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Biomass surveys of orange roughy spawning aggregations in ORH3B NWCR and ESCR management sub-areas in June-July 2016 using a net attached acoustic optical system

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1 Executive summary

Executive summary.

Between 18th June and 15th July a series of acoustic surveys of orange roughy, complemented by a combined biological trawl sampling program were conducted in the ORH3B North West Chatham Rise (NWCR) management sub-area at the Morgue-Graveyard complex, and in the East and South Chatham Rise (ESCR) management sub-area at Rekohu, Spawn Plume and Mt Muck. The primary acoustic instrument was the CSIRO-built Sealord Acoustic Optical System (AOS) from which biomass estimates were made using both 38 and 120 kHz calibrated frequencies. Vessel-based acoustics were also used to provide sustained observation of fish, their movement and behaviours in order to optimise the utilisation of the AOS for formal transect surveys. Additionally biomass estimates were made using the 38 kHz vessel acoustics when weather conditions were calm and when orange roughy could be clearly delineated from other sources of backscatter. As far as was possible, surveys were sequenced to coincide with the peak of orange roughy spawning events at each location. A summary of survey outcomes for each key location is as follows:

Graveyard

Very low backscatter at insufficient levels to allow biomass estimation to be made using either AOS or vessel-acoustics.

Morgue

Biomass estimates ranging from 10536 (survey CV 0.15) to 14288 (survey CV 0.18) including deadzone components. Separation of orange roughy from extreme signal regions (ESRs) at Morgue presented challenges but are believed to be robust through use of multiple indicators (multifrequency acoustics, optics, trawl, school structure and intensity). The potential for remaining positive bias is nevertheless noted and further work is needed at Morgue to progress the question of species composition to ensure robust results.

Rekohu

Large aggregations were observed during the third and final visit to this region between 1st and 6th of July. This period matched the peak spawn period as observed by the biological sampling. Biomass estimates ranged from 8605 tonnes (120 kHz AOS,CV 0.48, deadzone contribution 20.4%) to 45157 tonnes (38 kHz AOS, CV 0.19 tonnes, deadzone contribution 18.7%). The large range in biomass estimates is thought to be due to availability of the fish to the acoustics while noting survey sampling CV will contribute to variability. High levels of broadscale acoustic backscatter were observed at times at Rekohu which was likely a key factor in a vessel-based estimate being a factor of two higher than AOS-based estimates on one occasion. Given the vulnerability of vessel-acoustics to being biased high by inclusion of non-target species at Rekohu we recommend that multifrequency systems be the first choice. Vessel-based results may be appropriate in instances where weather is particularly calm and orange roughy clearly delineated from surrounding backscatter, and they have the advantage of a significantly faster speed compared to surveys using the deeply deployed AOS.

Spawn Plume

Orange roughy had commenced spawning by the time acoustic surveys were started at this location on the 7th of July. Biomass estimates ranged from 3888 tonnes to 18327 tonnes. Fish availability to the acoustics seems the most likely reason for this variation but noting also survey sampling variability is quite high for these surveys (ranging from 0.32 to 0.52). We note that at the start of the survey period the main spawning aggregation was approximately six nautical miles west of the historic Spawn Plume area centred around 177°15W, 42°50S. By the end of the surveys six days later the aggregations had moved further west by a further six nautical miles.

Mt Muck

A mix of gas and non-gas bladder species was present at Mt Muck. The AOS was effective in delineating regions of orange roughy from gas bladder species enabling biomass estimates with confident species identification to be made. Biomass estimates range from 326 to 7427 tonnes, noting that the deadzone component was high for this steep sided feature (ranging from 39% to 63 %).

Conclusions, future work and outstanding issues.

Deeply deploying the acoustic transducer will reduce deadzone region compared to vessel-based systems However on steep sided features such as Morgue and Mt Muck the deadzone estimate remains a significant component of the total biomass. New and novel methods are needed in order to better quantify the question of deadzone uncertainty.

The use of more than one frequency provides the opportunity to make separate biomass estimates each of which will encompass uncertainties in target strength, calibration, absorption estimates amongst others. For our analysis we have provided AOS-based biomass estimates at both 38 and 120 kHz. Given it is not known in which direction biomass estimates of any one frequency may be biased there is merit in averaging the 38 kHz and 120 kHz AOS results to improve robustness.

2 Introduction

From June 18th to July 15th 2016 a series of acoustic and biological survey activities were carried out to quantify orange roughy biomass during the winter spawning events in the Northwest Chatham Rise (NWCR) and East and South Chatham Rise (ESCR) fisheries management areas. The primary acoustic survey instrument was an Acoustic Optical System (AOS) attached to the headline of the survey vessel's demersal trawl net, which was towed at depth to conduct multi-frequency transect surveys. Demersal trawls provided biological samples which were processed to provide species composition and measures of fish length, weight, sex and spawning condition. The AOS-demersal trawls also provided acoustic target strength (TS) information at two frequencies, complemented by video and stereo digital still photographs. During AOS surveys the vessel's calibrated ES60 38 kHz echosounder was running concurrently. A Furuno FCV 30 triple beam echosounder was occasionally used during searches for fish to take advantage of the increased coverage provided by the side-looking echosounder beams. This report details the voyage activities, giving a brief overview of observations made at each of the spawning locations, summaries of biological measurements and acoustic-based biomass estimates.

Overall Objective:

To estimate the abundance of orange roughy (*Hoplostethus atlanticus*) in selected areas of the Northwest and Eastern Chatham Rise (Figure 1).

Primary Objectives:

1. To estimate the abundance of orange roughy from an acoustic survey with a target coefficient of variation (c.v.) of the estimate of 20-30% in winter 2016 for the main spawning areas associated with the Northwest Chatham Rise stock (primarily Graveyard hill and Morgue hill).
2. To estimate the abundance of orange roughy from an acoustic survey with a target coefficient of variation (c.v.) of the estimate of 20-30% in winter 2016 for the main spawning areas associated with the East and South Chatham Rise stock (primarily Rekohu, Spawn Plume and Mt Muck).
3. Collection of biological material to inform acoustic data and understanding of deepwater ecosystem.

Secondary objectives

1. Trials of real-time optic fibre capability
2. Trials of broadband acoustics for species identification and target strength
3. Further development of stereo optical methods

Voyage dates:

Depart Nelson Saturday 18th June 07:45 am (local)

Arrive Nelson Friday 15th July 06:00 (local)

Vessel: FV *Amaltal Explorer*

Figure 1 shows the area of operations.

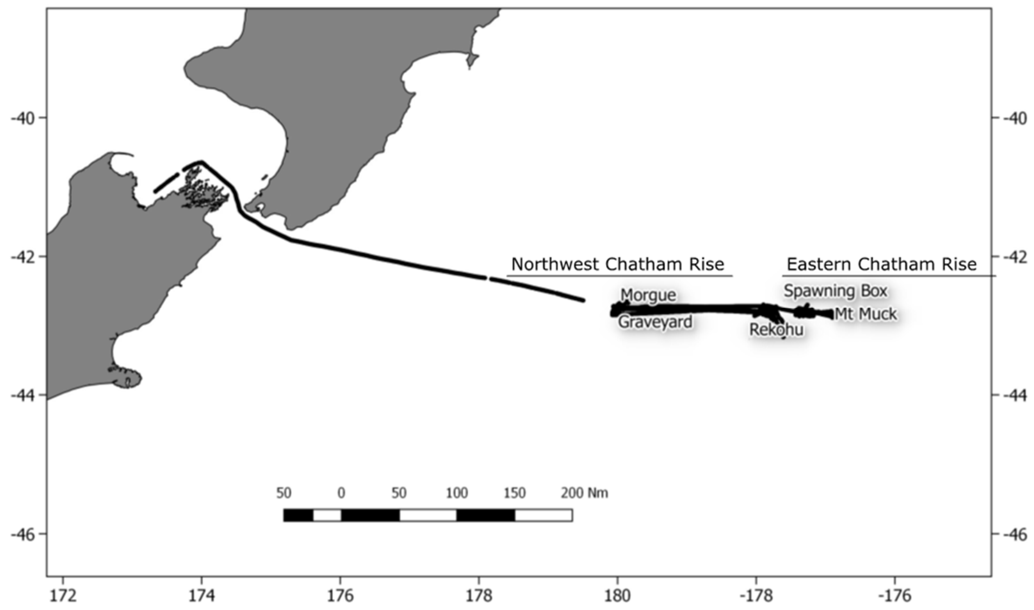

Figure 1. Voyage track for *Amaltal Explorer* orange roughy surveys.

3 Methods

3.1 Equipment

3.1.1 Acoustic instrument – AOS

The Sealord Acoustic Optical System (AOS) was the primary survey tool for estimating biomass using echo integration methods. It consisted of a sled-style platform that attaches to the headline of the vessel's demersal trawl net (Figure 2). This system was built as a collaborative project with Sealord and CSIRO ("Development and application of acoustic-optical technology for sustainable deep-sea fishing"), starting in 2012 based on previous successful developments and applications in Australia and New Zealand (Kloser et al., 2011a; Kloser and Ryan, 2011). It is similar in principle to the CSIRO AOS (Ryan et al., 2009) but with technological advances and modifications to improve ease of operation. For this survey the AOS housed a two -frequency acoustic system (38 and 120 kHz) based on Simrad ES60 transceivers. The system was battery powered with all data logged to internal storage media. Specifications of the Sealord AOS system are given in Table 1.

Table 1. Sealord AOS specifications

Component	Specifications
Physical	Dimensions: 1900 × 1400 × 500 mm, sled-style platform; weight: 750 kg in air,; operational depth: 1500 m.
Acoustics	Echosounders: Simrad ES60, 38 and 120 kHz split-beam transceivers, Simrad ES60 12 and 200 kHz; Transducers: 38 kHz - Simrad ES38DD (7° beam width), SN 28363 ; and 120 kHz - ES120–7CD (7° beam width), SN 115. Neptune Sonar 12 kHz (14 °beam width) with single element 8° beam width 200 kHz. Simrad ES60 38 and 120 kHz GPT's have new power supplies in 2016.
Video camera	Camera: Hitachi HV-D30P (3° × 1/3" CCD, colour); lenses: Fujion 2.8 mm lens (59° in water); Resolution: 752 × 582 pixels; Format: PAL.
Video capture	AXIS Q7401 Video encoder.
Video Lighting	Two 60 W LED arrays
Digital Stills	Paired Prosillica GX3300 Gigabyte Ethernet cameras with Zeiss F2.8, 25mm focal length Distagon F mount Lens. Quantum Trio strobe.
Reference scale	Two Laserex LDM-4 635 nm 8 mW red lasers set 400 mm apart.
Environmental	Seabird SBE37si CTD
Computing	Industrial Arc PC (running Simrad ES60 1.5.2 software, and providing time-reference for acoustic and video data). Intel NUC i7 computer for Gig-E digital still acquisition.
Motion reference	Microstrain 3DM-GX1
Power	Li-ion. Battery endurance: 18 hours

AOS calibration

AOS calibration was carried out as the final operation of the survey where calm weather made the operation viable. The AOS was lowered to 1000 m from the fibre-optic cable with a 38.1 mm tungsten carbide reference sphere suspended by thin Kevlar line 20 m beneath the transducer. The system was connected to the fibre-optic cable enabling real-time observation of the acoustic measurements throughout the deployment. Post-voyage review of the AOS calibration indicated a large jump in calibration offsets (~4dB) in the ES60 38 kHz echosounder compared to the previous year. As a follow up the Sealord AOS system was shipped to Australia for further testing. The 38 and 120 kHz ES60s were installed into CSIRO's Deepwater Calibration Facility (DeCaF) which was deployed to 1000 m depth during a voyage on the research vessel RV *Investigator*. The DeCaF accommodated the transducers on a gimballed base plate. The angles of the base plate can be controlled from the surface via optic-fibre connection. Hence it was possible to adjust the angle of the base plate to ensure that the calibration sphere was centred within the acoustic beam to provide a high quality calibration data set. Details of AOS calibration are given in Appendix A – Vessel and AOS calibration and are summarised in Table 2

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

Parameters			
System	AOS	AOS	Vessel
Frequency (kHz)	38	120	38
Calibration data set	September 2015*	July 2016	June 2016
Transducer model	Simrad ES38DD	Simrad ES120-7CD	Simrad ES38B
Serial Number	28363	115	30212 or 30301
Transceiver power (W)	2000	500	2000
Transceiver pulse length (ms)	**2.048**	**1.024**	**2.048**
Transducer gain (dB)	**23.73**	**27.73**	**25.7**
Sa correction (dB)	**-0.37**	**-0.34**	**-0.44**

3.1.2 AOS Operational modes

The net was deployed and retrieved using the procedures of a routine commercial trawl shot with only minor modifications to accommodate the presence of the AOS. There were two survey modes and a calibration mode (Table 3).

Table 3. Summary of AOS deployment modes

Mode	Objective	Height above seafloor	Comments
1	Echo-integration survey	250-350 m	Parallel or Star pattern transect lines
2	Target strength with concurrent optical images, biological samples from commercial and research catch	5-30 m	Conventional demersal trawl with net-attached instrumentation
3	Calibration: Transducer sensitivity as a function of depth	0-800 m in 100 m steps	Vertical deployment with AOS detached from net.

Mode 1: Echo-integration surveys

Acoustic echo-integration biomass surveys were done with the AOS attached to the headline of the vessel's demersal trawl net (Kloser et al., 2011b; Ryan and Kloser, 2016). These are referred to as Mode 1 surveys. To minimize gear avoidance by orange roughy and deadzone uncertainty, the AOS-net system was towed in the midwater at a distance of 250–350 m above the seafloor. Grid transect surveys were applied for the flatter grounds (Rekohu, Spawn Plume) and star pattern surveys for the smaller conical underwater features (Morgue, Mt Muck). Star survey patterns are a favourable design for these types of features (Doonan et al., 2003a), particularly for deep-towed systems where turning manoeuvres between transects can take a significant time.

Mode 2: Demersal trawls for target strength, species identification, biological samples

Demersal trawls with the AOS attached were undertaken to provide biological samples. 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 TS measurements. Standard definition video was taken to complement the TS measures. Stereo digital still images from a pair of Prosillica GX3300 Gig-E cameras with frame rate of 1 – 2 shots per second, were collected throughout the demersal trawl to enable accurate fish length determination.

3.1.3 Real-time fibre-optic connection

During selected operations a fibre-optic “third wire” was attached to the AOS providing real-time Ethernet connectivity. This enabled all acquisition (acoustics, video and GigE cameras) to be controlled and viewed from a computer installed on the bridge.

3.1.4 Optical instruments – AOS

The Sealord AOS has a wide-angle standard definition, low-light Hitachi video camera with a wide-angle Fujion lens. Two LED lights provided illumination. CSIRO provided a stereo digital still sub-frame system for this voyage. This comprised of a pair of Prosillica GX3300 Gigabyte Ethernet cameras with Zeiss 25 mm focal length F2.8 lenses. Stereo images were illuminated by a Quantum Trio strobe. The stereo cameras operated continuously at 1 -2 frames per second. AOS components are summarised in Table 1.

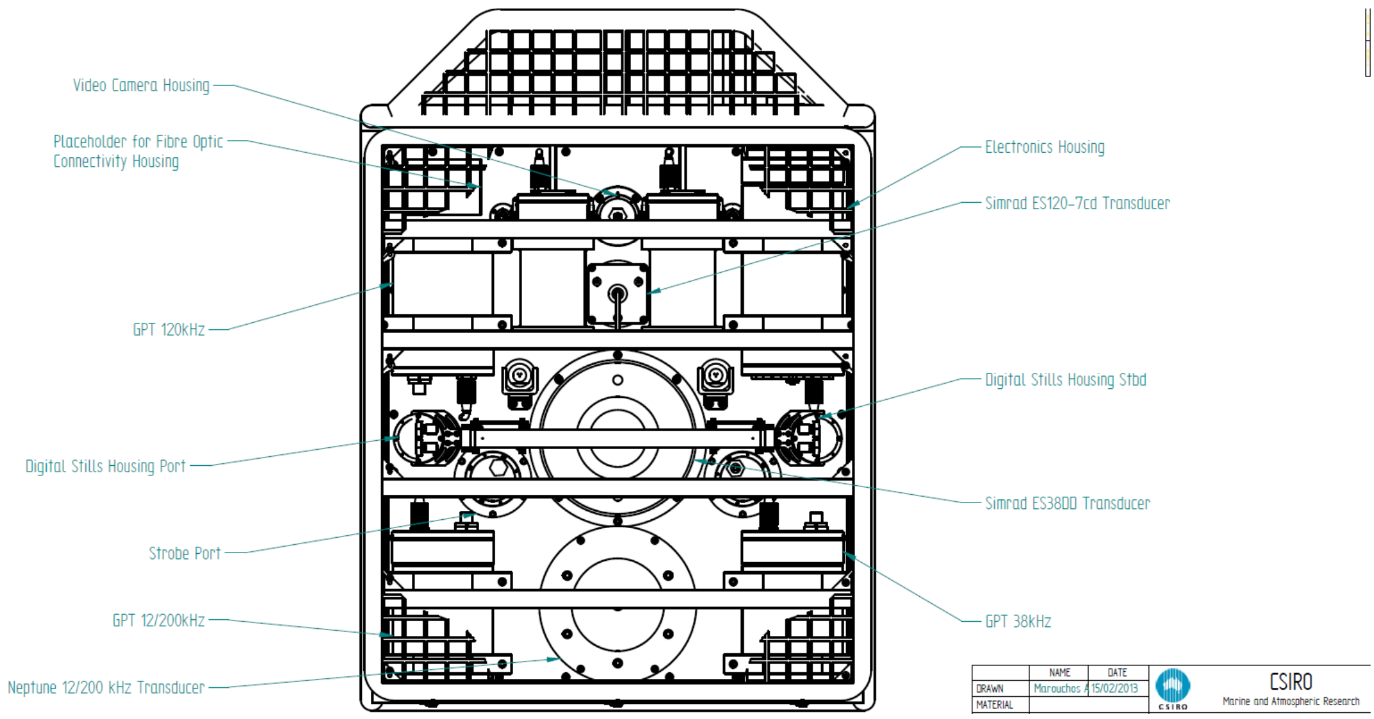

Figure 2. Sealord NZ Acoustic Optical System

3.1.5 Acoustic instruments – vessel mounted sounder

The *Amaltal Explorer*'s 38 kHz Simrad ES60 vessel-mounted echosounder provided continuous echogram data to guide AOS and trawl decisions. In calm conditions, Simrad ES60 vessel-acoustic data quality was good, enabling formal echo integration grid surveys to be carried out for the purpose of biomass estimation. This system was successfully calibrated on the first day of the survey. An uncalibrated Furuno FCV 30 triple beam echosounder provided additional observational data. At orange roughy depths (~800 m) this sounder covered a ~250 m "swath" by steering single beams at a 7 degree angle on the port and starboard sides in addition to its downward looking beam. The Furuno sounder was turned off during formal surveys as the additional signal would compromise calibration of the vessel-mounted Simrad ES60 echosounder.

Vessel calibration

The Vessel's Simrad ES60 38 kHz echosounder was calibrated in 30 m of sheltered water in Tasman Bay using the standard reference sphere method (Demer et al., 2015a) as the first operation of the survey. A 60 mm copper sphere was used as the reference. Details of the vessel calibration are given in Appendix A – Vessel and AOS calibration and are summarised in Table 2.

3.1.6 Acoustics: Seawater absorption

AOS acoustics

Values for seawater absorption at 38 and 120 kHz and sound speed were calculated from the equations of (Francois and Garrison, 1982a) 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 (Table 4). 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 the platform deviating above and below the nominal depth and changes of the range to the fish schools.

Table 4. Nominal seawater absorption and sound speed values for a nominal platform depth of 600 m and fish school depths of 900 m.

Parameter		
Frequency (kHz)	38	120
Absorption (dB/m)	0.00928**	0.03131**
Sound speed (m/s)	1500*	1500*

* Nominal Simrad values; ** calculated from CTD data

Vessel acoustics

Following the Deep Water Working Group's protocols, absorption estimates for application to the hull-mounted 38 kHz echosounder were made using the equations of Doonan et al. (2003a).

3.2 Data processing and interpretation

Processing of the acoustic data was done using Myriax Echoview 7.0 or higher acoustic analysis software (Myriax, 2014). 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).

3.2.1 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 S_v echograms for these two frequencies were visually inspected and regions of noise interference were marked as bad and removed from the analysis.

3.2.2 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, 1996) and, on sloping ground, due to seafloor backscatter from off-axis side-lobe signal coinciding with water column backscatter (Kloser, 1996; Ona and Mitson, 1996). For the steep-sided features 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.6.1 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 echo-integration 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 (i) above 'acoustic seafloor' and for (ii) above 'acoustic seafloor' plus a deadzone component were made.

3.2.3 Platform geolocation

Geolocation was established by applying a time offset between the vessel and the AOS data. The time offset was estimated by inspecting the AOS and vessel echograms, identifying either small terrain features or fish schools and noting the time difference between vessel and AOS as it passes through that same location. Errors in geolocation will occur if either the actual speed/time difference of the AOS differs from the estimated value or if there is an along track offset between the vessel and the AOS.

3.2.4 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 bladder 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 Gig-E 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.

3.3 Biological sampling

The catch composition was determined for all trawl catches taken during the voyage. For orange roughy, random samples comprising 10 fish bins were measured for length frequency (standard length to the nearest 1 cm below), weight (to the nearest 10 g), sex and gonad development stage (8-stage maturity scale). Where catch size exceeded ~15 t a second sample was taken and for catches over 30 t up to four samples were taken. Between 20 and 100 otolith pairs were collected from each bag with the objective of obtaining at least 300 otolith pairs from each area surveyed. Standard length measurements associated with otolith samples were to the nearest 1 mm below.

Species other than orange roughy were held in fish bins until the entire catch had been processed and the fish pounds were empty. They were then identified to species level, separated into bins and weighed. Most of the by catch was sampled for length with sex noted to allow length-frequency distributions separated by sex to be made.

Biological data are summarised in the results section, with further detail given in Appendix B - Catch Composition.

3.4 Biomass estimation

Biomass estimations were made at both AOS 38 kHz and 120 kHz based on regions that were interpreted to contain only orange roughy following procedures described in section 3.2.4

Vessel-based acoustic estimates at 38 kHz were also made where data quality was acceptable. Following protocols of the New Zealand Deepwater Working Group (DWWG), vessel acoustic data was processed without motion correction, the absorption estimation equation of Doonan et al. (2003b) applied and an empirical correction factor of 1.33 applied to account for signal loss due to vessel motion and bubble attenuation effects.

Echogram regions of high signal were marked to delineate schooling aggregations from surrounding backscatter and were echo-integrated in 100 m intervals to calculate the nautical area scattering coefficient, s_A (m^2 $n.mile^{-2}$)

Biomass estimations of orange roughy for star pattern acoustic surveys

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., 2003a). Uneven sampling can result in significant bias depending on the distribution of fish in relation to the centre of the star transect. To minimize the potential for this type of bias, the polar coordinate stratified techniques (Doonan et al., 2003a) were used to estimate the biomass.

Biomass estimation of orange roughy for grid transect acoustic surveys

Biomass estimates were calculated for 120kHz, 38 kHz data acquired from the AOS and vessel acoustic data using standard echo-integration methods (Simmonds and MacLennan, 2005). Orange roughy classified echogram regions were echo-integrated in 100 m intervals to calculate the per-interval nautical area scattering coefficient, s_A (m^2 n.mile^{-2}, (Maclennan et al., 2002)). These were averaged to give a mean s_A for the survey region ($\overline{s_A}$). This parameter along with estimates of mean population target strength ($\overline{TS}$, dB re 1 m^2), mean population fish weight ($\overline{W}$, kg) and measurement of the survey area (A, n.miles^2) were used to estimate orange roughy biomass (Equation 8). Population sex ratio was assumed to be 1:1 when estimating $\overline{TS}$ and $\overline{W}$.

$$B = \frac{\overline{S_A} \times \frac{\overline{W}}{1000} \times A}{4 \times \pi \times 10^{\frac{\overline{TS}}{10}}} \quad \text{(tonnes)} \qquad \text{Equation 1}$$

When assuming 100% orange roughy within the echogram-defined school regions

The associated survey sampling CV was calculated using intrinsic geostatistical methods implemented in the R software package RGeos.

3.4.1 Target strength estimates

Orange roughy TS estimates are based on results of (Kloser et al., 2013) which were based on a mean fish length of 34.5 cm. Values of -52.0 and -48.17 dB were used for 38 and 120 kHz respectively, noting that the 120 kHz estimated was adjusted from the Kloser et al. (2013) value of -48.7 dB to match the AOS calibration of this voyage which used a theoretical sphere TS value of ~-39.5 dB. A secondary adjustment was made to the nominal TS to scale values to the fish standard length (Ls) observed at each spawning ground, assuming a TS – length slope of 16.15*log10(Ls) (McClatchie et al., 1999).

4 Results and discussion

Results for each are presented on a region by region basis. A full list of survey activities is given in Table 21.

4.1 East and South Chatham Rise - Rekohu

4.1.1 Summary of survey program

The Rekohu orange roughy spawning ground is located on the north-eastern Chatham Rise and comprises an area of approximately seven nm^2 centred at 177:52 W, 42:48 S. It has a gently sloping sandy seafloor with no significant bathymetric features. Immediately to the north lies the Rekohu canyon system. Surveys were conducted during 3 visits: 20th – 22nd June, 26th – 28th June and 1st - 6th July.

During the first visit, patchy mobile orange roughy aggregations were seen on the vessel sounder with movement from deeper water up the slope to shallower water over a 24-hour cycle. These aggregations were more than adequate to sustain the vessel's commercial activities at full capacity without the need for extensive searching. Weather conditions affected the vessel acoustics preventing quantitative surveying at this time. A 6-transect AOS survey was conducted providing high quality 38 and 120 kHz acoustics but no significant aggregations were encountered. Biological sampling revealed orange roughy gonads to be maturing, with around 80% of females at stage 3.

During the second visit the usual combination of activities were carried out (AOS survey, vessel survey and AOS biological/fishing). Orange roughy were still quite mobile, with the two AOS surveys encountering occasional orange roughy aggregations, but no large, stable aggregations were observed. The proportion of ripe and spawning female gonads increased from 27% to ~35% and 1% to ~20% respectively over this three-day period.

Poor weather at the start of the third survey period prevented any acoustic surveying activity. Fishing shots were made with the AOS removed from the net as a precaution against damage. Calm weather then ensued allowing extensive vessel-acoustic surveys to map out the distribution and movement of the aggregations. The aggregations were generally more substantial and better defined than during the previous two visits, while the shallow-to-deep fish movements continued and were well documented by both vessel and AOS acoustics. The AOS surveys were adaptively designed to minimise the influence of fish movement by running transects perpendicular to the slope across which the fish were moving. Four interlaced AOS surveys were conducted with impressive aggregations observed on many transects. Spawning peaked during this third visit, with female gonads progressing from ~21% spawning and ~5% spent on 1st July to ~63% spawning and ~21% spent on 6th July. This spawning progression, along with the more stable and substantial aggregations present (Figure 3), suggested the survey timing had been optimal.

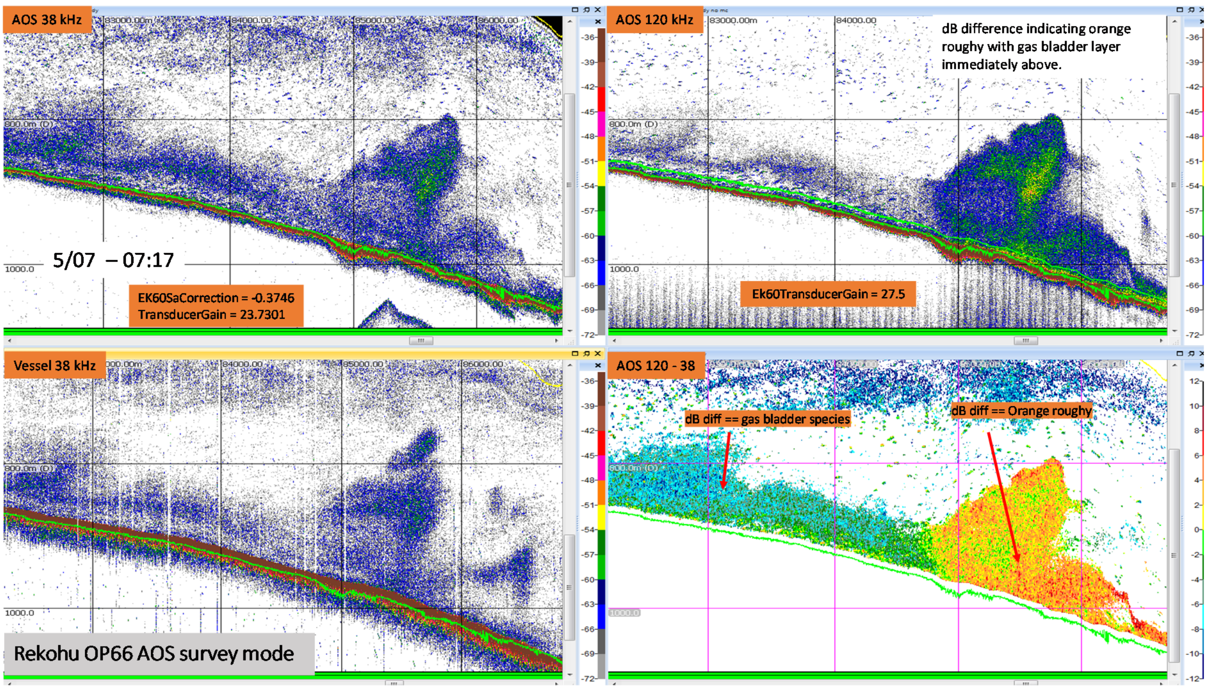

Figure 3. A large aggregation of orange roughy at Rekohu with adjacent region of backscatter dominated by gas bladder species. Colour scale on bottom RHS image indicates Sv_{120-38} where yellow-orange regions show a higher signal on 120 kHz allowing the region to be classified as orange roughy.

In summary, the surveys at Rekohu collected a series of high quality acoustic survey data complemented by a comprehensive biological sampling program. Table 5 details the survey activities carried out at Rekohu.

Table 5. Vessel and AOS surveys at Rekohu.

OP Number	Operation Type	Start date (UTC)	Start Time (UTC)	Comment
15	Vessel Survey	20/06/2016	23:30:00	Continuous grid surveying of Rekohu. No particularly large aggregations observed. Furuno turned on around 16:00 to aid searching power.
17	Vessel Survey	21/06/2016	15:00:00	Deteriorating weather, some marks observed but nothing spectacular
19	Vessel Survey	22/06/2016	3:54:00	Grid survey following fishing shot. Eventually gave it away as weather was poor
21	AOS Survey	22/06/2016	22:05:00	Six transect survey. AOS data reviewed. No orange roughy of any significance seen.
34	Vessel Survey	26/06/2016	8:01:00	Vessel acoustic survey at Rekohu, scouting region a bit shallower and more to the west of the area that was being worked on our first visit to Rekohu (mapping region surveyed in the 2013 survey). 10:15 very nice mark observed. Marks continued on successive transects giving good bounding of fish. Weather affecting every second transect will need some detailed cleaning if a biomass is to be obtained.
37	Vessel Survey	26/06/2016	18:45:00	Mapping of extensive weak-moderate orange roughy marks amongst a mix of background scatter within about 4 n.mile by 4.mile zone.
38	AOS Survey	27/06/2016	0:50:00	AOS survey starting out following transects of the previous vessel survey but soon became apparent that fish had dispersed or moved. Only one body of orange roughy observed on the vessel sounder on the second last transect over to the east.
41	AOS Survey	27/06/2016	17:33:00	6 transect AOS survey. Occasional low signal orange roughy but less impressive than first expected.
57	AOS Survey	2/07/2016	8:52:00	High quality survey, extensive marks present.
59	AOS Survey	2/07/2016	22:20:00	Good quality AOS survey with extensive marks. Toward the end of the initial interlace, fish continued to be seen.
61	Vessel Survey	3/07/2016	16:35:00	
62	Vessel Survey	3/07/2016	21:14:00	Second vessel survey of Rekohu.
64	Vessel Survey	4/07/2016	5:11:00	Vessel survey Rekohu while 40 tonne catch is being processed.
65	Vessel Survey	4/07/2016	12:06:00	
66	AOS Survey	4/07/2016	19:08:00	Long 16 hour AOS survey some good marks but also appeared a lot happening in terms of fish movement.
68	AOS Survey	5/07/2016	14:35:00	Retrieved after first transect to check system was logging. All ok.

4.1.2 Biological results

Four commercial and 12 biological tows at Rekohu yielded a total of 408.7 t of fish of which 99% was orange roughy. The bycatch by weight comprised mainly ribaldo, javelinfish, deepwater dogsharks and spiky oreo (Figure 4).

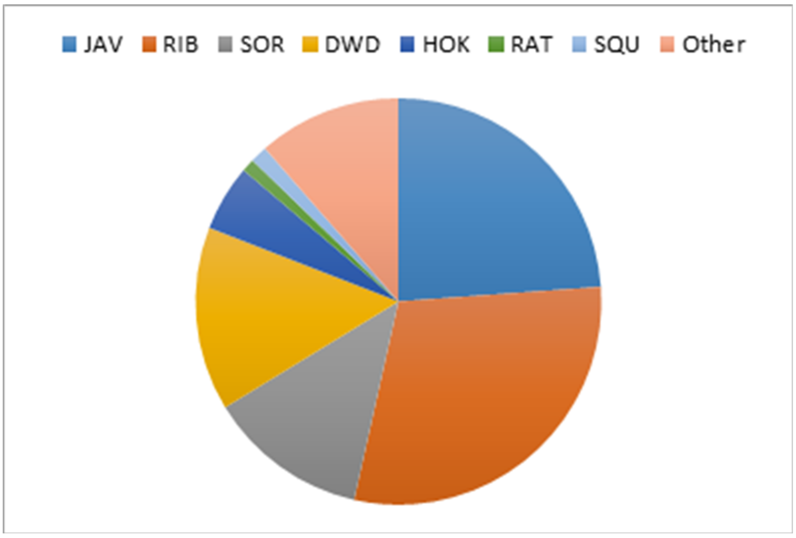

Figure 4. Bycatch composition (1.0% of total catch) – Rekohu.

A list of all species caught at Rekohu is provided in Appendix B - Catch Composition (Table 17).

ORH size frequency

The average lengths and weights were 33.13 cm and 1.28 kg for males and 34.9 cm and 1.63 kg for females. Average lengths and weights for sexes combined were 33.8 cm and 1.42 kg. The ORH size frequency (unstandardized) is provided in Figure 5.

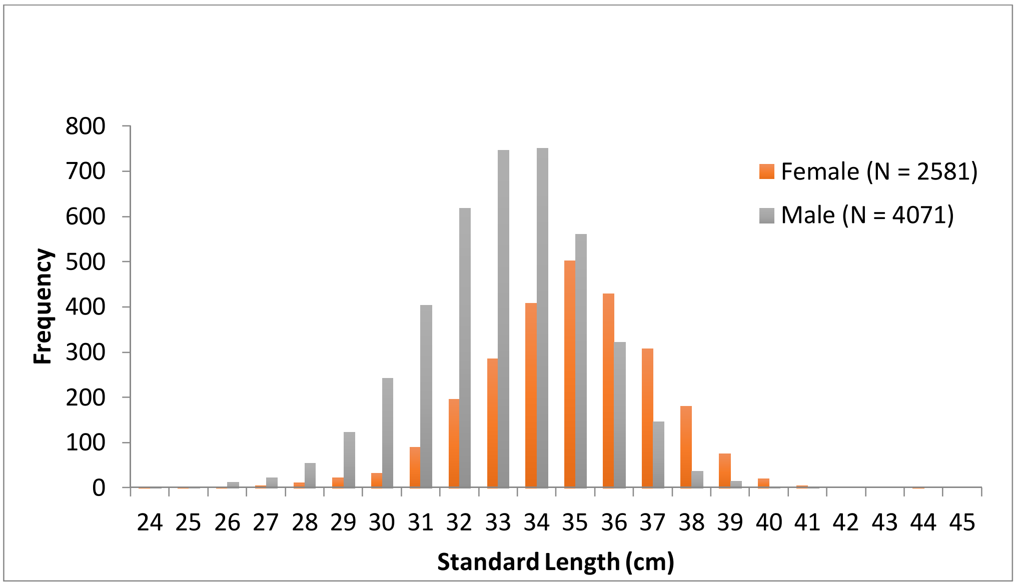

Figure 5. Orange roughy size frequency distribution (unstandardized) - Rekohu.

Spawning progression

The survey at Rekohu was well timed with respect to spawning progression. At survey commencement 90% of female gonads were mature or ripe and spawning was at a low level. Spawning progressed rapidly and continued through to the end of the survey period by which time 22% of female gonads were in spent condition (Figure 6).

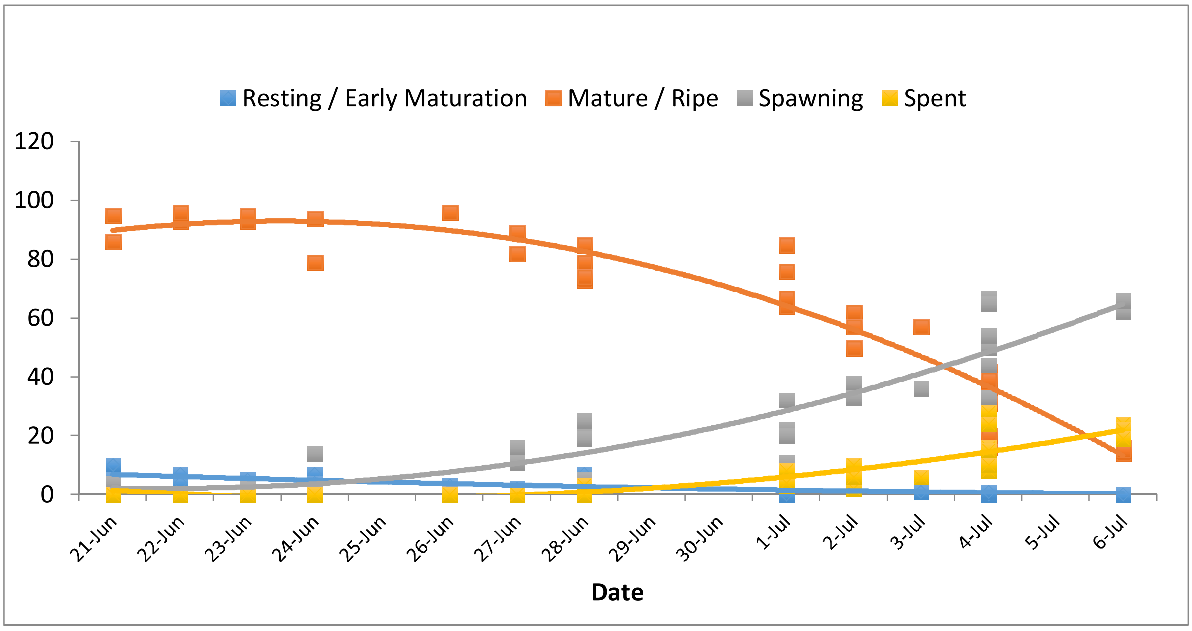

Figure 6. Orange roughy female spawning progression – Rekohu.

The sex ratio in catches was variable throughout the survey with an overall average of 44% females and 56% males. There was no obvious link between sex ratio and diurnal cycle (Figure 7).

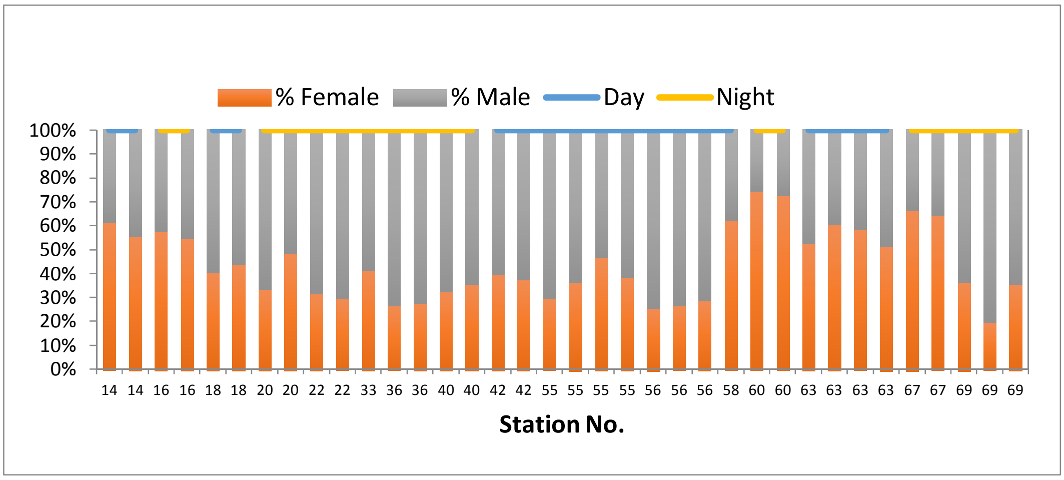

Figure 7. Orange roughy sex ratio in catches at Rekohu in relation to the diurnal cycle.

4.1.3 Acoustic biomass estimates

Snapshot acoustic biomass estimates at Rekohu that are recommended for consideration in the stock assessment process are presented in Table 6 in bold text. These surveys were considered to have suitably low bias and error due to species uncertainty, data quality and other sources of error. In particular vessel surveys were selected for analysis only when sea conditions were calm with corresponding high data quality and when orange roughy schools could be clearly delineated from surrounding backscatter.

To investigate potential bias in vessel-based estimates due to species delineation issues at Rekohu, biomass estimates were made from vessel-data collected during three AOS surveys. These are included in Table 6 in blue non-bold text for later discussion only (See Section 4.13.1) and are not recommended to be used for Rekohu stock assessment due to high potential biases.

Biomass estimates for recommended surveys only are summarised graphically in Figure 8. Including the deadzone biomass component total biomasses ranged from 8605 tonnes (CV 0.48, deadzone contribution 20.4%, 120 kHz AOS) to 45157 tonnes (CV 0.19 tonnes, deadzone contribution 18.7%, AOS 38 kHz).

Table 6. Biomass estimates based on AOS echo-integration surveys carried out at Rekohu in July 2016.

Date	Platform	OP	Frequency	Survey area (n.miles^2)	Mean NASC ($m^2/n.mi^2$)	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
2-Jul	AOS 120	57	120	19.9	34.3	**6852**	**0.48**	**1753 (20.4%)**	**8605**
	AOS 38		38	19.9	26.9	**7555**	**0.49**	**2082 (21.6%)**	**9637**
2-Jul	AOS 120	59	120	14.6	162.4	**18223**	**0.25**	**2091 (10.3%)**	**20314**
	AOS 38		38	14.6	82.4	**22664**	**0.25**	**4692 (17.2%)**	**27355**
							4.3		
	Vessel		38	5.4	107.7	4.2 14533		4.4 2663 (15.5%)	4.5 17197
4-Jul	AOS 120	66	120	18.2	157.8	**29499**	**0.16**	**5057 (14.6%)**	**34556**
	AOS 38		38	18.2	128.3	**36712**	**0.17**	**8445 (18.7%)**	**45157**
							4.7		
	Vessel		38	13.8	204.6	4.6 70445		4.8 6948 (9%)	4.9 77394
5-Jul	AOS 120	68	120	10.8	162.8	**21556**	**0.23**	**2586 (10.7%)**	**24142**
	AOS 38		38	10.8	141.4	**26827**	**0.24**	**4047 (13.1%)**	**30874**
							4.11		
	Vessel		38	14.0	86.3	4.10 30269		4.12 4644	4.13 34912
3-Jul	Vessel	61	38	12.5	80.1	**18080**	**0.43**	**2540 (12.3%)**	**20620**
3-Jul	Vessel	62	38	5.3	112.9	**15045**	**0.25**	**2440 (14%)**	**17485**
4-Jul	Vessel	64	38	10.3	93.1	**23981**	**0.24**	**4217 (15%)**	**28198**
4-Jul	Vessel	65*	38	10.2	71.8	**18296**	**0.28**	**1209 (6.2%)**	**19505**

* Not interlaced – continuous east-west transects

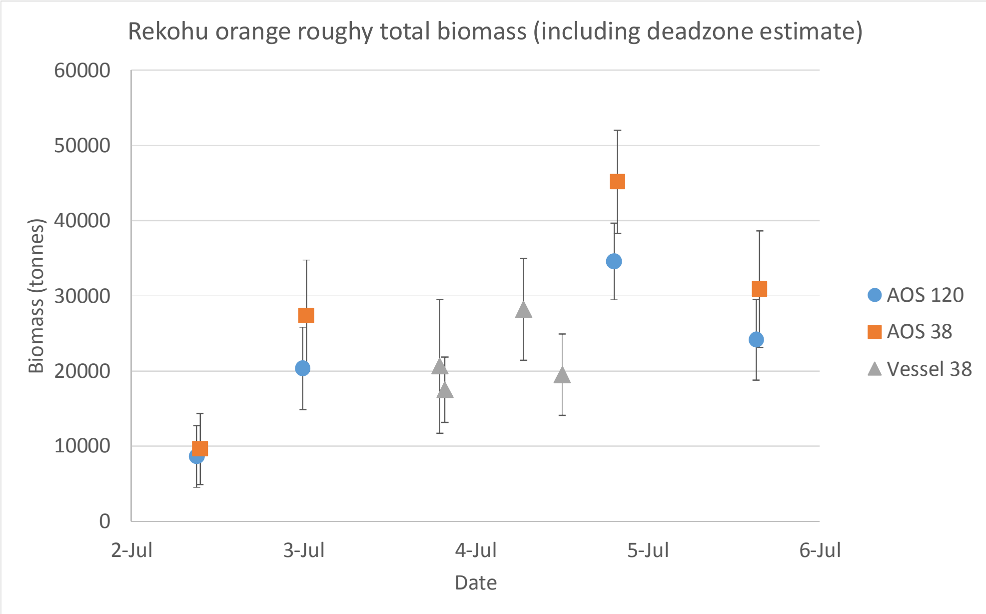

Figure 8. Biomass estimates for AOS 38 and 120 kHz and vessel 38 kHz at Rekohu. Error bars are +/- 1 sd. Dates for AOS 38 are slightly offset from AOS 120 so that error bars for both frequencies will be available.

4.13.1 Discussion

As was observed during the 2013 AOS surveys of Rekohu (Ryan and Kloser, 2014) orange roughy aggregations were initially highly mobile and somewhat ephemeral. The first and second of the three visits 20-22nd June and 26th – 28th June respectively) were essentially for commercial fishing purposes with low expectation of finding large spawning aggregations. These periods confirmed our expectations of low abundance but nevertheless provided useful observations of the situation at Rekohu prior to the main spawning event, highlighting the importance of survey timing when interpreting biomass estimates.

The third visit from the 1st to 6th of July encompassed the same dates as for the 2013 AOS surveys (2nd -5th July). During this period large aggregations of orange roughy were observed with species identification confirmed by AOS multi-frequency acoustics, school characteristics, optics and trawl catch. The mobility of the schools still proved to be challenging. However an observable trend of movement between shallow and deep, between night and day respectively, meant that survey designs with transects perpendicular to this movement were able to effectively bound the aggregations. For example Figure 32 shows an interlaced survey at Rekohu where the first set of transects encountered orange roughy in shallow water during the night while the return set of transects were conducted during the day observing aggregations in the deep.

The large range in biomass estimates (8605-45157 tonnes) is likely to be associated with fish availability to the acoustics with the additional survey sampling variability inevitably a factor. The biomass estimates map an upward trend where the lowest estimate occurred at the start of the series following no significant aggregations being observed on the prior visit to the region (26th- 28th June). Biological sampling indicated that the first evidence of spawning at Rekohu occurred on 23 June, but that spawning peaked on about 4 July when around 20% of female gonads were in spent condition. This observation ties in well with the observed peak in biomass.

The vessel-based acoustic surveys from which biomass estimates were made were chosen with some caution due to issues of species identification. Of particular issue is the very high signal individual gas bladder species that have been observed (Ryan and Kloser, 2014) and the level of background acoustic backscatter at Rekohu can be very high at times to the point where boundaries between orange roughy aggregations and the surrounding waters cannot be sensibly delineated. To explore the question of species delineation at Rekohu for vessel acoustics, vessel-based acoustic data sets collected concurrently with three AOS surveys were analysed (Ops 59, 66 and 68, Table 6). For the first survey, OP59, the 38 kHz vessel-based biomass was 30% lower than that of the AOS 38 kHz where attenuation due to poor weather is the likely reason for this lower value. The vessel-based biomass estimate for the last survey (OP68) was in reasonable agreement being 15% higher than the AOS 38 kHz estimate. The second survey stands out where the vessel based biomass estimate was a factor of two higher than the AOS 38 kHz estimate. Inspection of the vessel 38 kHz echogram shows extensive and high levels of background backscatter in and around orange roughy aggregations, which is the likely cause of this high positive bias. A key point with this analysis was that the AOS multi-frequency data were collected near concurrently (~ 10 minutes behind the vessel) and were used as far as possible to guide interpretation of the vessel echograms. Vessel-only surveys in 2016 (Ops 61, 62, 64 and 65) which did not have this extra information were interpreted based on the vessel-echogram itself and information obtained at other times (i.e. prior or post AOS surveys, trawl catch). Prior vessel-only acoustic surveys (2014 and 2015) would have no associated multi-frequency information and would have relied solely on vessel-echogram characteristics and trawl catch to interpret the data. This analysis has demonstrated the potential for large positive bias in Rekohu vessel-based estimates in some instances. Vessel-based results can only be robust in instances where orange roughy can be clearly delineated from background scatter, but may still be biased by inclusion of gas bladder species that are not apparent in the single-frequency echograms. For this reason continued use of multi-frequency acoustic systems at Rekohu is recommended and an appropriate degree of caution applied when using vessel-based acoustic surveys.

4.14East and South Chatham Rise – Spawn Plume

4.14.1 Summary of survey program

The Chatham Rise Spawn Plume is in a region of gently sloping mostly sandy seafloor with just a few small bathymetric features. Survey activities were conducted between the 7^{th} and 12^{th} of July with three side excursions to the nearby Mt Muck during this period. Activities at Spawn Plume included 5 vessel surveys, 4 AOS surveys and 5 AOS biological tows.

Initial biological tows indicated that orange roughy were well into the spawn on the 8^{th} of July with ~42% of females spawning and ~18% spent. At the end of surveying on the 12^{th} of July ~61% were spawning and ~31% spent.

Historically, Spawn Plume fishing and survey activities have located orange roughy within an area centred around 177°15W, 42°50S. In 2016 no significant aggregations were found here. Aggregations were found about six nautical miles to the west. Initial impressions from the three AOS surveys were that the orange roughy aggregations were generally not as large or extensive as those observed at the nearby Rekohu grounds. Nevertheless substantial aggregations were observed on at least some transects on each of the three AOS surveys. These could be clearly delineated from the surrounding backscatter as orange roughy, based on the Sv_{120-38} classification criteria (Figure 9). Similar to Rekohu the main orange roughy aggregations were quite mobile with north-south movement across the slope between shallower and deeper depths. Accordingly north-south transect lines were used to minimise the effects of fish movement on the survey error. A slower westward progression of the main body of orange roughy was apparent over the course of the six-day survey period.

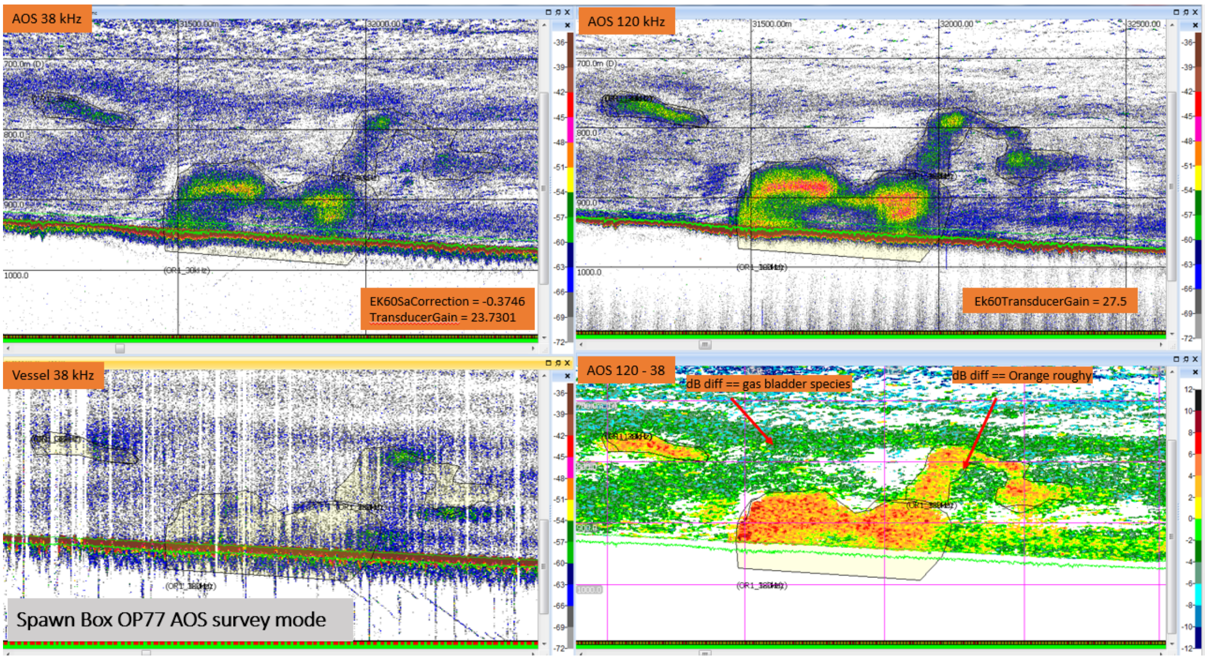

Figure 9. A large aggregation of Spawn Plume orange roughy with adjacent region of backscatter dominated by gas bladder species. Colour scale on bottom RHS image indicates Sv_{120-38} where yellow-orange regions show a higher signal on 120 kHz allowing the region to be classified as orange roughy.

Weather conditions were exceptionally favourable during the Spawn Plume surveys enabling strategic use of faster-to-execute vessel acoustic surveys to complement the AOS surveys. When large and strong aggregations were present the vessel-acoustics were effective in identifying orange roughy from the surrounding backscatter.

4.14.2 Biological results

Five biological tows yielded a total of 71.4 t of fish of which 99% was orange roughy. Bycatch by weight comprised mainly ribaldo, deepwater dogsharks and Johnson's cod (Figure 10).

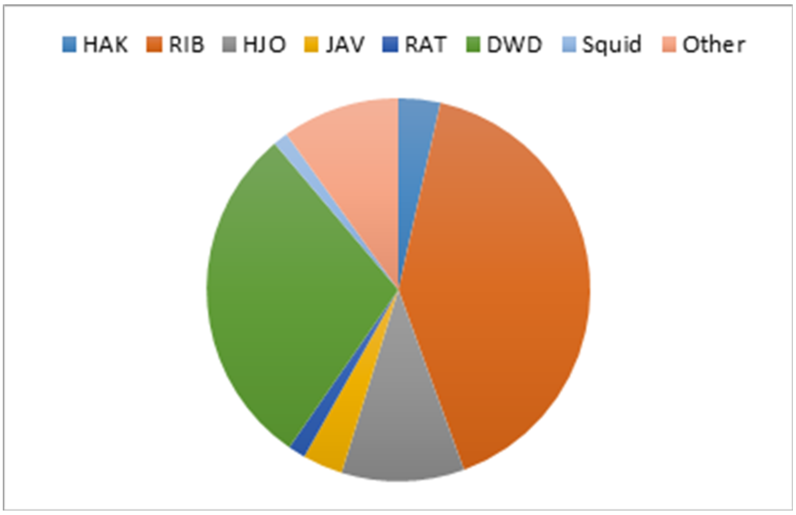

Figure 10. Bycatch composition (1.4% of total catch) - Spawn Plume.

The species composition by weight from Spawn Plume is provided in Appendix B (Table 18).

ORH size frequency

The average lengths and weights were 33.63 cm and 1.30 kg for males and 35.9 cm and 1.63 kg for females. Average lengths and weights for sexes combined were 35.1 cm and 1.51 kg. The ORH size frequency (unstandardized) is provided in Figure 11.

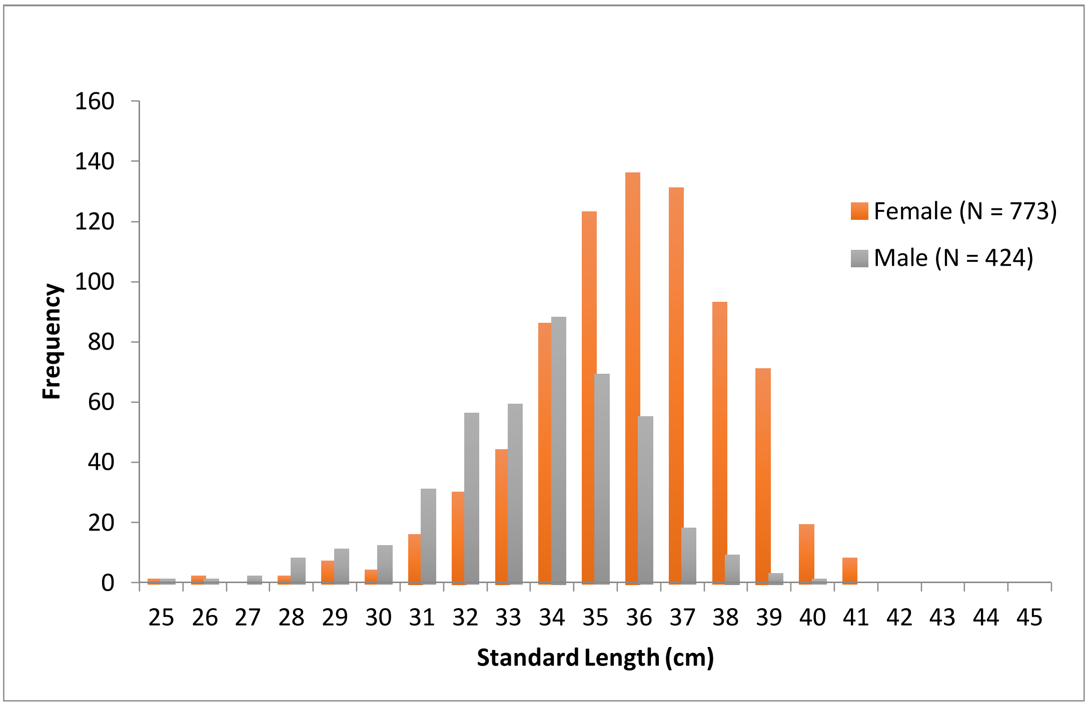

Figure 11. Orange roughy size frequency distribution (unstandardized) - Spawn Plume.

Spawning progression

Spawning was well underway at survey commencement on 8th July with 42% of female gonads in running condition and 18% in spent and/or partially spent condition. Spawning was still strong at the end of the 5-day survey period with 64% of female gonads in spawning condition and 31% spent and/or partially spent on 12 July (Figure 12).

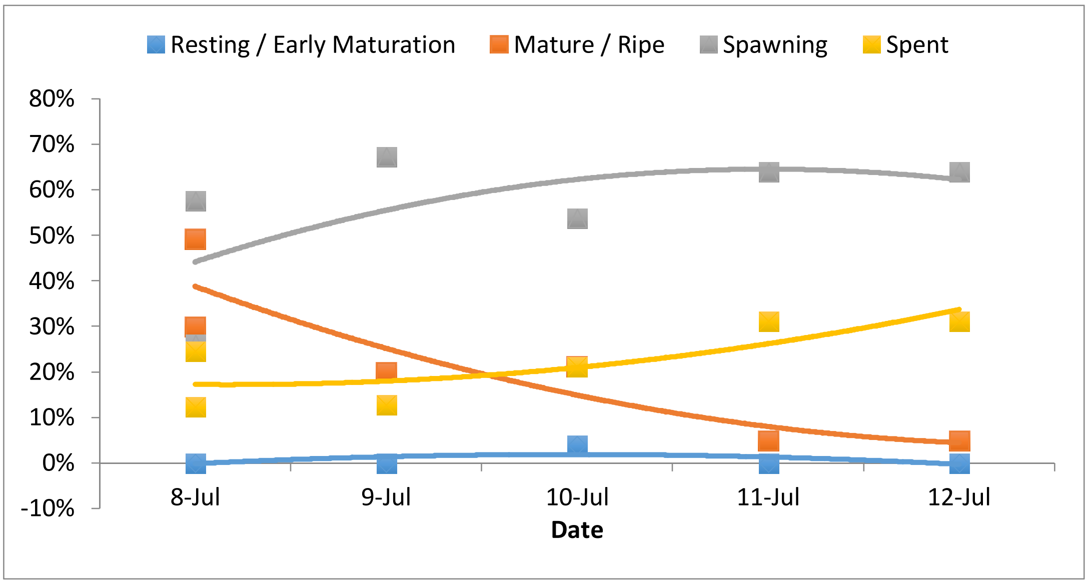

Figure 12. Female orange roughy spawning progression - Spawn Plume.

The sex ratio was strongly female-dominated over the first three days (i.e. 80% females : 20% males), while over the last two days it was male-dominated (i.e. 32% females : 68% males), indicative of dynamic behaviour associated with the spawning aggregations.

4.14.3 Acoustic biomass estimates

Biomass estimates from AOS 38 and 120 kHz vessel-based 38 kHz acoustic systems are presented in Table 7 and Figure 13. Estimates ranged from 3888 tonnes to 18327 tonnes where fish availability to the acoustics seems the most likely reason for this variation but noting also survey sampling variability is quite high (ranging from 0.32 to 0.52) due high transect-to-transect variability with large aggregations being observed on only a few of the transects.

Table 7. Biomass estimates based on AOS echo-integration surveys carried out at Spawn Plume in July 2016.

Date	Platform	OP	Frequency	Survey area (n.miles^2)	Mean NASC (m^2/n.mi^2)	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
8-Jul	AOS 120	75	120	13.4	18.0	5464	0.32	814 (13%)	6277
8-Jul	AOS 38	75	38	13.4	20.9	3888	0.32	631 (14%)	4519
8-Jul	AOS 120	77	120	15.0	74.4	16414	0.48	17 (0.1%)	16430
8-Jul	AOS 38		38		77.0	18327	0.52	643 (3.4%)	18971
10-Jul	AOS 120	85	120	9.9	66.8	8488	0.51	328 (3.7%)	8816
10-Jul	AOS 38		38		69.7	11390	0.52	493 (4.1%)	11882
7-Jul	Vessel 38	72	38	7.4	51.5	8872	0.36	997 (10.1%)	9870
8-Jul	Vessel 38	74	38	3.5	120.4	10179.0	0.39	537 (5%)	10716

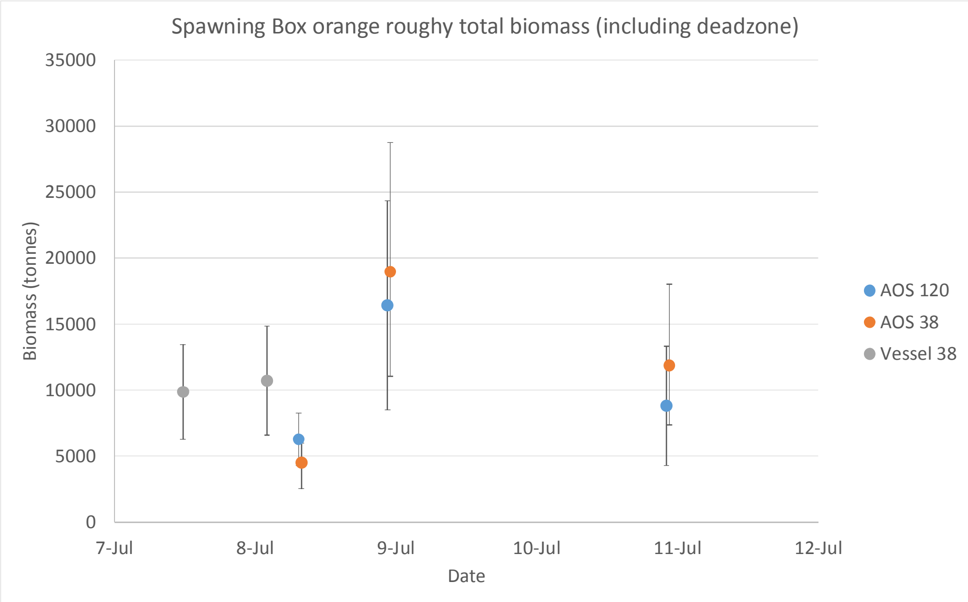

Figure 13. Biomass estimates for AOS 38 and 120 kHz and vessel 38 kHz at Spawn Plume. Error bars are +/- 1 sd. Dates for AOS 38 are slightly offset from AOS 120 so that error bars for both frequencies will be visible.

4.14.4 Discussion

The first trawl within the survey period indicated 42% of females spawning and 18% spent, suggesting that the spawn event was underway precluding the possibility of tracking the build-up either by biological sampling or acoustic observations. There is no obvious trend in the acoustic biomass estimates through the survey period with high error bars and survey-to-survey variability masking any potential trends.

Similar to Rekohu (see Section 4.13.1) the main orange roughy aggregations were quite mobile with north-south movement across the slope between the shallow and deeper depths over a 24-hour cycle. Accordingly transect lines perpendicular to the north-south fish movement were used to bound the aggregations. A slower westward progression of the main body of orange roughy was apparent over the course of the six-day survey period. Initially the main aggregation was approximately six nautical miles west of the historic Spawn Plume location, then over the course of the survey the main aggregations had progressed further west to be ~ 12 nautical miles west of the historic Spawn Plume, a rate of ~ 1 nautical mile westward movement per day. Interlaced survey design was used to minimise error due to this westward movement.

The biomass estimates presented are considered suitable for inclusion in the stock assessment process where AOS multi-frequency data combined with observations of school characteristics, optics and trawl catch data provide high certainty on species identification. Vessel-acoustic surveys were selected for analysis only when weather conditions were calm allowing for high quality acoustics and where orange roughy aggregations could be readily delineated from surrounding backscatter.

4.15 East and South Chatham Rise - Mt Muck

4.15.1 Summary of survey program

Mt Muck is a conical (Underwater Terrain Feature) UTF located at 176^{o}54.46' W, 42^{o}50.67' S, about 16 miles east of the Spawn Plume region centred on 177°21'W. A series of acoustic and biological sampling activities were completed at this hill between the 6th and 10th of July. These included three AOS star pattern surveys, two biological trawls with attached AOS and one vessel-acoustic survey. The vessel survey observed the strong mark at the top of the feature that is thought to be from cardinal fish; the most abundant swim bladder species in the two trawl shots at Mt Muck was cardinal fish, with catches of 200 and 339 kg respectively, suggesting this may be the most likely candidate for the regions of large gas bladder fish. Some sign of potential orange roughy was observed on the vessel acoustics down the sides but was difficult to resolve due to the vessel acoustics being degraded by weather and the large acoustic deadzone due to the steepness of the feature. The second transect of the first AOS survey at Mt Muck (9th July) encountered the largest body of orange roughy at this location. This aggregation was clearly delineated from an adjacent region of large gas bladder fish using AOS multi-frequency acoustics. The following night four-transect star pattern AOS surveys were conducted back-to-back to give sustained observations over most of the night-time hours. The aggregations were generally modest on the vessel-sounder but the close range AOS $Sv_{120\text{-}38}$ acoustics clearly indicated spatially separated regions of orange roughy and gas bladder species close to the seafloor (potentially within the deadzone region of the vessel acoustics) on both AOS surveys (Figure 14).

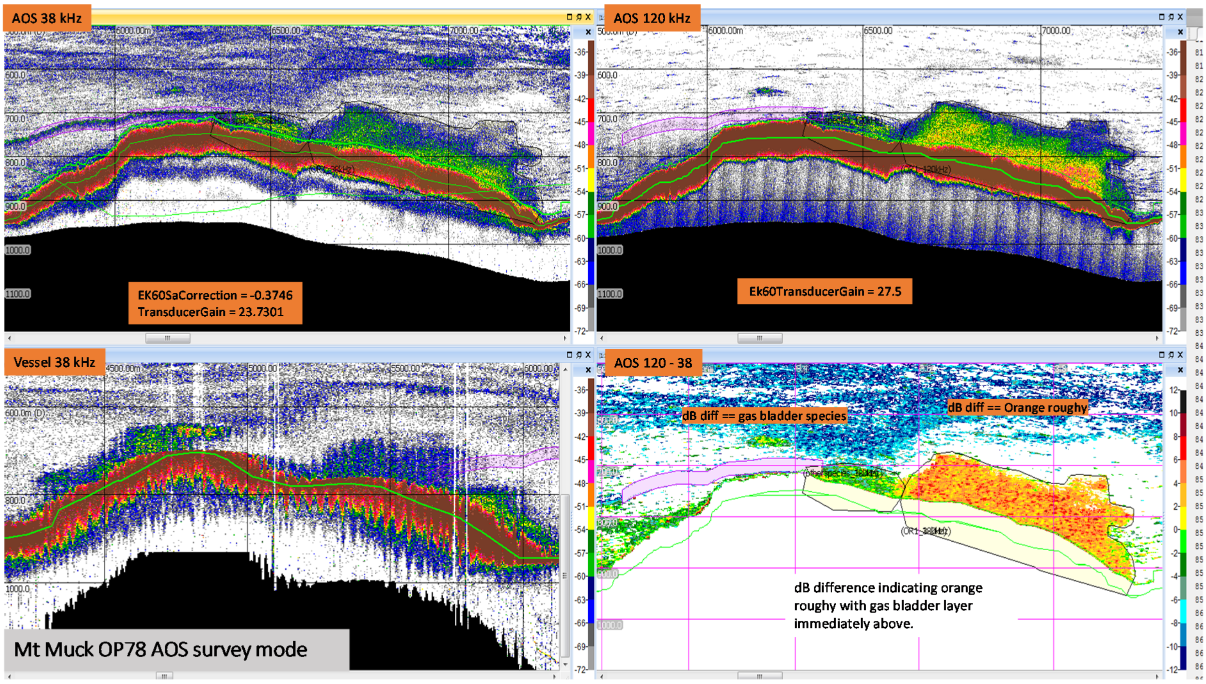

Figure 14. Large aggregation of orange roughy at Mt Muck with adjacent region of backscatter dominated by gas bladder species. Colour scale on bottom RHS image indicates $Sv_{120\text{-}38}$ where yellow-orange regions show a higher signal on 120 kHz allowing these to be classified as orange roughy.

4.15.2 Biological results

Two biological tows yielded a total of 25.7 t of fish of which 96.8% was orange roughy. Bycatch by weight comprised mainly cardinal, ribaldo and smooth oreo (Figure 15).

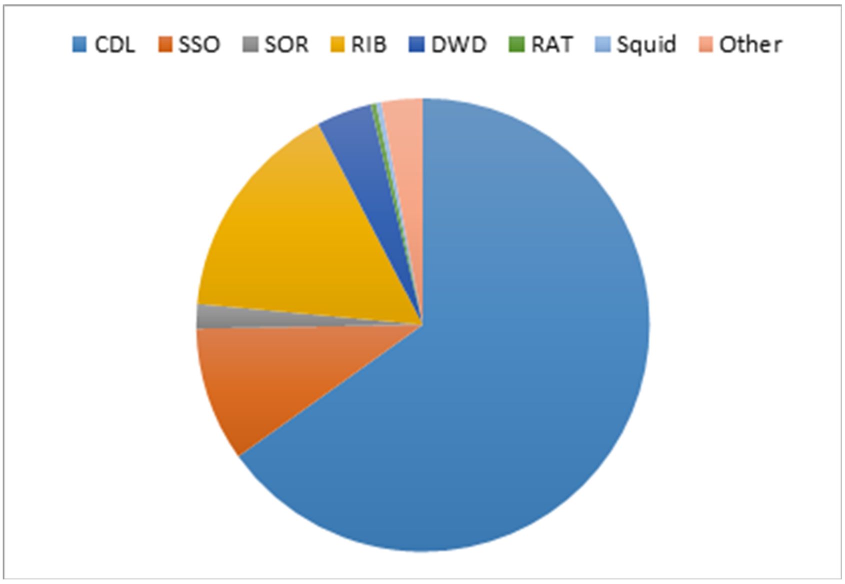

Figure 15. Bycatch composition (3.2% of total catch) - Mt Muck.

The species composition from Mt Muck is provided in Appendix B (Table 19).

ORH size frequency

The average lengths and weights were 33.9 cm and 1.31 kg for males and 36.7 cm and 1.75 kg for females. Average lengths and weights for sexes combined were 35.5 cm and 1.57 kg. The ORH size frequency (unstandardized) is provided in Figure 16.

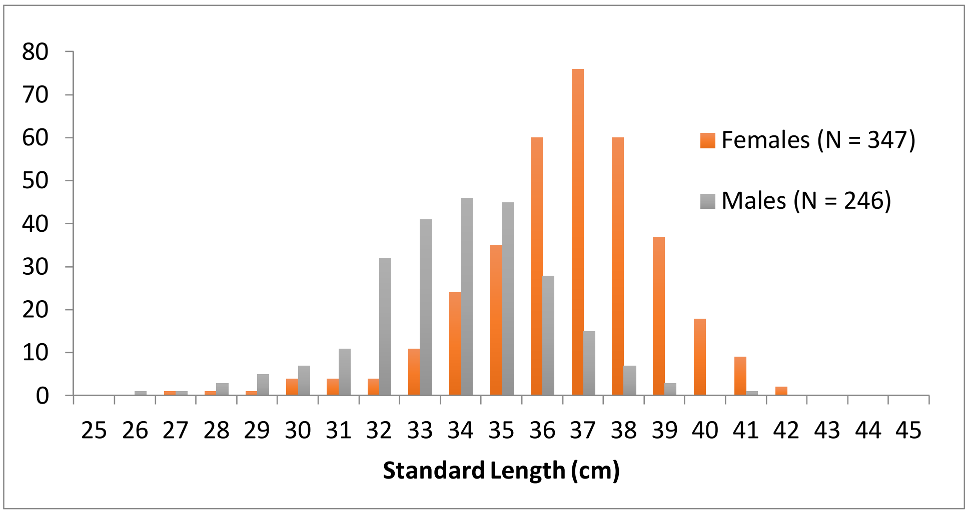

Figure 16. Orange roughy size frequency distribution (unstandardized) - Mt Muck.

Spawning progression

Spawning was well underway at survey commencement on 10th July with 76% of female gonads in running condition and 11% in spent and/or partially spent condition (noting that this sample comprised only 40 females). On 11th July 46% of female gonads were in running condition and 32% spent and/or partially spent (Figure 17).

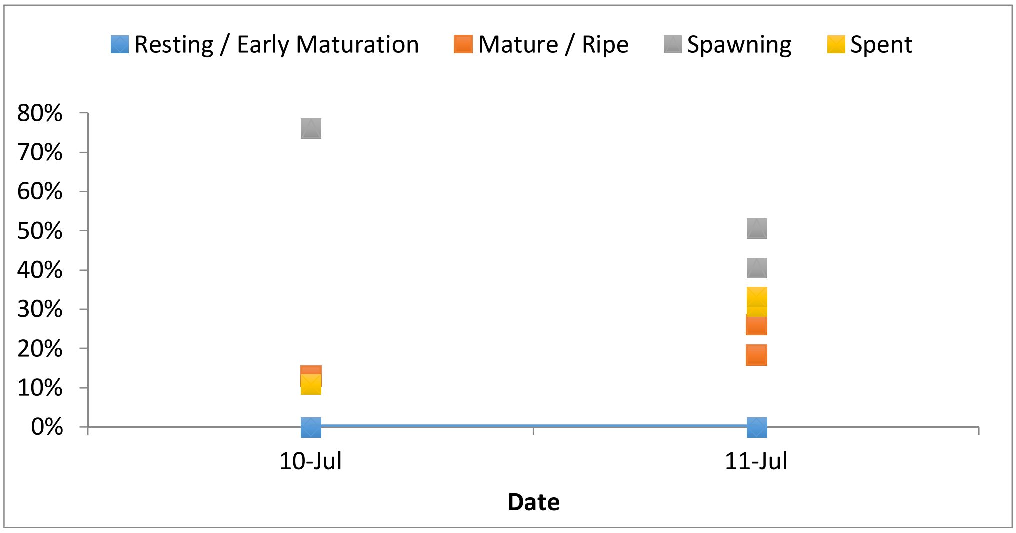

Figure 17. Orange roughy female spawning progression - Mt Muck.

The sex ratio in the first catch on 10th July was 28% females and 78% males, while in the second catch on 11th July it was reversed at 82% females and 18% males.

4.15.3 Acoustic biomass estimates

AOS-based acoustic biomass estimates at 38 and 120 kHz are given in Table 8 and Figure 18 with values ranging from 3236 to 7427 tonnes (including deadzone estimate).

Table 8. Biomass estimates based on AOS echo-integration surveys carried out at Mt Muck in July 2016.

Date	Platform	OP	Frequency	Survey area (n.miles²)	Mean NASC (m²/n.mi²)	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass
09/Jul	AOS 120 kHz	78	120	0.61	810	3745	0.52	2376 (38.8 %)	6121
09/Jul	AOS 38 kHz	78	38	0.61	369	4171	0.52	3256 (43.8 %)	7427
10/Jul	AOS 120 kHz	82	120	0.26	628	1226	0.24	2010 (62.1 %)	3236
10/Jul	AOS 38 kHz	82	38	0.26	331	1583	0.24	2633 (62.5 %)	4216
10/Jul	AOS 120 kHz	83	120	0.48	565	2044	0.31	1510 (42.5 %)	3554
10/Jul	AOS 38 kHz	83	38	0.48	267	2369	0.31	2011 (45.9 %)	4380

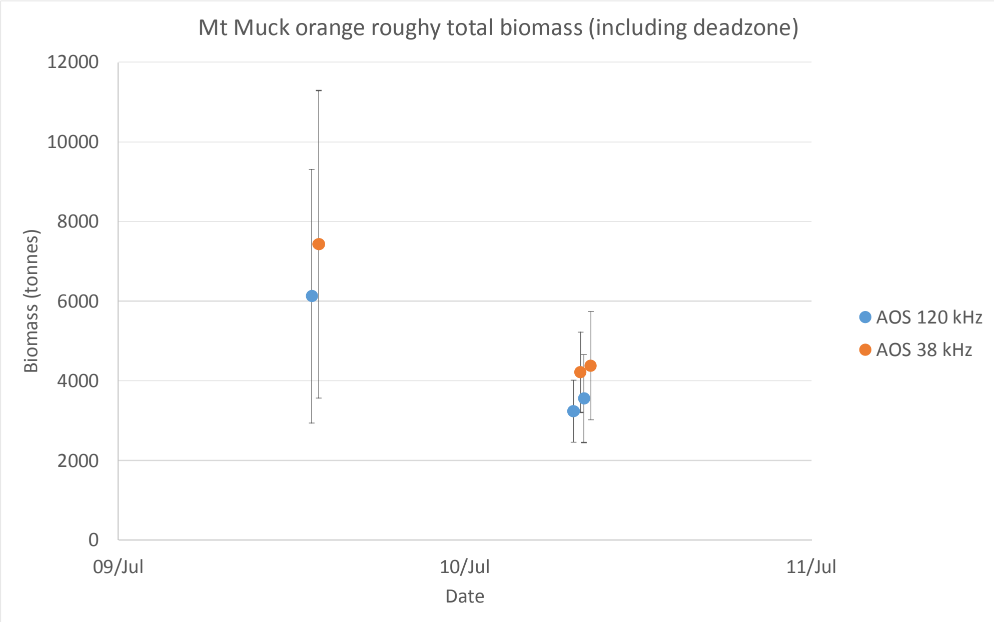

Figure 18. Biomass estimates for AOS 38 and 120 kHz at Mt Muck. Error bars are +/- 1 sd. Dates for AOS 38 are slightly offset from AOS 120 so that error bars for both frequencies will be visible.

4.15.4 Discussion

The closer range of the AOS platform served to reduce deadzone compared to vessel-based systems but nevertheless the deadzone component remains high due to the steepness of this feature (39% to 63% of the total estimate). Further reduction of the deadzone component will require new and novel methods to be developed. Vessel acoustic biomass estimates were not possible due to poor data quality in bad weather and difficulty in delineating gas bladder species from orange roughy. Thus the AOS was essential to provide suitable data quality while the multi-frequency data enabled clear delineation of orange roughy from gas bladder species. Hence the AOS-based biomass estimates are considered suitable for inclusion in the stock assessment process.

4.16Northwest Chatham Rise - Morgue and Graveyard region

4.16.1 Summary of survey program

Overview

The North West Chatham Rise (NWCR) fishery is focussed largely on Graveyard hill and the surrounding flats. An adjacent hill, Morgue, which is closed to fishing, is an important spawning area for orange roughy. These two hills are neighboured by around a dozen smaller UTFs collectively referred to as the 180^0 hills (Figure 19). Morgue (42:42.6S, 180:02E) and Graveyard (42: 45.6S, 180.00 E) hills are conical, steeply sloping features (~12 degrees), respectively rising from 1200 to 900 m and 1150 to 750 m depths. While much of the NWCR fishing activity has been historically focussed on these two features, Morgue hill has been closed to fishing since the year 2000.

Surveys were conducted in this region during three visits: 19^{th} - 20^{th} June, 24^{th} - 25^{th} June and 29^{th} – 30^{th} June. Twenty three acoustic and trawl survey activities were carried out during this time plus continuous recording of acoustic data from the vessel's Simrad ES60 38 kHz echosounder, which included brief passes over some of the lesser features.

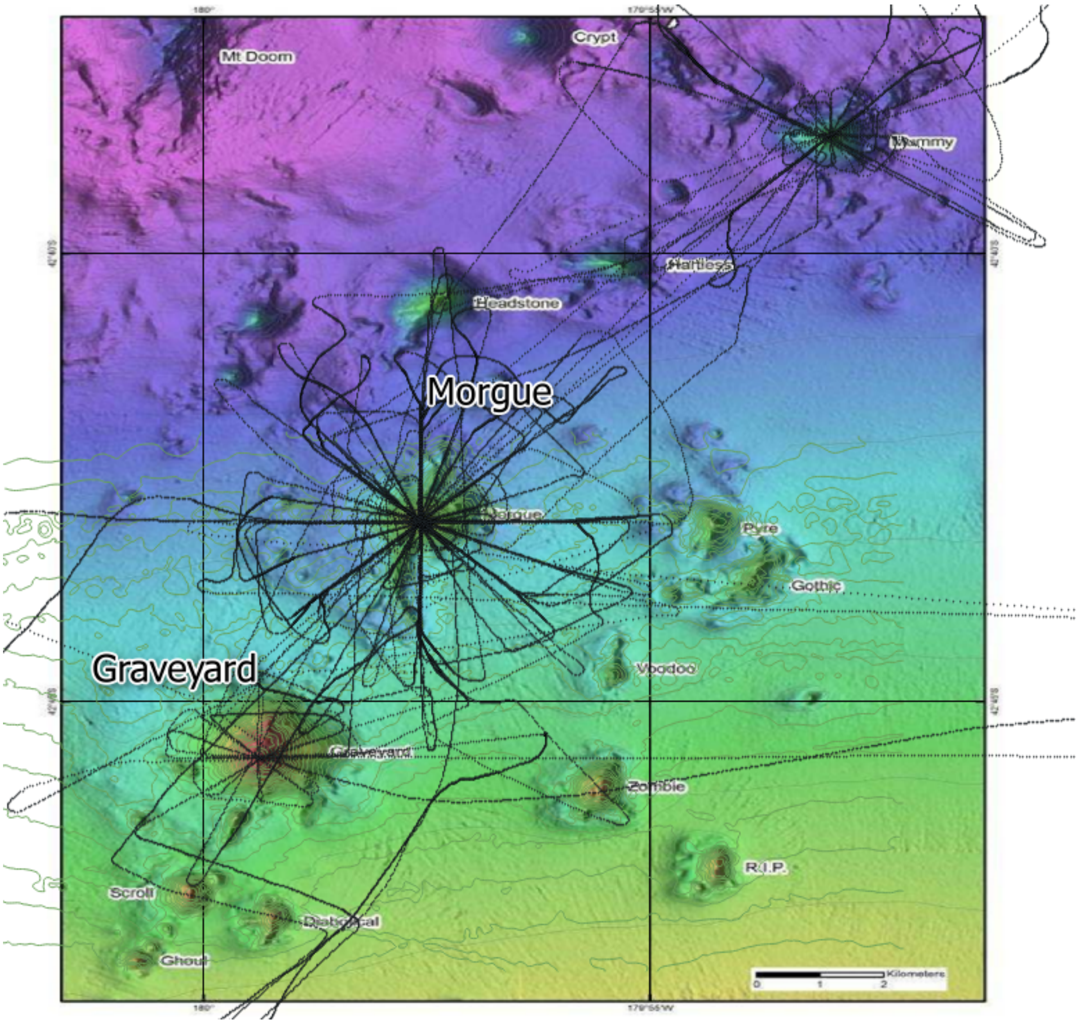

Figure 19. The 180⁰ hills complex in the NWCR management sub-area showing vessel tracks.

Graveyard

A vessel survey at Graveyard hill showed no obvious marks for both the first and second survey visits. On the third visit a moderate-intensity mark was present at the top of the feature with some small amount of signal down one side. Previous multi-frequency surveys at Graveyard indicated that the mark at the top of the feature was not orange roughy and is more likely from gas bladder species such as cardinal fish (Ryan and Kloser, 2014). The marks were not sufficient to motivate a full AOS survey and indeed were not considered worthwhile even for commercial fishing purposes (Figure 20). Priority was given to focus survey efforts on nearby Morgue which had orders of magnitude more acoustic signal but a high degree of complexity which required sustained observations to decode.

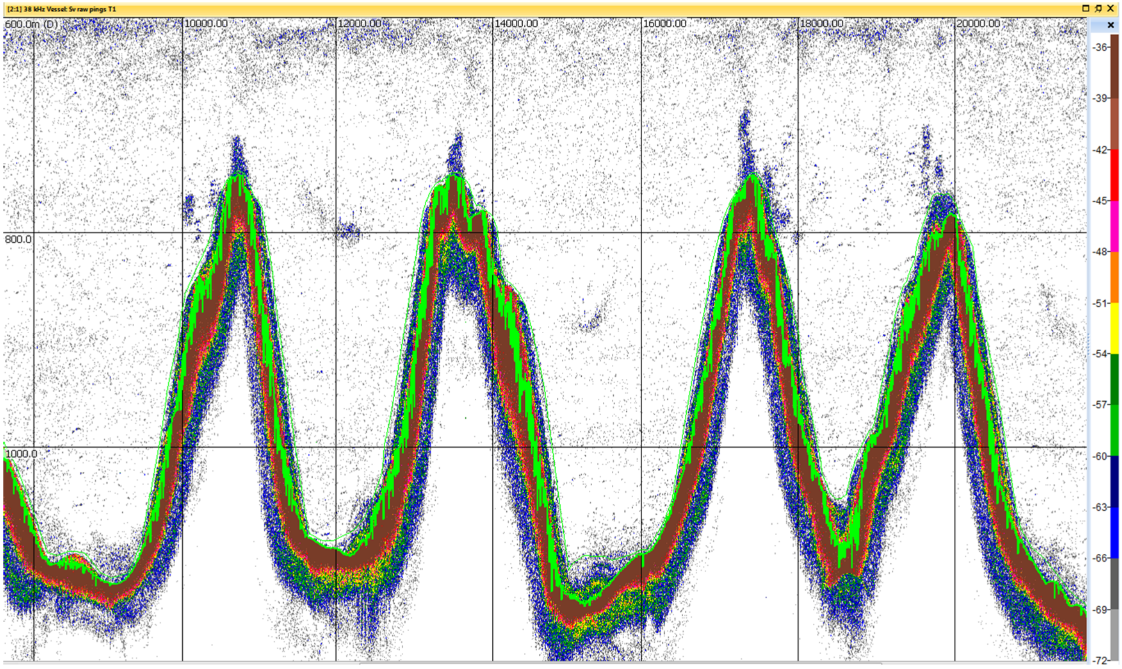

Figure 20. Vessel 28 kHz echogram of four-transect survey over Graveyard.

Once the period of voluntary closure to fishing had passed on 29th June, FV *Otakau* commenced fishing at the Graveyard catching a modest 24 tonnes of orange roughy from 6 trawl shots. Given the lack of significant acoustic school features no biomass estimates could be made for Graveyard for 2016.

Morgue

Morgue had extensive, strong and dynamic marks both above the feature and down the sides. Present on most, but not all occasions, was an extreme signal region (ESR) amongst the greater area of moderate signal (Figure 21).

Under the Ministry for Primary Industries' permit condition, bottom trawling was not permitted on Morgue. Close proximity sampling was constrained to keeping the ground chain of the net 20 m above the seafloor during the entire trawl. Three such trawls were permitted with the cod-end closed (extractive) while other tows were conducted with the cod-end open (non-extractive). Both types of trawl recorded video and stereo digital still images. These produced images of impressive, extensive orange roughy aggregations well away from the seafloor with only occasional by-catch species.

A lone male stage 3 orange roughy was caught in the AOS frame in an AOS non-extractive trawl on the 20th June. An extractive trawl but with no bottom contact on the 24th caught 8 tonnes of orange roughy, a large catch given the demersal net was a minimum of 20 m above the seafloor, effectively mid-water fishing. Gonad staging of this catch indicated spawning had commenced, with around 38% of female gonads in ripe-running condition (stage 5 of the 8-stage gonad maturation scale). During the second and third extractive trawls on 29th June, around 62% of female gonads were in spawning condition and 4% were spent. The third and final extractive tow caught 24 tonnes of orange roughy with little by catch.

The regions of extreme backscatter are most likely populated by fast moving large fish with large swim-bladders (high acoustic reflectivity) that are effective in avoiding being caught in the trawl net or detected by the optical systems.

We can conclude that Morgue hill a) is an important spawning location of NWCR orange roughy, b) orange roughy were observed in impressive numbers by the optics (Figure 22), c) the optics and acoustics did not provide evidence of suspected and elusive large gas bladder fish and d) as in the 2013 surveys, uncertainties in species composition at Morgue remain. Biomass estimates may be sensitive to interpretation assumptions even when guided by Sv_{120-38} differences.

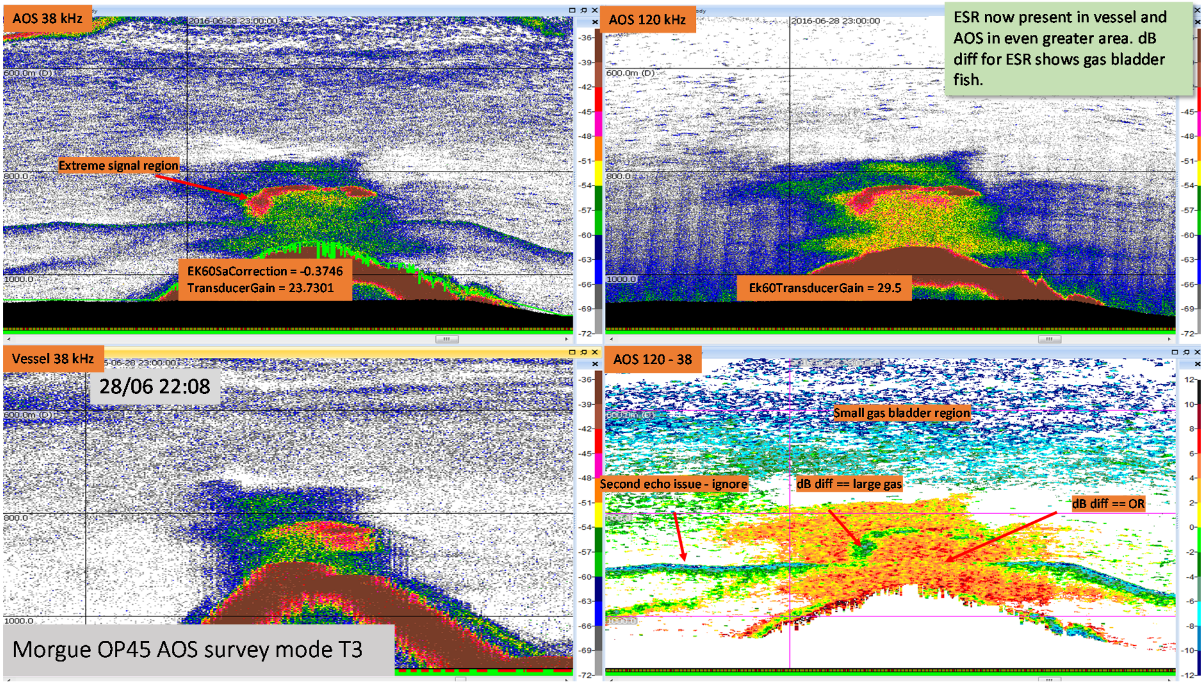

Figure 21. Op45. AOS survey at Morgue hill. Regions of extreme high signal (ESR) and likely orange roughy are marked. The difference between 120 kHz and 38 kHz volume backscatter, Sv (dB re 1m), Sv_{120-38} from hereon, suggested gas bladder species within this core region of extreme high backscatter. However some ambiguity remained where regions of extreme high signal merge into moderate signal regions and instances where the Sv_{120-38} did not indicate gas bladder fish as might be expected

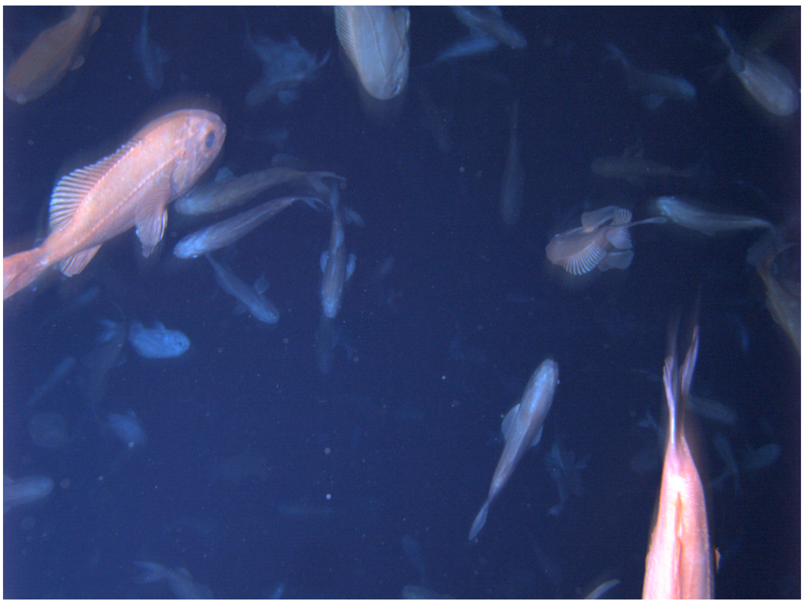

Figure 22. Dense aggregations of orange roughy at Morgue hill, 20/06/2016 10:11:24, Starboard digital still camera.

4.16.2 Morgue – biological results

Three mid-water biological tows yielded a total of 40.7 t of fish of which 97.2% was orange roughy. The bycatch by weight comprised mainly deep water dogsharks, smooth and black oreo (Figure 23).

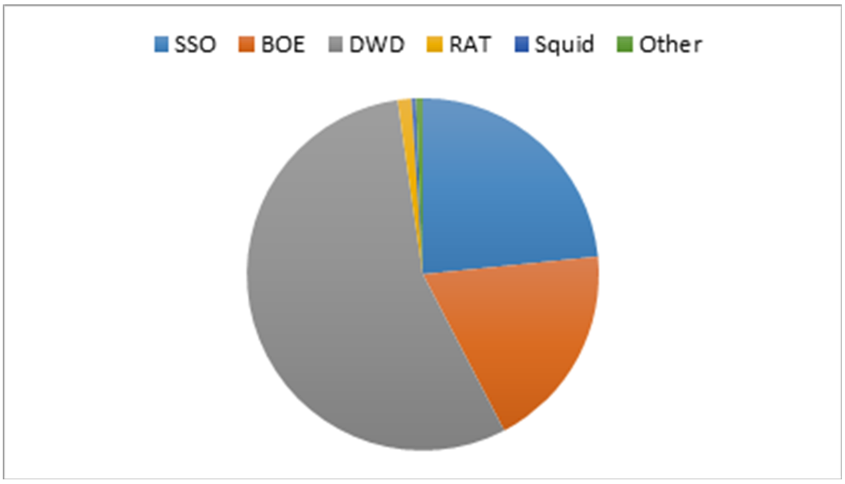

Figure 23. Bycatch composition (2.8% of total catch) - Morgue.

The species composition from Morgue is provided in Appendix B (Table 20).

ORH size frequency

The average lengths and weights were 33.8 cm and 1.30 kg for males and 35.7 cm and 1.54 kg for females. Average lengths and weights for sexes combined were 34.2 cm and 1.35 kg. The ORH size frequency (unstandardized) is provided in Figure 24.

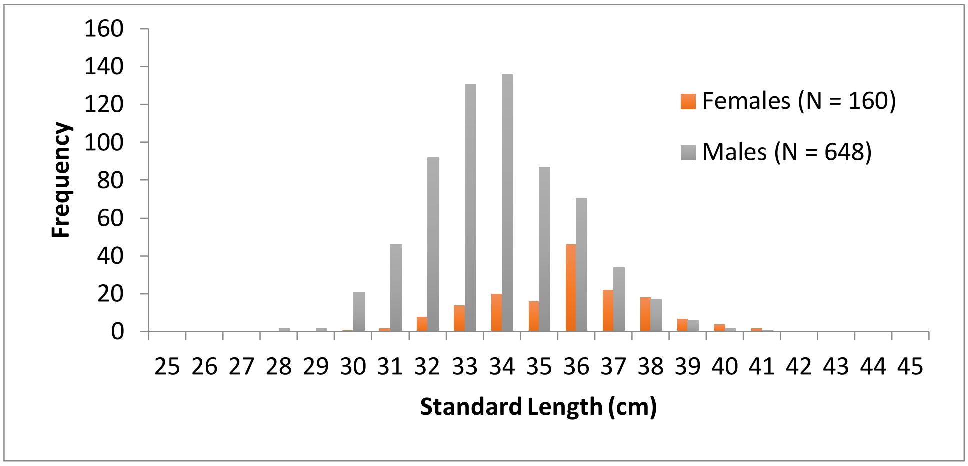

Figure 24. Orange roughy size frequency distribution (unstandardized) - Morgue.

Spawning progression

At commencement of surveying on Morgue on 25th June 38% of female gonads were in running condition and there were no spent females, suggesting spawning was at an early stage. At the end of the survey on 29th – 30th June around 67% of female gonads were in running condition and 9% were spent and/or partially spent, suggesting that spawning was well-underway but had not reached it's peak (Figure 25).

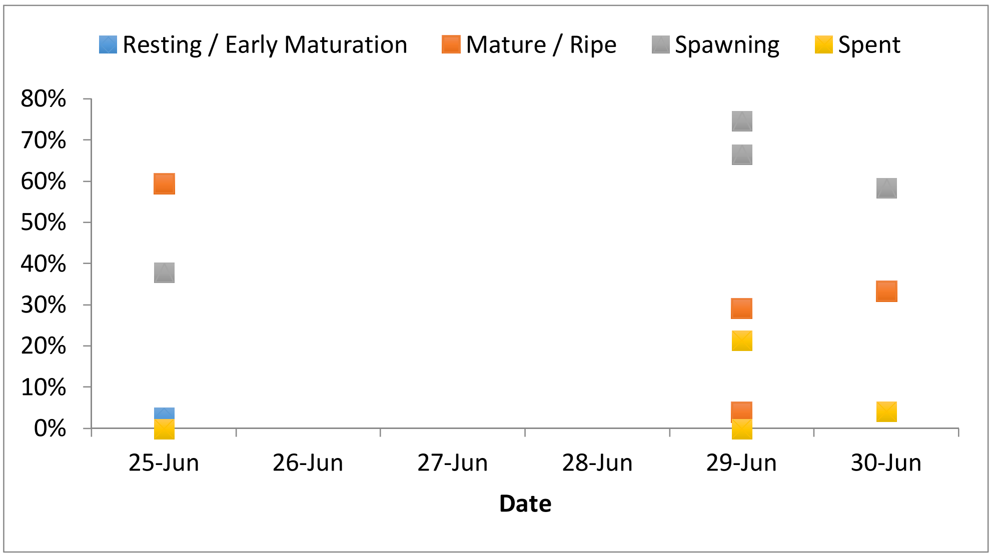

Figure 25. Orange roughy female spawning progression - Morgue.

The overall sex ratio from three catches on 25th, 29th and 30th June was 23% females and 77% males.

4.16.3 Morgue – Acoustic biomass estimates

AOS 38 and 120 kHz acoustic biomass estimates are given in Table 9 and Figure 26 with values ranging from 10536 to 15029 tonnes. Deadzone component is significant, due to the steep-sided feature, ranging from 23% to 42% of the total biomass).

Table 9. Biomass estimates based on AOS echo-integration surveys carried out at the Morgue in July 2016.

Date	Platform	OP	Frequency	Survey area (n.miles^2)	Mean NASC (m^2/n.mi^2)	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass
25/Jun	AOS 120 kHz	29	120	1.67	727	8780	0.18	5248 (37.4 %)	14027
25/Jun	AOS 38 kHz	29	38	1.67	327	9683	0.18	5346 (35.6 %)	15029
25/Jun	AOS 120 kHz	32	120	1.58	459	7830	0.17	5089 (39.4 %)	12919
25/Jun	AOS 38 kHz	32	38	1.58	266	7433	0.17	5408 (42.1 %)	12840
28/Jun	AOS 120 kHz	45	120	0.54	2060	8074	0.15	2463 (23.4 %)	10536
28/Jun	AOS 38 kHz	45	38	0.54	1143	10975	0.15	3313 (23.2 %)	14288

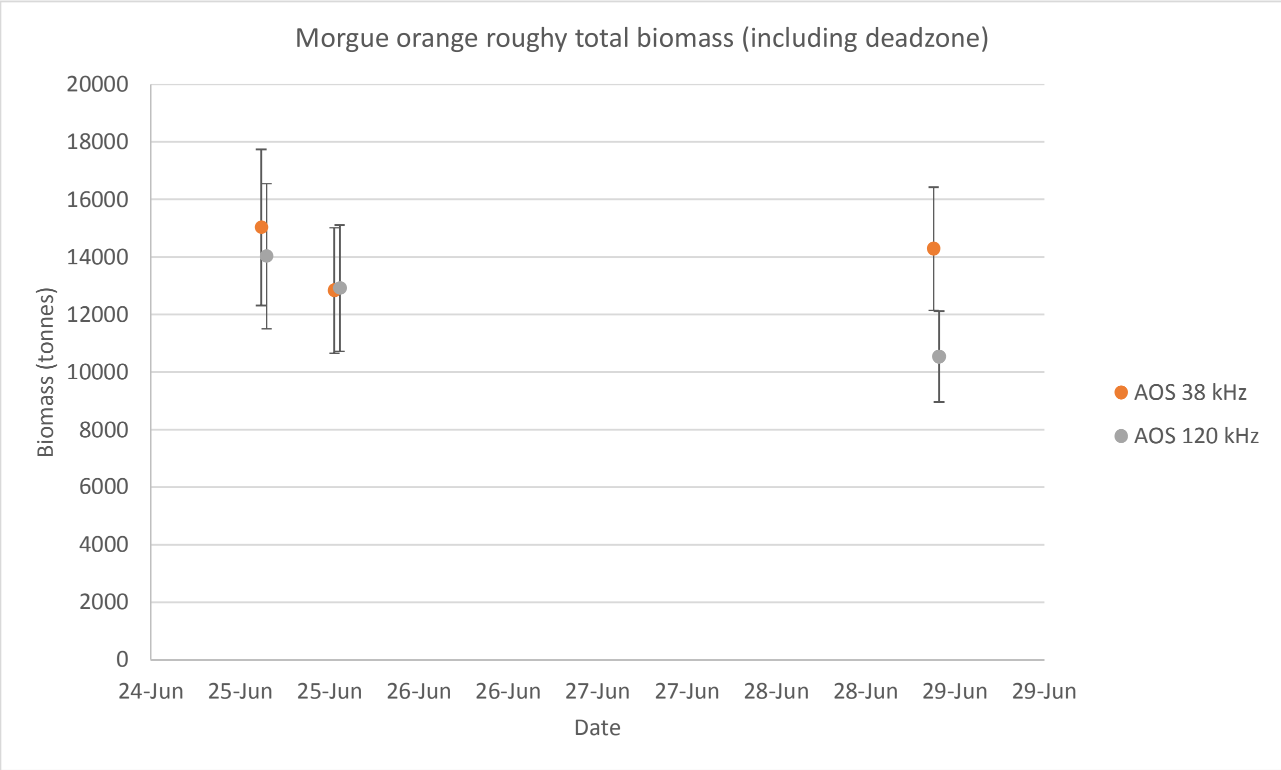

Figure 26. Biomass estimates for AOS 38 and 120 kHz at Morgue. Error bars are +/- 1 sd. Dates for AOS 38 are slightly offset from AOS 120 so that error bars for both frequencies will be visible.

4.16.4 Morgue - discussion

The presence of ESRs at Morgue has been well documented in previous surveys (Kloser & Ryan, 2011; Ryan & Kloser, 2014) and again were a feature of the 2016 surveys. These mobile high-signal regions have the potential to bias high biomass estimates of orange roughy at this location. In 2016 the ESR's were often (but not always) present amongst the moderate marks that were attributed to orange roughy. In most cases the AOS multi-frequency Sv120-38 decibel difference information was sufficient to identify and eliminate ESRs from the analysis. (Figure 21). In occasional instances Sv120-38 information did not indicate gas bladder fish where it was the magnitude of the signal in the ESR itself which suggested that it originated from high-signal gas bladder species. The mechanism that could result in a region of high-signal gas bladder fish having an orange roughy-like multi-frequency signature is not clear. The alternate possibility that ESRs contain orange roughy seems highly unlikely when packing densities are considered: assuming the ESR was orange roughy, then applying orange roughy target strength estimates to the volume backscatter would result in packing densities of up to 800 fish/m3 whereas values of 0.5 to 1 fish/m3 would be typical of even dense orange roughy aggregations.

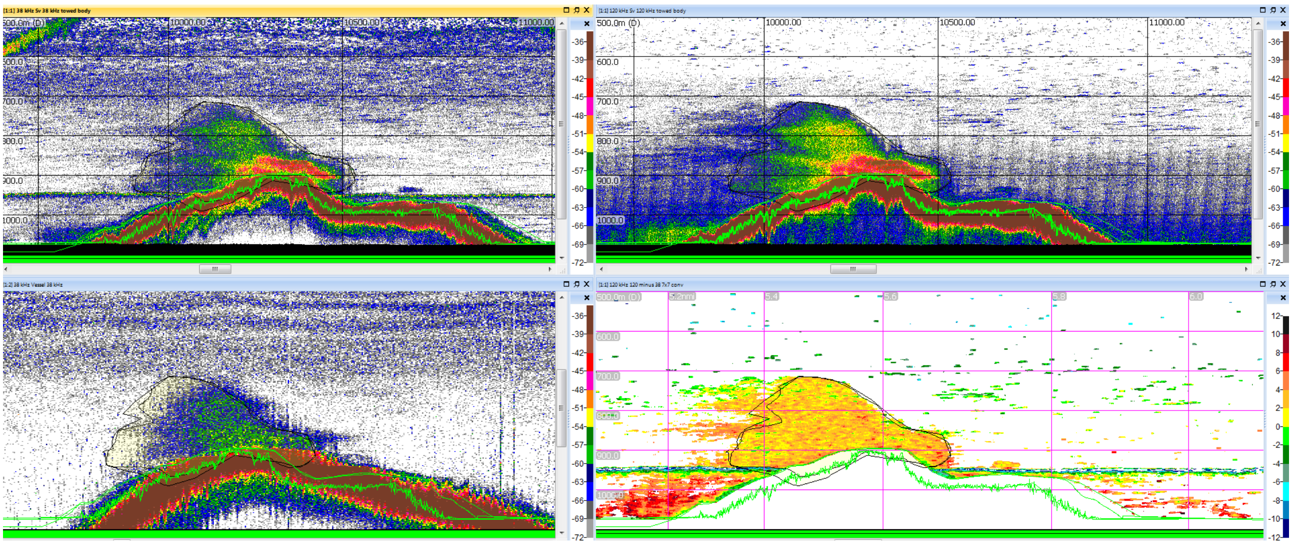

Figure 27. Example of situation at Morgue where multi-frequency information did not identify extreme signal region (ESR) as gass bladder species.

In this analysis biomass estimates were based on surveys either where ESRs could be clearly delineated using multi-frequency acoustics, excluded based on the magnitude of their signal or in some instances not observed on the transects at all. All other indicators showed that a large number of orange roughy with low numbers of co-occurring species were present at Morgue. These included trawl catches of up to 24 tonnes; a large catch considering the demersal net system was 20 m above the seafloor, impressive numbers of orange roughy observed in the optics with no sign of significant numbers of gas bladder species and multi-frequency data indicating extensive regions of non-gas bladder fish on all sides of Morgue. Thus given these indicators of high orange roughy abundance and careful exclusion of ESRs, the AOS biomass estimates are considered suitable for inclusion in the stock assessment process.

A concern remains that species within the ESRs might disperse into orange roughy regions without being detected and thus bias results high. Despite comprehensive acoustic, optical and trawl survey operations the species identify within the ESRs remains elusive. To improve certainty in biomass estimates at Morgue further research is recommended most likely requiring new and novel methods (e.g. broadband acoustics, and/or low frequency instrumentation).

Other locations

Excursions were also made to the lesser features at the 180^0 hills including Headstone, Hartless, Scroll, Diabolical, Zombie and Mummy. No significant aggregations were observed on any of these features except for Mummy, which is a small feature five nautical miles northeast of Morgue. There, two vessel-based acoustic surveys were carried out following observations of moderate and persistent marks above the top of the feature. An AOS single-pass, survey-mode transect was conducted with the system ‘flown’ at 100 m above the mark. The objective was to see if there was a scare reaction that might indicate orange roughy. At the top of the feature a diffuse region of strong individual targets (-27 dB to -35 dB) was observed. Down the side of the feature there was a region of homogenous scatter closer to the seafloor, which it was thought might be orange roughy (Figure 28). However the skipper of *Otakau* (fishing in the area post survey closure) noted that he had caught mostly sharks at this location. Further, deepwater shark species are expected to have a similar Sv_{120-38} signature as orange roughy. We conducted a single trawl shot catching ~

400 kg baxter's dog shark (67% of the total catch) and 168 kg of smooth and black oreos with no orange roughy caught. We conclude that the acoustic marks at Mummy in 2016 are unlikely to contain orange roughy and no biomass estimates will be made for this location.

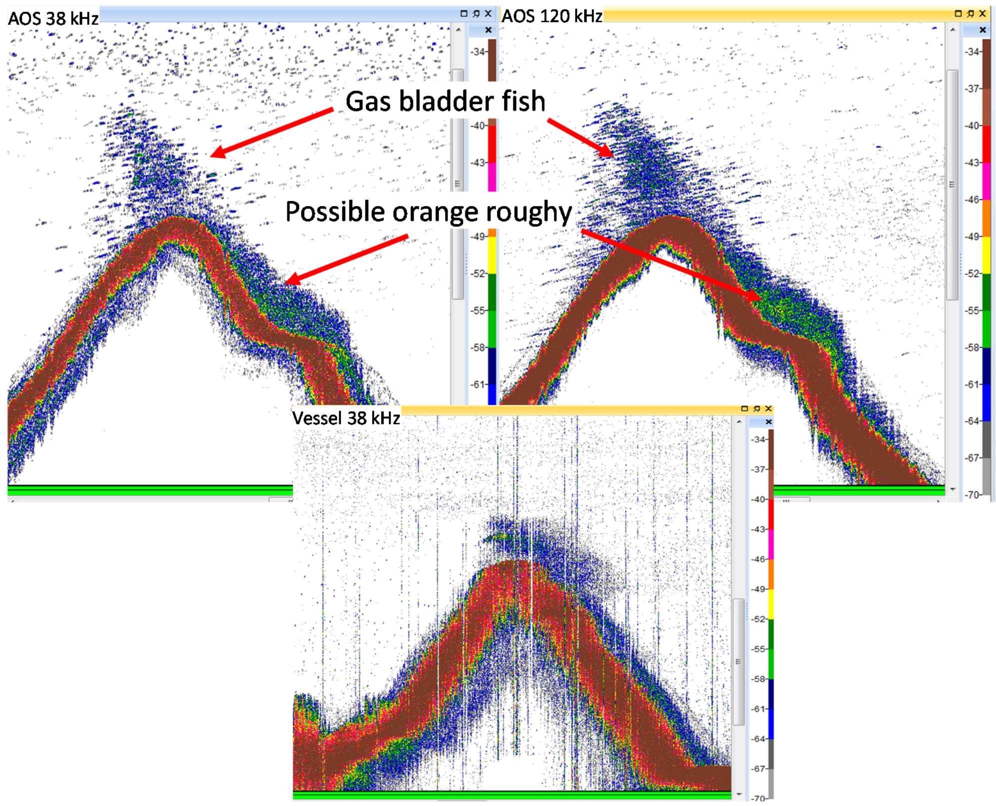

Figure 28. Single-pass, survey-mode transect at Mummy, showing (clockwise) AOS 38 kHz, 120 kHz and vessel 38 kHz echograms.

4.17 Other Activities

Optic fibre connectivity via a "third wire" was established and trialled on a number of occasions. This provided real-time connection to the optical systems (video, digital stills) and acoustics. A key benefit was its use on the final operation, to calibrate the AOS acoustics. For this the AOS was lowered through the water column via the fibre optic cable with a calibration sphere suspended 20 m beneath the transducers. The real-time connection enabled observation of the sphere to see if we were succeeding in recording sphere returns from the centre of the acoustic beam.

5 Appendix A – Vessel and AOS calibration

5.1 *Amaltal Explorer* ES60 calibration

The Amatal Explorer's Simrad ES60 vessel-mounted acoustic system was calibrated at the start of the survey in Tasman Bay with results given in Table 10 to Table 16.

5.1.1 Amaltal Explorer calibration

This report details the calibration experiments and results for *FV Amaltal Explorer* as per the information recorded below. The methods detailed in (Demer et al., 2015a) based on the suspended reference sphere method with on-axis analysis are broadly followed.

Summary of results that would be applied when post processing are given in Table 10.

Table 10. Summary of calibration results

Frequency (kHz)	Transducer serial no*	Power (W)	Pulse duration (ms)	on-axis gain (dB)	Sa correction (dB)	Adjusted equivalent beam angle (dB)
38	30212 and 30031	2000	2.048	25.5	-0.53	-20.58

* this vessel has two transducers, Serial numbers 30212 and 30031 but there is no information that will tell us which one is in service. EBA values are close at -20.6 and -20.8 respectively while factory tank temperatures were identical at 18 degree, freshwater. We use the mean of the factory EBA values (i.e. -20.7 dB) and adjust for local environmental conditions.

Table 11. Vessel and site

Vessel Name	Amaltal Explorer	**Vessel owner/operator**	Talley's New Zealand
Site name	Tasman Bay	**Country**	New Zealand
Calibration date	2016-06-18	**Time zone**	UTC+12
Latitude	41:04 S	**Longitude**	173:20 E
Seafloor depth (m)	32		
Sea state at start	Calm	**Sea state at end**	Calm
Start calibration time	10:36 (UTC+12)	**End calibration time**	11:05 (UTC+12)
Vessel and site comments	Tasman Bay ~ 1 hr steam from port until sufficient depth is obtained.		
Vessel acknowledgements	Skipper John Whitlock, and crew are thanked for their assistance.		

Table 12. Environmental

<table>
<tr><td>Salinity (psu)</td><td>34.5</td><td>Salinty source</td><td>estimated</td></tr>
<tr><td>Temperature (°C)</td><td>12.5 – 14.5</td><td>Temperature source</td><td>Wildlife computers MK9 logger</td></tr>
<tr><td>Sound absorption (dB/km)</td><td>8.3 at (38 kHz)</td><td>Sound absorption equation</td><td>(Francois and Garrison, 1982b)</td></tr>
<tr><td>Sound speed (m/s)</td><td>1497 at txdr face</td><td>Sound speed equations</td><td>(Mackenzie, 1981)]</td></tr>
<tr><td>Environmental comments</td><td colspan="3">Layer of colder water sitting over top of warmer water. Calculate sound speed at transducer face to adjust local EBA. Use mean sound speed and absorption for surface, mid depth and sphere depth (0, 12 m and 24 m).
<table>
<tr><td>Depth (m)</td><td>Absorption (dB/km)</td><td>Sound speed (m/s)</td></tr>
<tr><td>0</td><td>9.5</td><td>1497</td></tr>
<tr><td>12</td><td>9.3</td><td>1501</td></tr>
<tr><td>24</td><td>9.1</td><td>1504</td></tr>
<tr><td>Mean</td><td>9.3</td><td>1500.7</td></tr>
</table></td></tr>
</table>

Table 13. Calibration equipment

<table>
<tr><td>Calibration sphere</td><td colspan="3">60 mm copper sphere – supplier : Simrad</td></tr>
<tr><td>Counter weight</td><td>No</td><td>Counter weight-sphere distance (m)</td><td>N/A</td></tr>
<tr><td>Mechanical arrangement</td><td colspan="3">Calibration poles triangulated around the transducer. Using DWG automated calibration reels.</td></tr>
<tr><td>Equipment comments</td><td colspan="3"></td></tr>
</table>

Table 14. Echosounder transceivers*

Frequency (kHz)	38
Make	Simrad
Model	ES60
Serial number	
Operating software	ES60
Operating software version	1.5.2

Table 15. Echosounder transducers*

Frequency (kHz)	38	**Make**	Simrad
Model	ES38B	**Serial number**	30212
Beam	single-beam split-aperture	**Transducer depth**	
Factory equivalent two way beam angle (dB)	-20.6	**Factory tank temperature**	18
Factory tank salinity	0		
3-dB beamwidth alongships (°)	7.1	**3-dB beamwidth athwartships (°)**	7.1
Angle offset alongships (°)	Not available	**Angle offset athwartships (°)**	Not available

Frequency (kHz)	38	**Make**	Simrad
Model	ES38B	**Serial number**	30031
Beam	single-beam split-aperture	**Transducer depth**	
Factory equivalent two way beam angle (dB)	-20.8	**Factory tank temperature**	18
Factory tank salinity	0		
3-dB beamwidth alongships (°)	6.9	**3-dB beamwidth athwartships (°)**	7.1
Angle offset alongships (°)	Not available	**Angle offset athwartships (°)**	Not available

* this vessel has two transducers, Serial numbers 30212 and 30031 but there is no information that will tell us which one is in service. EBA values are close at -20.6 and -20.8 respectively while factory tank temperatures were identical at 18 degree, freshwater. We use the mean of the factory EBA values (i.e. -20.7 dB) and adjust for local environmental conditions.

Results

Table 16. Calibration calculations and results*

Frequency (kHz)	38
Calibration analysis method	On-axis
Run number	1
Max beam compensation (dB)	0.1
Number of targets	991
Adjusted Two-way equivalent beam angle (dB)**	-20.58
Power (W)	2000
Pulse duration (ms)	2.048
Sphere depth (m)	22.41
Sphere TS (dB)[+]	-33.53
On-axis gain (dB)	25.50
S_A correction (dB)	-0.53

[+] Calculated using Matlab solid_elastic_sphere_TS_fun as part of the Ex60 cal package.

5.2 AOS calibration results

The very last operation of the AMX2016 voyage was a deepwater calibration of the Sealord AOS in near-perfect conditions. The standard method of suspending a tungsten carbide sphere (38.1 mm) of known reflectivity beneath the platform was employed (Demer et al., 2015a) with the system vertically lowered, pausing at a series of depth-stations to establish calibration of the echosounders at the working depths. A key advance achieved during this survey was suspending the platform from a fibre-optic cable. This allowed real-time recording and observation of the target collection process from a PC installed on the bridge. This meant that a) we could be certain we were successfully collecting sphere single targets (which is not the case when recording internally when suspending from a trawl warp) and b) we could ensure that a sufficient number of targets was collected at a particular depth-station before moving to the next. Consequently suitable numbers of single targets were collected to enable characterisation of the relationship between system gain and depth. The 120 kHz system was successfully calibrated using this data set. Further inspection of the sphere data from 38 kHz system found that a gross loss of sensitivity (~ 5 dB) had occurred compared to the previous calibration carried out in 2015. A detailed investigation was carried out to establish when this large change had occurred in the 38 kHz AOS echosounder. It quickly became clear that the large downward step-change in AOS 38 kHz echosounder sensitivity occurred on the 2016 calibration deployment itself with the system appearing to be reliable through the survey period. The echosounder has since been returned to Simrad with faulty components found and repaired.

Further investigation was made to consider if the AOS 38 kHz calibration immediately prior to the 2016 survey (conducted in October 2015 but system not used in the intervening time) could be applied. We looked at 1) decibel difference between AOS 120 and 38 kHz for known orange roughy schools where on average 120 kHz is expected to be ~ 3.3 dB higher than 38 kHz (Ryan and Kloser, 2014), 2) AOS 38 kHz transmit pulse energy through time starting from 2015 AOS surveys of ORH3B Puysegur (Ryan and Tilney, 2015) through to the AOS 2016 calibration conducted at the end of this voyage and 3) along-track comparison of AOS 38 kHz and vessel 38 kHz seafloor and water column backscatter values. When applying 2015 calibration results we found dB difference values were within expectations for known orange roughy aggregations, transmit pulse varied by less than 0.1 dB between 2015 up until the penultimate deployment in 2016. Comparisons with along-track AOS 38 kHz and vessel 38 kHz water column and seafloor backscatter showed good agreement when 2015 calibration results were applied and gross disparity if 2016 calibration results were used (Figure 29).

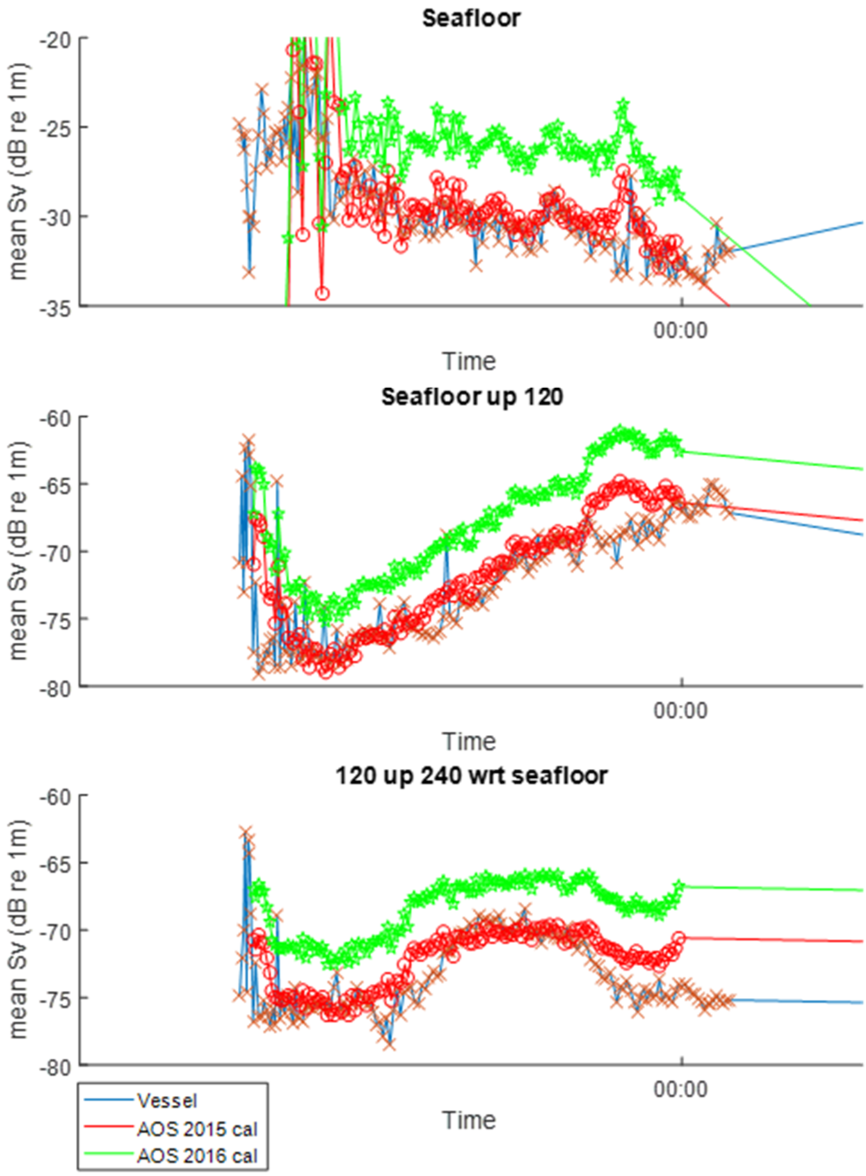

Figure 29. Comparison between AOS 38 kHz and 38 kHz vessel echointegrated backscatter for seafloor (top panel), 120 m immediately above the seafloor (middle panel) and layer from 120 m to 240 m above seafloor (lower panel) for two AOS 38 kHz calibration scenarios: Ii) using 2016 results and (ii) applying 2015 results.

We conclude that it is reasonable to apply the 2015 calibration results to the AOS 38 kHz data collected during the 2016 survey. AOS calibration values used for the 2016 surveys are given in Table 2.

6 Appendix B - Catch Composition

Table 17. Catch composition - Rekohu

Code	Common Name	Scientific Name	Weight (kg)	No.
BBE	Banded bellowsfish	*Centriscops humerosus*	0.70	1
BEE	Basketwork eel	*Diastobranchus capensis*	7.58	14
BOE	Black oreo	*Allocyttus niger*	10.54	19
BSH	Seal shark	*Dalatias licha*	2.46	1
BSL	Black slickhead	*Xenodermichthys spp.*	25.18	113
BSP	Big-scale pomfret	*Taractichthys longipinnis*	5.85	1
BTS	Prickly deepsea skate	*Brochiraja spinifera*	12.38	1
BYS	Alfonsino	*Beryx splendens*	4.79	3
CBA	Humpback rattail (slender rattail)	*Coryphaenoides dossenus*	5.77	3
CDL	Cardinalfish	*Epigonidae*	5.48	2
CDY	*Cosmasterias dyscrita*	*Cosmasterias dyscrita*	0.26	
CFA	Banded rattail	*Coelorinchus fasciatus*	0.92	8
CHA	Viper fish	*Chauliodus sloani*	0.03	1
CHY	Roughhead rattail	*Coelorinchus trachycarus*	0.13	1
CIN	Notable rattail	*Coelorinchus innotabilis*	3.03	34
CMA	Mahia rattail	*Coelorinchus matamua*	0.20	2
CRS	Airy finger sponge	*Callyspongia ramosa*	0.76	
CSE	Serrulate rattail	*Coryphaenoides serrulatus*	3.39	13
CSQ	Leafscale gulper shark	*Centrophorus squamosus*	107.91	14
CSU	Four-rayed rattail	*Coryphaenoides subserrulatus*	10.98	134
CTH	Roughhead rattail	*Coelorinchus acanthiger*	0.16	1
CUB	Cubehead	*Cubiceps spp.*	0.15	1
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	39.72	9
CYP	Longnose velvet dogfish	*Centroscymnus crepidater*	96.10	64
DMG	*Dipsacaster magnificus*	*Dipsacaster magnificus*	0.13	2
EGC	Egg case		0.01	1
EPR	Robust cardinalfish	*Epigonus robustus*	0.10	1
EPT	Deepsea cardinalfish	*Epigonus telescopus*	7.97	3
ETB	Baxters lantern dogfish	*Etmopterus baxteri*	131.17	89
FMA	*Fusitriton magellanicus*	*Fusitriton magellanicus*	0.31	10
GOC	Gorgonian coral	*Gorgonacea (Order)*	0.11	
GOR	*Gorgonocephalus spp*	*Gorgonocephalus spp.*	0.67	11
GSP	Pale ghost shark	*Hydrolagus bemisi*	8.80	8
HAK	Hake	*Merluccius australis*	103.68	20
HJO	Johnson's cod	*Halargyreus johnsonii*	183.15	432
HOK	Hoki	*Macruronus novaezelandiae*	220.93	72
IDI	Black dragonfishes	*Idiacanthus spp.*	0.04	2
JAV	Javelin fish	*Lepidorhynchus denticulatus*	1,000.56	3,523
MCA	Ridge scaled rattail	*Macrourus carinatus*	9.14	13
MIQ	Warty squid	*Onykia ingens*	50.96	30
MRQ	Warty squid	*Onykia robsoni*	3.20	2
ORH	Orange roughy	*Hoplostethus atlanticus*	404,524.00	303,502

PAO	*Pillsburiaster aoteanus*	*Pillsburiaster aoteanus*	0.06	1
PHO	Lighthouse fish	*Phosichthys argenteus*	0.29	3
PSI	Geometric star	*Psilaster acuminatus*	0.88	21
PTP	*Parantipathes spp.*	*Parantipathes spp.*	0.01	1
RAT	Rattails	*Macrouridae*	10.37	-
RBM	Rays bream	*Brama brama*	6.11	5
RCH	Widenosed chimaera	*Rhinochimaera pacifica*	0.76	1
RIB	Ribaldo	*Mora moro*	1,244.61	844
ROK	Rocks stones	*Geological specimens*	21.85	7
SBK	Spineback	*Notacanthus sexspinis*	2.25	9
SCO	Swollenhead conger	*Bassanago bulbiceps*	0.32	1
SEO	Seaweed		0.12	
SFI	Starfish	*Asteroidea & Ophiuroidea*	0.10	1
SMC	Small-headed cod	*Lepidion microcephalus*	5.92	19
SND	Shovelnose spiny dogfish	*Deania calcea*	236.59	99
SOR	Spiky oreo	*Neocyttus rhomboidalis*	535.47	724
SPE	Sea perch	*Helicolenus spp.*	0.96	1
SSO	Smooth oreo	*Pseudocyttus maculatus*	41.91	68
SVA	*Solenosmilia variabilis*	*Solenosmilia variabilis*	0.11	
TAM	Tam O shanter urchin	*Echinothuriidae & Phormosomatidae*	0.15	1
TET	Squaretail	*Tetragonurus cuvieri*	0.93	1
TUB	*Tubbia tasmanica*	*Tubbia tasmanica*	9.94	11
VSQ	Violet squid	*Histioteuthis spp.*	2.62	5
ZEL	Scalloped dealfish	*Zu elongatus*	8.46	2
ZOM	Rubbish other use metals		0.01	

Table 18. Catch composition – Spawn Plume

Code	Common Name	Scientific Name	Weight (kg)	No.
BEE	Basketwork eel	*Diastobranchus capensis*	3.39	4
BOE	Black oreo	*Allocyttus niger*	0.32	1
BSL	Black slickhead	*Xenodermichthys spp.*	2.02	10
BTS	Prickly deepsea skate	*Brochiraja spinifera*	0.21	1
BYS	Alfonsino	*Beryx splendens*	0.72	1
CFA	Banded rattail	*Coelorinchus fasciatus*	0.12	1
CIN	Notable rattail	*Coelorinchus innotabilis*	1.01	14
CMA	Mahia rattail	*Coelorinchus matamua*	0.33	1
CMX	*Coryphaenoides mcmillani*	*Coryphaenoides mcmillani*	0.07	1
CSE	Serrulate rattail	*Coryphaenoides serrulatus*	0.74	5
CSU	Four-rayed rattail	*Coryphaenoides subserrulatus*	5.13	62
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	5.95	2
CYP	Longnose velvet dogfish	*Centroscymnus crepidater*	13.03	10
EPR	Robust cardinalfish	*Epigonus robustus*	0.18	2
ETB	Baxters lantern dogfish	*Etmopterus baxteri*	62.81	52
GDU	Bushy hard coral	*Goniocorella dumosa*	0.53	
GLS	Glass sponges	*Hexactinellida (Class)*	0.11	
GSP	Pale ghost shark	*Hydrolagus bemisi*	4.33	4

HAK	Hake	*Merluccius australis*	21.62	5
HJO	Johnson's cod	*Halargyreus johnsonii*	64.18	139
HOK	Hoki	*Macruronus novaezelandiae*	14.88	9
JAV	Javelin fish	*Lepidorhynchus denticulatus*	26.02	80
LCH	Long-nosed chimaera	*Harriotta raleighana*	0.79	1
LNV	Rock star	*Lithosoma novaezelandiae*	0.07	1
MIQ	Warty squid	*Onykia ingens*	9.28	6
MSL	Starfish	*Mediaster sladeni*	0.04	1
NOS	NZ southern arrow squid	*Nototodarus sloanii*	0.61	1
ORH	Orange roughy	*Hoplostethus atlanticus*	59,251.50	40,396
PSI	Geometric star	*Psilaster acuminatus*	0.07	1
RIB	Ribaldo	*Mora moro*	252.33	180
ROK	Rocks stones	*Geological specimens*	0.45	1
SCO	Swollenhead conger	*Bassanago bulbiceps*	0.82	1
SMC	Small-headed cod	*Lepidion microcephalus*	0.63	2
SND	Shovelnose spiny dogfish	*Deania calcea*	141.17	42
SOR	Spiky oreo	*Neocyttus rhomboidalis*	17.05	68
SPE	Sea perch	*Helicolenus spp.*	2.28	2
SSO	Smooth oreo	*Pseudocyttus maculatus*	0.30	2
WHR	Unicorn rattail	*Trachyrincus longirostris*	0.50	2
WHX	White rattail	*Trachyrincus aphyodes*	2.73	2

Table 19. Catch composition – Mt Muck

Code	Common Name	Scientific Name	Weight (kg)	No.
BEE	Basketwork eel	*Diastobranchus capensis*	0.84	1
BNS	Bluenose	*Hyperoglyphe antarctica*	5.78	1
BSL	Black slickhead	*Xenodermichthys spp.*	0.87	5
CDL	Cardinalfish	*Epigonidae*	537.97	159
CFA	Banded rattail	*Coelorinchus fasciatus*	0.07	1
CIN	Notable rattail	*Coelorinchus innotabilis*	0.05	1
CMA	Mahia rattail	*Coelorinchus matamua*	0.79	3
COL	Olivers rattail	*Coelorinchus oliverianus*	0.10	1
CSE	Serrulate rattail	*Coryphaenoides serrulatus*	1.26	8
CSQ	Leafscale gulper shark	*Centrophorus squamosus*	6.74	1
CSU	Four-rayed rattail	*Coryphaenoides subserrulatus*	0.93	13
CYP	Longnose velvet dogfish	*Centroscymnus crepidater*	1.10	1
ETB	Baxters lantern dogfish	*Etmopterus baxteri*	11.56	7
GDU	Bushy hard coral	*Goniocorella dumosa*	0.05	
GLS	Glass sponges	*Hexactinellida (Class)*	0.10	
GSP	Pale ghost shark	*Hydrolagus bemisi*	0.84	2
HJO	Johnson's cod	*Halargyreus johnsonii*	1.33	4
HOK	Hoki	*Macruronus novaezelandiae*	11.52	5
JAV	Javelin fish	*Lepidorhynchus denticulatus*	2.82	12
MIQ	Warty squid	*Onykia ingens*	1.10	1
NOS	NZ southern arrow squid	*Nototodarus sloanii*	1.90	1
ORH	Orange roughy	*Hoplostethus atlanticus*	24,910.00	15,513
PYR	*Pyrosoma atlanticum*	*Pyrosoma atlanticum*	0.19	

RIB	Ribaldo	*Mora moro*	131.11	90
SND	Shovelnose spiny dogfish	*Deania calcea*	13.29	5
SOR	Spiky oreo	*Neocyttus rhomboidalis*	14.44	25
SSO	Smooth oreo	*Pseudocyttus maculatus*	79.08	138

Table 20. Catch composition – Morgue

Code	Common Name	Scientific Name	Weight (kg)	No.
ANO	Fangtooth	*Anoplogaster cornuta*	0.05	2
APR	Catshark	*Apristurus spp.*	1.27	1
BEE	Basketwork eel	*Diastobranchus capensis*	0.43	1
BJA	Black javelinfish	*Mesobius antipodum*	0.37	1
BOE	Black oreo	*Allocyttus niger*	215.76	207
CIN	Notable rattail	*Coelorinchus innotabilis*	0.48	7
CMX	*Coryphaenoides mcmillani*	*Coryphaenoides mcmillani*	0.25	4
CSE	Serrulate rattail	*Coryphaenoides serrulatus*	0.21	1
CST	Manefish	*Caristius sp.*	0.25	1
CSU	Four-rayed rattail	*Coryphaenoides subserrulatus*	12.44	196
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	9.93	1
CYP	Longnose velvet dogfish	*Centroscymnus crepidater*	61.79	25
ETB	Baxters lantern dogfish	*Etmopterus baxteri*	556.34	347
HJO	Johnson's cod	*Halargyreus johnsonii*	1.36	4
JAV	Javelin fish	*Lepidorhynchus denticulatus*	0.69	4
JFI	Jellyfish		0.04	1
LCH	Long-nosed chimaera	*Harriotta raleighana*	0.73	1
MIQ	Warty squid	*Onykia ingens*	1.59	3
ORH	Orange roughy	*Hoplostethus atlanticus*	39,514.00	29,143
PHO	Lighthouse fish	*Phosichthys argenteus*	0.14	2
SBK	Spineback	*Notacanthus sexspinis*	0.32	1
SND	Shovelnose spiny dogfish	*Deania calcea*	1.93	1
SSO	Smooth oreo	*Pseudocyttus maculatus*	266.28	238
TSQ	*Todarodes filippovae*	*Todarodes filippovae*	2.79	2
TUB	*Tubbia tasmanica*	*Tubbia tasmanica*	2.01	2
WHR	Unicorn rattail	*Trachyrincus longirostris*	0.31	2
WHX	White rattail	*Trachyrincus aphyodes*	0.49	1

7 Appendix C – Table of activities

Table 21. Table of activities.

Operation Number	Operation Type	Start Date & Time (UTC)	Location	Comment
1	Vessel calibration	17/06/2016 22:46	Tasman Bay	Good calibration with very little interference in the water column
2	Vessel Survey	19/06/2016 9:30	Mummy	Four transect vessel-acoustic star survey in calm conditions and good vessel acoustics. Strong mark on top of the "1032 m peak" extending 50 m into the water column.
3	AOS survey mode - single pass	19/06/2016 10:20	Mummy	Single pass AOS running towards northwest along the SW side of the peak Test AOS and attempt to key out the species id of the marks. AOS did not turn on so no data recorded. Issue identified and resolved.
4	AOS survey mode - single pass	19/06/2016 12:20	Mummy	Single pass AOS running towards northwest along the SW side of the peak. Test AOS and attempt to key out the species id of the marks. Mark had diminished somewhat but still adequate for testing purposes. Video logged, acoustics did not start.
5	AOS Survey	19/06/2016 16:16	Morgue	Full AOS survey
6	Vessel Survey	19/06/2016 22:15	Graveyard	No obvious marks
7	Vessel Survey	19/06/2016 23:40	Mummy	Quick vessel survey. Good mark on top of the feature
8	AOS survey mode - single pass	20/06/2016 0:37	Mummy	Single pass at ~ 250 m to try and key out species
9	AOS survey mode - single pass	20/06/2016 1:22	Mummy	Fly AOS at 100 m to see if a scare reaction can be observed. No sign of scare reaction of the main mark, some suggestion of orange roughy down the side of the hill. Individual targets could be observed in the main aggregation
10	AOS survey mode - single pass	20/06/2016 3:30	Morgue	Fly AOS at 100 m to see if a scare reaction can be observed. Acoustics did not start. 12/200 kHz channel had glitched out preventing the other channels from starting.
11	AOS survey mode - single pass	20/06/2016 5:32	Morgue	Fly AOS at 100 m to see if a scare reaction can be observed. 12 and 200 kHz taken out of the ES60 installation to allow the 38 and 120 kHz. GiG-E, Arc set ships GPS (UTC). AOS did not turn on due to configuration error. Resolved issue but no data for this deployment

Operation Number	Operation Type	Start Date & Time (UTC)	Location	Comment
12	AOS survey mode - single pass	20/06/2016 7:10	Morgue	Successful shot. Mark hard down a the top of the feature with diffuse large gas bladder fish observed as high strength individual targets off the side of the feature
13	AOS non extractive	20/06/2016 9:32	Morgue	Run in TS mode, no less than 20 m above seafloor. One unlucky orange roughy caught up in AOS. Extensive backscatter down the side looking like predominantly roughy with the occasional high target strength (gas bladder fish) individual. Gig-E images show densely packed orange roughy with only occasional oreo. Video did not work.
14	AOS biological	20/06/2016 20:55	Rekohu	AOS run in trawl mode. Acoustics, video, and GIG-E worked well. 18 t roughy caught
15	Vessel Survey	20/06/2016 23:30	Rekohu	Continuous grid surveying of Rekohu. No particularly large aggregations observed. Furuno turned on around 16:00 to aid searching power.
16	AOS biological	21/06/2016 12:18	Rekohu	Commercial tow at Rekohu at ~970 m depth. Caught ~ 14 t of roughy.
17	Vessel Survey	21/06/2016 15:00	Rekohu	Deteriorating weather, some marks observed but nothing spectacular
18	AOS biological	22/06/2016 1:33	Rekohu	16 t of roughy
19	Vessel Survey	22/06/2016 3:54	Rekohu	Grid survey following fishing shot. Eventually gave it away as weather was poor
20	AOS biological	22/06/2016 16:30	Rekohu	Commercial fishing shot, 18 t roughy. Acoustics, video?, and Gig-e worked well. Long tow with no marks of note until the last minute. Took fish in 1min.
21	AOS Survey	22/06/2016 22:05	Rekohu	Six transect survey. AOS data reviewed. No orange roughy of any significance seen.
22	AOS biological	22/06/2016 13:29	Rekohu	Shot targeting an orange roughy mark at ~ 1035m. 32 t roughy caught.
23	AOS Survey	24/06/2016 11:00	Morgue	Four transect cloverleaf, good marks coming on towards the end of the transect.
24	Random Trawl (TH)	24/06/2016 17:35	Diabolical-Flats	Fishing shot on the flats to the south of the main hill to test that net sensors bombs were not out. Thought to be 50m out. Test proved the net sensors are fine. Caught 50kg of roughy and 30 kg hoki.
Operation Number	Operation Type	Start Date & Time (UTC)	Location	Comment

25	AOS biological	24/06/2016 20:45	Morgue	AOS biological tow at the Morgue, with headline height >30m maintained, except on the first descent of the tow where the headline came within 22m (ground chain 12m) of the bottom for a split second. Large marks observed in AOS survey and vessel sounder. NZ MPI fisheries observer was present as instructed for the whole tow and took notes. 10 t of roughy was caught.
26	Vessel Survey	24/06/2016 22:40	Mummy	Vessel survey at Mummy, clear mark observed and extensive in east direction.
27	Vessel Survey	25/06/2016 0:53	Morgue	Vessel survey at Morgue. Star pattern rotated 20deg. Poor data quality
28	AOS Survey	25/06/2016 2:45	Morgue	Trial of optic fibre. Weld broke at termination staff while streaming out. Deployment aborted
29	AOS Survey	25/06/2016 4:00	Morgue	Four transect survey at Morgue completed successfully
30	AOS non extractive	25/06/2016 9:40	Morgue	Targeting high signal mark at Morgue away from the hill and up in the water column. Skipper John was able to aim under the mark with fish finding their way into the mouth of the net. Net monitor on high gain but saturated with ~ 50 m high fish going through. TS mode settings. Battery failed at critical moment taking out lights for stills and video. Some images of orange roughy just prior to failing. No sign of large gas bladder fish and acoustics does not indicate that we were successful in pushing them through the net.
31	Vessel Survey	25/06/2016 11:19	Morgue	Note Furuno was ON during this searching survey of the Morgue. Not a significant survey
32	AOS Survey	25/06/2016 12:12	Morgue	AOS survey with clear marks observed.
33	Fishing shot	26/06/2016 6:25	Rekohu	14 t roughy from 10 minute tow. AOS out of the net to remove 12 kHz and fit WBT
Operation Number	Operation Type	Start Date & Time (UTC)	Location	Comment

34	Vessel Survey	26/06/2016 8:01	Rekohu	Vessel acoustic survey at Rekohu, scouting region a bit shallower and more to the west of the area that was being worked on our first visit (mapping region surveyed in the 2013 survey). 10:15 very nice mark observed. Marks continued on successive transects giving good bounding of fish. Weather affecting every second transect will need some detailed cleaning if a biomass is to be obtained.
35	Fishing shot	26/06/2016 13:02	Rekohu	AOS not attached awaiting mounting of WBAT and fibre optic repair. Shooting commercial shot away from the main body of orange roughy. Did not find roughy mark. A small mixed bag with only 50 kg of roughy.
36	Fishing shot	26/06/2016 17:00	Rekohu	~ 32 tonne roughy. AOS not on the net.
37	Vessel Survey	26/06/2016 18:45	Rekohu	Mapping of extensive weak-moderate orange roughy marks amongst a mix of background scatter within about 4 n.mile by 4.mile zone.
38	AOS Survey	27/06/2016 0:50	Rekohu	AOS survey starting out following transects of the previous vessel survey but soon became apparent that fish had dispersed or moved. Only one body of orange roughy observed on the vessel sounder on the second last transect over to the east.
39	Vessel Survey	27/06/2016 9:08	Rekohu	Vessel searching survey following AOS. NOTE Furuno turned on at 09:52. Not structured. No major marks observed. Settled on shooting down into the deep end of the canyon 177 48.8 W on next shot (OP40)
40	AOS biological	27/06/2016 13:38	Rekohu	17 t roughy
41	AOS Survey	27/06/2016 17:33	Rekohu	6 transect AOS survey. Occasional low signal orange roughy but less impressive than first expected.
42	AOS biological	28/06/2016 4:21	Rekohu	22 t orange roughy after 8 minute tow.
43	AOS Survey	28/06/2016 8:51	178:20 W NWCR	3 transect AOS survey of newly observed mark at 178:20W within NWCR region. Was to be a 5 transect interlaced but called it early as not entirely sure if it is roughy. Review of AOS data quickly showed signal was being driven by gas bladder species.
Operation Number	Operation Type	Start Date & Time (UTC)	Location	Comment

44	Vessel Survey	28/06/2016 19:35	Morgue	Large mark extending 170 m off the top of the hill. High intensity scattering school sitting on the NE side of the hill.
45	AOS Survey	28/06/2016 20:44	Morgue	Star pattern survey at Morgue. Large extensive marks present and good survey results obtained.
46	AOS survey mode - single pass	29/06/2016 1:30	Morgue	AOS survey mode 100 m above mark. Fibre optic on, recording ES60 in real time.
47	AOS biological	29/06/2016 3:20	Morgue	AOS with all systems working - real time fibre optic, video, Gig-E and acoustics all recorded and viewed while conducting the deployment. Massive amount of roughy observed and 24 t caught
48	Vessel Survey	29/06/2016 6:59	Graveyard	Vessel survey Graveyard. Otokau had been here for last 24 hrs or so catching 24 tonnes in 5 or 6 shots. Some indication of roughy down the side of the hill but nothing much. Mark on top of the hill likely cardinal mark, but interestingly not high signal so sparse density; some indication of individual high ts fish even at the long range from the surface.
49	Vessel Survey	29/06/2016 9:42	Mummy	Very calm conditions, high quality vessel acoustics. Mark sitting above top of Mummy plus some scatter down the side. Nothing too exiting. Skipper Gavin from Otakou said over the radio that he had caught mostly sharks there over the years.
50	Vessel Survey	29/06/2016 11:24	Morgue	Calm seas, high quality acoustic. Star pattern survey of Morgue. Large mark on top of the hill with ESR (extreme signal region) just above seafloor at the top but absent from subsequent surveys
51	Vessel Survey	29/06/2016 12:47	Morgue	High quality acoustics. A second star pattern survey at 22:5 degree rotation to previous survey. Good marks away from the bottom. No sign of ESR apart from right at the start so continuing on. ESR comes into play in 2,3 and 4th transects
52	AOS Survey	29/06/2016 14:54	Mummy	Tiny mark on top of hill. 2 pass survey & 100 m low pass to look at small mark, thought to be sharks. No sign of significant roughy.
Operation Number	Operation Type	Start Date & Time (UTC)	Location	Comment

53	AOS biological	29/06/2016 20:47	Mummy	AOS biological/TS tow. The two forward 38kHz quadrants look like they have become less sensitive. No roughy caught. 400 kg Baxter's dog shark and 168 kg of oreo (smooth and black).
54	AOS biological	29/06/2016 23:47	Morgue	4 t roughy.
55	Fishing shot	30/06/2016 22:10	Rekohu	AOS removed from net to reduce the risk of damage during hauling. Large catch, 69 t roughy.
56	Fishing shot	1/07/2016 22:04	Rekohu	28t - No AOS rough seas
57	AOS Survey	2/07/2016 8:52	Rekohu	High quality survey, extensive marks present. Too noisy to work up vessel survey, could be workable with filters imbedded
58	AOS biological	2/07/2016 20:20	Rekohu	7 t roughy
59	AOS Survey	2/07/2016 22:20	Rekohu	Good quality AOS survey with extensive marks. Toward the end of the initial interlace, fish continued to be seen. Too noisy to work up vessel survey, could be workable with filters imbedded
60	AOS biological	3/07/2016 14:10	Rekohu	No video. AOS in survey mode not s/trawl mode so no video or Gig E. 26 t roughy
61	Vessel Survey	3/07/2016 16:35	Rekohu	
62	Vessel Survey	3/07/2016 21:14	Rekohu	Second vessel survey of Rekohu.
63	AOS biological	4/07/2016 2:02	Rekohu	Trawl shot with fibre optic cable connected. Video live feed and real time two frequency acoustics. No Gig E. 37 t roughy.
64	Vessel Survey	4/07/2016 5:11	Rekohu	Vessel survey Rekohu while 37 catch is being processed.
65	Vessel Survey	4/07/2016 12:06	Rekohu	Noisy data Conducting E-W interlaced survey at 0.4 n.mile
66	AOS Survey	4/07/2016 19:08	Rekohu	Long 16 hour AOS survey some good marks but also appeared a lot happening in terms of fish movement. Too noisy to work up vessel survey, could be workable with filters imbedded
Operation Number	Operation Type	Start Date & Time (UTC)	Location	Comment

67	AOS biological	5/07/2016 12:24	Rekohu	Shooting at large strong mark. AOS glitched out and did not record acoustics or video. 17 t roughy.
68	AOS Survey	5/07/2016 14:35	Rekohu	Retrieved after first transect to check system was logging.
69	AOS biological	6/07/2016 8:20	Rekohu	Final shot at Rekohu. Some difficulty in locating marks prior to shooting, perhaps an indication that it was indeed the right time to leave. 36 t roughy.
70	Vessel Survey	6/07/2016 21:46	Mt Muck	Furuno FCV on
71	Vessel Survey	7/07/2016 10:05	Spawn Plume	Localised vessel survey at the Plume. Aborted after a couple of transects as fish were not completely bound by the shallowest part and Furuno was left on.
72	Vessel Survey	7/07/2016 11:20	Spawn Plume	Recommencing vessel survey at Spawn Plume on reasonable aggregation.
73	AOS biological	7/07/2016 17:00	Spawn Plume	18 t roughy, 70% females, half of which are actively spawning or are spent. Improved GiG-E image quality after cameras were re-focused and shutter speed reduced to 20 msec., Aperture changed from 8 to 5.6. Significant improvements to imagery. (JC) Vessel shut down after shot to fix hydraulic leak on pitch control of the prop. (0700-11:50)
74	Vessel Survey	8/07/2016 2:11	Spawn Plume	Interlaced vessel grid survey following sighting of good marks during zig zag searching survey. Good marks observed.
75	AOS Survey	8/07/2016 7:17	Spawn Plume	AOS survey back over the aggregations that we had just been surveying.
76	AOS biological	8/07/2016 19:45	Spawn Plume	12 t roughy, 99% females spawning/spent Rough seas made it difficult to find a mark, tow was on the bottom for 25 min before coming across roughy. Stayed in mark for three minutes
77	AOS Survey	8/07/2016 22:25	Spawn Plume	
78	AOS Survey	9/07/2016 13:04	Mt Muck	AOS survey Mt Muck - night time
79	AOS biological	9/07/2016 18:00	Mt Muck	Optic fibre, top bridle broke. Did not fish efficiently. Strobes did not work on Gig-E. 3 t roughy.
Operation Number	Operation Type	Start Date & Time (UTC)	Location	Comment

80	Vessel Survey	9/07/2016 20:55	Spawn Box	East Spawn Plume area, 2013 grounds. When back in the area for 2016 spawn Furuno turned on for searching purposes Small marks hard down 800-850m
81	AOS biological	10/07/2016 3:01	Spawn Box	11 t roughy with few minutes bottom time
82	AOS Survey	10/07/2016 7:09	Mt Muck	Four transect star pattern survey
83	AOS Survey	10/07/2016 10:40	Mt Muck	Four transect star pattern survey, rotated at 22.5 degrees to previous pattern
84	AOS biological	10/07/2016 14:40	Mt Muck	22 t - ORH and 300kg cardinal - 60-70% females, spawning/spent.
85	AOS Survey	10/07/2016 21:40	Spawn Plume	Interlaced AOS grid survey with occasional decent marks observed on the vessel sounder
86	AOS biological	11/07/2016 9:21	Spawn Plume	19 t roughy.
87	Vessel Survey	11/07/2016 12:09	Spawn Plume	Vessel survey.
88	AOS biological	11/07/2016 19:30	Spawn Plume	11 t roughy.. Fibre optic connected
89	AOS calibration	12/07/2016 1:00	Spawn Plume	Very successful operation

8 Appendix D – Thematic maps of echo-integration outputs

8.1 Rekohu

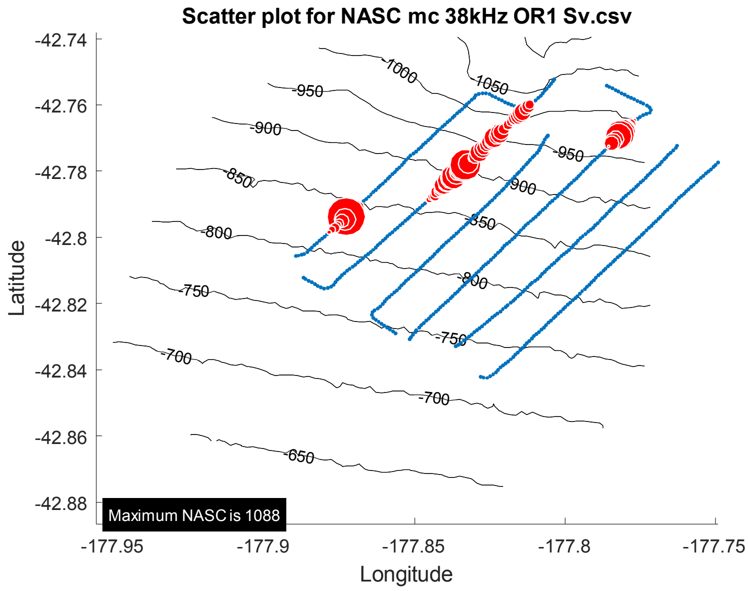

Figure 30. OP57 thematic map of AOS 38 kHz echointegration NASC values at Rekohu.

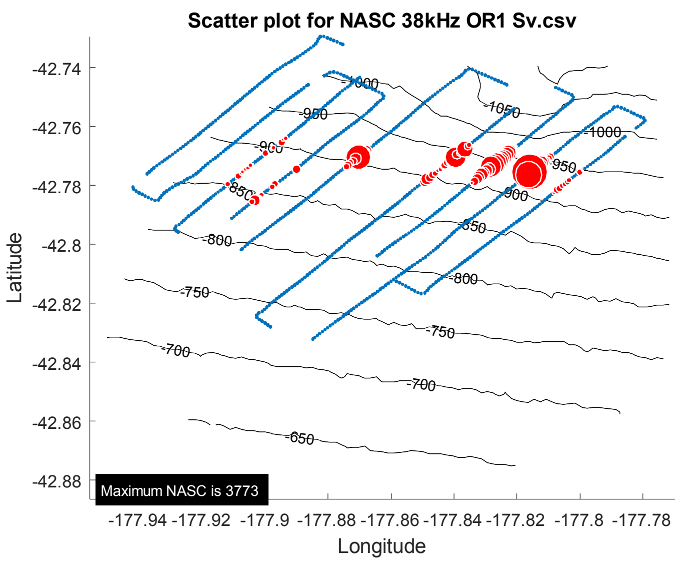

Figure 31. OP59 thematic map of AOS 38 kHz echointegration NASC values at Rekohu.

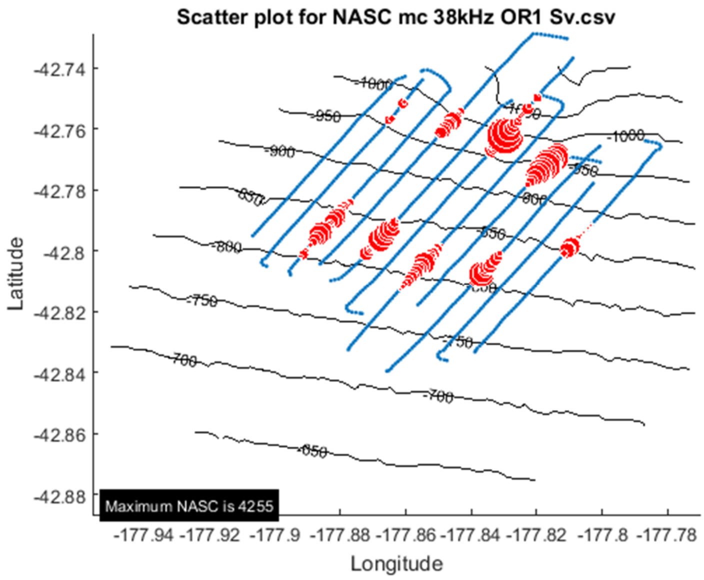

Figure 32. OP66 thematic map of AOS 38 kHz echointegration NASC values at Rekohu.

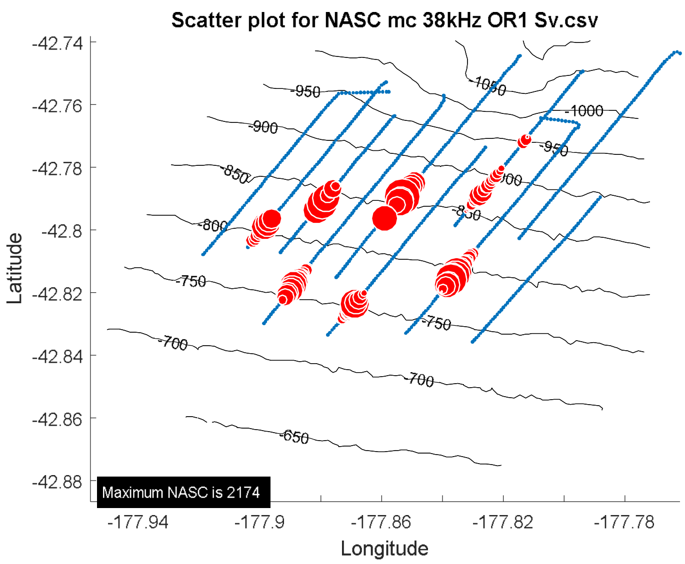

Figure 33. OP68 thematic map of AOS 38 kHz echointegration NASC values at Rekohu.

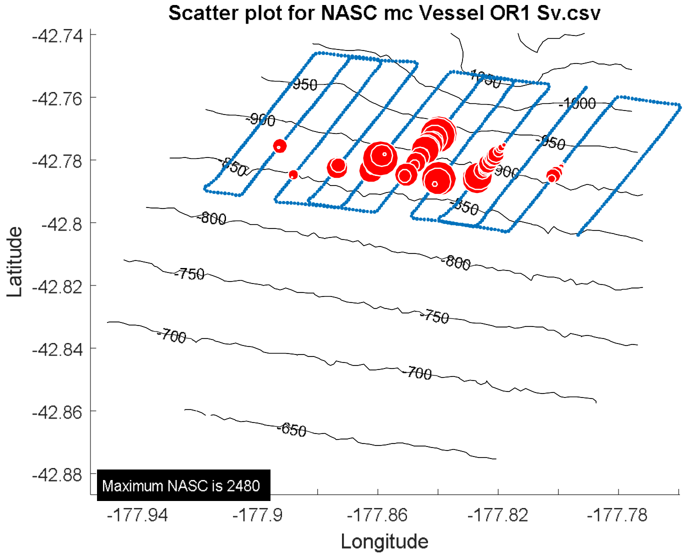

Figure 34. OP61 thematic map of echointegration NASC values at Rekohu Vessel 38 kHz.

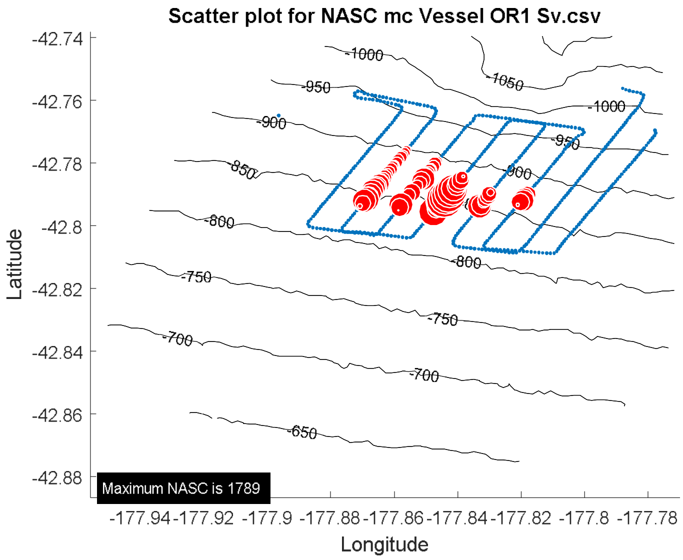

Figure 35. OP62 thematic map of vessel 38 kHz echointegration NASC values at Rekohu.

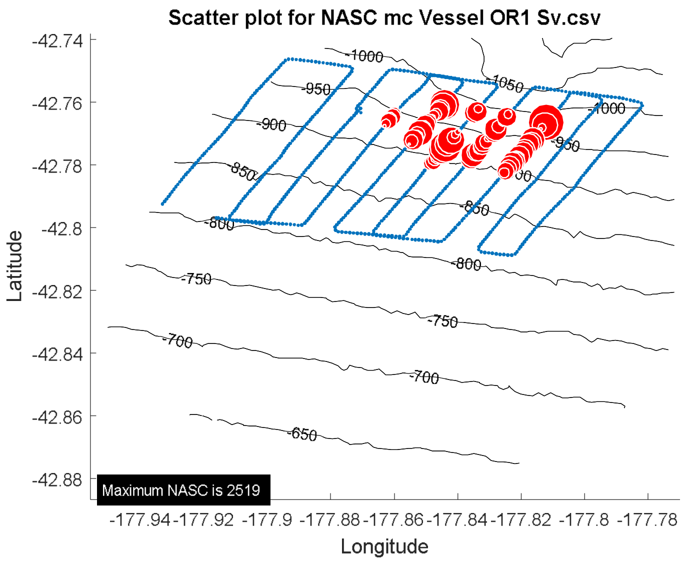

Figure 36. OP64 thematic map of vessel 38 kHz echointegration NASC values at Rekohu.

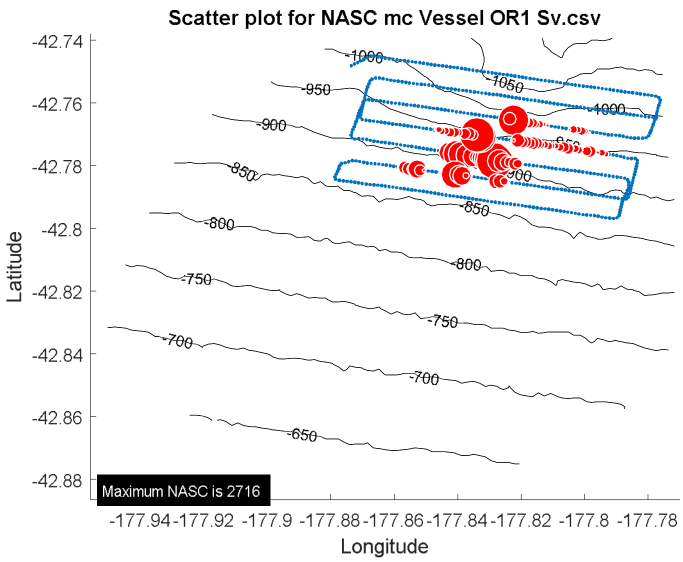

Figure 37. OP65 thematic map of vessel 38 kHz echointegration NASC values at Rekohu.

8.2 Spawn Plume

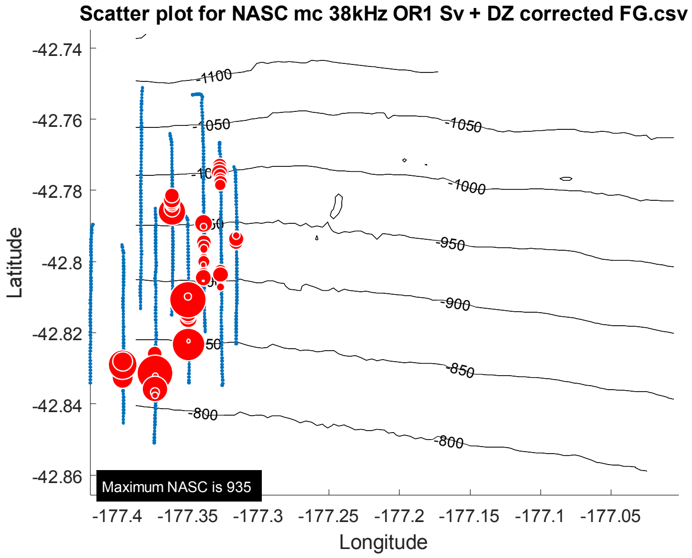

Figure 38. OP75 thematic map of vessel 38 kHz echointegration NASC values at Spawn Plume.

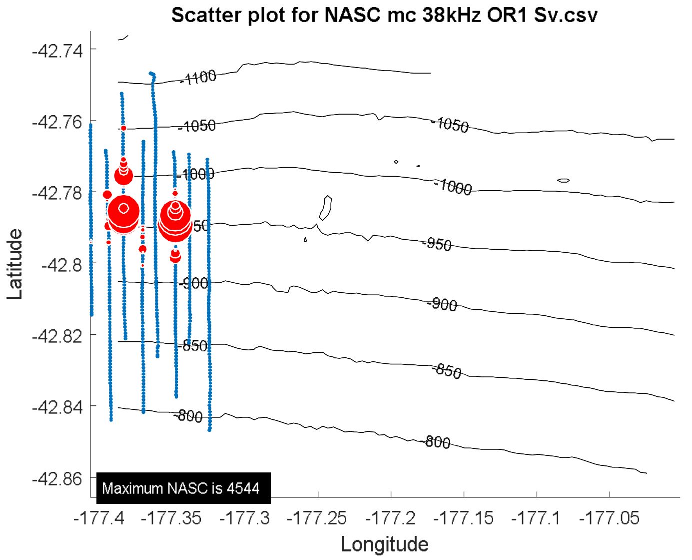

Figure 39. OP77 thematic map of vessel 38 kHz echointegration NASC values at Spawn Plume.

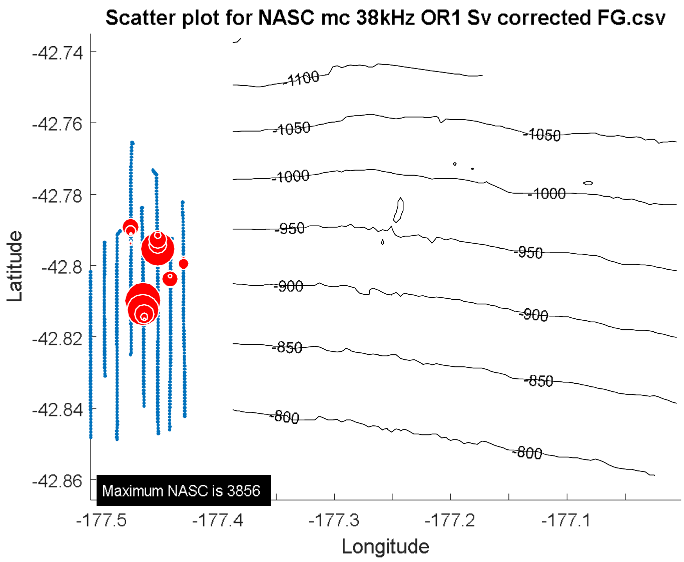

Figure 40. OP85 thematic map of vessel 38 kHz echointegration NASC values at Spawn Plume.

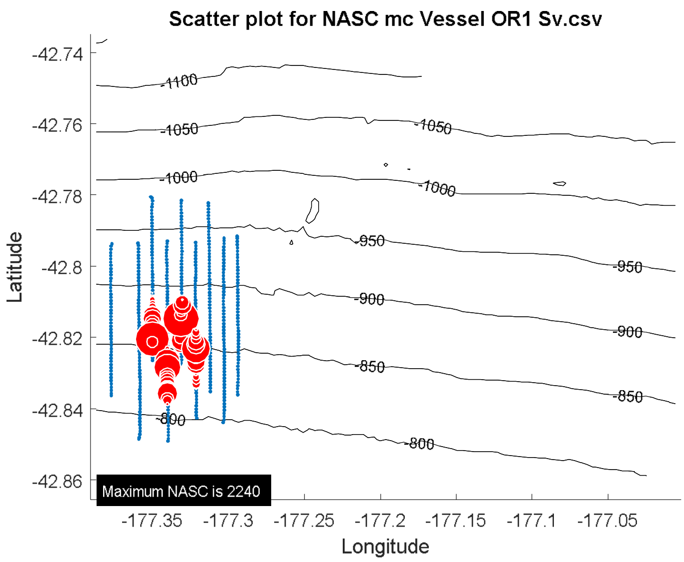

Figure 41. OP72 thematic map of vessel 38 kHz echointegration NASC values at Spawn Plume.

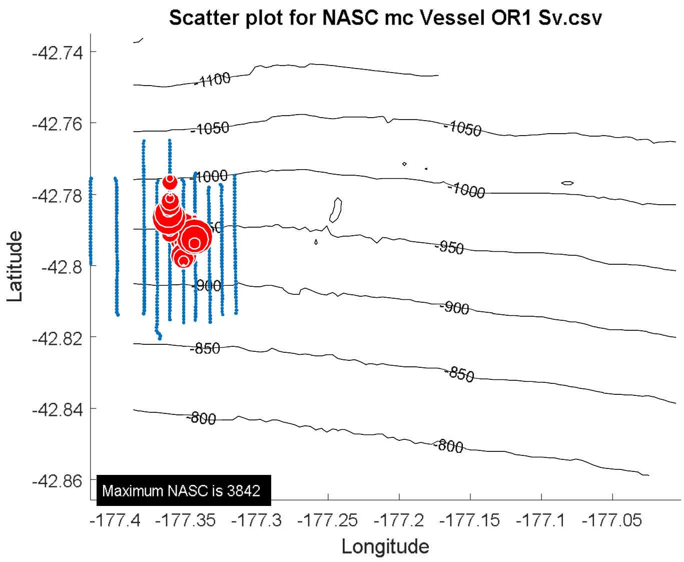

Figure 42. OP74 thematic map of vessel 38 kHz echointegration NASC values at Spawn Plume.

Mt Muck

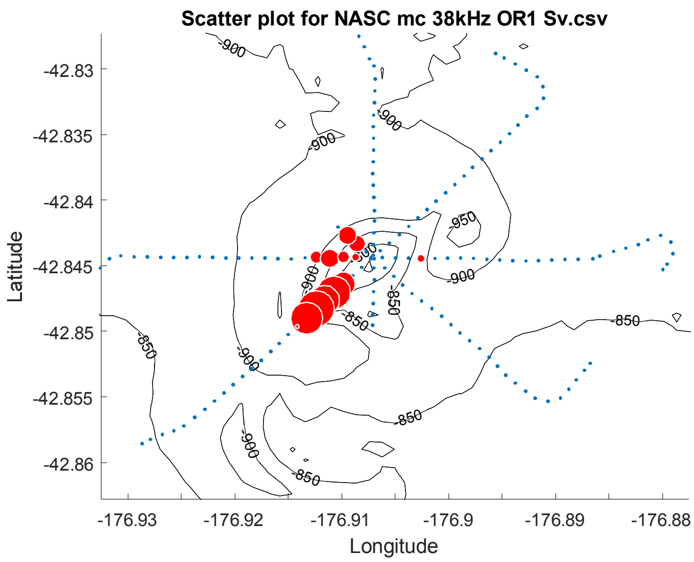

Figure 43. OP78 thematic map of AOS 38 kHz echointegration NASC values at Mt Muck.

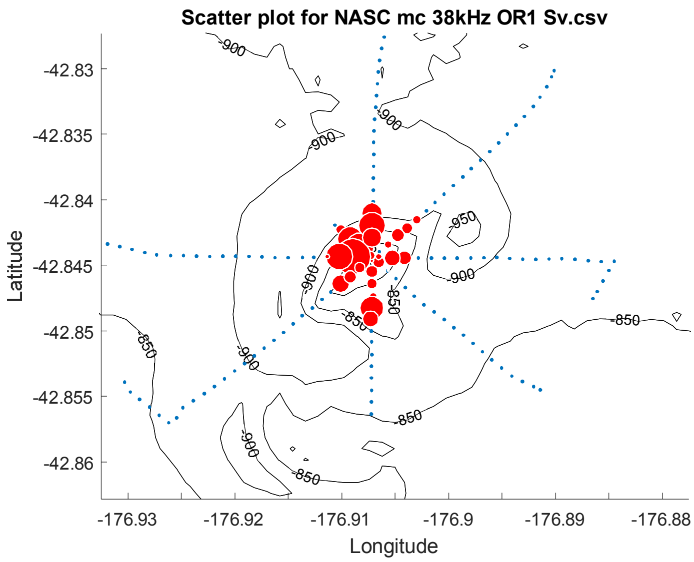

Figure 44. OP82 thematic map of AOS 38 kHz echointegration NASC values at Mt Muck.

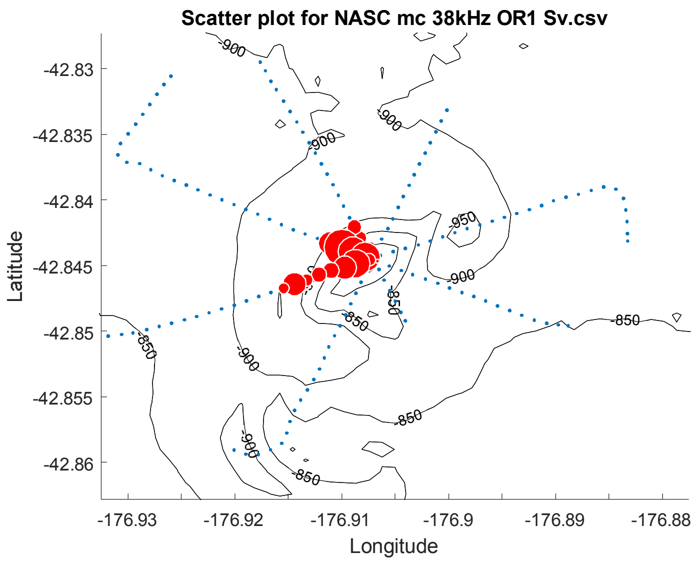

Figure 45. OP83 thematic map of AOS 38 kHz echointegration NASC values at Mt Muck.

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