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EXECUTIVE SUMMARY

Smith, M.H.; Hart, A.C.; McMillan, P.J.; Macaulay, G. (2008). Acoustic estimates of orange roughy abundance from the northwest Chatham Rise, June-July 2005: results from the wide-area and hill surveys.

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An orange roughy acoustic survey on the northwest Chatham Rise was carried out between 16 June and 7 July 2005. The programme objectives were to obtain three abundance estimates: an acoustic estimate of the fish aggregated on the Graveyard hills complex, and two estimates for the dispersed fish covering the wide-area along the flat slope of the northwest Chatham Rise, one an acoustic estimate and another using trawl survey data.

The Graveyard hills were surveyed acoustically by *Tangaroa* (Voyage TAN0509) and the associated trawl sampling on the hills that was required for species composition and mean length and mean weight data collection was carried out by the NIWA chartered commercial vessel *Amaltal Mariner* (AMA0501). Three acoustic snapshots of the Graveyard hills were carried out, and the flat area acoustic survey was successfully completed.

The estimated mature abundance on the Graveyard hills was 560 t (c.v. 42%), using the NIWA target strength. The abundance estimate for the Graveyard hills survey was low because fish aggregations (plumes), particularly on the Graveyard hill itself, were not observed at the time of the survey even though three, rather than the scheduled two, snapshots were carried out. The lack of aggregated fish above the hill could be due to any or all of lower fish abundance leading to lack of or less consistent spawning plume formation, spawning plume formation being later in the season than normal, or disruption of the spawning plume by commercial fishing.

The species composition estimates were problematical for Morgue as no recent species composition data are available for that hill because no fishing is allowed. The last research tows carried out in 1999 suggested a proportion of the mark was made up of smooth oreo and species other than orange roughy. On the Graveyard hill, orange roughy appeared to be close to the bottom at times because catches of several tonnes per tow were made by commercial vessels during the survey. The acoustic method is less effective for fish that are on or close to the bottom than for fish that are aggregated in plumes above the bottom.

The wide-area acoustic survey of the dispersed portion of the orange roughy population and the associated trawling on the flat slope was carried out by *Tangaroa* and covered an area of about 6083 km^2. A separate trawl estimate of relative orange roughy abundance was also provided because the *Tangaroa* trawling was carried out to a stratified random statistical design. As expected, most of the abundance came from the strata near the Graveyard hills complex. Only small amounts came from the strata at the west end of the survey area near 176° E, the region that includes a well known fishing area termed the "Hole".

The estimated acoustic mature (fish greater than or equal to 31 cm SL) abundance for flat strata 1–4 was 5910 t (c.v. 37%), and for the rest of the flat area (strata 8–72) it was 2300 t (c.v. 40%), giving a total mature abundance of 8770 t (c.v. 40%) for the hills plus flat (northwest Chatham Rise).

The trawl survey estimates of abundance for the wide-area dispersed population were estimated for all fish, for mature fish (greater than or equal to 31 cm SL), and for immature fish (less than 31 cm SL). Wingtip abundance estimates were 8038 t (c.v. 12.3%) for all fish, 4490 t (10.2%) for mature fish, and 3548 t (16.1%) for immature fish. Between trawl door abundance estimates assuming a constant swept area of 117 m were 1719 t (12.3%) for all fish, 960 t (10.2%) for mature fish, and 758 t (16.1%) for immature fish.

1. INTRODUCTION

Orange roughy (*Hoplostethus atlanticus*) are widely distributed in 700–1500 m depth within the New Zealand EEZ. They are a very slow-growing, long-lived fish and may live up to 130 years (Mace et al. 1990, Doonan 1994). Their maximum size in New Zealand waters is about 50 cm (standard length), with an average size around 35 cm (Clark et al. 2000). Spawning occurs between June and early August in several areas around New Zealand.

Information about abundance is essential to effective management of commercial fish stocks. However, this can be very hard to obtain, particularly for deepwater species such as orange roughy. Most of the biomass information for the northwest Chatham Rise orange roughy fishery has come from acoustic surveys. Since the mid 1990s the fishery has focused on the spawning aggregations of orange roughy found on the Graveyard hills complex, particularly the Graveyard hill itself. Dense aggregations of spawning roughy form characteristic plume-like marks on echosounders and aggregations are commonly referred to as 'plumes'. There is typically one main spawning plume on the Graveyard hill and lesser plumes on some of the other hills in the complex, including Deadringer, Morgue, Scroll, Zombie, and Casket/St Paul's. The Graveyard plume typically forms during mid-late June and dissipates in mid July. Outside the spawning season, orange roughy form aggregations for feeding, but these are less consistent than those formed for spawning.

Spawning orange roughy, in the past, have formed large off-bottom aggregations which are good candidates for the acoustic abundance estimation method. Acoustic methods for estimating orange roughy abundance have been developed over the last 16 years in New Zealand and Australia (Do & Coombs 1989, Elliott & Kloser 1993, Kloser et al. 1996). NIWA carried out pilot acoustic surveys of orange roughy on the Chatham Rise in 1986 (Do & Coombs 1989), 1995, and 1996, and more recent surveys included the Northwest hills on the Chatham Rise in 1999 (Bull et al. 2000) and 2002 (Doonan et al. 2003b). Industry surveys of the northwest hills using a hull transducer were carried out in 2003, 2004 and 2005 (I. Hampton, Fisheries Resource Surveys, pers. comm.).

Most plumes are almost exclusively orange roughy and are easily identified. The weakest aspect of current orange roughy acoustic methods concerns identifying the acoustic targets on the large areas of flat ground around spawning areas where typically there is a mixture of species.

The spawning population has two components; aggregations, where orange roughy are confined to a small area at high densities, and dispersed, in which orange roughy are at low densities over a very large area. The aggregations are relatively easy to survey using acoustic methods, but the low density component is problematical and can be surveyed by trawling to obtain a relative estimate, or an acoustic method which provides an absolute estimate but has problems with determining the species mix accurately.

Substantial quantities of orange roughy may be found in the low density area. The first acoustic survey to measure the low density orange roughy was carried out in 1998 on a restricted area around the spawning plume on the Northeast Chatham Rise (Doonan et al. 1999), where the abundance of fish in the low density area was 1.05 times that in the aggregation. More extensive areas were covered in the 2002 Northwest Chatham Rise survey, in which about 2670 km^2 were covered (Doonan et al. 2003b) and in the 2001 Mid-east Coast (MEC) survey, where about 4520 km^2 were covered (Doonan et al. 2003d). The ratio of abundance in the low density area compared to aggregations was estimated as 3.1 (1.4 if tow 45 was excluded from the low density survey) and 0.86 respectively for the Northwest and MEC analyses. For absolute abundance, the low density estimate is therefore a very important component of the abundance indices used in the stock assessment models.

Relative abundance estimates from the low density and aggregation components of the orange roughy population could be used in the stock assessment model analysis, but some monitoring of both parts of the population at the same time is required to estimate changes in both these parts of the population, or to establish that the fluctuations in the proportions of orange roughy between the two components are not major.

This report addresses the Ministry of Fisheries project ORH2004/01, which had the overall objective "To estimate the abundance of orange roughy (*Hoplostethus atlanticus*) in selected areas", and the specific objective:

1. To estimate the abundance, with a target coefficient of variation (c.v.) of the estimate of 20–30 %, of orange roughy over a short time period on the northwest Chatham Rise.

2. METHODS

The aim of the 2005 research was to survey both the low density and aggregated parts of the orange roughy fishery on the northwest Chatham Rise at the same time (Figure 1). Three abundance estimates were made; one for the aggregations using the acoustic method, and two wide-area estimates on the low density fish, one using acoustics and another using a stratified random trawl survey. These estimates were provided for a stock assessment in 2006 (A. McKenzie, NIWA, unpublished results). The survey work on the aggregations was carried out by NIWA but industry also carried out a parallel survey using *San Waitaki* (results will be reported elsewhere).

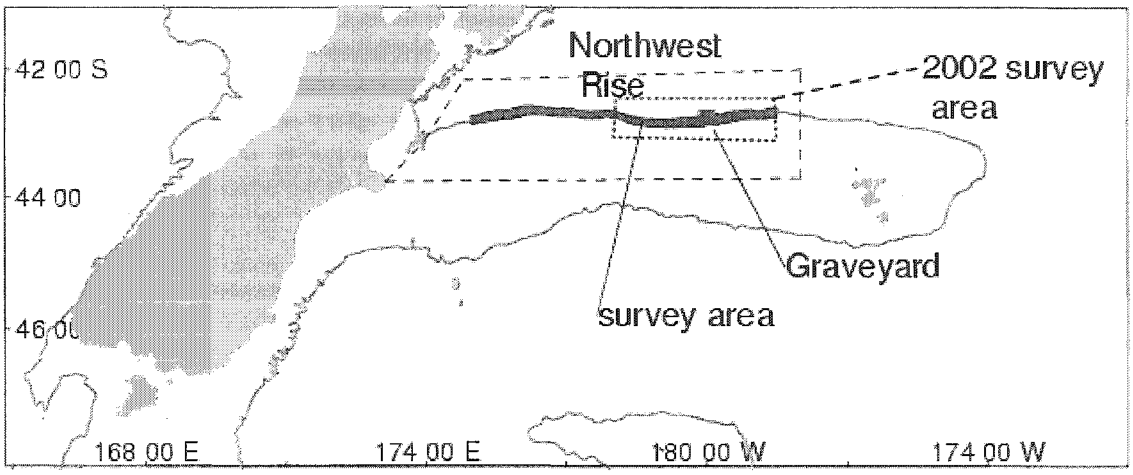


Figure 1: Location of the 2005 survey area (shaded) on the Northwest Chatham Rise (dashed line), and comparison with the 2002 survey area (shaded area within the dotted line box).

The low density wide-area surveys were also carried out by NIWA and the acoustic and trawl abundance estimates are reported here. The acoustic survey of hills used a star design method (Doonan el al. 2003a). The low density wide-area survey was based on strata developed in the previous 1999 and 2002 surveys (Bull et al. 2000, Doonan et al. 2003b), but the survey area was extended to the west to cover parts of the northwest Chatham Rise where orange roughy was known to be distributed based on commercial fishing information and previous trawl survey work (Figure 1). The acoustic survey was accompanied by an associated random trawl survey that used the same strata but was otherwise independent, i.e., trawls were allocated at random and were independent of the acoustic targets. Both surveys used a random stratified design within the same strata. The trawling provided species composition and mean length data for the acoustic survey analysis as well as catch rate and biological data required to estimate relative abundance from the trawl survey.

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. 2001), which was then apportioned using species composition derived from trawling. Areal backscatter is converted into total numbers of fish over all species per square metre by using a weighted (by number) average of the target strength over the species composition. The number of orange roughy per square metre is the total number times the fraction (in numbers) of orange roughy in the species composition. Abundance is obtained by converting numbers into weight per square metre using the average weight and multiplying up to the stratum area. Average weight is estimated from the trawl catches.

The detailed mathematical analysis used to estimate abundance from the survey results is the same as that used by Doonan et al. (1999) and a generic derivation is given in Appendix 1. Corrections were made to the backscatter for shadowing, towed body motion, and absorption of sound by seawater.

2.2 Acoustic equipment

The acoustic backscatter data were collected by *Tangaroa* with NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs et al. 2003). The configuration used was essentially the same as in previous deepwater acoustic surveys (Doonan et al. 2001, Coombs et al. 2003). A single split-beam system towed at between 100 and 700 m depth was used. The towed system (towbody 2) used throughout the survey was calibrated down to 875 m on 6 July 2005. The calibrations followed the approach described by Coombs et al. (2003) which in turn is based on Foote et al. (1987). A 38.1 mm ± 2.5 μm diameter tungsten carbide sphere with a nominal target strength of –42.4 dB was used as a calibration standard. The transducer 3 dB beamwidths were 7.0° (alongship) and 6.9° (athwartship) and its effective beam solid angle for integration was 0.0083 sr. The effective pulse length was 0.78 ms and the sample rate was 4 kHz. V_T, the in-circuit voltage at the transducer terminals for a target of unit backscattering cross-section at unit range (the linear equivalent of "SL+SRT", see Coombs et al. (2003)) was 1322 V when the towed body was shallower than 350 m and 1343 V when it was deeper. The voltage gain, G, of the receiver at 1 m with the system configured for echo-integration was 14 491.

Information on acoustic mark shapes and intensities was collected from the *Amaltal Mariner* echosounder by taking digital photographs of the echogram. Electronic data from the *Tangaroa* 12 and 38 kHz hull sounders were also recorded.

Salinity, temperature, and depth (CTD) data were collected during bottom trawling using a Seabird 37-SM MicroCAT CTD mounted on the headline of the net to allow the transducer temperature correction to be measured and to estimate sound absorption using the new relationship derived by Doonan et al. (2003c).

2.3 Trawl gear

Tangaroa

The net used during the wide-area survey was the NIWA full wing trawl ("rat-catcher"). The rat-catcher has upper and lower wings, about 25 m of wingspread, a door spread of about 115 m, a headline height of about 3.3 m, 6 inch mesh in the wings, 40 mm mesh (full inside mesh) codend, low (200 mm bobbins) ground gear. This net has small meshes and smaller ground gear (closer bottom contact) than the standard rough bottom orange roughy trawl, and ensured that smaller fish were retained. This was important for obtaining more comprehensive catches and therefore better estimates of the species composition during wide-area acoustic surveys. The trawl survey component of the project was envisaged as being the beginning of a new time series and so gear comparability with previous surveys was not a requirement.

The rough-bottom orange roughy trawl was also used to repeat 14 tows in strata 1–4 for comparison with the rat-catcher tows, and for comparison with the previous surveys that used the orange roughy trawl gear. This is an Alfredo-style trawl, with cut-away lower wings. Wingspread is about 26 m, with 6–7 m headline height, 12 inch mesh in the forepart of the net, and robust ground gear consisting of steel and rubber bobbins.

Amaltal Mariner
The net used for mark identification tows on hills was a Champion bottom trawl with a 100 mm mesh codend. A small, fine-mesh midwater net (the NIWA myctophid trawl) was also used to sample smaller organisms in midwater layers observed in the wide-area survey. This has a headline height of about 19 m and 10 mm mesh in the codend.

2.4 Survey design

2.4.1 Graveyard hills complex acoustic survey

The acoustic survey followed the 2002 acoustic survey of the Graveyard hills, using a 'star' transect pattern (Doonan et al. 2003a), and marks were trawled to establish species composition and to sample fish for length, sex, gonad stages, and other biological parameters. Hills were treated as separate strata and two temporal snapshots were planned. Only the hills surveyed in the 2002 survey (Doonan et al. 2003b) were sampled, and hills that had little spawning orange roughy in 1999 (typically deep hills) were omitted. A map of the hills surveyed is shown in Figure 2, and these plus other hills from the area are listed in Table 1. The five hills surveyed in 2005 had 97% of the spawning abundance of all the hills surveyed in 1999.

Some of the other hills (Figure 2, Table 1) were also briefly surveyed by *Amaltal Mariner* using the ship's sounder to determine if any large marks were present. Trawling was also carried out on some of these to verify the species composition of observed marks.

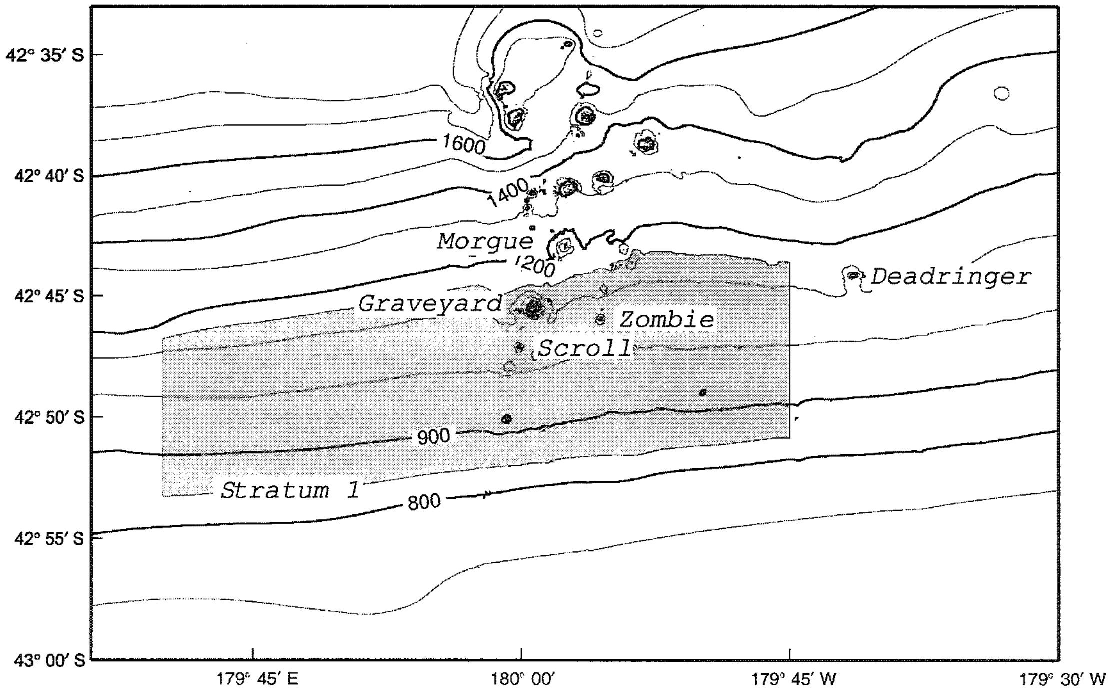


Figure 2: Graveyard complex hills and central flat stratum (Stratum 1).

Table 1: Graveyard hills complex.

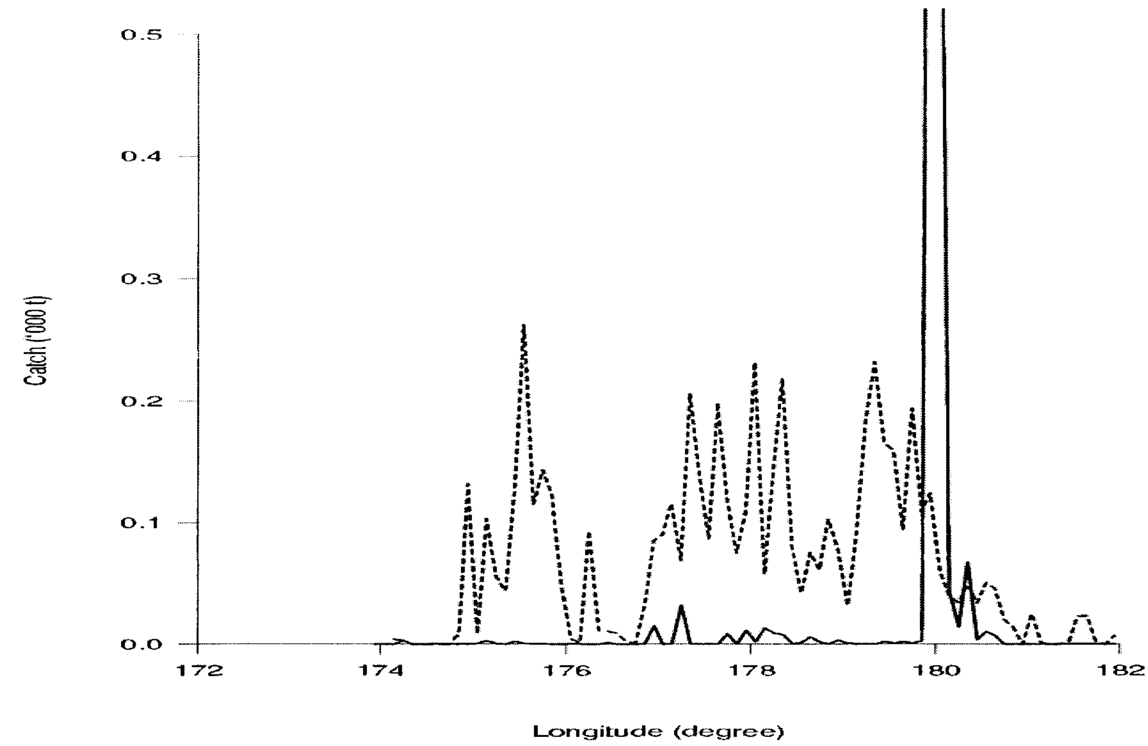
Hill	Code	Latitude/longitude of top		Depth of top (m)
Hills surveyed				
Morgue*	MORG	42 43.02 S	179 57.56 W	890
Graveyard	GRAV	42 45.59 S	179 59.34 W	750
Zombie	ZOMB	42 45.94 S	179 55.58 W	890
Scroll	SCRO	42 47.15 S	179 59.86 E	870
Deadringer	DEAD	42 44.14 S	179 41.42 W	820
Casket/St Pauls	CASK	42 50.09 S	179 59.19 E	792
Hills not surveyed				
Doom		42 37.82 S	179 59.50 E	1 263
Gloom		42 36.49 S	179 58.85 E	1 178
Crypt		42 37.58 S	179 56.43 W	1 145
Mummy		42 38.72 S	179 52.97 W	1 035
Headstone		42 40.51 S	179 57.44 W	1 000
Hartless		42 39.92 S	179 55.25 W	1 071
Diabolical		42 47.39 S	179 59.23 W	894
RIP		42 46.80 S	179 54.22 W	910
Gothic		42 43.62 S	179 53.89 W	987
Pyre		42 42.99 S	179 54.33 W	987
Wecnec		42 49.00 S	179 49.89 W	850
Hagar the Horrible		42 43.75 S	179 45.57 W	1 084
Ghoul		42 47.83 S	179 59.16 E	935
Soul Destroyer		42 41.34 S	179 59.69 W	1 161
Solless		42 40.74 S	179 59.38 W	1 126
Coffin		42 46.31 S	179 54.09 E	1 007
Vampire		42 43.22 S	179 57.27 E	>1 100
Grendel		42 42.57 S	179 50.43 W	1 087
Ghost		42 46.25 S	179 54.07 E	~1 000
Phantom		42 46.30 S	179 59.62 W	~950
Voodoo		42 44.79 S	179 55.37 W	~1 020
Gargoyle		42 40.46 S	179 48.20 W	~1 200

* Morgue is closed to trawling

2.4.2 Wide area acoustic survey

The survey was designed to cover as much of the spatial distribution of the stock as possible. The 1999 northwest Chatham Rise flat area acoustic survey did not cover the full northwest Chatham Rise area so the survey area was extended in the 2002 northwest Chatham Rise flat survey, but still covered only about 43% of the longitudinal length of the northwest Chatham Rise area. Coverage of the whole distribution in 2005 allowed for abundance estimates that did not have to be scaled up from a survey area to the entire stock area, with associated assumptions and increases in the uncertainties of the estimates.

The need to increase the survey area was based on an analysis of the commercial fishing patterns over time for the northwest Chatham Rise. This showed that there were two main fishing areas: the northwest hills (Graveyard complex near 180°) and the Hole (near 176° E) (Figure 3). In the early years of the fishery (1980s) most catches were taken outside the spawning season (June-July) and were spread along the Chatham Rise from 174° 52 E to 179° 00 W, but were concentrated around the Hole. In the later years (1995 to 2004) catches were mainly around the Graveyard hills during June-July. In the rest of the year, catches were also mainly around the Graveyard, plus a smaller concentration around the Hole, with the rest spread along the northwest Chatham Rise (Figure 3).



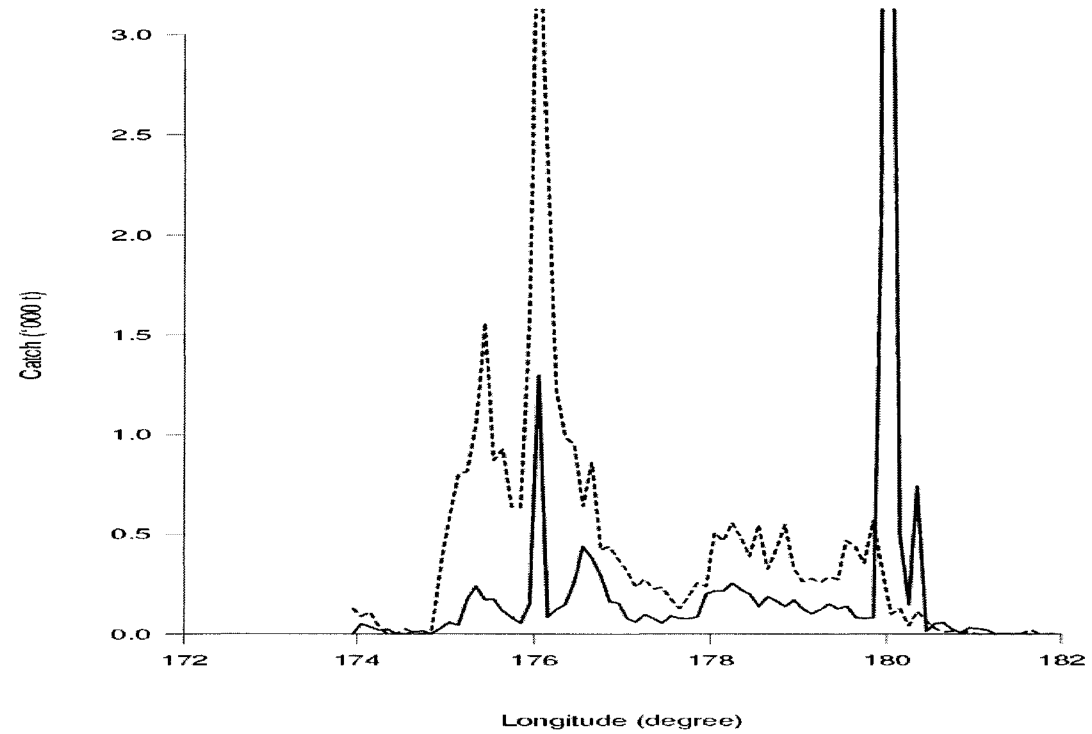


Figure 3: Cumulative catch by longitude along the Northwest Chatham Rise. Dotted line is the catch from the 1980s, solid line is the catch from 1995 to 2004. Top, catch taken during the spawning season (June & July); bottom, catch outside of the spawning season.

The survey of the wide-area used a stratified random design. The stratification used in the 2002 survey was used for the area around the Graveyard hills complex, and stratification of the rest of the area (west of 178° E) was based on a statistical analysis that used recursive partitioning in an attempt to decide on stratum boundaries. The data used included all TCEPR tows in the area from 1994–95 to 2002–03. The response variable was catch (per tow) and we allowed splits only on the variable longitude. The suggested splits carried no predictive power (using cross-validation methods). This resulted in the survey area being split into eight sub-areas including 1–4 used in the 2002 survey plus new sub-areas 5–7 and an additional new sub-area, 8, around the Hole. Within each sub-area up to 2 strata were defined based on previous (2002) stratum boundaries, and depth for new strata (Table 2, Figures 4–9).

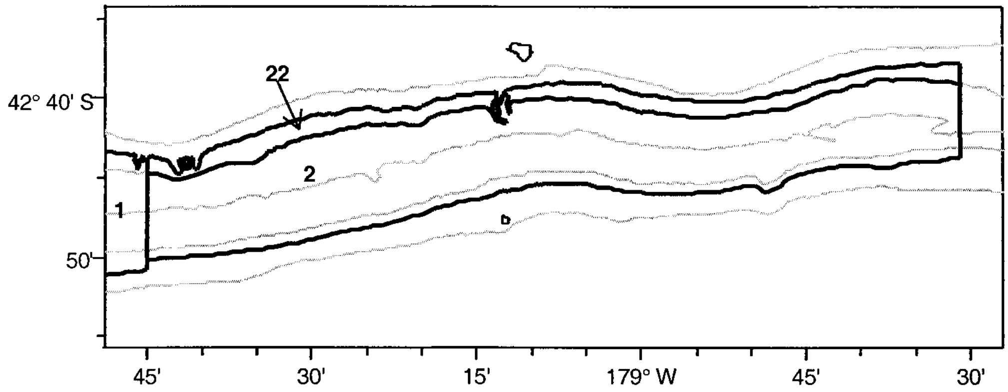


Figure 4: Location and extent of flat strata 2 and 22. 800 m, 900 m, 1000 m, 1100 m, and 1200 m depth contours are shown.

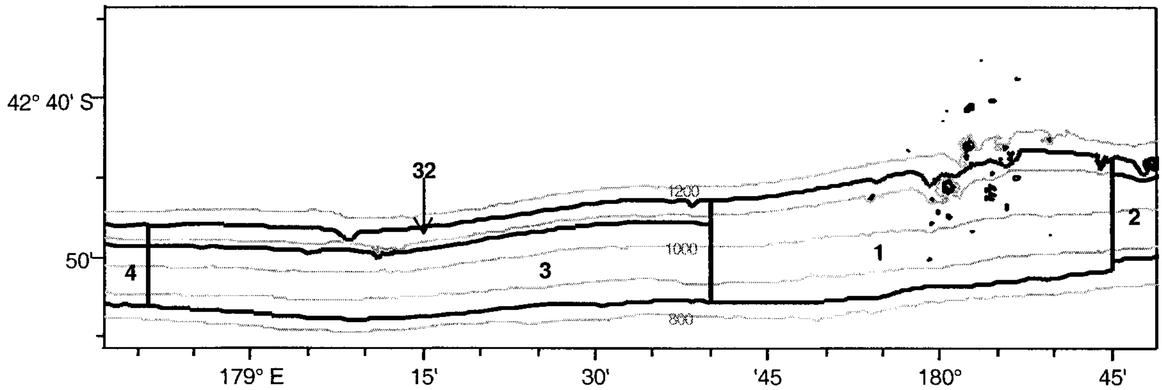


Figure 5: Location and extent of flat strata 1, 3, and 32. 800 m, 900 m, 1000 m, 1100 m, and 1200 m depth contours are shown.

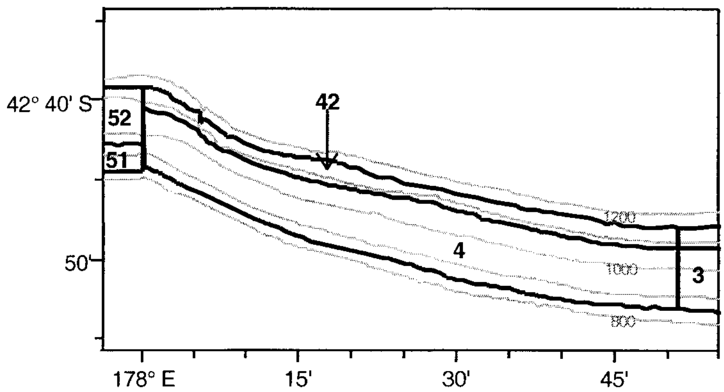


Figure 6: Location and extent of flat strata 4 and 42. 800 m, 900 m, 1000 m, 1100 m, and 1200 m depth contours are shown.

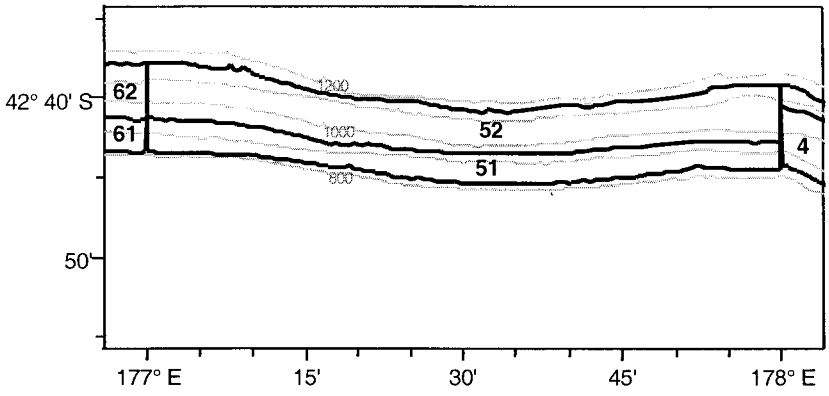


Figure 7: **Location and extent of flat strata 51 and 52. 800 m, 900 m, 1000 m, 1100 m, and 1200 m depth contours are shown.**

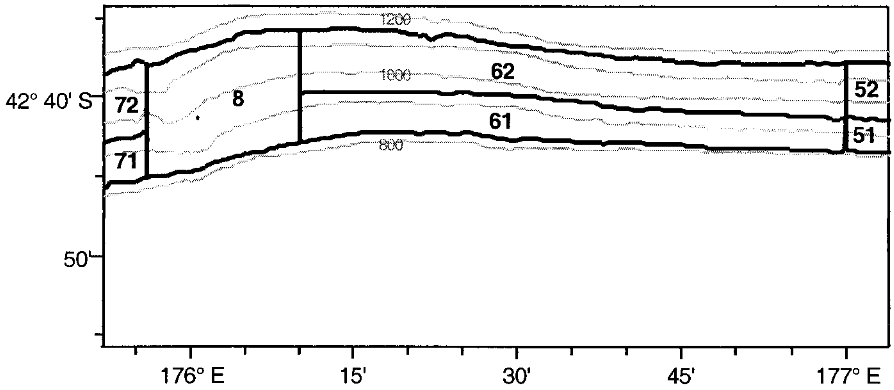


Figure 8: **Location and extent of flat strata 61, 62, and 8. 800 m, 900 m, 1000 m, 1100 m, and 1200 m depth contours are shown.**

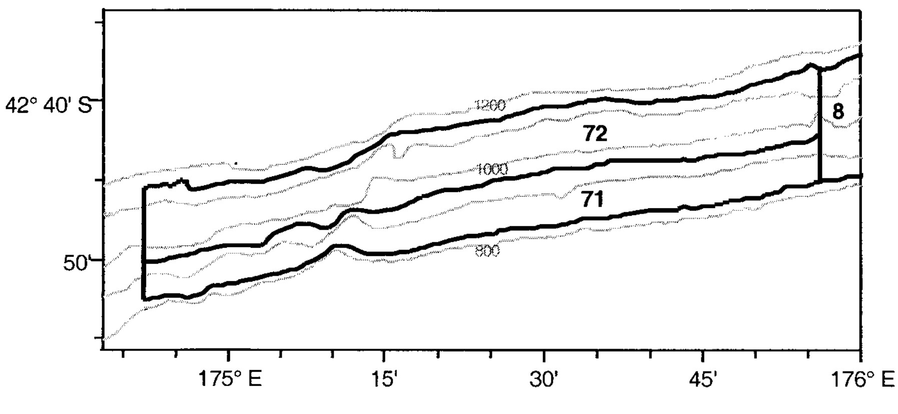


Figure 9: **Location and extent of flat strata 71 and 72. 800 m, 900 m, 1000 m, 1100 m, and 1200 m depth contours are shown.**

Parallel acoustic transects were randomly positioned by longitude within each stratum, running parallel to the north-south meridian. Because depth contours form the northern and southern boundaries of each stratum, every transect crossed the full depth profile of its stratum. Species composition and length data needed to decompose the acoustic backscatter to estimate orange roughy abundance were collected from trawls in the same stratum. Because the trawls formed a stratified random survey, the trawls were randomly positioned within each stratum.

In the 2002 flat area acoustic survey stratum 3 had a large abundance and also a large c.v. resulting in a total abundance estimate c.v. of about 64%. This was due to one tow that caught mainly orange roughy and very few other species. The 2002 survey tows were in July, and were possibly contaminated by the out-migration of the spawning aggregation from the Graveyard hill. In 2005, 10 tows were planned for stratum 3 for the first phase, and up to 14 tows for phase 2.

Table 2: Wide-area survey. Stratum area and depth boundaries, and stratum size.

Stratum	Code	E-W boundaries		Depth boundaries (m)		Area (km^2)
		East	West	South	North	
1	0001	179 40 E	179 45 W	840	1 150	640
2	0002	179 45 W	178 31 W	870	1 100	1 010
22	0022	179 45 W	178 31 W	1 100	1 150	192
3	0003	178 51 E	179 40 E	840	1 075	549
32	0032	178 51 E	179 40 E	1 075	1 150	166
4	0004	178 00 E	178 51 E	840	1 075	501
42	0042	178 00 E	178 51 E	1 075	1 150	157
51	0051	177 00 E	178 00 E	825	950	273
52	0052	177 00 E	178 00 E	950	1 150	470
61	0061	176 10 E	177 00 E	825	950	308
62	0062	176 10 E	177 00 E	950	1 150	430
71	0071	174 52 E	175 56 E	825	950	466
72	0072	174 52 E	175 56 E	950	1 150	651
8	0008	175 56 E	176 10 E	825	1 150	264

2.5 Biological sampling

Sampling to estimate species and size composition and other biological parameters was carried out by trawling. Trawl catches from each successful tow were sorted and weighed by species to the nearest 0.1 kg. For catches too large to be weighed, the orange roughy catch was estimated from the weighed, processed catch using a conversion factor. The estimated proportions of orange roughy and other species were used to apportion the acoustic backscatter in each stratum.

A random sample of 200 orange roughy was selected from each tow and staged length frequency measurements (i.e., frequency by sex and gonad stage, standard length to the nearest centimetre below) were made. For large catches, additional samples of 200 orange roughy were taken from different parts of the net to ensure sampling was representative of the catch. A further 20 orange roughy (more for large catches) were randomly selected for more detailed examination. Data collected were standard length (mm), weight (g), sex, and gonad stage.

Gonad stages are based on those of Pankhurst et al. (1987), with the addition of a further partially spent stage and one of mature-resting fish (Table 3). Length measurements (to the nearest millimetre below) and weights to the nearest 5 g were collected for samples of bycatch species.

Orange roughy mean lengths scaled by catch and sex ratio data were calculated for each stratum (each hill was counted as a stratum). The length-weight relationship for all species was estimated from data collected during the survey.

Table 3: Description of the macroscopic gonad stages used for orange roughy.

Stage	Male	Female
1	Immature	Immature
2	Early maturation	Early maturation
3	Maturing (mature)	Maturing (mature)
4	Ripe/running	Ripe
5	Spent	Running ripe
6		Spent
7		Atretic
8	Partially spent	Partially spent
9	Resting (mature)	Resting (mature)

2.6 Estimating absolute acoustic abundance

The overall procedure for estimating abundance was essentially the same as in previous orange roughy surveys (Bull et al. 2000, Doonan et al. 2001) (Appendix 1), except that the proportions of species (by number) from each catch were weighted by the square root of the catch size rather than catch size alone. Square root weighting was used because the small number of trawls means that the proportion estimates are not robust to a large catch with an atypical composition; square root weighting gives a more robust estimate. The total recruited abundance of the stock is required for stock assessment, and for orange roughy this is taken to be equal to the abundance of mature fish. This survey directly estimated only the abundance of spawning orange roughy in the areas surveyed. Spawning orange roughy were defined as those with a gonad stage of 3 or more. The variability associated with each estimate was also estimated and a sensitivity analysis carried out.

The following sections expand on aspects of the overall analyses that are specific to this survey.

2.6.1 Mark-types

The marks observed in the wide-area survey included a ubiquitous bottom layer that varied from 10 to 40 m in height above the bottom. The layer consisted of a low intensity backscatter with no clear structure, apart from height variations. On the northwest Chatham Rise this layer contains a mixture of species, the composition of which changed by area and with depth.

Mid-water layers were present in some areas, some of which appeared as more intense localised marks 10 or more metres off the bottom. *Amaltal Mariner* was used to carry out midwater trawling on layer marks observed by *Tangaroa* on the flat acoustic survey. This trawling aimed to determine the species composition of these marks and to measure the vertical distribution of the species of interest. Two separate marks were investigated on 20–21 and 25–26 June. A large midwater net with a 60 mm codend was used to sample large fish, and a mesopelagic net with a 10 mm codend was used to sample small fish and invertebrates. These midwater layers were not integrated in the acoustic analysis.

Large aggregation type marks were observed on Morgue during the third snapshot. These marks were interpreted using species composition data observed from the last research tows made, i.e., from data collected during the 1999 Graveyard hills complex survey (Bull et al. 2000). The marks on Morgue were composed of relatively intense backscatter which implies that this aggregation may have included species with a higher target strength than orange roughy.

The other hills, principally Graveyard, had smaller hilltop marks and these were interpreted as being orange roughy unless there was clear evidence from catches that they were not. *Amaltal Mariner* inspected and towed on Casket/St Pauls during the first snapshot but reported small catches. A mark was observed on the top of Casket but trawling and the transient nature of the mark suggested that it was more likely to be cardinalfish than orange roughy and consequently Casket was not included in snapshots 2 and 3.

2.6.2 Target strength

The target strength relationships used in this assessment were the same as those used by Doonan et al. (2001), except for smooth oreo and black oreo. The relationships between target strength and length are given in Table 4. For orange roughy, the relationships are based on measurements of live fish in a tank (McClatchie et al. 1999) combined with in situ results from Barr (2001), called the "NIWA" relationship in this report. An alternative abundance estimate was also made based on the Kloser & Horne (2003) results which were used here as an intercept of –77.82 dB with the same slope as the NIWA relationship.

The target strengths for the oreo species were derived from a Monte-Carlo analysis of *in situ* and swimbladder data (Macaulay et al. 2001, Coombs & Barr 2004) and the relationships used were:

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

for smooth oreo and

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

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

For other common species, relationships based on swimbladder modelling were used (Macaulay et al. 2001). Generic relationships were used for other species as detailed by Doonan et al. (1999).

Table 4: Target strength-length relationship coefficients used, where the relationship is of the form $TS = a + b\log_{10}(L) + c\sin(c_1 L - c_2)$.

				Sine term used		
Species	Code	Intercept (a)	Slope (b)	c	c_1	c_2
Orange roughy (*Hoplostethus atlanticus*) (NIWA)	ORH	-74.34	16.15			
Basketwork eel (*Diastobranchus capensis*)	BEE	-76.7	23.3			
Black javelinfish (*Mesobius antipodum*)	BJA	-70.6	17.8			
Black oreo (*Allocyttus niger*)	BOE	-78.05	25.2	1.62	0.082	-0.24
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			
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			
Smooth oreo (*Pseudocyttus maculatus*)	SSO	-82.16	24.63	1.03	0.117	1.77
White rattail (*Trachyrincus aphyodes*)	WHX	-62.1	18.1			
Cod-like		-67.5	20.0			
Deep water swimbladdered		-79.4	20.0			
No swimbladder		-77.0	20.0			

2.6.3 Trawl abundance index

Abundance indices were calculated by the area swept method described by Francis (1981, 1984). Abundance and its standard error were calculated from the following formulae:

$$B = \Sigma(X_i a_i)/cb$$

$$S_B = \sqrt{\Sigma S_i^2 a_i^2 / c^2 b^2}$$

where B is abundance (t), X_i is the mean catch rate (kg/km) in stratum i, a_i is the area of stratum i (km^2), b is the width swept by the gear (doorspread, m), c is the catchability coefficient (an estimate of the proportion of fish available to be caught by the net), S_B is the standard error of the abundance, and S_i is the standard error of X_i. Approximate 95% confidence limits (CL) were calculated as:

$$CL = B \pm 2S_B$$

The coefficient of variation (c.v.) is a measure of the precision of the abundance estimate:

$$c.v. = S_B/B*100$$

The catchability coefficient, c, is the product of the vulnerability, vertical availability, and areal availability (defined by Francis 1989). The effective width of the gear when fishing orange roughy schools is generally taken to be the wing–end spread, and so vulnerability is the ratio of the wing-end to the trawl doorspread b (here 0.12). Vertical availability is unknown, but was assumed equal to 1.0 because no fish marks were observed above the headline of the net during the survey. Areal availability was assigned a value of 1.0 because the estimated abundance was intended to apply solely to the area surveyed.

Length-weight parameters were used to apportion abundance by length groupings. A length-weight regression for fish measured and weighed during the survey was:

$$W = 0.0608 * L^{2.825} \qquad (W \text{ in g}, L \text{ in cm})$$

3. RESULTS

The survey took place between 16 June and 8 July 2005 with *Tangaroa* (voyage TAN0509) present for the whole period and *Amaltal Mariner* present from 17 to 27 June 2005 (AMA0501). *Tangaroa* carried out all the formal acoustic survey work for the hills and the wide-area surveys as planned and also completed the wide-area trawl survey. *Amaltal Mariner* carried out hill mark identification trawling, and also completed midwater trawling on layer marks observed by *Tangaroa* during the acoustic wide-area survey. The towed system (towbody 2) used throughout the survey was calibrated on 6 July down to 875 m (Table 5).

Table 5: Calibration data for the 38 kHz CREST towbody system used in the 2005 ORH 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 ('20 log R').

NIWA system number	2
Transducer model	ES38DD
Transducer serial number	28327
3 dB beamwidths (°)	7.0 × 6.9
Effective beam angle (sr)	0.0083
Operating frequency (kHz)	38.156
Transmit interval (s)	4
Transmiter pulse length (ms)	1
Effective pulse length (ms)	0.78
Filter bandwidth (kHz)	0.78
Initial sample rate (kHz)	60
Decimated sample rate (kHz)	4
V_T (V)	1311.50 ('flat' strata)
	1311.36 ('hill' strata)
G	14491

3.1 Graveyard hills complex acoustic survey

Three snapshots were carried out on 18–19, 22–23, and 25–26 June 2006. Two snapshots were planned but a third snapshot was added because of the absence of strong plume marks on Graveyard during snapshots 1 and 2. The three snapshots were carried out in between the wide-area acoustic survey of the surrounding strata to reduce the probability of double-counting fish. A commercial fishing vessel trawling on Graveyard hill about a day before the first snapshot of Graveyard may have disrupted orange roughy school formation. The snapshots also had to be fitted in between the trawling (mostly on Graveyard) and surveying activities carried out by *San Waitaki* (24 and 27 June), poor weather (23 and 26 June), and before the departure of *Amaltal Mariner* on 27 June. The elongated shape of the wide-area survey grounds also limited the practicality of easily returning to the Graveyard hills for a fourth snapshot. This was contemplated on 1 July and the Ministry of Fisheries was consulted but decided to continue with the wide-area survey. Table 6 summarises of the acoustic transects completed and used in the abundance analysis. A summary of tows made on each hill and used in the analysis is in Table 7. The species composition of nine tows made on Morgue during the 1999 survey (before it was closed to trawling) were used in the analysis to provide estimates of species composition for the acoustic analysis. The estimated mature abundances by hill, for each snapshot, are given in Table 8 and the corrections for the shadow zone, absorption of sound energy in water, and towbody motion applied to the backscatter are given in Table 9.

Table 6: Acoustic survey transects completed by *Tangaroa* and used in the analysis.

	Acoustic transects		
Hill stratum	Snapshot 1	Snapshot 2	Snapshot 3
Graveyard	4	4	4
Zombie	2	2	2
Deadringer	2	2	
Scroll	2	2	
Morgue	2	2	1
Casket/St Pauls	2		
Totals	14	12	7

Table 7: Acoustic survey tows completed by *Amaltal Mariner* and used in the analysis.

Hill	Number of tows
Graveyard	13
Zombie	1
Deadringer	3
Scroll	4
Morgue	9†
Casket/St Pauls	2

† 9 tows on Morgue from the 1999 *Tangaroa* survey were used.

Table 8: Orange roughy mature abundance estimates (t) for the hill acoustic survey. Mature fish have length greater than 31 cm SL.

	Abundance (c.v. %)		
Stratum	Snapshot 1	Snapshot 2	Snapshot 3
Casket	12 (129)		
Deadringer	4 (53)	8 (44)	
Graveyard	86 (47)	19 (44)	93 (72)
Morgue	438 (75)	354 (86)	1 391 (95)
Scroll	1 (40)	4 (50)	
Zombie	21 (17)	7 (54)	
Totals	562 (42)	392 (78)	1 484 (89)

Table 9: Backscatter correction factors used in the analysis of the hill acoustic survey.

Stratum	Shadow	Absorption	Motion
Casket	1.12	1.23	1.39
Deadringer	1.34	1.27	1.69
Graveyard	1.37	1.27	1.37
Morgue	1.13	1.26	1.27
Scroll	1.24	1.27	1.90
Zombie	1.48	1.28	1.46

The proportions of orange roughy in spawning condition on hills sampled by *Amaltal Mariner* are shown in Table 10. The proportion of spawning and spent male fish (stages 4–5, 8) on Graveyard hill was 15, 42, and 31% from snapshots 1–3 respectively, suggesting an initial increase in activity. The proportions of spawning and spent female fish (stages 4–6, 8) on Graveyard hill were 41, 57, and 63% from snapshots 1–3 respectively, suggesting an increase in activity. The proportion of spent male fish (stages 5 and 8) on Graveyard hill was 1, 4, and 10% from snapshots 1–3 respectively, suggesting that either spawning was at an early stage during the three snapshots or that spent fish had migrated away. The proportions of spent female fish (stages 6 and 8) on Graveyard hill were 2, 3, and 7% from snapshots 1–3 respectively, suggesting that spawning was at an early stage during the three snapshots.

Table 10: Percentage of orange roughy by gonad stage, sex, and snapshot for each hill sampled. –, not applicable.

	Gonad stage								
	1	2	3	4	5	6	7	8	9
Male									
Snapshot 1									
Casket	24	3	74	0	0	–	–	0	0
Deadringer	10	14	55	12	6	–	–	4	0
Graveyard	1	5	80	14	0	–	–	1	0
Scroll	1	23	68	9	0	–	–	1	0
Zombie	0	28	66	4	0	–	–	1	0
Snapshot 2									
Deadringer	0	40	40	20	0	–	–	0	0
Graveyard	2	13	42	38	1	–	–	3	0
Scroll	1	13	52	26	2	–	–	6	0
Snapshot 3									
Casket	4	4	4	87	0	–	–	1	0
Graveyard	2	27	40	21	3	–	–	7	0
Female									
Snapshot 1									
Casket	5	15	71	10	0	0	0	0	0
Deadringer	2	39	48	7	0	0	0	5	0
Graveyard	0	5	52	35	4	1	0	1	1
Scroll	1	4	60	28	4	0	0	0	3
Zombie	0	4	79	15	1	0	0	1	0
Snapshot 2									
Deadringer	11	56	33	0	0	0	0	0	0
Graveyard	1	3	37	49	5	0	0	3	1
Scroll	2	5	35	23	14	0	0	14	8
Snapshot 3									
Casket	0	13	32	46	5	3	0	3	0
Graveyard	1	3	32	48	8	1	0	6	0

3.2 Wide-area survey

The *Tangaroa* wide area survey comprised 84 acoustic transects, 70 rat-catcher trawl stations, 14 rough bottom trawl stations, and one mark identification bottom trawl station (rat-catcher) spread over 14 strata and a total area of 6083 km^2 (Table 11).

Table 11: Transects and trawl stations carried out using *Tangaroa* in the wide-area acoustic survey.

Stratum	Area (km^2)	Acoustic transects	Ratcatcher stations phase 1	Ratcatcher stations phase 2	Roughy gear stations	Mark ID stations
1	629	6	6		3	
2	1 014	6	6		3	
3	551	6	10	3	5	1
4	502	6	6		3	
22	188	6	3			
32	167	6	3			
42	157	6	3			
51	274	6	3			
52	472	6	3	2		
61	310	6	3			
62	432	6	3	2		
71	468	6	3			
72	654	6	3	2		
8	265	6	4	2		
Totals	6 083	84	59	11	14	1

Trawl station details are given in Appendix 2. Mature abundance estimates are given in Table 12 and include the corrections for the shadow zone, absorption of sound energy in water, and towbody motion applied to the backscatter. Correction factors for each stratum are given in Table 13.

Table 12: Orange roughy mature abundance estimates (t) for the wide-area acoustic survey.

Stratum	Abundance (t)	c.v. (%)
1	1 238	37
2	1 283	40
3	2 837	73
4	551	63
22	112	73
32	1 099	115
42	162	81
51	124	81
61	97	77
71	54	54
52	66	71
62	466	76
72	90	56
8	28	52
Total	8 208	40

Table 13: Backscatter correction factors used in the analysis of the wide-area acoustic survey.

Stratum	Shadow	Absorption	Motion
1	1.04	1.37	1.33
2	1.06	1.36	1.22
3	1.03	1.42	1.10
4	1.05	1.35	1.36
22	1.07	1.41	1.31
32	1.02	1.45	1.13
42	1.07	1.38	1.43
51	1.10	1.35	1.20
61	1.06	1.34	1.20
71	1.09	1.34	1.07
52	1.08	1.40	1.46
62	1.03	1.39	1.18
72	1.13	1.42	1.07
8	1.07	1.35	1.07

Most of the tows covered a distance of 1.5 n. miles at 3 knots. Four tows were shortened to reduce catch size. Bottom contact sensor results showed that the ratcatcher net groundrope made good contact with the bottom and good contact was also observed from polished chains, bobbins, wingtips, bridles and sweeps, and from the net monitor.

Orange roughy was the second most abundant species by weight caught during the trawl survey (Table 14). The most abundant species was the four-rayed rattail (*Coryphaenoides subserrulatus*). Four species, orange roughy, four-rayed rattail, white rattail, and Johnson's cod were caught in all the rat-catcher tows. About 201 species of fishes and invertebrates were recorded during the survey, with the swimming sea cucumber (*Enypniastes eximia* Théel, 1882) the third most abundant species (a few large tows) after the four-rayed rattail and orange roughy.

Table 14: The total catch weight (kg) and occurrence (as % of all tows) of the 10 most frequent fish species by occurrence caught using the rat-catcher net during the wide-area trawl survey.

Common name	Scientific name	Occurrence (%)	Catch (kg)
Four-rayed rattail	*Coryphaenoides subserrulatus*	100	11 731.9
Orange roughy	*Hoplostethus atlanticus*	100	6 984.7
Basketwork eel	*Diastobranchus capensis*	99	1 970.9
White rattail	*Trachyrincus aphyodes*	100	1 268.4
Smallscaled brown slickhead	*Alepocephalus australis*	69	1 137.5
Smooth oreo	*Pseudocyttus maculatus*	92	1 133.8
Smooth skin dogfish	*Centroscymnus owstoni*	83	1 011.8
Hoki	*Macruronus novaezelandiae*	69	978.9
Johnson's cod	*Halargyreus johnsonii*	100	865.5
Hake	*Merluccius australis*	63	837.8

Distribution of mature, immature, and spawning orange roughy

The proportions of orange roughy in spawning condition by stratum sampled by *Tangaroa* are shown in Table 15. There were low proportions of spawning and spent fish (males 4–5, 8 and females 4–6, 8) on the flat (strata 1–3) around the Graveyard hills early in the survey with males making up 32, 31, and 19% and females 18, 9, and 16% for strata 1–3 respectively. Other strata sampled later in the survey didn't show a marked progression of spawning cycle gonad stages, although strata 8 (The Hole) and 72 (further west) had 38 and 58% male spent (stages 5 and 8) and 20 and 19% female spent (stages 6 and 8) fish, suggesting possible local spawning.

Table 15: Proportion of orange roughy by gonad stage and sex for the strata in the wide-area suvey.

	Gonad stage								
	1	2	3	4	5	6	7	8	9
Male									
Stratum									
1	21	22	25	18	5			9	
2	33	29	7	13	7			11	
3	27	31	24	8	1			10	
4	47	21	3	10	7			13	
8	23	39	0	0	32			6	
22	31	48	5	3	3			11	
32	9	57	24	1	3			6	
42	19	28	0	4	23			26	
51	15	17	0	28	11			30	
52	20	53	2	0	21			5	
61	79	13	1	0	7			0	
62	21	44	3	3	26			3	
71	30	39	0	9	17			4	
72	13	18	5	5	42			16	
Female									
Stratum									
1	18	24	28	12	1	3	11	2	2
2	22	35	19	8	1	0	12	0	4
3	17	35	21	7	1	1	10	1	7
4	27	26	6	5	2	9	25	0	2
8	4	35	0	0	0	20	37	0	4
22	20	51	5	0	0	0	18	0	6
32	7	43	12	2	1	7	17	0	11
42	2	23	3	2	0	10	44	0	15
51	5	14	11	9	9	14	36	0	2
52	3	50	1	1	0	3	36	0	6
61	48	29	0	0	1	1	20	0	0
62	5	50	0	1	1	9	28	0	6
71	3	52	6	0	0	9	30	0	0
72	0	45	2	0	0	19	31	0	3

Biological data collected during the wide-area and hill surveys

Details of the biological data collected on *Tangaroa* are given in Appendix 3. A total of 28 430 fish were measured for length-weight, of which 2098 were orange roughy, with another 4241 orange roughy sampled for length and sex only. On *Amaltal Mariner*, 1253 fish were measured for length/weight, of which 658 were orange roughy, and a total of 6800 fish of various species were measured for length only (Appendix 4).

The length distributions of orange roughy sampled for gonad stage and otoliths on *Tangaroa* are given in Appendix 5 and the equivalent data collected on *Amaltal Mariner* are in Appendix 6.

Amaltal Mariner midwater trawling

Tows on layer marks completed and catches are summarised in Appendix 7. Seven tows were carried out on a well defined layer (experiment 1) which extended up to about 50 m above the bottom at 1070–1080 m. Tows 13–20 were carried out with the groundrope 3–51 m above the bottom. Some large catches of the four-rayed rattail (*Coyrphaenoides subserrulatus*), and also substantial amounts of the swimming sea cucumber (*Enypniastes eximia*), were made and suggests that the observed layers were mostly composed of these species with only a small contribution from orange roughy. No orange roughy were caught, even with the net fished as close as 3 m above the bottom. Orange roughy were caught by bottom trawl by *Tangaroa* (station 7) using the ratcatcher net underneath the layer marks.

Midwater tows were also carried out on much less well defined layer marks (experiment 2, tows 33–39), but results were not as conclusive with small catches.

3.3 Trawl survey abundance estimates

The trawl survey estimates of abundance for the wide area dispersed population were estimated for all fish, for mature fish (31 cm and over SL), and for immature fish (under 31 cm SL). Wingtip abundance estimates, were 8038 t (c.v. 12.3%) for all fish, 4490 t (c.v. 10.2%) for mature fish, and 3 548 t (c.v. 16.1%) for immature fish. Between trawl door abundance estimates assuming a constant swept area of 117 m were 1719 t (c.v. 12.3%) for all fish, 960 t (c.v. 10.2%) for mature fish, and 758 t (c.v. 16.1%) for immature fish.

The greatest mature and overall abundance was in the strata at the east end of the survey area near the Graveyard hills, most in strata 2 and 3 but also in strata 1 surrounding the hills surveyed. Abundance generally decreased away from the Graveyard hills (Table 16).

Table 16: Estimates of mature and total relative abundance (t) from the trawl survey by stratum (see Figures 4–9), c.v.s in parentheses, based on a swept area of 25 m (i.e., distance between trawl wingtips).

Stratum	Mature	c.v. (%)	Total	c.v. (%)
1	723	15	1 133	12
2	1 269	28	2 547	33
3	1 007	19	1 717	21
4	412	28	707	27
22	141	59	381	68
32	169	4	246	8
42	134	21	184	20
51	131	60	156	53
52	103	26	203	26
61	40	50	132	47
62	119	26	249	38
71	58	30	120	21
72	152	51	212	44
8	31	34	52	35

3.4 Northwest Chatham Rise orange roughy acoustic abundance estimates

An acoustic estimate of the abundance of mature orange roughy in the ORH 3B fishery from the 2005 survey is required for stock assessments. The survey was timed to coincide with the spawning season as was the case for the previous two acoustic surveys. Unlike the previous two surveys though, the 2005 survey was designed to cover the full extent of the northwest Chatham Rise fishery. This meant that a direct estimate of the mature abundance can be made using the species mix of mature orange roughy (defined to be of length greater than or equal to 31 cm) with immature roughy and other species in the trawls associated with the survey. Because the previous two surveys concentrated on the hills and surrounding flat area, where it was known that spawning was most concentrated, it was not possible to estimate mature abundance directly for those surveys and acoustic estimates of spawning (stage 3 or higher) abundances were calculated instead. Each was then scaled by a factor, determined from information outside the survey, to give estimates of mature abundance for the whole fishery (Bull et al. 2000, Doonan et al. 2003b).

Different numbers of snapshots were taken of the different hills included in the survey and the total abundance estimates for the hills were obtained by averaging over the snapshots for each hill and then adding (see Table 9). Mature abundance estimates on the wide area strata are made using the species mix from the ratcatcher trawl data. Separate abundance estimates were made using the NIWA (Barr & Coombs 2001) target strength-length relationship, the Kloser & Horne (2003) target strength-length relationship, and the average acoustic cross-section of the two relationships (which is the harmonic mean of the absolute target strength-length relationships). These target strength-length relationships (db) are: $-74.34 + 16.15\log_{10}(L)$, $-77.82 + 16.15\log_{10}(L)$, and $-75.74 + 16.15\log_{10}(L)$, respectively. The mature abundance estimates are given in Table 17.

Table 17: Mature abundance estimates (t) in 2005 for the hill and wide-area acoustic surveys together with the total, using the three target strength-length relationships.

	Barr & Coombs	Kloser & Horne	Average cross-section	c.v.
Hills	828	942	878	
Strata 1–4	5 908	5 943	5 925	
Strata 22–72, 8	2 299	2 306	2 302	
Total	9 035	9 191	9 105	40%

The c.v. of 40% for the total mature abundance was calculated using the NIWA target strength-length relationship and includes the uncertainty about the relationship. The estimates include corrections for the shadow zone, towed body motion, and sound absorption. The poor weather in parts of the survey meant that motion corrections were substantial in some strata (see Tables 9 & 12) and overall it was 31%. The shadow zone corrections were generally low with an overall mean of 13% but the sound energy absorption correction was also substantial with a mean of 35% (see Tables 9 & 13).

To assess comparability with the 2002 survey, about half of the trawl stations in strata 1–4 (the flat area of the 2002 survey) were repeated using orange roughy gear instead of ratcatcher gear (see Table 11). Estimates of mature abundance for strata 1–4 are given in Table 18. Except for stratum 3, the ratcatcher gear resulted in smaller abundance estimates.

Table 18: Comparison of mature abundance estimates using the species mix from the different trawl gear

Stratum	Roughy gear (c.v. %)	Ratcatcher (c.v. %)
1	1 399 (60)	1 238 (37)
2	1 631 (51)	1 283 (40)
3	2 340 (92)	2 837 (73)
4	1 281 (71)	551 (63)
Total	6 650 (48)	5 908 (37)

The strata comprising the whole flat area for the 2002 survey are the same strata 1–4 of the 2005 survey. However, the flat stratum of the 1999 survey has no comparability with the flat strata of the either two later surveys (see Bull et al. (2000) and Doonan et al. (2003b)). For comparison with the earlier surveys, spawning abundances (fish at stage 3 or higher) from the 2005 survey were calculated for the hills, strata 1–4, and the new strata. These are compared with spawning abundances from the two earlier surveys in Table 19.

Table 19: Acoustic estimates of spawning abundance (t) from the 1999, 2002, and 2005 surveys.

	1999	2002	2005 (c.v. %)
Hills	3 400	7 200	600 (42)
1999 flat stratum	2 500	-	-
Strata 1–4	-	22 500	4 600* (46)
Strata 22–72, 8	-	-	2 000 (41)
Total	5 900	30 000	7 200 (41)

* spawning abundance calculated using the species mix from ratcatcher trawl data. The total for strata 1–4 in 2005 was 5960 t (c.v. 47%) when the species mix from the roughy gear trawls was used

4. DISCUSSION

The small size of the plume marks on the Graveyard hills, particularly Graveyard itself, between 18 and 26 June 2005 was unusual compared to previous surveys. The 1999 Graveyard hills survey was carried out from 23 to 25 June (Bull et al. 2000), and the 2002 survey was from about 22 June to 2 July and both observed the characteristic plume marks associated with spawning schools of orange roughy. Commercial fishing vessels operating on the Graveyard hill before and during the 2005 survey were able to take commercial catches of orange roughy from known tow lines in spite of the lack of substantial plume marks.

Acoustic methods work well with marks that extend above the bottom, but there are problems with distinguishing targets that are on or very close to the bottom. There are a number of possible explanations for the lack of large marks on Graveyard during late June 2005. These include: too few orange roughy left to form large marks, disruption of spawning school formation by repeated commercial trawling, and delayed timing of spawning leading to later school formation. *San Waitaki* returned to the Graveyard hill later (3–5 July 2005) and reported larger marks (L. Hampton et al., unpublished report to the Deepwater Stock Assessment Working Group) and greater abundance compared to late June. Hampton suggested that orange roughy spawning may have been later in 2005 compared to previous years. Analysis of the NIWA and *San Waitaki* biological data (gonad stages) gives some support to that hypothesis, but hypotheses of lower population size resulting in more fragile mark formation or disruption of schools by commercial trawling are still possible causes for the apparent reduced plume marks.

The option of *Tangaroa* returning to Graveyard for a fourth snapshot was considered and MFish was consulted on 1 July 2005, but it was concluded that fish not aggregated on the hills would have been sampled by the wide-area survey and the decision to proceed with the wide-area survey was made. The final results show that most of the estimated mature orange roughy abundance (about 68%) was present in the wide-area strata near the Graveyard hills (strata 1–4), with about 26% in the rest of the flat wide-area strata (8–72) and only about 7% on the Graveyard hill complex. The importance of the wide-area survey is that it provided estimates of relative and or absolute orange roughy abundance for the rest of the northwest Chatham Rise (excluding the Graveyard hills) where estimates have previously been lacking.

Extensive layer marks on the flat ground are problematic because of the uncertain species composition of the marks above the bottom not sampled by bottom trawl. In the past, bottom trawl estimates of the species mix have been applied to the midwater part of a mark that may extend from the bottom up to about 50 m above the bottom. Midwater trawling was used to test the assumption that the marks above the bottom had a similar species composition to the marks underneath the layer marks sampled by bottom trawl. The experiments were partly successful and suggested that the observed layer marks were dominated by the four-rayed rattail. No orange roughy were caught in the midwater trawl even when it was fished only a few metres from the bottom, but a bottom trawl tow made on the mark did catch orange roughy. This suggests that layer marks should not be integrated up to tens of metres above the bottom with the assumption that the species composition of the vertical mark is the same as the species composition of a tow made on the bottom below the layer mark. One uncertainty with this suggestion is that orange roughy may react to a midwater (or bottom) trawl by diving to the bottom to avoid the net. This behaviour is reported anecdotally by fishers but needs to be tested experimentally.

One of the criticisms of carrying out a wide-area acoustic survey on flat ground is that orange roughy may be so close to the bottom that they are unable to be detected by the acoustic technique. This is an issue if the acoustic abundance estimates from the wide-area survey are used as absolute estimates, but may be less of an issue if the estimates are used as relative estimates. Again the vertical distribution of orange roughy and the acoustic detection/threshold relationship are issues that should be investigated in future.

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APPENDIX 1: GENERIC MARK-STRATUM ANALYSIS FOR ACOUSTIC SURVEYS

The following provides an account of the estimation of abundance when using mark-classes and strata for a generic deepwater species, called DEEPWATER in what follows, with code "XXX". In general, biomass is estimated separately for the flat and hills. For the former, the acoustic data are classified into mark-types where marks equate approximately to echogram images. The mark classification schemes are a result of analyses of concurrent data collection from trawling and the echogram of the mark trawled on. The biomass of DEEPWATER in each mark-type is estimated from the backscatter for each mark, the proportion by number of DEEPWATER 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 DEEPWATER in that mark-type. These are then summed over each stratum, scaled up by the stratum area, and the results are then summed over all strata.

Most hills (or isolated plumes) are surveyed using star transects and the biomass on each hill is estimated using the method of Doonan et al. (2003a). If there are too many hills to survey, then hills are grouped into classes and a random selection within each is surveyed. The mean biomass is calculated for each hill class, multiplied by the total number of hills in that class, and summed over all classes to give total biomass for all hills in the trawl survey area.

Flat

For the flat ground, the acoustic data are classified into types of 'marks' (mark-type). For stratum, i, the abundance of DEEPWATER in mark-type m, is given by $B_{i,m} = \frac{abscf_{i,m}}{\bar{\bar{\sigma}}_{bs,m}} \times p_{XXX,m} \times area_i \times \overline{w_m}$ where $area_i$ is the area of the stratum, $abscf_{i,m}$ is the mean backscattering (fish.m^{-2}), $\bar{\bar{\sigma}}_{bs,m}$ is the mean tilt-averaged acoustic cross-section for the species mix, $p_{XXX,m}$ is the proportion of DEEPWATER by number, and $\overline{w_m}$ is the mean weight of DEEPWATER. The mean tilt-averaged acoustic cross-section for the species mix is given by $\bar{\bar{\sigma}}_{bs,m} = \sum_j p_{jm} \bar{\bar{\sigma}}_{bs,jm}$ where j indexes each species, p_{jm} is the proportion in numbers of species j in the mix, and $\bar{\bar{\sigma}}_{bs,jm}$ is the mean tilt-averaged cross-section for species j (which depends on the length distribution of that species in mark-type m).

Mean cross-section, $\bar{\bar{\sigma}}_{bs,jm}$, is given by $\sum_l f_{XXX,m,l} 10^{\frac{\langle \mathrm{TS} \rangle_{sso}(l)}{10}}$ for DEEPWATER and by $\sum_l f_{j,m,l} 10^{\frac{\langle \mathrm{TS} \rangle_j (L_{jm})}{10}}$ for other species, where $f_{XXX,m,l}$ is the fraction of DEEPWATER in mark-type m with length l and $f_{j,m,l}$ is a similar fraction for the j^{th} species, $\langle \mathrm{TS} \rangle_j (l)$ is the tilt-averaged or in situ target strength-to-length function for species j, L_{jm} is the mean length of species j in mark-type m, $\langle \mathrm{TS} \rangle_j (l) = a_j + b_j \times \log_{10} l$ and a_j and b_j are constants.

The mean tilt-averaged acoustic cross-section is given by $\bar{\sigma}_{bs} = \int \sigma_{bs}(\theta) g(\theta) d\theta$, where θ is the tilt angle (in the pitch plane only), $\sigma_{bs}(\theta)$ is the acoustic cross-section as a function of θ, and $g(\theta)$ is the probability of a fish being at an angle θ. Tilt-averaged target strength, $\langle \mathrm{TS} \rangle$, is given by $10 \log_{10} \bar{\sigma}_{bs}$.

The lengths, mean weights, species composition, and proportion of DEEPWATER in the population are obtained by trawling during the survey.

For several strata (*strata*) and mark-types (*marks*) the total abundance, B_{Flat}, is given by $\sum_i^{strata} \sum_m^{marks} B_{i,m}$.

Hills

The total abundance for all hills (*Hills*), B_{Hills}, is given by $\sum_{h}^{Hill\text{-}class} N_h \bar{B}_h$, where $\bar{B}_h$ is the mean DEEPWATER abundance on hills in the h-th hill class, and N_h is the number of hills in the class. Each hill abundance is estimated using Equation 1 above, where i indexes the hill and there is only one mark-type used (plume = m). A 'star' transect pattern is used to survey most hills, and for this method the mean backscatter, $\text{abscf}_{i,plume}$ in $B_{i,plume}$ is over-sampled in the centre of the star and under-sampled at the edges. As most marks are usually entered in the middle of the star with relatively large sections of the transect outside the mark, the mean is biased high in relation to the area (taken from the two ends of the transects). To compensate for this effect, the mean backscatter for each transect is a weighted mean over all segments (10 pings in length) of the transect where the weights are proportional to the distance from the fifth ping in the segment to the centre of the star.

APPENDIX 2: SUMMARY OF TRAWL DATA

Table A1: Summary of tow details for TAN0509. All tows used the ratcatcher net except tows 30–37, 40–42, 50–52, which used the orange roughy rough bottom net. Data fields are: Date, date shot; Time, time shot; Lat, latitude shot, with 424967 meaning 42° 49.67' S (decimal minutes); Long, longitude shot, with 1792381 W meaning 179° 23.81' W; Depth, depth in m; P, gear performance (1, good, 3, poor); S, tow speed in knots; D, distanced towed in n. miles; H, average headline height in m; Dd, distance between doors in m.

Tow	Stratum	Date	Time	Lat	Long	Depth	P	S	D	H	Dd
1	3	19-Jun-5	20:33	425258	1785678 E	888	1	3.0	1.50	3.5	117
2	3	19-Jun-5	22:17	425257	1790271 E	901	1	3.0	1.50	3.5	117
3	32	20-Jun-5	0:48	424897	1790220 E	1107	1	3.0	1.51	3.5	117
4	3	20-Jun-5	5:51	424991	1790513 E	1057	1	2.9	1.50	3.2	117
5	3	20-Jun-5	8:03	425196	1790936 E	938	1	3.0	1.51	3.4	117
6	3	20-Jun-5	9:51	425337	1791397 E	857	1	3.0	1.01	3.4	117
7	3	20-Jun-5	16:46	424894	1792012 E	1076	1	3.0	1.02	3.4	117
8	3	20-Jun-5	18:24	424971	1791662 E	1053	1	3.0	1.04	3.4	117
9	32	20-Jun-5	20:06	424827	1791723 E	1131	1	3.0	1.50	3.4	117
10	3	21-Jun-5	0:38	425021	1792403 E	984	1	3.0	1.50	3.4	117
11	3	21-Jun-5	2:54	424850	1793058 E	1042	1	3.0	1.51	3.4	117
12	32	21-Jun-5	5:28	424702	1793371 E	1123	1	3.0	1.51	3.4	117
13	3	21-Jun-5	7:56	424967	1793650 E	985	1	3.0	1.50	3.4	117
14	3	21-Jun-5	9:38	425271	1793725 E	843	1	3.0	1.01	3.4	117
15	1	21-Jun-5	11:47	424767	1794457 E	1081	1	3.0	1.50	3.4	117
16	1	23-Jun-5	23:01	424971	1795145 E	954	1	3.0	1.50	3.4	117
17	1	24-Jun-5	0:55	424819	1795490 E	1006	1	3.0	1.50	3.4	117
18	1	24-Jun-5	2:42	425025	1795859 W	908	1	3.0	1.50	3.4	117
19	1	24-Jun-5	4:55	424455	1795050 W	1098	1	3.0	1.49	3.4	117
20	1	24-Jun-5	9:08	424909	1794559 W	920	1	3.0	1.51	3.4	117
21	2	24-Jun-5	11:15	424749	1794112 W	974	1	3.0	1.50	3.4	117
22	22	24-Jun-5	13:22	424155	1793071 W	1139	1	3.0	1.51	3.4	117
23	22	24-Jun-5	15:08	424081	1792381 W	1140	1	3.0	1.48	3.4	117
24	2	24-Jun-5	18:08	424241	1792900 W	1095	1	2.9	1.50	3.4	117
25	2	24-Jun-5	20:38	424635	1792758 W	953	1	3.0	1.50	3.4	117
26	2	24-Jun-5	22:31	424353	1792480 W	1028	1	3.0	1.51	3.5	117
27	2	25-Jun-5	1:52	424181	1790583 W	1018	1	3.0	1.50	3.5	117
28	22	25-Jun-5	3:37	424027	1785982 W	1123	1	3.0	1.51	3.5	117
29	2	25-Jun-5	6:16	424337	1785550 W	990	1	3.0	1.51	3.4	117
30	2	26-Jun-5	22:46	424349	1792479 W	1032	1	3.0	1.50	5.6	110
31	2	27-Jun-5	2:14	424633	1792763 W	957	1	3.0	1.51	5.6	110
32	2	27-Jun-5	7:52	424746	1794127 W	975	2	3.0	1.50	6.0	110
33	1	27-Jun-5	12:36	424816	1795498 E	1008	1	3.0	1.50	5.6	110
34	1	27-Jun-5	15:30	424968	1795149 E	957	1	3.0	1.51	5.6	110
35	1	27-Jun-5	19:07	424768	1794481 E	1072	1	3.0	1.50	5.6	110
36	3	28-Jun-5	1:24	424831	1792870 E	1060	1	3.0	1.50	5.6	110
37	3	28-Jun-5	5:49	425339	1791440 E	859	1	3.0	1.50	5.6	110
38	3	28-Jun-5	8:19	425207	1792786 E	874	1	3.0	1.50	3.4	117
39	3	28-Jun-5	11:00	424962	1792079 E	1032	1	3.0	1.51	3.4	117
40	3	28-Jun-5	14:05	425199	1790933 E	946	1	3.0	1.50	5.2	110
41	3	28-Jun-5	16:45	425255	1790275 E	906	1	3.0	1.52	5.4	110
42	3	28-Jun-5	19:34	425258	1785685 E	894	1	3.0	1.50	5.6	110
43	3	28-Jun-5	21:52	425050	1785548 E	1007	1	3.0	1.50	3.4	117
44	4	29-Jun-5	0:40	425166	1784614 E	927	1	3.0	1.50	3.4	117
45	4	29-Jun-5	3:22	424952	1783711 E	994	1	3.0	1.50	3.4	117

46	4	29-Jun-5	18:06	424522	1780958	E	962	1	3.0	1.50	3.4	117
47	4	29-Jun-5	19:50	424663	1781454	E	957	1	3.0	1.51	3.4	117
48	4	29-Jun-5	21:35	424663	1782247	E	1037	1	3.0	1.50	3.4	117
49	4	29-Jun-5	23:30	425081	1783117	E	879	1	3.0	1.51	3.4	117
50	4	30-Jun-5	1:36	424956	1783741	E	989	1	3.0	1.50	5.6	110
51	4	30-Jun-5	5:18	424662	1782240	E	1035	1	3.0	1.50	5.6	110
52	4	30-Jun-5	18:39	424675	1781482	E	974	1	3.0	1.51	5.8	110
53	42	30-Jun-5	21:37	424396	1781550	E	1135	1	3.0	1.50	3.4	117
54	42	30-Jun-5	23:42	424495	1782131	E	1127	1	3.0	1.55	3.4	117
55	42	1-Jul-5	1:43	424726	1783344	E	1091	1	3.0	1.50	3.4	117
56	52	2-Jul-5	10:24	423984	1770286	E	1044	1	3.0	1.50	3.5	117
57	52	2-Jul-5	12:33	424031	1770932	E	1032	1	3.0	1.50	3.6	117
58	51	2-Jul-5	14:52	424342	1771042	E	858	1	3.0	1.50	3.6	117
59	51	2-Jul-5	17:09	424403	1772811	E	910	1	2.9	1.51	3.5	117
60	52	2-Jul-5	19:01	424155	1773498	E	1111	1	3.0	1.49	3.5	117
61	51	2-Jul-5	20:59	424460	1774692	E	851	1	3.0	1.50	3.4	117
62	62	3-Jul-5	2:30	423834	1765650	E	1143	1	3.0	1.50	3.6	117
63	61	3-Jul-5	5:14	424287	1764676	E	833	1	3.0	1.50	3.5	117
64	62	3-Jul-5	19:16	423803	1763078	E	1078	1	3.0	1.50	3.5	117
65	61	3-Jul-5	23:27	424005	1762595	E	933	1	3.0	1.50	3.4	117
66	61	4-Jul-5	2:27	424095	1762179	E	886	1	3.0	1.50	3.6	117
67	62	4-Jul-5	6:09	423651	1761479	E	1101	1	2.9	1.49	3.5	117
68	8	4-Jul-5	9:09	423919	1760529	E	1003	1	3.0	1.51	3.5	117
69	8	4-Jul-5	10:55	423751	1760873	E	1055	1	3.0	1.50	3.5	117
70	8	4-Jul-5	13:27	424163	1760365	E	924	1	3.0	1.50	3.6	117
71	8	4-Jul-5	16:02	423831	1760202	E	1069	1	2.9	1.50	3.5	117
72	72	4-Jul-5	18:49	423996	1754366	E	1144	1	3.0	1.51	3.5	117
73	71	4-Jul-5	21:05	424479	1754586	E	886	1	3.0	1.51	3.5	117
74	71	4-Jul-5	22:34	424546	1753818	E	889	1	3.0	1.50	3.5	117
75	71	5-Jul-5	0:31	424633	1752534	E	899	1	3.0	1.50	3.6	117
76	72	5-Jul-5	2:39	424439	1752076	E	1023	1	3.0	1.51	3.6	117
77	72	5-Jul-5	14:45	424608	1750763	E	1054	1	3.0	1.50	3.6	117
78	8	6-Jul-5	14:24	424204	1760808	E	870	1	3.0	1.50	3.6	117
79	8	6-Jul-5	16:42	424289	1755546	E	921	1	3.0	1.51	3.6	117
80	72	6-Jul-5	18:33	424057	1755126	E	1058	1	3.0	1.51	3.5	117
81	72	6-Jul-5	20:39	424259	1753512	E	1032	1	3.0	1.50	3.5	117
82	62	7-Jul-5	1:20	423891	1762009	E	984	1	3.0	1.50	3.6	117
83	62	7-Jul-5	3:57	424010	1764321	E	1011	1	3.0	1.52	3.6	117
84	52	7-Jul-5	7:06	424158	1761345	E	992	1	3.0	1.49	3.5	117
85	52	7-Jul-5	9:03	424102	1762428	E	1115	1	3.0	1.50	3.5	117

Table A2: Summary of tow details for AMA0501. All tows used the champion bottom net except tows 13–18, 33–36, 38–39, which used the myctophid finemesh midwater net. Data fields are: Date, date shot; Time, time shot; Lat, latitude shot, with 424967 meaning 42° 49.67' S (decimal minutes); Long, longitude shot, with 1792381 W meaning 179° 23.81' W; Depth, depth in m; P, gear performance (1, good, 3, poor); S, tow speed in knots; D, distanced towed in n. miles; H, average headline height in m; Dd, distance between doors in m.

Tow	Stratum	Date	Time	Lat	Long	Depth	P	S	D	H	Dd
1	CASK	18-Jun-5	17:52	425089	1795893 E	818	1	2.8	0.26	7.8	150
2	DEAD	18-Jun-5	21:25	424343	1794142 W	860	1	2.9	0.50	6.0	-
3	ZOMB	19-Jun-5	-	-	-	-	-	-	-	-	-
4	SCRO	19-Jun-5	5:36	424772	1795900 E	910	1	3.1	0.25	6.5	-
5	SCRO	19-Jun-5	8:13	424774	1795899 E	918	1	3.0	0.25	6.5	-
6	GRAV	19-Jun-5	11:30	424563	1795945 E	862	1	3.0	0.29	6.5	-
7	GRAV	19-Jun-5	14:48	424522	1795829 E	820	1	2.9	0.12	5.2	-
8	DEAD	19-Jun-5	19:50	424380	1794044 W	858	1	2.9	0.44	6.2	-
9	GRAV	19-Jun-5	22:44	424533	1795837 W	785	1	2.9	0.17	6.0	-
10	GRAV	19-Jun-5	23:57	424586	1795941 E	824	1	3.0	0.24	7.5	-
11	ZOMB	20-Jun-5	3:00	424500	1795600 W	927	1	3.0	0.15		-
12	GRAV	20-Jun-5	4:30	424562	1795827 W	801	1	3.0	0.24	6.5	-
13	3	20-Jun-5	9:50	424876	1792243 E	1077	1	2.7	1.56	42	-
14	3	20-Jun-5	12:05	424881	1792095 E	1075	1	3.0	1.50	42	-
15	3	20-Jun-5	14:10	424884	1792055 E	1080	1	3.0	1.13	42	-
16	3	20-Jun-5	16:09	424948	1791579 E	1070	1	3.0	1.45	43	173
17	3	20-Jun-5	18:23	424941	1791515 E	1077	1	3.0	1.63	42	220
18	3	20-Jun-5	21:05	424929	1791634 E	1078	1	3.0	1.65	42	-
19	3	21-Jun-5	3:32	424938	1791596 E	1075	1	3.2	0.18	19	127
20	3	21-Jun-5	10:43	424948	1791859 E	1077	1	2.7	0.72	20	130
21	GRAV	22-Jun-5	16:37	424343	1794142 W	840	3	3.0	0.01	7.5	-
22	GRAV	22-Jun-5	20:27	424530	1795827 W	805	1	3.0	0.18	6.0	-
23	GRAV	22-Jun-5	23:06	424529	1795823 W	824	1	3.0	0.28	6.0	-
24	GRAV	23-Jun-5	1:10	424521	1795791 W	948	1	3.0	0.50	7.5	-
25	GRAV	23-Jun-5	22:15	424518	1795837 W	821	1	3.0	0.43	6.6	-
26	GRAV	24-Jun-5	1:43	424526	1795833 W	804	3				-
27	DEAD	24-Jun-5	4:08	424378	1794033 W	880	2	3.2	0.31	6.5	-
28	GRAV	24-Jun-5	6:58	424561	1795944 E	823	2	3.2	0.22	6.5	-
29	GRAV	24-Jun-5	8:36	424583	1795944 E	826	1	3.0	0.24	7.5	-
30	SCRO	24-Jun-5	10:04	424773	1795904 W	916	1	3.0	0.17	7.5	-
31	SCRO	24-Jun-5	12:15	424700	1795876 W	895	1	3.0	0.26	7.0	-
32	ZOMB	24-Jun-5	14:38	424594	1795677 W	965	3	3.0	1.00	6.0	-
33	1	24-Jun-5	21:05	425011	1795718 W	905	1	3.1	1.60	50	206
34	1	24-Jun-5	23:23	425185	1795688 W	835	1	3.1	1.50	60	-
35	1	25-Jun-5	8:04	425053	1795995 E	888	1	3.2	1.62	50	-
36	1	25-Jun-5	10:06	425359	1795989 E	780	1	3.1	1.45	40	215
37	CASK	25-Jun-5	14:59	425084	1795896 E	812	1	3.1	0.24	6.5	-
38	1	25-Jun-5	16:42	425324	1795809 W	788	1	3.1	1.78	40	237
39	1	25-Jun-5	18:52	425177	1795742 W	852	1	3.1	1.73	40	-
40	GRAV	26-Jun-5	1:54	424526	1795934 E	872	1	3.0	0.21	7.5	-
41	GRAV	26-Jun-5	3:32	424521	1795828 W	810	1	3.0	0.71	7.5	-

APPENDIX 3:

Table A3: Details of the occurrence (% of tows), catch (kg), number measured for length and weight (LW), number measured for length only (L) and number sampled for otoliths (O) for all species caught during TAN0509. Species are given in descending order of total catch weight.

Species code	Common Name	Scientific name	Occurrence (%)	Catch	LW	L	O
CSU	Four-rayed rattail	*Coryphaenoides subserrulatus*	100	12322.2	5400	269	
ORH	Orange roughy	*Hoplostethus atlanticus*	100	7654.6	2098	4241	811
HTH	Sea cucumber	Holothurian unidentified	42	6136.9	0	0	
BEE	Basketwork eel	*Diastobranchus capensis*	99	2099.9	1711	1	
WHX	White rattail	*Trachyrincus aphyodes*	96	1319.0	1444	22	
SSO	Smooth oreo	*Pseudocyttus maculatus*	88	1154.4	835	12	
SSM	Slickhead, smallscaled brown	*Alepocephalus australis*	62	1143.2	740	2	
MIQ	Warty squid	*Moroteuthis ingens*	98	1135.0	0	0	
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	81	1087.8	267	0	
HOK	Hoki	*Macruronus novaezelandiae*	66	1037.1	496	0	
SND	Shovelnose spiny dogfish	*Deania calcea*	84	918.2	515	0	
HAK	Hake	*Merluccius australis*	64	906.0	335	0	
HJO	Johnson's cod	*Halargyreus johnsonii*	100	906.0	1417	18	
ETB	Baxter's lantern dogfish	*Etmopterus baxteri*	94	830.5	548	0	
SBK	Spineback	*Notacanthus sexspinis*	92	775.6	1479	0	
RCH	Widenosed chimaera	*Rhinochimaera pacifica*	67	759.2	191	0	
SBI	Slickhead, bigscaled brown	*Alepocephalus* sp.	66	702.1	824	0	
MCA	Ridge scaled rattail	*Macrourus carinatus*	66	605.4	372	0	
CYP	Centroscymnus crepidater	*Centroscymnus crepidater*	81	477.6	260	0	
CIN	Notable rattail	*Coelorinchus innotabilis*	100	445.3	3363	0	
CSE	Serrulate rattail	*Coryphaenoides serrulatus*	100	397.5	2065	20	
JAV	Javelinfish	*Lepidorhynchus denticulatus*	67	364.1	804	1	
BRG	Brisingida	*Brisingida*	71	267.7	0	0	
JFI	Jellyfish		20	206.7	0	0	
CSQ	Centrophorus squamosus	*Centrophorus squamosus*	40	181.3	68	0	
RIB	Ribaldo	*Mora moro*	28	173.4	91	1	
LCH	Long-nosed chimaera	*Harriotta raleighana*	71	170.4	180	0	
GSP	Pale ghost shark	*Hydrolagus bemisi*	45	166.1	174	0	
HCO	Hairy conger	*Bassanago hirsutus*	66	145.7	461	0	
SCO	Swollenhead conger	*Bassanago bulbiceps*	55	135.9	456	1	
SMC	Small-headed cod	*Lepidion microcephalus*	92	131.8	485	4	
TAM	Tam o'shanter urchin	Echinothuriidae	53	128.4	0	0	
CHP	Chimaera, brown	*Chimaera* sp.	25	104.0	42	0	
EPR	Robust cardinalfish	*Epigonus robustus*	61	100.7	549	0	
CBA	Slender rattail	*Coryphaenoides dossenus*	40	87.5	52	0	
PSK	Longnosed deepsea skate	*Bathyraja shuntovi*	19	55.7	16	0	
PSY	Psychrolutes	*Psychrolutes microporos*	16	43.7	12	0	
SCC	Sea cucumber	*Stichopus mollis*	59	43.7	0	0	
CMA	Mahia rattail	*Coelorinchus matamua*	44	42.4	110	16	
BSH	Seal shark	*Dalatias licha*	6	34.8	10	0	
GRM	Sea urchin	*Gracilechinus multidentatus*	22	34.5	0	0	
ANT	Anemones	Anthozoa	53	33.1	0	0	
APR	Catshark	*Apristurus* spp.	44	31.4	57	0	
BJA	Black javelinfish	*Mesobius antipodum*	33	25.9	31	0	
EPT	Deepsea cardinalfish	*Epigonus telescopus*	12	22.7	10	0	1
RUD	Rudderfish	*Centrolophus niger*	2	22.1	2	0	
MRQ	Warty squid	*Moroteuthis robsoni*	6	21.1	0	0	

PLS	Plunket's shark	*Centroscymnus plunketi*	2	20.3	2	0
LHO	Lipkius holthuisi	*Lipkius holthuisi*	47	20.1	0	0
ACS	Deepsea anemone	Actinostolidae	21	18.1	0	0
SFI	Starfish	Asteroidea & ophiuroidea	26	18.1	0	0
WOE	Warty oreo	*Allocyttus verrucosus*	24	16.7	38	0
NEB	Neolithodes brodiei	*Neolithodes brodiei*	13	16.4	0	0
BOE	Black oreo	*Allocyttus niger*	19	14.9	30	0
BSL	Black slickhead	*Xenodermichthys* spp.	16	14.4	125	0
LAN	Lantern fish	Myctophidae	75	12.1	0	0
SPE	Sea perch	*Helicolenus* spp.	7	11.4	7	0
DSS	Deepsea smelt	*Bathylagus* spp.	41	11.3	6	0
BTH	Bluntnose skate	*Notoraja* spp.	24	10.6	3	0
SOR	Spiky oreo	*Neocyttus rhomboidalis*	16	10.2	26	7
LIN	Ling	*Genypterus blacodes*	2	9.3	2	0
HYB	Black ghost shark	*Hydrolagus* sp a	1	8.2	2	0
CFA	Banded rattail	*Coelorinchus fasciatus*	15	7.8	60	0
PLT	Plutonaster spp	*Plutonaster* spp.	11	7.3	0	0
LMU	Lithodes murrayi	*Lithodes murrayi*	5	7.1	0	0
VSQ	Violet squid	*Histioteuthis* spp.	28	7.1	0	0
TRS	Trachyscorpia capensis	*Trachyscorpia capensis*	2	6.8	3	0
NAN	Deepsea smelt	*Nansenia* spp.	36	6.6	9	0
DWO	Deepwater octopus	*Graneledone* spp.	18	6.3	0	0
SNE	Snubnosed eel	*Simenchelys parasiticus*	26	6.3	11	0
CHY	Roughhead rattail	*Coelorinchus trachycarus*	11	6.1	19	0
PHO	Lighthouse fish	*Photichthys argenteus*	41	5.4	0	0
TOP	Pale toadfish	*Ambophthalmos angustus*	4	5.3	2	0
ZOR	Rat-tail star	*Zoroaster* spp.	15	5.2	0	0
ASR	Asteroid (starfish)		16	5.0	0	0
COL	Olivers rattail	*Coelorinchus oliverianus*	7	5.0	54	0
APE	Acanthephyra pelagica	*Acanthephyra pelagica*	33	4.9	0	0
NEC	Nematocarcinus sp.	*Nematocarcinus* sp.	32	4.9	0	0
MAN	Finless flounder	*Neoachiropsetta milfordi*	5	4.8	1	0
PED	Scarlet prawn	*Aristaeopsis edwardsiana*	24	4.6	0	0
TSQ	Todarodes filippovae	*Todarodes filippovae*	5	4.6	0	0
OSQ	Octopoteuthiidae	Octopoteuthiidae	4	4.4	0	0
CAX	White brotula	*Cataetyx* sp.	8	3.9	4	0
ERA	Electric ray	*Torpedo fairchildi*	1	3.9	1	0
MPH	Big-scale fish	Melamphaidae	27	3.9	0	0
PBA	Pasiphaea barnardi	*Pasiphaea barnardi*	28	3.9	0	0
PDG	Prickly dogfish	*Oxynotus bruniensis*	1	3.4	1	0
ZEL	Scalloped dealfish	*Zu elongatus*	1	3.4	0	0
ODT	Pentagonal tooth-star	*Odontaster* spp.	13	3.0	0	0
ARI	Aristeus sp	*Aristeus* sp.	24	2.8	0	0
RBM	Rays bream	*Brama brama*	2	2.8	0	0
SWA	Silver warehou	*Seriolella punctata*	1	2.7	1	0
ACA	Acanthephyra spp	*Acanthephyra* spp.	18	2.6	0	0
PLY	Polychelidae	*Polycheles suhmi*	25	2.5	0	0
SEO	Seaweed		4	2.5	0	0
BCR	Blue cusk eel	*Brotulotaenia crassa*	2	2.4	0	0
CHQ	Cranchiid squid	Cranchiidae	15	2.4	0	0
ECR	Messmate fish	*Echiodon cryomargarites*	24	2.4	0	0
FMA	Fusitriton magellanicus	*Fusitriton magellanicus*	16	2.4	0	0
HPE	Common halosaur	*Halosaurus pectoralis*	6	2.4	12	0
SFN	Spinyfin	*Diretmoides parini*	2	2.4	2	0

SOT	Solaster torulatus	*Solaster torulatus*	5	2.4	0	0
GAS	Gastropods	Gastropoda	16	2.1	0	0
MAL	Loosejaw	Malacosteidae	18	2.1	0	0
PAS	Pasiphaea spp	*Pasiphaea* spp.	16	2.1	0	0
COU	Coral (unspecified)		14	2.0	0	0
GPA	Sea urchin	*Goniocidaris parasol*	14	2.0	0	0
ONO	Oplophorus novaezeelandiae	*Oplophorus novaezeelandiae*	20	2.0	0	0
BTS	Prickly deepsea skate	*Notoraja spinifera*	2	1.9	0	0
ONG	Sponges	Porifera (phylum)	12	1.9	0	0
PSI	Geometric star	*Psilaster acuminatus*	14	1.9	0	0
VCO	Violet cod	*Antimora rostrata*	4	1.9	3	0
ECH	Echinodermata		14	1.8	0	0
HMT	Deepsea anemone	Hormathiidae	6	1.8	0	0
NNA	Nezumia namatahi	*Nezumia namatahi*	19	1.8	10	0
NPU	Kuronezumia leonis	*Kuronezumia leonis*	4	1.7	2	0
NOS	NZ southern arrow squid	*Nototodarus sloanii*	2	1.6	0	0
VIT	Deep sea spider crab	*Vitjazmaia latidactyla*	6	1.6	0	0
CBO	Bollons rattail	*Coelorinchus bollonsi*	2	1.5	4	0
CHA	Viper fish	*Chauliodus sloani*	13	1.5	0	0
CTR	Abyssal rattail	*Coryphaenoides striaturus*	4	1.5	4	0
DMG	Dipsacaster magnificus	*Dipsacaster magnificus*	6	1.5	0	0
TRX	Velvet rattail	*Trachonurus gagates*	7	1.5	1	0
GNA	Gnathophausia sp	*Gnathophausia* sp.	13	1.4	0	0
ABR	Shortsnouted lancetfish	*Alepisaurus brevirostris*	1	1.3	0	0
PER	Persparsia kopua	*Persparsia kopua*	12	1.2	0	0
SRH	Silver roughy	*Hoplostethus mediterraneus*	9	1.2	1	0
DDI	Desmophyllum dianthus	*Desmophyllum dianthus*	8	1.1	0	0
OPI	Umbrella octopus	*Opisthoteuthis* sp.	4	1.1	0	0
PAG	Pagurid	Paguroidea	5	1.1	0	0
CPA	Pentagon star	*Ceramaster patagonicus*	5	1.0	0	0
CHX	Pink frogmouth	*Chaunax pictus*	4	0.9	0	0
HAT	Hatchetfish	Sternoptychidae	8	0.9	0	0
MEZ	Melanonus zugmayeri	*Melanonus zugmayeri*	6	0.9	0	0
SPL	Scopelosaurus sp	*Scopelosaurus* sp.	8	0.9	0	0
COF	Flabellum coral	*Flabellum* spp.	8	0.8	0	0
GLS	Glass sponge		5	0.8	0	0
MCN	Loosejaw	*Malacosteus niger*	8	0.8	0	0
ANO	Fangtooth	*Anoplogaster cornuta*	5	0.7	0	0
DIS	Discfish	*Diretmus argenteus*	7	0.7	0	0
ROK	Rocks stones	*Geological specimens*	1	0.7	0	0
ROS	Rotund cardinalfish	*Rosenblattia robusta*	8	0.7	0	0
TUB	Tubbia tasmanica	*Tubbia tasmanica*	1	0.7	0	0
CDO	Capro dory	*Capromimus abbreviatus*	6	0.6	0	0
IDI	Idiacanthus spp	*Idiacanthus* spp.	6	0.6	0	0
LAE	Laemonema spp	*Laemonema* spp.	6	0.6	0	0
NOR	Tubeshoulder	*Normichthys* sp.	6	0.6	0	0
SAL	Salps		2	0.6	0	0
AGI	Giant hatchetfish	*Argyropelecus gigas*	4	0.5	0	0
GAO	Filamentous rattail	*Gadomus aoteanus*	5	0.5	3	0
MYS	Mysid		4	0.5	0	0
SDE	Seadevil	*Cryptopsaras couesi*	5	0.5	0	0
ACT	Prickly flounder	*Achiropsetta tricholepis*	1	0.4	0	0
BCA	Barracudina	*Magnisudis prionosa*	2	0.4	0	0
LPA	Lampanyctus spp	*Lampanyctus* spp.	4	0.4	0	0

LPH	Haplophryne mollis	*Haplophryne mollis*	4	0.4	0	0
MEJ	Humpback anglerfish	*Melanocetus johnsonii*	2	0.4	0	0
MEL	Melanonus gracilis	*Melanonus gracilis*	4	0.4	0	0
MST	Melanostomiidae	Melanostomiidae	4	0.4	0	0
PSU	Deep-sea blind lobster	*Polycheles suhmi*	2	0.4	0	0
SID	Tubeshoulders	Platytroctidae	5	0.4	0	0
SPT	Heart urchin	*Spatangus multispinus*	5	0.4	0	0
VNI	Blackspot rattail	*Ventrifossa nigromaculata*	4	0.4	7	0
BOO	Bamboo coral	*Keratoisis* spp.	4	0.3	0	0
CJX	Upturned snout rattail	*Coelorinchus mycterismus*	2	0.3	0	0
FUN	Funchalia spp	*Funchalia* spp.	4	0.3	0	0
HIA	Prickly anglerfish	*Himantolophus appelii*	1	0.3	0	0
HOL	Tubeshoulder	*Holtbyrnia* sp.	1	0.3	0	0
LNV	Rock star	*Lithosoma novaezelandiae*	2	0.3	0	0
SAW	Sawtooth eel	*Serrivomer* sp.	2	0.3	0	0
SQX	Squid		4	0.3	0	0
ACO	Tam o shanter urchin	*Araeosoma coriaceum*	2	0.2	0	0
AIR	Hatchetfish	*Argyripnus iridescens*	2	0.2	0	0
CCR	Globosehead rattail	*Cetonurus crassiceps*	1	0.2	0	0
COB	Black coral	Antipatharia (Order)	1	0.2	0	0
CRU	Crustacea		1	0.2	0	0
DCO	Dwarf cod	*Notophycis marginata*	1	0.2	0	0
EPL	Bigeye cardinalfish	*Epigonus lenimen*	1	0.2	2	0
NEM	Slender snipe eel	*Nemichthys scolopaceus*	2	0.2	0	0
SCP	Scopelarchus sp	*Scopelarchus* sp.	2	0.2	0	0
STO	Stomiatidae	*Stomias* spp.	2	0.2	0	0
TVI	Trachonurus villosus	*Trachonurus villosus*	1	0.2	2	0
AFO	Royal red prawn	*Aristaeomorpha foliacea*	1	0.1	0	0
API	Alert pigfish	*Alertichthys blacki*	1	0.1	0	0
BOD	Tripod fish	*Bathypterois oddi*	1	0.1	0	0
DIA	Diaphus spp	*Diaphus* spp.	1	0.1	0	0
EPO	Limp eel pout	*Melanostigma gelatinosum*	1	0.1	0	0
GEL	Elongate lightfish	*Gonostoma elongatum*	1	0.1	0	0
GOU	Cidarid urchin	*Goniocidaris umbraculum*	1	0.1	0	0
GRC	Grenadier cod	*Tripterophycis gilchristi*	1	0.1	0	0
MMU	Pearlside	*Maurolicus australis*	1	0.1	0	0
NOT	Antarctic rock cods	Nototheniidae	1	0.1	0	0
OPH	Ophiuroid (brittle star)		1	0.1	0	0
PLN	Chipped fiberglass sponge	*Poecillastra laminaris*	1	0.1	0	0
PYC	Sea spiders	Pycnogonida	1	0.1	0	0
SCL	Scales		1	0.1	0	0
SEP	Sergia potens	*Sergia potens*	1	0.1	0	0
SYM	Symbolophorus spp	*Symbolophorus* spp.	1	0.1	0	0
SYN	Synaphobranchidae	Synaphobranchidae	1	0.1	0	0

APPENDIX 4:

Table A4: Details of the occurrence (% of all tows), catch (kg), number measured for length and weight (LW), number measured for length only (L) and number sampled for otoliths (O) for all species caught during AMA0501. Species are given in descending order of total catch weight.

Species code	Common Name	Scientific name	Occurrence (%)	Catch	LW	L	O
ORH	Orange roughy	*Hoplostethus atlanticus*	62	44748.0	658	4466	371
CSU	Four-rayed rattail	*Coryphaenoides subserrulatus*	62	5089.5	69	1479	
JFI	Jellyfish		35	1698.2	0	0	
ETB	Baxters lantern dogfish	*Etmopterus baxteri*	51	1052.6	134	214	
SAL	Salps		19	986.9	0	0	
SSO	Smooth oreo	*Pseudocyttus maculatus*	46	299.0	63	292	
CYP	Centroscymnus crepidater	*Centroscymnus crepidater*	62	132.2	46	25	
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	22	95.7	13	2	
CSQ	Centrophorus squamosus	*Centrophorus squamosus*	27	74.8	7	5	
EPR	Robust cardinalfish	*Epigonus robustus*	19	66.5	8	118	
EPT	Deepsea cardinalfish	*Epigonus telescopus*	19	65.9	14	10	
BEE	Basketwork eel	*Diastobranchus capensis*	49	53.1	13	7	
HAK	Hake	*Merluccius australis*	22	48.5	9	5	
MIQ	Warty squid	*Moroteuthis ingens*	32	43.5	1	0	
HOK	Hoki	*Macruronus novaezelandiae*	14	23.2	3	5	
RBM	Rays bream	*Brama brama*	16	22.6	7	13	
COB	Black coral	Antipatharia (Order)	5	20.1	0	0	
PLS	Plunkets shark	*Centroscymnus plunketi*	5	20.0	1	0	
MCA	Ridge scaled rattail	*Macrourus carinatus*	27	17.4	12	3	
RCH	Widenosed chimaera	*Rhinochimaera pacifica*	5	15.6	3	2	
CHG	Giant chimaera	*Chimaera lignaria*	5	13.5	1	0	
HJO	Johnson's cod	*Halargyreus johnsonii*	27	12.3	6	3	
SOR	Spiky oreo	*Neocyttus rhomboidalis*	11	11.6	8	3	
RUD	Rudderfish	*Centrolophus niger*	16	10.1	5	0	
SND	Shovelnose spiny dogfish	*Deania calcea*	11	8.3	4	0	
LAN	Lantern fish	Myctophidae	32	7.7	0	0	
CMA	Mahia rattail	*Coelorinchus matamua*	24	6.4	10	3	
GDU	Bushy hard coral	*Goniocorella dumosa*	5	5.4	0	0	
VSQ	Violet squid	*Histioteuthis* spp.	19	5.4	0	0	
TSQ	Todarodes filippovae	*Todarodes filippovae*	11	5.2	0	0	
CHA	Viper fish	*Chauliodus sloani*	32	5.1	59	12	
BOE	Black oreo	*Allocyttus niger*	14	4.5	5	2	
BSH	Seal shark	*Dalatias licha*	3	4.5	1	0	
JAV	Javelin fish	*Lepidorhynchus denticulatus*	32	4.2	8	10	
DSS	Deepsea smelt	*Bathylagus* spp.	22	4.0	6	16	
RIB	Ribaldo	*Mora moro*	3	3.7	0	1	
CBA	Slender rattail	*Coryphaenoides dossenus*	5	3.4	2	0	
ABR	Shortsnouted lancetfish	*Alepisaurus brevirostris*	11	3.1	6	2	
SQX	Squid		8	3.0	0	0	
CSE	Serrulate rattail	*Coryphaenoides serrulatus*	27	2.7	9	3	
SMC	Small-headed cod	*Lepidion microcephalus*	16	2.7	4	0	
APR	Catshark	*Apristurus* spp.	5	2.5	0	0	
MST	Melanostomiidae	Melanostomiidae	8	2.2	1	0	
RSQ	Ommastrephes bartrami	*Ommastrephes bartrami*	3	2.2	0	0	
CIN	Notable rattail	*Coelorinchus innotabilis*	24	2.0	5	16	
SUH	Schedophilus huttoni	*Schedophilus huttoni*	3	1.9	0	0	
SBI	Slickhead, bigscaled brown	*Alepocephalus* sp.	5	1.7	1	0	
BYS	Alfonsino	*Beryx splendens*	5	1.6	0	1	

PSQ	Pholidoteuthis boschmai	*Pholidoteuthis boschmai*	3	1.6	0	0
BCR	Blue cusk eel	*Brotulotaenia crassa*	3	1.4	0	0
OMI	Opostomias micripnus	*Opostomias micripnus*	3	1.1	2	0
PER	Persparsia kopua	*Persparsia kopua*	24	1.1	12	6
BJA	Black javelinfish	*Mesobius antipodum*	8	1.0	1	1
PHO	Lighthouse fish	*Photichthys argenteus*	19	0.9	3	3
MAL	Loosejaw	Malacosteidae	19	0.8	7	4
PBA	Pasiphaea barnardi	*Pasiphaea barnardi*	19	0.8	0	0
TET	Squaretail	*Tetragonurus cuvieri*	3	0.8	0	1
EPO	Limp eel pout	*Melanostigma gelatinosum*	11	0.7	2	1
ONO	Oplophorus novaezeelandiae	*Oplophorus novaezeelandiae*	14	0.7	0	0
PCA	Poromitra capito	*Poromitra capito*	5	0.7	0	16
SBK	Spineback	*Notacanthus sexspinis*	5	0.7	2	0
CBX	Cubehead	*Cubiceps baxteri*	3	0.6	3	0
DIS	Discfish	*Diretmus argenteus*	14	0.6	1	4
TRS	Trachyscorpia capensis	*Trachyscorpia capensis*	3	0.6	1	0
MOC	Madrepora oculata	*Madrepora oculata*	3	0.5	0	0
ROS	Rotund cardinalfish	*Rosenblattia robusta*	11	0.5	1	15
ECR	Messmate fish	*Echiodon cryomargarites*	11	0.4	3	8
GNA	Gnathophausia sp	*Gnathophausia* sp.	8	0.4	0	0
IDI	Idiacanthus spp	*Idiacanthus* spp.	11	0.4	0	5
KAI	Kali indica	*Kali indica*	8	0.4	1	3
SDE	Seadevil	*Cryptopsaras couesi*	5	0.4	2	0
SFN	Spinyfin	*Diretmoides parini*	3	0.4	0	1
SPL	Scopelosaurus sp	*Scopelosaurus* sp.	3	0.4	0	0
AGI	Giant hatchetfish	*Argyropelecus gigas*	8	0.3	2	0
OMU	Odontomacrurus murrayi	*Odontomacrurus murrayi*	3	0.3	1	0
TAM	Tam o shanter urchin	Echinothuriidae	3	0.3	0	0
WOE	Warty oreo	*Allocyttus verrucosus*	5	0.3	0	2
ANO	Fangtooth	*Anoplogaster cornuta*	5	0.2	1	2
BOO	Bamboo coral	*Keratoisis* spp.	3	0.2	0	0
CXH	Horrible rattail	*Coelorinchus horribilis*	3	0.2	0	0
FUN	Funchalia spp	*Funchalia* spp.	3	0.2	0	0
GUL	Gulper	*Eurypharynx pelecanoides*	5	0.2	0	2
MEL	Melanonus gracilis	*Melanonus gracilis*	3	0.2	0	3
NEM	Slender snipe eel	*Nemichthys scolopaceus*	3	0.2	0	0
NNA	Nezumia namatahi	*Nezumia namatahi*	3	0.2	1	0
RMW	Red-mouth whalefish	*Rondeletia loricata*	3	0.2	0	1
ACA	Acanthephyra spp	*Acanthephyra* spp.	3	0.1	0	0
CCO	Cooks rattail	*Coelorinchus cookianus*	3	0.1	1	0
CDO	Capro dory	*Capromimus abbreviatus*	3	0.1	1	0
COU	Coral (unspecified)		3	0.1	0	0
LPD	Lampadena spp	*Lampadena* spp.	3	0.1	0	1
LPH	Haplophryne mollis	*Haplophryne mollis*	3	0.1	0	0
MEN	Melanostomias spp	*Melanostomias* spp.	3	0.1	0	0
MYS	Mysid		3	0.1	0	0
ODN	Sabretooth	*Odontostomops normalops*	3	0.1	1	0
PAL	Barracudinas	Paralepididae	3	0.1	0	2
PLM	Plesionika martia	*Plesionika martia*	3	0.1	0	0
PRA	Prawn		3	0.1	0	0
PSI	Geometric star	*Psilaster acuminatus*	3	0.1	0	0
SAW	Sawtooth eel	*Serrivomer* sp.	3	0.1	0	0
SEP	Sergia potens	*Sergia potens*	3	0.1	0	0
STO	Stomiatidae	*Stomias* spp.	3	0.1	2	0

APPENDIX 5:

Table A6: Number of male orange roughy sampled for otoliths on board *Tangaroa* by length (to the nearest full cm below) and macroscopic maturity stage (1, immature; 2, maturing; 3, spermiated; 4, running; 5, spent; 8, partially spent; 9, resting).

	Maturity stage						
Length	1	2	3	4	5	8	9
9	2	0	0	0	0	0	0
14	2	0	0	0	0	0	0
15	2	0	0	0	0	0	0
16	5	0	0	0	0	0	0
17	1	0	0	0	0	0	0
19	2	0	0	0	0	0	0
20	6	0	0	0	0	0	0
21	8	0	0	0	0	0	0
22	14	0	0	0	0	0	0
23	20	0	0	0	0	0	0
24	26	3	0	1	0	0	0
25	39	1	1	1	0	0	0
26	33	7	0	0	0	0	0
27	21	14	0	0	1	0	0
28	18	14	2	1	6	1	0
29	11	14	1	1	6	1	2
30	12	13	1	0	7	0	5
31	2	10	2	7	14	2	2
32	2	16	4	4	10	2	4
33	0	8	6	5	14	3	4
34	1	8	2	3	13	3	5
35	0	3	2	5	12	1	1
36	0	0	0	9	4	1	0
37	0	0	3	3	2	0	0
38	0	0	0	1	0	0	0
39	0	0	1	2	0	0	0
40	0	0	0	1	1	0	0
Total	227	111	25	44	90	14	23

Table A7: Number of female orange roughy sampled for otoliths on board *Tangaroa* by length (to the nearest full cm below) and macroscopic maturity stage (1, immature; 2, maturing; 3, spermiated; 4, running; 5, spent; 8, partially spent; 9, resting).

	Maturity stage								
Length	1	2	3	4	5	6	7	8	9
8	1	0	0	0	0	0	0	0	0
15	1	0	0	0	0	0	0	0	0
16	1	0	0	0	0	0	0	0	0
17	4	0	0	0	0	0	0	0	0
18	2	0	0	0	0	0	0	0	0
19	3	0	0	0	0	0	0	0	0
20	6	0	0	0	0	0	0	0	0
21	11	0	0	0	0	0	0	0	0
22	9	0	0	0	0	0	0	0	0
23	18	1	0	0	0	0	0	0	0
24	14	3	0	0	0	0	0	0	0
25	16	4	0	0	0	0	0	0	1
26	19	14	0	0	0	0	0	0	2
27	7	21	0	0	0	3	0	0	3
28	2	14	0	0	1	2	0	0	5
29	2	18	0	0	0	6	0	0	4
30	1	19	0	1	3	12	0	4	8
31	0	25	1	1	1	10	0	0	10
32	0	14	1	0	3	15	0	2	7
33	0	15	0	1	4	18	0	5	10
34	0	12	2	2	5	21	0	2	5
35	0	17	3	6	6	22	1	3	5
36	0	6	3	5	2	10	0	3	2
37	0	1	2	5	6	14	0	1	2
38	0	1	3	4	5	10	0	3	0
39	0	1	1	2	2	9	1	3	0
40	0	0	2	4	2	2	0	1	0
41	0	0	0	2	1	1	0	0	0
Total	117	186	18	33	41	155	2	27	64

APPENDIX 6:

Table A8: Number of male orange roughy sampled for otoliths on board *Amaltal Mariner* by length (to the nearest full cm below) and macroscopic maturity stage (1, immature; 2, maturing; 3, spermiated; 4, running; 5, spent; 8, partially spent; 9, resting).

				Maturity stage	
Length	1	2	4	5	8
22	1	0	0	0	0
24	0	1	0	0	0
25	0	0	0	1	0
26	1	0	0	0	0
27	1	4	0	0	0
28	0	3	0	4	0
29	0	5	0	4	1
30	0	3	1	6	0
31	0	2	0	24	1
32	0	4	4	29	1
33	0	2	4	29	2
34	0	1	4	22	6
35	0	0	8	23	3
36	0	0	5	5	2
37	0	0	3	10	3
38	0	0	0	5	0
39	0	0	0	2	0
Total	3	25	29	164	19

Table A9: Number of female orange roughy sampled for otoliths on board *Amaltal Mariner* by length (to the nearest full cm below) and macroscopic maturity stage (1, immature; 2, maturing; 3, spermiated; 4, running; 5, spent; 8, partially spent; 9, resting).

						Maturity stage	
Length	1	2	3	4	5	6	8
26	1	1	0	0	0	0	0
27	1	2	0	0	0	0	0
28	0	2	0	0	1	1	0
29	1	7	0	0	1	3	0
30	0	7	0	0	3	0	0
31	1	9	0	1	1	5	0
32	1	5	0	0	1	5	0
33	1	6	1	2	1	7	1
34	0	2	0	3	3	9	0
35	0	3	0	3	3	9	2
36	0	0	0	4	9	11	0
37	0	0	0	1	3	8	0
38	0	1	0	3	3	7	2
39	0	0	0	0	1	6	0
40	0	0	0	1	0	2	0
41	0	0	0	0	0	1	0
42	0	0	0	0	0	1	0
Total	6	45	1	18	30	75	5

APPENDIX 7:

Table A10: ***Amaltal Mariner*** **midwater trawl station details. Method 6 is commercial midwater trawl with 60 mm codend, and Method 4 is the NIWA midwater mesopelagic or "myctophid" trawl with 10 mm codend.**

Station	Date	Time Start	Time Finish	Method	Latitude	Longitude	Depth (m) Gear	Depth (m) Bottom
Experiment 1								
13	20/06/2005	9:50	10:20	6	42 48.76	179 22.43 E	1040	1077
14	20/06/2005	12:05	12:35	6	42 48.81	179 20.95 E	1070	1075
15	20/06/2005	14:10	14:34	6	42 48.84	179 20.55 E	1040	1080
16	20/06/2005	16:09	16:39	6	42 49.48	179 15.79 E	1065	1070
17	20/06/2005	18:23	18:54	6	42 49.41	179 15.15 E	1030	1077
18	20/06/2005	21:05	21:37	6	42 49.29	179 16.34 E	1075	1078
19	21/06/2005	3:32	3:36	4	42 49.38	179 15.96 E	1024	1075
20	21/06/2005	10:43	10:58	4	42 49.48	179 18.59 E	1038	1077
Experiment 2								
33	24/06/2005	21:05	21:34	6	42 50.11	179 57.18 W	900	905
34	24/06/2005	23:23	23:53	6	42 51.85	179 56.88 W	830	835
35	25/06/2005	8:04	8:34	6	42 50.53	179 59.95 E	888	888
36	25/06/2005	10:06	10:37	6	42 53.59	179 59.89 E	740	780
38	25/06/2005	16:42	17:15	6	42 53.24	179 58.09 W	748	788
39	25/06/2005	18:52	19:23	6	42 51.77	179 57.42 W	811	852

Table A11: ***Amaltal Mariner*** **midwater trawls station catch summary.**

	Catchrate (kg/n. mile)					
Station	Rattails	Invertebrates	Morids	Sharks	Mesopelagic fish	Other
13	50.8	33.8	0.0	3.5	3.5	2.5
14	305.1	884.7	0.5	4.0	3.0	2.7
15	0.1	7.9	0.0	0.0	1.5	4.3
16	1 154.5	128.3	7.3	3.4	0.1	8.3
17	828.1	192.8	4.0	8.5	0.5	3.0
18	800.2	430.6	7.8	34.4	1.0	8.2
19	401.1	88.9	0.0	0.0	12.2	3.3
20	161.8	83.2	6.8	0.0	2.1	0.8
33	0.0	0.0	0.7	1.6	0.1	3.1
34	0.4	0.0	0.0	4.1	0.6	3.5
35	0.7	1.5	2.1	1.0	1.3	1.0
36	0.5	0.8	4.8	13.4	2.2	21.9
38	0.0	0.0	1.5	8.4	0.8	4.7
39	0.5	0.0	0.0	8.6	0.5	2.4