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Biomass estimates of orange roughy in June 2012 at Northwest Chatham Rise using a net attached acoustic optical system

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Executive summary

Acoustic biomass estimation surveys of orange roughy at the Morgue and Graveyard Seamounts on the New Zealand's Northwest Chatham Rise were carried out in June 2012 from the vessel FV Okatou. Biomass estimation results were based on measurements by a net-attached acoustic optical system (AOS) which conducted multiple deep-towed star pattern surveys of the seamount features. This system provided acoustic information at multiple frequencies which enabled application of multi-frequency species discrimination methods to minimise upward bias due to contamination of signal by other fish. Demersal tows with the AOS attached provided fine scale fish target strength measures, biological samples and optical images to support interpretation of species and target strength measures.

If it is assumed that process error is the dominant form of variation in seamount surveys, then estimates of the highest biomass with the lowest survey sampling CV and minimal deadzone estimate should be adopted. For the Morgue this occurred for operation 22 where the total biomass was 14812 tonnes (CV 0.11) at 38 kHz. The closest in time Graveyard survey was operation 18 where the total biomass was 4153 tonnes (CV 0.23) at 38 kHz. The combined schooling snapshot biomass of the region was estimated as 18965 tonnes (CV 0.1) at 38 kHz. This contrasts to a newly developed biomass estimate at 120 kHz of 13602 or 10083 tonnes (CV 0.1) for the Feb. and July calibration results. It is assumed for a 10 hr time difference between surveys there was no significant exchange of fish between the two sites.

The biomass estimates at 38 kHz and 120 kHz were significantly different and could be due to a number of factors as detailed in this report. Resolution of the 1.25 dB calibration variation for the 120 kHz frequency is needed prior to it being seen as a robust estimate. Recent research is suggesting that the 120 kHz frequency has less error due to contamination of gas-bladdered species in part due to an improved sensitivity to orange roughy and less variation due to orange roughy tilt angle. We recommend future work provides estimates at both 38 kHz and 120 kHz to explore the robustness and repeatability of the higher frequency and to establish 120 kHz based biomass estimates as a separate time-series.

The biomass estimate in the deadzone for these surveys represents ~29% of the total estimated biomass. We recommend future surveys monitor the proportion of biomass estimated in the deadzone and look at mechanisms to reduce this estimate.

1 Introduction

Orange roughy biomass surveys of the Morgue and Graveyard seamounts on New Zealand's Chatham Rise were done from the 17th to the 23rd of June, 2012 aboard the commercial fishing vessel *FV Otakou (Ryan, 2012)*. Acoustic biomass surveys were done using a multi-frequency Acoustic-Optical System (AOS) attached to the headline of the vessel's demersal trawl net (Ryan et al., 2009). These star pattern AOS surveys were designed to quantify the biomass of orange roughy using acoustic echo-integration methods whilst minimising known biases (Simmonds and MacLennan, 2005). Potential sources of bias in echo integration surveys for orange roughy at deepwater seamounts are; species identification; deadzone estimation; avoidance reaction.

Species identification was investigated using multiple acoustic frequencies combined with optical systems in order to achieve robust and objective partitioning of species (Kloser et al., 2002; Kloser et al., 2011; Ryan and Kloser, 2012,). To minimize the possibility of avoidance by orange roughy and minimise the deadzone the AOS-net system was towed in the mid-water at a distance of 200–400 m above the seafloor for echo-integration surveys. Demersal trawls with the AOS attached collected biological samples plus close range acoustic and optical measures of orange roughy and co-occuring bycatch species. These demersal trawls provided necessary biological metrics such as length, sex ratio, otoliths for ageing as well as concurrent acoustic and biological metrics for target strength and species identification.

Post-voyage review of the AOS echo-integration surveys concluded that orange roughy were present in significant numbers at both Morgue and Graveyard and that the execution of the survey transects and the acoustic data quality was acceptable for the purpose of biomass estimation (Ryan, 2012). As a result an analysis project was initiated with the following objective:

- Estimates of orange roughy biomass and their associated error from selected surveys based on the AOS surveys at the Morgue and Graveyard in June 2012

2 Methods

2.1 Equipment and operational modes

The AOS consisted of a sled-style platform that attaches to the headline of the vessel's demersal trawl net. The AOS housed a four frequency acoustic system (12, 38, 70 and 120 kHz) based on Simrad EK60 scientific transceivers. The 38 kHz and 120 kHz transceiver/transducer combinations were the key quantitative frequencies with the 12 kHz and 70 kHz aiding multi-frequency species discrimination and giving some redundancy. The system was battery powered with all data logged to internal storage media. The AOS system is described in detail in Ryan *et al.* (2009) with specifications of the current system given in Table 1.

Table 1. AOS specifications.

Component	Specifications
Physical	Dimensions: 1 600 × 1 100 × 500 mm, sled-style platform; weight: 483 kg in air, 325 kg in water; operational depth: 1000 m.
Acoustics	Echosounders: Simrad EK60, 38 and 120 kHz split-beam transceivers (2009), Simrad EK60 18 and 70 kHz added in 2010; Transducers: 38 kHz - Simrad ES38DD (7° beam width); and 120 kHz - ES120–7D (7°) (2009). Sensortech SX34-70 70 kHz (7° beam width); 12 kHz Neptune Sonar 14 degreed.
Video camera	Camera: Hitachi HV-D30P (3° × 1/3" CCD, colour); lenses: Fujion 2.8 mm lens (59°s in water); Resolution: 752 × 582 pixels; Format: PAL.
Video capture	Video card: Outrider; Conversion from PAL to QuickTime MOV format with user defined compression; storage: two sixteen GB Flash-RAM cards (two hours at 4:1 compression)
Video Lighting	Two 60 W LED arrays (two hour battery endurance)
Digital Stills	Two Canon EOS500D 15.1 mega pixel Digital SLR stereo pair with Canon EF 35 mm f/2 lens and Canon 580EXII Strobe. Cameras simultaneously fired by a trigger signal from the EK60 38 kHz echosounder when an object with TS greater than -60 dB and within range of 3 and 13 metres is detected.
Reference scale	Two Laserex LDM-4 635 nm 8 mW red lasers set 400 mm apart.
Computing	Industrial PC (running Simrad ER60 v2.1.1 software, and providing time-reference for acoustic and video data).
Motion reference	Microstrain 3DM-GX1
Power	Battery chemistry: NiMH and Li-ion; battery endurance: 18 hours

Mode 1: Echo-integration surveys

The Morgue and Graveyard fishing grounds are relatively small conical seamount features. Star survey patterns are a favourable design for these types of features (Doonan et al., 2003), particularly for deep-towed systems where it can take significant time to turn and move to the next transect. Echo-integration star pattern transect surveys with a minimum of four transects centred over the top of the seamount were conducted by towing the net-AOS system at 250-350 m from the seafloor (referred to as Mode 1). The range 250-350 m from the seabed is a compromise as: being too close to the seafloor can cause an avoidance reaction in orange roughy (Koslow et al., 1995, O'Driscoll et al., 2012): being too far away takes the system beyond the range of the higher 120 kHz frequency and also increases the acoustic deadzone height and other range-dependant errors including motion effects and seawater absorption. The vessel's skipper endeavoured to maintain the AOS within a range of 300 m +/- 50 m of the seafloor at all times using the vessels net monitoring system.

Mode 2: Demersal trawls for targets strength, species id, biological samples and commercial catch

Demersal trawls to catch fish for commercial purposes and to provide biological samples were conducted in addition to the Mode 1 echo-integration surveys. During these demersal trawls (referred to as Mode 2) the AOS remained attached to the net. For Mode 2 deployments the acoustic systems were set to a short pulse length (0.256 or 0.512 ms) and fast ping rate (~10 Hz) for close-range fish target strength (TS) measurements while standard definition video and calibrate stereo digital still images from Canon 500D DSLR cameras were obtained to complement the TS measures. The optical images provided a means of verifying species and metrics of fish length and orientation from the calibrated stereo images. At the Morgue seamount, the net was maintained at 10-20 m above the seafloor during Mode 2 deployments as the area is not open to bottom-contact trawling. However the cod-end was closed during these trawls enabling some biological samples to be obtained, albeit likely that catch efficiency was greatly reduced.

2.1.1 System calibrations

Acoustics: Transducer gain

Calibration of the AOS acoustics is done by detaching the platform from the net and lowering vertically through the survey operating depths (~800 m) with a 38.1 mm tungsten carbide calibration reference sphere of known TS suspended beneath the transducers by a thin mono-filament line. The on-axis sphere echo provides a reference against which the echosounder's transducer gain can be calibrated assuming the transducers equivalent beam angle is known. Transducer factory equivalent beam angles (EBA$_f$) were adjusted for the New Zealand 2012 surveys to calculate a local value, EBA$_{L,}$, to account for the difference in sound speed in the factory test tank (Co) and those encountered during the survey (Cs) as per Equation 1.

$$EBA_L = EBA_F + 10 * log_{10}\left(\left(\frac{C_s}{C_o}\right)^2\right) \qquad \text{Equation 1}$$

Almost perfect weather conditions are required for a calibration to be successful which unfortunately did not occur during the June 2012 surveys. As a consequence calibration results from previous AOS surveys in July 2010, Feb. 2012, and July 2012 with similar temperature and pressure conditions are applied to the New Zealand survey data as detailed in Table 2. For the 38 kHz system the most robust calibration with detailed mapping of the beam and good coverage occurred in 2010, spot checks of this calibration showed no drift or bias in Feb. 2012 and July 2012. A new 120 kHz transducer was calibrated in February 2012 and July 2012 that differed by 1.3 dB with the February result used in this report (Appendix A). This large difference between calibrations requires further investigation, with estimates of biomass at 120 kHz being preliminary.

Table 2. Calibration parameters for AOS 38 kHz and 120 kHz echosounders for Mode 1 echointegration surveys. Values marked in bold text were applied to the data in Echoview post processing software.

Parameters		
Frequency (kHz)	38	120
Calibration data set	July 2010, St Helens Hill	Feb. 2012 St Helens Hill
Transducer model	Simrad ES38DD	Simrad ES120-7CD
Serial Number	28332	109
Transceiver power (W)	**2000**	**500**
Transceiver pulse length (ms)	**2.048**	**1.024**
Transducer gain (dB)	**24.07**	**27.55**
Sa correction (dB)	**-0.6**	**-0.3**
Factory EBA (dB re 1 steradian)	-20.7	-20.3
Factory water temperature (^{o}C)	18	21
Factory sound speed in fresh water (m/s)	1476	1485
Survey sound speed at nominal 600 m (m/s)	**1489**	**1489**
EBA adjusted for local conditions (dB re 1 steradian)	**-20.62**	**-20.28**

Acoustics: Seawater absorption

Values for seawater absorption at 38 and 120 kHz and sound speed were calculated from the equations of Francois and Garrison (1982b) and Mackenzie (1981) respectively for a nominal platform depth of 600 m and fish school depths of 900 m using measured values of conductivity, temperature and depth (CTD) data recorded during the AOS deployments. The absorption and sound speed values were applied to the data in Echoview post processing software. A secondary adjustment was made to the echo integrated data to account for changes in absorption due to the combination of platform deviating above and below the nominal depth and the range to the fish schools changing (see Appendix B).

Table 3. Nominal seawater absorption and sound speed values based on CTD data recorded during AOS deployments for a nominal platform depth of 600 m and fish school depths of 900 m.

Parameter		
Frequency (kHz)	38	120
Absorption (dB/m)	0.00948	0.03233
Sound speed (m/s)	1489	1489

2.1.2 Biological sampling

Biological samples of both orange roughy and by-catch species were taken from Mode 2 trawls according to the following protocols (Table 4).

Table 4. Minimum biological measures

Measurement	Minimum requirement
Orange roughy length, sex, stage	100 per shot, but up to 200 if time permits
Bycatch ID & length	ID all bycatch and estimate weight of each species. Measure length of a representative sample (up to 100) if available
Otoliths (Orange roughy only)	300 (up to 500) from each major feature with significant biomass present –these will be obtained from 5-7 large shots.
Acoustic species group	Classify bycatch (by number) species group to give catch composition percentage of each acoustic species group.

2.2 Echogram processing and interpretation

Processing of the acoustic data was done using Myriax Echoview 5.2 acoustic analysis software (Myriax, 2012). Custom Matlab tools were used to extract and process platform depth and motion data that was embedded in the Simrad EK60 raw files. Platform depth data was applied to the towed body operator in Echoview to create echograms with an absolute depth reference. AOS platform motion was recorded at 10 kHz by a Microstrain 3DM-GX25 motion reference sensor. This data was applied to the motion correction operator (Dunford, 2005) in Echoview to correct for signal loss due to platform motion (Stanton, 1982).

2.2.1 Echogram scrutiny and quality control

Calibration offsets as per Table 2 were applied to the 38 kHz and 120 kHz volume backscattering strength (S_v dB re m^{-1}) echograms (Maclennan et al., 2002). The 12 kHz transceiver channel failed early in the survey and was not used in this analysis. The 70 kHz channel provided some redundancy but did not provide any additional species identification information. Further, the calibration accuracy of 70 kHz echosounder system is likely to be low as it is a single beam system and the equivalent beam angle of the 70 kHz Sensortech transducer is not quantified. Acoustic analysis therefore focussed on the key 38 kHz and 120 kHz frequencies. The S_v echograms for these two frequencies were visually inspected and regions of noise interference were marked as bad and removed from the analysis.

2.2.2 Acoustic deadzone estimate

The acoustic 'deadzone' is the region close to the seafloor where the acoustic signal cannot be measured due to the physical characteristics of the transmitted pulse (Ona and Mitson, 1996b) and, on sloping ground, due to seafloor backscatter from off-axis side-lobe signal coinciding with water column backscatter (Kloser, 1996, Ona and Mitson, 1996a). For the steep-sided Graveyard and Morgue seamounts the contribution to the deadzone due to the sloping ground was by far the greater effect. Orange roughy are a semi-demersal species that can occur at high densities within the deadzone region requiring an estimate to account for this biomass component. Previous acoustic observations of orange roughy schools suggest that scenarios of an increased and decreased density within the deadzone region are both possible. We assume that the density of fish immediately above the acoustic bottom was on average representative of the density within the deadzone region. An estimate of backscatter within the deadzone was made as follows. Firstly an 'acoustic seafloor' line was defined, that is the point at which water column signal became contaminated with seafloor reflection signal. The acoustic seafloor line was first generated via the maximum S_v seafloor detection algorithm implemented in Myriax's Echoview v.5.20 software. A back-step of 1.5 m was applied to this line to lift it away from the 'acoustic seafloor' signal. This line was visually inspected and manually adjusted if necessary to ensure that contamination by seafloor signal was avoided. A 'true seafloor' line was then defined based on the maximum S_v value for each ping. The samples between the 'acoustic seafloor' and the 'true seafloor' are deemed to be the deadzone region. The contaminated sample values in the deadzone region are replaced with an average of the S_v signal in the 5 metres immediately above the acoustic seafloor. Two echointegration signal summations are made: (i) includes only signal above the acoustic seafloor, i.e. uncontaminated by interference by the seafloor signal and (ii) includes both above acoustic seafloor and the estimated signal from within the deadzone region. From this data biomass estimates for above 'acoustic seafloor' and for above 'acoustic seafloor' plus a deadzone component were made.

2.2.3 Platform geolocation

When at survey depths the AOS platform can be ~1.5 km behind the vessel but its absolute position in space and time needs to be established in order to spatially locate identified orange roughy with respect to depth and correctly allocate survey area. To calculate AOS position, the seafloor depth along the transit line provided a common reference between the vessel and AOS location. The vessel moves along the transit line with the towed AOS following behind. Assuming there is no cross-track error, the deeply towed AOS later passes through the same locations at a time determined by length of towing wire, platform depth and towing speed (Figure 1a). Vessel UTC time, latitude and longitude were recorded continuously. The seafloor depth could be taken from the vessel's echosounder however a more accurate value was obtained by querying a high resolution multibeam database for each vessel position record. AOS UTC time was also recorded continuously while the corresponding seafloor depth at the AOS location was calculated by adding the depth of the AOS platform to the depth from the platform to the seafloor as measured by its 38 kHz echosounder. The profiles of seafloor depth vs. time for vessel and AOS were plotted to establish the time lag δt between each system (Figure 1b). AOS location at time T was interpolated from the recorded vessel locations at time $T - \delta t$ (Figure 1c).

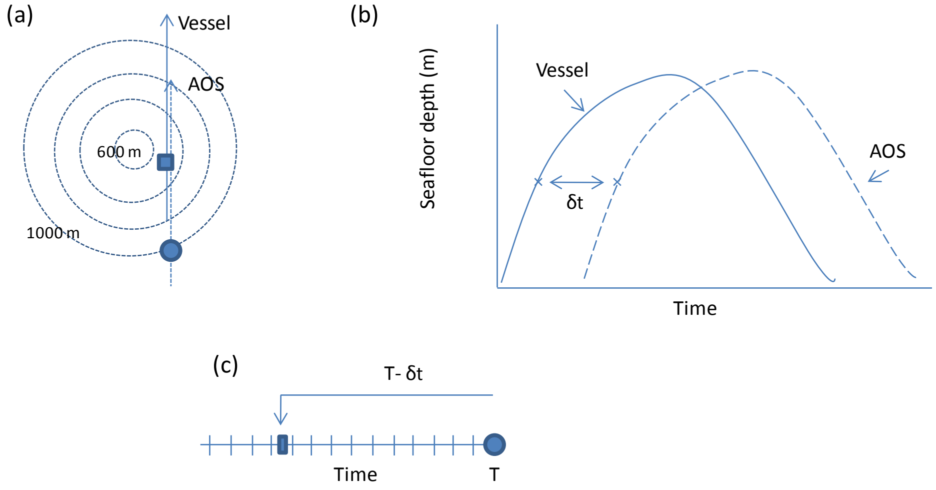


Figure 1 (a) Diagram of vessel and AOS transit across a seamount. Filled square and circle indicates respectively the position of the vessel and AOS at time T. (b) Seafloor depth at vessel and AOS platform location respectively plotted against UTC time. For a given depth, the time difference, δt, between systems can be estimated. (c) Diagram representing records of vessel longitude and latitude positions (vertical bars) as a function of time. An interpolation of vessel position records is made at time T – δt to give an estimate of AOS position (filled rectangle) at time T (filled circle).

2.2.4 Echogram interpretation and allocation of species

Quantitative analysis and subsequent biomass estimation was done for both 38 kHz and 120 kHz. Interpretation of the S_v echograms to partition according to species was a key step in this analysis. Echogram interpretation to distinguish between regions of orange roughy and other species considered multiple lines of evidence. Interpretation was primarily guided by (i) visualising the dB difference across frequencies as a “colour-mixed” echogram as per Kloser *et al.* (2002), (ii) a synthetic echogram that represents the decibel difference between 38 and 120 kHz according to a colour palette and (iii) as a graph showing the relative dB values for each frequency. Nominally, regions where mean backscatter was 2-4 dB higher at 120 kHz compared to 38 kHz were attributed to homogenous schools of orange roughy. Consideration was also given to the depth, location, shape and texture of echogram regions; echogram regions that are dominated by large high-reflectivity gas-bladdered fish may be inferred from a more heterogeneous “texture” with higher pixel-to-pixel variability compared to regions of orange roughy. Biological catch composition and inspection of video and DSLR still images to identify species obtained during Mode 2 operations were also used to support echogram interpretations. The absolute TS values obtained during Mode 2 operations also provided information regarding the presence of species with certain morphologies, e.g. very high TS values indicating the presence of large fish with a gas bladder.

2.3 Biomass estimation

Biomass estimates were calculated for both 38 kHz and 120 kHz acoustic data using standard echo-integration methods (Simmonds and MacLennan, 2005). Orange roughy classified echogram regions were echo-integrated in 0.02 n.mi intervals to calculate the nautical area scattering coefficient, $s_{A0.02}$ (m^2 n.mi^{-2}). Star pattern surveys have an uneven sampling intensity, with regions close to the centre of the survey receiving a higher sampling intensity relative to the outer regions (Doonan et al., 2003). Uneven sampling can result in significant bias depending on the distribution of fish in relation to the centre of the star transect. Both a depth contour (Kloser et al, 1996) and polar coordinate stratified techniques (Doonan et al., 2003) were used to estimate the biomass and sampling precision. The depth contour stratified method was used as the primary method in this analysis.

Depth contour method:

In a typical four transect star survey each contour annuli (of 20 m depth range in this analysis) would be sampled by 8 transect segments. A mean s_A was calculated for each transect segment within contour c, weighted by $\boldsymbol{n_t}$, the number of samples in the transect segment against $\bar{n}$, the mean number of samples per segment within contour c (Equation 2),

$$\overline{\mathbf{s_{At}}} = \frac{\sum_{\mathbf{i=1}}^{n_t} \mathbf{s_{A0.02_i}}}{n_t} * \frac{n_t}{\bar{n}} \qquad \text{Equation 2}$$

The mean s_A for each contour c was then calculated.

$$\overline{\mathbf{s_{Ac}}} = \frac{\sum_{\mathbf{j=1}}^{\mathbf{m}} \overline{\mathbf{s_{Atj}}}}{\mathbf{m}} \qquad \text{Equation 3}$$

Where *m* is the number of transect segments and $\overline{\mathbf{s_{Atj}}}$ the mean s_A of the *j*th transect segment within contour *c*.

Per-contour biomass, $\mathbf{B_c}$, was estimated using Equation 4.

$$\mathbf{B_c} = \frac{\overline{\mathbf{S_{Ac}}} \times \frac{\overline{\mathbf{W}}}{\mathbf{1000}} \times \mathbf{A_c}}{\mathbf{4 \times \pi \times 10^{\frac{TS}{10}}}} \qquad \textbf{(tonnes)} \qquad \text{Equation 4}$$

where *W* is the mean weight of orange roughy in kilograms for an assumed population sex ratio of 1:1, *Ac* the area of contour *c* in nmi^2 and TS the target strength dB re $1m^2$ of orange roughy at the relevant frequency for an assumed survey population sex ratio of 1:1.

The total biomass was calculated by summing the per-contour biomass (Equation 5).

$$\mathrm{B_T} = \sum_{\mathrm{k=1}}^{\mathrm{p}} \mathrm{B_{c(k)}} \qquad \text{(tonnes)} \qquad \text{Equation 5}$$

where *p* is the number of contour annuli.

The associated survey sampling CV was calculated by combining the per-contour standard deviations of values following Equation 9 of Simmonds et al. (1992).

$$\mathrm{var\_S_A} = \sum_{\mathrm{j=1}}^{\mathrm{m}} (\mathrm{A_{cj}}^2 * \mathrm{S_{cj}}^2 / \mathrm{n_{cj}}) / \mathrm{A}^2 \qquad \text{Equation 6}$$

and

$$\mathrm{CV} = \frac{\sqrt{\mathrm{var\_S_A}}}{\frac{(\sum_{j=1}^{m} \overline{s_{Ac}}_j)}{m}} \qquad \text{Equation 7}$$

where S_{cj} is the standard deviation of the per-sector mean backscatter values $\mathbf{s_{At}}$, for each contour j, $n_{cj}$the number of transect sectors in each contour j.

An alternate estimate of orange roughy biomass was made using the polar method described by Doonan et al. (2003).

2.3.1 Target strength estimates

TS estimates use the Kloser et al. (2013) results of -52.0 and -48.7 dB re 1m^2 for 38 kHz and 120 kHz respectively, which were based on a mean fish length 34.5 cm fish. This fish length is very close (within 0.2 cm) to the mean values measured for the Morgue and Graveyard of 34.59 and 34.31 cm respectively. Hence, the Kloser et al. (2013) TS values were used without modification in this analysis.

3 Results and discussion

3.1 Morgue Seamount

Between the 18th and 22nd of June four AOS multi-frequency star pattern surveys, one vessel hull mounted survey and three close range AOS 'no-contact trawls' (cod end closed but ground-rope not contacting the seafloor), were done at the Morgue seamount. The four AOS star pattern surveys were analysed to produce echo-integration based biomass estimates (Table 5). A full table of activities is given in Appendix B.

Table 5. Echo-integration surveys carried out at the Morgue seamount in June 2012

Operation Number	Operation Type	Start date (UTC)	Start time (UTC)	Location	Comment
2	AOS Echo-integration	18/06/2012	14:15:00	Morgue	Star survey at Morgue. Moderate conditions. Strong mark on top of hill observed on vessel sounder. Inspection of AOS data shows same strong mark, but extra detail shows low signal regions surrounding the mark that could be orange roughy.
6	AOS Echo-integration	19/06/2012	11:54:00	Morgue	Restarting star survey of Morgue. 12 kHz channel not installed.
15	AOS Echo-integration	21/06/2012	4:10:00	Morgue	Star survey at Morgue. NIWA mooring in place with its sounder not running but cameras coming on every two hours on the even hours.
22	AOS Echo-integration	22/06/2012	21:39:00	Morgue	Star survey at Morgue. 7 transect survey at Morgue.

3.1.1 Biological measures

Three close range no-contact trawls with the cod-end closed were carried out at the Morgue. Catch from the first two trawls was small and dominated by deepwater shark (Figure 2). In the third trawl, catch was larger with orange roughy the most abundant followed by oreo dory (high signal, large gas bladder species) and deepwater shark. The catch efficiency and species selectivity of the trawl net is expected to be altered from 'normal' bottom contact fishing by being held ~10-20 m off the seafloor and the total catch and its species composition needs to be considered in this context. In this regard, the 2000 kgs of orange roughy caught in the third trawl is considered to be a large catch for an off-seafloor trawl.

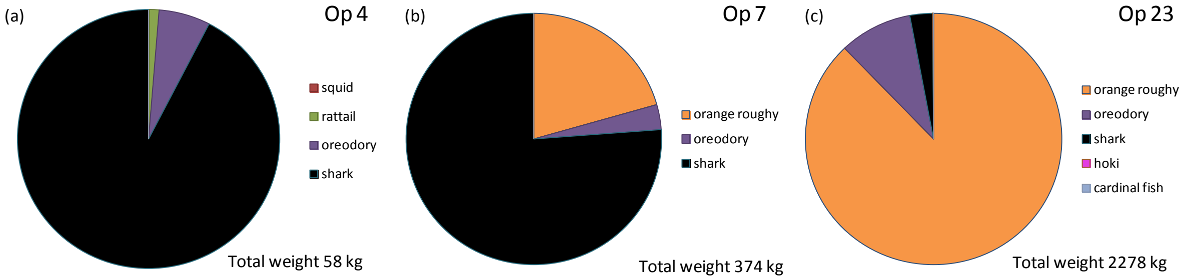


Figure 2. Pie charts of catch composition (by weight) for three non bottom contact trawls at the Morgue.

From the three trawls at the Morgue, 279 orange roughy were measured for length, weight, sex and stage with otoliths retained from each fish. Spawning condition of the females as per Pankhurst et al. (1987) at the Morgue showed that 35% of female fish were pre-spawning (stage 3 or lower), approximately 50% were mature (stage 4), 15% were running ripe (stage 5) and no spent-fish were observed. Length and weight measures are summarised in Table 6.

Table 6. Summary of biological length and weight measures for orange roughy captured at Morgue Seamount

Operation	Number Females	Number Males	Male length (cm)	Female length (cm)	Male weight (kg)	Female weight (kg)
7	45	14	33.7	33.8	1.30	1.32
23	182	38	34.2	35.6	1.32	1.58
Totals	227	52	34.08	35.10	1.32	1.51
Combined mean length – 1:1 sex ratio 34.59 (cm)						
Combined mean weight – 1:1 sex ratio 1.42 (kg)						

3.1.2 Biomass estimates

Biomass was calculated for the Morgue at both 38 and 120 kHz as described in the methods section for the star pattern surveys selected for full analysis using inputs of measured fish weight, estimated target strength and echo integrated volume backscatter signal (Table 7). Maps of the spatial distribution of acoustic backscatter attributed to orange roughy for each survey can be found in Appendix C.

Table 7. Orange rough biomass estimates for four AOS surveys at the Morgue Seamount.

		Biomass (tonnes)			
Op no.	Frequency (kHz)	Above acoustic bottom	Deadzone estimate	Total biomass	CV
2	120	3194	2119	5313	0.12
	38	4451	2934	7386	0.14
6	120	3203	2349	5552	0.13
	38	4690	3565	8255	0.15
15	120	1823	1775	3598	0.39
	38	3205	2690	5895	0.43
22	120	7809	2510	10319	0.11
	38	10831	3981	14812	0.11

The acoustic backscatter at the Morgue was generally high and extensive, extending to more than 100 m above the seafloor and running from one side of the seamount to the other, a distance of approximately 3 kilometres (Figure 3 and Figure 4). The acoustic backscatter regime was complicated, with broadly three regime types observed:

i. Medium intensity backscatter was situated beneath the high-intensity region on the top and over the sides of the seamount with 120–38 kHz dB difference of +2 to +6 dB indicative or orange roughy or possibly deepwater shark. Southern Lantern Sharks (*E. baxteri*) with mean length of 62 cm and weight of 1.5 kg were the dominant deepwater shark species. (Figure 3);

ii. Medium to light intensity backscatter with 120 - 38 kHz dB difference of ~ 0 dB that does not indicate orange roughy (Figure 3);

iii. Observed on most transects was a large feature with very high acoustic backscatter at the top of the seamount. The multi-frequency without 12 kHz frequency was not always able to clearly discriminate the backscatter as originating from gas-bladdered species on first inspection. However the high acoustic backscatter with highly variable location of this feature is indicative of fast moving fish species with gas bladders (Figure 4).

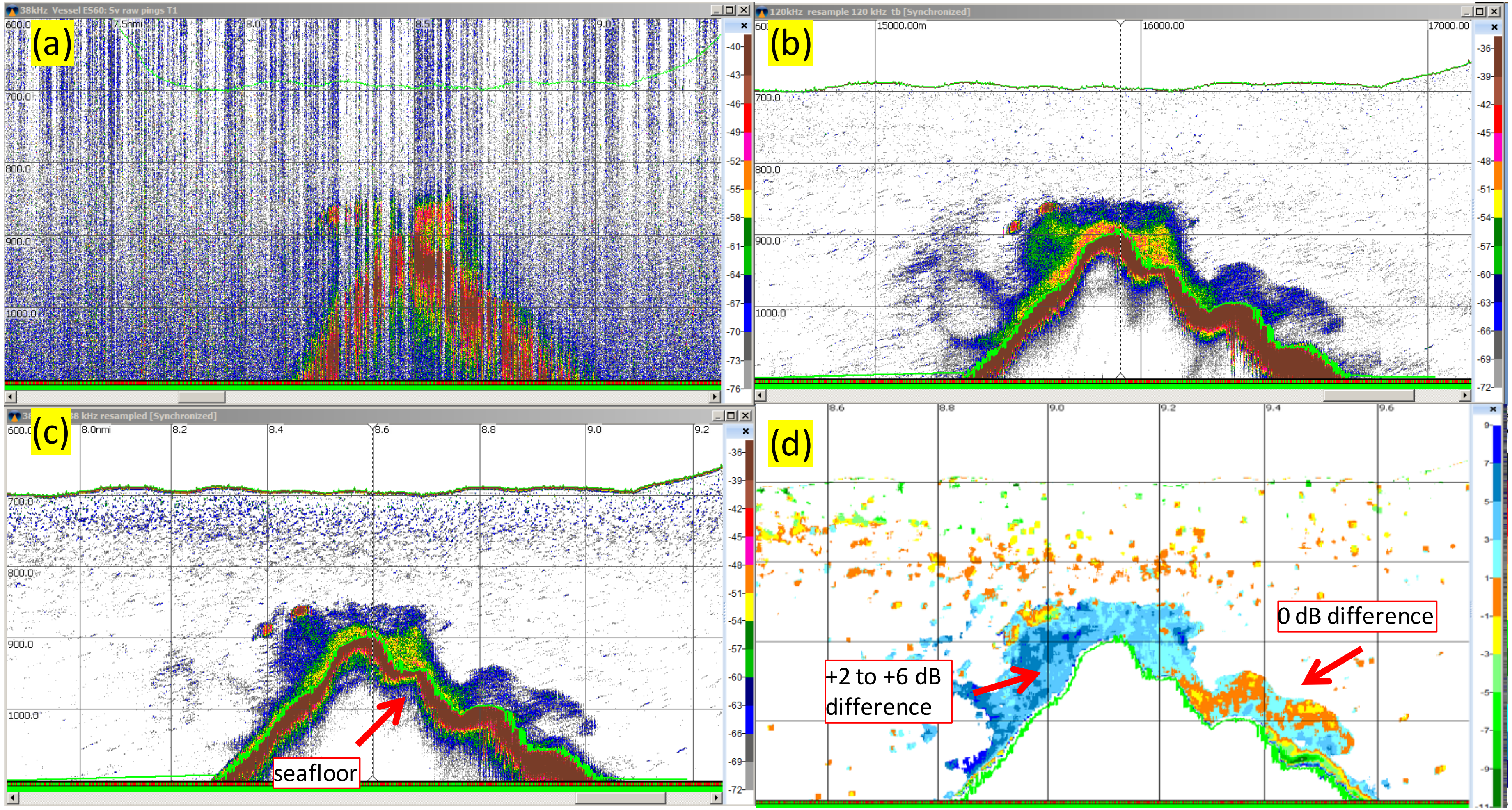


Figure 3. Example of vessel and AOS echograms at the Morgue seamount. Operation 2, transect 4. (a) 38 kHz vessel mounted echogram (note display gain sensitivity increased by 4 dB to adjust the un-calibrated sounder to approximate calibrated data allowing comparison with AOS images), (b) 120 kHz AOS echogram, (c) 38 kHz AOS echogram and (d) logarithmic difference between 120 kHz and 38 kHz AOS signal. Colour scales on the RHS of figures a, b and c indicates signal strength where red is strongest and grey is weakest. The colour scale on Figure d shows the logarithmic decibel difference between 120 kHz signal minus 38 kHz signal.

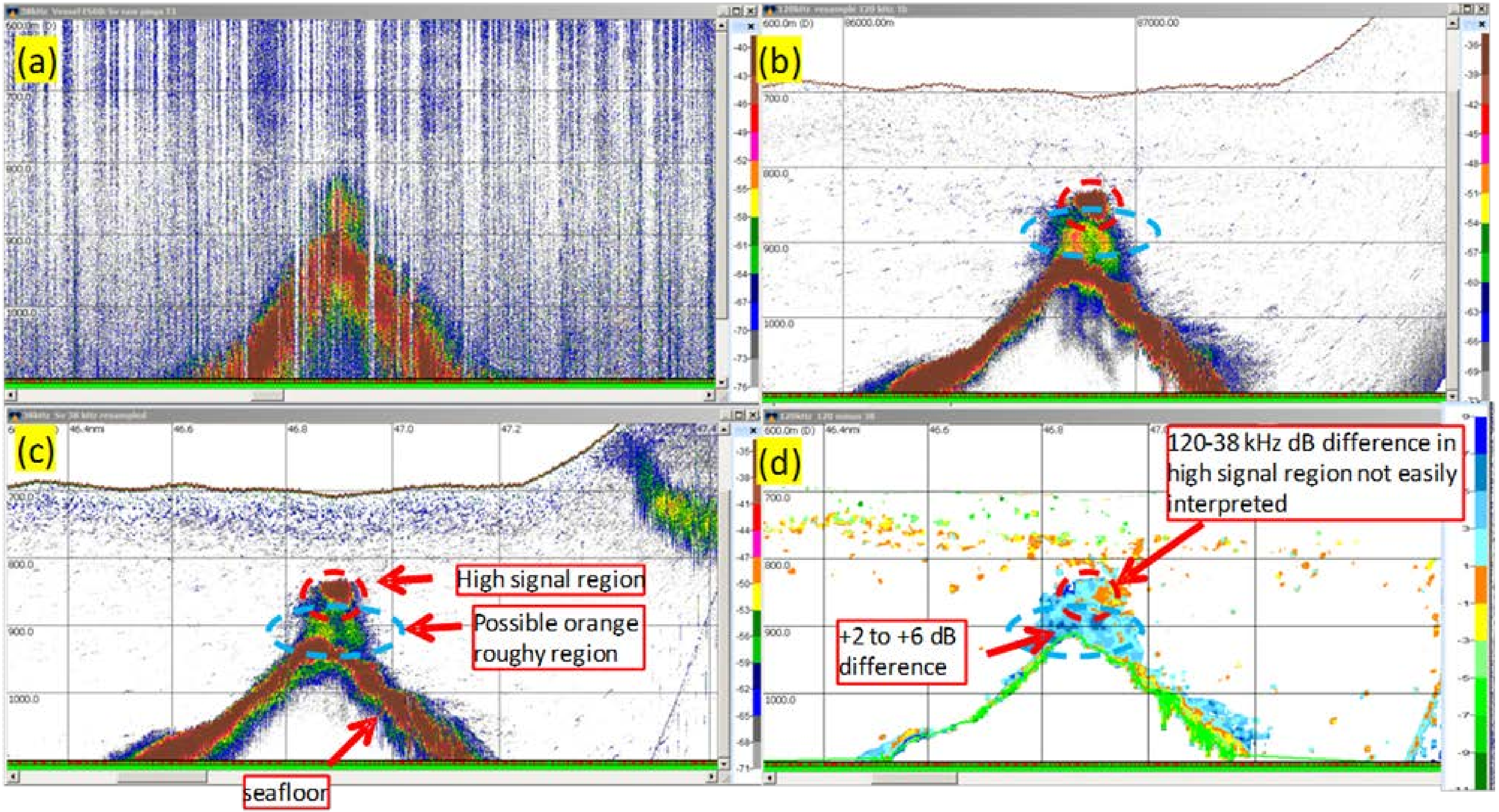


Figure 4. Example of vessel and AOS echograms at the Morgue seamount. Operation 2, transect 1. Region of high signal, presumably large gas bladder fish, denoted by red dashed oval in images b-d. Beneath this a region of moderate signal denoted by blue dashed oval with a multi-frequency signature indicating large non-gas bladder fish such as orange roughy or deepwater shark. (a) 38 kHz vessel mounted echogram (note display gain sensitivity increased by 4 dB to adjust the un-calibrated sounder to an image that approximates calibrated data allowing comparison with AOS images), (b) 120 kHz AOS echogram, (c) 38 kHz AOS echogram and (d) logarithmic difference between 120 kHz and 38 kHz AOS signal. Colour scales on the RHS of figures a, b and c indicates signal strength where red is strongest and grey is weakest. The colour scale on Figure d shows the logarithmic decibel difference between 120 kHz signal minus 38 kHz signal.

When calculating biomass, only regions where the 120 kHz signal was stronger than 38 kHz by +2 to +6 dB and where other lines of evidence supported the interpretation of dominant orange roughy were included. The presence of abundant deepwater shark could positively bias these biomass estimates. From first inspection the logarithmic decibel difference between 120 and 38 kHz for these shark species appears to be similar to orange roughy, thus their exclusion using multi-frequency methods is not readily achieved. These species lack a gas filled swimbladder and their TS appears to be similar to orange roughy. Therefore, unlike large gas filled swimbladder species that can dominate the acoustic signal even at low densities, sharks would need to be present in large numbers to significantly bias high the acoustic signal that was attributed to orange roughy.

Although caution must be used when considering inferences based on close-range optical observations and trawl catch, the indications were that orange roughy were by far the numerically most dominant. It is true that deepwater sharks were optically observed in abundance during sections of the close range AOS trawls however orange roughy were optically observed in their thousands during the same operation. Similarly deepwater sharks did feature in the trawl catch but on the one trawl that properly targeted the main acoustic mark, orange roughy were dominant. In this trawl ~ 2 tonnes of orange roughy were caught despite the catch efficiency of the net being compromised by being deliberately held away from the seafloor. Further information on species composition was obtained from an experiment carried out by NIWA during the same survey period. They placed a mooring on the Morgue at 940 m with an echosounder at 815 m, and cameras at 860, 908, and 933 m. The cameras were timed to start for 2 minutes every two hours. Initial findings have indicated that, at the location of the mooring at least, orange roughy were the numerically the dominant species (Odriscoll et al., 2012). Further surveys at the Morgue using an AOS and possibly moorings would be useful to help better understand the dynamic and complexity of the species assemblages at this location.

A detailed review of the extreme high acoustic backscatter regions was made to consider the possibility of these being occupied by densely packed orange roughy. To do this it was assumed that all signal was due to orange roughy therefore an orange roughy target strength value at 38 kHz of -52 dB re 1m^2 was applied the S_v data to convert it into a mapping of fish density as per Equation 8

$$n = \frac{10^{\frac{Sv}{10}}}{10^{\frac{TS}{10}}} \qquad fish/m^2 \qquad \text{Equation 8}$$

Inspection of the density map found that if the high acoustic backscatter regions were indeed occupied by orange roughy their density would of the order of 100–500 fish per m^3. This contrasts with regions where the evidence of multi-frequency and other indicators unambiguously suggested orange roughy, the density was in the order of 0.5–2 fish per m^3 (Figure 5). These figures are comparable with density measurements made in 1998 on the Chatham Rise orange roughy spawning plume where the maximum density for three selected schools ranged from 1.34 to 4.46 fish/m^3 (Kloser et al., 2000).

As a sensitivity test to this interpretation decision, two Morgue surveys were reanalysed with high signal regions assumed to be orange roughy and biomass estimated (Table 8).

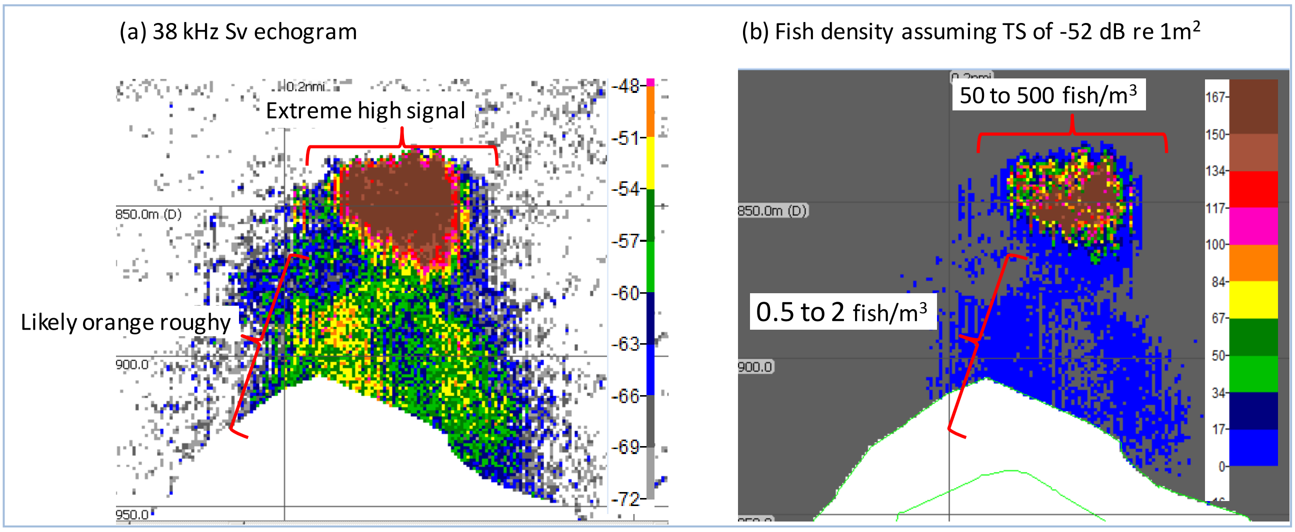


Figure 5. (a) 38 kHz echogram with below seafloor signal masked out, showing an example of high signal region at 800m depth located above a region at approx. 900 m depth that is highly likely to contain orange roughy. (b) Conversion of echogram to fish density for an assumed target strength of -52 dB re 1m^2.

Table 8. Estimates for total biomass (including deadzone component) for two interpretation scenarios from selected AOS surveys at The Morgue.

Op no.	Frequency (kHz)	Biomass, high density regions excluded (tonnes)	Biomass, high density regions included (tonnes)	Ratio of increased biomass
2	120	5313	22417	4.2
	38	7386	50683	6.9
22	120	10319	22640	2.0
	38	14812	68867	4.4

Based on density alone it does appear unlikely that the high signal regions are occupied by orange roughy. The biomass estimates associated with the contrary interpretation (all high density signal is due to orange roughy) would appear to be unusually high for such a small seamount feature. Further the ratio of increase in biomass would be expected to be similar if the high signal region was indeed due to orange roughy. This is not the case, with the 120 kHz and 38 kHz increasing by factor of 4.2 and 6.9 respectively for Op no. 2 and factors of 2.0 and 4.4 for Op no.22 (Table 8). A more likely interpretation is that the high signal regions are due to large fish species with large gas-filled swimbladder. The catch of a single cardinal fish at the Morgue, a species with very high target strength that is not readily caught in a demersal net, is notable as a possible candidate species. The high signal regions were not observed on all transects and appears to be a mobile feature which a fast moving species such as cardinal fish might account for.

3.2 Graveyard seamount

Between the 18th and 22nd of June a series of acoustic activities were completed at the Graveyard. These included three AOS multi-frequency star pattern surveys, one vessel hull mounted acoustic survey and four close range AOS demersal trawl shots (Table 9).

Table 9. Echo-integration surveys carried out at the Graveyard seamount in June 2012

OP Number	Operation Type	Start date (UTC)	Start time (UTC)	Location	Comment
3	AOS Echo integration	18/06/2012	20:40:00	Graveyard	Star survey at Graveyard. No marks observed by the vessel sounder.
11	AOS Echo integration	20/06/2012	14:34:00	Graveyard	Star survey at Graveyard. Echo integration mode.
18	AOS Echo integration	22/06/2012	11:22:00	Graveyard	18

3.2.1 Biological measures

Four short duration (bottom-contact) demersal trawls were carried out at the Graveyard with total catches ranging between 2600 kg to 28 000 kg of orange roughy. Length and weight measurements of orange roughy are summarised in Table 10.By-catch was very low being less than 2% of weight for each of the four trawls. (Figure 6).Total by-catch by weight was dominated by sharks (43%) and oreos (27%).

In total 642 orange roughy were measured for length, weight, sex and stage with otoliths retained from each fish. Spawning condition of the females indicated that 50% of the fish were pre-spawning (stage 3 or lower), 45% mature (stage 4), less than 5% running ripe (stage 5) and one spent fish observed.

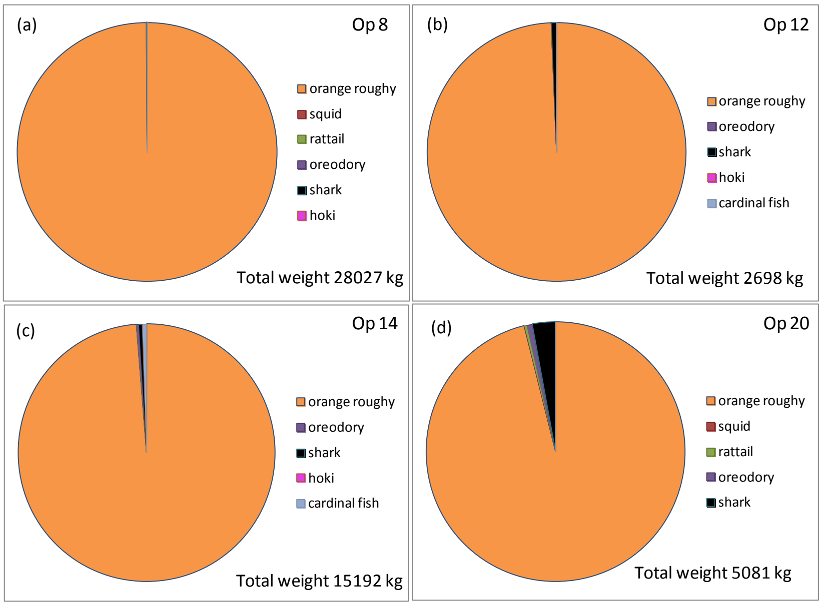


Figure 6. Pie charts of catch composition for four trawls at the Graveyard.

Table 10. Summary of biological length and weight measures for orange roughy captured at, Graveyard Seamount

Operation	Num Females	Num Males	Male length (cm)	Female length (cm)	Male weight (kg)	Female weight(kg)
8	151	52	33.4	34.8	1.29	1.50
12	89	8	33.4	34.3	1.27	1.45
14	90	71	33.6	36.2	1.25	1.65
20	64	117	33.2	34.9	1.22	1.51
Totals	394	248	33.41	35.22	1.26	1.55
Combined mean length - 50-50 sex ratio 34.31 (cm)						
Combined mean weight - 50-50 sex ratio 1.40 (kg)						

3.2.2 Biomass estimates

Biomass for the Graveyard at both 38 and 120 kHz were calculated as described in the methods section for the star pattern surveys selected for full analysis using inputs of measured fish weight, estimated target strength and echo integrated volume backscatter signal (Table 11). Maps of the spatial distribution of acoustic backscatter attributed to orange roughy for each survey can be found in Appendix C.

Table 11.Orange roughy biomass estimates for four AOS surveys at the Graveyard.

		Biomass (tonnes)			
Op no.	Frequency (kHz)	Above acoustic bottom	Deadzone estimate	Total biomass	CV
3	120	2680	2250	4930	0.31
	38	3410	3260	6670	0.28
11	120	2245	2305	4550	0.22
	38	2783	3045	5828	0.22
18	120	2299	984	3283	0.25
	38	2713	1440	4153	0.23

The acoustic backscatter at the Graveyard was not as strong or extensive as the Morgue but was nevertheless substantial. A reasonable sized region of acoustic backscatter was observed in the vessel mounted 38 kHz acoustics during star pattern echo integration surveys (Figure 7a). The more detailed 38 and 120 kHz AOS acoustics indicated that this region had the frequency response indicative of a species without a gas-filled swimbladder (e.g. +2 to +6 dB, orange roughy or sharks), (Figure 7b, c and d). In the example shown in Figure 7 the AOS system was inadvertently towed closer to the seafloor than is ideal and has appeared to cause an avoidance reaction in the fish. This is event marked in Figure 7c where the low signal region immediately above the region of higher signal just above the seafloor is interpreted as a ‘void’ left by fish as they rapidly vacated the water column for the safety of the seafloor. Such avoidance reactions are well documented for orange roughy (Kloser et al., 2000, Koslow et al., 1995, O'Driscoll et al., 2012) adding weight to evidence provided by the multi-frequency information. The interpretation of the Graveyard therefore concluded that the dominant acoustic backscatter could be attributed to orange roughy. Other species including deepwater sharks and gas bladdered species (in particular oreos dory and occasional cardinal fish) were present as observed in both the optical images and trawl catch. Within the limitations of the method these by-catch species were considered to be excluded from the acoustic backscatter signal through the application of multi-frequency acoustics and other lines of evidence that indicate species.

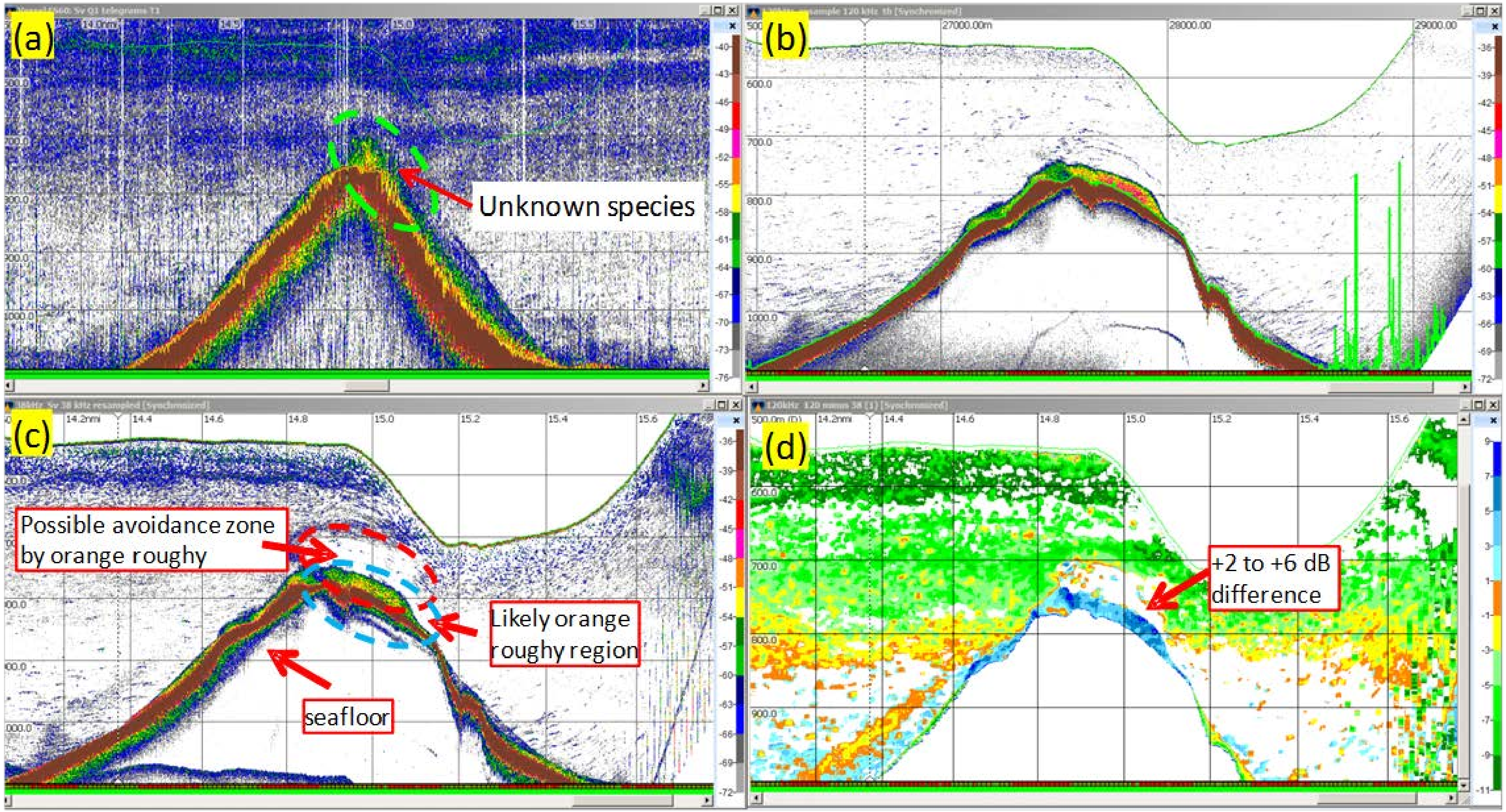


Figure 7. Example of vessel and AOS echograms at the Graveyard seamount. Operation 11 transect 4. Region of possible avoidance by orange roughy is denoted by red dashed oval in image c. A region of likely orange roughy is indicated in this same panel by the dashed blue oval close to the seafloor (a) 38 kHz vessel mounted echogram (note display gain sensitivity increased by 4 dB to adjust the un-calibrated sounder to approximate calibrated data allowing comparison with AOS images). A region of high signal but unknown species is denoted by the dashed green oval, (b) 120 kHz AOS echogram, (c) 38 kHz AOS echogram and (d) logarithmic difference between 120 kHz and 38 kHz AOS signal. Colour scales on the RHS of figures a, b and c indicates signal strength where red is strongest and grey is weakest. The colour scale on Figure d shows the logarithmic decibel difference between 120 kHz signal minus 38 kHz signal.

3.3 Discussion points relevant to both Morgue and Graveyard Surveys

3.3.1 Deadzone estimation

Quantification of the biomass of orange roughy contained in the acoustic deadzone is an on-going question. The Morgue and Graveyard seamounts are steep with respective gradients of approximately 10% and 30% which will result in a large acoustic deadzone. The estimated deadzone biomass ranged from 27% to 44% and 29% to 53% of the total biomass respectively for the Morgue and Graveyard surveys.

Deeply towing the acoustic system reduces the deadzone height in proportion to the range from platform to seafloor (Kloser, 1996) but does not eliminate it. For echo-integration surveys the AOS is endeavoured to be towed at ~ 300 m, not from the seafloor, but from the top of any significant regions of high acoustic bacsckatter. This towing range is a compromise. Being too close can risk causing an avoidance reaction in orange roughy while being further away increases the deadzone height.

Our approach to deadzone estimation uses the average of the acoustic signal in the 5 metres immediately above the 'acoustic bottom' (closest depth to the seafloor which is considered to contain no deadzone interference) and assumes that this average value is representative of the fish within the deadzone region (i.e. the region between the 'acoustic bottom and the 'true bottom' of the actual seafloor). The validity of this assumption is open to question. In past surveys we have acoustically observed in both New Zealand and Australia orange roughy schools that have lifted away from the seafloor that suggests a lesser density of fish within the deadzone region in those instances. Further O'Driscoll (2012) noted that in the mooring array data, lower orange roughy densities were observed in the camera images close to the seafloor compared to images taken from cameras higher in the water column. Conversely, there are numerous examples where the orange roughy appear to be 'hard down' on the seafloor suggesting an above average density within the deadzone. Also, there are also many instances where commercial fishers have caught large amounts of orange roughy when they trawl within the deadzone region despite there being little or no indication of fish on their echosounder. Our optical observations of orange roughy have shown extremely high densities but the strong herding effect of the trawl makes it difficult to draw inferences regarding the density of undisturbed orange roughy in the deadzone. We expect that the density of orange roughy in the deadzone is dynamic in time and space and that using an average density is the most appropriate assumption given the available information. To progress investigation of deadzone densities new approaches are needed. The obvious limitation of optical observations from moorings is the very limited spatial coverage but does have advantage of minimizing fish disturbance and potentially quantifying temporal effects. Experiments to better understand deadzone density could be made by carrying out transects with a transducer that can be angled so that its face is always perpendicular to the seafloor, although such a system would have a number of technical challenges.

3.3.2 Combined regional biomass

Survey results from separate spawning aggregations can be combined if it can be assumed there was minimal movement of fish between grounds. The Graveyard and Morgue features are separated by 5 kilometres with fish movement between sites possible during the voyage period. The highest biomass at the Morgue with associated low estimate of survey CV and estimated deadzone proportion was on the 22nd of June. Assuming minimal fish movement this biomass estimate can be added to the Graveyard survey that was 10 hrs prior. The combined schooling snapshot biomass of the region would be estimated as 18965 tonnes (CV 0.1) at 38 kHz and 13602 tonnes at 120 kHz (CV 0.1). The 120 kHz biomass estimate reduces by 35% to 10083 tonnes if the July calibration result is used. Combining of biomass results from the two regions could be explored with different assumptions of between-site fish movements. Biomass estimates at 120 kHz must be considered preliminary until a stable calibration result is obtained.

3.3.3 Biomass estimates at two frequencies

Previous applications of the AOS to the question of orange roughy TS has greatly advanced our knowledge and confidence in this critical measurement (Kloser et al., 2011, Macaulay et al., 2012). A key advance has been the high confidence *in situ* measurement of orange roughy TS at 120 kHz enabling echo integration-based biomass estimates to be made at this frequency. This gives an alternative estimate of orange roughy biomass that is partially independent of the 38 kHz estimate; measurements are concurrent at both frequencies along the same transect lines, but instrument channels, calibration and backscatter values are independent. The variation of 1.3 dB in calibration results for the new 120 kHz transducer makes use of the estimate in this work uncertain.

Notwithstanding calibration issues for our new 120 kHz transducer the 120 kHz frequency has significant advantages for orange roughy biomass estimation. Orange roughy backscatter signal at 120 kHz is approximately twice as strong as 38 kHz. Contaminating signal from co-occurring small gas bladder lantern fish (Myctophidae) species is reduced by approximately a factor of 10 while signal from large gas bladder species remains similar for both frequencies. Recent results by Kloser et al. (2013) indicates that volume backscatter measurements of orange roughy at 120 kHz should be less affected by the tilt-angle distribution within the fish school than volume backscatter measurements at 38 kHz. This finding was based on analysis of 38 kHz and 120 kHz orange roughy target strengths with concurrent stereo optical imaging where measurement of tilt angle enabled the relationships between TS and fish angle to be explored.

For the 2012 New Zealand surveys, when compared to 38 kHz results, the 120 kHz biomass estimates were between 27% and 39% lower for the four Morgue surveys and between 15% and 24% lower for the three Graveyard surveys. This difference in biomass between frequencies is higher than has been observed in other surveys. For example Kloser et al. (2011) reported results at both 38 and 120 kHz for the 2010 Tasmanian Eastern Zone orange roughy surveys at St Helens Hill where the biomass estimates were 5% lower on 120 kHz compared to 38 kHz. There are a number of reasons why 38 and 120 kHz results might differ. These included biases in calibration of either frequency, error in absorption estimate (120 kHz is particularly susceptible to this error), undetected inclusion of other species and tilt angle distribution within the school affecting target strength and therefore volume backscatter measures. This last point regarding tile angle distribution is presented in recent work by Kloser et al. (2013). Their work showed a significant negative correlation between tilt angle and the decibel difference between 38 kHz minus 120 kHz TS. The extension of this finding was that when estimating biomass a single TS value should not be used, but rather the 38 kHz TS, and to a lesser degree 120 kHz TS, should be adjusted according to the measured decibel difference between 120 kHz and 38 kHz volume backscatter. For example, for Morgue survey 22 the 120-38 survey S_v was 1.9 dB which if applying the adjustment suggested by Kloser et al. (2013), would result in TS values of -51 and -48.8 dB re 1m^2 for 38 and 120 kHz respectively instead of the nominal values of -52 and -48.7 used for the initial biomass estimates. If these corrections were applied the differences in biomass at 120 kHz when compared to 38 kHz results were between 16% and 0% lower for the four Morgue surveys and between 1% lower and 1% higher for the three Graveyard surveys. This correction provides an encouraging outcome by reducing the difference in biomass estimates between the two frequencies, but further application on future survey results is needed to prove the robustness and repeatability of this method.

The 38 kHz biomass results are traditionally used as their errors and assumptions accord with the long-standing body of research and biomass estimates at this frequency. However a body of recent research is suggesting that the 120 kHz frequency has less errors due to contamination of gas-bladdered species and less variation due to fish tilt angle. It is recommended that future acoustic surveys continue to produce estimates at 120 kHz to build a time-series to accompany the deep-towed 38 kHz estimates. With some further work on transducer calibration and other sources of error there are sound technical reasons why the 120 kHz based biomass estimates should ultimately be adopted as the primary measurement of orange roughy biomass. In these surveys the divergence of the 38 kHz and 120 kHz biomass estimates indicates there is a process error that needs to be addressed in either, calibration, species contamination by predominantly gas bladdered species or variation in target strength due to tilt angle. If the tilt-angle variation in target strength due to school backscatter dB difference are adopted it would account for the biomass estimate divergence observed in these surveys.

3.3.4 Process vs observational errors.

To interpret the acoustic survey results it is important to understand the sources of error and determine if these are observation or process dominated (Kloser et al. 2012). Examples of observation error dominance are when survey sampling CV's are high due to patchy distributions, fish movement or if there was a large temporal change in the fish target strength or dead zone estimates. Process error is more likely to be significant for orange roughy surveys for issues such as density detection thresholds, availability of fish to be surveyed in homogeneous schools and schools clear of the seabed echo.

The acoustic backscatter regimes at the Morgue and Graveyard were complex and highly dynamic. The reported variation in AOS biomass estimates are one indicator of this dynamic. A fuller understanding of this dynamic comes through observations made over a number of days using a combination of vessel acoustics, long range multi-frequency AOS surveys and close range optical, high resolution acoustics and fish capture using the demersal trawl net. Using this combination of observational tools, the extent, location and intensity of the acoustic marks were observed to change throughout the day with generally an overarching build-up or decline occurring over a number of days. It is presumed that during the less active periods that the orange roughy must either have dispersed into the water column at densities that are below the detection thresholds of the acoustics or occupying the deadzone region. Given the dynamic, it was not surprising that the AOS biomass surveys might give different estimates throughout the survey period and that those that were executed when the orange roughy were most available to the acoustic instruments would give the highest estimate. For example at the Morgue, the initial surveys recorded the lesser biomass. Following a 36 hour break to survey other locations the vessel returned to The Morgue where all indicators showed that the biological activity had greatly increased. It was during this period that the highest AOS biomass estimate was made.

Each biomass estimate will of course contain observation errors, and in particular survey sampling error and errors due to fish movement could account for a degree of inter-survey variability. The Morgue and Graveyard features are relatively small and the four-transect star pattern survey design provide a high degree of sampling intensity where the inter-transect spacing ranges from approximately 100 m to 300 m from the shallowest to deepest depths respectively. With this degree of coverage survey sampling error would not be expected to make a large contribution to inter-survey variability. Unlike grid surveys where fish can move with or against the procession of the transects, star surveys should be less susceptible to errors due to fish movement, as each transect on a star survey samples opposite sides of the seamount in a short period of time and all sectors of the seamount can be covered over a few hours. A degree of species identification error is inevitable but through application of multi-frequency methods and multiple lines of evidence this error is considered to be too small to account for large inter survey differences in the biomass estimates at the 120 kHz frequency in particular.

3.4 Conclusions

If it is assumed that process error is the dominant form of variation in seamount surveys, then estimates of the highest biomass with the lowest survey sampling CV and minimal deadzone estimate should be adopted. For the Morgue this occurred for operation 22 where the total biomass is 14812 tonnes (CV 0.11) at 38 kHz. At the Graveyard this situation occurs for operation 18 where the total biomass is 4153 tonnes (CV 0.23) at 38 kHz. As the time between surveys at the Graveyard and Morgue features was only 10 hrs it is assumed that there would be no movement of fish between the two sites. Hence the combined schooling snapshot biomass of the region would be estimated as 18965 tonnes (CV 0.1) at 38 kHz and 13602 or 10083 tonnes (CV 0.1) for the Feb. and July calibration results at 120 kHz (CV 0.1). These two frequency estimates are significantly different which could be due to a number of factors as discussed above including calibration variation. If this error is due to fish tilt angle target strength variations or inclusions of gas-bladdered species then the results at 120 kHz are preferred.

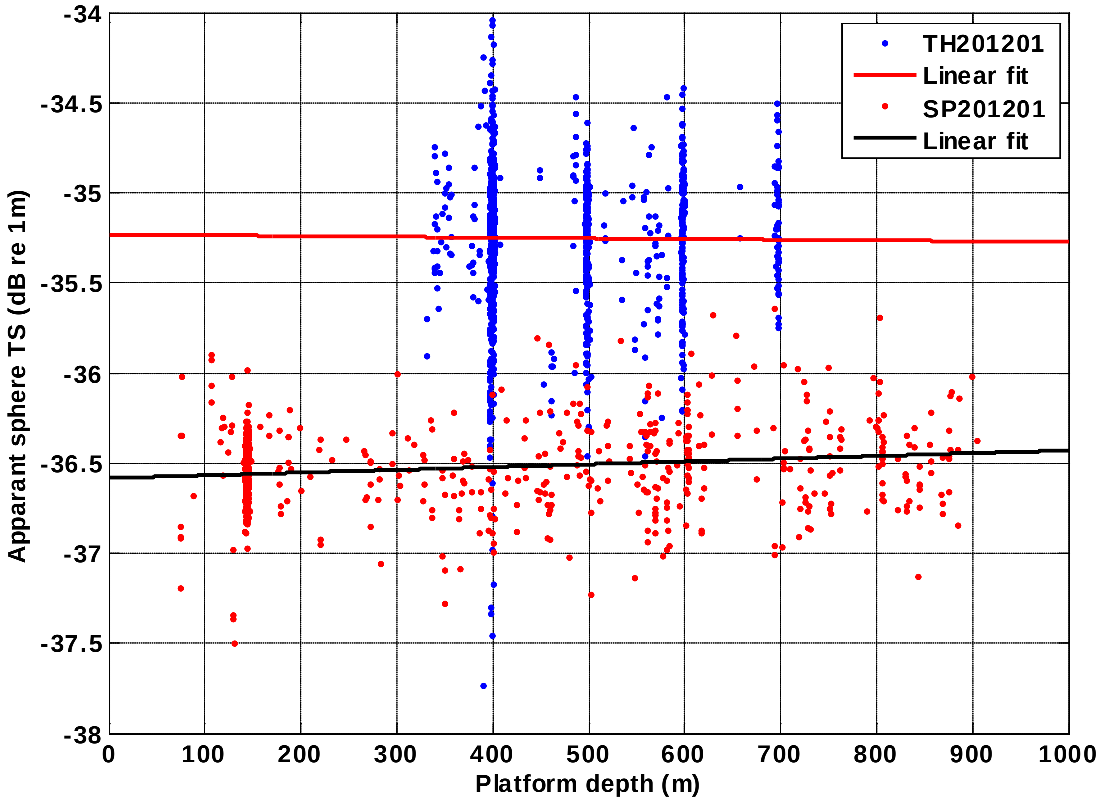
We recommend that the large variation between the 38 kHz and 120 kHz estimates is investigated in future surveys to determine its cause. The biomass estimate in the deadzone for these surveys represents ~29% of the total estimated biomass. We recommend future surveys monitor the proportion of biomass estimated in the deadzone and look at mechanisms to reduce this estimate.

Appendix A AOS calibration

On-axis transducer sensitivity

120 kHz transducer
Calibration date: SP201201 18-Feb-2012 and TH201201 July 2012
Location. Tasmanian St Helens Hill region
Model: ES120-7CD
Serial Number: 109
Factory equivalent beam angle: -20.3
Factory test temperature 21.0 degrees C (fresh water)
Figure A.1 On-axis transducer sensitivity as a function of depth for ES 120-7CD transducer (S. No 110) for nominal transducer gain settings of 26.0, power of 500 W and pulse length of 1.048 ms.
Calibration sphere 38.1 mm dia. TC with TS of -40 dB.

These calibrations were only partially successful with currents keeping the reference sphere out of the transducer beam for much of the deployment, particularly at depths greater than 350 m. Given the paucity of data points in the February (549) and July (1034) data at depth, TS value were considered on-axis if there was less than 1 dB of beam compensation applied. There was a large shift of 1.25 dB in the mean apparent sphere TS at 500 m depth between the Feb. 2012 (TS gain 27.75) and July 2012 (TS gain 28.37) calibrations. The reason for this shift is yet to be determined. In this report we used the Feb. 2012 results noting the effect and difference of the July calibration.



The Sa correction for this data set was calculated by echo-integrating sphere Sv data for only those pings where the sphere was within 0.3 dB.

A linear fit was made to the available Feb. 2012 data to establish a relationship between sphere TS as a function of platform depth as per y = p1*X – p2, where p1 and p2 are coefficients of the linear regression.

Results

Parameter	Value	Units
Regression coefficients	p1 = 0.00014035, p2 = -36.578	
Nominal platform depth	600	m
Transducer gain @ 600 m:	27.55	dB
Sa correction	-0.3	dB

38 kHz transducer

Calibration date: July 2010.
Location: St Helens Hill region
Model: ES38DD
Serial Number: 28332
Factory equivalent beam angle: -20.7
Factory test temperature 18.0 degrees C (fresh water)

Table 3-12. Gain and Sa correction settings for 38 kHz for a nominal platform depth of 500 m

Power (W)	2000
Pulse length (ms)	2.048
Nominal gain:	26.5
On-axis TSc at nominal depth of 500 m	-47.3
Theoretical TS	-42.4
Gain set as : 26.5 + (-47.26 - -42.4)/2 = 24.07 for nominal depth of 500 m	24.07
s_A correction (set to a nominal value)	-0.6

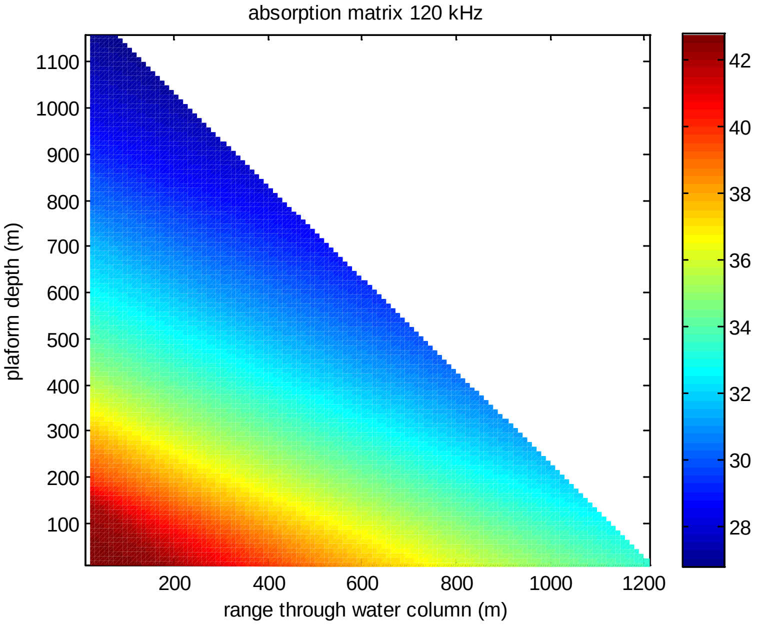
Checks on the detailed 2010 calibration were done in Feb. 2012 (TS gain 23.9) and July 2012 (TS gain 24.2) at depth with minimal coverage of the central part of the beam although no systematic bias or drift observed (less than +/-0.3 dB). Given that the 2010 had very good coverage with stable recordings at all depths it is adopted as the calibration standard for this voyage.

Secondary corrections to the estimate of seawater absorption

The signal loss from ensonified fish schools due to seawater absorption loss varies as a function of frequency, platform depth and range to the fish schools. Initial echo-integration was carried out with values of absorption calculated for nominal platform depth and range to fish schools of 600 m and 300 m respectively. Deviations from either the nominal platform depth or range will require a secondary correction to be final echo-integration values.

A Seabird SBE37 CTD was attached to the AOS, providing profiles of temperature and conductivity throughout each AOS deployment. This CTD data was input into the Francois and Garrison (1982a) equation for estimating seawater absorption to produce a matrix of absorption estimates at 38 kHz and 120 kHz as a function of platform depth and range through the water. Figure 8 shows an example for 120 kHz. The absorption correction for this frequency is much more significant than for 38 kHz.

Figure 8. Absorption matrix as a function of platform depth and range to fish for 120 kHz frequency.

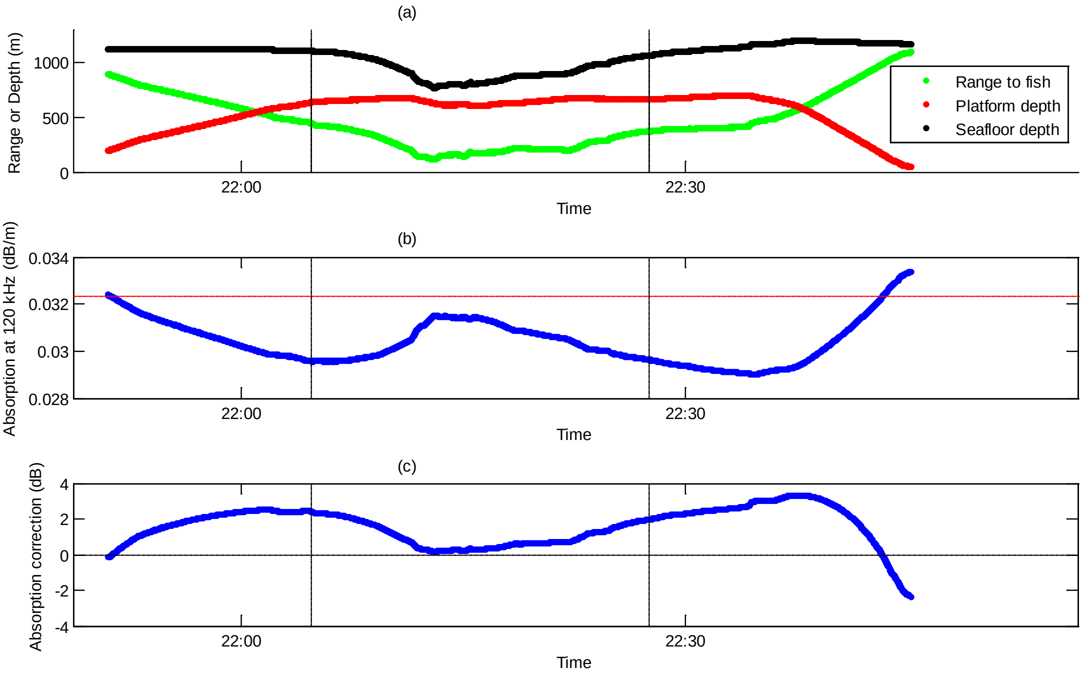


The absorption matrix was queried to give an absorption estimate based on the platform depth and range to fish associated with each echo-integration intervals. Each echo-integration interval NASC value was corrected as follows:

$$NASC\_corrected = \frac{NASC}{10^{\frac{(\alpha-\alpha_c)*(D-P-B)}{10}}}$$

where α is the nominal absorption value in dB/m, α_c the calculated absorption value in dB/m for the platform depth and range to fish associated with the echo-integration interval NASC value. The term $(D - P - B)$ is the range to fish where D is the seafloor depth, P the platform depth and B a backstep value based on half of the estimated mean height of orange roughy schools. An example of the absorption corrections for a selected transect from the Graveyard seamount is shown in Figure 9.

Figure 9. (a) Platform depth, range to fish and seafloor depth plotted against time. (b) absorption value as a function of platform depth and range to fish for 120 kHz plotted against time. Red dashed line indicates the nominal absorption value used for initial echo-integration processing. (c) Absorption correction plotted against time. The period between the vertical dashed black lines are an approximate indication of when the AOS was at depth and transecting across the seamount.



Appendix B Table of activities, FV Otakau Morgue and Graveyard surveys

Table B.1. Voyage activities for FV Otakau June 2012 voyage

OP Number	Operation Type	Start date (UTC)	Start time (UTC)	Location	Comment
1	Test shot	18/06/2012	1:49:00	Morgue	Test deployment to 600 m to check operation of all instruments. AOS frame torn on retrieval due to boat smashing down at the last moment. Made running repairs to frame. 12 kHz transceiver cards were loosened by the hit and these were re-seated.
2	AOS Echo integration	18/06/2012	14:15:00	Morgue	Star survey at Morgue. Moderate conditions. Strong mark on top of hill observed on vessel sounder. Inspection of AOS data shows same strong mark, but extra detail shows low signal regions surrounding the mark that could be orange roughy.
3	AOS Echo integration	18/06/2012	20:40:00	Graveyard	Star survey at Graveyard. No marks observed by the vessel sounder.
4	AOS no contact trawl	19/06/2012	4:50:00	Morgue	No-contact tow along 133 degrees. Photos unclear on id numbers.
5	AOS Echo integration	19/06/2012	9:18:00	Morgue	Aborted. AOS had not been swiped with magnet prior to deployment, so logging did not start. This was realised by the lack of interference marks on the ES60 sounder during the retrieval of the system at the end of transect 1. Restarting grid for OP6
6	AOS Echo integration	19/06/2012	11:54:00	Morgue	Restarting star survey of Morgue. 12 kHz channel not installed
7	AOS no contact trawl	19/06/2012	17:37:00	Morgue	No-contact tow over plume on top of Morgue. No date-time or depth on SD video. 12 kHz channel not installed.
8	AOS biological	20/06/2012	0:11:00	Graveyard	Shooting along 270 degree trawl line at Graveyard. Hazy mark on top of mount.
9	AOS calibration	20/06/2012	8:50:00	Graveyard	AOS calibration on echo integration settings for the four frequencies. Currents must have been too strong - sphere held out of beam and only just visible in the wider beam 12 kHz. Calibration unsuccessful.
10	AOS Echo integration	20/06/2012	13:16:00	Morgue	Single pass over Morgue over top of NIWA mooring.
11	AOS Echo integration	20/06/2012	14:34:00	Graveyard	Star survey at Graveyard. Echo integration mode.
12	AOS biological	20/06/2012	21:34:00	Graveyard	2680 kg roughy - pinned up on top of hill. Fished for about a minute. 2 kg smooth oreo, 1 hoki, 25 kg sharks. SD video filenames not clear,
13	AOS biological	21/06/2012	0:21:00	Graveyard	Missed top of hill and went straight over the top of a nice looking mark. Hauling and will reshoot.
14	AOS biological	21/06/2012	13:20:00	Graveyard	Tow along 70 degree line. Approx 15 tonnes roughy. Looks like a clean catch

15	AOS Echo integration	21/06/2012	4:10:00	Morgue	Star survey at Morgue. NIWA mooring in place with its sounder not running but cameras coming on every two hours on the even hours.
16	AOS biological	21/06/2012	16:15:00	Eastern Spot X	Biological shot Eastern Spot X. 42:41.96; 178:44.78. small catch of mixed species - rattails, basketwork eels, a hoki or two.
17	Vessel Hull Survey	21/06/2012	23:54:00	Rekou	Systematic grid survey at Rekou site. Only light hazy signal on sounder with no significant marks observed to motivate an AOS tow or survey.
18	AOS Echo integration	22/06/2012	11:22:00	Graveyard	Four AOS star transects over graveyard seamount.
19	Vessel Hull Survey	22/06/2012	15:15:00		Mini hull mounted grid at Graveyard to rapidly scope out extent of the mark.
20	AOS biological	22/06/2012	16:30:00	Graveyard	AOS biological trawl shot along 313 degree tow line towards 'the crucifix' north end of the mount. Approx 4 tonne roughy caught.
21	Vessel Hull Survey	22/06/2012	19:46:00	Morgue	Mini grid survey of Morgue ahead of an AOS star survey. Strong roughy like mark on the northern end with strong red mark notable in its absence.
22	AOS Echo integration	22/06/2012	21:39:00	Morgue	Star survey at Morgue. 7 transect survey at Morgue
23	AOS no contact trawl	23/06/2012	4:35:00	Morgue	

Appendix C Spatial distribution maps for Morgue and Graveyard surveys

Figure C.1 Morgue, Operation 2. 18-6-2012, 14:15 UTC

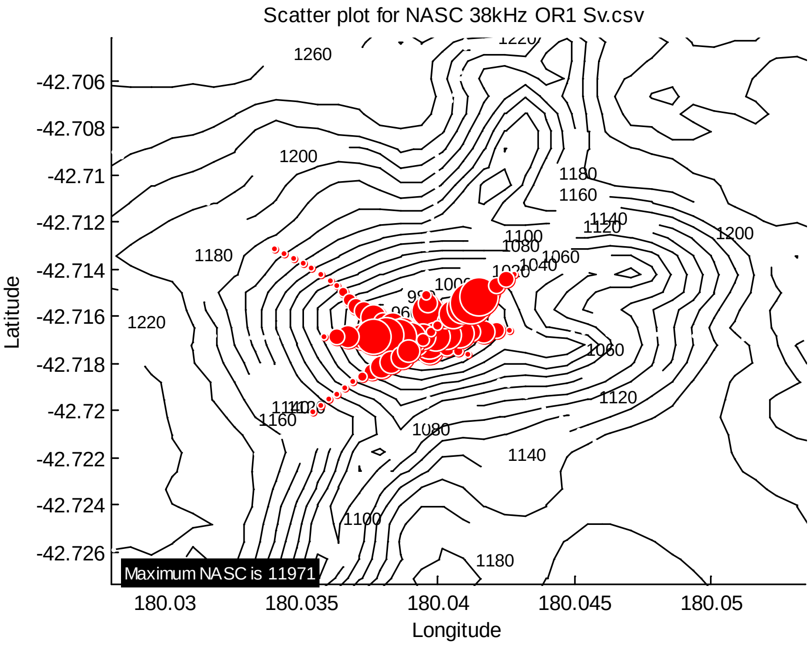


Figure C.2 Morgue, Operation 6. 19-6-2012 11:54 UTC

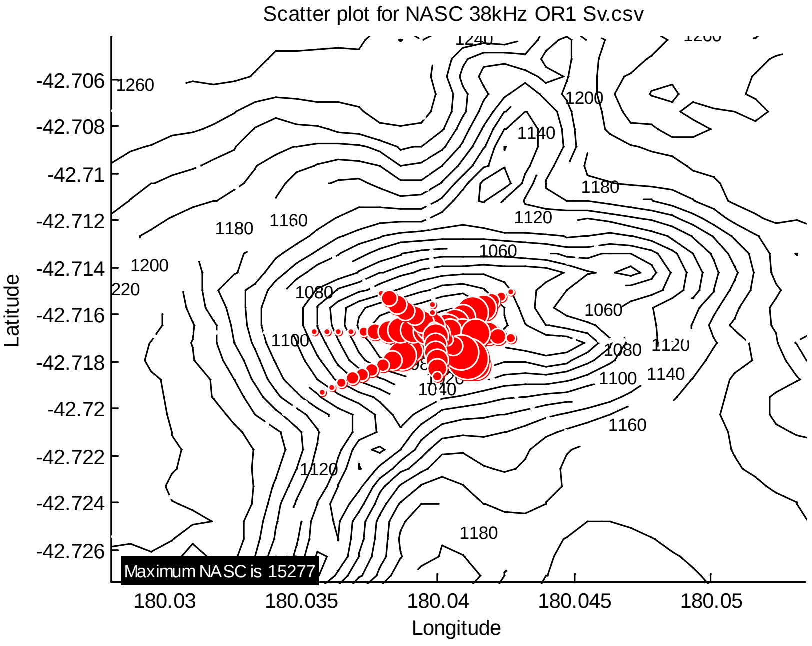


Figure C.3 Morgue, Operation 15. 21-6-2012 04:10 UTC

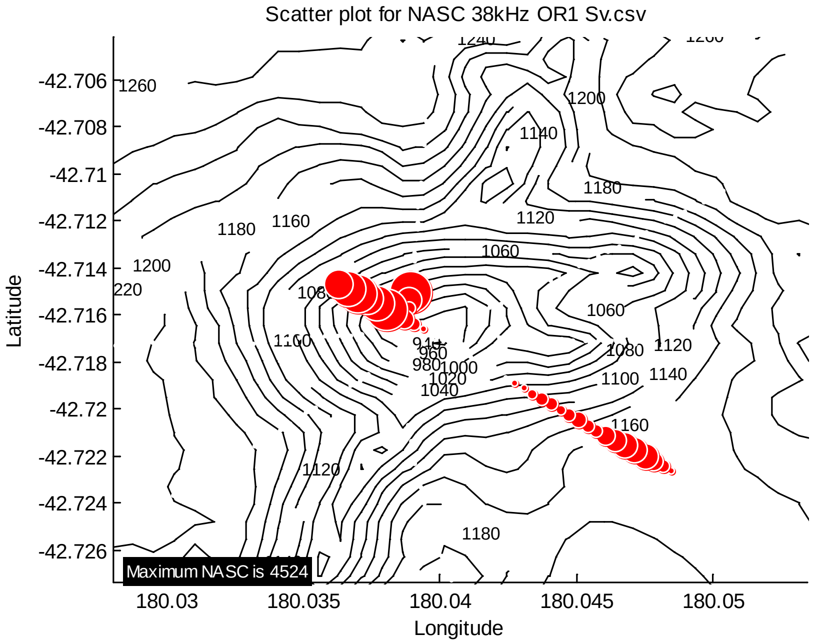


Figure C.4. Morgue, Operation 22 21-6-2012 04:10 UTC

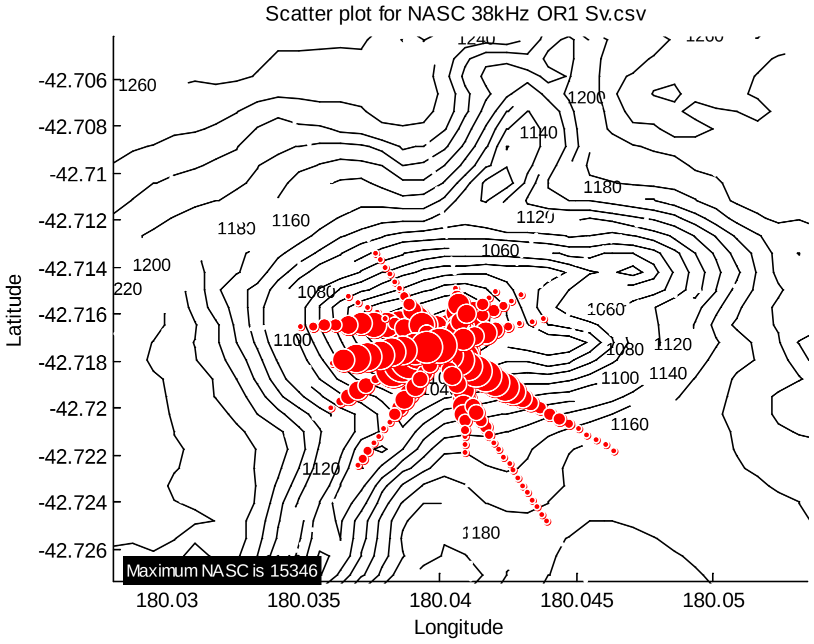


Figure C.5 Graveyard, Operation 3 18-6-2012 20:40 UTC

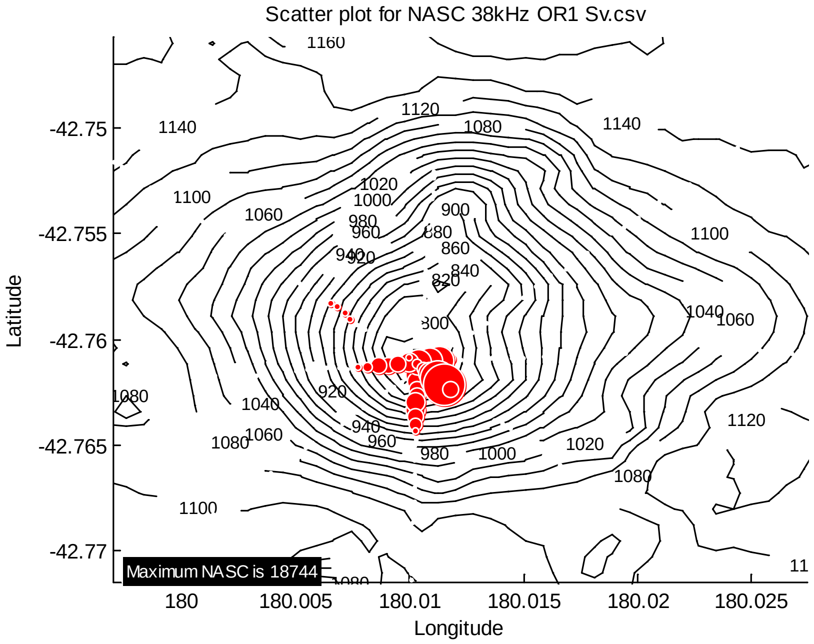


Figure C.6 Graveyard, Operation 11 20-6-2012 14:34 UTC

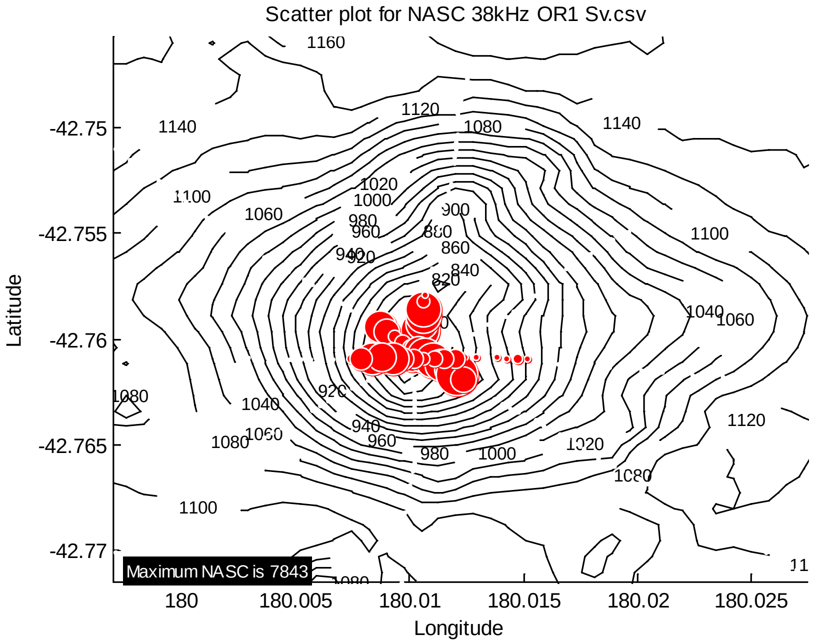
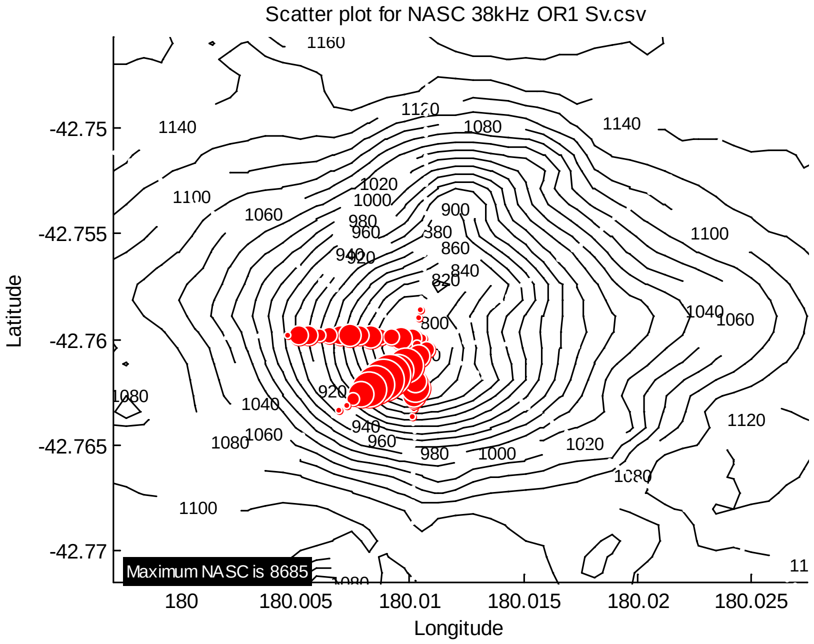


Figure C.7 Graveyard, Operation 18 22-6-2012 11:22 UTC



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