Biomass surveys of orange roughy and oreo species using a net-attached acoustic optical system for New Zealand ORH7B and ORH3B Puysegur management areas in June, July 2015

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Final Report to Deepwater Group Ltd, New Zealand

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Important disclaimer

Contents

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1 Executive summary

In late June and early July 2015, an 18-day acoustic survey program was conducted off the west coast of New Zealand's South Island in the ORH7B management area, and south of New Zealand's South Island in the ORH3B Puysegur region with objectives as below. The primary survey instrument was a net-attached acoustic optical system (AOS) that conducted echointegration transect surveys to quantify the biomass of orange roughy and oreo species. Video, stereo digital stills and trawl catch information complemented the multifrequency AOS acoustics to aid in species identification and provide biological samples. Calibrated vessel acoustics were also used to quantify the biomass in cases where data quality was high and identification of species appeared straightforward.

Survey objectives ORH7B management area

A. To estimate the abundance from an acoustic survey, with a target coefficient of variation (CV) of the estimate of 20 - 30%, of orange roughy (ORH) in winter 2015 for the ORH7B spawning stock.
B. Collection of biological material to inform acoustic data and understanding of the deepwater ecosystem.

Survey objectives Puysegur Bank ORH3B management area

C. To estimate the abundance from an acoustic survey, with a target coefficient of variation (CV) of the estimate of 20 - 30%, of orange roughy (ORH) in winter 2015 for the Puysegur Bank spawning stock.
D. To acquire AOS survey data on black (BOE) and smooth (SSO) oreo and provide an exploratory analysis of biomass.
E. Collection of biological material to inform acoustic data and understanding of deepwater ecosystem

1.1 ORH7B management zone.

Four main regions were surveyed between 28th June and 2nd July, being Cook Canyon, The Abut, Moeraki Canyon and SW flats. A further four small features at the southern end of ORH7B were briefly surveyed as the vessel transited to the Puysegur region. To achieve the target CV of 30% for acoustic surveys requires high confidence species identification and the schools aggregated to provide backscatter signal above the background noise. This is usually obtained for the low target strength (TS) orange roughy when they are in large schools. We found that all surveyed regions lacked such orange roughy schools that were suitable for acoustic surveying despite extensive searching with the vessel's echosounders. Consequently no formal acoustic surveys were conducted and therefore the objective of biomass estimates with CV of 20-30% could not be realised for the ORH7B management zone surveys.

The ORH7B region has extensive grounds at a suitable depth for orange roughy (~ 900m) of which our vessel searching covered only a small proportion. When the fishery was open prior to October 2007, multiple vessels operated, providing greater searching effort. Further, anecdotal information suggests that the fishing vessels were able to achieve their catch without necessarily encountering large orange roughy spawning aggregations. Given the large area to survey and limited information on the timing and areas of orange roughy spawning here, further observations are needed to establish whether suitable orange roughy schools can be located and effectively surveyed using acoustics in this management zone. If spawning aggregations of orange roughy are not readily located, alternative survey methods may be more appropriate.

1.2 ORH3B Puysegur region

The Puysegur Bank fishing grounds in the ORH3B fishery management area are located ~120 nautical miles southwest of South Island,. Eight key survey locations were encompassed in a 40 by 30 nautical mile area. Acoustic and trawl survey activities were carried out between the 3rd and 13th of July 2015.

The largest and most important region for orange roughy biomass was Goomzy. There, large catches of orange roughy with a low proportion of bycatch were taken and orange roughy aggregations were often observed on the vessel's echosounders. However these were quite mobile and ephemeral. Two comprehensive AOS surveys did not encounter significant aggregations of orange roughy at the time of survey, despite closely spaced transects. Thus no AOS based biomass estimates could be made.

Two vessel acoustic surveys at Goomzy were carried out in quick succession at a time when the orange roughy aggregations were available to the vessel acoustics and relatively stable. The vessel-based acoustic biomass estimates at Goomzy ranged from 4160 to 4235 tonnes with survey sampling CVs of 25% and 56% respectively and a dead zone component of approximately 18% (Table 1). As per the Deepwater Working Group recommendations, these estimates used the Doonan et al. (2003b) absorption equations, applied no direct motion correction but added a 33% correction factor to account for signal loss due to vessel motion and bubble attenuation. Alternative estimates that use the equations of Francois and Garrison (1982b) to estimate absorption and the Dunford (2005a) equations to directly correct for motion effects result in biomass estimates that are approximately 15% higher.

These vessel acoustic surveys were conducted during a period of good weather where the acoustic data quality was acceptable and when the aggregations were relatively stable. We note the primary intention of the surveys was to achieve biomass estimates based on the AOS system but this was thwarted by a lack of availability at the time of survey. The vessel-based estimates are presented noting higher uncertainties in species composition, absorption estimates, deadzone estimate and platform motion effects when compared to AOS-based estimates. The combined CV, taking into account all significant sources of error were 36% and 63% for operations 49 and 50 respectively, both of which are above the target of 20-30% (Table 1). Future surveys could potentially reduce the error if multiple surveys are achieved within the spawning window and assuming orange roughy aggregations are available and stable.

Table 1. Acoustic biomass estimates for vessel mounted surveys at Goomzy

OP no.	Above acoustic bottom (tonnes)	Survey sampling CV (%)	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)	Motion correction and bubble attenuation factor (%)	Combined CV (%)
49	3452	25	783 (18.5)	4235	33	36
50	3407	56	753 (18.1)	4160	33	63

The other seven survey locations at Puysegur generally had reasonable or even strong and extensive acoustic marks. Adverse weather, time constraints and logistics prevented comprehensive acoustic surveys being carried out at each of these seven locations. Prioritisation was made according to historic knowledge and observations in the early stages of the survey program. Three of the seven locations, Godiva, Porirua and Mt Duncan were a focus with vessel and AOS surveys complemented by demersal trawling. These three locations were identified as having mix species aggregations either by demersal trawl catch or AOS information. Black and smooth oreo (large gas bladder species) and orange roughy were typically the most numerically abundant species. Biomass estimates for black and smooth oreo and orange roughy were made using the demersal trawl catch composition to apportion the acoustic backscatter according to the numeric density of the dominant species and their target strength (TS) values. As stated in the project objectives, this was an exploratory analysis with results reported below. They have a high degree of uncertainty due to unquantified issues of trawl catch selectivity, species avoidance and TS uncertainty.

Table 2. Acoustic biomass estimates at 38 kHz of dominant species at three mixed species locations in the Puysegur fishery

		Biomass (tonnes)							
Location	Op	Orange roughy	Black oreo	Smooth oreo	Deepwater shark	Area ($n.mi^2$)	NASC (m^2 $n.mi^{-2}$)	System	Dead zone
Godiva	44	162	149	112		0.83	383	Vessel 38 kHz	No
		183	167	125		0.92	430		Yes
	45	100	92	69		0.97	203	Vessel 38 kHz	No
		179	164	123		0.97	362		Yes
	45	146	134	100		1.27	225	AOS 38 kHz	No
		266	244	183		1.27	410		Yes
Porirua	35	11	131	84		1.12	238.5	AOS 38 kHz	No
	35	13	161	104		1.12	293		Yes
Mt Duncan	39	497	533	334	276	2.6	557	AOS 38 kHz	No
	39	541	580	364	301	2.6	606.2	AOS 38 kHz	Yes

1.3 Conclusions and recommendations

The viability of acoustic surveys in the ORH7B management zone is dependent on suitable aggregations being present that are representative of the spawning population of orange roughy. If suitable spawning aggregations cannot be located alternative survey methods may be more appropriate.

In the ORH3B Puysegur management area the mobile and ephemeral nature of the Goomzy orange roughy aggregations meant that the two AOS surveys proved ineffective in providing a basis for biomass estimation and the target survey CV of 20-30% could not be met. The lower precision vessel-based estimates provided the only quantitative measure of acoustically derived orange roughy biomass at Goomzy. Further surveys will be needed in future years in order to obtain repeatable measures to corroborate the estimates made in 2015.

The uncertainty of biomass estimates at mixed species locations that use trawl catch species composition to partition the acoustic signal may be high if, as is likely, there is a mismatch between trawl catchability and acoustic vulnerability. As a minimum there needs to be time to conduct a sufficient number of demersal trawls in order to characterise a region. Further work on the target strength of the black and smooth oreo species may help reduce uncertainties for this key parameter. Emerging acoustic broadband techniques currently being explored may in future provide extra information that would allow better delineation of species and therefore more precise biomass estimates.

2 Introduction

From June 27th to July 13th 2015 a series of acoustic and biological survey activities were carried out to quantify orange roughy spawning biomass in the ORH7B fishery management area (West Coast, South Island) and Puysegur Bank fishing grounds in ORH3B (~100 nautical miles south of South Island), Figure 1 and Figure 2 respectively. The primary acoustic survey instrument was a trawl-net attached Acoustic Optical System (AOS) which was towed deeply to conduct multi-frequency transect surveys (Kloser et al., 2011a; Ryan and Kloser, 2016). These AOS surveys were designed to quantify the biomass of orange roughy using acoustic echo-integration methods whilst minimising known biases (Simmonds and MacLennan, 2005). Important sources of bias in echo integration surveys for orange roughy at deepwater locations are; species identification, target strength (TS), deadzone estimation, fish movement and avoidance reaction.

A secondary survey objective was to estimate biomass of smooth and black oreo species in the Puysegur region.

Demersal trawls, with the AOS attached to the headrope, provided biological information including species composition and measures of fish length, weight, sex and spawning condition. The AOS-demersal trawls also provided acoustic target strength (TS) information at two frequencies complemented by video and stereo digital still photographs. During AOS surveys the vessel's calibrated ES60 38 kHz echosounder was running concurrently. A Furuno FCV 30 triple beam echosounder was also used during searches for fish, taking advantage of the side-looking echosounder beams to increase survey coverage. This report covers the surveys undertaken and provides acoustic based biomass estimates of orange roughy and of oreo species where suitable aggregations were encountered.

Survey objectives ORH7B management zone

1. To estimate the abundance of the orange roughy spawning stock from an acoustic survey, with a target coefficient of variation (CV) of the estimate of 20 - 30%.
2. To collect biological material to inform the acoustic data and towards an improved understanding of the deepwater ecosystem.

Survey objectives ORH3B Puysegur Bank

1. To estimate the abundance of the orange roughy spawning stock from an acoustic survey, with a target coefficient of variation (CV) of the estimate of 20 - 30%.
2. To acquire data on black (BOE) and smooth (SSO) oreo using the AOS towards providing an exploratory analysis of biomass.
3. To collect biological material to inform the acoustic data and towards an improved understanding of the deepwater ecosystem.

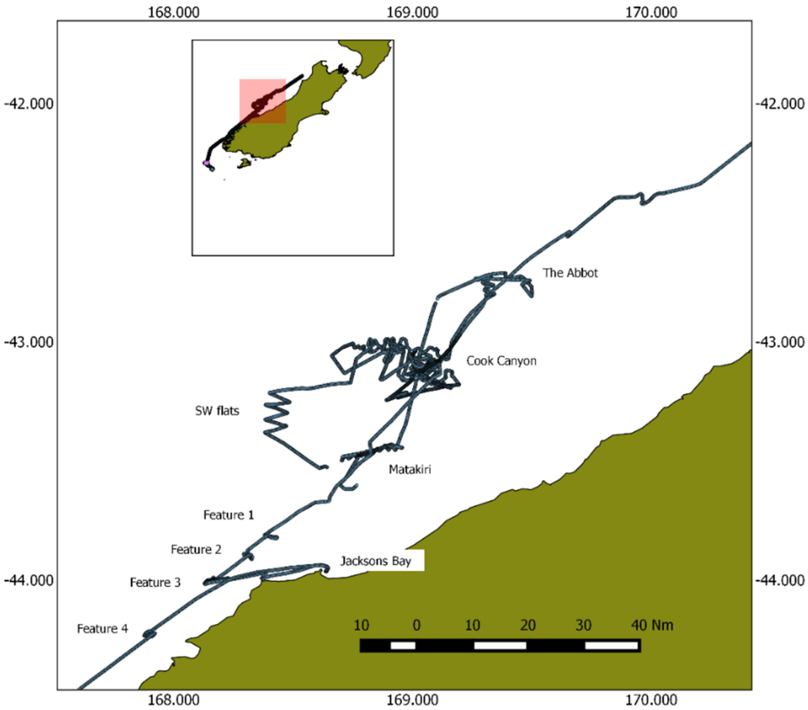


Figure 1. Survey tracks and areas in the ORH7B region.

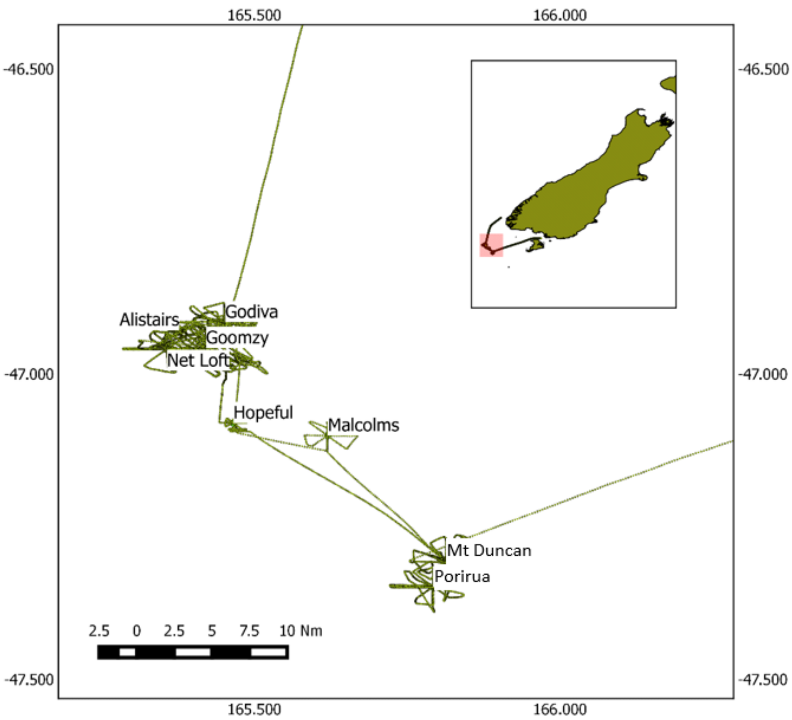


Figure 2. Puysegur Bank region in ORH3B showing locations of survey activities. Green line indicates vessel track. Inset shows location of survey region (pink box) in relation to South Island.

3 Methods

3.1 Equipment and operational modes

Sealord Group Ltd's AOS was used as the primary acoustic survey instrument. This system was built as a collaborative project with Sealord and CSIRO ("Development and application of acoustic-optical technology for sustainable deep-sea fishing"), starting in 2012 based on previous successful developments and applications in Australia and New Zealand (Kloser et al., 2011b; Kloser and Ryan, 2011). It is similar in principle to the CSIRO AOS (Ryan et al., 2009) but with technological advances and modifications to improve ease of operation.

The Sealord AOS consisted of a sled-style platform attached to the headline of the vessel's demersal trawl net. The AOS housed a four-frequency acoustic system (12, 38, 120 and 200 kHz) based on Simrad ES60 transceivers. The 38 kHz and 120 kHz transceiver/transducer combinations were the key quantitative frequencies. The system was battery powered with all data logged to internal storage media. Specifications of the Sealord AOS system are provided in Table 3.

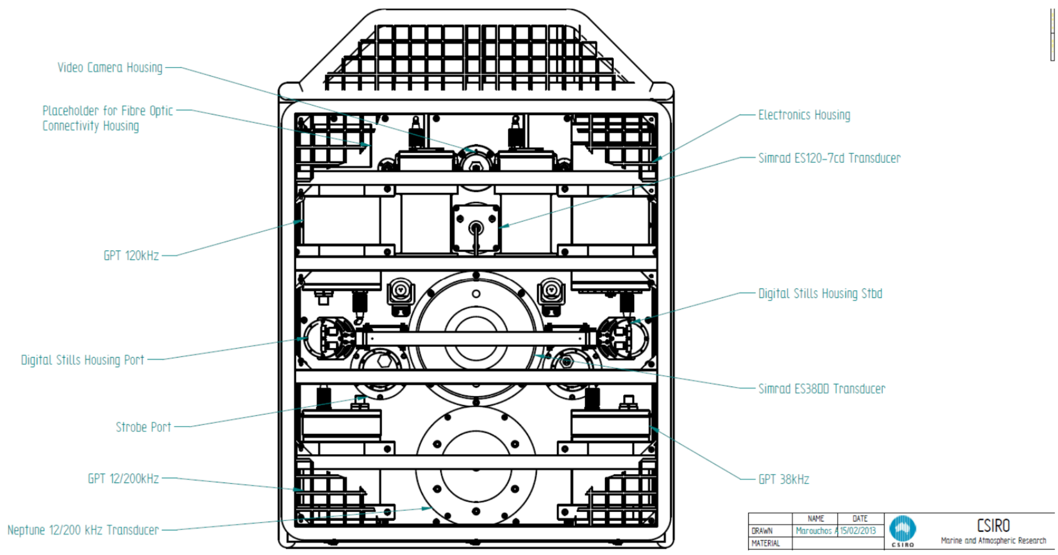


Figure 3. Sealord Acoustic Optical System (AOS)

Table 3. Sealord AOS specifications

Component	Specifications
Physical	Dimensions: 1.9 × 1.4 × 0.5 m, sled-style platform; weight: 750 kg in air,; operational depth: 1500 m.
Acoustics	Echosounders: Simrad ES60, 38 and 120 kHz split-beam transceivers, Simrad ES60 12 and 200 kHz; Transducers: 38 kHz - Simrad ES38DD (7° beam width), SN 28363 ; and 120 kHz - ES120–7CD (7° beam width), SN 115. Neptune Sonar 12 kHz (14 °beam width) with single element 8° beam width 200 kHz.
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 (two hour battery endurance)
Digital Stills	Paired Prosillica GX3300 Gigabyte Ethernet cameras with Zeiss F2.8, 25mm focal length Distagon F mount Lens. Quantum Trio strobe.
Reference scale	Two Laserex LDM-4 635 nm 8 mW red lasers set 400 mm apart.
Computing	Industrial Arc PC (running Simrad ER60 v2.1.1 software, and providing time-reference for acoustic and video data). Intel NUC i7 computer for Gig-E digital still acquisition.
Motion reference	Microstrain 3DM-GX1
Power	Li-ion. Battery endurance: 18 hours

Operational modes

The 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 main survey modes and a calibration mode (Table 4).

Table 4. Summary of AOS operational modes

Mode	Objective	Height above seafloor (m)	Comments
1	Echo-integration survey	250-350	
2	Target strength with concurrent optical images and collection of research catch for biological sampling	5-30 meters	Conventional demersal trawl with net-attached instrumentation
3	Calibration: Transducer sensitivity as a function of depth	0-800 m in 100 m steps	Vertical deployment with AOS detached from net

Mode 1: Echo-integration surveys

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

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

Demersal trawls with the AOS attached were undertaken to provide biological samples. For Mode 2 deployments the acoustic systems were set to a short pulse length (0.256 or 0.512 ms) and fast ping rate (~10 Hz) for close-range fish TS measurements. Standard definition video was taken to complement the TS measures. Stereo digital still images from a pair of Prosillica GX3300 Gig-E cameras with frame rate of 1 – 2 shots per second, were collected throughout the demersal trawl to enable accurate fish length determination. The Gig-E cameras were calibrated post-voyage in a local swimming pool using the target frame method described by (Shortis and Harvey, 1998) and processed using SeaGIS photogrammetric calibration software (Seager, 2008).

Mode 3: System calibrations

Acoustics: Transducer gain

The AOS system is normally calibrated by attaching to a trawl warp and lowering to working depths with a calibration sphere suspended beneath the transducers. This requires perfectly calm weather which did not eventuate during this voyage. The AOS components were shipped to Australia where they were installed in a deepwater calibration facility (Decaf) platform. Decaf has a gimballed transducer mounting plate and optic fibre connectivity to the surface. This enables adjustment of the transducer angle with real time viewing of sphere position. This facility greatly improves the chance of calibration success and, importantly, can be carried out in less than perfect weather. A successful calibration of the Sealord AOS 38 kHz and 120 kHz transceivers and transducers was carried out on the South Coast of Tasmania on the 7th of September.

Calibration results are provided in Appendix A – Vessel and AOS calibration), and are summarised below in Table 5.

Table 5. Calibration parameters for AOS 38 kHz and 120 kHz echosounders for Mode 1 echo-integration surveys. Values marked in bold text were applied to the data in Echoview post processing software.

Parameters			
System	AOS	AOS	Vessel
Frequency (kHz)	38	120	38
Calibration data set	September 2015	September 2014*	June 2015
Transducer model	Simrad ES38DD	Simrad ES120-7CD	Simrad ES38B
Serial Number	28363	115	30212 or 30301
Transceiver power (W)	2000	500	2000
Transceiver pulse length (ms)	**2.048**	**1.024**	**2.048**
Transducer gain (dB)	**23.8**	**27.6**	**25.7**
Sa correction (dB)	**-0.37**	**-0.37**	**-0.44**

* Best estimate to apply to 2015 survey results as September 2015 Decaf results indicated a step change in calibration results that is not consistent with 2014 calibration results or observations during survey.

Acoustics: Seawater absorption

AOS acoustics

Values for seawater absorption at 38 and 120 kHz and sound speed were calculated from the equations of (Francois and Garrison, 1982a) and Mackenzie (1981) respectively for a nominal platform depth of 600 m and fish school depths of 900 m using measured values of conductivity, temperature and depth (CTD) data recorded during the AOS deployments (Table 6). 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 6. Nominal seawater absorption and sound speed values for a nominal platform depth of 600 m and fish school depths of 900 m.

Parameter		
Frequency (kHz)	38	120
Absorption (dB/m)	0.00974*	0.0325**
Sound speed (m/s)	1500*	1500*

* Nominal Simrad values; ** calculated from CTD data

Vessel acoustics

Following the Deep Water Working Group's protocols, absorption estimates for application to the hull-mounted 38 kHz echosounder were made using the equations of Doonan et al. (2003a). As a sensitivity check absorption estimates were also made using the equations of Francois and Garrison (1982b).

3.2 Biological sampling

Biological samples of orange roughy and by-catch species were taken from Mode 2 trawls. Nominally, samples of the target species (i.e. orange roughy; black oreo; smooth oreo) comprised 200 fish which were measured for length, (rounded down), weight, sex and gonad stage. Otoliths were extracted from 60 fish per sample. Sampling of by-catch species was also undertaken when appropriate. Catch composition was determined for each trawl by sorting the catch to species and weighing. Total weights for abundant species were derived from factory production figures where necessary. Biological data are summarised in the results section, with further detail given in Appendix B.

3.3 Echogram processing and interpretation

Processing of the acoustic data was done using Myriax Echoview 6.1 or higher acoustic analysis software (Myriax, 2014). Custom Matlab tools were used to extract and process platform depth and motion data that was embedded in the Simrad EK60 raw files. Platform depth data was applied to the towed body operator in Echoview to create echograms with an absolute depth reference. AOS platform motion was recorded at 10 kHz by a Microstrain 3DM-GX25 motion reference sensor. This data was applied to the motion correction operator (Dunford, 2005b) in Echoview to correct for signal loss due to platform motion (Stanton, 1982).

3.3.1 Echogram scrutiny and quality control

Calibration offsets as per Table 5 were applied to the 38 kHz and 120 kHz volume backscattering strength (S_v dB re m^{-1}) echograms (Maclennan et al., 2002). The S_v echograms for these two frequencies were visually inspected and regions of noise interference were marked as bad and removed from the analysis.

3.3.2 Acoustic deadzone estimate

The acoustic 'deadzone' is the region close to the seafloor where the acoustic signal cannot be measured due to the physical characteristics of the transmitted pulse (Ona and Mitson, 1996) and, on sloping ground, due to seafloor backscatter from off-axis side-lobe signal coinciding with water column backscatter (Kloser, 1996; Ona and Mitson, 1996). For the steep-sided features the contribution to the deadzone due to the sloping ground was by far the greater effect. Orange roughy are a semi-demersal species that can occur at high densities within the deadzone region requiring an estimate to account for this biomass component. Previous acoustic observations of orange roughy schools suggest that scenarios of an increased and decreased density within the deadzone region are both possible. We assume that the density of fish immediately above the acoustic bottom was on average representative of the density within the deadzone region. An estimate of backscatter within the deadzone was made as follows. Firstly an 'acoustic seafloor' line was defined, that is the point at which water column signal became contaminated with seafloor reflection signal. The acoustic seafloor line was first generated via the maximum S_v seafloor detection algorithm implemented in Myriax's Echoview v.6.1 software. A back-step of 1.5 m was applied to this line to lift it away from the 'acoustic seafloor' signal. This line was visually inspected and manually adjusted if necessary to ensure that contamination by seafloor signal was avoided. A 'true seafloor' line was then defined based on the maximum S_v value for each ping. The samples between the 'acoustic seafloor' and the 'true seafloor' are deemed to be the deadzone region. The contaminated sample values in the deadzone region are replaced with an average of the S_v signal in the 5 metres immediately above the acoustic seafloor. Two echo-integration signal summations are made: (i) includes only signal above the acoustic seafloor, i.e. uncontaminated by interference by the seafloor signal and (ii) includes both above acoustic seafloor and the estimated signal from within the deadzone region. From this data biomass estimates for (i) above 'acoustic seafloor' and for (ii) above 'acoustic seafloor' plus a deadzone component were made.

3.3.3 Platform geolocation

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

3.3.4 Echogram interpretation and allocation of species

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

3.4 Biomass estimation

During this survey programme none of the AOS surveys encountered spawning homogeneous orange roughy aggregations. Therefore no single-species based biomass estimates were made using AOS data. Where the AOS surveyed mixed aggregations only the 38 kHz was used to estimate biomass, as the TS of the oreo species is not established at 120 kHz. Vessel-based acoustic estimates at 38 kHz were also made where data quality was acceptable. Following protocols of the New Zealand Deepwater Working Group (NZDWG), vessel acoustic data was processed without motion correction, the absorption estimation equation of Doonan et al. (2003b) applied and an empirical correction factor of 1.33 applied to account for signal loss due to vessel motion and bubble attenuation effects. We also present vessel-based biomass estimates where equations of Francois and Garrison (1982a) were used to estimate absorption and motion corrected using the equations of Dunford (2005b) when motion data was available. Echogram regions of high signal were marked to delineate schooling aggregations from surrounding backscatter and were echo-integrated in 0.02 nautical mile intervals to calculate the nautical area scattering coefficient, $s_{A0.02}$ (m^2 $n.mile^{-2}$)

Biomass estimations of orange roughy for star pattern acoustic surveys

Star pattern surveys have an uneven sampling intensity, with regions close to the centre of the survey receiving a higher sampling intensity relative to the outer regions (Doonan et al., 2003a). Uneven sampling can result in significant bias depending on the distribution of fish in relation to the centre of the star transect. To minimize the potential for this type of bias, the polar coordinate stratified techniques (Doonan et al., 2003a) were used to estimate the biomass.

Biomass estimation of orange roughy for grid transect acoustic surveys

Biomass estimates were calculated for both 38 kHz AOS and vessel acoustic data using standard echo-integration methods (Simmonds and MacLennan, 2005). Orange roughy classified echogram regions were echo-integrated in 0.05 nautical mile intervals to calculate the per-interval nautical area scattering coefficient, s_A (m^2 $n.mile^{-2}$, (Maclennan et al., 2002)). These were averaged to give a mean s_A for the survey region ($\overline{s_A}$). This parameter along with estimates of mean population target strength ($\overline{TS}$, dB re 1 m^2), mean population fish weight ($\overline{W}$, kg) and measurement of the survey area (A, $n.miles^2$) were used to estimate orange roughy biomass (Equation 8). Population sex ratio was assumed to be 1:1 when estimating $\overline{TS}$ and $\overline{W}$.

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

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

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

Biomass estimation for mix species aggregations

For surveys of mixed species the acoustic signal was partitioned using equation 9.11 of Simmonds and MacLennan (2005) according to the proportional contribution of the dominant species determined by their percentage-by-number of the total trawl catch and their estimated target strength using TS values currently accepted by the NZDWG (see section 3.4.1).

3.4.1 Target strength estimates

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

Oreo TS estimates at 38 kHz were based on the currently accepted results of (Coombs and Barr, 2004) using the following TS–length regressions of:

$TS_{BOE} = -78.05 + 25.3\log_{10}(L) + 1.62\sin(0.0815L + 0.238)$ and

TS_{SSO} = -82.16 + 24.63log$_{10}$(L) + 1.0275sin(0.1165L – 1.765)

for black and smooth oreos respectively.

3.5 Error estimation

Single species aggregations

Accurate estimates of error from acoustic surveys is a non-trivial task given the number of sources of potentially correlated errors (Simmonds and MacLennan 2005). We implement a method that estimates errors assuming Gaussian distributions and independence from multiple single frequency biomass estimates and check these estimates for acoustic surveys on orange roughy surveys in New Zealand (Hampton and Soule, 2002) and single and multi-frequency surveys of Antarctic Krill (Demer, 2004)

Within a frequency and for an absolute abundance estimate we estimate all significant sources of error assuming they were at the 95% confidence interval and then expressed them as a CV assuming Gaussian distribution. These estimates were assumed to be independent and could be combined (as per chapter 5 of Lever and Thomas (1974)) to give an overall estimate of error using

$$CV_{combined} = \sqrt{\sum_{i=1}^{n} e_i^{\,2}}$$

Where e_i is an independent error component.

Estimates of bias are also given where a negative value indicates that the biomass has been underestimated and vice versa for positive bias.

Mixed species aggregations

The objective for mixed species aggregations was for an exploratory analysis of biomass. The survey plan did not provide for a comprehensive trawl campaign that might sufficiently characterise the proportions of the dominant species. Instead indicative biomass results are presented noting that they will be highly sensitive to the proportion of gas bladder and non-gas bladder species where the errors associated with species composition are unquantified. Therefore no attempt to quantify the errors associated with the biomass estimates for mix species aggregations is made in this analysis.

4 Results and discussion

4.1 ORH7B region

4.1.1 Survey outcomes

An acoustic survey campaign was conducted in the ORH7B fisheries management area located off the west coast of New Zealand's South Island between 28th June and 2nd July, 2015. During the main survey period four regions were surveyed, being Cook Canyon, The Abut, Moeraki Canyon and SW flats. A further four small features at the southern end of ORH7B were briefly surveyed as the vessel transited to the Puysegur region in ORH3B. To achieve the target CV of 30% for acoustic surveys requires high confidence species identification. This is usually obtained for the low target strength (TS) orange roughy when they are in large schools. We found that all surveyed regions lacked such orange roughy schools that were suitable for acoustic surveying despite extensive searching with the vessel's echosounders. Consequently no formal acoustic surveys were conducted and therefore the objective of biomass estimates with CV of 20-30% could not be realised for the ORH7B management zone surveys.

With guidance by Fishing Master Craig Jones, who has extensive experience fishing this region, the main focus of acoustic and trawl sampling was at the Cook Canyon (Figure 4). Here one moderate orange roughy aggregation was located (Figure 5), from which a trawl produced a catch of ~18 tonnes of orange roughy on 30 June, of which approximately 70% were either ripe or spawning with 25% spent. This aggregation was too localised and ephemeral to allow an AOS grid survey. Subsequent trawl catches here were small (1-2 tonnes) and did not indicate the presence of large bodies of spawning orange roughy. By 1 July, around 46% of female gonads were in spent condition, suggesting the survey caught the tail end of the spawning event. Biological sampling results are given in Appendix B.

The ORH7B region has extensive grounds that are at a suitable depth for orange roughy of which our vessel searching covered only a small proportion. When the fishery was open prior to October 2007, multiple vessels operated, providing greater searching effort. Further, anecdotal information suggests that the fishing vessels were able to achieve their catch without necessarily encountering large orange roughy spawning aggregations. Given the large area to survey and limited information on the timing of orange roughy spawning, further observations are needed to establish whether suitable orange roughy schools can be located and effectively surveyed using acoustics in this management zone. If aggregations of orange roughy do not regularly occur in this management region alternative survey methods may be more appropriate.

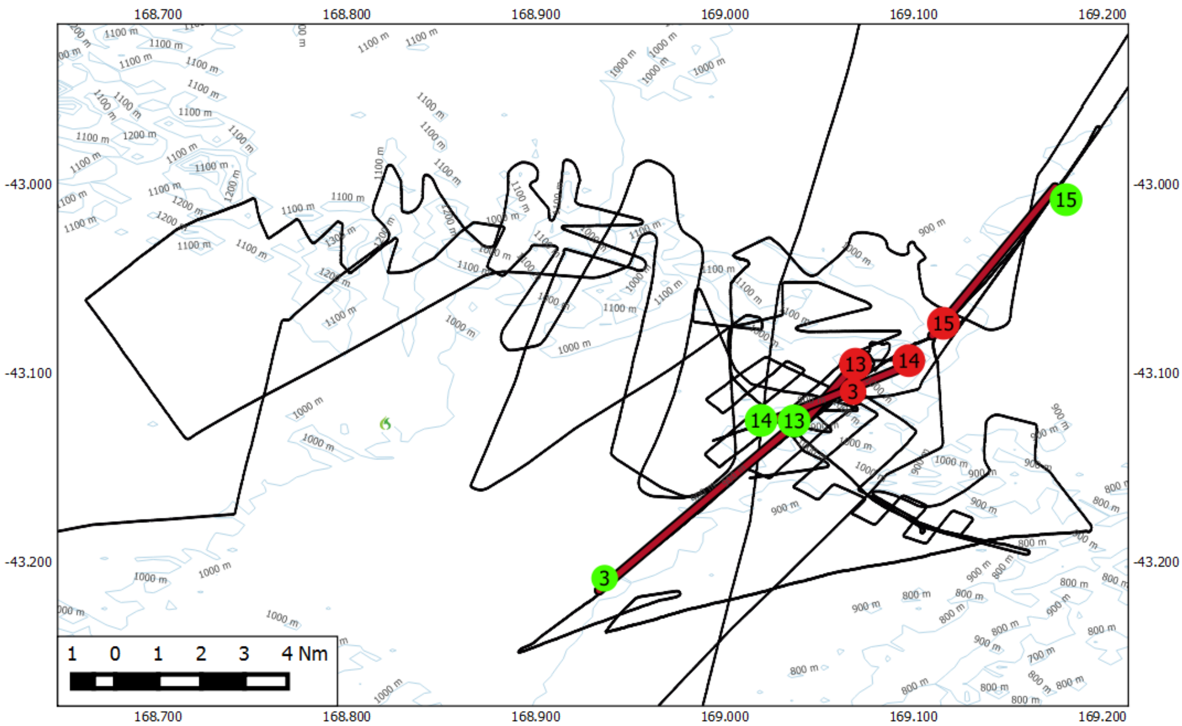


Figure 4. Vessel acoustic and survey and trawling activities at Cook Canyon. Solid black line indicates vessel track. Green circles indicate start of net-on-bottom, red circles point at which net was hauled. Solid red line indicates trawl line.

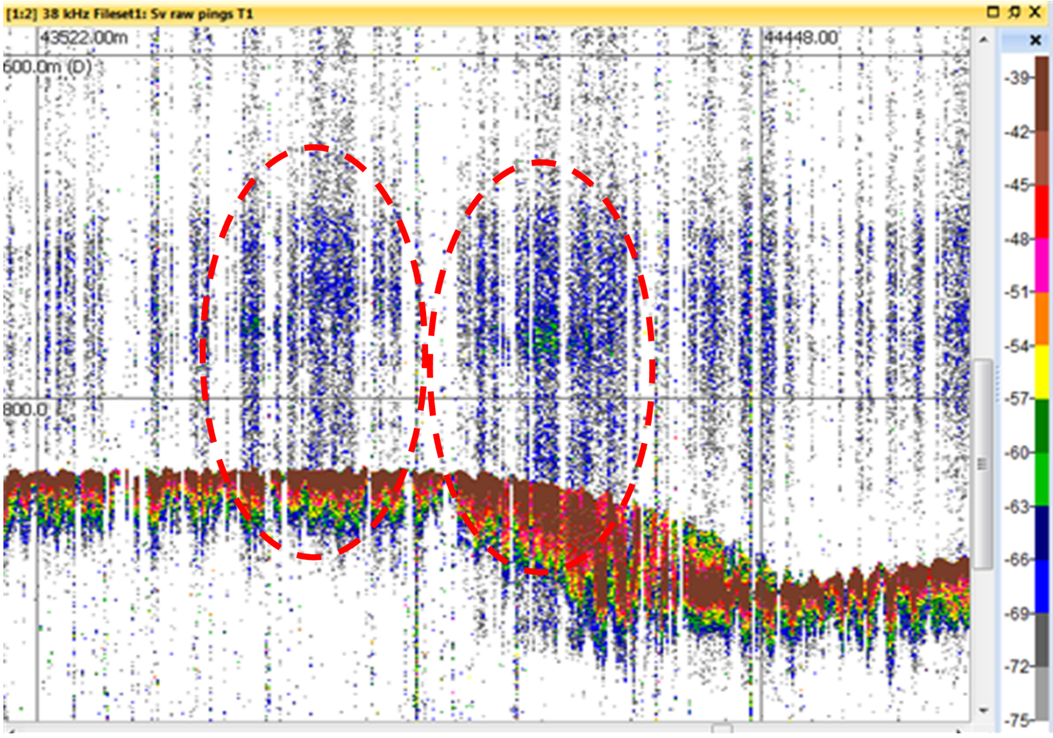


Figure 5. Vessel 38 kHz echogram showing spawning plume of orange roughy (dashed red lines). 18 tonnes of orange roughy was caught at this location. Tow was long (2.5 hrs) but video indicated most of the orange roughy was caught right at the end at this location in a few minutes.

4.2 ORH3B Puysegur Bank region – summary of survey activities

The Puysegur Bank ORH3B fishing grounds are located ~120 nautical miles Southwest of South Island (Figure 2). Eight key survey locations are encompassed in a 40 by 30 nautical mile area. These were surveyed between the 3rd and 13th of July. The northwest section has a cluster of four volcanic features, (Lady) Godiva, Goomzy, Net Loft and Alistair's. In the southeast section, surveys were conducted at two adjacent features. These two features seem to go by various names. We use what is understood to be their first naming; being Porirua for the southernmost feature and Mt Duncan to the north as depicted on the map (Figure 2). Other features surveyed were Malcom's Monument (Benthic Protected Area - vessel-mounted acoustics only) and briefly Hopeful Hill. Strong acoustic marks were observed on the vessel's 38 kHz echosounder for all of these features, although often the data quality was seriously degraded by poor weather. A combination of Mode 1 AOS surveys complemented by Mode 2 biological sampling with close range acoustic and optics were conducted in order to determine species composition of marks on six of the eight features. Prioritisation of survey effort was guided by historic knowledge of the ship's officers and in response to knowledge gained during the survey based on reviewing the acoustic and optical data and trawl catch. With the exception of Goomzy, trawl catch and (with some occasional ambiguity) AOS multifrequency acoustics indicated smooth and/or black oreos were the dominant source of acoustic backscatter in the majority of echosounder marks observed in the Puysegur region. Trawl catch showed that orange roughy were reasonably abundant at Net Loft and Godiva, accounting for 43 % and 42 % of the catch by weight respectively. Conversely, orange roughy only accounted for <4% of the catch at Alistair's, Porirua and Mt Duncan.

Inspection of AOS Mode 1 multi-frequency data, trawl catch composition and AOS Mode 2 acoustic video data was made for regions where oreo were present in significant proportions (i.e. all regions except Goomzy). We could not discern sufficient spatial separation between these highly reflective gas bladder species and orange roughy to directly partition the echograms to allow acoustic biomass estimates to be made for each species. Thus biomass estimates at these regions were made by proportioning the acoustic backscatter to species, based on trawl catch composition (see Section 4.2.8 for further discussion).

4.2.1 Summary of Puysegur Bank biological sampling program

A comprehensive trawl sampling program was undertaken at the Puysegur Bank region to complement the acoustic surveys and inform understanding of the deepwater biology. Twenty trawl shots were made with at least one demersal trawl shot taken at each of six acoustically surveyed locations. Full names of dominant species are given in Table 7. Full details of this sampling program can be found in the survey voyage report (Ryan and Tilney, 2015). A summary of mean population weight, length and estimates of TS for orange roughy and black and smooth oreos, as well as catch composition by weight and numeric proportion for dominant species, is given for each of the six survey locations in Table 8 and Table 9.

Table 7. Names of dominant species.

Acronym	Common name	Scientific name
ORH	orange roughy	Hoplostethus atlanticus
BOE	black oreo	Allocyttus niger
SSO	smooth oreo	Pseudocyttus maculatus
ETB	Baxter's lantern dogfish	Etmopterus baxteri
SSM	Smallscaled brown slickhead	Alepocephalus antipodianus
CSQ	Leafscale gulper shark	Centrophorus squamosus
CYP	Longnose velvet dogfish	Centroscymnus crepidator
HOK	hoki	Macruronus novaezelandiae

Table 8 Measures of mean population weight, length and estimates of TS for dominant species at Godiva, Goomzy and Net Loft.

				Males			Females			Combined male, female, 50:50 (ratio)		
Location	Species	Catch weight (kg)	Numeric proportion (%)	Mean weight (kg)	Mean length (cm)	Number of samples	Mean weight (kg)	Mean length (cm)	Number samples	Mean population weight (kg)	Mean population length (cm)	Mean population TS (dB re 1 m^2)
Godiva	ORH	15356	30.8	1.17	32.2	346	1.30	34.6	456	1.25	33.56	-52.2
4 trawls	BOE	14424	45.1	0.70	29.6	197	0.89	31.0	205	0.8	30.33	-39.9
Total catch 41048 kg	SSO	10535	23.6	1.02	36.9	109	1.20	37.7	93	1.1	37.23	-42.9
	ETB	54	0.3							0.535	45.78	
	CSQ	231										
	CYP	69	0.15							2.5	79.17	
	SSM	118	0.25							1.283	59.11	
Goomzy	ORH	113233	93.3	1.50	33.7	434	1.71	35.2	602	1.62	34.57	-52.0
7 trawls	BOE	474	1.4							0.4595	-	
Total catch 120325 kg	SSO	5025	4.8	1.22	38.7	162	1.53	41.4	138	1.36	39.94	-42.5
	ETB	472	0.3							1.959	58.41	
	HOK	284	0.17							2.229	85.83	
Net Loft	ORH	416	36.1	1.12	31.5	37	1.36	34.4	163	1.32	33.86	-52.1
1 trawl	BOE	207	40.2							0.554	-	
total catch 965 kg	SSO	215	17.9							1.292	-	
	ETB	26	2.6							1.12	60.48	
	CSQ	29	0.6							5.78	104	
	CYP	2										
	SSM	41	2.6							1.71	-	
	HOK	10	0.1							10.4	-	

Table 9. Measures of mean population weight, length and estimates of TS for dominant species at Alistair's, Porirua and Mt Duncan.

				Males			Females			Combined male, female, 50:50 (ratio)		
Location	Species	Catch weight (kg)	Numeric proportion (%)	Mean weight (kg)	Mean length (cm)	Number of samples	Mean weight (kg)	Mean length (cm)	Number samples	Mean population weight (kg)	Mean population length (cm)	Mean population TS (dB re 1 m^2)
Alistair's	ORH	12	1.5	1.46	35.4	8				1.46	35.38	-51.8
1 trawl	BOE	1	0.6							0.407	-	
Total catch 777 kg	SSO	699	92.4	1.22	39.0	57	1.56	42.1	43	1.37	40.3	-42.4
	ETB	18	2.6							1.65	47.33	
	CYP	12	0.4							5.75	78.5	
	SSM	19	2.6							1.34	58.54	
	HOK	7	0.5							2.41	90.67	
Porirua	ORH	417	3.3		33.0	4		36.0	2	1.192	34.00	-52.1
2 trawls	BOE	6308	62.3	0.82	33.7	94	1.07	35.6	106	0.95	34.68	-39.0
Total catch 11384 kg	SSO	4011	32.7	1.14	36.7	39	1.15	36.8	37	1.15	36.75	-43.0
	ETB	579	1.8							3.047	66.98	
Mt Duncan	ORH	2626	18	1.76	36.9	89	2.73	41.2	109	2.29	39.27	-51.1
2 trawls	BOE	1706	60	0.45	26.2	47	0.44	27.1	53	0.45	26.63	-40.9
Total catch 6444 kg	SSO	1021	11	1.34	39.8	32	1.64	42.8	68	1.54	41.87	-42.2
	ETB	908	10							1.44	64.67	-49.7
	CSQ	56								9.95	114.25	
	HOK	69								1.9	87.14	

4.2.2 Northwest features - Goomzy surveys (single species analysis)

The northwest region on Puysegur Bank has four locations where deepwater aggregations were observed. These were Alistair's, Net Loft, Godiva and Goomzy. Goomzy, the largest of the four features, hosted a substantial aggregation of spawning orange roughy motivating the greatest amount of survey effort to be focused here. The aggregation was at times quite mobile, making completion of effective surveys, and even locating suitable trawl lines, challenging. Three AOS interlaced grid surveys, four vessel acoustic surveys, one AOS single-pass transect and 8 AOS biological trawls were conducted. Orange roughy made up 93% of the trawl catch by numeric proportion. Smooth oreos were the second most abundant species (~5%). Surveys appeared to be well timed with respect to orange roughy spawning progression with ~8% spawning and 10% spent on 6 July progressing to ~36% spawning and 18% spent by 12 July. Plots of biological data can be found in Appendix B, section 6.4.

Establishing species identification at Goomzy

Three notably large catches of 22, 37 and 47 tonnes, with <5% by-catch, were taken in short-duration tows.

Two comprehensive AOS surveys were conducted at Goomzy (Ops 26 and 47). Despite the close transect spacing (0.4 nautical mile) no significant aggregations of fish were observed at that time. Hence, AOS based biomass estimates with direct multifrequency verification of species were not possible. This outcome is not completely surprising as our sustained observations of the vessel's echo sounder indicated that this aggregation was often highly mobile and quite ephemeral. Following the completion of the second comprehensive AOS survey on the 9th of July, a substantial school was located on the vessel's echosounder and was trawled (OP48). Soon after, two back-to-back vessel-based acoustic surveys were conducted on the 10th of July (Ops 49 and 50) during a period of apparent stability of the main aggregation. Immediately after the second vessel-based acoustic survey, a single pass AOS survey-mode transect (OP51) was conducted specifically for the purpose of multifrequency species identification. The orange roughy school did not persist for long enough to enable a follow-up AOS grid survey to be conducted. These activities are summarised in the timeline shown in Figure 6

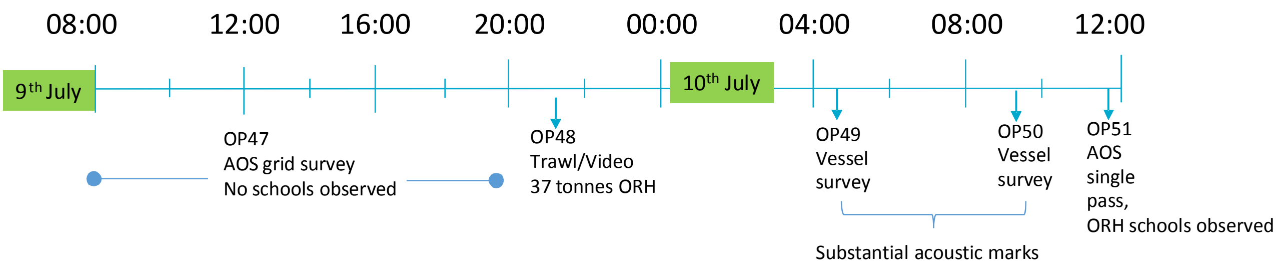


Figure 6. Timeline of key survey activities at Goomzy

Figure 7 shows example echograms from the two vessel-based acoustic surveys (top LHS and RHS). The centre image shows thematic maps of the vessel acoustic surveys (green dots OP49, purple dots OP50) with circle size is proportional to the acoustic backscatter from the main aggregation. Also shown is the location of the aggregation that was the target of demersal trawling (red dot) and the single pass AOS transect (orange dot), (OP48 and OP51 respectively). The bottom LHS panel shows the echogram from the vessel acoustics immediately prior to the demersal trawl. The bottom RHS panel shows a virtual echogram in which the AOS 38 kHz has been subtracted from the AOS 120 kHz. The region of orange pixels shows that the 120 kHz is 3.1 dB higher than 38 kHz indicating large non gas-bladder fish species, in all probability orange roughy given the lack of other candidate species (e.g. deepwater shark) in significant numbers in the trawl catch. We conclude that (a) the aggregations observed during the two vessel acoustic surveys are dominated by spawning orange roughy and that (b) these surveys were carried out in calm conditions such that vessel acoustic data quality is acceptable for echo-integration based biomass estimates.

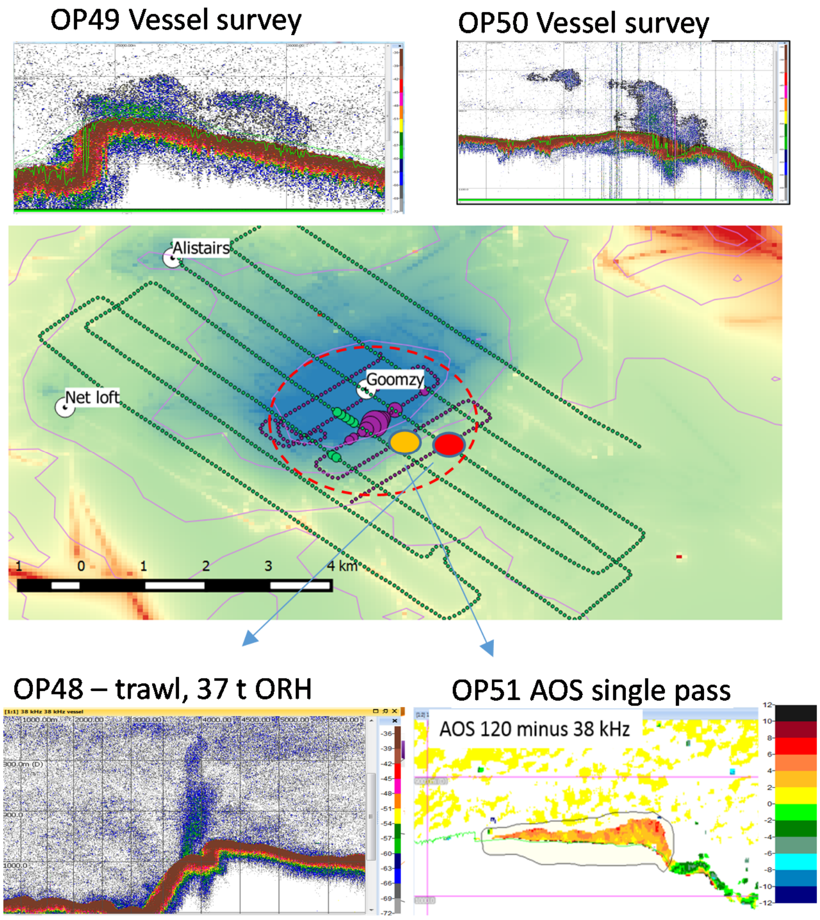


Figure 7. Overview of survey activities at Goomzy around 9th-10th July. Top panels show acoustic marks on echograms from two vessel-based acoustic surveys. The map shows the distribution of school-based acoustic backscatter from the two acoustic surveys with circle size proportional to acoustic backscatter NASC value (green and purple dots for OP49 and OP50 respectively). The single red dot shows the location of the school immediately prior to the vessel surveys. The orange dot shows the location of the school observed during the single AOS pass following the second acoustic survey. The lower left hand panel shows the school mark that was targeted during the demersal trawl. The lower right hand panel shows the AOS multi-frequency mixed echogram where the 120 kHz signal was ~3 dB higher than the 38 kHz indicating a large non-gas bladder fish, almost certainly orange roughy.

Table 10. Vessel and AOS surveys at Goomzy.

OP_Number	Operation_Type	Start_date (UTC)	Start_Time (UTC)	Comments
24	Vessel Survey	3/07/2015	20:45:00	ORH marks on NW side along single transect. Scoping survey poor data quality. Not suitable for biomass.
25	AOS Survey	3/07/2015	23:45:00	Net monitor issue. Cut survey short.
26	AOS Survey	4/07/2015	2:30:00	No orange roughy schools. Just occasional weak layers close to seafloor. No suitable for biomass
47	AOS Survey	9/07/2015	8:08:00	Extensive survey, no marks on Goomzy. No orange roughy biomass
49	Vessel Survey	10/07/2015	5:15:00	Likely orange roughy. Biomass estimation made
50	Vessel Survey	10/07/2015	10:22:00	One very good mark. Nothing on other transects. Biomass estimation made
51	AOS survey mode - single pass	10/07/2015	12:09:00	Reference orange roughy mark.
56	Vessel Survey	11/07/2015	8:22:00	Moderate marks, data quality marginal. Biomass possible but do not expect it to be high.

Biomass estimates

Biomass estimates following New Zealand Deep Water Working Group protocols for surveys at Goomzy are given in Table 11. These calculated biomass estimates use Doonan et al. (2003a) absorption equations, no correction is made to the data for motion effects but the final biomass is multiplied by an empirical correction factor of 1.33 to correct for vessel motion and bubble attenuation. As the data has direct measurement of vessel motion we also present biomass estimates that apply the Dunford (2005a) motion correction algorithm, and the earlier Francois and Garrison (1982b) algorithms for absorption (Table 12). The default survey design was interlaced transects. This was achieved for OP49. The interlaced survey was separated into two grids processing in opposite directions with the geometric mean of biomass estimates from each combined to give the overall biomass estimate. OP50 was a localised survey of the main aggregation where the need for rapid mapping of the aggregation prompted the use of a non-interlaced grid design. Echogram-defined schooling regions were assumed to contain 100% orange roughy.

The biomass estimates that apply the Doonan et al. (2003a) absorption equations ranged from 4160 to 4235 tonnes with survey sampling CVs of 0.56 and 0.25 respectively. These estimates include a deadzone estimate of approximately 18% (Table 11). The alternative biomass estimates that use the equations of Francois and Garrison (1982b) to calculate absorption and a correction for vessel motion based on direct measurement range from 4742 to 4876 tonnes. At the depths where orange roughy were observed (~900 m) the Francois and Garrison (1982b) equations will result in biomass estimates that are approximately 20% higher than estimates that use the Doonan et al. (2003a).

Table 11 . Vessel 38 kHz echo-integration surveys carried out at Goomzy spawning grounds in July 2015. Biomass calculations using Doonan et al. (2003a) absorption equations and factor of 1.33 empirical correction for vessel motion and bubble layer attenuation.

Species	ORH
Fish length (cm)	34.5
TS (dB)	-52
W (kg)	1.6

OP no.	Survey area (nautical miles^2)	Above acoustic bottom (tonnes)	Survey sampling CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)	Motion correction and bubble attenuation factor (%) * equations	Comment
49	10.1	3452	0.25	783 (18.5)	4235	33	Combined results from two grids from interlaced pattern
50	1.9	3407	0.56	753 (18.1)	4160	33	Non-interlaced pattern – rapid localised survey

* Echointegration done without motion correction being applied. Then final biomass multiplied by 1.33 as empirical correction for both motion and bubble layer attenuation as per DWWG protocols.

Table 12 . Vessel 38 kHz echo-integration surveys carried out at Goomzy spawning grounds in July 2015. Biomass calculations using Francois and Garrison (1982b) absorption equations and motion correction using the Dunford (2005a) algorithm.

OP no.	Survey area (nautical miles^2)	Above acoustic bottom (tonnes)	CV	Deadzone estimate (tonnes, % of total)	Total biomass (tonnes)	Motion correction factor (%) *	Comment
49	10.1	3959	0.25	918 (18.5)	4876	8.5	Combined results from two grids from interlaced pattern
50	1.9	3857	0.56	885 (18)	4742	10.6	Non-interlaced pattern – rapid localised survey

* Final biomass estimates include motion correction using measured pitch and roll data. Biomass would reduce by motion correction factor if motion correction was to be excluded from calculations.

Error budget for Goomzy vessel-based acoustic biomass estimates

An error budget as outlined in section 3.5 for the Goomzy vessel-based 38 kHz acoustic surveys are given in Table 13.

Table 13. Example of error budget for Goomzy vessel acoustic 38 kHz surveys.

	OP49		OP50			
	Random	Bias	Random	Bias*		
Error	estimated		estimated		source	confidence in estimate being bound
Target strength	10%		10%		measured	high
Survey sampling error	25%		56%		measured	Medium
Equivalent beam pattern	3%		3%		measured	High
Sound absorption	10%		10%		measured	High
on-axis calibration	3%		3%		measured	high
vessel motion	5%	0%	5%	0%	measured	high
aeration effects	0%	-10%	0%	-10%	estimated	medium
species classification	10%	0%	10%	0%	estimated	low
inclusion of non-target species	0%	15%	10%	15%	estimated	low
area of coverage	3%		3%		measured	high
fish weight	3%		3%		measured	high
fish migration	15%		15%		estimated	low (due to unknowns regarding fish movement)
deadzone estimation	10%		10%		estimated	medium
combined error estimate (excluding TS error component)	36%	5%	63%	5%		

* note, bias estimates are not applied to the reported biomass

Discussion – Goomzy surveys

The Goomzy feature received the greatest attention of the eight Puysegur regions that were surveyed. Survey activities were carried out in two blocks from 3rd to 5th July and 9th to 12th July. We believe that there was adequate survey coverage and that the timing with respect to the spawning event was suitable.

With some searching effort trawlable aggregations of orange roughy could be found but they typically occupied a limited area. Further, the main aggregation appeared to be mobile and its location highly variable within Goomzy's ~10 nautical mile area. Thus the AOS surveys were not well suited to rapid mapping of the localised and mobile aggregations that were observed in 2015. The most pragmatic solution was to conduct vessel-based acoustic surveys once the main aggregation had been located. The weather was fortuitously calm during a period when the main aggregation was relatively stable enabling good quality vessel acoustics to be obtained. The combination of trawl catch, video and AOS multifrequency acoustics support the conclusion that the main aggregation at Goomzy's was dominated by orange roughy.

We remark that the two estimates are vessel-based with associated higher uncertainties in species composition, absorption estimates, deadzone estimate and platform motion effects when compared to AOS estimates. The combined CV, taking into account all significant sources of error were 36% and 63% for operations 49 and 50 respectively, both of which are above the target of 20-30% . Notwithstanding the interlaced design for OP49, the errors due to fish movement may be significant given that the aggregation was generally mobile and ephemeral throughout the survey period. It is nevertheless encouraging that the two separate operations produced similar biomass estimates.

4.2.3 Northwest features - Godiva surveys (mixed species analysis)

Overview

Substantial plumes were routinely observed at Godiva on the vessel's 38 kHz echosounder. Three biological tows, two AOS star pattern surveys, one AOS survey mode single pass and two vessel star pattern acoustic surveys were completed at this location. Trawl catches indicated this region was dominated by oreos, either black (41%) or smooth (24%). Orange roughy accounted for 31% of the catch by numeric proportion. Spawning orange roughy were in low proportions (10%) at this location. Plots of biological data can be found in Appendix B, Section 6.5.

Acoustic surveys

Of the four dedicated vessel or AOS star pattern echo integration surveys two were found to be suitable for use in biomass estimation (OP44 and OP45, Table 14)

Table 14 . Vessel and AOS echo integration surveys carried out at Godiva in July 2015.

OP_Number	Operation_Type	Start_date (UTC)	Start_Time (UTC)	
19	Vessel survey	03/07/2015	11:30	Quick vessel search over Godiva. Reasonable marks on 38 kHz sounder
20	AOS Survey			AOS star survey, Godiva. Aborted due to technical fault on AOS
44*	Vessel survey	08/07/2015	20:53	Substantial marks. Other data (video, trawl, indicates mix of ORH, BOE and SSO) Data quality generally good. Biomass possible using signal decomposition based on trawl catch
45*	AOS Survey	08/07/2015	22:51	Mixed species aggregations. Good marks on NW side. Vessel acoustics also good for echointegration
54	AOS - single pass	11/07/2015	2:00:00	AOS real time observations

* biomass estimates made

Establishing species identification at Godiva

The acoustic marks at Godiva were generally extensive and strong. The trawl data suggests that the majority of the acoustic backscatter is due to large gas bladder species with more than 59% of the catch (by number) being either black or smooth oreo. The AOS multifrequency data however provided contrary evidence with the decibel difference of 120 kHz minus 38 kHz signal within the aggregation indicating regions of ~+2 to +4 dB suggesting large non-gas bladder fish were present (Figure 8).

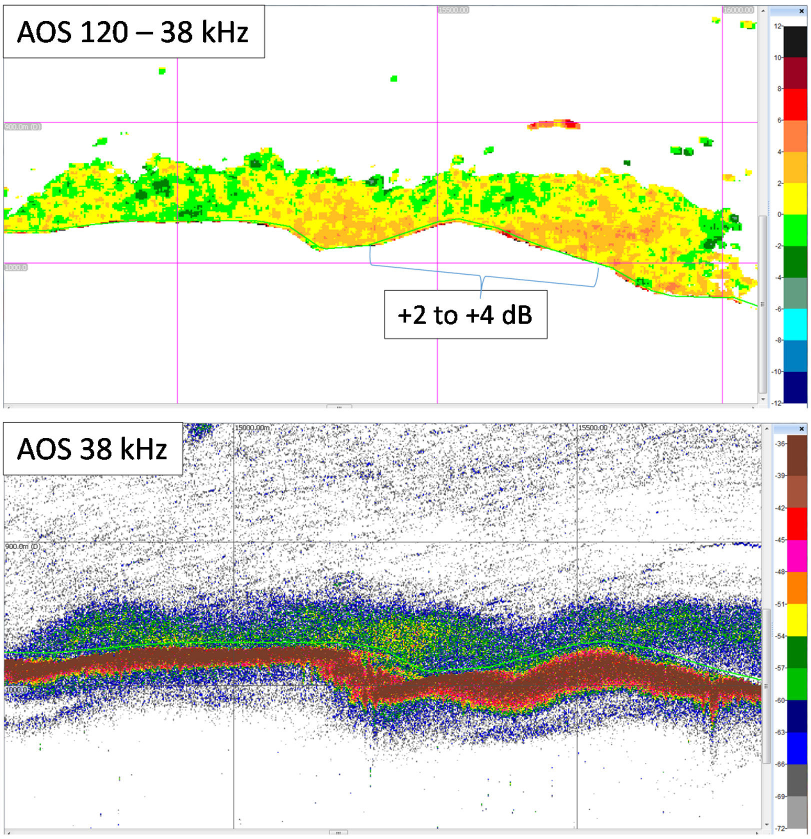


Figure 8. OP45. Top panel. 120 kHz minus 38 kHz AOS data. Bottom panel AOS 38 kHz echogram.

To resolve this ambiguity in the multifrequency acoustics we took advantage of real-time optic fibre connectivity from the AOS to the surface which was being trialled. Two transects were made at Godiva. A first pass was made with AOS initially held at ~140 m above the top of the main aggregation (OP54). This distance is expected to provoke an avoidance reaction if the aggregation was orange roughy (Ryan and Kloser, 2016). An avoidance reaction is inferred when a region of very low signal (i.e. "empty water") is seen in the echogram immediately above the high signal region that is "hard down" to the seafloor (Ryan and Kloser, 2016). No avoidance was detected in the real-time AOS acoustics as the platform passed above the aggregation. To further press the point the AOS was lowered a further 40 m to be 100 m above the aggregation but still no reaction was observed (Figure 9). The lack of reaction makes it highly unlikely that orange roughy were the dominant species at Godiva. The second real-time AOS transect was a mode 2 trawl operation. The real-time video indicated some spatial separation of species with mostly oreo for the first part of the trawl and a move into a region dominated by orange roughy. The mode 1 echo integration surveys at Godiva were unable to detect similar spatial separation between orange roughy and bycatch species. This may be because there was no clear cut spatial separation at the time of survey, or because the sampling volume of the AOS acoustic data at ~250 m range was large enough to smear along-track separation of species.

It is not clear why the AOS decibel difference was indicating evidence of non gas bladder orange roughy while the real-time observations gave the strong evidence against dominant orange roughy. The most likely cause was a calibration shift in one of the frequencies that would bias the decibel difference between the 120 and 38 kHz systems. We note the difference in 120 kHz calibration between September 2014 and Septembers 2015 experiments where the 120 kHz is 1.4 dB (40%) more sensitive compared to the 2015 results. We note that there were some technical issues with ES60 120 kHz power supplies with changes made during the surveys that could be the cause of this apparent calibration issue. Further note, that the uncertainty in the 120 kHz calibration does not have implications for biomass estimates presented in this report as estimates were based on either vessel or AOS 38 kHz. Biomass estimates at 120 kHz would be normally be given for AOS surveys of orange roughy where TS is established at that frequency. However no suitable AOS surveys of orange roughy aggregations were made. The AOS surveys of mixed species aggregations based biomass estimates only on 38 kHz data as TS at 120 kHz is not established for black and smooth oreos.

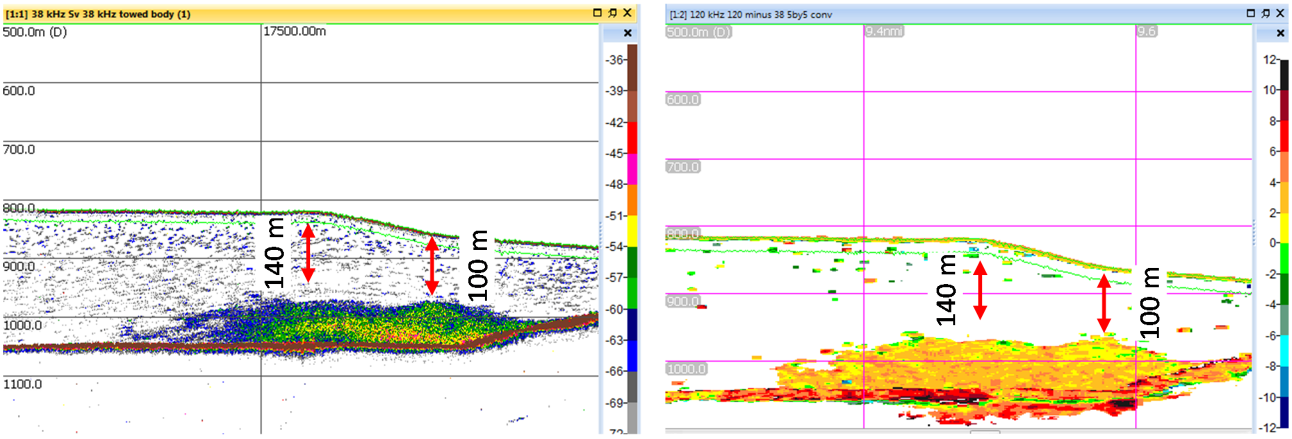


Figure 9. LHS panel. AOS 38 kHz echogram indicating platform distance above the main aggregation. RHS. Decibel difference between AOS 120 kHz minus AOS 38 kHz.

Although orange roughy are a significant part of the population at Godiva, the video observations, trawl catch data and behavioural responses to the AOS all point to high proportions of large gas bladder oreos being the source of the majority of the acoustic backscatter given their much higher TS (Table 15). Accordingly, biomass estimates at Godiva need to be based on mix species aggregations with backscatter apportioned according to the trawl catch data.

Table 15. Numeric proportion of three most abundant species and their contribution to the acoustic signal within defined schooling regions.

Species	Mean length (cm)	TS (dB re 1 m^2)	Numeric proportion (%)	Acoustic contribution (%)*
Orange roughy	33.6	-52.2	31	3.1
Black oreo	30.3	-39.9	45	76.5
Smooth oreo	37.3	-42.9	24	20.4

* other by catch species < 1% of total catch by weight thus contribution to total backscatter will not be significant

Biomass estimates

Input parameters and resulting biomass estimates for surveys at Godiva are given in Table 16.

Table 16. Biomass estimates at Godiva

Species	ORH	BEO	SSO				
Fish length (cm)	33.56	30.3	37.3				
TS (dB)	-52.2	-39.9	-42.9				
W (kg)	1.25	0.79	1.11				
Species comp (%)	45	0.45	24				
	Biomass (tonnes)						
Operation	ORH	BEO	SSO	Area (n.mi^2)	NASC (m^2 n.mi-^{2})	System	Deadzone
44	162	149	112	0.83	383	Vessel 38 kHz	No
	183	167	125	0.92	430		Yes
45	100	92	69	0.97	203	Vessel 38 kHz	No
	179	164	123	0.97	362		Yes
	146	134	100	1.27	225	AOS 38 kHz	No
	266	244	183	1.27	410		Yes

* Uncorrected for motion effects (no motion data available for these surveys).

As discussed (section 4.2.8) biomass estimates of the mixed species aggregations at Godiva are expected to have large error bars due to issues of representativeness of trawl-catch. The trawl campaign of eight tows was a reasonable number perhaps to characterise the region but errors due to the selectivity of the net and catchability coefficients of each species will have an unquantified influence on the biomass estimates. The high TS of black and smooth oreos compared to orange roughy will further compound the sensitivity of these biomass estimates to trawl-catch composition.

4.2.4 Northwest features - Net Loft

Overview

Substantial acoustic marks were observed on occasions at Net Loft on the vessel's echosounder during the survey period. A vessel-acoustic survey (OP23) was completed on the 3rd of July where only faint marks were observed and acoustic data quality was poor due to the weather conditions. A four transect star pattern AOS survey (OP29) was completed two days later. No significant aggregations were observed with only small acoustic marks close to the sea floor and of undetermined species composition. Biological catch composition was informed by just one tow with a one tonne catch. Given this single sample and small catch, catch composition results are unlikely to be robust. Trawl catch indicated similar characteristics to Godiva with black oreo, smooth oreo and orange roughy accounting respectively for 40%, 18% and 36% of the catch by numeric proportion and an almost complete absence of spawning orange roughy (2%). Plots of biological data can be found in Appendix B, Section 6.6.

Biomass estimates at this location were not pursued given the very low levels of acoustic backscatter and high level of uncertainty over species composition.

4.2.5 Northwest features - Alistair's

Overview

Substantial plumes were observed on Alistair's. One AOS biological tow, one single pass AOS transect (OP28) and one vessel-acoustic survey (OP22) were completed. Weak acoustic marks were observed during the vessel acoustic survey but the data quality was not suitable for analysis as it was severely affected by poor weather conditions. Similarly no significant marks were observed during the AOS transect. Biological catch composition was informed by just one tow with less than 1 tonne catch. Given this single sample and small catch, catch composition results are unlikely to be robust. The small catch was dominated by smooth oreo (92% by numeric proportion) with 1% orange roughy and 2% deepwater sharks. Plots of biological data can be found in Appendix B, Section 6.7.

No biomass estimates were pursued due to the limitations of the data and lack of significant acoustic marks.

4.2.6 Southeast features – Porirua (mixed species analysis)

Overview

Substantial acoustic marks were observed on Porirua (Figure 10). One AOS survey (OP35), one vessel survey (OP34) and two AOS biological tows (OP36, OP37) were completed.

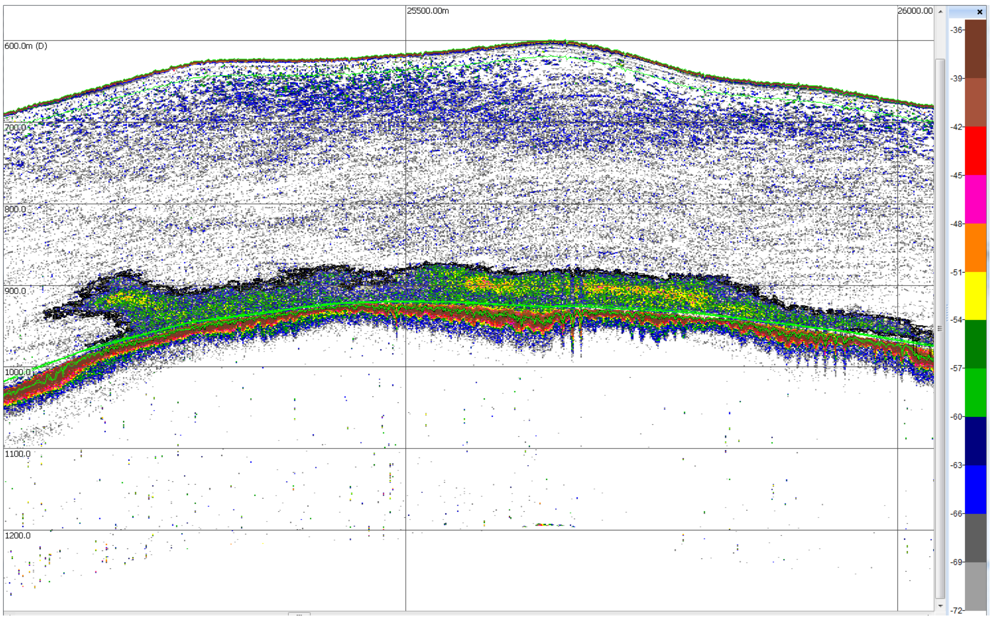


Figure 10. AOS 38 kHz echogram, OP35

Trawl catch composition was dominated by black and smooth oreo (respectively 62% and 33% of the catch by numeric proportion). Orange roughy were not significant, contributing only 4% (by number) to the total catch of 11.4 tonnes. There was no evidence of orange roughy spawning as the sampled fish were either in early maturation or maturing stages. Biomass estimates were made through decomposition of the acoustic signal according to the trawl catch composition (Table 17). Plots of biological data can be found in Appendix B, Section 6.8.

Biomass estimates

Biomass estimates for surveys at Porirua based on decomposition of the acoustic backscatter according to trawl catch composition are given in Table 17.

Table 17. Biomass estimates for orange roughy, black and smooth oreos at Porirua.

Species	ORH	BEO	SSO				
Fish length (cm)	34	34.68	36.75				
TS (dB)	-52.1	-39.0	-43.0				
W (kg)	1.19	0.95	1.15				
Species comp*	0.04	0.62	0.33	* Numeric proportion			
	Biomass (tonnes)						
Operation	ORH	BEO	SSO	Area ($n.mi^2$)	NASC (m^2 $n.mi^{-2}$)	System	Deadzone
35	11	131	84	1.12	238.5	AOS 38 kHz	No
	13	161	104	1.12	293		Yes

Discussion of biomass estimates at Porirua

Despite the observation of impressive acoustic marks at this location, the biomass estimates of black and smooth oreos are not high. The currently accepted target strength estimates for these species indicate high reflectivity which can result in high signal acoustic marks but with relatively modest biomass estimates. Further, our results have high uncertainty due to the limited trawl campaign (two shots) and issues of net selectivity and species avoidance (see also Section4.2.8).

4.2.7 Southeast features – Mt Duncan (mixed species analysis)

Overview

Substantial acoustic marks were observed here on both vessel and AOS echograms (Figure 11). In the echogram shown this mark is approximately 900 m long and extends vertically 150 m. One AOS survey (OP39), one vessel survey (OP33) and two AOS biological tows (OP40, OP41) were completed. Orange roughy comprised 18% (by numeric proportion) of the 6.4 tonne total catch. Greater than 90% of the female orange roughy gonads were either maturing or ripe. Of note is the average length and weight of the Mt Duncan orange roughy, being 39 cm and 2.29 kg respectively. This weight is approximately twice that of orange roughy at the other surveyed locations in the Puysegur region. Black and smooth oreos were the next most abundant (26% and 16% respectively by number). Deepwater sharks (DWS) were also present in significant numbers (15%) and so were included in the species decomposition when calculating biomass (Table 18). Plots of biological data can be found in Appendix B, Section 6.9

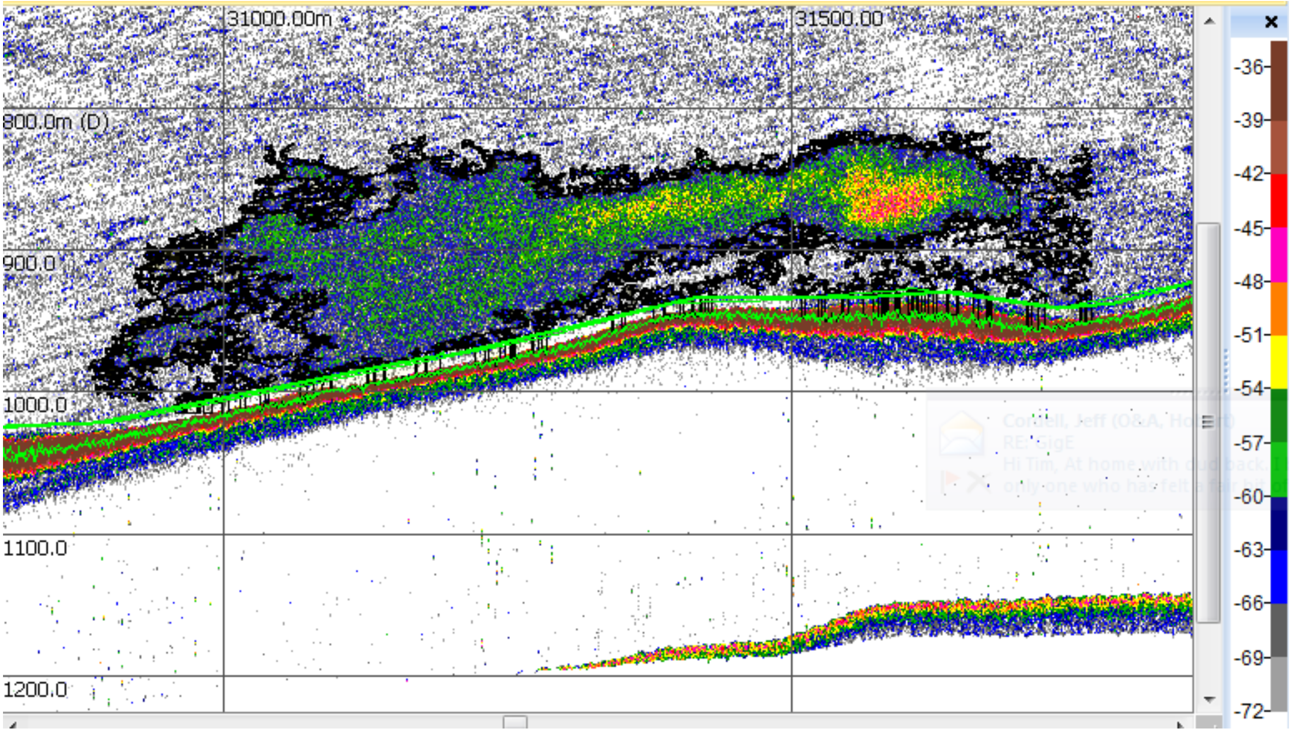


Figure 11. AOS 38 kHz echogram. OP39 showing substantial acoustic mark at Mount Duncan.

Biomass estimates

Biomass estimates for surveys at Mt Duncan based on decomposition of the acoustic backscatter according to trawl catch composition are given in Table 18.

Table 18. Biomass estimates at Mt Duncan

Species	ORH	BEO	SSO	DWS				
Fish length (cm)	39.27	26.63	41.87	64.67				
TS (dB)	-51.1	-40.9	-42.2	-49.7				
W (kg)	2.29	0.45	1.54	1.4				
Species comp*	0.11	0.6	0.11	0.1	* numeric proportion			
	Biomass (tonnes)							
Operation	ORH	BEO	SSO	DWS	Area (n.mi^2)	NASC (m^2 nmi^{-2})	System	Dead zone
39	497	533	334	276	2.6	557	AOS 38 kHz	No
	541	580	364	301	2.6	606.2	AOS 38 kHz	Yes

Discussion of biomass estimates at Mt Duncan

The biomass estimates at Mt Duncan are based on the standard method of partitioning acoustic backscatter according to trawl catch composition. The backscatter here was strong and extensive over a wide area resulting in a total biomass estimate of 1784 tonnes of the four most abundant species. This figure is highly sensitive to the trawl catch composition which was informed by just two trawl shots. We note also the high shot to shot variability with just four orange roughy caught in the first trawl and 50% orange roughy by weight or 16% by numeric proportion in the second trawl.

4.2.8 Discussion of biomass estimates for mix-species aggregations

Biomass estimates from mix species aggregations are expected to have high error bars for three key reasons.

First, in the absence of any guiding information our calculations assume that all species have an equal ratio of trawl catchability and acoustic vulnerability (O'Driscoll, 2003). This is unlikely to be the case (O'Driscoll, 2003) particularly given differences observed in the behaviour of each species . Orange roughy can be highly reactive to foreign objects at distances of less than 200 m (Koslow et al., 1995; Ryan and Kloser, 2016), herding en-masse towards the seafloor. However our AOS Mode 2 video shows that orange roughy can also be quite unreactive when the system is at close range (i.e. in the process of being trawled). This combination of herding to the seafloor then being less reactive makes this species highly vulnerable to demersal trawl-net systems. The oreo species are not known to react to distant objects in the same way as orange roughy (Koslow et al., 1995; Ryan and Kloser, 2016) and when observed on the video are generally slow moving and reasonably unreactive, presumably making them also vulnerable to the demersal trawl-net. It is difficult to know how these behavioural differences translate into relative vulnerabilities and trawl species composition between the three species.

Second, we note the mismatch in sampling between the demersal trawl net systems and the acoustics. Acoustic backscatter from schooling aggregations in the Puysegur region often extends high into the water column up to 150 m above the seafloor. The trawl catch on the other hand was sampling the first 5 to 10 m above the seafloor such that the net sampling mismatches the regions sampled by the acoustics. Thus, a ‘clean’ trawl catch dominated by one species may not be at all representative of the species mix up in the water column.

Third, uncertainty in the TS of each species will translate into an error in the biomass estimates. Orange roughy TS is thought to be well contained. Recent work in both New Zealand and Australia provided similar estimates where those studies used AOS data to provide TS measures with concurrent video and stereo digital still images to verify species and directly measures fish-tilt angle (Ryan et al., 2009; Kloser et al., 2013b; Macaulay et al., 2013). Similar acoustic-optical work was carried out to greatly reduce the uncertainty around hoki (blue grenadier) TS (Kloser et al., 2011c; Dunford et al., 2015). To date this approach has not been applied to oreo species but could be pursued if the uncertainty around current estimates is considered a priority. A consideration for future work would be to establish the TS at 120 kHz that would allow biomass estimation at both 38 kHz and this high-frequency when conducting deep towed acoustic surveys of oreo species, providing a second semi-independent biomass estimate to compare with the standard 38 kHz results (Ryan and Kloser, 2016).

Notwithstanding the above comments, a comprehensive trawl campaign is required to ensure that there is sufficient spatial coverage to sample the regions of high backscatter that are contributing to the biomass estimates. This was not possible in all instances during the 2015 surveys because of the need to scope out and survey eight locations in little over a fortnight.

A multifrequency acoustic approach may be effective if there is a sufficient spatial separation between the gas bladder oreo species and the non-gas bladder orange roughy. This did not appear to be the case in the regions where oreo species were present in significant numbers.

Aggregstions dominanted by orange roughy are expected to be between 2 to 4 dB higher on the 120 frequency. We expect gas bladder species such as oreos to have no significant difference between 38 and 120 kHz. If orange roughy are mixed with these species in the acoustic beam, the decibel difference will reduce. Given that these gas bladder species have a factor of 10 to 20 higher backscatter than orange roughy, they will have a disproportionate influence and even small numbers will serve to reduce the decibel difference.

5 Appendix A – Vessel and AOS calibration

5.1 *Amaltal Explorer* ES60 calibration

Calibration of the *Amaltal Explorer*'s ES60 38 kHz echosounder was carried out in Golden Bay, Nelson, New Zealand on the 26th of June 2015 in calm conditions (Table 19). A 60 mm copper calibration sphere was used giving high quality data with good signal to noise and little interference from water column biota. Analysis was carried out using Echoview 6.1 software. The first step was to measure the TS of the sphere when it was constrained to the on-axis location (on-axis defined by less than a user-defined level of beam compensation). A revised gain was calculated by comparing the measured TS with a theoretical value based on the sphere TS (calculated using SW Fisheries Science Centre's online calculator for theoretical sphere TS) and adjusting the Gain value so that measured and theoretical values agree. The revised gain value was entered into the Echoview supplementary calibration file. The sphere echointegration S_A value was measured for on-axis sphere returns. The measured S_A was compared to a theoretical value based on a 60 mm copper sphere at the measured range of the sphere to calculate the S_A. Further details on calibration of ES60 echosounders can be found in (Demer et al., 2015).

Table 19. Calibration system details

Calibration report			
Vessel	Amaltal Explorer	Date/Time (Local)	26th June 2015
Location	Golden Bay, Nelson	Echosounder	Simrad ES60
Frequency	38kHz	Transducer type	ES38B
Transducer location	Hull	Software version	1.5.2.7
Transducer serial number	30212 & 30301 (unsure which of these is in service). Factory test results for equivalent beam angle (EBA) are within 0.2 dB of each other. We average EBA values from the two transducers to constrain errors		
Firmware version	-	Echosounder serial #	-
Sea Temp	12.7	Salinity	34.5 (nominal estimate)
Sound speed		Absorption	
Bottom depth	34		
Nominal gain	26.5	Sa correction	0
Transducer test tank salinity	0 (fresh water)	Transducer test tank temperature	18
Transducer Equivalent Beamwidth ψ	-20.6 & -20.8. Average to use -20.7	Adjusted transducer equivalent beamwidth	-20.58
Angle sensitivity Along	21.9	Angle sensitivity athwart	21.9

3dB Along Beamwidth	7.1	3 dB Athwart Beamwidth	7.1
Along offset	0	Athwart offset	0

Run number 1. 2.048 ms pulse length

Sphere type	Copper	Sphere TS	-33.51
Start time (local)	20:57	End time (local)	21:24
Pulse duration (ms)	2.048		
Power (W)	2000	Pulse rate	Max
Sphere depth	18.4		
On-axis criteria (dB)	0.2		
Nominal Gain	26.5	On axis measured TS	-35.12
New Gain	25.7		
Measured NASC	5300	Theoretical NASC	6499
Sa correction	-0.44		
Overall offset in dB	-2.496		

Final result: Gain 25.7, Sa correction -0.44

Run number: 2. 1.024 ms pulse length

Sphere type	Copper	Sphere TS	-33.51
Start time (local)	21:24	End time (local)	21:53
Pulse duration (ms)	1.024		
Power (W)	2000	Pulse rate	Max
Sphere depth	18.34		
On-axis criteria (dB)			
Nominal Gain	26.5	Measured TS	-35.6
New Gain	25.5		
Measured NASC	4717	Theoretical NASC	6527
Sa correction	-0.7		
Overall offset in dB	-3.5		

Final result: Gain 25.5, Sa correction -0.7

5.2 AOS calibration results

Prior to 2014, the AOS platform was suspended vertically from a trawl warp and lowering to working depths down to 1000 m. A 38.1 mm tungsten carbide reference sphere was suspended at 20 m beneath the platform. The exercise required perfectly calm weather and low currents in order for the suspended sphere to remain within the acoustic beam. These conditions do not always happen during the survey period. To improve the chance of success and enable better characterisation of the transducer CSIRO developed a new platform for calibration of deepwater transducers – the Deepwater Calibration Facility (DeCaF). This platform has a gimballed plate to which the transducers attach. The angle of this platform can be adjusted in real time via an optic fibre connection to an on-board control station. The Sealord AOS transducers and transceivers were shipped to Hobart and fitted to the DeCaF platform. Calibration of the Sealord AOS transducers fitted to the DeCaF platform was carried out aboard *Pacific Crest* on 10 Sept 2015.

Summary results for combined up and down casts for September 2015 Decaf deployments are given in Table 20. Calibration offsets are applied by setting a Gain and Sa correction value at a nominal platform depth of 600 m when echointegrating. Echointegration values are then adjusted for changes in Gain and Sa correction as the platform moves above and below the nominal depth according to the third order polynomials given in Table 20.

Table 20. Summary results for Sealord AOS September 2015 calibrations

Transducer gain and polynomial.

Frequency	Pulse	Power	600 m bin	x depth3	+ x depth2	+ x depth	+ c
38 kHz	512	2000	23.5214	-1.22009e-09	-2.10307e-07	0.000198472	23.6054
38 kHz	2048	2000	23.7992	-6.88967e-09	8.13121e-06	-0.00329915	24.2705
120 kHz	1024	500	26.7313	-5.28147e-09	6.73741e-06	-0.00289111	27.1623
120 kHz	256	500	26.7377	-1.57372e-09	4.22233e-06	-0.00262183	26.9728
120 kHz	1024	1000	26.8201*	2.79581e-09	-6.05642e-06	0.00269767	26.5093
120 kHz	256	1000	26.7236		2.49974e-06	-0.00215272	27.1168

Sa correction polynomial

Frequency	Pulse	Power	600 m bin	x depth3	+ x depth2	+ x depth	+ c
38 kHz	512	2000	-0.6097	6.49585e-11	-5.4434e-08	0.000188778	-0.74238
38 kHz	2048	2000	-0.3910	1.16153e-10	-1.21579e-07	5.1226e-05	-0.386636
120 kHz	1024	500	-0.3355	2.93877e-10	-4.36943e-07	0.000174924	-0.331542
120 kHz	256	500	-0.6075	-1.29821e-10	1.4534e-07	-5.10727e-05	-0.600282
120 kHz	1024	1000	-0.3596*	3.39498e-09	-3.48613e-06	0.000980299	-0.393481
120 kHz	256	1000	-0.6092		3.75218e-07	-0.00035761	-0.529638

* - 500 m bin used as too few samples at 600 m

Historic and new Decaf results for AOS survey settings are given in Table 21.

Table 21. Historic and new calibration results for AOS echo integration survey (Mode 1) at nominal platform depth of 600 m

Year	Frequency (kHz)	Power (W)	Pulse length (ms)	Gain	Sa correction	Nominal gain	Offset from nominal gain (dB)	Calibration info
2013	38	2000	2.048	23.9	-0.45	26.5	-6.10	Amaltal Explorer NZ
2015*	**38**	**2000**	**2.048**	**23.8**	**-0.37**	**26.5**	**-6.14**	**Pacific Crest/Decaf, Australia**
2013	120	500	1.024	27.4	-0.3	27	0.2	Amaltal Explorer NZ
2014	120	500	1.024	27.6	-0.37	27	0.46	Will Watch, Mauritius
2015	120	500	1.024	26.7	-0.32	27	-1.24	Pacific Crest/Decaf, Australia

* Values used when estimating biomass

5.2.1 Discussion of AOS calibration results

The AOS 38 kHz results remained stable between the years 2013 to 2015. The AOS 120 kHz results on the other hand had significant variation of up to 1.4 dB. We note that there were technical difficulties with the 120 kHz AOS system during the 2015 voyage where the echosounder power supply became faulty, but it was repaired and continued in service for the latter half of the voyage. This is one possible reason why the calibration results have varied, although there may be other unidentified factors. The 120 kHz – 38 kHz decibel difference did not always give expected results, where we expect orange roughy to be 2-4 dB higher on the 120 kHz and regions of oreo species approximately equal across the two frequencies. With the DeCaf 2015 results applied we found examples where the 120 kHz backscatter was higher than the 38 kHz by at least two dB in regions where oreo species appeared to be dominant. We conclude that the post voyage, September 2015, calibration results for 120 kHz may not be applicable to the survey data. It appears that the 2014 calibration results for 120 kHz may be the most appropriate to apply to the survey data. We note that this uncertainty with the AOS 120 kHz calibration has not affected biomass estimates; no AOS biomass estimates were made of spawning orange roughy aggregations and for mixed species locations AOS biomass estimates were only made at 38 kHz due to a lack of TS information on oreo species at 120 kHz.

Assuming that the components remain stable, September 2015 calibration results should be appropriate for any subsequent survey work. It is highly recommended, however that a pre-voyage voyage calibration of the Sealord AOS echosounders are conducted ahead of the next quantitative survey. Using the DeCaf platform to do this is also strongly recommended. This would greatly improve the chance of success and also allows comprehensive calibration of a range of settings (i.e. Mode one and Mode two) in the one operation.

6 Appendix B. Biological sampling results

6.1 ORH7B: Cook Canyon biological results

Four biological tows were undertaken around the edges of Cook Canyon, yielding a total catch of 23.2 t of fish. Orange roughy catches were as follows: OP3 – 18.2 t; OP13 – 2.5 t; OP14 – 0.4 t; OP15 – 0.1 t. Orange roughy comprised 91.1 % by weight for all tows combined. Otolith samples: ORH x360 (Figure 12).

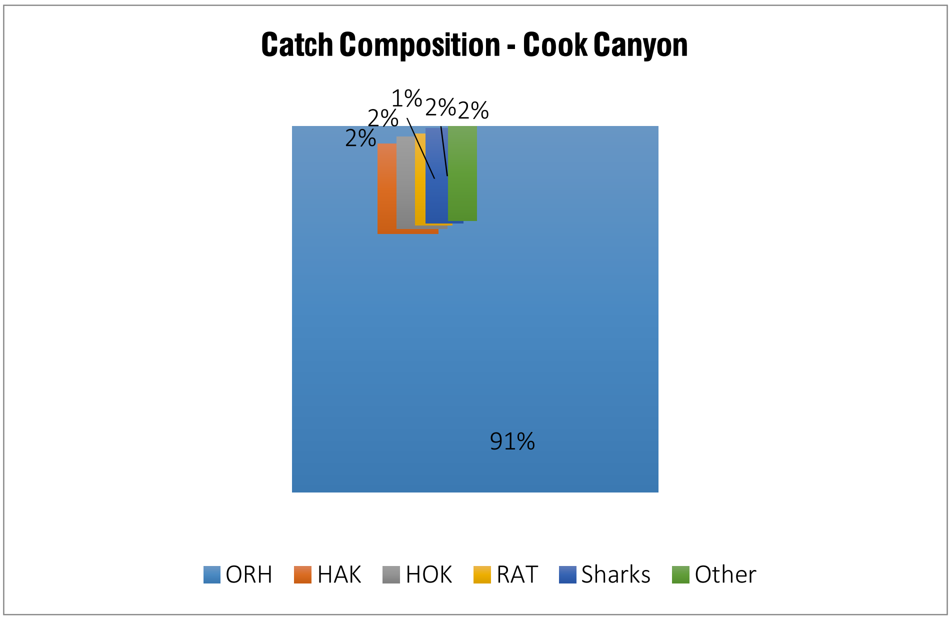


Figure 12. Catch composition – Cook Canyon

<u>ORH Size frequency</u>

The average lengths and weights were 31.0 cm and 0.98 kg for males and 32.4 cm and 1.24 kg for females (Figure 13). Average length and weight for sexes combined were 31.7 cm and 1.12 kg.

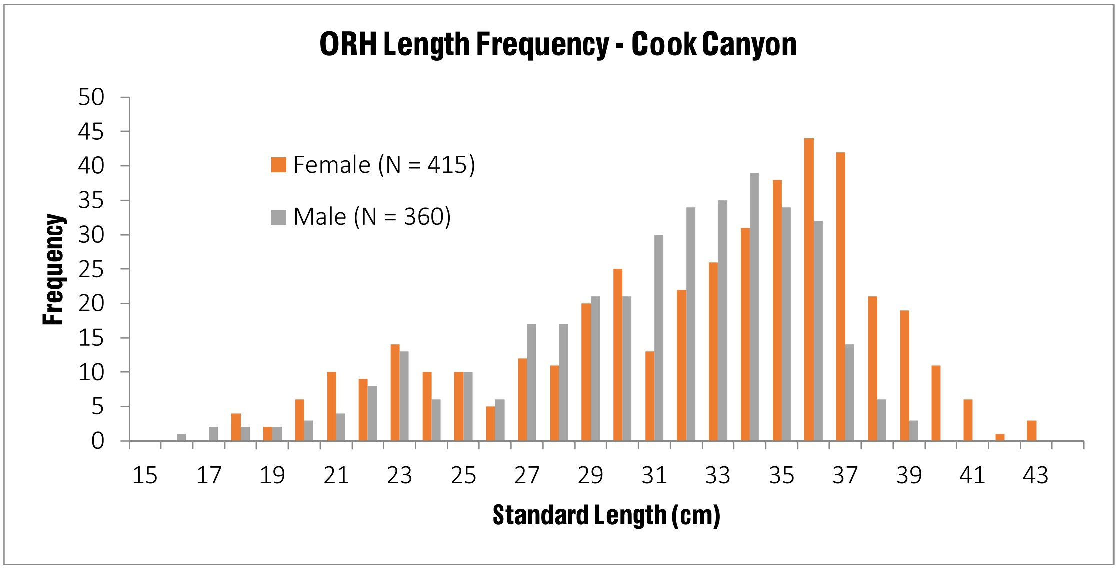


Figure 13. Orange roughy length frequency – Cook Canyon

ORH Spawning progression

Around 40% of fish were in spawning condition and 25% were spent at the start of the survey on 29 June, suggesting that spawning commenced at least a week prior to the survey (Figure 14). Three days later, on 2 July, around 70% of females were in resting condition, indicating that the spawning event was possibly over.

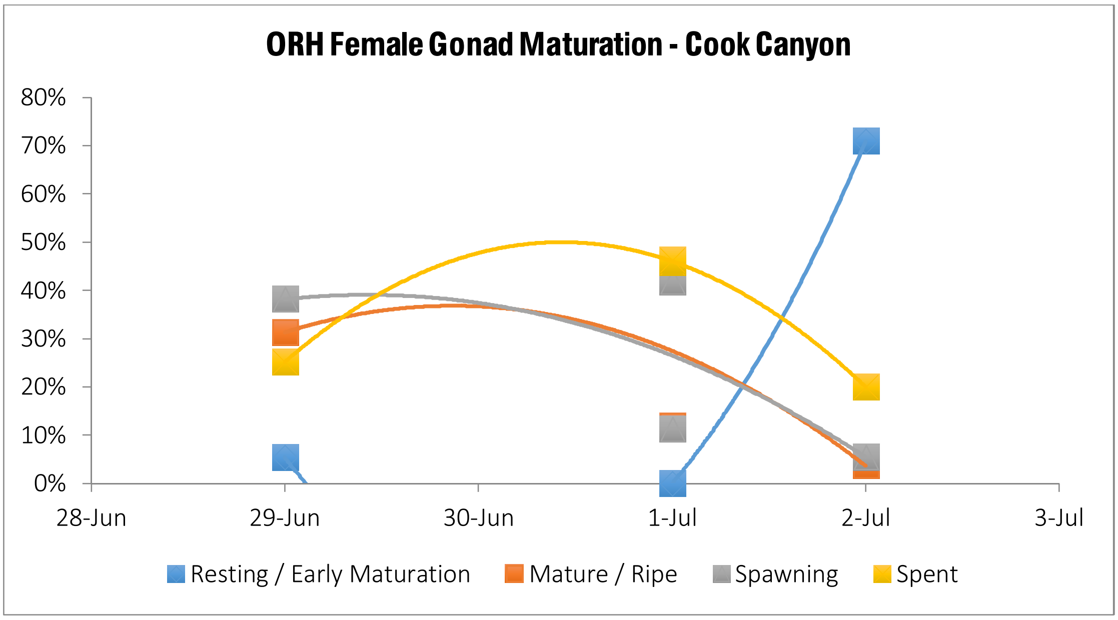


Figure 14. Orange roughy female gonad maturation – Cook Canyon

ORH Average spawning state

The Cook Canyon area is clearly an important orange roughy spawning area with over 70% of fish sampled being either in spawning, spent or post-spawning/resting condition (Figure 15).

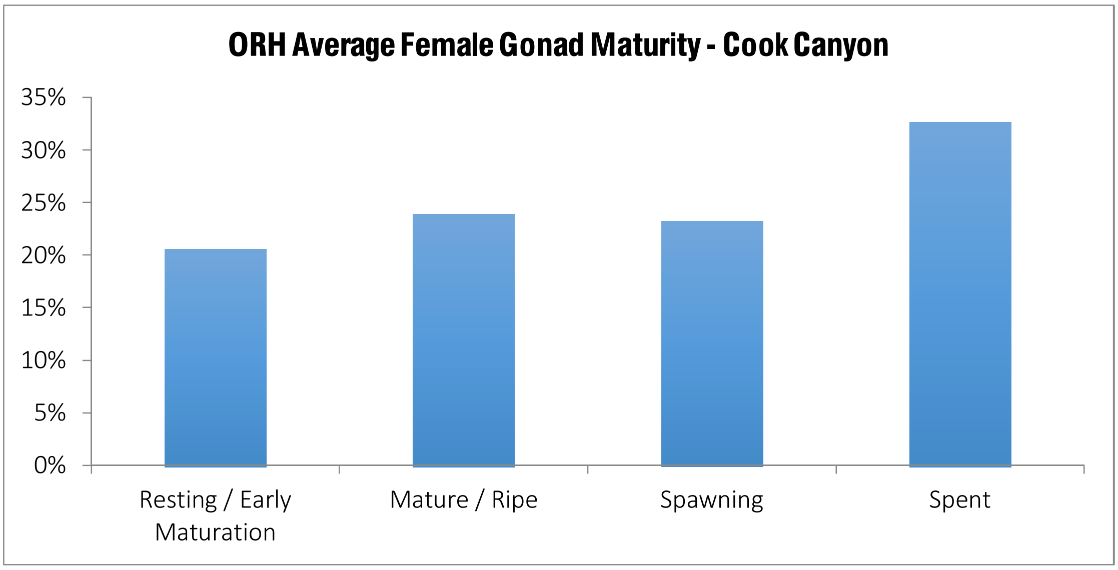


Figure 15. Orange roughy average female gonad maturity – Cook Canyon

6.2 ORH7B: Moeraki Canyon biological results

Moeraki Canyon

A single biological tow here (OP11) yielded less than one tonne of fish and 62 kg of orange roughy. The catch was mixed, with hoki (30 %), hake (13 %) and orange roughy (10 %) being the three main species (Figure 16). Otolith samples: ORH x100.

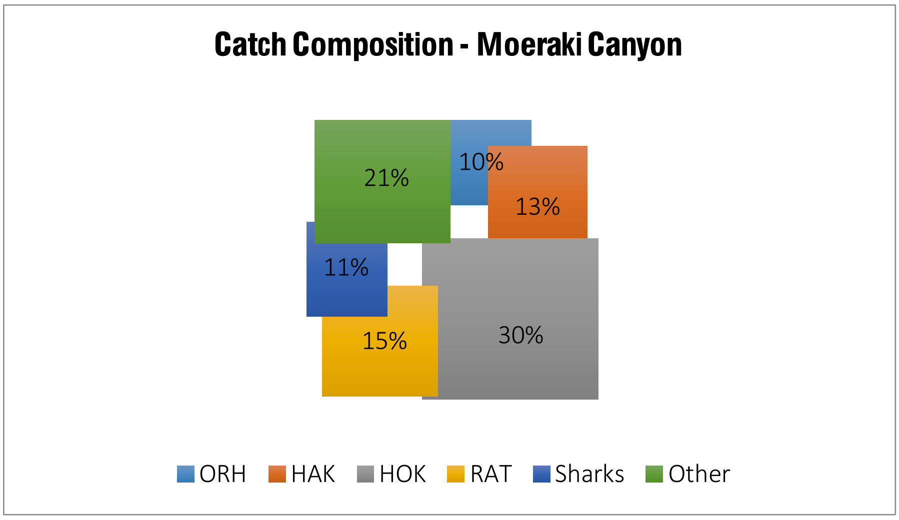


Figure 16. Catch composition – Moeraki Canyon

ORH Size frequency

The average lengths and weights were 23.8 cm and 0.51 kg for males and 24.6 cm and 0.62 kg for females (Figure 17). Average lengths and weights for sexes combined were 24.1 cm and 0.54 kg.

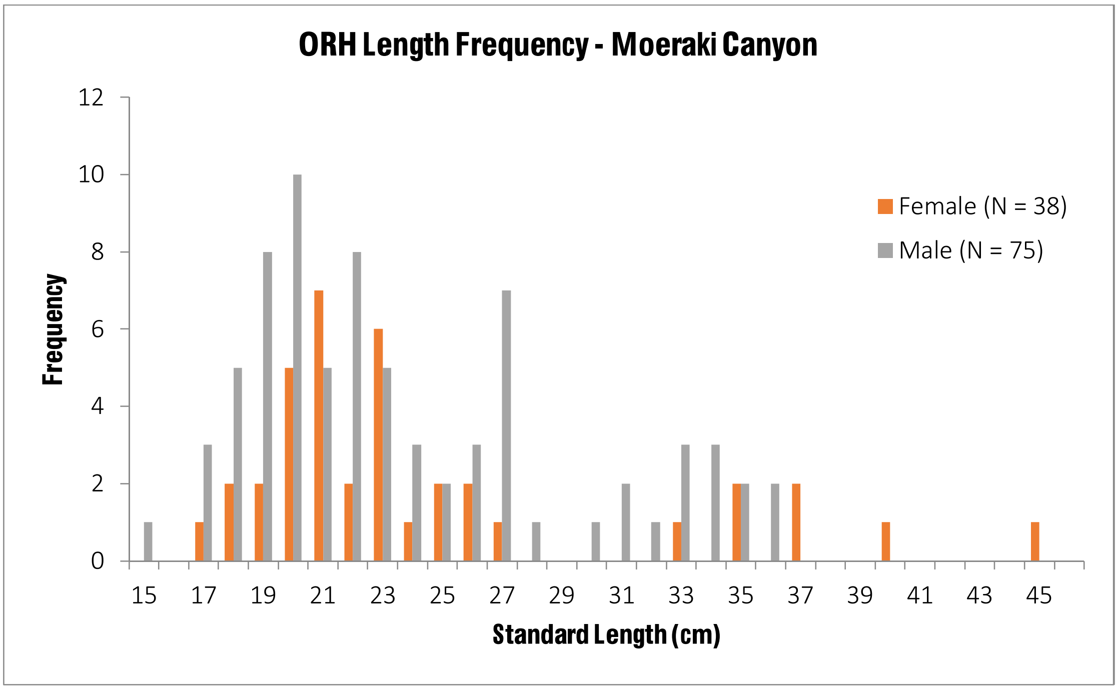


Figure 17. Orange roughy length frequency – Moeraki Canyon

ORH Average Spawning State

The majority of fish were in resting condition (>80%), (Figure 18). While there was evidence of some spawning activity here (3%), it was unlikely that the small catch will have yielded spawning information that was representative of the orange roughy population.

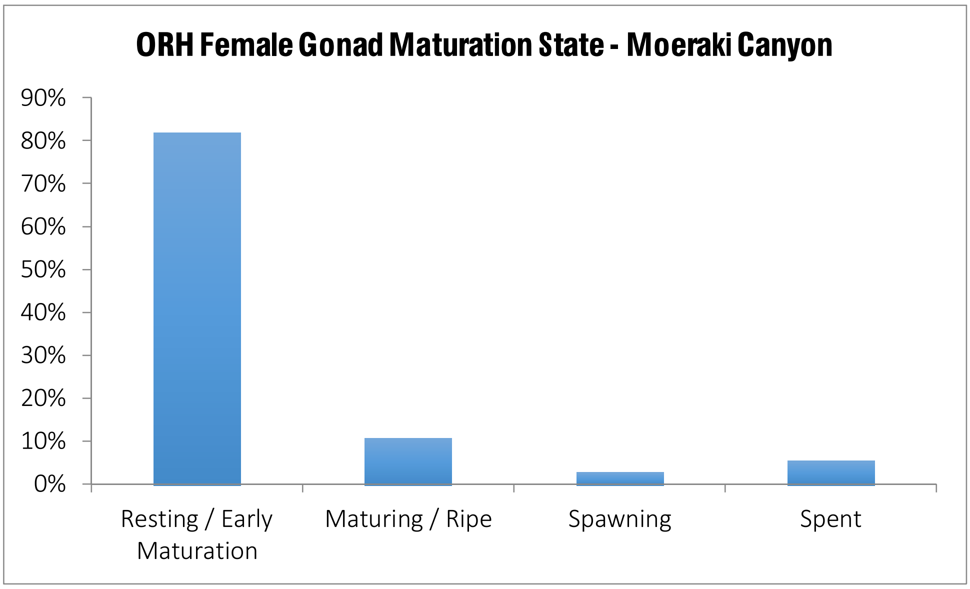


Figure 18. Orange roughy average female gonad maturity – Moeraki Canyon

6.3 ORH7B: Feature 3 biological results

Feature 3

A single biological tow undertaken here (OP17) yielded a mixed catch of 1.4 t. Orange roughy was the main species (33%), followed by small-scale slickhead (25%), hoki (12%) and hake (11%), (Figure 19). Otolith samples: ORH x40.

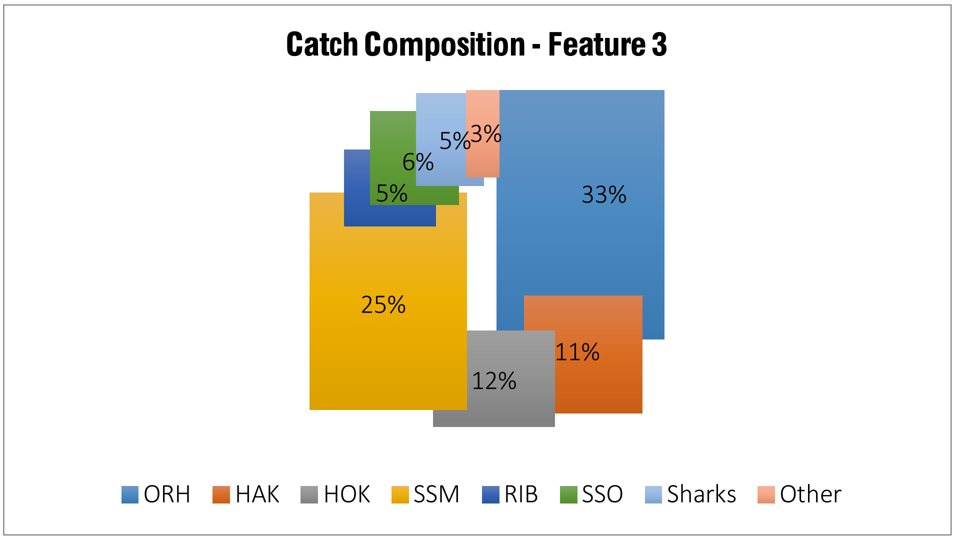


Figure 19. Catch composition – Feature 3

ORH Size frequency

Average lengths and weights were 28.4 cm and 0.75 kg for males and 29.7 cm and 0.85 kg for females (Figure 20). Average lengths and weights for sexes combined were 29.0 cm and 0.80 kg.

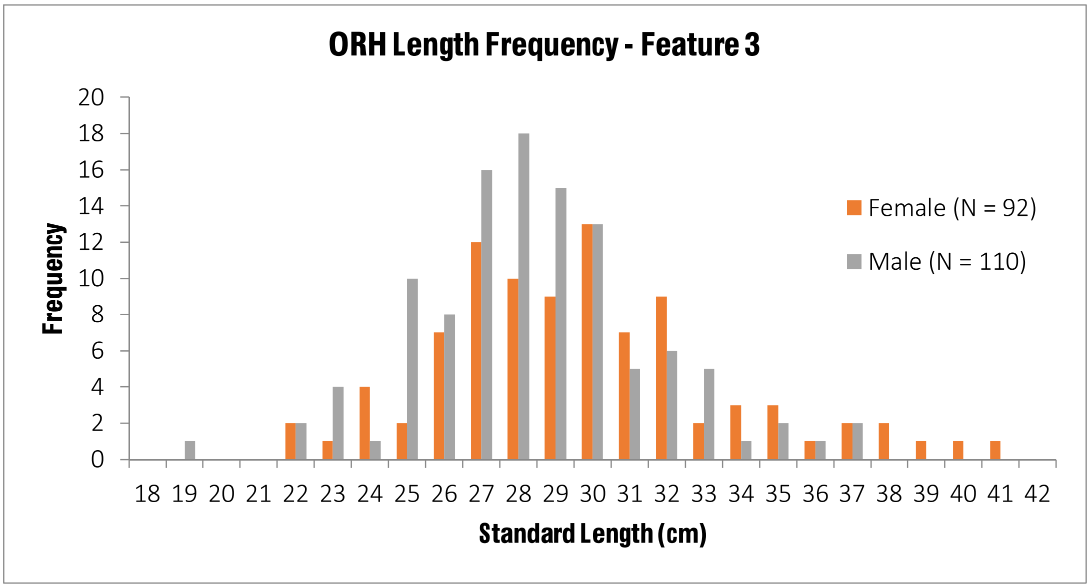


Figure 20. Orange roughy length frequency – Feature 3

ORH Average Spawning State

Fish were predominantly in resting condition (90%), suggesting that either spawning had occurred here well before the survey or that this is not a spawning area for orange roughy (Figure 21).

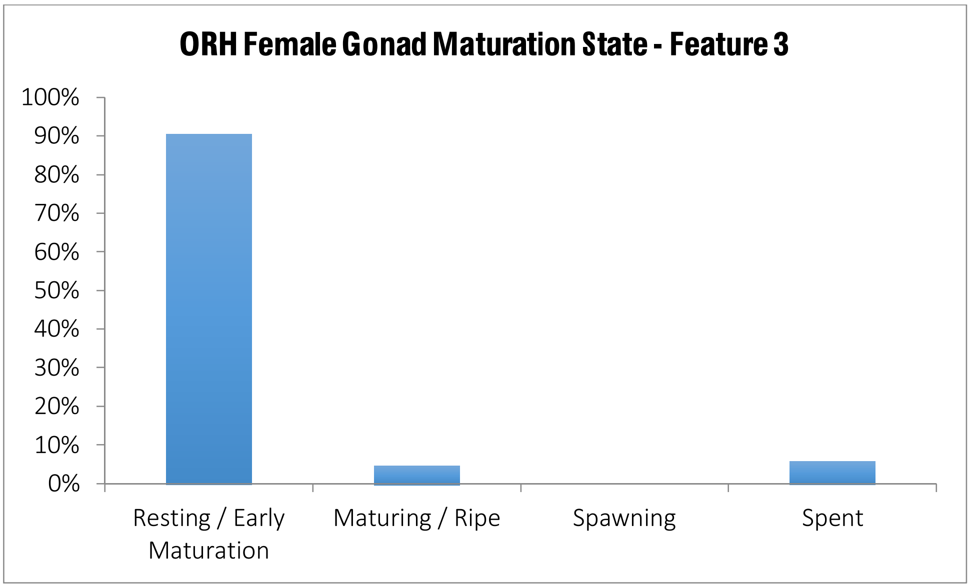
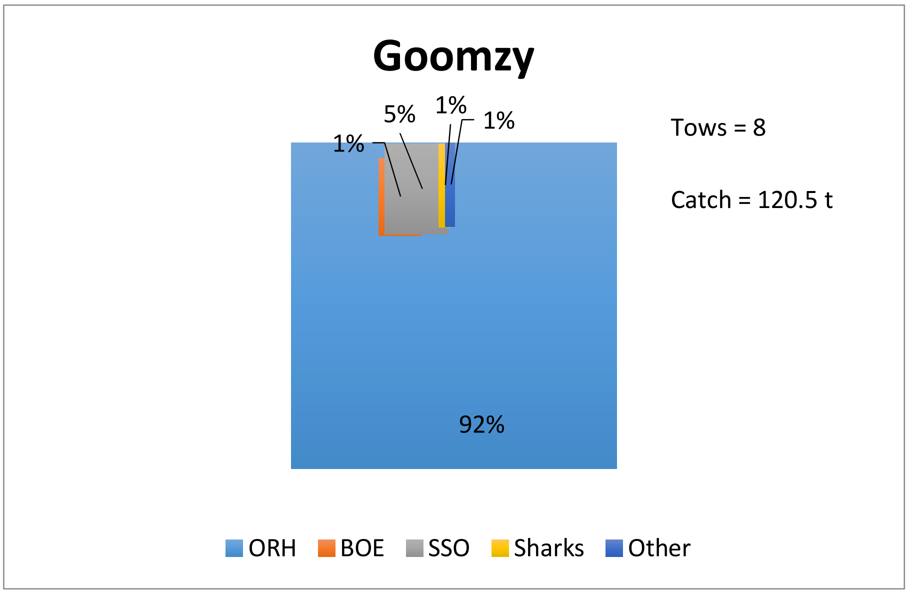


Figure 21. Orange roughy average female gonad maturity – Feature 3

6.4 ORH3B: Goomzy biological results

Eight biological tows were undertaken on Goomzy, yielding a total catch of 120.5 t of fish. Orange roughy comprised 111.3 t (92% by weight) for all tows combined (Figure 22). Otolith samples: ORH x350; SSO x120.



5==

Figure 22. Catch composition by weight– Goomzy

<u>ORH Size frequency</u>

The average lengths and weights were 33.6 cm and 1.25 kg for males and 35.6 cm and 1.53 kg for females (Figure 23). Average length and weight for sexes combined were 34.8 cm and 1.43 kg.

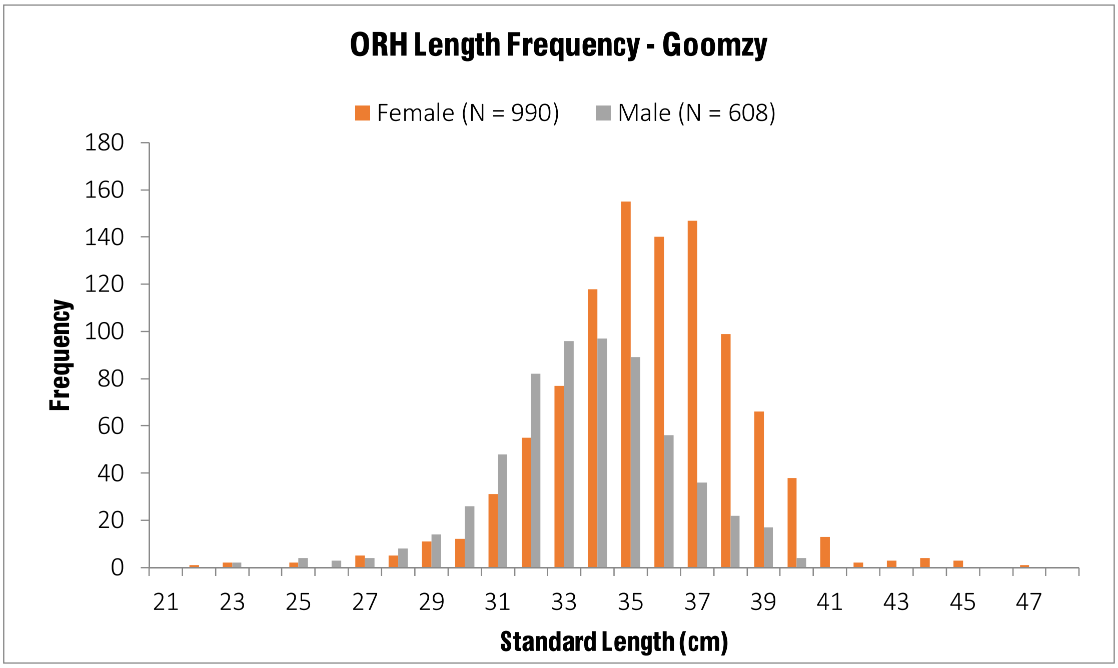


Figure 23. Orange roughy length frequency – Goomzy

ORH Spawning progression

Around 75% of fish were in ripe condition at the start of the survey on 6 July (Figure 24). Spawning commenced shortly thereafter, appearing to peak on about 10 July. By 12 July the percentage of spent fish ranged between 5 – 50%.

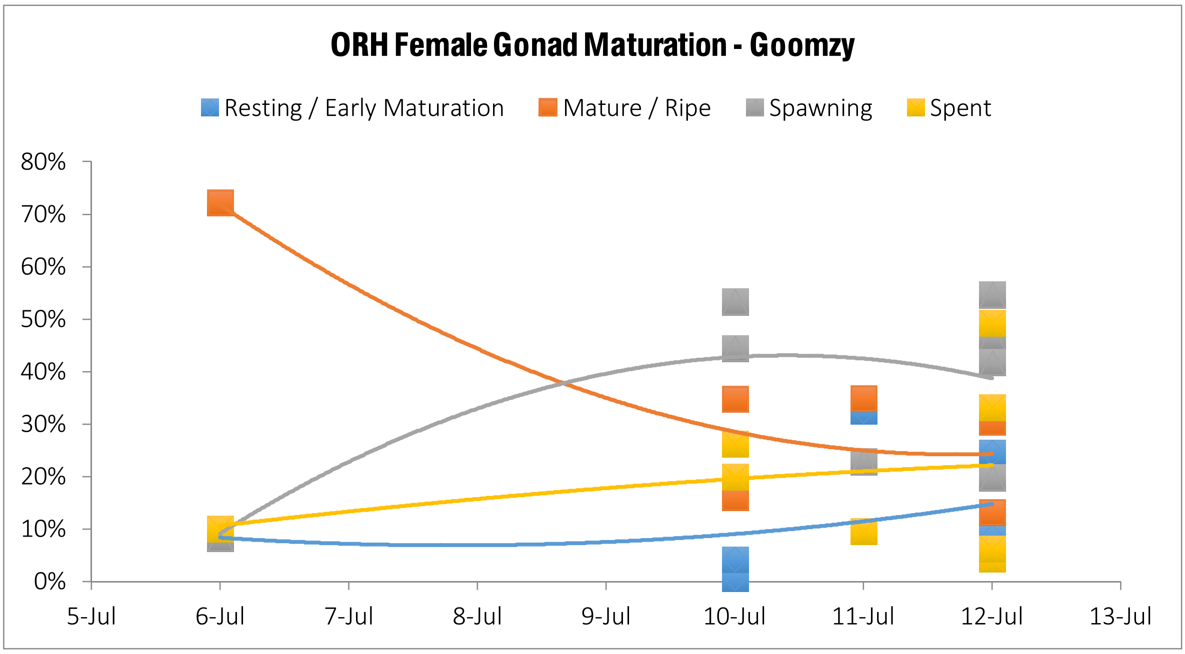


Figure 24. Orange roughy female gonad maturation – Goomzy

ORH Average spawning state

Goomzy is clearly an important orange roughy spawning area with over 85% of fish either in ripe, spawning or spent condition (Figure 25).

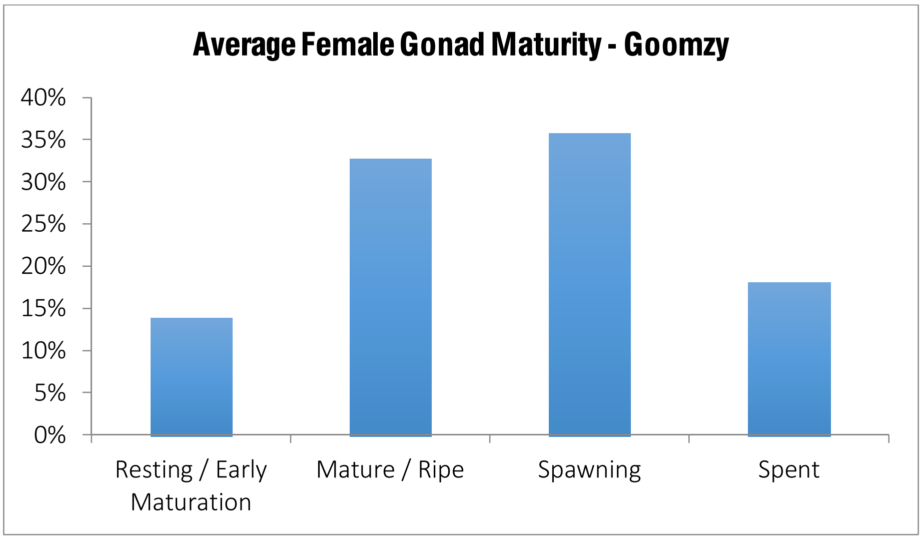


Figure 25. Orange roughy average female gonad maturity – Goomzy

6.5 ORH3B: Godiva biological results

The five biological tows undertaken yielded a total of 36.4 t of fish (Figure 26). Catches were mixed, with orange roughy, smooth oreo and black oreo being the major species.

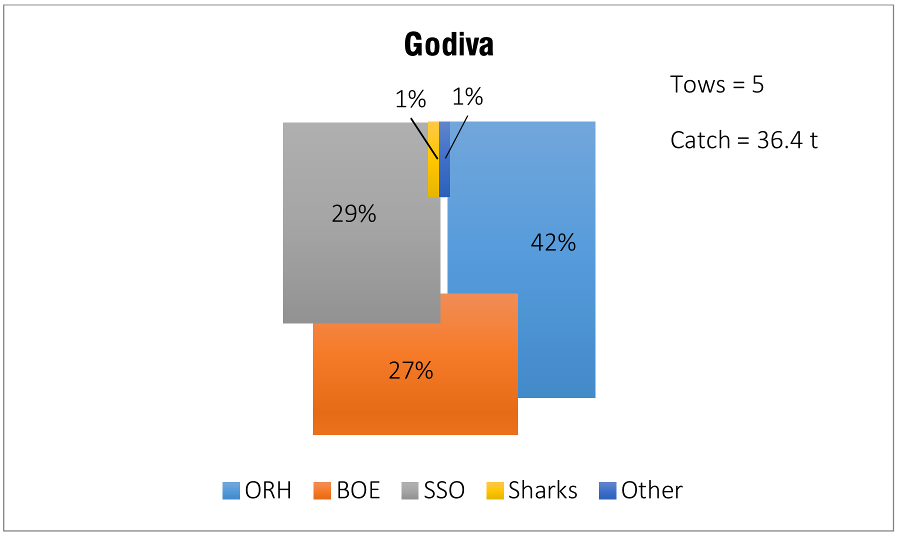


Figure 26. Catch composition – Godiva

ORH Size frequency

The average lengths and weights were 32.2 cm and 1.17 kg for males and 34.6 cm and 1.30 kg for females (Figure 27). Average lengths and weights for sexes combined were 33.6 cm and 1.25 kg.

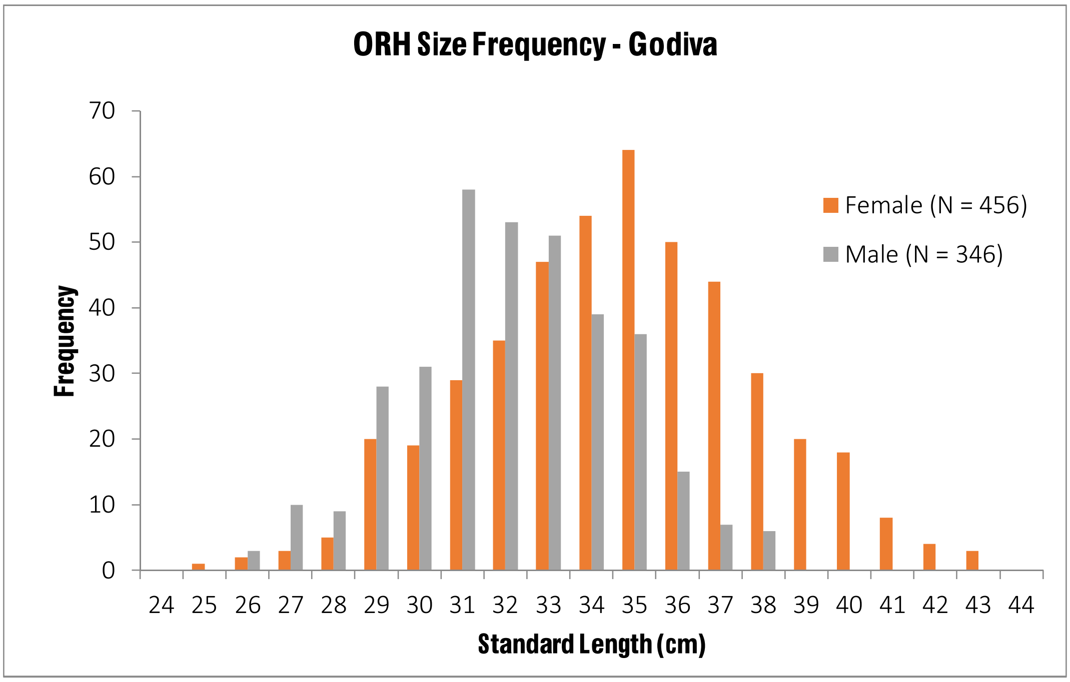


Figure 27. Orange roughy length frequency –Godiva

Spawning progression

Factors pointing to Godiva not being an important spawning area for orange roughy include: the high proportion of resting gonads here (50 – 60%) throughout the survey period, and the absence of a transition from ripe to spawning gonads over the survey period, suggesting that ripe fish were moving off to spawn elsewhere (Figure 28).

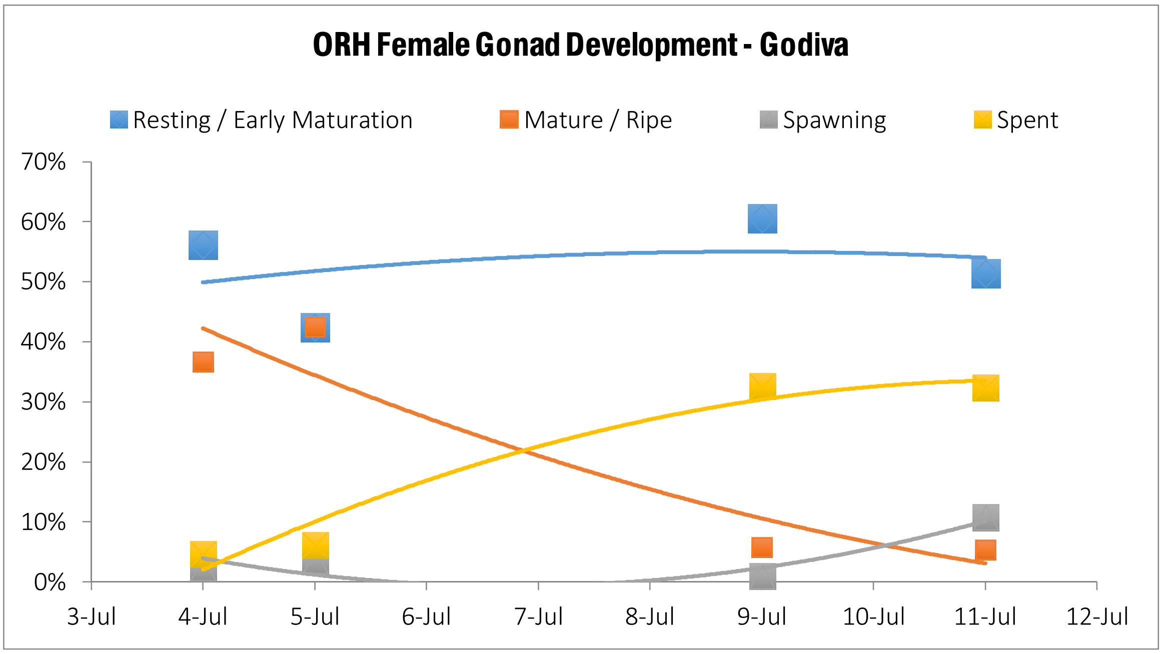


Figure 28. Orange roughy female gonad maturation – Godiva

ORH Average spawning state

The majority of fish were in resting condition (>50%), although there was evidence of at least some spawning activity here (Figure 29).

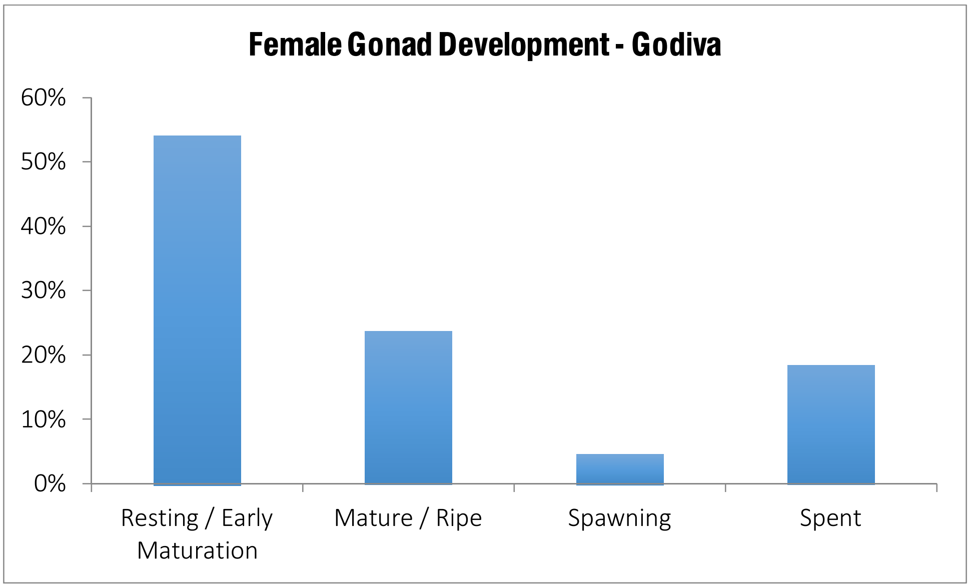


Figure 29. Orange roughy average female gonad maturity – Godiva

6.6 ORH3B: Net loft biological results

A single biological tow was undertaken, which yielded a mixed catch of just under one tonne. Orange roughy, smooth oreo and black oreo were the major species Figure 30.

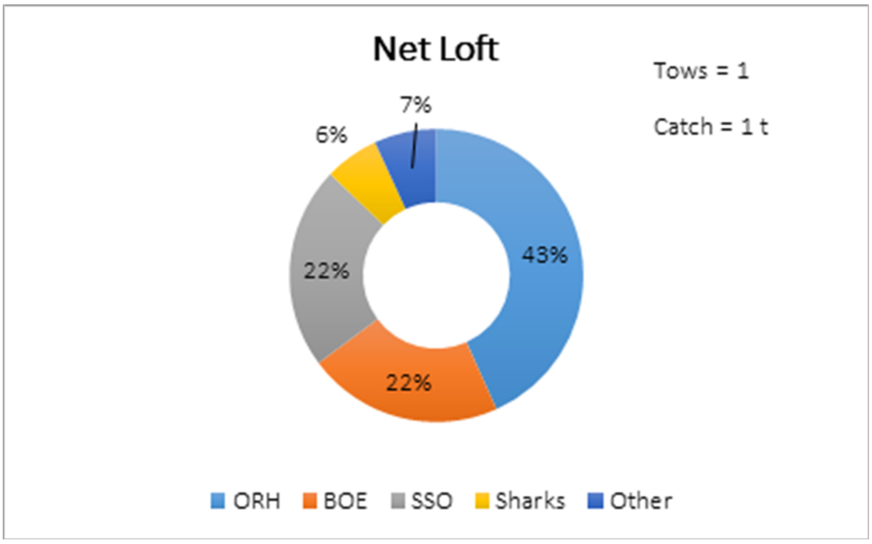


Figure 30. Catch composition – Net Loft

ORH Size frequency

Average lengths and weights were 31.5 cm and 1.12 kg for males and 34.4 cm and 1.36 kg for females (Figure 31). Average lengths and weights for sexes combined were 33.9 cm and 1.32 kg.

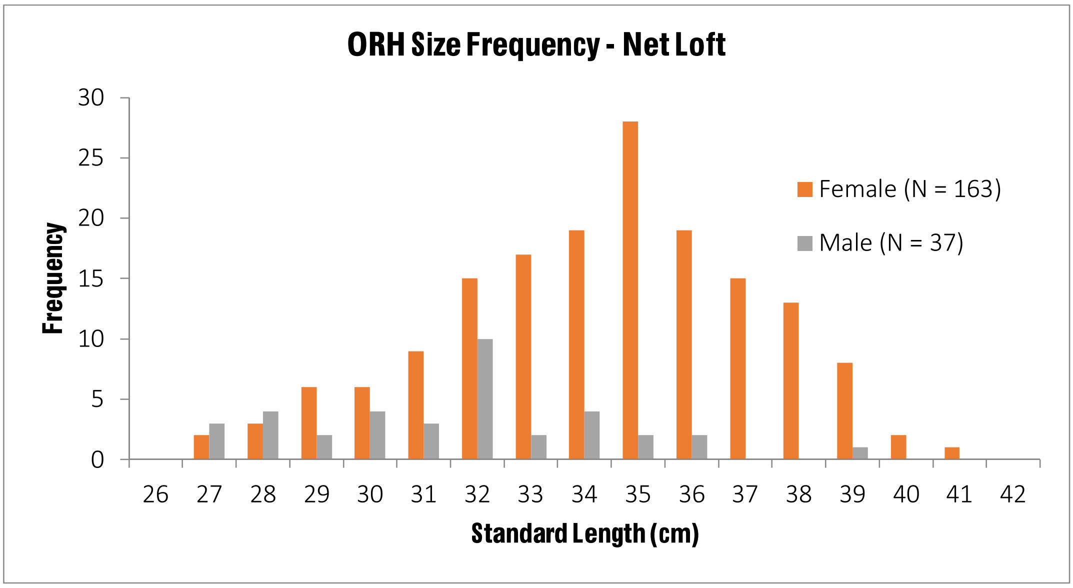


Figure 31. Orange roughy length frequency – Net Loft

ORH Average Spawning State

Fish were either spent (80%) or in resting condition (20%), suggesting that this feature may be a feeding area rather than a spawning site (Figure 32).

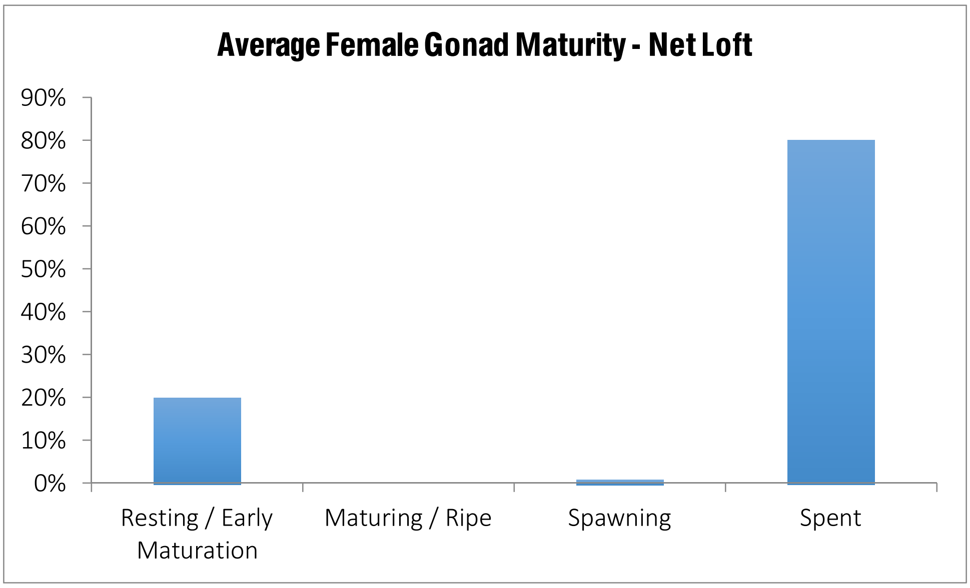


Figure 32. Orange roughy average female gonad maturity – Net Loft

6.7 ORH3B: Alistair's biological results

A single biological tow was undertaken, which yielded a catch of just under one tonne, of which smooth oreo comprised 92% by weight (Figure 33). Otolith samples: SSO x60.

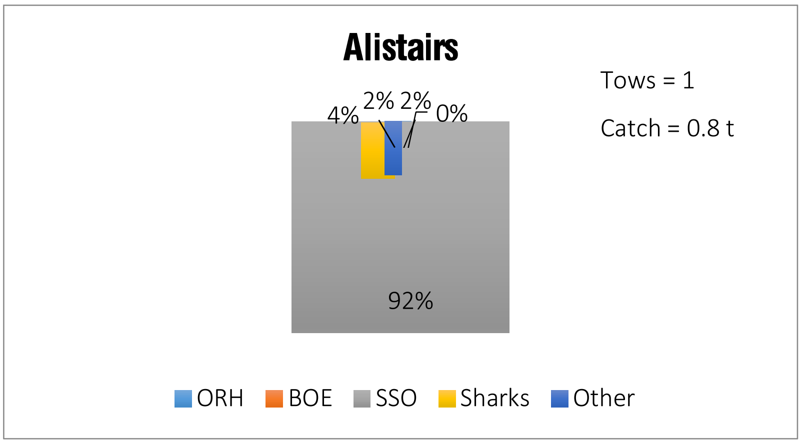


Figure 33. Catch composition – Alistair's

SSO Size Frequency

Average lengths and weights were 39.0 cm and 1.22 kg for males and 42.1 cm and 1.56 kg for females (Figure 34). Average lengths and weights for sexes combined were 40.3 cm and 1.37 kg.

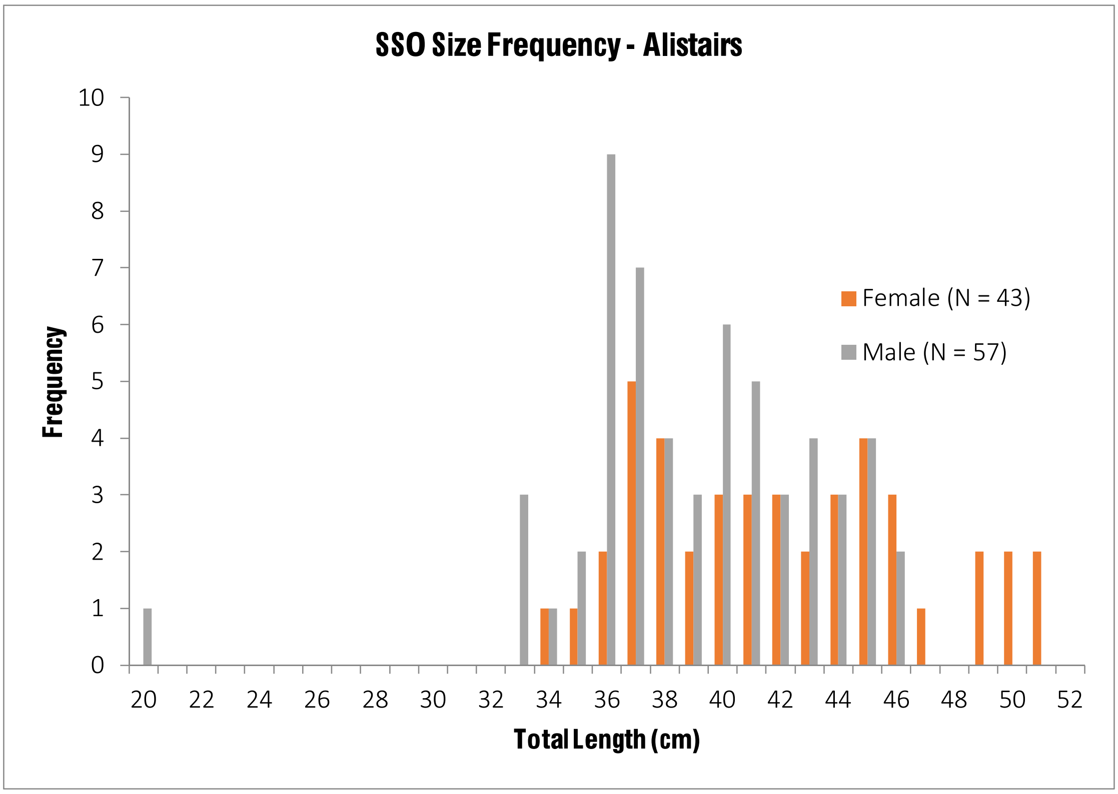


Figure 34. Smooth oreo length frequency – Alistair's

SSO Spawning state

No evidence of spawning. Gonads were in early maturation or maturing stages (Figure 35).

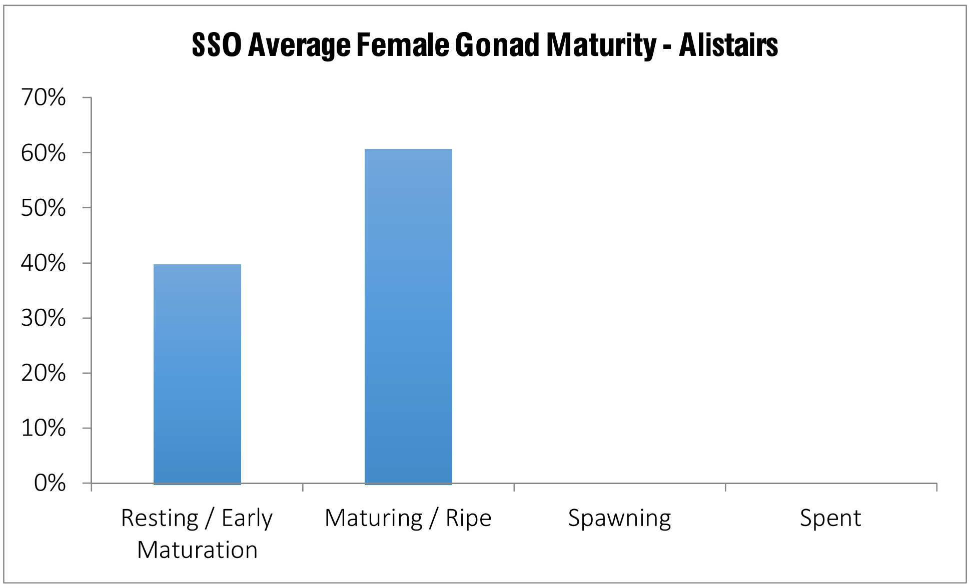


Figure 35. Smooth oreo average female gonad maturity – Alistair's

6.8 ORH3B: Porirua biological results

Two biological tows were undertaken, yielding a total catch of 11.4 t. Black and smooth oreo were the dominant species (Figure 36). Otolith samples: BOE x60.

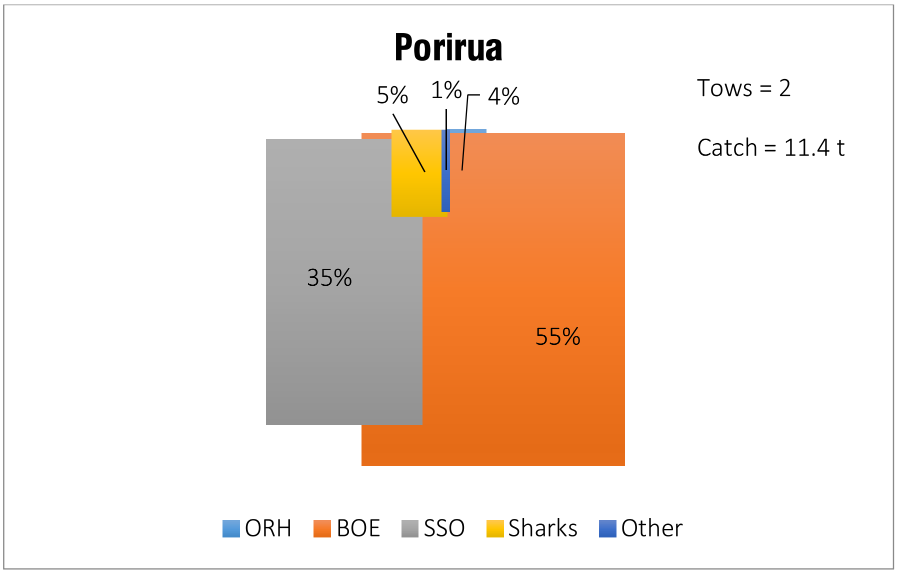


Figure 36. Catch composition – Porirua

<u>BOE Size frequency</u>

Average lengths and weights of BOE were 33.7 cm and 0.82 kg for males and 35.6 cm and 1.07 kg for females (Figure 37). Average lengths and weights for sexes combined were 34.7 cm and 0.95 kg.

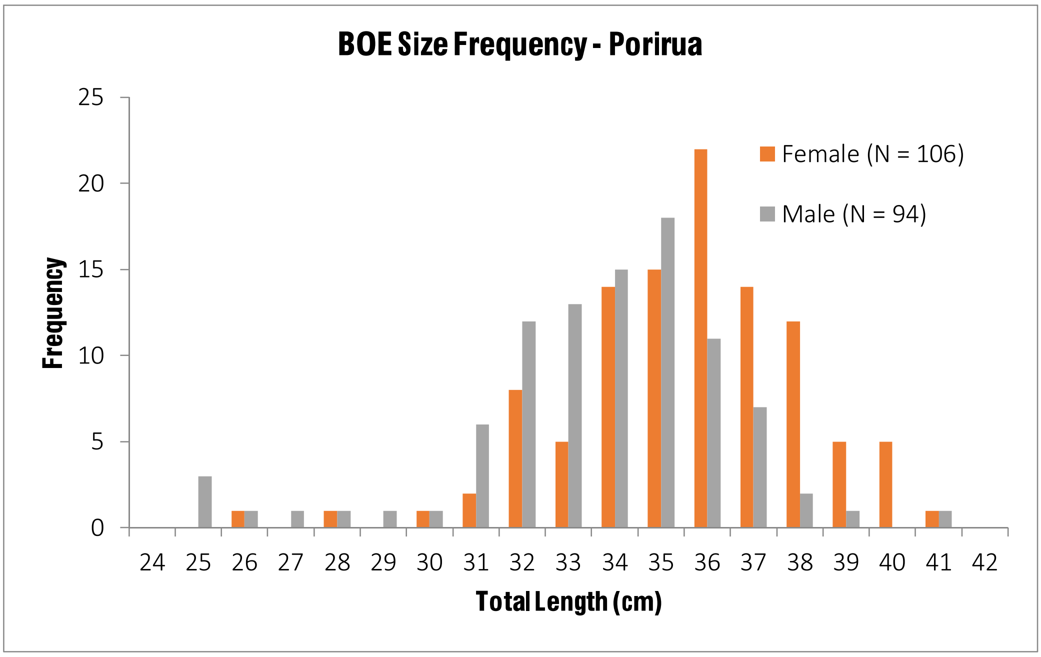


Figure 37. Black oreo length frequency – Porirua

BOE Spawning state

No evidence of spawning. Gonads were in early maturation or maturing stages (Figure 38).

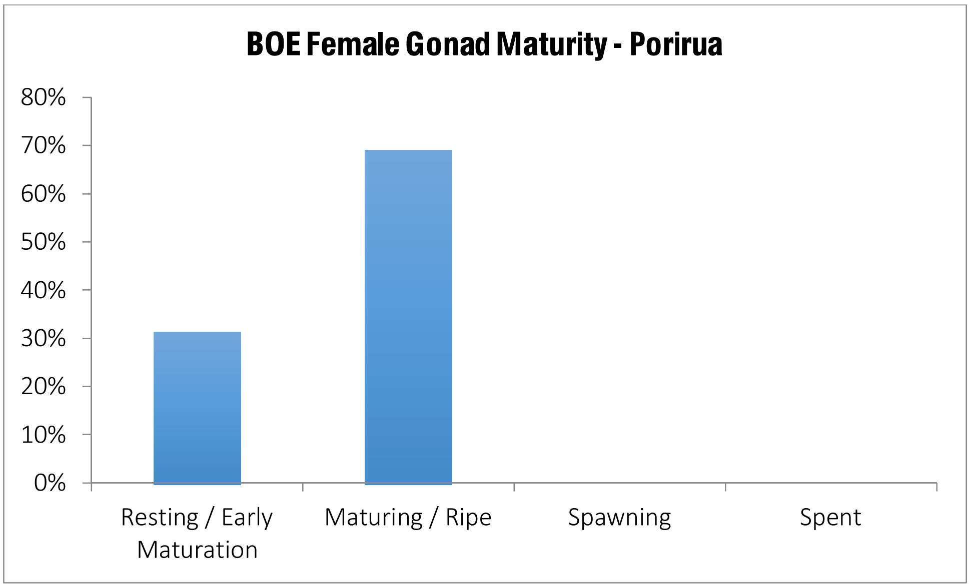


Figure 38. Black Oreo average female gonad maturity – Porirua

SSO Size frequency

Average lengths and weights of SSO were 36.7 cm and 1.14 kg for males and 36.8 cm and 1.15 kg for females (Figure 39). Average lengths and weights for sexes combined were 36.8 cm and 1.15 kg.

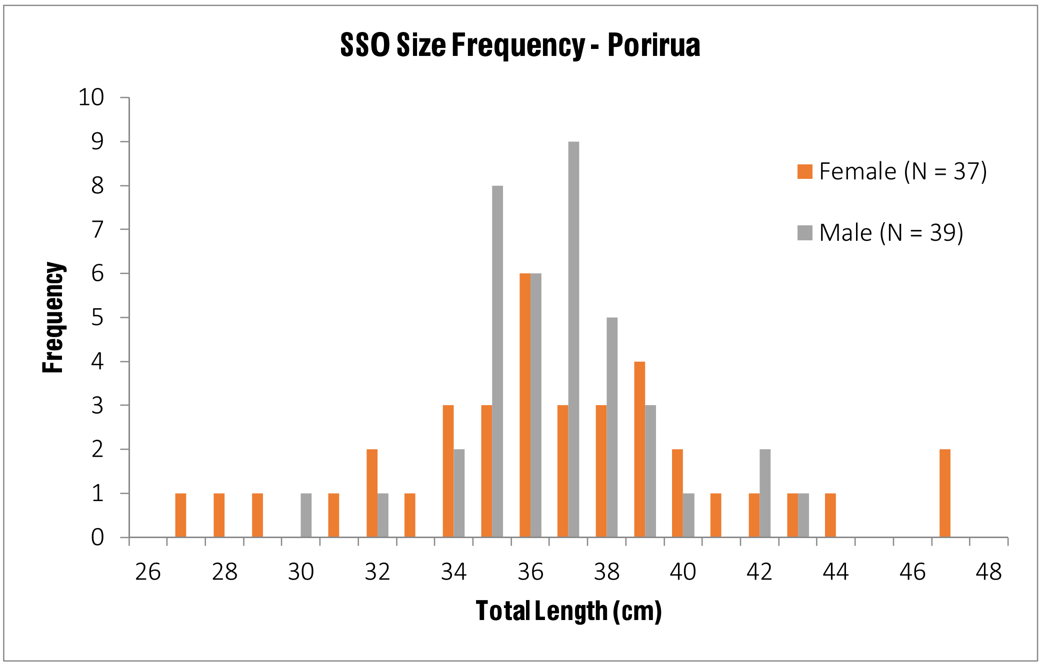


Figure 39. Smooth oreo length frequency – Porirua

<u>SSO Spawning state</u>

No evidence of spawning. Gonads were mainly resting or in early maturation (Figure 40).

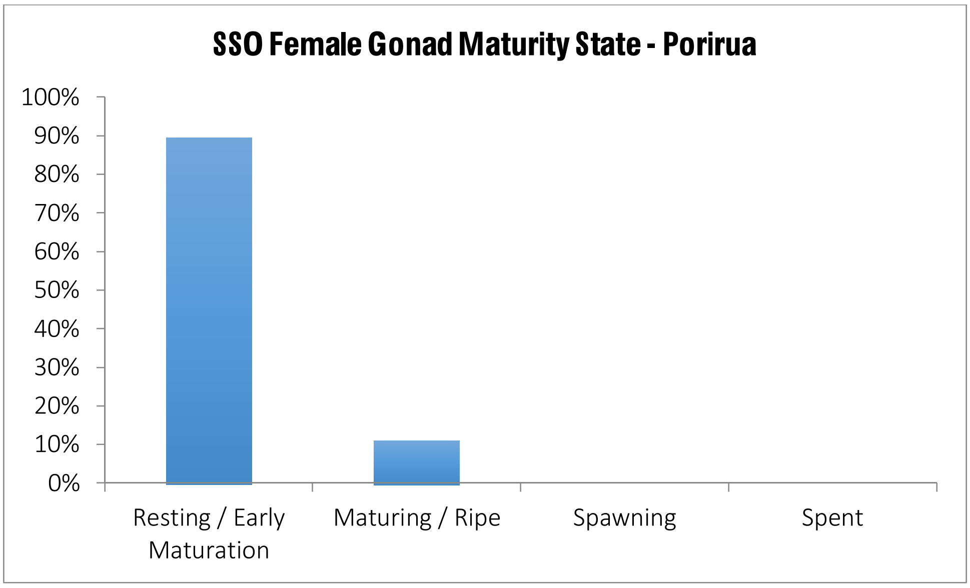


Figure 40. Smooth oreo average female gonad maturity – Porirua

6.9 ORH3B: Mt Duncan biological results

Two biological tows were undertaken, yielding a total catch of 6.4 t. Orange roughy was the most abundant species, followed by black oreo, smooth oreo and deepwater sharks (Figure 41). Otolith samples: ORH x100; BOE x60; SSO x60.

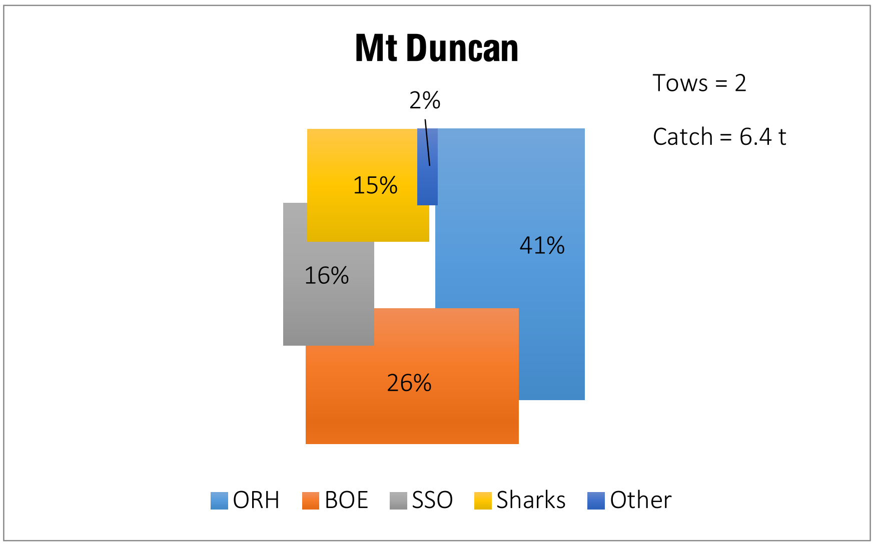


Figure 41. Catch composition – Mt Duncan

ORH Size frequency

Average lengths and weights were 36.9 cm and 1.76 kg for males and 41.2 cm and 2.73 kg for females (Figure 42). Average lengths and weights for sexes combined were 39.3 cm and 2.29 kg. The larger average size of orange roughy here than in other areas is interesting and suggestive of this feature being a preferred habitat for orange roughy.

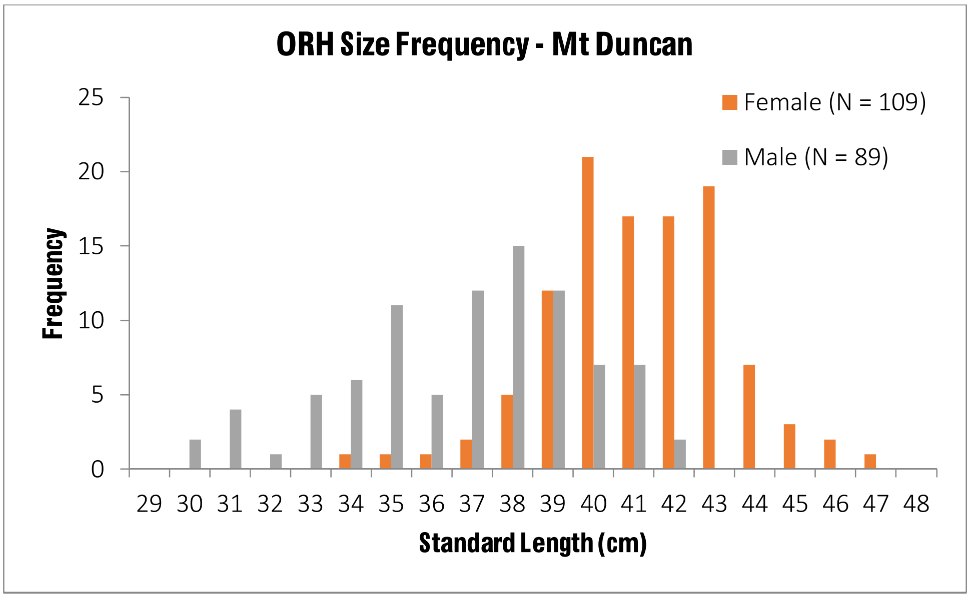


Figure 42. Orange roughy length frequency – Mt Duncan

ORH Spawning state

Most females were maturing or ripe and a small proportion was spawning (Figure 43).

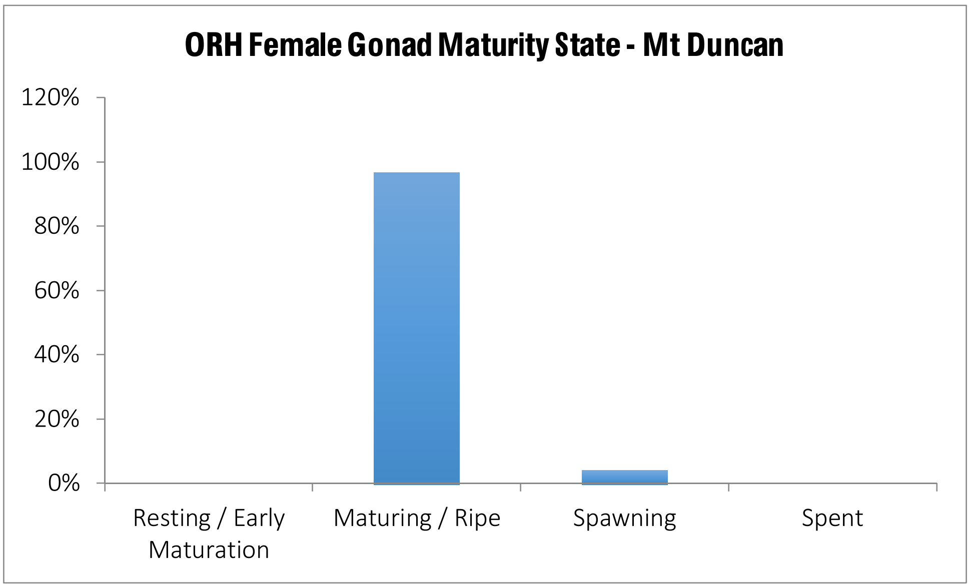


Figure 43. Orange roughy average female gonad maturity – Mt Duncan

SSO Size frequency

Average lengths and weights of SSO were 39.8 cm and 1.34 kg for males and 42.8 cm and 1.64 kg for females (Figure 44). Average lengths and weights for sexes combined were 41.9 cm and 1.54 kg.

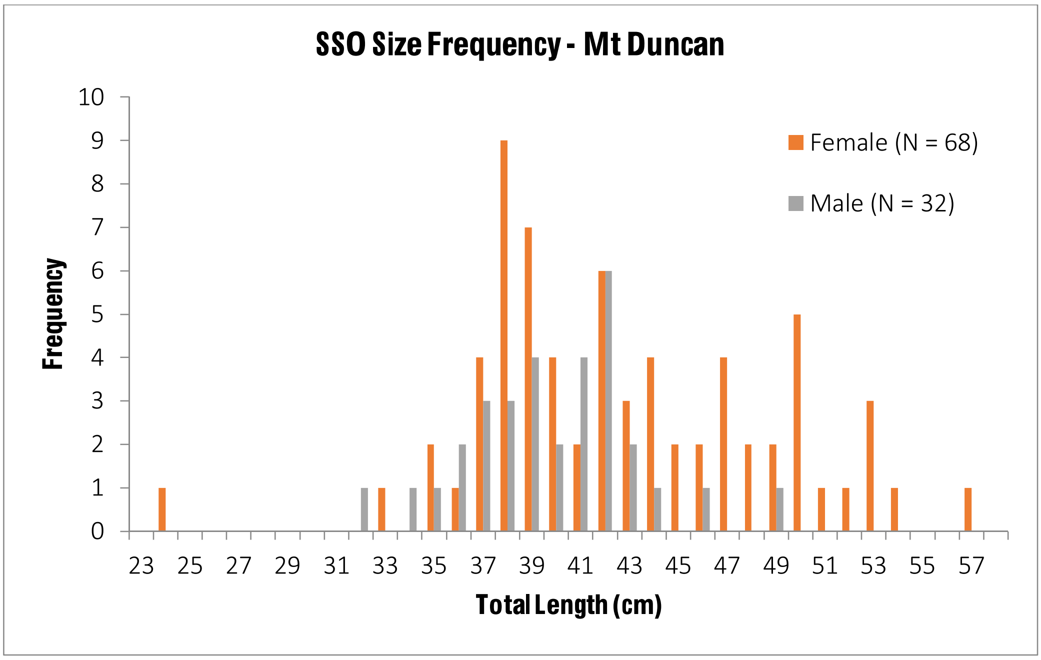


Figure 44. Smooth oreo length frequency – Mt Duncan

SSO gonad development state

No evidence of spawning. Gonads were mainly in the early maturation and maturing stages (Figure 45).

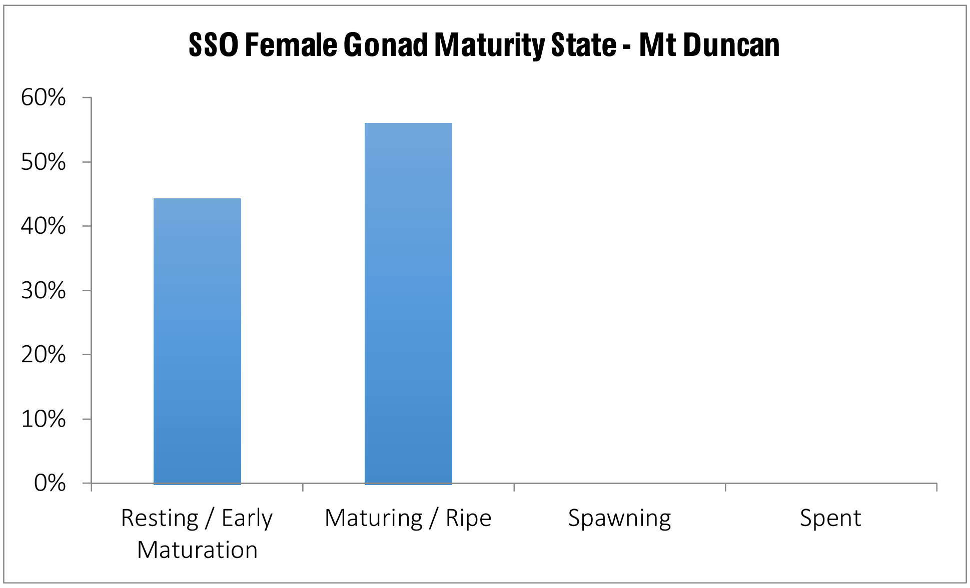


Figure 45. Smooth oreo average female gonad maturity – Mt Duncan

BOE Size frequency

Average lengths and weights of BOE were 26.2 cm and 0.45 kg for males and 27.1 cm and 0.44 kg for females (Figure 46). Average lengths and weights for sexes combined were 26.6 cm and 0.45 kg.

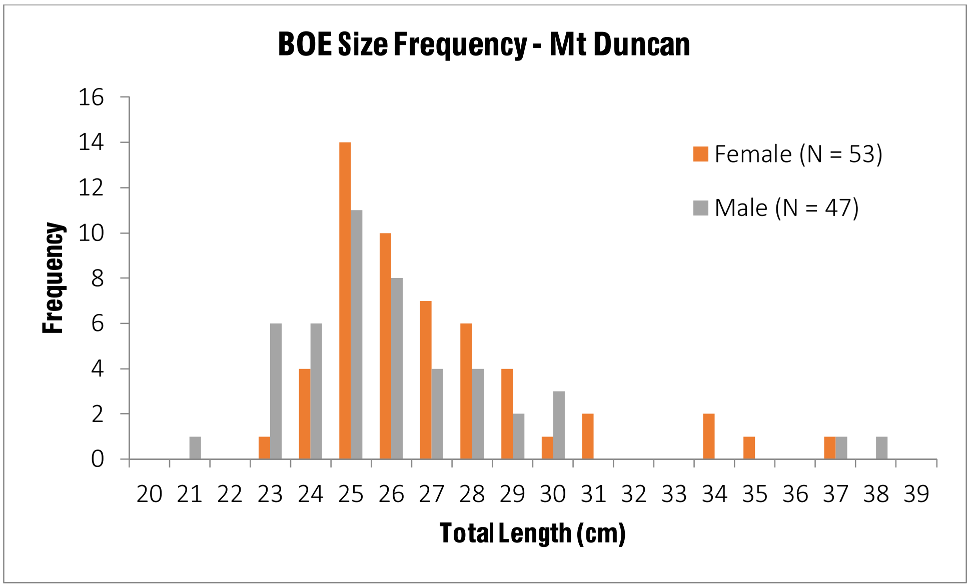


Figure 46. Black oreo length frequency – Mt Duncan

BOE Spawning State

No evidence of spawning. Gonads were mainly resting or in early maturation (Figure 47).

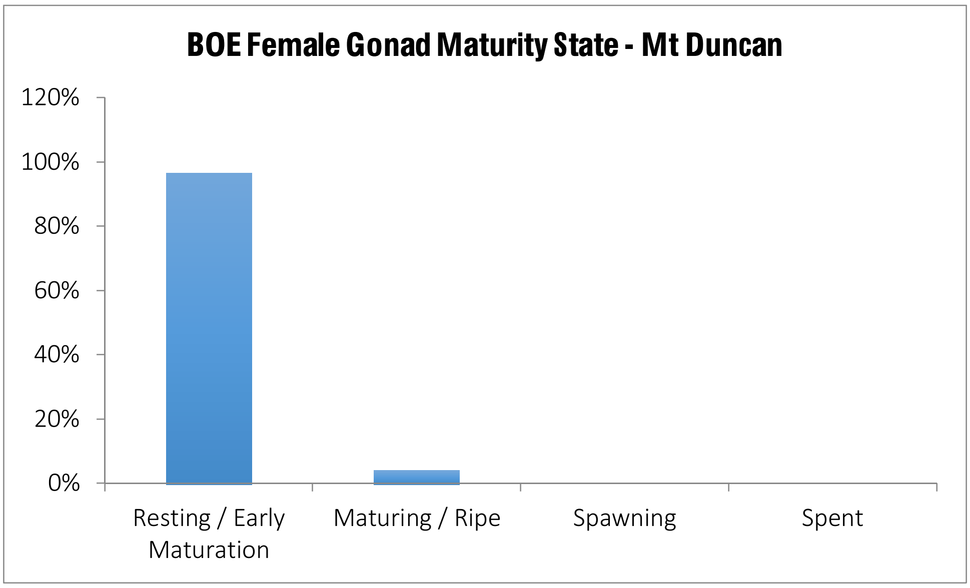


Figure 47. Black oreo average female gonad maturity – Mt Duncan

7 Appendix C – Table of activities

Table 22. Table of activities.

OP Number	Operation_ Type	Start_date (UTC)	Start_Time (UTC)	Location	Comment
1	Vessel calibration	26/06/2015	20:30:00	Off Pepin Island	Vessel calibration. 20:30 to 23:00. Perfect conditions. 60 mm copper sphere found easily. Calibration run at 2000 W and 2.024 and 1.024 ms pulse duration
2	Vessel Survey	28/06/2015	4:45:00	Cook Canyon (ORH7B)	Scoping survey with Furuno FCV sounder on
3	AOS biological	29/06/2015	0:45:00	Cook Canyon (ORH7B)	First trawl shot; NE tow across flat ground south of Cook Canyon along trawl shot known to Craig. A test of the AOS in fishing mode, and sample to determine orange roughy spawning condition. NUC computer not working, so no Gig E. Long tow, passing through roughy mark on the edge of the canyon. 18 tonne catch. GigE PC did not start.
4	Vessel Survey	29/06/2015	6:00:00	Cook Canyon (ORH7B)	Localised grid survey attempting to map out extent of mark where 18 tonnes of roughy had been caught just prior. No marks seen. Only hazy scatter at 700-800 m.
5	AOS survey mode - single pass	29/06/2015	10:50:00	Cook Canyon (ORH7B)	High tow with AOS ~300 m above seafloor to key out blue haze. No roughy marks observed on vessel sounder
6	Vessel Survey	29/06/2015	15:00:00	Cook Canyon (ORH7B)	Final look at Cook Canyon - the edges to the east and north of OP5 - then moved north to the Abut grounds. Completed a zigzag survey from SE to NW of Cook feature, then a cross to the north and eastern trawl areas before heading south back to the Cook fishing area in the SE. Small mark on SE area.
7	Vessel Survey	29/06/2015	21:40:00	The Abut	Location: Abut Doing a mini-survey across the only mark seen: Furuno sounder off. Nothing seen to warrant further work. Furuno on.
8	Vessel Survey	29/06/2015	21:55:00	The Abut	Continue searching survey at Abut - heading west, then south back towards Cook Canyon. Furuno on. No significant marks observed. Decided not to tow here are so little to look at.
9	Vessel Survey	30/06/2015	0:00:00	Transit	Transit down to Moeraki grounds. No marks observed. Then did zig zag survey.
10	AOS biological	30/06/2015	9:15:00	Moeraki	Biological shot at Moeraki. Small catch of hoki, hake and small roughy.

OP Number	Operation_ Type	Start_date (UTC)	Start_Time (UTC)	Location	Comment
11	Vessel Survey	30/06/2015		Cook Canyon (ORH7B)	Application error - had to restart and re-enter this operation, so start time indicative. 15:00 - moving across to the 'Southern Flats' (south of Cook Canyon) and searching in zigzag pattern to the NNE. Easterly transits with the weather give OK data, whereas westerly transits are very noisy. Only faint near-bottom fuzzy marks in places across Southern Flats area. Continued north back to Cook Canyon. 23:45- have now spent several hours completing zigzag surveys at Cook Canyon - mainly on northern edge of canyon, and focussing in areas not surveyed previously. Only faint scattered near-bottom marks seen to date.
12	Vessel Survey	1/07/2015	0:00:00	Cook Canyon (ORH7B)	Continuing search transits of Cook Canyon.
13	AOS biological	1/07/2015	6:11:00	Cook Canyon (ORH7B)	AOS biological shot, with objective to obtain otoliths and track spawning stage. Gig-E worked but issue with settings meant black images.
14	AOS biological	1/07/2015	8:55:00	Cook Canyon (ORH7B)	Replicate biological shot, Cook canyon. Very little seen on the net monitor. Towed right down the bank.
15	AOS biological	1/07/2015	11:45:00	Cook Canyon (ORH7B)	Tow south-south west back towards canyon drop-off. Nothing much seen on net monitor. Catch of about 0.5 tonne, including a good sample of roughy.
16	Vessel Survey	1/07/2015	15:00	Southern features	15:00 Moving south via a series of isolated hills at south end of OR7B before taking Craig Jones to shore. No marks on first three surveyed.
17	AOS biological	2/07/2015	0:02:00		A trawl tow on Feature 3 off Jackson Point for biological data at a southern location within Box 7B, AOS data, and newly configured GigE cameras.
18		2/07/2015	22:00:00	Transit	Commenced work on fibre-optic cable and winch: progressive streaming and retrieval of cable in deep water to test winch power and to ensure wire tension and spooling is correctly set up for AOS deployments.
19	Vessel Survey	3/07/2015	11:30:00	Godiva	Quick vessel search over Godiva. Reasonable marks on 38 kHz sounder.
20	AOS Survey	3/07/2015	12:20:00	Godiva	AOS star survey, Godiva. Pulled system out of water as no sign of AOS 38 kHz interference on the topside sounder. 38 kHz intermittent and will need investigation.
21	AOS biological	3/07/2015	15:00:00	Godiva	Tow on mark on the western side of Godiva: a ~20 tonne bag of mixed roughy and dory. AOS in survey mode settings so no TS data.
22	Vessel Survey	3/07/2015	18:00:00	Alistair's	Conducting a vessel survey over Alistair's; this is an elongate feature with 3 low peaks, each with a mark. We have done a central WSW-ENE line + 3 perpendicular transects which target the locations of marks – all transects go with the weather (to the SE) so there are extra noisy transits to exclude during processing.
23	Vessel Survey	3/07/2015	19:30:00	Net Loft	Conducting a vessel 2-pass cross survey over the small Net Loft feature – a pair of small peaks. Marks seen at northern extent of northernmost feature, and at centre and eastern margin of southernmost peak.
24	Vessel Survey	3/07/2015	20:45:00	Goomzy	Commenced an extensive searching survey over Goomzy – a small plateau with 2 small peaks and a raised flat section at the southern margin. Fish marks seen along the south/SW margin, and a ripper mark at the northernmost of the two peaks. Conducting a 2-pass cross survey at the peak.
25	AOS Survey	3/07/2015	23:45:00	Goomzy	Have planned an interlaced grid survey over Goomzy, 7 transects of about 3 n.m. Net monitor not seeing depth below platform so hauled net to replace net monitor.
26	AOS Survey	4/07/2015	2:30:00	Goomzy	Completed the interlaced grid survey at about 17:00. Very rough seas.
27	AOS biological	4/07/2015	22:30:00	Godiva	Trawl shot on Godiva (no fishable marks on Goomzy). Weather and sea state also limit activities at the moment (i.e., avoiding travelling too far, and shooting unknown or difficult bottom). ~ 4 tonne with a lot of oreos.
28	AOS Survey	5/07/2015	1:45:00	Alistair's	Star survey of Alistair's. Aborted as AOS 38 kHz was not working and no marks observed
29	AOS Survey	5/07/2015	5:10:00	Net Loft	Star survey of Net Loft feature. Some marks on north and east side.
30	AOS biological	5/07/2015	15:30:00	Net Loft	Shot on the side of Net Loft - small catch (~1 tonne) Full set of AOS data taken successfully
31	AOS biological	5/07/2015	18:25:00	Goomzy	AOS biological sample on Goomzy (OP31) – a pair of close plume-like marks. A large catch (23 tonnes) of mainly orange rough taken. Full set of AOS data taken successfully
32	Vessel Survey	5/07/2015	22:00:00	Hopeful Hill	Moving south to scope new features whilst last bag of fish being processed. First feature is Hopeful Hill, a small ridge with 2 peaks (also named 'Worthalook' in the ship's plotter). Reasonable mark on top of both peaks, and weather OK, so doing a 2-pass cross vessel survey over northern peak (~ SE-NW and NE-SW) and a 3-pass E-W transit survey over the southern peak

OP Number	Operation_ Type	Start_date (UTC)	Start_Time (UTC)	Location	Comment
33	Vessel Survey	6/07/2015	1:37:00	Mt Duncan	Three transects over Mt Duncan. First transect had Furuno on. Repeated first transect in opposite direction with Furuno off and then third transect perpendicular to previous. Good marks, particularly on SE section with 1 km
34	Vessel Survey	6/07/2015	3:10:00	Porirua	Single pass over Porirua. Moderate mark worth investigating with AOS.
35	AOS Survey	6/07/2015	5:32:00	Porirua	4 transect star pattern survey at Porirua. Conducted 5th transect with platform at 100 m above the top of the mark to see if there is a scare reaction that would indicate orange roughy.
36	AOS biological	6/07/2015	14:47:00	Porirua	Pinned up after a short time on the bottom. Very small catch of mixed species. Downloaded only ~700 GigE images from each camera due to the very large nos. collected (~7000) and the time required to download whilst waiting to re-shoot the gear.
37	AOS biological	6/07/2015	16:45:00	Porirua	Straightforward tow for about 11 tonnes (dory?). Very good images of Dory.
38	AOS Survey	6/07/2015	19:30:00	Mt Duncan	6 prong star survey started. Hauled after second transect as 38 kHz had stopped working. Aborted survey and headed for port as one of the science party needed medical assistance.
39	AOS Survey	7/07/2015	22:06:00	Mt Duncan	6 spoke star survey at Mt Duncan.
40	AOS biological	8/07/2015	8:50:00	Mt Duncan	Tried to go right through the big mark on top of the feature. Only a few images of oreos, a hoki or two. Held net off seafloor at ~10-15 m for most part and dropped down to fish only at the last.
41	AOS biological	8/07/2015	12:00:00	Mt Duncan	Vessel tow, Mt Duncan.
42	Vessel Survey	8/07/2015	16:40:00	Malcolm's Monument	Pass over Malcolm's Monument
43	Vessel Survey	8/07/2015	19:22:00	Hopeful Hill	Quick pass over Hopeful Hill
44	Vessel Survey	8/07/2015	20:48:00	Godiva	Furuno on for first pass. Good marks.
45	AOS Survey	8/07/2015	22:51:00	Godiva	Caught a few midwater fish - a few fresh roughy (x13), Baxter's dogfish (x16), leaf scale gulper shark (x2), Plunket's shark (x1), warty oreo (x1) and big-scale pomfret (x1).
46	AOS biological	9/07/2015	5:20:00	Godiva	About 2 tonnes, mainly smooth dory.
47	AOS Survey	9/07/2015	8:08:00	Goomzy	Goomzy interlaced survey
48	AOS biological	9/07/2015	22:06:00	Goomzy	Large catch clean roughy. ~38 tonnes.
49	Vessel Survey	10/07/2015	5:15:00	Goomzy	
50	Vessel Survey	10/07/2015	10:22:00	Goomzy	Fine scale survey of location where main marks were observed on full Goomzy survey
51	AOS survey mode - single pass	10/07/2015	12:09:00	Goomzy	Single pass AOS over largest section of the mark that was previously scoped in the mini-grid vessel survey.
52	AOS biological	10/07/2015	14:54:00	Goomzy	Tow on orange roughy mark, Goomzy. 7 tonne bag
53	AOS biological	10/07/2015	20:24:00	Goomzy	Pinned up. 150 kg catch. Marks mobile
54	AOS survey mode - single pass	11/07/2015	2:00:00	Godiva	Fibre optic trial with AOS survey mode over Godiva. Deliberately towed AOS down onto mark at about 100 m range to get an avoidance reaction.
55	AOS biological	11/07/2015	4:00:00	Godiva	AOS biological tow at Godiva. Able to move from AOS survey mode to AOS TS mode without bringing net/AOS back on board as real-time control allowed settings to be changed. Observed first oreo and then mix of oreo and roughy going in the net in real time. 16 tonne mixed bag of fish landed.
56	Vessel Survey	11/07/2015	8:22:00	Goomzy	
57	AOS biological	11/07/2015	15:46:00	Goomzy	About 1.5 tonne of mixed roughy and black dory.
58	AOS biological	11/07/2015	19:45:00	Goomzy	A 3 tonne bag of mainly roughy.
59	AOS biological	11/07/2015	23:40:00	Alistair's	Shots on hazy mark at Alistair's. Small catch of fish (~750 kg), mainly smooth dory.
60	AOS biological	12/07/2015	2:00:00	Goomzy	Shot at OR mark at Goomzy. Very mobile mark and had gone by the time the trawl had returned. Only small catch (~700 kg), about 50% roughy.
61	AOS biological	12/07/2015	5:38:00	Goomzy	Large catch clean orange roughy 45 tonnes. GigE did not work.

OP Number	Operation_ Type	Start_date (UTC)	Start_Time (UTC)	Location	Comment
62	Vessel Survey	12/07/2015	8:52:00	Hopeful Hill	Vessel survey of Hopeful Hill while catch is being processed.
63	AOS survey mode - single pass	13/07/2015	1:10:00	Hopeful Hill	Single pass survey over Hopeful Hill. 38 kHz has CSIRO EK60 120 kHz power supply.

8 Appendix D – Thematic maps of echo-integration outputs

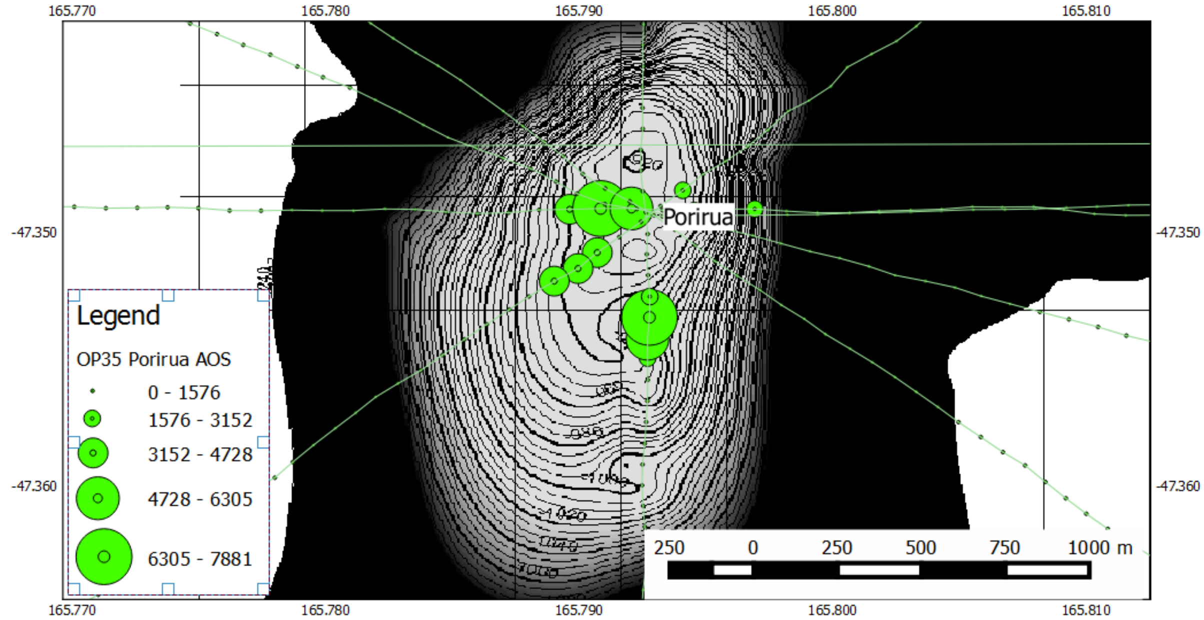


Figure 48. OP35 thematic map of echointegration NASC values at Porirua, AOS 38 kHz.

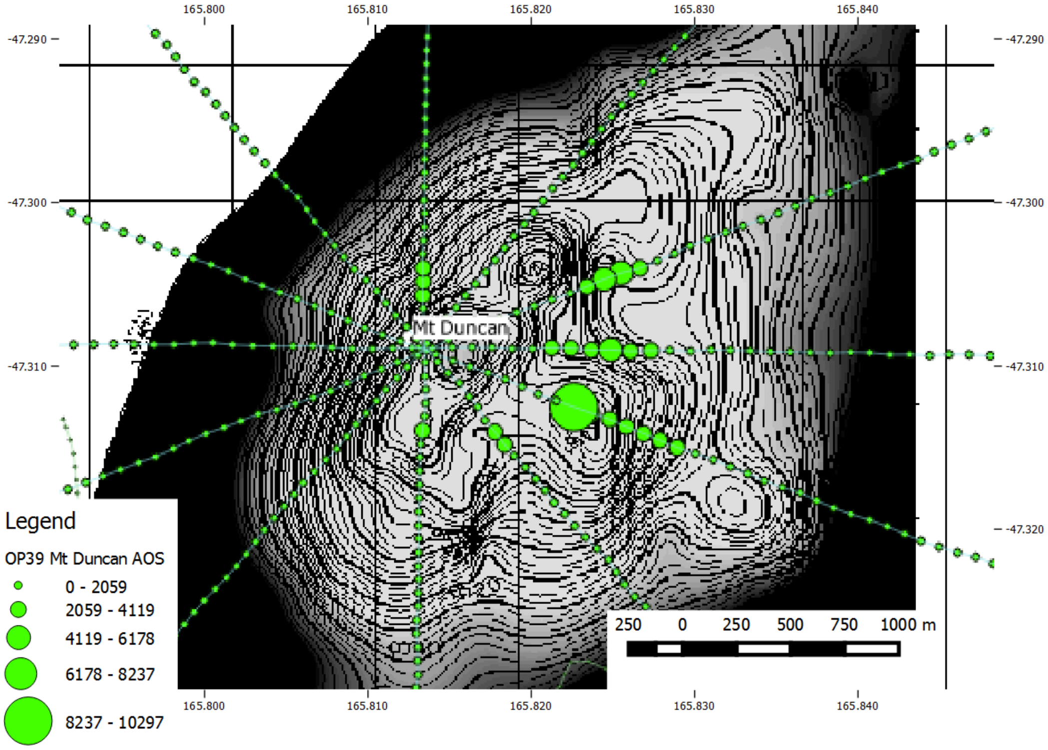


Figure 49. OP39 thematic map of echointegration NASC values at Mt Duncan, AOS 38 kHz.

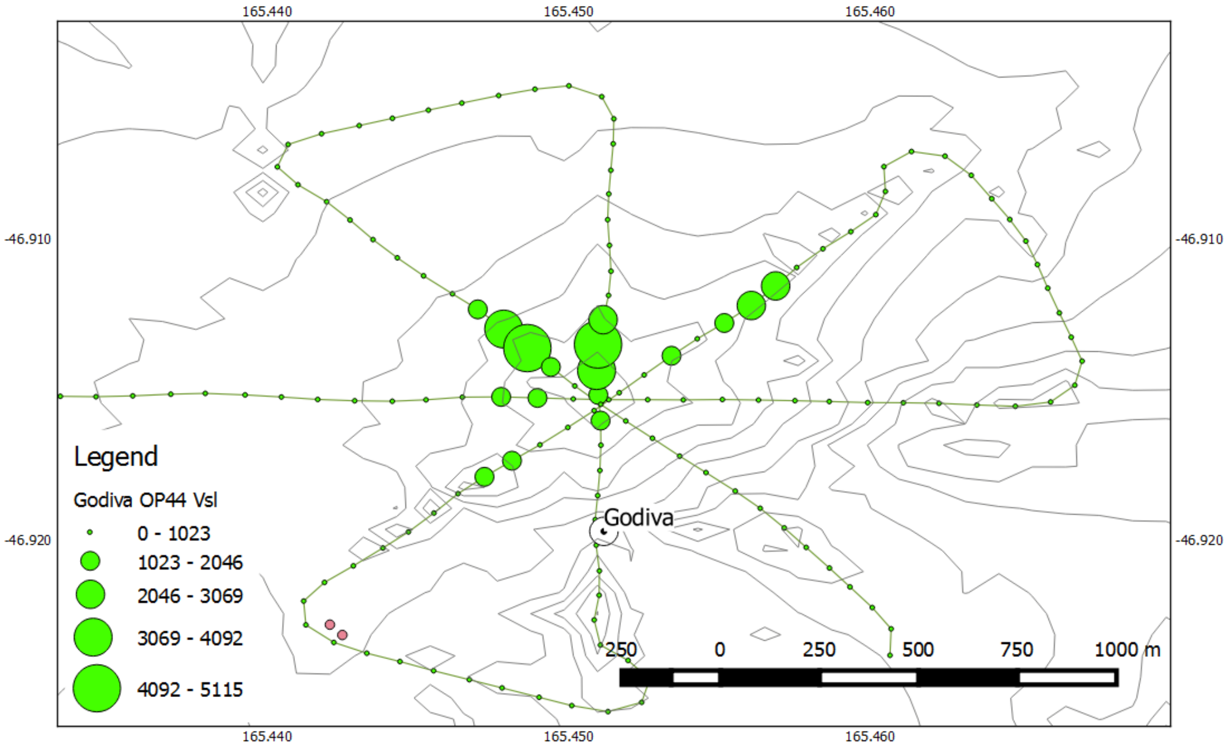


Figure 50. OP44 thematic map of echointegration NASC values at Godiva, Vessel 38 kHz.

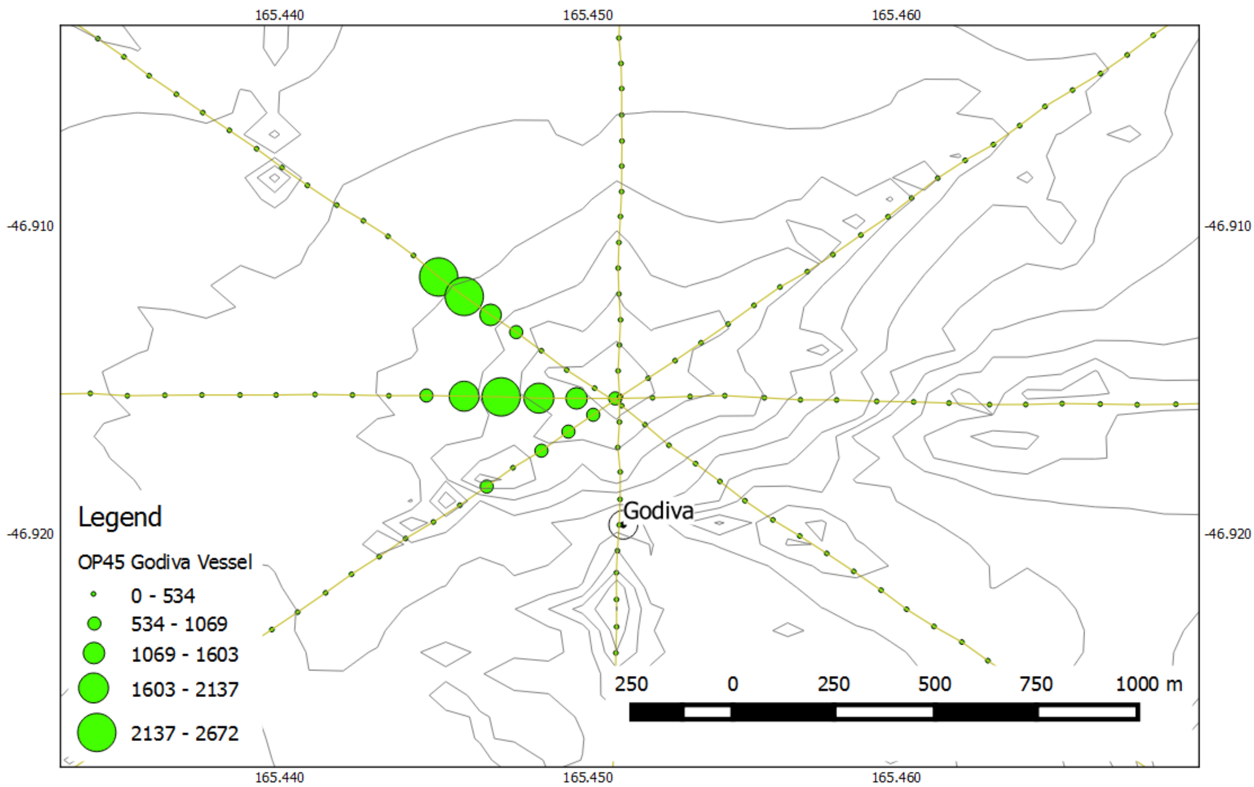


Figure 51. OP45 thematic map of echointegration NASC values at Godiva, Vessel 38 kHz.

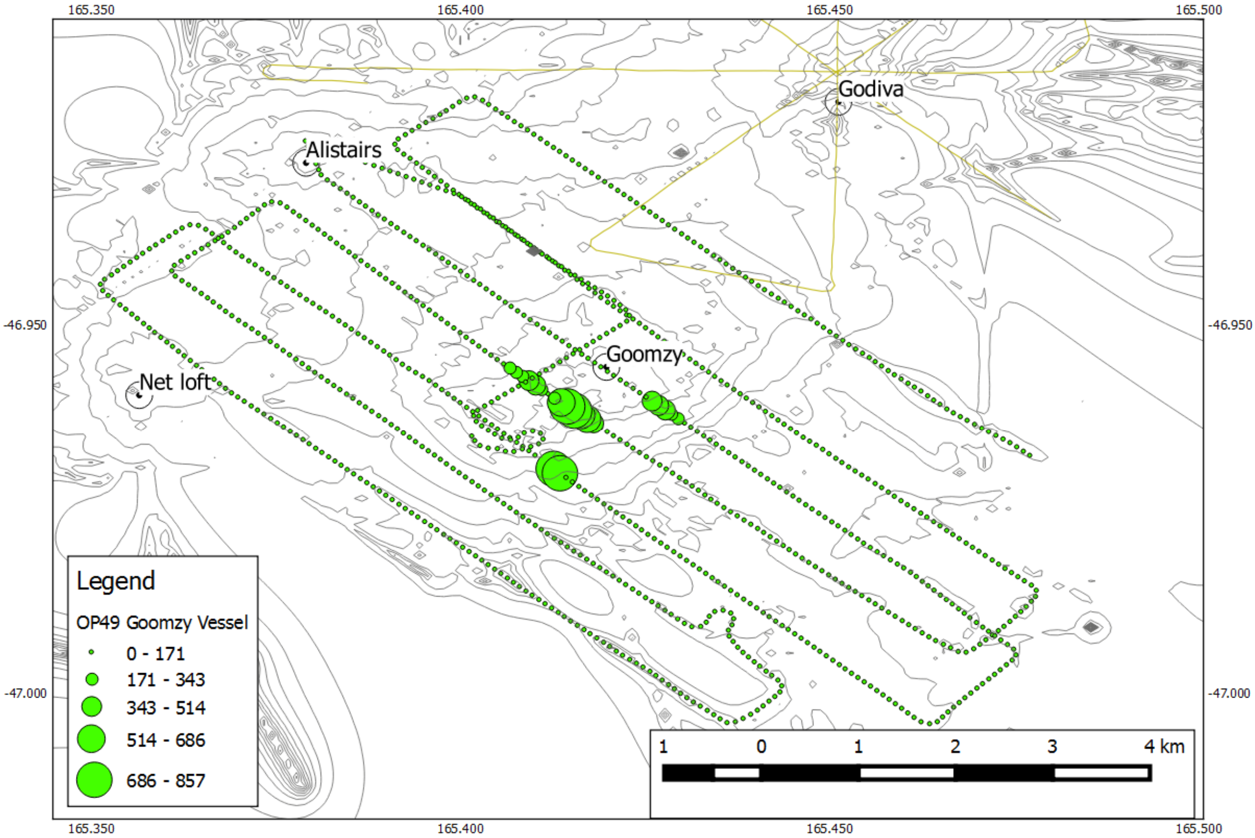


Figure 52. OP49 thematic map of echointegration NASC values at Goomzy, Vessel 38 kHz.

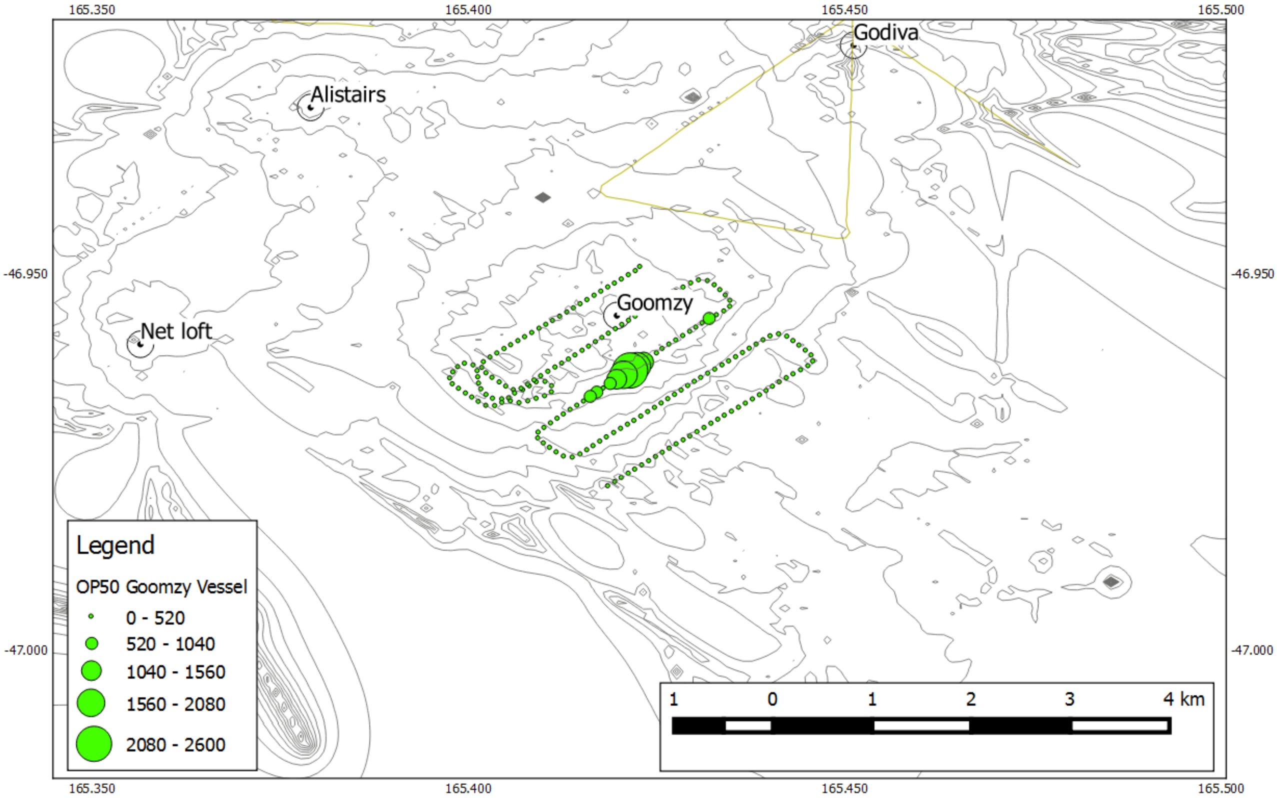


Figure 53. OP50 thematic map of echointegration NASC values at Goomzy, Vessel 38 kHz.

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