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Acoustic biomass surveys of orange roughy spawning aggregations in ORH 3B NWCR and ORH 3B ESCR Chatham Rise, June/July 2022

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PLAIN LANGUAGE SUMMARY

An acoustic biomass survey of spawning orange roughy was undertaken on aggregations at Morgue and Graveyard hills in ORH 3B North-West Chatham Rise and at Rekohu, Spawn Plume and Mt Muck in ORH 3B East & South Chatham Rise, during June and July 2022 aboard FV *San Waitaki*.

Acoustic data were recorded using the vessel's hull-mounted Simrad 38 kHz echosounder system and a dual-frequency (38 kHz & 120 kHz) Acoustic Optic System (AOS) deployed on the headrope of a trawl net.

In NWCR, spawning biomass at Morgue, a protected area, showed an increase over survey estimates in 2013, 2016 and 2021, while spawning biomass at Graveyard was considerably reduced compared to the previous survey estimate in 2013. In ESCR, spawning biomass at Rekohu in 2022 was lower than in 2013 and 2016, while at Spawn Plume the biomass was similar to that found in 2013 and 2016. At Mt Muck the biomass in 2022 was higher than the estimates in 2013 and 2016.

EXECUTIVE SUMMARY

Ryan, T.E.[1]; Tilney, R.L.[2] (2025). Acoustic biomass surveys of orange roughy spawning aggregations in ORH 3B NWCR and ORH 3B ESCR Chatham Rise, June/July 2022

***New Zealand Fisheries Assessment Report 2025/23.* 71 p.**

A successful acoustic and biological survey programme of the North-West and North-East Chatham Rise orange roughy spawning aggregations was carried out on FV *San Waitaki* during a 30-day voyage from 18 June to 18 July 2022. The dual objectives for the voyage were for the vessel to fill up with orange roughy catch during the spawning period and for a comprehensive scientific survey programme to be completed. Surveying was carried out mainly during vessel down-time while fish were being processed, with charter time used when survey operations delayed normal fishing operations. On-going cooperation between scientists and bridge officers during the voyage meant that *San Waitaki* was able to meet its catch target without compromising the survey programme, which was able to meet all primary objectives.

Acoustic Optical System (AOS) surveys were completed on Morgue and Graveyard hills in ORH 3B NWCR, and at Rekohu, Spawn Plume and Mt Muck on the North-East Chatham Rise (NECR) in ORH 3B ESCR. These were complemented by vessel-based acoustic surveys where appropriate. Each location received sufficient survey effort to provide a good understanding of the spawning stock. Some minor technical issues were resolved very early in the survey and recording of high-quality AOS and vessel-based acoustic data was achieved for the duration of the survey programme. Both AOS and vessel-acoustic systems were calibrated during the survey during a period of calm weather. Broadly, observations were that:

(i) There was a very large aggregation of orange roughy on Morgue compared to those surveyed in 2013 and 2016.
(ii) Graveyard held only a small amount of orange roughy, as was found in 2013 and 2016.
(iii) There were substantial aggregations across a reasonably large area at Rekohu but biomass did not appear to be as large as in previous years. Rekohu ended up requiring a lot of searching and survey effort as the aggregations were very mobile and never really settled as spawning progressed (as observed in 2013 and 2016). Hence surveying was quite challenging but four vessel-based acoustic surveys and two AOS surveys were completed.
(iv) The Spawn Plume aggregation was also quite mobile, but less dynamic than at Rekohu and good aggregations were surveyed by one vessel-based survey and three AOS surveys.
(v) Good aggregations were seen on Mt Muck. As in previous surveys, high aggregation variability occurred over 24-hour cycles, so it was pleasing to achieve two AOS surveys during periods when good aggregations of orange roughy were present.

Biological sampling was carried out on all catches during the voyage and served to comprehensively monitor the build-up to the spawn and achieved or surpassed the number of otolith samples required to be collected as a basis for age-structure determination from each of the survey locations.

Trials of the Seafloor Monitoring Automated Recording of Trawl (SMART-Cam) benthic observation camera were carried out. The automated operation, providing seamless transfer of images from trawl deck to bridge, was successful. Image quality was good when the trawl headline was close to the seafloor but light spillage significantly compromised the quality of the images when the headline was further from the seafloor. The trials provided an understanding of adjustments needed to improve image quality.

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NWCR - Morgue
Four high-quality AOS surveys were completed at Morgue between 25 and 28 June. Biomass estimated using the AOS 38 kHz system showed a steady upward trend between the earliest (9979 t) and the last survey (28 653 t). Four biological sampling trawls were carried out under a special permit to allow measurement of fish length, weight, sex, spawning state and to extract otoliths. Spawning stage information indicated that the peak spawning period had been captured, with a progression from running ripe to spent/partially spent observed between the initial sampling on 25 June compared to trawls carried out on 28 and 29 June.

NWCR - Graveyard
Only a small aggregation of orange roughy was observed at Graveyard, with an AOS 38 kHz biomass estimate of 225 t. One biological sampling tow was conducted, returning a catch of about 150 kg. The aggregation was not considered significant enough for further investment of effort for either survey or commercial catch purposes, given the survey priorities in other, more productive, areas.

NECR - Rekohu
Six biomass estimation surveys were carried out at Rekohu. The first four were conducted using vessel-based acoustics between 27 June and 1 July. The choice to run vessel surveys instead of using the AOS was driven by the mobility of orange roughy aggregations, where establishing their extent and executing the slower AOS surveys was not possible. Fortunately, weather conditions were favourable to this approach. The last two surveys were conducted using the AOS on 11 and 13 July, when aggregations had settled to some extent. Due to poor weather biomass estimates from the concurrent vessel 38 kHz system and AOS were not possible. Biomass estimates ranged from 9311 to 22 800 t for the vessel-based 38 kHz system and 13 088 to 16 713 t for the AOS system. Biological sampling commenced on 27 June and continued through to 15 July and showed a steady progression of the spawn; by the end of the survey 49% of the females were spent/partially spent indicating that peak spawning had been observed.

NECR - Spawn Plume
One vessel and three AOS surveys were carried out at Spawn Plume between 4 and 9 July. AOS 38 kHz biomass estimates ranged from 12 468 to 23 905 t. Biological sampling commenced early, between 20 and 24 June, while focus was on commercial fishing, through to 10 July. A steady progression of the spawn was observed with 32% of females in spent or partially spent condition by 10 July. The biological data indicated that the acoustic surveys were conducted around the spawning peak.

NECR - Mt Muck
Two AOS biomass surveys were conducted at Mt Muck, on the 6th and 8th of July. AOS 38 kHz biomass estimates were 9218 and 12603 tonnes. Spawning was well underway on 8 July with 50% of the females running ripe and 25% spent or partially spent.

1. INTRODUCTION

In 2021 a survey of orange roughy spawning aggregations was undertaken in ORH 3B North-West Chatham Rise (NWCR) and on the North-East Chatham Rise (NECR) in ORH 3B ESCR on FV *Amaltal Apollo* (Ryan et al. 2023). Unfortunately, this voyage was cut short due to mechanical issues. NWCR surveys were carried out successfully but in a shortened timeframe due to delays in sailing and ongoing mechanical problems. Large aggregations of orange roughy were surveyed at Morgue during three Acoustic Optical System (AOS) surveys. Biomass estimates ranged from 13 481 to 19 837 t. These estimates are comparable to estimates in 2016 that ranged from 12 000 to 15 000 t. Despite the abbreviated survey period of only 36 hours, it appeared that our surveys had quantified Morgue orange roughy biomass during the peak spawning period such that this survey objective was met.

In 2021, NECR survey outcomes were mixed. Only one AOS survey was completed at Rekohu before the voyage was abandoned. Two vessels were fishing commercially during the spawn and were able to make some impromptu opportunistic surveys. *Amaltal Mariner* was able to complete a vessel-based acoustic survey at Rekohu. Biomass estimates were respectively 6466 and 12 543 t for the *Amaltal Apollo* AOS and *Amaltal Mariner* vessel-based surveys. These are compared to estimates of 10 000 to 45 000 tonnes measured in 2016 where a full survey programme was completed. No AOS surveys were possible for the Spawn Plume or Mt Muck in 2021. *San Waitaki* completed a vessel-mounted acoustic survey of the Spawn Plume observing large aggregations over a wide area with a biomass of 35 155 tonnes estimated: this was a factor of 3.5 higher than vessel-based surveys in 2016. These results indicate that Rekohu biomass had reduced while Spawn Plume had increased but the limited sampling makes it difficult to draw firm conclusions. Consequently, a voyage with similar objectives to the 2021 design was instigated in 2022 to help clarify the status of the stocks.

A summary of the planned survey program and objectives in June/July 2022 were as follows:

Vessel: FV *San Waitaki*

Survey area: ORH 3B NWCR and NECR in ORH 3B ESCR

Voyage dates: 18 June to 18 July 2022

Key Personnel:

- Survey and acoustics lead – Tim Ryan (CSIRO)
- Vessel master – Tom Jackman
- Survey management and biological lead – Rob Tilney (Thalassa)
- Vessel Management – Darryn Shaw, Shane Hales (Sanford)

Research survey objective:

To obtain estimates of orange roughy spawning biomass in ORH 3B NWCR and ORH 3B ESCR in terms of the Medium-Term Research Plan for Deepwater Fisheries 2020/21 – 2024/25, to inform updated stock assessments.

Primary objectives:

- To estimate the abundance of spawning orange roughy using a net-mounted Acoustic Optical System (AOS) and a hull-mounted acoustic system.
- To collect biological information from trawl catches on aggregations to inform the acoustic data and to collect otolith samples for population age structure determination.

Ancillary objectives:

- To trial a Seabed Monitoring Automated Recording of Trawl (SMART-Cam) benthic observation camera.

Special Permit exemptions

A special permit exemption was approved for undertaking the following survey activities within the Morgue and Pyre-Gothic Seamount Closure Areas:

- Acoustic survey transects above the seabed using a net-mounted AOS.
- Non-seabed-contacting target identification trawl tows (maximum of six tows).

Survey timing and areas:

Survey timing was planned to align with the peak spawning period in NWCR (late June) and in NECR (first half of July). The survey areas are shown in Figure 1.

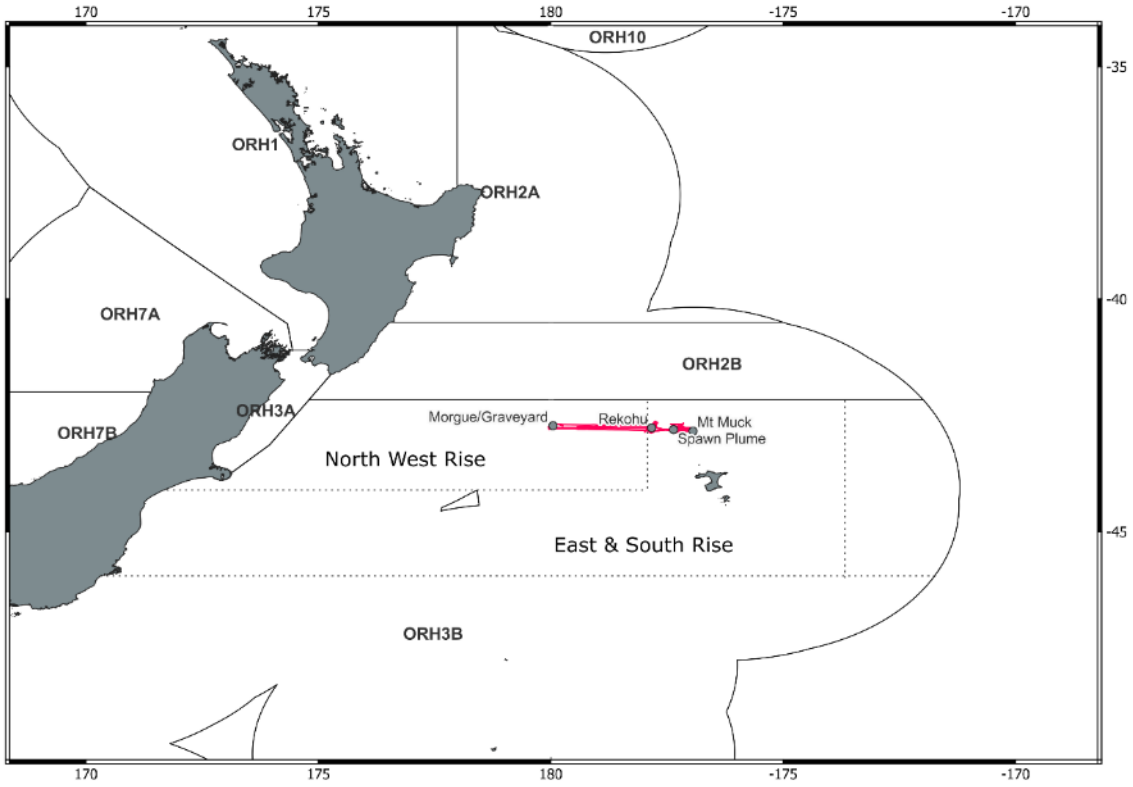

Figure 1: Area of operations with vessel track for 2022 surveys shown in red.

This report presents the acoustic-based biomass estimates and associated biological sampling results for the 2022 ORH 3B Chatham Rise spawning aggregations.

2. METHODS

2.1 Survey overview and equipment

2.1.1 Acoustic Optical System (AOS)

The Sealord 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 (Figure 2).

This system was built as a collaborative project between Sealord and CSIRO, starting in 2012 based on previous successful developments and applications in Australia and New Zealand (Kloser et al. 2011; Kloser & Ryan, 2011). It is similar in principle to the CSIRO AOS (Ryan et al. 2009) but with technical advances and modifications to improve ease of operation. For this survey the AOS housed a two -frequency acoustic system (38 and 120 kHz) based on Simrad ES60 transceivers. The system

was battery powered with all data logged to internal storage media. Specifications of the Sealord AOS system are given in Table 1.

Table 1: Sealord AOS specifications.

Component	Specifications
Physical	Dimensions: 1900 × 1400 × 500 mm, sled-style platform; weight: 750 kg in air; operational depth: 1500 m
Acoustics	Echosounders: Simrad ES60, 38 and 120 kHz split-beam transceivers, Transducers: 38 kHz - Simrad ES38DD (7° beam width), SN 28363; and 120 kHz - ES120–7CD (7° beam width), SN 115
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. [Not working due to damage that occurred early in the voyage]
Reference scale	Two Laserex LDM-4 635 nm 8 mW red lasers set 400 mm apart
Environmental	Seabird SBE37si CTD
Computing	Industrial NUC i7 PC running Simrad ES80 1.3.1 software for acoustic acquisition. Video and digital still acquisition is also controlled by this computer which provides a common time reference
Motion reference	Microstrain 3DM-GX1
Power	Li-ion. Battery endurance: 18 hours

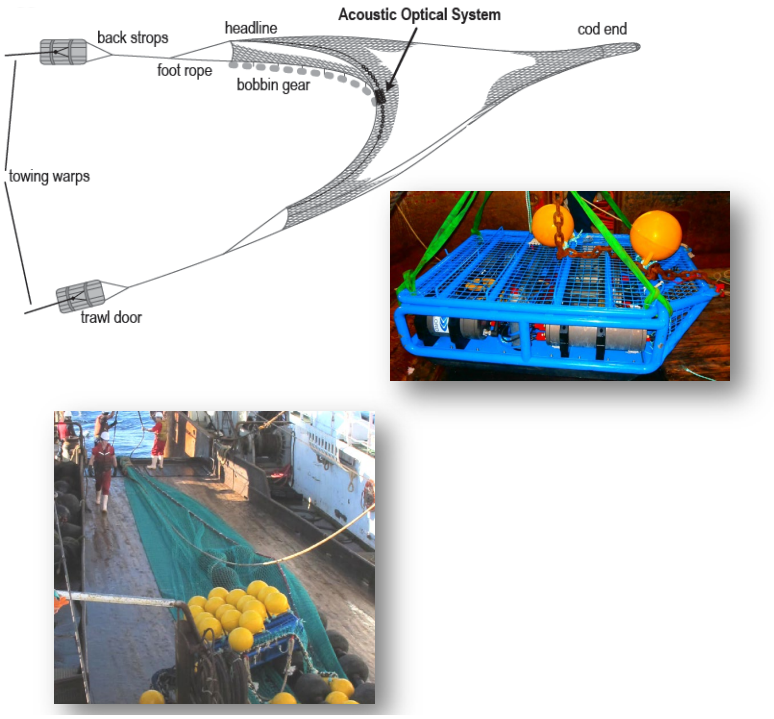

Figure 2: Sealord Acoustic Optical System with conceptual diagram of its attachment to the headline of the demersal trawl net and the system in the trawl net on the aft deck.

2.1.1.1 AOS operational modes

The demersal net was deployed and retrieved using the procedures of a routine commercial trawl shot with only minor modifications to accommodate the presence of the AOS. There were two survey modes and a calibration mode, Table 2.

Table 2: Summary of AOS deployment modes.

Mode	Objective	Height above seafloor	Comments
1	Echo-integration survey	250–350 m	Parallel or Star pattern transect lines with net-attached instrumentation
2	Target strength with concurrent optical images, biological samples from commercial and research catch	5–30 m	Conventional demersal trawl with net-attached instrumentation
3	Calibration: Echosounder sensitivity as a function of depth	0–900 m in 100 m steps	Vertical deployment with AOS detached from net, and a calibration sphere suspended underneath

Mode 1: Echo-integration surveys

Acoustic echo-integration biomass surveys were undertaken with the AOS attached to the headline of the vessel's demersal trawl net as per Ryan & Kloser (2016). These are referred to as Mode 1 surveys. To minimize gear avoidance by orange roughy and deadzone uncertainty (see Section 2.2.2), the AOS-net system was towed in the midwater at 250–350 m above the seafloor. Parallel transect surveys were applied for the flatter grounds (Rekohu, Spawn Plume) and star pattern surveys for the smaller conical underwater features (Morgue, Graveyard, Mt Muck). Star survey patterns are a favourable design for these types of features (Doonan et al. 2003a), particularly for deep-towed systems as turning manoeuvres between transects can take a significant amount of time.

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

Demersal trawls with the AOS attached were undertaken to provide biological samples and commercial catch. For Mode 2 deployments the acoustic systems were set to a short pulse length (0.256 or 0.512 ms) and fast ping rate (~10 Hz) for close-range fish target strength (TS) measurements. Standard definition video was taken to complement the TS measures. Stereo digital still images were recorded using a pair of Prosillica GX3300 Gig-E cameras with a frame rate of 1–2 shots per second. The still and video camera data provided a line of evidence to support species identification.

2.1.2 Sealord AOS calibration

The Sealord AOS 38 and 120 kHz echosounders were calibrated on the voyage using the standard sphere method (Demer et al. 2015) during a calm period on 28 June over the platform's operational depths during transect surveys. The AOS was lowered on a trawl warp vertically from the surface down to 700 m with a 38.1 mm tungsten carbide calibration sphere suspended 9 m beneath the transducers. The system was paused for 10 minutes at 150, 300, 400, 500, 600, and 700 m to collect sets of target returns for each depth station. A similar sequence was followed for the upward cast. The success of the calibration cannot be determined until the AOS is retrieved and data reviewed. Ideally there will be many target-returns through the depths, but this can be affected by currents and/or the reference sphere not traversing the transducer beams. To improve chances of having the sphere within the beam the winch was hauled in and out by 10 m a few times at each depth station. This movement causes the AOS to swing, with the hope of facilitating movement of the reference sphere through the acoustic beam. For this experiment the 120 kHz target positions were well spread across the transducer beam (Figure 3).

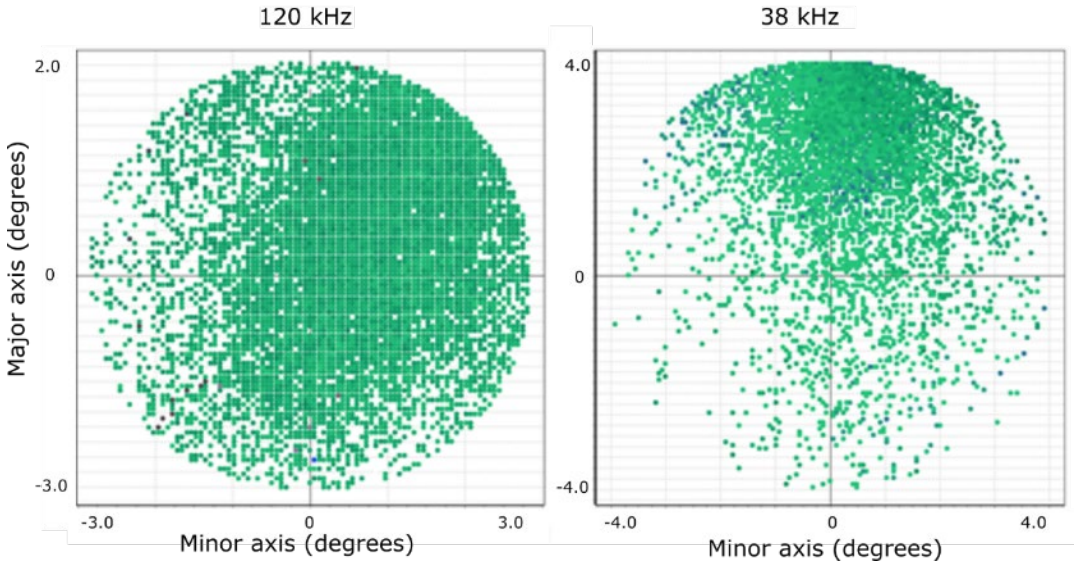

Figure 3: Location of reference target sphere within the acoustic beam for 120 and 38 kHz AOS echosounders for all platform depths.

The 38 kHz sphere targets were centred around the minor axis but were mostly around +3 degrees on the major axis (Figure 3). This was not ideal as a quite large beam compensation had to be applied to have sufficient data to work with. Beam compensation parameters were tuned to provide a 'flat' response and to minimize variance errors in the beam compensation correction, which increases with off-axis sphere position.

A sensitivity test was made to check on the relationship between compensated sphere target strength and the amount of beam compensation. Ignoring the secondary effect of depth on transducer gain, the set of all sphere target returns was filtered for a range of beam compensation values (Table 3). The acoustic data were visually reviewed in Echoview software to ensure data quality was high and not

affected by artefacts such as fish within the acoustic beam. What remains are sphere returns from the calibration sphere suspended in clear water within the acoustic beam; that is, these should be 'clean' measures of the standard reference sphere as the 'point of truth' with no obvious mechanisms for bias. The sphere returns with minimal beam compensation (0.5 and 1 dB) were constrained to be within the on-axis region where any errors in the beam compensation model would have little influence. As the beam compensation criteria are relaxed the number of sphere returns increases as does the amount of compensation applied. Despite this, the mean compensated TS showed only small variability as a function of beam compensation. This sensitivity analysis indicates that errors due to the larger beam-compensations applied to most of the data that were centred around +3.5 degrees on the minor axis, are not going to greatly affect the final calculation of system gain.

Table 3: 38 kHz mean sphere TS values for measurements filtered for beam-compensation.

Beam compensation (dB)	4	3	2	1	0.5
Mean TS (dB re 1 m^2)	-48.15	-48.29	-48.34	-48.37	-48.31
Number of targets	1242	712	372	189	106

Calibration data were analysed to provide primary values for on-axis Gain and S_a correction at the average working depth of the AOS platform. As these parameters can change with depth, we also applied a secondary correction to account for any depth-related changes that may occur as the AOS platform moves along a transect line. The corrections were applied to each along-track echo integration interval based on a polynomial relationship between Gain and S_a correction as a function of platform depth, derived based on data recorded during the calibration profiles (Figure 4, Figure 5).

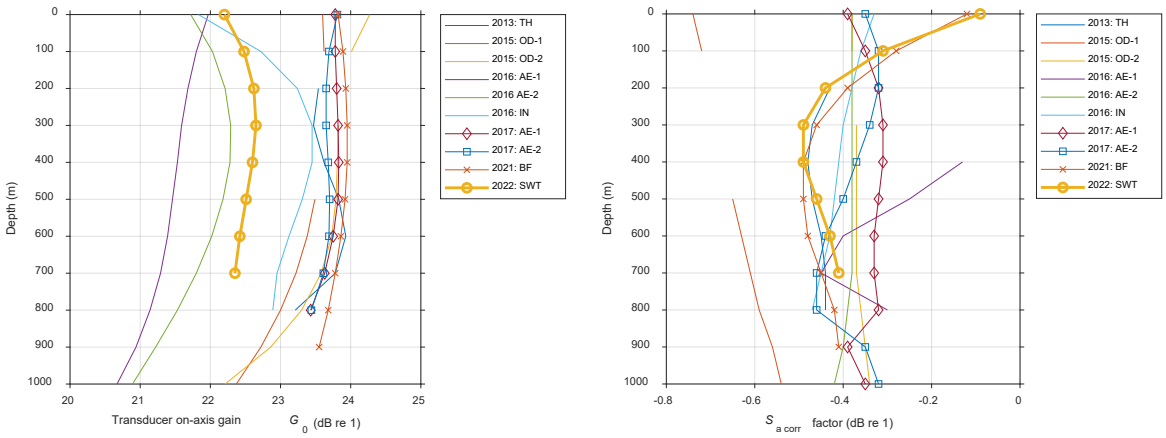

Figure 4: Profiles of gain vs depth (left panel) and S_a correction vs depth (right panel) for 38 kHz AOS transducer.

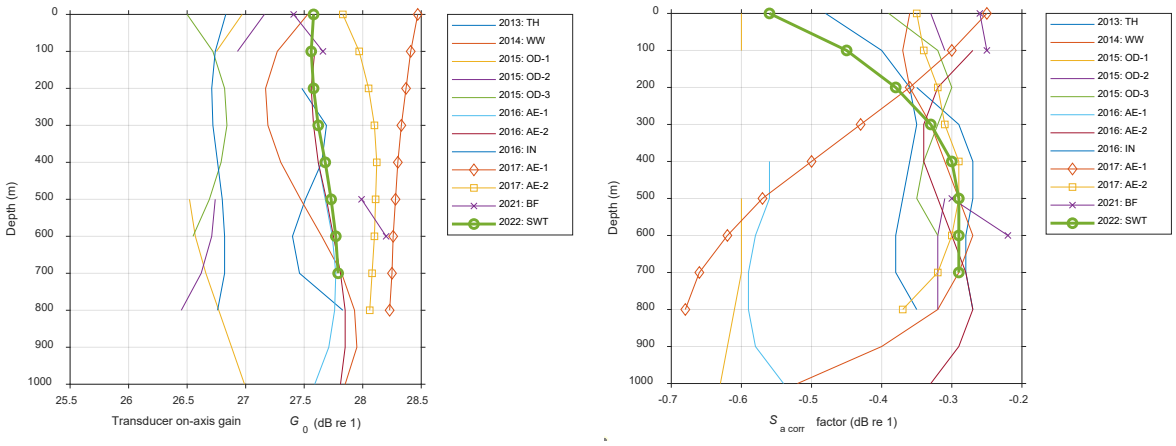

Figure 5: Profiles of gain vs depth (left panel) and S_a correction vs depth (right panel) for 120 kHz AOS transducer.

The calibration parameters for a nominal operating depth of 600 m based on a polynomial relationship for gain-depth are provided in Table 4. Polynomial coefficients for secondary correction to account for variations in Gain above or below the nominal 600 m platform depth are provided in Table 5 and Table 6 for 38 kHz and 120 kHz echosounders respectively.

Table 4: Transceiver settings for 38 and 120 kHz Sealord AOS echosounder systems for nominal platform depth of 600 m.

	General Purpose Transceiver (GPT) settings	
Frequency f (kHz)	38	120
Transmit power p_{et} (W)	2 000	400
Pulse duration τ (ms)	2.048	1.024
	Calibration parameters	
Transducer on-axis gain G_0 (dB re 1)	22.42	27.73
S_a (m^2 m^{-2}) correction factor $S_{a\,\mathrm{corr}}$ (dB re 1)	-0.43	-0.29
Adjusted equivalent two-way beam angle Ψ (dB re 1 sr)	-20.74	-20.27
Absorption coefficient α_a (dB m^{-1})	0.009460	0.033033
sound speed c_w (m s^{-1})	1 492	1 492

Table 5: Polynomial coefficients $[p(x) = p_3x^3 + p_2x^2 + p_1x + p_0]$ for 38 kHz echosounder where x is the platform depth.

	Combined down and up casts			
	P_3	P_2	P_1	P_0
Transducer on-axis gain (G_0)	5.7447e-09	-8.94469e-06	0.00366428	22.1971
S_a correction factor ($S_{a\,\mathrm{corr}}$)	-4.03349e-09	6.25133e-06	-0.00286288	-0.086864

Table 6: Polynomial coefficients $[p(x) = p_3x^3 + p_2x^2 + p_1x + p_0]$ for 120 kHz echosounder where x is the platform depth.

Combined down and up casts

	P_3	P_2	P_1	P_0
Transducer on-axis gain (G_0)	-2.16061e-09	2.5126e-06	-0.000399139	27.5763
S_a correction factor ($S_{a\,\mathrm{corr}}$)	9.58345e-10	-1.93556e-06	0.00126592	-0.558804

The 2022 calibration results show that the AOS 120 kHz calibration has good agreement with the previous calibration conducted in April 2021. The AOS 38 kHz results (at a nominal depth of 600 m) however were approximately a factor of two more sensitive than the previous result from 2021: Gain of 23.8 in 2021 minus Gain of 22.4 in 2022; (23.8-22.42)×2 dB = 2.8 dB change, a factor of 1.9. Our default is to use the calibration obtained during the current survey as it is closest in time to the survey data. However, we note that applying the 2021 results would halve the 2022 38 kHz biomass estimates. The reason for the change in system gain is not understood, but the transducers repeatedly experience extremely large pressure and temperature gradients as the platform moves from the surface to survey depths and back, which may be the driver of these changes.

The large difference between the 2022 and 2021 AOS 38 kHz calibrations warranted further investigation. As a secondary check, an analysis applying 2022 calibrations was made using echointegrated water column backscatter from the 38 kHz vessel mounted acoustics and near concurrent AOS 38 kHz data (about 10 minutes behind the vessel), (Figure 6). The moderately strong and relatively continuous deep scattering layer provided a reference source common to both acoustic systems. The assumption was that, despite variations in the data caused by layback and different sampling volumes between vessel-based and deployed system, a sufficiently large dataset would average out localised variability to enable a comparison between the systems.

Fortuitously, two trial AOS deployments were made during the voyage to check the platform trim and roll and to adjust the trawl warp lengths to achieve stable operations. For these exercises, the AOS was taken to 400 to 500 m depth. These data sets provided a useful means of comparison with the vessel 38 kHz echosounder as the AOS was held steady for an approximately 15 minute period at depth, something that does not happen during trawls or AOS transect surveys. A time offset for the AOS data to allow for layback was estimated by inspection of distinctive features in the 38 kHz vessel echogram. With layback time-offset applied, the depth-time profile of the AOS data was used to mask the vessel echogram (Figure 6, solid red line). Both echograms were echointegrated in 100 m intervals. Box plots of AOS and vessel 38 kHz echo integration values for the two AOS deployments were used to visualise the mean and distribution of the data (Figure 7).

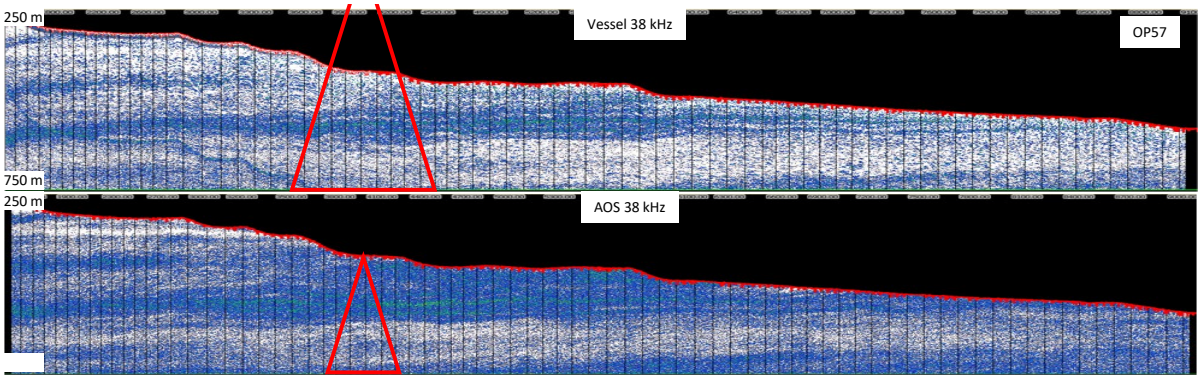

Figure 6: 38 kHz Echograms from vessel and AOS echosounders showing integration intervals. The red triangle highlights the difference in sampling volumes from the respective systems.

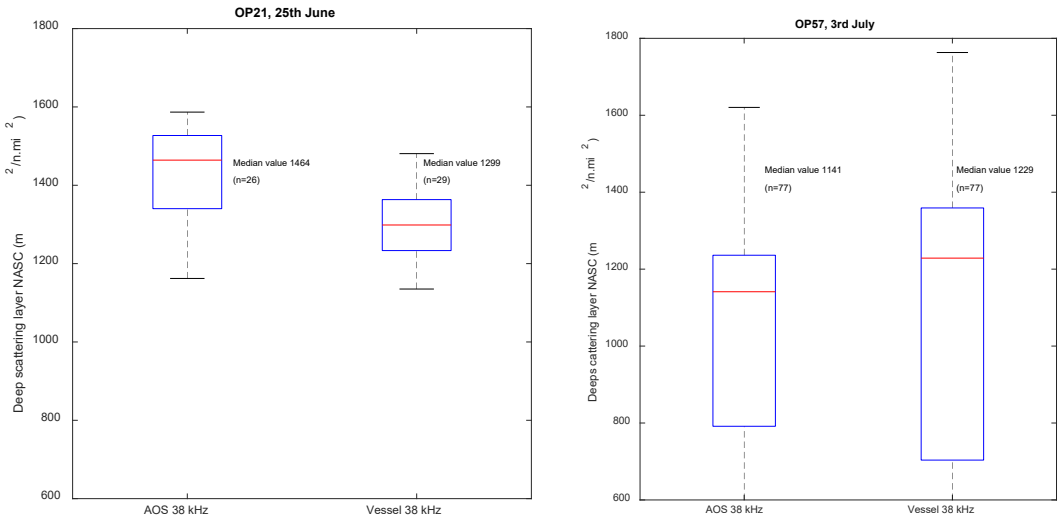

Figure 7: Box plots of along-track echo integration values (NASC) for near-concurrent Vessel 38 kHz and AOS 38 kHz echosounders for deployments carried out on 25 June and 3 July 2022.

The vessel 38 kHz and AOS 38 kHz NASC values show reasonable agreement. The AOS 38 kHz median NASC is 11% higher than the vessel 38 kHz for the first deployment and 7% lower for the second.

From this analysis, we conclude that the 2022 AOS calibration results can reasonably be applied to the survey data. The 120 kHz calibration collected a large number of targets throughout the deployment and there is no indication of any issues with the final result. Despite 38 kHz sphere targets being off-axis, the sensitivity check for beam-compensation and the close comparison with vessel-38 kHz echosounder data indicates that this calibration can reasonably be applied to the 2022 data.

2.1.3 Vessel-mounted acoustic instruments

San Waitaki runs Simrad ES80 38 kHz and Furuno FCV30 38 kHz echosounders for fish finding. The Furuno FCV 30 was turned off during acoustic surveys to avoid interference that would compromise the calibration and quality of the ES80. The 38 kHz ES80 system was calibrated in calm open water during the voyage on 28 June using the standard target sphere method (Demer et al. 2015). A 60 mm copper sphere was used, providing good stability at 38 kHz and a strong return signal that was well above the general backscatter from biological sources. The sphere was suspended from monofilament

fishing line from three motorised reels that were adjusted using a control box on the bridge. Calibrations were conducted at the survey setting of 2.048 ms pulse duration and at 1.024 ms pulse duration to allow comparison with historic calibrations. Calibration details and results are provided in Table 7.

Table 7: Calibration parameters for *San Waitaki* ES80 38 kHz echosounder for 1.024 ms and 2.048 ms pulse duration.

Vessel	San Waitaki	San Waitaki
Date	28-06-2022 03:10	28-06-2022 02:59
Frequency (kHz)	38	38
Calibration data set	28th June 2022	28th June 2022
Transducer model	Simrad ES38-7	Simrad ES38-7
Serial Number	144	144
Calibration sphere	60 mm copper	60 mm copper
Temperature (degrees Celsius)	14.1	14.1
Salinity (psu)	35.15	35.15
Sound speed (m/s) (Mackenzie 1981)	1504	1504
Absorption (dB/m). (Francois and Garrison, 1982)	0.009187	0.009187
Transceiver power (W)	2000	2000
Transceiver pulse length (ms)	2.048	1.024
Transducer gain (dB)	25.9709	25.7392
Sa correction (dB)	-0.0680	-0.165
Factory two-way beam angle (dB re 1 steradian)	-20.5	-20.5
Factory test tank water temperature (degrees Celsius)	22	22
Factory test tank water salinity (ppt)	0	0
Local temperature (degrees Celsius)	14.1	14.1
Local salinity (Mackenzie 1981, ppt)	35.14	35.14
Local sound speed (m/s)	1504	1504
Two-way beam angle (dB re 1 steradian), adjusted for local conditions	-20.407	-20.407

2.1.4 Survey execution

The *San Waitaki*'s 38 kHz echosounder provided continuous observations of the fishing grounds to guide both fishing trawls and acoustic survey design. Acoustic transect surveys were conducted over spawning orange roughy aggregations using both calibrated vessel 38 kHz acoustics and the net-attached AOS. Depending on the situation, dedicated vessel-based surveys could be conducted at 10 knots, providing a means to cover a wider area in less time. This was helpful in establishing the extent and behavioural dynamics of aggregations, particularly on the flat grounds at Rekohu and Spawn Plume where location and extent of aggregations are not tied to defined seafloor features. For vessel-based biomass estimations to be made, weather conditions need to be calm, generally less than 20 knots of wind, and orange roughy schools need to be distinguishable from the surrounding backscatter. However, wind speed is not a hard and fast criterion. Echogram quality can depend on various factors including vessel hull design, weight of catch in the hold, wind speed and direction, swell and heading of the vessel with respect to these. Hence, we assess the quality of the echogram data for suitability on a case-by-case basis. Vessel-mounted surveys will have higher uncertainty due to range-dependant effects of absorption and vessel motion (Kloser, 1996; Dunford, 2005) with potential for positive bias from high-signal gas-bladder species. We note the distinction of dedicated vessel-based acoustic surveys with near-concurrent vessel acoustic data recorded during dedicated AOS transect surveys. For the latter, AOS multifrequency data, which can be used to reduce uncertainty around species identification, are available to help strengthen interpretation of the vessel-based data.

For the AOS surveys, the trawl net was maintained 300 to 400 m above the seafloor and about 250 m above orange roughy aggregations. This kept the AOS platform within the working range of the 120 kHz echosounder while maintaining sufficient distance from the top of the schools to avoid a scare reaction (Koslow et al. 1995). On steep grounds where there were large aggregations such as at Morgue, the challenge was to maintain the height above the school while adjusting AOS platform depth to keep within range of the bottom of the school as the transects moved across the feature.

2.2 AOS acoustic data processing

Processing of the AOS acoustic data was done using Echoview 13 analysis software. Custom Matlab tools were used to extract and process platform depth and motion data that was embedded in the Simrad raw files. Platform depth data was 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. The acquisition rate was above the Nyquist sampling criteria, allowing the Dunford (2005) operator-implemented facility in Echoview to correct for signal loss due to platform motion.

2.2.1 Echogram scrutiny and quality control

Calibration offsets 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 or interference were marked as 'bad' and removed from the analysis.

2.2.2 Acoustic dead-zone estimate

The acoustic dead-zone is the region close to the seafloor where backscatter from a fish school is difficult to distinguish from bottom echo 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 signals 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 is a semi-demersal species that can occur at high densities within the dead-zone region requiring an estimate to account for this potentially significant biomass component that cannot be directly observed by the echosounders. Previous acoustic observations of orange roughy schools immediately above the dead-zone suggest that both increased (schools 'hard down') and decreased densities (schools extending high into the water column) within the dead-zone region are 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 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.

2.2.3 Platform geolocation

Geolocation was established by applying a time-offset between the vessel and the AOS data. The time-offset was estimated by inspecting the AOS and vessel echograms, identifying either small

terrain features or fish schools and noting the time difference between vessel and AOS as it 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.

2.2.4 Seawater absorption and sound speed: AOS acoustics

Values of 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 data recorded by a Seabird SBE 39 sensor during the AOS deployments (Table 8). The use of the Francois & Garrison (1982) equation (instead of the Doonan et al. 2003b) equation is consistent with previous deep-towed acoustic surveys of Chatham Rise orange roughy that commenced in 1998 (Kloser et al. 2000). The difference in estimates between the two absorption equations is noted as being significant, more so for vessel-based acoustics where differences up to 30% can occur as the range to target is approximately double that of the AOS data sets. The absorption and sound speed values were applied to the data in Echoview post-processing software. A small 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 in the range to the fish schools.

Table 8: Nominal seawater absorption and sound speed values for a nominal platform depth of 600 m and fish school depths of 900 m. Absorption values were calculated using the equations of Francois & Garrison (1982).

Parameter	Frequency (kHz)	
	38	120
Absorption (dB/m)	0.009359	0.032
Sound speed (m/s)	1494.78	1494.78

2.2.5 AOS Echogram interpretation and delineation of species

Quantitative analysis and subsequent biomass estimation were performed using both 38 kHz and 120 kHz echogram data. Interpretation of the S_v echograms, to partition according to species and exclude contributions from non-orange roughy sources, 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 visualising the backscatter difference between frequencies by subtracting 38 kHz S_v values from 120 kHz (Figure 8). Nominally, regions where mean backscatter was 2–4 dB higher at 120 kHz compared to 38 kHz were attributed to homogenous schools of orange roughy (Kloser et al. 2002). 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 at lower numeric densities may be inferred from a more heterogeneous 'texture' with higher pixel-to-pixel variability compared to regions of orange roughy. Biological catch composition and inspection of video to identify species obtained during Mode 2 operations (Table 2) 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.

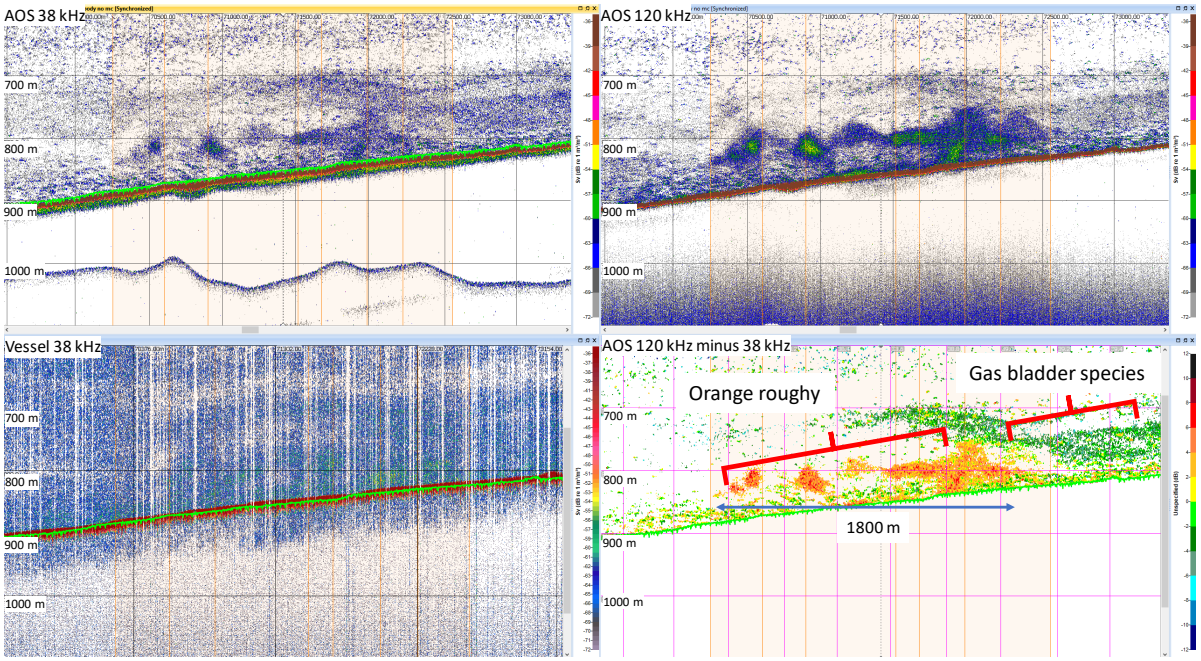

Figure 8: Example of multifrequency echograms from a Sealord AOS transect at Rekohu in July 2021 (top panels). Bottom left panel shows the echogram from the *Amaltal Apollo*'s 38 kHz echosounder.

2.3 Vessel acoustic data processing

2.3.1 Echogram scrutiny and quality control

Calibration offsets provided in Table 7 were applied to the 38 kHz volume backscattering strength (S_v dB re m^{-1}) (Maclennan et al. 2002) echograms. The 38 kHz S_v echograms were visually inspected with regions of noise interference marked as 'bad' and removed from the analysis.

2.3.2 Acoustic dead-zone estimate

Acoustic dead-zone estimates followed the same method as described in Section 2.2.2 for the AOS data.

2.3.3 Motion correction

At present, the Deep Water Working Group protocol for vessel-based acoustic surveys of orange roughy does not require a direct correction for vessel motion. Instead, following their protocols, a correction factor of 1.33 to the vessel-based acoustic data is applied that is intended to account for signal loss due to the combined effects of surface bubble attenuation and motion. We note that direct compensation for vessel motion is possible as motion data was logged above the Nyquist sampling rate during the acquisition of the echosounder data while the degree of signal loss due to surface bubble attenuation is unknown and will vary with weather conditions. However, for consistency with previous studies, we work with the original echosounder data uncorrected for motion effects and apply the 1.33 correction factor.

2.3.4 Seawater absorption and sound speed: 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. (2003b) Absorption estimates used Conductivity, Temperature and Depth values from a Seabird SBE39 recorded by the AOS for each deployment. Further, we note the choice of which equation to use (Doonan et al. 2003b or Francois & Garrison (1982) remains the greatest uncertainty, where difference in absorption estimates can affect biomass estimates by as much as 30%.

2.3.5 Interpretation of vessel-based echograms

Interpretation of vessel-based echograms is generally more uncertain than for deeply deployed multifrequency systems as there is only a single acoustic frequency. This, combined with range dependant effects of reduced signal-to-noise, weather attenuation and noise effects, absorption losses and the larger footprint of the acoustic beam further contribute to uncertainty (Kloser, 1996). In calm weather and when orange roughy are densely aggregated in large schools, vessel-based echograms can be interpreted, and species delineation achieved with a reasonable degree of confidence.

Interpretation can be aided by consideration of the depth, location and form of the schooling regions as orange roughy can form quite distinct spawning plumes. Trawl catch information, skipper and/or scientists' experience, can further assist interpretation. When data quality is degraded by weather effects or prospective orange roughy aggregations blend into the surrounding backscatter, biomass estimates become unreliable and susceptible to positive bias if high signal from co-occurring gas bladder species could be included. Figure 8, lower left panel, provides an example of a vessel-based echogram that contains a large orange roughy aggregation (in this example confirmed by the AOS multifrequency acoustics) that cannot be confidently delineated from the surrounding backscatter. Conversely, Figure 9 shows an example of a well-defined school region where data quality is high, improving confidence in interpretation.

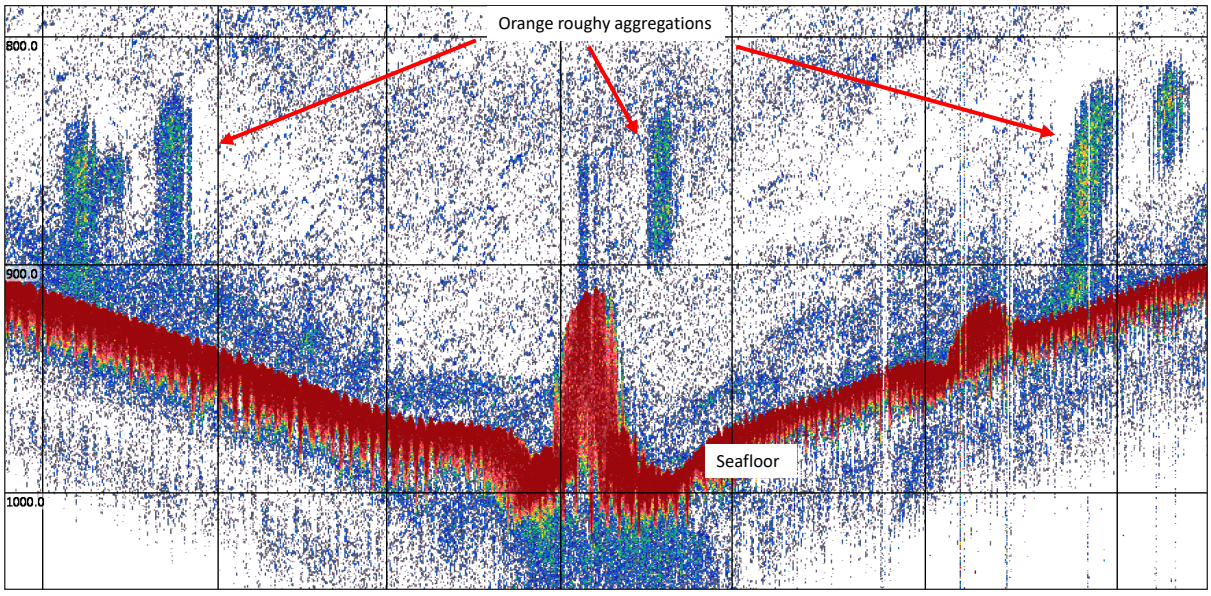

Figure 9: San Waitaki 38 kHz Simrad ES80 echogram showing well defined orange roughy aggregations.

2.4 Acoustic based biomass estimation

2.4.1 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.

2.4.2 Parallel transect acoustic surveys

For large regions such as at Rekohu and Spawn Plume, 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 where possible. This involves a set of transects being completed with a certain inter-transect spacing (Survey A). A second set of transects offset at half the inter-transect spacing of the first set of transects, is then completed in the reverse direction (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 at 38 kHz for the vessel acoustic data using standard echo-integration methods (Simmonds & MacLennan, 2008).

2.4.3 Biomass estimation parameters

Echogram regions classified as orange roughy 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 (Renard et al. 2015).

Biological samples provided mean fish weight where a 50:50 sex ratio was assumed. TS was estimated using a length-TS regression that was applied separately for males and females. A mean population TS was calculated by taking the linear mean of the male and female TS estimates and converting back to dB re 1 m^2, again a 50:50 population sex ratio was assumed. Length-TS regression parameters for 38 and 120 kHz using slope provided by Hampton & Soule (2002) and intercept provided by Kloser et al. (2013) for a regression relationship of TS = a*log10(SL) – b (Table 9).

Table 9: Standard length - TS regression parameters at 38 and 120 kHz.

Freq (kHz)	a	b
38	16.15	76.84
120*	16.15	73.01

* For 120 kHz estimate intercept of 73.01 has an adjustment of +0.6 dB to account for a small error in the 120 kHz calibration that was used in the analysis for the Kloser et al. 2013 article.

2.5 Biological sampling

San Waitaki had the objective to fill up its holds with orange roughy catch during this voyage and therefore needed to maintain maximum factory throughput. To maintain quality, catches of 20–30 t were desirable. Excessively large catches were avoided as far as possible as these caused a backlog on the trawl deck, preventing deployment of the AOS until cleared. On completion of each acoustic survey of orange roughy aggregations, one or more dedicated fishing tows were undertaken to collect representative biological information required to inform the acoustic data (i.e., lengths, weights, spawning condition, species composition) and to collect otolith samples for age-frequency determination. Trawls targeted the fringes of aggregations where high catch rates were achieved, which helped to meet the commercial fishing objectives and which also meant they were considered to be representative of the acoustically observed population.

Biological sampling was conducted on all trawl catches during the voyage. Sampling was performed using a Bioscribe electronic measuring board interfaced with a Marel M1100 motion-compensated electronic scale. Sampling of orange roughy included recording of individual standard lengths, weights, sex and spawning condition from samples of 100 fish and collection of otoliths from 25–100 fish, with a target of 500 otolith samples from each surveyed aggregation. Bycatch species composition was determined by weight and number of individuals per species and lengths were recorded for abundant species. For catches greater than 10 t, two-or-more samples of 100 orange roughy were taken depending on the time available and the rate at which the catch was moved through the factory. Orange roughy gonad development was recorded using an 8-stage scale for females and a 6-stage scale for males (Table 10), modified after Doonan et al. (2000).

Table 10: Macroscopic stages used for determining male and female orange roughy gonad maturity state.

Stage	Female	Male
1	Immature/Resting	Immature/Resting
2	Maturing	Maturing
3	Ripe	Ripe
4	Hydrated	Running ripe
5	Running ripe	Spent
6	Spent	-
7	Atretic	-
8	Partially spent	Partially spent

A maximum of six off-bottom tows were allowed at Morgue under a special permit as this is a Seamount Closure Area.

3. RESULTS

3.1 The survey programme

The acoustic and biological sampling programme on NWCR and NECR was carried out during a 30-day voyage that departed from Timaru on 18 June 2022. The voyage was considered a complete success with each of the priority spawning locations receiving comprehensive survey coverage that was well-timed with respect to the peak spawning period, while the vessel met its catch objective of approximately 600 tonnes of orange roughy product. *San Waitaki* has excellent seakeeping capability and is acoustically quiet, providing for high-quality acoustics from the hull sounder in all but the worst of weather conditions. Some small amount of survey time was lost due to AOS technical issues, but these were quickly resolved with high-quality, stable multifrequency acoustics recorded throughout the voyage. The difficult task of calibrating the AOS was carried out during a brief period of calm weather, with acceptable results. The opportunity to calibrate *San Waitaki'*s vessel acoustics in open ocean was taken at the same time, with good outcomes. A summary of all survey activities is provided in Appendix A. The biological sampling programme measured 8835 orange roughy and extracted a total of 3870 otolith samples. A summary of all catch by species is provided in Appendix B.

3.2 Morgue-Graveyard Complex, North-West Chatham Rise

The Morgue-Graveyard hills complex consists of a cluster of Underwater Topographic Features (UTFs) in an area 18 km × 12 km in extent. Survey activities focused mainly on the Morgue feature as this has by far the largest aggregations of orange roughy in this area. The nearby Graveyard received some attention as a location that has historically produced good catches of spawning orange roughy. A quick, cursory pass over the Pyre and Gothic features was made where the vessel's echosounder

showed there were no aggregations present. Acoustic survey activities at Morgue and Graveyard are provided below (Table 11).

Table 11: Survey activities carried out at Morgue and Graveyard hills.

OP_Number	Location	Operation_type	Visit	Start time (NZ)	End time (NZ)
1	Graveyard	Vessel survey	1st	20/06/2022 2:52	20/06/2022 3:19
2	Morgue	Vessel survey	1st	20/06/2022 3:36	20/06/2022 4:01
22	Morgue	Sealord AOS Survey	2nd	25/06/2022 6:53	25/06/2022 12:16
23	Graveyard	Sealord AOS Trawl	2nd	25/06/2022 14:22	25/06/2022 16:00
25	Morgue	Sealord AOS Survey	2nd	25/06/2022 21:57	26/06/2022 3:15
26	Morgue	Sealord AOS Survey	2nd	26/06/2022 3:46	26/06/2022 8:33
27	Morgue	Sealord AOS Trawl	2nd	26/06/2022 9:01	26/06/2022 8:45
28	Morgue	Sealord AOS Trawl	2nd	26/06/2022 10:12	26/06/2022 11:00
29	Morgue	Sealord AOS Trawl	2nd	26/06/2022 12:54	26/06/2022 14:02
31	Graveyard	Sealord AOS Survey	2nd	26/06/2022 15:21	26/06/2022 19:57
39	Morgue	Sealord AOS Survey	3rd	28/06/2022 22:33	29/06/2022 2:34
40	Morgue	Sealord AOS Survey	3rd	29/06/2022 2:58	29/06/2022 7:05
41	Morgue	Sealord AOS Trawl	3rd	29/06/2022 7:28	29/06/2022 8:53
42	Morgue	Sealord AOS Trawl	3rd	29/06/2022 10:12	29/06/2022 11:23

3.2.1 Morgue

Morgue was visited on three occasions as follows:

First visit – 20 June 03:36 – 4:01

The *first visit* was made on 20 June when the *San Waitaki* made a small diversion *en route* to the NECR grounds. This was a unique opportunity to have a first look at the region well ahead of the peak spawning period. During the 2016 survey here, peak spawning occurred around 29 June.

A brief vessel-mounted survey was made involving two perpendicular transects. A large aggregation was observed on both passes over the top of the feature (Figure 10). From visual inspection these aggregations appeared to be as substantial as those observed on the vessel's acoustics later in the survey. Although there is high confidence that the aggregations are predominantly orange roughy, biomass estimates are not made using the 38 kHz vessel-based acoustics due to the presence of high signal from large gas bladder species that the AOS multifrequency information reveals. This early observation of orange roughy at Morgue indicated that orange roughy had gathered well ahead of the peak spawn that was expected to happen about 10 days later. There was no intention to conduct an AOS survey at this early stage. Similarly, biological sampling was held off as trawling at Morgue was limited under a special permit to six tows that needed to be carefully managed to focus on sampling during the peak spawn. *San Waitaki* continued to NECR to fish commercially with the intention of returning once the spawn build-up had progressed.

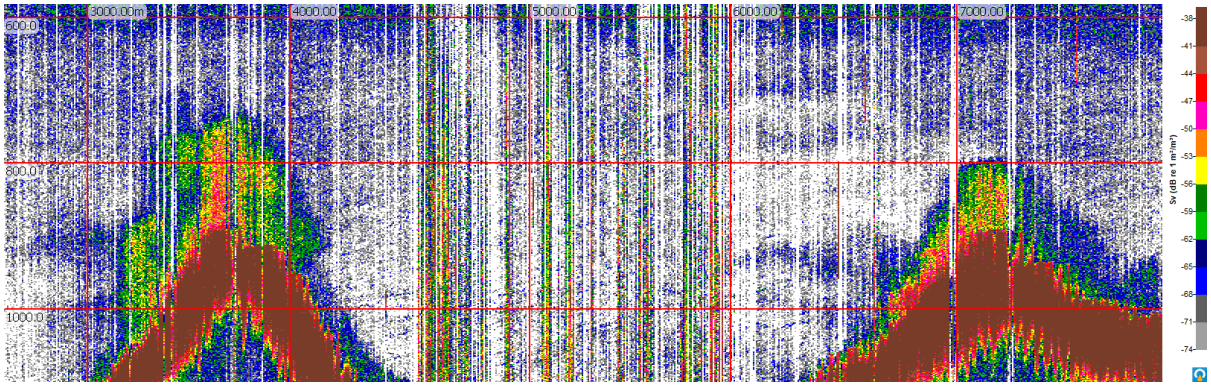

Figure 10: 38 kHz vessel echogram from two perpendicular transects at Morgue, showing large aggregation of orange roughy. OP2 20 June 2022 03:30.

Second visit 25 June 06:53 – 26 June 12:16

The *second visit* to Morgue was on 25 June. The first activity was a four-transect star pattern AOS survey. This survey was unsuccessful as the power supply on the 38 kHz AOS echosounder failed. A replacement power supply resolved this issue allowing two four-transect star pattern surveys to be carried out in quick succession (Figure 11, Figure 12). The observations at Morgue were similar to those of historic surveys. That is, large aggregations of orange roughy were indicated by the AOS multifrequency data on all sides of the feature and across the peak. Additionally, there were occasional regions of very high backscatter, that were attributed to large gas-bladder species, in amongst the broader aggregations of orange roughy. Regions of mobile, very high backscatter gas-bladder species have been a consistent presence at Morgue during previous surveys and were again observed this year. Biomass estimates will be biased high if signal from these fish is not eliminated. Multifrequency AOS acoustics were able to identify these regions that had approximately the same backscatter on both 38 kHz and 120 kHz echosounders, contrasting with non-gas-bladder species (e.g. orange roughy, deepwater sharks) that will have ~3 dB higher (i.e. double) backscatter on 120 kHz echosounders.

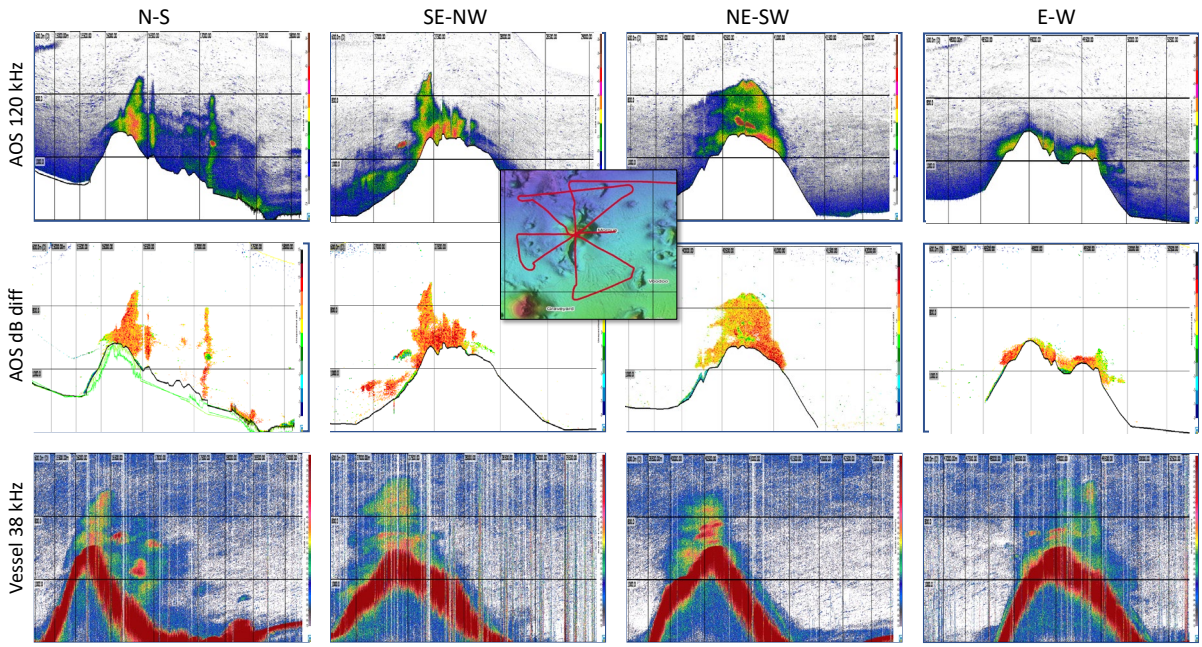

Figure 11: AOS survey at the Morgue. OP25, 25 June 2022 21:57. Top images show the AOS ES60 120 kHz echograms. Lower set of images shows the vessel ES80 38 kHz echograms. Middle set of images shows the subtraction of 120 kHz from 38 kHz backscatter. Orange pixels occur when backscatter at 120 kHz is approximately twice as high as 38 kHz, indicative of large fish without a gas bladder (e.g. orange roughy). Green pixels occur when backscatter signal is approximately equal on both frequencies indicating large gas bladder species. The map shows star pattern vessel survey track over the top of the Morgue feature.

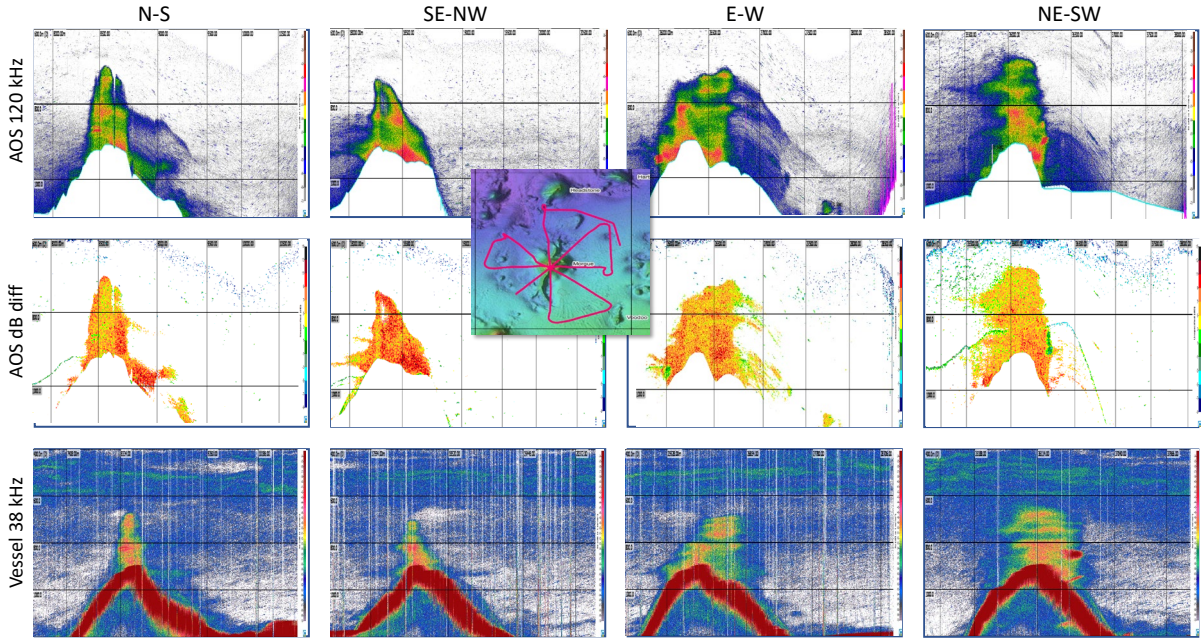

Figure 12: AOS survey at the Morgue. OP26, 26 June 2022 03:46. Top images show the AOS ES60 120 kHz echograms. Lower set of images shows the vessel ES80 38 kHz echograms. Middle set of images shows the subtraction of 120 kHz from 38 kHz backscatter. Orange pixels occur when backscatter at 120 kHz is approximately twice as high as 38 kHz, indicative of large fish without a gas bladder (e.g. orange roughy). Green pixels occur when backscatter signal is approximately equal on both frequencies indicating large gas bladder species. The map shows star pattern vessel survey track over the top of the Morgue feature.

Two target identification trawl tows were carried out at Morgue during the *second visit* under a special permit to obtain biological samples. These samples were processed for species composition, length, weight, sex, gonad maturity stage and otolith extraction.

A review of the AOS video recorded during the two trawls showed that for both recordings, deepwater dogfish sharks were seen in reasonable numbers in the early part of the trawl. These sharks lack a swim-bladder so they would be expected to have a similar 120 kHz–38 kHz frequency difference to orange roughy, but with a higher absolute backscatter as they are larger animals. The presence of these sharks could bias orange roughy biomass estimates high, but their numbers do not appear to be excessive. Video observations suggest that they were present as individuals that were physically separate from the main aggregation. When the trawl moved into the main aggregation, orange roughy was by far the most abundant species present, with only occasional sharks observed (Figure 13).

Figure 13: Image from AOS video as the system moved through the main aggregation at Morgue showing a high concentration of orange roughy.

Third visit - 28 June 22:33 – 29 June 11:23

The opportunity to return to Morgue for a *third visit* was taken when a large (45 t) commercial catch of orange roughy was taken at Rekohu, enabling the eight-hour return transit and a portion of the survey work to be carried out while the factory was processing catch. Two four-transect AOS star pattern surveys were carried out in succession on 28 June with just a brief break to retrieve the AOS and download and check the AOS acoustic data after the first survey was completed.

The AOS was kept at a steady depth during the first of the two surveys in order to minimize the oversampling due to an AOS pitch angle issue that was observed during the *second visit*. The trade-off was that the deeper parts of the Morgue feature were not within the range of the AOS 120 kHz echosounder. This was considered a reasonable compromise as the deeper backscatter observed on the vessel echosounder was negligible when compared to that of the large aggregations around the peak of the feature. Review of the acoustic data following the first survey motivated for an increase to the 38 kHz range from 600 m to 800 m. This was to allow the AOS to be held steady at a depth that would clear the top of the school mark by at least 250 m while the 38 kHz would be able to record the backscatter to the very bottom of the Morgue feature. Both AOS surveys observed the familiar large aggregation on all transects, with smaller regions of very high backscatter on some of the transects (Figure 14, Figure 15).

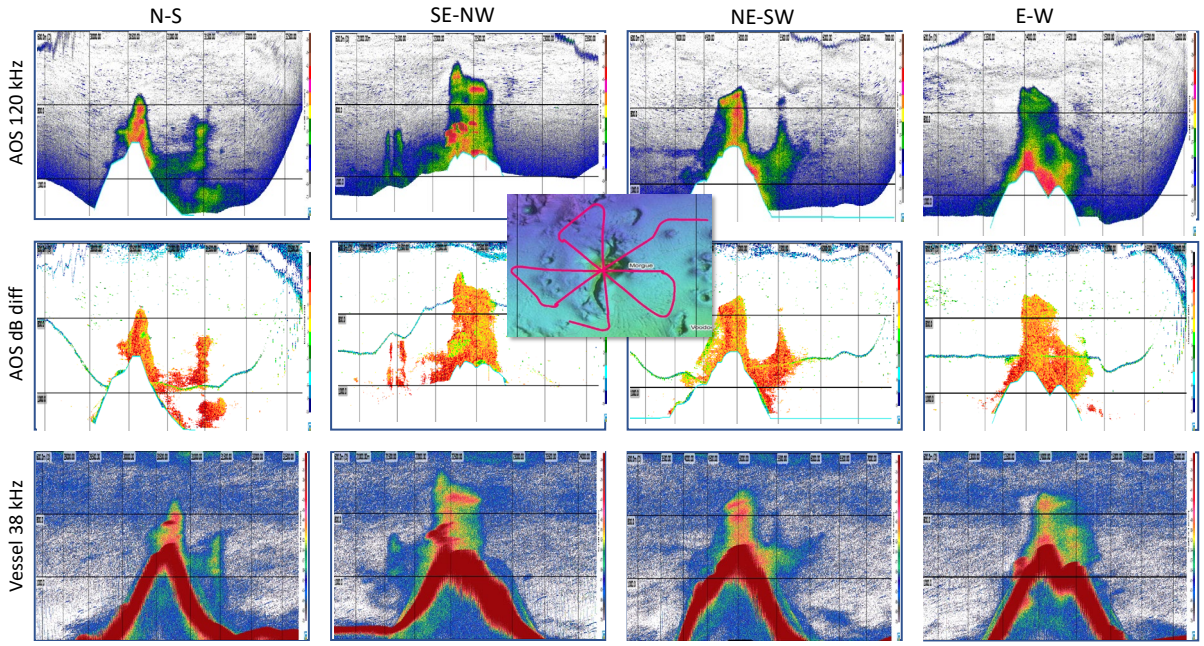

Figure 14: AOS survey at Morgue. OP39, 28 June 2022 22:33. Top images show the AOS ES60 120 kHz echograms. Lower set of images shows the vessel ES80 38 kHz echograms. Middle set of images shows the subtraction of 120 kHz from 38 kHz backscatter. Orange pixels occur when backscatter at 120 kHz is approximately twice as high as 38 kHz, indicative of large fish without a gas bladder (e.g. orange roughy). Green pixels occur when backscatter signal is approximately equal on both frequencies indicating large gas bladder species. The map shows star pattern vessel survey track over the top of the Morgue feature.

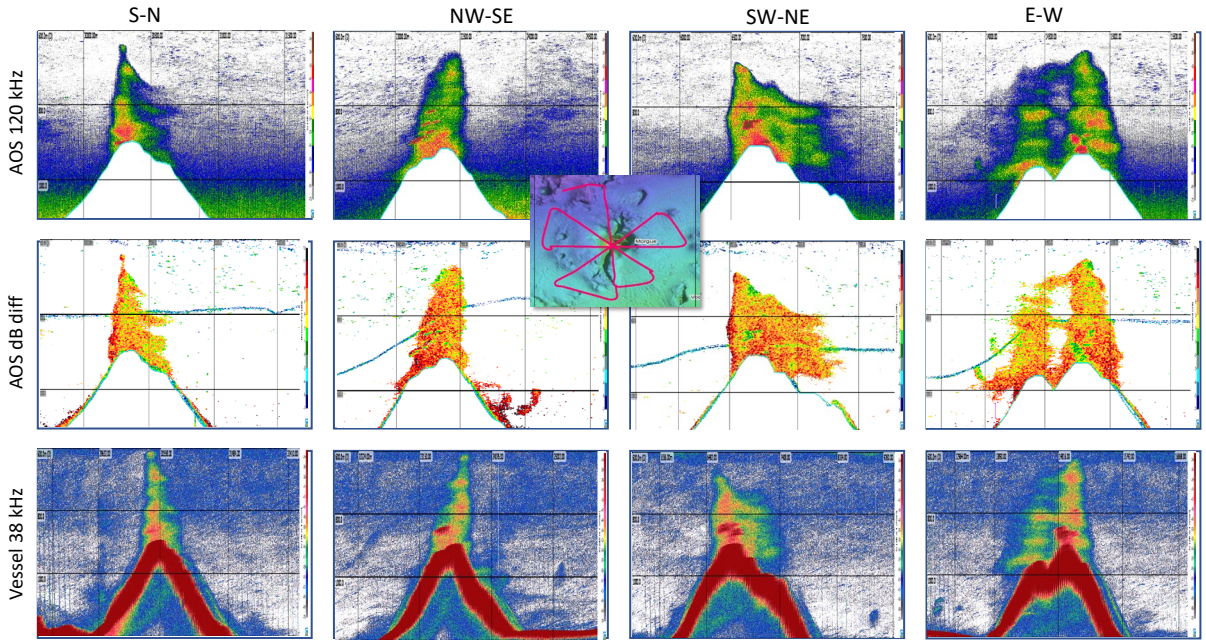

Figure 15: AOS survey at Morgue. OP40, 29 June 2022 02:58. Top images show the AOS ES60 120 kHz echograms. Lower set of images shows the vessel ES80 38 kHz echograms. Middle set of images shows the subtraction of 120 kHz from 38 kHz backscatter. Orange pixels occur when backscatter at 120 kHz is approximately twice as high as 38 kHz, indicative of large fish without a gas bladder (e.g. orange roughy). Green pixels occur when backscatter signal is approximately equal on both frequencies indicating large gas bladder species. The map shows star pattern vessel survey track over the top of the Morgue feature.

3.2.1.1 Biological sampling

A further two trawl shots were carried out on the Morgue aggregation under special permit during the *third visit* to obtain biological samples. These samples, taken three days after the *second visit,* provided information on the progress of the spawn, which for females had developed from 51% running-ripe and 11% spent on 25–26 June, to 58% running-ripe and 20% spent on 28–29 June (Table 12, Figure 16). We conclude that the acoustic surveys had captured the peak spawning period. A total of 613 otolith pairs was collected.

Table 12: Female orange roughy spawning state at Morgue.

Date	Resting & Maturing	Ripe & Hydrated	Running Ripe	Spent & Partially Spent
25–26/06/22	0%	38%	51%	11%
28–29/06/22	0%	23%	58%	20%

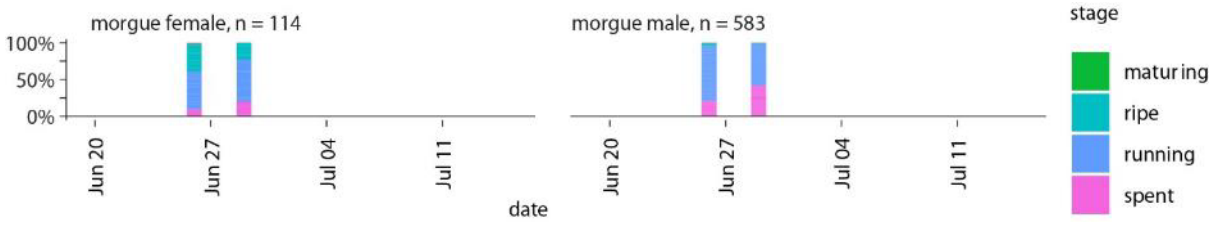

Figure 16: Female and male orange roughy spawning state at Morgue on 25–26 and 28–29 June 2022.

Mean standard lengths for orange roughy at Morgue were 35.9 cm for females, 34.2 cm for males and 34.5 cm for the sexes combined. The catches were dominated by males (Figure 17). Mean weights were 1697 g for females, 1346 g for males and 1404 g for the sexes combined.

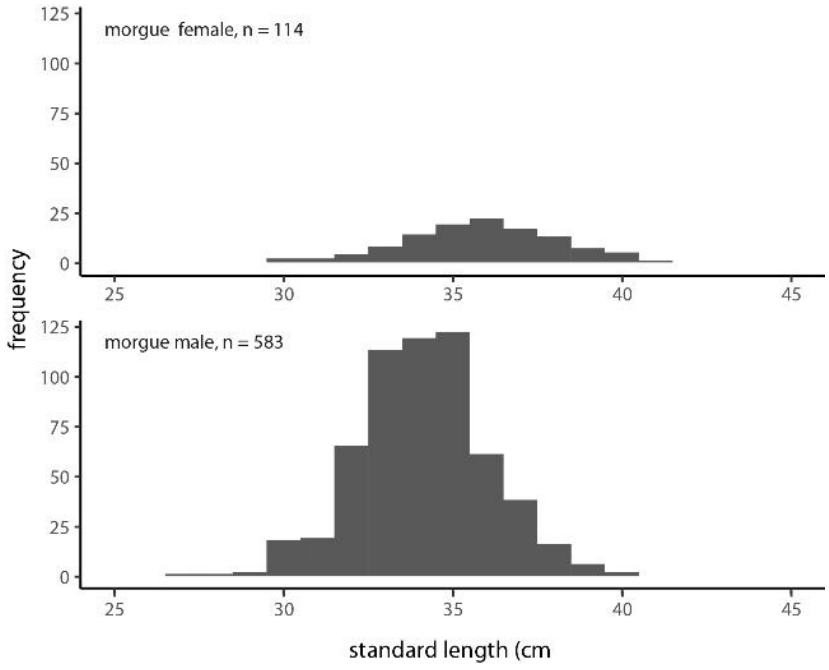

Figure 17: Orange roughy length-frequency distributions at Morgue (four trawl tows).

The four target-identification trawl tows on Morgue produced a total of approximately 10.2 t of which orange roughy comprised 90.6%. Abundant bycatch species included Baxter's lantern dogfish (7.5%), black and smooth oreo (1.4%) and longnose velvet dogfish (0.3%) (Figure 18).

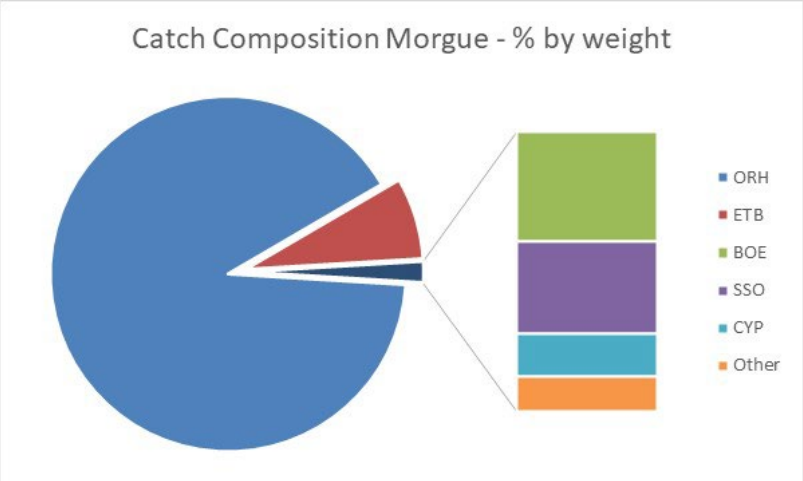

Figure 18: Catch composition from four off-the-seabed tows at Morgue (ORH orange roughy, ETB Baxter's lantern dogfish, BOE black oreo, SSO smooth oreo, CYP longnose velvet dogfish).

3.2.1.2 Morgue summary

Four AOS surveys were completed at Morgue along with passes made over the feature with the vessel echosounder recording. A very large acoustic mark was observed from the very first pass on 20 June and was still there on our departure on 29 June. On most but not all transects, smaller regions of very high backscatter were embedded in the larger aggregation. These are believed to be large, mobile gas-bladder fish. The multi-frequency acoustics were used to eliminate these regions when echo-integrating to estimate biomass. Multi-frequency may not be able to delineate deepwater sharks that are expected to have a similar frequency response to orange roughy. Video observations and trawl indicated that sharks were quite abundant (also observed in previous surveys at Morgue). However, video information indicated that the sharks were on the outer edges of the aggregations while the proportion of orange roughy increased in the main part of the aggregations.

3.2.1.3 Biomass estimates

Estimates of mean population TS and fish length and weight are provided in Table 13.

Table 13: Estimates of mean fish length and weight and target strength for Morgue.

Parameter	Male	Female	Combined (50/50 sex ratio)
TS 38 kHz	-52.07	-51.73	-51.89
TS 120 kHz	-48.24	-47.90	-48.06
Weight	**1 346**	**1 697**	1 521.5
Length	**34.2**	**35.9**	35.05

Biomass estimates for Morgue 2022 AOS surveys are provided in Table 14 and visualised in Figure 19.

Table 14: Biomass estimate for Morgue AOS surveys in June 2022 based on 38 and 120 kHz echosounder data.

Date (UTC+12)	Platform	OP	Frequency (kHz)	Survey area (nmi^2)	Mean NASC (m^2 nmi^{-2})	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
25/Jun 21:05	AOS 38 kHz	25	38	1.15	465	6 303	0.14	3 676 (36.8 %)	9 979
25/Jun 21:05	AOS 120 kHz	25	120	1.15	882	3 947	0.14	3 939 (49.9 %)	7 886
26/Jun 03:46	AOS 38 kHz	26	38	2.29	371	13 612	0.18	2 115 (13.4 %)	15 727
26/Jun 03:46	AOS 120 kHz	26	120	2.00	738	10 077	0.17	1 358 (11.9 %)	11 435
28/Jun 22:50	AOS 38 kHz	39	38	1.17	1 042	18 694	0.15	4 042 (17.8 %)	22 735
28/Jun 22:50	AOS 120 kHz	39	120	1.17	1 718	12 930	0.14	2 694 (17.2 %)	15 624
29/Jun 03:22	AOS 38 kHz	40	38	1.72	891	21 481	0.15	7172 (25. %)	28 653
29/Jun 03:22	AOS 120 kHz	40	120	1.72	1 476	15 179	0.14	4 598 (23.2 %)	19 776

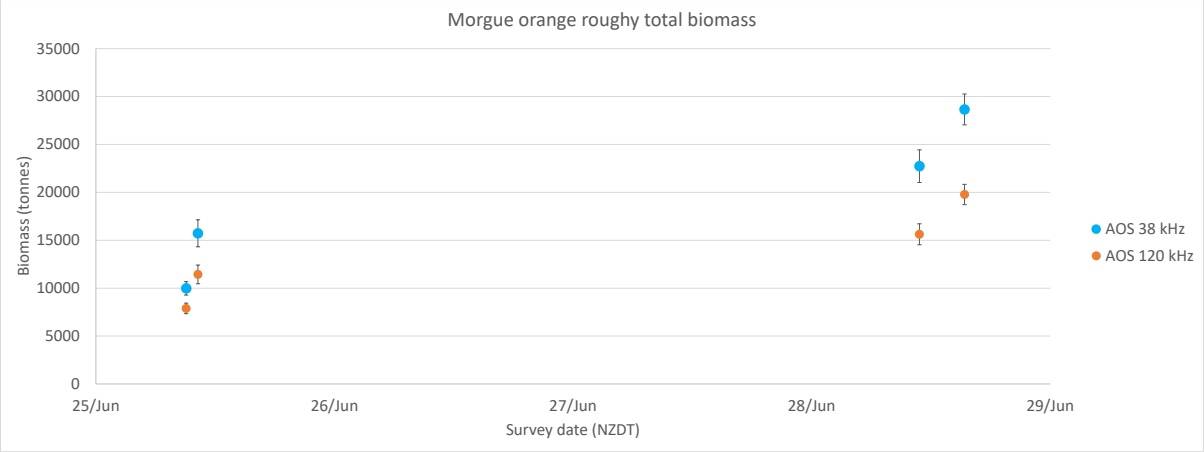

Figure 19: Biomass estimates for AOS surveys of Morgue for 38 and 120 kHz echosounder data. Total biomass including deadzone estimates are shown. Error bars show 1 standard deviation based on survey sampling CV.

Results for the 2022 AOS surveys are added to the time-series from 2013 onwards (Figure 20).

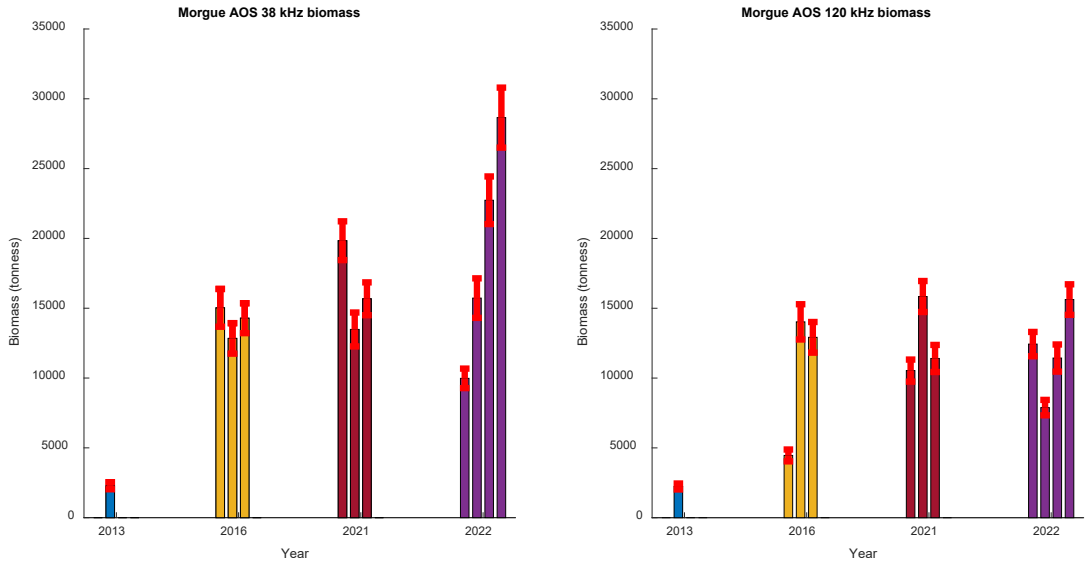

Figure 20: Time series of biomass estimates for Morgue for AOS 38 kHz and 120 kHz echosounders. Error bars show 1 standard deviation based on survey sampling CV.

3.2.2 Graveyard

Graveyard hill is similar in size to Morgue and in close proximity, being 5 km to the south but has not shown large aggregations of fish in recent years. Inspection of the vessel-mounted acoustics as *San Waitaki* passed over the feature at the start of the voyage confirmed there was only a very small mark present (Figure 21). This observation guided allocation of effort to focus on Morgue, which held much greater biomass.

First visit

A quick two-transect pass was made over the top of Graveyard on 20 June as the vessel transited to the Rekohu grounds. A small roughy-like mark was observed on the top of the feature (Figure 21). At the time the wind was 30–40 knots and given the prospect of only a small catch, the decision was made not to trawl or do an AOS survey.

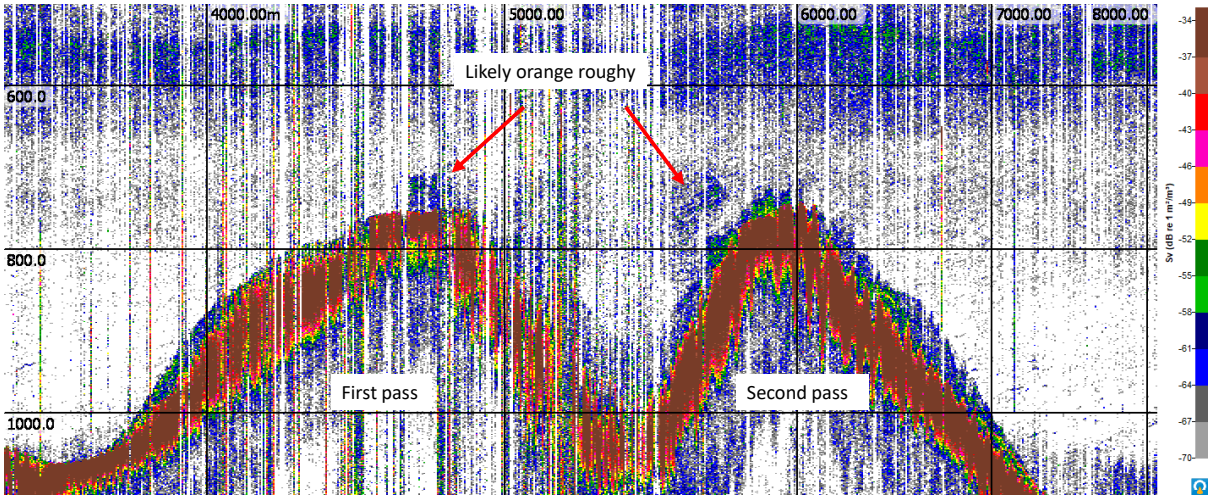

Figure 21: *San Waitaki* ES80 38 kHz echogram from passes over the Graveyard feature on the 20th June 2022.

Second visit

A second visit was made on 26 June. A single trawl tow was carried out returning a small catch. A four-transect star pattern AOS survey was carried out to provide more detailed observations (Figure 22). The AOS 120-38 kHz difference in acoustic backscatter indicated that there was an aggregation of orange roughy present on all passes. Of note was the quite extensive area of backscatter observed on the vessel's ES80 38 kHz echosounder. The higher quality AOS echosounder data showed that this area of backscatter was a complex mix of gas-bladder species and likely orange roughy. This example highlights how vessel acoustics can sometimes be quite misleading. The last two transects had larger areas of discrete orange roughy, although they were very small when compared to the AOS echograms recorded at Morgue.

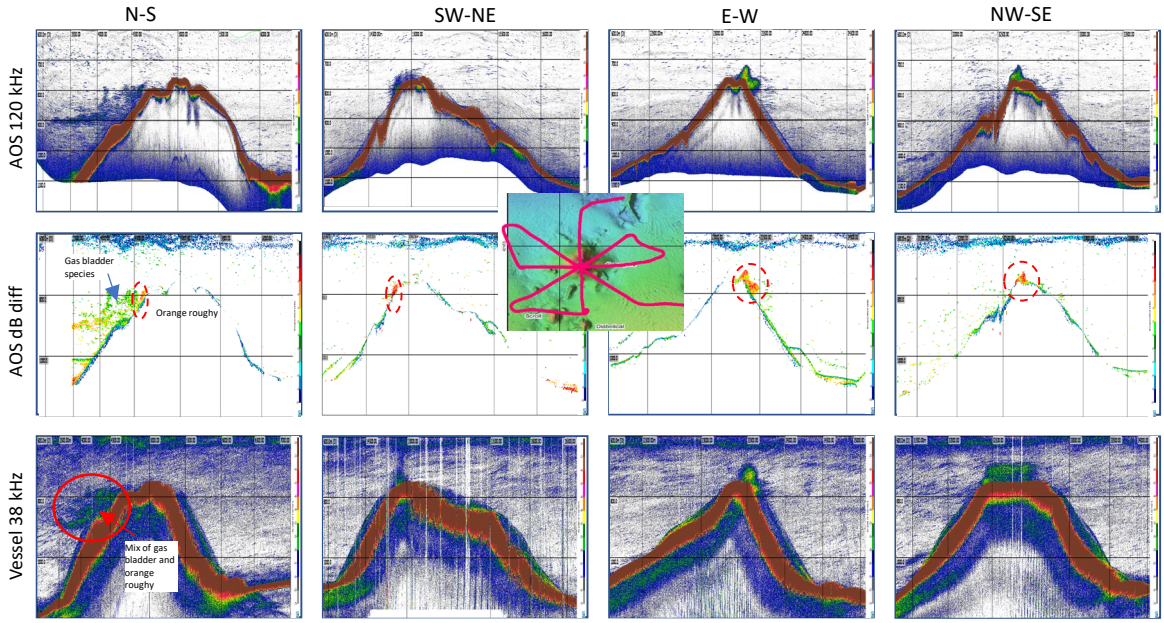

Figure 22: AOS survey at Graveyard hill. OP31, 26 June at 15:21. Top images show the AOS ES60 120 kHz echograms. Lower set of images shows the vessel ES80 38 kHz echograms. Middle set of images shows the subtraction of 120 kHz from 38 kHz backscatter. Orange pixels occur when backscatter at 120 kHz is approximately twice as high as 38 kHz, indicative of large fish without a gas bladder (e.g. orange roughy). These regions are noted with a red-dashed circle or oblong. Green pixels occur when backscatter signal is approximately equal on both frequencies indicating large gas bladder species. The map shows the star pattern vessel survey track over the top of the Graveyard feature.

Biological sampling

Mean standard lengths for orange roughy at Graveyard were 36.1 cm for females, 34.8 cm for males and 35.7 cm for the sexes combined, based on only a single sample of 100 fish (Figure 23). Mean weights were 1637 g for females, 1386 g for males and 1556 g for the sexes combined.

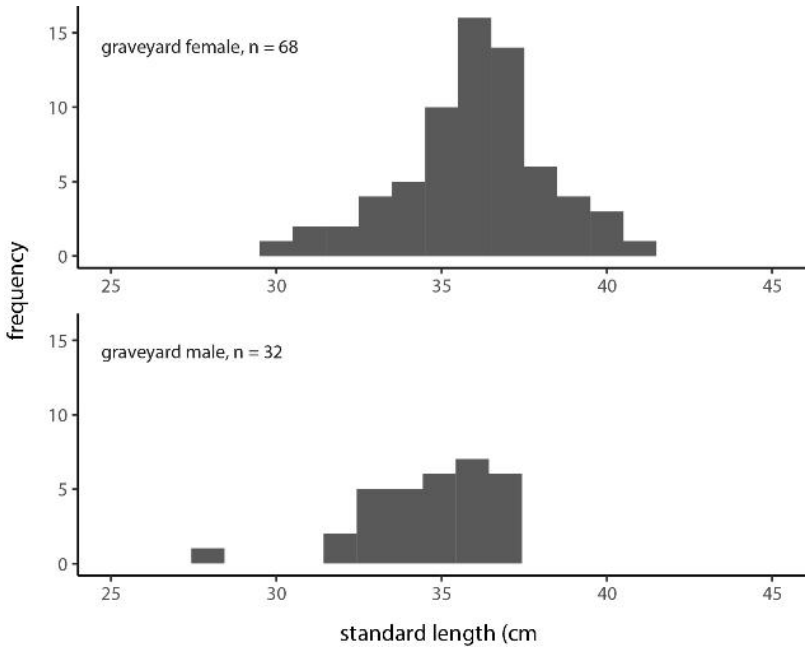

Figure 23: Orange roughy length-frequency distributions at Graveyard (one trawl tow).

Sampling of gonad maturity state on 26 June indicated that while the majority of female gonads were in pre-spawning, ripe or hydrated condition, the spawn was well underway with 18% of females being in spent or partially spent condition (Table 15, Figure 24). A total of 100 otolith pairs was collected.

Table 15: Female orange roughy gonad maturity state at Graveyard.

Date	Resting & Maturing	Ripe & Hydrated	Running Ripe	Spent & Partially Spent
26/06/2022	4%	51%	26%	18%

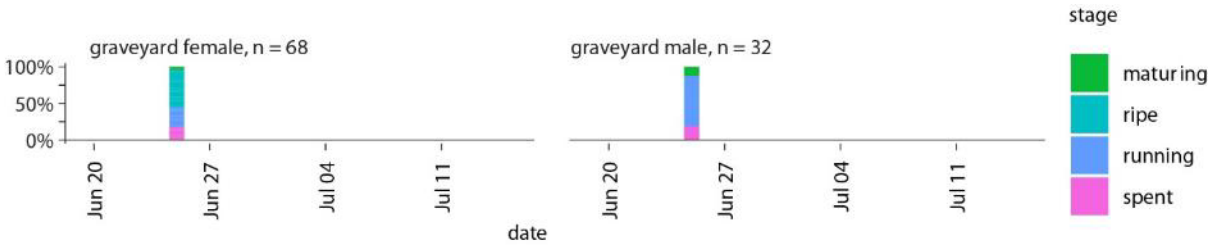

Figure 24: Female and male gonad maturity states at Graveyard on 26 June 2022.

The single trawl shot on Graveyard produced a catch of approximately 150 kg, of which orange roughy comprised 43%. Abundant bycatch species included longnose velvet dogfish (41%), seal shark (5%) and smooth oreo (5%), (Figure 25).

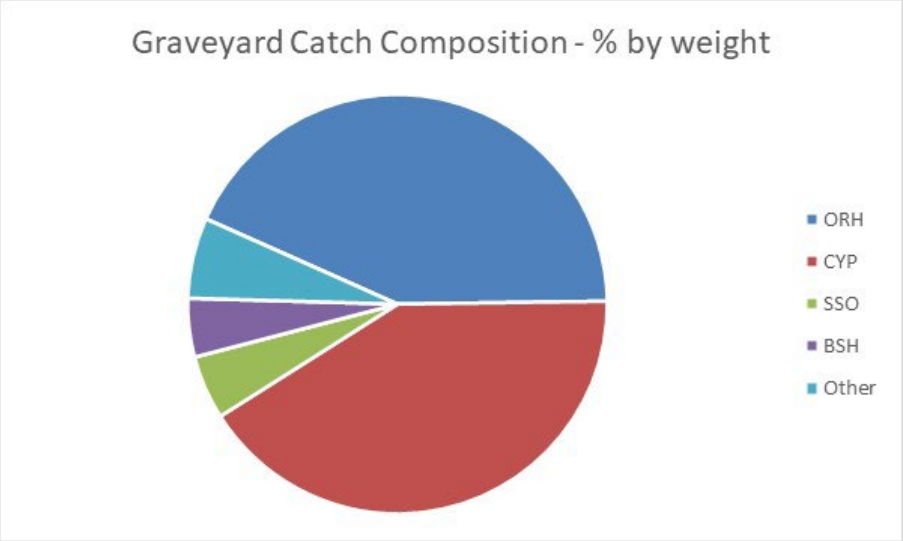

Figure 25: Graveyard catch composition (ORH orange roughy, CYP longnose velvet dogfish, SSO smooth oreo, BSH seal shark).

No further trawls were carried out due to time constraints and the need to focus available survey time in areas with greater biomass.

3.2.2.1 Graveyard summary

The brief survey activities at Graveyard were sufficient to confirm, using AOS multifrequency acoustics, that there were spawning orange roughy present but in relatively small numbers compared to Morgue. Given this, survey effort was prioritised accordingly. Biomass estimates were made from the single AOS survey.

3.2.2.2 Biomass estimates

Biomass estimates for the Graveyard AOS survey are provided in Table 16 and visualised in Figure 26.

Table 16: Biomass estimates for 2022 AOS surveys of Graveyard.

Date (UTC + 12)	Platform	OP	Frequency (kHz)	Survey area(nmi^2)	Mean NASC (m^2 nmi^{-2})	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
26 Jun 15:17	AOS 38 kHz	31	38	0.23	52	107	0.66	118 (52 %)	225
26 Jun 15:17	AOS 120 kHz	31	120	0.23	29	73	0.66	53 (42 %)	127

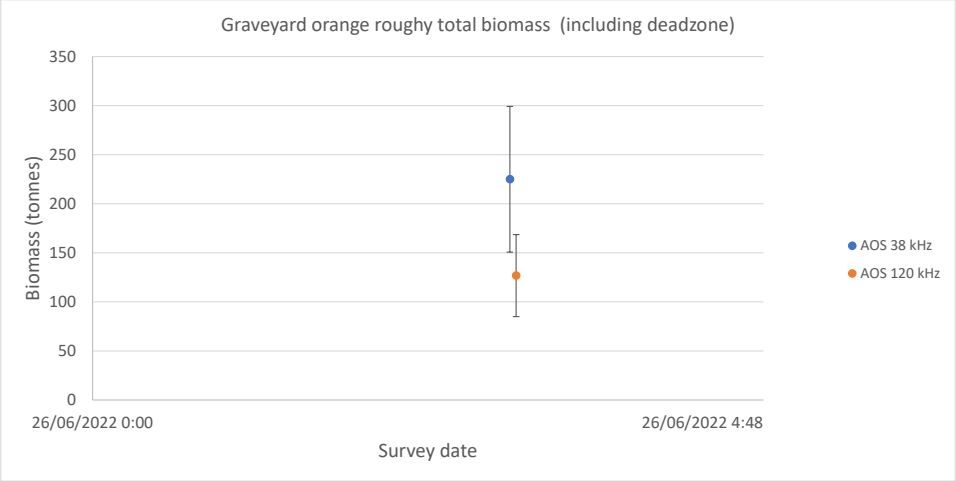

Figure 26: Biomass estimates for AOS surveys of Graveyard for 38 and 120 kHz echosounder data. Total biomass including deadzone estimates is shown. Error bars show 1 standard deviation based on survey sampling CV.

Results from the 2022 surveys are added to the time series of biomass surveys (Figure 27). The AOS 38 kHz echosounder was not working for the first survey in 2013 leaving the estimate from the 120 kHz echosounder. Differences between AOS 38 and AOS 120 kHz biomass estimates should be the same if calibration and TS at both frequencies are accurate. In practice we have observed variability of up to 30% (Ryan & Kloser, 2016). Nevertheless, the 120 kHz estimates of biomass at Graveyard in 2022 was dramatically less than was observed nine years prior. A likely orange roughy aggregation of modest size and intensity was observed at Graveyard in 2021 which would have been expected to return a biomass in the hundreds, rather than thousands, of tonnes. Unfortunately, there were issues with the vessel's echosounder in that year which meant that biomass estimates were not possible. In 2016 a similar sized aggregation was observed above the peak of the Graveyard feature. With a far more significant aggregation at Morgue, survey efforts were focussed there. We conclude that the 2016, 2021 and 2022 surveys indicate consistently low numbers compared to 2013.

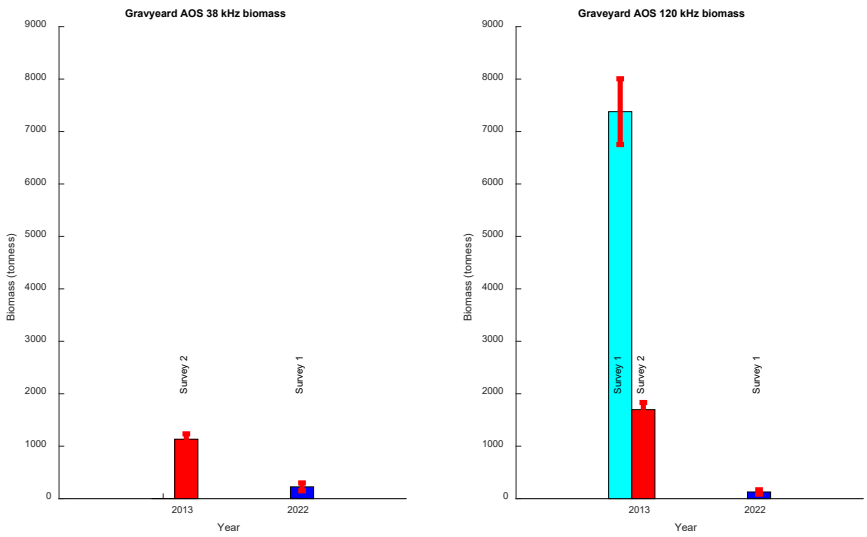

Figure 27: Time series of biomass estimates for Graveyard for AOS 38 kHz and 120 kHz echosounders. Error bars show 1 standard deviation based on survey sampling CV. Note that there are no results for the AOS 38 kHz for the first survey in 2013 as that failed.

3.3 North-East Chatham Rise – Rekohu, Spawn Plume and Mt Muck

3.3.1 Rekohu

3.3.1.1 Overview of survey activities

Rekohu was visited three times during this voyage, initially with a focus exclusively on commercial fishing ahead of the peak spawn period. This provided an opportunity for early observations of this region that helped guide both survey and fishing effort as the spawning period progressed.

First visit 24 June 18:30 – 25 June 4:28

San Waitaki moved over from Spawn Plume to Rekohu on the 24 June for a first look and to trawl should any acoustic marks be found. A single trawl shot produced a small catch of about 3.5 t and it was decided to head over to the Morgue/Graveyard area in NWCR to commence surveys there.

Second visit 27 June 05:22 – 4 July 11:15

The primary focus was still on commercial fishing while waiting for the spawn to progress, but this provided opportunity to get a feel for the location and behaviour of the aggregations. Acoustic marks were starting to be seen regularly. The mode of fishing changed from long tows catching sparse, 'hard-down' orange roughy to targeting aggregations. The target catch size was 25–30 tonnes to maintain product quality and as a result, larger aggregations were avoided to prevent over-catching. Orange roughy aggregations were mobile and somewhat ephemeral. They were sometimes located in the deep at about 980 m while at other times moved shallower to about 780 m. Fishable aggregations could generally be found within one-to-two hours of searching, but quiet periods, when aggregations were not found, were common from early afternoon through to about 10 pm. Some spawning females were present, but the majority were in pre-spawning condition. Movement of aggregations was being closely monitored in anticipation of commencing an AOS survey. Aggregations were persistently mobile to the point where an AOS survey was held off as there was a high risk of fish moving during the execution of a survey grid. Further, the aggregations became difficult to locate around 3 July, although a good catch of 30 tonnes was taken on 4 July. The decision was made to move east to the Spawn Plume area and to use factory processing time to scope out the location of aggregations there. The hope was that the orange roughy aggregations at Rekohu would settle as they moved towards full spawn.

Third visit 10 July 05:43

San Waitaki returned to Rekohu on 10 July after a 46 tonne catch at Spawn Plume. This large catch allowed time to undertake a vessel survey at Rekohu to scope out the extent of the aggregation. Our experience from acoustic surveys at Rekohu in 2013 and 2016 was that the aggregations became less mobile and more densely aggregated once they commenced spawning. During this voyage the aggregations settled to some extent but probably not as much as in previous years. Their mobility meant that devising and executing survey grids was an ongoing challenge. There was a consistent pattern of back-and-forth movement from north to south with the aggregations in deeper water at night and shallower water during the day. To account for this, survey lines were run from north to south and return so that the aggregations would be encountered at some point. More challenging was that the aggregations also moved back and forth in an east-west direction. These movements meant that the survey transects had to be adapted to the anticipated distribution of the aggregations, but with the likelihood that it might change during survey execution. Survey transects were continued until no fish were observed, to establish the outer extents of the aggregations. To optimise the use of vessel time and minimize bias due to fish movement, when conditions allowed, we used quicker vessel-based transects to locate the outer extents of the aggregations and only then commenced AOS-based transects.

3.3.1.2 Biological sampling

Sampling of orange roughy gonad maturity states showed that female gonads were primarily in ripe condition from 27–28 June, with signs of some early spawning occurring. The spawn developed from

29 June through to 4 July and had reached a peak by 10 July with 23% being in spent or partially spent condition. By 15 July nearly 50% of female gonads were in spent condition (Table 17, Figure 28). A total of 1624 otolith pairs was collected.

Table 17: Female orange roughy spawning state at Rekohu.

Date	Resting & Maturing	Ripe & Hydrated	Running Ripe	Spent & Partially Spent
27/06/2022	0%	94%	2%	4%
28/06/2022	0%	91%	8%	1%
29/06/2022	1%	58%	34%	7%
30/06/2022	0%	85%	7%	8%
1/07/2022	0%	74%	15%	11%
2/07/2022	0%	77%	12%	11%
3/07/2022	1%	72%	15%	12%
4/07/2022	1%	71%	18%	10%
10/07/2022	0%	40%	37%	23%
12/07/2022	1%	14%	51%	34%
13/07/2022	1%	25%	35%	39%
14/07/2022	0%	18%	39%	43%
15/07/2022	0%	13%	38%	49%

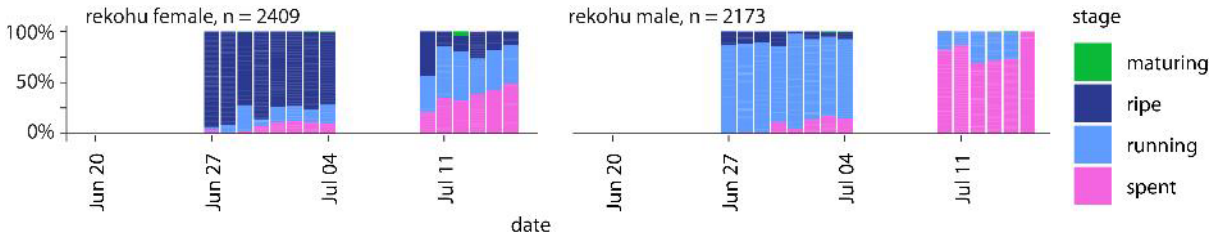

Figure 28: Female and male orange roughy gonad maturity at Rekohu during the period 27 June – 15 July 2022.

Mean standard lengths for orange roughy at Rekohu were 36.0 cm for females, 33.8 cm for males and 35.0 cm for the sexes combined. The sex-ratio was balanced (Figure 29). Mean weights were 1686 g for females, 1305 g for males and 1505 g for the sexes combined.

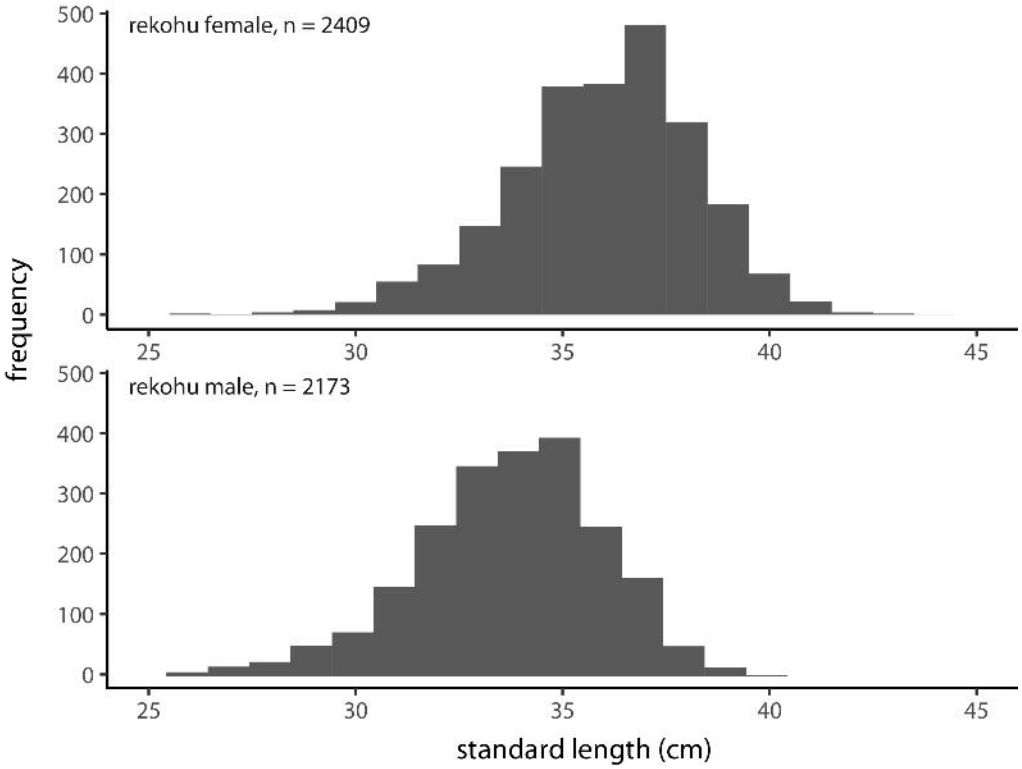

Figure 29: Orange roughy length-frequency distributions at Rekohu (29 trawl tows).

Catches comprised 98.8% orange roughy by weight. Abundant bycatch species included ribaldo (0.6%), spiky oreo (0.1%), hake (0.1%), hoki (0.1%), Johnson's cod (0.1%) and shovelnose spiny dogfish (0.1%) (Figure 30).

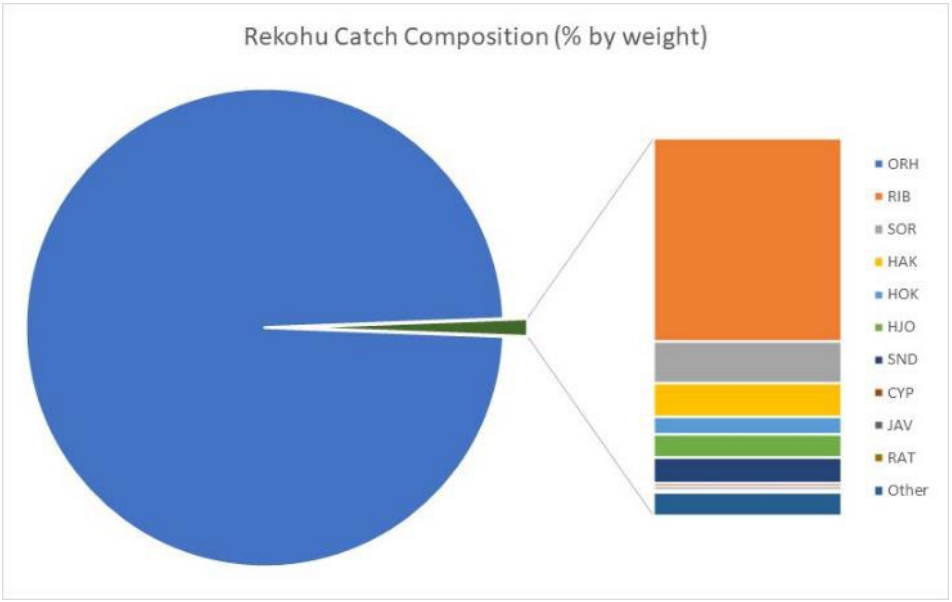

Figure 30: Catch composition by weight for all trawl tows in the Rekohu area (ORH orange roughy, RIB ribaldo, SOR spiky oreo, HAK hake, HOK hoki, HJO Johnson's cod, SND shovelnose spiny dogfish, CYP longnose velvet dogfish, JAV javelinfish, RAT mixed rattails).

3.3.1.3 Biomass estimates

Biomass estimates for Rekohu AOS and vessel-mounted acoustic surveys are provided in Table 18 and visualised in Figure 31.

Table 18: Biomass estimate for Rekohu AOS surveys in June and July 2022 based on 38 and 120 kHz echosounder data and vessel based 38 kHz echosounder.

Date (UTC + 12)	Platform	OP	Frequency (kHz)	Survey area (nmi^2)	Mean NASC (m^2 nmi^{-2})	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
27-Jun 14:55	Vessel	33	38	4.5	117.9	7 847	0.35	1 464 (0.16%)	9 311
30-Jun 05:23	Vessel	45	38	5.4	245.4	21 633	0.14	1 247 (0.05%)	22 880
30-Jun 14:22	Vessel	47	38	4.7	268.2	12 441	0.17	296 (0.02%)	12 737
1-Jul 03:28	Vessel	49	38	8.4	87.2	15 897	0.17	913 (0.05%)	16 810
11-Jul 01:25	AOS 120	86	120	16.8	91.5	8 836	0.21	451 (4.9%)	9 287
11-Jul 01:25	AOS 38	86	38	16.8	87.0	12 343	0.22	744 (5.7%)	13 088
13-Jul 20:00	AOS 120	94	120	14.4	128.8	10 858	0.28	391 (3.5%)	11 249
13-Jul 20:00	AOS 38	94	38	14.4	124.4	16 050	0.28	663 (4%)	16 713

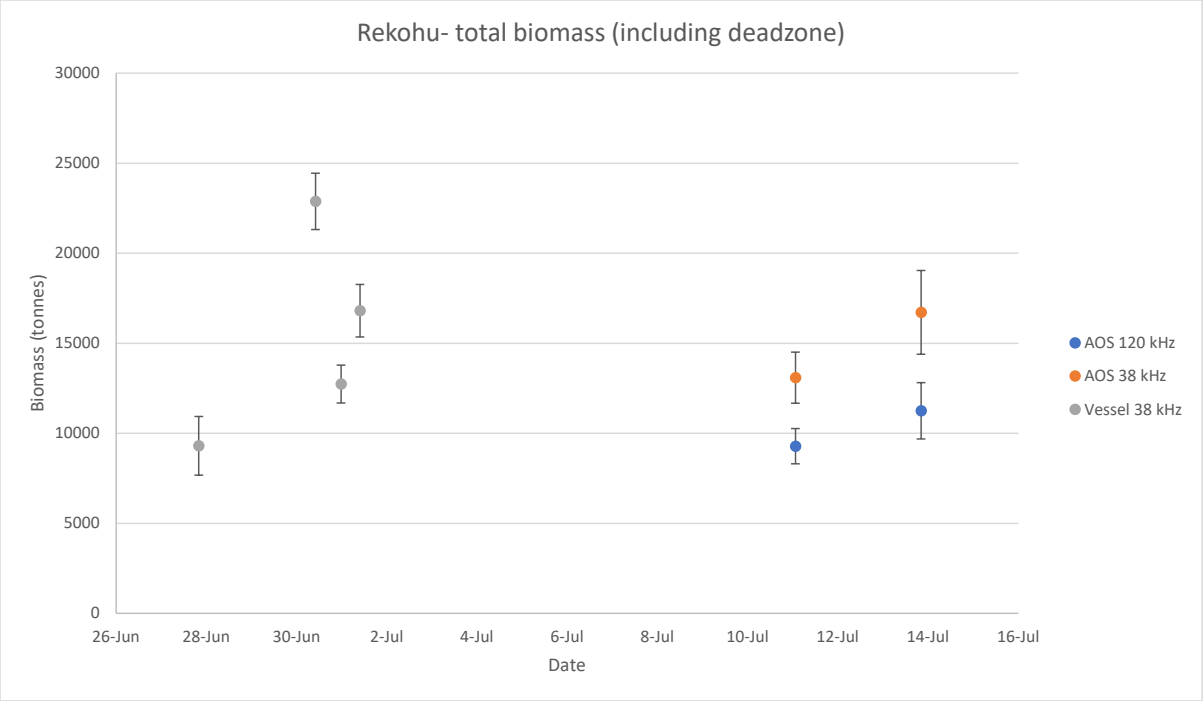

Figure 31: Biomass estimates for AOS surveys of Rekohu in 2023 for AOS 38 kHz and 120 kHz and vessel 38 kHz echosounder data. Total biomass including deadzone estimates is shown. Error bars show 1 standard deviation based on survey sampling CV.

Time series of Rekohu biomass estimates for 2013, 2016, 2021 and 2022 surveys are provided in Figure 32 for 38 kHz and 120 kHz AOS with the same platform used in each year. Estimates were made from hull-mounted 38 kHz calibrated echosounders in each year. The participating vessels for hull-mounted surveys were *Amaltal Explorer* in 2013 and 2016, *Amaltal Mariner* as an opportunistic survey in 2021 and *San Waitaki* in 2022.

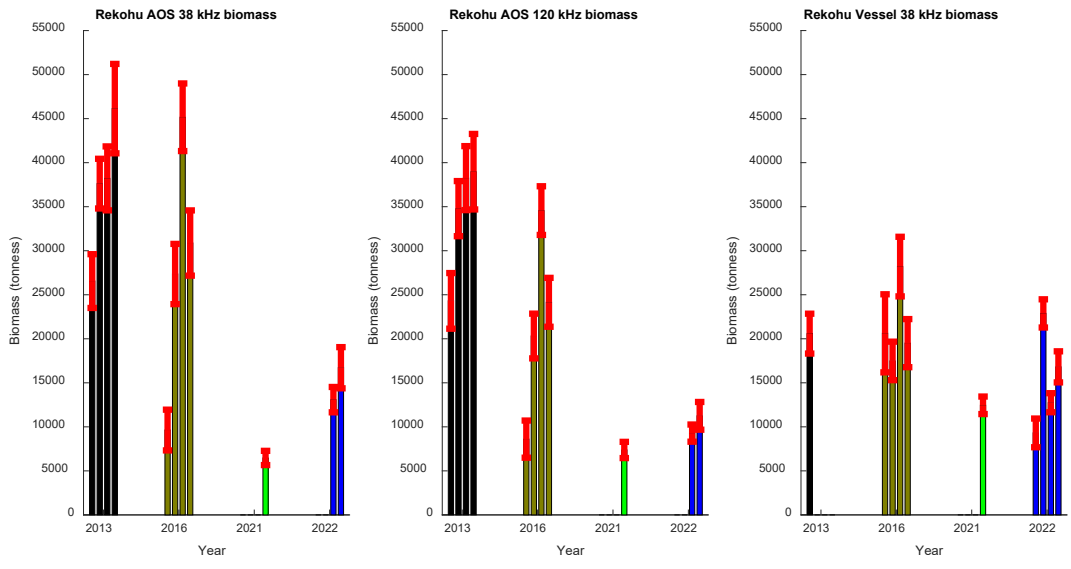

Figure 32: Time series of biomass estimates for Rekohu AOS 38 kHz and 120 kHz and vessel 38 kHz echosounders. Error bars show 1 standard deviation based on survey sampling CV.

3.3.2 Spawn Plume

3.3.2.1 Overview of survey activities

First visit: 20 June 16:30 to 24 June 14:30

Following the brief dogleg via Morgue/Graveyard, *San Waitaki* made its way to the Spawn Plume area to commence commercial fishing on the 20 June where 17 trawl shots were completed. Many tows were long (approximately 4 hours) for only small catches. During this period there were only occasional roughy-like acoustic marks observed and large unequivocal spawning plumes were absent. This was not completely surprising as the peak spawning event was 10–14 days away.

Second visit: 04 July 14:00 to 06 July 16:50

During the second visit to Spawn Plume a combination of vessel-based acoustic surveys, AOS surveys and commercial fishing trawls were carried out. A vessel-based survey was carried out at Spawn Plume as a first activity while catch from the last Rekohu trawl was being processed (Spawn Plume is about 20 nautical miles east of Rekohu). This helped establish the location of the main body of orange roughy and acoustic data quality was suitable for biomass estimation. The vessel-based survey found that orange roughy aggregations had formed up after the first visit (Figure 33). Biological sampling from commercial trawl catches showed that the females were in full spawn by 5 July (Table 19).

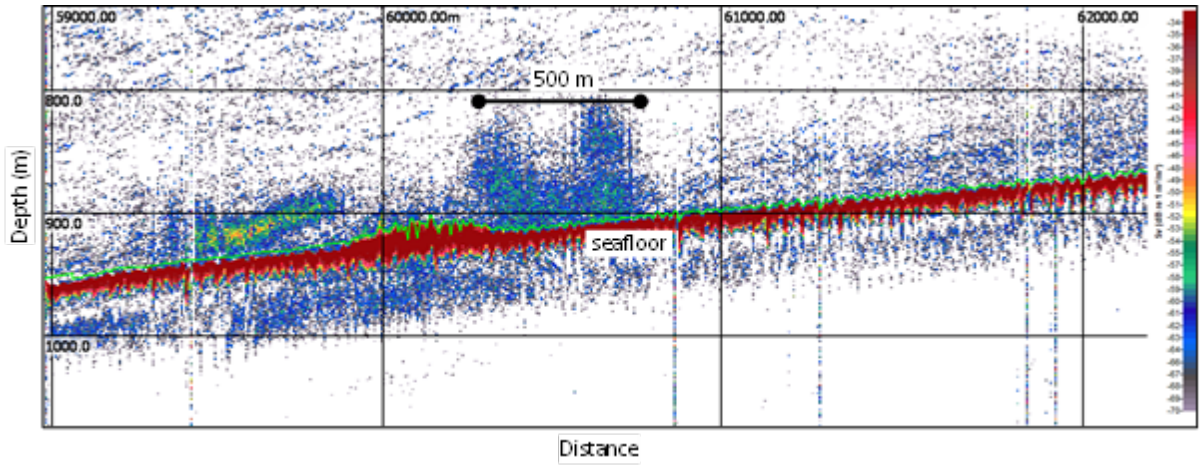

Figure 33: Image from *San Waitaki*'s Simrad 38 kHz ES80 vessel echosounder (OP64 4 July 2022) showing two sizeable aggregations of orange roughy.

Two AOS surveys were conducted during the second visit to the Spawn Plume region. Both surveys located marks that were typical of orange roughy spawning aggregations. That is, stacked vertically with two distinct high signal regions, one close to the seafloor and the other up high (Figure 34).

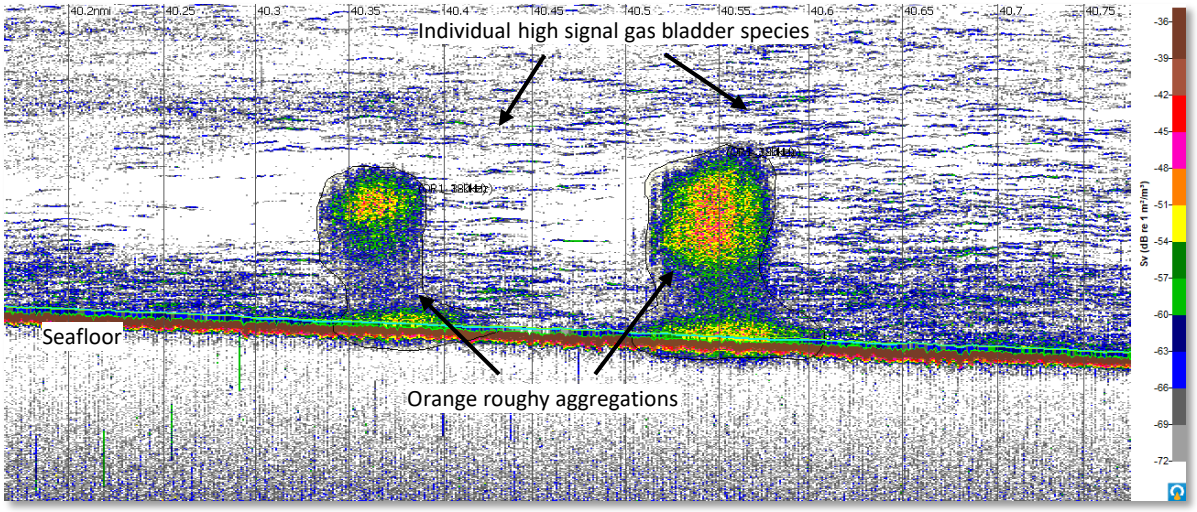

Figure 34: Example echogram from 120 kHz AOS echosounder (OP67 5 July 2022 14:30) showing two orange roughy aggregations. Nearby are high signal individual large gas bladder fish.

Figure 35 highlights the presence of large gas bladder species at Spawn Plume and the importance of excluding their contribution to the biomass estimates. In the right-hand image, a single fish track is highlighted which has a mean target strength (TS) of -24 dB at 120 kHz. This is 24 dB (factor of 250) higher than the 120 kHz TS of a typical orange roughy. The AOS multifrequency acoustics is generally effective at delineating aggregations that are assumed to be 100% orange roughy. It is possible that there might be signal from the occasional gas bladder species blended in with that of orange roughy, but generally the orange roughy aggregations have a homogeneous appearance consistent with dense aggregations of low-signal fish. Vessel-mounted acoustics are twice the distance from orange roughy aggregations compared to the AOS and there is no multifrequency information to assist interpretation. This, combined with its much larger footprint, makes it almost inevitable that there will be some signal from other species present. Caution is therefore needed when utilising vessel-based data. Nevertheless, there can be a degree of robustness if the unequivocal spawning aggregations are classified and are the primary contributors to biomass estimates. As a case in point, despite the uncertainties, historic vessel-based surveys at Spawn Plume were able to effectively index the decline in Spawn Plume stock in the years before the nearby Rekohu was discovered in 2010 (Doonan et al. 2012).

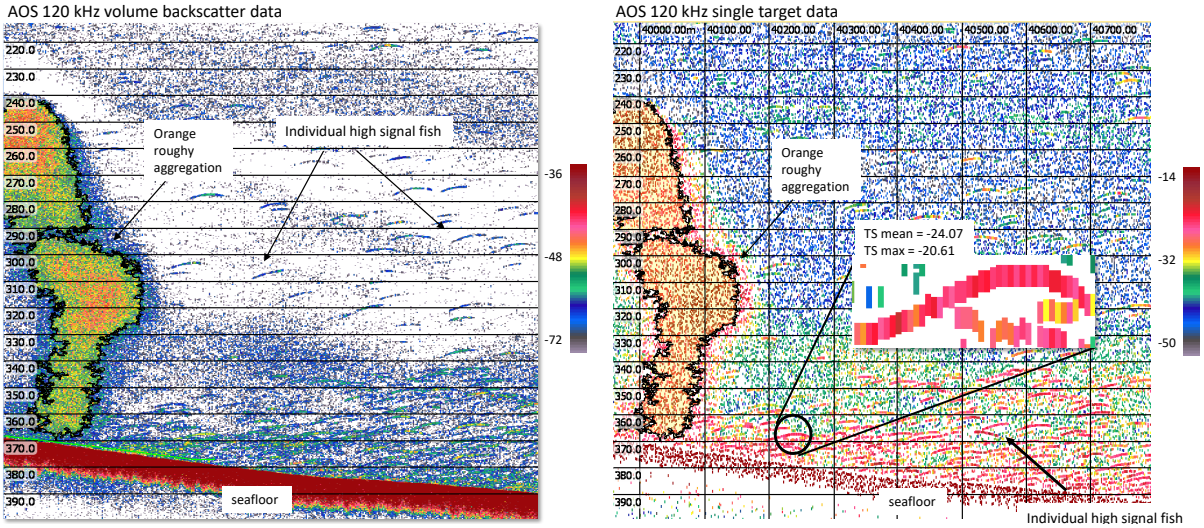

Figure 35: Left image. 120 kHz volume backscatter echogram at Spawn Plume (OP67, 5 July 2022) showing an orange roughy aggregation with backscatter from individual high-signal fish. Right image. Single targets at 120 kHz. The continuous red lines are backscatter from high signal individual fish as they move through the acoustic beam.

Third visit: 8 July 15:47 – 10 July 12:52

San Waitaki returned to the Spawn Plume area following completion of the second and final visit to Mt Muck. A large catch of orange roughy on Mt Muck left fish on the trawl deck which prevented the immediate commencement of the third AOS survey at Spawn Plume. Instead, a wide-area vessel survey was conducted with the objective of having a look further to the west to ensure we were not missing any large aggregations. In part, this was motivated by the outcomes of a 2016 survey of Spawn Plume that found that the main body of orange roughy aggregations was consistently about 4 n.miles further west than previous surveys. This vessel survey in 2022 to the west did not find any sign of orange roughy. Ideally, a couple more transects would have been completed to take *San Waitaki* right through the 2016 survey area, but bad weather prevented this.

The third AOS survey of Spawn Plume was carried out while, for the first part, fish were still being processed in the factory. The last six hours were conducted on charter time when the factory was out of fish. Orange roughy marks were observed across multiple transects on the AOS echograms, the best of which is shown below (Figure 36).

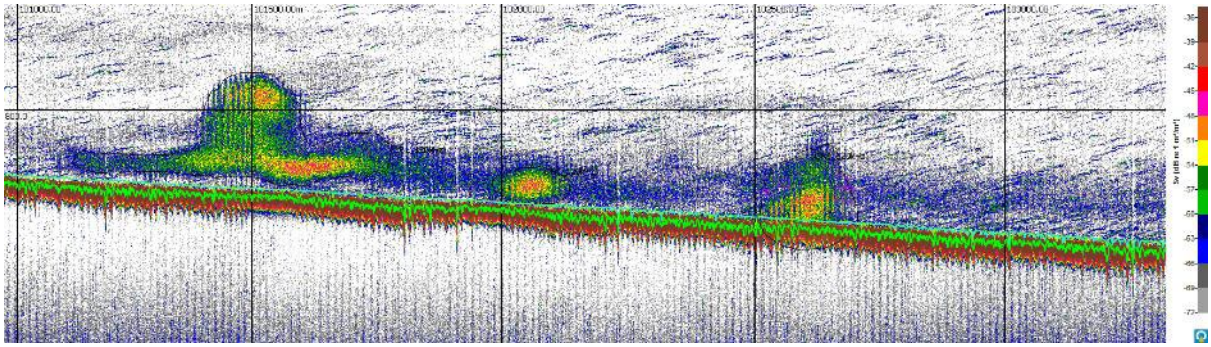

Figure 36: AOS 120 kHz echogram for third AOS survey at the Spawn Plume (OP80, 9 July 15:25).

Following a large catch of about 45 tonnes, *San Waitaki* returned to Rekohu to recommence survey work and commercial operations there.

3.3.2.2 Biological sampling

Sampling of orange roughy gonad maturity states showed that female gonads were in ripe condition over the period 20 – 24 June but that spawning had not commenced. By 5 July, 15% of female gonads were in spawning condition and 16% were spent or partially spent. By 10 July, 38% were spawning and 32% were spent or partially spent (Table 19, Figure 37). A total of 1042 otolith pairs was collected.

Table 19: Female orange roughy spawning state at Spawn Plume.

Date	Resting &	Ripe & Hydrated	Running Ripe	Spent & Partially Spent
20–24/06/2022	1%	99%	0%	0%
5/07/2022	2%	67%	15%	16%
6/07/2022	0%	50%	35%	15%
7–8/07/2022	1%	37%	39%	23%
10/07/2022	1%	29%	38%	32%

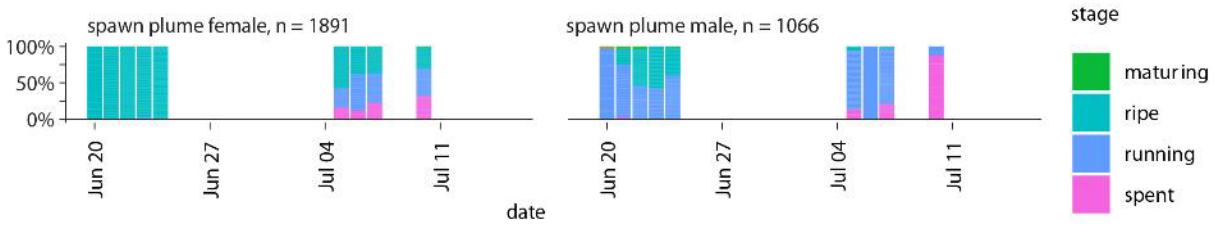

Figure 37: Female and male orange roughy gonad maturity state at Spawn Plume during the period 20 June – 10 July 2022.

Mean standard lengths of orange roughy at Spawn Plume were 36.6 cm for females, 34.2 cm for males and 35.8 cm for the sexes combined. The sex-ratio of 1.8:1 favoured females (Figure 38). Mean weights were 1762 g for females, 1366 g for males and 1617 g for the sexes combined.

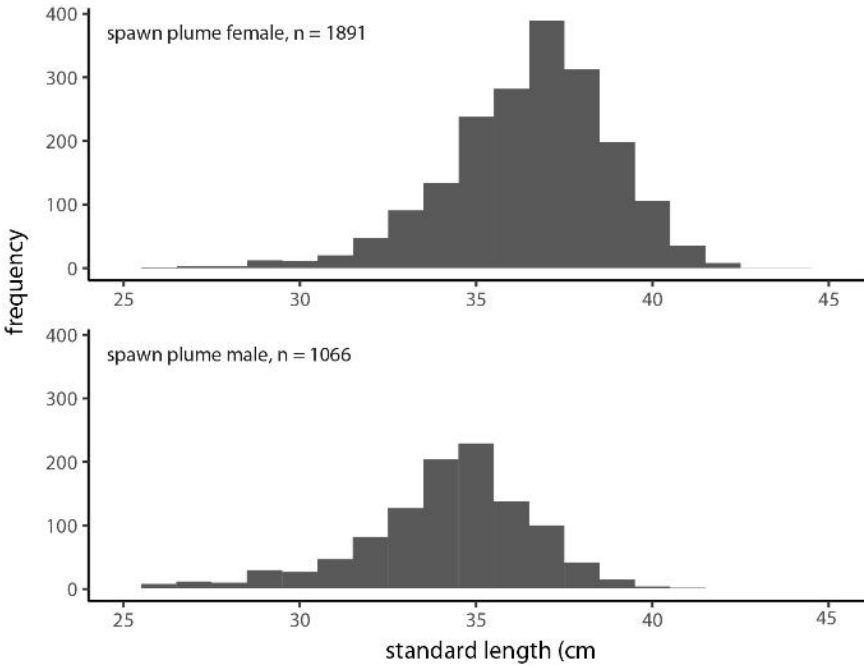

Figure 38: Orange roughy length-frequency distributions at Spawn Plume (19 trawl tows).

The catches in aggregate comprised 97.1% orange roughy. Abundant bycatch species included Johnson's cod (1.2%), ribaldo (0.5%), hoki (0.2%), javelinfish (0.2%), while hake, shovelnose spiny dogfish, longnose velvet dogfish, mixed deepwater dogfish, rattails and warty squid each comprised 0.1% of the catch (Figure 39).

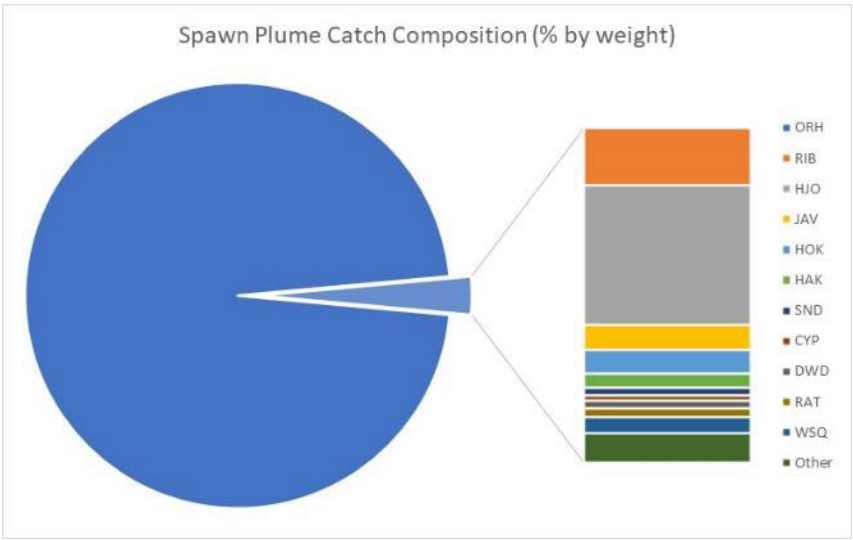

Figure 39: Catch composition from all trawl tows in the Spawn Plume area (ORH orange roughy, RIB ribaldo, HJO Johnson's cod, JAV javelinfish, HOK hoki, HAK hake, SND shovelnose spiny dogfish, CYP longnose velvet dogfish, DWD mixed deepwater dogfish, RAT mixed rattails, WSQ warty squid).

3.3.2.3 Biomass estimates

Biomass estimates for Spawn Plume AOS and vessel-mounted acoustic surveys are provided in Table 20 and visualised in Figure 40.

Table 20: Biomass estimate for Spawn Plume AOS surveys in July 2022 based on 38 and 120 kHz echosounder data and vessel based 38 kHz echosounder.

Date (UTC +12)	Platform	OP	Frequency (kHz)	Survey area (nmi^2)	Mean NASC (m^2 nmi^{-2})	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
4-Jul 20:49	Vessel	64	38	5.136	221.5	19 172	0.29	1 307 (6 %)	20 479
5-Jul 05:26	AOS 120	67	120	8.769	164.9	9 464	0.35	349 (3.6%)	9 814
	AOS 38	67	38	8.769	159.0	11 955	0.36	514 (4.1%)	12 468
6-Jul 03:26	AOS 120	70	120	16.047	124.9	12 141	0.29	36 (0.3%)	12 177
	AOS 38	70	38	16.047	124.6	15 810	0.29	78 (0.5%)	15 888
9-Jul 06:24	AOS 120	80	120	14.337	173.2	16 735	0.24	645 (3.7%)	17 379
	AOS 38	80	38	14.337	166.8	21 461	0.28	2 445 (10.2%)	23 905

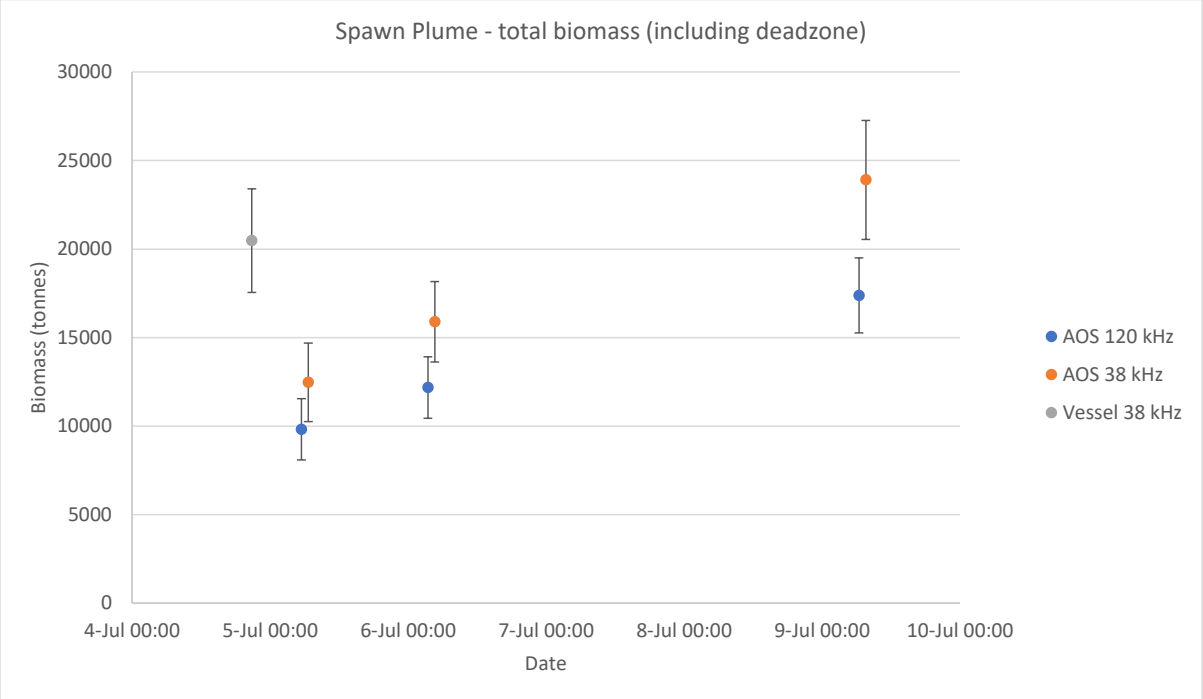

Figure 40: Biomass estimates for AOS surveys of Spawn Plume in 2022 for AOS 38 kHz and 120 kHz and vessel 38 kHz echosounder data. Total biomass including deadzone estimates is shown. Error bars show 1 standard deviation based on survey sampling CV.

Time series of Spawn Plume biomass estimates for 2013, 2016, 2021 and 2022 surveys are provided in Figure 41 for 38 kHz and 120 kHz AOS with the same platform used each year. Estimates were also made from hull mounted 38 kHz calibrated echosounders in each year. The participating vessels for hull-mounted surveys were *Amaltal Explorer* in 2013 and 2016, *San Waitaki* as an opportunistic survey in 2021 and *San Waitaki* in 2022.

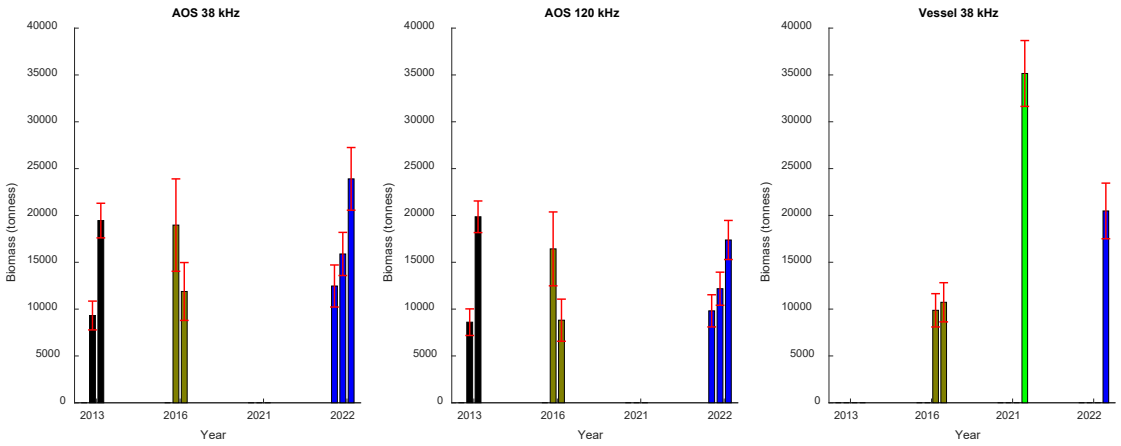

Figure 41: Time series of biomass estimates for Spawn Plume AOS 38 kHz and 120 kHz and vessel 38 kHz echosounders. Error bars show 1 standard deviation based on survey sampling CV.

3.3.3 Mt Muck

3.3.3.1 Overview of survey activities

Mt Muck, a volcanic feature located about 15 n.mile east of Spawn Plume, is a known orange roughy spawning location. This feature was surveyed twice, using vessel down-time while fish were being processed (Table 21). Both surveys were timed to enable surveying at night, as historic knowledge indicated aggregations were likely to be more abundant at that time.

Table 21: Survey operations at Mt Muck.

OP No.	Operation type	Start date (NZ)	End date (NZ)	Visit
72	Sealord AOS Survey	6/07/2022 20:15	7/07/2022 0:08	1st
75	Vessel survey	7/07/2022 22:47	8/07/2022 1:18	1st
76	Sealord AOS Survey	8/07/2022 3:39	8/07/2022 7:50	2nd
77	Fishing shot + SMART-Cam	8/07/2022 12:21	8/07/2022 14:05	2nd

First visit: 6 July 19:27 – 07 July 00:08

A 20 t catch of orange roughy was taken at Spawn Plume on the afternoon of 6 July, providing a window of opportunity to take a first look at Mt Muck during fish processing time. Mt Muck was understood to have better aggregations at night so the timing of this first visit was fortuitous. During a single pass over the feature, the echogram data showed a good aggregation on the top of Mt Muck. This was followed by a star pattern AOS survey starting at 20:15. Good orange roughy aggregations were observed on all transects, particularly on the south-west side of the feature (Figure 42). A trawl-shot had been planned but weather conditions deteriorated to the point where the risk of fishing this steep and complex feature was considered too high and *San Waitaki* returned to the Spawn Plume area to continue fishing operations there.

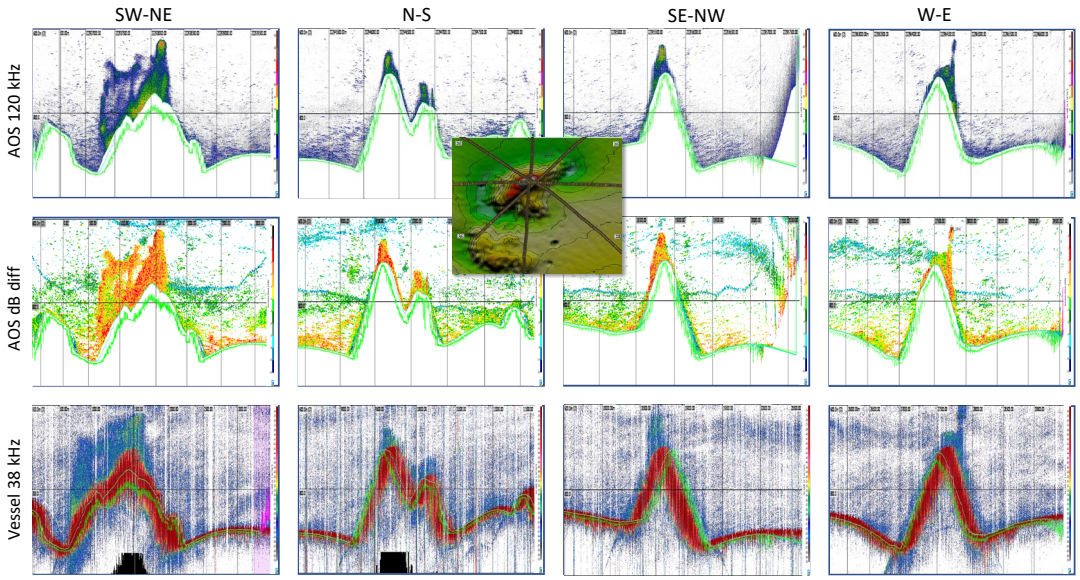

Figure 42: Echograms from first AOS survey of Mt Muck (OP72 6 July 2022). Top images show the 120 kHz echograms. Lower set of images shows the 38 kHz echograms. Middle set of images shows the subtraction of 120 kHz from 38 kHz backscatter. Orange pixels occur when backscatter at 120 kHz is approximately twice as high as 38 kHz, indicative of large fish without a gas bladder (e.g. orange roughy).

Second visit: 7 July 22:47 - 8 July 14:05

A large 60 tonne catch at Spawn Plume was taken on the afternoon of 7 July which provided a window of opportunity during fish processing to return to Mt Muck for a second visit. Weather conditions had eased allowing a second AOS survey and a trawl shot to take place. The AOS survey encountered good aggregations on each transect with the south-west to north-east line having the highest abundance (Figure 43). Historically, the aggregations at Mt Muck have been found to be quite mobile and this was also the case during the two visits, where passes by the vessel showed that the aggregations had shifted around the feature. It was therefore pleasing to see that the two AOS surveys were quite repeatable. Following vessel passes to identify a suitable tow line, a trawl shot was taken around midday on 8 July. The tow produced a large, clean catch of about 63 t of orange roughy, taken during a brief bottom contact of eight minutes.

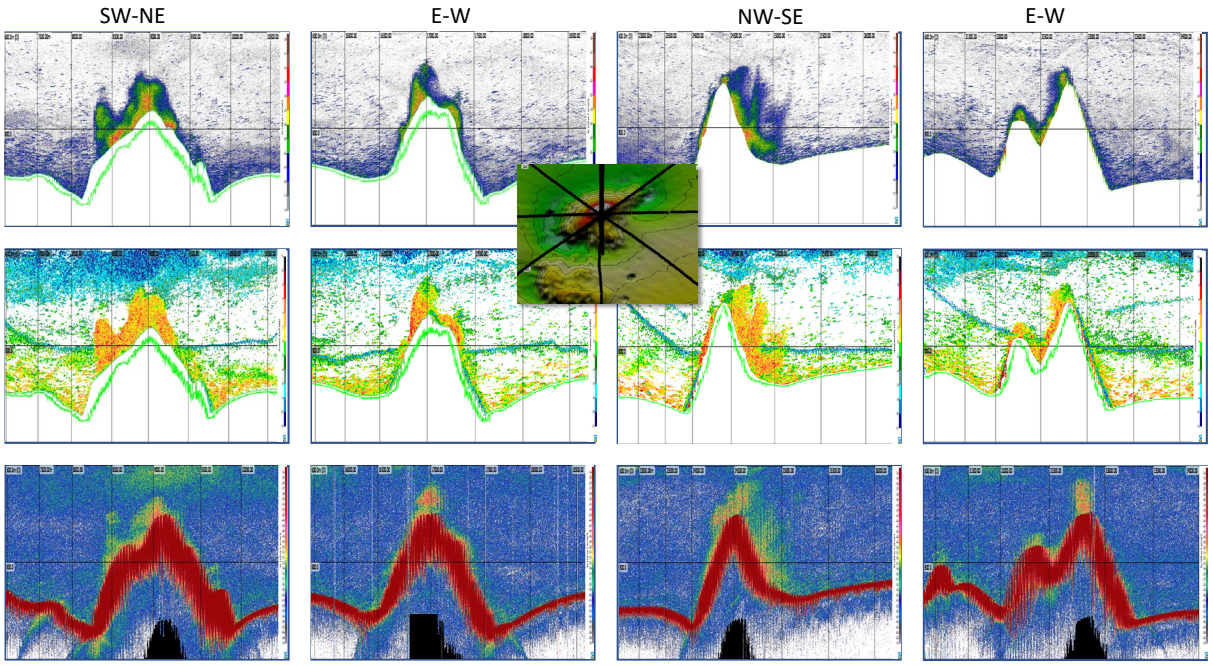

Figure 43: Echograms from second AOS survey of Mt Muck (OP76, 8 July 2022). Top images show the 120 kHz echograms. Lower set of images shows the 38 kHz echograms. Middle set of images shows the subtraction of 120 kHz from 38 kHz backscatter. Orange pixels occur when backscatter at 120 kHz is approximately twice as high as 38 kHz, indicative of large fish without a gas bladder (e.g. orange roughy).

3.3.3.2 Biological sampling

The single large catch, sampled six times, was dominated by males (87%). Spawning was well underway at Mt Muck on 8 July, with 50% of female gonads in ripe-running condition and 25% spent or partially spent (Table 22, Figure 44). A total of 494 otolith pairs was collected.

Table 22: Female orange roughy gonad maturity state at Mt Muck on 8 July 2022.

Date	Resting & Maturing	Ripe &	Running Ripe	Spent & Partially Spent
8/07/2022	0%	25%	50%	25%

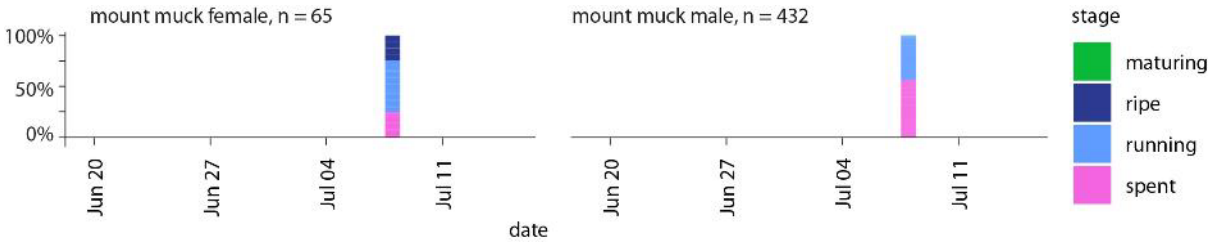

Figure 44: Female and male orange roughy gonad maturity states at Mt Muck on 8 July 2022.

Mean standard lengths for orange roughy at Mt Muck were 36.9 cm for females, 34.9 cm for males and 35.1 cm for the sexes combined. The sex-ratio of 6.6:1 strongly favoured males (Figure 45). Mean weights were 1730 g for females, 1392 g for males and 1436 g for the sexes combined.

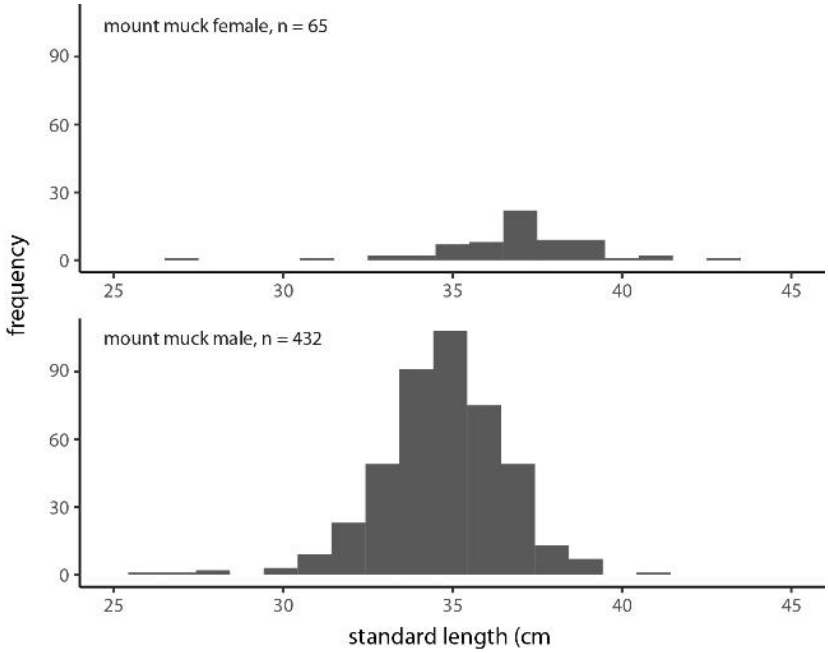

Figure 45: Orange roughy length-frequency distributions at Mt Muck (one trawl tow).

The single large catch comprised 99.6% orange roughy by weight. Abundant bycatch species included cardinalfish (0.3%) and smooth oreo (0.1%) (Figure 46).

As no further fishing was planned on Mt Muck, the requisite number of otolith samples needed to be taken from this single catch and 497 were collected.

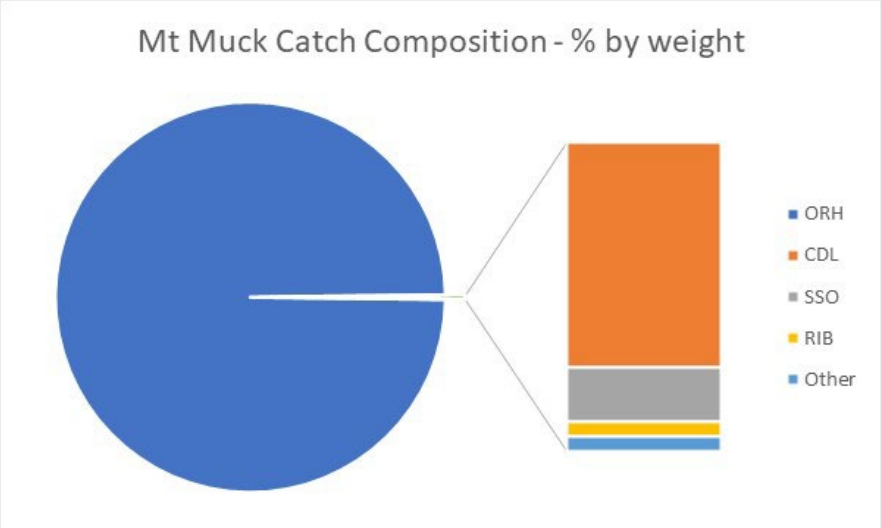

Figure 46: Catch composition at Mt Muck (ORH orange roughy, CDL deepwater cardinalfish, SSO smooth oreo, RIB ribaldo).

3.3.3.3 Biomass estimates

Biomass estimates for Mt Muck AOS and vessel-mounted acoustic surveys are provided in Table 23 and visualised in Figure 47.

Table 23: Biomass estimate for Mt Muck AOS surveys in July 2022 based on 38 and 120 kHz echosounder data and vessel based 38 kHz echosounder.

Date (UTC +12)	Platform	OP	Frequency (kHz)	Survey area (nmi^2)	Mean NASC (m^2 nmi^{-2})	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
6/07/2022 20:15	AOS 38 kHz	72	38	0.933	535	5 160	0.14	4 057 (44. %)	9 218
	AOS 120 kHz	72	120	0.933	775	3 460	0.14	2 068 (37.4 %)	5 528
8/07/2022 03:39	AOS 38 kHz	76	38	0.668	1022	6 889	0.18	5 714 (45.3 %)	12 603
	AOS 120 kHz	76	120	0.668	1483	4 329	0.17	3 239 (42.8 %)	7 567

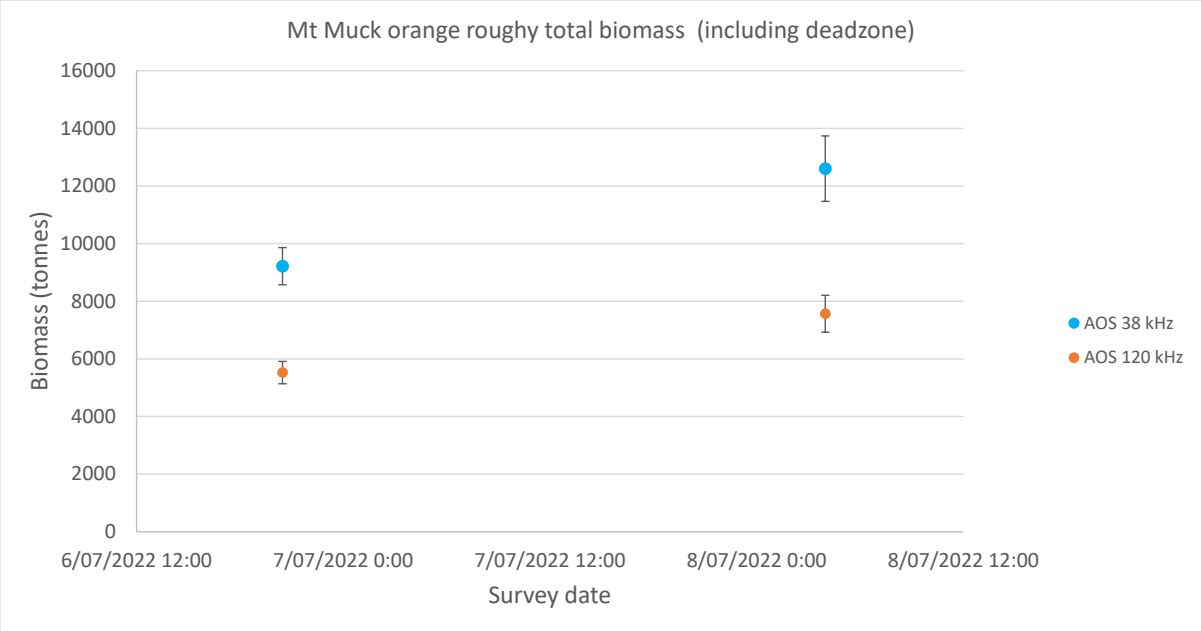

Figure 47: Biomass estimates for AOS surveys of Mt Muck in 2022 for AOS 38 kHz and 120 kHz. Total biomass including deadzone estimates is shown. Error bars show 1 standard deviation based on survey sampling CV.

Results for the 2022 AOS surveys are added to the time-series from 2013 onwards (Figure 48).

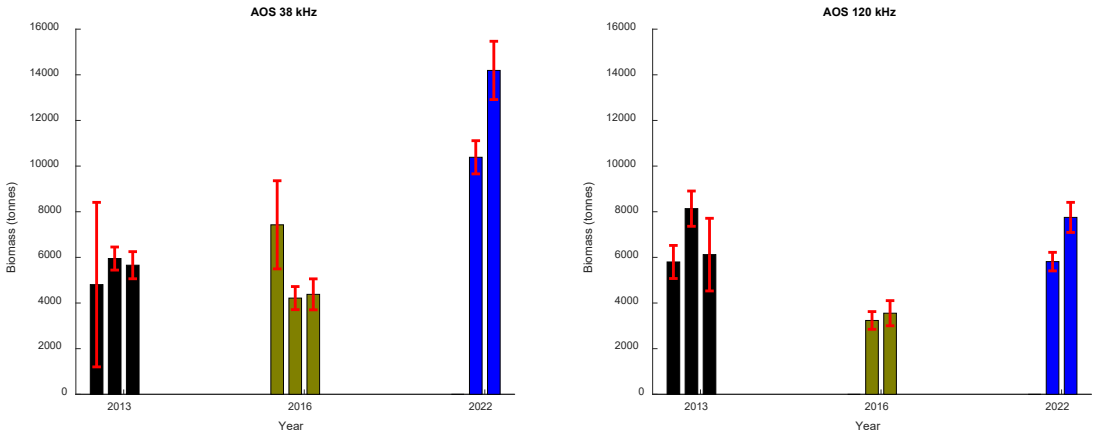

Figure 48: Time series of biomass estimates for Mt Muck for AOS 38 kHz and 120 kHz echosounders. Error bars show 1 standard deviation based on survey sampling CV.

4. DISCUSSION

4.1 Overview of survey outcomes

All the primary objectives of this survey were successfully met. The survey arrangement was to combine commercial fishing with acoustic surveying and biological sampling. A week of solely commercial fishing had been included at the start of the voyage to allow the vessel to take some fish on and take pressure off the survey activities that needed to occur during periods of peak abundance. Unfortunately, this did not work as planned, with only minimal catch being taken from multi-hour tows during the early stages of the voyage. Despite this, the objectives of both the science party and

ship's crew were met, with the required number of surveys being completed and the vessel's hold being filled. The five charter days available to the survey were fully used to enable surveying to be carried out at the expense of fishing at various points during the voyage. Otherwise, surveys were carried out while catch was being processed such that fishing efficiency was minimally affected. The ship's officers and shore management of *San Waitaki* are thanked for their close cooperation to ensure that surveys were conducted appropriately at a time when the opportunity cost for fishing was extremely high.

4.2 North-West Chatham Rise

Morgue

The Morgue AOS surveys showed impressive aggregations of orange roughy on all transects across the conical feature. Although it can be difficult to visually compare echograms, the impression was that the aggregations were the most substantial observed since AOS surveys began in 2013; they rose to approximately 150 m above the peak of the feature and continued down the sides to the base. Biological sampling was limited, due to the constraints of fishing under a permit in this Seamount Closure Area, but was sufficient to show that the fish were mostly either ripe or running ripe. The pair of AOS surveys carried out on 28 June returned a biomass that was approximately double that of 25 June, suggesting that the surveys were tracking a build-up, although more surveys would be needed, and over a longer time-period, to be sure. We note that on the first visit on 20 June a large aggregation was observed on the vessel acoustics indicating that orange roughy were present in numbers at that early stage.

Consistent with historic surveys, there were regions of extremely high backscatter attributed to highly mobile, large-gas-bladder species. Although species identification cannot be definitive it appears likely that they are cardinalfish which are known to hang around the tops of underwater features. Multifrequency acoustics in combination with absolute backscatter was able to identify these regions and remove them from the analysis. Deepwater sharks are another source of potential positive bias. These do not have gas bladders so are expected to have a similar multifrequency signature to orange roughy, albeit with higher absolute backscatter as they are much larger animals. This means that the acoustics might not be able to easily distinguish them from orange roughy. Video observations during AOS trawls shows that there was a degree of spatial delineation between deepwater sharks and orange roughy; deepwater sharks were observed at moderate densities upon approach to the main part of the aggregations followed by a transition to very high densities of almost exclusively orange roughy.

Biological sampling estimated 90% orange roughy across four trawls with 7.5% being deepwater sharks. Permit conditions required trawling to avoid seafloor contact, which meant that the net needed to be held higher in the water column where the sharks were residing, potentially making it more selective of those species. We conclude that while echogram interpretation has been guided by best available information, any biases will be positive should contributions of large-gas-bladder fish and higher signal deepwater sharks not be fully excluded.

Biomass estimates ranged between 9979 and 28 653 tonnes for the 38 kHz AOS echosounder. The contribution from the biomass estimated within the dead-zone region was quite significant ranging from 12% to 36 % of the total and accounting for 25% of the contribution to the largest biomass of 28 653 tonnes. This large dead-zone component is not unexpected given that the steepness of the Morgue feature increases the dead-zone height due to side-lobe interference. Biomass estimates at 120 kHz were between 21% and 31% percent lower than those at 38 kHz. This is within the bounds observed by Ryan & Kloser (2016). In principle, if calibration, target strength estimates and corrections for absorption are accurate the biomass estimates should be the same across frequencies. However, we note that the high range-dependant sensitivity of absorption estimates for the 120 kHz sounder, combined with the high school height at Morgue (150 m) and extensive depth range that the orange roughy schools occupied, may be the reason for the observed difference.

The initial review of the Morgue surveys indicated that there was a degree of double counting due to the AOS platform being tilted slightly upwards on approach to the feature and being slightly downwards on departure. This would be a source of positive bias. We note that this situation would have occurred for historical AOS surveys at steep-sided features where AOS platform depth had to be adjusted during the transect. Further, the Sealord AOS has had improvements in 120 kHz noise floor to extend the working range to about 450 m compared to 350 m when first used. This meant that the earlier surveys would have had to be more proactive in adjusting the platform depth above the schools, consequently increasing the range of pitch angles on approach to, and departure from, the features. The pitch angle data for the 2022 surveys were reviewed with respect to the scale of the Morgue feature and the transducer beam intersecting the orange roughy schools. It was concluded that the degree of positive bias should not be significant. Notably, for the last AOS survey of Morgue, the platform was held as high as possible while traversing the feature, with minimal adjustment to pitch, to reduce this possible source of bias. This survey returned the highest biomass of the four AOS surveys. Further work on a model to adjust for this possible bias would provide a more definitive quantification of the level of error. This model would include inputs of platform depth and tilt angle, transducer beam angle and school geometry with respect to seafloor location (which could be provided by the vessel-acoustics data).

Graveyard

Similar to the 2021 surveys, only a very small aggregation of orange roughy was observed at Graveyard. Species identification was inferred from multifrequency acoustics. A single trawl caught 150 kg of which 43% comprised orange roughy. We note that the likely orange roughy school was well above the top of the feature, at low density and of limited extent, while the trawl shot ran down the slope and would have had only a brief intersection, if any, with the orange roughy school. Hence there was a mismatch between what the trawl and the acoustics were sampling.

The surveys from 2013 encountered much larger aggregations at Graveyard with an estimate of orange roughy of about 7500 tonnes based on the 120 kHz AOS echosounder (concurrent 38 kHz was not possible as the echosounder had failed). This change may indicate an abundance decline or alternatively a shift by aggregations to the Morgue feature that is only 3 n.miles away. Similar ebb-and-flow between features has been observed in the Tasmanian Eastern Zone fishery where St Helens Hill had reduced from being the largest fishery to barely detectable levels in 1999 while St Patricks Head 30 n.miles to the south held impressive aggregations of orange roughy. The situation reverted in 2010 with St Helens hill again holding the largest proportion of the stock following a seven-year closure (Kloser et al. 2011).

4.3 North-East Chatham Rise

Rekohu

Two AOS-based surveys were achieved at Rekohu while four had been planned. In part this reflects the large area where orange roughy might be found and the mobility of the aggregations during the survey period. In the earlier surveys in 2013 and 2016 we had similar challenges, but the aggregations did settle after a few days of tracking them using vessel-acoustics and once they did settle, large aggregations were surveyed with consequent high biomass estimates. In 2022, the aggregations did settle to some extent, but survey design had to be adapted to anticipate likely extent and movement directions. The 38 kHz AOS estimates were 13 088 and 16 713 tonnes. The four vessel-based surveys ranged from 9311 tonnes to 22 800 tonnes. These estimates are significantly lower than those of the 38 kHz AOS of 2013 and 2016 where estimates of over 40 000 tonnes were made in both years.

Spawn Plume

Biomass estimates at Spawn Plume were made from three AOS surveys and a 38 kHz vessel-based survey. These ranged from 20 479 tonnes for the vessel survey to 23 905 tonnes for the highest 38 kHz AOS survey. There is no obvious trend in the AOS 38 kHz or 120 kHz 2013–2022 time series. The large vessel-based biomass estimate of 35 000 t in 2021 stands out as the highest in the whole

data set. Although this was an opportunistic, vessel-based survey with associated uncertainties, the echograms of the aggregations in 2021 were indeed impressive and, importantly, were extensive over a wide area.

The apparent downward trend at Rekohu when compared to the surveys of 2013 and 2016 raises the possibility of a shift in location between Rekohu and Spawn Plume, as was discussed for the Morgue/Graveyard situation. Such shifts could be caused by fishing disturbance sustained over many years. We recall that surveys of Spawn Plume in the 2000s showed a steady decline (Doonan et al. 2012; Hampton et al. 2013) before Rekohu was discovered around 2010. In the following years Rekohu has received intensive fishing effort that may have motivated aggregations to move to Spawn Plume. Future surveys need to allow sufficient time to survey both of these large locations and to be able to switch surveying between them as needed. Long-term monitoring will be needed to determine whether changes are driven by disturbance, catch or a combination of both.

Mt Muck

Mt Muck held good aggregations of orange roughy in 2022. Biomass estimates ranged from 9218 and 12 603 tonnes based on the AOS 38 kHz echosounder. These estimates are approximately a factor of two higher than those from 2103 and 2016 surveys, while we note the 120 kHz estimates are lower and are not indicating change. Mt Muck is a steep sided feature that is a difficult location to survey and hard to fish with only limited tow lines. Large gas bladder fish are present which required multifrequency acoustics to remove their signal from the analysis. Positive biases due to inclusion of gas bladder species are possible where we can only assume that such biases are at least consistent between years. Errors due to absorption losses at 120 kHz also may be high given the depth range that the schools occupy.

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7. APPENDIX A. TABLE OF ACTIVITIES

Table 24: Table of activities for San Waitaki 2022 survey.

OP Number	Location	Operation type	Start_date (NZ)	Comment
1	Graveyard	Vessel survey	20/06/2022 2:52	Graveyard transect w-e then s-n small mark on top and west side. Due to wind did not shoot
2	Morgue	Vessel survey	20/06/2022 3:36	Two transects across morgue, good fish marks on top >100 m high
3	Spawn Plume	Fishing shot + SMART-Cam	20/06/2022 16:40	Hauling net after long tow. Took some ORH marks. First SMART-Cam deployment. Retrieved ok, wifi automatic connection worked with images transferred to bridge PC within ~10-15 minutes. Images generally overexposed and adaptive exposure algorithm looked like it was hunting for the right exposure, never staying on the same ISO Exposure settings for SMART Cam Pixel luminance threshold 240 target percent pixels above threshold 2
4	Spawn Plume	Fishing shot + SMART-Cam	20/06/2022 20:58	Targeting good ORH mark for catch. Mark a bit high off the seafloor for an easy catch. SMART-Cam frame got torn away from pressure case. Retrieved ok as had safety rope around the frame Exposure settings for SMART Cam Pixel luminance threshold 240 target percent pixels above threshold 2
5	Spawn Plume	Fishing shot	21/06/2022 3:22	small mark at end of tow ~15 tonnes roughy
6	Spawn Plume	Fishing shot	21/06/2022 9:03	fishing shot mixed bag
7	Spawn Plume	Fishing shot	21/06/2022 13:20	fishing on mark 850 m water depth. 1 tonne
8	Spawn Plume	Fishing shot	21/06/2022 18:55	no decent marks, net in water to see what it can scrape up. Maybe a 1 tonne catch at best
9	Spawn Plume	Fishing shot	22/06/2022 0:01	Starting deep, heading west at Spawn Plume across to Rekohu small catch ~3 tonne
10	Spawn Plume	Fishing shot	22/06/2022 3:15	3.5 hr tow in the deep 1300 m for ~2 tonnes
11	Spawn Plume	Fishing shot	22/06/2022 7:58	target trawling to small marks in 1080 m of water, turned into a large mark midwater. Catch ~35 tonnes
12	Spawn Plume	Fishing shot + SMART-Cam	22/06/2022 18:08	SMART-Cam on with modified mounts and extra lashing around the body of SMART-Cam. Catch ~ 7 tonnes Headlines height was ~ 4 meters.
13	Spawn Plume	Fishing shot + SMART-Cam	22/06/2022 21:35	Exposure settings for SMART-Cam Pixel luminesce threshold 200 target percent pixels above threshold 2 small mark at end then pinned up for a while Smart cam not downloading images when on deck.
14	Spawn Plume	Fishing shot	23/06/2022 5:28	After some net repairs shooting on marks in 1030 m water depth. Marks off bottom. Removed SMART-Cam as it was not downloading images. Needed to bring in headline to untwist net monitor. On inspection of SMART-Cam one quadrant of LED lights were on. Replaced batteries. Nice catch ~25 tonnes
15	Spawn Plume	Modular AOS trawl	23/06/2022 15:19	M-AOS first deployment. 120 kHz ES120-7CD and ES38-18DK. 0.256, 0.512 ms pulse length. CW. About 12 tonnes.
16	Spawn Plume	Modular AOS trawl	23/06/2022 19:49	Targeting tall ORH mark on the sounders. No time to download M-AOS data. Doing back-to-back shots and will download at later time. Wire out 2020, depth 887 m A couple of other 'haystack' ORH marks came along during this very long trawl but did not appear to take many fish. 12 tonnes Swapped out AOS battery and started to download lots of data.

OP Number	Location	Operation type	Start_date (NZ)	Comment
17	Spawn Plume	Modular AOS trawl	24/06/2022 3:56	Changed AOS to 18 deg 120 kHz. Downloaded data - issue with video maybe CODEC? Logging range for 120 kHz odd only 30 m? 38 kHz corrupted with headline monitor. Images over exposed and time stamps on all files odd. No CTD or motion data? Small catch ~6 tonnes
18	Spawn Plume	Fishing shot	24/06/2022 10:41	Shooting hill Eric? Small mark on side with smaller trawl and no M-AOS. 5 tonne catch
19	Spawn Plume	Modular AOS trawl	24/06/2022 12:48	Shoot with larger trawl M-AOS attached - 750-850 m set up in broad band mode - video and light off. 1.3 tonne
20	Rekohu	Fishing shot	24/06/2022 18:30	Modular AOS attached but was turned off as was having issues pinging reliably. Long tow at Rekohu with no sign of ORH. ~ 3 tonnes
21	Rekohu	Sealord AOS single pass	25/06/2022 3:20	Calibration of AOS to establish the trim of the net at 400 m depth. 03:30 Settled at 410 m depth on auto trawl mode stb 833m prt 831 m 3:35 out of auto trawl stb 836 m prt 836 m hold stb and move port 3:40 prt 834 m 3:43 prt 832 m 3:47 prt8363:30:00 3:52 prt 838 3:55 prt 840 3:58 prt 842 4:01 back in auto mode stb 835 and port 837 4:09 hauling Heading west with a 20-25 knot northerly
22	Morgue	Sealord AOS Survey	25/06/2022 6:53	First survey of morgue starting with a SW-NE pass over graveyard. Left winch in auto mode to determine if due to weather and tide it was a good compromise? 7:00 start Graveyard pass 8:00 start N-S Morgue pass 8:55 end first S-N pass of Morgue 9:05 start NW-SE pass of Morgue 9:43 end NW-SE pass of Morgue 10:15 start W-E pass Morgue 10:47 end W-E pass Morgue 11:16 start SW-NE pass Morgue 11:57 end SW-NE pass Morgue Echosounders intermittent. Power supply issue. Usual problem of vibration affecting onboard components. Replacing power supply
23	Graveyard	Sealord AOS Trawl	25/06/2022 14:22	MK9 temperature logger moved over from large net to small net. 150 kg fish
24	North West Rise	Sealord AOS Trawl	25/06/2022 17:00	Commercial trawl between Morgue and Headstone heading east. Negligible catch. AOS in trawl mode but did not start. Reason unclear. Set to survey mode and tested ahead of Morgue survey
25	Morgue	Sealord AOS Survey	25/06/2022 21:57	T1: N-S Heading 180 degrees. Large mark right across the top and south side of Morgue. Regions of large gas bladder fish. Brought AOS to deck to download and check data as a precaution ahead of continuing on to T2. Check AOS - all ok. T2: Heading NW. 23:19 shooting away. 26/6 00:11 hauling. T3 - NE to SW. 26/06 01:00. Hauling 26/06 01:43. Schools of large gas bladder fish prominent in amongst ORH. Tick marks indicate AOS is working T4- W-E hauling 02:51 high fish school-- seems like there was a strong set to the south on gear and we did not cross the peak? Data download and checked ok battery 15.6 v Turned off and on.
26	Morgue	Sealord AOS Survey	26/06/2022 3:46	Survey of Morgue

OP Number	Location	Operation type	Start_date (NZ)	Comment
				T1- N-S 3:46 end 04:37 nice mark on top and to south, ticks T2 SE-NW start 05:13, hauling 5:59, ticks T3 W-E start 06:24, hauling 6:55, ticks T4 NE-SW start 07:31, hauling 8:07.
27	Morgue	Sealord AOS Trawl	26/06/2022 9:01	Targeted off bottom trawl of Morgue - aborted whilst deploying net as net monitor stopped working
28	Morgue	Sealord AOS Trawl	26/06/2022 10:12	Targeted non-contact trawl for fish biologicals, went through mark at around 50 m off bottom contact through the mark of fish. Shot yielded a small ~ 1 tonne catch of roughy with sharks …
29	Morgue	Sealord AOS Trawl	26/06/2022 12:54	Repeat trawl over Morgue 140 deg. Mark re-established after previous shot. Nice tow through top of mark ground rope 18 m off bottom. Hauling after going through mark very dense on net monitor. Small catch ~1 tonne. Ticking on way up. Video fish start at 01:31:02, thick at 01:31:28, thin 01:32:06
30	North West Rise	Vessel survey	26/06/2022 14:00	Quick scout over pyre and gothic. No marks to speak of.
31	Graveyard	Sealord AOS Survey	26/06/2022 15:21	T1 - Graveyard. Light haze on the side but nothing spectacular.
32	Rekohu	Fishing shot	27/06/2022 5:22	Nice mark at 820 m on sounder shooting for this. Held in mark good echoes going into net monitors and high school observed above net. ~ 40 tonnes -- windows activated.
33	Rekohu	Vessel survey	27/06/2022 14:55	Vessel survey during fish processing time. Scoping out Rekohu grounds. Just one modest mark in the middle of the survey area and nothing elsewhere.
34	Rekohu	Sealord AOS calibration	28/06/2022 0:37	Sealord AOS calibration - moved north from Rekohu to get to deeper water. AOS swung at 90 degrees as it went down the ramp, 50/50 whether line was cut but going ahead now that AOS is in the water. 00:38 at 150 m 00:45 at 300 m 00:55 at 400 m 1:08 at 500 m 1:21 at 600 m 1:35 at 700 xx at 600 2:00 at 500 2:08 at 400 2:18 at 300 m 2:24 hauling to surface data checked ball was attached and calibration looks ok Calibrated vessel sounder at 1 ms and 2 ms pulse lengths
35	Rekohu	Vessel calibration	28/06/2022 2:00	Vessel calibration in open water immediately following the AOS calibration.
36	Rekohu	Sealord AOS Trawl	28/06/2022 6:01	Trawl shot on marks looked like a large catch but only ~ 10 tonne. No video
37	Rekohu	Sealord AOS Trawl	28/06/2022 8:37	Trawl issues with net fishing? Measured net and adjusted
38	Rekohu	Sealord AOS Trawl	28/06/2022 11:33	Fishing on good mark - very dense mark through headline - could be issues with net as not performing as expected. Noticed issue with form time and local/utc? Very large catch 60 tonnes
39	Morgue	Sealord AOS Survey	28/06/2022 22:33	AOS survey at Morgue. Perfect condition. Getting exceptionally good quality acoustics on the vessel system. T1 - Start at 22:30 Hauling at 23:07. Exceptionally large aggregation over the Morgue. No sign of the region of large gas bladder fish. Hauled AOS onto back deck to download data and set range to 800 m in order to get both the top of the school and fish down the slope

OP Number	Location	Operation type	Start_date (NZ)	Comment
40	Morgue	Sealord AOS Survey	29/06/2022 2:58	Start of 4th survey of Morgue - range 800 m and net flown steady across the hill. T1: SW-NE end 03:35 T2: E-W end 4:34 T3: NW-SE end 5:38 T4: S-N end 6:32 Data checked, good survey very stable and operated well on 800 m setting. Changed settings to a trawl and turned video on. Main battery 15.1 v.
41	Morgue	Sealord AOS Trawl	29/06/2022 7:28	Targeted off bottom trawl yielded a small catch of ~ 1tonne. Data downloaded and good TS at 120 kHz. Battery on AOS low ~14.9v and 19.4v, very low on the video. Changed both batteries.
42	Morgue	Sealord AOS Trawl	29/06/2022 10:12	Targeted shot of the Morgue, after clearing one top a second ridge appeared and the trawl came close to the seafloor for a brief moment. About 4 tonne No tick marks on sounder on retrieval. No data was recorded of acoustics or video. Both Rob and myself observed that the power and lights were on for deployment.
43	Rekohu	Fishing shot	29/06/2022 19:43	Fishing shot at Rekohu after returning from Morgue. Good catch with 26 tonnes
44	Rekohu	Fishing shot	30/06/2022 0:21	
45	Rekohu	Vessel survey	30/06/2022 5:23	Vessel survey of Rekohu follow contours squares for fish Transects 4 n.miles direction 105 deg. And 286 deg. done 0.5 n.miles apart. Furuno on for first two transects :(off at 6:05). 4 transects to the north and then headed east to fill in the top transect. No fish observed on the southern shallow transect at ~800 m. End 07:30 ~ 2 hrs for 5 transects Doing interlaced transects at offset 0.25 n.miles. End 10:05 no fish seen on last transects to North deeper. Moving to South shallower and pick up transects.
46	Rekohu	Fishing shot	30/06/2022 12:17	Fishing shot after surveying fish on the move. Large mark ~30 tonne.
47	Rekohu	Vessel survey	30/06/2022 14:22	FCV30 was on for the first transect but no fish seen. FCV 30 was off for the remainder of the survey. Marks very quiet for the first part of the survey with no significant aggregations found on the deep-to-shallow phase. On the return interlaced shallow-to-deep phase marks showed up on the northernmost transects. Needed to keep putting in extra transects in order to bound the aggregations. Ran tie-line perpendicular to the survey aiming to pick up maximum fish. Very large aggregations observed that were too big to fish. 1st Mate ceased survey tie line as needed to go and look for a suitably small mark that would allow fishing
48	Rekohu	Fishing shot	1/07/2022 1:06	Fishing shot following vessel-mounted survey. Large marks in the area, trying to target more modest mark to avoid over-catch. Large catch ~ 40 tonnes!
49	Rekohu	Vessel survey	1/07/2022 3:28	Start survey from deep 1080 m (north) to shallow (south) at 0.7 n.mile spacing. Symbol cpn 'snag'. After 6 transects ended at 06:43. Started interlaced transects 0.35 n.mile spacing 6:44. Wind picked up half way through and vessel acoustics degraded.

OP Number	Location	Operation type	Start_date (NZ)	Comment
				Ended 09:34
50	Rekohu	Fishing shot	1/07/2022 16:00	Fishing shot. Kept trawl down at 800m for 1.5 hours as factory was not quite ready. Weather was rough so spent processing time steaming around keeping an eye on the marks but not possible to do systematic transects
51	Rekohu	Fishing shot	2/07/2022 4:17	Aggregation had moved small catch
52	Rekohu	Fishing shot	2/07/2022 8:00	Found nice mark in 805 m depth. Catch ~17 tonnes
53	Rekohu	Fishing shot	2/07/2022 14:44	Large marks were not located, doing a tow down through thick haze near seafloor in hope of pulling in some roughy. Nice 18 tonne bag of fish
54	Rekohu	Fishing shot	2/07/2022 20:46	Shooting good mark down in the deeper part after not seeing much on the sounders. Big mark appeared during trawl shot followed by an even bigger one. Pulled up early but still got 16 tonnes
55	Rekohu	Fishing shot + SMART-Cam	3/07/2022 0:49	SMART Cam back on. Set hist value down from 200 to 180. Set with electronic shutter. ~20 tonnes
56	Rekohu	Fishing shot + SMART-Cam	3/07/2022 8:19	SMART Cam back on. Set hist value down from 180 to 160. Set with electronic shutter. Shooting a mark in 780 m of water. Slow feed of marks into net monitor ~18 tonnes. Image quality at 160/2 percent was good exposure,
57	Rekohu	Sealord AOS single pass	3/07/2022 10:36	Test of the tow speed with the big net - codend open. Seas slight low swell. Tow tests achieved 5 knots at 450 m depth with 1270 m wire out. Data checked ok. Note no ticks detected on launching but seen on retrieval.
58	Rekohu	Fishing shot	3/07/2022 16:02	12 tonnes roughy
59	Rekohu	Fishing shot + SMART-Cam	3/07/2022 21:10	Long search for aggregations to shoot on, located mark in the deep but was not extensive. Long trawl through light scatter and weak ORH mark. Took light catch all the way down the line without running into large amount of fish. 14 tonnes
60	Rekohu	Fishing shot + SMART-Cam	3/07/2022 23:51	Shooting for ORH mark - not all that strong but good for fishing. SMART-Cam hist value 160. Exposure about right. Marine snow an issue for a lot of the images. For some reason SC is setting the date to 3rd March. ~ 10 tonnes
61	Rekohu	Fishing shot + SMART-Cam	4/07/2022 5:25	Found mark on bottom in NE section and shooting - looks like marks are moving up the slope to the south as on previous nights. Fish not hard on bottom gradual trickle into net ~14 tonne caught. Searching for marks if none moving to spawn plume
62	Rekohu	Vessel survey	4/07/2022 7:00	Opportunistic vessel survey zig-zag transects heading from west to east. Furuno was on? Marks ran for 5 n.mile in the 750-800 m depth range.
63	Rekohu	Fishing shot + SMART-Cam	4/07/2022 9:53	Shooting trawl along tie line 775 m depth. Catch 30 tonnes
64	Spawn Plume	Vessel survey	4/07/2022 14:00	Grid survey of Spawn Plume after taking a 30 tonne catch at Rekohu. Good marks along 912 m contour on multiple passes. Nice vessel survey in relatively calm conditions 10-14 knots. Acoustic data quality high
65	Spawn Plume	Vessel survey	4/07/2022 21:05	Doing tie-line run back through the mark that is at about 981 m. Running FCV30 in triple beam mode to see if we can pick up marks on the outer beams. FCV30 was extremely helpful in understanding which side of the vessel the marks were on. Estimate ~ 350-400 m footprint with two side beams at 10 degree tilt.

OP Number	Location	Operation type	Start_date (NZ)	Comment
66	Spawn Plume	Fishing shot + SMART-Cam	4/07/2022 23:49	Trawl shot on edges of main aggregation. Perfect size catch of ~ 35 tonnes. Can go down in one tip to give maximum time for AOS survey.
67	Spawn Plume	Sealord AOS Survey	5/07/2022 5:05	Start of AOS survey after searching and bounding with the vessel. AOS turned on lights flashing. Bit of gear fixing on way down 5:24. Furuno off. T1 end 06:47 after seeing some deep marks on vessel sounder ticks! T2 end 08:46 only fish seen at 803 m ticks on up, T3 end 10:18 no fish on transect so heading east 0.5 n.mile, ticks T4 end 11:45 no fish! Ticks Issue with net monitor bringing in to check, headline parted changed net, AOS battery changed, finished 13:25. T5 end. Finish survey with zero line out to the east at the 1 nmile spacing - at 17:50 did a run up the inside of the outer line at 0.5 nmile spacing and saw large mark ….
68	Spawn Plume	Fishing shot	5/07/2022 18:54	Big bag of fish - 45t
69	Spawn Plume	Vessel search	5/07/2022 21:35	Some 2-3 tonnes left on back deck that would not fit into the pounds. Doing a vessel search to scope out the location of fish so that we are ready to go with AOS survey as soon as back deck is cleared. Marks seen well to the east. Completed a zero line with the vessel ahead of putting the AOS in.
70	Spawn Plume	Sealord AOS Survey	6/07/2022 3:21	Start AOS survey from east to west, vessel bounded eastern end. Net aim 450 m at shallow moving to 500 at deep end of transect T1 start 03:30 end 04:18 at vessel 930 m. Ticks 2 schools T2 start 04:40 end 5:30 at vessel 755 m. Ticks 2 schools T3 start 06:00 end 07:08 at vessel 957 m. 2 small marks ticks. T4 start 07:48 end 9:12 at vessel 738 m. 2 schools ticks T5 start 09:42 end 10:37 at vessel 974 m 1 school ticks T6 start 11:07 end 12:12 at vessel 743 m 1 school ticks T7 start 12:36 end 13:23 at vessel 945 m 1 small school Hauling in.
71	Spawn Plume	Fishing shot	6/07/2022 15:51	25 tonne catch. Heading to Mt Muck T1 - 20:25 to 20:52 SW to NE. very nice mark down side and across the top
72	Mt Muck	Sealord AOS Survey	6/07/2022 20:15	Good mark on top of feature. T1 - SW-NE. Big mark on SW side and over the top T2. Net damaged during this survey.
73	Spawn Plume	Fishing shot	7/07/2022 3:54	Target at the 830-850 m nice size mark. ~25 tonnes
74	Spawn Plume	Fishing shot	7/07/2022 15:10	Fishing shot on very good mark. Took about 60 tonnes
75	Mt Muck	Vessel survey	7/07/2022 22:47	Transited from Spawn Plume to Mt Muck. Large catch still being processed with 20 tonnes still on back deck. Decided to move to Mt Muck to take advantage of brief easing of weather that should allow us to shoot a trawl following AOS survey. Transects over Mt Muck to scope out feature. Furuno on. Keeping a steady course while fish being processed.
76	Mt Muck	Sealord AOS Survey	8/07/2022 3:39	AOS survey of Mt Muck T1 SW-NE start 03:40 end 04:19, ticks, issue with net all ok. T2 E-W start 4:45, end 5:28,ticks T3 NW-SE start 5:52, end 6:22, ticks T4 S-N start 06:54, end 7:29, ticks At end Vbat 15.6 volts Data checked ok. AOS turned off. No Furuno net monitor.
77	Mt Muck	Fishing shot + SMART-Cam	8/07/2022 12:21	Trawl shot at Mt Muck S-N fish had moved to the Northern slope nice mark. Large Catch 70 Tonnes. No shots on smart cam.
78	Spawn Plume	Vessel survey	8/07/2022 15:47	Scoping/transect survey. Making good use of time while large catch being processed, and deck backed up with fish. Had to take time to put ship on steady line after first

OP Number	Location	Operation type	Start_date (NZ)	Comment
				transect. Weather deteriorates with winds up to 50 knots. Was able to get quite a way west to confirm there were no marks.
79	Spawn Plume	Vessel survey	9/07/2022 4:09	Vessel survey to bound eastern transects for AOS survey. No fish start on next transect with AOS into weather
80	Spawn Plume	Sealord AOS Survey	9/07/2022 6:17	Start S-N transects 1.0 n.mile spacing. T1 start 06:30, end 07:31, 1 small school, ticks T2 start 07:57, end 09:04, 1 large school, ticks T3 start 09:27, end 10:29, 0 school, ticks T4 start 10:56, end 11:58, 0 school, ticks T5 start 12:09, end 13:12, 1 small school, ticks T6 start 13:31, end 14:35. Two moderate schools, ticks T7 start 14:58, end 16:07, Large strong mark, ticks T8 start 16:32, end 17:25, small strong mark, ticks T9 start 17:49, end 18:49, no marks, bounding line, ticks added extra line at the end as what was supposed to be the end line had a small ORH mark.
81	Spawn Plume	Fishing shot	9/07/2022 20:18	Shooting on small mark to avoid over-catch. Mark moved by the time trawl was set up, only tiny catch.
82	Spawn Plume	Fishing shot	9/07/2022 23:17	Having another go at similar location to previous trawl. Marks high up and quite light. Trawled through reasonable mark but only for short time.
83	Rekohu	Vessel survey	10/07/2022 5:43	Scoping survey of the ground starting from the north moving to south at 1 n.mile spacings. WNW-ESE T1 1000-1028 no marks T2 950 m no marks end 06:58 T3 900 m no marks end 07:52 T4 830 m several schools end 08:30 T5 780 m no schools end 09:26 start 0.5 mile transects T6 750 no schools end 10:17 T7 800 m several schools long mark off to starboard on Furuno T8 850 m schools end 11:55 T9 920 m no schools end 12:52
84	Rekohu	Fishing shot	10/07/2022 14:46	Depth temperature logger on net.
85	Rekohu	Vessel search	10/07/2022 18:05	Running mini searching grid to scope out eastern extent of the aggregation prior to AOS survey. Fish being processed. Eastern-most line will be used as a zero line for the AOS
86	Rekohu	Sealord AOS Survey	11/07/2022 1:25	NB vessel did zero line one mile to the east. First AOS transect will run up line where fish were seen on the vessel sounder. 0.8 n.mile spacing. T1 start 01:26, small school, end 02:31, ticks T2 start 02:55, 2 small schools deep, end 04:07, ticks T3 start 4:30, 4 large schools 890-850,end 5:40 at 750 m depth, ticks T4 start 6:04, 3 schools 815, end 06:52, ticks T5 start 07:21, 3 schools 820 - 787, End 8:15 ticks T6 start 8:36, 3 schools 787 - 823, End 9:24, Ticks check if gear down early enough? T7 start 9:51 2 schools 813 m, End 10:39, ticks on transect Furuno observed fish to starboard so need to do another transect. T8 start 11:01, no schools, End 11:45, Bring up to down load data and change battery
87	Rekohu	Sealord AOS Survey	11/07/2022 12:14	Start of interlaced transects heading east at 0.4 n.mile spacing. T9 Start 12:15,1 school 829 m, end 13:25, ticks T10 Start 13:43,
88	Rekohu	Fishing shot	11/07/2022 23:15	Large catch - 65 tonnes
89	Rekohu	Vessel survey	12/07/2022 1:56	Vessel survey while fish on deck 1 n.mile transects East to West T2 T3 Fish in 860 m depth T4 04:40 excellent run of big schools! Off to port high starboard low T5 05:10 fish schools smaller T6 small school with colour so extending to another transect T7 6:51 no schools head back interlaced.

OP Number	Location	Operation type	Start_date (NZ)	Comment
				T8 08:00 small mark at 800 m depth T9 08:53 small mark at 800 m depth Fish in the pound at 9:30 wind increasing T10 small mark T11 T12 etc end 11:46
90	Rekohu	Fishing shot	12/07/2022 18:18	Holding off on AOS to wait this front moving through.
91	Rekohu	Fishing shot	13/07/2022 7:24	Weather abating, shot for fish large marks in the 780-820 m depth range central west transects. Nice catch 18-25 tonnes
92	Rekohu	Vessel search	13/07/2022 9:30	West to East search of fish at 0.5 n.mile spacing. Broke from survey around 17:30 to look for the next fishing shot. Calling this operation a vessel search as did not cover the entire region to allow a biomass estimate to be made
93	Rekohu	Fishing shot	13/07/2022 18:16	
94	Rekohu	Sealord AOS Survey	13/07/2022 20:00	Running 2nd AOS survey of Rekohu. Reviewed T1 – outer-line to the east. No aggregations. T2 - aggregations expected around 860 m, but no sign down to 1000 m T3. Excellent Mark at 880 m. T4. Good marks at 835 m plus some marks in the water column. Less dense than previous marks but enough to motivate an extra transect line T5 no schools, end 02:48,ticks T6 no schools, end 04:09,ticks T7 one school 750 m depth ,end 05:28, ticks T8 several schools 750 m depth, end 06:43,ticks T9 two schools depth 730 m, end 08:11, ticks T10 extended for another line just to cover 700 - 850 m depths, no fish observed. Vbat = 15.4v at end Noticed blue cable loose out the back of AOS
95	Rekohu	Fishing shot	14/07/2022 10:02	Shot on 710 m depth mark, had moved to seabed whilst shooting. ~15 tonnes
96	Rekohu	Fishing shot	14/07/2022 14:10	Nice 28 tonnes catch.
97	Rekohu	Sealord AOS Survey	14/07/2022 17:35	T0 - Ran zero line with vessel, then moving in 0.5 n.miles. Will need to include knowledge of this zero line when analysing AOS T1. Small amount of ORH at 960 m on the first transect. Furuno off just after the mark at 875 m passed through. T2. End 2013: ORH down deep at 984, pretty much same depth as when we were here a month ago. Had to extend transect to take in these deep features. T3. Large aggregation and high as well. Looks like one of the best that we have seen at Rekohu. Fish are moving shallower. T4. Fish about the same depth as previous. Good marks but not as strong as previous, but enough to motivate doing a line to the west at 1 n.mile spacing T5. No fish on most western transects T6 - first of fill in transects. Light marks at 860 m up in water column. No Ticks after end of T2. AOS retrieved on deck after T6, Inspection by Rob and no easy fix seen so ended up finishing survey with the vessel sounder. Fish found shallow 750 s on transects back east. Had to do an extra bounding transect to east. Slight mark so we seem to have reached the end. Ended vessel survey at 04:40 hrs with light mark on vessel sounder at 800 m.

OP Number	Location	Operation type	Start_date (NZ)	Comment
				Decided to replace the AOS with the MAOS and if time permits have another survey?
98	Rekohu	Fishing shot	15/07/2022 5:15	Fishing shot on the 760 m east mark,
99	Rekohu	Modular AOS survey mode	15/07/2022 7:33	Survey of Rekohu starting east to west on vessel track that saw a small mark. Problem with MAOS communication, had to get Rob up and we changed the lead and it started working? T1 ticks at start, 2 small schools first transect!, ticks end 08:28 T2 one large school at end 723 m depth, ticks end 09:46 T3 small mark, end 10:40, ticks T4 no mark end ticks T5 no marks , end 12:46, ticks T6 T7 Likely ORH at 700, up 50 m in water column T8 ORH on easternmost transect. Had to put in another one at 1.0 nmile spacing to ensure zero line
100	Morgue	Vessel survey	16/07/2022 6:34	Quick vessel survey of Morgue, slight dogleg from transit to check out if there were any ORH lingering. Very nice plume still above feature high into the water column plus a star pattern over Graveyard - a bit of a mark but nothing special

8. APPENDIX B. VOYAGE CATCH

Common name	Weight (kg)	No. caught	No. stations
Abyssal rattail	2.3	8	4
Alfonsino	11.4	6	4
Alfonsino & long-finned beryx	0.9	1	1
Banded rattail	5.5	32	12
Barracudina	0.3	1	1
Basketwork eel	503.0	382	30
Baxters lantern dogfish	886.2	614	37
Bigscaled brown slickhead	314.7	581	9
Black dragonfishes	0.1	1	1
Black ghost shark	3.1	1	1
Black javelinfish	0.6	1	1
Black oreo	93.0	106	15
Black slickhead	8.5	6	5
Blackspot rattail	0.1	1	1
Blue Skate	0.2	1	1
Blue-eye lantern shark	11.1	14	7
Bulbous rattail	0.3	1	1
Cape scorpionfish	14.1	13	4
Cardinalfish	270.5	158	25
Catshark	2.1	5	4
Coryphaenoides mcmillani	8.7	77	9
Deepwater octopus	1.0	1	1
Diaphus spp	0.1	1	1
Fangtooth	1.0	1	1
Finless flounder	2.8	3	3
Four-rayed rattail	74.7	999	12
Fusitriton magellanicus	0.0	1	1
Ghost shark	5.2	3	3
Giant chimaera	4.3	1	1
Giant lepidion	58.4	9	3
Giant stargazer	9.0	1	1
Gorgonocephalus spp	0.1	1	1
Guttigadus globiceps	0.4	1	1
Hake	1 268.4	251	40
Hoki	1 252.1	546	40
Humpback rattail	7.2	9	6
Javelin fish	1 525.3	2 584	39
Jellyfish	0.4	4	2
Johnson's cod	5 557.4	3 168	43
Kaiyomaru rattail	5.5	62	4
Lantern fish	0.2	2	1
Large scaled blackchin	0.1	1	1
Leafscale gulper shark	116.1	14	10
Lighthouse fish	0.2	2	2
Ling	70.1	15	12
Longnose velvet dogfish	577.3	362	30
Long-nosed chimaera	8.4	6	2
Longnosed deepsea skate	15.0	1	1
Lookdown dory	3.1	5	5
Lucifer dogfish	0.6	2	1
Mahia rattail	24.0	67	17
Mirror lanternfish	0.1	2	2
Nezumia namatahi	0.4	2	3
Notable rattail	33.5	416	29
Orange roughy	1 161 015.6	755 183	57
Ostenfeld's lanternfish	0.0	1	1
Pale ghost shark	24.3	20	12

Common name	Weight (kg)	No. caught	No. stations
Pointynose blue ghost shark	7.0	1	1
Polychelidae	0.1	3	2
Prawn	0.1	1	1
Psychrolutes	2.1	1	1
Rattails	14.1	3	2
Ribaldo	6 722.1	4 723	45
Ridge scaled rattail	23.1	23	10
Roughhead rattail	42.4	143	11
Rudderfish	0.9	1	1
Seal shark	68.3	10	7
Serrulate rattail	42.3	233	29
Shovelnose spiny dogfish	909.4	325	43
Siboga sea pen	0.1	1	1
Silver roughy	0.1	1	1
Smallscaled brown slickhead	0.9	3	1
Smooth headed rattail	0.1	1	1
Smooth oreo	146.3	243	18
Smooth skin dogfish	55.3	15	6
Southern loosejaw	0.1	1	1
Spiky oreo	969.2	1 455	38
Spineback	10.4	34	13
Squaretail	1.0	1	1
Tam O' shanter urchin	0.1	1	1
Thin tongue cardinalfish	0.4	5	1
Toadfish	3.0	1	1
Tubeshoulder	2.9	2	1
Umbrella octopus	1.1	3	2
Unicorn rattail	8.2	3	2
Unidentified	1.6	2	1
Upturned snout rattail	0.8	4	2
Violet cod	15.3	40	18
Violet squid	1.0	1	1
Viper fish	0.4	3	2
Warty squid	714.2	192	31
White rattail	146.6	67	12
Widenosed chimaera	44.5	9	5

9. APPENDIX C. THEMATIC MAPS OF ACOUSTIC BIOMASS SURVEYS

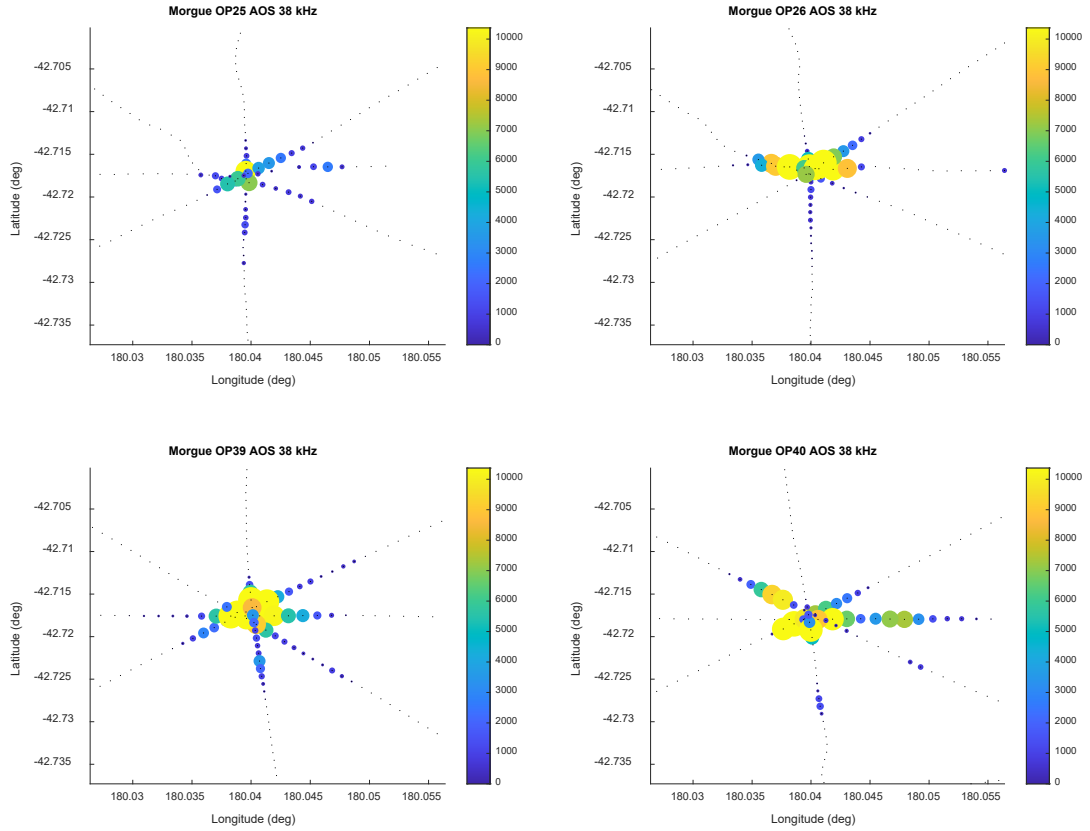

Figure 49: Map of biomass surveys at Morgue with circle size indicating backscatter (NASC) value for each echo integration interval. Bubble size is scaled by the largest NASC value observed across all four surveys to enable comparison between surveys. Colour bar indicates NASC values.

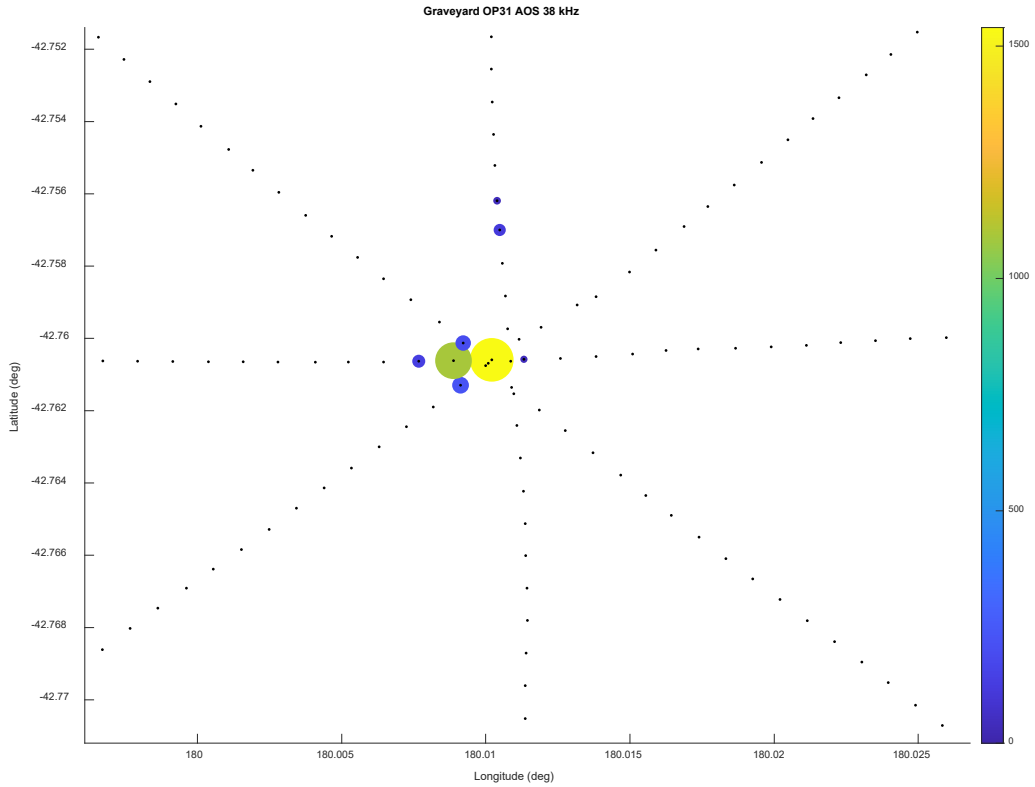

Figure 50: Map of biomass surveys at Graveyard with circle size indicating backscatter (NASC) value for each echo integration interval. Bubble size is scaled by the largest NASC value for the surveys. Colour bar indicates NASC values.

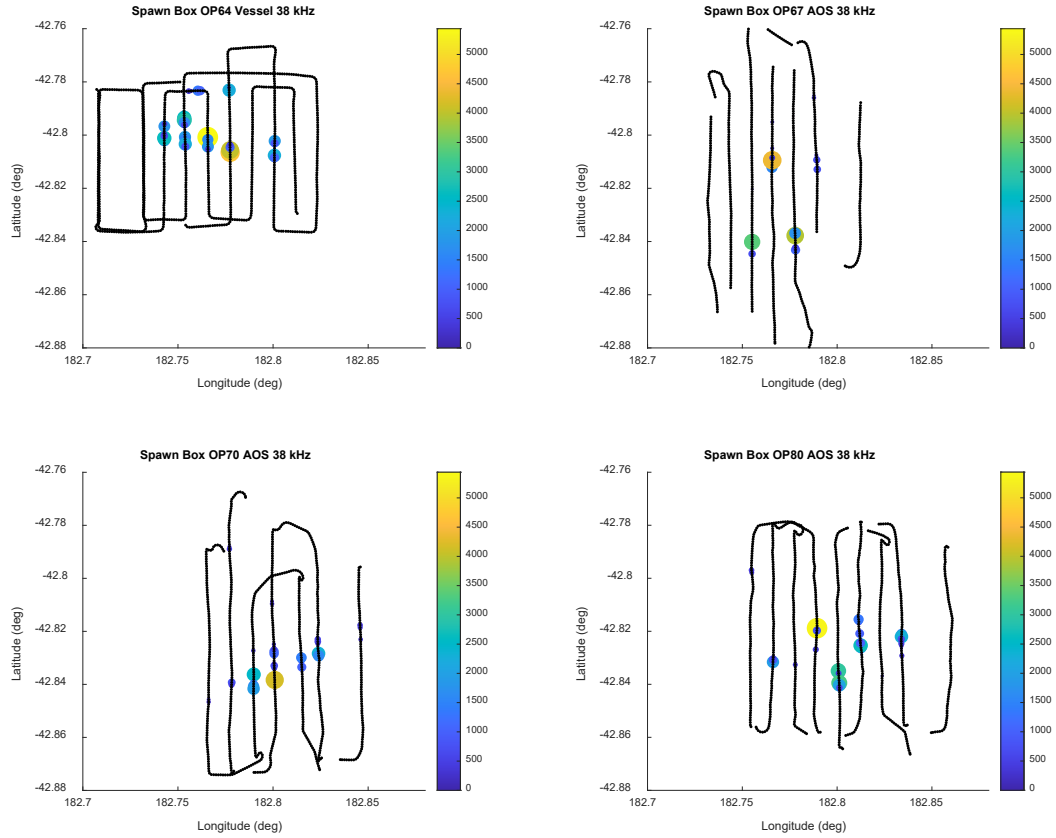

Figure 51: Map of biomass surveys at Spawn Plume with circle size indicating backscatter (NASC) value for each echo integration interval. Bubble size is scaled by the largest NASC value for the surveys. Colour bar indicates NASC values.

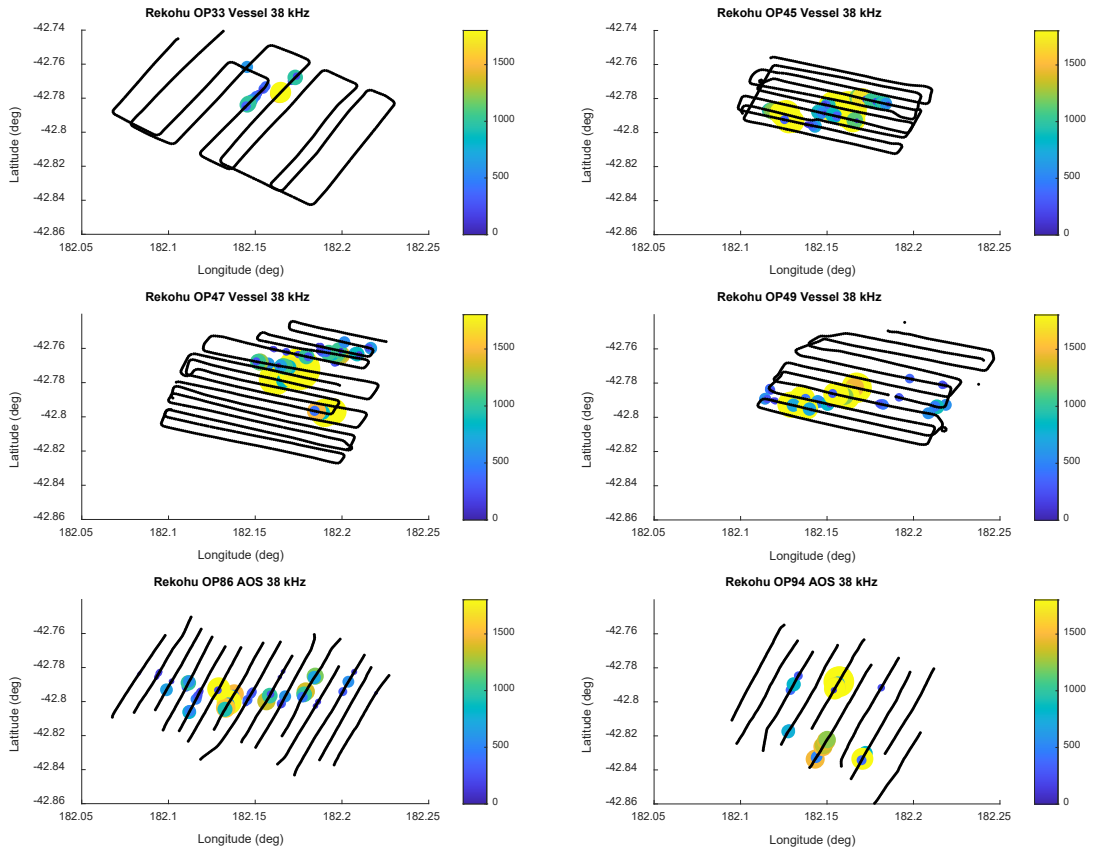

Figure 52: Map of biomass surveys at Rekohu with circle size indicating backscatter (NASC) value for each echo integration interval. Bubble size is scaled by the largest NASC value for the surveys. Colour bar indicates NASC values.

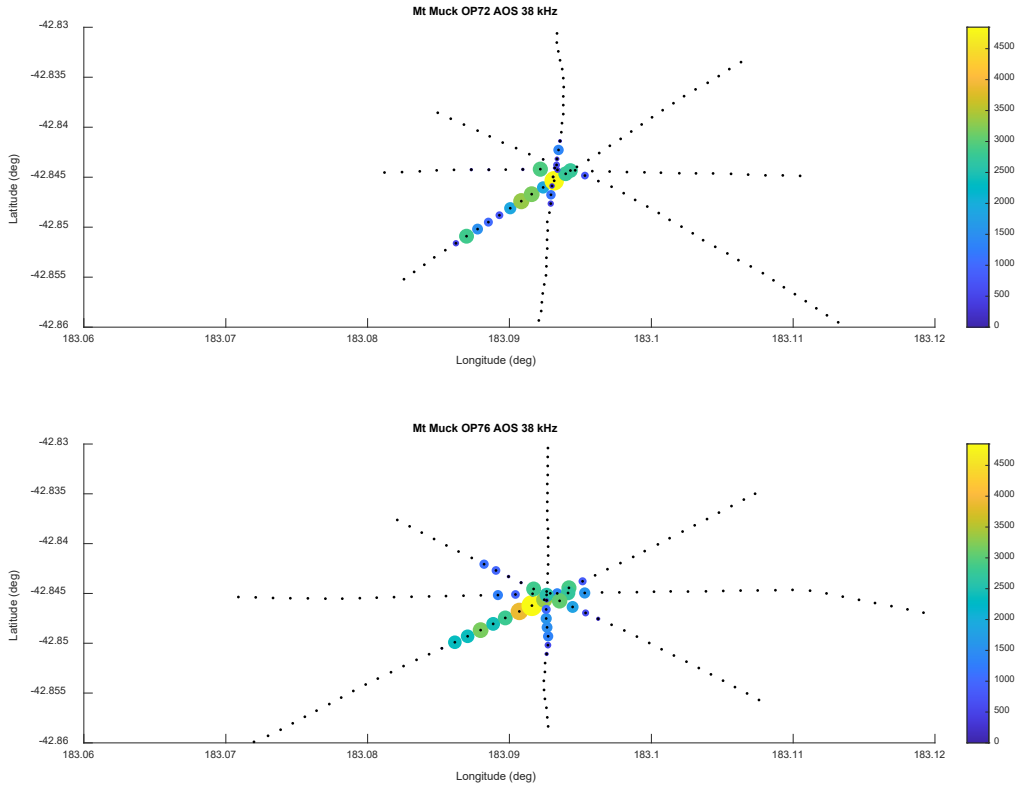

Figure 53: Map of biomass surveys at Mt Muck with circle size indicating backscatter (NASC) value for each echo integration interval. Bubble size is scaled by the largest NASC value for the surveys. Colour bar indicates NASC values.