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Orange roughy abundance estimates of the north Chatham Rise Spawning Plumes (ORH3B), *San Waitaki* acoustic survey, June-July 2011

New Zealand Fisheries Assessment Report 2012/28

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EXECUTIVE SUMMARY

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The abundance of the orange roughy in the spawning aggregation on the northeast Chatham Rise (ORH3B) were estimated from a hull mounted transducer acoustic survey carried out between 22 June and 25 July 2011 using the industry vessel, FV *San Waitaki* (voyage SWA1101). There were two spawning plumes surveyed this year: the known aggregation, referred to as the Spawning Plume, for which acoustic biomass estimates have been made each year from 2002 to 2010, and a new aggregation, named the West Spawning Site, situated about 25 n. miles west of the Spawning Plume and surveyed for the first time in 2011. Overall biomass estimates were the mean of several acceptable (i.e., “good” weather) acoustic survey snapshots of each aggregation.

For the Spawning Plume, the overall estimated abundance was 16 422 t (c.v. 7.5%) from 12 acceptable snapshots. Most of these snapshots were in a period that was about one week later than those used in the 2010 estimate, and were all in July. For the West Spawning Site, the overall abundance was 28 114 t (c.v. 18.4%) from 6 acceptable snapshots, most were conducted in late June.

Sampled catches from each aggregation indicated that fish were larger in the Spawning Plume than in the West Spawning Site, especially females. Spawning appears to have been about four days earlier at the West Spawning Site than at the Spawning Plume. The spawning progression of the Spawning Plume was similar to that in 2010.

1. INTRODUCTION

This report documents the analysis and reporting of the Ministry of Fisheries project ORH2010/01 which has 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 (c.v.) of the estimate of 20–30 %, of orange roughy over a short time period for the ORH 3B spawning plume,
2. and to calibrate acoustic equipment used in the acoustic survey.

From the beginning of the Chatham Rise orange roughy (*Hoplostethus atlanticus*) fishery in the late 1970s, the highest fish densities occurred 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 has usually been one main plume in the Spawning Box, hereafter referred to as the Spawning Plume, which appears in early July and dissipates in late July and early August. It is 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 2950 t for the 2010–11 fishing year (Ministry of Fisheries 2010).

Initial monitoring of the Spawning 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 during the spawning season (Clark et al. 2000, Dunn et al. 2008). However, trawl surveys were abandoned after 1994 because the biomass 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 biomass surveys which provided biomass 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), which was then repeated in 2000, 2004, and 2007 (Doonan et al. 2001, 2006, 2009). CSIRO also carried out an acoustic survey of the Spawning Plume in July 1998 (Kloser et al. 2000). Surveys of the Spawning Plume, and occasionally aggregations on the Northeast Hills, have also been 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, Hampton 2010a, Dunn et al. 2008).

Because the orange roughy swim bladder is not filled with air, but with a waxy ester, orange roughy have a low target strength relative to many other deepwater species, and 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 Spawning Plume, but not on the Northeast Hills and other hills within this stock (although trawl-independent methods for species identification could make hill estimates acceptable). The current acoustic survey series on the Spawning Plume, which started in 2002, was not initially used in formal management of the stock, but following a revision of the management approach it is now the primary monitoring tool (Ministry of Fisheries 2010).

The survey reported here was a repeat of the Spawning Plume surveys carried out on the *San Waitaki* from 2002 to 2010, coordinated by the Orange Roughy Management Group and subsequently (after its reorganisation) the Deepwater Management Group. The overall approach has been to measure acoustic backscatter of the orange roughy aggregations on the flat using a parallel transect-based design, completing as many snapshots as possible between normal commercial orange roughy fishing operations.

At the end of the 2010 Spawning Plume survey, another possible spawning aggregation was found to the west of the Spawning Plume (Figure 1) and this aggregation was fished during this survey to confirm that it was indeed spawning orange roughy. The aggregation, named the West Spawning Site to distinguish it from the original Spawning Plume, was also surveyed in 2011, using the same method and analysis as that used for the Spawning Plume.

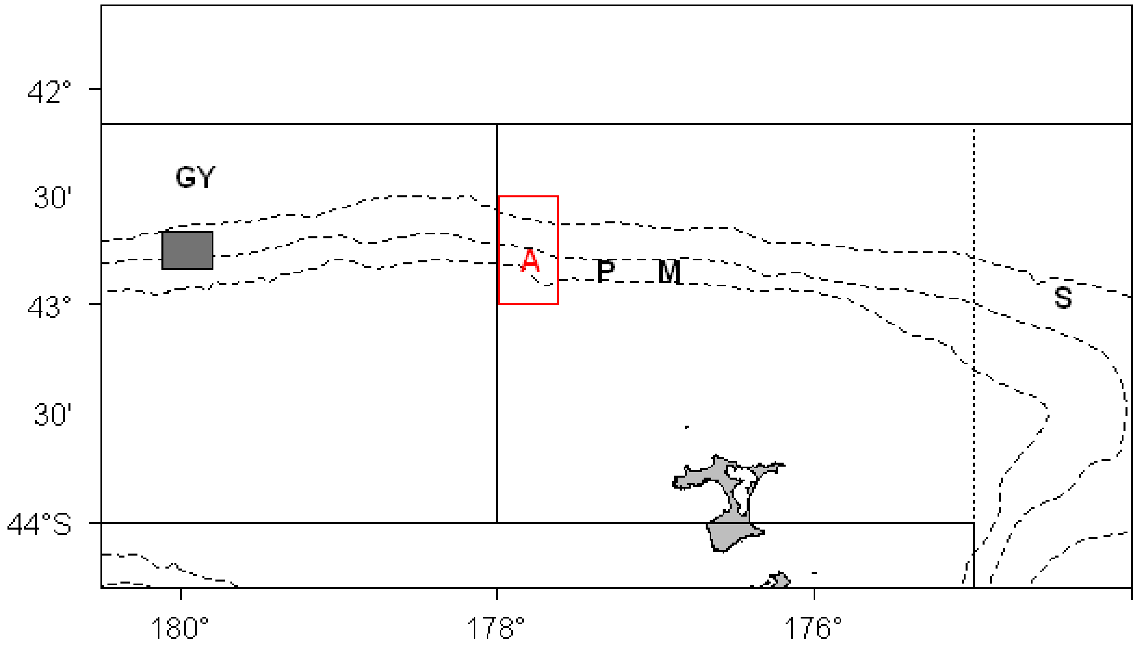

Figure 1: Spawning aggregations: P original aggregation (Spawning Plume), A, the new spawning aggregation, West Spawning Site. Hills: GY, Graveyard; M, Mt. Muck; S, Smiths City (M. Dunn, pers. comm.).

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 at the beginning of the voyage following 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 Spawning Plume, which is usually found at depths between 800 and 950 m and between longitudes 177° 45' W and 176° 45' W. The West Spawning Site was about 25 n. miles further to the west, was in similar depths to the Spawning 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 had been made. Biological data (standard length, total weight, sex, maturity status) on orange roughy were sampled from the commercial catches. In addition, acoustic search surveys were conducted in several areas. No other fish aggregations were found, or were seen when steaming from area to area.

Each snapshot was planned to include about 10 parallel transects in the north-south direction (i.e., across the depth contour) at an average of about 0.5 n. miles apart, with the vessel steaming at about 10 knots and usually taking about 5 hours to complete. However, during the survey a smaller than expected along-depth extent of the aggregations meant that 0.3 n. mile separations were used to obtain more transects over the main body of fish. 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. Vessel officers and scientific staff reached agreement during each snapshot to determine when each transect was clear of the mark at the other end, i.e., outside transects at each end were clear of the aggregation. The intervals between transects was constant (systematic survey design).

The acoustic estimates of the Spawning Plume biomass 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, Cordue 2010a). 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 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).

In 2009, the c.v. of the mean biomass estimate was 5% over 16 snapshots, which gave a sampling c.v. for an individual snapshot of 20% (i.e. 5 times the square root of 16), i.e., at the lower end of the target sampling c.v. for this objective (20–30%). The individual snapshot c.v. was similarly less than or equal to 20% for five of the surveys from 2002 to 2009, and it was about 30% for the other three. Hence, theoretically, at worst only one snapshot would be needed to complete this objective. Given that previous surveys had a c.v. under 10% for the mean, and that the vessel would remain fishing until their catch plan was completed, we disregarded the 20–30% target range for planning purposes.

The number of snapshots to aim for can be found by looking at the expected c.v. by the number of snapshots as follows:

Number of accepted snapshots	4	9	12
Mean c.v. when c.v. of a single snapshot is 20%	10	7	6
Mean c.v. when c.v. of a single snapshot is 30%	15	10	9

Most of the significant increase in precision occurs by the time there have been nine snapshots and, thereafter, any more snapshots would give only a small increase in precision. The plan was therefore to aim for nine weather acceptable snapshots which would give an expected c.v. of between 7 and 10%.

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. In a few cases, trawling on the background layers was done to check that high densities of orange roughy were not present away from the main aggregation.

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. This has been the basis of past surveys in this series and has been retained here.

The backscatter from all of the marks identified as containing orange roughy was then integrated. To plot the distribution of backscatter within snapshots, another version of the results was generated in which integrated backscatter was broken down into 10-ping bins (i.e. vertical slices). Acoustic backscatter was corrected for three effects: shadowing using the full formula of Barr in Doonan et al. (1999), based on mean acoustic densities in the region 10 m above the detected bottom; calculated sound absorption by seawater (see Appendix 2); and a systematic error in ES60 data (Ryan & Kloser 2004). Pitch and roll data were not available for most of the trip so corrections for vessel motion (Dunford 2005) and the bubble field generated by wind near the surface could not be made in the usual way (see weather correction below).

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.

2.3.1 Weather correction used in 2011

The distribution of the overall weather corrections from 2002 to 2009 is shown in Figure 2. The regression correction method was Model blm3 (Cordue 2010b) as applied by Hampton (2010b). The c.v. of the mean is very low for fisheries work at 5% which suggests that using this mean correction should result in only a modest increase in error.

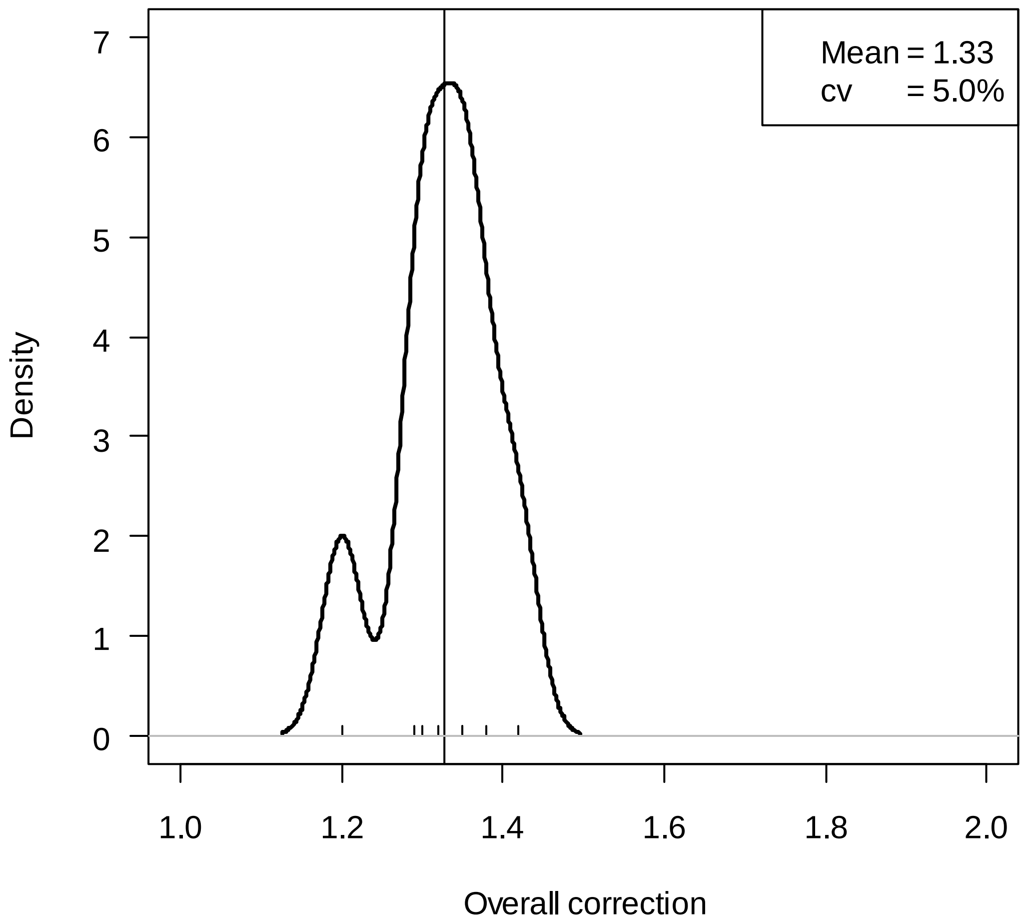

Figure 2: Distribution of the overall weather corrections that were applied in previous Spawning Plume *San Waitaki* acoustic surveys. The rug represents data points.

Of course, this is for the overall correction, but corrections are calculated and applied to individual snapshots. To assess what potential difference, or bias, this could make, individual corrections of the 2011 Spawning Plume snapshots were applied in three ways: (1) using the maximum correction for all the relatively high abundances (1.42) and lowest correction for all the relatively low abundances (1.2), (2) reversing the allocations in (1), and (3) using a random allocation of past overall corrections from 2002to 2009. Differences between treatments were minor (Table 1).

Table 1: Weather corrections using various methods: mean abundance relative to using 1.33 for all snapshots.

Method	Mean relative abundance (%)
Using historical mean (1.33)	100
High snapshots use 1.20, low use 1.42	98
Reverse above	98
Random allocation of 2002–2009 overall corrections to individual snapshots	99

Further, applying the historical mean (1.33), rather than the estimated overall correction, to past surveys gave only minor differences in the overall trend of the series. Consequently, it did not seem profitable to explore the correction method in any more detail and so the mean historical correction (1.33) was applied.

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 from the trawl catches to get the target strength, multiplying by the mean weight of orange roughy and the area of the snapshot (see Appendix 3 for details). Corrections applied to the abundance estimate were 1.33 (weather) and 1.16 (to keep the calibration in the same style used in past surveys, see section 2.5 below).

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 cm.

For each spawning aggregation, the mean abundance and c.v. 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). There has also been an informal criteria that across the snapshots used, there should be no definite trend or sharp step in abundance. In previous surveys coordinated by the Deepwater Working Group, sections of snapshots had been 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.

Sources of variance in the biomass 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 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 that from source 3, the target strength of orange roughy, and this overwhelms all other sources, although source 2 may generate a bias. Only the c.v. from sources 1 and 4 are given here, i.e., the 5% c.v. from the weather correction is added onto the sampling c.v. using the formula cv = $\sqrt{cv_{sampling}^2 + 0.05^2}$.

2.5 Acoustic system and calibration

Survey work used the *San Waitaki's* SIMRAD ES 60 echo-sounder with a 38-kHz split-beam transducer that was mounted in the bulbous bow. Acoustic data was logged from the ES-60 via an Ethernet link to a NIWA laptop as SIMRAD raw files and then converted into NIWA's format to use in NIWA's echo integration program, esp2, format for analysis (McNeill 2001).

The transducer was calibrated off Banks Peninsula on the morning of the 23 June. Full details are given in Appendix 1.

The peak gain used in the calculation of the calibration can be estimated in one of three ways: (1) on-axis TS from beam-fitting (a curve fitted through the data by the angle off centre, so on-axis is at 0.0 degrees), (2) the mean TS for data within 0.20° of on-axis, and (3) the maximum TS for data within 0.20° of on-axis. NIWA's standard protocol is to use (1). For scientific transducers, the method chosen is not significant, since the differences between the results are trivial. However, for commercial transducers (such as on the *San Waitaki*), there are differences between the three methods. Past surveys have used method (2), which gives a calibration factor from factory default settings of 1.81 (Mike Soule pers. comm.), which is the same value estimated in 2010 (Table 2). Using NIWA's calibration calculation gives 1.56 (Appendix 1) so this estimate was multiplied by 1.81/1.56 = 1.16 to ensure that biomass estimates were compatible over the whole series. Which calculation method is best is still under discussion in the international acoustics community (R. O'Driscoll pers. comm.).

Table 2: Calibration for the 2002–2011 surveys (peak from mean TS within 0.20□ of beam centre).

Parameter	2004	2005	2006	2007	2008	2009	2010	2011
S_A gain (dB)	25.38	25.44	25.49	24.61	25.23	25.29	25.23	25.9
S_A correction (dB)	-0.90	-0.84	-0.80	-0.85	-0.74	-0.76	-0.64	-.69
Correction factor	1.68	1.63	1.60	2.40 (1.64 □)	1.82	1.76	1.80	1.81

□ This value used in the estimation for 2007.

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 done 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.

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 processing figures. From each sampled tow, a random sample of up to 200 orange roughy was selected from the catch to measure fish length, weight, macroscopic gonad stage, and sex. 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 stages. Weight was measured to the nearest 5 g on motion compensated scales. No otoliths were collected by NIWA staff or by the MFish 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

2.7 Other data

In addition to the above, the following ancillary data were collected:

- True wind speed and direction data on a regular basis.
- CTD (conductivity, temperature and depth) data from the survey areas, by attaching a CTD unit to the trawl net headline.

Unfortunately the pitch/roll sensor failed early in the survey and so no useable pitch/roll data were available for this analysis.

3. RESULTS

3.1 Survey details

Example echograms are shown in Figure 3 for the Spawning Plume and West Spawning Site orange roughy aggregations. Acoustic marks at the West Spawning Site 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 Spawning Plume. The voyage was extended by one week, to 25 July, which enabled us to meet the target number of snapshots within the weather parameters.

The timetable was:

22 June	Departed Timaru
23 June	Calibration off Akaroa
7 June – 4 July	Western Spawning Site: 6 snapshots
7–11 July	Spawning Plume: 1 acceptable and 3 marginal snapshots
12–18 July	Continuous poor weather
19–25 July	Good weather Spawning Plume: 11 acceptable and 3 marginal snapshots
25 July	Return to Timaru

Only snapshots that had acceptable weather conditions or that had acceptable wind speeds, but had wave heights between 2 and 3 m (marginal) are reported here.

Forty-seven snapshots were completed, 37 on the Spawning Plume, 9 at West Spawning Site, and one in the Rocks area (comprised of two small features in the main Spawning Box), to give a total of 621 acoustic transects. A number of snapshots were actually searches for aggregations, and occurred on Mt. Muck, the "Rocks" area, "Spot V", where some fish was observed during vessel transiting between the West Spawning Site and the Spawning Box, and the "NE corner", an area about 65 n. miles east of the Spawning Box where orange roughy have been seen outside of the spawning period. Apart from the Spawning Plume and West Spawning Site, no more spawning aggregations were found.

Mt Muck was visited on three occasions during the survey. Tows down the hill slope caught large quantities of orange roughy. However, no substantial marks thought to be comprised primarily of orange roughy, were observed on the hull echosounder. Hence, no formal snapshots were undertaken on Mt. Muck.

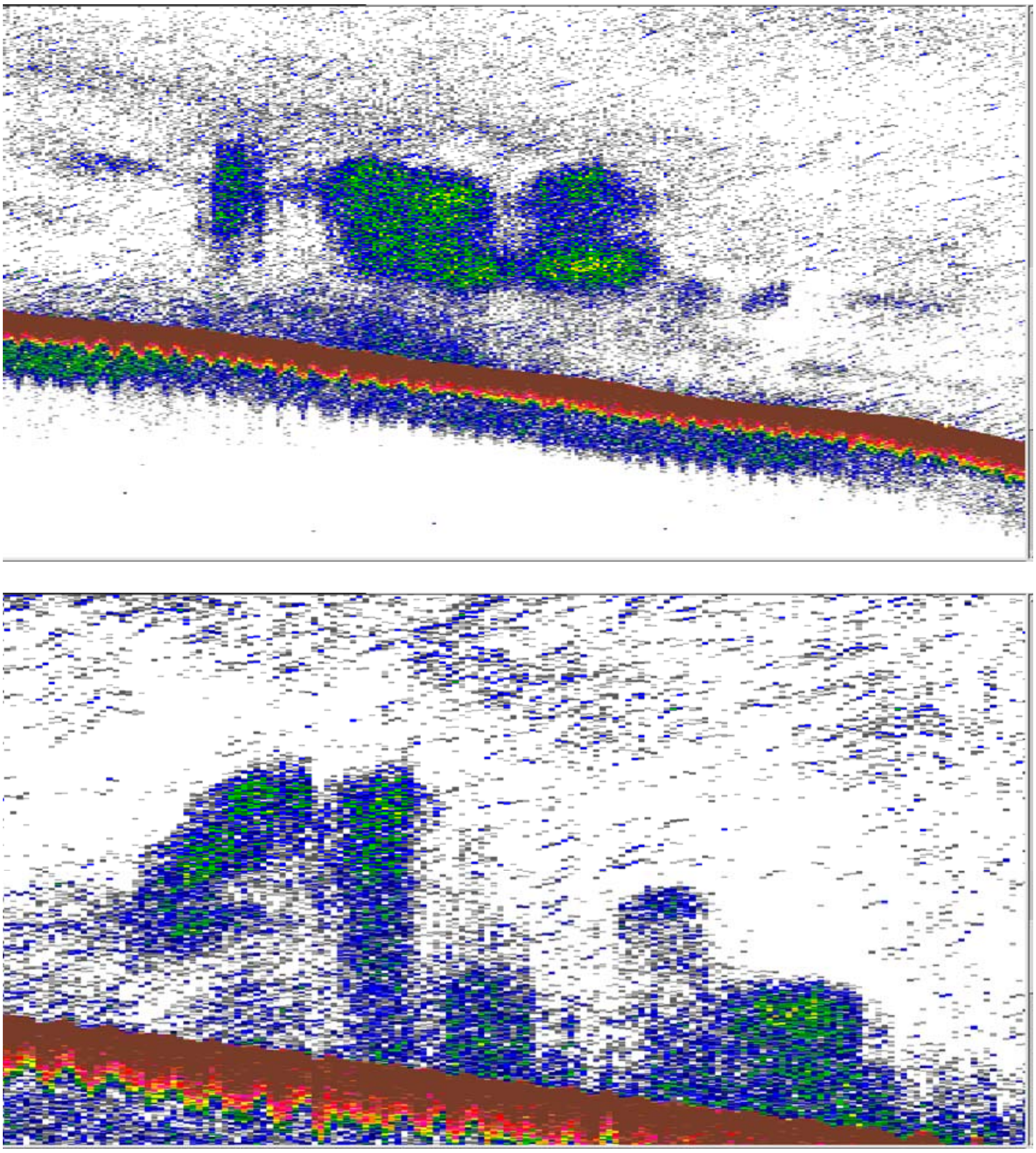

Figure 3: Echograms of spawning aggregation north-south at the West Spawning Site (upper panel) and at the Spawning Box (lower panel). The West Spawning Site mark is about 140 m high and 1.3 km long while the Spawning Box mark is about 97 m high and 1.4 km long.

A total of 45 commercial tows were completed: 32 on the Spawning Plume; 9 on the West Spawning Site, 3 on Mount Muck, and 1 at Spot V. Mean catches per tow from each area were 29 t from the Spawning Plume tows, 31 t from West Spawning Site, and 26 t from Mt Muck, although these catches were all from tows where an open window in the net was used. Of the 45 tows, 3 background tows were carried out to identify species in non-plume marks, typically on background layers. The latter caught little orange roughy and the catch mostly consisted of other species.

The headline mounted Seabird CTD was successfully deployed on 19 tows with 14 recordings at the Spawning Plume, 4 at the West Spawning Site, and one from Spot V.

3.2 Biological analyses

Mean trawl headline height was 4.2 m (range 3.5 to 7.0 m), mean speed over the ground 3.4 knots (range 2.7 to 4.5 kts) and mean tow distance 0.7 n.miles (range 0.13 to 2.3 n.miles).

A total of 11 488 orange roughy were sampled for length, sex, and gonad maturity stage. Numbers sampled by area were 7359 (2777 males and 4582 females) from the Spawning Plume 3010 (1485 males and 1525 females) from West Spawning Site and 1126 (833 males and 293 females) from Mount Muck.

A total of 1064 orange roughy were sampled for length, sex, gonad maturity stage and individual fish weight. The length-weight relationship was $4.00 \times 10^{-5} L^{2.94}$ kg, where L is the standard length in cm.

The progression of gonad maturity stages, and for the Spawning Plume the spent proportion over time, was very similar to that seen in 2010 (Figure 4). The West Spawning Site may be a separate spawning aggregation to the Spawning Plume on the basis of the distance between them, the overlap in timing of spawning, and a distinct earlier progression in female gonad stages at the West Spawning Site compared to the Spawning Plume (about four days, see Figure 4). Two indicators of spawning interval were used, (1) the date when the maturing proportion falls to 30%, and (2) when the spent proportion reached 20%. These are somewhat arbitrary, but frame the spawning, and are interpreted as the start of active spawning (1) and the beginning of the end of spawning (2). For the Spawning Plume, the spawning dates were 30 June and 11 July respectively. For the West Spawning Site, the dates were 26 June and 5 July respectively, although the latter date was not well determined.

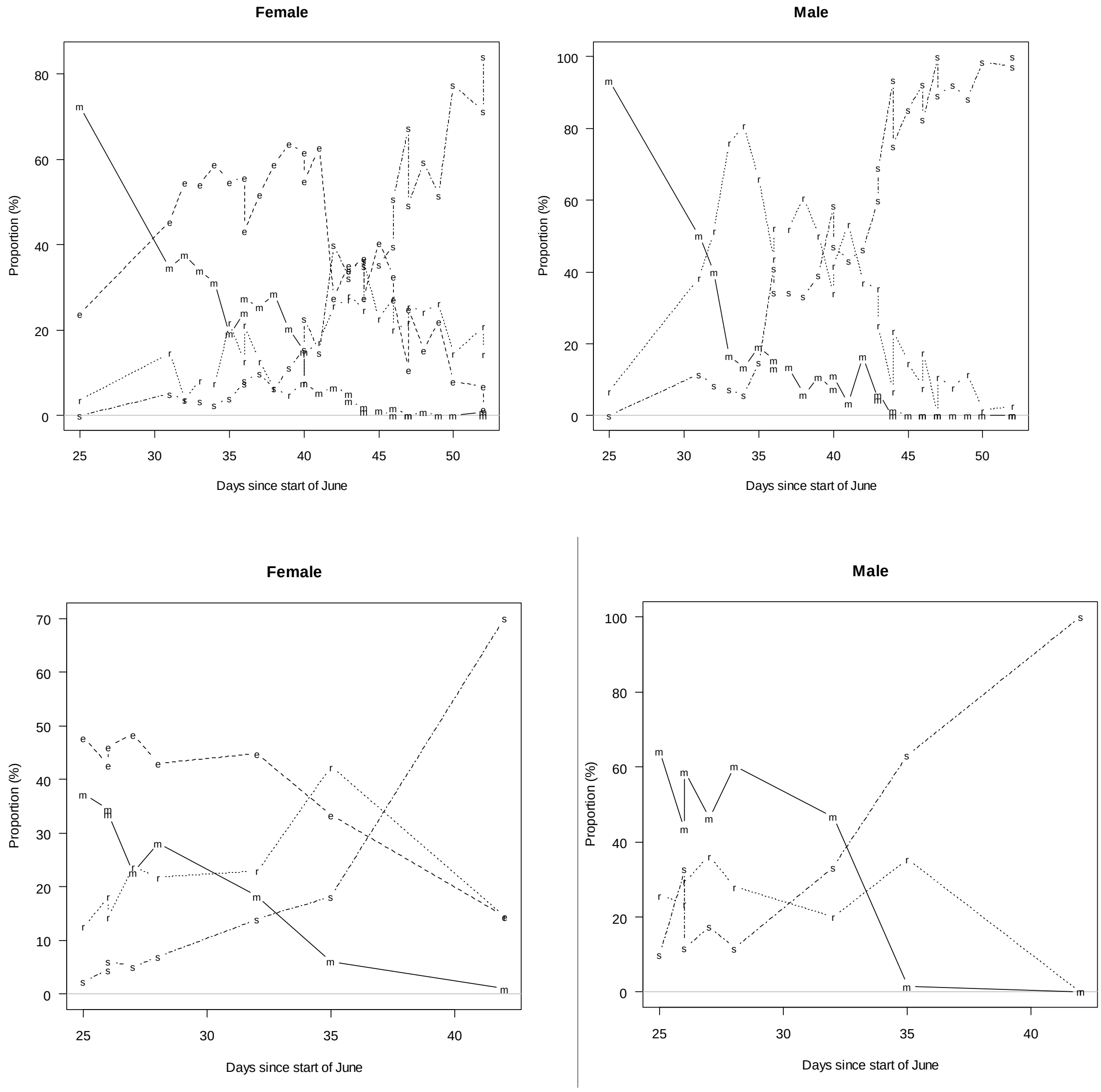

Figure 4: Proportion of gonad stage for males and females by spawning area and date (days from the start of June, i.e., 31=1 July). Stages considered were maturing (m), ripe (e), running ripe (r), and spent (s) (including partially spent). Top, Spawning Box; bottom, West Spawning Site.

Length frequency distributions by sex for the spawning aggregations are shown in Figure 5, from tows where the catch was 10 t or more. Although the male length distributions are similar, the female fish were about 2 cm larger at the Spawning Plume compared to the West Spawning Site.

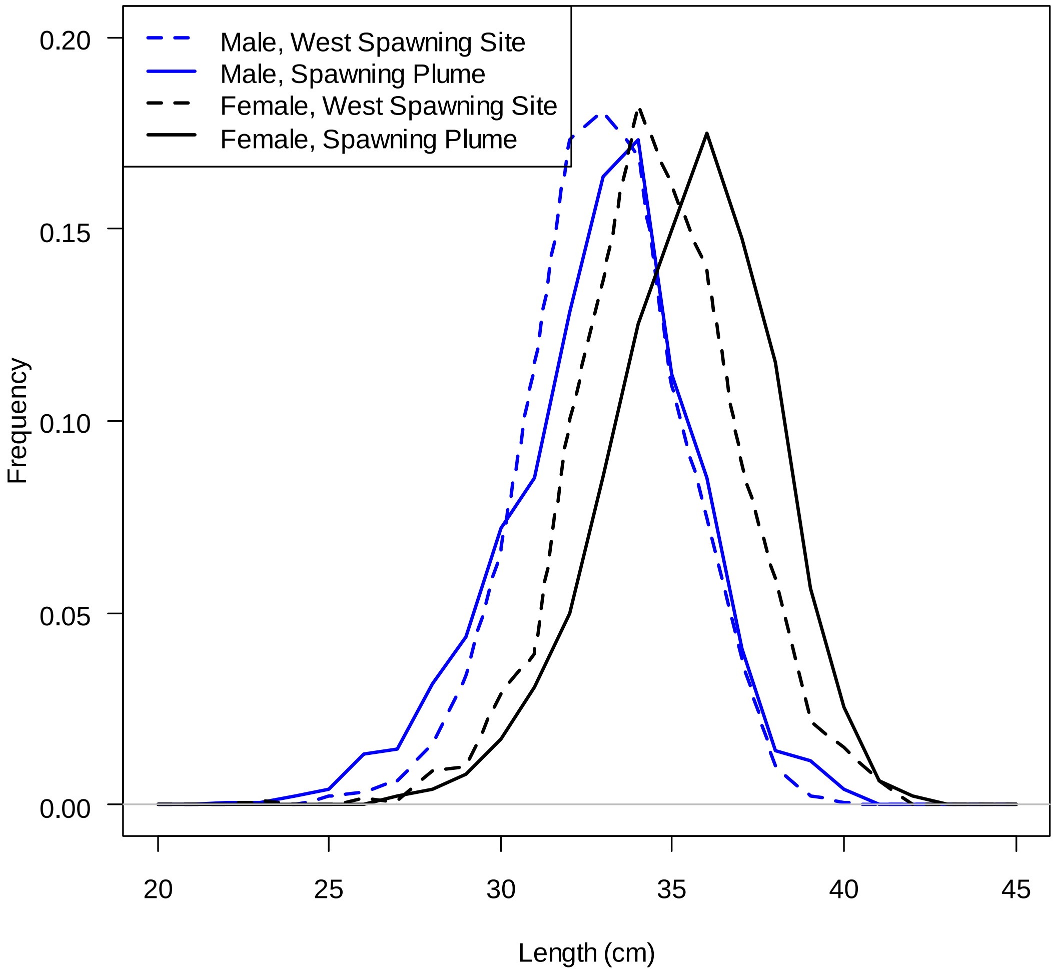

Figure 5: Length frequency of orange roughy by sex in the two spawning aggregations. Data are from tows with a catch greater than 10 t and frequencies are weighted by catch size.

The overall (combined sex) length frequency distribution is shown in Figure 6. For the Spawning Plume, the mean length was 34.7 cm and mean weight 1.32 kg, and for the West Spawning Site, it was 34.2 cm and 1.26 kg

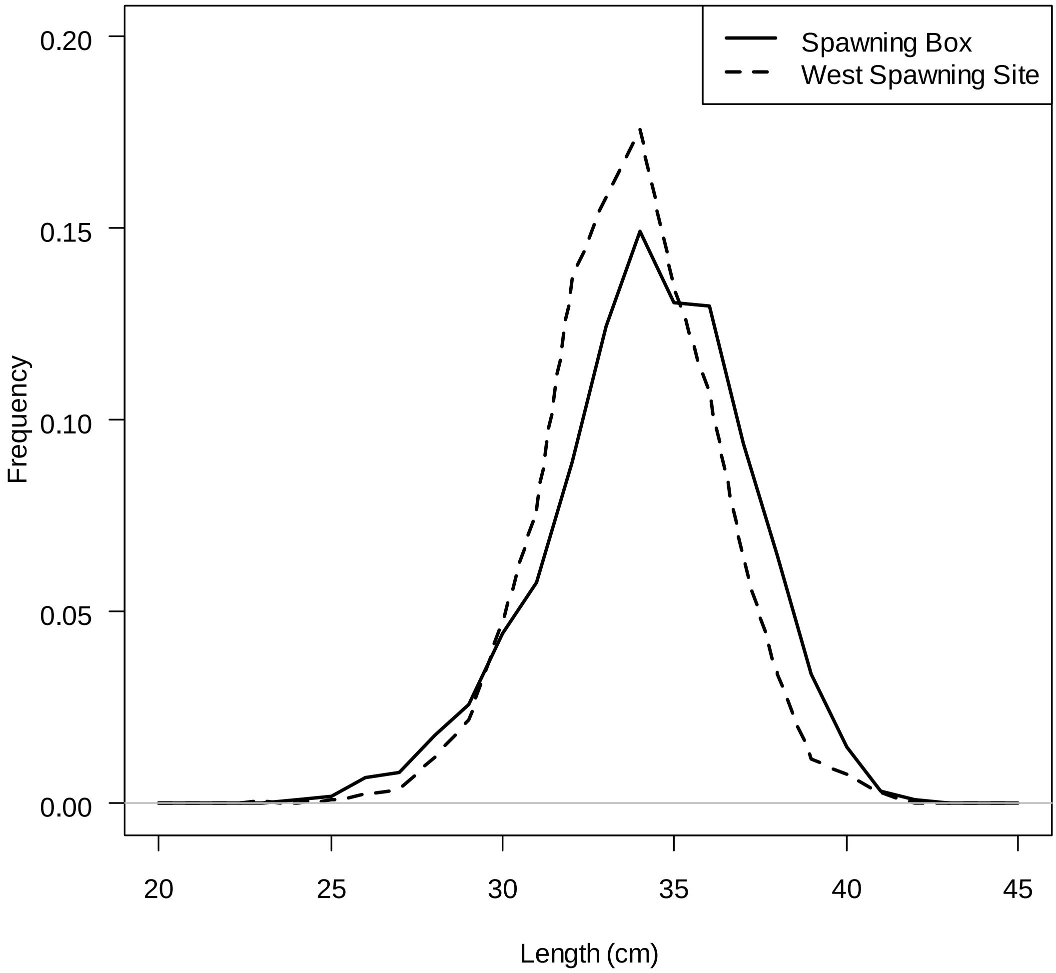

Figure 6: Length frequency of orange roughy in the two spawning aggregations. Frequencies are composed from the mean of the male and female frequencies assuming a 50:50 sex ratio.

3.3 Abundance estimates

The aim of getting at least nine acceptable acoustic snapshots on the Spawning Plume was met, although most snapshots were later in July than in previous surveys. The target strength for orange roughy was estimated from sampled mean length and the relationship shown in section 2.4 at 51.92 dB for the Spawning Plume, and -52.02 dB for the West Spawning Site.

Appendix 4 shows details of the snapshots analysed, i.e., those that had wind speeds below 20 knots and swell height less than 3 m. The snapshots accepted for the final mean biomass estimate had recorded swell heights 2 m or less. The number of acceptable snapshots was 12 for the Spawning Plume, and 6 for the West Spawning Site. Appendix 5 shows the backscatter distribution for snapshots used in the final biomass estimate.

Tables 3 and 4 show the abundance estimates by snapshot for the two spawning sites. For the Spawning Plume, individual abundances ranged from about 10 000 t to 22 000 t with no clear change in trend over time; the contribution from the shadow zone correction was low, at about 3%. For the

West Spawning Site, abundances ranged from 15 000 t to 44 000 t, and similarly the contribution from the shadow zone correction was low, at about 3%.

Table 3: Spawning Plume abundance estimates and c.v. (%) (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, the percentage of the abundance that was in the outside (edge) transects, and the increase in abundance from the shadow zone correction. Highlighted snapshot numbers were used in the overall estimate.

	Part 1		Part 2						
Snapshot	Biomass	c.v.	Biomass	c.v.	Number of transects	Biomass	c.v.	Edge Biomass (%)	Shadow zone correction
5	14 503	30	11 013	38	8	12 638	24	3	1.03
6	16 270	34	13 010	46	14	14 549	29	0	1.02
7	12 313	35	12 968	39	9	12 637	26	0	1.02
8	21 818	55	12 668	75	6	16 625	47	0	1.02
10	18 363	53	25 817	17	7	21 773	28	0	1.03
24	10 479	39	9 845	23	8	10 157	22	0	1.07
25	14 022	14	7 847	36	14	10 490	20	0	1.04
26	13 489	37	12 245	56	5	12 852	34	0	1.04
27	15 794	90	24 982	60	11	19 864	54	0	1.03
28	17 870	22	10 298	37	12	13 566	22	0	1.05
29	10 205	30	19 785	60	7	14 210	34	0	1.03
30	16 134	21	14 434	49	8	15 260	27	0	1.02
31	14 983	27	11 372	45	8	13 053	26	0	1.04
32	15 807	29	13 134	38	8	14 409	24	0	1.04
33	17 296	51	18 434	46	6	17 856	34	0	1.03
34	19 229	53	19 728	60	7	19 477	40	0	1.03
35	17 742	37	22 653	39	13	20 048	27	0	1.05
36	16 200	36	11 409	3	5	13 595	18	0	1.04
37	13 314	58	14 634	42	7	13 958	36	0	1.04

Table 4: West Spawning Site abundance estimates and c.v. (%) (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, the percentage of the abundance that was in the outside (edge) transects, and the increase in abundance from the shadow zone correction. All snapshots were used in the overall estimate.

	Part 1		Part 2						
Snapshot	Biomass	cv	Biomass	cv	Number of transects	Biomass	Cv	Edge Biomass (%)	Shadow zone correction
1	30 757	77	7 336	41	4	15 021	44	0	1.04
3	34 563	47	37 625	39	11	36 061	30	0	1.03
4	20 301	28	24 160	28	4	22 146	20	0	1.02
5	34 642	72	35 836	64	6	35 234	48	0	1.01
6	40 391	28	48 881	43	9	44 434	26	0	1.02
8	33 191	38	7 510	25	11	15 788	23	0	1.03

For the Spawning Plume, the overall abundance estimate was 16 422 t (c.v. 7.5%).

For the West Spawning Site, the overall abundance estimate was 28 114 t (c.v. 18.4%).

4. DISCUSSION

4.1 Timing of the survey

For the Spawning Plume, the timing of spawning was similar to that observed in 2010. However, the date for the main body of accepted snapshots in 2011 was about one week later than the end of the 2010 survey. Plotting the snapshot abundance by date (those analysed, so that it includes some snapshots where the wave height was between 2 and 3 m, i.e., marginal snapshots) shows that there was no trend over time, although there was only one accepted snapshot in the early part of the survey, so it is hard to judge for certain (Figure 7). The early group of snapshots is at the same time of month when some of the 2010 snapshots were done. Figure 8 shows the snapshot abundances for 2010 and this includes some snapshots done after the survey proper, by the vessel skipper without scientific staff on board. These later ones are later in July than the 2011 survey and suggest that the abundance was constant out to 25 July, after which the measured abundance stepped down to a new level, presumable this decline after 26 July indicates the start of the outward migration.

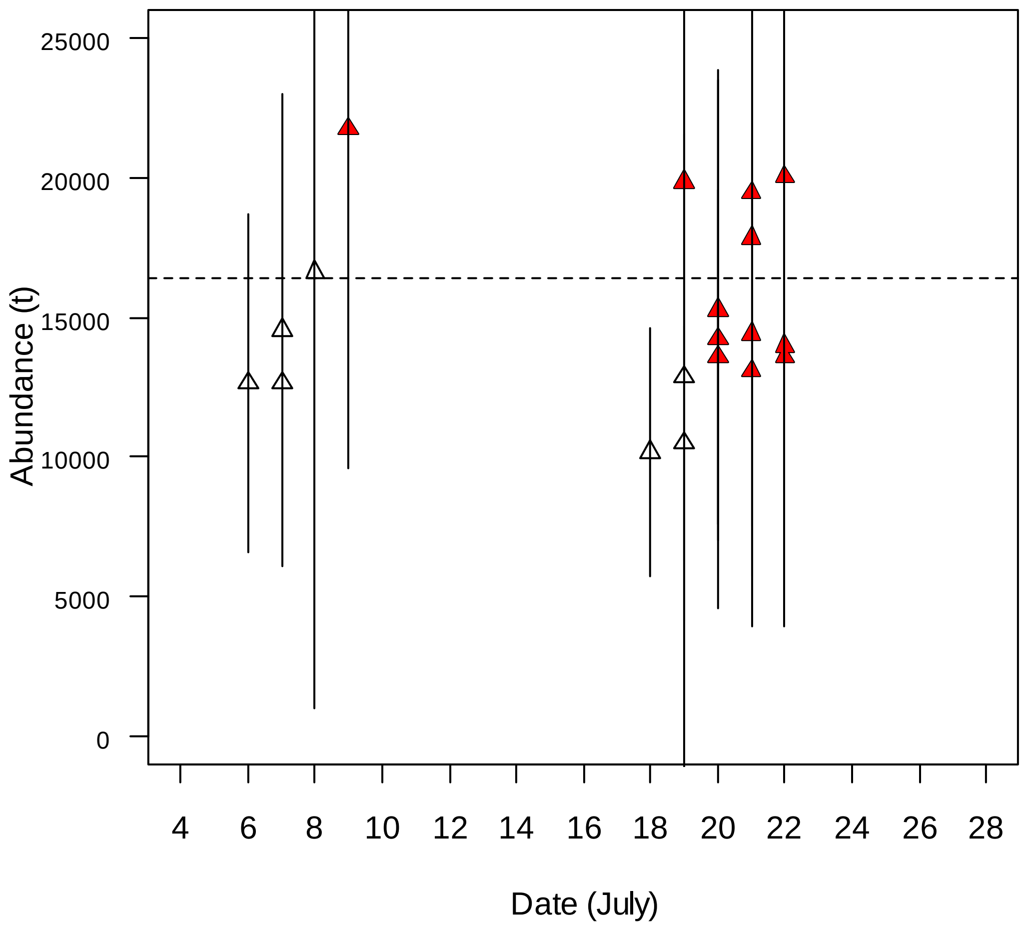

Figure 7: Spawning Plume 2011 abundance by date with ±2 standard deviation. Filled triangles are the snapshots included in the overall estimate.

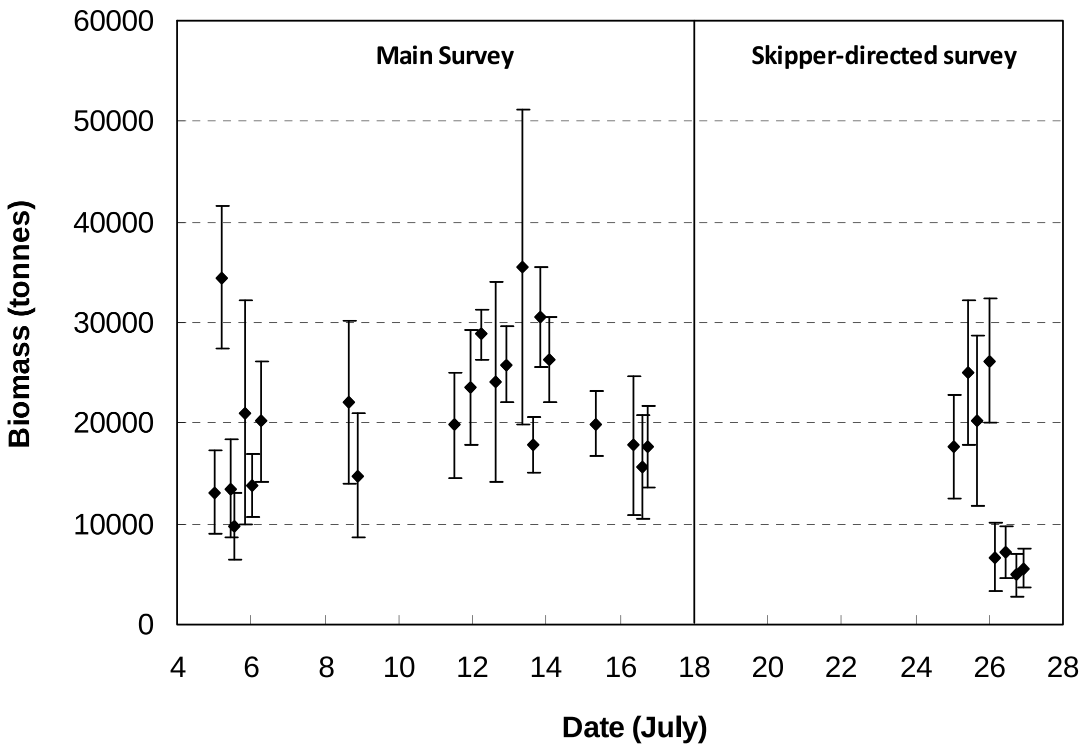

Figure 8: For 2010 survey, snapshot abundances (biomass on y-axis) by date from Ian Hampton (unpublished report, reproduced with permission).

4.2 Comparison with previous surveys

For the Spawning Plume, hull transducer acoustic surveys using the *San Waitaki* have been done every year since 2002 so there are now 11 surveys. The 2011 estimate was consistent with a recent downward trend in abundance (Figure 9). Several linear regressions were put through the abundance estimates and these extrapolate to zero in either 2014 or 2015. Although such extrapolations are obviously uncertain, the warning is clear; recent quota reductions have had little effect on arresting a linear decline in the Spawning Plume biomass. In 2006–07, the quota was 8650 t for the east and south Chatham Rise stock (for which the Spawning Plume has always been considered to be the primary spawning location), which was reduced by 40% in 2009–10 and then by 65% in 2010–11 (Ministry of Fisheries, 2010). In roughly the same period (2007 to 2011), the Spawning Plume abundance had reduced by 52%.

Apart from abundance declines, there may be other factors at play that progressively compound any observed abundance decline. In no particular order or likelihood, these effects may include:

- an increased disturbance by fishing (as the abundance is lower, the disturbance is relatively larger) which means that orange roughy are dispersed and thus hidden from the acoustic surveys (on the bottom or in layer/clumps to one side of the aggregation)
- disturbance is affecting fish orientation in a way that decreases the target strength (which is known to vary with the tilt-angle of the fish)
- the frequency of skipped spawning is increasing, e.g., more reliance on younger fish that have longer periods between spawning, or poor quality feeding now in home hills, because of fishing disturbance or habitat damage, resulting in poorer fish condition and so longer recovery intervals between spawning (Dunn & Forman 2011)
- some fish are now diverted to the West Spawning Site
- there is unobserved fishing mortality (e.g., escapees through the net window that later die from damage or stress)

- a stock dominated by young fish, resulting in a disconnect of recruits with adults, where new recruits do not "know" the way to historical spawning grounds.

Getting data that would measure any of these would be difficult.

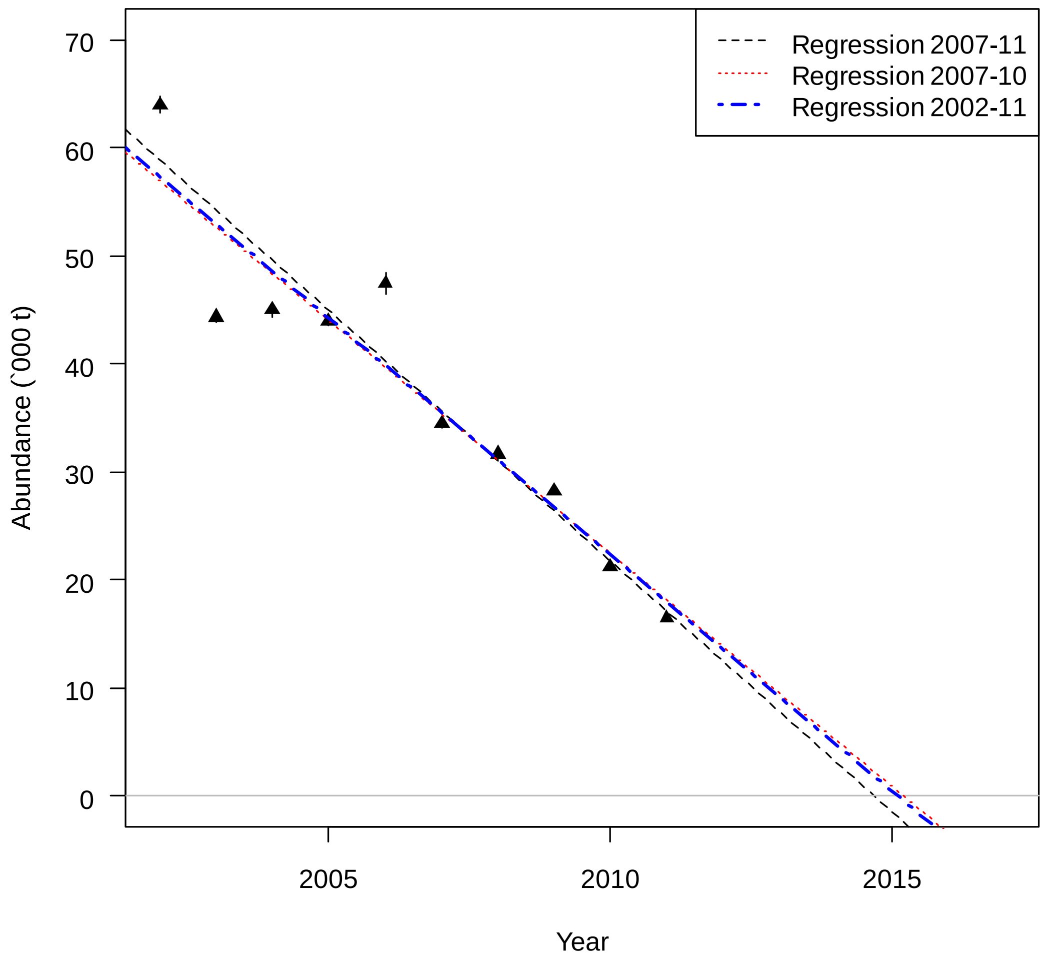

Figure 9: Spawning Plume estimates from 2002 to 2011 with ±2 standard deviation (vertical lines). Three regressions are also shown through the abundance estimates.

4.3 West Spawning Site

As outlined above, the West Spawning Site (WSS) appears to be different fish to that in the Spawning Plume, given the larger females in the Spawning Plume, geographical separation, and earlier but overlapping spawning time. It is difficult to know whether there has always been a spawning aggregation at the WSS. In the 1980s, there were 10 or fewer tows each year within the arbitrary box around "P" shown in Figure 1 (P-box). The later tows were mainly in May to July, but tow durations were 1 to 2 hours on average, and so not consistent with towing on large aggregations where tows are usually less than 30 minutes. However catch rates peaked in 1981 at 11 t hr^{-1} so they were unlikely to be directly targeting a spawning aggregation. In 2004 and 2005, a fishery developed in the P-box over the period October to May, where total catches were just over 1000 t each year, but after 2005, catches were only 59 to 183 t each year. Catch rates averaged about 1 t hr^{-1}. Consequently, it does not seem that the spawning aggregation, if present, was fished directly before 2011, although there does appears to have consistently been fish in the area, and at densities large enough to support a moderate fishery for two years.

The spawning aggregation was first reported in 2010, having been seen on a steam back to port after the 2010 Spawning Plume survey. Since the *San Waitaki* had caught its quota for 2010, no fishing was attempted until June 2011. The WSS is on the steaming path to the northeast hill complex (Graveyard. Morgue and others) from the Spawning Plume so it is possible that the failure to observe it earlier means that it is a new plume, presumably starting around 2010. However, given the small size of the aggregation, and the need to have an fisher on watch at the time that could reliably recognise an orange roughy spawning plume at the right time, it could easily be that the WSS has always been present, but not sighted until 2010. An age frequency distribution from the WSS aggregation could be informative, if compared to one from the Spawning Plume, as it could indicate whether the WSS is composed of only young fish (potentially naïve about spawning location), or whether it had a similar age composition to the Spawning Plume, including some older fish (it may be that both are composed of young fish).

5. ACKNOWLEDGMENTS

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Thanks to Sanford Ltd management, notably Steve Collier for their help and logistic support and for extending the voyage. Thanks to Matt Dunn who reviewed the report.

6. REFERENCES

Clark, M.R.; Anderson, O.F.; Francis, R.I.C.C.; Tracey, D.M. (2000). The effects of commercial exploitation on orange roughy (*Hoplostethus atlanticus*) from the continental slope of the Chatham Rise, New Zealand, from 1979 to 1997. *Fisheries Research 97*: 1–22.

Cordue, P.L. (2008). Review of estimates of Chatham Rise orange roughy biomass from plume surveys. Report for New Zealand Ministry of Fisheries, 30 August 2008. 39 p. (Unpublished report held by the Ministry for Primary Industries, Wellington.)

Cordue, P.L. (2010a). Refining the bottom-reference weather-correction method. Deepwater Fishery Assessment Working Group Document DWWG 2010/45 Final Research Report for project XXXXX. (Unpublished report held by the Ministry for Primary Industries, Wellington).

Cordue, P.L. (2010b). Linear-model derived bottom-referenced corrections for the Chatham Rise orange roughy plume acoustic time series 2002–2009 (Unpublished report held by the Ministry for Primary Industries, Wellington).

Doonan, I.J.; Bull, B.; Dunford, A.; Coombs R.F.; Grimes, P.; Tracey, D.; Hart, A. (2001). Acoustic estimates of the biomass of aggregations of orange roughy in the Spawning Box and on the Northeastern and Eastern Hills, Chatham Rise, July 2000. *New Zealand Fisheries Assessment Report 2001/70*. 31 p.

Doonan, I.J.; Coombs R.F.; McClatchie, S.; Grimes, P.; Hart, A.; Tracey, D.; McMillan, P. (1999). Estimation of the absolute abundance of orange roughy on the Chatham Rise. Final Research Report for Ministry of Fisheries Research Project ORH9701. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Doonan, I.J.; Dunn, M.; Dunford, A.: Hart, A.C.; Tracey. D. (2006). Acoustic estimates of orange roughy abundance on the Northeastern and Eastern Chatham Rise, July 2004: wide-area survey and hill survey. *New Zealand Fisheries Assessment Report 2006/58* 45 p.

Doonan, I.J.; Dunn, M.; Hart, A.C. (2009). Abundance estimates of orange roughy on the Northeastern and Eastern Chatham Rise, July 2007: wide-area trawl survey and hill acoustic survey (TAN0709). *New Zealand Fisheries Assessment Report 2009/20.* 41 p.

Dunford, A.J. (2005). Correcting echo integration data for transducer motion. *Journal of the Acoustical Society of America 118*: 2121–2123.

Dunn, M.R.; Anderson, O.F.; Doonan, I.J. (2008). An evaluation of stock status for orange roughy on the east and south Chatham Rise in 2008. *New Zealand Fisheries Assessment Report 2008/65*. 30 p.

Dunn, M.R.; Forman, J.S. (2011). Hypotheses of spatial stock structure in orange roughy Hoplostethus atlanticus inferred from diet, feeding, condition, and reproductive activity. PLoS ONE 6(11): e26704. doi:10.1371/journal.pone.0026704.

Hampton, I. (2010a). Re-calculation of estimates of ORH biomass in ORH3B spawning plume: 2002 – 2009. DWWG 2010–37 (Unpublished report held by Ministry for Primary Industries, Wellington).

Hampton, I. (2010b). Comparison of bottom reference weather corrections: 2002 – 2009. DWWG 2010–34 (Unpublished report held by Ministry for Primary Industries, Wellington).

Hampton, I.; Soule, M.A.; Nelson, J.C. (2008). Standardisation of acoustic estimates of orange roughy biomass in the North Chatham Rise Spawning Plume between 1996 and 2007, made with vessel-mounted transducers. Report presented by Fisheries Resource Surveys cc., Cape Town, South Africa, to New Zealand Deep Water Fisheries Assessment Working Group, 6 August, 2008, DWWF/2008-60. (Unpublished report held by Ministry for Primary Industries, Wellington). 20p.

Hampton, I.; Soule, M.A.; Nelson, J.C. (2009a). Acoustic survey of ORH: Chatham Rise, June/July 2009. DWWG 2010–04, presentation to the Deepwater Working Group (Unpublished report held by Ministry for Primary Industries, Wellington).

Hampton, I.; Soule, M.A.; Nelson, J.C. (2009b). Corrections to the time series of acoustic estimates of orange roughy spawning biomass in the Spawning Plume in area ORH3B from vessel-mounted transducers, 1996 to 2008. Report by Fisheries Resource Surveys cc. to New Zealand Ministry of Fisheries, Wellington. (Unpublished report held by Ministry for Primary Industries, Wellington.) 29p.

Jolly, G.M.; Hampton, I. (1990). A stratified random transect design for acoustic surveys of fish stocks. *Canadian Journal of Fisheries and Aquatic Sciences 47*: 1282–1291.

Kloser, R.J.; Ryan, T.E.; Williams, A.; Soule, M. (2000). Development and implementation of an acoustic survey of orange roughy in the Chatham Rise spawning box from a commercial factory trawler, FV *Amaltal Explorer*. CSIRO Marine Research, Hobart, Australia. Report 597, 64. 90 p.

Macaulay, G.; Kloser, R; Ryan, T. (2008). Visually verified *in situ* target strength measurements of orange roughy from the Chatham Rise, July 2007. Final Research Report (by NIWA and CSIRO) for Ministry of Fisheries Research Project ORH2006-01A Objective 2. 43 p. (Unpublished report held by Ministry for Primary Industries, Wellington).

MacLennan, D.N.; Simmonds, E.J. (1992). Fisheries acoustics. London, New York: Chapman & Hall. 325 p.

McNeill, E. (2001). ESP2 phase 4 user documentation. NIWA Internal Report 105. 31 p. (Unpublished report held by NIWA library, Wellington.)

Ryan, T.; Kloser, R. (2004). Quantification and correction of a systemic error in Simrad ES60 echosounders. Technical note presented at the ICES WGFAST 2004, Gdynia, Poland. 9 p.

Ministry of Fisheries (2010). Report from the Fisheries Assessment Plenary, May 2010: stock assessments and yield estimates. Ministry of Fisheries. 1158 p.

APPENDIX 1: Calibration Report: San Waitaki

Calibration of the Simrad ES60 echosounder on *San Waitaki* took place near Banks Peninsula (43° 56.80 S 172° 50.04 E) on 23 June 2011. Water depth was about 30 m (below the transducer). This was the first time that the ES60 on this vessel has been calibrated by NIWA, however there have been calibrations since 2004 by external agencies.

The calibration was conducted broadly as per the procedures in MacLennan & Simmonds (1992). The ES60 was configured to recommended settings (2000 W power and 1.024 ms pulse). A weighted line was passed under the keel to facilitate setting up the three lines and calibration sphere. Long (3.8 m) fibreglass calibration poles were used to help keep the calibration lines clear of the hull and to allow the rods to point forward. 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 10–15 knot northeast breeze, little swell and some chop. The vessel was allowed to drift, and the drift speed was about 0.5 knots. The sphere was located in the beam at 10:26 NZST. Calibration data were recorded into a single ES60 raw format file (L0012-D20110623-T102637-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 1.1.

Water temperature measurements were taken using an RBR-2050 temperature depth probe. The salinity was not measured and was assumed to be 35 PSU. 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 files 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 1.2.

The calibration results are given in Table 1.3. The estimated beam pattern and sphere coverage are given in Figure 1.1. 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 1.2 and confirms that the transducer beam pattern is correct. The RMS of the difference between the Simrad beam model and the sphere echoes out to 3.4° off axis was 0.20 dB (Table 1.3), indicating that the calibration was of acceptable quality (less than 0.4 dB is poor, less than 0.3 dB good, and less than 0.2 dB excellent).

The estimated peak gain (G_0) in 2011 was of the same order of magnitude as those measured previously by Ian Hampton and others (Hampton et al. 2004) (see Table 1.3). As these earlier comparisons were done using a copper sphere and different analysis methods they are primarily useful for qualitative comparison purposes only.

Acknowledgements

Thanks to the Captain and the crew of *San Waitaki* for their assistance. The calibration was funded by Ministry of Fisheries Research Project ORH2010/01.

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.

Fofonoff, P.; Millard, R., Jr (1983). Algorithms for computation of fundamental properties of seawater. *UNESCO Technical Papers in Marine Science. No. 44*. 53 p.

Hampton, I.; Soule, M.A.; Nelson, J.C. (2004). Acoustic survey of orange roughy aggregations in the spawning plume and northeast hills, North Chatham Rise, New Zealand, July 2004. Report on work commissioned by the Orange Roughy Management Company, Tauranga, New Zealand and carried out by Fisheries Resource Surveys Limited, Cape Town, South Africa. 74 p.

MacLennan, D.N.; Simmonds, E.J. (1992). Fisheries Acoustics. *Fish and Fisheries Series 5.* Chapman & Hall, London. 325 p.

Ryan, T.; Kloser, R. (2004). Quantification and correction of a systemic error in Simrad ES60 echosounders. Technical note presented at the ICES WGFAST 2004, Gdynia, Poland. 9 p.

Table 1.1. ES60 transceiver settings and other relevant parameters during the calibration.

Parameter	Value
Echosounder	ES60
ES60 software version	1.5.2.77
Transducer model	ES38B
Transducer serial number	985
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)	2000
Pulse length (ms)	1.024
Transducer peak gain (dB)	26.5
Sa correction (dB)	0.0
Bandwidth (Hz)	2425
Sample interval (m)	0.192
Two-way beam angle (dB)	–20.60
Absorption coefficient (dB/km)	9.75
Speed of sound (m/s)	1500
Angle sensitivity (dB) alongship/athwartship	21.90/21.90
3 dB beamwidth (°) alongship/athwartship	7.10/7.10
Angle offset (°) alongship/athwartship	0.0/0.0

Table 1.2. Auxiliary calibration parameters derived from depth/temperature measurements.

Parameter	Value
Mean sphere range (m)	17.0
S.D. of sphere range (m)	0.8
Mean sound speed (m/s)	1 494
Mean absorption (dB/km)	9.39
Sphere TS (dB re 1m^2)	–42.4

Table 1.3: Calculated echosounder calibration parameters for *San Waitaki*. 2011 values were calculated using version 6818 of NIWA's Matlab calibration function. Values prior to 2011 are from Ian Hampton (pers. comm.).

Parameter	2011	2010	2009	2008	2007	2006	2005	2004
Mean TS within 0.20° of centre	-43.6644							
Std Dev. of TS within 0.20° of centre	0.36015							
Max TS within 0.20° of centre	-42.9677							
No. of echoes within 0.20° of centre	93							
On axis TS from beam-fitting	-43.5551							
Transducer peak gain (dB)	26.22	25.87	26.05	25.97	25.47	26.29	26.28	26.28
Sa correction (dB)	-0.69	-0.64	-0.76	-0.74	-0.85	-0.80	-0.84	-0.9
Beamwidth (º) alongship/athwarthship	6.5/6.9	7.13/7.04	6.80/6.98	6.81/6.98	6.90/6.90	7.22/7.08	7.03/7.03	7.1/7.3
Beam offset (º) alongship/athwarthship	0.00/0.00	+0.02/+0.06	-0.14/+0.04	-0.08/+0.21	-0.07/+0.14	-0.16/-0.16	-0.02/+0.03	-0.18/+0.13
RMS deviation	0.20							
Number of echoes	21471							

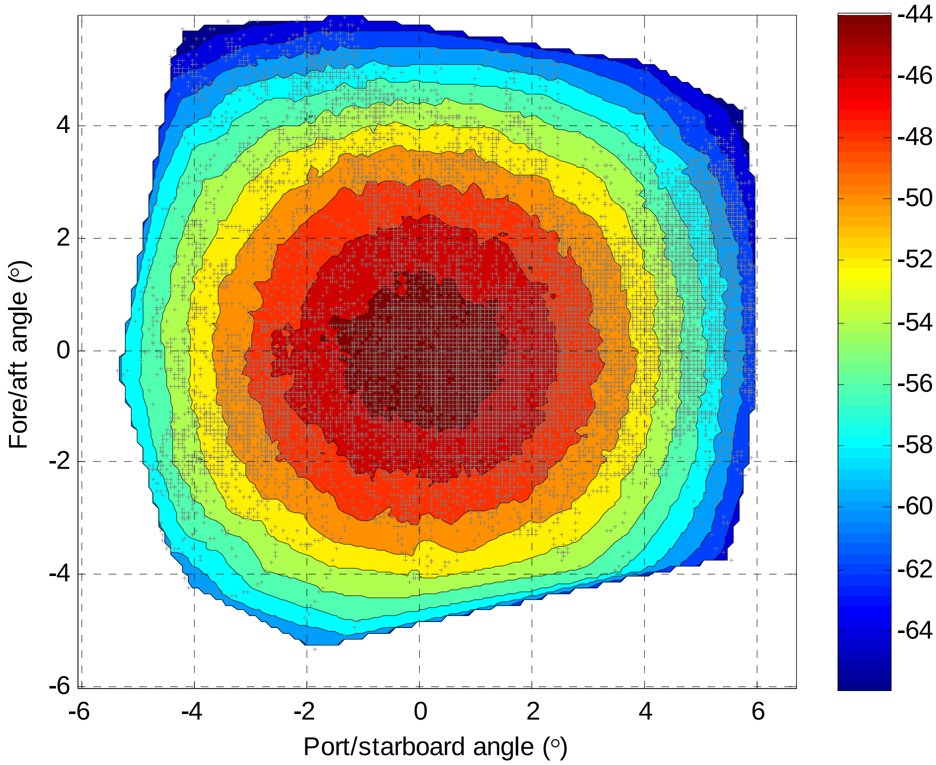

Figure 1.1. The estimated beam pattern from the sphere echo strength and position for the calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

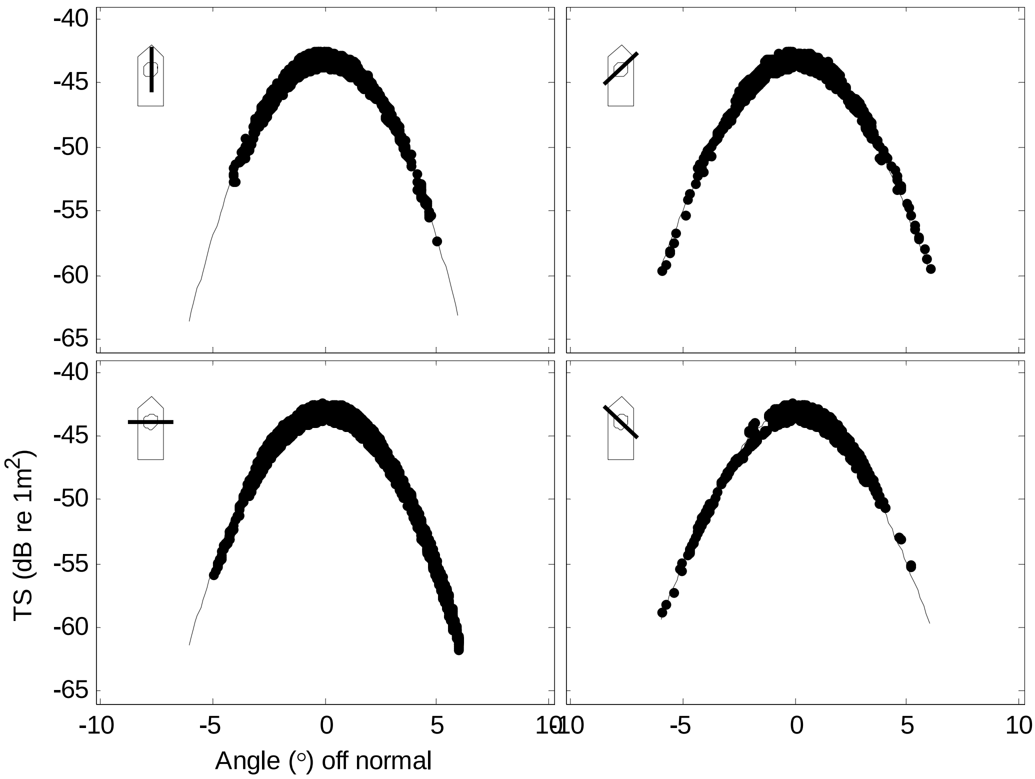

Figure 1.2. Beam pattern results from the calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

APPENDIX 2 Calculation of sound absorption coefficients

For the Spawning Plume, CTD drops were made on tow numbers 7, 14, 19, 20, 21, 25, 29, 32, 35, 37, 40, 42, 43, 44, and 45. For the West Spawning Site, CTD data was collected on tow numbers 1, 6, 12, and 16. The dataset from each drop 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 Spawning Plume the median depth of tows that caught 10 t or more was 870 m and this depth was used as the depth of the aggregation. Transducer depth was taken to be 3 m. For the West Spawning Site, the median tow depth was 856 m. Individual sound absorption estimates are shown in Table 2.1. For each site, the median value is used in the integrations.

For both sites the sound absorption used was 8.83 dB km^{-1}.

Table 2.1. Sound absorption by CTD drop (dB km^{-1}).

West Spawning Site

8.84	8.83	8.84	8.80

Spawning Plume

8.77	8.79	8.86	8.78
8.85	8.83	8.84	8.82
8.82	8.82	8.82	8.84
8.86	8.85	8.83	

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:

$$B_{orh,s,j} = A_{s,j}\ \overline{w_s}\ abscf_{s,j} \big/ \overline{\sigma_s}, \qquad (1)$$

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 $\left(\mathbf{0.5}/\sqrt{\boldsymbol{B1\,B2}}\right)\sqrt{\boldsymbol{cv1^2+cv2^2}}\boldsymbol{(B1\,B2)}$, 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 $\boldsymbol{V(Y) \sim [f'(E[X])]^2\ V(X)}$.

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 analysed

Table 4.1: Acoustic snapshots analysed for the Spawning Plume (SP) and West Spawning Site (WSS) with their details and whether it was used in the final mean.

Stratum	Snapshot number	Date	Time interval	Number of transects	Transect spacing (n.mile)	Weather	Used in final mean
WSS	1	25 Jun-11	0650–1140	9	0.5	15–20 kts WNW, 1.5–2 m	Yes
WSS	3	28 Jun-11	0210–0922	15	0.3	10–20 kts dying SSW, 2 m swell	Yes
WSS	4	28 Jun-11	1050–1540	9	0.3	10–15 kts dying SSW, 2 m swell	Yes
WSS	5	28 Jun-11	1650–2230	11	0.3	5 kts southerly 2 m swell	Yes
WSS	6	29 Jun-11	0120–0904	15	0.3	10 kts SSE building, 2 m swell	Yes
WSS	8	4 Jul-11	1427–2340	16	0.3	15–20 kts NE, 1.5–2 m confused swell	Yes
SP	5	6–7 Jul-11	2252–0406	11	0.5	~15 kts NW, 3 m+ confused swell	No
SP	6	7 Jul-11	1115–2105	19	0.3	~12–15 kts NW, 2–3 m confused swell	No
SP	7	7–8 Jul-11	2219–0426	14	0.3	~12–15 kts NW, 2–3 m confused swell	No
SP	8	8 Jul-11	0851–1912	13	0.3	~10 kts, 2–3 m confused swell	No
SP	10	9 Jul-11	0420–1150	15	0.3	15 kts variable, ~1.5–2 m confused swell	Yes
SP	24	18–19 Jul-11	2250–0415	13	0.3	15 kts SW, 3 m swell	No
SP	25	19 Jul-11	0433–1239	19	0.3	15 kts SW, 2–3 m swell	No
SP	26	19 Jul-11	1445–1913	11	0.3	10 kts SW, 2–3 m swell	No
SP	27	19–20 Jul-11	2027–0314	13	0.3	0–8 kts SW, 2 m swell	Yes

Stratum	Snapshot number	Date	Time interval	Number of transects	Transect spacing (n.mile)	Weather	Used in final mean
SP	28	20 Jul-11	0343–1020	17	0.3	0–5 kts SW, 1.5–2 m swell	Yes
SP	29	20 Jul-11	1026–1630	16	0.3	0–10 kts N, 1.5 m swell	Yes
SP	30	20 Jul-11	1709–2140	14	0.3	15 kts NW, 1 m swell	Yes
SP	31	21 Jul-11	0407–0805	12	0.3	15 kts WNW, 1 m swell	Yes
SP	32	21 Jul-11	1132–1529	11	0.3	15 kts SW, 1–1.5 m swell	Yes
SP	33	21 Jul-11	1615–2110	14	0.3	10 kts SW, 1 m swell	Yes
SP	34	21–22 Jul-11	2212–0147	10	0.3	5 kts variable, 1–1.5 m swell	Yes
SP	35	22 Jul-11	0342–0917	18	0.3	15 kts SW, 1–1.5 m swell	Yes
SP	36	22 Jul-11	0923–1404	13	0.3	15 kts SW, 1–1.9 m swell	Yes
SP	37	22 Jul-11	1410–1924	15	0.3	15 kts SW, 2–3 m swell	Yes

APPENDIX 5: plots of backscatter by snapshot

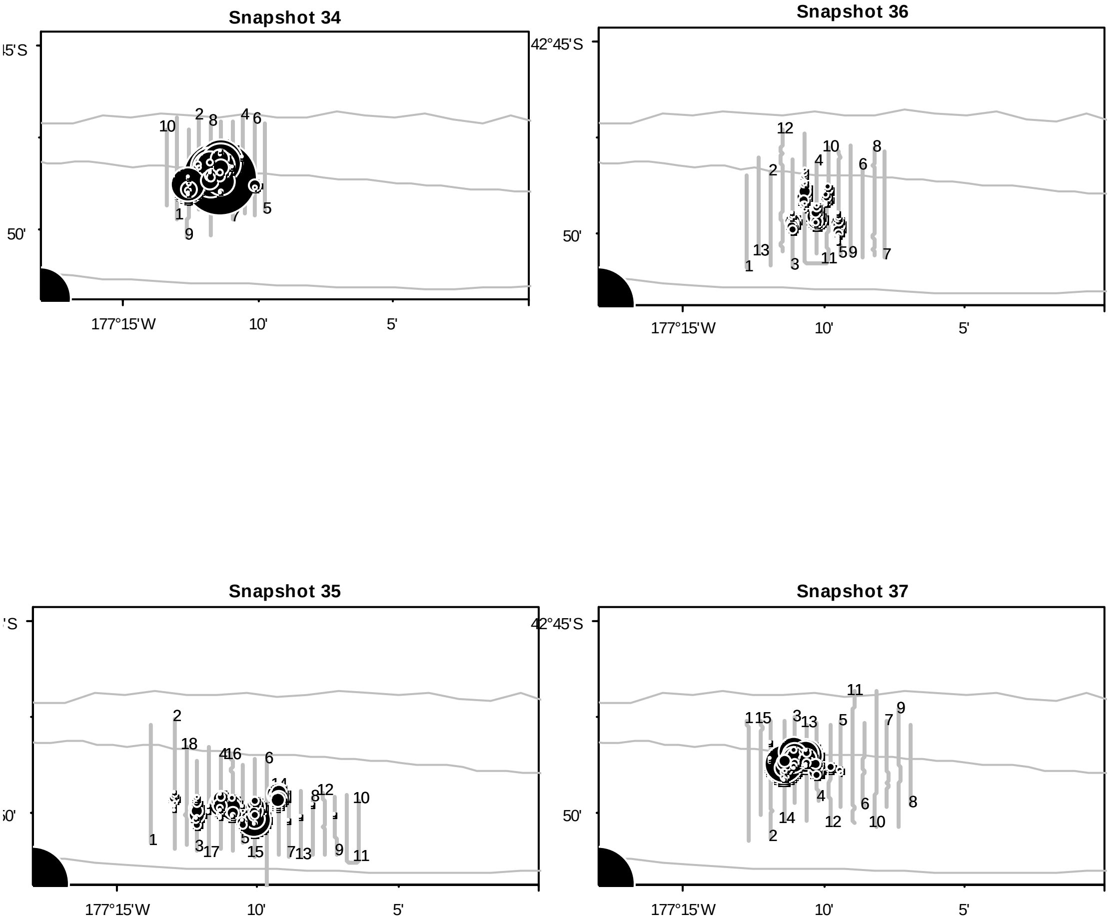

Figure 5.1. Spawning Plume, transects and backscatter (circles, area proportional to backscatter) for snapshots that were analysed. Quarter circle in lower left corner is the reference value (same for all plots). Transect numbers are in order of steaming (numbers at one end of each transect).

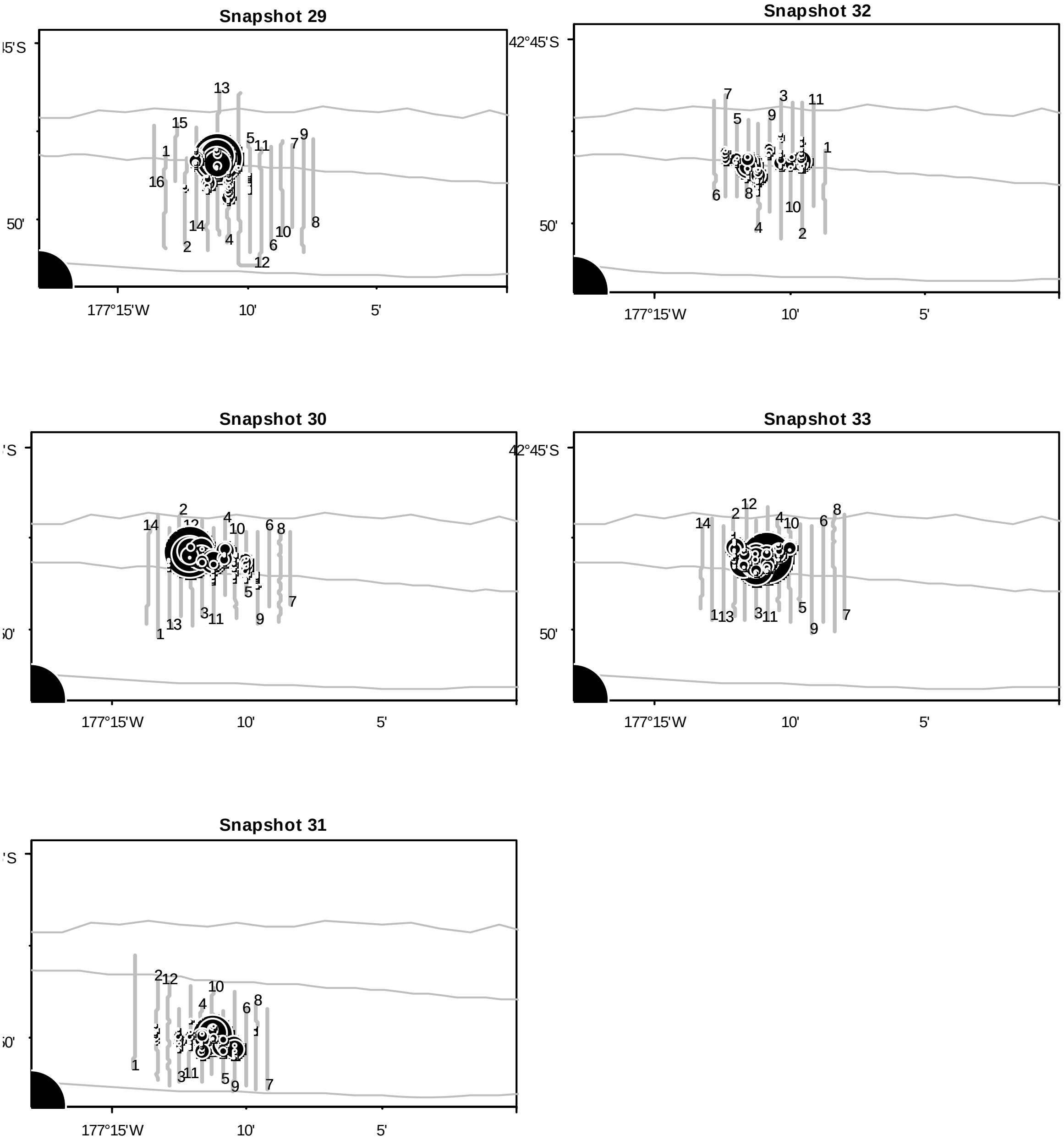

Figure 5.1. (cont.). Spawning Plume, transects and backscatter (circles, area proportional to backscatter) for snapshots that were analysed. Quarter circle in lower left corner is the reference value (same for all plots). Transect numbers are in order of steaming (numbers at one end of each transect).

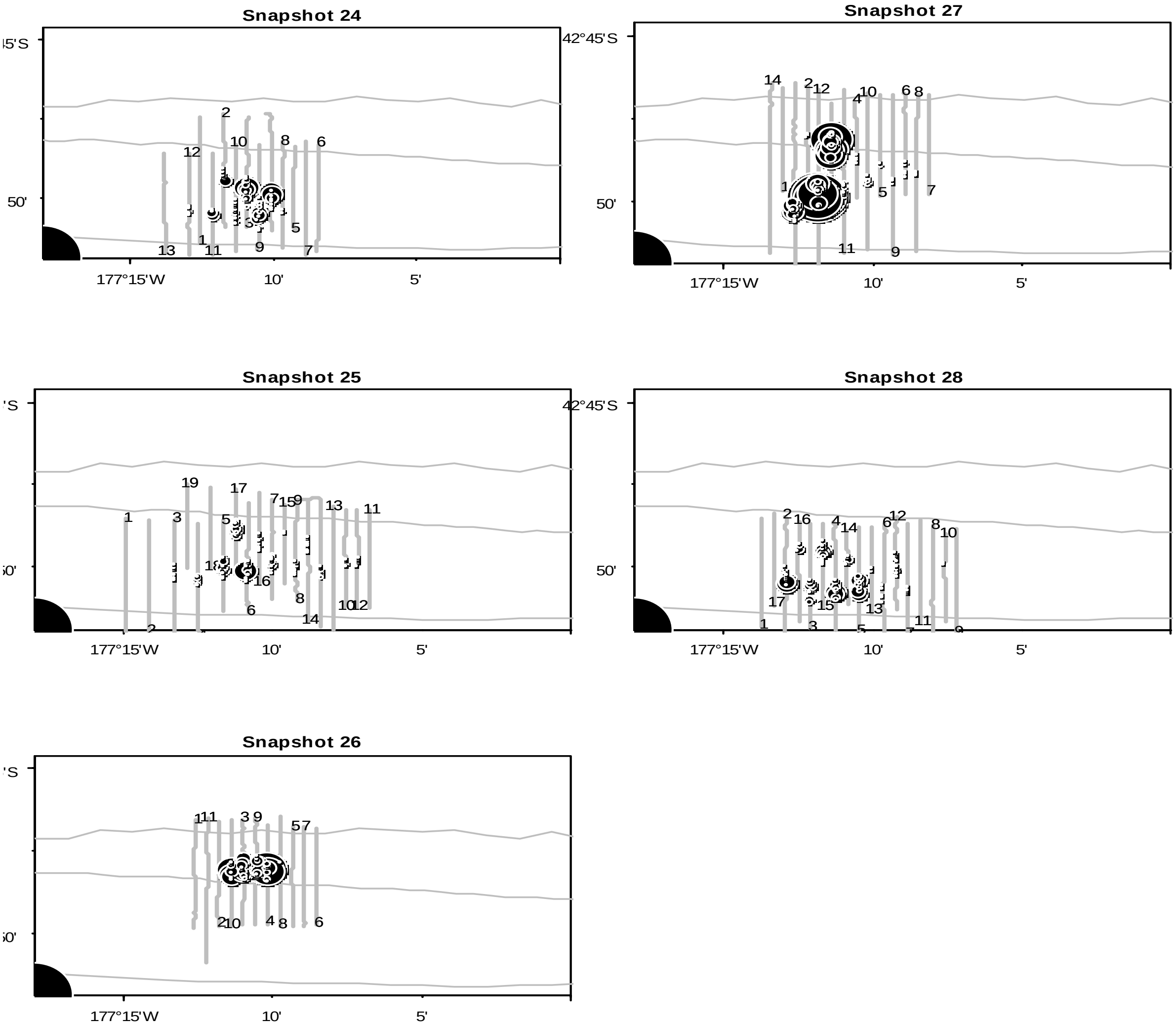

Figure 5.1. (cont.). Spawning Plume, transects and backscatter (circles, area proportional to backscatter) for snapshots that were analysed. Quarter circle in lower left corner is the reference value (same for all plots). Transect numbers are in order of steaming (numbers at one end of each transect).

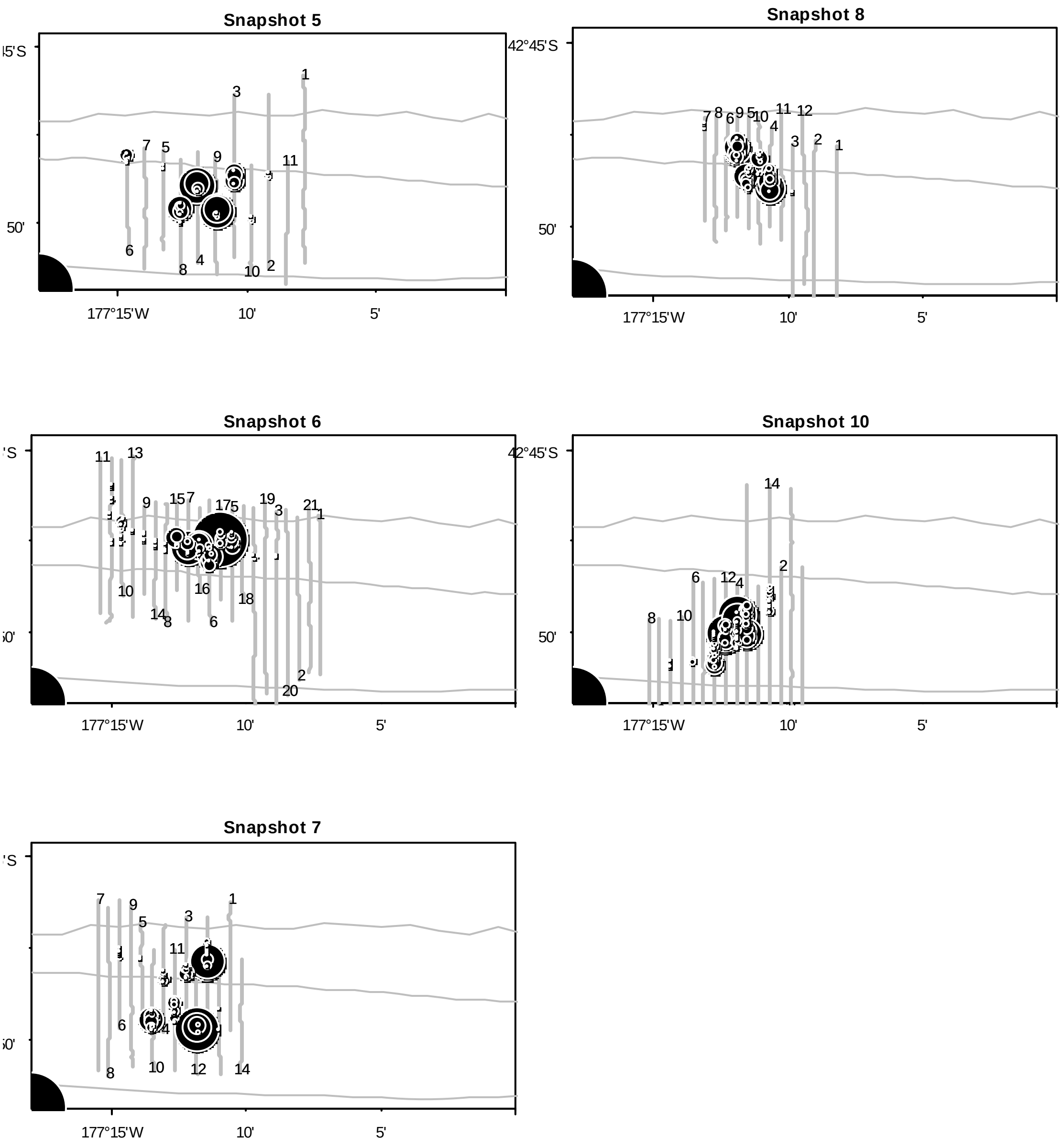

Figure 5.1 (cont.). Spawning Plume, transects and backscatter (circles, area proportional to backscatter) for snapshots that were analysed. Quarter circle in lower left corner is the reference value (same for all plots). Transect numbers are in order of steaming (numbers at one end of each transect).

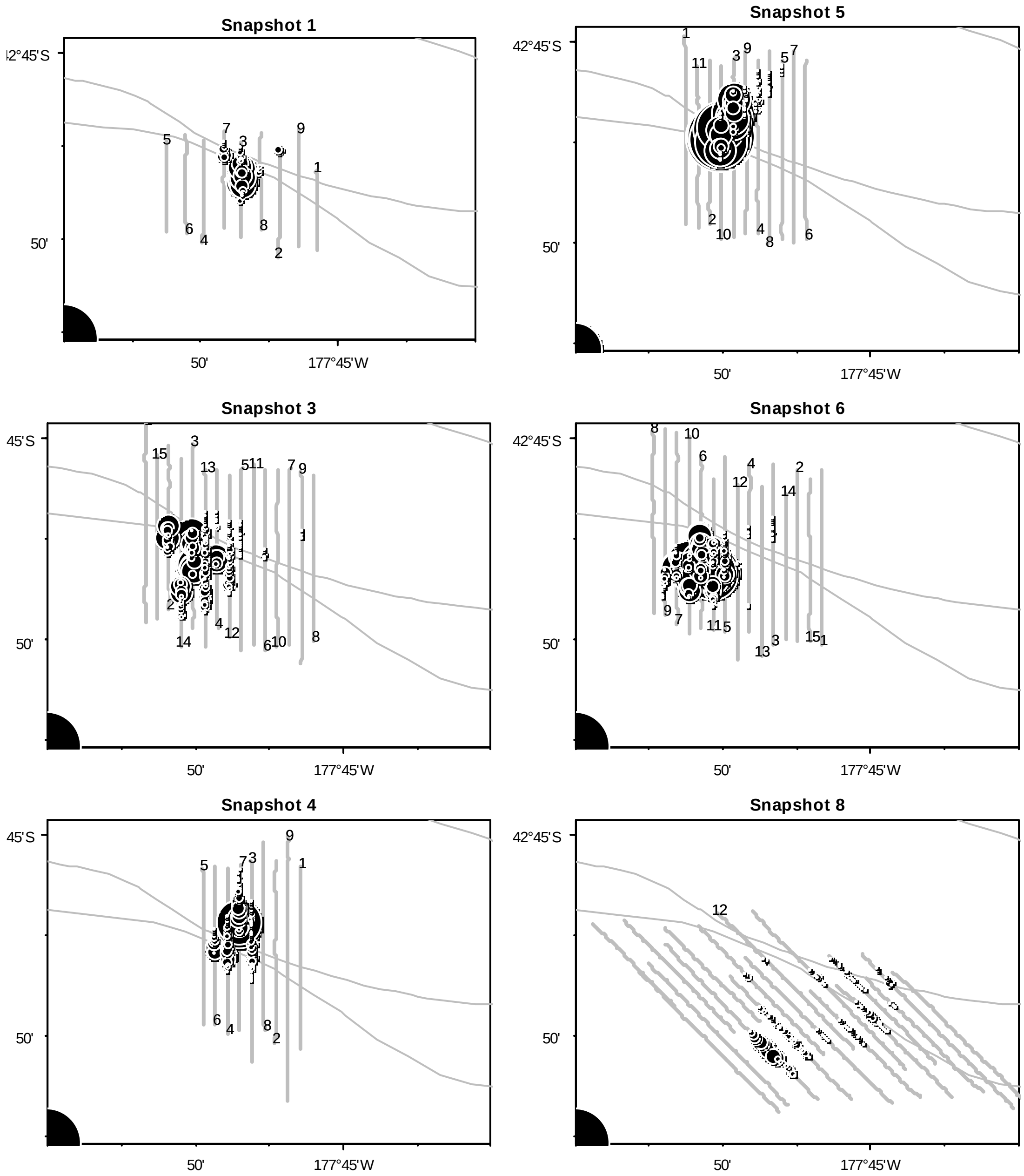

Figure 5.2. West Spawning Site, transects and backscatter (circles, area proportional to backscatter) for snapshots that were analysed. Quarter circle in lower left corner is the reference value (same for all plots). Transect numbers are in order of steaming (numbers at one end of each transect).