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Orange roughy abundance estimates of the north Chatham Rise Spawning Plumes (ORH3B), *San Waitaki* acoustic survey, June-July 2014

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I. J. Doonan;
A. C. Hart;
B. Wood;
A. Dunford.

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EXECUTIVE SUMMARY

Doonan, I.J.; Hart A.C.; Wood, B.; Dunford, A. (2016). Orange roughy abundance estimates of the north Chatham Rise Spawning Plumes (ORH3B), *San Waitaki* acoustic survey, June-July 2014.

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The abundance of the orange roughy in the spawning aggregation on the northeast Chatham Rise (ORH3B) was estimated from a hull mounted transducer acoustic survey carried out between 30 June and 20 July 2014 using the fishing industry vessel, FV *San Waitaki* (voyage SWA1401). Two spawning plumes were surveyed: the Old Plume, for which acoustic abundance estimates were made each year from 2002 to 2012, and the newer aggregation, named the Rekohu Plume, situated about 25 n. miles west of the Old Plume which was surveyed for the first time in 2011. Overall abundance estimates were the mean of several acceptable (i.e., "good" weather) acoustic survey snapshots of each aggregation, but poor weather meant that most snapshots were not acceptable.

For the Old Plume, the overall estimated abundance was 17 668 t (CV 18.5%) from 4 acceptable snapshots. For the Rekohu Plume, the overall abundance was 40 066 t (CV 25.5%) from 2 acceptable snapshots.

1. INTRODUCTION

This report documents the analysis and reporting of the Ministry of Fisheries (now Ministry for Primary Industries, MPI) project ORH2010/01 which had the overall objective: to estimate the abundance of orange roughy (*Hoplostethus atlanticus*) in selected areas, and the specific objectives**:**

1. To estimate the abundance with a target coefficient of variation (CV) of the estimate of 20–30 %, of orange roughy over a short time period for the ORH 3B spawning plume.
2. To calibrate acoustic equipment used in the acoustic survey.

The highest fish densities of orange roughy (*Hoplostethus atlanticus*) in the Chatham Rise fishery have occurred since the start of the fishery (in the late 1970s) in a relatively small area where fish aggregate to spawn, known as the 'Spawning Box'. The dense aggregations of spawning orange roughy form characteristic plume-like marks on echosounders, and are commonly referred to as 'plumes'. In recent years there was usually one main plume in the Spawning Box, hereafter referred to as the Old Plume, which appears in early July and dissipates in late July and early August. It formed over an area of flat seabed, and is not tied to an obvious feature, such as a canyon, pinnacle, or hill. The Spawning Box is part of the East and South Chatham Rise fishery, which was one of the first orange roughy fisheries and has always been the most important in the world. Despite a series of TACC reductions in the last three years, this fishery remains the largest in the world, with a catch limit of 3100 t for the 2013–14 fishing year (Ministry for Primary Industries, 2015).

Initial monitoring of the Old Plume used stratified random trawl surveys, which started in 1981, and showed that over the early years of the fishery there was a marked contraction in the geographical extent of orange roughy density during the spawning season (Clark et al. 2000, Dunn et al. 2008). However, trawl surveys were abandoned after 1994 because the abundance estimates became very imprecise.

After 1994, monitoring focus switched to acoustic surveys as the large single-species aggregations that spawning orange roughy form made them potentially good subjects for this technique. Acoustic abundance surveys that provided abundance estimates used in subsequent stock assessments began with the 1998 survey of the Northeast Hills (part of the East and South Rise stock) and the Spawning Box (Doonan et al. 1999). These were then repeated in 2000, 2004, and 2007 (Doonan et al. 2001, 2006, 2009). CSIRO also carried out an acoustic survey of the Old Plume in July 1998 (Kloser et al. 2000). Surveys of the Old Plume, and occasionally aggregations on the Northeast Hills, were conducted for fishing industry representatives by South African researchers from an industry vessel using a hull mounted transducer between 2002 and 2010 (I. Hampton, Fisheries Resource Surveys, pers. comm., Hampton et al. 2009a & b, Hampton 2010a, Dunn et al. 2008), and also in 2012 (Hampton et al. 2014). NIWA conducted the 2011 survey (Doonan et al. 2012). Experimental work was carried out in the area in July 2013 by CSIRO (Tim Ryan & Rudy Kloser, pers. comm.).

Orange roughy have a low target strength relative to many other deepwater species because the swim bladder is not filled with air, but with a waxy ester. As a result acoustic surveys are best restricted to aggregations where species identification of the acoustic mark is known to be almost 100% orange roughy. This situation is found in the Old Plume, but not on the Northeast Hills and other hills within this stock because aggregations of other deepwater species such as Johnson's cod (*Halargyreus johnsonii*) were observed to be present with orange roughy on some hills. In the future trawl-independent methods for species identification could make hill abundance estimates for orange roughy acceptable for stock assessment. The most recent acoustic survey series on the Old Plume, which started in 2002, was not initially used in formal management of the stock, but following a revision of the management approach it became the primary monitoring tool (Ministry of Fisheries 2010), and later the estimates were used in a stock assessment (Ministry for Primary Industries 2015).

The survey reported here was a repeat of the Old Plume surveys carried out on the *San Waitaki* from 2002 to 2012, coordinated by the Orange Roughy Management Group and subsequently (after its reorganisation) the Deepwater Management Group, and by NIWA in 2011. The overall approach was to measure acoustic backscatter of the orange roughy aggregations on the flat using a parallel-transect survey design, completing as many snapshots as possible between normal commercial orange roughy fishing operations.

At the end of the 2010 Old Plume survey another orange roughy spawning aggregation, Rekohu Plume, was found to the west of the Old Plume (Figure 1). It was surveyed in 2011 and 2012 using the same survey design and analysis as that used for the Old Plume. Rekohu Plume was also surveyed in 2013 using a net-attached Acoustic-Optical System in an experimental field program (Tim Ryan & Rudy Kloser, pers. comm.).

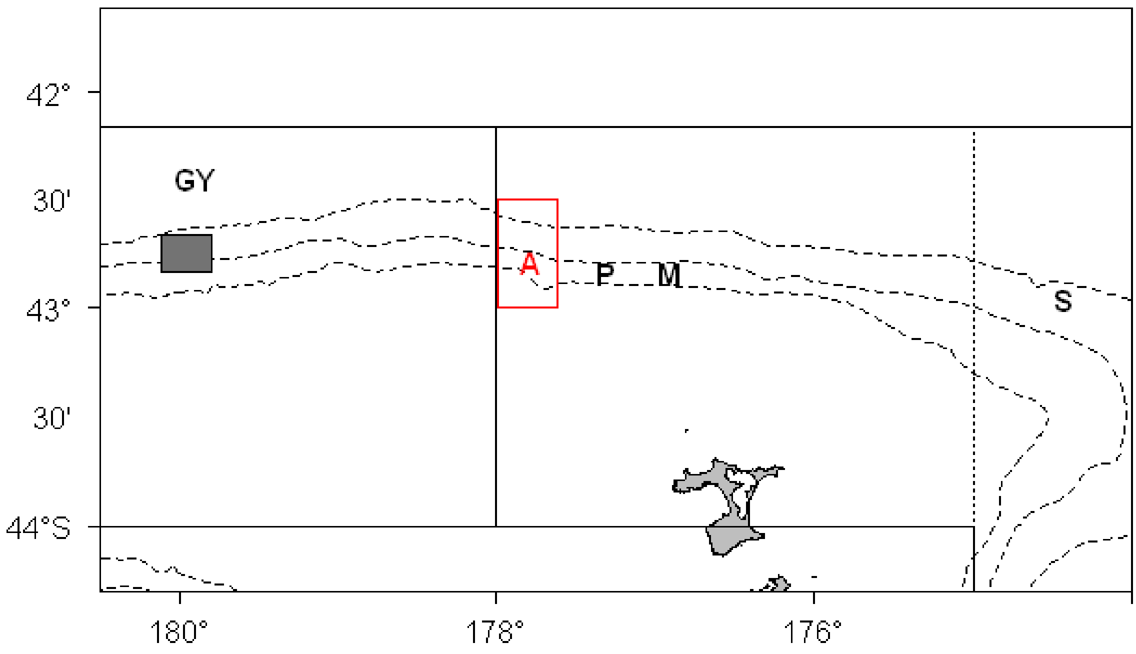

Figure 1: Spawning aggregations: P original aggregation (Old Plume), A, the new spawning aggregation, Rekohu Plume. Hills: GY, Graveyard; M, Mt. Muck; S, Smiths City (M. Dunn, pers. comm.).

2. METHODS

2.1 Acoustic survey equipment

Acoustic data were collected using the *FV San Waitaki*'s Simrad ES60 echosounder operating through a hull-mounted 38-kHz split-beam transducer. Data were logged on a vessel bridge PC and to a hard drive supplied by NIWA. The echosounder was calibrated off Akaroa Harbour well after the voyage (17 October) since attempts at the time of the survey met with procedural problems. The calibration followed standard scientific procedures (MacLennan & Simmonds 1992). Details on the calibration are given in Appendix 1.

A Seabird SM-37 Microcat CTD datalogger was mounted on the headline of the trawl net during some tows to collect temperature, salinity and depth data, which were then used to estimate the acoustic absorption coefficient during the survey (Appendix 2). Vessel attitude was logged continually during the voyage using a MicroStrain 3DM-GX1 gyro enhanced orientation sensor at a measurement rate of 5 Hz. Wind speed and direction were measured using a Navman WIND 3100 anemometer, and recorded at the start and finish of each acoustic transect.

2.2 Acoustic survey design

The acoustic survey focused on the Old Plume, which is usually found at depths between 800 and 950 m and between longitudes 177° 45' W and 176° 45' W. The Rekohu Plume was about 25 n. miles further to the west, at similar depths to the Old Plume, and seemed to be associated with a small canyon feature.

For all targeted orange roughy aggregations, several acoustic surveys were planned (snapshots) using parallel transect designs over each spawning plume aggregation. The parallel transect survey design followed Jolly & Hampton (1990). The survey was part of a normal commercial trip so acoustic snapshots were carried out during fish processing time after a large catch was made. Biological data (standard length, total weight, sex, maturity status) on orange roughy were sampled from the commercial catches. No other fish aggregations were found, or were seen when steaming from area to area.

Each snapshot was planned to include about 10 parallel north-south transects (i.e., across the depth contours) at an average of about 0.3 n. miles apart, with the vessel steaming at about 10 knots and usually taking about 5 hours to complete. Snapshots started with a randomly allocated transect clear of the fish mark, determined after a quick search at the eastern or western boundary of the aggregation, as agreed by vessel officers and scientific staff. The intervals between transects was constant (systematic survey design).

The acoustic estimates of the Old Plume abundance were thoroughly reviewed and revised in 2008–09 (Cordue 2008; Doonan et al. 2009; Hampton et al. 2008, 2009b) and again in 2010 (Hampton 2010a & b, Cordue 2010a & b). From this revision, survey protocols were developed and these were used during the 2011 survey. The relevant design protocols used in the 2011 survey were:

- Weather acceptance criteria to limit excessive signal loss due to poor weather. In practice, this meant that a snapshot was acceptable only if the wind speed was less than 20 knots and if the wave height was under 2 m.
- That there was no interruption of the acoustic snapshot once it has started, e.g., to do a fishing tow.
- That movement of the fish during the snapshot was to be allowed for. To achieve this, for each snapshot, every second transect was completed in a first pass over the aggregation followed by a second pass in the opposite direction, which picked up the remaining transects. This method aimed to cancel out any consistent movement during the snapshot. Otherwise, a complicated analysis on movement would be required to estimate a correction, and the snapshot would only be included in the acoustic abundance if the estimated correction was below 20% (Cordue 2008; Hampton et al. 2008).

As outlined in the 2011 survey (Doonan at al. 2012), we disregarded the 20–30% CV target range for planning purposes since the theoretical CV for one snapshot is about 20%, so only one snapshot needs to be planned. As the vessel would remain fishing until their catch plan was completed, we planned to do snapshots throughout the trip.

Catch sampling from commercial trawls on or near aggregations were used to obtain spawning stage, mean length, and the length-weight relationship, and to check that aggregations were nearly 100% orange roughy.

2.3 Acoustic data analysis

Acoustic data collected during the survey were analysed using standard echo-integration methods to estimate areal backscatter of acoustic energy by fish (MacLennan & Simmonds 1992). Acoustic analysis was carried out using NIWA's Echo Sounder Package (ESP2) software (McNeill 2001).

Echograms were first visually examined, and the bottom determined by a combination of an in-built bottom tracking algorithm and manual editing. Noise spikes and missing pings were manually defined as 'bad transmits' so these were not included in subsequent analysis. Marks corresponding to orange roughy type marks were then identified. Marks were classified subjectively, based on their appearance on the echogram (shape, structure, depth, strength, etc.), and using information from mark identification trawls. The analysis was restricted to clearly defined aggregations that yielded nearly 100% of orange roughy when trawled, as in previous surveys.

The backscatter from all of the marks identified as containing orange roughy was integrated. Another version of the results was generated in which integrated backscatter was broken down into 10-ping bins (i.e., vertical slices) to plot the distribution of backscatter within snapshots. Acoustic backscatter was corrected for four effects: shadowing using the full formula of Barr in Doonan et al. (1999) and applied to the mean acoustic densities in the region 10 m above the detected bottom; using the correct sound absorption by seawater (see Appendix 2); the known systematic error in ES60 data (Ryan & Kloser 2004); and motion corrections combined with bubble layer attenuation. The factor used for the latter effect was 1.33 (CV 5%) as estimated by Doonan et al. (2012).

Any zero abundance transects outside the limiting bounds of the aggregation were deleted, as were the portions of transects that were outside of the aggregation. Mean acoustic backscatter was calculated for each transect. For snapshots, the mean acoustic densities were the weighted (by transect length) average of the transect density estimates.

2.4 Acoustic abundance estimation

Snapshot abundance was estimated from the mean backscatter assuming that all backscatter was from orange roughy, using the length frequency data from the trawl catches to get the target strength, multiplied by the mean weight of orange roughy and the area of the snapshot (see Appendix 3 for details). A correction was applied to the abundance estimate, 1.16, to keep the calibration in the same style used in past surveys (Doonan et al. 2012).

The target strength (TS) assumed for orange roughy (Macaulay et al. 2008) was

$$TS = 16.15\, Log(l) – 76.81,$$

where l is the standard length in centimetres.

For each spawning aggregation, the mean abundance and CV over the snapshot estimates was calculated. Snapshots were excluded from the stratum mean if they did not meet the weather criteria, the snapshot was interrupted part way through, or the bounding transects of the snapshot had 10% or more of the abundance (these are supposed to have zero abundance if the protocol was followed correctly). Because of the continual poor weather conditions, there were very few snapshots that clearly met the good weather criteria and most were close to the 20 knot limit, but with wind speeds sometimes over the limit for part of the snapshot. To make the decision less subjective, we used the estimated median recorded wind speed to accept/reject a snapshot. The wind speed data used were means over sets of 150 pings (about 5 minutes) and the median of these data was compiled for each snapshot.

There was also an informal criterion that there should be no definite trend or sharp step in abundance across the snapshots used. In previous surveys coordinated by the Deepwater Working Group, sections of snapshots were discarded at the point where the abundance stepped down a level and persisted at a low level thereafter and also when early snapshots were on aggregations that did not seem to be fully formed. This criterion was activated for this study (*see* Results section).

Sources of variance in the abundance estimate are:

1. sampling error in the mean backscatter
2. the proportion of orange roughy in the acoustic survey area
3. variance in the estimate of orange roughy target strength
4. the sampling error in the weather correction.

For relative estimates, sources 1 and 2 are the most important. No account of the effect from source 2 was made, as this is dealt with in the stock assessment process. For absolute estimates, the most important source of variance is the target strength of orange roughy (source 3), and this overwhelms all other sources. Only the CV from sources 1 and 4 are given here, i.e., the 5% CV from the weather correction is added onto the sampling CV using the formula

$$\text{cv} = \sqrt{\text{cv}_{sampling}^2 + 0.05^2}.$$

2.6 Trawling and catch sampling

San Waitaki used a two-panel (74.4 m) Champion bottom trawl, with rock hopper ground gear, headline floats and Poly-Ice doors. The rock hopper section had a length of 18.3 m (total groundrope 69.3 m), the bridles were 45 m long, sweeps 45 m long, and the cod-end had 120 mm mesh. Trawl parameters recorded included a mean headline height, mean speed over the ground, and tow distance.

Trawling was all part of the normal commercial fishing operation, apart from three tows carried out on the background layers to check that there were no hidden concentrations of orange roughy outside of the main aggregation. Maximum catch size was controlled by using an escape window in the net.

The catch sampled from each tow was sorted by species and weighed on motion compensating scales to the nearest 0.1 kg. Large catches of fish were sub-sampled and the total catch estimated from processed figures. A random sample of up to 200 orange roughy was selected from the catch to measure standard length, weight, macroscopic gonad stage, and sex from each sampled tow. All length frequency samples were scaled to the catch. Up to 20 individuals of orange roughy, other quota species and commonly taken non quota species were selected for more detailed biological analysis. This included fish length, weight, sex, and gonad stage. Weight was measured to the nearest 5 g on motion compensated scales. Otoliths were collected by NIWA staff or by the MPI observers as part of the catch sampling.

NIWA's portable electronic fish measuring system was used to get fast and accurate collection of the required data.

The deepwater macroscopic gonad staging method used for orange roughy is:

Stage	Females	Males
1	Immature	Immature
2	Resting/Maturing	Resting/Maturing
3	Mature	Ripe
4	Ripe	Running ripe
5	Running ripe	Spent
6	Spent	-
8	Partially spent	Partially spent

3. RESULTS

3.1 Survey details

Example echograms are shown in Figure 2 for the Old Plume and Rekohu Plume orange roughy aggregations. Acoustic marks at the Rekohu Plume appeared to be quite dense at times, and the aggregation was about 5 n. miles long in one snapshot.

Weather conditions were very poor for much of the voyage with sustained periods of gales and rough seas. Up until the last week of the survey, the threshold requirements for a successful snapshot of less than 20 knots of wind and 2 m of swell were rarely met for the Old Plume. The voyage was extended by one week, to 25 July, which enabled us to meet the target number of snapshots.

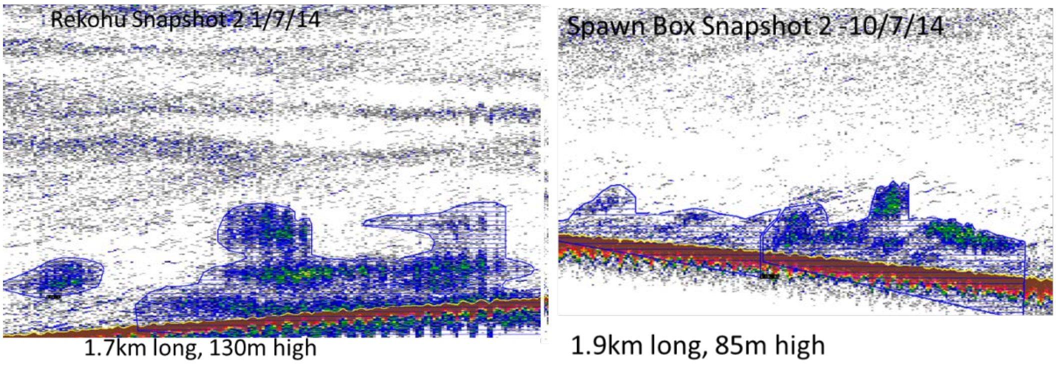

Figure 2: Echograms of spawning aggregations north-south at the Rekohu Plume (left panel) and at the Spawning Box (right panel).

The timetable was:

June 2014

25–29	NIWA staff joined FV *San Waitaki* in Timaru, set up the echosounder and installed the portable wetlab and scientific gear. Sailed to Banks Peninsula for an attempted calibration of the hull EK60. Berthed at Lyttleton to fix an electrical problem before transiting to the 'Hole' fishing ground for a test shot and then several tows on the Graveyard flats and two tows on Graveyard.
30	One snapshot in poor weather at Rekohu and one tow followed by a steam to the Old Plume area followed by a search for the aggregation. Winds were over 30 knots NNE with a 4 m swell.

July 2014

1–2	Steamed to Rekohu Plume for two tows. One marginal and one acceptable snapshot completed on Rekohu Plume and three further tows. Steamed to the Graveyard Hill.
3–4	Tows on the Graveyard Hill.
5–12	Steamed to Rekohu Plume. Wind in excess of 40 knots. Then back and forth between Rekohu and Old Plumes. Several tows on both aggregations with mostly poor weather acoustic snapshots on both, but four acceptable snapshots were obtained on Old Plume.
13–14	Tows on the Graveyard hill, Deadringer hill, Tombstone hill and flats.
15–18	More back and forth between Rekohu and Old Plumes with mostly poor weather acoustic snapshots and tows on both aggregations.
19–20	Six acceptable snapshots on the Old Plume and two tows, wind 7–19 knots SE, 3–4 m swell dropping over the survey period. Depart for Timaru (2108 hrs).

Twenty seven snapshots were completed: 16 on Old Plume, and 11 at Rekohu Plume, but poor weather meant that few were acceptable so the criteria for analysing snapshots were relaxed to obtain a series that covered the survey period. These were then pruned back to get the snapshots to use in the final abundance estimate.

A total of 66 commercial tows were completed: 12 of which were from the Old Plume, and 20 from Rekohu Plume. Mean catches were 21 t from Old Plume tows and 33 t from Rekohu Plume.

The headline mounted Seabird CTD was successfully deployed on 19 of the tows to provide data to correct for the sound absorption coefficient in both survey areas: 8 recordings at Old Plume, 11 from the Rekohu Plume.

3.2 Biological analyses

A total of 11 733 orange roughy were sampled for length, sex, and gonad stage condition using the NIWA portable wetlab system. Numbers sampled by area were 2902 (1250 males and 1652 females) from Old Plume; 6260 (3795 males and 2465 females) from Rekohu Plume. A total of 2217 orange roughy were also sampled for individual fish weight, important for the calculation of length-weight parameters. A total of 559 pairs of otoliths were collected from Old Plume and 1201 from Rekohu Plume.

The progression of female maturing and spent gonad maturity stages indicated that both aggregations were 3 to 5 days ahead in development compared to the aggregations in 2011 and 2010 (Doonan et al. 2012) (Figure 3). Because sampling started late on Old Plume, active spawning was well underway when snapshots were started.

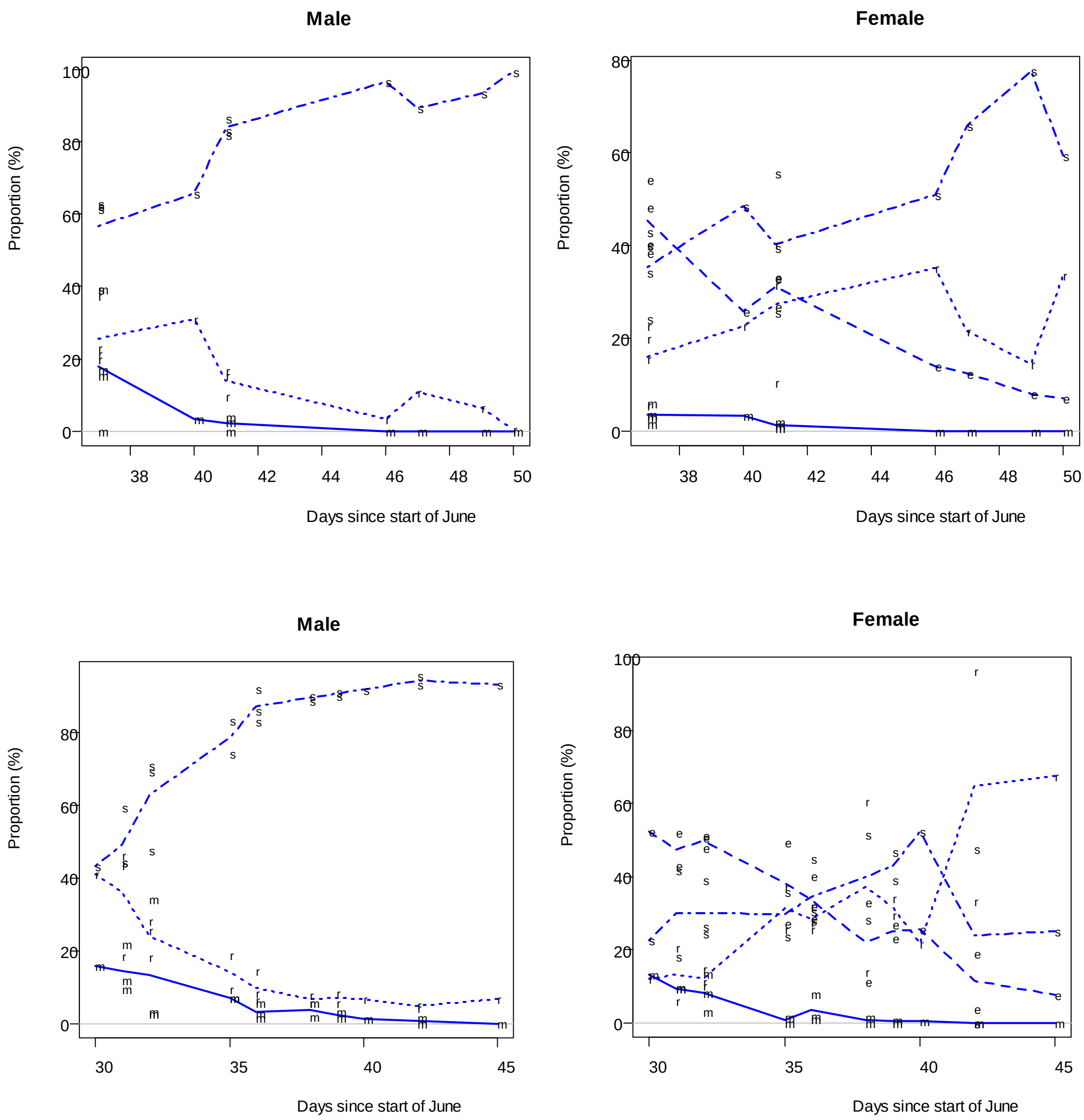

Figure 3: Proportion of gonad stage for males and females by spawning area and date (days from the start of June, i.e., 31=1 July). Stages considered were maturing (m), ripe (e), running ripe (r), and spent (s) (including partially spent). Top, Old Plume; bottom, Rekohu Plume.

Length frequency distributions by sex for the spawning aggregations from tows where the catch was 10 t or more are shown in Figure 4. As seen in previous surveys, the fish were larger at the Old Plume compared to the Rekohu Plume, especially for females.

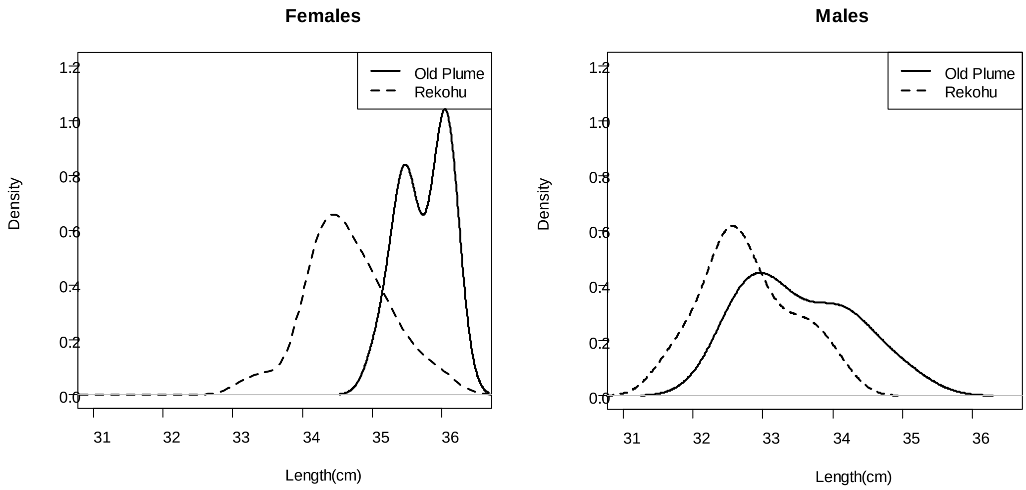

Figure 4: Length frequency distributions of orange roughy by sex in the two spawning aggregations. Data are from tows with a catch greater than 10 t and frequencies are weighted by catch size.

The overall (combined sex) length frequency distributions are shown in Figure 5. For the Old Plume, the mean length was 35.1 cm and mean weight 1.34 kg, and for the Rekohu Plume, they were 34.3 cm and 1.25 kg.

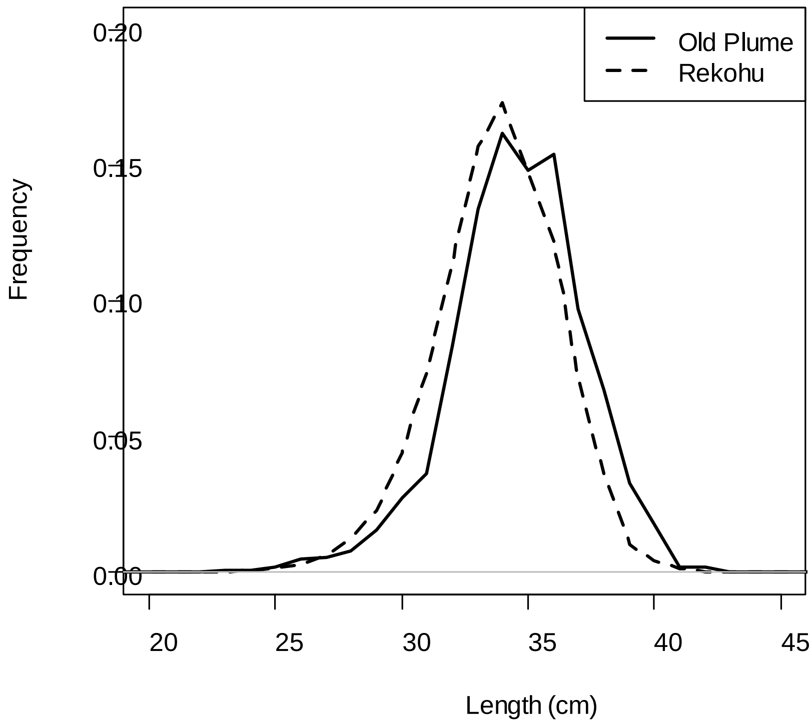

Figure 5: Length frequency distributions of orange roughy in the two spawning aggregations. Frequencies are composed from the mean of the male and female frequencies using a 50:50 sex ratio.

3.3 Abundance estimates

The target strength for orange roughy was estimated from the sampled mean length and the relationship shown in Section 2.4. Estimated target strength was -52.3 dB for the Old Plume and -52.46 dB for the Rekohu Plume.

Appendix 4 shows details of the snapshots for which backscatter was integrated and Tables A4.1 and A4.2 show the abundance estimates by snapshot for the two spawning sites. Appendix 5 shows the backscatter distribution for the snapshots analysed.

Snapshots were used for the overall mean abundance if the median wind speed was below 20 knots. This gave nine snapshots for Old Plume and three for Rekohu Plume. However, some were excluded since they showed a persistent decrease in abundance towards the end of the survey period.

For the Old Plume, when abundances are plotted by date, there is a clear drop in abundance after about 12 July, so the five acceptable weather snapshots in the latter period were excluded (Figure 6). The overall mean abundance for the remaining four acceptable snapshots was 19 360 t (CV 7.2%; range from about 17 500 t to 21 500 t) with no clear trend over time; the contribution from the shadow zone correction was low, at about 4% (Table 1).

Table 1: Old Plume abundance estimates and CV (%) (all corrections applied) by snapshot for the first (Part 1) and second (Part 2) passes and total, total number of transects used in the estimate (N), the percentage of the abundance that was in the outside (edge) transects, and the increase in abundance from the shadow zone correction. Shaded snapshot numbers were used in the overall estimate (*see* text above for details).

	Part 1		Part 2			Total		Edge	Shadow
Snapshot	Abundance	CV	Abundance	CV	N	Abundance	CV	abundance (%)	zone correction
2	39 123	36	23 324	56	6	30 208	33	0	1.01
3	20 113	30	15 808	28	8	17 831	21	0	1.02
4	21 403	35	19 881	30	11	20 628	23	0	1.06
5	12 356	82	24 804	88	5	17 507	60	0	1.04
6	21 314	49	21 638	39	6	21 475	31	3	1.03
7	17 983	42	15 018	33	9	16 434	27	0	1.03
8	5 185	33	2 817	32	6	3 822	23	0	1.01
9	3 675	19	873	60	6	1 791	31	8	1.1
10	6 811	36	5 359	21	10	6 042	21	0	1.02
11	3 974	61	477	100	4	1 377	58	0	1.1
12	2 428	78	3 632	52	5	2 970	47	0	1.04
13	2 275	33	3 436	33	9	2 796	24	0	1.02
14	2 621	19	2 423	21	12	2 520	14	2	1.11
15	2 723	10	3 955	23	16	3 281	12	6	1.06
16	2 364	75	818	57	4	1 390	47	0	1.07

For Rekohu Plume, there also appeared to be a drop in abundance towards the end (Figure 7). When the mean of the first two Rekohu snapshots was compared to the estimate for the last snapshot, it was statistically significantly different (t-test at the 5% level). However, as there was only one snapshot in the latter period, we have also reported the mean estimate for the survey using all three acceptable-weather snapshots.

For the Rekohu Plume, acceptable snapshots abundances were about 46 000 t and 42 000 t (and 14 000 t for the last snapshot), and the contribution from the shadow zone correction was also low, at about 2% (Table 2). The overall abundance estimate was 44 210t (CV 25.5%) using the two early snapshots, and 34 200 t (CV 22.2%) for all three.

Table 2: Rekohu Plume abundance estimates and CV (%) (all corrections applied) by snapshot for the first (Part 1) and second (Part 2) passes and total, total number of transects used in the estimate (N), the percentage of the abundance that was in the outside (edge) transects, and the increase in abundance from the shadow zone correction. Shaded snapshot numbers were used in the overall estimate (*see* text above for details). Snapshot 10 was included for the alternative three snapshot estimate.

	Part 1		Part 2			Total		Edge	Shadow
Snapshot	Abundance	CV	Abundance	CV	N	Abundance	CV	Abundance (%)	zone correction
1	40 373	57	33 292	57	10	36 662	40	0	1.03
2	33 431	65	64 134	38	9	46 304	38	0	1.02
3	36 203	38	49 983	50	7	42 538	32	0	1.01
5	35 899	52	29 504	36	6	32 544	32	0	1.03
7	19 144	17	23 034	38	7	20 999	21	0	1.01
10	21 456	59	9 008	49	7	13 903	39	0	1.02

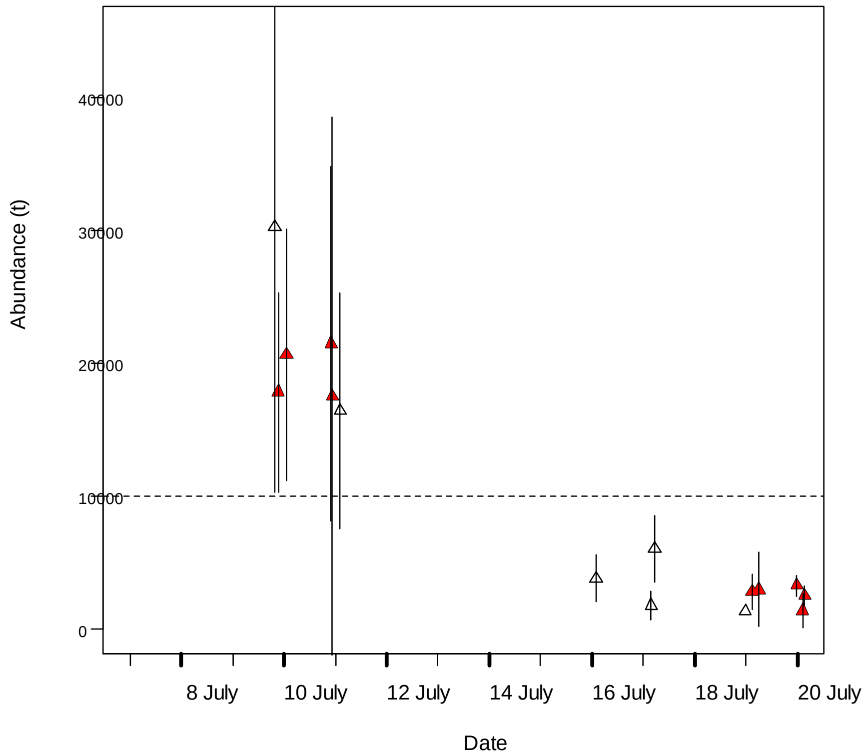

Figure 6: Old Plume, comparison of abundance estimates (triangles) and 95% CI (vertical lines) by date. Filled triangles are snapshots that met the median wind criteria. Dashed horizontal line is mean of filled triangles.

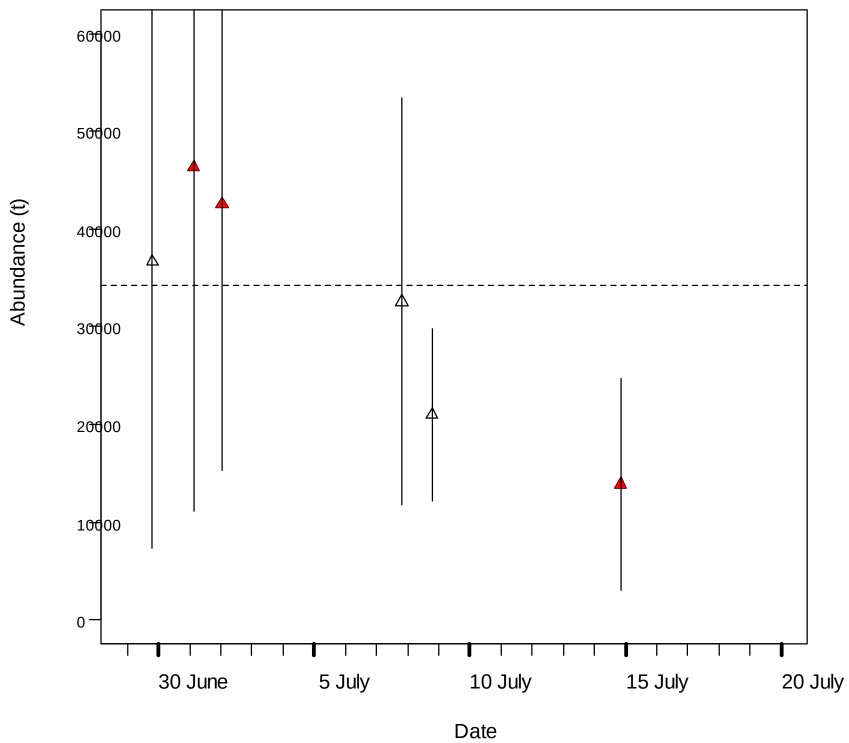

Figure 7: Rekohu Plume, comparison of abundance estimates (triangles) and 95% CI (vertical lines) by date. Filled triangles are snapshots that met the median wind criteria. Dashed horizontal line is mean of filled triangles.

4. DISCUSSION

Comparison with previous surveys

For the Old Plume, hull transducer acoustic surveys using the *San Waitaki* were carried out every year since 2002, except in 2013, so there are now 13 surveys that used the same protocol and analysis. The 2014 estimate was consistent with a recent flattening out of the abundance (Figure 8).

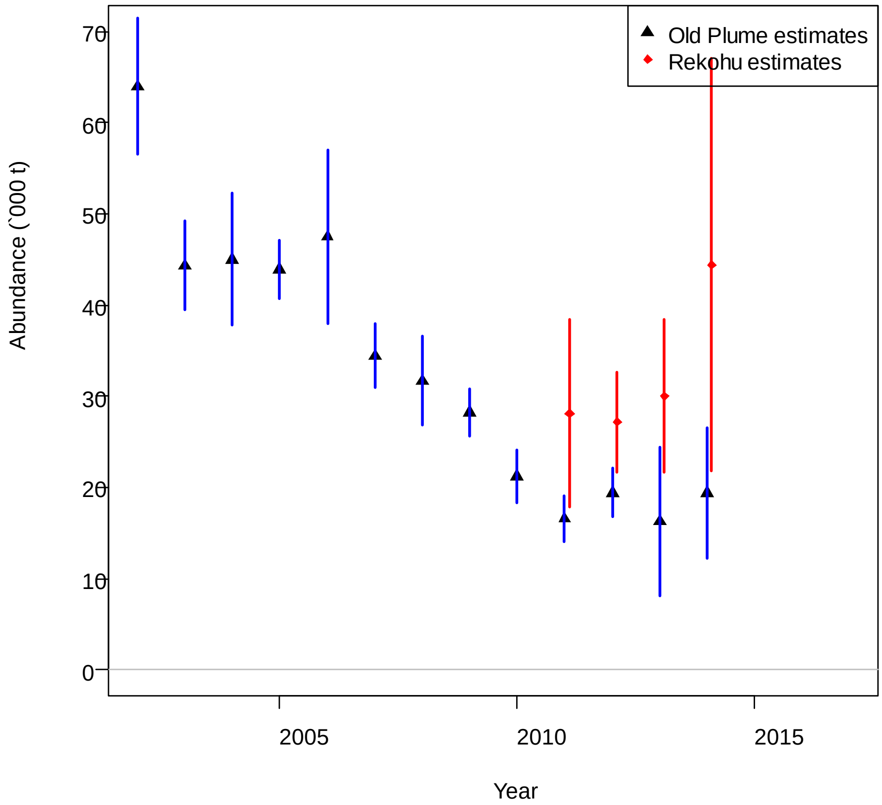

Figure 8: Old Plume estimates from 2002 to 2014 and Rekohu estimates from 2011 to 2014, with ±2 standard deviation (vertical lines). Both plume estimates for 2013 are those used in the Cordue (2014) stock assessment.

For the Rekohu Plume, there are now three abundance estimates using the same protocol and analysis (Figure 8), and a fourth if the experimental study estimate is included. The 2014 estimate is about a third larger than the other estimates in this series (two acceptable snapshots) or similar to the previous ones when the three acceptable snapshots estimate is used. The 2014 estimate is based on only two snapshots taken on consecutive days and so it is vulnerable to the effects of sampling error. Snapshot estimates around 40 000 t were reported in 2011 and 2013 [for 2012, there are no data on individual snapshots]. In 2011, Doonan et al. (2012) reported values between 35 000 and 44 000 t in three of the six snapshots analysed. The experimental study in 2013 had four snapshots using the 120 and 38 kHz AOS system and three of these were about 40 000 t. In addition, there were two vessel hull transducer snapshots (38 kHz) with one estimate of around 40 000 t (Tim Ryan & Rudy Kloser, pers. comms.).

5. ACKNOWLEDGMENTS

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APPENDIX 1: Calibration Report: *San Waitaki*

Calibration of the Simrad ES60 echosounder on *San Waitaki* took place near Banks Peninsula (43° 54.60 S 172° 54.07 E) on 17 October 2014. Water depth was about 35 m (below the transducer). In 2011 the vessel had a new ES38B transducer fitted and this is the second calibration by NIWA of the new transducer.

The calibration was conducted broadly as per the procedures in Demer et al. (2015). The ES60 was configured to recommended settings (2000 W power and 1.024 ms pulse). The three lines were clipped together, the weight and sphere attached, and this was lowered down to vessel crew in the workboat and released. Long (3.8 m) carbon fibre calibration poles were used to help keep the calibration lines clear of the hull. The sphere and associated lines were immersed in a soap solution prior to entering the water. A lead weight was also deployed about 2 m below the sphere to steady the arrangement of lines. The sphere was centred in the beam to obtain data for the on-axis calibration and was then moved around the beam to obtain data for the beam shape calibration.

The weather was moderate with a 20–25 knot breeze and slight swell. Because of the conditions the vessel was anchored off the port anchor. The sphere was located in the beam at 08:18 NZDT. Calibration data were recorded into a single ES60 raw format file (L0001-D20141016-T191801-ES60.raw). Raw data are stored in the NIWA Fisheries Acoustics Database. The ES60 transceiver settings in effect during the calibration are given in Table A1.1.

A temperature/salinity/depth profile was taken using a Seabird SBE21 conductivity, temperature, and depth probe (CTD). An estimate of acoustic absorption was calculated using the formulae in Doonan et al. (2003) and an estimate of sound speed was calculated using the formulae of Fofonoff & Millard (1983).

The data in the ES60 file were extracted using custom-written software. The amplitude of the sphere echoes was obtained by filtering on range and choosing the sample with the highest amplitude. Instances where the sphere echo was disturbed by fish echoes were discarded. The alongship and athwartship beam widths and offsets were calculated by fitting the sphere echo amplitudes to the Simrad theoretical beam pattern:

$$compensation = 6.0206\left(\left(\frac{2\theta_{fa}}{BW_{fa}}\right)^2 + \left(\frac{2\theta_{ps}}{BW_{ps}}\right)^2 - 0.18\left(\frac{2\theta_{fa}}{BW_{fa}}\right)^2\left(\frac{2\theta_{ps}}{BW_{ps}}\right)^2\right),$$

where θ_{ps} is the port/starboard echo angle, θ_{fa} the fore/aft echo angle, BW_{ps} the port/starboard beamwidth, BW_{fa} the fore/aft beamwidth, and *compensation* the value, in dB, to add to an uncompensated echo to yield the compensated echo value. The fitting was done using an unconstrained nonlinear optimisation (as implemented by the Matlab `fminsearch` function). The Sa correction was calculated from:

$$S_{a,corr} = 5\log_{10}\left(\frac{\sum P_i}{4P_{\max}}\right),$$

where P_i is the sphere echo power measurement and P_{max} the maximum sphere echo power measurement. A value for $S_{a,corr}$ is calculated for all valid sphere echoes and the mean over all sphere echoes is used to determine the final $S_{a,corr}$.

A correction for the triangle wave error in ES60 data (Ryan & Kloser 2004) was also applied as part of the analysis.

Analysis

The mean range of the sphere and the sound speed and acoustic absorption between the transducer (about 4 m deep) and the sphere are given in Table A1.2.

The calibration results are given in Table A1.3. The estimated beam pattern and sphere coverage are given in Figure A1.1. The symmetrical nature of the pattern and the zero centre of the beam pattern indicate that the transducer and ES60 transceiver were operating correctly. The fits between the theoretical beam pattern and the sphere echoes is shown in Figure A1.2 and confirms that the transducer beam pattern is correct. The square-root of the arithmetic mean of the squared (RMS) difference between the Simrad beam model and the sphere echoes out to 3.4° off axis was 0.20 dB (Table A1.3), indicating that the calibration was of acceptable quality (<0.4 dB is poor, <0.3 dB good, and <0.2 dB excellent).

The estimated peak gain (G_0) in October 2014 was of the same order of magnitude as those measured previously (Table A1.3) but about 0.03 dB lower. Other long-term time series of echosounder calibrations have also observed gradual declines in peak gain, possibly as a function of transducer ageing (Knudsen, 2009).

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Table A1.1. ES60 transceiver settings and other parameter values relevant to the calibration.

Parameter	Value
Echosounder	ES60
ES60 software version	1.5.2.77
Transducer model	ES38B
Transducer serial number	31135
ES60 GPT serial number	Not recorded
GPT software version	Not recorded
Sphere type/size	tungsten carbide/38.1 mm diameter
Operating frequency (kHz)	38
Transducer draft setting (m)	4
Transmit power (W)	2 000
Pulse length (ms)	1.024
Transducer peak gain (dB)	26.5
Sa correction (dB)	0.0
Bandwidth (Hz)	2 425
Sample interval (m)	0.192
Two-way beam angle (dB)	–20.60
Absorption coefficient (dB/km)	9.75
Speed of sound (m/s)	1 500
Angle sensitivity (dB) alongship/athwartship	21.90/21.90
3 dB beamwidth (º) alongship/athwartship	7.10/7.10
Angle offset (º) alongship/athwartship	0.0/0.0

TableA1. 2. Auxiliary calibration parameters derived from depth/temperature measurements.

Parameter	Value
Mean sphere range (m)	19.3
S.D. of sphere range (m)	0.2
Mean sound speed (m/s)	1 494.4
Mean absorption (dB/km)	9.25
Sphere TS (dB re 1m2)	–42.41

Table A1.3: Calculated echosounder calibration parameters for *San Waitaki*. July 2012 values are from Mike Soule (pers comm.).

Parameter	Oct 2014		Jul 2012		Dec 2011
Calibration analysis method	ExCal	Lobe	Echoview	Graphical	ExCal
Mean TS within 0.2° of centre	-42.7518				-43.1022
Std dev of TS within 0.2° of centre	0.39566				0.38422
Max TS within 0.2° of centre	-42.1238				-42.2851
No. of echoes within 0.2° of centre	105				107
On axis TS from beam-fitting	-42.7712				-42.8697
Transducer peak gain (dB)	26.3268	26.68	26.48	26.47	26.57
Sa correction (dB)	-0.63	-0.70	-0.70		-0.64
Beamwidth alongship (º)	7.0	6.81		7.14	6.9
Beam offset alongship (º)	0.00	-0.03		-0.02	-0.08
Beamwidth athwarthship (º)	6.9	6.76		7.06	6.9
Beam offset athwarthship (º)	0.00	0.06		0.06	+0.10
RMS deviation	0.20	0.18			0.21
Number of echoes	19 929				23 585

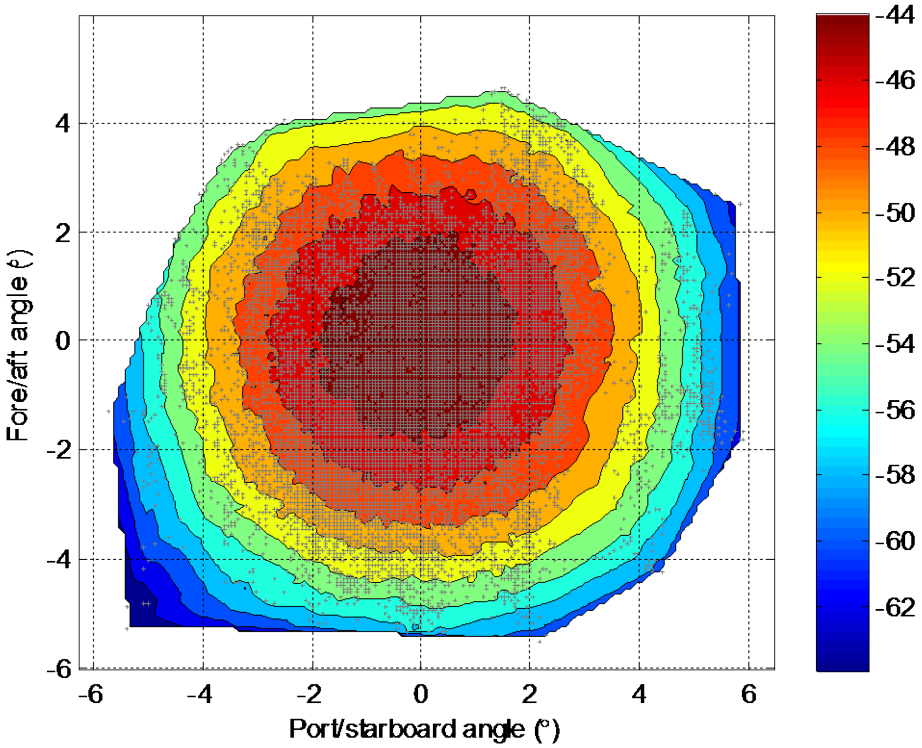

Figure A1.1. The estimated beam pattern from the sphere showing echo strength and position for the October 2014 calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB per 1 m^2.

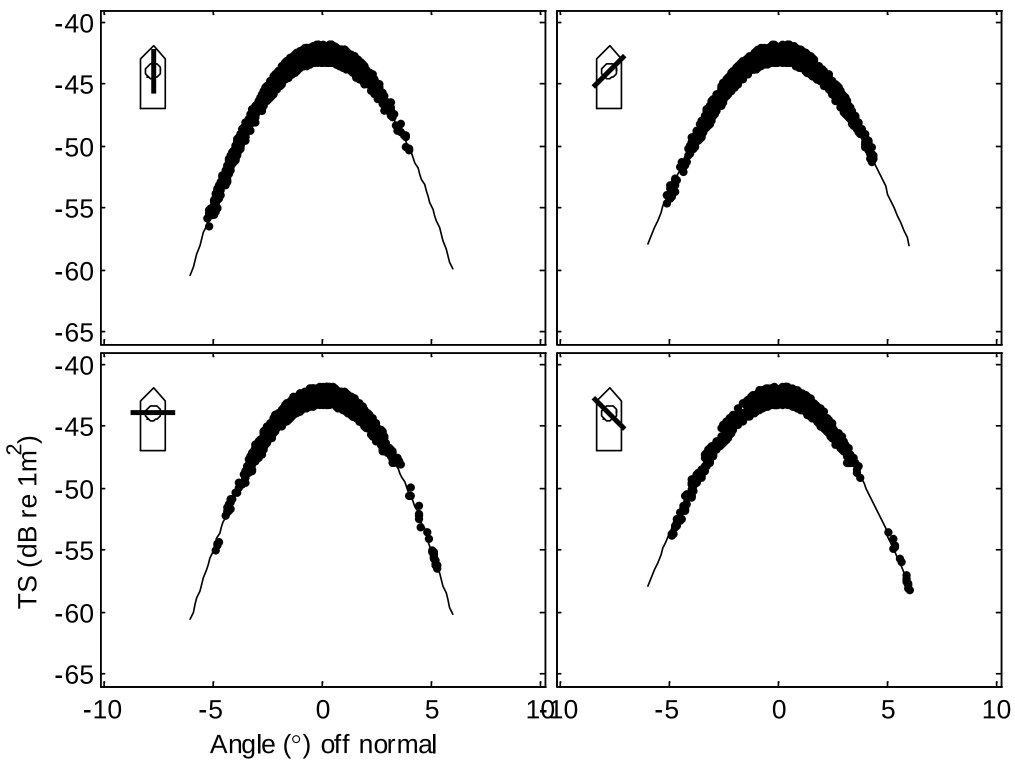

Figure A1.2. Beam pattern results from the calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam, shown top left for each quadrant.

APPENDIX 2: Calculation of sound absorption coefficients

For the Rekohu Plume, CTD data was collected on tow numbers 9, 10, 11, 12, 29, 36, 37, 38, 40, 45, and 46. For the Old Plume, the CTD data was collected on tow numbers 32, 33, 35, 41, 42, 43, 44, and 66. The dataset from each tow was smoothed to get consistent values at 1 m intervals and then the smoothed profiles were used to estimate sound absorption for the water column between the transducer and the aggregation, using the relationship derived by Doonan et al. (2003). Some CTD drops did not cover the depth range required, so in these cases, the data from the deepest data point was propagated through to the lower depth range. For the Old Plume, the median depth of tows that caught 10 t or more was 840 m and this depth was used as the depth of the aggregation. Transducer depth was taken to be 3 m. For the Rekohu Plume, the median tow depth was 783 m. Individual sound absorption estimates are shown in Table A2.1. For each site, the median value is used in the integrations.

The sound absorption used for Old Plume was 8.77 dB km^{-1} and for Rekohu it was 8.81 dB km^{-1}.

Table A2.1. Sound absorption for each CTD deployment (dB km^{-1}).

Rekohu Plume				
	8.81	8.84	8.83	8.83
	8.79	8.78	8.85	8.86
	8.79	8.77	8.80	
Old Plume				
	8.79	8.80	8.79	8.83
	8.75	8.73	8.72	8.74

References

Doonan, I.; Coombs, R.; McClatchie, S. (2003). The absorption of sound in seawater in relation to estimation of deep-water fish biomass. *ICES Journal of Marine Science 60* (5): 1047–1055.

APPENDIX 3: Acoustic abundance estimation

For stratum (in this case spawning site), s, and snapshot, j, the abundance of orange roughy ($B_{orh,,s,j}$) was estimated from the expression:

$$B_{orh,s,j} \quad = \quad A_{s,j}\ \overline{w_s}\ \frac{absc f_{s,j}}{\overline{\sigma_s}}, \qquad (1)$$

where $A_{s,j}$ is the stratum area in the j[th] snapshot, $\overline{w_s}$ the mean weight of individual orange roughy in the stratum, $abscf_{s,j}$ the mean areal back-scattering in the stratum and snapshot, and $\overline{\sigma_s}$ is the mean cross-section for orange roughy.

The mean cross-section, $\overline{\sigma_s}$, is given by:

$$\sum_l g_{l,orh,s} 10^{TS_{l,orh,s}/10},$$

where $TS_{l,orh,s}$ is the target strength of orange roughy that has a standard length of l cm, $g_{l,orh,s}$ is the proportion of roughy with length l.

For the parallel transect surveys, area was estimated as:

ns /(ns - 1) / As,

where ns is the number of transects, and As is the area defined by the transect ends.

To correct for movement of the aggregations during a snapshot, parallel transect surveys can be done in two sweeps with every second transect done in one sweep and the remaining ones done in the reverse direction. The abundance is then given by:

$B_{s,j} = \sqrt{}\ B_{s,j,part1}\ B_{s,j,part2}$

where $B_{s,j,part1}$ is the abundance from the first sweep and $B_{s,j,part2}$ is the estimate from the second sweep.

The within snapshot standard deviation for the estimate is approximately given by:

$$\left(0.5 / \sqrt{B1\,B2}\right) \sqrt{cv1^2 + cv2^2}\,(B1\,B2),$$

where B1 and B2 are the estimates for each part, and cv1 and cv2 are the c.v. for each part.

The derivation uses the result that:

if $Y = f(X)$, then $V(Y) \sim [f'(E[X])]^2\, V(X)$.

Mean weight of orange roughy, $\overline{w_s}$, was estimated from the weight frequency that is derived from the length frequency and the length-weight relationship.

APPENDIX 4: Acoustic snapshots of spawning aggregations that were integrated

Table A4.1: Acoustic snapshots analysed for the Old Plume with a summary of details and whether it was used in the final mean. Final selection depended on good weather and the time period when the aggregation was fully formed.

Stratum	Snapshot number	Date	Number of transects	Transect spacing (n. mile)	Swell	Median wind (knots)	Upper quartile wind (knots)	Used in final mean
Old Plume	2	10-Jul-14	10	0.3	1–2m swell dropping	22.5	24.7	No
Old Plume	3	10-Jul-14	14	0.3	1m swell	18.6	21.3	Yes
Old Plume	4	10-Jul-14	16	0.3	1m swell	17.6	20.1	Yes
Old Plume	5	11-Jul-14	9	0.3	1m swell	17.8	20.3	Yes
Old Plume	6	11-Jul-14	11	0.3	1m swell	16.4	18.1	Yes
Old Plume	7	11-Jul-14	12	0.3	1m swell	21.1	23.5	No
Old Plume	8	16-Jul-14	13	0.3	3m swell	22.5	23.6	No
Old Plume	9	17-Jul-14	13	0.3	2m swell	20.9	21.8	No
Old Plume	10	17-Jul-14	16	0.3	2m swell	24.4	26	No
Old Plume	11	19-Jul-14	12	0.3	4m swell	22.9	23.9	No
Old Plume	12	19-Jul-14	11	0.3	3–4m swell dropping	17.9	18.6	No
Old Plume	13	19-Jul-14	14	0.3	3–4m swell	15	16.5	No
Old Plume	14	20-Jul-14	18	0.3	3m swell	16.7	17.7	No
Old Plume	15	20-Jul-14	26	0.3	3m swell	18.5	20.3	No
Old Plume	16	20-Jul-14	19	0.5	2–3m swell	18.3	19.6	No

Table A4.2: Acoustic snapshots analysed for Rekohu Plume with a summary of details and whether it was used in the final mean. Final selection depended on good weather and the time period when the aggregation was fully formed.

Stratum	Snapshot number	Date	Number of transects	Transect spacing (n.mile)	Swell	Median wind (knots)	Upper quartile wind (knots)	Used in final mean
Rekohu Plume	1	30-Jun-14	17	0.3	2–3m swell	22.8	23.9	No
Rekohu Plume	2	1-Jul-14	15	0.3	~2–3+m confused swell	13.2	15	Yes
Rekohu Plume	3	2-Jul-14	15	0.3	~1–2m confused swell	15.1	17.9	Yes
Rekohu Plume	5	8-Jul-14	14	0.3	3+m swell	22.8	23.7	No
Rekohu Plume	7	9-Jul-14	15	0.3	2–3m swell	24.7	26.5	No
Rekohu Plume	10	15-Jul-14	19	0.3	3–4m swell dropping	19.4	21.9	No

APPENDIX 5: Plots of backscatter for snapshots that were integrated.

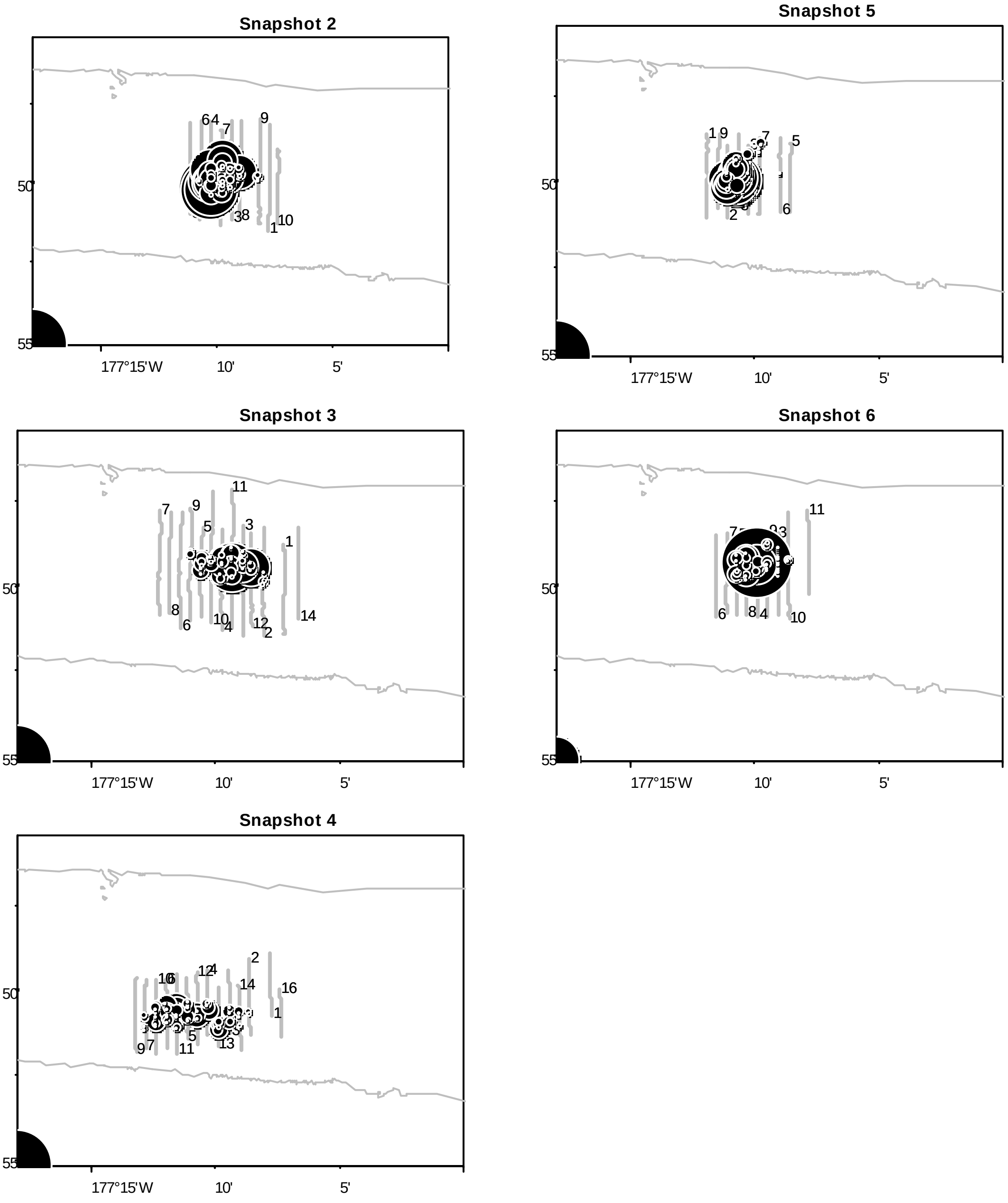

Figure A5.1. Old Plume, transects and backscatter (circles, area proportional to backscatter) for snapshots that were analysed. Quarter circle in lower left corner is the reference value (same for all plots). Transect numbers are in order of steaming (numbers at one end of each transect).

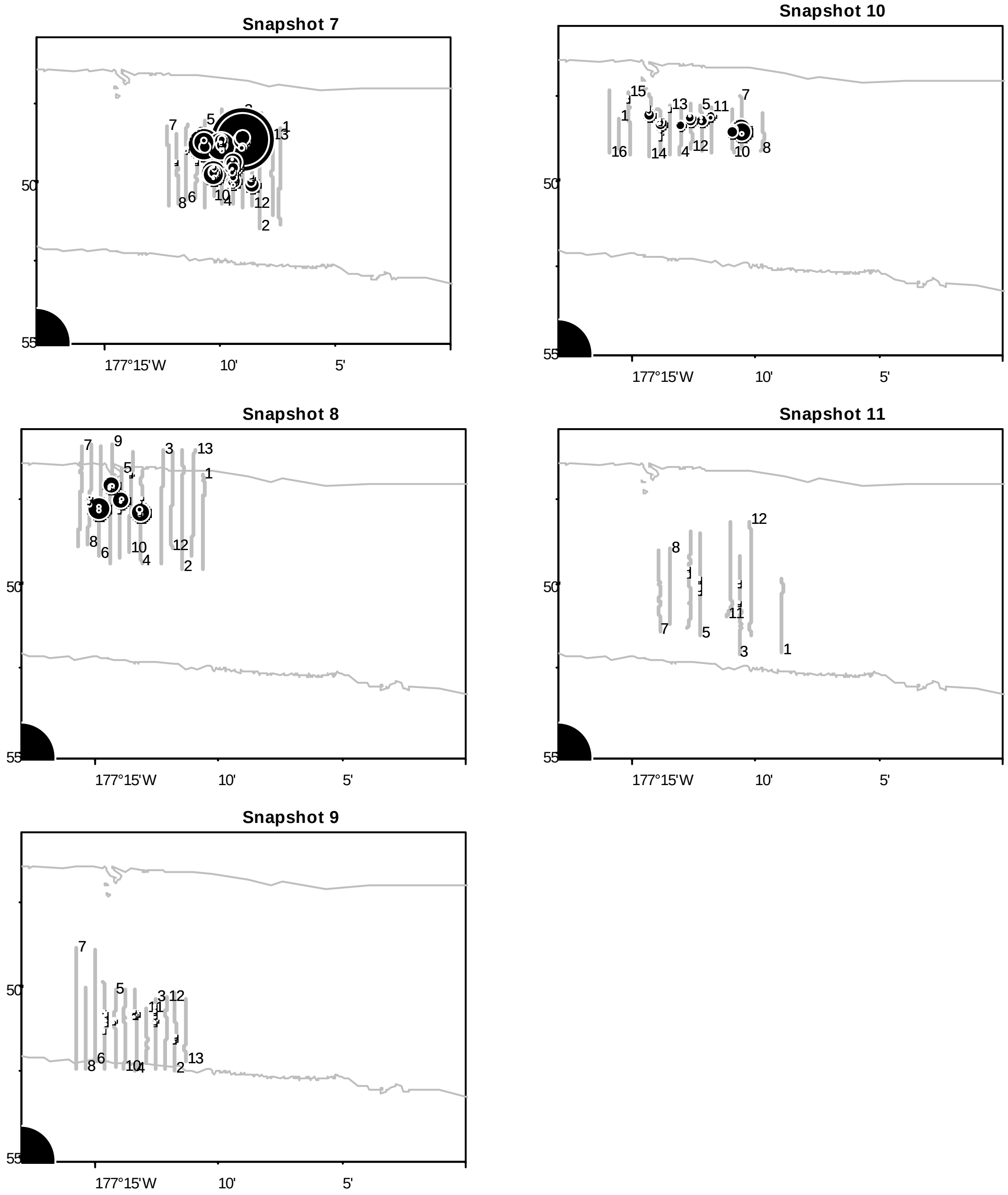

Figure A5.1 continued …

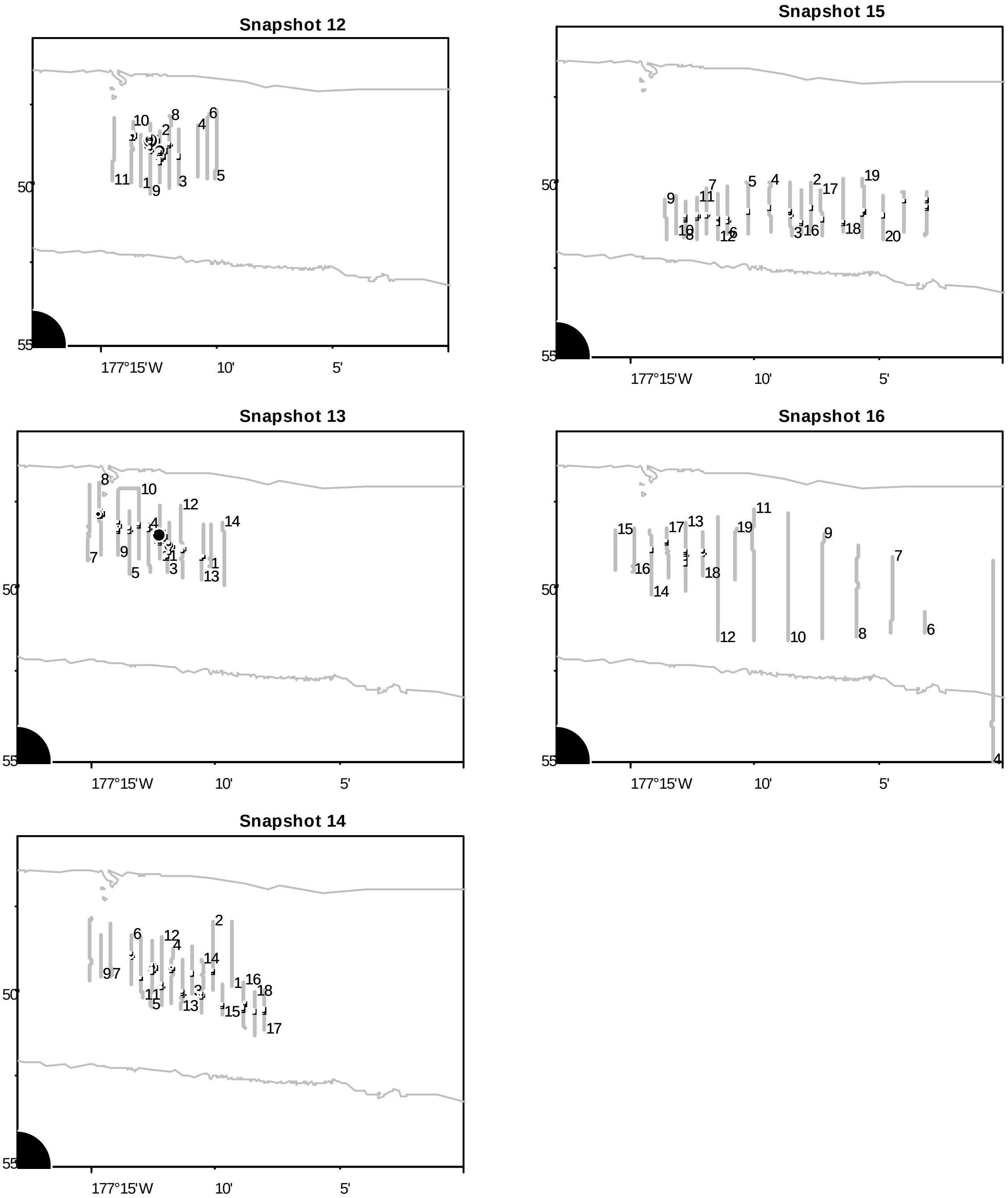

Figure A5.1 continued …

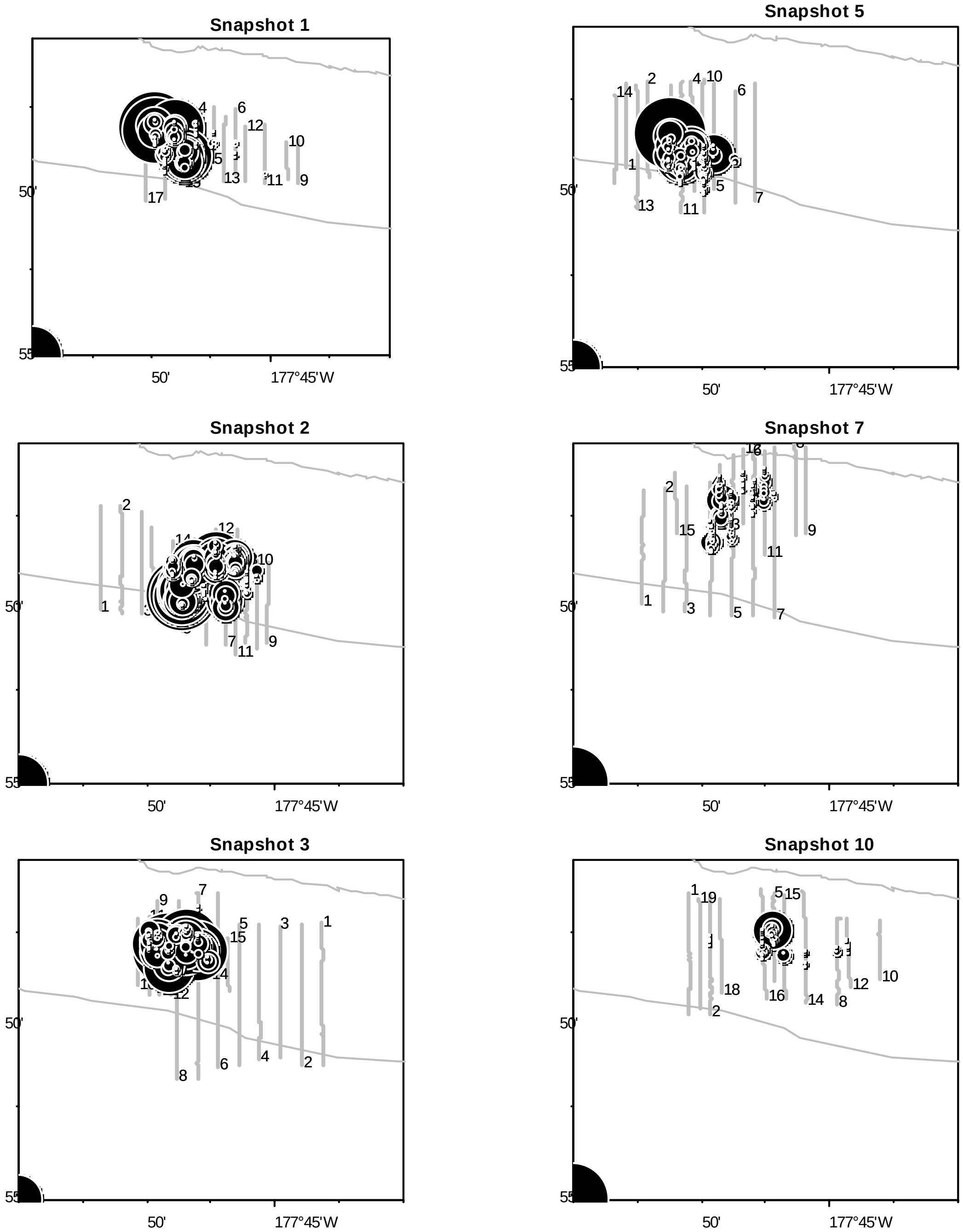

Figure A5.2. Rekohu Plume, transects and backscatter (circles, area proportional to backscatter) for snapshots that were analysed. Quarter circle in lower left corner is the reference value (same for all plots). Transect numbers are in order of steaming (numbers at one end of each transect).