

Figure 2: Flat strata and hills surveyed (filled triangles) in 2005. Hills not surveyed are the open triangles.

2.4.1 Flat

On the flat, a conventional stratified random approach was used (Jolly & Hampton 1990) and strata were chosen to cover the main smooth oreo areas. In each stratum, a number of randomly positioned north-south acoustic transects were generated. We assumed that most of the fish were in schools and randomly chosen schools in each stratum were sampled by trawling to obtain species composition and length-frequencies of smooth oreo, black oreo, and other species.

The survey was designed to achieve a c.v. of 25% for the estimate of total abundance. Three sources of variation were considered when allocating the numbers of acoustic transects and tows in each stratum:

- 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.

Ten strata were surveyed (Table 2). The strata and stratum numbers were the same as those used in the 2001 survey.

We assumed that there was no movement in and out of the acoustic survey area during the time of sampling and therefore we treated all the information for the area and time of sampling as being synoptic or instantaneous. We also assumed that the distribution of smooth oreo in and out of the acoustic survey area has been relatively constant since 1992 and that this distribution was measured by the trawl surveys carried out in OEO 4 in 1992, 1993, and 1995. The latter is needed because these surveys define the scale up factor needed to convert the acoustic abundance into that for the trawl survey area.

Table 2: **Flat area strata: area, depth range, longitude range, and the relative importance of each stratum as indicated by its % contribution to the total abundance of smooth oreo from the 2001 acoustic survey°.**

Stratum	Area (km^2)	Depth (m)	Longitude range	Importance in 2001 survey (%)
East strata				
4	1 050	800–1 200	178° 10´W–177° 35´W	12
42	760	800–1 200	177° 35´W–177° 15´W	11
5	1 188	800–1 200	177° 15´W–176° 40´W	9
52	1 487	800–1 200	176° 40´W–175° 20´W	33
8	1 885	1 200–1 400	178° 20´W–176° 40´W	9
82	1 046	1 200–1 400	176° 40´W–175° 10´W	15
West strata				
2	1 594	850–1150	178° 15´E–178° 50´E	3
			179° 10´E–179° 30´E	
22	558	850–1150	178° 50´E–179° 10´E	0
9	367	800–1000	179° 50´E–179° 50´W	1
3	1 543	850–1150	179° 35´W–179° 10´W	7
			178° 50´W–178° 10´W	

2.4.2 Hills

Each hill was taken to be a stratum. The approach to surveying hills was to use randomly allocated parallel transects or systematically allocated transects in a 'star' pattern (Doonan et al. 2003b). The hills to be surveyed were chosen from the set of known south Chatham Rise hill complexes (Doonan et al. 2000). It was desirable to select randomly from homogeneous subsets of hills (i.e., hills with similar catch histories and similar sizes) and they were ranked using the following criteria and grouped into three categories, A, B, and C.

1. Catch history, i.e., hills which produced large catches of smooth oreo in the last 6 years were ranked high priority. The ranking was based on analyses of MFish smooth oreo catch and effort data carried out by NIWA.
2. Relative size and potential as oreo habitat.

The total abundance of smooth oreo on hills from the 2001 survey was 13 400 t (c.v. 32%) with the main contributions from one hill (Hegerville) in category A and one hill (Nielsons) in category C. Nielsons was therefore put into category A for the 2005 survey because it had the highest abundance of all the hills surveyed in 2001.

Fifteen hills were sampled including all the category A hills (11), 2 in category B, and 2 in category C. The hills for categories B and C were selected at random from those listed below. Hegerville and Nielsons are large hills, and Possum is a ridge so these were surveyed with five parallel transects.

A Most important hills (catches greater than 300 t total in the last two three-year periods). All hills were surveyed. † change from 2001

Chucky's	44° 51.4´	177° 01.6´ W
Trev's Pinni	44° 27.0´	179° 16.3´ W
Hegerville	44° 42.6´	177° 03.5´ W
Dolly Parton	44° 46.4´	176° 34.6´ W
Paranoia	44° 44.3´	176° 32.4´ W
†Nielson's	44° 43.5´	176° 47.0´ W
†Possum (Andes)	44° 13.1´	174° 28.8´ W

†Cathy (Andes)	44° 10.7′	174° 30.6′ W
†Cotopaxi (Andes)	44° 9.9′	174° 26.8′ W
†Sir Michael (Andes)	44° 11.1′	174° 24.3′ W
†Jimmy (Andes)	44° 13.1′	174° 35.3′ W

B Important hill complex

The Big Chief complex, defined as a box bounded by 44° 35.0′ to 44° 45.0′ S and 175° 25′ to 175° 05′ W. Hills surveyed denoted by *:

*Big Chief	44° 39.72′	175° 12.90′ W
Tomahawk	44° 38.70′	175° 10.62′ W
Hiawatha	44° 43.32′	175° 15.30′ W
Charlie Horsecock	44° 40.68′	175° 20.52′ W
*Flintstone	44° 37.20′	175° 16.98′ W
Cooks	44° 43.20′	175° 20.40′ W
Teepee	44° 36.90′	175° 9.78′ W

C Other fishing hills. Hills surveyed denoted by *.

Mt Kiso	44° 25.9′	178° 43.2′ W
Fletcher's Pin	44° 13.7′	179° 12.3′ E
Mt Nelson	44° 16.9′	179° 52.3′ E
Dory Pimple	44° 36.8′	178° 06.1′ W
*Amaltal Pimple	44° 34.8′	177° 50.4′ W
Der Spriggs	44° 41.6′	176° 45.0′ W
Triple catch	North of Dolly Parton (tops: 700, 714, 800m)	
*Featherlite	44° 39.7′	176° 03.1′ W
Condom's	44° 36.4′	175° 45.3′ W
Mangrove	44° 41.8′	175° 28.3′ W
Dickies (Andes)	44° 7.5′	174° 34.3′ W
Icecube (Andes)	44° 8.8′	174° 32.0′ W
Ladies Night (Andes)	44 °11.0′	174° 27.0′ W

2.5 Estimating absolute abundance

The overall procedure for estimating abundance was essentially the same as in previous oreo surveys (Doonan et al. 1998, 2000, 2003c). The total abundance of the stock is required for stock assessment.

Abundance was estimated separately for the flat and hills. For the former, the acoustic data were classified into mark-types where marks equate approximately to echogram images. The mark classification scheme was an updated version of that used for the 1998 survey (Doonan & McMillan 2000, Doonan et al. 2000, Barr et al. 2002). The abundance of smooth oreo in each mark-type was estimated from the backscatter for each mark, the proportion of smooth oreo 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 smooth oreo in that mark-type. These were then summed over each stratum, scaled up by the stratum area, and the results summed over all strata (Doonan et al. 2000).

The abundance on each hill was estimated using the method of Doonan et al. (2003b). The mean abundance was calculated for each hill class, multiplied by the total number of hills in that class, and summed over all classes to give total abundance for all hills in the trawl survey area.

The smooth oreo abundance for the whole of OEO 4 was estimated by scaling up the flat abundance to the trawl survey area, adding the hill abundances and scaling the sum up to the whole OEO 4 area.

The overall analysis scheme is shown diagrammatically in Figure 3 and the following sections expand on aspects of the overall analyses that are specific to this survey.

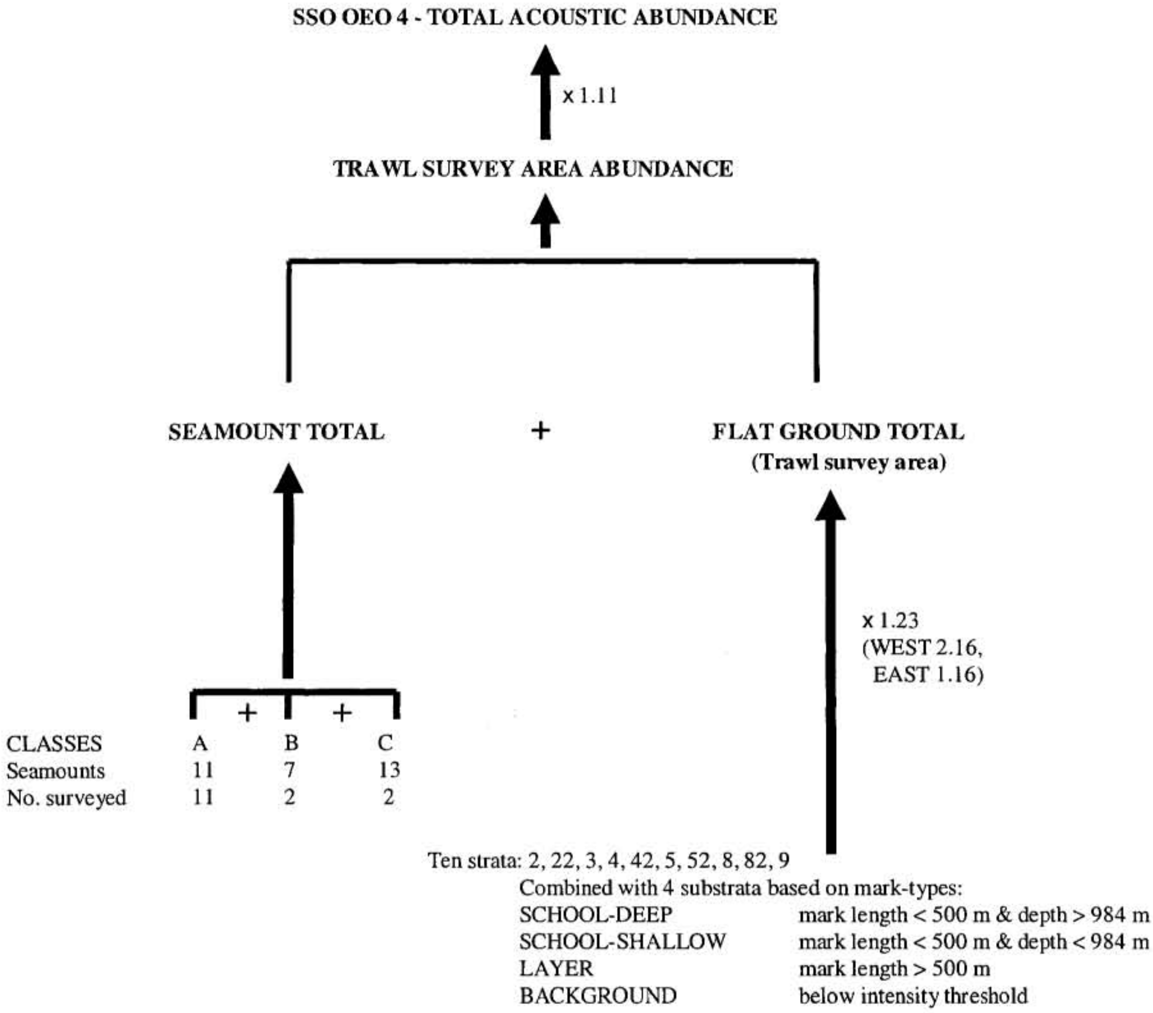

Figure 3: Schematic plan of calculations applied to the smooth oreo (SSO) survey acoustic abundance estimates to derive a total abundance estimate for OEO 4. See Section 2.4 for an explanation of the survey design for hills and 2.5.2 for an explanation of mark-types.

2.5.1 Abundance scaling factors

Two abundance scaling factors were used, first to multiply the flat acoustic survey area up to the trawl survey area and second to multiply the trawl area up to the overall OEO 4 area. The first factor was calculated using data from three trawl surveys (TAN9210, TAN9309, and TAN9511) to estimate the fraction of smooth oreo in the acoustic survey area compared to the trawl survey area (McMillan & Hart 1994c, 1995, 1998). A mean smooth oreo density was estimated for each tow stratum and was applied to the subareas in the stratum resulting from splitting off the part, where applicable, in the acoustic survey area. For the total area the factor was 1.23 (6% c.v.); for the west 2.16 (2% c.v.) and for the east 1.16 (4% c.v.).

The second factor was estimated from the ratio of catches in the total OEO 4 area to those in the trawl survey area. The ratio used was 1.11 (85 300/76 800) with a c.v. of 2%, calculated from data for the fishing years 1986–87 to 2000–01. There is a temporal trend in the ratio with the value increasing from 1.03 in the late 1980s to 1.25 in 1999–2000 and 2000–01.

2.5.2 Mark-types

As noted above, the acoustic data were classified into different kinds of marks for the analysis. The same four types that were identified in the 1998 survey were used (Background, Layer, School-shallow and School-deep) but the classification criteria were modified slightly in 2001 using the new data collected during that survey (Doonan & McMillan 2000, Doonan et al. 2000, Barr et al. 2002). The scheme is tabulated in Table 3.

Table 3: Classification of echogram marks into smooth oreo mark-types and the mean percentage of recruited smooth oreo (SSOr) in catches.

Mark-type	Mean SSOr	Mark criteria	East-west split
Background	6	Below intensity threshold	None
Layer	7	Mark length > 434 m	178° 30′ W & 179° 15′ W
School-shallow	29	Length ≤ 434 m & depth < 984 m	178° 30′ W
School-deep	75	Length ≤ 434 m & depth ≥ 984 m	None

2.5.3 Target strength

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

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

and

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

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

The relationship used for orange roughy is based on measurements of live fish in a tank (McClatchie et al. 1999) combined with in situ results from Barr & Coombs (2001). For other common species we used relationships based on swimbladder modelling (Macaulay et al. 2001). Generic relationships were used for species for which no specific relationships are available as detailed by Doonan et al. (1999). A more conventional formulation of the form $TS = a + b\log_{10}(L)$ was used for all species other than oreos and these are shown in Table 4.

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

Species	Code	Intercept (a)	Slope (b)
Basketwork eel (*Diastobranchus capensis*)	BEE	-76.7	23.3
Black javelinfish (*Mesobius antipodum*)	BJA	-70.6	17.8
Four-rayed rattail (*Coryphaenoides subserrulatus*)	CSU	-92.5	31.8
Hoki (*Macruronus novaezelandiae*)	HOK	-74	18.0
Javelinfish (*Lepidorhyncus denticulatus*)	JAV	-73.5	20.0
Johnson's cod (*Halargyreus johnsonii*)	HJO	-74.0	24.7
Notable rattail (*Coelorinchus innotabilis*)	CIN	-107.8	44.9
Orange roughy (*Hoplostethus atlanticus*)	ORH	-74.34	16.15
Ribaldo (*Mora moro*)	RIB	-66.7	21.7
Ridge scaled rattail (*Macrourus carinatus*)	MCA	-95.5	35.6
Robust cardinalfish (*Epigonus robustus*)	EPR	-70.0	23.2
Serrulate rattail (*Coryphaenoides serrulatus*)	CSE	-135.0	59.7
White rattail (*Trachyrincus aphyodes*)	WHX	-62.1	18.1
Cod-like		-67.5	20.0
Deepwater swimbladdered		-79.4	20.0
No swimbladder		-77.0	20.0

2.6 Estimating variance and bias

Estimation of variance and bias was also essentially the same as in previous oreo surveys (Doonan et al. 1998, Doonan et al. 2000). Variance was estimated separately for the flat and for hills and then combined. 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 smooth oreo
- error in the target strengths of other species in the mix
- variance in the estimate of smooth oreo target strength
- sampling error of fish lengths (negligible)
- variance of the mean weight, $\overline{w}$, for smooth oreo.

2.6.1 Flat

The total c.v. of the abundance estimate was calculated in two parts: one for the abundance in the survey area, and a second resulting from scaling up the abundance in the acoustic survey area to that of the larger trawl survey area. Total c.v. was given by:

$$\sqrt{(cv_p^2+1)(cv_A^2+1)}$$

where cv_A is the c.v. of the abundance in the acoustic survey area, and cv_p is the c.v. of the factor to account for the proportion of abundance outside the acoustic survey area. To estimate cv_A 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 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, the a value 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.)

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

2.6.2 Hills

The equivalent abundance c.v. (cv_A) was calculated for each hill. However, there was also a between-hill variance contribution, $\sigma_B^{\ 2}$, because for each of the three hill categories only a subsample of the hills was surveyed (i.e., each hill had a different true abundance and we sampled only a few of them).

The model used to estimate the mean abundance of the *j*-th hill in the *i*-th hill category is given by:

$$b_{i,j} = \mu_i + \gamma_{i,j} + \varepsilon_{i,j}$$

where μ is the mean for the category, γ accounts for deviations of a hill from the category mean and so has zero mean and standard deviation $\sigma_{\mathrm{B,i}}$, and ε accounts for measurement error on a specific hill. The abundance for the *i*-th category is $N_i\overline{b_{i.}}$ where N is the total number of hills in the category and so the variance is:

$$\begin{aligned} &\mathrm{N_i^2 Var}\left(\overline{\mathrm{b_{i.}}}\right) \\ &= \mathrm{N_i^2}\left\{\mathrm{Var}\left(\overline{\gamma_{\mathrm{i.}}}\right) + \mathrm{Var}\left(\overline{\varepsilon_{i.}}\right)\right\} \\ &= \mathrm{N_i^2}\left\{(1-f)\frac{\sigma_{B,i}^{\ 2}}{\mathrm{n_i}} + \frac{\overline{\sigma_{W,i}^2}}{\mathrm{n_i}}\right\} \end{aligned}$$

where n is the number sampled, *f* is the sample fraction ((n-1)/(N-1)) of hills and $\overline{\sigma_{W,i}^2}$ is the mean variance of sampling error of the surveys on the hills. $\overline{\sigma_{W,i}^2}$ can be estimated and $\sigma_{B,i}^{\ 2}$ can be found from the sample variance of the estimated hill abundances which is equal to $\sigma_{B,i}^{\ 2} + \overline{\sigma_{W,i}^2}$. For the total hill abundance, the variance is the sum of the variances of the three hill categories.

2.6.3 Bias

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)
- 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 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 hills and flat
- estimating target strengths from swimbladder casts.

3. RESULTS

3.1 Flat

The numbers of tows and acoustic transects carried out are shown in Table 5 and Table 6 shows the number of tows by mark-type and strata, and how tows were supplemented so that all mark-type/stratum combination had tow data. An unknown mark observed in stratum 82 was excluded from the analysis since it appears unlikely to be smooth oreo (Appendix A).

Table 5: The numbers of transects and tows for each stratum, (except those on Background marks). A further 7 tows were made on the Background mark-type.

Stratum	Number of transects	Number of tows
2	8	1
3	12	9
4	12	14
5	11	5
8	12	7
9	3	1
22	6	4
42	12	11
52	20	11
82	20	4

Table 6: Number of tows in flat strata by mark-type and the numbers when stratum-mark-type combinations have been supplemented with tows from adjacent strata.

	On the 2005 survey			Supplemented					
	Number of tows			Number of tows			Source of supplemented tows (strata)		
Stratum	School-deep	School-shallow	Layer	School-deep	School-shallow	Layer	School-deep	School-shallow	Layer
West strata									
2	0	0	0	2	4	5	22	3, 22	3
22	2	1	0	2	4	5		3	3
3	0	3	5	2	3	5	22		
9	0	0	1	2	3	6	22‡	3	3
East strata									
4	2	2	7	2	2	7			
42	2	2	5	2	2	5			
5	1	0	4	4	2	4	8, 42	42	
52	1	0	7	5	2	7	82	42	
8	1	0	2	5	0	2	82	§	
82	4	0	0	4	0	2		§	8

‡ Strictly not needed since there were no marks of this type in the survey.
§ Stratum too deep for this mark-type.

3.2 Hills

The number of transects and tows carried out on each hill is shown in Table 7.

Table 7: The number of transects and tows for each hill.

Hill	Number of tows	Number of transects
Amaltal Pimple	2	2
Big Chief	1	3
Cathy	1	3
Chucky's	3	3
Cotopaxi	1	3
Dolly Parton	2	3
Featherlite	2	3
Flintstone	1	3
Hegerville	4	5
Jimmy	1	3
Nielson's	4	5
Paranoia	2	3
Possum	1	2
Sir Michael	1	2
Trev's Pinni	2	3

3.3 Abundance estimates and variances

3.3.1 Flat

The abundance estimate for the flat acoustic survey area was 79 600 t with a c.v. of 26%. A breakdown of the percentage of the abundance by stratum is shown in Table 8 from which it can be seen that most was in the east strata. The School-deep and School-shallow mark-types accounted for 52%, Background 3%, and Layer 45%. No source of variance was dominant (Table 9).

Table 8: Flat abundance: percentage by flat stratum.

	West				East					
Stratum	2	22	3	9	4	42	5	52	8	82
Relative abundance (%)	2	3	10	2	4	6	9	41	11	12

Table 9: The c.v. of the smooth oreo acoustic abundance estimates for the flat ground for each variance source using that source alone (see 2.6.1), i.e., in the catches source, tows were re-sampled within each mark-type.

Source	c.v. (%)
Catches	14
Backscatter	10
Target strength of other species	13
Target strength of oreo species	12
Scaling acoustic area to trawl survey area	6

3.3.2 Hills

The results of the hill survey are summarised in Table 10, and show that the abundance varied widely, from nothing on Flintstone to 2300 t on Hegerville. The estimated total abundance of smooth oreo on hills was 6150 t with a c.v. of 25%. The contributions of the four hill categories are shown in Table 11. The between-hill variances were swamped by the sampling variances so the estimate of $\sigma_B^{\,2}$ was zero. Most of the sampling variation was due to sampling error in the backscatter (Table 12).

Table 10: Hills surveyed, abundance estimates (t), and the sample error of the abundance estimates. –, n.a.

Hill	Category	Abundance (t)	c.v. (%)
Chucky's	A	889	38
Trev's Pinni	A	89	28
Hegerville	A	2 336	40
Dolly Parton	A	850	52
Paranoia	A	79	84
Nielson's	A	973	32
Big Chief	B	13	47
Flintstone	B	0	80
Featherlite	C	92	29
Amaltal Pimple	C	27	71
Cathy	Andes	2	71
Cotopaxi	Andes	8	91
Jimmy	Andes	1	59
Possum	Andes	15	40
Sir Michael	Andes	24	18

Table 11: Total hill abundance and c.v. by hill category.

Category	Number of hills		Total abundance	
	Surveyed	Total	SSO (t)	c.v. (%)
A	6	6	5 200	28
B	2	7	48	46
C	2	14	830	30
Andes	5	5	50	27
Total	15	32	6 150	25

Table 12: The c.v. (%) from each variation source alone (see Section 2.6) and the median c.v. for each source over all the hills surveyed for smooth oreo. E.g., in the catches source, tows were re-sampled within each mark-type. *TS* is target strength.

	Variation source			
Hill	Catch	Backscatter	$TS_{\text{OTHER SPECIES}}$	TS_{SSO}
Chucky's	4	34	0	23
Trev's Pinni	4	19	3	20
Hegerville	12	35	3	20
Dolly Parton	2	46	1	23
Paranoia	60	52	21	14
Nielson's	18	16	4	19
Big Chief	21	27	18	1
Flintstone	62	12	38	0
Featherlite	6	19	15	11
Amaltal Pimp	13	61	18	11
Cathy	22	57	17	3
Cotopaxi	9	84	7	16
Jimmy	42	22	27	3
Possum	13	31	20	1
Sir Michael	9	3	13	5
Median	13	31	15	11

3.3.3 Total abundances for area OEO 4

The abundance from both the flat (combined scale-up factor = 1.23*1.10) and hills (scale-up factor = 1.10) was scaled up to the overall OEO 4 area and this gave an estimate of the total abundance of smooth oreo of 115 500 t with a c.v. of 28%.

For stock assessment, the overall abundance was split into east and west parts, separated by a north-south line at 178° 20′ W. The scale-up factor for the trawl survey area to the whole of OEO 4 was unchanged (1.11). The east area included five of the category A hills, all of the B and Andes hills, and 11 of the C hills. Abundance estimates are presented in Table 13.

Table 13: Total abundances (t) and c.v.s (%) in the west and east parts for the flat and hills. Scale-up factors applied.

	West		East	
	Abundance	c.v.	Abundance	c.v.
Flat	31 900	31	85 300	30
Hill	300	25	6 500	25
Total	32 200	31	91 800	30

3.4 Bias and sensitivity

3.4.1 Flat

The sensitivity of the flat abundance estimate to changes in values of contributing parameters is shown in Table 14. Several sources of uncertainty in the 2005 survey produced abundance changes greater than the total c.v. (26% for smooth oreo), and so can be considered as potential sources of bias.

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 switching all of one group into another (e.g., using cod target strength-length relationship for deepwater-like species).

The largest sensitivities, causing a 30–40% change in abundance, occurred when the target strength-length relationship for smooth oreo was changed by ±3 dB. The next most important sensitivity was shifts in the intercept of the target strength-length curve for species other than smooth oreo. The 3 dB used in the sensitivities was considered extreme and intended to capture the maximum possible error in our current target strength estimates.

Table 14: Bias sources for acoustic survey abundance estimates, smooth oreo, OEO 4, flat ground. †, magnitude exceeds c.v. for flat abundance (smooth oreo 26%). *TS*, target strength.

Source	Smooth oreo abundance change (%)
***TS* estimate, other species**	
Lower intercepts by 3 dB	42†
Increase intercepts by 3 dB	-32†
***TS* estimate of target smooth oreo**	
Lower intercept by 3 dB	35†
Increase intercept by 3 dB	-29†
Catchability of other species	
Twice that for target smooth oreo	29†
Half that for target smooth oreo	-26
Species mix used	
Exclude basketwork eel (largest effect)	19
Exclude Johnson's cod (second largest effect)	10
Exclude four-rayed rattail (third largest effect)	8
Exclude any others	<3

The catchabilities of other species are unknown, and it is also not known if smooth oreo is more or less catchable than other species. The sensitivities used should be viewed as a mean change for all the other species because there would be a range of values over all the species. When individual species were excluded from the catch, the maximum change in abundance was 19%, but the rest combined contributed 10% or less, 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 29%.

3.4.2 Hills

The sensitivity of the hill abundance estimate to changes in values of contributing parameters is shown in Table 15. Again, only sources of uncertainty which produced abundance changes greater than the total c.v. (25%) were considered as sources of potential bias. The most important effect was a change in the target strength of smooth oreo. The proportion of black oreo in the species composition was also important.

Table 15: Bias sources for smooth oreo acoustic survey abundance estimates, OEO 4, hills. † exceeds c.v. for total hill abundance (25%). *TS*, target strength.

Source	Abundance change (%)
***TS* estimate, other species**	
Lower intercepts by 3 dB	72†
Increase intercepts by 3 dB	-44†
***TS* estimate of smooth oreo**	
Lower intercept by 3 dB	11
Increase intercept by 3 dB	-14
Catchability of other species	
Twice that for smooth oreo	11
Half that for smooth oreo	-13
Species mix used	
Exclude black oreo (largest effect)	13
Exclude BEE (second largest effect)	6
Exclude any other species	<2

4. DISCUSSION

The main source of uncertainty in the estimates is from potential bias in target strength, both for smooth oreo and for other species. There is also uncertainty due to the relatively high proportion of the smooth oreo abundance (45%) from Layer mark-types because these contain a mix of species and the acoustic technique is not good with mixed species marks compared to single species marks. As noted in the 2001 survey (Doonan et al. 2003c), these biases may have effects similar to or higher than the total variability from sampling sources and are now more important to improving the accuracy of the survey abundance estimates. Reducing the uncertainty from target strength work would require more data from modelling and in situ studies covering a wider size range of fish. Some data for this work were collected on the 2005 survey and was also the subject of experimental study and is reported elsewhere.

There were some slight differences in the way abundance estimates were calculated for the three surveys so abundances were re-estimated to make the method exactly the same for 1998 as for 2001 and 2005. The weighting was changed from catch size to the square root of catches for the 2001 abundance estimates, but this was not applied retrospectively to the 1998 estimate. Applying the new weightings to the 1998 survey abundance estimates decreased the total abundance by 16% (Table 16).

Table 16: Re-estimated smooth oreo abundance (t) for the OEO 4 management area from the 1998 survey using the square-root of tow catches as weights (as for the 2001 and 2005 estimates).

	West		East		Whole area	
Area	Abundance	c.v.	Abundance	c.v.	Abundance	c.v.
Flat	19 778	63	147 223	40	162 884	38
Hills	8 301	90	15 333	40	23 635	50
Total	28 079	52	162 557	37	186 520	33
Previous total	34 926	52	192 031	37	221 639	33

The three surveys used different nets and codend mesh, i.e., the 1998 survey used *Tangaroa* for fishing with the rough bottom net and 100 mm codend mesh, the 2001 survey used the *Amaltal Explorer* for fishing with a Champion net and 100 mm codend mesh, the 2005 survey used the *San Waitaki* for fishing with a Champion net and 60 mm codend mesh. The 2005 survey used finer codend mesh resulting in more small fish being retained and this changed the relationship of smooth oreo catch rate with respect to other species. For example, using the 2001 flat tows for the 2005 estimate increased the total from 115 000 t to 187 000 t. Although there were no clear cut differences across the board, slender species (long and narrow) did appear to have a higher catchability in 2005 than in the other two surveys (Appendix B).

The Deepwater Stock Assessment Working Group decided to incorporate this shift in catchability by retrospectively adjusting the estimates from the 1998 and 2001 so that all surveys' could be compared and have the same catchability. The non-oreo catch composition of past surveys trawling was replaced with the non-oreo catch data from the 2005 survey, i.e., the smooth oreo and black oreo catch rates for past surveys were not altered. Since the number of tows are different in various strata in the different surveys, the selection of 2005 tows to apply to each past tow was random within the mark-type and stratum, but this was repeated several times so that a distribution of results was obtained (i.e., similar to a bootstrap). The mean abundance estimates from the various catch data sets were used in the stock assessment analysis (Doonan et al. 2008) (Table 17). Apart from one estimate, the c.v. values obtained by applying this procedure are in the 2–5% range and so no adjustment was made to the overall c.v. for the estimates.

Table 17: Re-estimated abundance values using the 2005 non-oreo catch rates to make the catchabilities comparable across the survey series. C.v.s were estimated from "bootstrapping" the 2005 catch-rates on to the other surveys. The "Ratio to previous estimate" used the results from Table 16 for 1998. These estimates were used in the stock assessment. The 2005 results are presented for comparison. –, na.

Survey	Area	Abundance (t)	c.v. (%)	Ratio to previous estimate
1998	West	22 600	5	0.81
	East	127 000	5	0.78
	All	146 000	4	0.79
2001	West	43 000	17	0.83
	East	183 200	2	0.78
	All	218 200	3	0.78
2005	West	32 200	–	–
	East	91 800	–	–
	All	115 500	–	–

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Appendix A: Unknown mark

A mark (School-deep mark-type) was encountered in stratum 82 that was far higher and more intense than the usual smooth oreo marks (Figure A1). Including the unknown mark in the abundance analysis increased the total flat abundance to about 131 000 t (cf. 76 000 t) and approximately doubled the c.v. to 49%. The Deepwater Working Group considered this mark and decided to exclude it from the survey data since its height and intensity were far beyond the range of all the other smooth oreo mark data (Figures A1 & A2). The identity of the species forming the unknown mark can't be determined because it was not fished, but it seems likely to be caused by a species with a large swimbladder (larger than smooth oreo). A possible contender is cardinalfish (*Epigonus telescopus*) which produces similar types of mark (Figure A3).

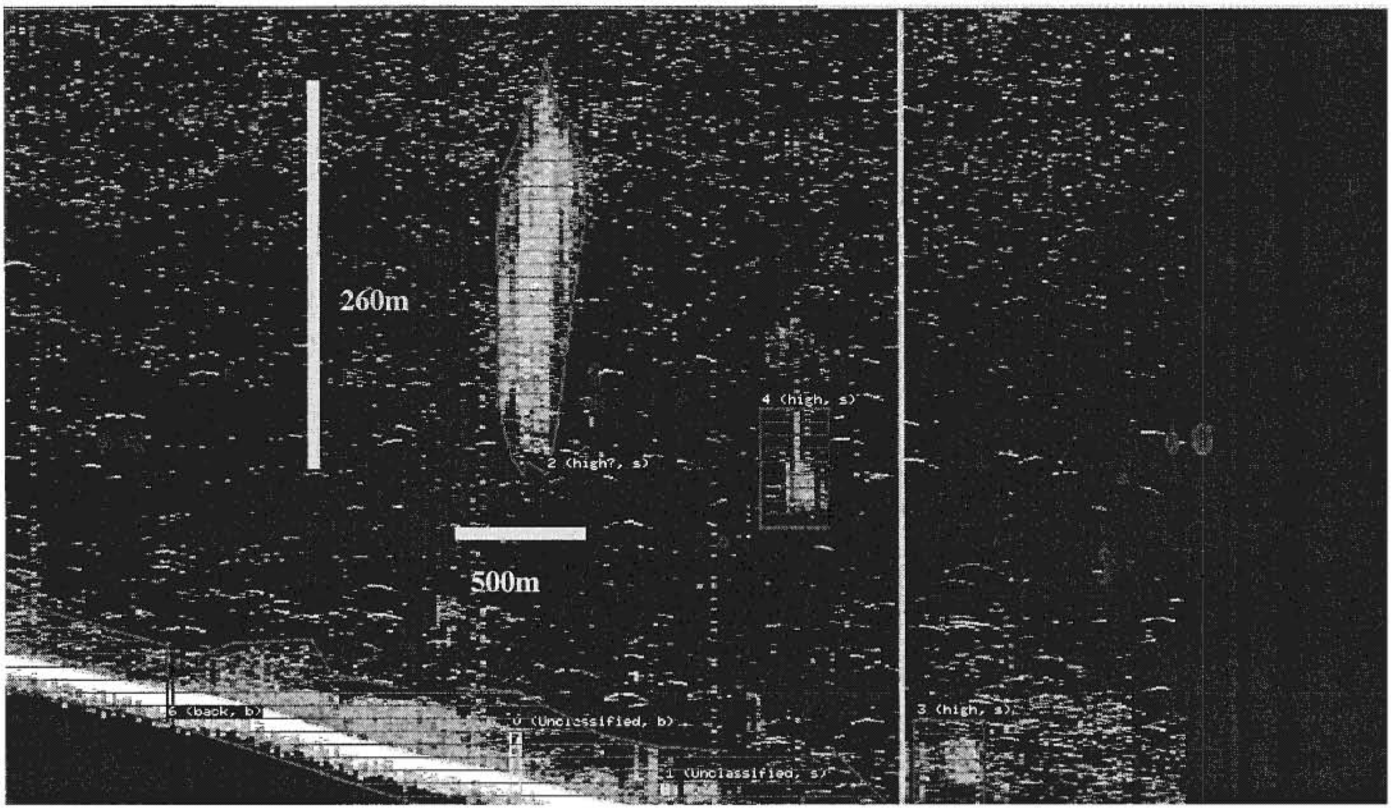
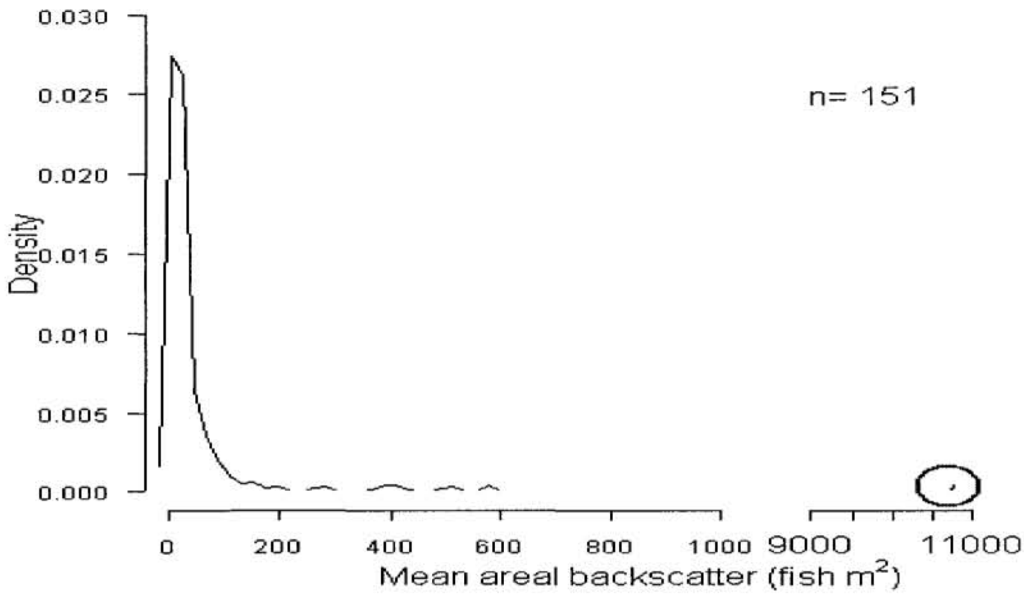


Figure A1: Unknown mark. Echogram from the towbody (not seen on the hull CREST echo-sounder) of a mark in Stratum 82 on transect 6. The lowest part of the mark is about 270 m above the bottom (depth, 1120 m).



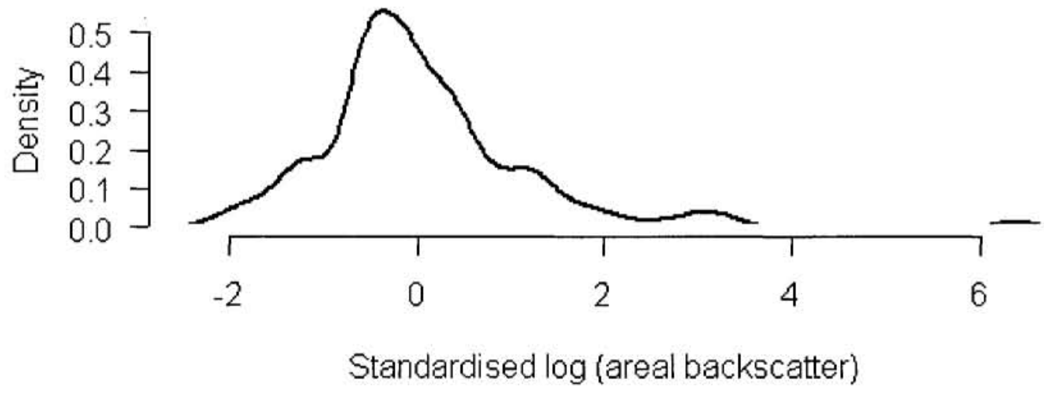


Figure A2: Distribution of mean areal backscatter from smooth oreo acoustic survey marks, School-shallow and School-deep (upper plot). The circle is the unknown mark (stratum 82, transect 6). The standardisation in the lower plot is from the data excluding the unknown mark.

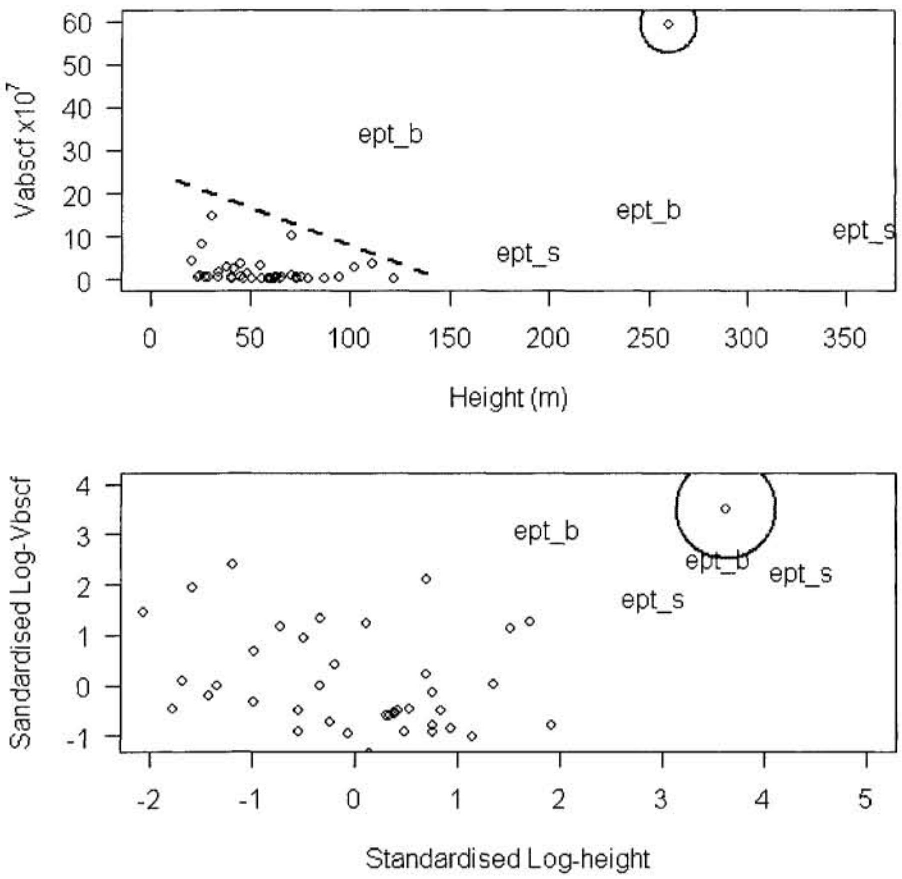


Figure A3: Mean volume backscatter versus mark height (upper plot) for selected smooth oreo survey marks (circles) compared to example cardinalfish marks (ept_b, ept_s) for the Mid-East Coast survey in 2001. Selections were based on those that were over a threshold, i.e., the higher intensity marks. Circle is unknown mark (stratum 82, transect 6). The standardisation in the lower plot is from the smooth oreo data excluding the unknown mark.

Appendix B: Net selectivity differences between surveys

Three different catcher vessels have been used with consequent differences in the nets used:

- *Tangaroa* in 1998
- *Amaltal Explorer* in 2001 (fishing for a daily quota of smooth oreo, some research tows)
- *San Waitaki* in 2005 (charter to NIWA)

There is some evidence that the gear selectivity of slender fish species was different between 1998, 2002, and 2005, probably because different nets were used for target identification trawling. Other hypotheses are: a decline in smooth oreo abundance in 2005, and that catchability of species had changed.

These changes were investigated using length frequencies and catch rates over similar strata from the three surveys, data permitting. Length frequencies for the Layer marks (those that contain a mixture of species) were compared for strata 4, 42, 5, and 52. Data for both sexes were combined and there was no scale-up for catch or area, but data for each tow was limited to an equivalent of 200 fish. Stratum 52 has both small and large fish, whilst the other strata have mainly larger fish so the strata were split into two groups: 52 and the rest.

Figure 1 shows that there are no consistent differences in the sizes for smooth oreo and black oreo, although there are some changes for large smooth oreo outside stratum 52, i.e., more big fish in 2005 which is the reverse of the expected trend. When comparing the small slender species, basketwork eel (BEE), four-rayed rattail (CSU), notable rattail (CIN), and robust cardinalfish (EPR) there is an effect between species (Figure B2) and these species are important when decomposing the backscatter into that for smooth oreo (Table B1). Table B2 gives the percentages of slender species in the catch and their catch rates, which shows that the 2005 survey caught more of the slender species in general, although in a relative way the 2005 survey was not always more efficient than the 1998.

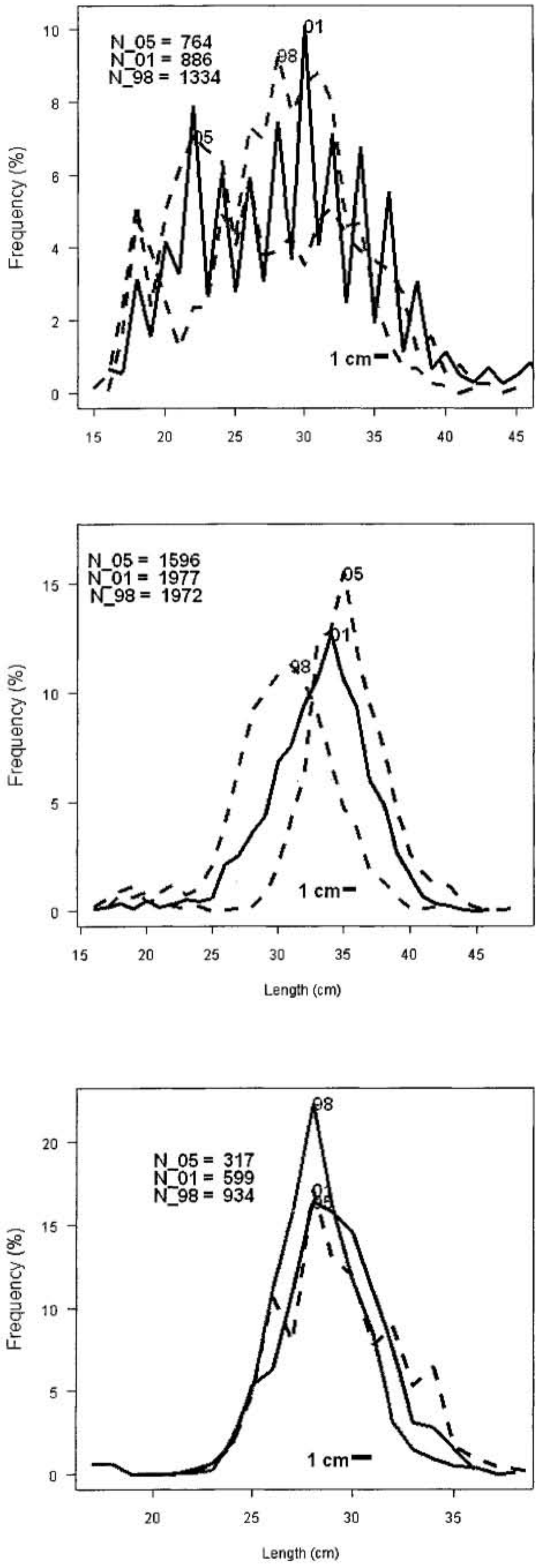


Figure B1: Length frequency of smooth oreo in Layer marks for stratum 52 (upper plot) and strata 4, 42, and 5 (middle plot) and for black oreo in strata 4, 42, 5, and 52 (lower plot).

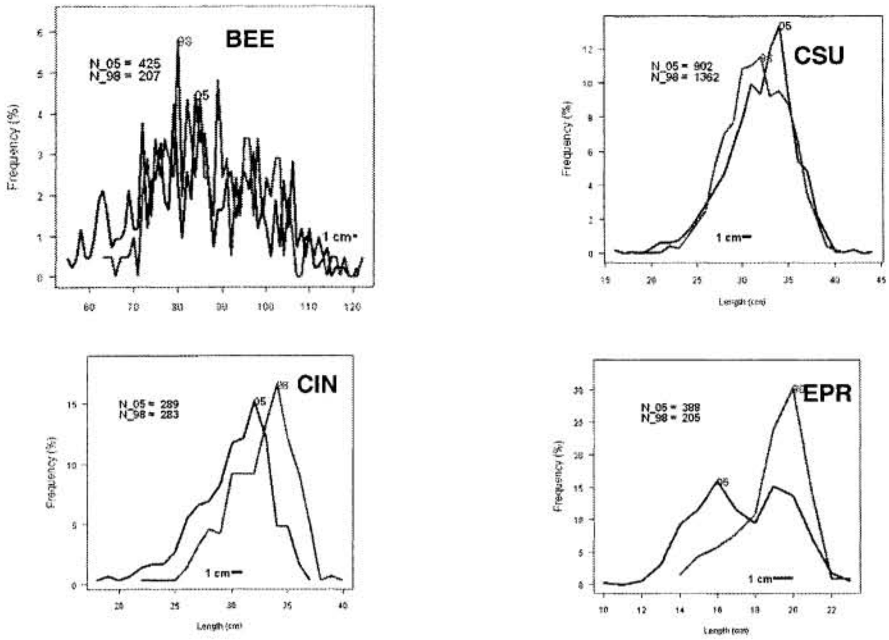


Figure B2: Length frequency plots for the slender species in the 2005 and 1998 surveys, basketwork eel (BEE), four-rayed rattail (CSU), notable rattail (CIN), and robust cardinalfish (EPR). There were too few length measurements made in 2002 to use.

Table B1: Species influence on the 2005 smooth oreo abundance estimate for Layer marks using trawl data from each survey. Percent increase in smooth oreo abundance when each species is excluded from the catch data. HJO, Johnson's cod; MCA, ridge-scaled rattail.

			Layer
Species	1998	2001	2005
BEE	21	4	21
CSU	6		17
HJO	13	13	14
MCA	5	15	5
BOE	6	7	

Table B2: Comparison of slender species catch-rates and percentage in the species composition for tows in Layer marks in strata 4, 42, 5, and 52.

	Number of tows			Mean catch (%)			Mean catch rate (t/tow)		
Stratum	**98**	**01**	**05**	**98**	**01**	**05**	**98**	**01**	**05**
CSU									
3	4	3	5	2	3	2	0.01	0.03	0.01
4	6	6	7	7	0	3	0	0	0.01
42	8	2	5	0	0	7	0	0	0.01
5	3	7	4	10	0	6	0.02	0	0.07
52	7	6	7	10	2	12	0.04	0.01	0.07
BEE									
3	4	3	5	2	3	9	0.01	0.02	0.03
4	6	6	7	8	0	8	0.01	0	0.03
42	8	2	5	2	1	7	0.01	0	0.02
5	3	7	4	4	1	10	0.01	0	0.04
52	7	6	7	2	0	2	0	0	0.01
CIN									
3	4	3	5	0	0	0.4	0	0	0.001
4	6	6	7	1	0	0.286	0.001	0	0.001
42	8	2	5	0	0	0.6	0	0.001	0.002
5	3	7	4	1	0	0.25	0.001	0	0.001
52	7	6	7	0.429	0	0.714	0.002	0	0.004
EPR									
3	4	3	5	0	0	0.2	0	0	0.001
4	6	6	7	0.667	0	0.286	0.001	0	0.001
42	8	2	5	0	0	0.4	0	0	0.001
5	3	7	4	0	0	1	0	0	0.005
52	7	6	7	0.286	0	0.143	0.003	0	0.002