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Acoustic biomass surveys of orange roughy in ORH 3B North Chatham Rise, June/July 2021

New Zealand Fisheries Assessment Report 2023/45

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Overview

An acoustic survey programme of the North Chatham Rise orange roughy (*Hoplostethus atlanticus*) spawning grounds was conducted between the 4th and 8th of July 2021 on the *Amaltal Apollo*. The voyage departure was delayed due to engine issues that emerged during the voyage forcing an early return to port. Consequently, survey priorities needed to be refocussed. A comprehensive series of Acoustic Optical System (AOS) surveys were completed at Morgue, the location of highest orange roughy biomass on the North West Chatham Rise. The vessel issues meant that only limited survey efforts were possible at the nearby Graveyard. Just one AOS survey at Rekohu on the East Chatham Rise was possible before the survey programme ceased. Fortunately, the *San Waitaki* and *Amaltal Mariner* were able to conduct opportunistic vessel-based acoustic surveys at Rekohu and Spawn Plume in addition to their commercial fishing activities.

Morgue

Three high quality AOS surveys were completed at Morgue. One successful target identification trawl with a 5.5 tonne catch was achieved at Morgue where the vast majority (89%) of the orange roughy were males and these were mainly in spawning/partially spent and spent condition. Female gonads were predominantly in spawning/partially spent condition. Biomass estimates ranged from 13 481 to 19 837 tonnes. These can be compared with the 2016 estimates that ranged from 12 000 to 15 000 tonnes. Despite the compressed survey period of 36 hours, it appears that our surveys had quantified the Morgue orange roughy during their peak spawning period. These results are considered suitable for inclusion in a stock assessment.

Graveyard

At the nearby Graveyard feature, a vessel-based acoustic survey observed a modest aggregation with a single-pass AOS transect confirming the aggregation was that of a large non-gas bladder species, almost certainly orange roughy. Technical issues with the vessel's newly installed ES80 echosounder meant that a vessel-based biomass estimate was not possible at this location. The biomass would be expected to be quite small compared with that of Morgue as the aggregation only had moderate backscatter and did not occupy a large area.

Rekohu

One AOS survey and one vessel-based survey conducted by *Amaltal Mariner* at Rekohu estimated biomasses of 6466 and 12 543 tonnes, respectively. The limited survey effort might have meant that the peak biomass was not captured and explain why the 2021 estimates are lower than the 10 000 to 45 000 tonnes measured in 2016. A full survey programme will be needed to properly establish the current status of the Rekohu orange roughy population. Given the limited survey programme these results are not proposed for use in a stock assessment.

Spawn Plume

A single vessel-based acoustic survey carried out at the Spawn Plume by *San Waitaki* on the 16th of July 2021 was suitable for biomass estimation. A biomass of 35 155 tonnes was estimated. Given the limited survey programme this result is not proposed to be used in a stock assessment. Nevertheless the survey indicated a large biomass was present and had persisted beyond the peak spawn period. Contrary to the Rekohu results, the 2021 estimate for the Spawn Plume was higher than those of 2016: the one

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2021 vessel-based biomass estimate was a factor of 3.5 higher than 2016 vessel-based estimates and factor of 2 higher than the highest AOS 38 kHz from 2016. It is possible that the lower biomass at Rekohu and higher biomass at Spawn Plume are due to a shift between the two locations separated by only 30 n. miles. As per Rekohu, a full survey programme will be needed to establish the current status of the Spawn Plume orange roughy population.

1. INTRODUCTION

A programme of acoustic surveys on the North Chatham Rise (ORH 3B North West Chatham Rise (NWCR) and ORH 3B East & South Chatham Rise (ESCR)) orange roughy was planned to take place between the 24th of June to the 18th of July 2021 aboard the fishing vessel *Amaltal Apollo,* which was under full charter to the Deepwater Group. Additionally, the voyage was to include a pilot exercise to survey selected benthic features using a deep-towed camera system. Due to delayed dry-docking of the survey vessel, the sailing date was postponed by four days to 28th June. Departure was further delayed to allow a strong weather front to move through and to resolve an over-heating issue with the main engine. *Amaltal Apollo* arrived at the Morgue/Graveyard complex in NWCR to commence survey activities on 4th July 2021. Mechanical issues forced the survey to be curtailed on 8th July 2021. The consequence of these delays and early exit were that survey activities needed to be re-prioritised and the full programme could not be completed by *Amaltal Apollo*. As a contingency, two vessels of opportunity, *Amaltal Mariner* and *San Waitaki,* were requested to conduct vessel-based acoustic surveys on the East Chatham Rise aggregations at Rekohu and Spawn Plume for potential use in biomass estimation.

A summary of the planned survey programme and objectives follows.

Vessel: FV *Amaltal Apollo* (ID 62373)
Survey area: North Chatham Rise (ORH 3B NWCR and ORH 3B ESCR)

On site survey period: 4th July to 8th July 2021 [Depart Nelson 1st July, return 11th July]. Vessel returned early ahead of planned 24th July completion date due to main engine issues.

Key Personnel:

- Project Proponent – George Clement (Deepwater Group Ltd)
- Principal Investigator/Voyage Leader – Tim Ryan (CSIRO)
- Vessel Management – Andy Smith (Talley's Group Ltd)
- Biological sampling and survey management – Rob Tilney (Thalassa).

Research survey objective:

To obtain estimates of orange roughy spawning biomass in ORH 3B NWCR and ORH 3B ESCR as scheduled in 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 an Acoustic Optical System (AOS) and a hull-mounted acoustic system.
- To undertake mark identification trawls on aggregations to collect the biological information required to inform the acoustic data and to collect otolith samples for population age structure determination.

Ancillary objectives:

- To undertake towed camera transects of the seabed on key Underwater Terrain Features (UTFs) to map the nature and extent of their benthic biodiversity.
- To trial CSIRO's new modular AOS to test for operation, noise performance, optimise camera settings for image quality, and measure fish target strength (TS) using new wide-beam transducers.
- To use CSIRO Modular AOS to measure TS of aggregated basketwork eels at Smith's City along with biological measures of length, gonad stage, sex, and swimbladder cavity. Collect tissue samples from up to 50 basketwork eels for genetic analysis.

This report presents the acoustic-based biomass estimates and associated biological sampling results for the 2021 Chatham Rise spawning season. Results from the *Amaltal Apollo* Acoustic Optical System (AOS) surveys and those vessel-based acoustic surveys conducted by *Amaltal Mariner* and *San Waitaki* are provided. The limitations of the survey results are discussed with respect to timing and in terms of the inherently higher uncertainty of vessel based acoustic surveys. The Ancillary objectives were not achieved due to the reduced survey duration and are not discussed further. A summary of survey activities is provided in Table 1.

Table 1: Summary of acoustic surveys and biological sampling.

Location	Completed surveys	Comment	Intended
NWCR Morgue	3 AOS surveys (4th – 5thJuly 2021). 3 off-the-seabed ID trawls (73 kg, 115 kg, and 5500 kg).	High quality, large stable aggregation.	4 AOS surveys.
NWCR Graveyard	1 vessel survey (5thJuly 2021). 1 AOS single pass for species ID.	Weak aggregation, high quality vessel acoustics. Single AOS pass multifrequency acoustics confirmed ORH. Issue with new ES80 system found post-voyage prevented biomass estimation.	2–4 AOS and/or vessel surveys.
Other locations NWCR	None.	Time constraints prevented exploration of other locations.	Scout around nearby features in between Morgue and Graveyard surveys.
ESCR Rekohu	1 AOS survey. 1 Trawl. 2 vessel acoustic surveys, one each by *Amaltal Mariner*, *San Waitaki*.	One AOS survey suitable for biomass, difficult conditions and very long survey (22 hr). One *Amaltal Mariner* vessel-based survey suitable for biomass estimation.	4 AOS surveys, multiple trawls to track spawn progression.
ESCR Spawn Plume	One *San Waitaki* vessel-based survey in calm conditions, extensive orange roughy. 7 *Amaltal Mariner* surveys at Spawn Plume. When weather was good no ORH found, some good marks surveyed during poor weather with quality unsuitable for biomass estimation.	Only the *San Waitaki* vessel-based survey was suitable for biomass estimation.	4 AOS surveys plus extra vessel surveys as conditions allow. Multiple trawl shots to track spawn progression.
ESCR Mt Muck	None.		2–4 AOS surveys + multiple trawls.

A summary of all survey activities is provided in Appendix B.

2. METHODS

2.1 Equipment

2.1.1 Acoustic Optical System deployed from *Amaltal Apollo*

The Sealord Acoustic Optical System (sAOS) was the primary survey tool for estimating biomass using echo integration methods. It consisted of a sled-style platform that attaches to the headline of the vessel's demersal trawl net (Figure 1).

This system was built as a collaborative project involving Sealord and CSIRO starting in 2012 based on previous successful developments and applications by CSIRO in Australia and New Zealand (Kloser & Ryan 2011, Kloser et al. 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 2.

Table 2: 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, 25 mm focal length Distagon F mount Lens. Quantum Trio strobe.
Reference scale	Two Laserex LDM-4 635 nm 8 mW red lasers set 400 mm apart.
Environmental	Seabird SBE37si CTD.
Computing	Industrial 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.

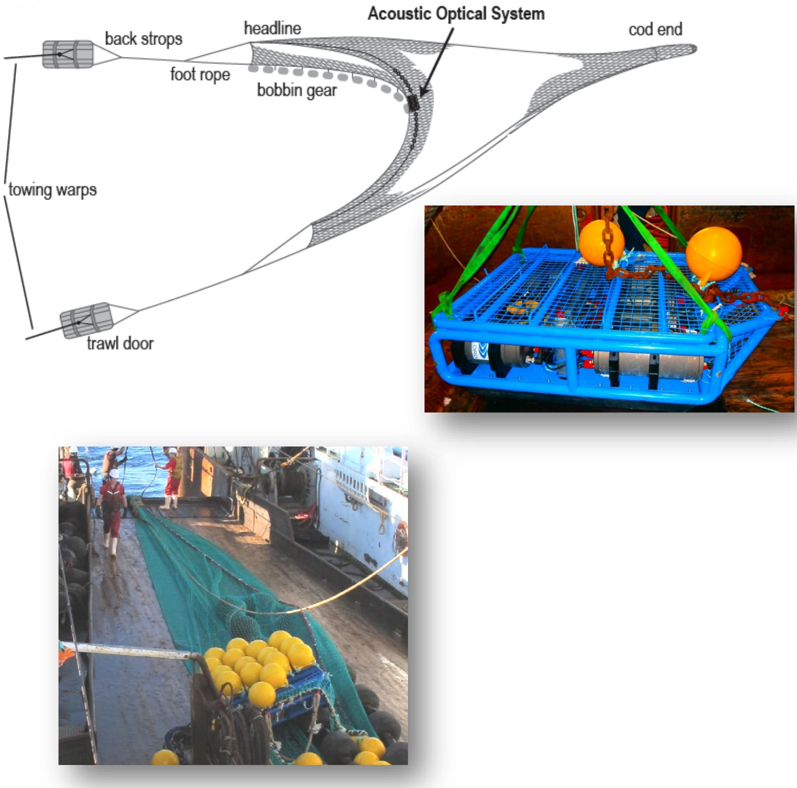


Figure 1: Sealord NZ Acoustic Optical System with conceptual diagram of its attachment to the headline of the demersal trawl net and the system in the trawl net on the back deck.

2.1.2 AOS operational modes

The demersal trawl 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 as summarised in Table 3.

Table 3: Summary of AOS deployment modes.

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

Mode 1: Echo-integration surveys

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

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

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

2.1.3 AOS calibration

Calibration of the 38 and 120 kHz echosounder on the sAOS was attempted off the East Coast of Tasmania in April 2021 during a dedicated trials voyage aboard the MV *Bluefin*. To do this, the AOS was lowered to 1000 m from the vessel's trawl warp. The purpose of calibrating the system through a range of depths is to characterise depth-related changes in echosounder gain that can be significantly different than calibration of the system at the surface. A 38.1 mm tungsten carbide sphere was suspended ~ 20 m beneath the platform by a monofilament line. The acoustic data were recorded internally with no real-time information on sphere location available during the calibration. The lowering was paused at 100-m intervals to allow collection of multiple returns from the calibration sphere. Tide and currents can mean that the calibration sphere might be outside the footprint of the narrow beam transducers. To improve the chances of the sphere being within the acoustic beam the sAOS platform was raised up and down by ~ 0–20 m when at each 100 m depth to swing the sphere at some point through the beam. An issue with the 120 kHz transceiver's power supply was identified and resolved after the calibration was complete. There was no opportunity to re-deploy the sAOS to complete the 120 kHz calibration. For this reason, historical 120 kHz echosounder calibration results, from a July 2017 survey using the sAOS, were used. The sAOS 38 kHz echosounder was successfully calibrated. This is the key instrument from which the biomass estimates are made for application in the stock assessment model.

The calibration data were analysed to provide primary calibration values for Gain and S_A correction at the average working depth of the sAOS platform (Table 4). However, as the sAOS moves along a transect line, the platform depth will deviate above and below the average depth. As the Gain may change with depth this will have a small effect on calibration. Hence a secondary correction is applied to each along-transect echo-integration interval based on a polynomial relationship between Gain and SA as a function of platform depth (Table 5, Table 6).

Table 4: Calibration parameters for AOS 38 kHz and 120 kHz echosounders for Mode 1 echo-integration surveys. Values marked in bold text were applied to the data in Echoview post-processing software.

System	AOS	AOS
Frequency (kHz)	38	120
Calibration data set	April 2021	8th July 2017
Transducer model	Simrad ES38DD	Simrad ES120-7CD
Serial Number	28363	115
Transceiver power (W)	2000	300
Transceiver pulse length (ms)	2.048	1.024
Transducer gain (dB)	23.86	28.09*
Sa correction (dB)	-0.48	-0.3*
Two way beam angle (dB re 1 steradian), adjusted for local conditions	-20.72	-20.25

* 120 kHz results based on calibration done on 08th July 2017 for 500W, 1.024 ms.

Table 5: Secondary correction parameters for 38 kHz echosounder where *x* is the platform depth.

$$p(x) = p_3x^3 + p_2x^2 + p_1x + p_0$$

Combined down and up casts				
	p_3	p_2	p_1	p_0
Transducer on-axis gain (G_0)	7.10273e-11	-1.3398e-06	0.000852869	23.8171
s_a correction factor ($S_{a\,\mathrm{corr}}$)	-1.4156e-09	3.04754e-06	-0.00191463	-0.118596

Table 6: Secondary correction parameters for 120 kHz echosounder where *x* is the platform depth.

$$p(x) = p_3x^3 + p_2x^2 + p_1x + p_0$$

Combined down and up casts				
	p_3	p_2	p_1	p_0
Transducer on-axis gain (G_0)	1.43445e-09	-2.79754e-06	0.00160241	27.8321
s_a correction factor ($S_{a\,\mathrm{corr}}$)	-7.89063e-10	5.32988e-07	5.09443e-05	-0.354276

2.1.4 Acoustic instruments — vessel mounted

Three vessels participated in this survey programme. *Amaltal Mariner* and *San Waitaki* came into the survey programme following the early exit of *Amaltal Apollo*. All three vessels had either Simrad ES70 or ES80 38 kHz commercial fisheries echosounders that can record the acoustic data to allow transect surveys to be conducted. Furuno FCV30 echosounders are also installed on these vessels. These echosounders use the same frequency as the Simrad 38 kHz systems and will cause interference if they are operated at the same time. To avoid this issue, the FCV30 was turned off during formal acoustic transect surveys. *Amaltal Mariner* and *San Waitaki* were fishing at Rekohu and Spawn Plume, both relatively flat and featureless locations where orange roughy may aggregate over large areas. For these reasons a grid-transect survey design was considered most appropriate. The ships' officers on both vessels conducted opportunistic parallel transect surveys when extensive aggregations were located and weather conditions allowed. The survey patterns were devised by the ships' officers following basic guidelines to maintain a minimum transect spacing (0.3 n.mile) and to endeavour to bound the aggregation within the survey area by ensuring the outermost transect lines had no significant schools.

2.1.5 Vessel calibrations

The Simrad 38 kHz echosounders on the three participating vessels were calibrated using the suspended sphere method (Table 7). *Amaltal Apollo* conducted one vessel-based acoustic survey during the survey voyage, but analysis of the calibration data found that the beam pattern shape was compromised such that quantitative measurements were not possible.

Table 7: Summary of vessel calibrations.

Vessel	Acoustic systems	Calibration	Comments
Amaltal Apollo	Simrad ES80 38 kHz, Furuno FCV 30 multibeam echosounder	11th July 2021, Tasman Bay	Phase-issue with newly installed Simrad ES80 echosounder identified when post-processing calibration data. This issue caused the beam pattern to be oval-shaped instead of the expected circular shape. **Consequently vessel-based acoustic surveys by *Amaltal Apollo* cannot be used for quantitative biomass estimation.** FCV 30 turned off during transect surveys.
San Waitaki	Simrad ES80 38 kHz, Furuno FCV 30 multibeam echosounder	2nd February 2022, Timaru.	FCV 30 turned off during transect surveys. Calibration conducted at 1.024 ms, survey data were collected at 2.048 ms. Correction factor estimated to allow application of these calibration results (see Appendix A).
Amaltal Mariner	Simrad ES60 38 kHz running ES80 software, Furuno FCV 30 multibeam echosounder		FCV 30 turned off during transect surveys. Calibrations conducted at 1.024 ms, data were collected at 2.048 ms. Correction factor estimated to allow application of these calibration results (see Appendix A).

2.1.6 Vessel calibration parameters

With *Amaltal Mariner* and *San Waitaki* coming late into the survey programme and delays in post-voyage calibration, our workflow was to first calculate biomass using nominal values then follow up with correction factors to arrive at the final biomass estimates. Two correction factors were required. The first correction factor (cf_1) adjusted for the difference between nominal values of Gain and Sa correction and post-voyage calibration results that were obtained using the standard sphere method (Demer et al. 2015). In the case of *San Waitaki*, Simrad default nominal values were used for initial biomass estimation. For *Amaltal Mariner* initial biomass estimates, Gain and Sa correction values from a previous calibration were used. Unfortunately, both vessels recorded field data at 2.048 ms pulse duration, whereas post voyage calibrations were conducted at 1.024 ms. A second correction factor (cf_2) was needed to account for the consequent effect on calibration. To do this we reviewed our historical calibration database to find instances where any vessels had been calibrated at both 1.024 ms and 2.048 ms in a single outing. For each calibration outing, the differences in Gain and Sa correction for the two pulse durations were combined to give a single offset factor. The mean of the offset factors from multiple calibrations provided a best estimate for cf_2. *Amaltal Mariner* has a different transducer model than *San Waitaki*. Hence this exercise had to be done for each of the transducer models. Calibration parameters used for initial calibration of biomass are provided in Table 8. The correction factors applied to the initial biomass to arrive at a final biomass are provided in Table 9. Biomass estimates from *San Waitaki* and *Amaltal Mariner* surveys have the combined correction factor (cf_1 x cf_2) applied. A full description of how the calibration factors were derived is provided in Appendix A.

Table 8: Calibration parameters applied to initial estimates of biomass and calibration results for 1.024 ms pulse duration.

Vessel	*Amaltal Mariner*	*San Waitaki*
Frequency (kHz)	38	38
Calibration data set	June 2019	2nd February 2022
Transducer model	Simrad ES38B	Simrad ES38-7
Serial Number	Unknown	
Transceiver power (W)	2000	2000
Transceiver pulse length (ms)	2.048	2.048
Transducer gain (dB)	27.04*	25.5*
Sa correction (dB)	-0.29	0
Two-way beam angle (dB re 1 steradian), adjusted for local conditions	-20.7**	-20.7**

* Gain values for calibrations carried out at 1.024 ms pulse duration were applied to the field data collected at 2.048 ms.
** Factory transducer test report cannot be located. Using nominal values.

Table 9: Application of correction factors cf_1 and cf_2 to respectively apply the calibration results for 1.024 ms pulse duration and to translate a correction to the surveys carried out at 2.048 ms pulse duration.

Location	Vessel	cf_1	cf_2	combined correction factor (cf_1 x cf_2)
Rekohu	*Amaltal Mariner*	1.128	0.893	1.008
Spawn Plume	*San Waitaki*	0.866	1.07	0.927

2.2 AOS acoustic data processing

Processing of the sAOS acoustic data was done using Echoview 11 analysis software. Custom Matlab tools were used to extract and process platform depth and motion data that were embedded in the Simrad EK60 raw files. Platform depth data were applied to the towed body operator in Echoview to create echograms with an absolute depth reference. The AOS platform motion was recorded at 10 Hz by a Microstrain 3DM-GX25 motion reference sensor. These data were applied to the Dunford (2005) operator that corrects for signal loss due to platform motion.

2.2.1 Echogram scrutiny and quality control

Calibration offsets as per Table 4 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 the acoustic signal cannot be measured due to the physical characteristics of the transmitted pulse (Ona & Mitson 1996) and, on sloping ground, due to seafloor backscatter from off-axis, side-lobe signal coinciding with water column backscatter (Kloser 1996, Ona & Mitson 1996). For the steep-sided features the contribution to the dead zone due to the sloping ground was by far the greater effect. Orange roughy are a semi-demersal species that can occur at high densities within the dead-zone region requiring an estimate to account for this biomass component. Previous acoustic observations of orange roughy schools suggest that scenarios of an increased and decreased density within the dead-zone region are both possible. It was assumed that the density of fish immediately above the acoustic bottom was on average representative of the density within the dead-zone region. An estimate of backscatter within the dead zone was made as follows. Firstly an 'acoustic seafloor' line was defined, that is the point at which the water column signal became contaminated with the seafloor reflection signal. The acoustic seafloor line was first generated via the maximum S_v seafloor detection algorithm implemented in Echoview. A back-step of 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 for seawater absorption at 38 and 120 kHz and sound speed were calculated from the equations of Francois & Garrison (1982) and Mackenzie (1981), respectively, for a nominal platform depth of 600 m and fish school depths of 900 m, using measured values of temperature and depth data recorded during the AOS deployments (Table 10) and a nominal salinity value of 34.5 ppt. Use of a nominal salinity value was necessary due to a fault with the CTD instrument. Absorption is highly sensitive to temperature but far less so to salinity. Hence the use of a nominal value as against measured value will have minimal effect. 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 absorption and sound speed values were applied to the data in Echoview post-processing software. A secondary adjustment was made to the echo-integrated data to account for changes in absorption due to the combination of the platform deviating above and below the nominal depth and changes of the range to the fish schools.

Table 10: **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	0.034376
Sound speed (m/s)	1494	1494

2.2.5 AOS Echogram interpretation and allocation of species

Quantitative analysis and subsequent biomass estimation were performed for both 38 kHz and 120 kHz acoustic survey data. Interpretation of the S_v echograms to partition according to species was a key step in this analysis. Echogram interpretation to distinguish between regions of orange roughy and other species considered multiple lines of evidence. Interpretation was primarily guided by visualising the dB difference across frequencies by subtracting 38 kHz S_v values from 120 kHz values (Figure 2). Nominally, regions where mean backscatter was 2–4 dB higher at 120 kHz compared with 38 kHz were attributed to homogenous schools of orange roughy. Consideration was also given to the depth, location, shape, and texture of echogram regions; echogram regions that are dominated by large high-reflectivity gas bladder fish may be inferred from a more heterogeneous 'texture' with higher pixel-to-pixel variability compared with regions of orange roughy. Biological catch composition and inspection of video and Gig-E still images to identify species obtained during Mode 2 operations were also used to support echogram interpretations. The absolute TS values obtained during Mode 2 operations also provided information regarding the presence of species with certain morphologies, e.g., very high TS values indicating the presence of large fish with a gas bladder.

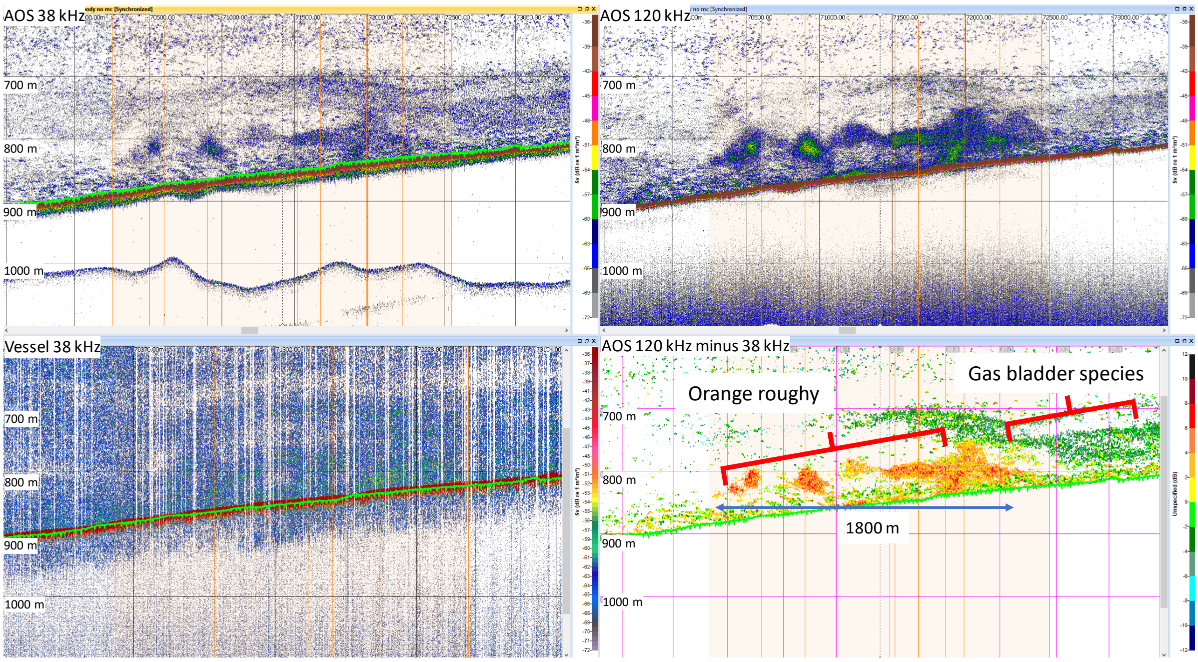


Figure 2: **Example of multifrequency echograms from a Sealord AOS transect at Rekohu in July 2021 (top panels). Bottom left panel shows the echogram from the *Amaltal Apollo*'s 38 kHz echosounder.**

2.3 Vessel acoustic data processing

2.3.1 Echogram scrutiny and quality control

Calibration offsets as per Table 8 were applied to the 38 kHz volume backscattering strength (S_v dB rem^{-1}, Maclennan et al. 2002) echograms. The 38 kHz S_v echograms were visually inspected, and regions of noise interference were 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 sAOS data.

2.3.3 Motion correction

Correction for acoustic signal loss due to motion effects using the Dunford (2005) algorithm requires recording of vessel motion above the Nyquist sampling rate. The *Amaltal Mariner* and *San Waitaki* came into the survey programme late and had not been fitted with motion loggers. Hence correction for acoustic signal loss was not possible. At present the Deepwater Working Group protocol for vessel-based acoustic surveys of orange roughy does not require a direct correction for vessel motion. Instead, a correction factor of 1.33 to the vessel-based acoustic data is applied with the intention to account for signal loss due to the combined effects of surface bubble attenuation and motion.

2.3.4 Seawater absorption and sound speed: Vessel acoustics

Following the Deepwater 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 (Table 11). Absorption estimates used Temperature-Depth Recorder (TDR) values from Morgue recorded by the sAOS and an assumed salinity of 34.5 ppt. The vessel-acoustic surveys by *Amaltal Apollo* and *San Waitaki* were carried out at Rekohu and Spawn Plume. These vessels did not have the means to measure temperature or salinity, whereas our direct measurements of temperature vs. depth were carried out at Morgue, ~ 100 n.mile to the west. Comparison between our temperature measurements at Morgue and CARS oceanographic model data of the Rekohu and Spawn Plume region found only minimal differences (~ 0.2 degree) that could be due to model uncertainty or the differences in the water masses. Irrespective, the small differences in temperature gave confidence that using Morgue TDR data for Rekohu and Spawn Plume absorption calculations is reasonable where the time of year is likely to have the greater influence on temperature. Further, the choice of which equation to use (e.g., 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%. A nominal sound speed value of 1490 m s^{-1} was used for analysis of vessel-based acoustic data.

Table 11: Absorption and sound speed parameters applied to vessel-based 38 kHz acoustic data. Absorption was calculated using the equations of Doonan et al. (2003b).

Parameter	Value
Absorption (dB/m)	0.0086
Sound speed (m/s)	1490

2.3.5 Interpretation of vessel-based echograms

Interpretation of vessel-based echograms is generally more uncertain than deeply deployed multifrequency systems due to there being only a single-acoustic frequency combined with range dependent effects of reduced signal-to-noise, weather attenuation and noise effects, absorption losses, and the larger footprint of the acoustic beam (Kloser 1996). In calm weather and when orange roughy are densely aggregated in large schools, vessel-based echograms can be interpreted with delineation of species achieved with a reasonable degree of confidence. Interpretation can be aided by consideration of the depth, location, and form of the schooling regions where orange roughy can form quite distinct spawning plumes. Trawl-catch information, and the experience of the skipper and/or scientists, 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 highly unreliable and susceptible to positive bias if the high signal from gas bladder species is included. Figure 2, 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 22 shows an example of a vessel-based echogram showing a well-defined school region where data quality is high, as is confidence in interpretation.

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 Rekohu 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 is then completed in the reverse direction offset at half the inter-transect spacing of the first set of transects (Survey B). Survey results are combined by calculating the geometric mean of the biomass estimated from the two sets of transects: Combined biomass = sqrt (Survey A biomass * Survey B biomass). Biomass estimates were calculated for 120 kHz and 38 kHz data acquired from the AOS and at 38 kHz for the vessel acoustic data using standard echo-integration methods (Simmonds & MacLennan 2008).

Orange roughy classified echogram regions were echo-integrated in 100-m intervals to calculate the per-interval nautical area scattering coefficient, S_A (m^2 n.mile^{-2}) (Maclennan et al. 2002). These were averaged to give a mean S_A for the survey region ($\overline{S_A}$). This parameter along with estimates of mean population target strength ($\overline{TS}$, dB re 1 m^2), mean population fish weight ($\overline{W}$, kg) and measurement of survey area (A, n.mile^2) were used to estimate biomass (Equation 1)

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

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).

2.5 Biological sampling

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. Tows were taken into the edges of aggregations to avoid excessively large catches. Catch sensors were positioned on the cod end to trigger at approximately 5 tonnes and catches of around 5–10 tonnes were anticipated per tow. A maximum of three, off-bottom tows were permitted to be undertaken at Morgue, a Seamount Closure area.

3. RESULTS

3.1 The survey programme

This survey programme used *Amaltal Apollo* as the main survey vessel. *Amaltal Apollo* was equipped with a Simrad ES80 38 kHz vessel-mounted echosounder and with the net-attached sAOS system as the primary acoustic survey instrument. The vessel carried out targeted trawls with its demersal net to provide biological samples. The *Amaltal Apollo* survey of orange roughy in the ORH 3B North West Chatham Rise region was delayed due to dry-dock delays followed by waiting out a large storm front for ~ 48 hours. The voyage was cut short due to main engine issues forcing the vessel to return to port 13 days early on the 8th of July. Figure 3 shows the voyage track of the *Amaltal Apollo* survey along with those from four previous orange roughy surveys conducted between 2007 and 2016. The survey programme was supported by opportunistic vessel-based acoustic surveys undertaken by the fishing vessels *San Waitaki* and *Amaltal Mariner* that provided this assistance in response to the shortened *Amaltal Apollo* survey. Table 12 summarises the on-ground survey dates of the three participating vessels.

Table 12: Summary of survey activities by three participating vessels.

Vessel	Survey dates	Locations
Amaltal Apollo	4th to 8th July 2021	Primarily Morgue, one AOS survey at Rekohu and brief vessel-based scoping at Spawn Plume before returning to port
San Waitaki	7th July to 16th July 2021	Rekohu and Spawn Plume
Amaltal Mariner	4th July to 8th July 2021	178° W, Rekohu and Spawn Plume

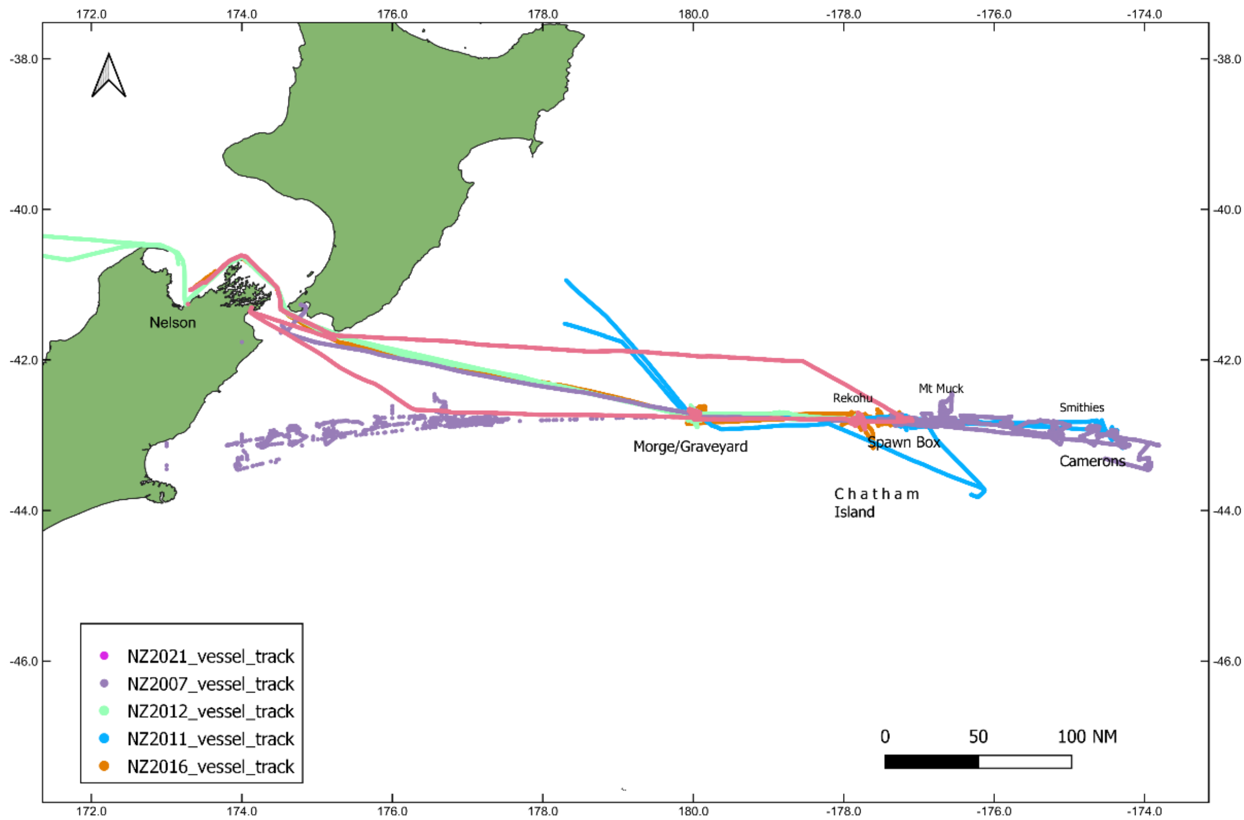


Figure 3: Survey tracks of the 2021 (magenta) and of recent historical surveys on the North Chatham Rise.

3.2 Morgue-Graveyard Complex North West Chatham Rise

(2021-07-04 11:35 to 2021-07-05 10:54)

The 180° hills on the North West Chatham Rise comprise a dozen-or-so underwater topographic features, with Morgue and Graveyard being the largest and historically the locations of highest spawning orange roughy abundance (Figure 4). Accordingly, Morgue and Graveyard were planned to receive the most attention in the original survey design but with excursions to surrounding features to determine if they too had spawning orange roughy. With the departure delays, survey activities were adapted to focus solely on Morgue and Graveyard with emphasis on the former as the location of highest historical biomass. A 36-hour acoustic and biological survey of Morgue and Graveyard commenced at 1:00 am on 4th July 2021. Weather conditions were calm throughout, providing for high quality vessel acoustics.

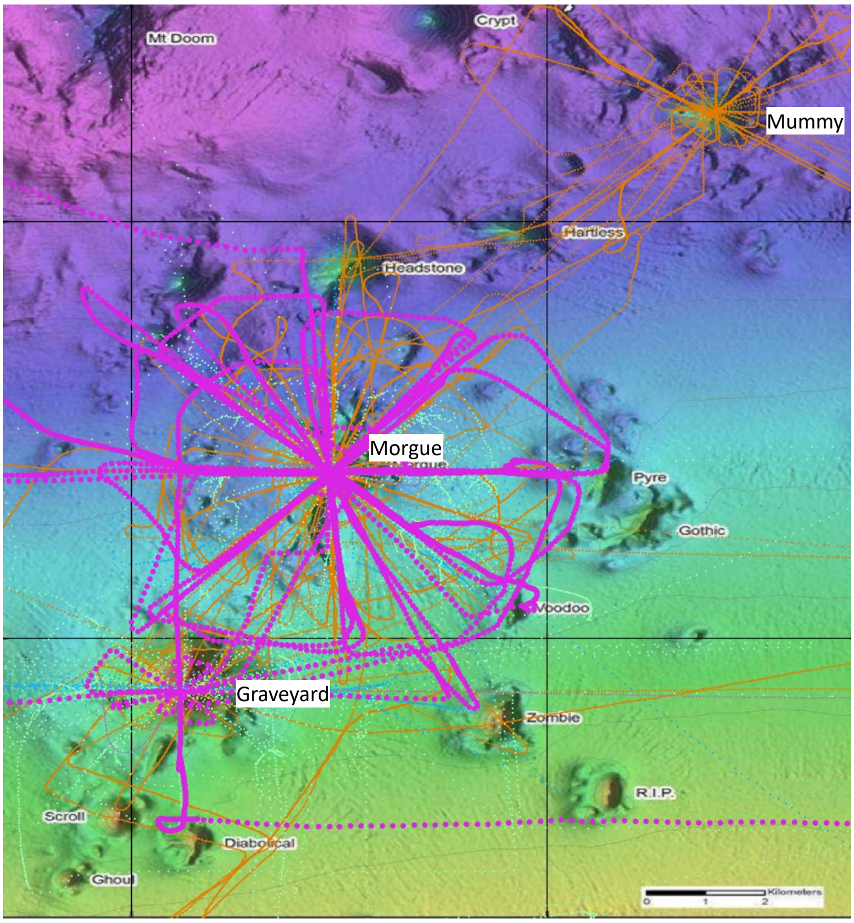


Figure 4: Morgue/Graveyard complex. Magenta lines show the vessel track of *Amaltal Apollo* in 2021. Other vessel tracks are from various survey activities in 2011, 2012, and 2016.

3.2.1 Morgue

3.2.1.1 Acoustic surveys

Three high quality AOS surveys were completed on Morgue, where a large and relatively stable aggregation persisted throughout the survey period. The nature of the aggregation was very similar to that observed during the 2016 survey (Ryan & Tilney 2017). That is, an extensive and relatively high-signal region of backscatter of typically ~ 1000 m length and 150 m height (Figure 5) was observed on all sectors of the feature. The AOS multifrequency acoustics within the high signal regions measured 120 kHz backscatter at a factor of two or more than the 38 kHz indicating large non-gas bladder species, i.e., orange roughy. A three-dimensional visualisation of all four transects shows that there is a continuous aggregation of fish right around the Morgue feature (Figure 6). A catch of around 5 tonnes from the third and final AOS biological trawl shot permitted here under special permit, along with video and still images (Figure 7), showed high-density orange roughy supporting this interpretation. As seen during the 2016 survey, small regions of extremely high backscatter were observed within the larger aggregations on some but not all transects. These extreme high-signal regions were quite mobile, changing form and location within a short period of time, and are almost certainly not orange roughy. Multifrequency AOS acoustics indicated that these extreme high-signal regions contain large gas bladder species (backscatter approximately the same on both frequencies). The identity of these large gas bladder species remains elusive. Cardinalfish are the most likely candidate as they have high acoustic backscatter and are known to aggregate on the tops of features, while their high mobility makes them difficult to catch.

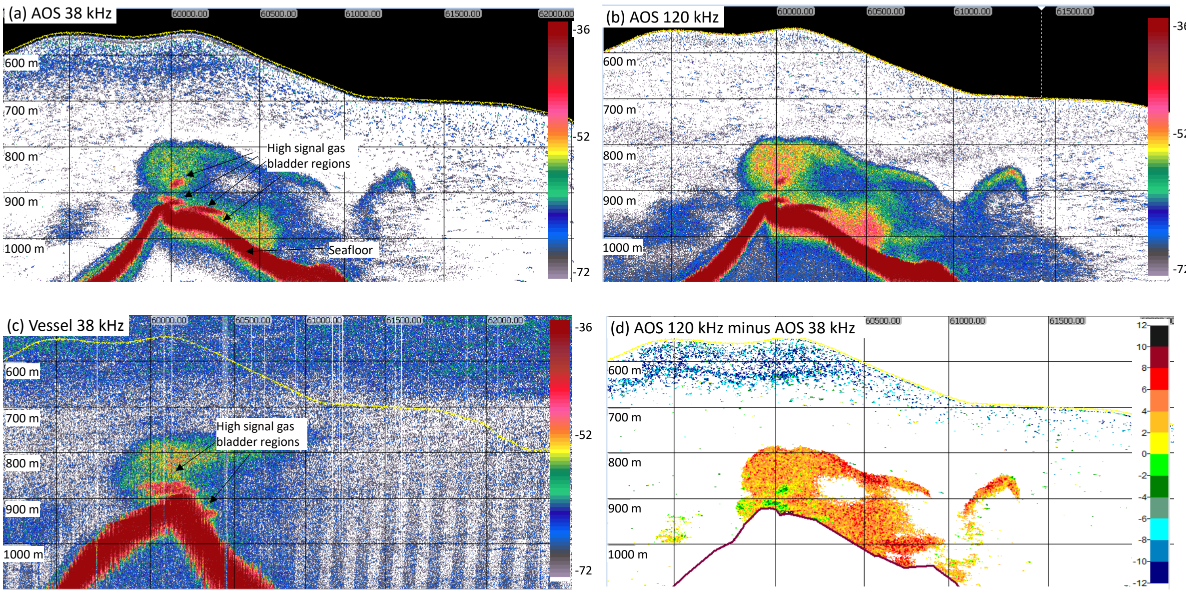


Figure 5: Echograms of a large aggregation of orange roughy, with regions associated with large gas bladder fish, on Morgue. OP2, 4th July 2021 09:40. Legend is shown for colour display range. Panel d shows the subtraction of AOS 38 kHz from AOS 120 kHz echogram data. Pixels that are +2 dB or more (orange–red pixels) indicate regions dominated by non-gas bladder species. Pixels that are around 0 dB (green) indicate regions dominated by large gas bladder species

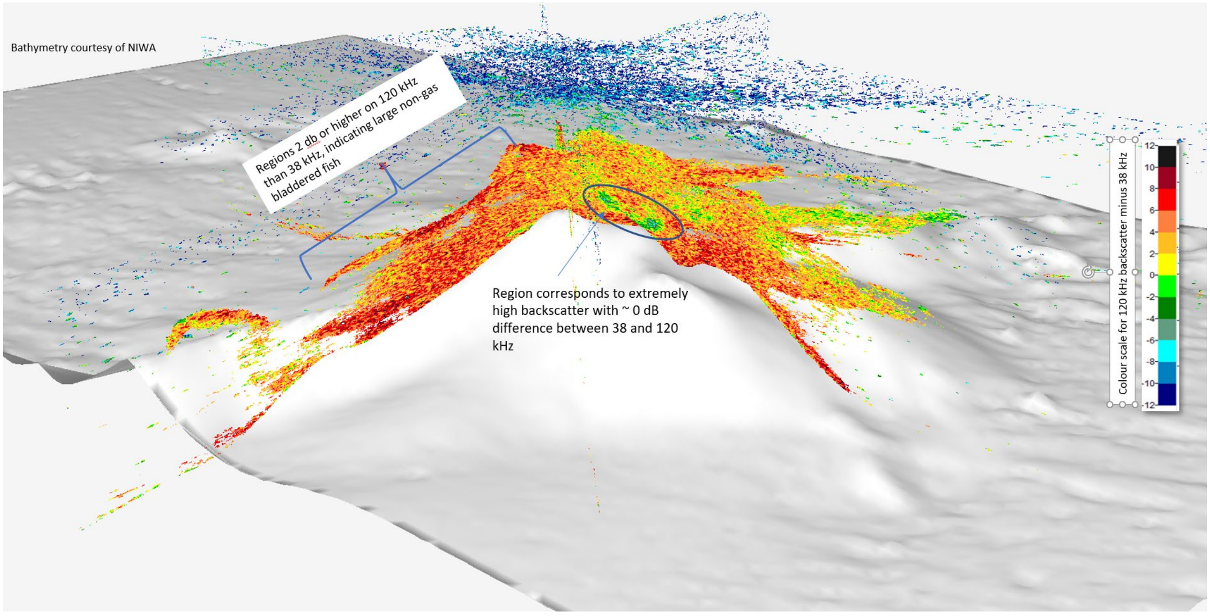


Figure 6: Three-dimensional view of the first AOS survey at the Morgue on 4th July 2021. A synthetic echogram is shown generated by subtraction of 38 kHz backscatter values from 120 kHz. Values of +2 dB or more indicate large non-gas bladder fish.

Figure 7: Image from GigE camera while trawl net was moving through the large aggregation of orange roughy on Morgue (OP7, 2021-07-05 00:43).

3.2.1.2 Biological sampling results

Three trawl tows were undertaken under a special permit arrangement in this Seamount Closure area. The first two tows were ~ 50 m above the seafloor and missed the aggregation, catching only a small quantity of orange roughy (4 kg and 0 kg). During the third tow the footrope was ~ 5 m above the seafloor and caught 5.5 tonnes of which 97% comprised ORH. Also caught were deepwater sharks (2%) and oreo (1%) (Figure 8).

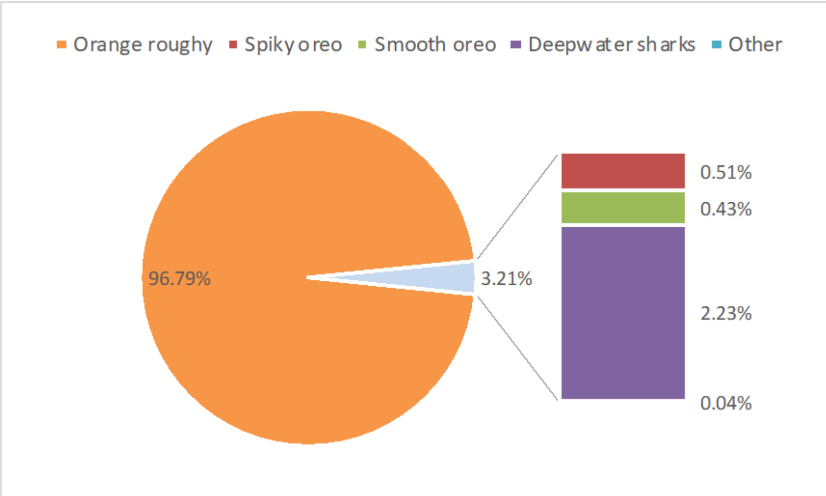
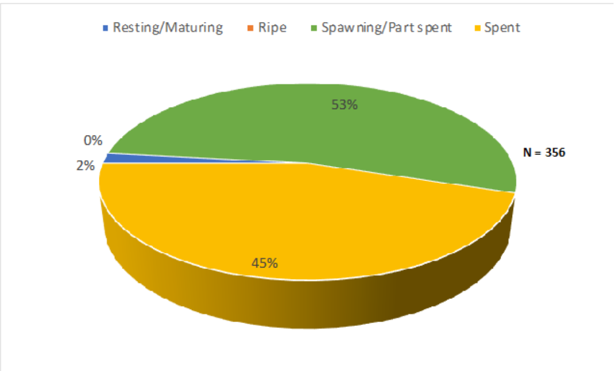


Figure 8: Catch composition on Morgue on 5 July 2021(tow 3 of 3).

The vast majority (89%) of the orange roughy were males and these were mainly in spawning/partially spent and spent condition. Female gonads were predominantly in spawning/partially spent condition (Figure 9).



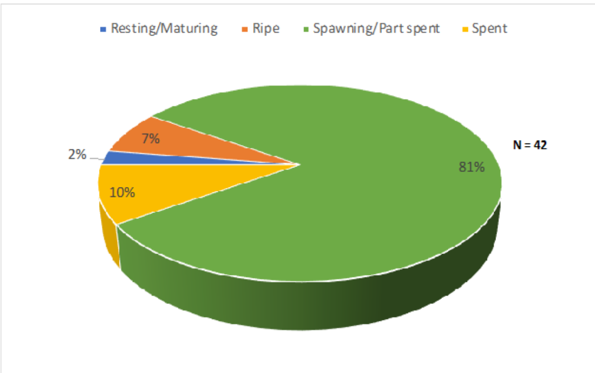


Figure 9: Male (left) and female (right) orange roughy spawning state, Morgue, 5th July 2021.

Average weights for males and females were 1.34 kg and 1.68 kg, respectively. For sexes combined the average weight was 1.37 kg. Mean standard lengths for males and females were 34.1 cm and 36.2 cm, respectively. For the sexes combined the mean standard length was 34.3 cm (Figure 10).

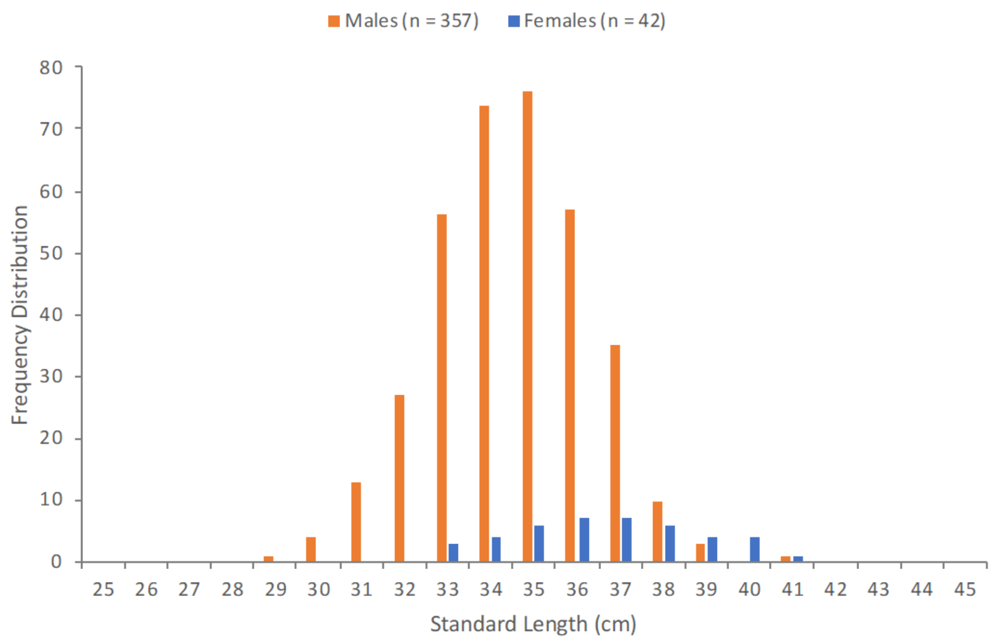


Figure 10: Orange roughy length-frequency distribution on Morgue.

3.2.1.3 Morgue Biomass Estimates

Biomass estimates from three sAOS surveys are provided in Table 13 and visualised in Figure 11.

Table 13: Biomass estimate for Sealord AOS surveys at The Morgue.

Date	Platform & Frequency	OP	Biomass above acoustic bottom (tonnes)	CV	Dead-zone estimate (tonnes, % of total)	Total biomass (tonnes)
04/Jul 03:51	AOS 38 kHz	2	15 780	0.14	4057 (20.5 %)	19 837
04/Jul 04:34	AOS 120 kHz	2	12 091	0.14	3752 (23.7 %)	15 843
04/Jul 12:04	AOS 38 kHz	3	10 807	0.18	2674 (19.8 %)	13 481
04/Jul 12:47	AOS 120 kHz	3	8 639	0.17	2766 (24.3 %)	11 405
05/Jul 04:54	AOS 38 kHz	9	12 610	0.15	3068 (19.6 %)	15 678
05/Jul 05:37	AOS 120 kHz	9	9 802	0.14	2634 (21.2 %)	12 435

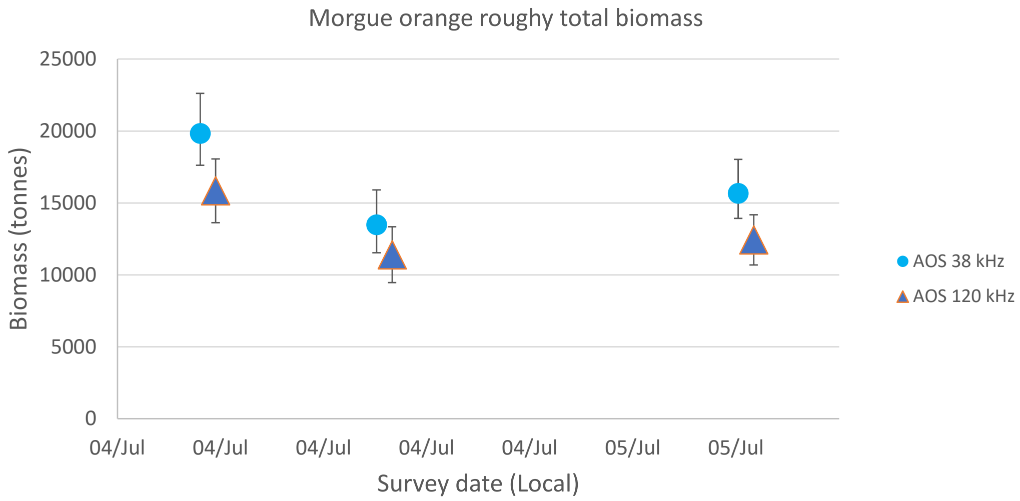


Figure 11: Plot of biomass estimates from Sealord AOS 38 kHz and 120 kHz echosounders. Error bars indicate CV uncertainty of 1 s.d.

3.2.1.4 Morgue discussion

The sAOS 38 kHz biomass results ranged from 13 481 to 19 837 tonnes, including the dead-zone contribution that was consistently around 20% of the total. The relatively high dead-zone component is not unexpected. On steep features such as Morgue the dead-zone height is high which, combined with the high densities of fish above the 'acoustic' bottom, led to the estimated dead-zone biomass being significant. Survey sampling CVs were quite low due to relatively consistent backscatter on all transects resulting in low variance.

The 120 kHz based estimates are included as a second independent measure of biomass. This provides a check on the primary 38 kHz measure using the same basic methods; in principle, estimates from both frequencies should be the same. However, input parameters for each frequency will have their own uncertainties. The 120 kHz biomass estimates used TS and absorption estimates based on that frequency, with calibration parameters measured for a separate echosounder/transducer combination. The 120 kHz frequency has the advantage of having a factor of ~ 2 higher sensitivity to orange roughy and is ~ 10 times less sensitive to confounding contributions from small gas-bladder species (e.g., myctophids). A disadvantage for 120 kHz is that seawater absorption is factor of four greater than at 38 kHz. This means that there will be a higher uncertainty associated with this parameter when estimating biomass. The biomass estimates for 120 kHz were between 20 and 22% lower than for 38kHz which is within the +/- 30 % range reported by Ryan & Kloser (2016). Differences may be due to errors in TS, absorption, calibration for both 38 or 120 kHz, or a combination of these. It is noted that a calibration from July 2017 was used for the 120 kHz echosounder because an updated calibration was not achieved during an April 2021 trials voyage.

Timing of acoustic surveys and context with historical results

Orange roughy spawning progresses through pre-spawning, spawning, and post spawning phases. In past surveys we have observed that aggregations can be more mobile and less available to the acoustics during the lead up to peak spawning (Ryan & Tilney 2017). At peak spawning, and for a period afterwards, aggregations can be more stable. Ideally a survey programme would allow time to monitor the aggregation build-up and conduct surveys during peak abundance. Our arrival at Morgue on 4th July 2021 was five days later than planned. Large aggregations were observed upon arrival and the one successful trawl shot of 5.5 tonnes recorded 81% of females spawning and 10% spent. This suggests that we were past the build-up phase and that surveying was occurring somewhere within the spawning window. The most recent previous survey was in 2016 when there was ample time to observe the build-up and survey at peak abundance. The 2021 biomass estimates might have been less than in 2016 if the surveys were taking place outside peak abundance. However, in 2016, three surveys gave biomass estimates ranging from 12 000 to 15 000 tonnes, while in 2021 estimates ranged from 13 000 to 20 000 tonnes. In summary, the observed stability of the aggregations, the biological sampling, and the higher abundances provide a reasonable degree of confidence that the 2021 surveys quantified biomass within the peak abundance window.

Biological sampling at Morgue

Morgue is a Seamount Closure area, closed to commercial fishing operations. For this survey a special permit was provided by Fisheries New Zealand to allow three off-the-seabed trawls to enable collection of biological samples of orange roughy for the purposes of monitoring their spawning condition and for collection of otoliths for population age-structure determination. Ideally, to obtain representative data, multiple trawl shots of moderate catch (5–10 tonnes) would be spread out over time to enable representative samples of aggregating orange roughy to be collected. At Morgue, good catches have been taken previously under special permits while avoiding bottom contact. However, it is an exacting exercise. If the trawl net is held too far from the seafloor, little or no catch is likely. Conversely, flying the net closer to the seafloor risks bottom contact and the large and dense orange roughy aggregations may result in very large catches. For this survey the skipper exercised caution for the first two trawls keeping the net ~ 50 m above the seafloor. While this ensured there would be no seafloor contact, no fish were caught. For the third of the permitted trawls the net was taken much closer to the seafloor. For a moment, the footrope of the trawl net could be observed in the sAOS video ~ 1–2 m above the seafloor, confirming that bottom contact was avoided. A catch of 5.5 tonnes was taken. The outcome was that all biological sampling had to be taken from this one successful trawl. Further, the limitation on the number of trawls (as against measures such as limiting allowable catch), resulted in this 'last chance' scenario where the skipper had to balance the stakes of either lowering the net very close to the seabed or not procuring any catch at all as a basis for the required biological sampling. To avoid this situation a more flexible approach to sampling at Morgue would help to ensure that biological information is robust and representative of the spawning population. This might use a catch limit, if required, rather than a cap on the number of trawls. Trawling would cease once the requisite number of biological samples were obtained or if a catch limit had been reached. This would allow the skipper to cautiously conduct the trawls to avoid bottom contact as a priority, knowing that repeat trawls could be made if the biological samples were insufficient.

3.2.1.5 Morgue conclusions

The sAOS 38 kHz biomass estimates at Morgue were 13 481, 15 678, and 19 837 tonnes. These are higher than the 2016 estimates that ranged from 12 000 to 15 000 tonnes The biological data suggest that the surveys were conducted somewhere within a peak abundance window. The stability of the aggregation and biological samples (albeit from one trawl) support this conclusion. We propose that the 2021 biomass estimates would be suitable for inclusion in a stock assessment.

3.2.2 Graveyard

The nearby smaller feature known as Graveyard was also surveyed, albeit with less effort due to time limitations and lower expectations of significant biomass. Taking advantage of the perfectly calm conditions, a four-transect, vessel-mounted acoustic survey of the Graveyard feature was undertaken. A single, low-backscatter plume was observed on the summit of the feature. This plume was ~ 200 m in length and ~ 100 m high (Figure 12).

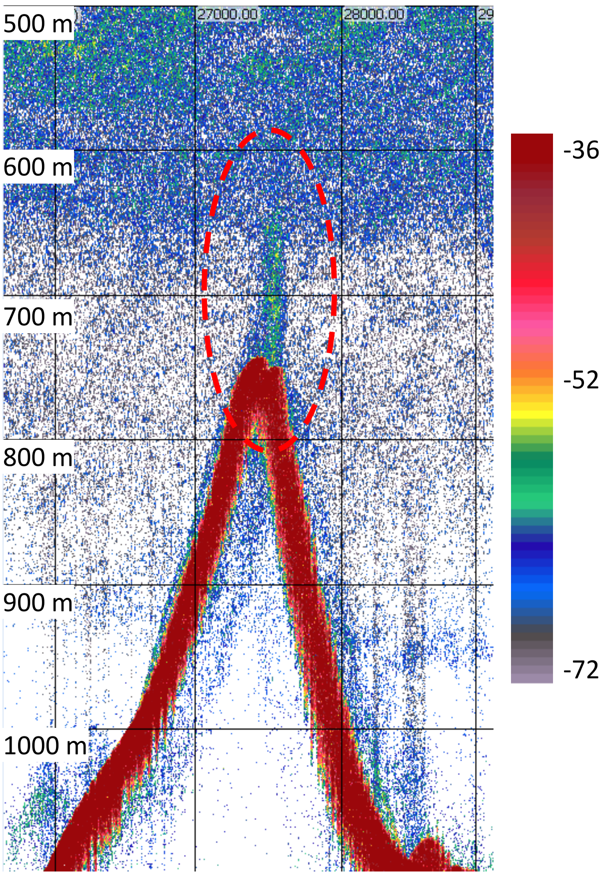


Figure 12: Vessel 38 kHz echogram showing likely ORH school on Graveyard (OP4). Vertical grid line spacing is 1000 m. Likely ORH school marked by red dashed line.

Two vessel-based transect passes, one E-W, the second N-S were made over the Graveyard aggregation on a second occasion with the mark again observed at the top of the feature, but this time a bit weaker. Time constraints meant that a full AOS survey of the Graveyard aggregation could not be carried out. Instead, as a final survey activity for NWCR, a single-pass AOS transect was carried out across the top of the aggregation for the purpose of species identification (Figure 13). Multifrequency acoustics indicated the aggregation was ORH. This single pass was important to support interpretation of the vessel-based acoustic survey data that could potentially enable a biomass estimate to be made.

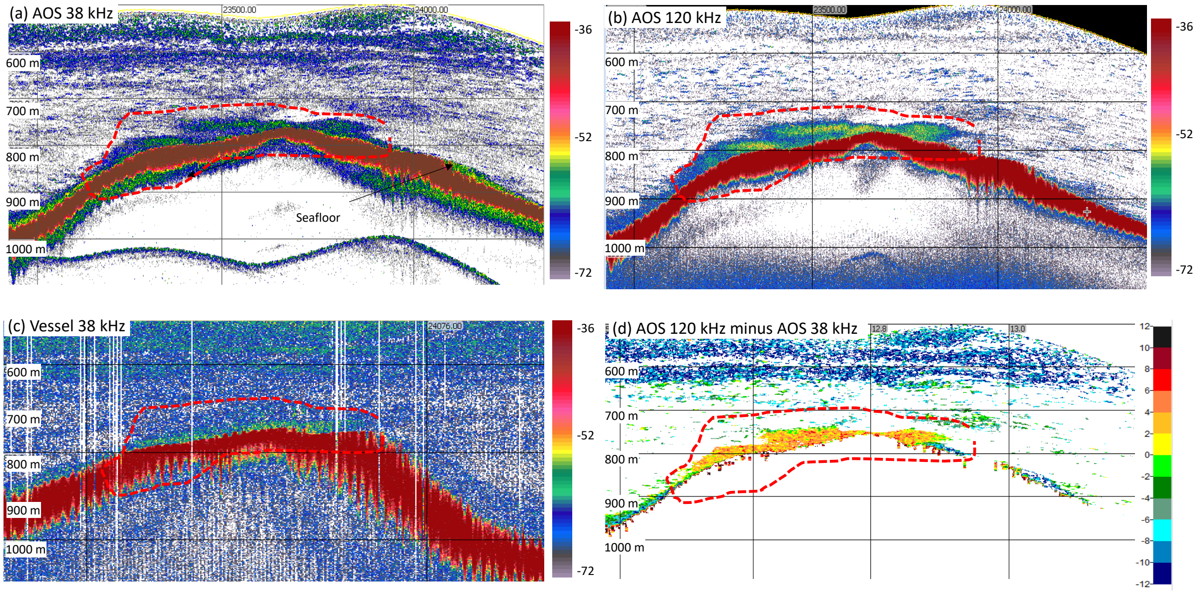


Figure 13: Echograms of the orange roughy aggregation at Graveyard OP10, 5th July 2021 10:54. Legend is shown for colour display ranges. Panel d shows the subtraction of AOS 38 kHz from AOS 120 kHz echogram data. Pixels that are +2 dB or more (orange–red pixels) indicate regions dominated by non-gas bladder species. Red-dashed polygon indicates region of ORH aggregation. Backscatter from ORH is only just above the background noise for the vessel 38 kHz acoustics (Panel c).

Our expectation was that a vessel-based biomass estimate would be possible for the two Graveyard surveys given confirmation of orange roughy by the AOS single pass. *Amaltal Apollo's* newly installed Simrad ES80 38 kHz echosounder system was calibrated at the end of the voyage using the suspended sphere method. At the time of calibration, the system appeared to be working correctly with physical movement of the calibration sphere corresponding with the phase-measured movements. On-axis gain values looked sensible. However post-voyage analysis of the calibration data found that the transducer beam angle in the athwartship direction was 12 degrees instead of the expected 7 degrees. This will mean that the transducers Equivalent Beam Angle (EBA) will not match the manufacturer's factory measurement. This ill-defined transducer beam-pattern means that estimation of biomass for the Graveyard will not be possible.

3.2.2.1 Graveyard conclusions

The observations of the Graveyard are in keeping with previous surveys where large and extensive orange roughy aggregations are not observed (Ryan & Tilney 2017). Due to unanticipated instrument calibration issues a biomass estimate is not possible for Graveyard in 2021. It is difficult to put a figure on what the biomass might have been at the Graveyard. However, given the orange roughy aggregation was of moderate backscatter and occupied a small area, biomass was not anticipated to be high. Future surveys can quite readily give an appropriate level of focus on this location; it is so close to Morgue that it can be monitored by quick side trips or even when setting up to survey Morgue.

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

The North-East Chatham Rise (NECR) main spawning grounds consist of Rekohu and Spawn Plume, 30 n. miles further east, and the nearby volcanic feature Mt Muck. These three areas were included in the survey schedule. Rekohu and Spawn Plume received curtailed survey efforts due to the early exit of *Amaltal Apollo*. For the same reason, no survey activities could be carried out at Mt Muck.

3.3.1 Rekohu

3.3.1.1 Summary of survey programme

The Rekohu orange roughy spawning ground is located on the north-eastern Chatham Rise and comprises an area of approximately 7 n.mile^2 centred at 177:52 °W, 42:48 °S. It has a gently sloping sandy seafloor with no significant bathymetric features. Immediately to the north lies the Rekohu canyon system.

The survey programme of Rekohu was somewhat piecemeal due to a combination of the early exit by *Amaltal Apollo* and poor weather which hampered the efforts of *Amaltal Mariner* and *San Waitaki* to conduct vessel-based acoustic surveys of suitable quality. Note those vessels were primarily concerned with commercial fishing so their contributions to the survey programme were very welcome.

***Amaltal Apollo* surveys of Rekohu**

Upon arrival at Rekohu, *Amaltal Apollo* commenced a search to locate the main spawning aggregation using the vessel's echosounder. The weather had deteriorated with winds over 20 knots degrading the quality of the vessel acoustics, but enough signal was obtained to locate the main spawning aggregation. An sAOS survey of this aggregation commenced five hours after arrival. This survey took about 20 hours to complete due to a combination of poor weather slowing progress, winches being slow to haul, a winch breakdown for ~ 2 hr and the large extent of the aggregation that was being surveyed. Orange roughy aggregations were observed on all transects over an east-west extent of 4 km (Figure 14a), noting that densities varied. On some transects orange roughy were observable on the 120 kHz echograms but marginal on the concurrent 38 kHz echogram due to the lower reflectivity at that frequency and higher reflectance of other backscatter sources. On other transects extensive orange roughy aggregations with reasonable signal were observed (Figure 15). Unfortunately, the AOS survey did not bound the western extent of the aggregation. This was due to vessel acoustics being degraded to the point where the orange roughy aggregation was not readily discernible from the surrounding backscatter on what was thought to be the transect that would bound the aggregation.

In previous years, multiple vessel and AOS surveys were conducted at Rekohu which enabled the extent of the aggregations to be established. Had there been more time, and if conditions were more favourable, subsequent AOS and/or vessel-based surveys would have built an understanding of the aggregation extent to ensure survey transects included bounding lines. Biomass estimates will potentially under-represent the actual biomass here by an unknown amount due to the outer transect not bounding the aggregation.

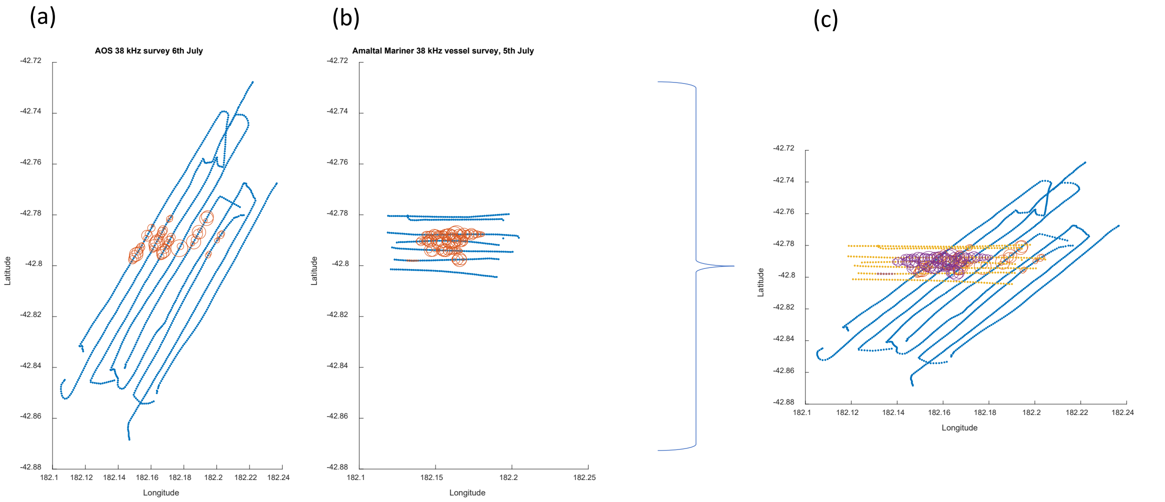


Figure 14: Thematically mapped acoustic surveys where circle size is proportional to the backscatter from orange roughy aggregations conducted by *Amaltal Apollo* using Sealord AOS (a), *Amaltal Mariner*'s vessel mounted 38 kHz echosounder survey (b), and combined for both surveys (c). The combined surveys indicate that the aggregation was observed in approximately the same location within a 24-hour period.

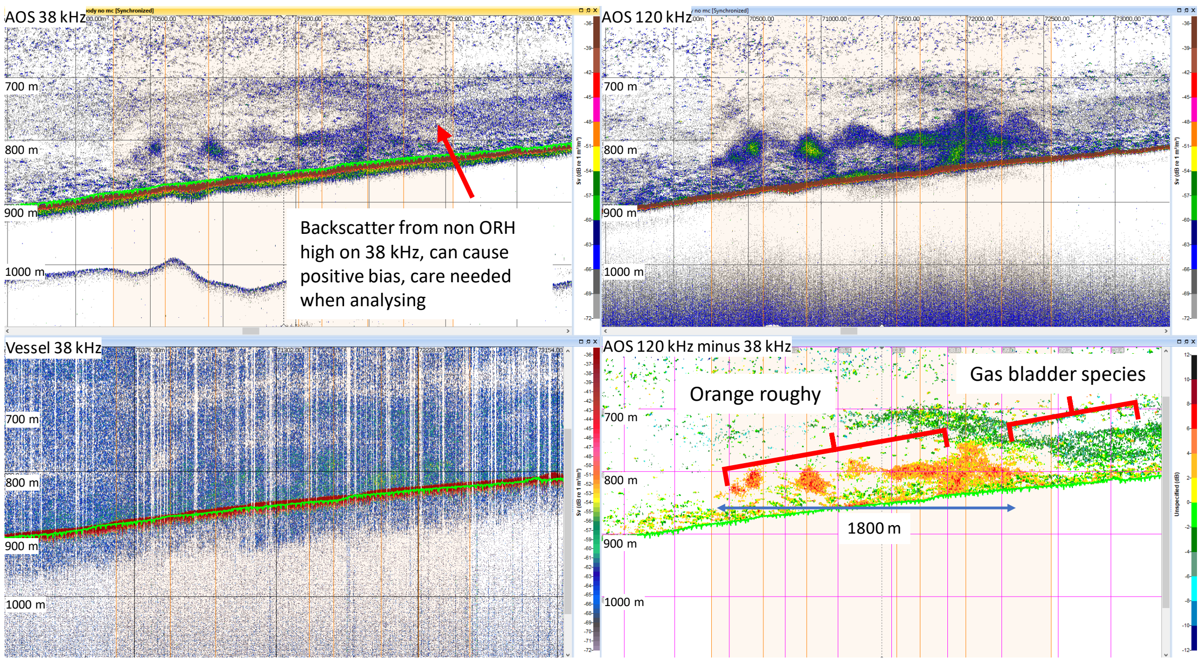


Figure 15: Echograms of the large aggregation of orange roughy at Rekohu. OP11, 6th June 2021. Legend is shown for colour display range. Panel d shows the subtraction of AOS 38 kHz from AOS 120 kHz echogram data. Pixels that are +2 dB or more (orange–red pixels) indicate regions dominated by non-gas bladder species. Pixels that are around 0 dB (green) indicate regions dominated by large gas bladder species.

Rekohu biological sampling – *Amaltal Apollo*

A single biological trawl was conducted by *Amaltal Apollo* at Rekohu. For this exercise the AOS was removed as it was compromising signal quality from the Marport net monitor which provides the primary source of information that guides the skipper when trawling. A 22-tonne catch of orange roughy was caught from an 8-minute tow. A smaller catch of ~ 5–10 tonnes would have been ideal but catch sensors did not trigger in time to help limit the catch. The catch was almost entirely of orange roughy (99%), with small quantities of spiky oreo, ribaldo, hake, and deepwater sharks also present (Figure 16).

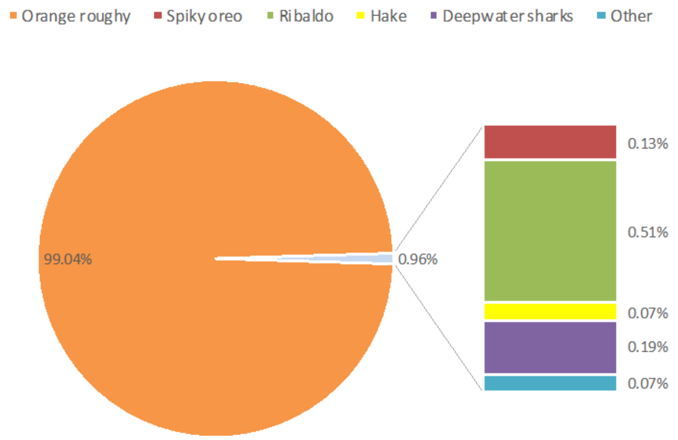


Figure 16: Catch composition from the single target ID tow on the Rekohu aggregation on 7th July 2021.

The orange roughy sex ratio was skewed, with 79% being males. Spawning was well underway with 80% of males in spawning and partially spent condition and 18% spent. For females, 20% were in ripe or hydrated condition, 58% in spawning and partially spent condition, and 21% were spent (Figure 17).

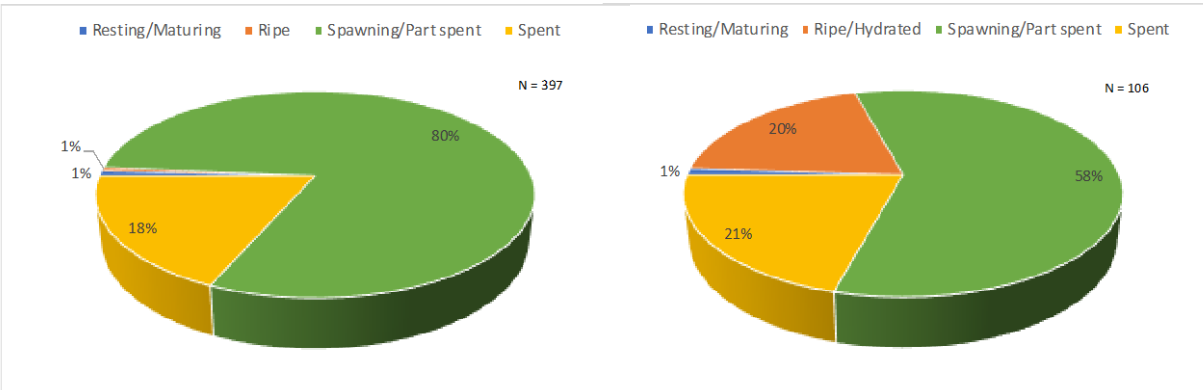


Figure 17: Gonad maturity stages for male (left) and female (right) orange roughy from the Rekohu aggregation on 7th July 2021.

Average weights for males and females were 1.24 kg and 1.52 kg, respectively. For sexes combined the average weight was 1.30 kg. Mean standard lengths for males and females were 34.3 cm and 36.1 cm, respectively. For the sexes combined the mean standard length was 34.6 cm (Figure 18).

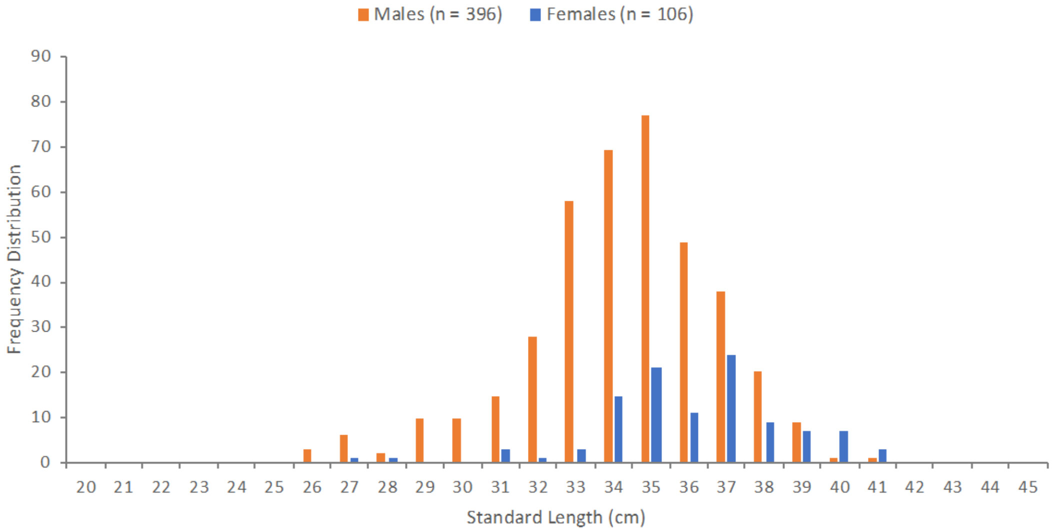


Figure 18: Orange roughy length frequency distribution from the Rekohu aggregation.

Rekohu biological sampling – *Amaltal Mariner*

Observer sampling of orange roughy gonad development state revealed that spawning was likely at a peak during 5th–7th July, evidenced by the very large component (99%) of spawning females and a very low proportion (0.5%) of spent females (Figure 19).

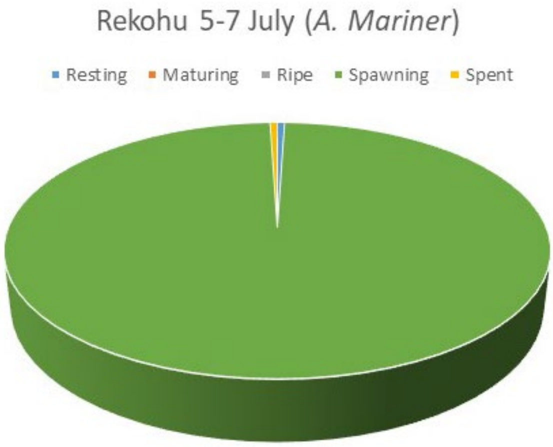


Figure 19: Orange roughy female spawning state at Rekohu on 5th July 2021.

Mean standard lengths for males and females were 33.2 cm and 35.9 cm, respectively, while for the sexes combined the mean standard length was 35.0 cm. The sex ratio was skewed in favour of females (68%) (Figure 20).

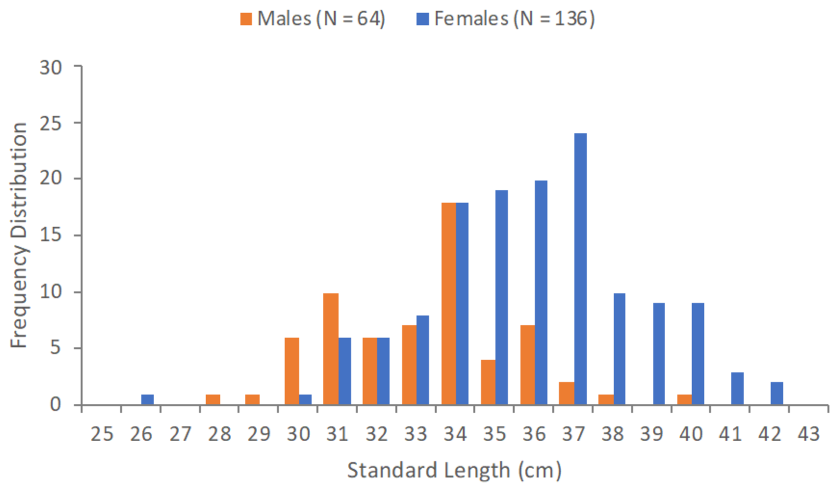


Figure 20: Orange roughy length frequency distribution, Rekohu aggregation, 5th July.

Rekohu spawn progression

Biological samples collected from the Rekohu aggregation by *Amaltal Apollo*, *Amaltal Mariner*, and *San Waitaki* showed that spawning likely peaked on 7 July, when up to 21% of female gonads were in spent condition. However, on 12th July only 4% of female gonads were in spent condition and there had been an increase in the proportion of ripe female gonads, suggestive of a new wave of spawners (Figure 21).

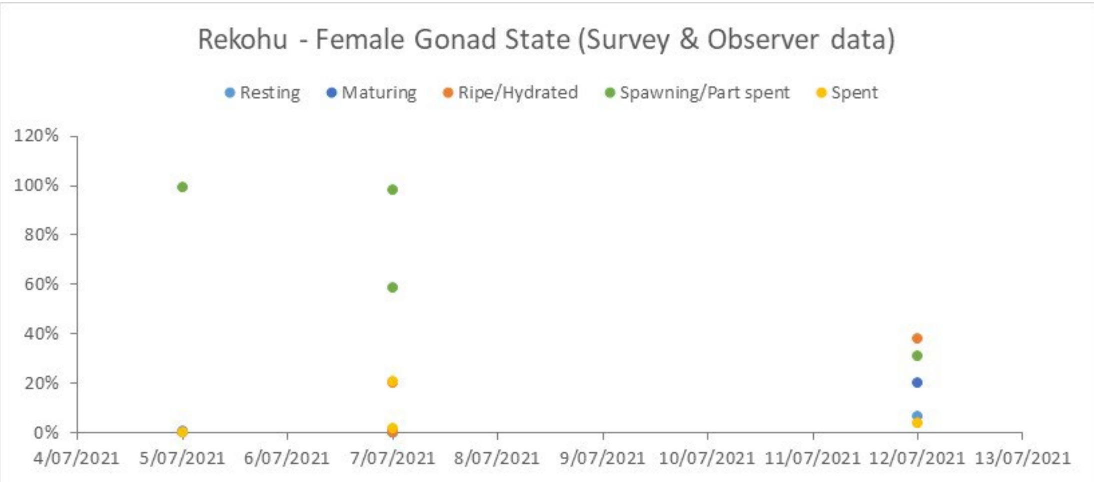


Figure 21: Female spawn progression at Rekohu from 5 to 12 July 2021.

Amaltal Mariner vessel-based acoustic surveys at Rekohu

Amaltal Mariner conducted three vesselbased acoustic surveys at Rekohu (Table 14). Of these the second survey on the 5th of July was conducted in calm conditions that allowed acoustic data quality to be suitable for biomass estimation. During that survey large aggregations of orange roughy were encountered on two of the five transects (Figure C.5 in Appendix C). Delineation of the weak-to-moderate orange roughy aggregations from the surrounding backscatter was difficult in some instances and a precautionary approach was adopted in the analysis to avoid inclusion of signal from other species causing positive bias (Figure 22). Orange roughy aggregations were observed on the other two surveys at Rekohu on 5th and 8th July, but aggregations could not be clearly separated from background backscatter, thus those surveys are not suitable for biomass estimation.

Table 14: Time and location of 38 kHz acoustic surveys carried out by *Amaltal Mariner*. The entry with bold text indicates the one *Amaltal Mariner* survey that was considered suitable for biomass estimation.

1	4/07/2021 14:59	4/07/2021 17:00	West of 180° at 178 °W
2	5/07/2021 01:15	5/07/2021 03:45	Rekohu
3	**5/07/2021 06:09**	**5/07/2021 09:45**	**Rekohu**
4	5/07/2021 14:14	5/07/2021 17:20	Spawn Box
5	5/07/2021 22:15	6/07/2021 02:13	Spawn Box
6	6/07/2021 06:02	6/07/2021 10:30	Spawn Box
7	6/07/2021 13:28	6/07/2021 18:30	Spawn Box
8	6/07/2021 20:05	6/07/2021 23:35	Spawn Box
9	7/07/2021 01:49	7/07/2021 04:30	Spawn Box
10	7/07/2021 18:30	7/07/2021 20:45	Spawn Box
11	8/07/2021 00:24	8/07/2021 04:30	Rekohu

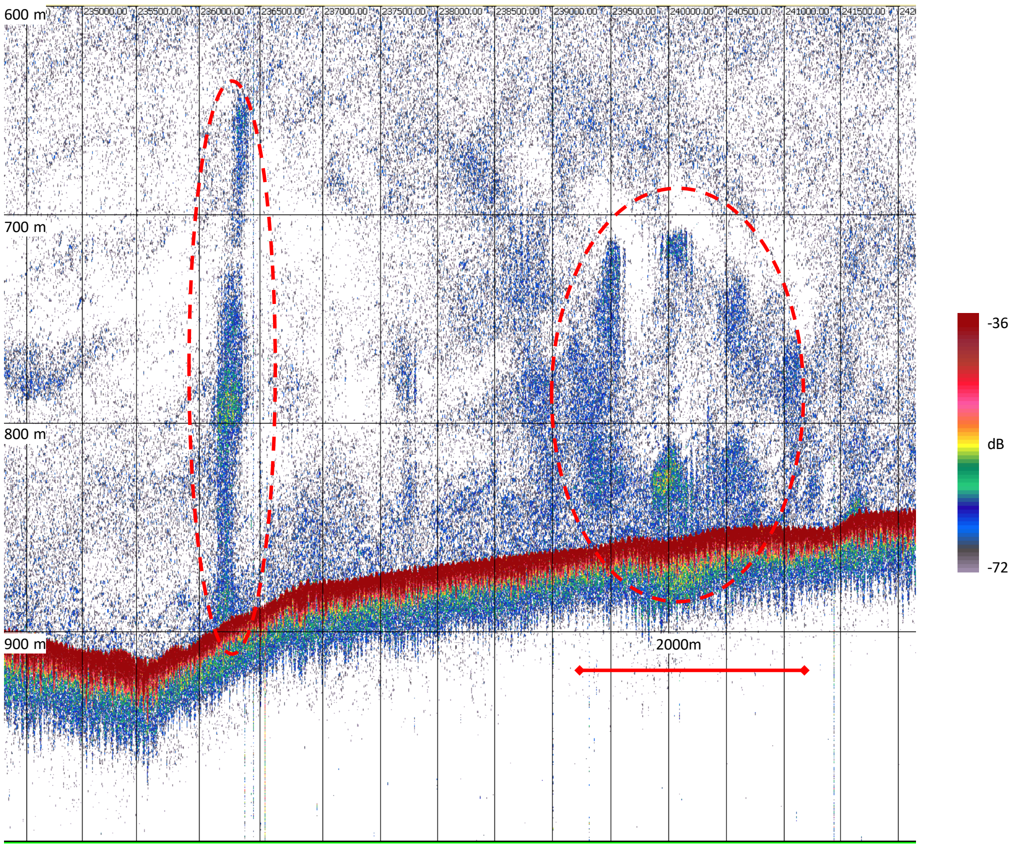


Figure 22: Orange roughy aggregations at Rekohu, *Amaltal Mariner* Survey, 5th July 2021 07:10 local. Orange roughy aggregations marked by red-dashed lines. The left red-dashed line contains an aggregation with reasonable contrast from the surrounding backscatter. The right-dashed line contains several aggregations with varying degrees of contrast from the surrounding backscatter.

San Waitaki vessel-based acoustic surveys of Rekohu

Following the premature curtailment of the *Amaltal Apollo* survey on the 7th July, *San Waitaki* arrived in the ORH 3B NECR region to fish commercially. While there, the vessel conducted two surveys, one at Rekohu on 12th July and one at Spawn Plume on 16th July.

At Rekohu, *San Waitaki*'s acoustic survey on 12th July was conducted in calm conditions. Orange roughy aggregations were observed but surrounding backscatter was very high. Robust delineation of orange roughy from other sources that would bias biomass estimates high was not possible (Figure 23).

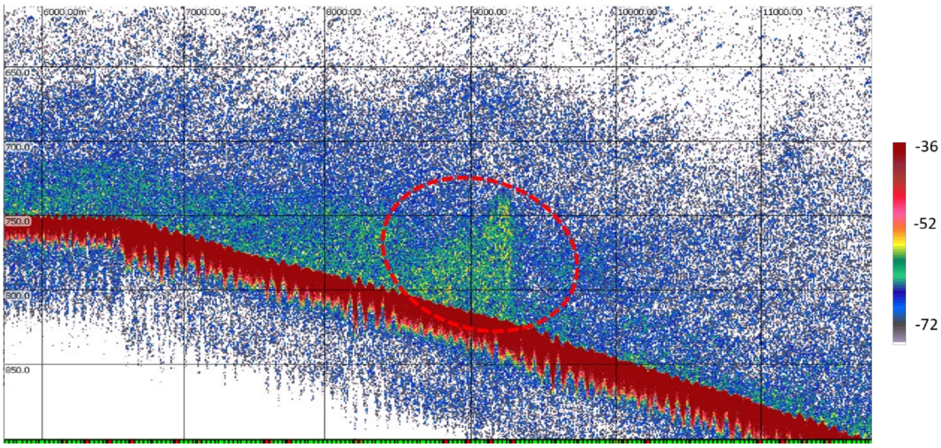


Figure 23: Example of possible ORH aggregation surveyed by *San Waitaki* at Rekohu that cannot confidently be separated from surrounding backscatter.

3.3.1.2 Biomass estimates for Rekohu aggregation

Biomass estimates for Rekohu for one sAOS and one vessel-based survey conducted by *Amaltal Mariner* are given in Table 15 and visualised in Figure 24.

Table 15: Biomass estimates at 38 and 120 kHz from sAOS survey at Rekohu and for vessel-based 38 kHz survey by *Amaltal Mariner*.

Date	Platform & Frequency	OP	Biomass above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)
05/Jul	Vessel 38 kHz	15	11 362	0.16	1 181 (9.4%)	12 543*
06/Jul	AOS 38 kHz	11	5 891	0.25	575 (8.9%)	6 466
06/Jul	AOS 120 kHz	11	6 795	0.25	578 (7.8%)	7 373

* Vessel estimate – no motion correction, Doonan et al. (2003b), 1.3 DWWG multiplier for motion and surface bubble attenuation applied and combined calibration correction factor of 1.008 (see Appendix A).

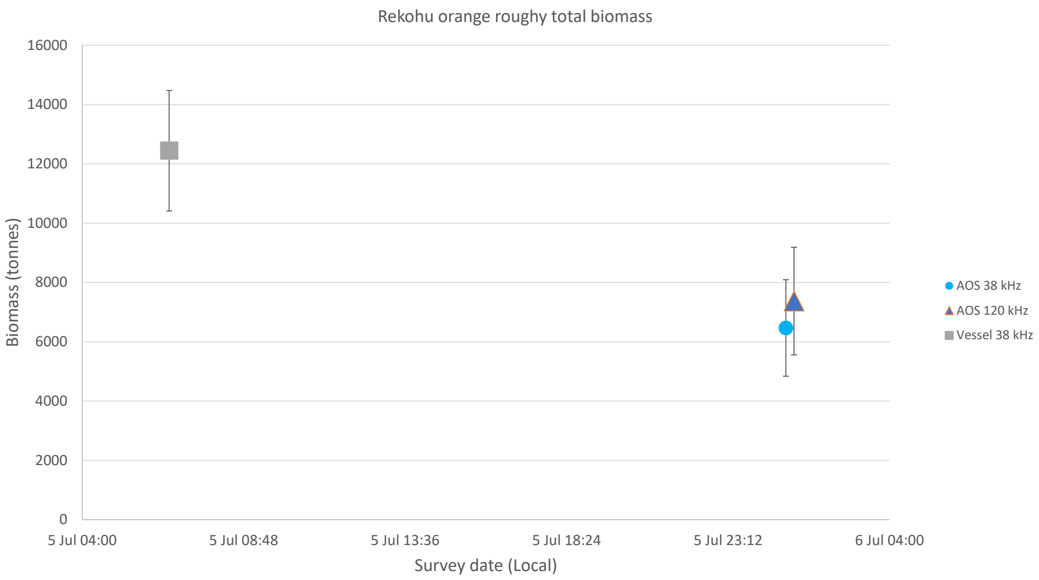


Figure 24: Biomass estimates for Rekohu on 5th July 2021 for sAOS survey by *Amaltal Apollo* and 38 kHz vessel-based survey by *Amaltal Mariner*. Error bars indicate survey sampling CVs.

3.3.1.3 Rekohu discussion

The Rekohu spawning grounds are large and required at least 12–24 hours to search for and locate the main body of orange roughy. Our experience from surveys in 2016 (Ryan & Kloser 2016) found that orange roughy schools were widely dispersed and highly mobile during the pre-spawn build up. During these early stages, acoustic surveys were not possible even with the more mobile vessel-based acoustics. As the spawn progressed orange roughy aggregated into very large schools that stabilised to allow multiple AOS surveys to be conducted. Biomass estimates in 2016 ranged from 10 000 to 45 000 tonnes (Figure 25).

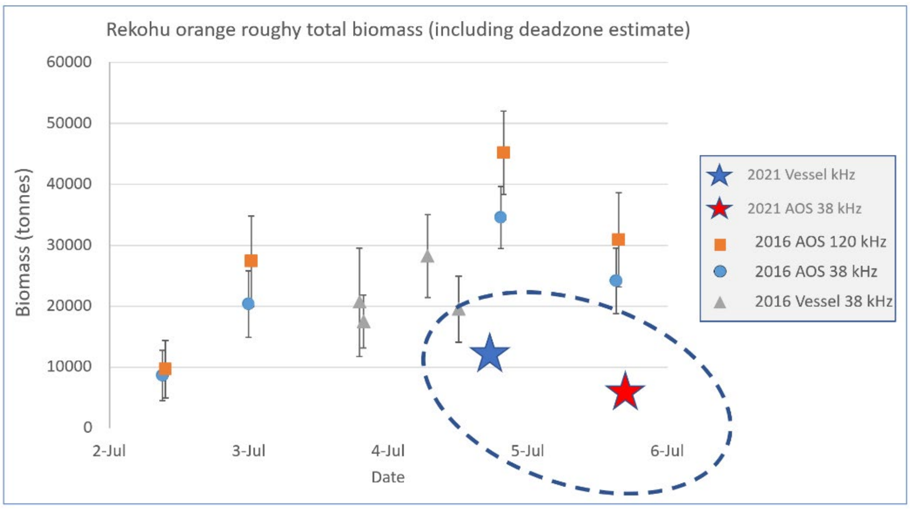


Figure 25: 2016 and 2021 biomass estimates. Error bars on the 2016 biomass estimates indicate survey sampling CV. 2021 results (blue and red stars) are highlighted within the dashed blue line.

The 2021 sAOS 38 kHz biomass estimate was 6466 tonnes, about 40% less than the lowest of the 2016 estimates and a factor of ~ 8 lower than the highest estimate of 45 000 tonnes. The 38 kHz vessel-based estimate for 2021 was double that of the sAOS at 12 543 tonnes. However, we note the higher uncertainty of vessel-based surveys, and particularly for Rekohu, that has the possibility of significant positive bias due to inclusion of background scatter.

The limited biological sampling indicated spawning was well underway such that the 2021 surveys might have occurred during the window of peak abundance. The 2021 survey dates align with the peak abundance observed in 2016, lending weight to this conclusion.

However, firm conclusions for 2021 are not possible due to the very limited surveying effort and difficult conditions in which the sAOS survey was conducted.

The lower biomass estimates compared with 2016 may indeed reflect the true situation, although multiple surveys spread over time are needed to properly quantify Rekohu biomass. It is possible that the two 2021 surveys had not fully scoped the available orange roughy aggregations and the limited number of surveys may not be capturing the true biomass.

3.3.1.4 Rekohu conclusions

Given the failure to achieve a comprehensive survey programme we do not recommend use of the 2021 biomass estimates in a stock assessment. However, the results are presented here as a point of observation that can be considered against future survey estimates. The 2021 estimates may be indicative of a downward trend or may be proven to be unrepresentative of the Rekohu spawning stock.

3.3.2 Spawn Plume

3.3.2.1 Summary of survey programme

Amaltal Apollo was able to make a brief vessel-based scoping survey on the Spawn Plume region on 8th of July. ORH aggregations were observed on the vessel's 38 kHz echosounder. An sAOS survey would have followed but at this point *Amaltal Apollo* had to return to port due to main engine issues.

Amaltal Mariner fished and conducted seven vessel acoustic surveys at Spawn Plume between the 5th and 7th of July. They reported observing good aggregations and that the spawn was well underway. The initial surveys were in calm weather resulting in high quality echograms; however no significant orange roughy aggregations were observed. On later surveys, substantial orange roughy aggregations were observed with reasonably strong backscatter, but unfortunately weather degraded the data quality to a point where these surveys were not suitable for biomass estimation (Figure 26).

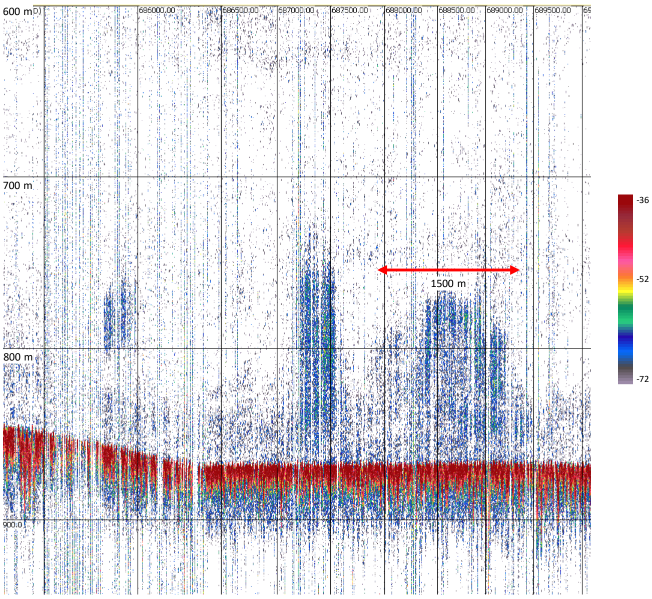


Figure 26: Example of a 38 kHz echogram from *Amaltal Mariner*'s Simrad ES60 echosounder acquired using Simrad ES80 software. The region of high backscatter shows classic form of orange roughy spawning plumes at the Spawn Plume recorded during a transect-based biomass survey, 7th July 2021 02:58 local. Although there is high confidence in interpreting this echogram it was obtained in rough weather that compromised data quality making it unsuitable for biomass estimation.

San Waitaki entered the ORH 3B North-East Chatham Rise region to fish commercially on the 7th of July following the curtailment of the *Amaltal Apollo* survey. At Spawn Plume, *San Waitaki* conducted an acoustic survey in calm conditions on the 16th of July where ORH aggregations were observed over a large area (Figure 27). Review of the data found that it was possible to distinguish ORH from surrounding backscatter in most instances. *San Waitaki's* echosounder was calibrated post-voyage. Unfortunately, calibration was carried out at 1.024 ms pulse duration, while field data was acquired at 2.048 ms. A correction factor to account for the difference between these two pulse durations was derived by reviewing historical calibration results obtained from multiple vessels that have the same model transducer. Details of this correction factor are provided in Appendix A.

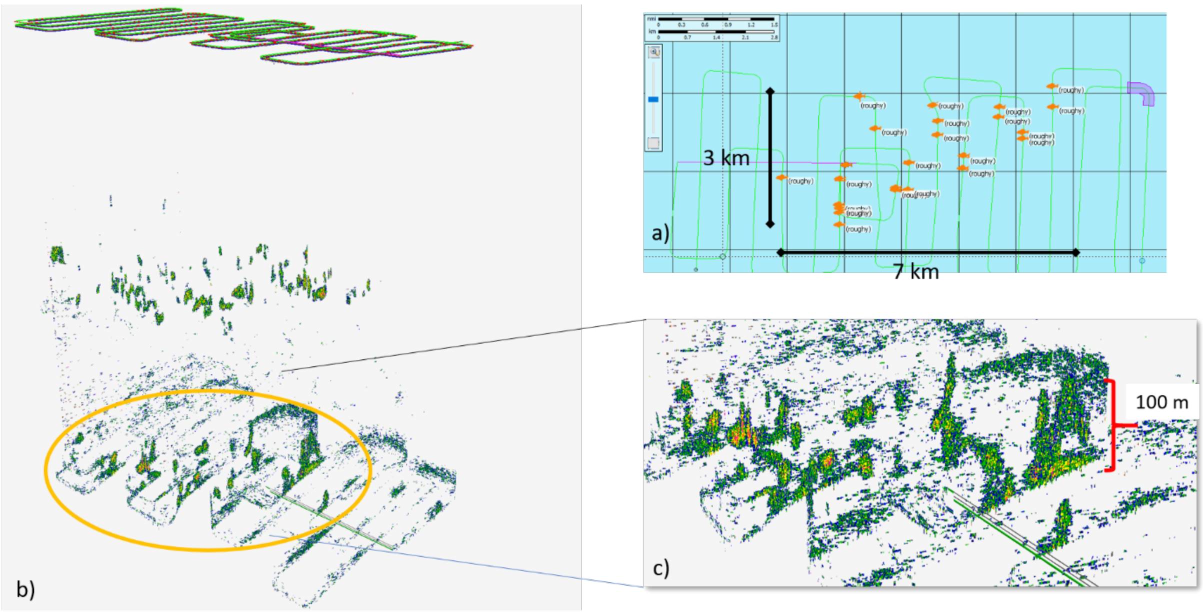


Figure 27: Summary of a hull-mounted acoustic survey at Spawn Plume by *San Waitaki* on 16th July 2021. a) The vessel track during the survey and spatial extent of the survey (7 km east/west and 3 km north/south) b) The three-dimensional scattering observed during the survey. c) A zoomed in view of the scattering, typical of ORH.

3.3.2.2 Biological sampling at Spawn Plume

Biological data were collected by the observer aboard *Amaltal Mariner* from 5th to 7th July and by the observer aboard *San Waitaki* on 16th July. Female gonad development states indicated that spawning may have been at a peak at around 6th July when 20% of gonads were recorded to be in spent condition (Figure 28). These data indicate that spawning at Spawn Plume peaked at around the same time as at Rekohu.

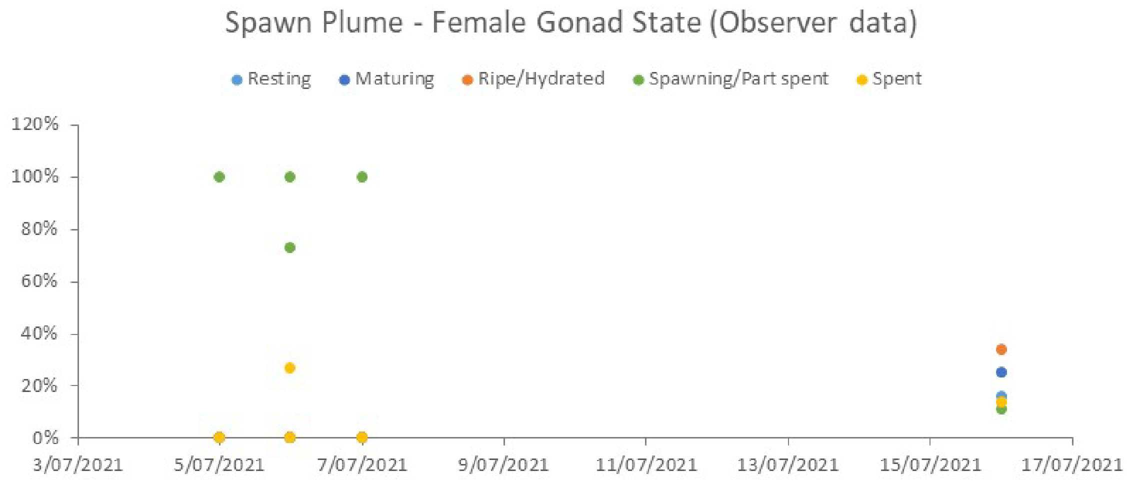


Figure 28: Female spawn progression at Spawn Plume from 5 to 16 July 2021.

On 16th July 2021, 34% of female gonads were recorded to be in ripe (i.e., pre-spawning) condition, suggestive of a new wave of spawners joining the aggregation; 16% were in resting condition, indicative of fish that would not have spawned during the 2021 season. It is not uncommon to see large aggregations of orange roughy persisting well after the spawning peak (Figure 29).

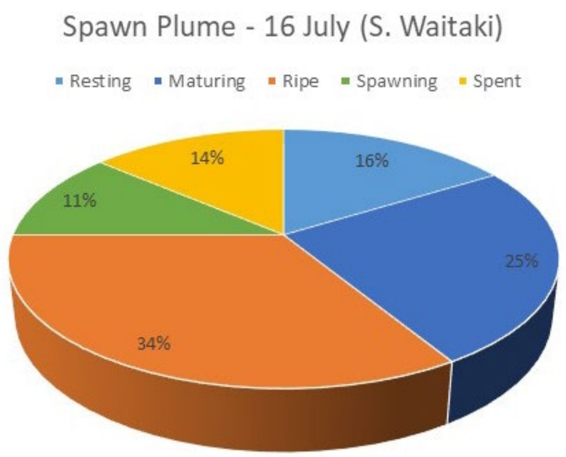


Figure 29: Female orange roughy spawning state at Spawn Plume 16th July 2021.

Mean standard lengths for males and females from the *San Waitaki* samples were 32.7 cm and 37.3 cm, respectively, while for the sexes combined the mean standard length was 36.4 cm. Individual fish weights were not determined from this sample. The sex ratio was skewed, with 80% being females (Figure 30).

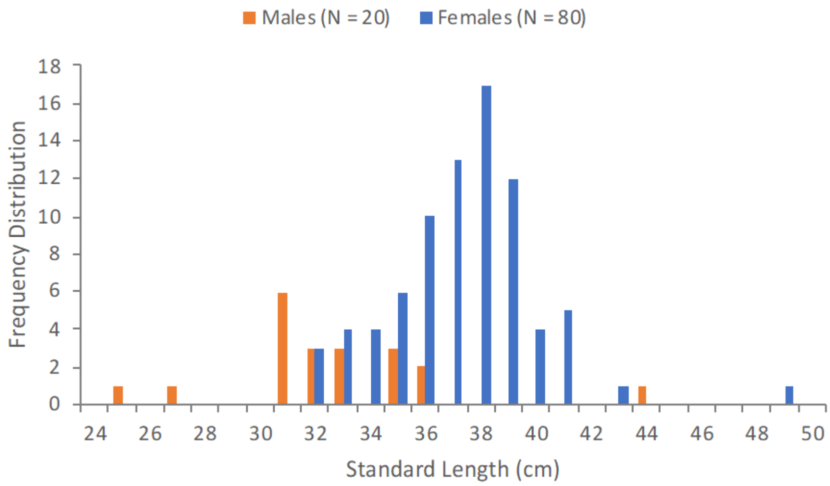


Figure 30: Orange roughy length frequency distribution in the Spawn Plume, 16th July 2021.

3.3.2.3 Biomass estimates for Spawn Plume

A single biomass estimate of 35 155 tonnes was made for the Spawn Plume based on the *San Waitaki*'s 38 kHz vessel-based echosounder (Table 16).

Table 16: Biomass estimates for *San Waitaki* vessel-based 38 kHz acoustic survey at Spawn Plume.

Date	Above acoustic bottom (tonnes)	CV	Dead-zone estimate	Total biomass (tonnes)
16th July 2021	30 308	0.20	4 846 (13.8%)	35 155*

* Vessel estimate – no motion correction, Doonan et al., (2003b), 1.3 DWWG multiplier for motion and surface bubble attenuation applied and combined calibration correction factor of 0.927 (see Appendix A).

3.3.2.4 Spawn Plume discussion

Ideally a full AOS survey would have been conducted at the Spawn Plume in 2021 in order to provide multiple biomass estimates with higher confidence by using multifrequency information, to enable exclusion of non-ORH species. Notwithstanding the limitations and potential biases with vessel-based acoustics, the single vessel-based estimate in 2021 has quantified a large biomass that was ~ 3.5 times higher than the two vessel-based biomass estimates from 2016 and ~ 2 times higher than the largest AOS based biomass estimates from the same year (Figure 31).

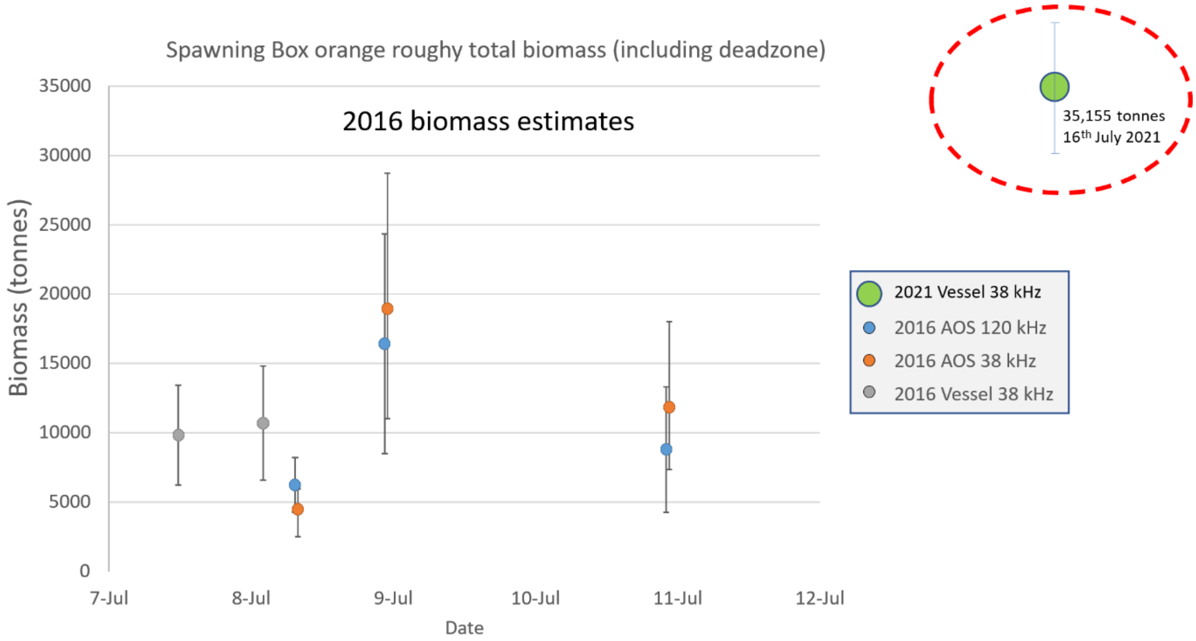


Figure 31: AOS and vessel-based biomass estimates from 2016 survey of Spawn Plume plus the single biomass estimate from 2021.

4. DISCUSSION

The 2021 survey programme achieved some useful outcomes despite being curtailed by issues with the main survey vessel that forced an early return to port. Three high quality AOS surveys were completed at Morgue in NWCR. Biomass estimates ranged from 13 481 to 19 837 tonnes. These can be compared with the 2016 estimates that ranged from 12 000 to 15 000 tonnes. Despite the compressed survey period of 36 hours, it appears that the surveys had quantified the Morgue orange roughy during their peak spawning period. These results are considered suitable for inclusion in a stock assessment. A small aggregation of orange roughy was observed at the nearby Graveyard and the single vessel-based acoustic survey should have enabled biomass estimation. However, a post-voyage calibration revealed a technical issue with the vessel's newly installed Simrad ES80 echosounder that compromised the transducer's beam-pattern and prevented estimation of the biomass.

Following the early exit of *Amaltal Apollo*, after a single AOS snapshot had been conducted, *San Waitaki* and *Amaltal Mariner* entered the ESCR fishery area and were able to conduct parallel transect surveys at Rekohu and Spawn Plume. Four opportunistic vessel-based surveys were completed at Rekohu, of which one conducted by *Amaltal Mariner* was suitable for biomass estimation. The other surveys were compromised by weather and/or orange roughy aggregations could not be delineated from the surrounding backscatter. The AOS and vessel-based biomass estimates were 6466 and 12 543 tonnes, respectively (Table 15). Given the limited survey effort, these biomass estimates are not proposed to be used in a stock assessment. The 2021 results can be compared with biomass estimates from 2016 that ranged from 10 000 to 45 000 tonnes. The lower biomass estimates in 2021 may be a consequence of the limited survey programme and the timing of surveys in relation to spawning, but they could represent a downward trend at Rekohu. Contrary to the Rekohu biomass estimates, the single 2021 Spawn Plume biomass estimate is higher than the previous 2016 estimate (between 2 and 3.5 times higher than vessel and AOS biomass estimates, respectively). The observed lower biomass at Rekohu and higher biomass at Spawn Plume could be due movement of spawning fish between the two locations that are only separated by 30 n.mile. A follow-up comprehensive survey programme will be needed to clarify the situation.

In 2021, the Spawn Plume was surveyed only by the two commercial fishing vessels that were working in the area. Of the eight vessel-based surveys only one was suitable for biomass estimation. Degradation of the acoustic signal due to weather and/or a lack of clearly distinguishable orange roughy aggregations prevented biomass estimates being determined from the other surveys. This one survey with suitable quality was carried out very late in the spawning period on the 16th of July, yet large aggregations of orange roughy were observed across multiple transects. The vessel-based estimate of 35 155 t is a factor of 3.5 higher than 2016 vessel-based acoustic biomass estimates and factor of 2 higher than the highest 2016 AOS 38 kHz estimate. As mentioned in the Rekohu discussion, the apparently lower biomass at that location and higher biomass at Spawn Plume could be due to a shift in the spawning populations for these two locations that are only 30 n.mile apart. A future full survey programme for ECR will help to clarify the aggregation status at both locations.

Uncertainty

The AOS-based biomass estimates at Morgue have reasonably low uncertainty compared with vessel-based acoustics due to the combined effects of having the acoustics closer to the aggregations (lower absorption losses, better signal-to-noise), the high degree of platform stability (with consequent low signal loss due to motion effects), and interpretation aided by multifrequency acoustics. The very high-signal, mobile aggregation of large gas bladder fish can potentially bias biomass estimates high if not segregated. We were able to exclude regions where the signal was extremely high and/or multifrequency information indicated gas bladder species were present. It is not possible to be sure that 100% of gas bladder species are eliminated, particularly if only part of the aggregation is within the beam such that the signal might be similar to that of orange roughy aggregations. However, in general it seems that for AOS surveys in 2013, 2016, and 2021, the large-gas-bladder species aggregations were often not present or we were able to effectively eliminate them, thereby providing reasonably consistent biomass estimates.

The vessel-based acoustic surveys have several range-dependent parameters that will result in higher uncertainty compared with deeply deployed acoustic systems. Further, the lack of multifrequency information means that vessel-based echogram interpretation must rely on the appearance and location of aggregations and, if available, trawl catch information. The large acoustic footprint and lower resolution data mean that inclusion of non-target species may bias results high. Despite these limitations, vessel-based acoustic surveys are still able to provide estimates that may be compared across the years. In 2021 we had an additional uncertainty due to the vessel calibrations being conducted at 1.024 ms pulse duration while field data were collected at 2.048 ms. Our analysis of historical data showed that an error of around +/- 10% would occur if no attempts were made to derive a correction factor. The standard deviation of our statistically derived correction factor was ~ 2% which is likely a fair estimate of the residual error once the correction for the pulse duration effects had been applied.

Conclusions

The 2021 survey programme was challenging for reasons described. Nevertheless, useful information was obtained. A return voyage involving a full survey programme will be needed to properly establish the status of the Chatham Rise orange roughy spawning populations.

5. ACKNOWLEDGEMENTS

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APPENDIX A – A CORRECTION FACTOR FOR THE EFFECT OF PULSE DURATION DIFFERENCES BETWEEN CALIBRATION AND FIELD DATA

a. Introduction

San Waitaki and Amaltal Mariner were not formally part of the original 2021 survey plan but came into the programme in response to the early exit of the *Amaltal Apollo*. They were able to conduct opportunistic vessel-based surveys of Rekohu and Spawn Plume that were of suitable quality for biomass estimation. *Amaltal Mariner* was last calibrated in 2019. Results from the 2019 calibration were applied for initial biomass for the one suitable survey at Rekohu. We have no calibration history for *San Waitaki* so initial biomass estimates for the one suitable survey of the Spawn Plume were made using manufacturer nominal values. Post-voyage calibration of both vessels was carried out using the standard sphere method (Demer et al. 2015). This method provides estimates of on-axis gain ($G_o, dB\ re$ 1), and the S_a correction factor ($S_{a\ corr}, dB\ re$ 1). Unfortunately, the calibrations were only done for pulse durations of 1.024 ms, whereas survey data were recorded at 2.048 ms. In the absence of calibration results for this longer pulse duration, we establish a correction factor to allow calibrations results for 1.024 ms to be applied to 2.048 ms data.

b. Methods

Two correction factors are required. First, a correction factor (cf_1) is calculated to account for the difference between the calibration values applied to the ***initial*** estimates of biomass (i.e., 2019 results and nominal manufacturer results respectively for *Amaltal Mariner* and *San Waitaki)* and the values obtained from the recent calibrations that were done for each vessel for 1.024 ms pulse duration.

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$$\Delta G_0 = G_{0\ (initial)} - G_{0\ (1.024ms)}\ (dB) \qquad (1)$$

$$\Delta S_{a\ corr} = S_{a\ corr\ (initial)} - S_{a\ corr(1.024\ ms)}\ (dB) \qquad (2)$$

ΔG_0 and $\Delta S_{a\ corr}$ are multiplied by 2 to account for two-way transmit-receive effect.

$$COMBINED_{initial\ to\ 1.024ms} = 2\Delta G_0 + 2\Delta S_{a\ corr}\ (dB) \qquad (3)$$

The combined difference is converted to linear to calculate cf_1:

$$cf_1 = 10^{\left(\frac{COMBINED_{initial\ to\ 1.024\ ms}}{10}\right)} \qquad (4)$$

A second correction factor (cf_2) was calculated to account for the differences in G_o and $S_{a\ corr}$ between 1.024 ms and 2.048 ms pulse durations. To estimate cf_2, we first collated examples from our archives where calibrations had been conducted for both 1.024 and 2.048 ms pulse durations as part of the one calibration outing. This analysis was done for the Simrad ES38B transducer model that is installed on *Amaltal Mariner* (n=21, 10 vessels) and the newer ES38-7 model that is installed on *San Waitaki* (n=7, 4 vessels).

Our concern was not with the absolute values of G_o or $S_{a\ corr}$, but rather the difference between these values when moving from 1.024 ms to 2.048 ms pulse duration. These differences were calculated as follows:

$$\Delta G_0 = G_{0\ (1.024\ ms)} - G_{0\ (2.048\ ms)}\ (dB) \qquad (5)$$

$$\Delta S_{a\ corr} = S_{a\ corr\ (1.024\ ms)} - S_{a\ corr(2.048\ ms)}\ (dB) \qquad (6)$$

ΔG_0 and $\Delta S_{a\ corr}$ are multiplied by 2 to account for two-way transmit-receive effect.

$$COMBINED_{1.024\,ms\,to\,2.048ms} = 2\Delta G_0 + 2\Delta S_{a\,corr}\,(dB) \qquad (7)$$

The combined effect of ΔG_0 and $\Delta S_{a\,corr}$ is converted to linear to provide a correction factor.

$$cf_2 = 10^{\left(\frac{COMBINED_{1.024s\,to\,2.048\,ms}}{10}\right)} \qquad (8)$$

The initial biomass calculations can be converted to a final biomass estimate by multiplying by the two correction factors.

$$final_{biomass} = original_{biomass} * cf_1 * cf_2 \qquad (tonnes)$$

c. Results

The first correction factor, cf_1, was based on the differences between initial and measured calibration values at 1.024 ms are provided for both vessels in Table A.1.

Table A.1: Linear correction factor cf_1, to adjust for difference between initial calibration parameters applied to biomass estimates and the calibration results carried out at 1.024 ms.

Vessel	$G_{0\,(initial)}$	$S_{a\,corr\,(initial)}$	$G_{0\,(1.024ms)}$	$S_{a\,corr(1.024\,ms)}$	Combined offset (dB)	cf_1
San Waitaki	25.5	0	25.86	-0.05	-0.62	0.866
Amaltal Mariner	27.036	-0.56	26.85	-0.56	0.525	1.128

The second correction factor, cf_2, is based on the differences between calibrations at 1.024 ms and 2.048 ms observed for archived calibration experiments. These are visualised in Figure A.1 and Figure A.2 for ES38 and ES38-7 transducers, respectively.

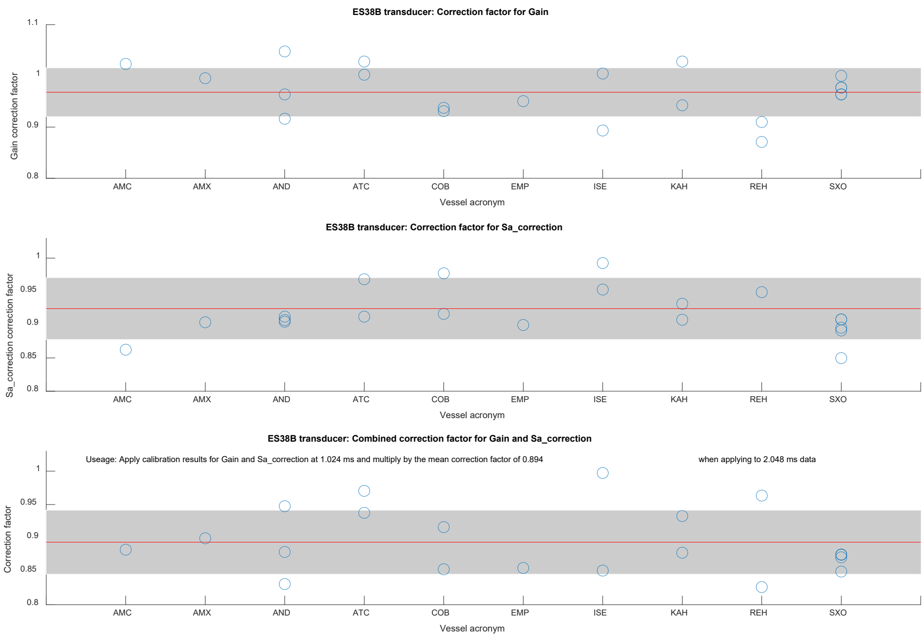

Figure A.1: Linear correction factors for Gain (G_0) *(top panel),* Sa correction ($S_{a\,corr}$) (middle panel) and these factors combined (bottom panel) to give an overall correction factor for Simrad ES38B transducer. The blue circle indicates results of each experiment where calibrations were carried out at 1.024 and 2.048 ms pulse durations in the one outing. The solid red line indicates mean of the overall correction factors while the grey shaded area represents the standard deviation.

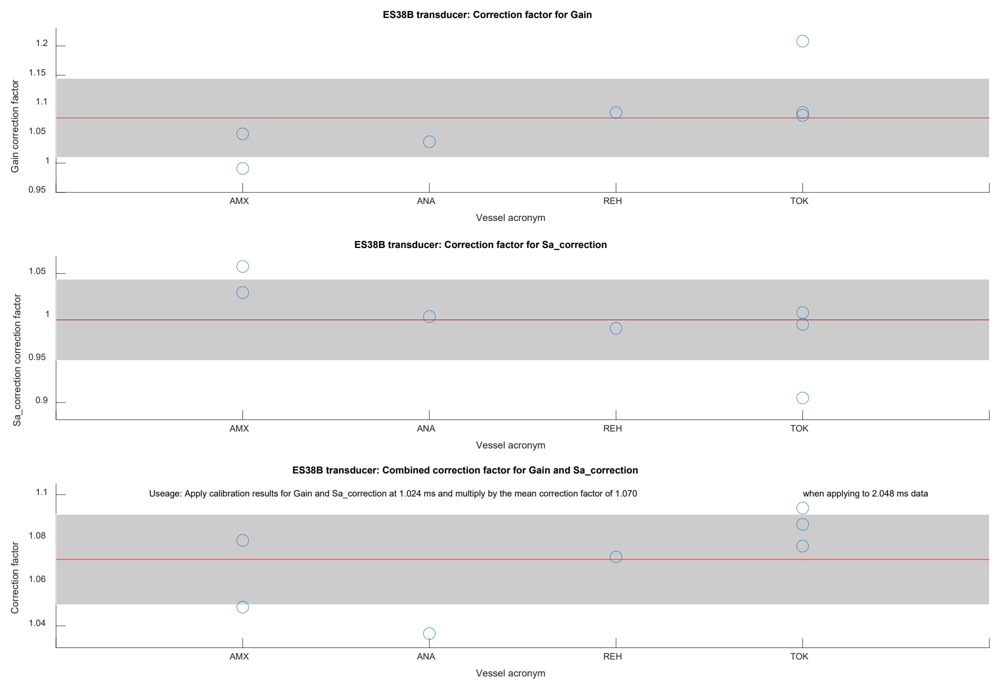

Figure A.2: Linear correction factors for Gain (G_0) *(top panel)*, Sa correction ($S_{a\,corr}$) (middle panel) and these factors combined (bottom panel) to give an overall correction factor for Simrad ES38-7. The blue circle indicates results of each experiment where calibrations were carried out at 1.024 and 2.048 ms pulse durations in the one outing. The solid red line indicates mean of the overall correction factors while the grey shaded area represents the standard deviation.

Table A.2: Correction factor cf_2 to adjust biomass estimates that were based on data collected at 2.048 ms pulse durations using calibration results collected at 1.024 ms pulse duration. cf_2 estimates based on multiple archived calibration experiments carried out for 1.024 ms and 2.048 ms as part of the one outing.

Transducer	Number of vessels	Number of calibration experiments	Mean cf_2	Standard deviation cf_2
ES38-7*	4	7	1.07	0.02
ES38B**	7	21	0.893	0.04

* The same model that is installed *San Waitaki,* ** the same model that is installed on *Amaltal Mariner.*

Table A.3: Application of correction factors cf_1 and cf_2 to respectively apply the calibration results for 1.024 pulse duration and to translate a correction to the surveys carried out at 2.048 ms pulse duration.

Location	Vessel	cf_1	cf_2	combined correction factor (i.e. cf_1 x cf_2)
Rekohu	*Amaltal Mariner*	1.128	0.893	1.008
Spawn Plume	*San Waitaki*	0.866	1.07	0.927

Table A.4: Final biomass results for vessel-based surveys of Rekohu and Spawn Plume. Numbers in red font are for estimates calculated using the initial values for G_0 and $S_{a\,corr}$.

Location	Vessel	Combined correction factor	Biomass above acoustic bottom (t)	CV	Dead-zone estimate (tonnes, % of total)	Total biomass (t)
Rekohu	*Amaltal Mariner*	1.008	11 362 (11 272)	0.16	1 181 (9.4%) (1 172)	12 543 (12 444)
Spawn Plume	*San Waitaki*	0.927	30 308 (32 672)	0.2	4 846 (13.8) (5 225)	35 155 (37 897)

APPENDIX B – TABLE OF ACTIVITIES

Table B.1: Table of activities for *Amaltal Apollo* survey.

OP	Activity	Start Date	Location	Comment
1	Vessel Survey	2021-07-04 00:58	Morgue	Large marks, high-signal gas bladder regions present
2	AOS Survey	2021-07-04 01:57	Morgue	Large marks, high-signal gas bladder regions present
3	AOS Survey	2021-07-04 11:35	Morgue	
4	Vessel Survey	2021-07-04 18:00	Graveyard	Tall mark above top of feature
5	AOS biological	2021-07-04 19:05	Morgue	Net too far off bottom, negligible catch
6	AOS biological	2021-07-04 22:17	Morgue	Net too far off bottom, negligible catch
7	AOS biological	2021-07-05 00:43	Morgue	Perfect shot – 5.5 tonnes ORH.
8	Vessel Survey	2021-07-05 03:24	Graveyard	Quick two-transect pass. Backscatter from ORH in amongst background noise.
9	AOS Survey	2021-07-05 04:16	Morgue	Large marks, high-signal gas bladder regions present
10	AOS survey mode - single pass	2021-07-05 10:54	Graveyard	Confirm mark on Graveyard is ORH
11	AOS Survey	2021-07-06 00:43	Rekohu	Very long survey, slow going with weather and ~ 2 hrs gap when winch spooling gear was fixed. 08:20 UTC - ran adjustment exercise to trim up roll on AOS - moved port winch out 3 turns then stepped back through three turns in one turn increments
12	Biological sample, no AOS	2021-07-07 20:24	Rekohu	Biological sampling shot. AOS had to be taken off as it was affecting Marport sensor placement which meant that skipper was not getting a clear picture to see fish going in the net on the previous shot. Large mark observed on vessel sounder just prior. 22 tonne bag of roughy
13	Wide Area Search	2021-07-08 03:07	Spawn Plume	No substantial marks observed, thick haze. Search abandoned due to vessel issues, steaming to Napier.
14	Vessel calibration	2021-07-11 06:57	Nelson Bay	Calibration completed successfully for 2.048 and 4.096 ms. 60 mm copper sphere used. Water temp 9.5 degrees.

Table B.2: Vessel-based 38 kHz acoustic surveys conducted by *Amaltal Mariner.* Bold text indicates that survey was suitable for biomass estimation.

Survey number	Start Time	End time	Location
1	4/07/2021 14:59	4/07/2021 17:00	West of 180s at 178 W
2	5/07/2021 01:15	5/07/2021 03:45	Rekohu
3	**5/07/2021 06:09**	**5/07/2021 09:45**	**Rekohu**
4	5/07/2021 14:14	5/07/2021 17:20	Spawn Box
5	5/07/2021 22:15	6/07/2021 02:13	Spawn Box
6	6/07/2021 06:02	6/07/2021 10:30	Spawn Box
7	6/07/2021 13:28	6/07/2021 18:30	Spawn Box
8	6/07/2021 20:05	6/07/2021 23:35	Spawn Box
9	7/07/2021 01:49	7/07/2021 04:30	Spawn Box
10	7/07/2021 18:30	7/07/2021 20:45	Spawn Box
11	8/07/2021 00:24	8/07/2021 04:30	Rekohu

Table B.3: Vessel-based 38 kHz acoustic surveys conducted by *San Waitaki.* Bold text indicates that survey was suitable for biomass estimation.

Survey number	Start Time	End time	Location
1	12/07/2021 04:55	12/07/2021 12:11	Rekohu
2	**16/07/2021 07:02**	**16/07/2021 11:58**	**Spawn Plume**

APPENDIX C – THEMATIC MAPS SHOWING ORANGE ROUGHY BACKSCATTER FOR EACH SURVEY

Morgue

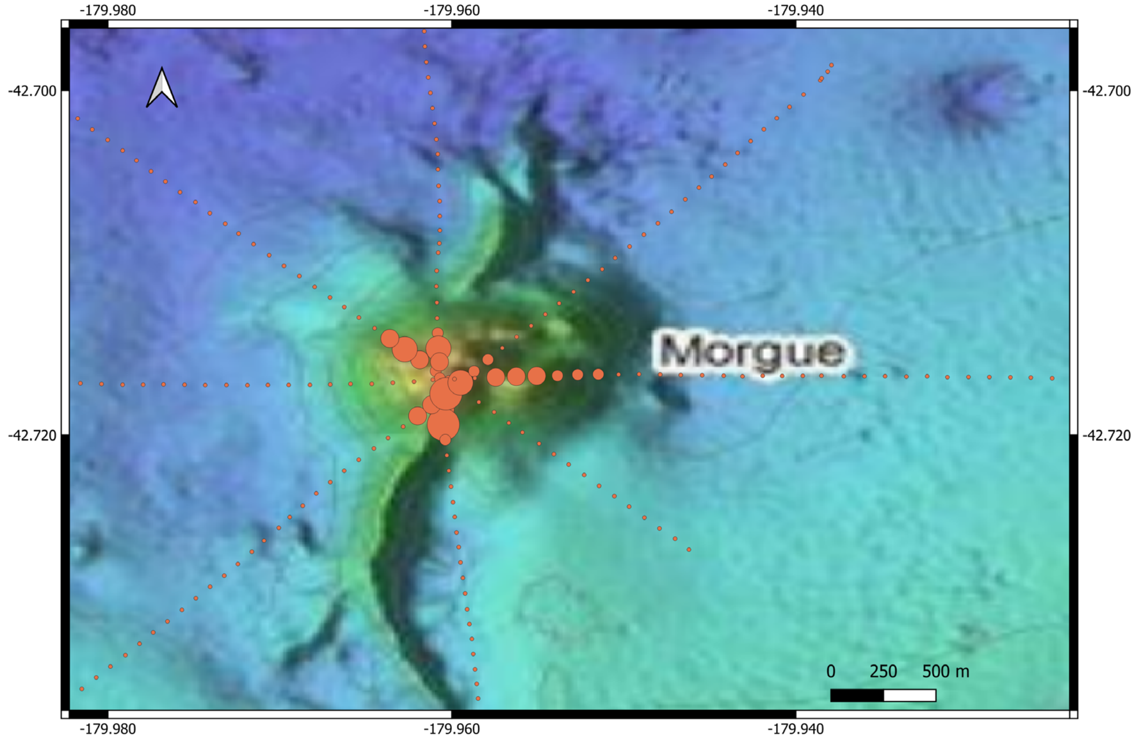

Figure C.1: Thematic map of AOS 38kHz backscatter from regions classified as orange roughy. Morgue. OP2. 2021-07-04 01:57. Circle size is proportional to summed backscatter for each 100 m interval.

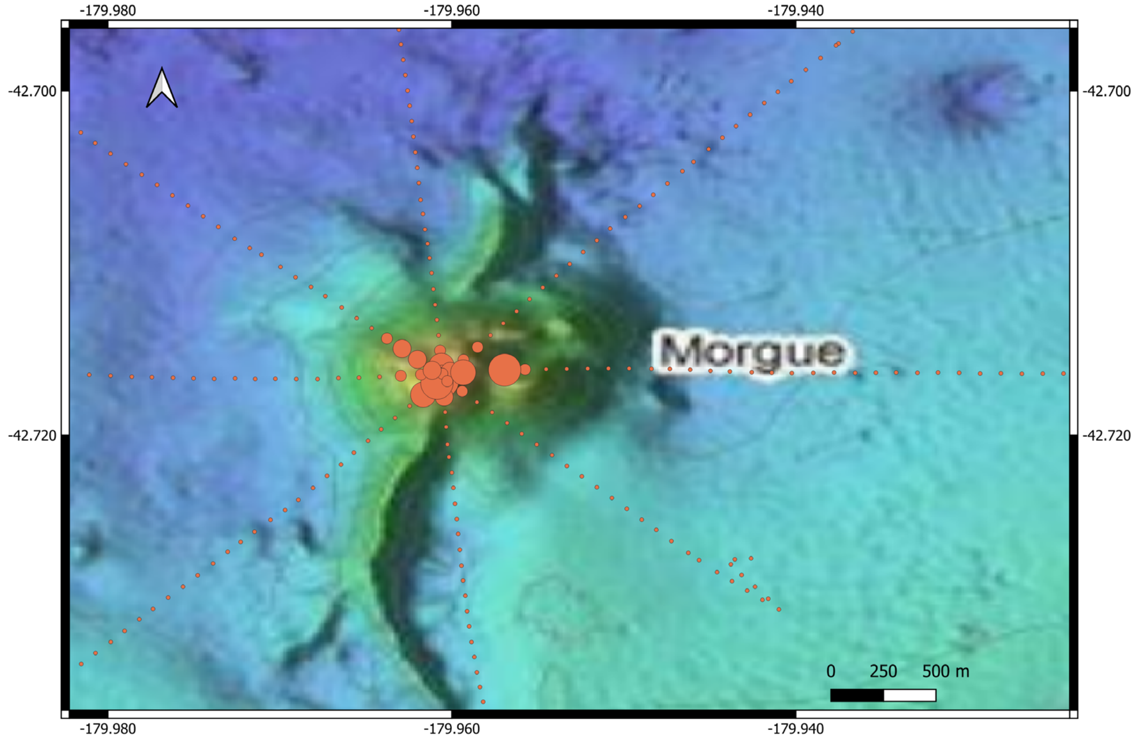

Figure C.2: Thematic map of AOS 38kHz backscatter from regions classified as orange roughy. Morgue. OP3. 2021-07-04 11:35. Circle size is proportional to summed backscatter for each 100 m interval.

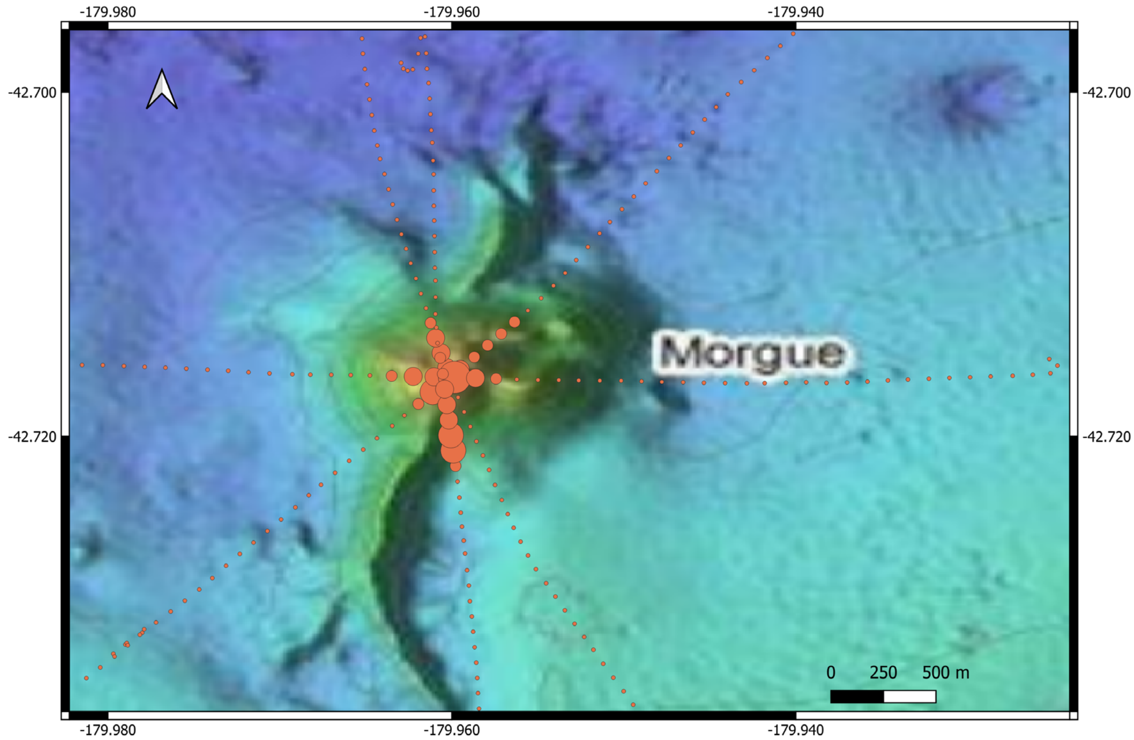

Figure C.3: Thematic map of AOS 38kHz backscatter from regions classified as orange roughy. Morgue. OP9. 2021-07-05 04:16. Circle size is proportional to summed backscatter for each 100 m interval.

Rekohu

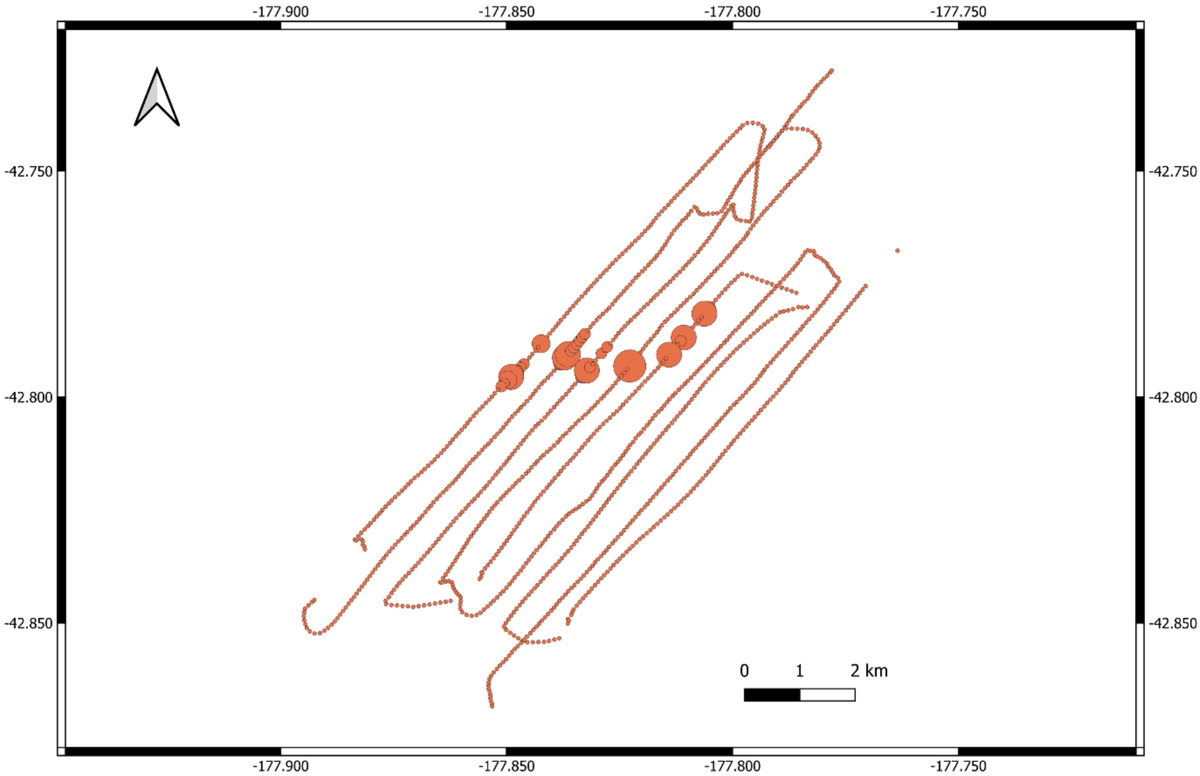

Figure C.4: Thematic map of AOS 38kHz backscatter from regions at Rekohu classified as orange roughy. 2021-07-06 00:43. Circle size is proportional to summed backscatter for each 100 m interval.

Figure C.5: Thematic map of *Amaltal Mariner* vessel-based 38kHz backscatter from regions at Rekohu classified as orange roughy. 2021-07-06 00:43. Circle size is proportional to summed backscatter for each 100 m interval.

Spawn Plume

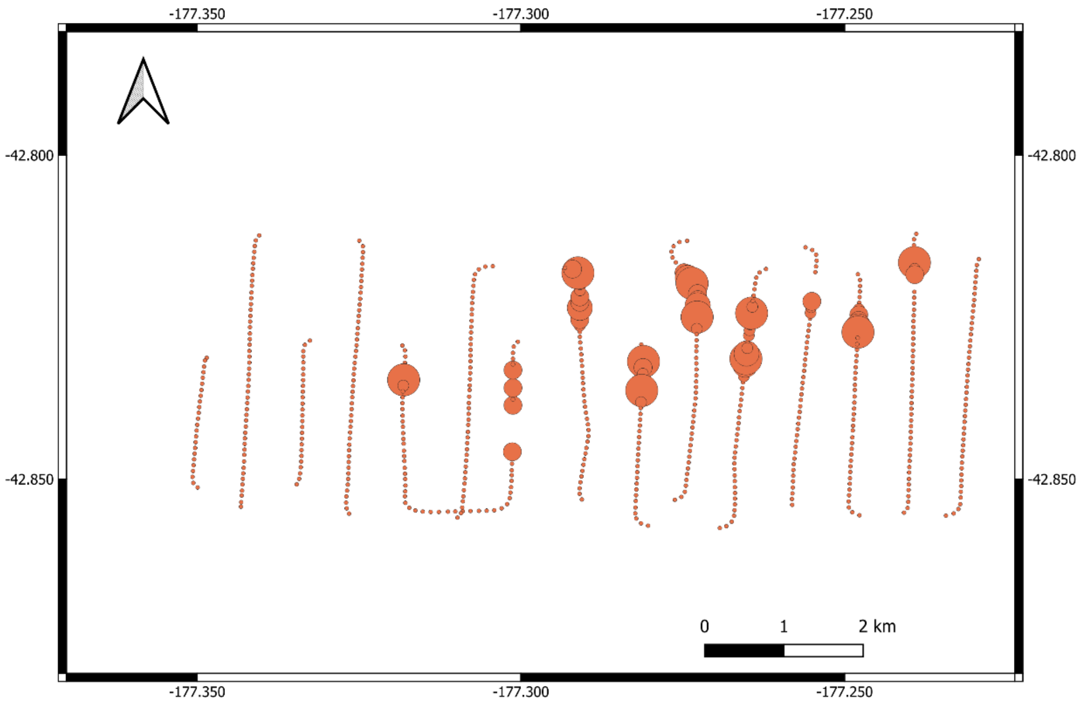

Figure C.6: Thematic map of *San Waitaki* vessel-based 38kHz backscatter from regions at Spawn Plume classified as orange roughy. 2021-07-16 06:49. Circle size is proportional to summed backscatter for each 100 m interval.

APPENDIX D – SURVEY CATCH RECORD

Code	Common Name	Scientific Name	Weight (kg)	No. Caught	No. Stations
BOE	Black oreo	*Allocyttus niger*	1	1	1
CMX	*Coryphaenoides mcmillani*	*Coryphaenoides mcmillani*	0	2	1
CYP	Longnose velvet dogfish	*Centroscymnus crepidater*	15.5	15	3
ETB	Baxters lantern dogfish	*Etmopterus baxteri*	300.7	179	4
GSP	Pale ghost shark	*Hydrolagus bemisi*	1.5	1	1
HAK	Hake	*Merluccius australis*	14.4	3	1
HJO	Johnson's cod	*Halargyreus johnsonii*	2.6	6	1
HOK	Hoki	*Macruronus novaezelandiae*	7.1	2	1
JAV	Javelin fish	*Lepidorhynchus denticulatus*	1.2	4	1
LIN	Ling	*Genypterus blacodes*	8.1	1	1
LIT	Intricate lanternfish	*Lampanyctus intricarius*	0.1	1	1
LNT	Notal lanternfish	*Lampadena notialis*	0	1	1
ORH	Orange roughy	*Hoplostethus atlanticus*	27443.8	20928	3
PHO	Lighthouse fish	*Phosichthys argenteus*	0.2	3	3
PLS	Plunket's shark	*Proscymnodon plunketi*	12.8	2	2
RIB	Ribaldo	*Mora moro*	112.4	77	1
SBK	Spineback	*Notacanthus sexspinis*	0.3	1	1
SND	Shovelnose spiny dogfish	*Deania calcea*	23.2	5	1
SOR	Spiky oreo	*Neocyttus rhomboidalis*	60.3	79	2
SSO	Smooth oreo	*Pseudocyttus maculatus*	27.9	29	3
VSQ	Violet squid	*Histioteuthis spp.*	1.1	1	1
WHX	White rattail	*Trachyrincus aphyodes*	3.2	1	1
WSQ	Warty squid	*Onykia spp.*	0.9	1	1

APPENDIX E – *AMALTAL APOLLO* VOYAGE PERSONNEL:

Science Party

Tim Ryan (CSIRO)	Voyage leader, acoustic specialist/survey operations
Rob Tilney (Thalassa)	Project management/Biological Leader
Rob Gregor (CSIRO)	Technical support, deep-camera operations
Nick Mortimer (CSIRO)	Technical support, deep-camera operations
Ryan Downie (CSIRO)	Acoustic specialist/survey operations
Clinton Grobbler	Biological sampling
Stephen Punnet	Fisheries New Zealand Observer and biological team member

Personnel - *Amaltal Apollo*

Darryl Saunders	Captain
Poul Scott	1st Mate
Craig Madigan	Factory Manager

and crew.