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South-west Challenger Plateau trawl and acoustic biomass survey, June-July 2018

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Overview
Biomass estimation surveys of Challenger Flats and Westpac Bank were completed over an 11-day period starting on the 27th of June 2018 on the factory freezer trawler FV *Thomas Harrison*. Acoustic biomass estimates were made using a net-attached Acoustic Optical System (AOS) and 38 kHz echosounder. During the same survey a random stratified trawl survey (RSTS) was conducted at the Challenger Flats region.

Challenger Flats
Acoustic surveys
At Challenger Flats Core West region an extensive aggregation of orange roughy was located and acoustically surveyed. Biomass estimates from the AOS 38 kHz were 10 758, 11 497, and 14 098 t. Vessel-based 38 kHz estimates ranged from 6557 to 11 865 t. Biological sampling of the aggregations indicated that the surveys were conducted during the peak spawning period. The Core East region returned high catch rates on three of the RSTS trawls, but no aggregations were found that could have justified the time investment in conducting a full AOS survey.

RSTS survey
The random stratified trawl survey was conducted in the Challenger Flats area using operational and gear parameters consistent with previous trawl surveys in the time series. There were 6 strata and 47 phase 1 stations. The planned phase 2 stations were not done due to weather and gear problems. The biomass estimate for orange roughy at least 27 cm in length (the estimate reported for stock assessment) was 48 000 t (CV 51%). The estimate of biomass was very uncertain because of three very high catch rates in the Core East stratum due to shortened tows. The biomass estimate is sensitive to the treatment of the shortened tows in the biomass calculation. The reported estimate uses the same short tow adjustment that was applied to the other trawl survey results in the time series.

Volcano
Two AOS surveys were conducted at Volcano with substantial plumes of orange roughy extending by as much as 200 m into the water column. The two 38 kHz estimates were 4449 and 4072 t. Early vessel-based observations on the first visit found that orange roughy aggregations were present but at low density. Later in the survey, aggregations were more readily observed above the surrounding backscatter. This, and the biological data, suggested that the survey was early and peak-of-spawning may not have been reached. Future surveys should allow extra time to follow the spawning progression using biological sampling and observation of the plumes over a longer timeframe to provide estimates that best represent the population at peak-of-spawning.

Overall outcomes
Extended surveys at an offshore location are costly. Combining RSTS and acoustic surveys offered potential synergies while optimising the use of vessel time. The acoustic programme needed to locate and survey the spawning aggregation. This required sustained observations and a high degree of flexibility to devise survey patterns. The RSTS operated in an opposite manner with pre-defined trawl

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stations randomly located within strata over the wider region. The surveys made best use of the vessel given these conflicting needs but note there is a risk with this type of combined survey that either or both programmes can be compromised. Should future surveys attempt to combine acoustics and RSTS, it is the possibile that meeting survey objectives of either or both programmes might be at risk because of competing needs.

Conclusions, future work, and outstanding issues

The current Deepwater Working Group protocol is to multiply vessel-based acoustic biomass estimates by a factor of 1.33 to account for signal loss due to motion and bubble attenuation. Consideration should be given to separating these factors. The motion data are available and thus can be used to make a direct correction for motion related loss that is independent of considerations of bubble loss. Loss due to motion ranged between 7% and 15%. Loss due to bubble attenuation is a separate question and will be dependent on current and prior weather conditions and vessel design and requires further work to better quantify this effect. The AOS does not suffer from bubble attenuation effects when at depth and motion loss is less than 1% because the platform is highly stable when attached to the trawl net.

Loss due to signal absorption by seawater differs by about 20 % for vessel-based 38 kHz data depending which equation is used; using the Francois & Garrison (1982) equation will result in a higher biomass than if the equation of Doonan et al. (2003a) is used. The closer range of the AOS reduces this range-dependent loss. However, the AOS 120 kHz has a factor of 4 higher loss compared with the 38 kHz and thus has a proportionally higher potential for error. Further work on absorption estimates is recommended.

At the time of the survey, the spawning orange roughy were migrating and forming plumes. Both these activities cause problems for the random trawl survey. There is the potential for double counting because fish move around and at the same time the potential to under-estimate the biomass if fish are concentrated in spawning plumes that are excluded from RSTS sampling. Although the trawl survey has served as a useful backup to the acoustic survey in previous years, the last two surveys have CVs of over 50%. It may be that it is now best to concentrate all the survey effort on the acoustic survey. This would allow more time to search for and survey spawning plumes.

1. INTRODUCTION

From the 27th June to the 8th of July 2018 a programme of trawl and acoustic surveys was conducted aboard the factory freezer trawler FV *Thomas Harrison* on the south-west Challenger Plateau within New Zealand's ORH7A fisheries management area and on the adjacent Westpac Bank beyond the 200 n.mile Exclusive Economic Zone (EEZ) boundary. The orange roughy fishery in these two areas is managed as a straddling stock (Figure 1).

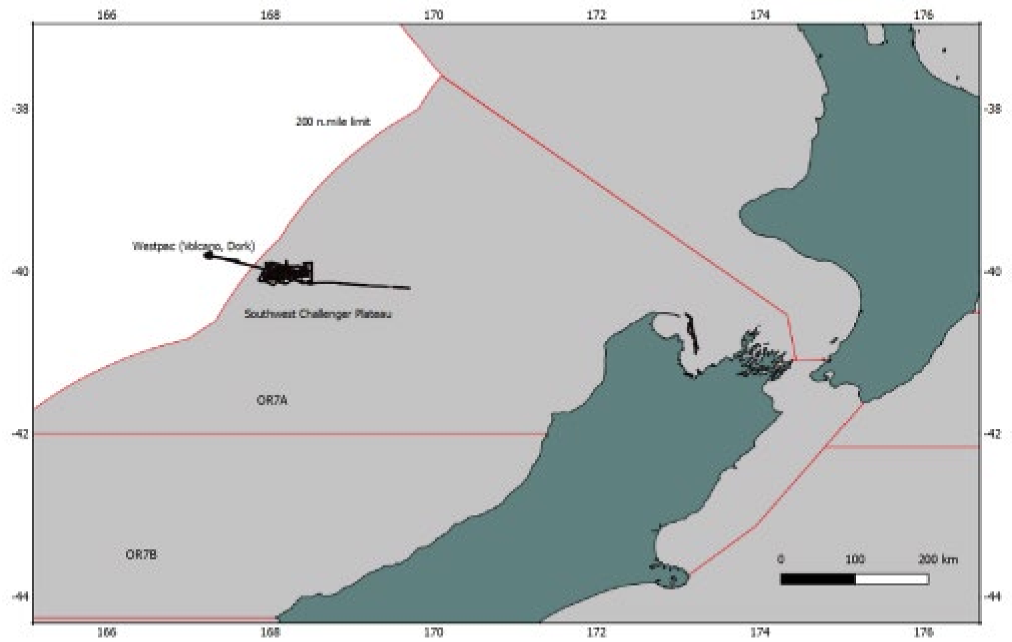

Figure 1: Overview map of the ORH7A Fishery Management Area showing the regions where survey activities were conducted on the south-west Challenger Plateau and on the adjacent Westpac Bank.

Background

The orange roughy fishery on the south-west Challenger Plateau started in 1981 and catches increased rapidly thereafter with the discovery of spawning aggregations, mainly on the Challenger Flats and outside the EEZ on the Westpac Bank (Figure 1). The fishery was managed as a single straddling stock through the setting of Total Allowable Commercial Catch limits (TACCs) which were increased progressively from 4950 t in 1984/85 to a high of 12 000 t in 1987/88. TACCs were subsequently progressively reduced to 1900 t in 1989/90 when stock assessments suggested that the stock had been fished down to below B_{MSY} (Clark & Francis 1990). The TACC was retained at this level up to 1997/98, after which it was reduced to 1425 t in 1998/99 following concerns that the stock was not rebuilding. In 2000, reassessment of the stock using standardised CPUE indices in a stock reduction model suggested that the stock was at about 10% of B_{MSY} (Field & Francis 2001). The fishery was consequently closed from 1 October 2000 with a nominal TACC of 1 t in an attempt to rebuild the stock at the maximum rate.

An exploratory trawl survey of the area in 1983 led to further, more restricted and focused surveys, between 1984 and 1986, followed by a time series of random stratified trawl surveys (RSTS) between 1987 and 1990 (Clark & Tracey 1994).

The first combined acoustic and random stratified trawl survey of the south-western Challenger Plateau (including the Westpac Bank) was conducted in 2005 (Clark et al. 2005) from a commercial vessel FV *Thomas Harrison*, followed by similar surveys from the same vessel in 2006 (Clark et al. 2006), 2009 (Doonan et al. 2009), 2010 (Doonan et al. 2010), 2011 (Hampton et al. 2013), 2012 (Hampton et al. 2014), and 2013 (Boyer et al. in prep). These surveys covered the same core area which was expanded to the east of the Pinnacles in 2006 and further east in 2009 to include an area where concentrations of orange roughy had been found in the 2006 survey. The surveys included Westpac Bank in all years except 2012, when surveying here was omitted due to the shortage of available vessel time.

This 2018 survey marked the eighth combined trawl and acoustic biomass survey of orange roughy on the south-west Challenger Plateau (including Westpac Bank) conducted from the Sealord vessel FV *Thomas Harrison*. This report summarises the activities of the voyage and presents acoustic and trawl-based biomass estimates.

Specific project objectives

Overall objective: Using acoustic and trawl survey methodology aboard a commercial trawler to obtain:

a.) a trawl biomass estimate of orange roughy over flat ground with a target CV of 30% or less, and
b.) acoustic estimates of spawning orange roughy biomass in aggregations over flat ground and on Volcano Hill with a target sampling CV of 20% or less.

The intent of the survey was to extend the Challenger Plateau trawl time series and to provide an acoustic estimate comparable with the stand-alone estimate of 2009. Failing that, the backup plan was to combine the acoustic and trawl estimates to be comparable with the 2010 and 2013 surveys.

Voyage objectives

1. Carry out a 2-phase random stratified trawl survey (RSTS) of the defined area on the south-west Challenger Plateau (excluding Underwater Topographic Features (UTFs).
2. Undertake Acoustic and Optical System (AOS) transects over fish aggregations found on the south-west Challenger Plateau in ORH7A to establish whether they are orange roughy.
3. Complete a minimum of five acoustic snapshots on each orange roughy aggregation found, using either the AOS or the hull (not on UTFs) echosounder, for biomass determination. Undertake targeted bottom trawling to secure the biological information required to inform the acoustic data and to provide species composition and biological data for key bycatch species.
4. Carry out a minimum of five AOS snapshots of the aggregation on Volcano Hill in the adjoining Westpac Bank designated area. Carry out AOS snapshots on other UTFs should time allow.
5. Collect otoliths from at least 500 fish from each spawning aggregation to enable the estimation of an age frequency for each aggregation.
6. Calibrate the ES60/70 echosounder on FV *Thomas Harrison* at the beginning and/or the end of the survey and undertake a deep calibration of the AOS acoustic systems, weather permitting.
7. Collect temperature/depth profiles from all areas surveyed acoustically.
8. Protected corals found identified and recorded as per the normal MPI observer protocol.

2. METHODS

Two survey methods for biomass estimation were used during this voyage. These are 1) random stratified trawl survey and 2) acoustic transect surveys. The respective biomass estimation methods and the results are described separately below.

Broadly, the acoustic transect surveys were focused on aggregations in two areas: an area known as ‘Challenger Flats’ on the south-west Challenger Plateau within ORH 7A and on Volcano, a UTF on Westpac Bank. The RSTS occurred entirely in the Challenger Flats area and excluded UTF features, as has been the practice since 2012.

2.1 Acoustic surveys

2.1.1 Acoustic instrumentation

The CSIRO Acoustic Optical System (AOS) was the primary survey tool for estimating biomass using echo integration methods. It consisted of a sled-style platform attached to the headline of the vessel's demersal trawl net. For this survey, the AOS housed a three-frequency acoustic system (12, 38, and 120 kHz) using Simrad EK60 transceivers. The 38 and 120 kHz frequencies were for quantitative measures whereas the 12 kHz frequency was to provide a lower frequency to help discriminate large gas bladder species. The system was battery powered with all data logged to internal storage media. The optical system had wide-angle standard definition, low-light, Hitachi video camera with a wide-angle Fujion lens. Two LED lights provide illumination. In addition, stereo digital stills were recorded by 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 2 frames per second. Specifications of the CSIRO 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 EK60, 12, 38 and 120 kHz split-beam transceivers. Transducers: AirMar 12 kHz (14° single beam), 38 kHz - Simrad ES38DD (7° beam width), SN 28362; and 120 kHz - ES120–7CD (7° beam width), SN 109.
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 n.mile 8 m W red lasers set 400 mm apart.
Environmental	Seabird SBE37si CTD.
Computing	Industrial Arc PC (running Simrad EK80 1.1.12 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.

2.1.1.1 AOS calibration

Calibration of the AOS was carried out on the 4th of July 2018 in calm conditions. This involved lowering system through the range of working depths (900 m) with a 38.1 mm tungsten carbide reference sphere suspended at about 19 m beneath the platform. Unfortunately, the platform was about 8 degrees from level, possibly due to bridles being snagged, unbalancing the system. This meant that the calibration sphere only occasionally passed within the transducer beam. Weather conditions deteriorated so a second attempt was not possible. As a consequence, the data set was limited but was sufficient to give a preliminary estimate of calibration parameters as a first pass approximation. A follow-up calibration exercise was carried out in February 2019 off the west coast of Tasmania. This exercise was far more successful. Five deployments were carried out. The platform was close to level with large numbers of sphere target measures made on each deployment. Having multiple deployments has enabled investigation of calibration repeatability, a key question when operating the AOS through large pressure changes many times as is done over the course of a survey. The February calibration exercise showed that the ES38DD 38 kHz was highly repeatable over multiple deployments with typical variation 0.2 dB. Because of this, and that there was an abundance of sphere measurements throughout all working ranges, the February calibration results were used for 38 kHz in preference to the preliminary estimates from the July 2018 calibration.

The CSIRO 120 kHz transducer (SN109) was not available for the February 2019 calibration. This means that results from the July 2018 calibration derived from the limited data were used for the 120 kHz data. 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.

System	AOS	AOS	Vessel
Frequency (kHz)	38	120	38
Calibration data set	February 2019	4th July 2018	26th June 2018
Transducer model	Simrad ES38DD	Simrad ES120-7CD	Simrad ES38B
Serial Number	28362	109	
Transceiver power (W)	2000	280	2000
Transceiver pulse length (ms)	2.048	1.024	2.048
Transducer gain (dB)	23.04	27.3	24.21
Sa correction (dB)	-0.42	-0.3	-0.393
Two way beam angle (dB re 1 steradian), adjusted for local conditions	-20.96	-20.31	-20.44

2.1.1.2 AOS Operational modes

The AOS was fixed to the headline of the vessel's "Mother" demersal trawl net and operated in two modes plus a calibration mode (Table 3). 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.

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 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. 2011, Ryan & Kloser 2016). These are referred to as Mode 1 surveys. To minimise gear avoidance by orange roughy and dead-zone uncertainty, the AOS was towed in the midwater at a distance of 250–350 m above the seafloor. Grid transect surveys were applied at Challenger Flats because they were appropriate for the distribution of orange roughy aggregations that were found within a rectangular survey box. At Volcano, the survey followed the recommendations of Doonan et al. (2003a) where star pattern surveys were appropriate for the orange roughy that were distributed around a central bathymetric feature.

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

Demersal trawls with the AOS attached were targeted at the spawning aggregations to collect biological samples that are representative of the acoustically surveyed population. Note that these trawls were entirely separate from those of the RSTS which used a different net and were conducted at pre-defined locations across the Challenger Flats survey region. The acoustic systems were set to a short pulse length (0.256 or 0.512 ms) and a fast ping rate (~10 Hz) for close-range fish target strength (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 a frame rate of 1–2 shots per second were collected throughout these demersal trawls to enable accurate fish length determination.

2.1.2 Acoustic instruments – vessel-mounted sounder

The FV *Thomas Harrison*'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 calibrated as the first operation of the voyage on the 25th of June. Details of vessel calibration are given in Appendix A: Vessel and AOS calibration. The FV *Thomas Harrison* had a pair of single-beam 38 kHz echosounders, angled at 14 degrees from vertical one to port and the other to starboard, giving extra observational coverage that was helpful when searching or when surveying to understand fish distribution away from the transect lines. The calibrated 38kHz echosounder was set to passive for a period to check that these 'side-angled' transducers were not causing interference. This test confirmed that there was no problem with running the three 38 kHz systems concurrently. The FV *Thomas Harrison* also had an 11-degree 18 kHz echosounder which was operational throughout the survey. This lower frequency provided echograms with some subtle differences compared with the 38 kHz echograms that helped interpretation, particularly for regions of backscatter from low numbers of high-signal gas bladder fish, which might otherwise be misinterpreted as orange roughy.

2.1.2.1 Vessel calibration

The vessel's Simrad ES60 38 kHz echosounder was calibrated in Tasman Bay as the first operation of the voyage using the standard reference sphere method (Demer et al. 2015). A 60 mm copper sphere suspended from three mono-filament lines was used as the reference. Results of the vessel calibration are summarised in Table 2 and a detailed report given in Appendix A: Vessel and AOS calibration.

2.1.3 Acoustics: seawater absorption

AOS acoustics

Values for seawater absorption at 38 and 120 kHz and sound speed were calculated from the equations of Francois & Garrison (1982) 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)	0.00954**	0.035**
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).

2.1.4 Data processing and interpretation

Processing of the acoustic data was done using Echoview 9 analysis software. 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 were applied to the towed body operator in Echoview to create echograms with an absolute depth reference. The AOS platform motion was recorded at 10 Hz by a Microstrain 3DM-GX25 motion reference sensor. Test data sets were processed to quantify the difference between motion-corrected (Dunford 2005) and uncorrected results. Due to the high stability of the AOS platform when attached to the net, and relatively close range to the fish schools (about 300 m), motion correction increased biomass by less than 1%. Correcting data for motion has a large processing overhead and was not applied as a matter of routine given that it makes such a small difference.

2.1.4.1 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.

2.1.4.2 Acoustic dead-zone estimate

The acoustic dead zone is the region close to the seafloor where the acoustic signal cannot be measured due to the physical characteristics of the transmitted pulse (Ona & Mitson 1996) and, on sloping ground, due to seafloor backscatter from off-axis, side-lobe signal coinciding with water column backscatter (Kloser 1996, Ona & Mitson 1996). For the steep-sided features the contribution to the dead zone 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 dead-zone 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 dead-zone region are both possible. It was assumed that the density of fish immediately above the acoustic bottom was on average representative of the density within the dead-zone region. An estimate of backscatter within the dead zone was made as follows. Firstly an 'acoustic seafloor' line was defined, that is the point at which the water column signal became contaminated with the seafloor reflection signal. The acoustic seafloor line was first generated via the maximum S_v seafloor detection algorithm implemented in Echoview. A back-step of 1.5 m was applied to this line to move it away from the 'acoustic seafloor' signal. This line was visually inspected and manually adjusted where necessary to ensure that contamination by the 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 dead-zone region. The contaminated sample values in the dead-zone 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 the acoustic seafloor signal and the estimated signal from within the dead-zone region. From these data, biomass estimates for (i) above 'acoustic seafloor' and for (ii) above 'acoustic seafloor' plus a dead-zone component were made.

2.1.4.3 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 passed 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.

2.1.4.4 Echogram interpretation and allocation of species

Quantitative analysis and subsequent biomass estimation were 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 given by 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 than at 38 kHz were attributed to homogenous schools of orange roughy (Ryan & Kloser 2016). 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 with regions of orange roughy. A 12 kHz echosounder with 14-degree transducer was used for the first time on this voyage with the expectation of providing extra information, particularly highlighting large gas bladder species. However, the system was excessively noisy, most likely due to low frequency mechanical noise from the trawl-net system. 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.

2.1.5 Biological sampling in support of acoustic surveys

Two biological sampling programmes were carried out during this survey. The RSTS survey programme was conducted to estimate orange roughy biomass across the broader region of the Challenger Plateau and is described elsewhere (section 2.2). To support the acoustic survey programme, trawl shots were made that targeted acoustically significant aggregations to aid with mark identification and collection of biological data to parameterise inputs into the biomass estimation equation of mean orange roughy weight and target strength. These trawls were carried out following completion of an acoustic survey. The AOS was attached to an 'Otakau Mother' trawl. This had 50 m sweeps, 28 m bridles, 100 mm codend mesh, and a 22 m ground-rope.

The catch from each tow was sorted by species to determine catch composition by weight and number of individuals. Orange roughy gonad development stages were determined using an 8-stage maturity scale to monitor the progression of spawning. Length frequencies of abundant species were determined to provide the biological information required to inform the acoustic data. Deepwater sharks were measured for length, sexed, and staged. From each tow a random sample of up to 100 orange roughy was taken from the catch to record standard length, gonad development stage, sex, and to collect otoliths. The aim was to collect a minimum of 300 otoliths from each aggregation. Samples of 20–40 orange roughy stomachs were examined for content, digestion state, and fullness. Catch details are given in Appendix D: Catch composition.

2.1.6 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 2.1.4.4.

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 were 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 minimise 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

For large regions such as the Challenger Flats where orange roughy locations were not centred around a single feature, parallel transect surveys were the most appropriate choice. To minimise possible bias due to fish movement orthogonal to transect lines, an 'interlaced' survey pattern was followed. This involves a set of transects being completed with a certain inter-transect spacing (Survey A). A second set of transects are then completed in the reverse direction that are offset at half the inter-transect spacing of the first set of transects (Survey B). Survey results are combined by calculating the geometric mean of the biomass estimated from the two sets of transects: Combined biomass = sqrt(Survey A biomass * Survey B biomass). Biomass estimates were calculated for 120 kHz and 38 kHz data acquired from the AOS and vessel acoustic data using standard echo-integration methods (Simmonds & 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 survey area (A, $n.mile^2$) were used to estimate biomass (Equation 1)

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

The echogram-defined school regions were assumed to comprise 100% orange roughy.

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

2.1.7 Target strength estimates

Orange roughy TS estimates used were from Kloser et al. (2013), based on a mean fish length of 34.5 cm and TS values of -52.0 and -48.17 dB were used for 38 and 120 kHz, respectively, noting that the 120 kHz estimate 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 (SL) observed at each spawning ground, assuming a TS–standard length slope of 16.15*log10(Ls) (Hampton & Soule 2002).

2.2 Trawl survey

A two-phase stratified random design, as recommended by Francis (1984), was applied. This design is comparable with that used in the 1987–1990 series of trawl surveys, and in the trawl component of the trawl and acoustic surveys between 2005 and 2013.

The survey strata were modified over previous surveys here, comprising two core strata (i.e., Core West and Core East) encapsulating areas where previous surveys and commercial tows had produced high catch rates, and four bounding guard strata (i.e., Guard North, Guard South, Guard East, Guard West) (Figure 2). The revised strata incorporated an area where over 95% of the biomass was encountered during previous trawl surveys in ORH7A. The survey design is provided in the Voyage Plan (Ministry for Primary Industries 2018) and is based on documents presented to, and considered by, the DWWG (Cordue 2014, Doonan et al. 2014, McMillan et al. 2014).

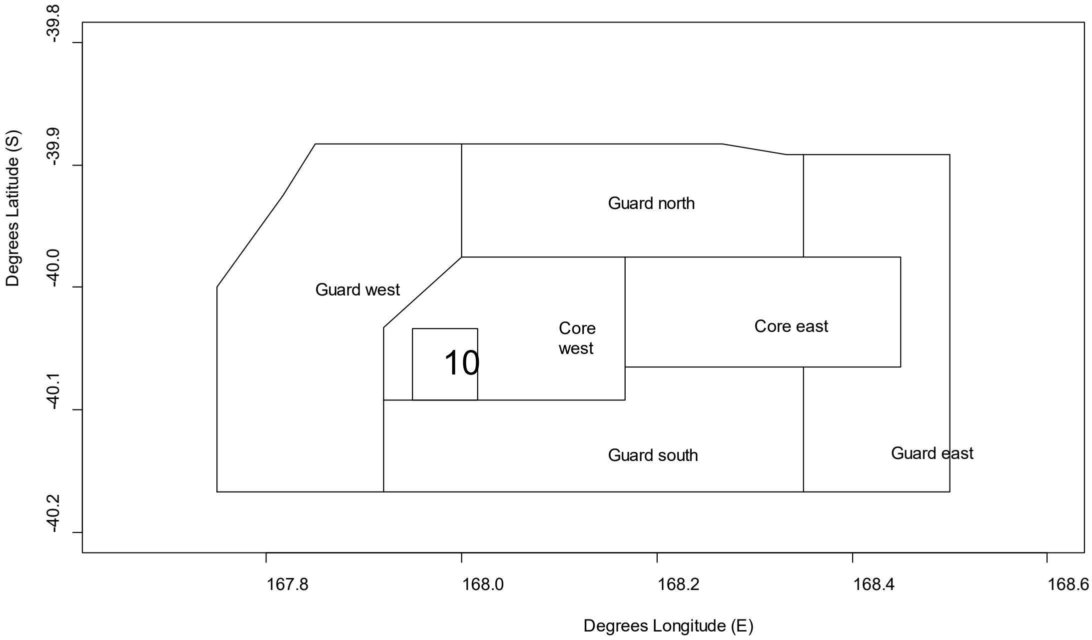

Figure 2: The 2018 trawl survey strata on the south-west Challenger Plateau in ORH 7A. The hill stratum (10) was excluded from the trawl survey.

The trawl survey excluded UTF areas within the survey area and no trawl surveying occurred within hill strata. For phase 1, three tows were undertaken in each of the four guard strata, 14 and 21 tows were undertaken in the east and west core strata, respectively. The survey plan made allowance for an additional six phase 2 tows to be undertaken should they be required to achieve the target CV for the survey.

Tows were carried out at a speed over the ground of 3 knots for a distance of 1.5 n.mile (approx. 30-minute tow duration). Tows were only shortened if there were indications that a dense aggregation/plume had been encountered (e.g., net sensors were triggered), because of rough ground, or for safety reasons.

The four-panel Arrow Trawl net with cutaway lower wings and bobbin rig were provided by Sealord and were set up according to the specifications for surveys undertaken for this area in previous years using FV *Thomas Harrison*. The specifications were as follows: codend mesh of 100 mm; two codends and a single lengthener; rubber and steel bobbin rig; 24 headline floats; 0.5 m layback; 50 m bridles, 70 m sweeps; high-aspect Super-Vee trawl doors (2300 kg, 7 m^2). The net had an expected doorspread of 135–140 m, wingspread of 17 m, and headline height of 5.0–5.5 m.

Door and net sensors were used to monitor doorspread, headline height and bottom contact and every effort was made to ensure that the trawl survey parameters were consistent with those of previous surveys (e.g., tow distance, tow speed, headline height, doorspread). Data from the sensors were communicated to the vessel during all trawls via a trawl monitoring system (Simrad ITI). Tow speed was adjusted where necessary to achieve consistent gear performance, particularly door spread and headline height.

If the gear was hauled early because of rough ground and the tow was less than 1 n.mile and was in a guard stratum then a replacement tow was required (to ensure that there were at least 3 tows in the stratum). The replacement tow was done on the same heading as the original tow with the gear on the bottom at the first occurrence of sufficient flat ground after the encountered rough ground.

If the gear was hauled early because the catch sensors were triggered and/or, given the marks seen on the sounder there was the fear of an extremely large catch, a replacement tow was not needed. The approach used in the 2014 stock assessment (Cordue 2014) was applied where a mean catch rate was used for the trawl station based on a ‘low’ catch rate (assuming the remainder of the tow had zero orange roughy) and a ‘high’ catch rate (the actual catch rate from the tow).

If a random trawl position was such that the gear was not deployed because of the fear of an extremely large catch (i.e., the tow was likely to land in a plume), then a replacement tow would be conducted. Replacement tows were required to be on the same heading as the original tow but with the gear on the bottom approximately 0.75 n.mile before obvious signs of the plume on the sounder (i.e., marks greater than 15 m in vertical extent), with the objective being to sample the plume. If a replacement tow had to be hauled early the provisions of the previous paragraph would apply and the replacement tow would be used as a target identification tow.

The phase 1 tows in the two core strata were required to be done at one time and without a large time gap (i.e., days) between them.

Tow start positions were the vessel’s position when the gear reached the seabed, rather than the trawl net position, which is difficult to accurately determine. Tow start positions were separated by a minimum of 1.5 n.mile in the core strata and 4.0 n.mile in the guard strata and tow tracks were not allowed to intersect. The starting point of each tow (gear on bottom) was either the nominated point or 1.5 n.mile before this point so that the gear left the bottom at the nominated position. This was determined by proximity to other tow lines and strata boundaries, both of which were not allowed to cross, if at all possible. Tows were run parallel to depth contours, weather dependent. The positions of the tows in each stratum were randomly generated, conditional on the minimum specified separation.

The stratum areas and the number of tows planned in each stratum are provided in Table 5.

Table 5: Trawl survey stratum areas and numbers of planned Phase 1 tows.

Stratum	Description	Area (km^2)	Planned Phase 1
1	Core stratum west	248	21
2	Core stratum east	241	14
3	Guard stratum west	492	3
4	Guard stratum east	306	3
5	Guard stratum north	302	3
6	Guard stratum south	353	3
	Total survey area 2018 survey	1 942	47

2.2.1 RSTS biomass estimation

Biomass calculation

The biomass estimate in each stratum was calculated from the mean catch rate within the stratum and the stratum area:

$$B_i = a_i \frac{1}{n_i} \sum_j r_{ij}$$

where

B_i = biomass estimate for stratum i
a_i = area of stratum i
n_i = number of random trawls in stratum i
r_{ij} = orange roughy catch rate of *j*th trawl in stratum *i*.

The catch rate for each trawl was calculated using the distance towed (over ground from start and end positions for the trawl), the mean doorspread as measured during the survey, and the wingspread to doorspread ratio measured on previous surveys (0.127, see Doonan et al. 2009, appendix 9.6), and the orange roughy catch:

$$r_{ij} = \frac{c_{ij}}{w\bar{s}d_{ij}}$$

where

c_{ij}	=	orange roughy catch on the *j*th trawl in stratum *i*
w	=	wingspread to doorspread ratio (0.127)
$\bar{s}$	=	mean doorspread as measured during the survey
d_{ij}	=	distance towed over ground on the *j*th trawl in stratum *i*.

The variance of the biomass estimate in each stratum was calculated using the sample variance from the catch rates assuming the catch rates were independent and identically distributed random variables:

$$Var(B_i) = \frac{a_i^2 var\{r_{ij}\}}{n_i^2}$$

where *var*{} returns the sample variance.

The above equations were used to obtain the total biomass estimate and the biomass estimate for fish with lengths of at least 27 cm (the estimate used in stock assessment). For the latter, the catch on each tow was calculated using the tow specific length frequency and mean weight (individual length and weight measurements were available on every tow except station 41; for station 41 lengths were available and these were converted to weight using a length-weight relationship estimated for the survey).

Short tow adjustment

In the Core East stratum there were three short tows and in addition to the calculation described above three alternative biomass calculations were made for this stratum:

- Use the catch rate assuming no more orange roughy would have been caught and a tow distance of 1.5 n.mile (this defines the 'low catch rate').
- Use the mean catch rate for a lognormal distribution defined by the 'low catch rate' and the unadjusted catch rate (the 'high catch rate' which uses the original catch and trawl distance) being the middle 99% of the distribution.
- Use the mean catch rate for a lognormal distribution defined by the 'low catch rate' and the 'high catch rate' being respectively the 1st percentile and the 95th percentile of the distribution.

The last alternative is the calculation that has been used for previous trawl surveys in this area.

The variance of the average catch rate (for the Core East stratum) was assumed to have an additional component from the lognormal distributions:

$$Var_{east} = \frac{n_{east} var + \sum_{k=1}^{k=3} LN_k}{n_{east}^2}$$

where

Var_{east}	=	estimated variance for the mean catch rate in Core East
n_{east}	=	number of trawls in Core East (which is 14)
var	=	sample variance for the catch rates after substitution of the lognormal means
LN_k	=	variance of the lognormal distribution for the *k*th shortened trawl.

3. RESULTS AND DISCUSSION

A total of 73 survey activities were conducted at the south-west Challenger Plateau between the 27th of June and the 9th of July. Activities are summarised in Table 6. A full list of survey activities is given in Appendix F.

Table 6: Summary of survey activities.

Survey activity	ORH7A Challenger Flats	Westpac Bank - Dork	Westpac Bank - Volcano	ORH7A Megabrick/Twin Tits
RSTS	47 +1	N/A	N/A	N/A
AOS survey	3	0	2	0 (single pass only)
Biological trawls	4	0	3	0
Vessel survey	5	2	2	0

Results are presented on a region-by-region basis. Thematic maps of acoustic backscatter classified as originating from orange roughy are given in Appendix E. Surveying occurred in two main areas: Challenger Flats, a region of relatively featureless terrain located close to the 200 nautical mile limit in ORH7A, and Volcano, a UTF situated beyond the New Zealand EEZ on adjacent Westpac Bank, a 4-hour steam from the Challenger Flats area (Figure 1).

3.1 Acoustic survey results – Challenger Flats

3.1.1 Summary of Challenger Flats survey programme

Substantial aggregations of spawning orange roughy were located in the Core West stratum in and around 168° 08´ E, 40° 01´ S, referred to as the 'Western Aggregation', with surveys focusing on an area of about 7 by 6 nautical miles. The location of biological and acoustic survey activities conducted at Challenger Flats is shown in Figure 3.

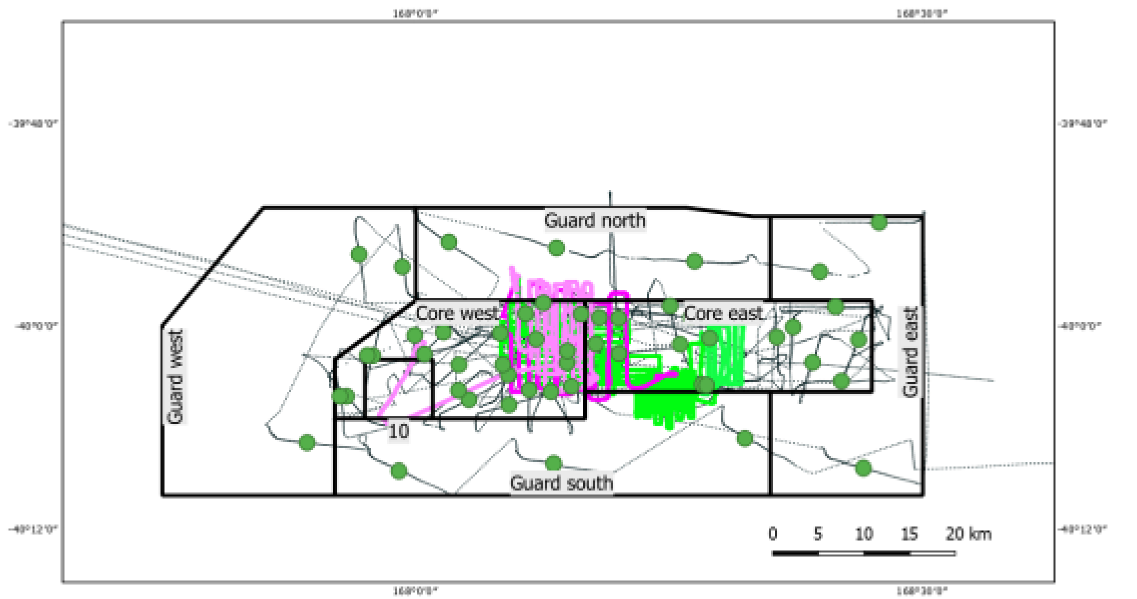

Figure 3: Summary image of activities conducted at the Challenger Flats. RSTS strata are labelled. Green dots indicate start/end location of RSTS trawls. Magenta lines indicate AOS transect surveys, green lines show vessel transect surveys. Dotted black lines indicate underway vessel GPS positions.

The acoustic surveys showed that the main body of aggregated orange roughy moved from the north-west to south-east over a distance of approximately 15 kilometres over an 11-day period (Figure 4).

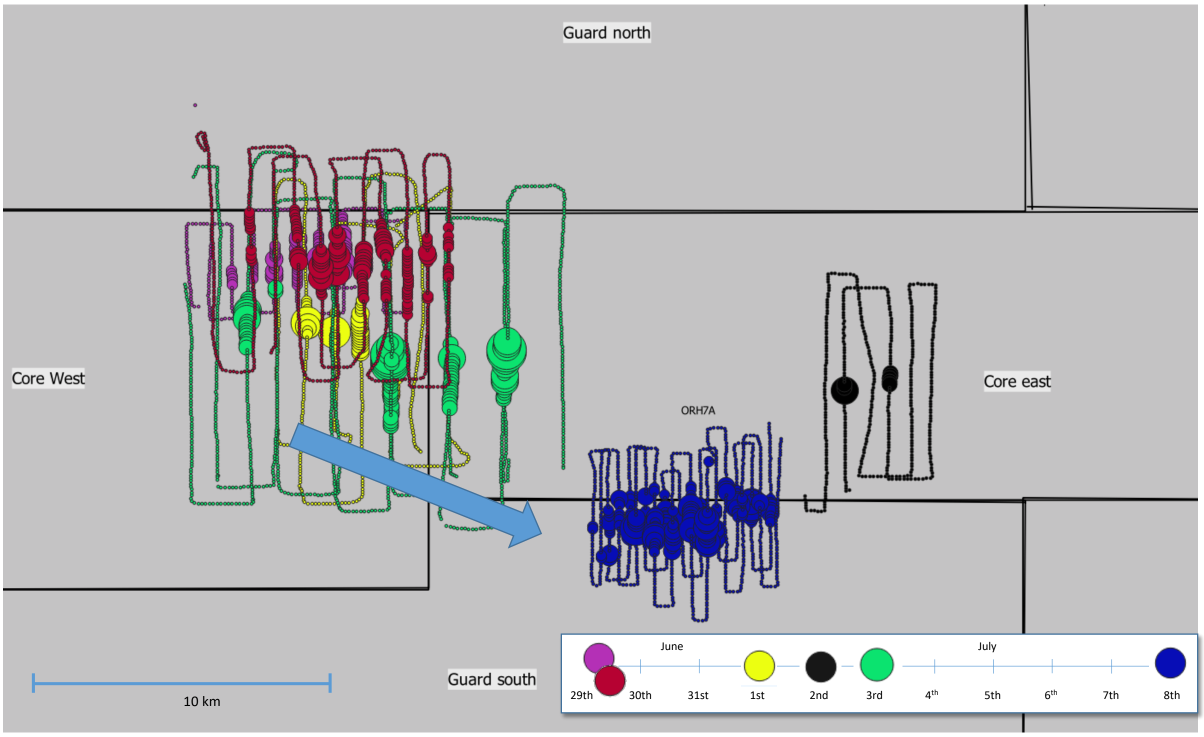

Figure 4: Thematic map showing along-track echo-integrated Nautical Area Scattering Coefficient (NASC) values for six AOS and vessel surveys. The inset is a timeline with coloured circles providing a legend relating to the thematic map.

Figure 5 shows echograms from a large aggregation of orange roughy obtained during an AOS survey on the 1st of July. The survey grid patterns in 2018 were compared with the historic surveys on viewed FV *Thomas Harrison*'s chart plotter and were found to cover similar areas.

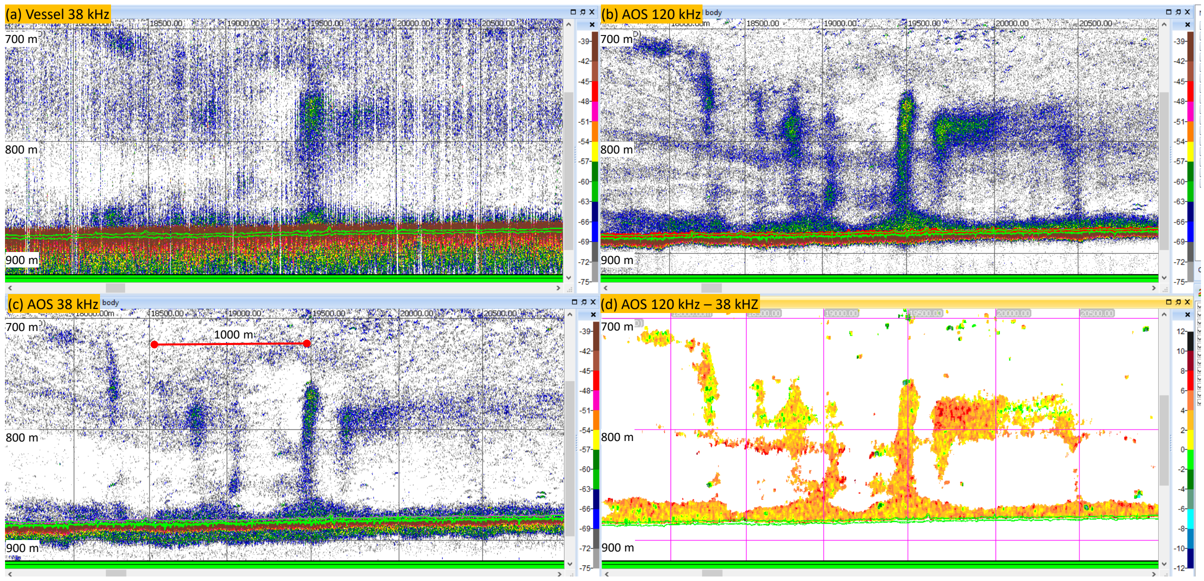

Figure 5: Echogram images of a large aggregation of orange roughy at Challenger Flats, OP35, 1st July 1700 h. (a) Vessel 38 kHz acoustics, (b) AOS at 120 kHz, (c) AOS at 38 kHz, and (d) AOS 120 kHz minus AOS 38 kHz.

Figure 6 shows a three-dimensional view of 120 kHz echogram regions classified as orange roughy at the Challenger Flats. The schools are extensive where echogram 'slices' show along-track distances of up to 1800 m long that extend from the seafloor up to 170 m. Aggregations of lesser size and density were observed across a 5 km east-west distance.

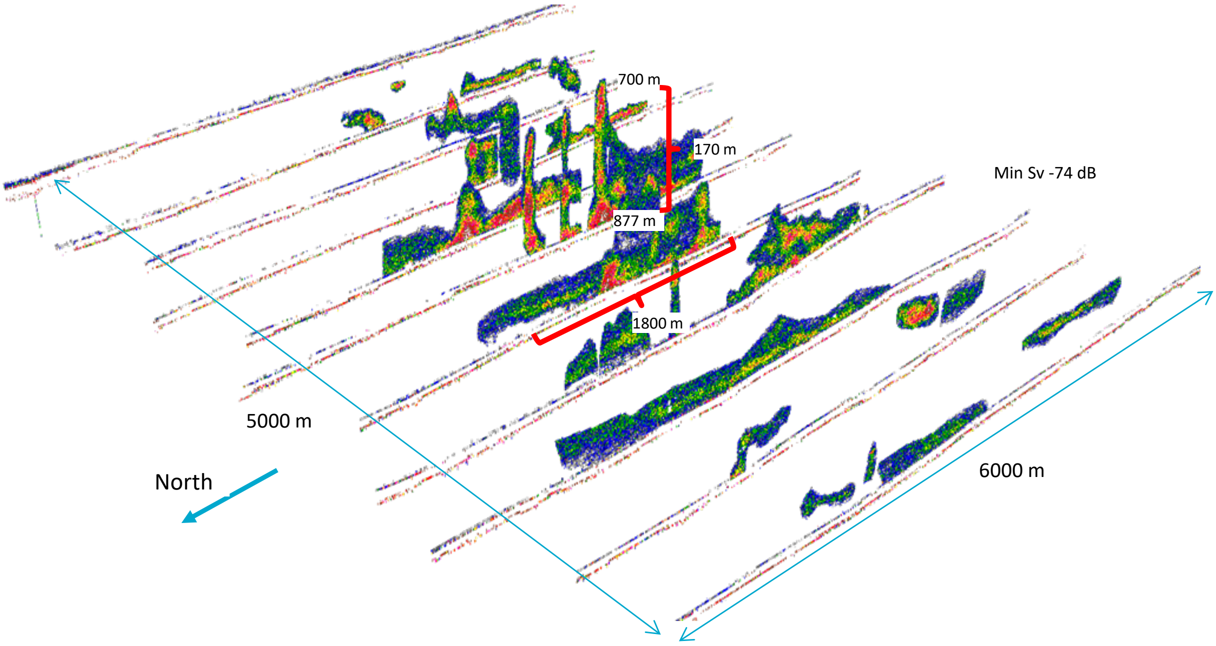

Figure 6: Three-dimensional echogram image showing regions classified as orange roughy from AOS 120 kHz echosounder for Challenger Flats acoustic survey, OP23, 29th July.

Western aggregation

Biological sampling was undertaken on catches from three target identification tows on the western aggregation during the period 30/06/18 to 04/07/18 (OP24, OP36, & OP46). These tows yielded catches of 13 t, 28 t, and 5 t, respectively. Sexes were highly skewed with females making up 90%, 25%, and 24% of the catch by number in the three tows. The average ratio of females to males was 46:54. In total, 300 otolith samples were collected from these target identification tows.

Spawning stage

Monitoring of gonad development stage revealed a high proportion of females in ripe condition at the commencement of acoustic surveying on 30 June, whereas males were predominantly in spawning condition. At the conclusion of surveying on 4 July, 25% of females and 8% of males were in spent condition (Figure 7).

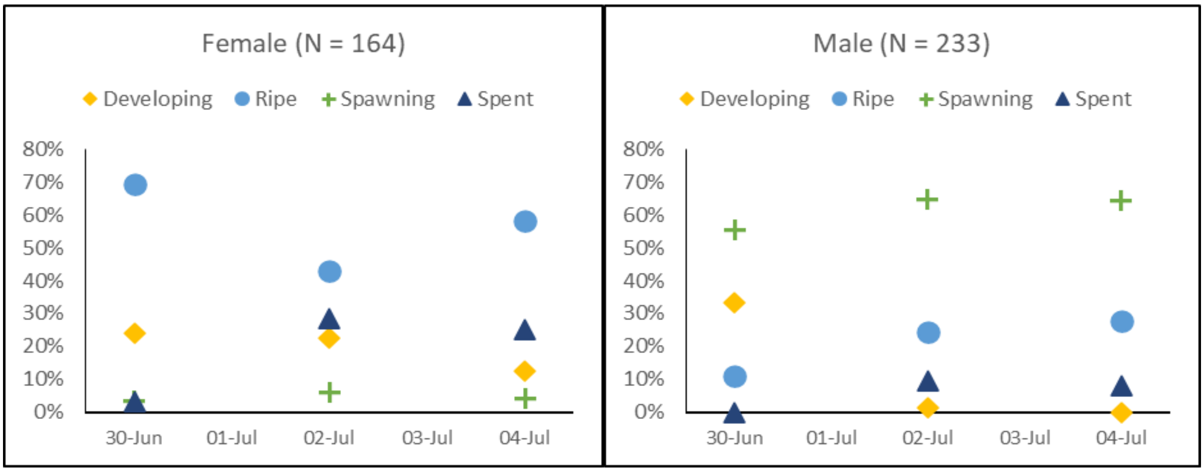

Figure 7: Orange roughy female and male gonad development stage in the western aggregation.

Catch composition

Catches in the western aggregation were almost 'clean' orange roughy (98.9%). The 'other QMS species' component comprised mainly ribaldo and spiky oreo. The main deepwater sharks were leafscale gulper shark and longnose velvet dogfish, and abundant non-QMS teleost species included Johnson's cod, black slickhead, and serrulate rattail (Figure 8).

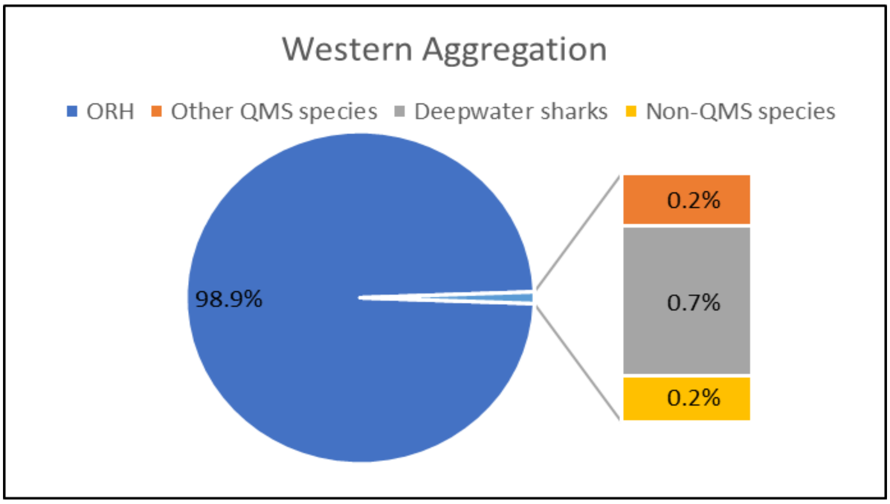

Figure 8: Catch composition of the western aggregation.

Size frequency

The females were generally larger than the males (Figure 9). Mean length was 32.2 cm for females and 30.4 cm for males.

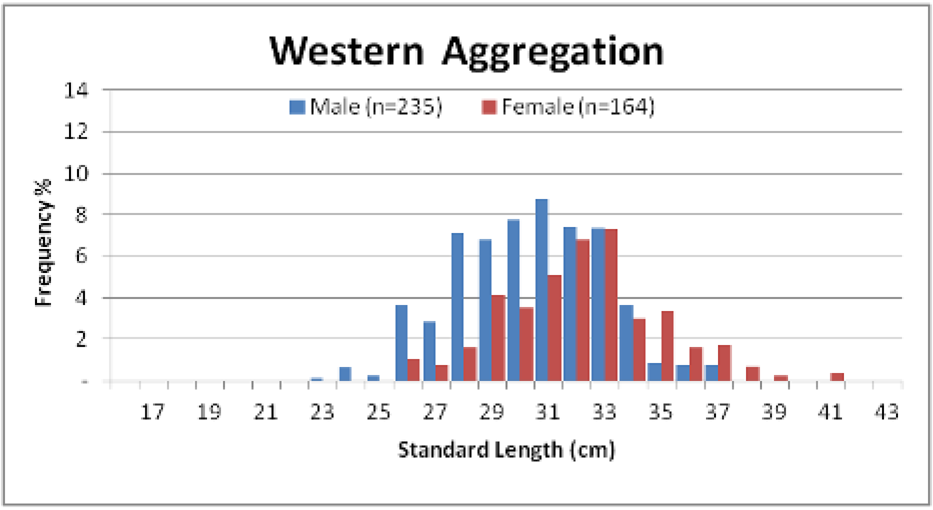

Figure 9: Catch-weighted length frequency distribution of orange roughy in the western aggregation and the number of measured orange roughy by sex.

Core East high-density area

In previous surveys (e.g., 2013) a significant aggregation of orange roughy was acoustically observed and surveyed in the vicinity of the Core East stratum. In 2018 this aggregation was not observed in the acoustics as a significant feature during extensive searching effort or in the intensive RSTS. There were, however, acoustic marks close to the seafloor, but they were not extensive enough to acoustically survey.

No target identification tows were undertaken in the Core East high-density area. However, three RSTS tows either sampled the close-to-seafloor high density region/aggregation (OP67; tow 50) or occurred in the immediate vicinity of it (OP58 & OP62, tows 41 & 45), producing catches of 14 t, 27 t, and 20 t respectively. The catches were dominated by males, which made up 70%, 63%, and 87% of the catch by number in the three tows. The average ratio of females to males was 28:72.

FV *San Waitaki*, which fished in this area immediately after the survey, found a plume 100 m high at 40° 00.9' S, 168° 23.1' E during the period 11th–13th July, suggestive of a dynamic situation where pluming was transient, perhaps due to pulses of spawners arriving on the grounds. The gonad maturity information from this area provides some support for this suggestion (Figure 10).

Spawning stage

On 6th July, 42% of female gonads were ripe and 35% spent, suggesting the spawn was past its peak. On 7th July, 59% were ripe, and spent gonads had reduced to 25%, suggestive of a pulse of 'new' spawners into the aggregation. This observation was also evident in male gonad data for which the proportion spent reduced from 40% on 6th July to 5% on 7th July (Figure 10).

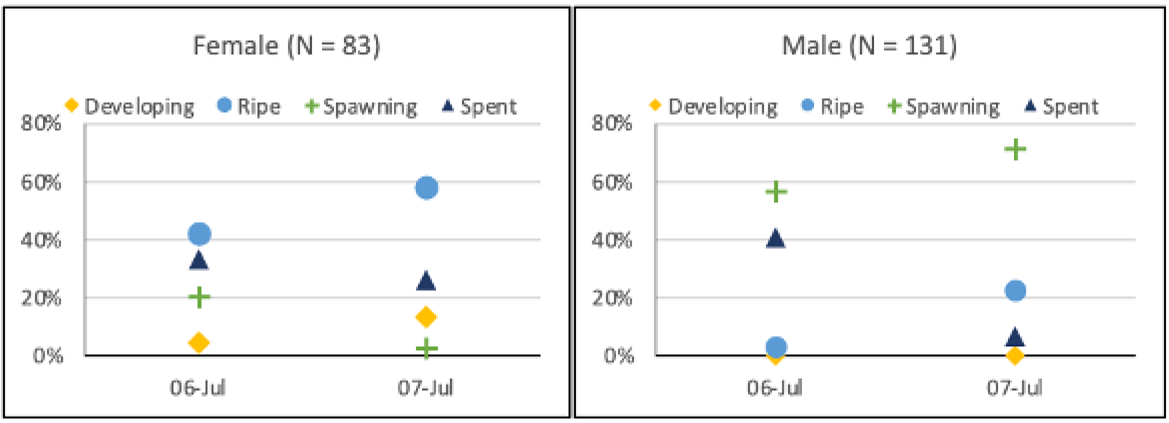

Figure 10: Orange roughy female and male gonad development stage in the Core East high-density area.

Catch composition

Catches in the Core East high-density area were almost entirely of 'clean' orange roughy (99.7%). The 'other QMS species' component comprised mainly ribaldo. Deepwater sharks included leafscale gulper shark and shovelnose dogfish, and the most abundant non-QMS teleost species were four-rayed, mahia, and serrulate rattails (Figure 11).

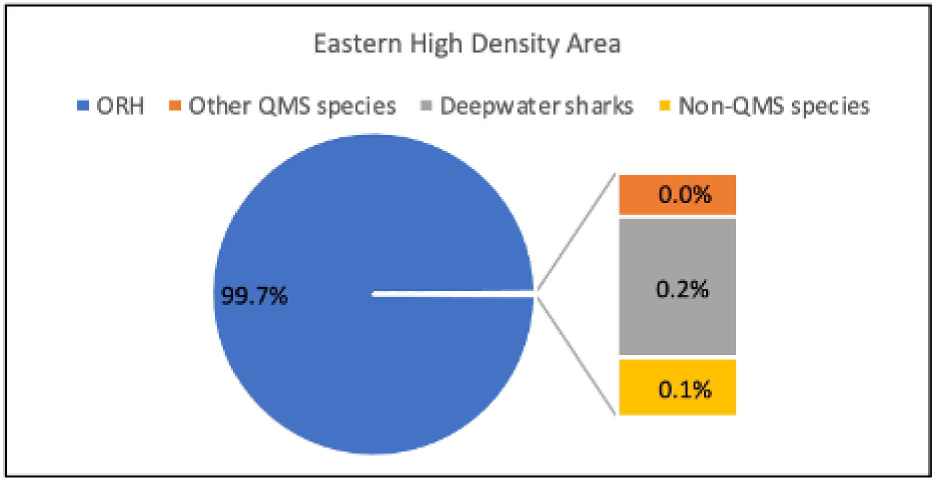

Figure 11: Catch composition of the Core East high-density area.

Size frequency

The size distribution for both males and females was unimodal, with the male distribution slightly smaller than that of females (Figure 12). Mean length was 31.8 cm for females and 30.7 cm for males.

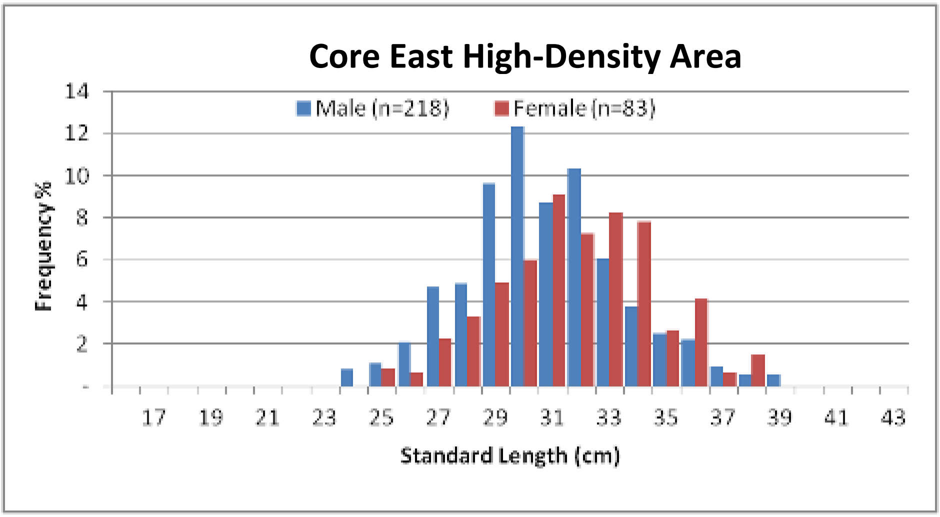

Figure 12: Catch-weighted length frequency distribution of orange roughy in the Core East high-density area and the number of orange roughy measured by sex.

3.1.2 Acoustic biomass estimates – Challenger Flats

Biomass estimates are summarised in Table 7 and Figure 13.

Table 7: Biomass estimates based on AOS and vessel echo-integration surveys carried out at Challenger Flats in June/July 2018. OP is operation number and NASC is Nautical Area Scattering Coefficient.

Date	Platform	OP	Frequency	Survey area	Mean NASC	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
29-Jun	Vessel	22	38	4.7	56	5738	0.30	819(12.5%)	6557
29-Jun	AOS	23	120	13.2	60.1	7425	0.19	823(10%)	8248
29-Jun	AOS	23	38	13.2	53.5	9547	0.20	1212(11.3%)	10758
29-Jun	Vessel	23	38	10.9	30	6192	0.19	1355(18%)	7548
1-Jul	AOS	34	120	10.9	72.6	10253	0.41	524 (6.5%)	8204
1-Jul	AOS	34	38	10.9	66	10443	0.43	1052 (9.2%)	11497
2-Jul	AOS	43	120	21.9	43.4	10253	0.24	1171(10.3%)	11424
2-Jul	AOS	43	38	21.9	37.4	12168	0.26	1930(13.7%)	14098
2-Jul	Vessel	43	38	19.1	26	10486	0.32	1378(11.6%)	11865
3-Jul	Vessel	44	38	18.9	25	10289	0.26	876(7.8%)	11165
7-Jul	Vessel	72	38	6.0	79	9341	0.12	535(5.4%)	9876

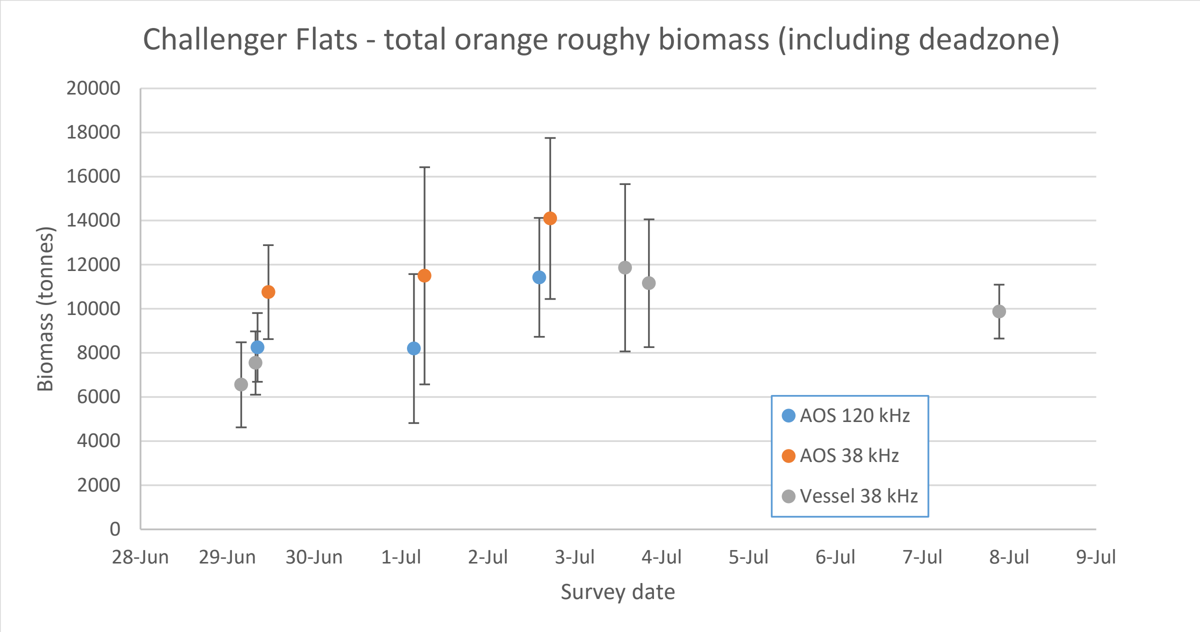

Figure 13: Biomass estimates for AOS 38 and 120 kHz and vessel 38 kHz at Challenger Flats. Error bars are +/- 1 sd. Dates for AOS 38 are slightly offset from AOS 120 so that error bars for both frequencies will be visible.

Vessel 38 kHz estimates given in Table 7 are calculated as: original estimate * 1.33 correction factor for motion and bubble layer attenuation, as required by the DWWG protocols. Following presentation of the preliminary results in December 2018, the DWWG requested that estimates also be made that include only the correction for motion correction component. To do this, the original biomass estimate is used and is multiplied by a motion correction factor. This correction for each vessel-based survey was calculated as the ratio of the mean of motion corrected NASC values to mean of uncorrected NASC values. Biomass estimates for original, original with motion correction, and original multiplied by 1.33 correction factor are given in Table 8.

Table 8: Challenger Flats vessel-based biomass estimates including dead-zone component (original) with corrections for just motion effects and DWWG 1.33 correction factor for motion and bubble attenuation. OP is operation number.

OP	Original estimate (t)	Motion correction factor	Original multiplied by motion corrected factor (t)	Original multiplied by factor of 1.33 (t)
22	4 930	1.107	5 458	6 557
23	5 675	1.057	5 999	7 548
43	8 921	1.094	9 759	11 865
44	8 395	1.058	8 881	11 165
72	7 426	1.134	8 421	9 876

Discussion of Challenger Flats acoustic surveys

Biomass estimates from three AOS surveys at Challenger Flats were calculated. For two of these AOS surveys, near concurrent vessel-based estimates were possible given good weather conditions. A further three vessel-only estimates were made. These surveys were all conducted in the Core West region. The AOS 38 kHz estimates were 10 758, 11 497, and 14 098 t. Vessel-based estimates have higher uncertainty due to the range dependent effects of absorption estimation, weather effects (motion, bubble attenuation), and species discrimination. Vessel-based estimates that include the DWWG 1.33 correction factor ranged from 6557 to 11 865 t. Biological sampling of the aggregations indicated that the surveys were conducted during the peak spawning period. The orange roughy aggregations were dynamic over short periods (6–24 hours) and also showed an overall progress to the south-east of about 15 km over the 11-day survey period. Regular observation through vessel-acoustics via dedicated search patterns or during other activities enabled tracking of this movement and development of survey designs to bound the aggregations and sample at an appropriate intensity. Previous surveys (Doonan et al. 2009, Doonan et al. 2010, Boyer et al. in prep) had located a smaller but significant aggregation in the Core East region. The RSTS trawls encountered high catch rates in this region with catches of 14, 27, and 20 t. Despite this, there were no pluming aggregations observed that might motivate a full AOS acoustic survey. Given a tight survey programme, the time investment to conduct further investigations would have reduced monitoring and surveying effort of the main aggregation at Core West.

3.1.3 Megabrick/Twin Tits

A brief excursion was made to transect across the Megabrick and Twin Tits features which are located in the Core West RSTS stratum (see Area 10 in Figure 3). A single pass was made with the AOS in 'survey mode' to provide multifrequency information to identify species within any marks that might be observed. Past fishing experience suggests that Megabrick is an area where orange roughy are found, whereas Twin Tits is dominated by spiky dory. The AOS multifrequency information confirmed that this was likely to be the case where regions of approximately equal signal on 38 and 120 kHz were observed at Twin Tits, indicating gas bladder species, and regions where 120 kHz backscatter signal was higher than 38 kHz at Megabrick, indicating orange roughy (Figure 14). This location was not a survey priority and with time limitations no further activities were conducted here.

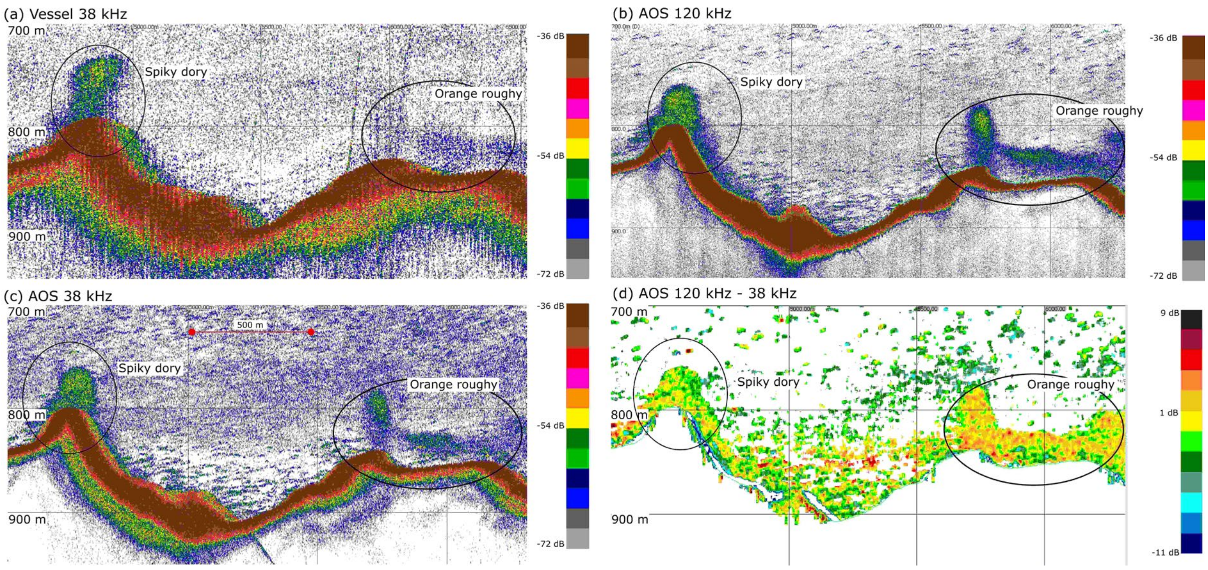

Figure 14: Echogram images from single-pass AOS transect over the Twin Tits/Megabrick feature. AOS multifrequency acoustics identified a region of gas bladder species (likely spiky oreo) at Twin Tits and a region of non-gas bladder species, likely orange roughy at Megabrick.

3.2 Acoustic survey results – Westpac Bank (Volcano)

3.2.1 Summary of survey programme

Volcano and Dork on Westpac Bank are UTFs of volcanic origin (Figure 15). The region was visited between the 4th and 5th of July and once more on the 8th and 9th of July. Three vessel-based surveys were conducted in calm conditions at the start of this first visit. Orange roughy marks were forming but were very weak and mixed with the general backscatter. Because of this, biomass estimates could not be made from these vessel-based surveys. An AOS survey provided useable results with better resolution and multifrequency information to guide interpretation. On this survey good marks were observed, which were notable for their height from the seafloor; up about 230 m into the water column (Figure 16 & Figure 17).

During the second visit an AOS survey was completed in deteriorating weather conditions that forced adoption of a parallel transect design instead of the preferred star pattern.

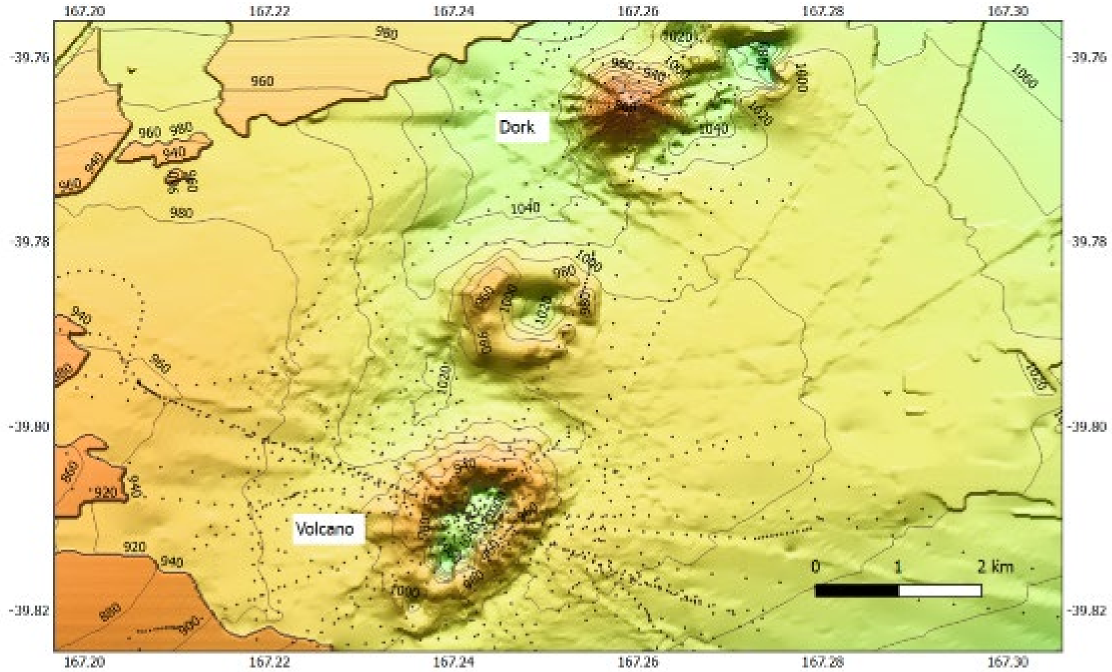

Figure 15: Volcano and Dork UTFs on Westpac Bank.

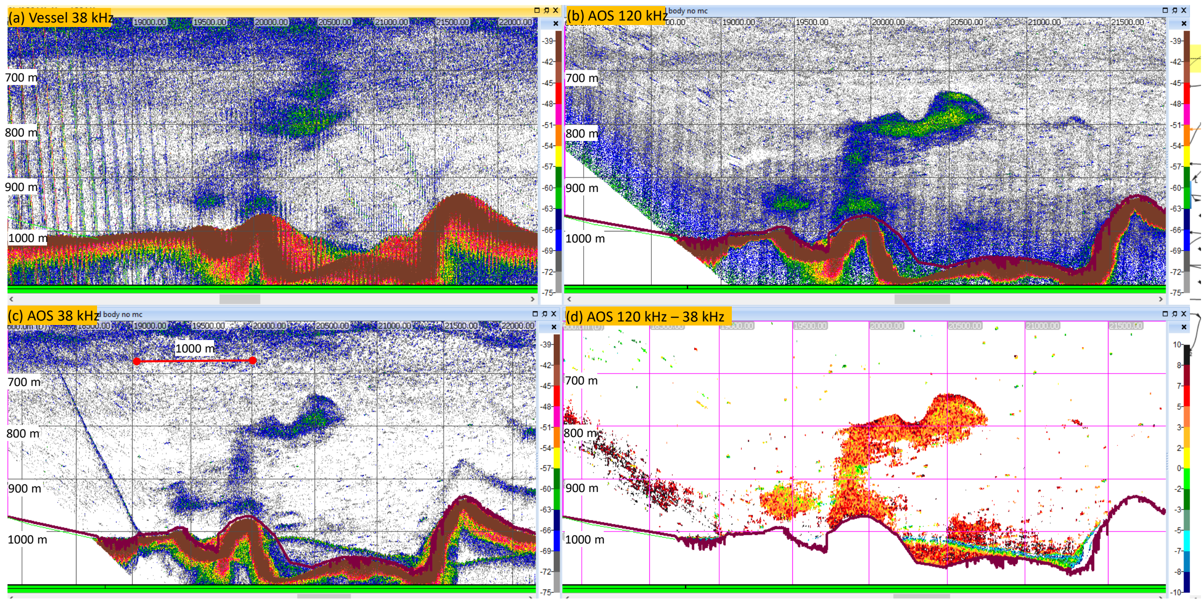

Figure 16: Echogram images of a large aggregation of orange roughy at Volcano on the 4th of July. (a) Vessel 38 kHz acoustics, (b) AOS at 120 kHz, (c) AOS at 38 kHz and (d) AOS 120 kHz minus AOS 38 kHz.

Biological sampling proved to be difficult at Volcano with three trawls attempted on the first visit, each of which 'pinned up', that is the trawl net was stuck for a period on the seafloor before coming free. In that situation catchability is usually greatly reduced. The third trawl caught about 50 t of orange roughy in a very short trawl after coming free.

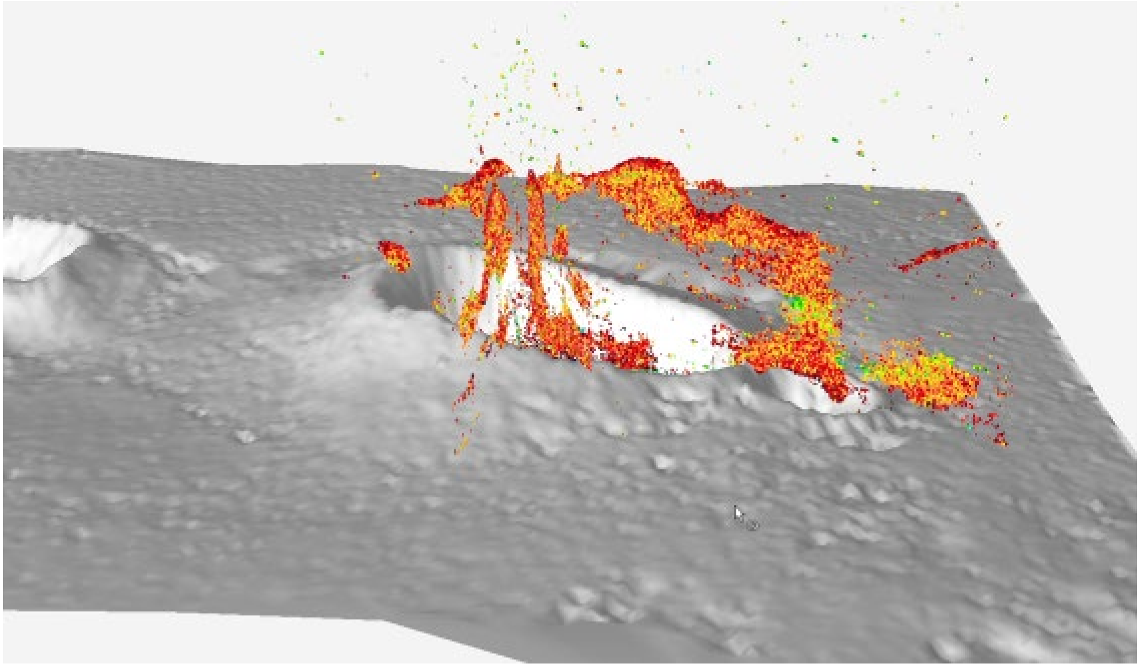

Figure 17: Survey conducted on 4th July showing a 3-dimensional view of Volcano bathymetry (3x vertical exaggeration) with acoustic backscatter classified as orange roughy based on the AOS 120 kHz signal being about 3 dB higher than that of the 38 kHz signal.

Two vessel-based star pattern surveys were conducted at the nearby Dork feature where strong marks were observed on the peak of the pinnacle. These were similar in appearance to those observed in 2014 where AOS multifrequency acoustics and video footage found that the region was dominated by spiky oreo. Given the high signal strength of the marks and the past survey history it seems unlikely these marks might now be orange roughy in 2018. Time, equipment, and weather constraints meant that there was no follow up with AOS surveys at Dork to confirm this conclusion.

Volcano was revisited on the 8th of July. Deteriorating weather conditions meant that it wasn't possible to sail to all points of the compass, so the desired star pattern design was not possible. Instead a parallel transect design was adopted with lines restricted to running directly into and with the weather (Figure 18). Six lines had been planned with a further five return transects to give an interlaced pattern. Increasing weather and a winch issue meant that the survey had to be aborted after five transects. These five transects almost covered the Volcano feature but a 'zero' line on the outer edge of the survey box could not be completed. Data from the vessel's port and starboard side-angled 38 kHz transducer were inspected to determine if a zero line could be inferred; that is that there were no significant fish north of the final AOS line. The port-looking side-angled echosounder data showed a very faint orange roughy mark in about 900 m depth at a range of between 170 m and 330 m (based on the footprint of the 7 degree transducer at angle of 14 degrees for this range). Had the weather conditions allowed, the 6th line would have been located at 500 m further north. It was likely that this line would not have had significant orange roughy given the observation of only a weak mark by the port-looking sounder and the fact that there were no observations of large bodies of orange roughy away from the north of the Volcano feature in either of the 2014 and 2018 surveys. The conclusion reached was that this survey had effectively bound the aggregation. The second issue is that this survey could not be interlaced due to the adverse weather conditions. Although the fish aggregations can be quite dynamic at Volcano they tend to cluster around the centre of the feature without any obvious movement of the greater body of fish in a particular direction. If that does occur, this non-interlaced survey may not be greatly biased one way or the other by fish movement.

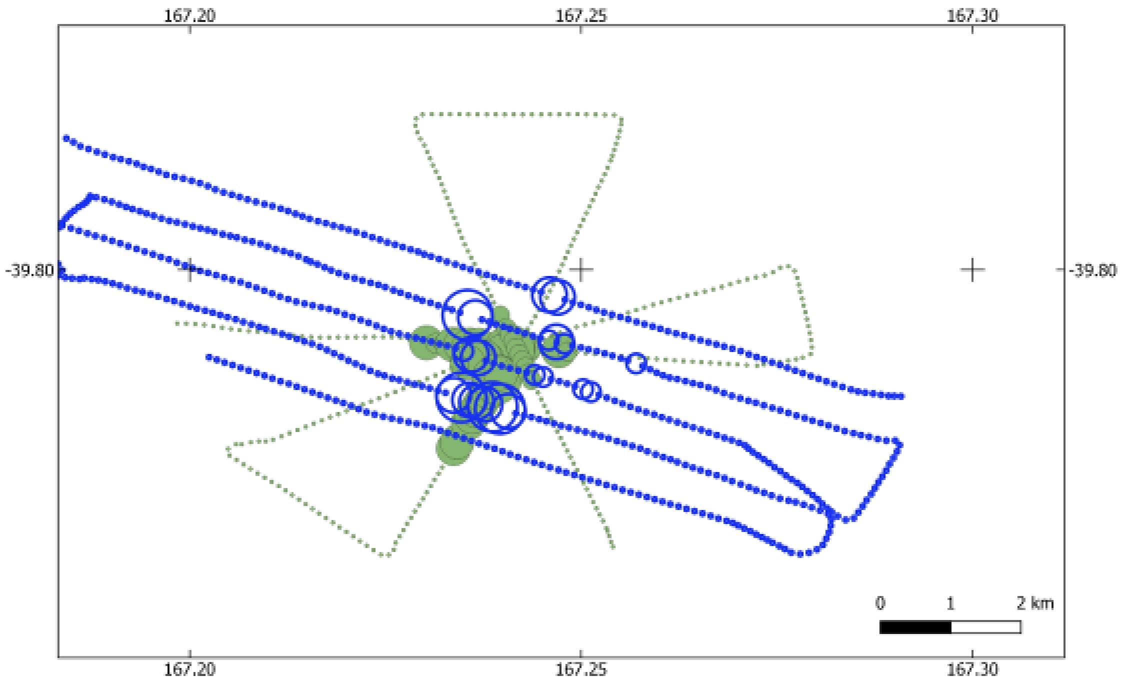

Figure 18: Thematic map showing along-track echo-integrated NASC values for two AOS surveys at Volcano.

Poor weather and winch issues prevented trawling at this time. The vessel returned inside the line to continue surveying at Challenger Flats, but on the 9th of July an engine issue forced a return to port, with no possibility of further work being done at Westpac Bank.

Three tows were undertaken on Volcano. The first two came fast and yielded catches of 63 kg and 82 kg respectively. The third tow came fast briefly before freeing up and resulted in a catch of 52 t. Three samples were taken from this tow. The female to male sex ratio was 46:54. In total, 263 otolith samples were collected from the Volcano aggregation.

Spawning stage

Most (90%) females were in gonad stages 2 and 3 (i.e., developing) on the 5th July, whereas 68% of males were in ripe condition. Only 5% of females and 3% of males were in spent condition, indicating that spawning was at an early stage (Figure 19), and that the timing of spawning at Volcano appeared to be several days behind that in the Central Flats area.

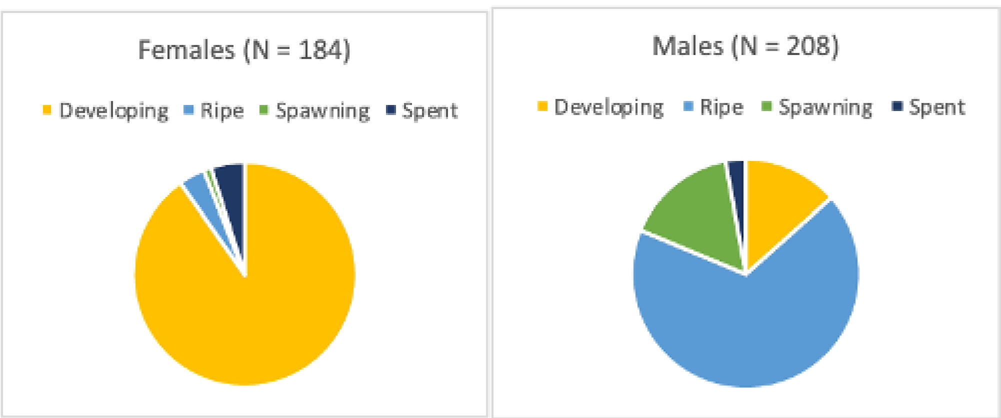

Figure 19: Orange roughy of female and male gonad development stage in the Volcano aggregation.

Catch composition

Catches in the Volcano aggregation were 99.88% orange roughy. The ‘other QMS species’ component comprised mainly spiky oreo. Deepwater sharks were mainly Baxter’s and smooth skin dogfish, and the most abundant non-QMS species were viper fish, the squid *Todarodes filippovae*, and warty squid (Figure 20).

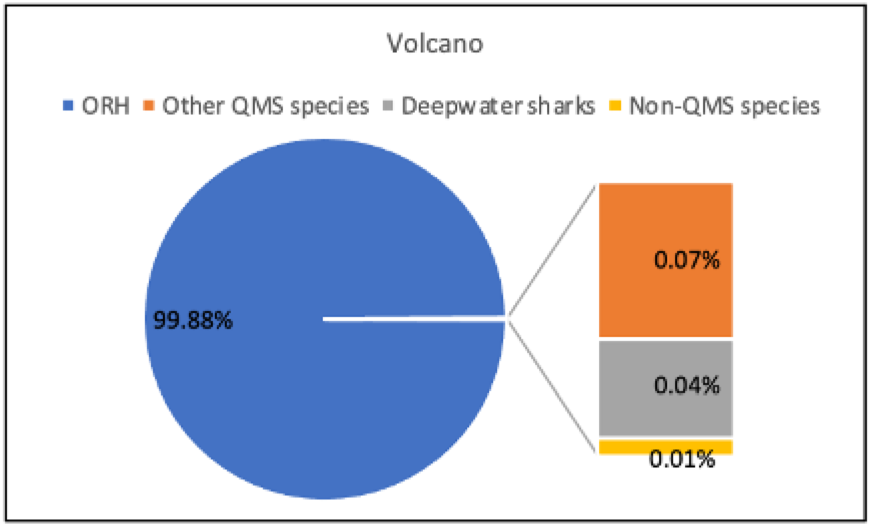

Figure 20: Catch composition from the Volcano aggregation.

Size frequency

The mean length for female orange roughy (35.1 cm) at Volcano was markedly larger than that for males (33.3 cm) (Figure 21). Both sexes were markedly larger than those sampled at Challenger Flats.

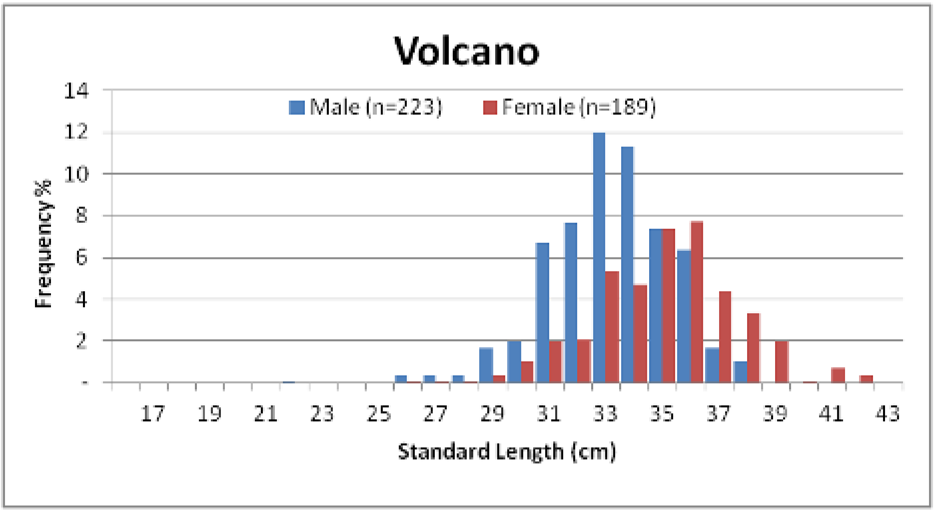

Figure 21: Catch-weighted length frequency distribution of orange roughy in the aggregation at Volcano and the number of orange roughy measured by sex.

3.2.2 Acoustic biomass estimates

Snapshot acoustic biomass estimates at Volcano are presented in Table 9 and Figure 22. 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.

Table 9: Biomass estimates based on AOS and vessel echo-integration surveys carried out at Volcano in July 2018.

Date	Platform	OP	Frequency	Survey area	Mean NASC	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
4-Jul	AOS 120	48	120	2.9	118	3 032	0.19	393 (11.5%)	3 426
4-Jul	AOS 38	48	38	2.6	78	4 270	0.19	178 (4%)	4 449
4-Jul	Vessel 38	48	38	2.3	119	5 158	0.18	369(7%)	5 527
8-Jul	AOS 120	73	120	2.2	146	2 713	0.28	329 (10.8%)	3 042
8-Jul	AOS 38	73	38	2.2	91	3 616	0.30	456 (11.2%)	4 072

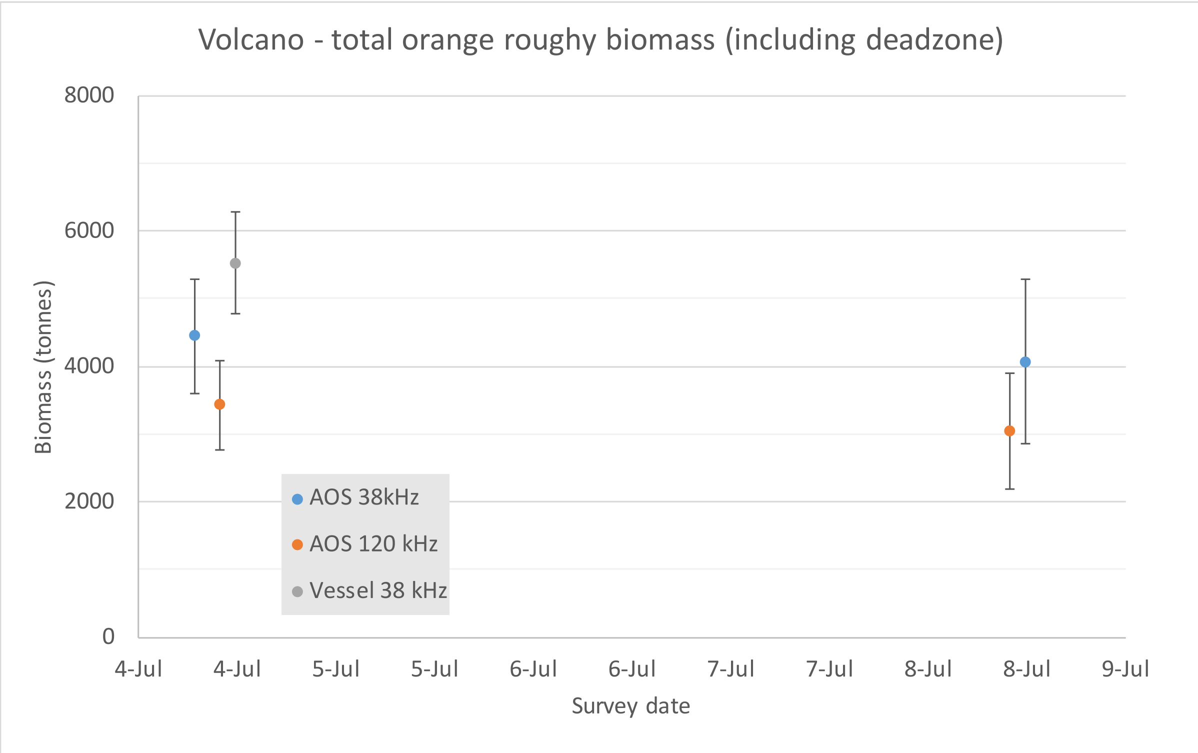

Figure 22: Biomass estimates for AOS 38 and 120 kHz and vessel 38 kHz at Volcano. Error bars are +/- 1 sd. Dates for AOS 38 are slightly offset from AOS 120 so that error bars for both frequencies will be available.

As discussed in section 3.1.2, biomass estimates are provided for the vessel-based data with the original estimate without correction, original estimate with correction for motion, and original estimate with the DWWG recommended correction factor of 1.33 (Table 10).

Table 10: Volcano vessel-based biomass estimates including dead-zone component (original), corrections for just motion effects, and DWWG 1.33 correction factor for motion and bubble attenuation. OP is operation number.

OP	Original estimate (t)	Motion correction factor	Original multiplied by motion corrected factor (t)	Original multiplied by factor of 1.33 (t)
48	4 155	1.07	4 454	5 527

3.2.3 Discussion

The biological sampling at Volcano was constrained by time and the difficulty in trawling this high relief feature. The limited data indicated that spawning was some days behind the Challenger Flats. In the 2014 survey, aggregations at Volcano were quite dynamic but there appeared to be an overall upward trend through time as the fish came on to spawn (Ryan et al. 2015). In 2018 both acoustic and biological data suggested that the survey was early and the 'peak of spawning' may not have been reached prior to the survey programme finishing. The survey had planned for more visits to Volcano for exactly this reason; ideally to measure pre-spawning, spawning, and post- spawning orange roughy. Unfortunately, the weather, mechanical issues, and competing demands of the Challenger Plateau RSTS and acoustic survey meant this could not be achieved.

3.3 Trawl survey results

3.3.1 Summary of the trawl survey programme

The survey commenced in the Guard South stratum on 27th June and all target stations in the southern and western guard strata were completed. A single station in the middle of Core West stratum was then completed to check on the stage of the spawning. About 90% of the females were developing so it was decided that there was sufficient time to complete the northern and eastern guard strata before concentrating on the two core strata.

The 12 stations in the guard strata yielded small catches ranging from 2.7 kg to 107 kg of orange roughy, although half of the stations yielded catches of less than 10 kg of orange roughy. Notwithstanding the small catches, the high variability in catch size resulted in high CVs for the four guard strata. However, given the low biomass in these strata this had little impact on the overall survey CV.

Trawl stations in the core strata were closely spaced (Figure 23), with very little steaming time between stations (e.g., 12 stations were completed on the 28th of June). On most days, between 6 and 8 stations were completed. All the planned stations in Core West (21 tows) and Core East (14 tows) were completed.

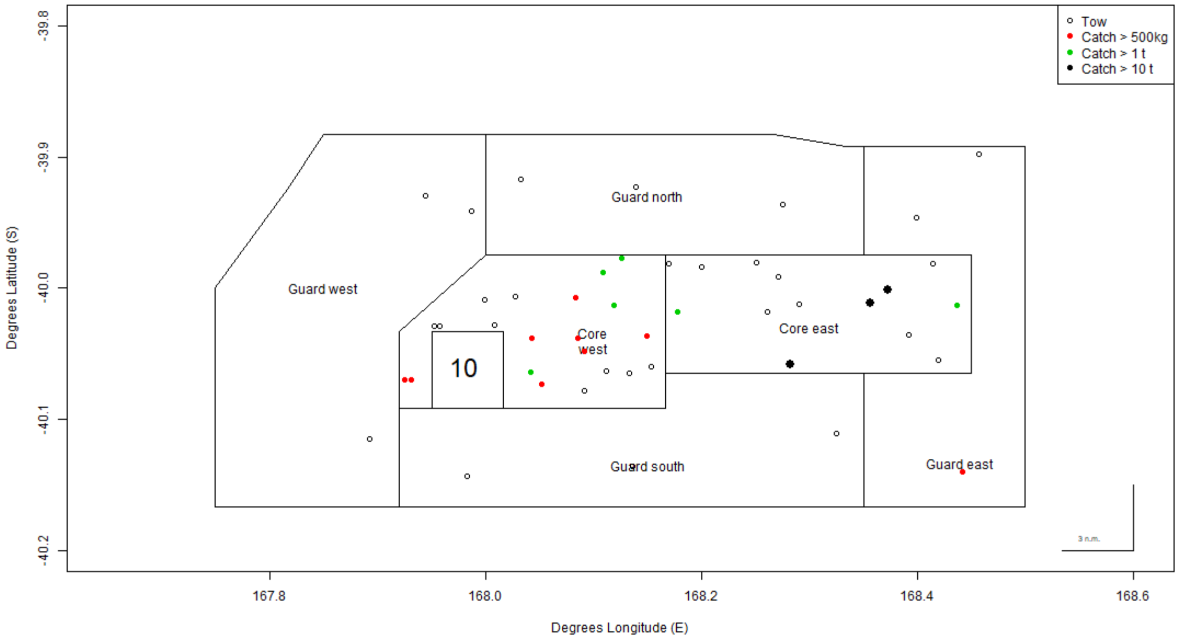

Figure 23: Trawl survey stations and associated catch rates for orange roughy.

In the Core East stratum, modest orange roughy marks were detected on the echo sounder while the gear was being shot at Station 50 (OP68) and a catch of 20 t was made with a tow distance of only 0.33 n.mile. Interpretation of the trawl survey protocols led to the conclusion that because aggregations were detected during shooting, this tow was invalid. A replacement tow was therefore undertaken (OP72, Station 54). It was subsequently clarified that the rule providing for a replacement tow only applies when it is not possible to undertake the selected tow because the gear would have landed in an aggregation. Station 50 is therefore a valid tow and Station 54 is not regarded as part of the survey (i.e., although 48 random tows were completed only 47 are accepted as valid RSTS tows). In total three RSTS tows were curtailed early because codend catch sensors were triggered (Table 11).

The mean trawl speed, distance towed, door spread and headline height achieved during the trawl survey were within the range of means achieved during the previous surveys here from 2005 to 2013 (Table 12). During the 2012, 2013, and 2018 surveys, the headline height was below the specification of 5.0–5.5 m (Appendix C). The addition of extra headline buoys failed to remedy the headline height issue during these surveys. The survey nets were routinely serviced by the manufacturer (MotNets, Nelson) prior to each survey and it is not known why the headline height was somewhat reduced from 2012.

Table 11: The station number, distance towed, and orange roughy catch for the random stations where the gear was hauled before 1.5 n.mile had been towed.

Station	Distance (n.mile)	ORH catch (t)
41	0.41	14
45	0.72	27
50	0.33	20

Table 12: The vessel speed, distance towed, and measured gear parameters for the random trawl stations during the 2018 survey, and the means for the surveys from 2005 to 2013. N is the number of stations on which measurements were made in 2018. The measurements are averages for each station.

	N 2018	Minimum 2018	Maximum 2018	Mean 2018	Means 2005–2013
Speed (knots)	44	3.0	3.5	3.3	3.0–3.4
Distance towed (n.mile)	47	0.33	1.75	1.45	1.40–1.66
Doorspread (m)	47	130	148	138	134–147
Headline height (m)	47	4.0	5.0	4.6	4.5–5.9

Spawning stage

Analysis of gonad maturity revealed that most females were in the developing and ripe stages during the early days of the survey. The onset of spawning was rapid with the spawning peak (i.e., when 20% of gonads were in spent condition) occurring at around 2nd July. By the end of the survey on 7th July, about 50% of females were spent (Figure 24).

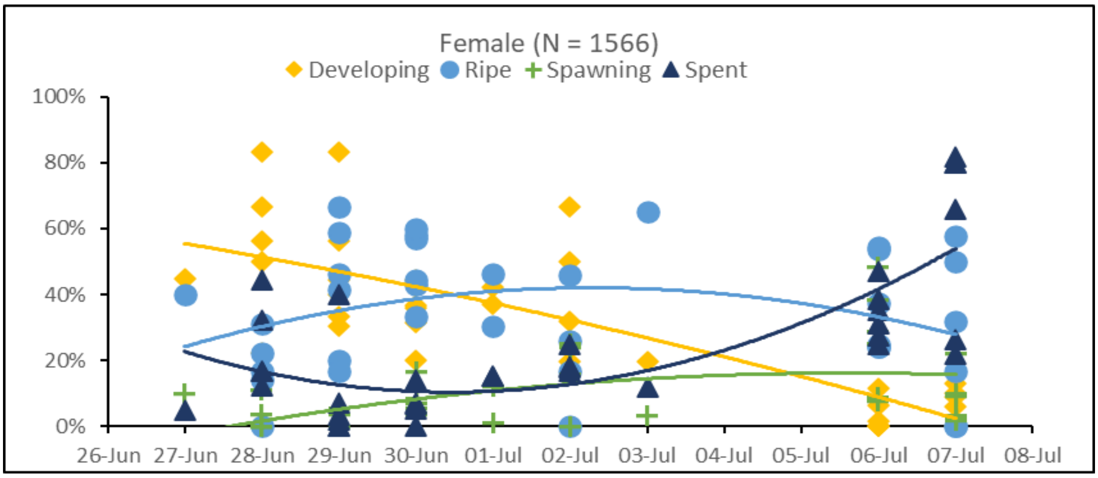

Figure 24: Orange roughy female gonad development stage over the period of the random stratified trawl survey. Lines are 2nd order polynomials.

Male gonad development showed a similar trend with the exception that overall, a higher proportion of gonads in ripe-running condition were in evidence throughout the survey period (Figure 25).

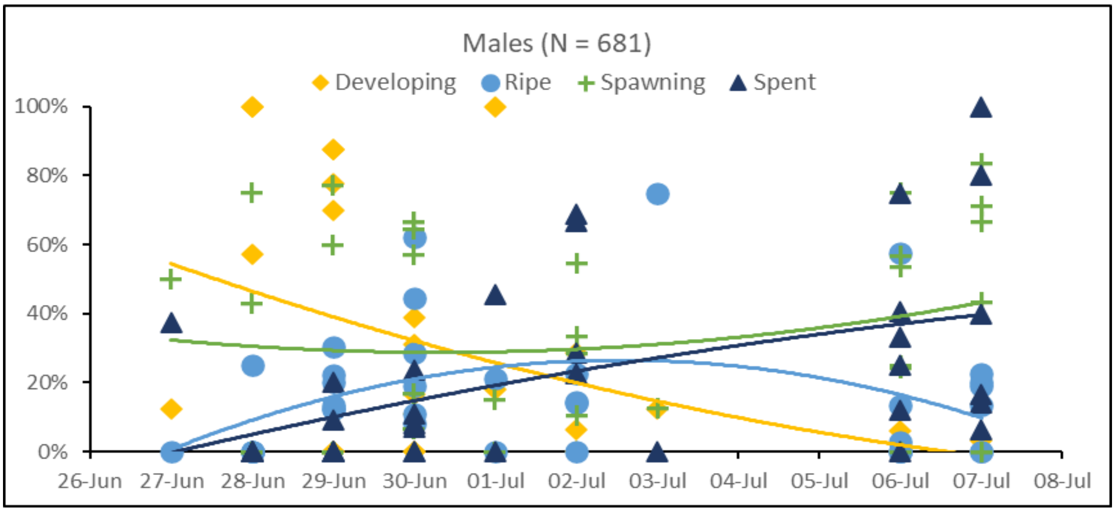

Figure 25: Orange roughy male gonad development stage over the period of the random stratified trawl survey. Lines are 2nd order polynomials.

Catch composition

Orange roughy made up 97% of catches overall. The 'other QMS species' component comprised mainly ribaldo and spiky oreo, with hake, hoki, and pale ghost shark somewhat abundant. Deepwater sharks were mainly shovelnose dogfish, followed by longnose velvet dogfish, smoothskin dogfish, and leafscale gulper shark. The most abundant non-QMS teleost species were Johnson's cod, followed by white, mahia, serrulate, and four-rayed rattails. The catch composition of all RSTS tows combined are presented in Figure 26. In total, 532 orange roughy otolith samples were collected during the RSTS. The catch composition breakdown for all species and from all trawls are provided in Appendix D.

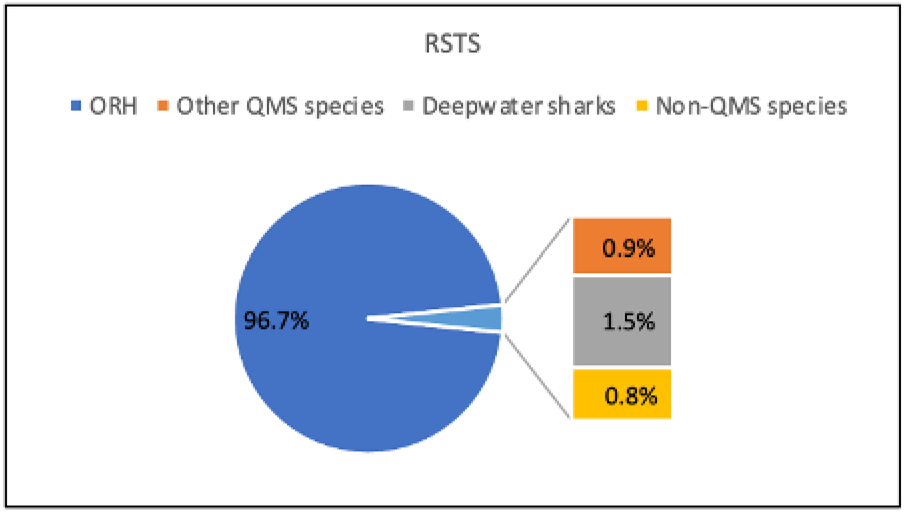

Figure 26: Catch composition from the random stratified trawl survey, all stations combined.

Size frequency

The catch-weighted length frequency distribution (i.e., observed length frequency scaled-up to whole catch and then summed over all stations) for all the RSTS stations for male and female orange roughy are presented in Figure 27. It is noticeable that there were many more females (76%) than males (24%) and that the females were generally larger (mean length 32.0 cm) than the males (mean length 29.6 cm).

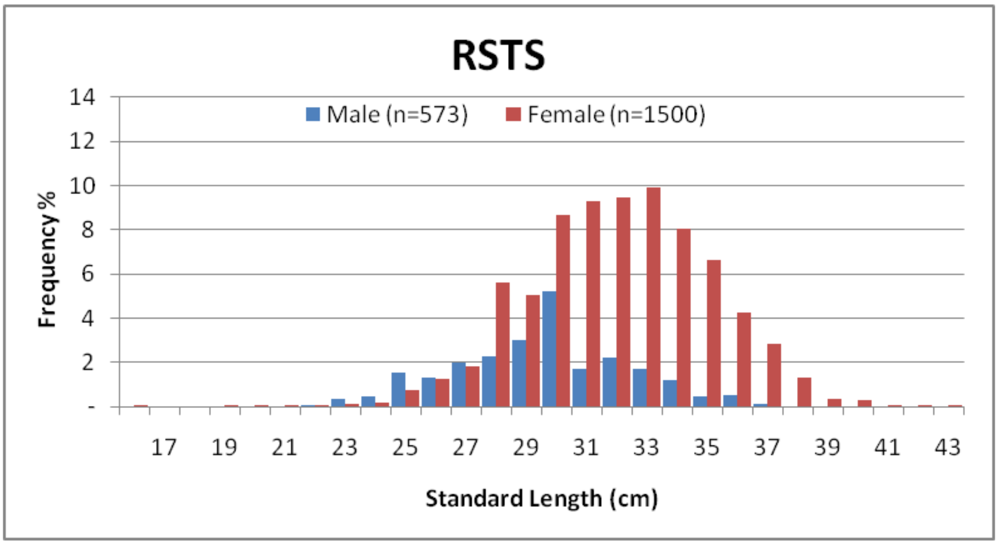

Figure 27: Catch-weighted length frequency distribution of orange roughy for all RSTS tows combined and the number of orange roughy measured by sex.

On completion of the phase 1 RSTS tows on the 7th of July, a second excursion to Volcano was undertaken for acoustic surveying. During this time, analysis of RSTS stratum biomass and associated CVs was undertaken and this indicated it would be desirable to implement all of the phase 2 tows in the Core East stratum to reduce the CV. However, the vessel developed engine trouble while at Volcano and had to return to port for repairs, thereby effectively curtailing any further survey activity. Given the vessel was reduced to a steaming speed of around 4 to 5 knots, the earliest it could have returned to the survey grounds would have been four days later (i.e., assuming 24 hours for repairs in Nelson). Following consultation with MPI and the vessel owners and, given the advanced stage of the spawning period (i.e., over 40% of females were in spent condition on the 7th of July), it was deemed unlikely that the outcome from any further trawl or acoustic surveying would be accepted by the DWWG for use in biomass estimation. The survey was therefore terminated at 19:35 on the 9th of July.

3.3.2 RSTS biomass estimates

The random trawl survey stations had low catch rates in the guard strata, moderate catch rates within the Core West stratum, and from the three shortened tows, three very high catch rates in the Core East stratum (see Figure 23). As a consequence, the biomass estimate from the Core East stratum provides almost all the biomass estimate for the full survey area (Table 13).

The full survey biomass estimate depends on the treatment of the short tows. With no adjustment, the 'high catch rates' biomass is estimated at 72 000 t but if the 'low catch rate' is assumed for each tow then biomass is estimated at just 26 000 t (Table 13). The adjustment for previous surveys uses the low and high catch rates to define the 1st and 95th percentiles of a lognormal distribution which puts survey biomass at 48 000 t (CV 51%) (Table 14).

Table 13: Prior to adjustment for the three short trawls: orange roughy biomass estimates for all fish (total) and fish with length ≥ 27 cm together with the associated CVs for each stratum and for the total survey area.

		East	West	Guard E	Guard N	Guard S	Guard W	Total
Total	Biomass (000 t)	71	2.5	0.2	0.1	0.2	0.1	74
	CV (%)	53	38	85	70	35	35	51
≥ 27 cm	Biomass (000 t)	70	2.5	0.2	0.1	0.2	0.0	72
	CV (%)	53	38	84	77	34	58	51

Table 14: Comparison of eastern and total orange roughy biomass (≥ 27 cm) before and after adjustment for the three short trawls. 'Adjust LN 99%' uses the low and high catch rates to define the middle 99% of a lognormal distribution. 'Adjust LN 1-95%' uses the low and high catch rates to define from the 1st percentile to the 95th percentile. 'Tows all 1.5 n.mile' assumes the actual catch for each tow but that they were 1.5 n.mile long. This is the 'low catch rate'. The 'high catch rate' uses the actual length of each short tow.

	East		Total	
	Biomass (000 t)	CV (%)	Biomass (000 t)	CV (%)
No adjustment	70	53	72	51
Adjust LN 99%	40	53	43	49
Adjust LN 1-95%	45	54	48	51
Tows all 1.5 n.m.	23	50	26	44

3.4 Discussion of overall outcomes

Acoustic calibration and uncertainty

Calibration of the deepwater acoustic systems is a challenging but essential part of the biomass estimation process. The sensitivities of the transducers change through the range of deployment depths and this needed to be characterised by a calibration that measures target sphere response throughout the working depths of the system. It is not always possible to achieve this during a voyage because calm weather and low current is needed for the calibration sphere to locate within the narrow acoustic beam. Further, calibrating during a rare calm weather window comes at an opportunity cost for survey activities. For this project a second calibration exercise was required where a fishing boat was chartered in Tasmania for only this purpose. Although this added to the cost and overheads of this project, having dedicated extended vessel time enabled five deployments that recorded an abundance of sphere target measurements. The high degree of repeatability between deployments gave confidence that robust calibration results were available to apply to the key 38 kHz biomass estimates. The AOS 120 kHz transducer was not available for the February 2019 calibration and the results from the July calibration were applied.

The CSIRO ES38DD transducer was last calibrated in late 2016. The February 2019 calibration indicated that the sensitivity of the transducer had reduced by about 2 dB. The lower sensitivity through time is indicative of an ageing transducer presumably due to changes in the properties of the piezoelectric elements. This change highlights the importance of establishing calibration history and that calibration of the system should be done close to the time of the survey, either within the voyage window, or as soon as practical afterwards.

The 120 kHz biomass estimates were on average 23% higher (n=5, min 18%, max 28%) than the 38 kHz estimates. This may be due to error in calibration of either, or both, of the frequencies, although there is greater uncertainty about the 120 kHz calibration due to the limited data set. Uncertainty due to errors in absorption estimates are reduced by having the platform closer to the fish (about 300 m vs. 900 m for vessel), but the 120 kHz absorption is about a factor of four higher than the 38 kHz and accordingly has a greater uncertainty.

The 38 kHz vessel-based estimates have higher uncertainty for range dependent factors of absorption, losses due to motion, and acoustic footprint due to greater range between the platform and fish. The DWWG protocol is for vessel-based acoustic estimates based on the Doonan et al. (2003b) absorption estimation equation. At orange roughy depths (about 800 m) this results in a lower backscatter value (and therefore biomass) of about 20% than if the alternative equation of Francois & Garrison (1982) is used. Further experimentation is recommended to reduce the uncertainty in absorption estimation in the environment in which orange roughy reside.

The DWWG protocol increases biomass estimates by a factor of 1.33. This factor is to account for signal loss due to motion and bubble layer attenuation. This correction factor was based on studies of seabed backscatter at the Chatham Rise in a range of weather conditions (Cordue 2010). Whether this single correction factor can be universally applied to different vessels at different locations and across a range of weather corrections is open to question. At the request of the DWWG, vessel motion data were used to calculate a correction factor to apply to the biomass estimate prior to inclusion of the 1.33 correction. Correction factors ranged from 1.06 to 1.13 across six surveys that were conducted in good weather conditions. This means that bubble layer attenuation would range from 20% to 27% if the DWWG 1.33 correction factor is indeed correct. Further work is recommended to quantify the magnitude of bubble layer attenuation across a range of conditions to test this assumption.

Survey considerations

Combining RSTS and acoustic surveys had potential synergies. Acoustic recordings made during the RSTS programme provided real-time observations across the greater region. They provided the potential to locate significant aggregations that might be suitable for acoustic surveying. The acoustic surveys were also able to guide the relocation of RSTS transects to ensure they did not run right through large spawning aggregations. RSTS trawls also provided biological information on spawning progress, noting that the spawning situation within aggregations may differ.

In practice, executing both survey programmes was challenging. Both programmes have quite different approaches. There is some limited scope for adjusting the RSTS design in response to information collected in the early part of the voyage, but the design is largely pre-defined. The acoustic programme on the other hand needs to be highly flexible. It requires searching to locate significant aggregations followed by an adaptive design to bound the aggregation. Orange roughy aggregations can be quite mobile and their behaviour and distribution change as spawning progresses. Sustained observations and multiple surveys are needed to adequately measure the bulk of the spawning population. This need for focus on the spawning aggregation can conflict with that of the RSTS trawls that is premised on sampling the wide-area population away from aggregations. A further complication was the need to survey Volcano. This small feature could be surveyed quite quickly with multiple surveys and trawls in less than 24 hours but required about 16 hours to sail there and back; essentially is was a 40 hour break from the Challenger Plateau activities. This meant that the location of the main spawning aggregation needed to be re-established when returning through quite time consuming searching. There was also a requirement to give 24 hour notification to MPI when moving in and outside the 200 nautical mile limit to get to Volcano. This needed to be pre-empted before our understanding of the amount of time actually required could be known. Future surveys should seek an exemption of this requirement in order to optimise survey outcomes.

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APPENDIX A: Vessel and AOS calibration

FV *Thomas Harrison ES70* calibration

The FV *Thomas Harrisons* Simrad ES70 vessel-mounted acoustic system was calibrated at the start of the survey in Tasman Bay, with results given in (Tables 15 to 21).

This report details the calibration experiments and results for FV *Thomas Harrison* as per the information recorded below. The methods detailed by Demer et al. (2015) 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 15).

Table 15: 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	30884	2000	2.048	24.21	-0.39	-20.44
18	2121	2000	1.024	21.38	-0.53	-16.84

Table 16: Vessel and site information.

Vessel Name	FV *Thomas Harrison*	**Vessel owner/operator**	Sealord Group Ltd.
Site name	Tasman Bay	**Country**	New Zealand
Calibration date	2018-06-25	**Time zone**	+12
Latitude (° S)	40:57.471	**Longitude (° E)**	173:14.097
Seafloor depth (m)	31		
Sea state at start	Calm	**Sea state at end**	Calm
Start calibration time	23:30	**End calibration time**	00:30
Vessel and site comments	Location transducer is near to the bulbous bow and requires positioning a pole directly forward of the bow (vessel has modified pole), and two lines aft of the wheel-house to obtain required spread to map the beam of the transducer. Vessel calibrated as a delivery of 2018 Challenger Plateau ORH stock assessment survey.		

Table 17: Environmental information.

Salinity (psu)	35.0	**Salinity source**	Nominal
Temperature (°C)	14	**Temperature source**	CTD
Sound absorption (dB/km)	9.338 (38 kHz) 0.0026547 (18 kHz)	**Sound absorption equation**	Francois & Garrison (1982)
Sound speed (m/s)	1503.49	**Sound speed equations**	Mackenzie (1981)
Environmental comments	Water well mixed. Using single value for sound speed and absorption.		

Table 18: Calibration equipment.

Calibration sphere	60 mm copper
Counterweight	No
Mechanical arrangement	Calibration polls triangulated around the transducer.
Equipment comments	See vessel and site comments above

Table 19: Echosounder transceivers.

Frequency (kHz)	38	18
Make	Simrad	Simrad
Operating software	ES70	ES70

Table 20: Echosounder transducers*.

Frequency (kHz)	38	**Make**	Simrad
Model	ES38-B	**Serial number**	30884
Beam	split-aperture	**Transducer depth**	~5
Factory equivalent two way beam angle (dB)	-20.6	**Factory tank temperature (°C)**	20.5
Factory tank salinity	0		
3-dB beamwidth alongships (°)	7.0	**3-dB beamwidth athwartships (°)**	7.2

Frequency (kHz)	18	**Make**	Simrad
Model	ES18	**Serial number**	2121
Beam	split-aperture	**Transducer depth**	~5
Factory equivalent two way beam angle (dB)	-17.1	**Factory tank temperature (°C)**	23.0
Factory tank salinity	0		
3-dB beamwidth alongships (°)	10.6	**3-dB beamwidth athwartships (°)**	10.6

Results

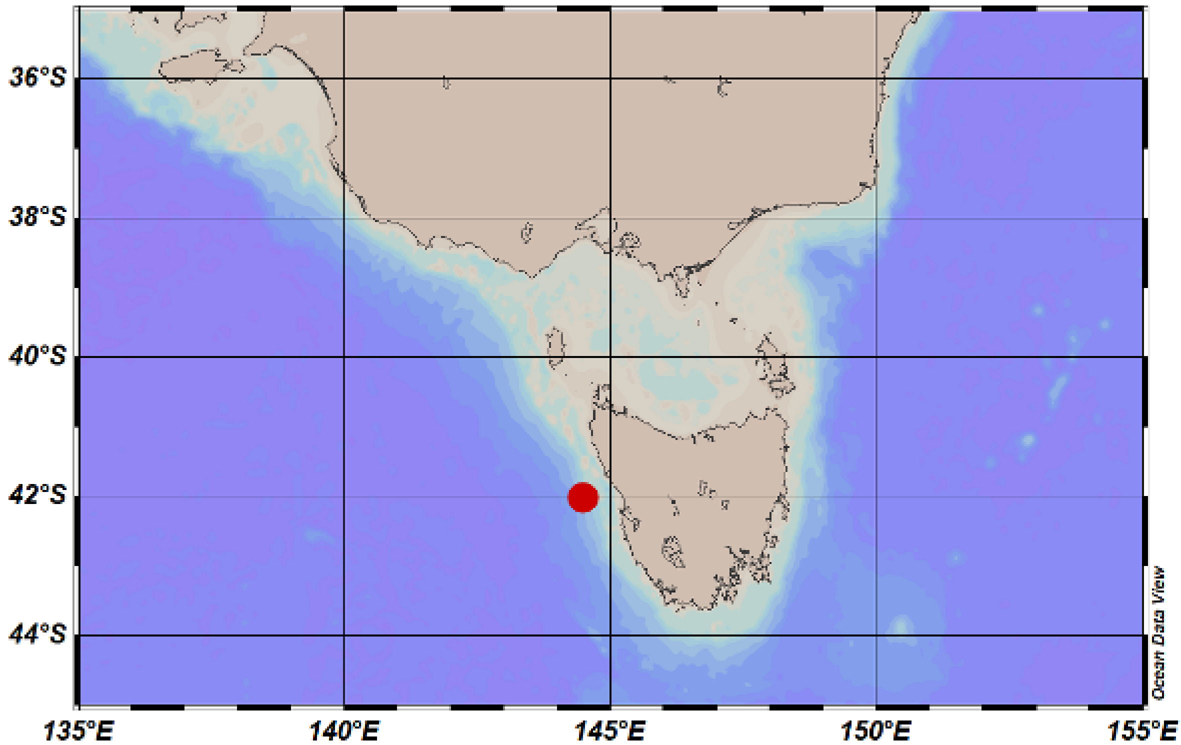
Table 21: Calibration calculations and results.

Frequency (kHz)	38	18
Calibration analysis method	On-axis	On-axis
Run number	1	2
Max beam compensation (dB)	on axis method	On-axis method
Number of targets	510	31
Adjusted Two-way equivalent beam angle (dB)**	-20.44	-16.84
Power (W)	2000	2000
Pulse duration (ms)	2.048	1.024
Sphere depth (m)	16.36	16.36
Sphere TS (dB)	-33.511	-35.26
On-axis gain (dB)	24.21	21.38
S_A correction (dB)	-0.39	-0.53

AOS calibration results

CSIRO AOS calibration report

Calibration date:	21–22 February 2019
Vessel:	FV *Empress Pearl*
Location:	42.0589° S, 144.5108° E
Calibration sphere:	38.1 mm tungsten carbide
Sphere depth:	11 m
Line used:	0.6 mm monofilament line, sphere is in a mono basket
Prepared by:	Haris Kunnath, Tim Ryan
Report date:	27 March 2019



Five back to back calibrations were made where the AOS was lowered and raised through working depths. The calibration parameters for combined up and down casts are tabulated below at 600m.

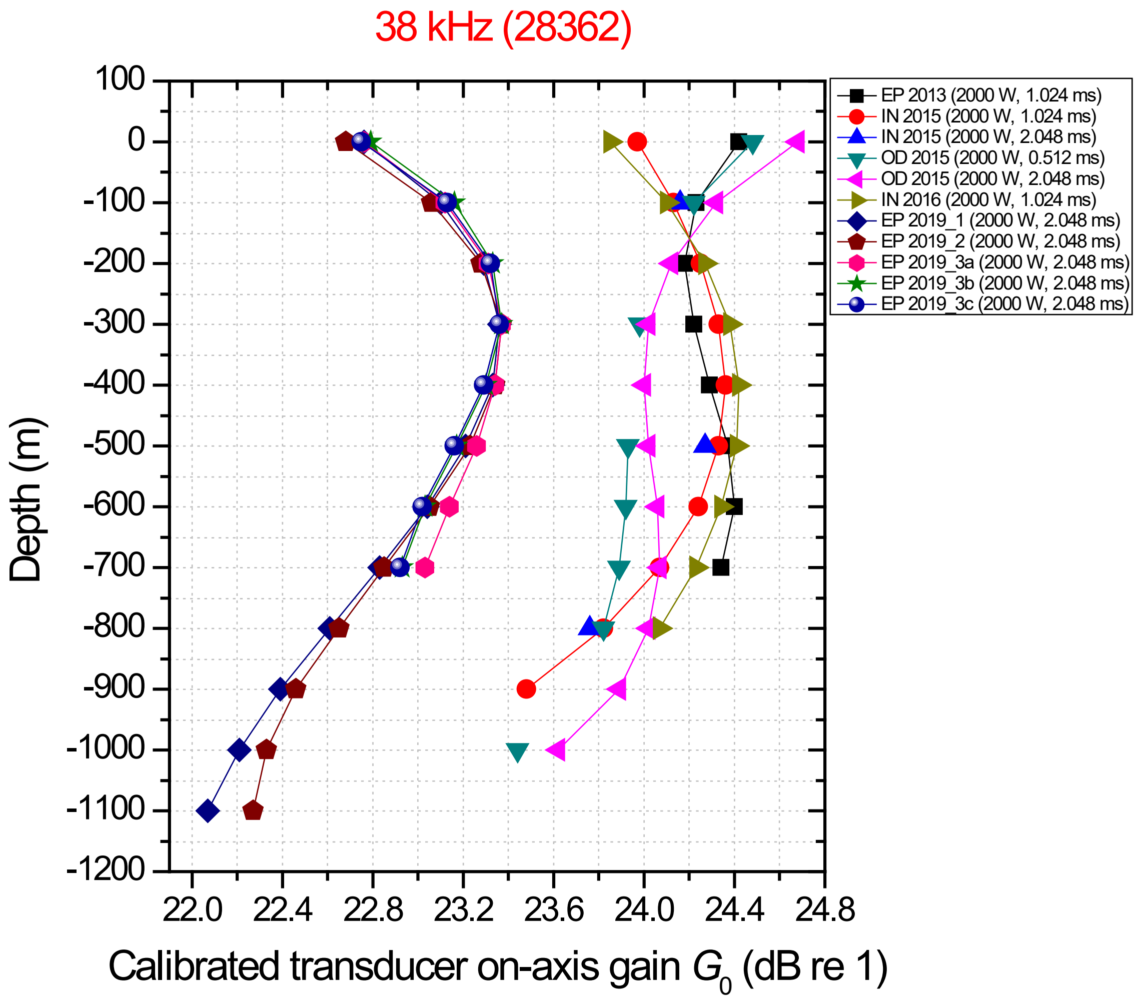
Year	**2019**	
Voyage	**Empress Pearl**	
GPT settings		
Transducer model	Simrad ES38-DD	Simrad ES120-7CD
Serial number	28362	123
Frequency (kHz)	38	120
Power (W)	2000	250
Pulse length (ms)	2.048	1.024
Calibration parameters – deployment 1		
Gain (dB) @ 600 m	23.04	27.46
Sa correction (dB) @ 600 m	-0.42	-0.38
Adjusted equivalent beam angle (dB re 1 sr)	-20.96	-20.21
Absorption @ 600 m (dB/m)	0.009381	0.03371
Sound speed @ 600 m (m/s)	1494	1494
Calibration parameters – deployment 2		
Gain (dB) @ 600 m	23.05	27.43
Sa correction (dB) @ 600 m	-0.41	-0.38
Adjusted equivalent beam angle (dB re 1 sr)	-20.96	-20.21
Absorption @ 600 m (dB/m)	0.009382	0.03379
Sound speed @ 600 m (m/s)	1494	1494
Calibration parameters – deployment 3a		
Gain (dB) @ 600 m	23.14	27.47
Sa correction (dB) @ 600 m	-0.41	-0.39
Adjusted equivalent beam angle (dB re 1 sr)	-20.96	-20.21
Absorption @ 600 m (dB/m)	0.009379	0.03385
Sound speed @ 600 m (m/s)	1494	1494
Calibration parameters – deployment 3b		
Gain (dB) @ 600 m	23.03	27.57
Sa correction (dB) @ 600 m	-0.40	-0.38
Adjusted equivalent beam angle (dB re 1 sr)	-20.96	-20.21
Absorption @ 600 m (dB/m)	0.009373	0.03395
Sound speed @ 600 m (m/s)	1494	1494
Calibration parameters – deployment 3c		
Gain (dB) @ 600 m	23.02	27.50
Sa correction (dB) @ 600 m	-0.39	-0.38
Adjusted equivalent beam angle (dB re 1 sr)	-20.96	-20.21
Absorption @ 600 m (dB/m)	0.009378	0.03387
Sound speed @ 600 m (m/s)	1494	1494

Polynomial fits were made to the data to characterise the response as a function of depth. This allows a secondary correction to be made based on platform depth as it deviates from the nominal working depth of 600 m.

Summary of polynomials – 38 kHz

38 kHz – deployment 1				
	x d^3	+ x d^2	+ x d	+ c
Gain polynomial parameters	3.69387e-09	-8.46367e-06	0.00422024	22.7558
Sa corr polynomial parameters	-7.5664e-10	1.57751e-06	-0.000800102	-0.34196
38 kHz – deployment 2				
	x d^3	+ x d^2	+ x d	+ c
Gain polynomial parameters	4.43071e-09	-9.53152e-06	0.00474741	22.6805
Sa corr polynomial parameters	-4.79125e-10	1.09919e-06	-0.000569368	-0.358571
38 kHz – deployment 3a				
	x d^3	+ x d^2	+ x d	+ c
Gain polynomial parameters	5.68665e-09	-9.81685e-06	0.00447644	22.7604
Sa corr polynomial parameters	-5.97482e-10	1.08256e-06	-0.000484941	-0.376515
38 kHz – deployment 3b				
	x d^3	+ x d^2	+ x d	+ c
Gain polynomial parameters	7.41032e-09	-1.17361e-05	0.00478228	22.7879
Sa corr polynomial parameters	-1.18349e-09	1.9843e-06	-0.000866432	-0.342844
38 kHz – deployment 3c				
	x d^3	+ x d^2	+ x d	+ c
Gain polynomial parameters	7.64962e-09	-1.20613e-05	0.00493365	22.754
Sa corr polynomial parameters	-1.73724e-09	2.48096e-06	-0.000930718	-0.346971

Historical results and those from these most recent calibration experiments are given in the following figure.



The large jump from earlier calibrations is noted, where the lower gain value in 2019 represents ~ 2 dB decrease in sensitivity for this transducer.

The 120 kHz used during the 2018 survey failed just prior to the 2019 calibration exercise. Therefore, no results can be reported for that transducer. The limited amount 120 kHz calibration data collected during the 2018 survey was used when calculating biomass.

APPENDIX B: Trawl station details

Tow no.	Strata + Stations	Date	Latitude (S)	Longitude (E)	Depth (m)	Distance Towed (nm.)	ORH catch (kg)
1	Gs-3	27 Jun 18	-40:06.67	168:19.50	888	1.17	34
2	Gs-1	28 Jun 18	-40:08.15	168:08.17	906	1.45	22
3	Gs-2	28 Jun 18	-40:08.58	167:59.00	920	1.34	11
4	Gw-3	28 Jun 18	-40:06.92	167:53.56	930	1.43	9
5	Gw-2	28 Jun 18	-39:56.50	167:59.20	915	1.52	4
6	Gw-1	28 Jun 18	-39:55.76	167:56.64	964	1.49	3
7	W-05	28 Jun 18	-40:02.30	168:02.56	885	1.24	263
8	Gn-3	28 Jun 18	-39:55.03	168:01.96	910	1.34	3
9	Gn-2	28 Jun 18	-39:55.38	168:08.34	844	1.45	37
10	Gn-1	28 Jun 18	-39:56.17	168:16.52	828	1.67	7
11	Ge-2	28 Jun 18	-39:56.79	168:23.94	825	1.53	11
12	Ge-1	28 Jun 18	-39:53.87	168:27.42	801	1.58	5
13	Ge-3	29 Jun 18	-40:08.41	168:26.49	885	1.54	107
14	W-19	29 Jun 18	-40:03.59	168:09.22	884	1.59	74
15	W-01	29 Jun 18	-40:01.76	167:57.45	894	1.52	3
16	W-02	29 Jun 18	-40:00.56	167:59.94	894	1.49	16
17	W-03	29 Jun 18	-40:00.43	168:05.01	875	1.56	369
18	W-04	29 Jun 18	-40:00.79	168:07.13	870	1.47	3160
19	W-06	29 Jun 18	-40:02.90	168:05.48	892	1.53	128
20	W-ID	30 Jun 18	-39:59.30	168:09.80	870	3.19	13142
21	W-14	30 Jun 18	-40:02.19	168:08.96	880	1.46	526
22	W-17	30 Jun 18	-40:03.90	168:08.00	886	1.5	59
23	W-09	30 Jun 18	-40:04.68	168:05.52	893	1.51	28
24	W-16	30 Jun 18	-40:04.37	168:03.15	894	1.67	134
25	W-18	30 Jun 18	-40:03.82	168:02.53	885	1.48	1847
26	W-08	01 Jul 18	-40:03.78	168:06.72	900	1.51	50
27	W-13	01 Jul 18	-39:59.27	168:06.51	868	1.56	2078
28	W-11	01 Jul 18	-40:01.75	167:57.13	904	1.66	5
29	W-ID	02 Jul 18	-40:01.49	168:08.98	874	1.18	28366
30	W-07	02 Jul 18	-40:04.17	167:55.90	903	1.5	142
31	W-10	02 Jul 18	-40:04.17	167:55.51	908	1.51	113
32	W-12	02 Jul 18	-40:01.67	168:00.51	884	1.49	18
33	W-20	02 Jul 18	-40:00.37	168:01.64	875	1.48	8
34	W-15	02 Jul 18	-40:02.29	168:05.16	880	1.52	131
35	W-21	03 Jul 18	-39:58.64	168:07.56	860	1.53	1311
36	W-ID	04 Jul 18	-40:01.64	168:12.04	867	0.33	5203
37	Vo-ID	05 Jul 18	-39:49.07	167:15.79	980	0.39	63
38	Vo-ID	05 Jul 18	-39:48.10	167:13.20	960	0.12	82
39	Vo-ID	05 Jul 18	-39:48.14	167:13.33	965	0.36	52413
40	E-02	06 Jul 18	-40:00.81	168:26.21	839	1.51	2912
41	E-03	06 Jul 18	-40:00.07	168:22.36	845	0.41	13977
42	E-11	06 Jul 18	-39:58.86	168:24.86	835	1.06	78
43	E-10	06 Jul 18	-40:02.16	168:23.51	857	1.49	78
44	E-07	06 Jul 18	-40:03.27	168:25.19	864	1.69	45
45	E-05	06 Jul 18	-40:01.49	168:21.44	857	1.56	27219
46	E-12	06 Jul 18	-39:58.82	168:15.07	850	1.46	5
47	E-08	07 Jul 18	-39:59.55	168:12.01	854	1.57	15
48	E-13	07 Jul 18	-39:59.51	168:10.88	860	2.31	38

Tow no.	Strata + Stations	Date	Latitude (S)	Longitude (E)	Depth (m)	Distance Towed (n.m.)	ORH Catch (kg)
49	E-01	07 Jul 18	-40:01.09	168:15.66	868	1.59	80
50	E-04	07 Jul 18	-40:03.47	168:16.97	875	0.33	19815
51	E-09	07 Jul 18	-40:01.07	168:10.67	872	1.57	2863
52	E-14	07 Jul 18	-39:59.49	168:16.28	849	1.75	8
53	E-06	07 Jul 18	-40:00.73	168:17.41	856	1.55	10
54*	E-04	07 Jul 18	-40:03.51	168:17.22	874	0.1	2007

*E-04 repeat tow - not used for biomass estimation.
Strata: Gn=guard north; Gs=guard south; Ge=guard east; Gw=guard south; W=core west; E=core east;
Vo=Volcano.
Latitude and Longitude in degrees and minutes to two implied decimal places.

APPENDIX C: Trawl parameters 2005–2018

Net performance in random trawl surveys on Challenger Flats by FV *Thomas Harrison* between 2005 and 2018. Note that for the 2012 and 2013 surveys only trawls which nominally ran the prescribed distance of 1.5 n.mile have been included. For all other surveys all trawls, irrespective of distance towed, are included.

	Number	Minimum	Maximum	Mean
THH0501				
Speed (kts)	44	2.7	3.5	3.1
Distance (n.miles)	44	0.27	1.81	1.40
Doorspread (m)	39	118	146.5	138
Headline height (m)	44	5.4	9.5	5.9
THH0601				
Speed (kts)	54	3	3.5	3.2
Distance (n.miles)	54	0.23	1.83	1.43
Doorspread (m)	47	119	145	134
Headline height (m)	54	3.4	8.4	5.5
THH0901				
Speed (kts)	64	2.8	3.5	3.09
Distance (n.miles)	64	0.28	1.58	1.40
Doorspread (m)	64	120	147.1	137
Headline height (m)	64	4.7	7.1	5.5
THH1001				
Speed (kts)	68	2.8	3.4	3.1
Distance (n.miles)	68	0.18	1.63	1.40
Doorspread (m)	67	117.6	153.3	143
Headline height (m)	68	4.3	7.1	5.3
THH1101				
Speed (kts)	61	2.8	3.4	3.0
Distance (n.miles)	61	0.16	1.66	1.46
Doorspread (m)	61	133	155	144
Headline height (m)	61	4.5	5.9	5.4
THH1201				
Speed (kts)	49	2.8	3.6	3.3
Distance (n.miles)	49	1.33	1.87	1.66
Doorspread (m)	46	126	156	147
Headline height (m)	49	3.7	4.8	4.5
THH1301				
Speed (kts)	76	2.5	4.2	3.4
Distance (n.miles)	77	1.34	1.67	1.41
Doorspread (m)	75	131	163	146
Headline height (m)	75	3.7	6.3	4.6
THH1801				
Speed (kts)	44	3.0	3.5	3.3
Distance (n. miles)	47	0.33	1.75	1.45
Doorspread (m)	47	130	148	138
Headline height (m)	47	4.0	5.0	4.6

APPENDIX D: Catch composition

Catch composition - Challenger Flats (RSTS and target identification trawls)

Code	Common name	Scientific name	Catch Weight (kg)	Number in catch	Number of stations
APR	Catshark	*Apristurus* spp.	1.9	1	1
ASE	Snaggletooths	*Astronesthes* spp.	0.1	2	2
ASR	Asteroid (starfish)		0.7	2	2
BEE	Basketwork eel	*Diastobranchus capensis*	7.3	6	4
BRG	Brisingida (Order)	*Brisingida*	0.5	2	3
BSH	Seal shark	*Dalatias licha*	6.3	2	2
BSL	Black slickhead	*Xenodermichthys* spp.	20.3	62	19
BTA	Smooth deepsea skate	*Brochiraja asperula*	0.4	1	1
BTS	Prickly deepsea skate	*Brochiraja spinifera*	0.3	3	3
CBA	Humpback rattail (slender rattail)	*Coryphaenoides dossenus*	2.3	4	3
CBO	Bollons rattail	*Coelorinchus bollonsi*	1.2	2	2
CDX	Dark banded rattail	*Coelorinchus maurofasciatus*	0.4	2	1
CHA	Viper fish	*Chauliodus sloani*	0.3	5	4
CHX	Pink frogmouth	*Chaunax pictus*	0.8	8	8
CHY	Roughhead rattail	*Coelorinchus trachycarus*	0.2	1	1
CIN	Notable rattail	*Coelorinchus innotabilis*	1.1	16	8
CJA	Sun star	*Crossaster multispinus*	0	1	1
CMA	Mahia rattail	*Coelorinchus matamua*	24.8	67	33
CMP	Cheiraster monopedicellaris	*Cheiraster monopedicellaris*	0.1	3	3
CMT	Feather star	*Comatulida*	0.4	5	1
CMX	Coryphaenoides mcmillani	*Coryphaenoides mcmillani*	14.1	30	10
CSE	Serrulate rattail	*Coryphaenoides serrulatus*	15	73	27
CSQ	Leafscale gulper shark	*Centrophorus squamosus*	700.7	48	16
CSU	Four-rayed rattail	*Coryphaenoides subserrulatus*	3.8	50	16
CYL	Portugese dogfish	*Centroscymnus coelolepis*	12.4	2	2
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	290.2	47	25
CYP	Longnose velvet dogfish	*Centroselachus crepidator*	126.2	75	29
DMG	Dipsacaster magnificus	*Dipsacaster magnificus*	0.1	1	1
DWO	Deepwater octopus	*Graneledone* spp.	0.9	5	4
EEX	Enypniastes eximia	*Enypniastes eximia*	5.2	98	18
EPT	Deepsea cardinalfish	*Epigonus telescopus*	17.8	4	4
EPZ	Epizoanthus spp.	*Epizoanthus* spp.	0.1	4	3
ETB	Baxter's lantern dogfish	*Etmopterus baxteri*	16	10	9
ETL	Lucifer dogfish	*Etmopterus lucifer*	0.5	1	1
ETP	Etmopterus pusillus	*Etmopterus pusillus*	2.1	2	2
FHD	Deepsea flathead	*Hoplichthys haswelli*	0.2	1	1
GBT	Deepsea lightfish	*Gonostoma bathyphilum*	0	2	2
GOR	Gorgonocephalus spp	*Gorgonocephalus spp.*	0.4	3	3
GRM	Sea urchin	*Gracilechinus multidentatus*	0.5	7	1
GSP	Pale ghost shark	*Hydrolagus bemisi*	21	23	14
HAK	Hake	*Merluccius australis*	117	66	33

HCO	Hairy conger	*Bassanago hirsutus*	0.2	1	1
HEC	Henricia compacta	*Henricia compacta*	0.6	19	4
HJO	Johnson's cod	*Halargyreus johnsonii*	141.2	206	36
HOK	Hoki	*Macruronus novaezelandiae*	65.8	28	19
HPE	Common halosaur	*Halosaurus pectoralis*	1.7	9	3
JAV	Javelin fish	*Lepidorhynchus denticulatus*	2.1	5	3
JFI	Jellyfish		2.4	26	15
LAG	Laetmogone spp.	*Laetmogone* spp.	0.1	2	2
LAN	Lantern fish	*Myctophidae*	0.1	2	1
LCH	Long-nosed chimaera	*Harriotta raleighana*	9.5	6	4
MRQ	Warty squid	*Onykia robsoni*	9.6	6	6
MSL	Starfish	*Mediaster sladeni*	0.1	2	2
NBU	Bulbous rattail	*Kuronezumia bubonis*	0.8	2	2
OCM	Octopoteuthis megaptera	*Octopoteuthis megaptera*	8.5	1	1
OMI	Opostomias micripnus	*Opostomias micripnus*	0.1	1	1
OMU	Odontomacrurus murrayi	*Odontomacrurus murrayi*	0.4	1	1
OPI	Umbrella octopus	*Opisthoteuthis* spp.	1.7	1	1
ORH	Orange roughy	*Hoplostethus atlanticus*	126 576.5	107 071	51
PAO	Pillsburiaster aoteanus	*Pillsburiaster aoteanus*	0.1	1	1
PDS	False frostfish	*Paradiplospinus gracilis*	0.2	1	1
PHO	Lighthouse fish	*Phosichthys argenteus*	0.5	4	4
PLS	Plunket's shark	*Proscymnodon plunketi*	96.7	6	6
PSQ	Pholidoteuthis boschmai	*Pholidoteuthis boschmai*	23.5	7	5
PYR	Pyrosoma atlanticum	*Pyrosoma atlanticum*	1.3	-	4
RAG	Ragfish	*Pseudoicichthys australis*	3.4	1	1
RCH	Widenosed chimaera	*Rhinochimaera pacifica*	77.8	28	21
RIB	Ribaldo	*Mora moro*	547.0	289	48
RUD	Rudderfish	*Centrolophus niger*	5.3	3	2
SAW	Sawtooth eel	*Serrivomer* spp.	0.1	1	1
SBI	Bigscaled brown slickhead	*Alepocephalus australis*	1.3	2	2
SBK	Spineback	*Notacanthus sexspinis*	0.3	1	1
SCO	Swollenhead conger	*Bassanago bulbiceps*	1.5	4	3
SFN	Spinyfin	*Diretmichthys parini*	17.6	22	19
SMC	Small-headed cod	*Lepidion microcephalus*	1.7	1	1
SMO	Cross-fish	*Sclerasterias mollis*	0.2	2	1
SMX	Mixed shell		0.5	3	1
SND	Shovelnose spiny dogfish	*Deania calcea*	284.4	122	38
SOR	Spiky oreo	*Neocyttus rhomboidalis*	122.9	233	46
SOT	Solaster torulatus	*Solaster torulatus*	0.1	1	1
SPE	Sea perch	*Helicolenus* spp.	30.7	40	17
SPL	Scopelosaurus sp	*Scopelosaurus* sp.	0.2	2	2
SQU	Arrow squid	*Nototodarus sloanii* & *N. gouldi*	1.3	3	3
SQX	Squid		0.7	2	2
SSK	Smooth skate	*Dipturus innominatus*	44.8	1	1
SSM	Smallscaled brown slickhead	*Alepocephalus antipodianus*	4.6	6	4
STA	Giant stargazer	*Kathetostoma spp.*	3	2	1
SUH	Schedophilus huttoni	*Schedophilus huttoni*	2.9	2	2
TAM	Tam O shanter urchin	Echinothuriidae & Phormosomatidae	1.4	21	14

TET	Squaretail	*Tetragonurus cuvieri*	0.6	1	1
TOP	Pale toadfish	*Ambophthalmos angustus*	8.5	4	4
TRS	Cape scorpionfish	*Trachyscorpia eschmeyeri*	18	16	13
TRX	Velvet rattail	*Trachonurus gagates*	0.4	2	2
TSQ	Todarodes filippovae	*Todarodes filippovae*	7.0	8	8
TUB	Tubbia tasmanica	*Tubbia tasmanica*	2.2	1	1
VSQ	Violet squid	*Histioteuthis* spp.	23.6	23	17
WHX	White rattail	*Trachyrincus aphyodes*	219.9	77	32
WSQ	Warty squid	*Onykia* spp.	4.3	2	2
ZAS	Velvet dogfish	*Zameus squamulosus*	3.1	3	2
ZOR	Rat-tail star	*Zoroaster* spp.	0.2	2	2

Catch composition – Volcano (target identification trawls)

Code	Common name	Scientific name	Catch weight (kg)	Number in catch	Number of stations
ASE	Snaggletooths	*Astronesthes* spp.	0.1	1	1
CHA	Viper fish	*Chauliodus sloani*	0.1	2	1
CTR	Abyssal rattail	*Coryphaenoides striaturus*	0	1	1
CYO	Smooth skin dogfish	*Centroscymnus owstoni*	10	1	1
EEX	Enypniastes eximia	*Enypniastes eximia*	0	1	1
ETB	Baxter’s lantern dogfish	*Etmopterus baxteri*	10	5	2
HEC	Henricia compacta	*Henricia compacta*	0	1	1
LHE	Hector's lanternfish	*Lampanyctodes hectoris*	0.1	1	1
MBE	Mirrorbelly	*Opisthoproctus grimaldii*	0	1	1
ORH	Orange roughy	*Hoplostethus atlanticus*	52 557.9	39 251	3
PHO	Lighthouse fish	*Phosichthys argenteus*	0.1	1	1
PYR	Pyrosoma atlanticum	*Pyrosoma atlanticum*	0.1	1	1
RIB	Ribaldo	*Mora moro*	1.3	1	1
ROK	Rocks stones	Geological specimens	0.4	3	1
SND	Shovelnose spiny dogfish	*Deania calcea*	1.9	1	1
SOR	Spiky oreo	*Neocyttus rhomboidalis*	24.6	21	1
SPL	Scopelosaurus sp	*Scopelosaurus* sp.	0.1	1	1
SSO	Smooth oreo	*Pseudocyttus maculatus*	9	4	1
TSQ	Todarodes filippovae	*Todarodes filippovae*	1.6	2	1
VSQ	Violet squid	*Histioteuthis* spp.	0.3	2	1
WSQ	Warty squid	*Onykia* spp.	1.5	1	1

APPENDIX E: Thematic maps of echointegrated outputs

1. Challenger Flats

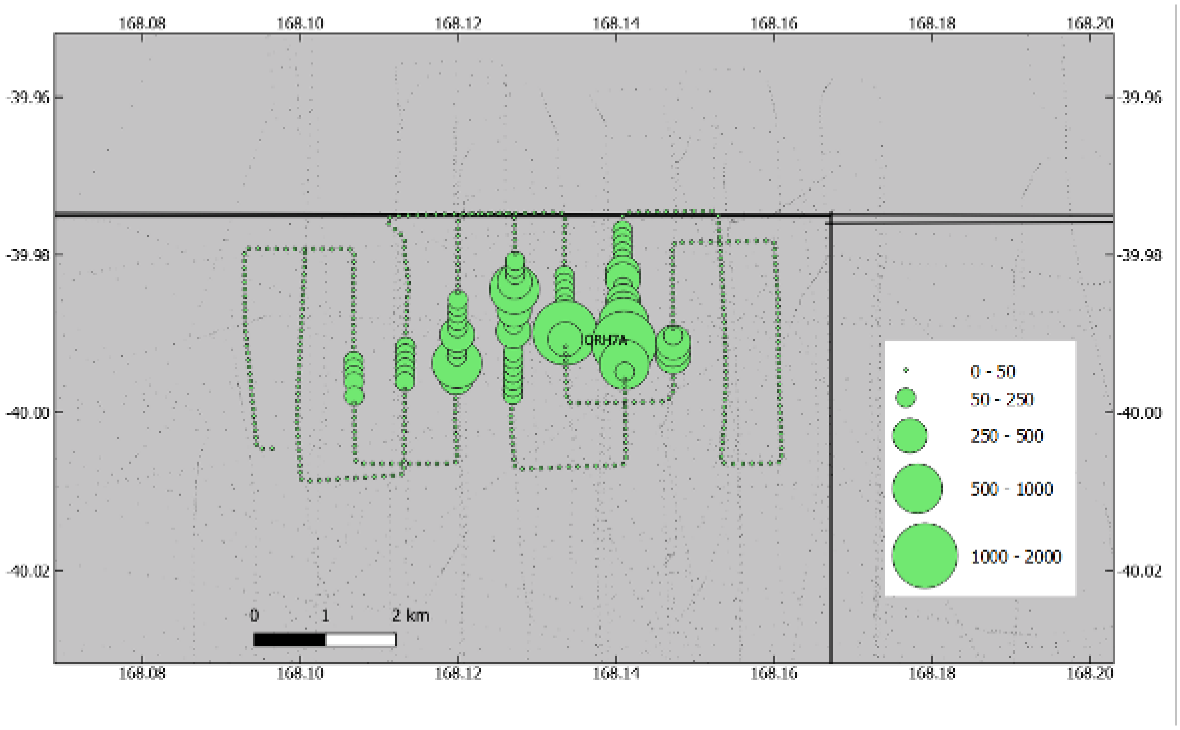


Figure 28: OP 22 thematic map of Vessel 38 kHz echo-integration NASC values at Challenger Flats.

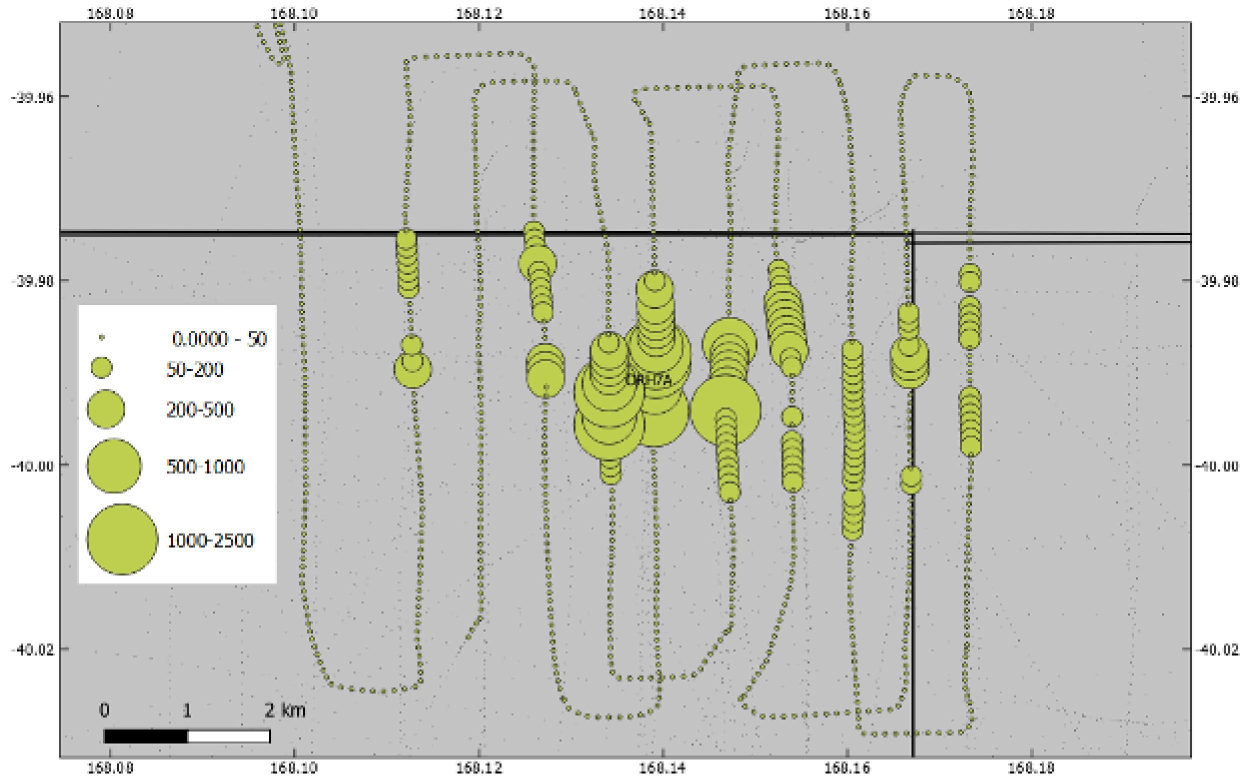


Figure 29: OP 23 thematic map of AOS 38 kHz echo-integration NASC values at Challenger Flats.

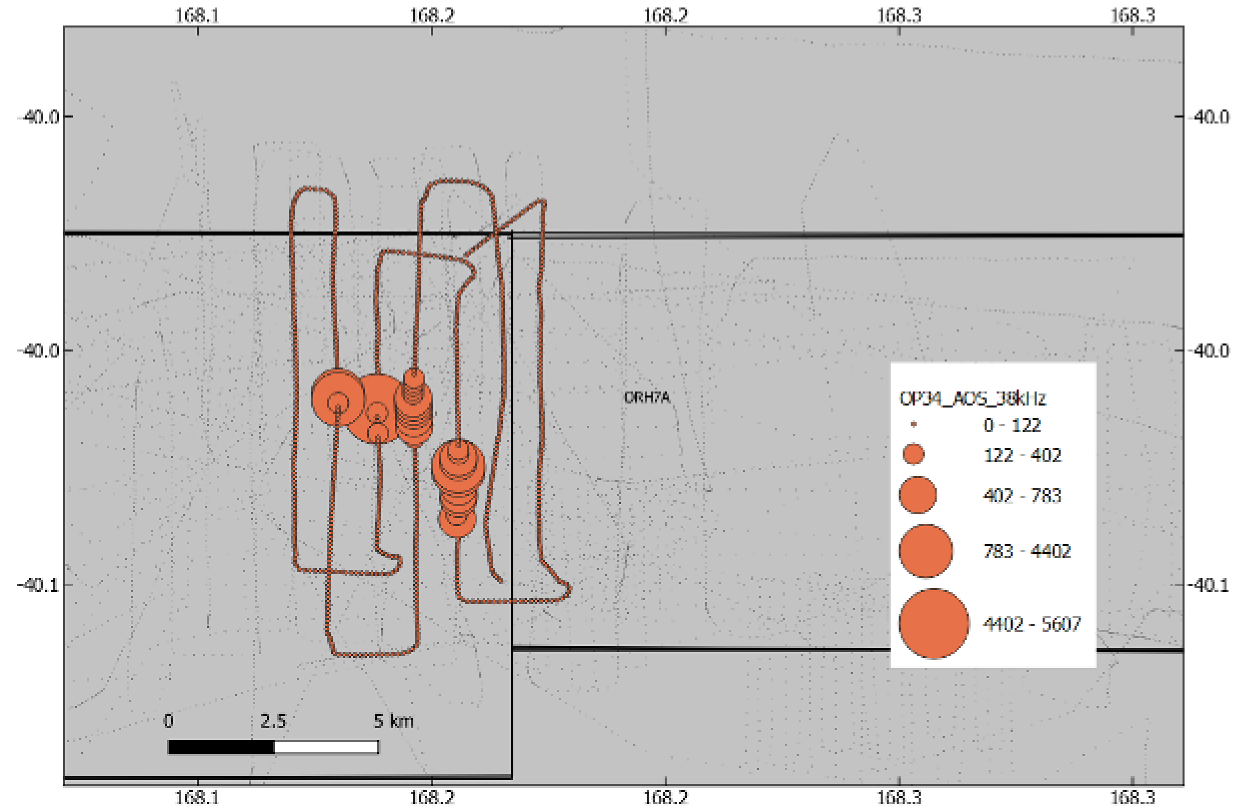


Figure 30: OP 34 thematic map of AOS 38 kHz echo-integration NASC values at Challenger Flats.

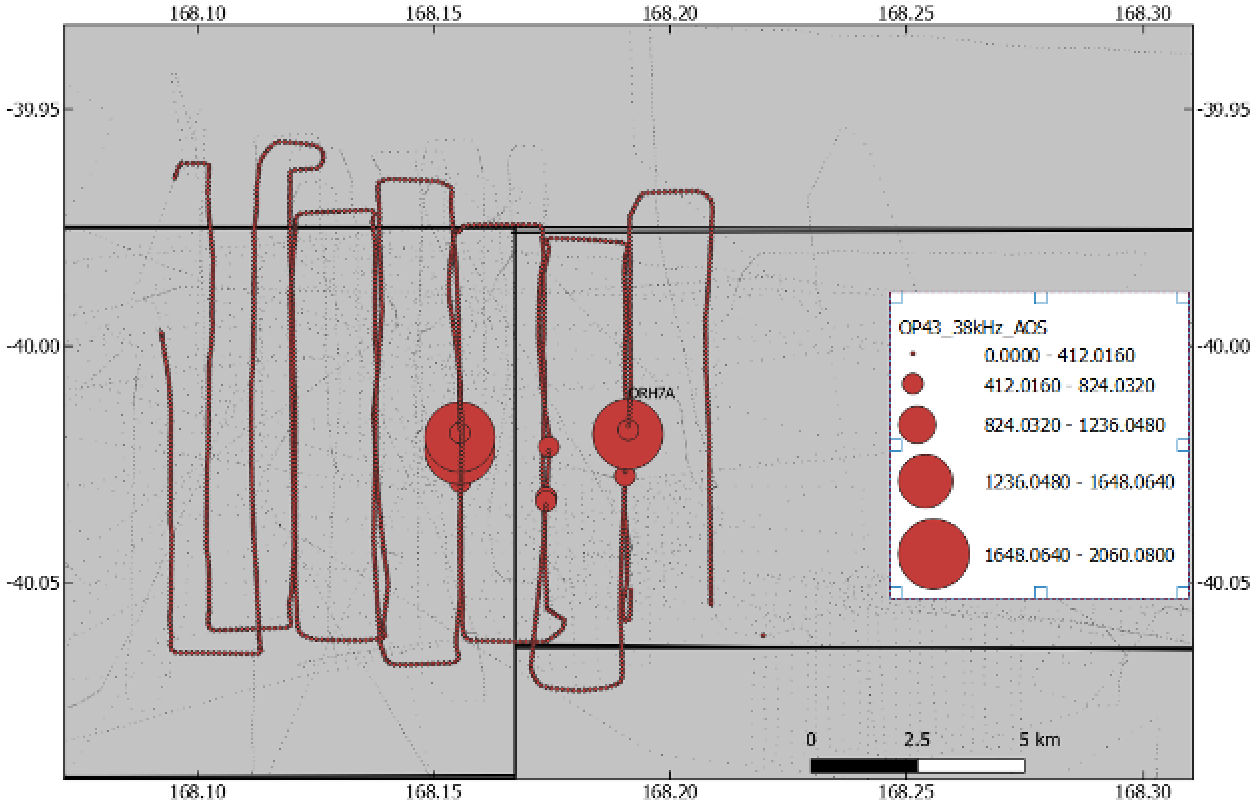


Figure 31: OP 43 thematic map of AOS 38 kHz echo-integration NASC values at Challenger Flats.

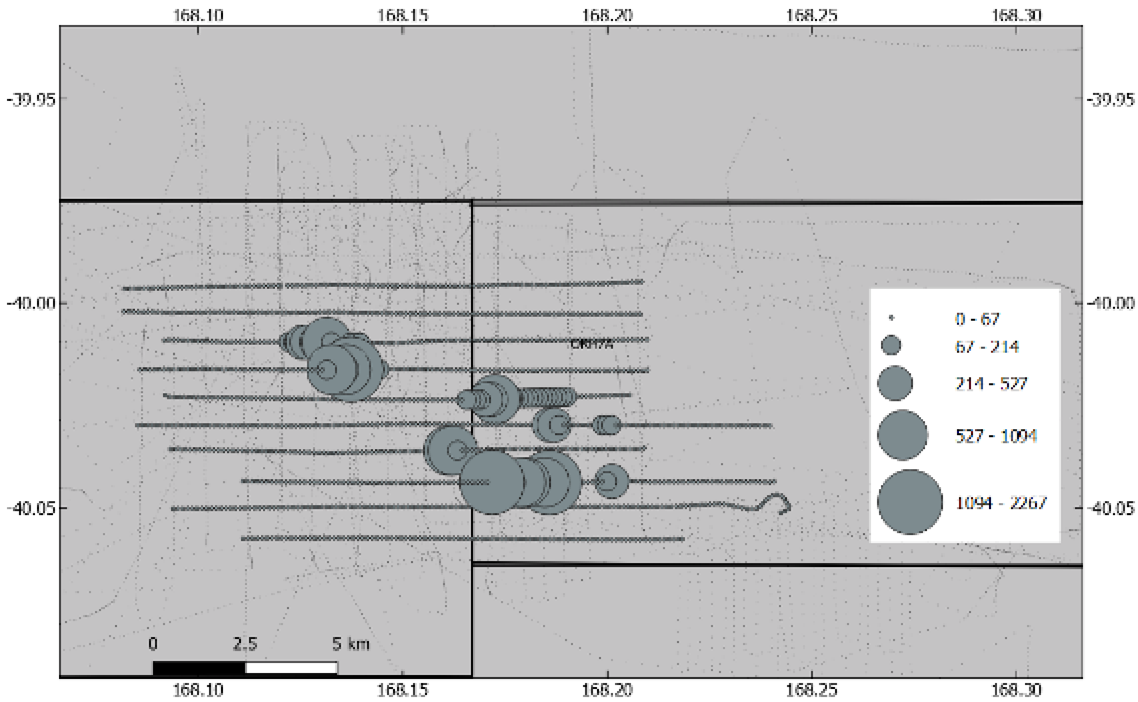


Figure 32: OP 44 thematic map of Vessel 38 kHz echo-integration NASC values at Challenger Flats.

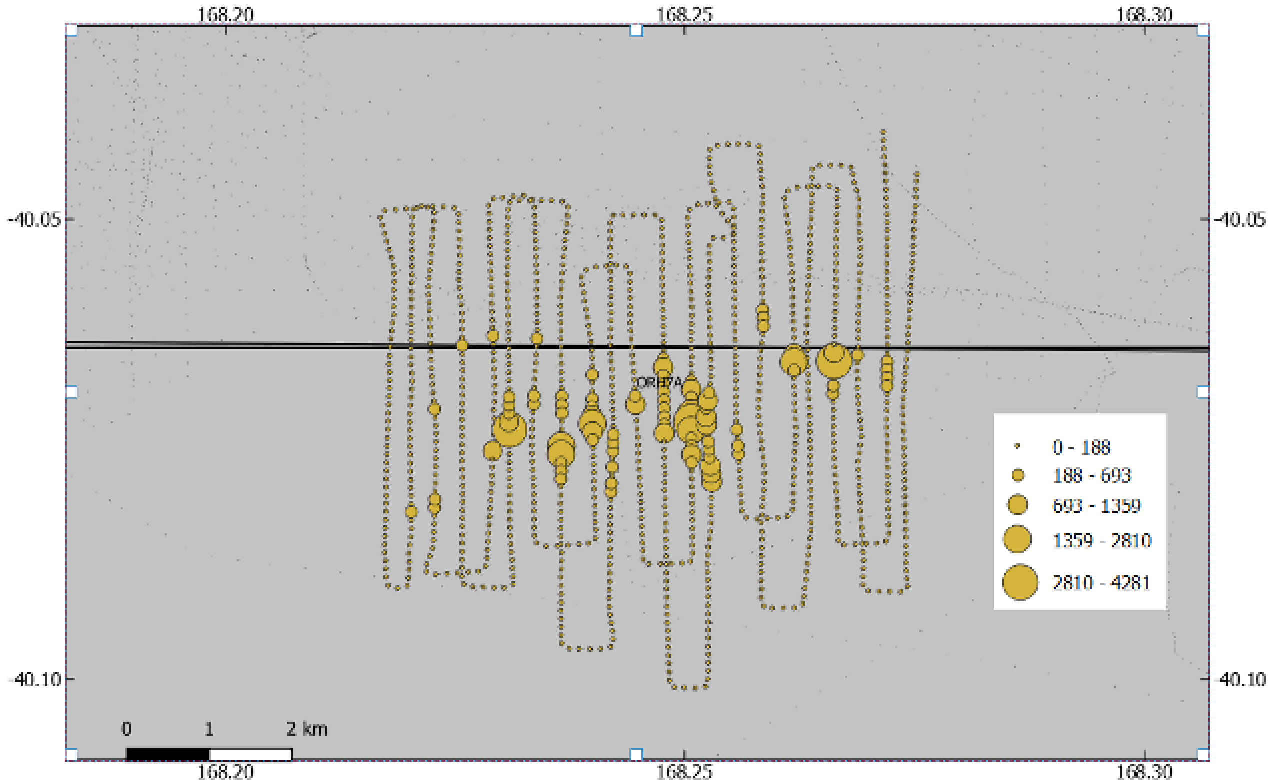


Figure 33: OP 72 thematic map of Vessel 38 kHz echo-integration NASC values at Challenger Flats.

2. Volcano

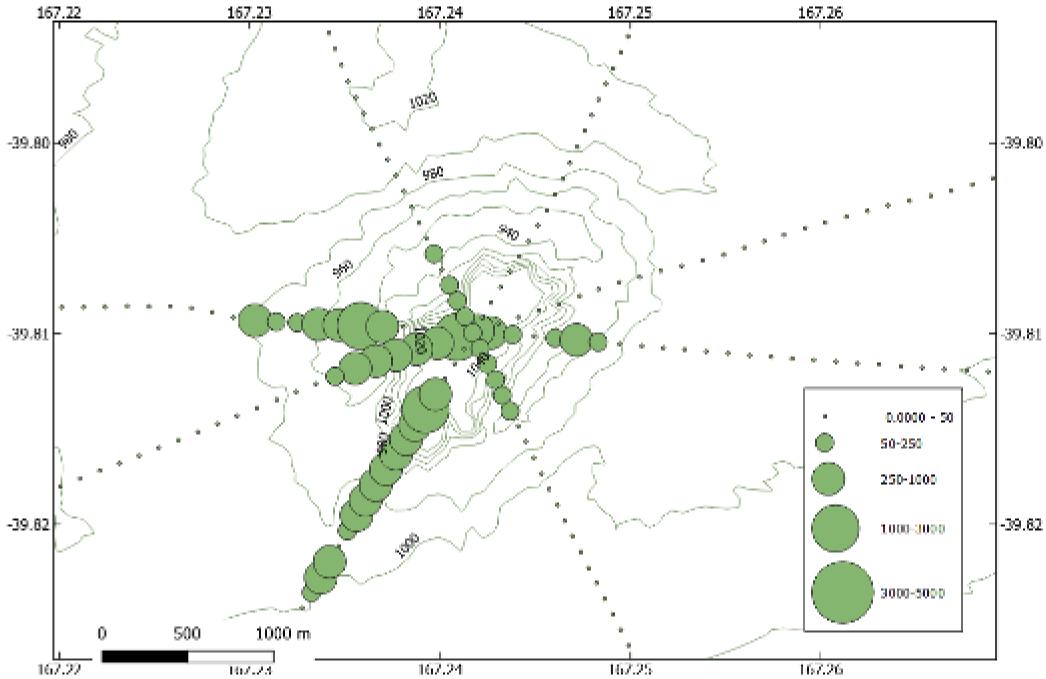


Figure 34: OP 48 thematic map of AOS 38 kHz echo-integration NASC values at Volcano.

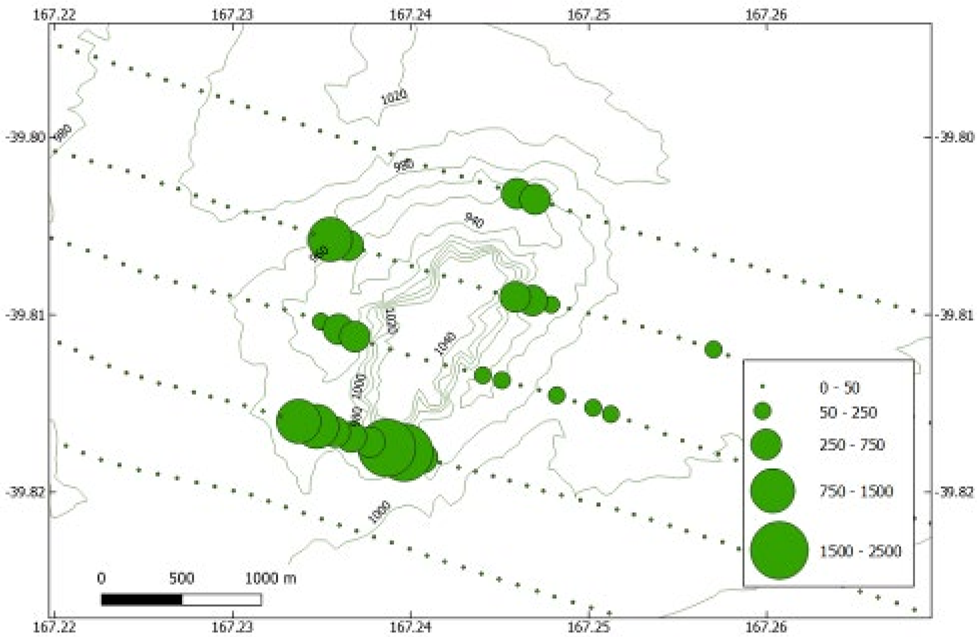


Figure 35: OP 72 thematic map of AOS 38 kHz echo-integration NASC values at Volcano

APPENDIX F: Table of activities

Operation Number	Operation Type	Start Date (NZ local)	Location	Comment
1	Vessel calibration	25/06/2018 23:30	Nelson Bay	Calibration of vessel 38 kHz and 18 kHz ES60s in ~ 35 m water in Tasman Bay
2	RSTS	27/06/2018 21:59	Challenger Flats	Trawl 1, GS3
3	RSTS	28/06/2018 0:15	Challenger Flats	Trawl 2, GS1
4	RSTS	28/06/2018 2:30	Challenger Flats	Trawl 3, GS2
5	RSTS	28/06/2018 4:00	Challenger Flats	Trawl 4, GW3
6	RSTS	28/06/2018 7:03	Challenger Flats	Trawl 5, GW2
7	RSTS	28/06/2018 8:57	Challenger Flats	Trawl 6, GW1
8	RSTS	28/06/2018 11:31	Challenger Flats	Trawl 7, W05
9	Vessel Search	28/06/2018 12:45	Twin Tits, Megabrick	mark on top of Twin Tits - most likely spiky oreo. Possible roughy mark on top of Megabrick
10	RSTS	28/06/2018 15:51	Challenger Flats	Trawl 8, GN3
11	RSTS	28/06/2018 17:54	Challenger Flats	Trawl 9 GN2
12	RSTS	28/06/2018 19:42	Challenger Flats	Trawl 10 GN1
13	RSTS	28/06/2018 21:30	Challenger Flats	Trawl 11, GE2
14	RSTS	28/06/2018 23:20	Challenger Flats	Trawl 12, GE1
15	RSTS	29/06/2018 2:20	Challenger Flats	Trawl 13, GE3
16	RSTS	29/06/2018 4:49	Challenger Flats	Trawl 14, W19
17	RSTS	29/06/2018 6:57	Challenger Flats	Trawl 15, W01
18	RSTS	29/06/2018 8:44	Challenger Flats	Trawl 16, W02
19	RSTS	29/06/2018 10:46	Challenger Flats	Trawl 17, W03
20	RSTS	29/06/2018 12:38	Challenger Flats	Trawl 18, W04
21	RSTS	29/06/2018 14:33	Challenger Flats	Trawl 19, W06
22	Vessel Survey	29/06/2018 16:32	Challenger Flats	Good marks
23	AOS Survey	29/06/2018 20:30	Challenger Flats	AOS 12, 38, and 120 EK60. Survey mode. 0–600 m. 30/06/2018 - 04:54 - CHANGE NET MONITOR
24	AOS biological	30/06/2018 11:48	Challenger Flats	Trawl 20, target id tow. 13 t roughy.
25	RSTS	30/06/2018 15:59	Challenger Flats	RSTS Trawl 21. W14
26	RSTS	30/06/2018 17:44	Challenger Flats	RSTS Trawl 22. W17
27	RSTS	30/06/2018 19:29	Challenger Flats	RSTS Trawl 23. W09
28	RSTS	30/06/2018 21:21	Challenger Flats	RSTS Trawl 24. W16
29	RSTS	30/06/2018 23:05	Challenger Flats	RSTS Trawl 25. W18
30	RSTS	1/07/2018 0:52	Challenger Flats	Trawl 26, W08
31	RSTS	1/07/2018 7:48	Challenger Flats	Trawl 27, W13
32	RSTS	1/07/2018 9:45	Challenger Flats	Trawl 28, W11
33	AOS survey mode - single pass	1/07/2018 11:55	Challenger Flats	Single-pass over Twin Tits/Megabrick complex with AOS in survey mode. Multifrequency acoustics tuned to key out gas bladder mark and ORH1 mark as a useful exercise to confirm empirical tuning of 120 kHz calibration was set to give correct species identification
34	AOS Survey	1/07/2018 15:31	Challenger Flats	AOS survey of the main aggregation. Prior to starting conducted 1–2 hrs vessel surveying to re-establish location of main aggregation. Plume had moved south-east by ~ 1.4 n.mile from where they were observed on the first AOS survey. Good marks on multiple transects
35	AOS biological	2/07/2018 3:55	Challenger Flats	Target id tow, trawl 29. 28 t ORH.
36	Vessel Survey	2/07/2018 7:00	Challenger Flats	Vessel survey to the east.
37	RSTS	2/07/2018 14:11	Challenger Flats	Trawl 30, W07

Operation Number	Operation Type	Start Date (NZ local)	Location	Comment
38	RSTS	2/07/2018 16:10	Challenger Flats	Trawl 31, W10
39	RSTS	2/07/2018 17:58	Challenger Flats	Trawl 32, W12
40	RSTS	2/07/2018 20:10	Challenger Flats	Trawl 33, W20
41	RSTS	2/07/2018 22:19	Challenger Flats	Trawl 34 W15
42	RSTS	3/07/2018 0:03	Challenger Flats	Trawl 35, W21
43	AOS Survey	3/07/2018 2:31	Challenger Flats	Transect survey at 0.8 n.mile intervals followed by return transects offset at 0.4 n.mile. Strong aggregations observed on one transect in particular. Moderate and then very strong mark on the far west end of the survey required extension of the survey leading to long survey duration.
44	Vessel Survey	4/07/2018 2:00	Challenger Flats	
45	AOS biological	4/07/2018 9:56	Challenger Flats	Trawl 36. ID tow. ~5t ORH
46	AOS deep calibration	4/07/2018 13:45		Calibration down to 900 m at 100, 300, 500, 600, 700, 800 and 900 m stations.
47	Vessel Survey	4/07/2018 19:01	Volcano	Vessel star pattern survey of Volcano. Likely ORH1 marks high off the seafloor up to 200 m up into the water column.
48	AOS Survey	4/07/2018 20:37	Volcano	AOS survey of Volcano. ORH1 marks high off seafloor, up to 200 m away. Note to apply caution with vessel 38 and 18 kHz data where second echo is sometimes appearing at similar depths to ORH1 and not always easy to distinguish. AOS data should clarify any ambiguity.
49	AOS biological	5/07/2018 3:10	Volcano	Trawl 37. Target id tow. Pinned up at top of hill. 60 kg of ORH caught. Set AOS to EK38-18CDK 2.048 ms pulse duration, FM up, 120 kHz CW.
50	AOS biological	5/07/2018 4:57	Volcano	Trawl 38. Target id tow. Pinned up at top of hill. 80 kg of ORH caught.
51	Biological sample, no AOS	5/07/2018 6:58	Volcano	Trawl 39. Using Arrow Trawl with no AOS on net. Needing biological samples but not wanting to risk AOS. Pinned up then released. Net was in strong part of mark for very brief period (< 10 seconds) then rapid haul to avoid taking excessive fish. Despite this ~50 t ORH caught.
52	Vessel Survey	5/07/2018 8:45	Dork	Roughy like mark off the NW of the of the hill, but inspection of both 18 kHz and 38 kHz data indicates that this is likely second echo interference.
53	Vessel Survey	5/07/2018 10:20	Volcano	Vessel survey at Volcano. Marks sitting 100m off the top of Volcano and connected to the DSL.
54	Vessel Survey	5/07/2018 12:20	Dork	Star pattern survey at Dork. High backscatter mark, likely to be spikey dory based on information obtained on this feature in the 2014 survey.
55	Vessel Survey	5/07/2018 13:52	Volcano	Catch still being processed so conducted vessel survey in good conditions. Final survey at Volcano before breaking off and heading back "inside the line" to recommence RSTS surveys.
56	Vessel Survey	5/07/2018 23:56	Challenger Flats	Fine scale vessel search upon first locating reasonable mark. Turn this into a grid survey where moderate marks were observed straddling along the 870 m contour in east-west direction.
57	RSTS	6/07/2018 5:42	Challenger Flats	Trawl 40, E02. 3 t ORH.
58	RSTS	6/07/2018 9:30	Challenger Flats	Trawl 41, E03. 14 t ORH. Hauled after 8 minutes because net sensors had pinged - travelled 0.385 n.mile.
59	RSTS	6/07/2018 12:06	Challenger Flats	Tow 42, E11. 80 kg ORH.
60	RSTS	6/07/2018 15:00	Challenger Flats	Tow 43, E10. 80 kg ORH.
61	RSTS	6/07/2018 16:49	Challenger Flats	Tow 44, E07. 45 kg ORH.
62	RSTS	6/07/2018 20:17	Challenger Flats	Tow 45, E05. 27 t ORH from 14-minute tow. Hauled early to avoid over-catch.
63	RSTS	6/07/2018 22:47	Challenger Flats	Tow 46, E12. 5 kg ORH.
64	RSTS	7/07/2018 0:41	Challenger Flats	Tow 47, E08. 15 kg ORH.
65	RSTS	7/07/2018 2:44	Challenger Flats	Tow 48, E13. 40 kg ORH.

Operation Number	Operation Type	Start Date (NZ local)	Location	Comment
66	RSTS	7/07/2018 10:12	Challenger Flats	Tow 49, E 01 80kg ORH.
67	RSTS	7/07/2018 12:20	Challenger Flats	Tow 50, E04. Hauled as net sensors triggered ~20t. Marks observed prior to touching down, and then took marks and catch sensors triggered shortly after touching down. Plan to redo this station due to taking large catch in short time/distance.
68	RSTS	7/07/2018 17:06	Challenger Flats	Tow 51. EO9. 3 t ORH.
69	RSTS	7/07/2018 19:24	Challenger Flats	Tow 52. E14. 10 kg ORH.
70	RSTS	7/07/2018 21:36	Challenger Flats	Tow 53. E06. 10 kg ORH.
71	RSTS	7/07/2018 23:43	Challenger Flats	Tow 54. E04. Repeat of earlier tow line that caught ~ 20 t ORH. This time started taking fish upon landing with strong marks on net sensor. Hauled early to avoid over-catch. 2 t ORH.
72	Vessel Survey	8/07/2018 0:20	Challenger Flats	Commenced extended vessel search to locate marks on eastern part of survey region and then head to western sector to see if we could locate the main mark that was surveyed with the AOS around the 4th of July.
73	AOS Survey	8/07/2018 16:30	Volcano	Transect survey of Volcano. Rough weather prevented a star pattern design. Instead set up parallel transects at 0.3 n.mile spacing to run into and with the sea. Had to cease operations as weather had increased and issues with winches