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Tini a Tangaroa

Smooth oreo abundance estimates from the October-November 2016 acoustic survey of the south Chatham Rise (OEO 4)

New Zealand Fisheries Assessment Report 2018/58

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Doonan, I.J.; Hart, A.C.; Ladroit, Y.; McMillan, P.J. (2018). Smooth oreo abundance estimates from the October-November 2016 acoustic survey of the south Chatham Rise (OEO 4).

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An acoustic survey to determine the absolute abundance of smooth oreo (*Pseudocyttus maculatus*) on the southeast slope of Chatham Rise (area OEO 4) was carried out from 16 October to 8 November 2016 using *Amaltal Explorer* (AEX1602) for both the acoustic work and for trawling. The survey was the sixth full acoustic survey of the area. Previous acoustic surveys were carried out in 1998, 2001, 2005, 2009, and 2012. The 2016 survey covered the same area as the 2001, 2005, 2009, and 2012 surveys, but strata 2, 22, and 9 at the western end of the survey area, covered in previous surveys, were excluded, and a new stratum (83) was created to enclose a small area where high-density marks were observed in past surveys. 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 97 transects and 24 successful mark identification tows over 8 flat area strata. The hill survey included 35 transects and 14 tows over 12 hills, although 2 hills had no acoustic marks. There were also 9 target strength tows (7 on smooth oreo and 2 on robust cardinalfish, *Epigonus robustus*), and 8 unsuccessful tows (missed the mark or suffered gear malfunction).

The total estimated abundance of smooth oreo for OEO 4 in 2016, based on School mark-types only, was 34 000 t with a coefficient of variation (CV) of 32%. The estimates for the 2012 survey were 88 600 t and 42%, although 39% of the 2012 survey smooth oreo flat abundance estimate was from the Layer and Background mark-types which contained mixed species. No high-density marks were observed in the new stratum 83 in 2016, in contrast to 2012 when about 18% of the total estimate came from one school mark on the flat (which was not fished). The other main difference to 2012 was that in 2016 the hills contributed 67% of the total abundance (compared to 13% in 2012).

1. INTRODUCTION

The southeast Chatham Rise (OEO 4) is the main smooth oreo (*Pseudocyttus maculatus*) fishing area in the New Zealand EEZ (Figure 1), with mean annual catch from 1997–98 to 2007–08 of 5300 t (Ministry for Primary Industries 2017). There is also a substantial orange roughy fishery in the area (Ministry for Primary Industries 2017).

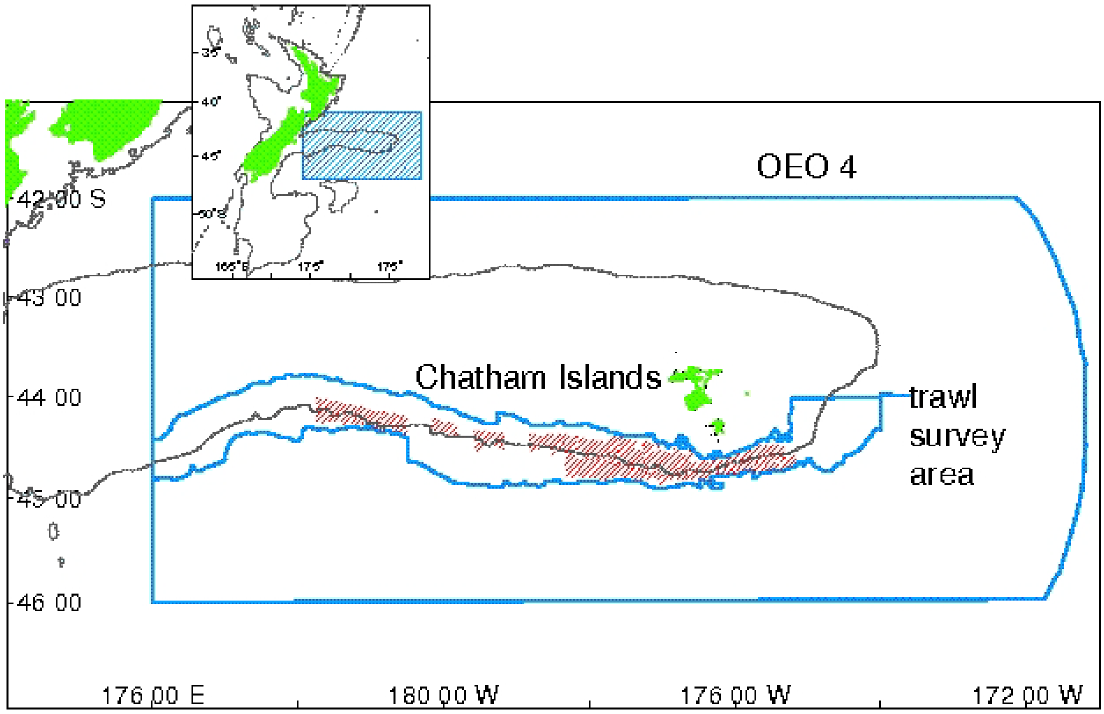

Figure 1: OEO 4 with boundaries of the previous trawl survey area and the 2012 acoustic survey area (brown shaded area). Stratum 2, 22, and 9 at the west end of the acoustic survey area were not surveyed in 2016.

Both smooth oreo and black oreo (*Allocyttus niger*) are widespread in OEO 4 between depths of about 600 and 1200 m and typically form aggregations or schools, particularly when spawning. Schools show on echosounder traces as ‘pyramid’ or ‘ball’ marks. Black oreo and smooth oreo 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 populations and the low probability of encountering a school 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 distributions is a problem for trawl surveys, aggregations are much better suited to acoustic techniques, particularly since they are largely monospecific. Some initial investigations of acoustic methods 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), 2009 (Doonan et al. 2011), 2012 (Doonan et al. 2014), and 2016 (Hart & Doonan, 2017). The last survey is the subject of this report.

The work described in this report was carried out for the Ministry for Primary Industries research project DEE201606, titled “Estimation of the abundance of smooth oreo in OEO 4 using acoustic surveys”. The overall objective for this project was: To estimate the abundance of smooth oreo (*Pseudocyttus maculatus*) in OEO 4 on the Chatham Rise using an acoustic survey. The specific objectives were:

1. To estimate the abundance of smooth oreo in OEO 4 on the Chatham Rise using acoustic survey

2. To calibrate acoustic equipment used in the acoustic survey.

2. METHODS

The 2016 survey took place from 16 October to 8 November 2016 using *Amaltal Explorer* (AEX1602) for both the acoustic work and mark identification trawling. The approach to both survey design and analysis followed that used in previous acoustic surveys. The survey measured acoustic backscatter together with information on the size and age structure of smooth oreo and the mix of species present in acoustic marks obtained by trawling. A stratified random approach was used (Jolly & Hampton 1990) with strata based on the trawl surveys, modified by the 1998 acoustic survey results and recent commercial catch data.

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 (biomass) 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 several physical factors that affect the accuracy of the estimates of backscatter and the most important for oreo surveys are shadowing, motion of the echosounder (both hull and Acoustic Optical System (AOS) see Section 2.2), and absorption of sound by seawater (Doonan et al. 2000). 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 seafloor, then the seafloor reflection from the central part of the beam swamps the reflections from fish close to the seafloor in the outer parts of the beam. There is thus a volume close to the seafloor 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, on the pulse length used and on the local slope of the bottom. The shadow zone on a flat seafloor is typically around 1 metre, but can be as big as 30 metres or more on steep hills. 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 included 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) for the AOS data. An average correction of 1.33 (2012 survey result) was used to correct the 2016 survey hull data because hull motion recording was not synchronised with the echosounder recording during the 2016 survey. The final abundance estimate included 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 range is involved (e.g., deeper strata). The absorption coefficient was estimated from temperature and salinity data using the relationship derived by Doonan et al. (2003b) 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

Acoustic data were collected mostly with the *Amaltal Explorer* hull mounted Simrad ES60 echosounder, but the NIWA Acoustic Optical System (AOS) was used when weather conditions were adverse, for all hill survey, and for target strength work. The AOS consisted of a Simrad EK60, 38 kHz echosounder, a high-definition video camera, lights, batteries, and an acquisition/recording computer, that was installed into a steel frame designed for mounting on a trawl. The system was autonomous and did not communicate with the surface. It operated in two different modes: survey mode or target strength mode. In survey mode it behaved similarly to a hull system, without the use of camera or lights, and recorded acoustic data (with a 1500 m range and 1 ping every 3 seconds), and depth and temperature data from auxiliary sensors. In target strength mode, it recorded short range acoustic data (to 50 m from echosounder), at a faster ping rate (5 times a second) and was synchronized with the video recorder and lights were turned on. O'Driscoll et al. (2013) gave a full description of the system. The AOS was mounted on the headline of the vessel trawl net and this was towed at about 5 knots at depths of approximately 100–300 m on flat ground and 250–500 m over the hills. Excellent weather meant that most of the flat area strata were surveyed with the hull echosounder. The 38 kHz hull and AOS data were used in all abundance estimation.

A deep calibration of the AOS was carried out during the survey on 20 October 2016 and NIWA calibrated the *Amaltal Explorer* hull Simrad ES60 echosounder on 13 August 2016 in Tasman Bay. The calibrations 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. Calibration results are summarised in Appendix 1.

2.3 Acoustic transects

Transects were surveyed only during good weather, i.e., wind strength below 20 knots, otherwise bubbles in the sub-surface layer would cause problems with the acoustic signal. There are two sources of bubbles. First, bubbles from the surface move down under the hull and some cross the transducer face and cause drop-outs in the echogram. Drop-outs can be seen on the echogram and were excluded in the analysis. Secondly, and more importantly, are tiny bubbles caused by wind in the upper layers of the sea (sea state i.e., waves, and temperature are factors also, but wind alone is used to index the effect). These bubbles are microscopic (the most common size is about 0.05 mm) and reduce the acoustic signal, once as the signal goes down, and again for the return signal. The effect is that the acoustic return signal from fish schools is at a lower intensity than it should be and a correction should be applied. The stronger the wind, the higher the correction, e.g., experimental results by Dalen & Løvik (1981) gave a correction of 3.8 times at 30 knots cf. 1.73 at 20 knots, and a theoretical analysis by Novarini & Bruno (1982) gave corrections of 20.7 times at 30 knots and 1.1 times at 20 knots (transducer depth unknown). The Deepwater Stock Assessment Working Group decided that corrections were too unreliable at wind speed greater than 20 knots so acoustic survey work using hull sounders should therefore be restricted to wind speeds less than about 20 knots.

The NIWA AOS, mounted on the headline of the trawl net, was used when wind speeds were over 20 knots, and the ship hull transducer was used when wind speeds were below 20 knots. The hull transducer was used with a vessel speed of about 10 knots, but the AOS was restricted to about 5 knots or less, which would increase the length of the acoustic survey over the relatively large survey area on the south Chatham Rise. The AOS was also used for hills to enable the transducer to be closer to the bottom to minimise the shadowing effects of sloping sea-bottoms.

2.4 Target strength experiments

A meeting of the Deepwater Working Group that considered the 2016 OEO 4 smooth oreo acoustic survey proposed that target strength work should be attempted if time allowed during the survey, after the abundance survey was complete. The survey proceeded smoothly, largely due to very good weather and consequently it was possible to carry out several acoustic mark target strength experiments. The primary target for measurement of target strength was smooth oreo, but experiments were also carried out on substantial marks of uncertain identity observed at smooth oreo depths. Target strength data were recorded using the NIWA AOS attached to the headline of the net while trawling on target marks. The codend of the net was closed so that the species identity and size of the individual fish in the mark could be measured and recorded. Such tows were confined to the target mark and were therefore often of relatively short duration.

2.5 Trawl gear

Amaltal Explorer used a two-panel Explorer Lioness bottom trawl net for most of the tows. This had a total footrope of 76 m, and the net was fished with 45 m sweeps and 45 m bridles and used a 100 mm mesh codend. For tows on the flat with this net, doorspread distance was 122–161 m (mean 144.8 m) measured on 14 tows, and headline height was 4–7 m (mean 5.1 m) measured on 31 tows. Two experimental mark identification tows on midwater marks were made with a midwater net supplied by the vessel.

2.6 Survey design

The survey area (Figure 2) 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 included both flat and undulating ground (‘flat’), and hills, and was chosen to yield a target coefficient of variation (CV) of 30% or less while minimising the time taken to complete the work. The 2001, 2005, 2009, and 2012 surveys had the same flat area and used two survey vessels, one for the acoustic survey and the second for mark identification trawling.

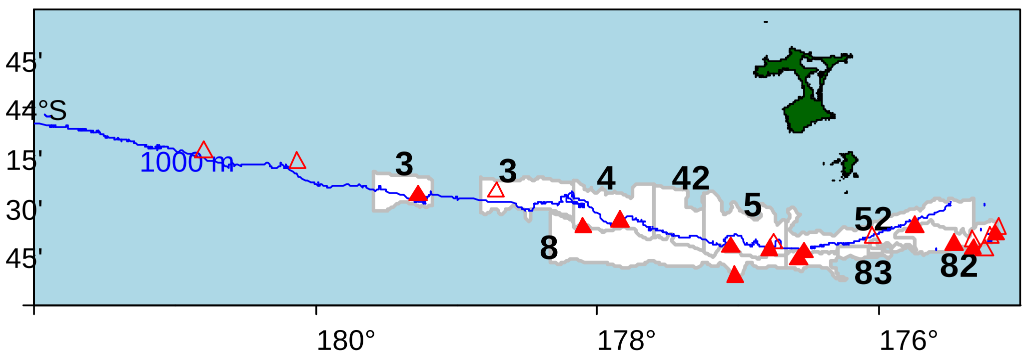

Figure 2: Survey strata and selected hills (filled triangles) for the 2016 smooth oreo acoustic survey of OEO 4. Bold numbers are the flat area strata. Stratum 3 and 82 had two separate parts. Hills not surveyed are the open triangles.

2.6.1 Flat area

A conventional stratified random approach was used (Jolly & Hampton 1990) and strata were chosen to cover the main smooth oreo fishing areas and abundance observed from previous research surveys. In each stratum, several randomly positioned north-south acoustic transects were generated. Where appropriate, the same transect 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. 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.
- There was no movement in or out of the acoustic survey area during the survey. We treated all the information for the area and duration of the survey as being synoptic or instantaneous.
- The proportion of smooth oreo in and out of the acoustic survey area has remained relatively constant since 1992. This proportion was measured by the trawl surveys carried out in OEO 4 in 1992, 1993, and 1995. This assumption was required for scaling up the acoustic abundance to the larger trawl survey area.

The survey was designed to achieve a CV of 25% for the estimate of total abundance, i.e., within the 20–30 % stated in the contract. 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 black oreo and smooth oreo in the species mix.
- Experimental error in the determination of the target strength of both oreos.

The 2016 flat survey area was reduced for the acoustic survey and all trawling. Three strata (2, 9, and 22) surveyed in previous surveys were excluded. These strata had persistently low short-mark abundances, i.e., they collectively averaged 7.5% of the total short-mark abundance over the last four surveys (Table 1). The previous abundance contribution of the two parts of stratum 3 was also analysed to determine if one or both parts could be omitted, but each had similar numbers of short marks with relatively high abundance estimates from some surveys, i.e., 2005 and 2009. A small stratum (83) was constructed to enclose a part of stratum 82 where large acoustic marks were observed in the 2009 and 2012 surveys. The other strata surveyed in 2016 were the same as those used in the 2001, 2005, 2009, and 2012 surveys and are described in Table 2, along with the number of planned transects.

Table 1: Relative proportions of short-mark abundance by flat strata for the 2001, 2005, 2009, and 2012 surveys. Rounding means that numbers may not sum to 100%.

Stratum	2	22	3	9	4	42	5	52	8	82	2 + 22 + 9
2001	2	0	7	0	12	18	10	13	1	36	3
2005	2	5	16	4	3	9	3	14	21	22	11
2009	3	8	26	2	9	2	13	17	0	20	13
2012	2	0	0	1	8	3	4	57	17	8	3
Mean	3	3	12	2	8	8	7	25	10	22	7

Table 2: Flat area strata surveyed in 2016: area, depth range, longitude range, and planned transects. Transects were bounded by depth, e.g., 800 to 1200 m rather than latitude, except for the northern boundary of stratum 83† which was bounded at 44º 42.5´S. ‡ stratum 3 had two parts

Stratum	Area (km^2)	Depth (m)	Longitude range	Transects
3‡	1 543	850–1150	179 35'W–179 10'W	10
			178 50'W–178 10'W	
4	1 050	800–1 200	178 10'W–177 35'W	6
5	1 188	800–1 200	177 15'W–176 40'W	6
8	1 885	1 200–1 400	178 20'W–176 40'W	8
42	760	800–1 200	177 35'W–177 15'W	6
52	1 435	800–1 200	176 40'W–175 20'W	18
82	992	1 200–1 400	176 40'W–175 10'W	18
83	107	†–1 400	176 18'W–176 05'W	7

Stratum 83

During the 2005 and 2012 surveys, large and intense acoustic marks were observed in an area in strata 52 and 82 south of Pitt Island. One mark observed but not fished in stratum 52 on transect 8 (at about 176° 9′ W over a bottom depth of 1150 m) in 2012 was assumed to be smooth oreo and contributed about 16 000 t (67 %) of the smooth oreo abundance from stratum 52 and about 25% of the total survey smooth oreo abundance estimate. It is important to determine the catch composition of very large marks by trawling because of the potential large contribution to the abundance estimate. A new stratum, 83 (Figure 2, Table 2), was therefore constructed for this area to isolate these marks from the rest of the stratum. About one day of survey time was specifically allocated to trawling on any large marks that were found, and to run a grid of acoustic transect lines (regularly spaced north-south or vice versa lines) over such marks.

2.6.2 Hills

Each hill was defined as a stratum and was surveyed with randomly allocated parallel transects or systematically allocated transects in a ‘star’ pattern (Doonan et al. 2003a). The initial set of hills to be surveyed was chosen from a set of south Chatham Rise hill complexes and individual hills (agreed at a meeting between the then Ministry of Fisheries, NIWA, and the then Orange Roughy Management Company 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 those selected were grouped into three categories, A, B, and C (Table 3), 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 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 at around 44º 10’ S 174º 30’ W. However, the 2005 survey estimated only about 55 t of smooth oreo (Doonan et al. 2008) on the Andes, i.e., about 0.05% of the total abundance. The Andes were therefore removed from the hill list in 2009, which saved about one survey day, and the Andes was not considered in 2016. The Group B hills (Big Chief complex) contributed a relatively low abundance in past surveys, so fewer (two rather than three) hills were surveyed in 2016, and Flintstone, which was surveyed three times with the highest abundance of 1 t, was deleted from the list of Group B hills. The survey effort on hills in 2016 was similar to the effort in 2009 and 2012, and the hills selected in 2016 are shown in Figure 2, and Table 3.

Twelve hills were selected for the 2016 survey including all category A hills (6), 2 in category B, and 4 in category C, (Figure 2, and Table 3). 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.

Table 3: Hill strata: position of hill top and relative importance. ‡, hill selected.

A: Most important hills (mean catches greater than 250 t total since 2005, former group A hills with good abundances in past surveys). All hills were selected.

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
Nielson's	44° 43.5´	176° 47.0´ W
Amaltal Pimple†	44° 34.8´	177° 50.4´ W

† New in 2016

B: Cluster of hills, Big Chief complex, defined as a box bounded by 44° 35.0´ to 44° 45.0´ S and 175° 25´ to 175° 05´ W. Two hills were selected, ‡.

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
Cooks	44° 43.20´	175° 20.40´ W ‡
Teepee	44° 36.90´	175° 09.78´ W

C: Other fishing hills. Four hills were selected, ‡.

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 ‡
Der Spriggs	44° 41.6´	176° 45.0´ W
Paranoia[†]	44° 44.3´	176° 32.4´ W ‡
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 ‡

† In Group A prior to 2016

2.7 Estimating absolute abundance

The overall procedure for estimating abundance was the same as that used for the 2012 smooth oreo survey (Doonan et al. 2014), i.e., a one area model (no west/east split). Abundance was estimated separately for the flat area 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). Only the School-shallow and School-deep mark types were used in the abundance estimates. 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. (2003a). The mean abundance was calculated for each hill category (A, B, or C), multiplied by the total number of hills in that category, and summed over all categories 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 total flat abundance to the trawl survey area, adding the total hill abundance and scaling the sum up to the whole OEO 4 area. The following sections expand on aspects of the overall analyses that are specific to this survey.

2.7.1 Abundance scaling factors

Three abundance scaling factors were used for the 2016 flat survey. The first was new and was calculated by scaling up (multiplying) the reduced 2016 acoustic survey area to the previous (2012) acoustic survey area, and is summarised in Table 4.

The second scaled up the (adjusted) acoustic survey area abundance to the trawl survey area. This was calculated using data from three trawl surveys (TAN9210, TAN9309, and TAN9511) to estimate the inverse of the proportion 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 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% CV).

The third multiplied the trawl survey area data up to the overall OEO 4 area. This 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 CV of 2%, calculated from data for the fishing years 1986–87 to 2000–01. There was a temporal trend in the ratio and the value increased from 1.03 in the late 1980s to 1.25 in 1999–2000 and 2000–01.

Table 4: The new (first) scale-up factor for the reduced 2016 acoustic survey area to the previous (2012) acoustic survey area flat survey.

Survey	Percentage of abundance in un-sampled strata (2, 22, and 9)	Scale-up factor for 2016 survey	Without large mark in 2012
2001	2.9	1.03	–
2005	11.2	1.126	–
2009	12.9	1.148	–
2012	2.9	1.03	1.057
Mean	–	1.084	1.09
CV (%)	–	2.9	2.6
Population CV (%), i.e., cv_{A1}	–	5.8	5.1

2.7.2 Mark-types

The acoustic data were classified into different kinds of marks for the analysis. In previous analyses, e.g., for the 2012 survey, Doonan et al. (2014) analysed four mark-types, i.e., Background, Layer, School-shallow, and School-deep. The 2016 survey analysis used only the School-shallow, and School-deep marks, because the base case for the last stock assessment (Fu & Doonan 2015) only required abundance estimates from these mark-types. The mark-types and the planned number of tows on each mark-type for the 2016 survey are in Table 5.

Table 5: Planned number of tows by mark-type (School-shallow, School-deep, Layer) and stratum for the flat survey. –, not applicable because stratum 8, 82, and 83 are deeper than 984 m..

Stratum	Mark length < 500 m and depth < 984 m (School-shallow)	Mark length < 500 m and depth > 984 m (School-deep)	Mark length > 500 m (Layer) Lowest priority work
3, 4	3	3	–
5, 42	3	3	–
52	3	3	3
8	–	3	–
82	–	4	–
83†	–	Unspecified, but one day was set aside for trawls and surveys	–
Totals	9	16	3

Species composition was derived from trawl catches from target tows on each mark-type. Tows were carried out on each mark-type within each flat stratum where they were observed. The aim was to get at least 3 tows per mark-type per stratum to enable species composition to be estimated using catch data from that stratum only. However, this was not practical due to time constraints and the difficulty of finding certain mark-types in some strata. For bootstrapping purposes and to avoid reliance on 1 or 2 tows in a stratum, trawl data was supplemented by trawls in the same mark-type in adjacent strata.

2.7.3 Target strength

The target strength relationships for black oreo and smooth oreo used in these analyses were derived from a Monte-Carlo analysis of in situ and swimbladder data (Macaulay et al., 2001; Coombs & Barr 2004) and were:

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

and

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

for smooth oreo and black oreo respectively and where *TS* is the target strength and *L* the fish total length. Estimates for orange roughy and hoki were those used by Doonan et al. (2003c), and for other common species we used relationships based on swimbladder modelling (Macaulay et al. 2001; Table 6). A generic relationship was used for species for which no specific relationship was available as detailed by Doonan et al. (1999).

Table 6: Fish length-target strength relationships used where relationships are of the form TS = $a + b\log_{10}(L)$ from Macaulay et al.)2001) except that **the orange roughy estimates are derived from Macaulay et al. (2013) for the intercept, and for the slope, from McClatchie et al. (1999).**

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	-74.0	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	-76.71	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	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

2.8 Estimating variance and bias

The method of estimating variance and bias was 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 were:

- 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.

2.8.1 Flat area

The total CV of the abundance estimate was calculated in three parts: one for the abundance in the survey area, and two resulting from scaling up the abundance in the new acoustic survey area to that for the previous acoustic area and then to that of the larger trawl survey area. Total CV was given by:

$$\sqrt{(cv_p^2+1)(cv_{A1}^2+1)(cv_{A2}^2+1)}$$

where cv_p is the CV of the abundance in the acoustic survey area, cv_{A1} is the CV of the factor to account for the proportion of abundance outside the new acoustic survey area, but within the old acoustic area, and cv_{A2} is the CV of the factor to account for the proportion of abundance outside the old acoustic survey area. To estimate cv_p , the following sources of variation were combined using simple bootstrapping.

- For acoustic sampling, acoustic transects were re-sampled from those within a stratum.
- For catch sampling, the tows 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_{A2} 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, and 1995) were used.

2.6.2 Hills

The equivalent abundance CV (cv_A) was calculated for each hill. However, there was also a between-hill variance contribution, σ^2_B, 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 some of them).

The model used to estimate the mean abundance of the *j*-th hill in the *i*-th hill category ($b_{i,j}$) 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 $\sigma^2_{B,j}$, 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:

$$N_i^2 \mathrm{Var}\left(\overline{b}_{i.}\right)$$
$$= N_i^2 \left\{ \mathrm{Var}\left(\overline{\gamma}_{i.}\right) + \mathrm{Var}\left(\overline{\varepsilon}_{i.}\right) \right\}$$
$$= N_i^2 \left\{ (1-f)\frac{\sigma_{B,i}^{\ 2}}{n_i} + \frac{\overline{\sigma_{W,i}^2}}{n_i} \right\}$$

where n was 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 was the sum of the variances of the three hill categories.

2.6.3 Bias

Potential sources of bias were:

- Classification of marks.
- Differences in relative catchability of other species compared to oreos.
- 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 the 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

The catches of the top 10 species caught, and the occurrence of these species in all mark identification tows (flat and hills) shows that most of the total catch was the survey target species, smooth oreo (Table 7). Black oreo catch was the next most important part of the catch, and this species is known to form mixed schools with smooth oreo in some areas, particularly OEO 3A at the west end of Chatham Rise, and at shallower depths, probably less than about 1100 m.

Table 7: Catches of the top 10 species caught, and the occurrence of these species in all mark identification tows (flat and hills) in the 2016 survey.

Species code	Common name	Occurrence in all tows (%)	Catch (kg)
SSO	Smooth oreo (*Pseudocyttus maculatus*)	94	94 047
BOE	Black oreo (*Allocyttus niger*)	78	3 394
ETB	Baxters dogfish (*Etmopterus granulosus*)	85	1 112

SSM	Smallscale brown slickhead (*Alepocephalus antipodianus*)	50	587
HOK	Hoki (*Macruronus novaezelandiae*)	39	427
ORH	Orange roughy (*Hoplostethus atlanticus*)	69	411
SND	Shovelnose spiny dogfish (*Deania calcea*)	31	352
PLS	Plunket's shark (*Proscymnodon plunketi*)	9	204
HJO	Johnson's cod (*Halargyreus johnsonii*)	48	193
BEE	Basketwork eel (*Diastobranchus capensis*)	37	172

3.1 Flat

The numbers of acoustic transects carried out are shown in Table 8. Table 9 shows the number of tows by mark-type and strata, and the adjacent strata used to supplement tow data with tows from the same mark-type so that all mark-type/stratum combinations had adequate catch data for assessment of species composition. Supplementation was carried out to get adequate numbers of tows for bootstrapping, i.e., we aimed for 3 tows, if possible. Examples of School-shallow, and School-deep mark-types are in Figures 3 and 4. Catch rates for the top three species caught, by mark-type are in Table 10.

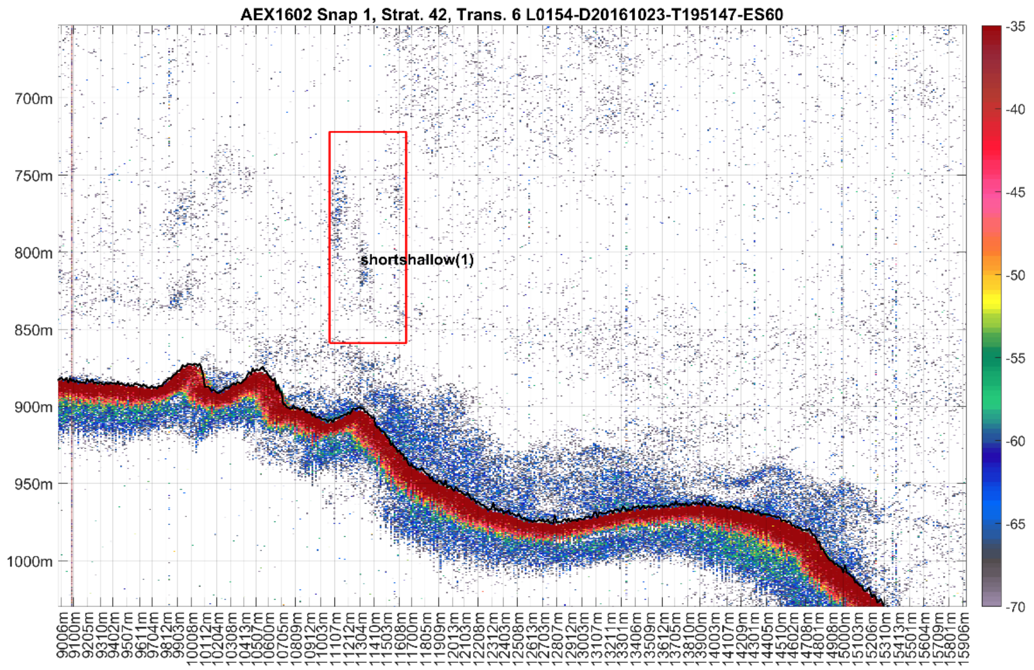

Figure 3: Echogram of volume backscattering coefficient showing diffuse aggregation of mark-type School-Shallow in stratum 42 during transect number 6 (hull data).

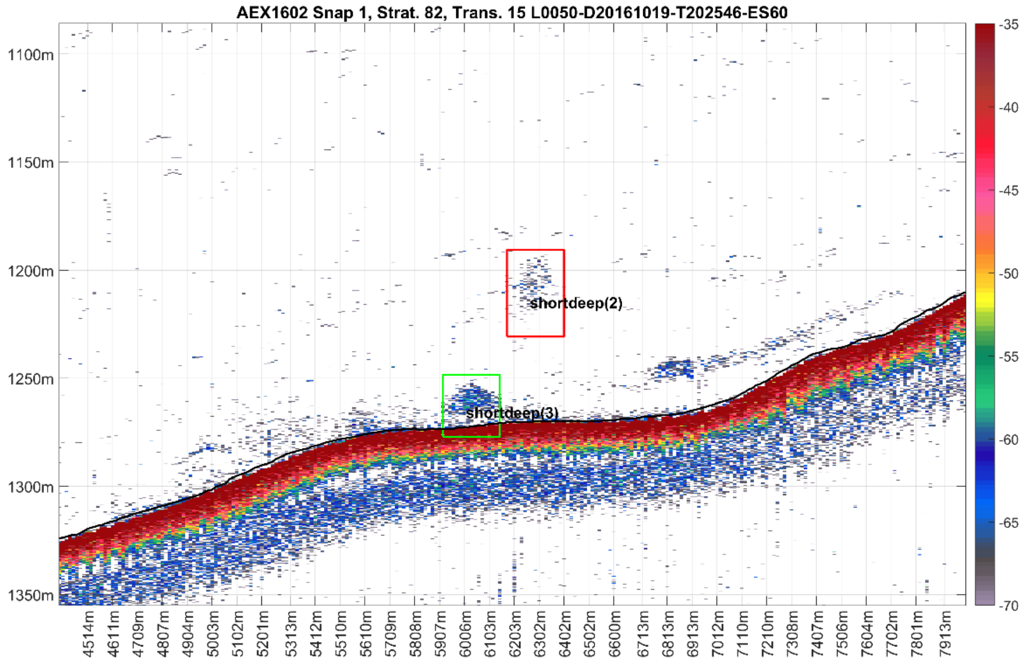

Figure 4: Echogram of volume backscattering coefficient showing diffuse aggregation of mark-type School-Deep in stratum 82 during transect number 15 (hull data).

Many dense School-deep marks were observed in stratum 8 at 30–275 m off the bottom at 1200–1300 m depth (Figure 5). In previous survey analyses these were assigned as smooth oreo marks. In 2016, two target bottom tows were made on these marks and a total of 10 smooth oreo and a few robust cardinalfish were caught. Two midwater tows were also carried out and caught about 30 kg and 60 kg robust cardinalfish, some rattails, and no smooth oreo. These stratum 8 marks were assigned as robust cardinalfish in the abundance analysis.

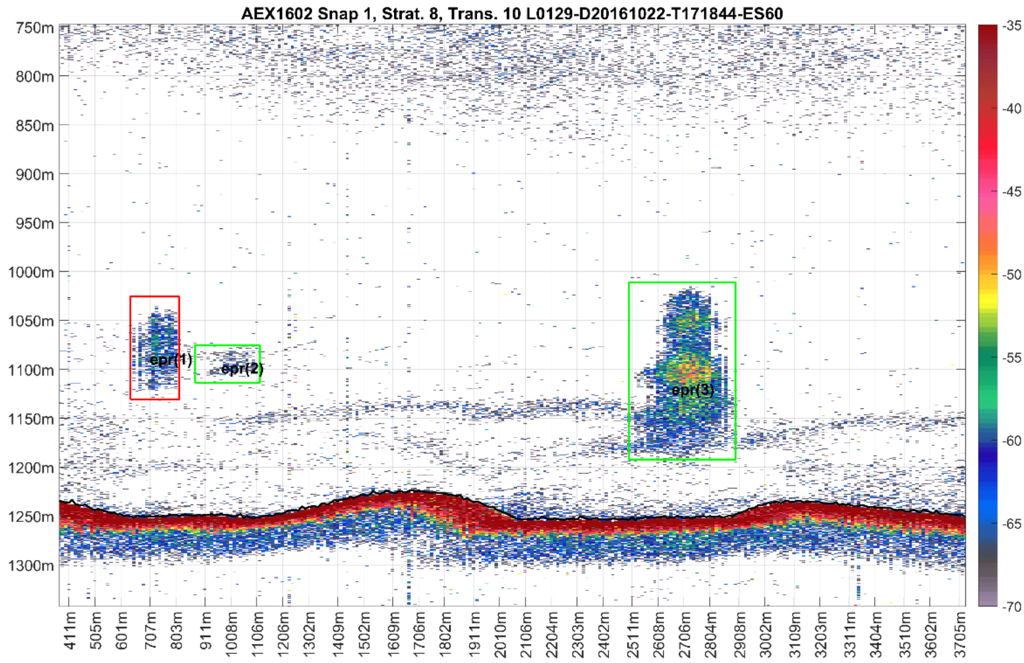

Figure 5: Echogram of volume backscattering coefficient showing dense aggregation that waereattributed to robust cardinalfish in stratum 8 during transect number 10 (hull data).

Table 8: Numbers of planned and completed acoustic transects for each stratum.

	Number of transects		
Stratum	Planned	Completed	Comment
Phase 1			
3	10	10	
4	6	13	
5	6	6	
8	8	13	
42	6	12	
52	18	17	
82	18	18	
83	7	7	No marks seen
Phase II			
52-2	0	6	Part stratum only
82-2	0	6	Part stratum only
42-2	0	2	Not completed
83-2	0	7	

Table 9: Number of 2016 survey tows from flat strata by mark-type, and the total number of tows used in the abundance analysis when stratum-mark-type combinations were supplemented with 2016 tows from adjacent strata. –, Stratum too deep for this mark type. †, included for age estimation analysis (reported separately).

	2016 tows		Total tows		Stratum of supplemented tow	
Stratum	School-deep	School-shallow	School-deep	School-shallow	School-deep	School-shallow
3	2	1	2	5		4
4	3	4	3	4		
42	4	6	4	6		
5	0	0	7	6	42, 52	42
52	3	0	7	6	42†	42
8	0	–	4	0	42	
82	0	–	7	0	42†, 52	

Table 10: Catch rates (kg/km) for the top three species caught, by mark-type for 2016 survey tows from flat strata. SSO smooth oreo (*Pseudocyttus maculatus*), SND shovelnose dogfish (*Deania calcea*), BOE black oreo (*Allocyttus niger*), ORH orange roughy (*Hoplostethus atlanticus*).

Mark-type	Species 1	Catch rate	Species 2	Catch rate	Species 3	Catch rate
School-deep	SSO	8 629	SND	60	BOE	35
School-shallow	SSO	16 575	BOE	201	ORH	49

3.2 Hills

The number of transects and tows carried out on each hill is shown in Table 11. Amaltal Pimple, one of the Group A hills listed in Table 3, was not sampled. Example echograms for hill marks are shown in Figures 6 and 7.

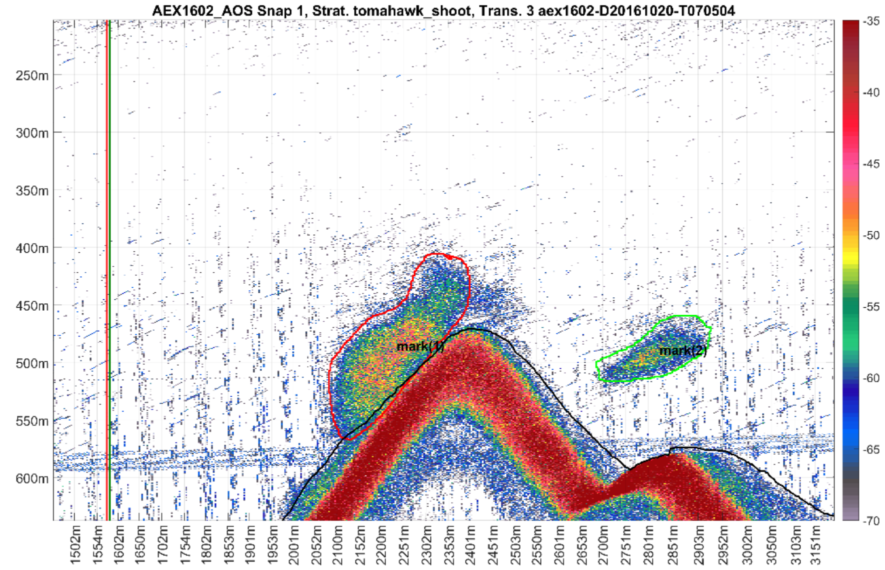

Figure 6: Echogram of volume backscattering coefficient showing dense aggregation on Tomahawk hill during transect number 3 (AOS data).

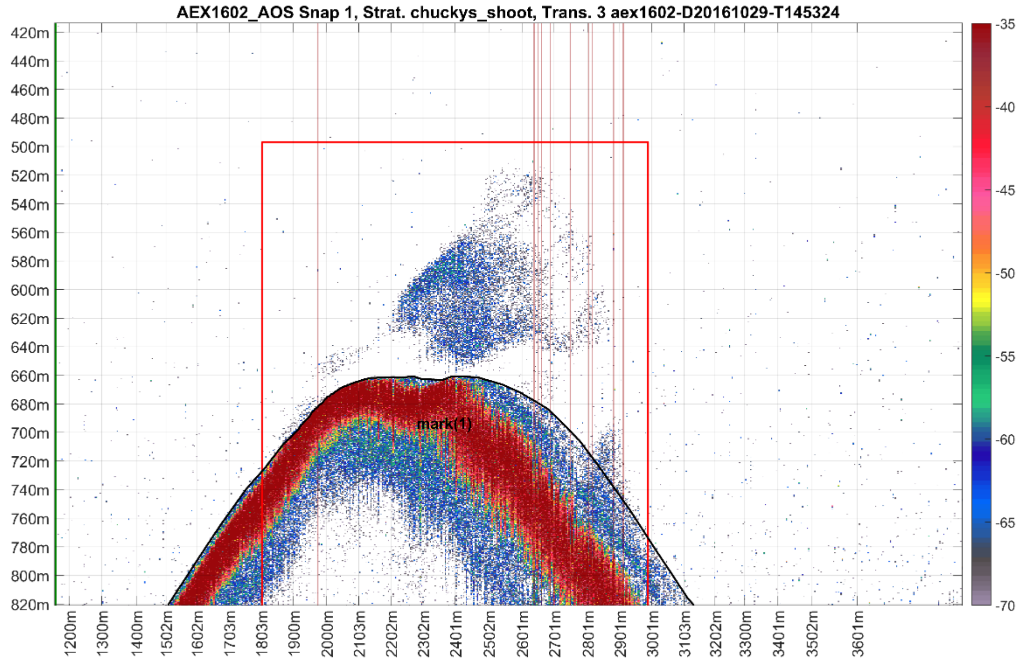

Figure 7: Echogram of volume backscattering coefficient showing diffuse aggregation on Chucky's hill during transect number 3 (AOS data).

Table 11: The number of transects and tows for each hill surveyed in 2016. †, no substantial marks observed during initial survey so no further work carried out (abundance = zero).

Hill Group	Stratum	No. of transects	Survey design	No. of tows
A	Chucky's	3	Star	1
A	Trevs Pinni*	3	Star	1
A	Hegerville	5	Parallel	2
A	Dolly Parton	3	Star	1
A	Nielson's	5	Parallel	2
B (Big Chief)	Tomahawk	3	Star	2
B (Big Chief)	Cooks†	0	Not surveyed	0
C	Condom's	3	Star	3
C	Mangrove	3	Star	1
C	Paranoia	3	Star	2
C	Dory Pimple†	0	Not surveyed	0

3.3 Abundance estimates and variances

3.3.1 Flat

The acoustic abundance analysis used data from the phase 1 transects only, because phase 2 was incompletely sampled, and only acoustic abundance from School-shallow and School-Deep mark-types were used in the analysis. The abundance estimate for the flat acoustic survey area was 10 080 t with a CV of 31%. A breakdown of the percentage of the abundance by stratum for 2016 compared to the previous four surveys is shown in Table 12, and showed that in 2016 relatively more of the abundance came from the west strata compared to the east strata. In previous surveys, strata 5, 52, 8 and 82 contributed most of the abundance, but in 2016 most of the abundance came from strata 3, 4, and 42. No large or high-density marks were seen during the survey, including within stratum 83 where dense marks were observed on previous surveys.

Table 12: Percentage of flat survey abundance by stratum for the School-shallow and School-deep mark-types for the 2001, 2005, 2009, 2012, and 2016 acoustic surveys.

	Relative abundance (%)				
Stratum	2001	2005	2009	2012	2016
3	7	11	3	4	22
4	13	4	11	10	33
42	11	6	3	9	30
5	9	10	28	5	1
52	34	44	35	46	8
8	9	12	8	16	0
82	16	13	12	10	5

3.3.2 Hills

The results of the hill survey are summarised in Table 13, and show that the abundance varied widely, from 0 t at Cooks and Dory Pimple to 3324 t at Tomahawk. The estimated total abundance of smooth oreo on hills was 20 569 t with a CV of 45%. The contributions of the three hill categories are shown in Table 14. The between-hill variances were swamped by the sampling variances so the estimate of σ_B^2 was zero.

Table 13: Hills surveyed, abundance estimates (t), and the sample error of the abundance estimates. –, no estimate (no data).

Hill Group	Stratum	Abundance (t)	CV (%)
A	Chucky's	227	65
A	Trevs Pinni*	83	145
A	Hegerville	691	56
A	Dolly Parton	478	61
A	Nielson's	560	44
B (Big Chief)	Tomahawk	3 324	65
B (Big Chief)	Cooks	0	–
C	Condom's	210	54
C	Mangrove	1 987	57
C	Paranoia	584	49
C	Dory Pimple	0	–

Table 14: Total hill abundance and CV by hill category for the 2016 survey.

Category	Number of hills		Abundance	
	Surveyed	Total	Tonnes	CV (%)
A	5	5	1 985	30
B (Big Chief)	2	7	11 633	65
C	4	11	6 951	45
Total	11	23	20 569	45

3.3.3 Total abundance estimates for area OEO 4

The abundance from both the flat (combined scale-up factor = 1.084 ×1.23×1.10) and hills (scale-up factor = 1.10) scaled up to the overall OEO 4 area gave an estimate of the total abundance of smooth oreo of 34 022 t with a CV of 32% (Table 15).

Table 15: Total abundances (t) and CV for the 2016 survey of the flat and hills with scale-up factors applied. The scale-up factor combines both the 2016 acoustic and 2012 acoustic survey area to trawl survey area factor and the trawl survey area to OEO 4 management area factor.

	Abundance (t)	CV (%)
Flat	11 190	32
Hill	22 831	45
Total	34 022	32

4. DISCUSSION

The time-series of OEO 4 smooth oreo total abundance estimates used for stock assessment are shown in Figure 8 and Table 16. The 2016 survey abundance estimate was relatively low, but similar to the 2012 and 2009 values, and contrasted with the higher mean estimates from the 1998, 2001 and 2005 surveys. The last published smooth oreo stock assessment for OEO 4 was that of Fu & Doonan (2015), and used the series of acoustic survey abundance estimates up to and including the 2012 acoustic survey. That assessment suggested that “the current biomass of OEO 4 smooth oreo is at or near management targets, but the large decline in the 2009 acoustic abundance estimate and the subsequent rapid increase in the 2012 estimate suggests that continued monitoring of the stock would be useful to detect future changes.” The 2016 survey estimate confirms that smooth oreo abundance has been lower after 2005.

Table 16: Time-series of OEO 4 smooth oreo total abundance estimates (t) and CV for school-deep and school-shallow mark-types only from the acoustic surveys of the flat and hills used for stock assessment. 2012†, abundance from one large acoustic mark included. 2012‡ abundance from one large mark excluded.

Year	1998	2001	2005	2009	2012†	2012‡	2016
Abundance (‘000 t)	66	82	63	27	59	37	34.0
CV	0.26	0.26	0.25	0.26	0.3	0.3	0.29

The total abundance estimate from hills was greater than the total flat abundance in the 2016 survey. This contrasted with all other estimates in the survey series, which were dominated by the flat abundance (Table 17). The reason for the 2016 result is unknown, but anecdotal evidence suggests that there may be substantial movement of smooth oreo between the flat and hills. For example, Chucky’s hill is regularly fished and at times supports smooth oreo schools even though it is isolated from other hills, and is a very deep hill with a peak of about 1120 m surrounded by flat bottom of more than 1400 m depth. This suggests that fish may recruit to Chucky’s hill when conditions are favourable.

There was relatively greater smooth oreo estimated abundance from the western end of the survey area in 2016 compared to previous surveys, i.e., from strata 3, 4 and 42 (see Table 11). Stratum 52 provided the highest estimates of abundance (34–46% of the total flat value) from the 2001, 2005, 2009, and 2012 surveys, but was the fourth highest abundance stratum (8%) in 2016. Relative abundance by stratum varied between years in other surveys, e.g., stratum 5 had 28% in 2009 but only 5% in 2012, but the reasons for this inter-annual variability are unclear.

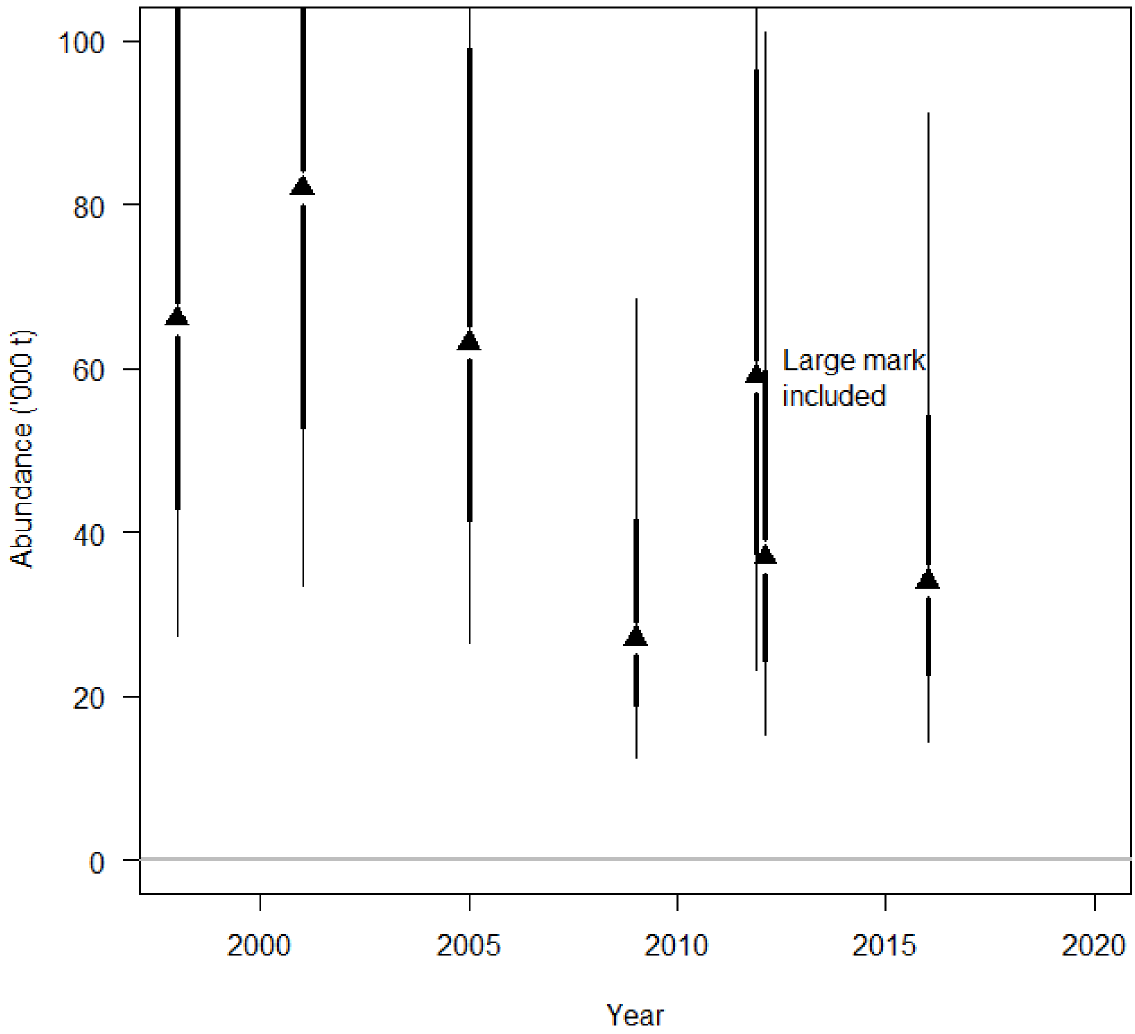

Figure 8: Total estimated abundance OEO 4 smooth oreo for school marks only from the 1998, 2001, 2005, 2009, 2012 (with and without large acoustic mark) acoustic surveys, and the 2016 survey. Mean – triangles; ± 1 s.d. - thick dark lines; ± 2 s.d. - thin dark lines.

Table 17: Proportion of the total survey abundance estimate from the flat survey for all the surveys in the series where hills were sampled, i.e., excluding 1998 survey which did not sample hills.

Year	Proportion of total abundance in the flat strata (%)
2001	82
2005	88
2009	78
2012	80
2016	33

No large marks were observed during the 2016 survey within the specially constructed stratum 83, or in the surrounding stratum (82). This survey area should continue to be included in future surveys because of the potential importance of large intense marks on the total survey abundance. Trawling on any large marks observed as soon as possible after they are observed and recognised, to determine the species composition, is vital.

The target CV of the total smooth oreo abundance was almost achieved (32% compared with the aim of 20–30%), so the survey was considered a success. The success of the survey can be partly attributed to the unusually good weather encountered from 16 October to 8 November 2017, which enabled most of the acoustic survey to be carried out using the hull echosounder.

Conclusions and recommendations

1. The smooth oreo abundance estimates from the last three surveys (2009, 2012 and 2016) suggest a lower abundance compared to the first three surveys (1998, 2001, and 2005).
2. The survey series should be continued in future to monitor trends in smooth oreo abundance.
3. Large or intense marks seen in future surveys should be identified quickly and trawled upon as soon as possible to reduce the uncertainty caused by lack of mark identification, as happened in 2005 and 2012. These large marks with un-verified species composition can have a potentially large influence on the survey total abundance.
4. If large marks are not identified, the uncertain composition should be reflected in any stock assessment analysis where it is used.

5. ACKNOWLEDGMENTS

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APPENDIX 1. Calculated echosounder calibration parameters for the *FV Amaltal Explorer* hull Simrad ES60 and the AOS Simrad EK60 calibration. Values were calculated using ESP3 software version 0.6.1. Calibration was done using a tungsten carbide/38.1 mm diameter sphere in both cases. Temperature was measured using a RBR duo to derive absorption.

Echosounder	AOS EK60 38 kHz	Hull ES60 38 kHz
Mean TS within 0.21° of centre	-46.82	-44.46
Std dev of TS within 0.21° of centre	0.25	0.20
Max TS within 0.21° of centre	-45.92	-44.18
No. of echoes within 0.21° of centre	412	77
On axis TS from beam-fitting	-46.76	-44.32
Transducer peak gain (dB) mean TS	24.27	25.56
Sa correction (dB)	-0.50	-0.74
Beam width (º) along/athwart ship	7.34/7.31	7.1/6.8
Beam offset (º) along/athwart ship	-0.06/-0.04	-0.04/0.08
RMS deviation	0.13	0.18
Number of echoes	21 194	7243