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EXECUTIVE SUMMARY

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An acoustic survey to determine the absolute abundance of smooth oreo (*Pseudocyttus maculatus*) in area OEO 4 was carried out between 2 and 18 November 2009 using *Tangaroa* (TAN0910) for acoustic work and *San Waitaki* (SWA0901) for trawling. The survey covered the south slope of the eastern Chatham Rise and was the fourth full acoustic survey of the area; previous surveys were in 1998, 2001, and 2005. The area covered was the same as that in the 2001 and 2005 survey, which is slightly more than that in 1998. 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. The flat survey included 118 transects and 62 tows over 10 flat area strata (6 strata in 1998, 10 strata in 2001 and 2005), and the hill survey included 40 transects and 13 tows over 12 hills (8 hills in 1998, 14 in 2001, and 15 in 2005).

The total estimated abundance of smooth oreo for OEO 4 was 66 500 t with a c.v. of 37%. Abundance estimates were also made separately for the areas west and east of a north-south line at 178° 20′ W. These were 28 100 t with a c.v. of 51% for the west and 46 900 t with a c.v. of 35% 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 (27%) and the target strength of species other than oreos (18% c.v. contribution). For the hills, the main source of variability was sampling error from surveying the backscatter (30%). A potential source of bias was that 65% of the smooth oreo abundance came from the Layer and Background mark-types which contain mixed species with 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 6900 t from 1998–99 to 2008–09 (Ministry of Fisheries Science Group, 2010). There is also a substantial orange roughy fishery in the area with reported 2008–09 landings of 1200 t (Ministry of Fisheries Science Group, 2010). Oreos from hills have made up an increasing proportion of the total oreo catch in recent years.

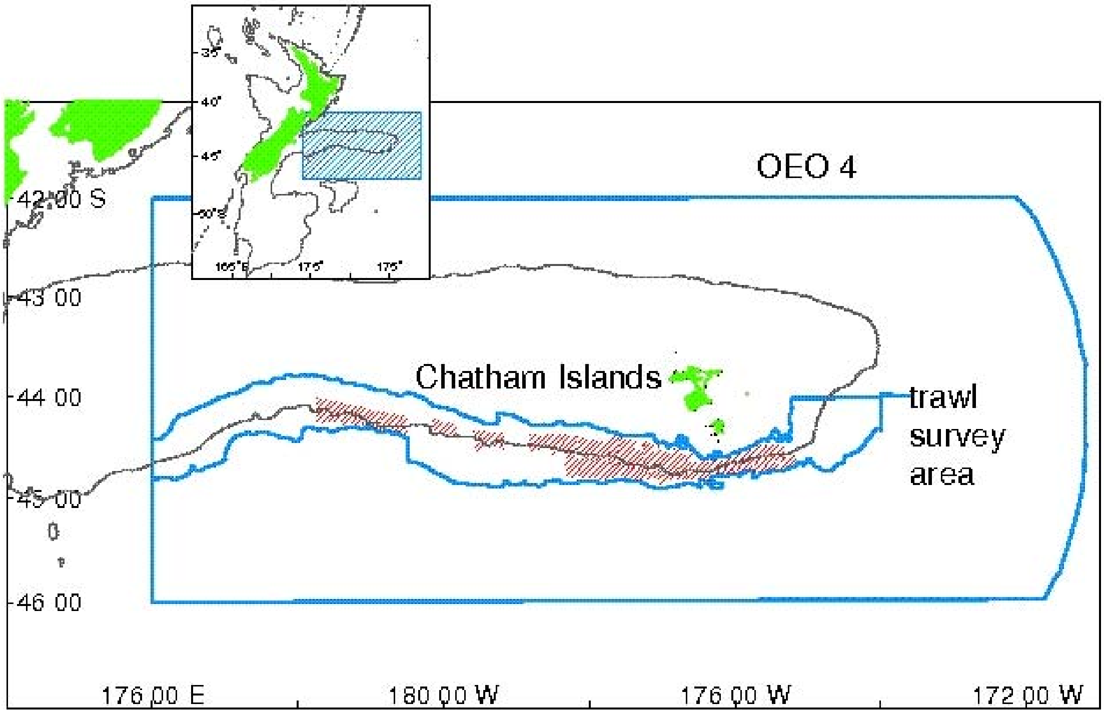

Figure 1: OEO 4 with boundaries of the previous trawl survey area and the 2009 acoustic survey area (shaded area).

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), 2005 (Doonan et al. 2008), and 2009. The last survey is the subject of this report.

The 2009 survey took place from 2 to 18 November 2009 and used *Tangaroa* for the acoustic work and *San Waitaki* for mark identification trawling. The approach to both survey design and analysis was similar to that for the 1998, 2001, and 2005 surveys.

The work described in this report was carried out under Ministry of Fisheries project OEO2009/02, having the overall objective "*To estimate the abundance of black oreo (*Allocyttus niger*) and smooth oreo (*Pseudocyttus maculatus*) in selected areas.*", and the specific objective "*To estimate the abundance, with a target coefficient of variation (c.v.) of the estimate of 20-30% for smooth oreo in OEO 4 on the Chatham Rise*"

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 depths of 100–300 m on flat ground and 200–700 m over the hills. *Tangaroa* successfully completed a deep towbody calibration on both towbody systems on 3 November and another on towbody 4 on 17 November. Because a fuse blew in towbody 4 midway through the survey, putting it onto half power, two calibrations were needed (4a and 4b). Towbody 4a applies to all data collected using Towbody 4 up to 14:30 November 6 (file d33) while Towbody 4b applies to all Towbody 4 data from this point on. 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. Note that V_T (V) has also been compensated for the depth hysteresis of the transducers (using 150 m depth for the flats and 450 m for transects over the hills).

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

System	Towed body 3 - Flat	Towed body 3 - Hills
Transducer serial no.	28332B	28332B
Nominal 3dB beam-width (°)	7.0 x 6.9	7.0 x 6.9
Effective beam angle (sr)	0.0093	0.0093
Effective pulse length (ms)	0.78	0.78
V_T (V)	1214.91	1155.28
Transducer depth (m)	100 – 300	200 – 700
G	12 866	12 866

System	Towbody 4a - Flat	Towbody 4a - Hills	Towbody 4b - Flat	Towbody 4b - Hills
Transducer serial no.	28337	28337	28337	28337
Nominal 3dB beam-width (°)	6.6 x 6.7	6.6 x 6.7	6.6 x 6.7	6.6 x 6.7
Effective beam angle (sr)	0.0081	0.0081	0.0081	0.0081
Effective pulse length (ms)	0.78	0.78	0.78	0.78
V_T (V)	1109.86	1122.49	526.24	536.97
Transducer depth (m)	100 – 300	200 – 700	100 – 300	200 – 700
G	15 208	15 208	15 208	15 208

2.3 Trawling gear

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. For tows on the flat with this net, doorspread was 130–144 m (mean 136 m) measured on 14 of the 40 tows, and headline height was 4–7 m (mean 5.4 m) measured on 40 tows. Tows on layer marks were made with the NIWA 6 panel wing net (ratcatcher) 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 128–146 m (mean 137 m) measured on 4 of the 14 tows with this net, and headline height was 3–5.0 m (mean 4.1 m) measured on 14 tows.

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 2009 survey area was the same as that used in 2001 and 2005. 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).The 2009 survey had a similar level of sampling to that used in 2005. For the hills, the overall survey effort in 2009 on hills was less than that in 2005. Because the total hill abundance was not a large proportion of the total abundance, the hills are over-sampled in a strictly statistical sense. The flat area and hills surveyed are shown in Figure 2.

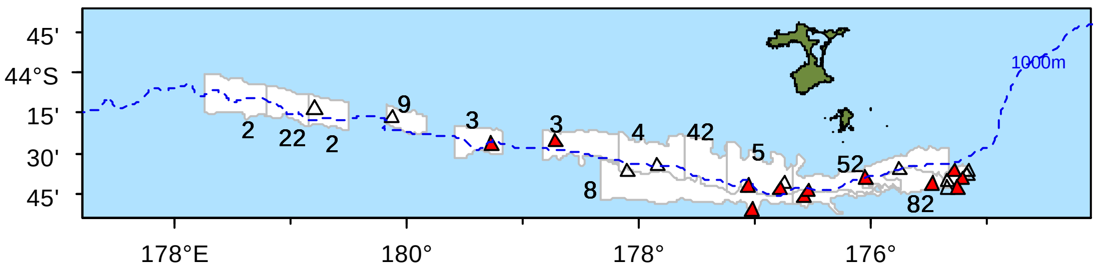

Figure 2: Flat strata and hills surveyed (filled triangles) in 2009. Hills not surveyed are the open triangles.

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. Where appropriate, the same transects line covered both strata where these overlapped longitudinally, i.e., stratum 8 with strata 4, 42, and 5; and stratum 82 with stratum 52 (Figure 2). 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 flat strata were surveyed (Table 2). The strata and stratum numbers were the same as those used in the 2001 and 2005 surveys.

We assumed that there was no movement in or 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 proportion of smooth oreo in and out of the acoustic survey area has been relatively constant since 1992 and that this proportion was measured by the trawl surveys carried out in OEO 4 in 1992, 1993, and 1995. This assumption is required if we want to scale up 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 and 2005 acoustic survey°.

	Stratum	Area (km^2)	Depth (m)	Longitude range	Importance in survey (%) 2001	2005
East strata						
	4	1 050	800–1 200	178° 10′W–177° 35′W	12	4
	42	760	800–1 200	177° 35′W–177° 15′W	11	6
	5	1 188	800–1 200	177° 15′W–176° 40′W	9	9
	52	1 487	800–1 200	176° 40′W–175° 20′W	33	41
	8	1 885	1 200–1 400	178° 20′W–176° 40′W	9	11
	82	1 046	1 200–1 400	176° 40′W–175° 10′W	15	12
West strata						
	2	1 594	850–1150	178° 15′ E–178° 50′ E 179° 10′ E–179° 30′ E	3	2
	22	558	850–1150	178° 50′ E–179° 10′ E	0	3
	9	367	800–1000	179° 50′ E–179° 50′W	1	2
	3	1 543	850–1150	179° 35′W–179° 10′W 178° 50′W–178° 10′W	7	10

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 initial set of hills to be surveyed was chosen from the set of known south Chatham Rise hill complexes and individual hills (agreed at a meeting between the Ministry of Fisheries, NIWA, and ORMC held on 23 September 1997), as modified by the results of the 1998 survey, catch data, and by recommendations from fishing skippers. It was desirable to select randomly from homogeneous subsets of hills (i.e., hills with similar catch histories and similar sizes) and they were grouped into three categories, A, B, and C, based on rankings using the following criteria.

1. Catch history, i.e., hills which produced large catches of smooth oreo in the 6 years before 1998 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.

In 2005, analysis of catch data from 1998–99 to 2003–04 suggested that the survey should be extended to include the Andes complex of hills near 44º 10’ S 174º 30’ W. However, the 2005 survey estimated only about 55 t (Doonan et al. 2008) from the Andes, i.e., about 0.05% of the total abundance. In 2009, the Andes were removed from the hill list which saved about 1 day (the rest of the OEO 4 survey takes about 14 days).

Twelve hills were sampled including all category A hills (6), 3 in category B, and 3 in category C. The hills for categories B and C were selected at random from those listed below. Hegerville and Nielson’s are large hills 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. † added in 2005

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

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° 09.78′ 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

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 by an west/east split 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.

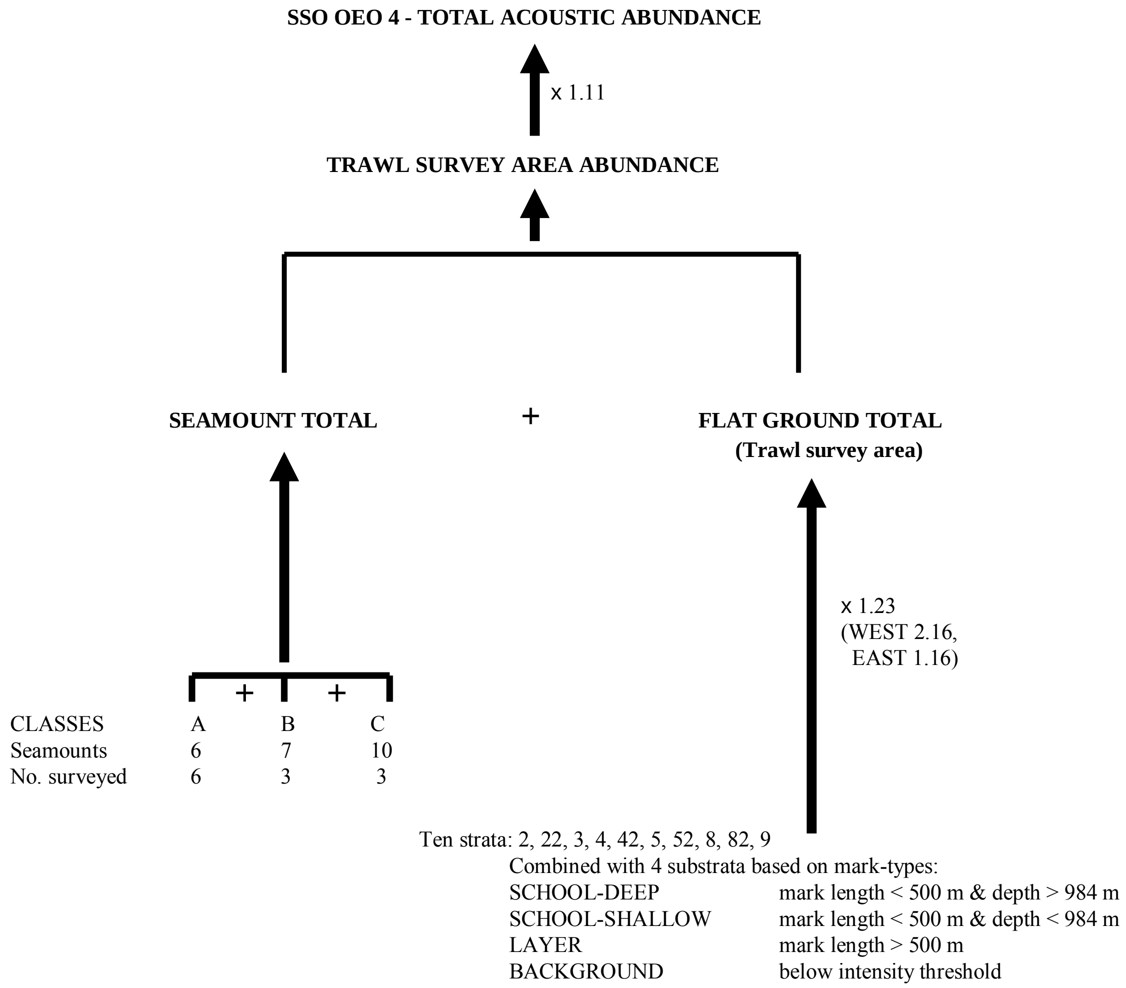

Figure 3: Schematic plan of calculations applied to the smooth oreo (SSO) survey acoustic abundance estimates to derive a total abundance estimate for OEO 4. See Section 2.4 for an explanation of the survey design for hills and 2.5.2 for an explanation of mark-types.

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). The factor is then the inverse of the proportion. A mean smooth oreo density was estimated for each trawl stratum and this was then applied to the subareas in the stratum that were inside the acoustic survey area. The fraction of smooth oreo abundance in the acoustic area was the sum over strata of the mean stratum density times the area within the ground surveyed by acoustics divided by the abundance in the trawl survey area. For the total acoustic area, the factor was 1.23 (6% c.v.). Estimates were required for the west and eastern parts. For each part, only the data in each part was used for the factor which gave 2.16 (2% c.v.) for the west, and 1.16 (4% c.v.) for the east. Note that defining factors this ways means that the sum of the abundances for the west and east will not necessary add up to that for the total area once the ratio of the east:west abundance moves away from that in the early 1990s.

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. The 1.11 value has been used in the 2001 and 2005 surveys too.

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 from the 1998 and 2001 data.

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 Macaulay et al. (2008). 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	-76.81	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, 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 $\sigma_{B,i}$, 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:

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

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. Two unknown marks observed in stratum 82 were excluded from the analysis since they appear unlikely to be smooth oreo. Six tows on the flat were not used in the flat strata, five of which missed the target mark. The sixth tow was on the background but caught more than half a tonne of SSO and therefore was excluded as background tow.

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

Stratum	Number of transects	Number of tows
2	8	3
22	6	2
3	10	6
9	5	0
4	10	11
42	10	8
5	9	10
52	20	17
8	20	1
82	20	4
Total	118	62

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 2009 survey Number of tows			Supplemented Total number of tows used			Supplemented Source of supplemented tows		
Stratum	School-deep	School-shallow	Layer	School-deep	School-shallow	Layer	School-deep	School-shallow	Layer
West strata									
2	1	2	0	‡0	5	‡0	‡	22, 3	‡
22	1	1	0	4	5	6	2, 3	2, 3	3, 4
3	3	2	1	3	6	6		4	4
9	0	0	0	‡0	5	‡0	‡	2, 22, 3	‡
East strata									
4	2	4	5	6	4	5	3, 42		
42	1	3	4	4	3	4	4, 5		
5	1	1	8	5	‡0	8	42, 52	‡	
52	3	1	13	4	2	13	5	5	
8	1	0	0	5	§0	*2	82	§	*8
82	4	0	0	4	§0	*2		§	*8

‡ Supplementary tows not required since there were no marks of this type on transects in the stratum.
§ Stratum too deep for this mark type.
* Supplementary tows for both strata are from stratum 8 of the 2005 survey.

3.2 Hills

The number of transects and tows carried out on each hill is shown in Table 7. Parallel transect designs rather than star transect designs were used for Hegerville and Nielson's.

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

Hill	Number of transects	Number of tows
Chucky's	3	1
Trev's Pinni	3	1
Hegerville	5	3
Dolly Parton	3	2
Paranoia	3	2
Nielson's	5	1
Big Chief	3	1
Hiawatha	3	1
Flintstone	3	‡0
Mt Kiso	3	1
Featherlite	3	‡0
Mangrove	3	1

‡ Tows from the 2005 survey were supplemented.

3.3 Abundance estimates and variances

3.3.1 Flat

The abundance estimate for the flat acoustic survey area was 44 900 t with a c.v. of 37%. 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 35%, Background 24%, and Layer 41%. 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 (%)	5	4	1	14	8	2	21	28	6	10

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. Total c.v. is approximately given by $\sqrt{\sum_i cv_i^2} \approx 36$ % (cf 37 % above).

Source	c.v. (%)	Cumulative c.v. (%)
Sampling error from catch data	27	27.0
Estimation error in target strength of other species	18	32.5
Sampling error from backscatter data	12	34.6
Estimation error in target strength of oreo species	7	35.3
Estimation error in the scaling factor from acoustic area to trawl survey area	6	35.8

3.3.2 Hills

The results of the hill survey are summarised in Table 10, and show that the abundance varied widely, from 0.5 t on Flintstone to 494 t on Chucky's. The estimated total abundance of smooth oreo on hills was 4710 t with a c.v. of 23%. 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 σ_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.

Hill	Category	Abundance (t)	c.v. (%)
Chucky's	A	494	30
Trev's Pinni	A	135	38
Hegerville	A	360	69
Dolly Parton	A	321	34
Paranoia	A	232	48
Nielson's	A	491	39
Big Chief	B	78	33
Hiawatha	B	102	76
Flintstone	B	1	78
Mt Kiso	C	488	68
Featherlite	C	26	51
Mangrove	C	163	60

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	2 030	26
B	3	7	420	47
C	3	10	2 250	40
Total	12	23	4 710	23

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. Cumulative c.v. is calculated from the median c.v.s using $\sqrt{\sum_i cv_i^2}$.

	Variation source			
Hill	Backscatter	TS_{SSO}	$TS_{OTHER\ SPECIES}$	Catch
Chucky's	18	21	4	1
Trev'sPinni	31	22	0	0
Hegerville	27	8	27	50
DollyParton	24	22	1	4
Paranoia	43	21	3	2
Nielson's	28	10	21	7
Big Chief	26	11	10	6
Hiawatha	71	22	0	0
Flintstone	74	1	20	12
Mt Kiso	20	3	18	61
Featherlite	43	11	17	7
Mangrove	54	21	1	0
Median	30	16	7	5
Cumulative c.v. (%)	30.0	34.0	34.7	35.1

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 66 500 t with a c.v. of 36%.

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 (Andes) hills, and 11 of the C hills. Abundance estimates are presented in Table 13A.

Table 13: Total abundances (t) and c.v.s (%) in the west and east parts for the flat and hills (A) with scale-up factors applied, and abundance by flat stratum (`000 t) with no scale-up factors, scale-up factors derived for the whole trawl survey area (1.35), and scale-up factors by east (1.28) and west (2.38) applied. The scale-up factor combines both the acoustic to trawl area factor and the trawl to OEO4 management area factor.

A)

	West		East	
	Abundance	c.v.	Abundance	c.v.
Flat	26 400	51	43 600	36
Hill	1 800	52	3 300	25
Total	28 100	51	46 900	35

B)

	West				East					
Stratum	2	22	3	9	4	42	5	52	8	82
No scale-up factors	2 364	1 878	487	6 265	3 689	970	9 523	12 693	2 514	4 498
Using scale-up factor derived from the whole trawl survey area	3 198	2 541	659	8 477	4 991	1 312	12 885	17 174	3 401	6 086
Using east/west scale-up factors	5 617	4 462	1 157	14 886	4 707	1 238	12 151	16 196	3 208	5 739

Notice that the sum of the east and west estimated abundances do not add up because the balance of abundances between east and west has shifted from the ratio that was present in the early 1990s when the trawl data used to derive the scale-up factors was sampled. Table 13B shows the effect on the flat strata abundances when the alternative scale-up factors are applied.

3.4 Bias, sensitivities, and corrections

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 2009 survey produced abundance changes greater than the total c.v. (37% 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 46–58 % change in abundance were when the relative catchabilities of species other than smooth oreo were changed by a factor of two. The next most important sensitivity occurred when the intercept of the target strength-length curve for species other than smooth oreo was changed by ±3 dB. 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. Also, the 3 dB used in the sensitivities was considered extreme and intended to capture the maximum possible error in our current target strength estimates.

When individual species were excluded from the catch, the maximum change in abundance was 22% for excluding basketwork eels and 15% for excluding Johnson's cod. Excluding other species had much smaller effects.

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

Source	Smooth oreo abundance change (%)
***TS* estimate, other species**	
Lower intercepts by 3 dB	57†
Increase intercepts by 3 dB	-38†
***TS* estimate of target smooth oreo**	
Lower intercept by 3 dB	23
Increase intercept by 3 dB	-21
Catchability of other species	
Twice that for target smooth oreo	46†
Half that for target smooth oreo	-58†
Species mix used	
Exclude basketwork eel (largest effect)	22
Exclude Johnson's cod (second largest effect)	15
Exclude ridge scaled rattail (third largest effect)	8
Exclude black oreo (fourth largest effect)	6
Exclude four rayed rattail (fifth largest effect)	5
Exclude any other species	<5

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. (23%) 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 (23%). *TS*, target strength.

Source	Abundance change (%)
***TS* estimate, other species**	
Lower intercepts by 3 dB	23
Increase intercepts by 3 dB	-19
***TS* estimate of smooth oreo**	
Lower intercept by 3 dB	62†
Increase intercept by 3 dB	-38†
Catchability of other species	
Twice that for smooth oreo	21
Half that for smooth oreo	-33†
Species mix used	
Exclude black oreo (largest effect)	55†
Exclude black javelinfish (second largest effect)	7
Exclude four rayed rattail (third largest effect)	7
Exclude any other species	<2

3.4.3 Corrections

Average corrections for each stratum are shown in Table 16. Apart from the hills, shadow zone corrections are small. However, motion corrections are large, with hills being the worst since the vessel goes slower to get the tow body lower in the water column which makes it move more. For the flat strata, transects were aligned north-south and the eastern strata (4, 42, 5, 52, 8, and 82) showed a significant difference in the mean motion correction between the two directions. The major component seems to be swell height and this is approximately indexed by wind speed. Mean daily wind speed was over 20 knots for all but 3 days in the field (Figure 4) and the wind speed was best (lowest) at the end of the survey when the western strata were surveyed.

The nature of the effect of weather on the motion correction is seen for stratum 52 in Figure 5. Here, towing the towbody north results in consistently lower motion correction than when travelling south.

Table 16: For each stratum, average corrections from shadow zone and towbody motion. For flat strata, motion correction by direction travelled over the transect (calculated from backscatter over all mark classes, not SSO biomass as in column 4). Base biomass does not have any scale-up factors applied to it.

Stratum	Base biomass (t)	Correction(%)			Motion correction (%)	
		shadow	motion	both	North-south	South-north
2	1959	4	17	21	18	20
22	1581	3	16	19	16	22
3	5307	5	14	18	22	21
4	2689	10	28	37	19	47
42	679	9	34	43	69	23
5	6844	6	33	39	87	18
52	8821	6	38	44	69	23
8	1325	17	72	90	66	61
82	2704	6	60	66	111	41
9	382	2	25	27	9	31
Big Chief	51	11	43	53	–	–
Chucky's	192	19	138	157	–	–
Dolly Parton	117	46	128	175	–	–
Featherlite	10	76	75	151	–	–
Flintstone	0.24	47	87	106	–	–
Hegerville	247	7	39	46	–	–
Hiawatha	37	38	136	174	–	–
Mangrove	89	22	61	83	–	–
Mt Kiso	423	4	11	15	–	–
Nielson's	213	26	104	130	–	–
Paranoia	86	54	115	170	–	–
Trev's Pinni	105	10	18	28	–	–

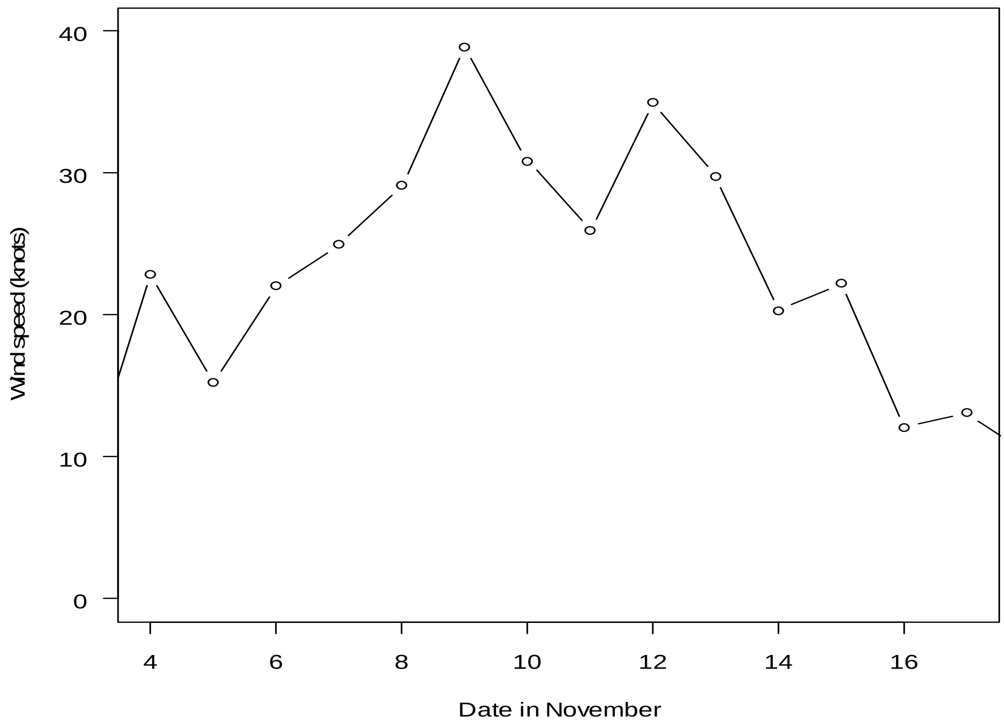

Figure 4: Mean daily wind speed for days in the field (4–17 November 2009).

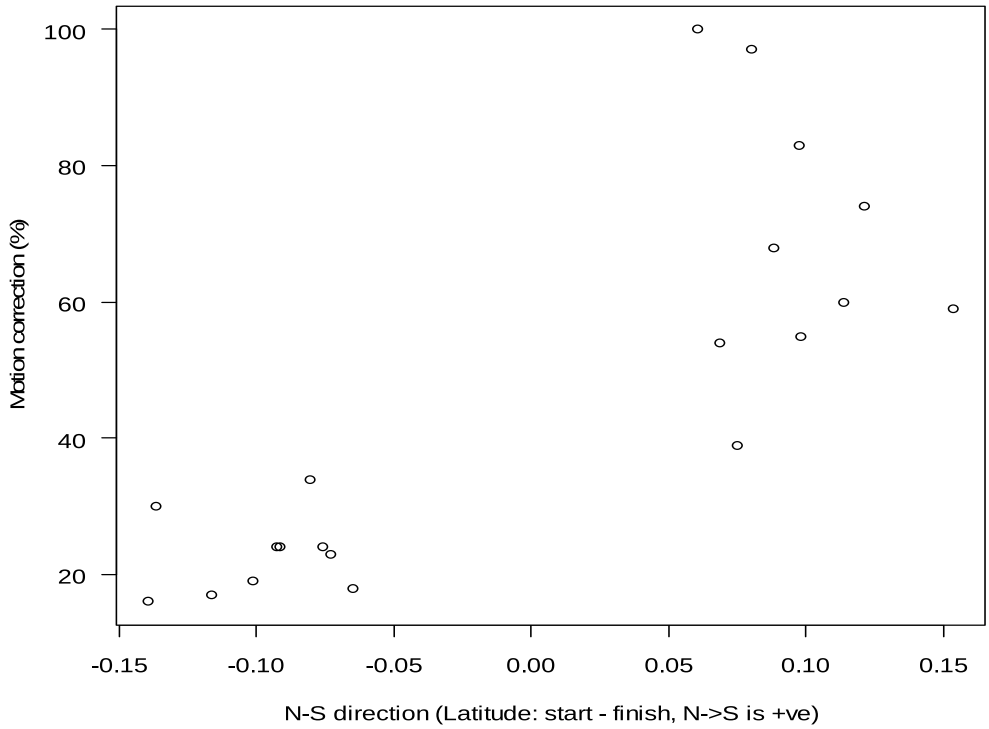

Figure 5: For stratum 52 by transect, motion correction.

4. CONCLUSIONS

For comparison, the estimates that will be used in the stock assessment and the total abundances using the total area scale-up factors are shown in Table 17. By their nature, the scale-up factors for the acoustic to trawl survey area when broken down into west and east components do not necessarily give the same results when using the factor for the total survey area. Table 17 shows that the total abundance is approximately the sum of the west and east parts, except for 2009 where it deviates markedly. This appears to be because the balance of abundances between east and west has shifted from the ratio that was present in the early 1990s when the trawl data used to derive the scale-up factors was sampled. The west:east ratio of abundance has increased over the series from 0.18 in 1998, 0.23 in 2001, 0.35 in 2005, and 0.60 in 2009. The main driver is the greater overall change in the east abundance over the series compared to the west.

Table 17: Abundance values as used in the OEO 4 smooth oreo stock assessment and the total estimated abundance.

	West		East		Total	
Survey year	Abundance (t)	c.v. (%)	Abundance (t)	c.v. (%)	Abundance (t)	c.v. (%)
1998	22 600	52	127 000	37	146 000	33
2001	43 000	35	183 200	22	218 200	22
2005	32 200	31	91 800	30	115 500	28
2009	28 100	51	46 900	35	66 500	36

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 (65%) from Layer and Background 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.

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