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EXECUTIVE SUMMARY

Doonan, I.J.; McMillan, P.J.; Hart, A.C.; Coombs, R.F. (2003). Smooth oreo abundance estimates from the October-November 2001 acoustic survey of the south Chatham Rise (OEO 4).

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An acoustic survey to measure the absolute abundance of the smooth oreo (*Pseudocyttus maculatus*) population in area OEO 4 was carried out between 16 October and 14 November 2001 using *Tangaroa* for acoustic work and *Amaltal Explorer* for trawling. The survey covered the southern slopes of the eastern half of the Chatham Rise and was the second full acoustic survey of the area, covering slightly more ground than the first in 1998. A stratified design using randomly allocated transects was used for flat ground and a random sample of seamounts was surveyed with either random or systematic 'star' transects. Data were collected concurrently on both towed and hull-mounted acoustic systems.

Two survey vessels with dedicated acoustic or trawl tasks enabled the survey to be more extensive than that in 1998, and reduced the variability in the results. The flat survey included 138 transects and 84 trawls over 10 flat area strata (6 strata in 1998) and the seamount survey included 46 transects and 36 trawls over 14 seamounts (8 seamounts in 1998). For the flat, the main sources of variability in the abundance estimates were the target strength of species other than oreos (13% c.v. contribution) and the variability in the species proportions in the trawl catches (12%). For the hills, the main source of variability was the backscatter (30%). A potential source of bias was that 58% of the smooth oreo abundance came from the LOW mark-type, whereas in 1998 49% came from the HIGH and MEDIUM mark-types. Some uncertainty in calibration resulted from a faulty transducer.

The total estimated abundance of smooth oreo for OEO 4 was 279 000 t with a c.v. of 22%. Abundances were also estimated separately for the areas west and east of a north-south line at 178° 20′ W. These were 51 700 t with a c.v. of 35% for the west and 236 000 with a c.v. of 22% for the east.

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 mean annual catches of 5267 t from 1991–92 to 2000–01 (Annala et al. 2002). There is also a substantial orange roughy fishery in the area with reported 1999–2000 landings of 1100 t. Oreos from seamounts have made up an increasing proportion of the total oreo catch in recent years.

Both smooth and black oreos 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 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), and 2001. The last is the subject of this report.

The 2001 survey took place between 16 October and 14 November 2001. The approach to both survey design and analysis was closely similar to that for the 1998 survey (Doonan et al. 2000).

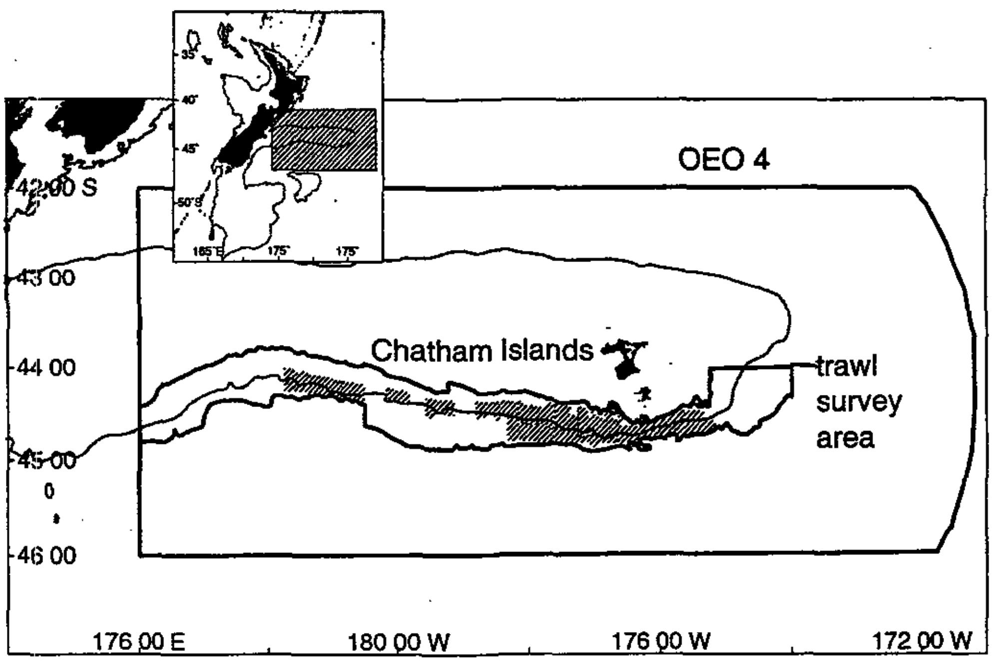

Figure 1: OEO 4 with boundaries of past trawl survey area and the 2001 acoustic survey area (shaded area).

2. METHODS

The survey design and analysis were closely similar to those of Doonan et al. (2000). 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 70 m research vessel *Tangaroa*, which carried out all of the acoustic work and some of the trawl sampling, and *Amaltal Explorer* a 66 m factory trawler, which carried out most of the trawl sampling. *Explorer* is owned by Amaltal Fishing Company Limited and was provided through the Orange Roughy Management Company Limited.

2.1 Acoustic principles

The conventional approach of echo-integration was used to estimate areal backscatter of acoustic energy by fish (Burczinsky 1982, Do & Coombs 1989, Doonan et al. 2000), which was then apportioned using a mark classification scheme based on extensive matched trawl and acoustic data, primarily from the 1998 survey (Doonan & McMillan 2000, Doonan et al. 2000, Barr et al. 2002). Areal backscatter that has been apportioned to different species is converted to numbers of each species by dividing by its target strength and to biomass by multiplying by its average weight.

The detailed mathematical analysis used to estimate biomass 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 seamounts or on sloping seafloors. The acoustic transducer projects a conical beam down through the water column with the wave-front forming part of the surface of a sphere. If the axis of the beam is perpendicular to a flat sea bottom, then the sea bottom reflection from the central part of the beam swamps the reflections from fish close to the bottom in the outer parts of the beam. There is thus a volume close to the sea bottom, which is not visible to the acoustic gear, called the 'shadow zone'. The size of the shadow zone depends on the distance of the transducer from the bottom and particularly on the steepness of the nominal bottom. For the transducers used in this survey, on a flat seafloor it is typically about 1 m, but on steep hillsides it can be over 30 m. We estimated the thickness of the shadow zone using the method of Barr (in Doonan et al. 1999) and assumed that the orange roughy 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 biomass estimate includes shadow zone correction.

Transducer motion during a transmit results in the transducer pointing in different directions when transmitting and receiving. Corrections for the decrease in acoustic signal strength due to this motion were made using the method of Dunford (Unpublished results). Transducer movement data were collected synchronously with the acoustic data at 50 ms intervals. These data were interpolated to match the acoustic data 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 biomass 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. (in press) 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 1994) and the configuration used was the same as described by Doonan et al. (2001). The backscatter data were collected with two split-beam systems towed at between 200 and 400 m. These were calibrated in the large tank at Greta Point before and after the survey, and a deep-drop calibration (see Doonan et al. 2001) was carried out during the survey. The calibrations 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. Both systems operated at 38.156 kHz and transmitted at 2 s intervals. Other calibration data are summarised in Table 1.

Data for mark identification were collected for each trawl using hull-mounted transducers on both *Tangaroa* and *Amaltal Explorer*. For the former, a dual-frequency *CREST* system operating at 12 and 38 kHz was used with a 1 ms pulse length and time between transmits of 4 s. On *Amaltal Explorer*, a *CREST* receiver was slaved to a 38 kHz Simrad ES60 echosounder; the pulse length was 3 ms and the time between transmits variable, depending on the water depth and the fishing operation. Decimation rates and filter specifications were the same as for the towed systems. Calibration data for the 38 kHz channels are also shown in Table 1.

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

System	Towed body 2	Towed body 3	*Tangaroa* hull	*Explorer* hull
Transducer serial no.	28327	28331	23421	–
Nominal 3dB beamwidth (°)	7.0x6.9	7.2x7.0	7.2x7.3	–
Effective beam angle (sr)	0.0083	0.0087	0.0091	0.0081
Effective pulse length (ms)	0.78	0.78	0.78	2.00
V_T (V)	1 318	1 059	331	436
Transducer depth (m)	200–700	200–400	6.5	7
G	12 589	12 589	38 459	5 095

Some difficulties were experienced with both the towed systems during the survey. The underwater container of the preferred system (towed body 2) developed a leak, which was traced to a damaged o-ring surface and eventually remedied. The backup system (towed body 3) was used while towed body 2 was out of service. After 80 or so transects with towed body 3, the echograms became fainter than expected and it was found that one channel was lower than the others. A check of the data already collected showed that two channels had been variable for most of the transects and that the fault had been slowly getting worse. The manufacturer eventually found that the transducer had leaked.

A deep calibration was carried out while the towed body 3 transducer was in a workable but faulty state, and this was used for the abundance estimate. For most of the transects, channels 3 and 4 appeared to be working correctly and the data in the other two channels were multiplied up on a ping-by-ping basis, first using channel 3 as a reference and then channel 4. Some transects were re-run when towed body 2 was back in commission. Biomass estimates from towed body 3 data were made with channel 3 as a reference and this is reflected in the calibration in Table 1. However, the alternative referenced to channel 4 was used as a sensitivity case and V_T for this was 1059.

2.3 Trawl gear

All trawls by *Amaltal Explorer* used a two-panel Champion 74.4 m net with rockhopper groundrope. Total footrope length was 47.3 m, and the net was fished with 45 m sweeps and 45 m bridles. Typical doorspread was about 150 m, 12–14 m wingspread, and 4–5 m headline height. *Tangaroa* 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).

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 (Figure 1). The area includes both flat and undulating ground ('flat') and seamounts. The survey area was chosen to yield a target c.v. of 30% or less while minimising the time taken. The survey area was adapted from that used in 1998, based on an analysis of the latter's precision (Doonan et al. 2000). The overall c.v. for this was 32% made up of flat (43 800 t, c.v. 37%) and seamount (13 900 t, c.v. 53%) abundances. The 2001 survey was redesigned to reduce the c.v. for the flat and seamount abundance components and aimed to yield a c.v. for the total abundance estimate (all sized fish) of about 24%.

The flat area covered was increased by 36% compared to 1998, which was about 20% of the trawl survey area and was expected to contain 80% of the abundance measured in past trawl surveys. The flat strata were separated into those west and east of 178° 20′ W. The area and hills surveyed are shown in Figure 2.

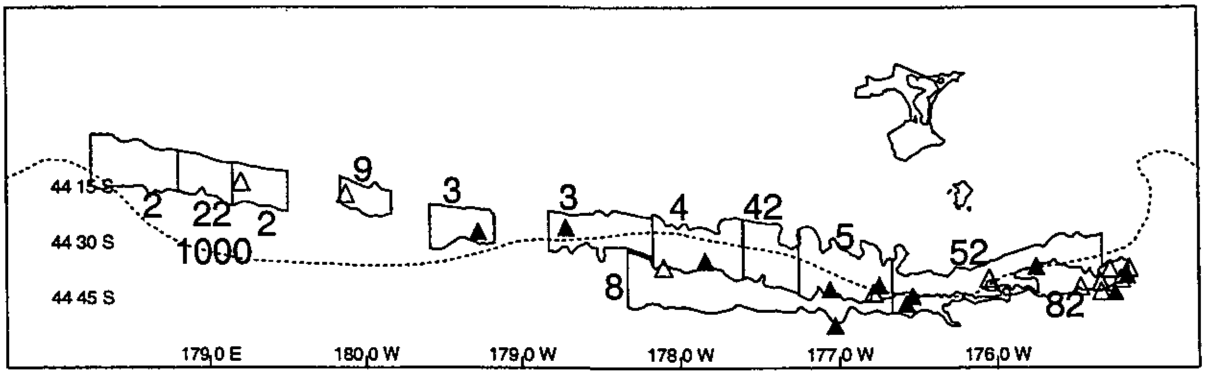

Figure 2: Flat strata and hills surveyed (filled triangles) in 2001. Hills not surveyed are the open triangles. The dotted line is the 1000 m depth contour.

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 defined. We assumed that most of the fish were in schools and randomly chosen schools in each stratum were sampled by trawl 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 29% for the estimate of total abundance. Three sources of variation were considered when allocating the numbers of acoustic transects and trawls in each stratum:

- sampling error in the acoustic data
- sampling error in the proportions of 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 stratum numbers were the same as those used in the 1998 survey (2, 22, 3, 4, 42, 5), except that a new stratum, 52, was split from stratum 5 and stratum 3 was extended. Strata 8, 82, and 9 were new.

Table 2: Flat area strata: area, depth range, longitude range, and the relative importance of the strata to the total abundance of smooth oreo. –, no data.

Stratum	Area (km^2) 1998 survey	Depth (m)	Longitude range	Importance Trawl survey	/ commercial
East strata					
4	1 050	800–1 200	178 10'W – 177 15'W	High	High
42	760	800–1 200	178 10'W – 177 15'W	High	High
5	1 188	800–1 200	177 15'W – 176 40'W	Medium	High
52	1 487	800–1 200	176 40'W – 175 20'W	Medium	High
8	1 885	1 200–1 400	178 20'W – 176 40'W	Medium	–
82	1 046	1 200–1 400	176 40'W – 175 10'W	Medium	–
West strata					
2	1 594	850–1150	178 15'E – 179 30'E	High	Low
22	558	850–1150	178 15'E – 179 30'E	High	Low
9	367	800–1000	179 50'E – 179 50'W	Low	–
3	1 543	850–1150	179 35'W – 179 10'W	Low	Low

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

2.4.2 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. The seamounts to be surveyed were chosen from the set of known south Chatham Rise seamount complexes (Doonan et al. 2000). It was desirable to select randomly from homogeneous subsets of seamounts (i.e., seamounts 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., seamounts which produced large catches of smooth oreo in the last 6 years were ranked high priority. Ranking was based on analyses of smooth oreo catch and effort data.
2. Relative size and potential as oreo habitat.

A Most important seamounts (catches over 300 t total in the last two three-year periods). All seamounts were surveyed.

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

B Important seamount complexes (smooth oreo caught on most of constituent seamounts, but since they are geographically close they are treated as a single group). Seamounts surveyed are marked by *.

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. Seamounts surveyed are marked 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 seamounts that are not part of a seamount complex. Seamounts surveyed are marked 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
Nielson's	44° 43.5′	176° 47.0′ W
Der Spriggs*	44° 41.6′	176° 45.0′ W
Triple catch	North of Dolly Parton (tops: 700, 714, 800 m)	
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

The total abundance of recruited smooth oreos on seamounts from the 1998 survey was 13 900 t (c.v. 53%) with the main contribution from category A. The target c.v. for the 2001 survey was 36% and it included all of the category A seamounts, 2 in category B, and 4 in category C. The seamounts for categories B and C were selected at random from those listed above. Each seamount (except Hegerville) was surveyed using three transects in a star pattern. Hegerville was surveyed with five parallel transects. At least two trawls on marks were planned for each seamount.

2.5 Estimating absolute abundance

The overall procedure for estimating biomass was essentially the same as in previous oreo surveys (Doonan et al. 1998, 2000). The total recruited biomass of the stock is required for stock assessment and for smooth oreos this is taken to be equal to the biomass of mature fish.

Biomass was estimated separately for the flat and seamounts. 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 biomass 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).

Most seamounts were surveyed using star transects and the biomass on each mount was estimated using the method of Doonan et al. (2003). The mean biomass was calculated for each seamount class, multiplied by the total number of seamounts in that class, and summed over all classes to give total biomass for all seamounts in the trawl survey area.

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

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

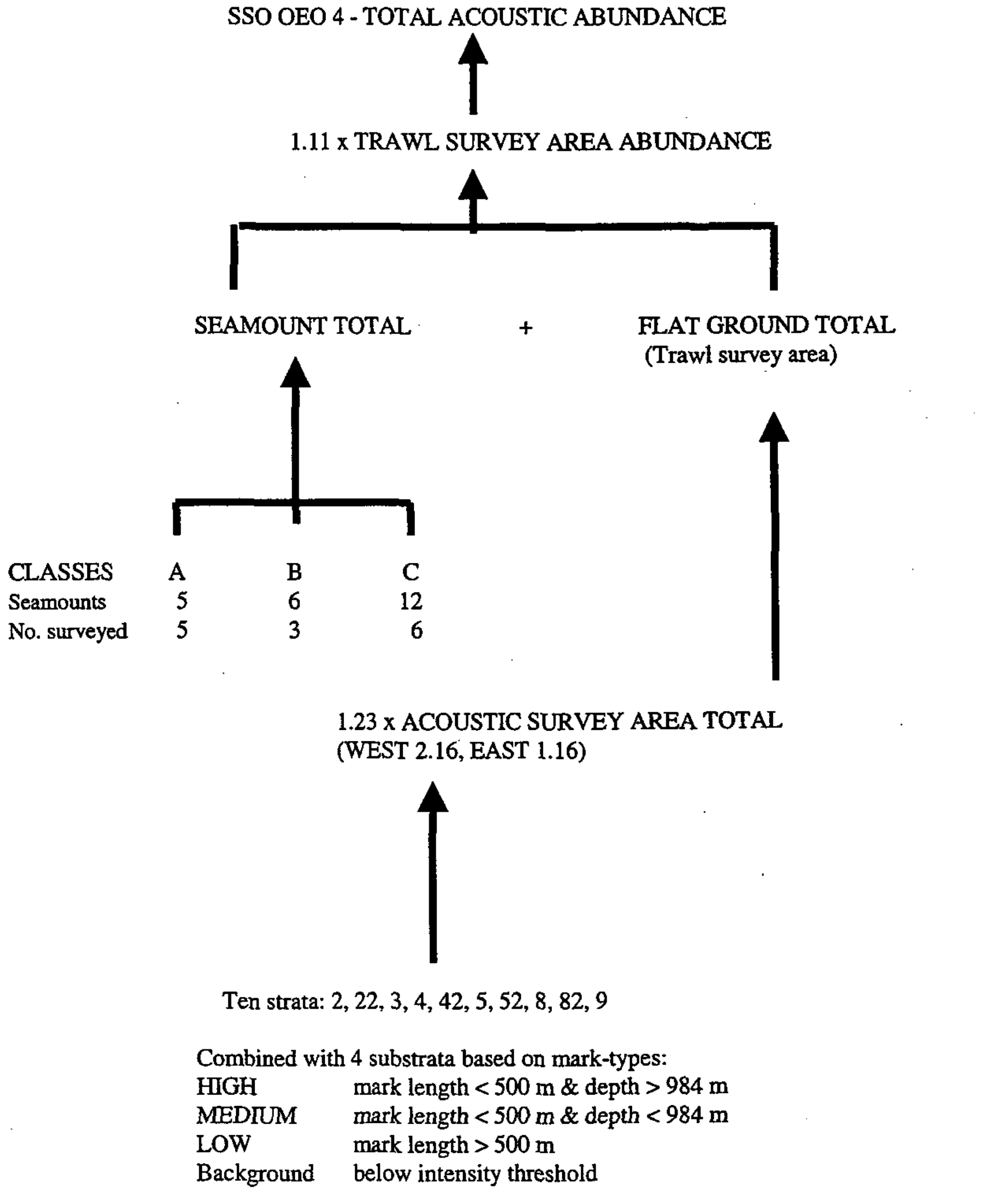

Figure 3: Schematic plan of calculations applied to the smooth oreo (SSO) survey acoustic abundance estimates to derive a total abundance estimate for OEO 4. See Sections 2.4 for an explanation of the survey design for seamounts and 2.5.2 for an explanation of mark-types.

2.5.1 Biomass scaling factors

Two biomass 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 trawl 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, LOW, MEDIUM, and HIGH) but the classification criteria were modified slightly using the new data collected during the survey (Doonan & McMillan 2000, Doonan et al. 2000, Barr et al. 2002). The scheme is tabulated in Table 2.

Table 2: Classification of echogram marks into smooth oreo mark-classes 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
LOW	7	Mark length > 434 m	178° 30′ W & 179° 15′ W
MEDIUM	29	Length ≤ 434 m & depth < 984 m	178° 30′ W
HIGH	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 used by Doonan et al. (2001) apart from the two oreo species. The latter were derived from a Monte-Carlo analysis of in situ and swimbladder data (Macaulay et al. 2001, Coombs & Barr unpublished results) and the relationships used were:

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

for smooth oreos and

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

for black oreos, where TS is the target strength and L the fish length.

Table 3: **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 telescopus*)	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

The relationship used for orange roughy is based on measurements of live fish in a tank (McClatchie et al. 1999) corrected for depth (McClatchie & Ye 2000) and combined with in situ results from Barr & Coombs (2001). For other common species we used relationships based on swimbladder modelling (Macaulay et al. 2001). Generic relationships were used for species for which no specific relationships are available as detailed by Doonan et al. (1999). A more conventional formulation of the form *TS* = *a*+*b* log10(*L*) was used for all species other than oreos and these are shown in Table 3.

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, 2000). Variance was estimated separately for the flat and for seamounts 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 smooths
- 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 oreos.

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:

$$\sqrt{\left(cv_p^2+1\right)\left(cv_R^2+1\right)-1}$$

where cv_R is the c.v. of the abundance in the acoustic survey area, cv_p is the c.v. of the factor to account for the proportion of abundance outside the acoustic survey area.

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 intercept of the target strength-length relationship was randomly shifted using a normal distribution with a zero mean and a standard deviation of 1.0 dB.
- For species with a target strength determined by swimbladder modelling, a in the relationship $TS = a + b \log_{10}(L)$ had a random value added to it from a normal distribution that had a zero mean and a standard deviation of 3 dB.
- For target strength of other species, bootstrapping was carried out in two independent parts: one for cod-like species and another for deepwater species. The target strength for each species was re-sampled as described by Doonan et al. (2000) and involved random shifts in the intercepts of the target strength-length relationships (the slope was constant at 20.)

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 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 had a different true biomass 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 seamount 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 $\sigma_{B,i}$, 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 seamounts in the category and so the variance is:

$$\begin{aligned} & \mathrm{N}_i^2 \mathrm{Var}\left(\overline{\mathrm{b}}_{i.}\right) \\ &= \mathrm{N}_i^2 \left\{\mathrm{Var}\left(\overline{\gamma}_{i.}\right) + \mathrm{Var}\left(\overline{\varepsilon}_{i.}\right)\right\} \\ &= \mathrm{N}_i^2 \left\{(1-f)\frac{\sigma_{B,i}{}^2}{\mathrm{n}_i} + \frac{\overline{\sigma^2_{W,i}}}{\mathrm{n}_i}\right\} \end{aligned}$$

where n is the number sampled, f is the sample fraction ((n-1)/(N-1)) of seamounts and $\overline{\sigma^2_{W,i}}$ is the mean variance of sampling error of the surveys on the seamounts. $\overline{\sigma^2_{W,i}}$ can be estimated and $\sigma_{B,i}{}^2$ can be found from the sample variance of the estimated seamount abundances which is equal to $\sigma_{B,i}{}^2 + \overline{\sigma^2_{W,i}}$. For the total seamount abundance, the variance is the sum of the variances of the three seamount 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 the time the distribution was measured in the trawl surveys (1992, 1993, and 1995) and 1998
- fish movements, including oreos moving to the background population from schools on both seamounts and flat
- estimating target strengths from swimbladder casts.

3. RESULTS

The transects and seamounts surveyed are shown in Figure 4.

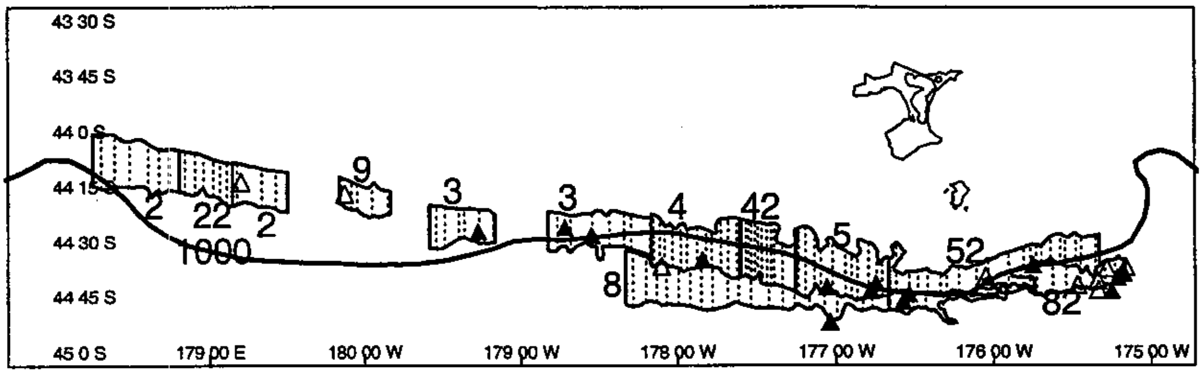

Figure 4: Flat ground strata and seamounts surveyed (solid triangles). Seamounts not surveyed are the open triangles. The dotted lines are the transects completed and the heavy solid line is the 1000 m depth contour.

3.1 Flat

The numbers of tows and acoustic transects carried out are shown in Table 4.

Table 4: 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	10	10
22	8	7
3	13	16
4	12	16
42	8	15
5	26	7
52	20	9
8	18	1
82	18	3
9	5	0

3.2 Seamounts

The number of transects and trawls carried out on each seamount is shown in Table 5. Three additional seamounts were surveyed: Big Chief (group B), Nielsons (group C), and Buccaneer Steps (group C). The Buccaneer Steps were seen on a flat strata transect, and although this complex was known in the 1980s it seems to have been forgotten and is not now fished. It increased the number of seamounts in group C by one.

Table 5: The number of transects and tows for each seamount.

Seamount group	Stratum	Number of transects	Number of tows
A	Chucky's	6	4
A	Dolly Parton	3	4
A	Hegerville	4	3
A	Paranoia	3	3
A	Trev's	2	2
B	Big Chief	2	0
B	Hiawatha	3	3
B	Tomahawk	3	5
C	Amaltal pimple	3	2
C	Condoms	2	2
C	Der Spriggs	3	1
C	Mt. Kiso	3	2
C	Nielsons	5	3
C	Pom Rock	4	2

3.3 Abundance estimates and variances

3.3.1 Flat

The biomass estimate for the flat acoustic survey area was 195 000 t with a c.v. of 21%. The scaled up estimate for the trawl survey area was 266 000 t with a c.v. of 22%. A breakdown of the percentage of the biomass by stratum is shown in Table 6 from which it can be seen that most was in the eastern strata. The HIGH and MEDIUM mark-types accounted for 25%, BACKGROUND 16%, LOW 58%. Several sources of variance were important in the estimate of abundance (Table 7), the major effect being the target strength estimates for species other than smooth oreos.

Table 6: Flat abundance: percentage by flat stratum.

Stratum	%
West strata	
2	3
22	0
3	7
9	1
East strata	
4	12
42	11
5	9
52	33
8	9
82	15

Table 7: 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), e.g., in the catches source, trawls were re-sampled within each mark-type.

Source	c.v.(%)
Catches	12
Backscatter	9
Target strength of other species	14
Target strength of oreo species	10
Scaling acoustic area to trawl survey area	6

3.3.2 Seamounts

The results of the seamount survey are summarised in Table 8, from which it can be seen that the biomass varied widely, from nothing on Der Spriggs to 3500 t on Nielsons. The estimated total biomass of smooth oreos on seamounts was 13 400 t with a c.v. of 32%. The contributions of the three seamount categories are shown in Table 9. The between-hill variances were swamped by the sampling variances and the estimate of σ_B^2 was zero. Most of the sampling variation was due to sampling error in the backscatter (Table 10).

Table 8: Seamounts surveyed, abundance estimates, and the sample error of the abundance estimates. –, na.

Seamount	Category	Abundance (t)	C.v. (%)
Chucky's	A	194	35
Trev's Pinni	A	11	30
Hegerville	A	3 287	69
Dolly Parton	A	442	42
Paranoia	A	131	58
Big Chief	B	62	59
Tomahawk	B	51	70
Hiawatha	B	8	45
Der Spriggs	C	0	–
Amaltal Pimple	C	62	77
Condoms	C	36	36
Mt Kiso	C	91	91
Nielsons Pinni	C	3 545	32
Buccaneer Steps	C	93	42

Table 9: Total seamount abundance and c.v. by seamount category.

Category	Number of seamounts		Total abundance	
	Surveyed	Total	SSO (t)	c.v. (%)
A	5	5	4 500	56
B	3	7	310	51
C	6	12	8 500	30
Total	14	24	13 400	32

Table 10: The c.v. (%) from each variation source alone (see Section 2.6.1) and the median c.v. for each source over all the seamounts surveyed for smooth oreo. E.g., in the catches source, trawls were re-sampled within each mark-type. *TS* is target strength.

	Variation source			
Seamount	Catch	Backscatter	$TS_{\text{OTHER SPECIES}}$	TS_{SSO}
Chucky's	5	30	1	19
Trev's Pinni	5	21	7	15
Hegerville	52	27	18	10
Dolly Parton	1	35	2	19
Paranoia	2	55	3	17
Big Chief	22	54	33	4
Tomahawk	49	47	37	4
Hiawatha	18	19	27	4
Amaltal Pimple	1	77	6	18
Condoms	1	29	4	17
Mt Kiso	55	48	43	2
Nielsons Pinni	100	6	12	14
Buccaneer Steps	2	21	32	7
Median	5	30	12	14

3.3.3 Total abundances for area OEO 4

The biomass from both the flat and seamounts was scaled up to the overall OEO 4 area and this gave an estimate of the abundance of smooth oreos of 279 000 t with a c.v. of 22%.

For stock assessment, the overall biomass was split into eastern and western 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 eastern area included four of the category A seamounts, all of the B seamounts, and eight of the C seamounts. Abundance estimates are presented in Table 11.

Table 11: Total abundances (t) and c.v.s (%) in the west and east partitions for the flat and seamounts.

	West		East	
	Abundance	c.v.	Abundance	c.v.
Flat	51 300	39	223 000	22
Seamount	430	31	11 700	33
Total	51 700	35	236 000	22

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 12. In contrast to the 1998 survey, several sources of uncertainty in the 2001 survey produced abundance changes greater than the total c.v. (22% for smooth oreo), and so can be considered as potential sources of bias. In part, this is because the sampling variability was much lower in 2001, by design, compared to the 1998 survey.

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 perhaps extreme and intended to capture the maximum possible error in our current target strength estimates.

Table 12: Bias sources for acoustic survey abundance estimates, smooth oreo, OEO 4, flat ground. †, magnitude exceeds c.v. for flat abundance (smooth oreo 22%). *TS*, target strength.

Source	Abundance change (%) Smooth oreo
***TS* estimate, other species**	
Lower intercepts by 3 dB	34†
Increase intercepts by 3 dB	-30†
***TS* estimate of target oreo**	
Lower intercept by 3 dB	39†
Increase intercept by 3 dB	-33†
Catchability of other species	
Twice that for target oreo	29†
Half that for target oreo	-26†
Species mix used	
Exclude black oreo (largest effect)	18
Exclude ridge-scaled rattail & Johnson's cod (second largest effect)	7

The catchabilities of other species are unknown, and it is also not known if oreos are more or less catchable than other species. The sensitivities used should be viewed as a mean change for all 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 18%, but the rest combined contributed 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 29%.

3.4.2 Seamounts

The sensitivity of the seamount abundance estimate to changes in values of contributing parameters is shown in Table 13. Again, only sources of uncertainty which produced abundance changes greater than the total c.v. (32%) 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 13: Bias sources for smooth oreo acoustic survey abundance estimates, OEO 4, seamounts. † exceeds c.v. for total seamount abundance (32%). *TS*, target strength.

Source	Abundance change (%)
***TS* estimate, other species**	
Lower intercepts by 3 dB	20
Increase intercepts by 3 dB	-23
***TS* estimate of smooth oreo**	
Lower intercept by 3 dB	53†
Increase intercept by 3 dB	-37†
Catchability of other species	
Twice that for smooth oreo	19
Half that for smooth oreo	-21
Species mix used	
Exclude black oreo (largest effect)	32
Exclude orange roughy (second largest effect)	5

4. DISCUSSION

The survey was the third acoustic survey of OEO 4 and provided the second set of absolute abundance estimates of smooth oreos. The survey was complex and covered large areas of flat ground plus the relatively tiny areas occupied by seamounts. There was a high degree of variability in the 1998 survey results and experience from that survey was used to improve the design of the 2001 survey. The main effort was aimed at covering more ground and this was achieved primarily by using two vessels, one for acoustic work (*Tangaroa*) and the other for trawling (*Amaltal Explorer*). As a result, the 2001 survey covered 10 flat strata compared to 6 in 1998 and 14 seamounts compared to 8 in 1998 (Doonan et al. 2000). In addition, the 2001 survey was designed to estimate only smooth oreo biomass whilst the 1998 survey also included black oreos.

The survey analysis differed from that in 1998 (Doonan et al. 2000) in that abundance of all smooth oreos was estimated rather than only that of recruited fish. This approach was taken because of difficulty in establishing the age and length at recruitment of black oreos in OEO 3A (Annala et al. 2002) and it was considered that a similar problem existed for both oreos in OEO 4. To make a comparison, we have made an estimate of the total smooth oreo biomass for the 1998 survey and this is 222 000 t with a c.v. of 34%. Although the 2001 result is higher at 279 000 t, the difference is not statistically significant.

This survey used a new oreo target strength relationship fitted explicitly to the data (Macaulay et al. 2001, Barr & Coombs unpublished results) rather than the usual log-linear relationship (Doonan et al. 2000). In this the target strength of large fish is a little lower than in the previous relationship, but much the same for small and medium sized fish. The effect is to increase the biomass relative to the old relationship by about 10% overall and up to 20% on seamounts.

The greater survey coverage succeeded in reducing the variability, and the c.v. for the flat estimate was 22% compared to 31% for 1998. This improved result came mainly from adding strata 8 and 82 both directly and because they substantially reduced the variability from scaling up the abundance estimates from the acoustic to the trawl survey areas with a reduction in c.v. from 22% to 6%. For seamounts, the c.v. was 32% compared to 36% in 1998.

The main source of uncertainty in the estimates resulted from uncertainty in target strength, both of oreos and of other species. For the latter, the c.v. was 14% for the flat survey and 12% for seamounts and for oreos, 10% for the flat survey and 14% for seamounts. For seamounts variability in backscatter also made a substantial contribution at 30%. Reducing the uncertainty from target strengths in future would require more data from modelling and in situ studies covering a range of sizes and oreo mark-types. The great success of reducing abundance estimate variability achieved by redesigning the survey in 2001 means that sources of variability not related to survey design are now relatively more important to improving the accuracy. These variability sources, and also potential bias sources, should be the focus for improvements to possible future surveys.

Although a considerable improvement over the earlier surveys, another problem is now apparent: a relatively high proportion of the smooth oreo biomass (58%) was in the LOW mark-type. In contrast, in 1998 most of the smooth oreo biomass (49%) was in the HIGH and MEDIUM mark-types. This difference could reflect a change in fish behaviour, abundance, or both. However, there are no data available to shed any light on the matter. Depending on the reasons for the change, this could be a significant source of bias. In addition, the problems with the acoustic equipment resulted in uncertainty about the reliability of the calibration of the faulty transducer.

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