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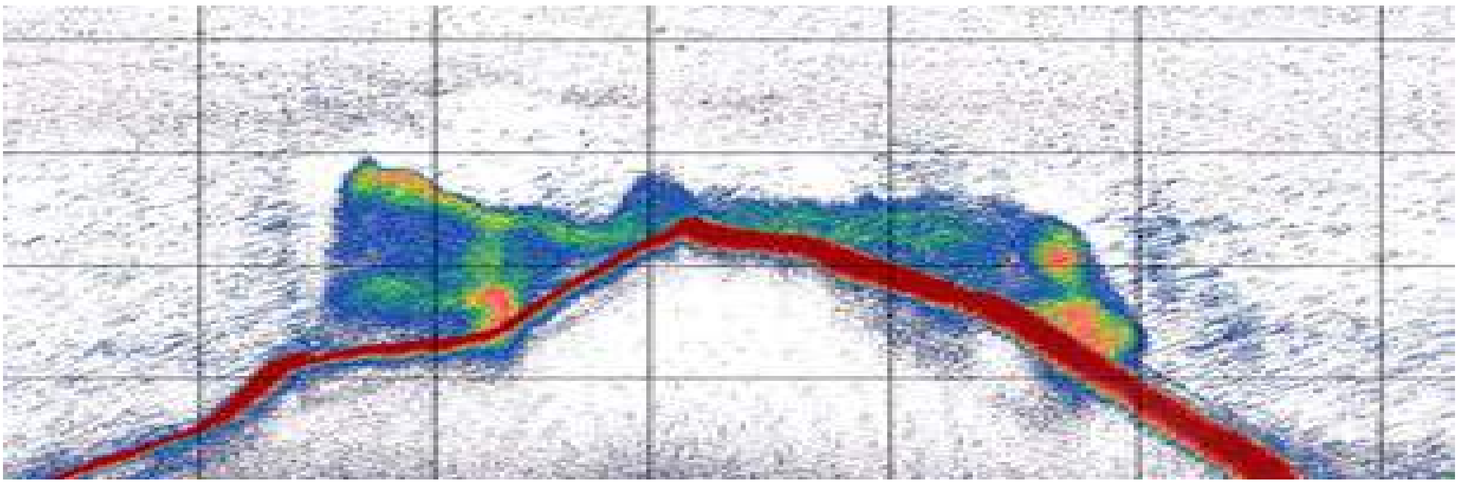
Orange roughy eastern zone spawning biomass 2019

Rudy Kloser and Caroline Sutton

June 2020

SETFIA

Simon Boag



Citation

Kloser, R.J. and Sutton, C.A. (2020) Orange roughy eastern zone spawning biomass 2019. Report to South East Trawl Industry Association. Copy held at CSIRO Marine and Atmospheric Research, Hobart. CSIRO Report No. EP204430.

DOI:

National Library of Australia Cataloguing-in-Publication entry

Author: Kloser, R.J. (Rudolf Josef), 1960- author

Title: Orange roughy eastern zone spawning biomass 2019

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ISBN: 978-0-6482821-3-6

Subjects: Orange roughy, fish populations, underwater acoustics, echo sounding in fishing

Other Authors/Contributors: Sutton, C.A.

CSIRO. Marine and Atmospheric Research, issuing body.

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Contents

Acknowledgments

The Australian Fisheries Management Authority and South East Trawl Fishing Industry Association (SETFIA) are thanked for funding and co-ordinating this project, in particular Daniel Corrie and Simon Boag. CSIRO's Oceans and Atmosphere is thanked for their support and funding contribution. Skipper Jamie Dunkley-Price and crew of the *FV Saxon Onwards* were instrumental in the success of this survey through their professional and enthusiastic efforts. Thanks to Jeff Cordell and the CSIRO Equipment and Technology Group for engineering and testing the new Acoustic Optical System (AOS). Ryan Downie, Tim Ryan and Ben Scoulding are thanked for their contributions at sea, collecting the biological and acoustic data in a wide variety of sea conditions, Appendix A. Haris Kunnath is thanked for processing the deep-water and wharf side AOS calibration data in Appendix B. Ben Scoulding is thanked for the review of new technologies trials in Appendix C. Geoff Tuck is thanked for internally reviewing the draft document.

Executive summary

Based on the 2019 acoustic survey the biomass of spawning orange roughy on the St Helens and Patricks Head grounds at 38 kHz and 120 kHz range from 36 900 to 50 300 (CV ~0.2) tonnes for observation or process error analysis respectively. There has been a significant 1.5 - 1.7 times increase in spawning biomass at the spawning grounds since 2016. The 38 kHz snapshot survey biomass estimate in 2019 of 42 600 tonnes (CV 0.18) extends the index of survey observations since 1990 (Figure 1).

The estimates of 2019 acoustic biomass all exceed the latest stock assessment model base case for 2017 where B_{2019}=22000 tonnes and B_{48} =36 400 tonnes being 48 % of the long term equilibrium biomass (table 12, Haddon 2017) (Figure 4-1). There appears to be an increasing disconnect between the acoustic biomass estimates and the stock assessment model. Resolution to this may uncover a bias(s) in the acoustic method or other assumptions in the stock assessment model.

The 120 kHz biomass estimates were on average ~10% greater than the 38 kHz estimates and inconsistent with previous surveys (Ryan and Kloser, 2016). This difference between 38 kHz and 120 kHz biomass estimates indicates a source or sources of bias in one or both data sets. The 120 kHz transducer is new and calibrated at depth in Feb. 2019, more confidence is gained using an instrument where there is a time series of calibration results.

The long-term biological trends of length, weight and age were continued and provide the information needed for stock assessment. Of note was the long-term calculation of at sea measured weights that were consistently higher ~10% than the length derived weights from Lyle et al. (1991). If the at sea weights were used it would increase biomass by 10%. We recommend an investigation into updating the Lyle et al. (1991) length to weight formula.

The acoustic systems used are ~ 10 years old and are being superseded with new models and functions. During the voyage new generation technologies were trialled that will reduce the size and hopefully improve the utility of the net attached AOS system. Importantly there are broadband technologies that need to be assessed if they can improve the biomass estimates. Ideally it would be beneficial if monitoring was done more regularly at a reduced cost. Ongoing investigation of new technology and methods is recommended to future proof the surveys and improve the precision and accuracy whilst being cost effective.

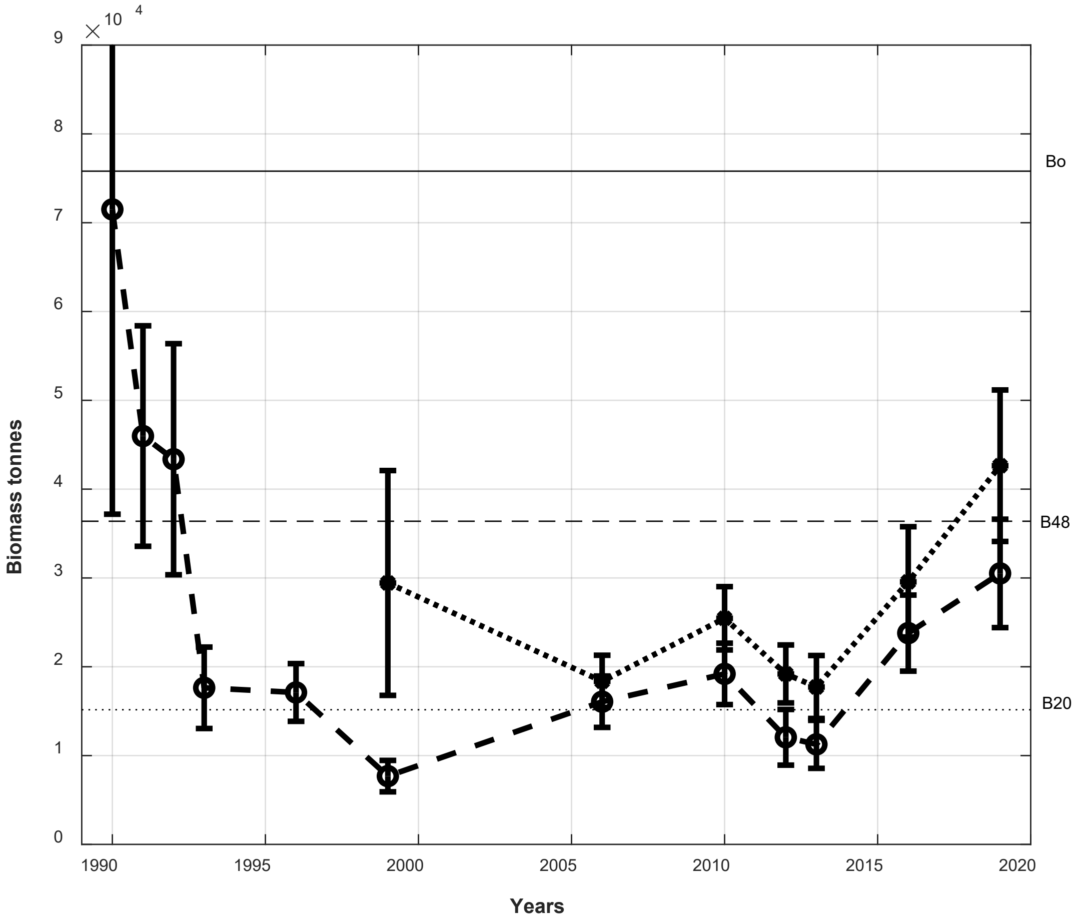


Figure 1. Estimated change in spawning biomass at St Helens Hill (dashed line, s.d. solid line) based on a vessel mounted survey in 1990 and towed body surveys from 1991 to 2019 [Table 5 Kloser *et al.* (2015) and Table 4-1]. Combined St Patricks and St Helens spawning orange roughy estimate of acoustic biomass in 1999, 2006 to 2019 (dot dashed line, s.d. solid line). The pre-fishery equilibrium biomass (Bo solid line), 20% Bo (dotted line) and 48 % Bo (dashed line) are shown based on proposed base case M=0.36 Haddon 2017 assuming female to male ratio 1:1 and male weight ~0.83 female weight.

1 Introduction

The Eastern Zone orange roughy fishery was reopened in 2014 based on a sustained monitoring program since 2006 that, combined with an updated stock assessment model showed the stock was recovering and was above the 20% pre fishery equilibrium level (Upston *et al.*, 2014; Kloser *et al.*, 2015). A major index for the eastern zone spawning stock has been the acoustic surveys that due to multi-frequency species identification and optically verified target strengths provide an estimate of stock biomass at two frequencies (Kloser *et al.*, 2013; Kloser *et al.* 2016). As part of the management requirements for the fishery an acoustic survey of the two known spawning sites of St Patricks Head and St Helens Hill was required in 2019 (Figure 1-1).

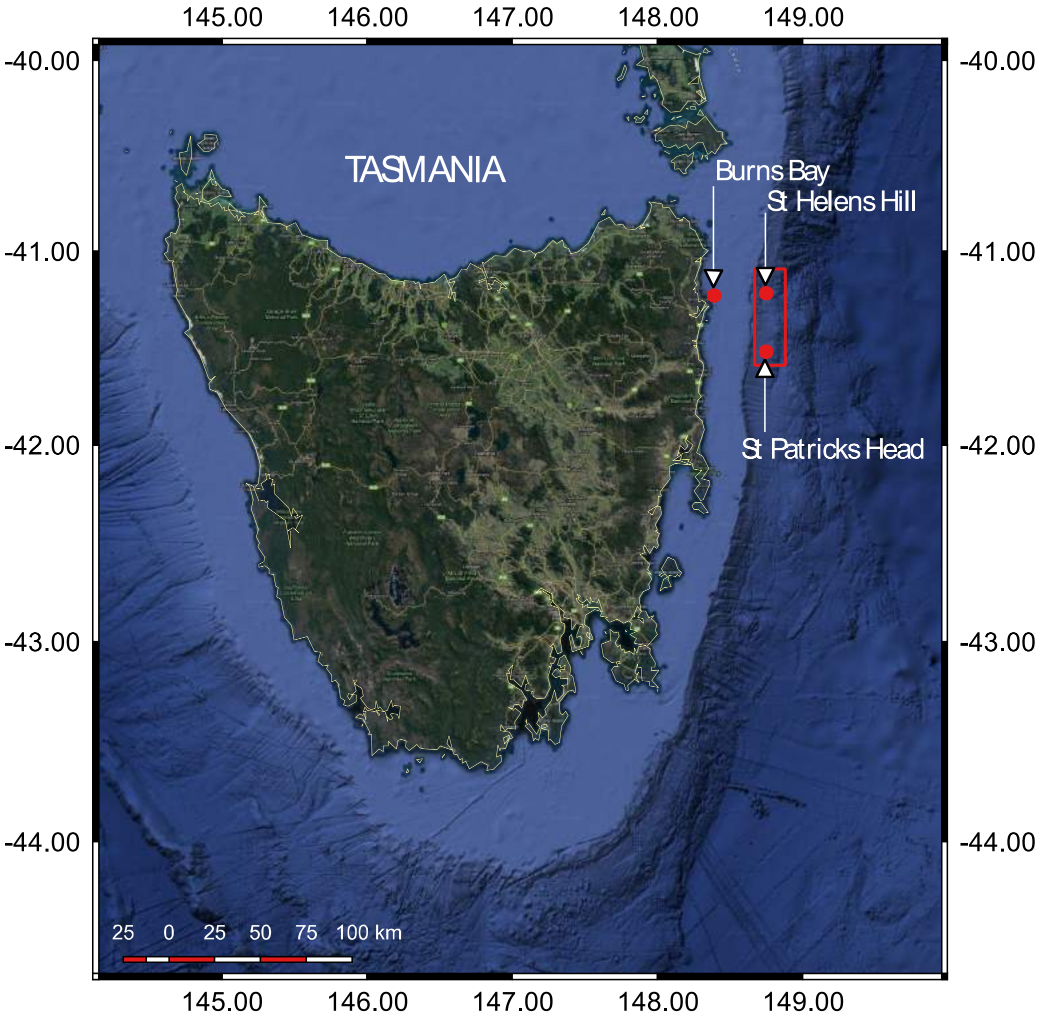


Figure 1-1 Area of operations for the survey, highlighting the Burns Bay, St Helens Hill and St Patricks head locations.

1.1 Scientific objectives

1. Acoustic biomass of spawning orange roughy in the Eastern Zone in 2019.

2. To collect biological data to support target strength, age, length, weight and environmental analyses in 2019.

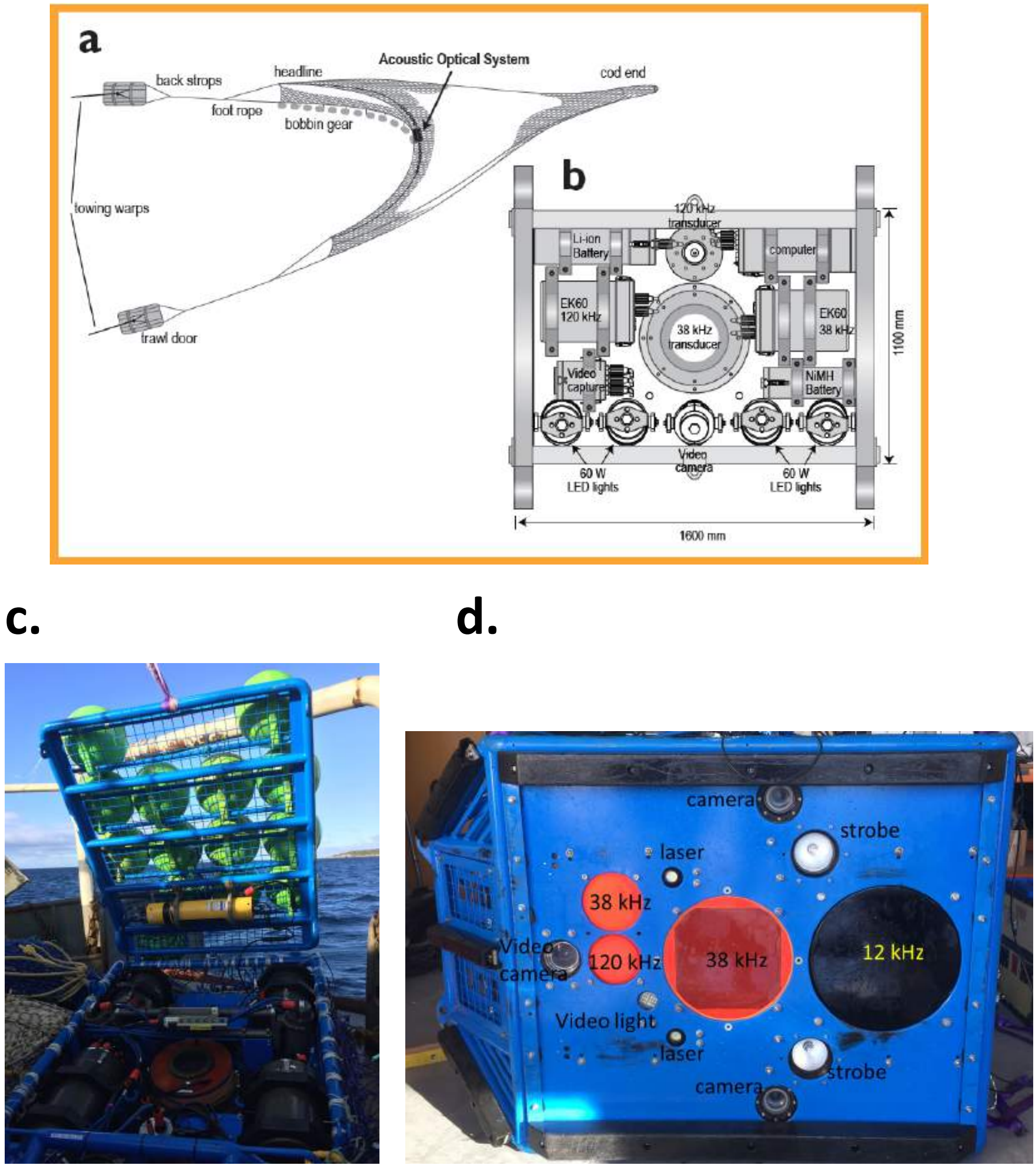


Figure 1-2. Acoustic optical system a, b), attached to the headline of a trawl net with the AOS system, c. attached to the net on Saxon Onwards with the lid open and d. the underneath of the system showing the transducer, camera and light placements for this voyage.

The voyage on the FV *Saxon Onward* occurred between the 9th to 19th July when 35 operations were done with voyage report operations outlined in Appendix A (Table 1-1). In summary there were large schools of fish at St Helens Hill and smaller schools of fish at St Patricks. The wind was strong for most of the voyage that dictated the need to use the net attached AOS for most of the surveys as the vessel acoustics was poor (Figure 1-2).

In summary we focused more survey time and biological sampling at St Helens Hill where more fish were observed. The surveys at St Patricks indicated a smaller but significant population.

Table 1-1 Summary of main activities from 35 operations.

Activity	Number
AOS biomass surveys	8 (4 St Helens, 4 St Patricks)
Vessel surveys	1 St Patricks
AOS Target strength + biological trawls	17 (11 St Helens, 6 St Patricks)
Broadband AOS WBT trials	5 deployments
Total catch	~ 100 tonnes

2 Biological sampling

2.1 Biological sampling equipment and methodology

Fish were collected from the trawler *FV Saxon Onward* with a demersal orange roughy net with windows (Table 2-1). The vessel *FV Saxon Onwards* is a larger than the *FV Empress Pearl* used in 2013 and 2016 and while biological sampling was similar for the spawning aggregations a larger vessel with larger carrying capacity meant catches per shot were larger and in general targeted on denser parts of the aggregations. This mode of capture was more similar to vessels used prior to 2012.

Biological data collected and recorded onboard include; total catch weight, catch composition, length, weight, sex, and gonad condition. Otoliths were also taken for offshore age estimates. Lengths were measured as *Standard Length*. *Standard Length* refers to the length from the tip of the snout to the hypural plate at the base of the tail (Kloser et al., 2012).

Since 2012 all lengths were measured using a manual fish measuring board to the lowest cm. In the previous years when using manual measuring boards, fish were measured to the lowest cm but the measuring boards had a deliberate +0.5 cm offset which in effect rounds the measures to the nearest cm. When electronic measuring boards were used, fish were measured to the nearest mm and then rounded to the nearest cm. For the 2019 survey fish were measured to the nearest mm and no length adjustments were required, but lengths were rounded to the nearest cm to be comparable with the times series data from previous surveys.

A subset of fish was weighed, and individual fish weights were measured on motion stabilised scales and recorded in grams to the nearest 100 grams. The scales were calibrated using 1 litre of fresh water (= 1 kilogram). Gonad condition was determined following the CSIRO Orange Roughy Gonad Staging Protocol (Cathy Bulman unpublished guide based on Pankhurst et al. (1987), Table 2-2). All averages are weighted for sample size unless otherwise stated. Spawning Area "population" averages are estimated assuming an even sex ratio.

Table 2-1. Orange Roughy trawl net parameters

Net attribute	
Wing end spread	30 m
Average headline height	3 m (average)
Door spread	100-120 m
Mesh size @ mouth	225 mm
Mesh size @ cod end	110 mm
Average tow speed	3 knots

Table 2-2 Orange Roughy Gonad Stages

Gonad Stage	Female	Male
1	Immature/resting	Immature/resting
2	Maturing	Maturing
3	Maturing (yolked eggs present)	Maturing (spermiated, viscous milk present)
4	Mature/Ripe	Ripe (milk freely flowing)
5	Running Ripe	Spent
6	Spent	Spent
7	Atretic	

A total of 839 otoliths were collected from all shots at both grounds where between 51 and 103 otoliths were taken per shot; 448 from St Helens (304 and 144 from female and male fish respectively) and 391 from St Patricks (177 and 214 from female and male fish respectively). Otoliths were placed into envelopes and labelled with Operation number (OP), Standard Length (SL), sex (SX) and specimen number (S#). Note that no otoliths were collected from Shot 30.

Table 2-3 Number of male and female orange roughy otoliths successfully read from the 2012, 2016 and 2019 surveys from St Helens and St Patricks.

	2012		2016		2019	
	female	male	female	male	female	male
St Helens	186	275	242	204	304	144
St Patricks	240	270	96	43	177	214

2.2 Biological Results

2.2.1 Shot data and bycatch summary

The biological component of the survey was conducted between July 11 and July 18 2019 with 16 successful shots for the survey. The total catch weight was 97 900 kg, with 81 900 kg from 10 shots at St Helens Hill and 16 000 kg from 6 shots at St Patricks. Total catch weights by shot were variable and ranged from 18 000 kg to 200 kg, with lowest catches at St Patricks. By-catch and estimates of Orange Roughy catch are not recorded here.

Table 2.2-4 Summary of shot dates and weights for St Helens and St Patricks, Eastern Zone, 2019 (* no fish collected from these shots)

Ground	Shot	Date	Shot Weight (kg)	F	M	Total Nos Fish
St Helens	8	2019-07-12	2500	91	108	199
St Helens	15	2019-07-14	200	80	47	127
St Helens	16	2019-07-14	18000	149	53	202
St Helens	23	2019-07-16	9000	181	24	205
St Helens	24	2019-07-16	10000	50	174	224
St Helens	29	2019-07-17	18000	214	5	219
St Helens	30	2019-07-18	4500	91	27	118
St Helens*	31	2019-07-18	700			
St Helens*	32	2019-07-18	14000			
St Helens*	35	2019-07-18	5000			
St Patricks	5	2019-07-11	2500	124	72	196
St Patricks	11	2019-07-13	800	114	80	194
St Patricks	12	2019-07-13	700	112	92	204
St Patricks	19	2019-07-15	8000	31	174	205
St Patricks	20	2019-07-15	1500	103	102	205
St Patricks	28	2019-07-17	2500	42	169	211
St Helens Total			81900	856	438	1294
St Patricks Total			16000	526	689	1215
Survey Total			97900	1382	1127	2509

2.2.2 Length

2.2.2.1 Average Length

Average length for fish captured at St Helens was 36.76 cm for females and 34.46 cm for males. For St Patricks average length was 36.68 cm for females and 34.52 cm for males. Fish captured in the 2019 survey were longer relative to those from the previous 2016 survey for all fish at both grounds. Female fish measured between 1 and 0.5 cm longer than those from the 2016 survey (up from 36 cm and 36.1 cm at St Helens and St Patricks respectively). Male fish were on average 1 cm longer than fish captured in 2016 (up from 33.5 and 33.3 at St Helens and St Patricks respectively). Length estimates have been relatively stable from 2004, until 2016 when there was increase in average fish length for both sexes particularly for female fish. Since the 2013 survey there has been on average a 2.5 cm increase in length for female fish and a 3 cm increase for male fish. Fish at both grounds are now within the size range of fish captured in the early days of the fishery (Figure 2-1, updated from Kloser et al. (2012)). The length vs weight relationship is detailed below to explore the validate of this observed increase in length.

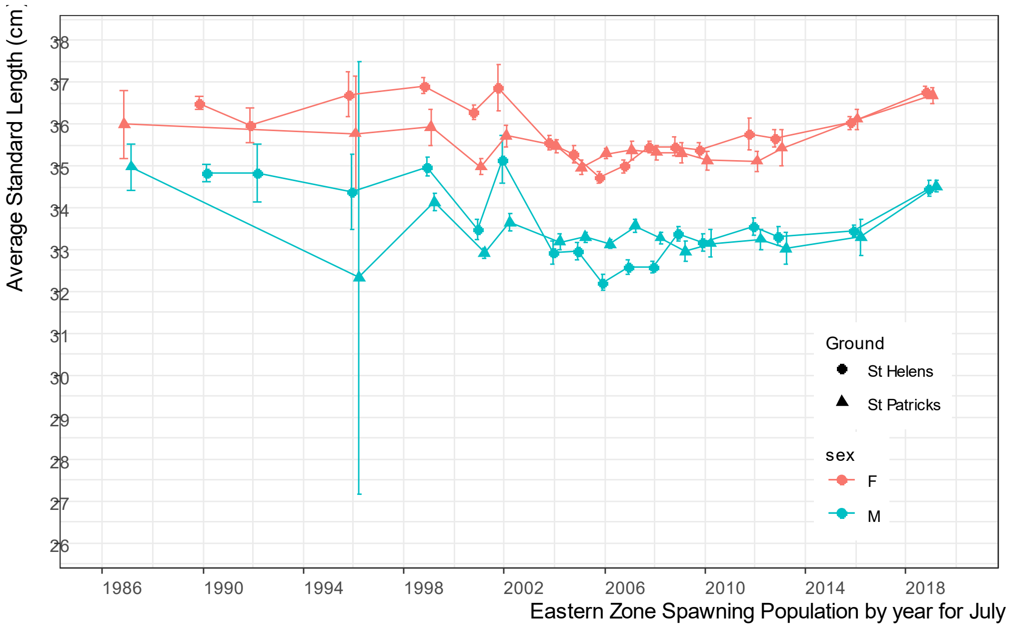


Figure 2-1 Average Standard Length (cm) of orange roughy Eastern Zone spawning population, showing males and females at St Helens and St Patricks for 1987 to 2019. Error bars are 95% confidence limits (updated from Kloser et al. 2012).

2.2.2.2 Length Frequencies and Mode

As with previous surveys, length frequencies were uni-modal for both Grounds. The mode was 36 cm for female fish and 34 cm for male fish at St Helens, relative to the 2016 survey most female fish were 1 cm longer and there was no change for most male fish. From 2007 the mode for female fish at St Helens has oscillated between 25 and 36 cm, and for male fish the mode has been steadily increasing. At St Patricks the mode was 37 cm for female fish and 34 for male fish, which is a 1 cm increase for both sexes relative to 2016. At St Patricks, the mode for female fish has generally been steadily increasing since 2006, for male fish this result represents the first increase in mode since 2002 (Figure 2-2).

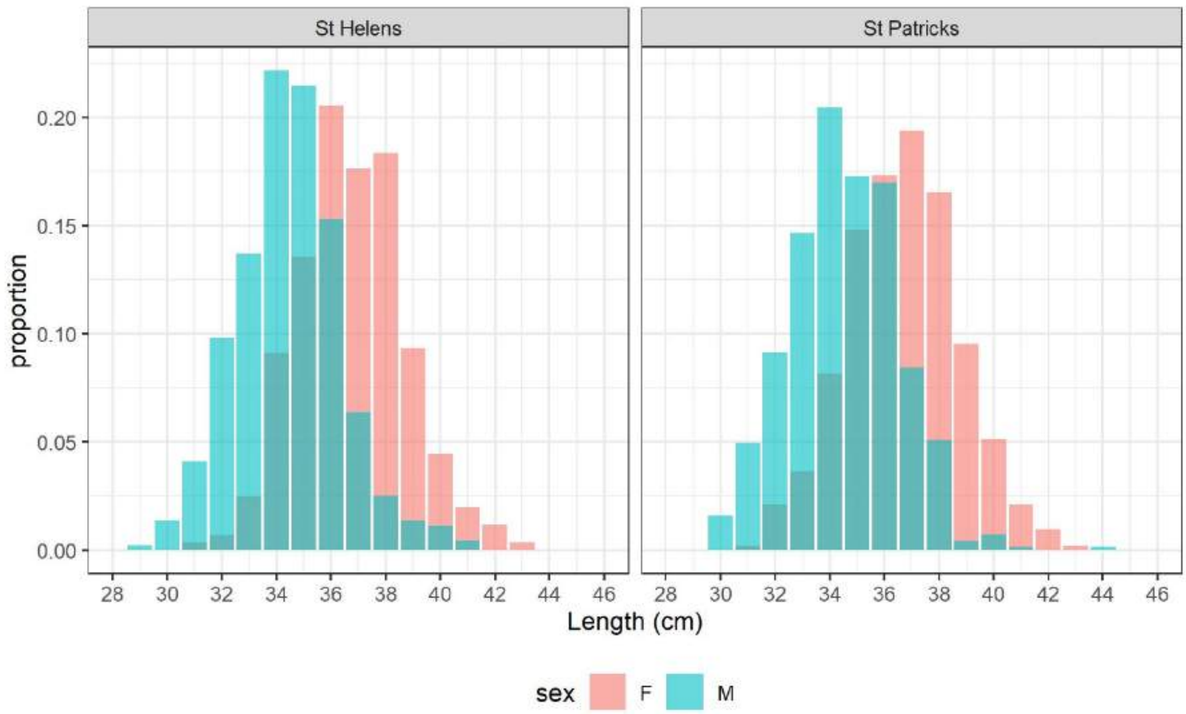


Figure 2-2 Length frequencies (cm) for the 2019 orange roughy Eastern Zone spawning population, showing males (M = blue) and females (F= red) at St Helens and St Patricks. Data presented as percentage occurrence of females (F) and males (M) for each cm category. Samples numbers are as follows: SH F = 856, SH M = 438, SP F = 526 and SP M = 689.

Cumulative length frequencies show that the two grounds have very similar length structures and across all grounds and sexes the lengths of captured fish are increasing. At both grounds 50% of female fish were longer than 36 cm, which is an increase of 1 and 2 cm from the 2016 and 2013 surveys respectively. For male fish 50% were longer than 34 cm at both grounds which is an increase of 1 and 2 cm for males at St Helens and St Patricks respectively. For male fish there were a very slight proportion of larger fish, i.e. greater than 40 cm caught at St Helens relative to St Patricks but this represents very few fish and overall, the age structure for both Grounds are very similar. (Figure 2-3).

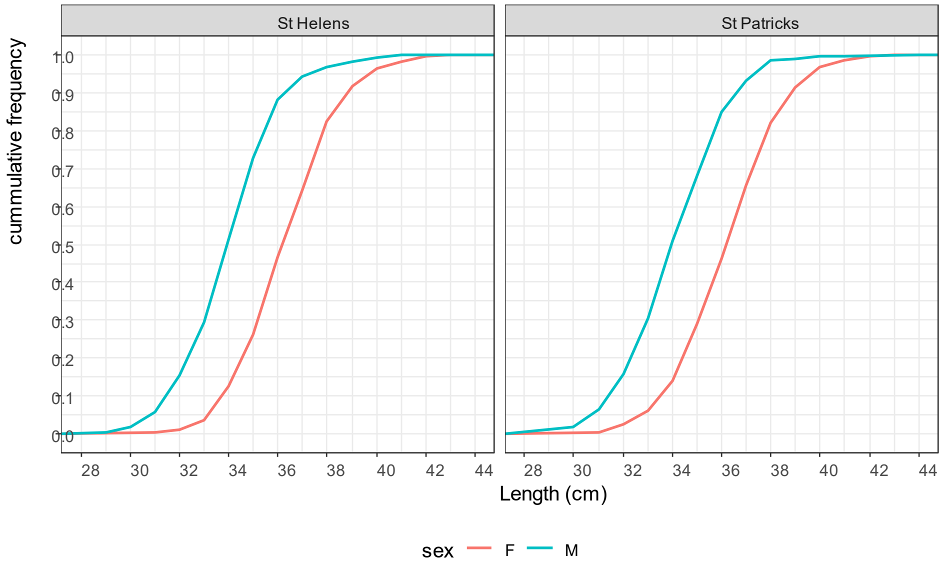


Figure 2-3 Cumulative length frequency (cm) for the 2019 orange roughy Eastern Zone spawning population showing females (red) and males (blue) at St Helens and St Patricks Hill.

Table 2-5 Number of fish measured and mode for standard lengths for males and females measured at St Helens and St Patricks from 1987 to 2019, updated from Kloser et al. 2012.

	St Helens, Female		St Helens, Male		St Patricks, Female		St Patricks, Male	
Year	Mode (cm)	Nos. Fish	Mode (cm)	Nos. Fish	Mode (cm)	Nos. Fish	Mode (cm)	Nos. Fish
1987	NA	NA	NA	NA	37	146	36	181
1990	35	800	35	459	NA	NA	NA	NA
1992	36	248	36	92	NA	NA	NA	NA
1996	37	128	33	49	37	17	30	3
1999	38	840	34	506	36	199	34	550
2001	37	971	33	478	35	691	32	1352
2002	38	59	36	77	35	332	34	612
2004	35	1295	32	368	34	886	33	470
2005	35	702	33	488	34	608	33	1193
2006	34	1520	32	740	35	1394	33	1752
2007	35	1064	32	672	35	362	33	690
2008	35	1402	33	735	36	639	33	889
2009	35	425	33	670	36	334	33	220
2010	35	704	33	355	36	304	33	179
2012	36	211	33	358	36	279	33	323
2013	36	548	33	284	35	107	33	103
2016	35	902	34	791	36	287	33	126
2019	36	856	34	438	37	526	34	689

2.2.2.3 Between shot variability

Lengths ranged from 13 cm (St Patricks male and female fish) to 56 cm (St Patricks, male fish). Standard deviation about the means ranged between 1.48 cm to 2.34 cm.

Average lengths for females at St Helens for the seven shots ranged from 36.2 cm to 37.30 cm. Length estimates were consistent between the 7 shots with error estimates generally plus or minus 1 cm about the means. Average lengths for males at St Helens were more variable between the 7 shots and ranged from 32.20 cm to 34.77 cm, although the error estimates were more variable, particularly when the catches were small (e.g. shot 29, n = 5).

Average lengths for the six shots at St Patricks ranged from 36.20 cm and 36.79 cm for female fish and 33.75 cm and 35.05 cm for male fish (Figure 2-4). Error estimates for both sexes were consistent, generally 1 cm plus or minus about the mean.

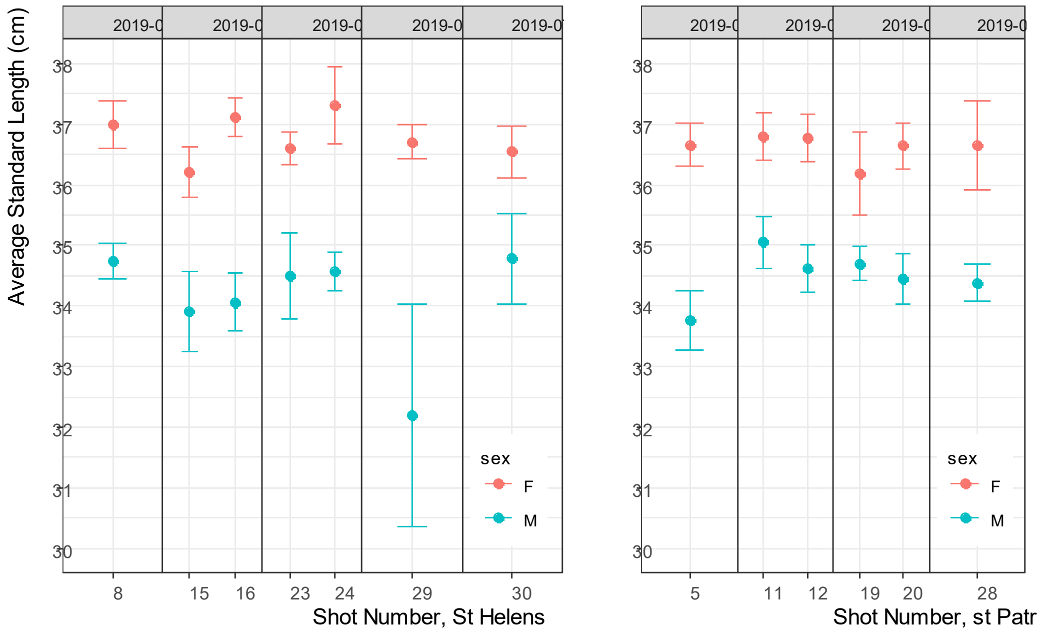


Figure 2-4 The average Standard Length (cm) by shot for female and males fish for the Eastern Zone spawning population at St Helens and St Patricks for 2019. Error bars are 95% confidence intervals.

Average weight for female fish was 1.65 kg for St Helens and 1.70 kg for St Patricks, which is on average between 180 - 185 g heavier than the previous 2016 survey measures. Weights for female fish ranged from 1.03 - 2.72 kg, which is within the range of the 2016 survey but slightly reduced on both ends of the range (2016 female fish = 0.90–2.80 kg). Average weight for male fish was 1.32 kg at both Grounds, which is between 180 – 210 g heavier than the 2016 survey measures. Male weights ranged from 0.87 - 2.25 kg, which is a greater range than the 2016 survey particularly at the heavier end (2016 male fish = 0.2 – 1.7 kg). Female fish were on average 360 g heavier than male fish which is comparable to the 2016 survey (i.e. 350 g). Table 2-6provides the weight summary for the 2019 survey.

Table 2-6 Average weight (kg) by shot for male and female fish for the 2019 Orange Roughy Eastern Zone spawning population. SD = Standard Deviation (±) of the sample, n = sample size.

		Females			Males		
Ground	Shot	weight (kg)	SD	n	weight (kg)	SD	n
St Helens	8	1.73	0.25	91	1.34	0.18	108
	15	1.59	0.25	80	1.29	0.22	47
	16	1.71	0.28	149	1.28	0.20	53
	23	1.62	0.27	181	1.26	0.17	24
	24	1.82	0.29	50	1.36	0.24	174
	29	1.58	0.24	214	1.05	0.19	5
	30	*	*	91	*	*	27
St Patricks	5	1.79	0.30	124	1.33	0.22	72
	11	1.74	0.28	114	1.33	0.20	80
	12	1.67	0.32	112	1.32	0.19	92
	19	1.57	0.28	31	1.34	0.18	174
	20	1.69	0.32	103	1.32	0.25	102
	28	1.60	0.28	42	1.30	0.18	169

*Not measured

2.2.3 Sex Ratio

The sex ratio for the total survey combining both grounds, was relatively even (57:45) and has remained stable between surveys. Sampling was relatively even between grounds with respect to the number of fish measured, although the sex ratio differed between the grounds with a relatively higher number of female fish captured at St Helens (66:34) compared to St Patricks (43:57). There did not appear to be a clear relationship between shot size and sex ratio, although all the largest shots were skewed to one sex or the other. At St Helens 4 shots were dominated by female fish (> 70 %), 1 shot dominated by male fish (> 78 %) and 2 shots had a relatively even sex ratio. At St Patricks most shots had a relatively even sex ratio (2 slightly skewed to female fish) and 2 shots were dominated by male fish (> 80 %) (Table 2-7).

Table 2-7 Sex Ratio by shot, spawning area and for the total survey 2019

Ground	Shot	Shot Weight (kg	nos fish	F ratio	M ratio
St Helens	8	2500	199	0.46	0.54
St Helens	15	200	127	0.63	0.37
St Helens	16	18000	202	0.74	0.26
St Helens	23	9000	205	0.88	0.12
St Helens	24	10000	224	0.22	0.78
St Helens	29	18000	219	0.98	0.02
St Helens	30	4500	118	0.77	0.23
St Patricks	5	2500	196	0.63	0.37
St Patricks	11	800	194	0.59	0.41
St Patricks	12	700	204	0.55	0.45
St Patricks	19	8000	205	0.15	0.85
St Patricks	20	1500	205	0.50	0.5
St Patricks	28	2500	211	0.20	0.8
St Helens combined			1294	0.66	0.34
St Patricks combined			1215	0.43	0.57
Survey combined			2509	0.55	0.45

2.2.4 Gonad Stage

The examination of gonad stage data shows evidence that the fish were actively spawning during the survey. Figure 2-5 shows the proportion of fish at each gonad development stage for males and females at both grounds.

The staging data indicate that most female fish were caught during or a little bit after the peak spawning event. Greater than 70 % of all female fish sampled at both grounds had either ripe gonads (Stage 4) or were actively spawning (running ripe = Stage 5) or where either spent or partially spent (stage 6). The percentage of spent fish (Stage 6) increased from no spent females before July 13 to between 30 to 60 % by the end of the survey, which supports the observation that peak spawning coincided with the start of the survey. There was little variability between grounds, although the St Helens spawning event may have been a little earlier relative to St Patricks.

The staging data for males also suggest that the survey was conducted just prior to peak spawning. At the start (July 11) 20 % of male fish were ripe (stage 4) increasing to ~60 % by mid survey (July 13). After July 14 the percentage of spent fish (stage 5 and 6) started to increase, although they were variable between 20 to 40 % for most shots. Similar to the female fish, the spawning event appears to be slightly earlier at St Helens with one shot (29) of >75 % spent fish.

Unlike the 2013 and 2016 surveys there were no immature fish observed (stage 2) indicating that the survey was conducted during the peak spawning event.

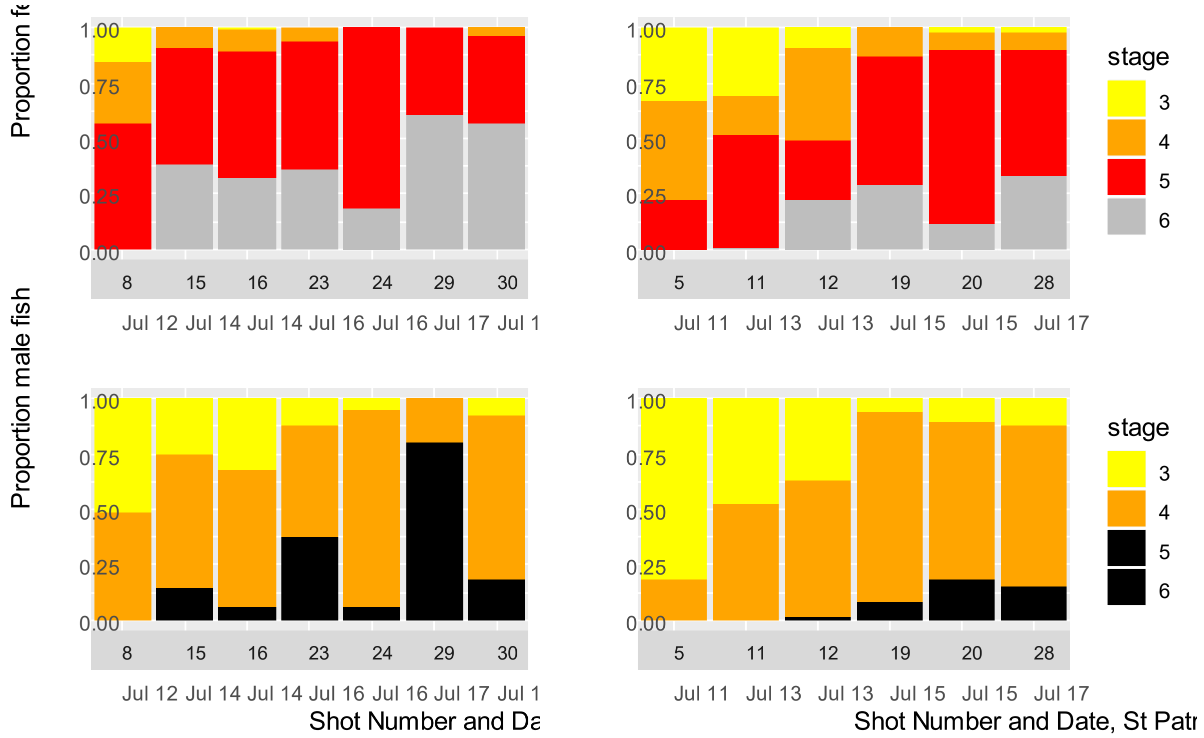


Figure 2-5 Gonad maturity stage for the 2019 Eastern Zone spawning population, showing the number of immature, ripe and spent fish in each shot for males and females at St Helens and St Patricks. See table 2-2 for key to stages.

2.2.5 Proportions, sex ratios and weighted averages for length and weight by spawning ground

Fish lengths were almost the same for both St Helens and St Patricks for male and female fish. However for the male and female combined average, length was 0.5cm longer at St Helens relative to St Patricks (Table 2-8). Correspondingly fish were on average slightly heavier at St Helens relative to St Patricks (Table 2-9). This is the reverse trend for the 2016 and the same for the 2013 survey results and is likely reflective of the annual variability within the population or a sampling bias.

Table 2-8 The proportion of male and female fish at each ground and their associated weighted averages for fish length (cm) for the 2019 Eastern Zone spawning population.

Spawning Ground	Sex	No of fish	Prop	Average length (cm)	Estimated weight (kg) based on Lyle et al. (1991)
St Helens	F	856	0.66	36.76	1.49
St Helens	M	438	0.34	34.46	1.23
St Patricks	F	526	0.43	36.68	1.48
St Patricks	M	689	0.57	34.52	1.24
St Helens	M & F	1294	0.52	35.98	1.4
St Patricks	M & F	1215	0.48	35.45	1.34
SH and SP	F	1382	0.55	36.73	1.49
SH and SP	M	1127	0.45	34.49	1.24
Survey total	all fish	2509	1	35.72	1.37

2.2.6 Length vs weight relationship

Length and weight data from the 2019 survey with the accepted length to weight relationship used for the stock assessments (Upston *et al.*, 2014) are shown in Figure 2-6. The length vs weight for both females and males from 2019 were scattered above the length-weight equation line estimated by Lyle *et al.* (1991). Unlike the 2016 survey the observed increase in length is supported by a corresponding increase in weight. Previous surveys have discussed concerns regarding the shipboard measured weights which did not reflect the changes in the measured lengths, however the consistency between the two measures suggests that the changes are real and may not be a sampling artefact or error. Although, over the years there has been variability between surveys with respect to the observed and predicted length to weight relationship based on the Lyle equation ((Lyle 1991), Figure 2-7). However, the survey results from 2019 indicate that fish are not only longer and heavier, but heaver with respect to length and that a revision of the accepted length to weight relationship should be considered. Over the at sea weights time series it appears that measured weights are on average 10% higher than length derived weights with a few anomalies in the series for example 1999 and most recently 2016 (**Error! Reference source not found.**). Based on the 2016 anomaly we decided to standardise on the Lyle et al. (1991) derived weight equation but the data suggests that the equation should be updated.

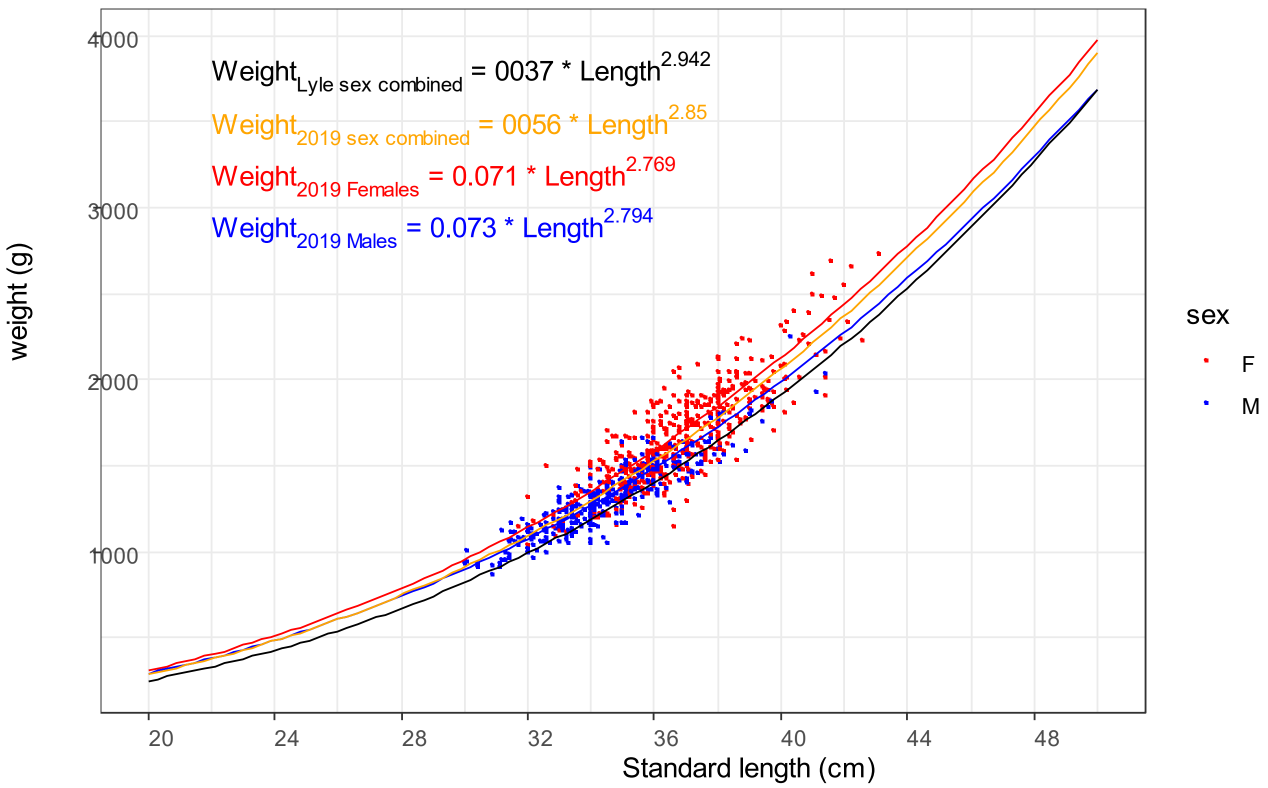


Figure 2-6 Standard Length (cm) vs weight (kg) for the Eastern Zone spawning population, 2019 both grounds combined, showing the predicted values (plotted black line) from Lyle (1991).

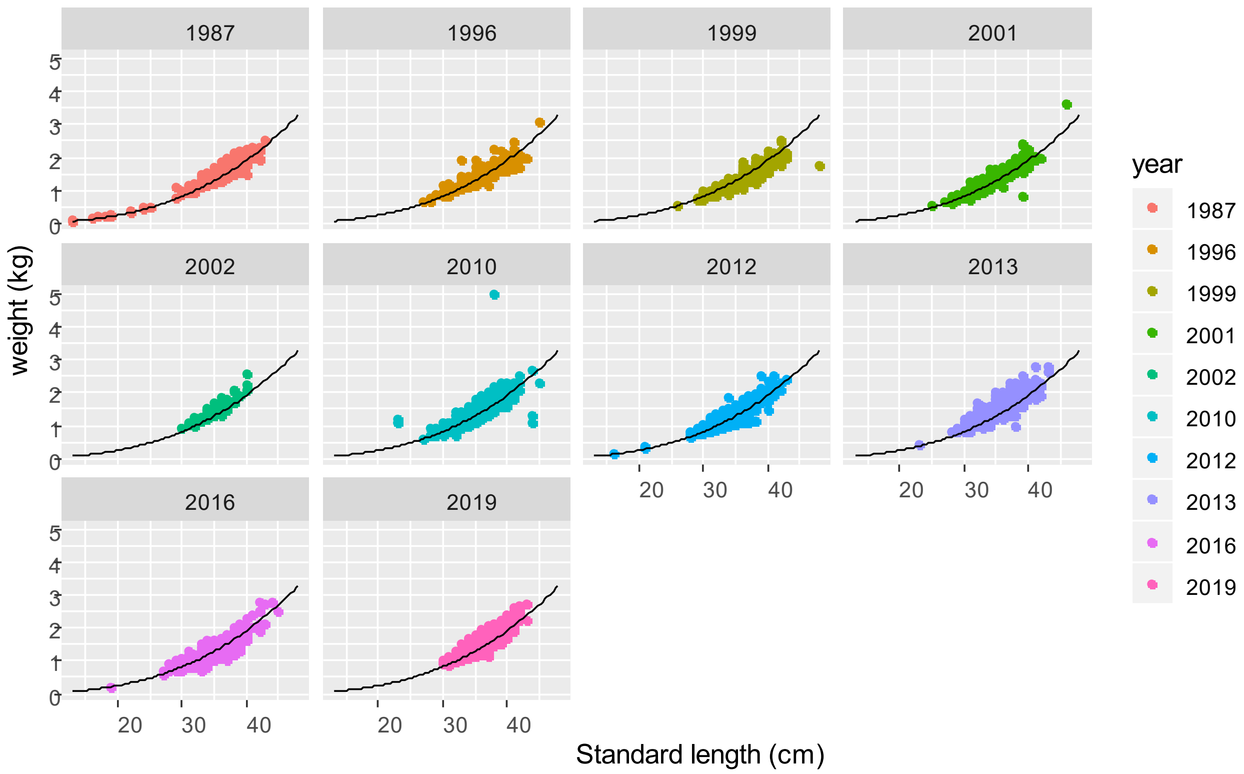


Figure 2-7. Standard Length (cm) vs measured weight (kg) for the Eastern Zone spawning population from 1987 to 2019 for both grounds combined, showing the predicted values based on length (plotted black line) from Lyle (1991).

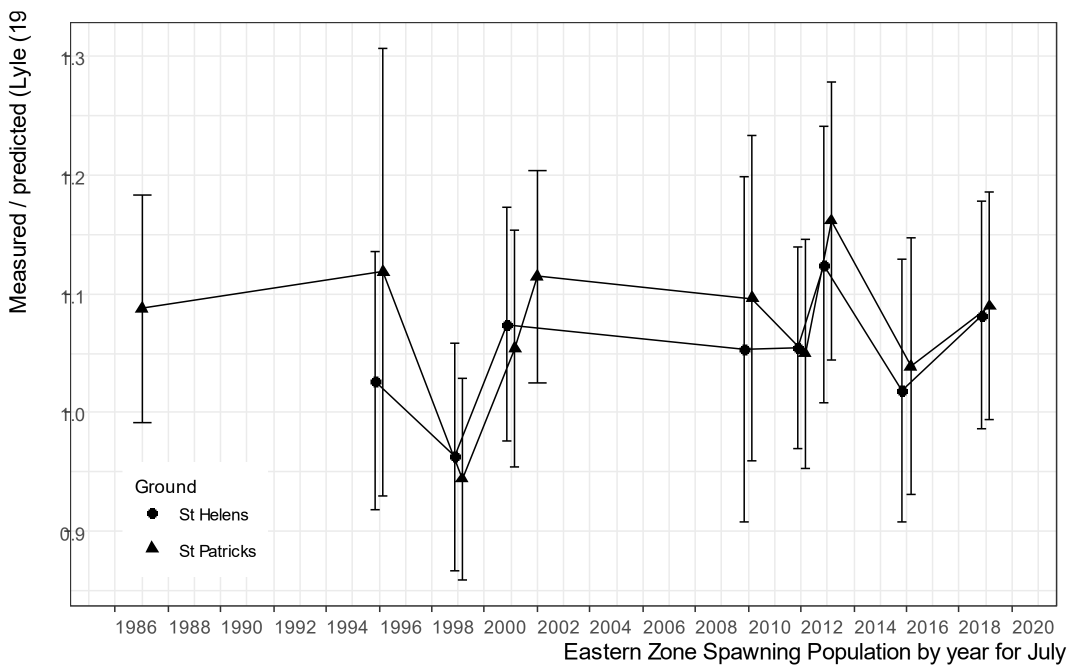


Figure 2-8 Ratio of measured by predicted (Lyle 1991)) weight (kg) by year and ground for the Orange Roughy Eastern Zone Spawning population. Error bars are standard deviations.

Table 2-9 The proportion of male and female fish at each ground and their associated averages for shipboard measured fish weights and estimated fish weights (kg) for the 2019 Orange Roughy Eastern Zone Spawning population. Note that this subset of fish were also sampled for otoliths.

Spawning Ground	Sex	Number of fish weighed	Proportion	Average of measured weight (kg)	Estimated weight (kg) based on Lyle et al. (1991)
St Helens	F	304	0.68	1.65	1.49
St Helens	M	144	0.32	1.32	1.23
St Patricks	F	177	0.45	1.7	1.48
St Patricks	M	214	0.55	1.32	1.24
St Helens	M and F	448	0.53	1.55	1.4
St Patricks	M and F	391	0.47	1.49	1.34
SH and SP	F	481	0.57	1.67	1.49
SH and SP	M	358	0.43	1.32	1.24
Survey total	all fish	839	1	1.52	1.37

2.2.7 Age

The ageing of the otoliths collected for the 2019 survey were not available and will likely be completed by July 2020 (Kye Krusic-Golub personal communication). Otolith weight for 2019 was available and a summary for the years 1987 to 2019 is shown in Figure 2-9. Otolith weight has been found to be correlated with age and may be used as a proxy for certain purposes and the age index is shown in Figure 2.10 (Kloser *et al.* 2012).

Based on the age index from Kloser et al. (2016, Figure 2.10), "average age for both sexes and areas has stabilised since the decline observed in the early days of the fishery. Based on a linear model there has been a significant decline in average age ($p < 0.001$) for both areas and sexes from 1987 to 2016. Specifically the decline in age is - 0.6 per year for females at St Helens, - 0.4 per year for females at St Patrick, - 0.9 per year for males at St Helens and - 0.8 per year for males at St Patricks. However, average age of male and female fish at both grounds increased up to 5 years from the 2010 survey, with average age increasing from 2010 to 2012 and then decreasing from 2012 to 2016 for all fish except for female fish at St Patricks. Despite the observed variability between 2012 and 2016 there is an indication that the decline in average age has stabilised. Based on a linear model the average age for female fish at St Patricks significantly increased by 0.8 per year ($p < 0.001$) from 2010 to 2016. The slight changes observed for the other time series were not significant (0.2 per year for females at St Helens, 0.7 per year for females at St Patricks, - 0.2 per year for males at St Helens and 0.1 per year for males at St Patricks)".

The otolith weight data from 2019 suggest that the age of captured males at both grounds has increased significantly from the 2016 survey, while the age of captured females has remained relatively stable. This trend in male age is also supported by the increase in male length observed during the survey. The female otolith weight has remained stable indicative of no age change whilst the length of the fish measured in 2019 has increased. More insights into these observations and any potential bias will become apparent when the otoliths are aged.

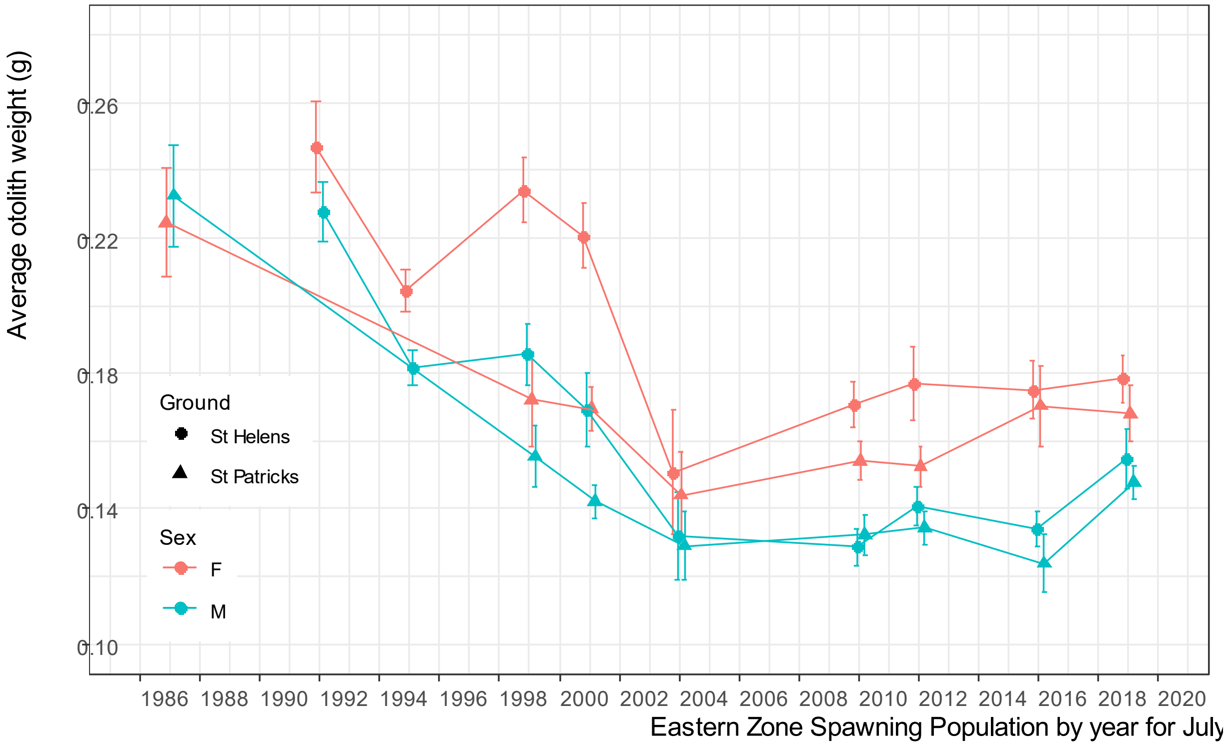


Figure 2-9 Otolith weight (g) by age (years) for female and male fish at St Helens and St Patricks from 1987 to 2018.

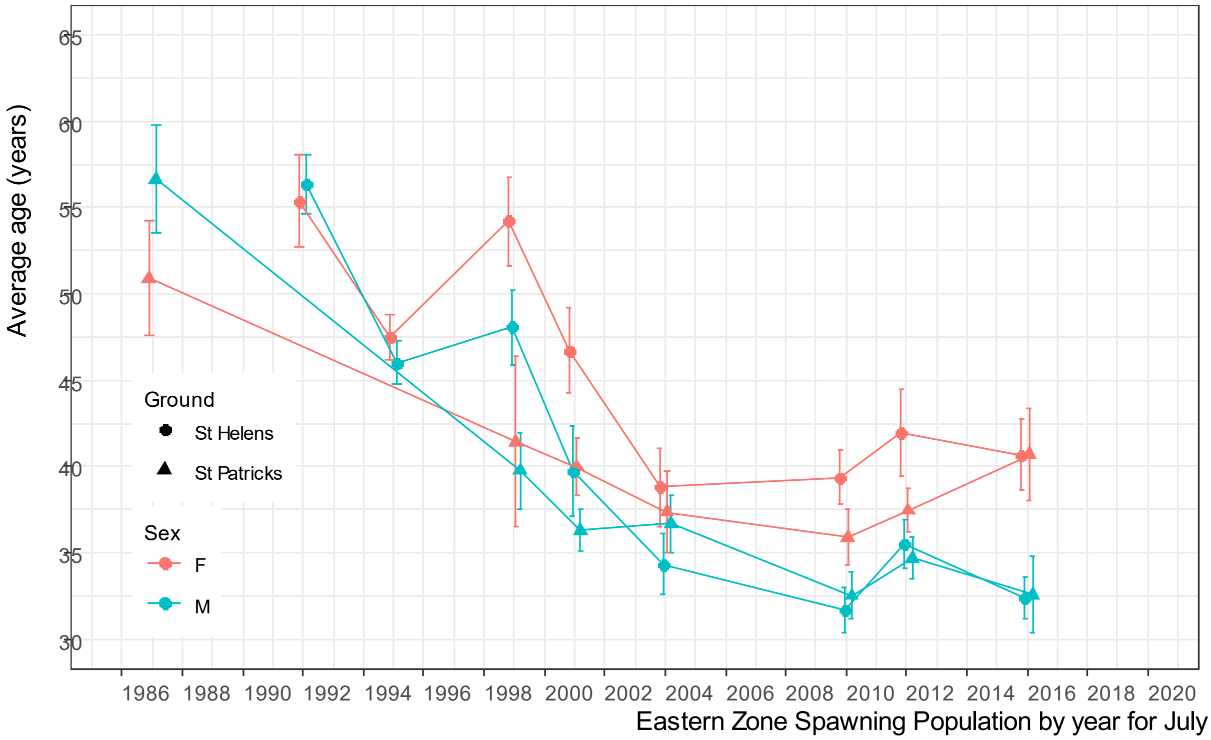


Figure 2-10 Average age of Orange Roughy males and females at St Helens and St Patricks from 1987 to 2016. Selection filter applied (Eastern Zone, July, spawning population). Error bars are 95% confidence intervals. Details of this index are given in Kloser et al (2017).

3 Acoustic surveys

3.1 Methods

Methods used were followed as outlined in Kloser *et al.* (2011) in order to remain consistent with the time series for the recovery monitoring program. Details of the methods are described in Kloser *et al.* (2011) and Ryan *et al.* (2014).

The key survey analysis inputs of absorption equation, target strength at 38 kHz and 120 kHz and weight to convert the acoustic data to biomass are given in Table 3-1.

Table 3-1 Acoustic survey analysis information to estimate biomass assuming a 1:1 ratio of male and females and weights and lengths derived from section 2.

Acoustic Parameters	St Helens	St Patricks	Comment
Calibration	AOS at depth	AOS at depth	Refer to Table 3-2 and Haris 2019
Absorption equation	F&G	F&G	Francois and Garrison (1983)
Mean Length (cm)	36.0	35.5	Assumed M&F sex ratio 1:1
Target strength 38 kHz (dB re 1 m^2)	-51.6	-51.8	Derived from Scoulding and Kloser (in press)
Target strength 120 kHz (dB re $1m^2$)	-47.8	-47.9	Derived from Scoulding and Kloser (in press)
Mean Weight (kg)	1.40	1.34	Derived from the length data using Lyle *et al*. (1991)
Survey design	grid interlaced	grid Interlaced	Survey mean
Survey CV process error	geostatistics	geostatistics	Highest combined survey St Helens and St Patricks within 24 hrs
Survey CV observation error	average	average	Between survey variability

The acoustic calibration parameters used for the survey were based on the Feb. 2019 (Haris 2019) and historic deep-water calibration data for the transducers (Table 3-2). Note a new 120 kHz transducer (SN123) was used for the 2019 survey due to a water ingress failure of the previous transducer. The Feb. 2019 deep-water 38 kHz calibration was found to have been contaminated with a damaged transmitter for one of the quadrants. This fault was corrected prior to the voyage and a test derived to monitor the transmitters throughout the survey. Independent tests of the effect of the failure on the Feb. 2019 calibration through shallow water wharf side experiments in April and May 2020 enabled a correction factor of 1.18 dB to the system gain to be derived. The modified parameters of the Feb. 2019 deep water calibration at 38 kHz were consistent with two previous deep-water calibrations. Appendix B summarises the depth correction coefficients for the AOS at 38 kHz and 120 kHz used for the survey analysis. A correction factor was used to account for the AOS operating depth and the range to the centre of the fish school from the nominal settings (Appendix B).

Table 3-2 Acoustic calibration parameters for the AOS at a mean operating depth of 600 m and vessel used in the survey, refer to Haris (2019) for details of Feb 2019 calibration results and Appendix B. Sound absorption and sound speed is the nominal integrated mean at 800 m depth.

AOS calibration parameters	38 kHz	120 kHz
Serial number	28362	123
Power (W)	2000	280
Pulse length (mS)	2048	1024
EBA (dB re 1 ster.)*	-20.96	-20.21
Gain (dB)	24.24	27.50
Sa corr. (dB)	-0.40	-0.38
Sound speed m s^{-1}	1494	1494
Absorption (dB/m)	0.00938	0.03339
Beam width (deg.)	6.9	7.4\7.3
Vessel settings 38 kHz		
Power (W)	2000	
Pulse length (mS)	2048	
EBA (dB re 1 ster.)	-20.53	

***Measured value 38 kHz based on deep water calibration of beam pattern Kloser et al. 2017**

3.2 Acoustic survey results

During the voyage there were four St Helens' and four St Patricks' AOS surveys (Appendix A). A large body of fish was seen at St Helens that had its largest concentration on the western transects at the start of the surveys (Figure 3-1). Of note was the observation that fish were found in the deep section of the western side of the hill throughout the survey. The performance of the AOS system for the 38 kHz and 120 kHz had increased noise from the 2016 survey at 38 kHz due to use of a Furuno headline monitor and reduction of power from 500 W to 280 W for the 120 kHz transducer. This reduction in power was done to standardise with other surveys and reduce a potential effect of non-linear gain at range. Despite this increased noise the 120 kHz system had a functional range of 500 m and enabled the AOS to be operated well above the schooling fish with the aim of 300 m.

The acoustic and biological sampling at St Helens and St Patricks were influenced by strong winds throughout the survey (Figure 3-2 .a). These strong winds reduced the utility of the vessels' acoustics for surveys (Figure 3-2.b) compared to the results from the deeply towed AOS (Figure 3-2.c). It was not possible to use the vessel sounder to locate schools at St Helens and St Patricks hence the extent of the marks had to be inferred and only confirmed once the AOS was retrieved. This meant that some schools were still observed on the outside transects. The wind also effected the vessel course at times so adhering to the transect lines was difficult at times. The net attached system was also susceptible to increased roll (usually less than 10 deg.) on some transects that was not easily detected or corrected during a survey.

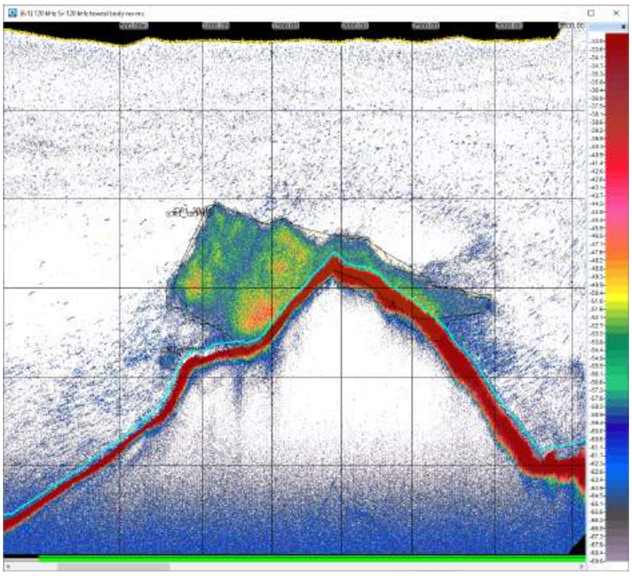
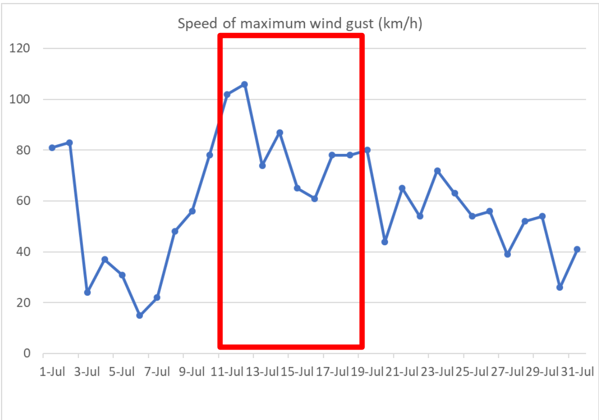
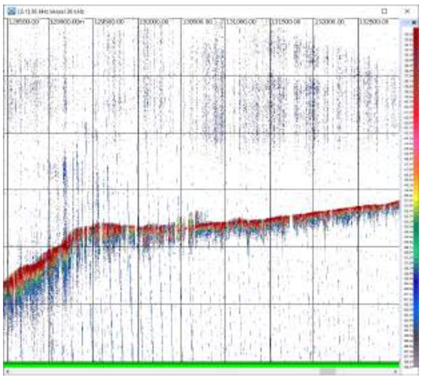


Figure 3-1 St Helens Hill example of Acoustic Optical System (AOS at ~500 m depth) volume reverberation (Sv dB re 1m-1) data highlighting the orange roughy schools (black outline) for Operation 01 Transect 3, frequency 120 kHz north to south. Grid 500 m horizontal and 100 m depth vertically. Identification of orange roughy dominant schools based on 38 kHz and 120 kHz frequency differencing (Kloser *et al.*, 2013).

a.



b.



c.

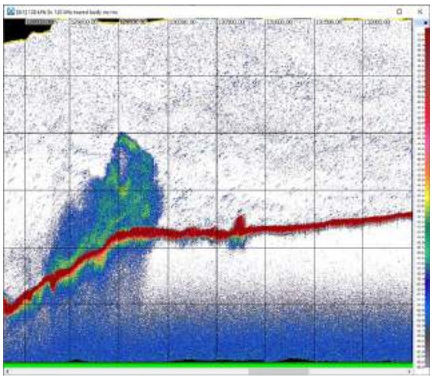


Figure 3-2. (a) Winds (as measured at Eddystone Point) encountered during the survey boxed in red that reduced the quality of the (b) vessels' 38 kHz acoustics when compared to the (c) deeply towed (500 m depth) 120 kHz AOS

example for the St Patricks ground. Grid 500 m horizontal and 100 m depth vertically for the volume reverberation data (Sv dB m-1) with Sv minimum of -69 dB and -66 dB for the vessel and AOS acoustic data respectively.

3.2.1 St Helens Hill

The survey strategy at St Helens involved interlaced transects where the odd and even were done separately. This was done for two reasons; first it enabled the AOS to be checked after each even and odd survey to ensure it was functioning correctly and secondly it enabled the survey mean to be determined using a combined and interlaced mean method if fish movement was a factor for the surveys. As there was no statistical difference between the non-interlaced and interlaced means only the non-interlaced means are reported. The survey biomass estimates ranged from 22 400 tonnes to 35 400 tonnes between 4 surveys and two frequencies. The mean of the four surveys was 27 000 tonnes and 28 600 tonnes respectively for 38 and 120 kHz with a combined frequency estimate of 27 800 tonnes and a CV of 15% (Table 3-3).

The position of the schools at St Helens changed during the voyage although they were dominant in the western and north western regions. During the first two surveys more fish were observed in the eastern side of the hill (Figure 3-3). This differed from the 2016 survey where the highest consistent concentrations were in the northern central region. In general, the schools observed in 2019 were well clear of the seabed and easily available to the acoustic survey. This is reflected by the low proportion of fish estimated in the “deadzone”, being ~10% for the combined surveys. This is half the estimate of the 2016 surveys “deadzone” biomass, where fish schools were more intense closer to the seabed. Of note was the large variation (CV 0.19) in the 4 survey means from the 120 kHz transducer compared to the 4 38 kHz transducer surveys (CV 0.10) (Table 3-3). The reason for this is unknown and may be due to changes in target strength or calibration/absorption correction issues with changing AOS depth and school range. Further investigation is required to establishing the mechanisms for this difference (Figure 3-5).

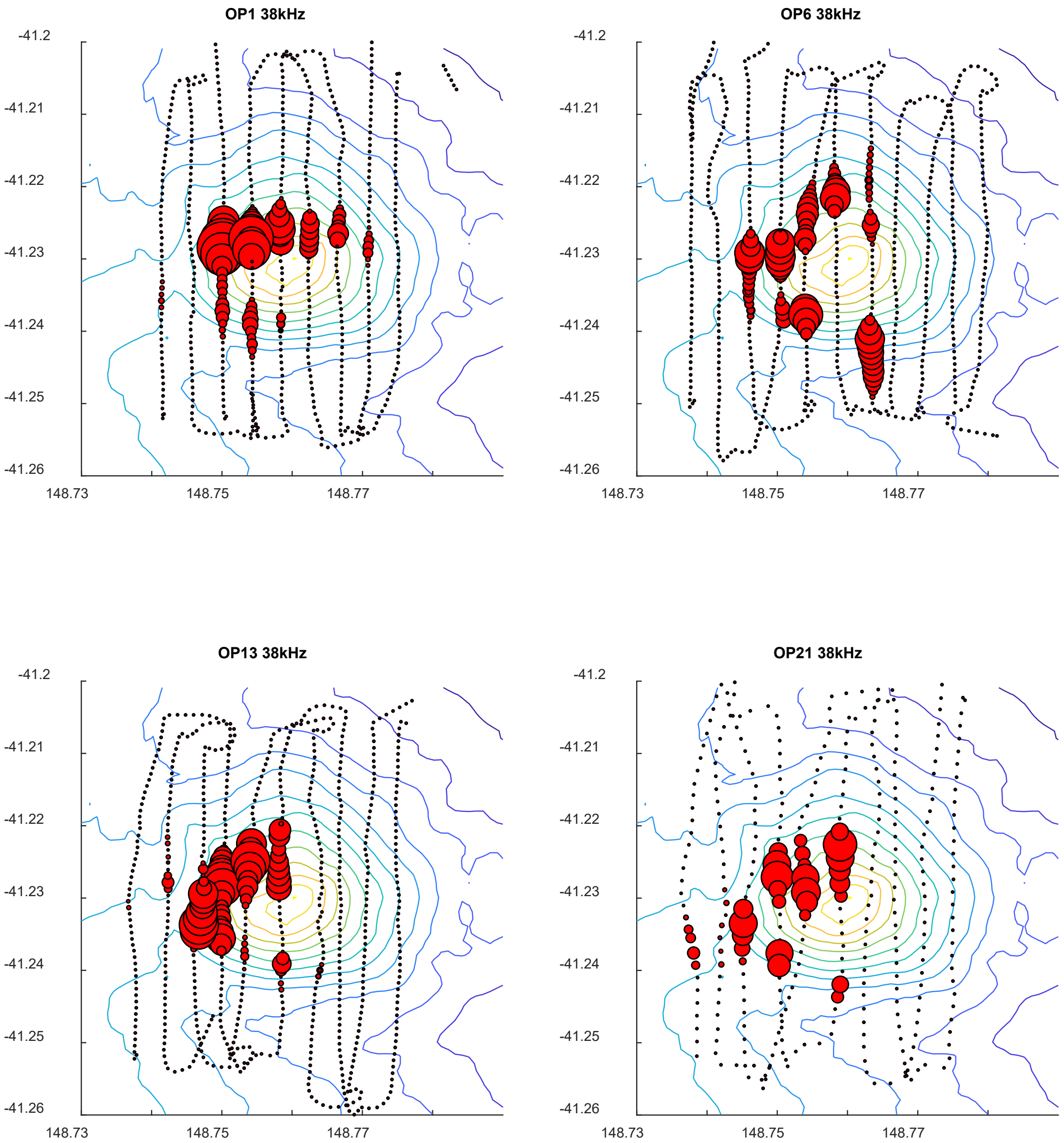


Figure 3-3 Maps of the relative biomass of orange roughy at 38 kHz using the net attached AOS at St Helens Hill, the surveys summarised in Figure 3-5 and Table 3-3. Underlay of the bathymetry contours in 50 m intervals, 600 to 1200 m. Echogram of transect 3(T3) for OP01 is shown in a.

Table 3-3 Summary of St Helens Hill surveys at 38 kHz and 120 kHz for the above deadzone echo biomass, deadzone (DZ) biomass and total biomass in tonnes with an estimated coefficient of variation (CV). Maximum survey at St Patricks and St Helens is highlighted in italicised bold assuming process error dominates the survey variability. The observation mean of the 38 kHz, 120 kHz and combined frequency surveys is highlighted in bold.

Date UTC	OP	Frequency kHz	Biomass (t) above DZ	Biomass (t) DZ	Biomass (t) Total	CV	DZ %
10-Jun-19	01-02	38	24652	3756	28408		13%
		120	28404	3607	32011		11%
12-Jun-19	06-07	38	20765	3656	24421		15%
		120	20690	1703	22393		8%
14-Jul-19	***13-14***	***38***	28950	1563	***30513***	***0.16***	***5%***
		120	32145	3248	***35393***	***0.14***	***9%***
15-Jul-19	21-22	38	22490	2134	24625		9%
		120	23088	1358	24446		6%
Mean		**38**	**24214**	**2778**	**26992**	**0.10**	10%
		120	**26082**	**2479**	**28561**	**0.19**	9%
Observation error mean combined frequencies biomass					**27776**	**0.15**	**9.5%**

3.2.2 St Patricks

The survey strategy at St Patricks followed St Helens and involved interlaced transects where the odd and even were done separately. This was done for two reasons; first it enabled the AOS to be checked after each even and odd survey to ensure it was functioning correctly and secondly it enabled the survey mean to be determined using a combined and interlaced mean method if fish movement was a factor for the surveys. As there was no statistical difference between the non-interlaced and interlaced means only the non-interlaced means are reported. The survey biomass estimates ranged from 5 800 tonnes to 15 100 tonnes between 4 surveys and two frequencies. The mean of the four surveys was 9 900 tonnes and 11 700 tonnes respectively for 38 and 120 kHz with a combined frequency estimate of 10 800 tonnes and a CV of 30% (Table 3-4 and Figure 3-5).

The large between survey CV (26-32%) at St Patricks is primarily due to the first survey where fish appeared very dispersed and over the central survey region. The lightly concentrated fish meant that the frequency difference method for identifying ~100% orange roughy aggregations would fail if other fish species with gas bladders were in the sampled region. For later surveys there were clear high intensity schools that were easy to characterise with the frequency difference method and the between survey CV (11-19%) is greatly reduced (Figure 3-4). Of note the biomass observed at St Patricks is greater than twice that observed in 2016 with the vessel mounted transducer. There is also a greatly reduced portion of fish estimated in the “deadzone” in 2019 being on average only 4% compared to 16% in 2016.

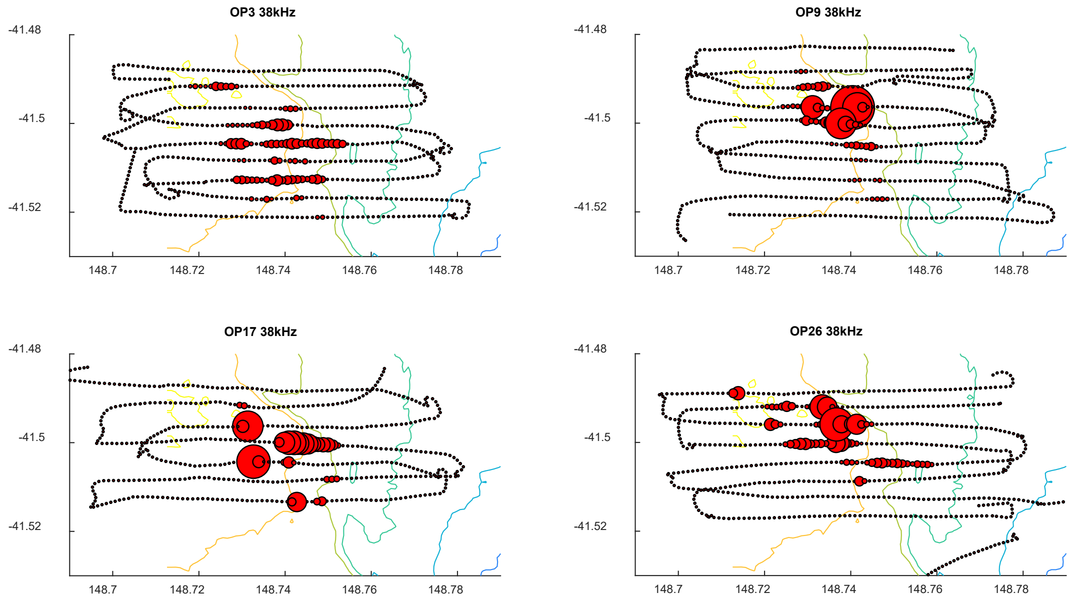


Figure 3-4 Maps of the relative biomass of orange roughy at St Patricks Head with the net attached AOS 38 kHz transducer for the surveys summarised in Table 3-4. Underlay of the bathymetry contours in 50 m intervals, 600 to 1200 m.

Table 3-4 Summary of St Patricks Head surveys at 38 kHz and 120 kHz for the above deadzone echo biomass, deadzone (DZ) biomass and total biomass in tonnes with an estimated coefficient of variation (CV). Maximum survey at St Patricks and St Helens is highlighted in italicised bold assuming process error dominates the survey variability. The observation mean of the 38 kHz, 120 kHz and combined frequency surveys is highlighted in bold.

Date	OP	Frequency kHz	Biomass (t) above DZ	Biomass (t) DZ	Biomass (t) Total	CV	DZ %
11-Jun-19	03-04	38 120	5518 5996	266 234	5784 6230		5% 4%
13-Jun-19	09-10	38 120	11082 14331	892 808	11974 15139		7% 5%
15-Jul-19	***17-18***	***38*** ***120***	11714 14758	412 198	***12125*** ***14956***	***0.23*** ***0.29***	***3%*** ***1%***
17-Jul-19	26-27	38 120	9584 9865	194 440	9777 10305		2% 4%
Mean		**38** **120**	**9474** **11237**	**441** **420**	**9915** **11657**	**0.26** **0.32**	4% 4%
Observation error mean combined frequencies biomass					**10786**	**0.30**	4%

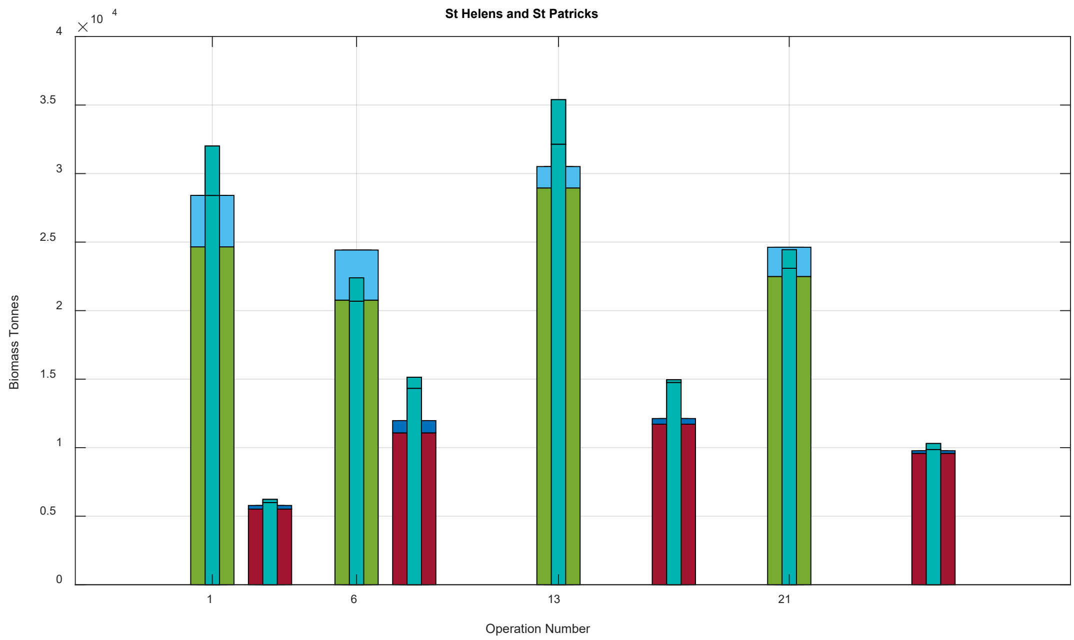


Figure 3-5. Stacked bar chart summary of the survey biomass estimates for the various operations for St Helens 38 kHz, green above seabed echo and blue estimate of biomass in the "dead zone". The 120 kHz biomass estimate is shown as the narrow aqua bar with the above and "dead zone" biomass estimates separated by a bar. The St Patricks biomass at 38 kHz in red for above seabed echo and blue estimate of biomass in the "dead zone". The 120 kHz biomass estimate is shown as the narrow aqua bar with the above and "dead zone" biomass estimates separated by a bar. Details outlined in Tables 3.4 and 3.5.

3.2.3 Combined ground biomass

The combined biomass for the two grounds can be estimated in two ways assuming either observation or process errors dominate (Kloser et al. 2011).

If observation error dominates it assumes that fish are equally available between surveys and the average of all the surveys would be a good indication of the biomass from both St Helens and St Patricks' grounds. If this is the case then the combined biomass (38 kHz and 120 kHz averaged) at both grounds is 38 600 tonnes with a CV of 22% (Table 3-4and Table 3-5). With the 38 kHz estimate 36 900 tonnes and the 120 kHz estimate 40 200 tonnes.

If process error dominates and it is the availability of fish to the acoustic survey that causes most variation between surveys then the maximum biomass within a 24 hour window is the best estimate of the biomass. In this case for the 38 kHz frequency it is 42 600 tonnes (CV of 18%) and 50 300 tonnes (CV 18.5%) for the 120 kHz surveys (Table 3-5). The mean process error biomass estimate combining frequencies is 46 500 tonnes (CV 19%).

Table 3-5 Biomass estimates based on 38 kHz and 120 kHz AOS surveys at St Helens Hill and St Patricks Head. Estimates based on the maximum biomass scenarios for total biomass (addition of above acoustic bottom and estimated deadzone component in bold Table 3-3 and 3-4.

	Operation	**120 kHz biomass (tonnes)**			**38 kHz biomass (tonnes)**			**CV**
		OR1	DZ	Total	OR1	DZ	Total	
St Helens	13-14	32145	3248	35393	28950	1563	30513	0.16
St Patricks	17-18	14758	198	14956	11714	412	12125	0.23
Combined biomass		**46903**	**3446**	**50349**	**40663**	**1975**	**42638**	**0.18**

4 Discussion

Acoustic

Based on the historic combined ground time series from 1999 (Table 4-1) and since 2016 there has been a ~6 700 tonne increase in biomass observed at St Helens Hill. At St Patricks Head the estimate of biomass has more than doubled from the 2016 survey, and previous to that there were major variations (Table 4-1 and Figure 4-1). Based on the long term series of surveys from 1990 to 2016 the 2019 survey results are consistent with a recovering fishery. The snapshot biomass estimate range (36 900 to 50 300 tonnes) using observation and process derived estimates at single or combined frequencies means the current estimates is greater than B48=36 400 tonnes being 48% of the long term equilibrium biomass using the 2017 base case model estimates (Figure 4-1). This assumes a 1:1 female to male ratio and male weight is 0.83 times female weight where the 2019 biomass (B2019) is estimated to be 22 000 tonnes (table 12, Haddon 2017). There appears to be an increasing disconnect between the acoustic biomass estimates and the stock assessment model. Resolution to this may highlight a bias(s) in the acoustic method or other fundamental assumptions in the stock assessment model. Resolution of these differences may become more apparent in future years of monitoring.

The snapshot acoustic derived biomass estimates do not account for the proportion spawning or any turn over on the fishing grounds. It is possible that there is a systematic bias in the estimates, but to the extent possible this is greatly reduced when deriving estimates from two frequencies and over multiple surveys within the spawning season. The biomass estimates are best viewed over multiple years to account for any natural variations in the proportion of fish that spawn at the grounds in any year and the availability of the fish to the survey method or any other process bias. It is possible that the low biomass years of 2012 and 2013 when there was no commercial fishing was a result of a low proportion of the adult population coming to the grounds to spawn.

The 120 kHz biomass estimates were on average ~10% greater than the 38 kHz estimates and inconsistent with previous surveys (Ryan and Kloser, 2016). This difference between 38 kHz and 120 kHz biomass estimates indicates a source or sources of bias in one or both data sets. The 120 kHz transducer is new and calibrated at depth in Feb. 2019, more confidence is gained using an instrument where there is a time series of calibration results. Prior to the survey the 38 kHz system was corrected for a transmitter fault and a correction made to the Feb. 2019 calibration result to match previous calibrations for this transducer and verified with independent wharf side tests in April 2020 (Appendix C). Until the source of bias(s) is found the average of the 38 kHz and 120 kHz estimates is recommended. The combined ground estimate (averaged over frequencies) is 46 500 tonnes (CV 19) assuming process error dominant and 38 600 tonnes (CV 0.22) assuming observational error dominant. The large 20% difference in process and observational biomass estimates is worth investigating. In part some of that difference (~5%) is due to the low biomass estimate from the first survey at St Patricks when fish were dispersed and school scattering weak.

This indicates a situation of a process error problem where the survey method is not suited to surveying dispersed fish at low intensities.

Table 4-1 Biomass series based on the 38 kHz biomass estimate (maximum within 24 hrs with DZ included) at St Helens Hill and St Patricks Head from 1999 to 2019 and proportion of total at St Helens Hill (Kloser *et al.*, 2015). The 1999 survey has high CV's due to a low number of transects (3) with one transect having a high biomass.

	Year						
Location	**1999**	**2006**	**2010**	**2012**	**2013**	**2016**	**2019**
St Helens Hill	7688	16066	19200	12058	11265	23790	30513
St Patricks Head	21748	2293	6259	7136	6458	5773	12125
Percentage at St Helens Hill	26	88	76	63	64	80	72
Total (tonnes) CV	29436 0.43	18359 0.16	25459 0.14	19194 0.17	17723 0.2	29563 0.21	42638 0.18

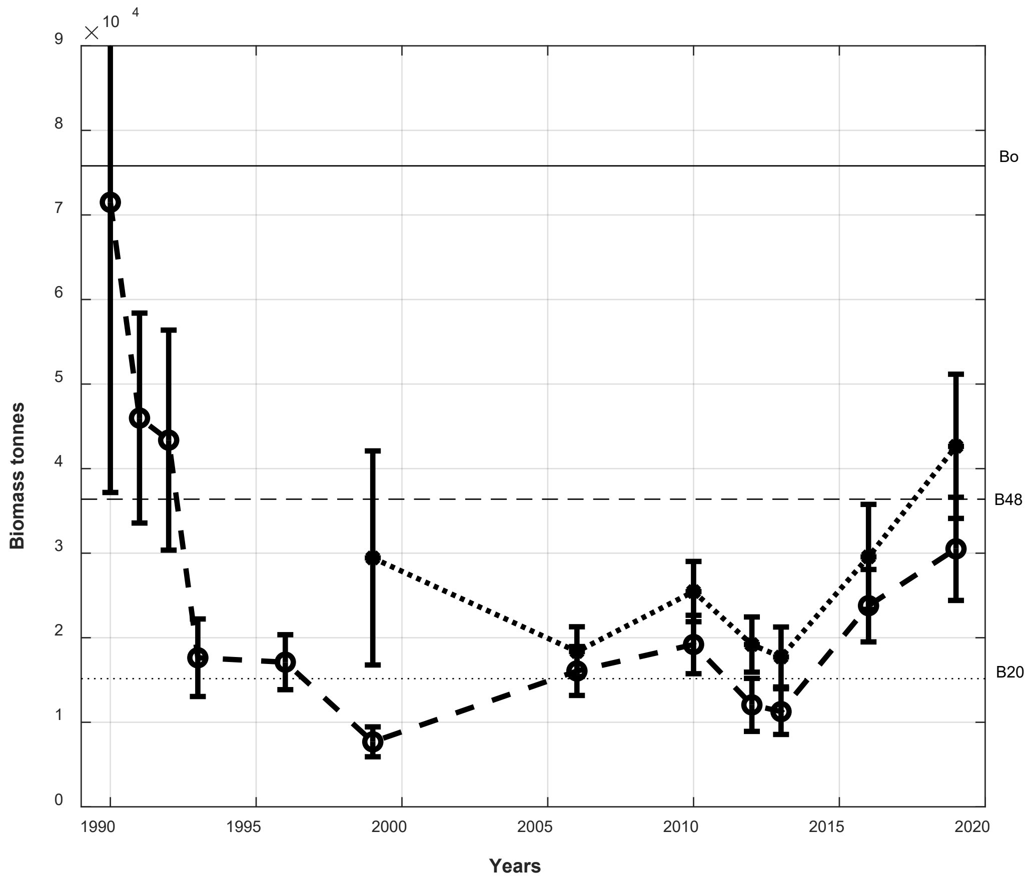


Figure 4-1 Estimated change in spawning biomass at St Helens Hill (dashed line, s.d. solid line) based on a vessel mounted survey in 1990 and towed body surveys from 1991 to 2019 [Table 5 Kloser *et al.* (2015) and Table 4-1]. Combined St Patricks and St Helens spawning orange roughy estimate of acoustic biomass in 1999, 2006 to 2019 (dot dashed line, s.d. solid line). The pre-fishery equilibrium biomass (Bo solid line), 20% Bo (dotted line) and 48 % Bo (dashed line) are shown based on proposed base case M=0.36 Haddon 2017 assuming female to male ratio 1:1 and male weight ~0.83 times female weight.

Biological

Biological sampling differed this year due to using the *FV Saxon Onwards* being a larger vessel with a different operation where larger catches (~ 5-10 tonnes) were captured and retained during the survey (~100 tonnes). Catches were within the 5 to 10 tonne target range and in particular at St Patricks were higher than in previous years (2013 and 2016) of ~ 2 to 5 tonnes. This change in fish targeting may have unintended consequences for the biological time series for captured fish of a given sex, length and or age. The mode of capture is more reflective of pre 2013 surveys. The 2019 survey was also done a few days earlier than normal starting on the 10th of July. This earlier start is supported by the gonad results that show fish were rapidly moving from pre spawning to spent during the survey.

The biological time series of length, weight and age represents a useful view of the changing fishery (Kloser et al. 2015). The length measures of male and females at both St Helens and St Patricks has increased markedly from the 2013 survey. Of note is the decoupling of at sea measured weights compared to those estimated using the historic Lyle et al. 1991 length to weight equation. Using the calibrated at sea measured weights would increase the reported biomass by 11%. Both at sea weights and Lyle et al (1991) derived weights are reported here and an investigation of which to use for future surveys is needed. At the time of reporting the otoliths collected on the voyage had not been aged but a proxy of otolith weight was available. The time series of otolith weight highlights a large increase in male otolith weight and should be associated with increases in age and length. Future reporting will include both measured otolith weight and age to observe relative changes in both are consistent with expectations.

The acoustic systems used are in excess of 10 years old and are being superseded with new models and functions. During the voyage new technologies were trialled (Appendix C) that will reduce the size and targeted to improve the robustness of the net attached AOS system. Importantly there are broadband technologies that need to be assessed for utility to improve the biomass estimates. Ideally it would be beneficial if monitoring was done more regularly at a reduced cost. Ongoing investigation of new technology and methods is recommended to future proof the surveys and improve the precision and accuracy whilst being cost effective.

Appendix A: Operations undertaken during the voyage

Operation	Operation Type	Start_date (EST)	Start_Time (EST)	Location
1	AOS Survey	10/07/2019	12:39	St Helens Hill
2	AOS Survey	10/07/2019	18:14	St Helens Hill
3	AOS Survey	11/07/2019	9:20	St Patricks Head
4	AOS Survey	11/07/2019	15:48	St Patricks Head
5	AOS biological	11/07/2019	21:43	St Patricks Head
6	AOS Survey	12/07/2019	2:24	St Helens Hill
7	AOS Survey	12/07/2019	8:03	St Helens Hill
8	AOS biological	12/07/2019	17:12	St Helens Hill
9	AOS Survey	12/07/2019	21:52	St Patricks Head
10	AOS Survey	13/07/2019	4:00	St Patricks Head
11	AOS biological	13/07/2019	11:00	St Patricks Head
12	AOS biological	13/07/2019	13:51	St Patricks Head
13	AOS Survey	13/07/2019	18:30	St Helens Hill
14	AOS Survey	14/07/2019	0:46	St Helens Hill
15	AOS biological	14/07/2019	14:21	St Helens Hill
16	AOS biological	14/07/2019	16:24	St Helens Hill
17	AOS Survey	14/07/2019	21:09	St Patricks Head
18	AOS Survey	15/07/2019	2:38	St Patricks Head
19	AOS biological	15/07/2019	11:23	St Patricks Head
20	AOS biological	15/07/2019	14:25	St Patricks Head
21	AOS Survey	15/07/2019	19:10	St Helens Hill
22	AOS Survey	16/07/2019	1:17	St Helens Hill
23	AOS biological	16/07/2019	8:31	St Helens Hill
24	AOS biological	16/07/2019	11:33	St Helens Hill
25	Vessel Survey	16/07/2019	15:00	St Patricks Head
26	AOS Survey	16/07/2019	18:07	St Patricks Head
27	AOS Survey	17/07/2019	1:15	St Patricks Head
28	AOS biological	17/07/2019	10:40	St Patricks Head
29	AOS biological	17/07/2019	20:40	St Helens Hill
30	AOS biological	18/07/2019	1:32	St Helens Hill
31	AOS biological	18/07/2019	7:15	St Helens Hill
32	AOS biological	18/07/2019	8:55	St Helens Hill
32	AOS Single pass	18/07/2019	11:07	St Helens Hill
34	AOS Single pass	18/07/2019	13:08	St Helens Hill
35	AOS biological	18/07/2019	14:46	St Helens Hill

Appendix B: AOS calibration summary

Kunnath Haris and Rudy Kloser

For the 2019 survey data the net attached AOS 38kHz and 120 kHz systems needed to be adjusted for calibration settings and sound absorption at the operating depth. Corrections to the survey data were done by adjusting the nominal gain and Sacorr by those at the mean AOS depth within the 100 m echo integration interval. The nominal absorption coefficient was corrected for the range from the mean AOS depth within a 100 m integration interval to the average range of the school in the interval from the AOS. The absorption coefficients were calculated using the AOS CTD data from the region and the Francis and Garrison (1983) absorption equation.

4.1 Deep water AOS calibration:

The AOS system was deep water calibrated in February 2019 using the FV Empress Pearl (Harris 2019). A summary of that calibration is provided below. A fault was uncovered after the calibration in the 38 kHz EK60 transmitter where one quadrant (#2) had failed. This was corrected prior to the July 2019 survey and the system monitored throughout the voyage to ensure no reoccurrence of the fault. This was done by monitoring the transmitter data in the data file and setting known limits of expected power in the raw telegrams.

Year	**2019**	
Voyage	**Empress Pearl**	
GPT settings		
Transducer model	Simrad ES38-DD	Simrad ES120-7CD
Serial number	28362	123
Frequency (kHz)	38	120
Power (W)	2000	250
Pulse length (ms)	2.048	1.024

A summary of the deep water calibration for the two parameters Gain and Sa corr (y) by depth (d) coefficients (x and c) is given in Table 1 of the form y = xd3 + xd2 + xd + c.

Table-2 Average of all deployments calibration coefficients for the AOS transducers at 38 kHz and 120 kHz with depth (d) and the calibration parameter at the nominal depth of 600 m (Haris 2019). Note fault in transmitter for the 38 kHz transducer Q2 faulty.

38 kHz – average all deployments with fault					
y	x d^3	+ x d^2	+ x d	+ c	@600m
Gain polynomial parameters	5.77E-09	-1.03E-05	4.63E-03	2.27E+01	23.06
Sa corr polynomial parameters	-9.51E-10	1.64E-06	-7.30E-04	-3.53E-01	-0.40

120 kHz – average all deployments					
y	x d^3	+ x d^2	+ x d	+ c	@600m
Gain polynomial parameters	2.83E-09	-4.36E-06	2.34E-03	2.70E+01	27.50
Sa corr polynomial parameters	2.83E-11	2.49E-07	-3.06E-04	-2.95E-01	-0.39

4.2 Wharf Calibrations

To correct the 38 kHz February calibration data several wharf side calibrations were done with and without the fault (Haris 2020). A summary of the calibrations is shown in Table 2 to determine the effect on both Gain and Sa corr at a pulse length of 2 mS. Based on the experiments the gain factor needed to be adjusted by 1.18 dB and 0 dB respectively.

Table 3 Summary of the wharf side calibration to determine the effect of the fault (transmitter disconnected for quadrant 2) and no fault. Two trials were done to investigate the repeatability (Harris 2020).

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Test	Pulse length (ms)	Instantaneous received power (dB re 1 W)*	Sphere TS (dB re 1 m^2)	Sphere NASC (m^2 nautical $mile^{-2}$)	Transducer on-axis gain (dB re 1)	$S_{a\ corr}$ (dB re 1)	EBA Ψ (dB re 1 sr)**
Test 2: all sector enabled	2.048	26.54 ± 0.01	-47.03 ± 0.19	1417 ± 65	24.17	-0.58	-20.81
Test 3: all sector enabled	1.024	26.59 ± 0.04	-47.44 ± 0.46	1200 ± 238	24.18	-0.70	-20.81
Test 4: sector 2 disabled	1.024	24.28 ± 0.01	-49.66 ± 0.23	765 ± 42	22.89	-0.71	-20.81
Test 5: sector 2 disabled	2.048	24.25 ± 0.02	-49.35 ± 0.14	838 ± 35	23.01	-0.58	-20.81

13 May 2020

Test	Pulse length (ms)	Instantaneous received power (dB re 1 W)*	Sphere TS (dB re 1 m^2)	Sphere NASC (m^2 nautical $mile^{-2}$)	Transducer on-axis gain (dB re 1)	$S_{a\ corr}$ (dB re 1)	EBA Ψ (dB re 1 sr)**

Test 2: all sector enabled	2.048	26.59 ± 0.01	-46.27 ± 0.49	1700 ± 180	24.51	-0.55	-20.81
Test 3: all sector enabled	1.024	26.66 ± 0.01	-46.54 ± 0.33	1570 ± 123	24.39	-0.67	-20.81
Test 4: sector 2 disabled	1.024	24.29 ± 0.01	-49.26 ± 0.57	835 ± 129	22.98	-0.67	-20.81
Test 5: sector 2 disabled	2.048	24.23 ± 0.02	-49.29 ± 0.34	845 ± 64	23.01	-0.56	-20.81

Note: Power, sphere TS, and sphere NASC values in above table were derived from nominal gain = 26.5 dB, Sa correction = 0, and EBA = -20.93 (ICES DeCAF paper).
*** Peak value of instantaneous received power (aka transmit pulse) between 0-1 m range. While comparing power values confirm that nominal gain setting used during data acquisition is consistent across test\deployments.**
**** EBA value based on ICES DeCAF paper – this value has been adjusted for local sound speed, calculated using nominal temperature 15 °C and salinity 34.5 psu.**

The 1.18 dB Gain correction for the 38 kHz transducer was applied and the corrected gain compensation is given in Table 4.

Table 4 Corrected calibration coefficients for the 38 kHz transducer used for the 2019 survey data.

38 kHz – average all deployments fault corrected					
y	x d^3	+ x d^2	+ x d	+ c	@600m
Gain polynomial parameters	5.77E-09	-1.03E-05	4.63E-03	2.27E+01	24.24
Sa corr polynomial parameters	-9.51E-10	1.64E-06	-7.30E-04	-3.53E-01	-0.40

The efficacy of the correction was checked by comparing it to historic calibrations to ensure they were within the bounds of previous deployments (Haris 2019).

Appendix C: Future proofing survey and target strength methods

Ben Scoulding

Introduction

Trials of a Simrad wideband transceiver (WBT) tube connected to a wide beam (18° beamwidth) 38 kHz and narrow beam (7° beamwidth) 120 kHz transducers were tested during the last day of the acoustic survey. The WBT tube was in combination with the optical technologies on the AOS. The aim of this work was to future proof survey and target strength methods, testing new generation acoustic broadband technologies. Firstly, we investigate broadband target strength measurements of orange roughy and blue grenadier and discuss the benefits and limitations of broadband acoustics and the current configuration of the AOS platform. We then use the WBT tube in continuous wave (CW) to test the survey capability of the system.

Objective

1- Test new acoustic and optical technologies for future survey and target strength estimates.

Sampling equipment and methodology

Broadband target strength

Broadband target strength data were collected using a Simrad WBT tube operating at 38 (18° beamwidth) and 120 kHz (18° beamwidth) during three AOS operations (OP30, OP31, OP32) on St Helens on the 28th July 2019 (Table 1). The frequency spectrums were 35-45 kHz and 90-160 kHz, for the 38 and 120 kHz echosounders, respectively. The pulse duration was 2.048 ms for both frequencies and the power were 450 W and 250 W for 38 kHz and 120 kHz, respectively. The temperature was 9°C, salinity 35 psu and sound speed 1496 ms^{-1}.

Unfortunately, one of the quadrants on the 120 kHz wide beam transducer was damaged at some during an AOS operation, as evident in Figure 1, and therefore the 120 kHz data is not considered further in our analysis. Instead we demonstrate the utility of broadband using the 38 kHz data.

Table 1. Summary of WBT tube AOS deployments.

Voyage	Operation	Date	Start time (UTC)	End time (UTC)	Bottom down (UTC)	Bottom Up (UTC)	Location	Comment
SXO2019	30	28/07/19	01:32	02:10	15:50	16:11	St Helens	Target strength
SXO2019	31	28/07/19	21:08	21:35	21:10	21:33	St Helens	Target strength
SXO2019	32	28/07/19	08:55				St Helens	Target strength
SXO2019	33	28/07/19	00:39	02:18	-	-	St Helens	Survey
SXO2019	34	28/07/19	02:44	04:24	-	-	St Helens	Survey

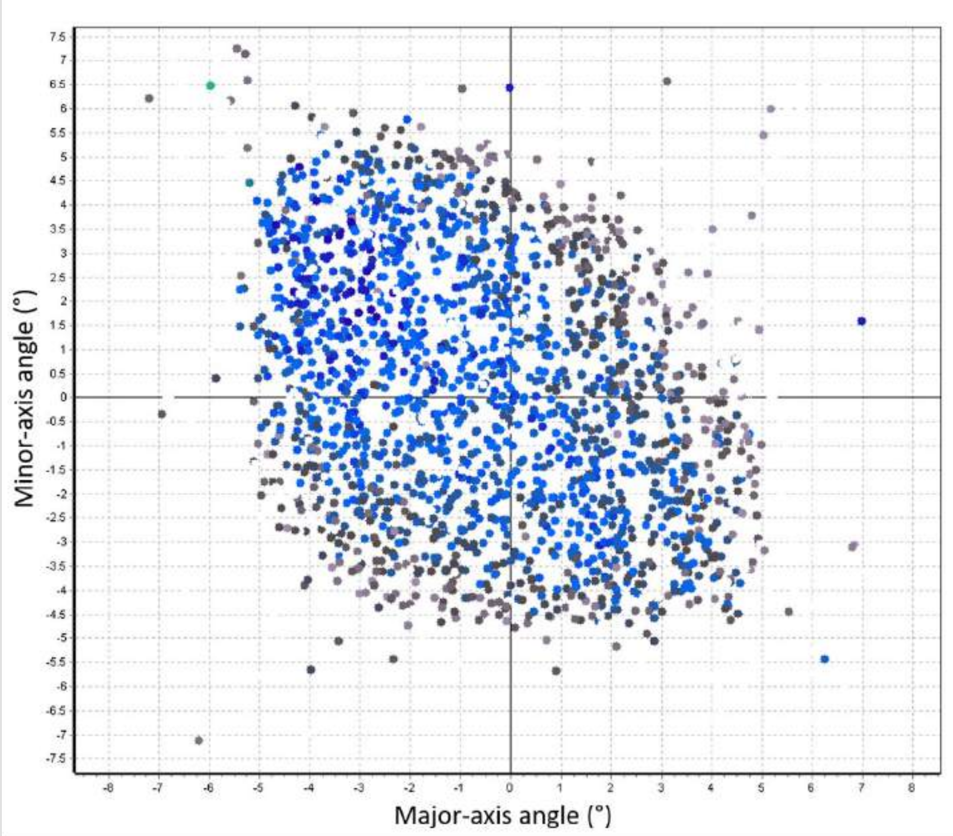


Table 1. Single target angles at 120 kHz.

Broadband target strength (*TS*, dB re 1 m^2) measurements of orange roughy and blue grenadier *in situ* were made from 35-45 kHz. The AOS data was assessed according to the procedure described in Scoulding and Kloser (*in press*). The acoustic data were processed in Echoview version 10.0.257 (Echoview software, 2019). The video footage was synced to the acoustic data and stereo images by identifying the necessary offset values (Table 2).

Table 2. Image and video offsets.

Operation	**Image time**	**Video time**	**Video offset**
30	160527.156	160524.766	+2.390
31	212405.172	212400.599	+4.573
32	231130.155	231125.699	+4.456

A combination of *TS*, angular and optical information were used to identify target selection. Targets above an acoustic detected bottom and below a 2.75 m near-field line were excluded from analysis. Potential orange roughy and blue grenadier regions between these two lines were identified by synchronising the video and stereo images with the echogram data. Only acoustic targets visually verified by the video were considered for analysis. Once a target was verified a region was manually drawn around it to fully contain the single targets. *TS* were derived at 38 kHz using the single target detection algorithm in Echoview (TS threshold = -70 dB, Pulse determination level = 6 dB, minimum normalised pulse length = 0.5, maximum normalised pulse length = 1.5, minimum target separation = 0.2 m, maximum standard deviation of minor- and major-axis = 2° and maximum beam compensation = 35 dB). Single targets were used as input to Echoview's fish tracking algorithm.

The wideband frequency response r(f) of orange roughy and blue grenadier were exported from Echoview. The averaged r(f) for all targets belonging to an individual were exported, as well for all targets in the echogram. The window size was 0.40 m and the maximum acceptable time difference from reference was 1 second.

Survey mode

Survey data were collected in CW mode at 38 and 120 kHz during two AOS deployments (OP33 and OP34) (Table 1). The AOS was flown 200-400 m over aggregations of orange roughy. The pulse duration was 2.048 ms at 38 kHz during both ops and 1.024 ms and 0.256 ms at 120 kHz for OP33 and OP34, respectively. The power settings were 450 and 280 W for 38 kHz and 120 kHz, respectively. The environmental values were the same as above. For OP33 the WBT tube was connected to main battery and in OP34 the WBT tube was powered by an independent battery.

Results

Broadband target strength

The wideband frequency response for all single targets (Figure 2) and the averaged wide frequency response (Figure 3) for individuals are given for orange roughy and blue grenadier. Figures 2 and 3 highlight the variable nature of target strength over a wide frequency spectrum. The frequency responses are flat for both orange roughy and blue grenadier across the 35-45 kHz spectrum. For unknown reasons the frequency response from 35-37 kHz and 43-45 kHz during OP32 (Figure 2c and 3c) increase dramatically.

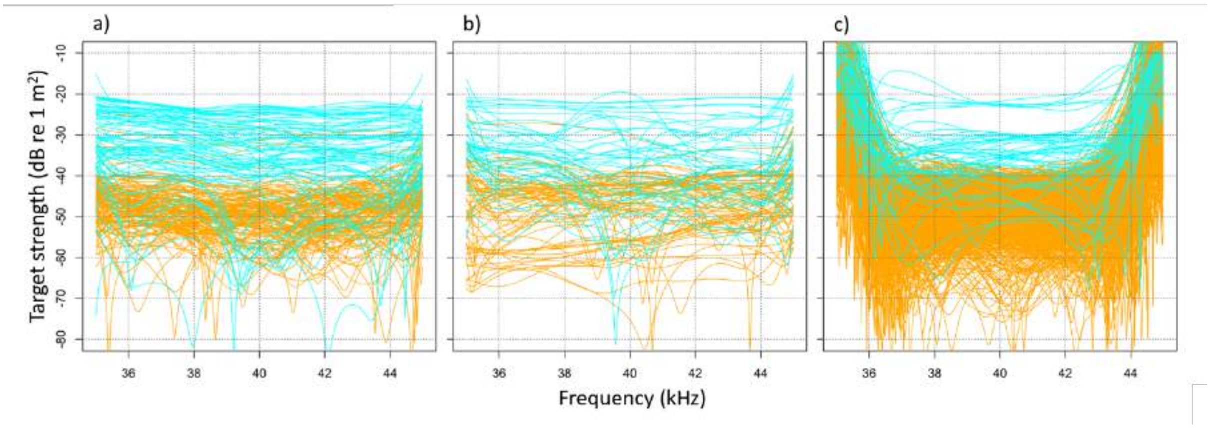


Figure 2. Wideband frequency response for all single targets identified as orange roughy (orange lines) and blue grenadier (blue lines) for AOS operations OP30 (a), OP31 (b) and OP32 (c). Note: calibration values have not been applied to the data.

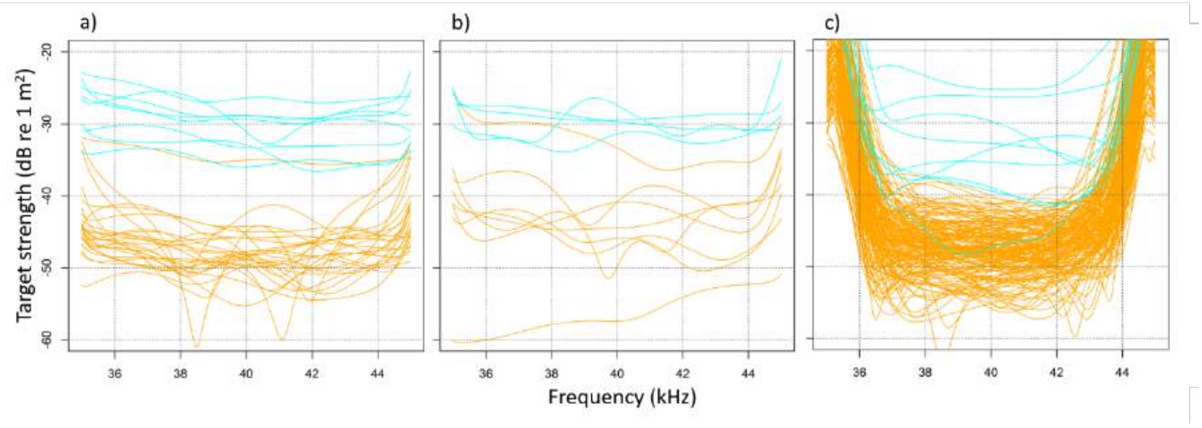


Figure 3. Averaged wideband frequency response for individual orange roughy (orange lines) and blue grenadier (blue lines) for AOS operations OP30 (a), OP31 (b) and OP32 (c). Note: calibration values have not been applied to the data.

Survey mode

Two transects were performed in survey mode (Figures 4 and 5) using the WBT tube. The 38 kHz channel easily achieved the desired range and 120 kHz was useful down to around 400 m before the signal to noise decreased (Figures 4 and 5). Connecting the WBT tube to an independent battery supply appeared to have no effect on the usable range at either 38 or 120 kHz. It should be noted that the pulse duration at 120 kHz was changed from 1.024 ms in OP33 to 0.256 ms in OP34, however, this did not appear to change the achievable range.

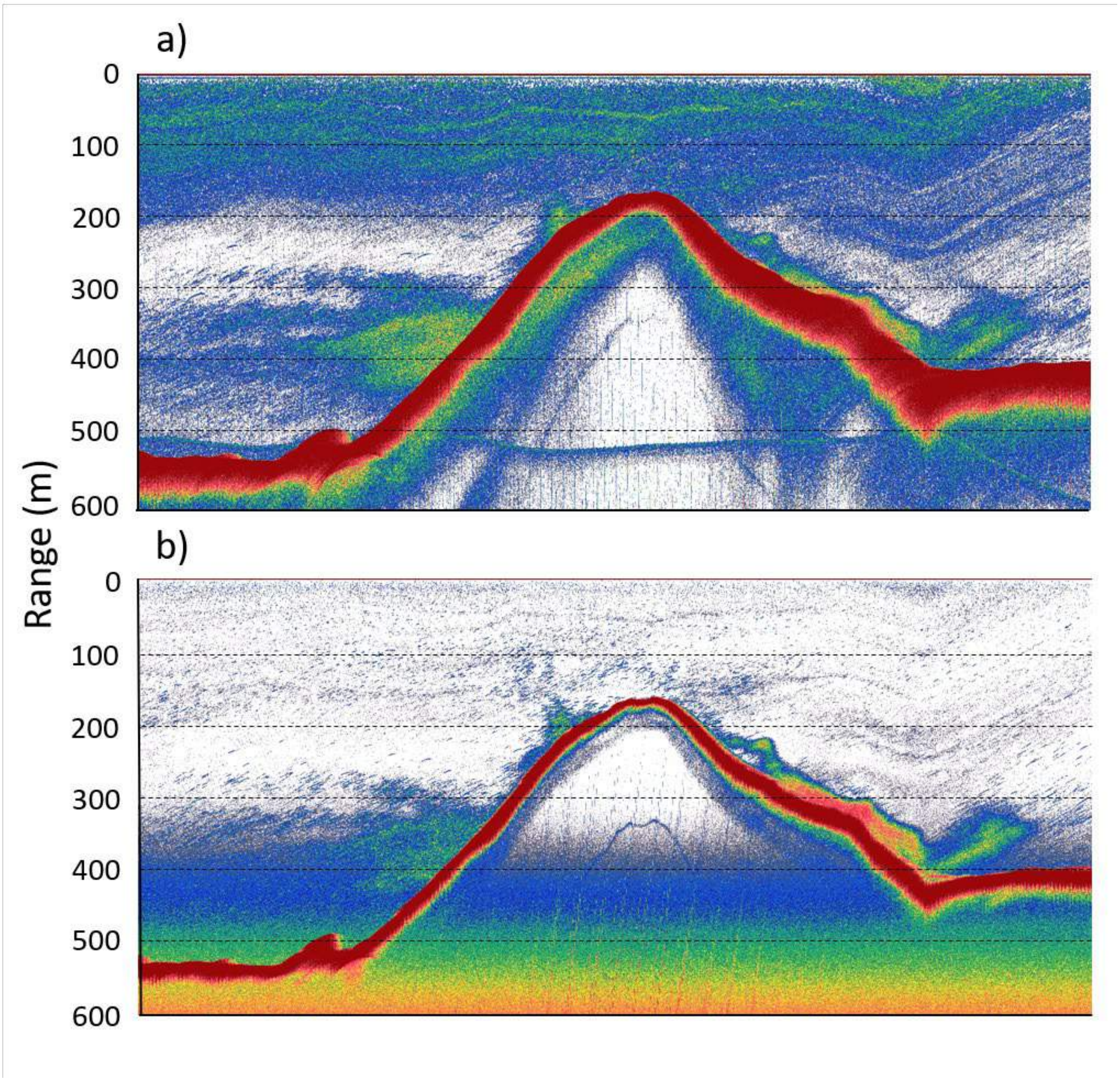


Figure 4. AOS transect during OP33 above an aggregation of orange roughy at a) 38 kHz and b) 120 kHz. The WBT tube was connected to a wide beam 38 kHz transducer and a narrow beam 120 kHz transducer with power supplied by the main battery.

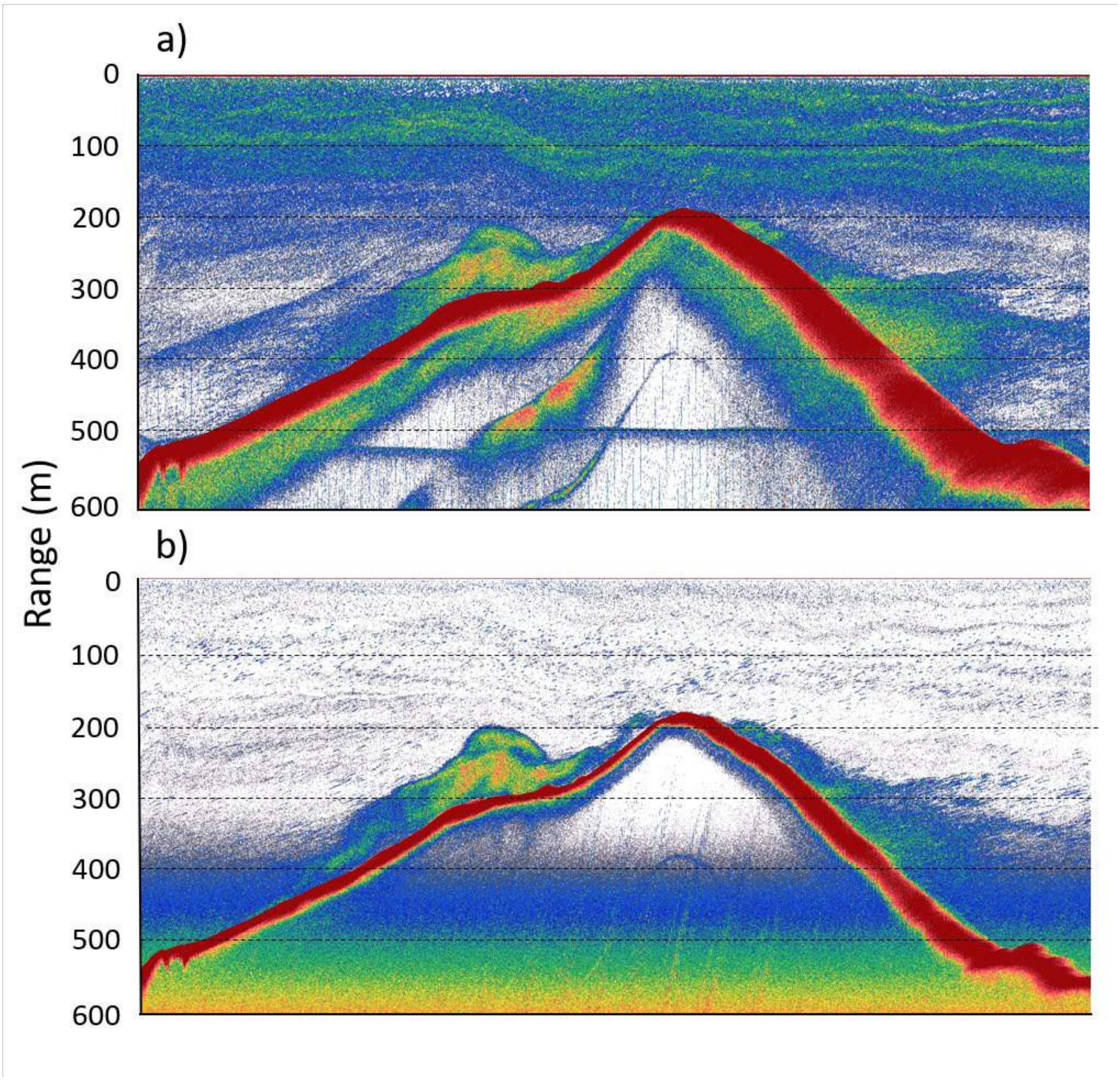


Figure 5. AOS transect during OP33 above an aggregation of orange roughy at a) 38 kHz and b) 120 kHz. The WBT tube was connected to a wide beam 38 kHz transducer and a narrow beam 120 kHz transducer with power supplied by an independent battery pack.

Discussion

Although the frequency response of orange roughy and blue grenadier is flat across the frequency spectrum tested (35-45 kHz), the usefulness of broadband data is apparent. The frequency response spectrums from the two species are clearly separated, however, the true power of broadband acoustics will not become evident until a wider range of frequencies are tested (i.e. 95-160 kHz).

Initial results indicate that the WBT tube achieves the required ranges to carry out biomass surveys at 38 and 120 kHz. The WBT tube connected to wide beam transducers will significantly reduce the overall size of the AOS and hence reduce the logistics of using the system onboard commercial vessels.

<u>Benefits and limitations</u>

Broadband echosounders offer several potential benefits over narrowband echosounders. These include:

- Improved vertical resolution (bandwidth dependent),
- Characterise target strength as a function of frequency,

- Potential to measure fish length,
- Improved boundary conditions (ability to separate fish close to the seabed),
- Versatile, compact and robust installation options,
- Improved species discrimination (swimbladdered versus non-swimbladdered),
- Improved target separation,
- Improved single to noise ratio (TS echograms).

However, given broadband acoustics are still an active area of research there remain many unknowns and uncertainty in the correct treatment of broadband data, including:

- Difficulty knowing the best single target detection settings,
- Treatment of single target data,
- Wideband seabed detection,
- Data volume,
- Reduced single to noise ratio (Sv echogram),
- Use of appropriate thresholds.

In addition to testing broadband echosounders, we also took the opportunity to investigate the use of wide beam transducers. Wide beam transducers are useful for several reasons:

- Reduced near field,
- Detection of targets at closer ranges,
- Greater overlap with the optical systems.

However, they also have their limitations:

- Sidelobes hit trawl (Figure 6),
- Greater acoustic dead zone,
- Greater transducer ring-down (Figure 6),
- Multiple targets in sampled volume (horizontal separation).

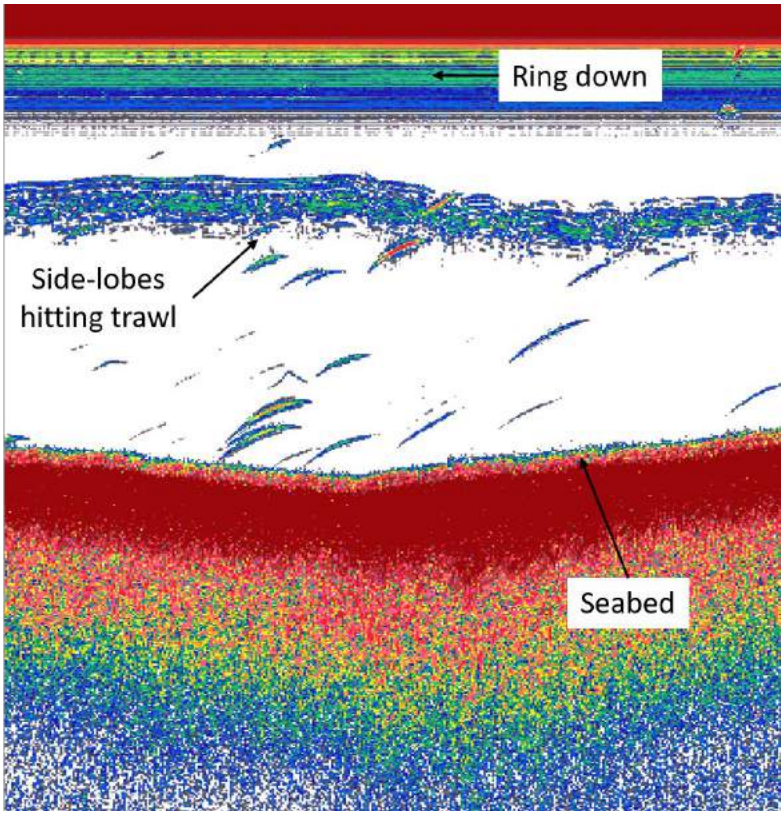
-


Figure 6. Example broadband echogram (35-45 kHz) showing transducer ringdown and the side-lobe effect.

Before the true potential of broadband echosounders and wide beam transducer can be realised, there are issues with the current setup of the AOS which need to be addressed. These include,

- Transducers are too far back from the stereo cameras. This means at close range there is little overlap between the acoustic beam and the field of view of the cameras (Figure 7).
- The current frame rate to slow to capture most fish detected by the acoustics.
- The video on the AOS turns on was very close to bottom. potential missed opportunities

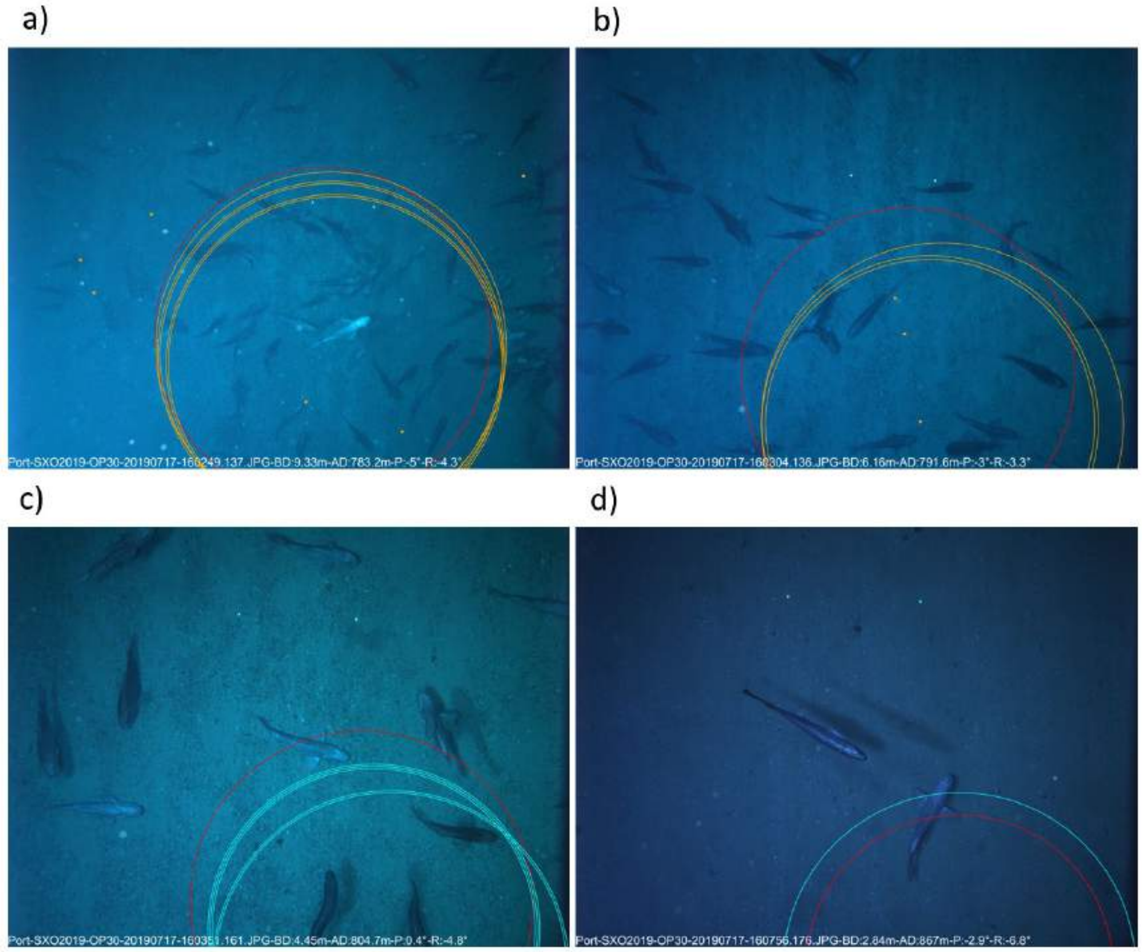


Figure 7. Port side still images recorded by the AOS at a) 9.3 m, b) 6.1 m, c) 4.5 m and d) 2.8 m above the seabed. The overlap between the acoustic beam (coloured circles) and optical field of view increases with range from seabed. The red circle is the beam diameter at the range of the seabed. The orange circles show the beam diameter at the range of orange roughy single target detections and the blue circles show the beam diameter at the range of blue grenadier single target detections.

Recommendations

- Bring the transducers and cameras as close together possible to maximise overlap between the acoustic beam and optical field of view.
- Continue to experiment with broadband echosounders connected to wide beam transducers.
- Collect TS measurements across a wider frequency spectrum (i.e. 35-45, 90-160 kHz).
- Compare biomass estimates from broadband and narrowband Sv transects.

References

Demer, D., Berger, L., Bernasconi, M., Bethke, E., Boswell, K., Chu, D., Domokos, R., et al. 2015. Calibration of acoustic instruments. ICES Cooperative Research Report 326. 133 pp.

Kloser, R., Sutton, C., and Krusic-Golub, K. 2012. Australian spawning population of orange roughy: eastern zone acoustic and biological index fished from 1987 to 2010. Report to the South East Trawl Fishing Industry Association. CSIRO Hobart: CSIRO Marine and Atmospheric Research. 70 pp.

Kloser, R. J., Knuckey, I. A., Ryan, T. E., Pitman, L. R., and Sutton, C. 2011. Orange roughy conservation program: Eastern Zone surveys and trials of a cost-effective acoustic headline system. Final report to the South East Trawl Fishing Industry Association. CSIRO Hobart: CSIRO Marine and Atmospheric Research, CSIRO: EP115915. ISBN: 9781921826535. 153 pp.

Kloser, R. J., Macaulay, G. J., Ryan, T. E., and Lewis, M. 2013. Identification and target strength of orange roughy (Hoplostethus atlanticus) measured in situ. The Journal of the Acoustical Society of America, 134: 97-108.

Kloser, R. J., Sutton, C., Krusic-Golub, K., and Ryan, T. E. 2015. Indicators of recovery for orange roughy (Hoplostethus atlanticus) in eastern Australian waters fished from 1987. Fisheries research, 167: 225-235.

Lyle, J. M., Kitchener, J. A., and Riley, S. P. 1991. An assessment of the Orange Roughy Resource off the coast of Tasmania. Final report to the Fishing and Industry Research and Development Council. Project 87/65.

Malan, J., Marouchos, A., Sherlock, M., Ryan, T., and Kloser, R. 2016. Deep water acoustic calibration facility: Development of a platform. *In* OCEANS 2016-Shanghai, pp. 1-5. IEEE.

Pankhurst, N., McMillan, P., and Tracey, D. 1987. Seasonal reproductive cycles in three commercially exploited fishes from the slope waters off New Zealand. Journal of Fish Biology, 30: 193-211.

Ryan, T., Sutton, C., and Kloser, R. 2014. Biomass estimates of orange roughy at the Tasmanian Eastern Zone spawning grounds in July 2013 using a net attached acoustic optical system. Report to South East Trawl Fishing Industry Association. CSIRO Hobart: CSIRO Marine and Atmospheric Research, CSIRO: EP145457. 41 pp.

Ryan, T. E., and Kloser, R. J. 2016. Improved estimates of orange roughy biomass using an acoustic-optical system in commercial trawlnets. ICES Journal of Marine Science, 73: 2112-2124.

Simmonds, J., and MacLennan, D. N. 2005. Fisheries acoustics: theory and practice*,* Blackwell Science. 456 pp.

Upston, J., Punt, A. E., Wayte, S., Ryan, T., Day, J., and Sporcic, M. 2014. Orange Roughy (Hoplostethus atlanticus) Eastern Zone stock assessment incorporating data up to 2014. Australian Fisheries Management Authority. CSIRO Hobart: CSIRO Marine and Atmospheric Research, CSIRO: EP15552. 66 pp.