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Acoustic estimates of southern blue whiting from the Campbell Island Rise, August–September 2011 (TAN1112)

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The tenth acoustic survey of southern blue whiting (SBW) on the Campbell Island Rise was carried out from 28 August to 25 September 2011 (TAN1112). Two snapshots of the survey area were completed, on 4–12 September and 12–22 September respectively. Some SBW were detected at or beyond stratum boundaries in the first snapshot, so boundaries were modified in snapshot 2, with some strata extended and others reduced in an attempt to better reflect the distribution of fish. Twenty-one bottom trawls were carried out during the survey to collect data on species composition, length frequency, and spawning state of SBW. An autonomous acoustic-optical system was deployed on 10 trawls (8 mark identification tows and 2 additional tows) to collect *in situ* data on the acoustic target strength (TS) of SBW.

Pre-spawning adult SBW were detected in three areas during snapshot 1: in the north (stratum 2); east (stratum 8E); and south (stratum 7S). Extensive post-spawning marks were detected in eastern (strata 3S, 6N, 8N, and 8E) and northern areas (strata 2 and 4) during snapshot 2. Spawning appeared to occur from about 12–16 September while *Tangaroa* was in the southern area, with a second spawning period from 23–29 September after the acoustic survey was finished. Immature southern blue whiting marks were abundant and widespread in both snapshots, occurring in depths shallower than 380 m in strata 2 and 4, and shallower than 430 m in strata 5, 7N, and 7S. These were fish with lengths between 20 and 27 cm from the 2009 year-class (i.e., 2-year-olds). No juvenile marks were observed.

Biomass estimates were calculated for adult and immature SBW using the target strength (TS) to fork-length (FL) relationship of $TS = 38 \log_{10}FL - 97$, length frequency information from commercial and research trawls, and the calculated sound absorption coefficient of 9.44 dB km^{-1}. The estimate of adult SBW biomass for all strata was 103 346 t (c.v. 44%) in the first snapshot and 132 897 t (c.v. 18%) in the second snapshot, giving an average adult estimate of 118 122 t (c.v. 22%). Most of the biomass was from the eastern aggregation (74% of total adult biomass averaged over both snapshots), with smaller contributions from the northern (23% of biomass) and southern (3% of biomass) areas. The estimate of immature SBW biomass for all strata was 55 937 t (c.v. 16%) in the first snapshot and 73 273 t (c.v. 27%) in the second snapshot, giving an average immature estimate of 64 605 t (c.v. 17%). A 42% decline in adult biomass from 2009 was driven primarily by the very low estimate from the southern aggregation.

Adult and immature categories were decomposed to provide estimates of age 1, 2, 3, and 4+ fish. No SBW of age 1 were observed during the survey or caught in the fishery, therefore there are no estimates for this age class. The biomass estimate of age 4 and older fish (116 396 t) was the highest since 1998, following the recruitment of the strong 2006 and 2007 year-classes into the fishery. However, the 2011 survey suggested that these two year-classes are not as strong as indicated by the 2009 survey. The estimate of 2-year-olds (2009 year-class) was also relatively high (61 512 t), suggesting that this year-class is above average. Few 3-year-old fish (2008 year-class) were observed.

1. INTRODUCTION

Southern blue whiting (*Micromesistius australis*) is one of New Zealand's largest volume fisheries, with annual landings averaging 30 000 t in the last ten years (Ministry of Fisheries 2011). Southern blue whiting (SBW) occur in Sub-Antarctic waters, with known spawning grounds on the Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise (Hanchet 1999). The SBW fishery was developed in the early 1970s by the Soviet fleet. Landings have fluctuated considerably, peaking at 75 000 t in the 1991–92 fishing year, when almost 60 000 t was taken from the Bounty Platform stock. Southern blue whiting was introduced into the QMS from 1 April 2000 with separate TACCs for each of the four main stocks in SBW6. The TACC for the Campbell Island stock was increased from 20 000 t in 2009 to 29 400 t in 2011, based on the 2011 assessment which suggests that the biomass of the stock is expected to increase over the next one to two years as the strong recent year classes from 2006 and 2007 grow and enter the fishery (Ministry of Fisheries 2011).

Spawning occurs on the Bounty Platform from mid August to early September and three to four weeks later in the other areas (Hanchet 1998). During spawning, SBW typically form large midwater aggregations. Commercial and research fishing on spawning SBW aggregations result in very clean catches of SBW. The occurrence of single-species spawning aggregations allows accurate biomass estimation using acoustics.

A time series of acoustic surveys for SBW on the Campbell Plateau was started in 1993. The acoustic surveys have been used to measure relative abundance of adult SBW and also to predict pre-recruit numbers in each stock. The movement of fish during the survey period has required the development of an adaptive survey design to increase efficiency; alternative survey designs result in different biases in the estimate of biomass. There have been nine previous surveys of the Campbell grounds, in 1993, 1994, 1995, 1998, 2000, 2002, 2004, 2006, and 2009. The 2009 survey recorded the highest estimate of 2 year old fish and the second highest estimate of 3 year old fish in the time-series (Gauthier et al. 2011).

The Campbell SBW fishery is strongly recruitment driven and is currently dependent on fewer than 5 year classes, compared with up to 15 year classes in the past (Hanchet & Dunn 2010). As the fish recruit at 2 and 3 years of age to the fishery, surveys are required at regular intervals to keep the stock assessment model up to date. In 2009 and 2010, the catch on the Campbell Plateau was dominated numerically by the incoming 2006 and 2007 year classes which appear to be exceptionally strong and similar in size to the 1991 year class (Ministry of Fisheries 2011). The objective of this voyage was to obtain a further fisheries independent estimate of the size of recent year classes and to extend the time series of acoustic estimates for the Campbell Island Rise from 9 to 10 points in time for the 2012 stock assessment (Ministry of Fisheries Research Project DEE2010/02SBW).

This report summarises the data collected during the tenth research acoustic survey of SBW on the Campbell Island Rise in August–September 2011 and presents biomass estimates, fulfilling the reporting requirements for Objectives 1 and 2 of Ministry of Fisheries Research Project SBW2010/04A:

1. To estimate pre-recruit and spawning biomass at Campbell Island using an acoustic survey, with a target coefficient of variation (c.v.) of the estimate of 30 %.
2. To calibrate acoustic equipment used in the acoustic survey.

Data collected for estimating SBW target strength are summarised here, but analysis of and results from these data will be described in full in a separate report.

2. METHODS

2.1 Survey design

The time series of acoustic estimates for the Campbell Island SBW stock are from area-based surveys which provide fishery independent monitoring of the recruited part of the population as well as predicting the strength of year classes about to enter the fishery. An aggregation-based survey design is not appropriate for this fishery. Although much of the adult spawning biomass may be concentrated in one or more localised aggregations, a variable proportion of the biomass occurs away from these aggregations. The acoustic survey is also used to estimate abundance of pre-recruit SBW, which typically occur outside the area being fished by the commercial fleet. Attempts have also been made to survey the main SBW spawning aggregations on the Campbell Island Rise from industry vessels in 2003 (O'Driscoll & Hanchet 2004), 2006 (O'Driscoll et al. 2006), and 2010 (O'Driscoll 2011), but these gave much lower estimates of SBW biomass than those obtained from wide-area surveys. For example, the aggregation-based survey by two industry vessels in 2006 gave estimates of abundance which were only 10–15% of those from the wide-area research survey in the same year (O'Driscoll et al. 2006, 2007).

The best time to survey SBW acoustically is when they aggregate to spawn. On the Campbell Island Rise the onset of spawning over the past 10 years has typically been from 6 to 17 September (range 3–20 September). The 2011 survey was carried out from 28 August to 25 September 2011 to maximise the chances of covering the spawning period. The 29-day booking of *Tangaroa* allowed for 20 days in the survey area, 1 day for acoustic calibration, 2 days for loading and unloading, and 5 days steaming to and from Wellington. Within the 20 days of survey time, allowance was made for one day for target strength work and two days for bad weather.

We aimed to carry out at least two snapshots of the Campbell Island Rise spawning area. To achieve an overall target c.v. of 30% (as specified by the Ministry of Fisheries) required individual snapshot c.v.s both to be about 40%. The survey followed the two-phase design recommended by Dunn & Hanchet (1998) and Dunn et al. (2001), incorporating the modifications recommended by Hanchet et al. (2003).

The initial stratification and transect allocation for snapshot 1 (Table 1, Figure 1) was based on that used in the most recent survey of the area in 2009 (Gauthier et al. 2011). The core strata (2–7) have been included in all previous acoustic surveys. Stratum boundaries for 2011 were re-evaluated before the survey by examining the location of the commercial fishing fleet up to and including 2010 (Figure 2). Based on this analysis of the distribution of effort, we retained the adjusted stratum boundaries used for snapshot 1 of the 2009 survey, with minor modifications (see lower panel in Figure 1). Stratum areas for 8N, 8S, and 7S were the same as those surveyed in 2009. The latitude boundaries of stratum 8E were shifted slightly so that these align with stratum 8N. The area of stratum 9 was the same as that used for snapshot 2 in 2009 (Gauthier et al. 2011), with the area reduced slightly compared to snapshot 1 in 2009 by shifting the northern boundary south from 51° 27' S to 51° 30' S.

The stratum boundaries appeared to adequately encompass the distribution of most of the fishing fleet during the first snapshot in 2011, but there was some fishing east of stratum 8E and southwest of stratum 7S. At the time we surveyed stratum 8E on 8 September, all vessels were within the survey area. However, we extended the southern end of the western four transects in stratum 7S on 10 September from 53° 27'S to 53° 30'S because marks were detected close to the stratum boundary. Actual survey boundaries for snapshot 1 including approximate location of transects and trawls are shown in Figure 3.

Several modifications were made to stratum boundaries for snapshot 2 based on the location of the main fish aggregations during snapshot 1 and the activity of commercial fishing fleet (Table 1, Figure 4). These were:

1. Dividing stratum 7S into two (7SW and 7SE). Stratum 7SW was extended to the west and south.
2. Reducing stratum 6S by shifting the southern boundary north from 53˚ 25’S to 52˚ 30’S.
3. Reducing stratum 8S by shifting the southern boundary north from 52˚ 40’S to 52˚ 30’S.
4. Extending stratum 8E by shifting the southern boundary south from 52˚ 12’S to 52˚ 20’S.

The transect allocation in snapshot 2 was similar to that in snapshot 1 (Table 1), but one additional transect was added to 8E, one fewer transect was carried out in stratum 4, and the number of transects in stratum 7S (7SW and 7SE combined) was reduced from 10 to 8.

2.2 Acoustic data collection

Acoustic data were collected with NIWA’s Computerised Research Echo Sounder Technology (CREST) system (Coombs et al. 2003) and the multifrequency (18, 38, 70, 120, and 200 kHz) Simrad EK60 system on *Tangaroa*. A towed CREST system (Towbody 3), with a 38-kHz split-beam transducer, was used for most acoustic data collection along survey transects. A second towbody (Towbody 4) was carried as a spare, and was calibrated, but was not used during the survey. Data were also collected using the hull-mounted EK60 system throughout the voyage. The 38 kHz hull transducer was not transmitting during survey transects with the towed system to prevent interference, but was switched on when the towbody was on board the vessel. The 38 kHz hull system was also used for some survey transects when the weather conditions were suitable.

Both towbodies and the multifrequency hull echosounders were calibrated in the outer Marlborough Sounds on 30 August. The hull calibration showed that all five frequencies were operating correctly, with estimated calibration coefficients similar to default values obtained from a calibration in May 2008 (Appendix 1). Calibration values for Towbody 3 were comparable with previous calibrations, but the sphere was rarely near the centre of the beam. The calibration of Towbody 4 was not useful because there was a wiring fault in the winch which meant that the towbody appeared to have been operating on half-power during the calibration. Both towbodies were recalibrated in Perseverance Harbour on Campbell Island on 14 September, while sheltering from rough weather. Calculated calibration parameters for Towbody 3 are provided in Appendix 2.

Transect locations were randomly generated, and were carried out at right angles to the depth contours (i.e., from shallow to deep or vice versa). The minimum distance between transect midpoints varied between strata, and was calculated as follows:

$$m = 0.5 * L/n \qquad (1)$$

where m is minimum distance, L is length of stratum, and n is the number of transects..

The survey area extended from the 300 m depth contour in the west to its eastern boundary, which varied in depth from about 480 to 600 m. Transects were run at speeds of 6–10 knots (depending on the weather and sea conditions) with the acoustic towbody deployed 30–70 m below the surface. There is no evidence for a strong diel variation in SBW backscatter on the Campbell grounds (Hanchet et al. 2000a), so transects were carried out during day and night. Acoustic data collection was interrupted between transects for mark identification trawls.

2.3 Trawling

Trawling was carried out for mark identification, to collect biological data, and in support of TS data collection using the AOS (see Section 2.4). All trawls were carried out using the ratcatcher bottom trawl with 40 mm mesh codend. No fishing was carried out with the NIWA 119 hoki midwater trawl or mesopelagic trawl because a generator breakdown part-way through the voyage meant that we had reduced trawling capability. Acoustic recordings were made for all trawls using the five frequency hull-mounted transducers.

Most target identification work was focused on:
1. establishing species mix proportions away from dominant heavy marks, which are easily identified as SBW;
2. distinguishing less dense adults marks from pre-recruit marks in areas where they occur in similar depths;
3. identifying the size and age composition of SBW in the less dense pre-recruit marks including 1, 2, and immature 3 year old fish;
4. obtaining a sample of adult SBW in areas which were not being fished by the commercial fleet.

Trawling was carried out both day and night. For each trawl all items in the catch were sorted into species and weighed on Seaway motion-compensating electronic scales accurate to about 0.1 kg. Where possible, finfish, squid, and crustaceans were identified to species, and other benthic fauna to species or family. A random sample of up to 200 SBW and 50–200 of other important species from every tow was measured. In most tows the sex and macroscopic gonad stage (Appendix 3) of all SBW in the length sample were also determined. More detailed biological data were collected on a subsample of up to 20 SBW per trawl, and included fish length, weight, sex, gonad stage, gonad weight, and occasional observations on stomach fullness and contents, and prey condition. Otoliths were also collected from up to 20 SBW per trawl to augment those collected by the scientific observer programme.

Estimated SBW length frequencies from research trawls were constructed by scaling length frequencies from individual tows by the SBW catch in the tow.

2.4 Target strength data collection

In situ target strength measurements were attempted on ten trawls using the new acoustic-optical system (AOS) developed by NIWA. The AOS uses an autonomous EK60 38-kHz echosounder coupled to a high-definition underwater video, which can be mounted in a frame in the headline of a trawl. The trawl is used to herd fish under the AOS where visually verified estimates of target strength (TS) can be made.

A shallow calibration of the AOS was also carried out in Perseverance Harbour on 14 September. The AOS was then calibrated in deep water (down to about 500 m depth) in the north of stratum 2 on 20 September, and again, off the southeast coast of the South Island, on the steam home on 23 September.

2.5 Other data collection

A Seabird SM-37 Microcat CTD datalogger (serial number 2958) was mounted on the headline of the net during 19 bottom trawls to determine the absorption coefficient and speed of sound, and to define water mass characteristics in the area (Appendix 4). CTD drops were also carried out in conjunction with all the acoustic calibrations.

2.6 Commercial catch data

Additional information on the species composition, size, and spawning state of adult SBW in the survey area was obtained from commercial catch data collected by scientific observers. Data from the 2011 fishery were extracted from the Ministry of Fisheries Observer database in December 2011. Scaled length frequency distributions were calculated as the weighted (by catch) average of individual length samples. Data on female gonad stage (using the five-stage observer scale given by Hanchet (1998)) were summarised by date.

2.7 Acoustic data analysis

Acoustic data collected during the survey were analysed using standard echo-integration methods (MacLennan & Simmonds 1992), as implemented in NIWA's Echo Sounder Package (ESP2) software (McNeill 2001).

Echograms were visually examined, and the bottom determined by a combination of an in-built bottom tracking algorithm and manual editing. Regions were then defined corresponding to different acoustic mark types. Following the approach used in previous years, SBW acoustic marks were initially classified into adult (recruited fish), immature (mainly 2 year olds), and juvenile (1 year olds). Marks were classified subjectively, based on their appearance on the echogram (shape, structure, depth, strength, etc.), and using information from research trawls. Hanchet et al. (2002) provided representative examples of the different mark types.

Backscatter from regions identified as SBW was then integrated to produce an estimate of acoustic density (m^{-2}). During integration acoustic backscatter was corrected for the sound absorption by seawater. The calculated sound absorption for the area based on CTD data was 9.44 dB km^{-1} (Appendix 4).

Acoustic density was output in two ways. First, average acoustic density over each transect was calculated. These values were used in biomass estimation (see Section 2.8). Second, acoustic backscatter was integrated over 10-ping bins (vertical slices) to produce a series of acoustic densities for each transect (typically 100–700 values per transect). These data had a high spatial resolution, with each value (10 pings) corresponding to about 100 m along a transect, and were used to produce plots showing the spatial distribution of acoustic density (see Section 3.4).

2.8 Biomass estimation

Acoustic density estimates were converted to SBW biomass using the ratio, *r*, of mean weight to mean backscattering cross-section (linear equivalent of target strength). The ratio for immature SBW was calculated from the scaled length frequency distribution of SBW from research trawls by *Tangaroa* during the survey. The ratios for adults were calculated using the length frequency distribution of the commercial catch from observer data. There were differences in the size distribution of fish caught by commercial vessels from the northern, eastern, and southern aggregations (see Section 3.2) so three separate ratios were estimated for the three areas,

Acoustic target strength was derived using the target strength to fork length (TS-FL) relationship of Dunford and Macaulay (2006):

$$TS = 38 \log_{10}FL - 97 \qquad (2)$$

Where TS is in decibels (dB re $1m^2$) and FL in centimetres (cm).

SBW weight, w (in grams), was determined using the combined length-weight relationship for spawning SBW from Hanchet (1991):

$$w = 0.00439 * FL^{3.133} \quad (3)$$

Mean weight and mean backscattering cross-section (linear equivalent of TS) for each category (northern adult, eastern adult, southern adult, and immature) were obtained by transforming the scaled length frequency distribution for both sexes combined by Equations 3 and 2 respectively, and then calculating the means of the transformed distributions.

Biomass estimates and variances were calculated from transect density estimates using the formulae of Jolly & Hampton (1990). The mean SBW stratum density for each category was multiplied by the stratum area to obtain biomass estimates for each stratum, which were then summed over all strata to produce an estimate for the snapshot. The two snapshots were averaged to produce the survey estimate. The sampling precision (c.v.) of the mean biomass estimate from the survey combined the variance from each snapshot, assuming that each snapshot was independent. Note that the sampling precision will greatly underestimate the overall survey variability, which also includes uncertainty in acoustic deadzone, TS, calibration, and mark identification (Rose et al. 2000).

Biomass estimates were then decomposed to provide estimates of 1, 2, 3, and age 4+ fish using the length frequency data together with the age-length key derived from commercial and research tows on the Campbell Island Rise in 2011 following Hanchet et al. (2000c).

3. RESULTS

3.1 Data collection

All surveys objectives were achieved. Only about 48 hours of survey time was lost because of poor weather conditions. A particularly bad weather system was encountered while steaming south at the beginning of the survey so arrival in the survey area was delayed by 36 hours. This was followed by relatively good conditions (by southern ocean standards) for the remainder of the voyage. Strong winds and large swells stopped work on 13 September and the vessel steamed to shelter at Campbell Island, where we carried out a calibration. Although weather and sea conditions allowed collection of acoustic data for the majority of the voyage, it was marginal between 4 and 12 September, with 30–40 knot winds and 4–8 m swells. These conditions reinforced the value of using specialist towed acoustic systems, as data quality on the hull echosounders during this period was poor. A total of 462 acoustic data files (187 towbody and 275 hull) were recorded during the survey.

Twenty one bottom trawls were made to identify targets and collect biological samples (Table 2, Figures 3 and 4). There were three additional tows: trawl 1 was a gear trial in Cook Strait, and trawls 14 and 22 were AOS-only tows, with the codend open. Tow length ranged from 0.40 to 2.28 n. miles at an average speed of 3.4 knots (Table 2). The total trawl catch was 16 095.3 kg. This was made up of 78 species or species groups. Most tows were dominated by southern blue whiting (82.6% of total catch, Table 2). The most abundant bycatch species were ling (3.9%), pale ghost shark (2.0%), and javelinfish (1.9%). A total of 8877 fish and squid of 18 different species were measured (Table 3). Of these, 1424 fish were also individually weighed (Table 3), and 420 sets of SBW otoliths were collected for ageing.

In situ target strength measurements were attempted on ten trawls using the new acoustic-optical system (AOS). Use of the AOS was limited by weather conditions as it could only be deployed in winds less than about 25 knots and swell less than 2 m to prevent damage to equipment. Suitable conditions occurred on 11 September, and 15–20 September. Only 6 of the 10 AOS deployments were successful. The first AOS deployment (on trawl 11) was unsuccessful because the lights did not turn on. The deployments on trawls 13, 14, and 21 were unsuccessful because the microprocessor controller did not switch on the echosounder and camera. The six successful AOS deployments yielded images and acoustic data from both immature and adult SBW (e.g., Figure 5). This should enable us to greatly improve our estimate of SBW TS (Dunford & Macaulay 2006, Pedersen et al. 2011).

The 19 CTD profiles showed that the water column was unstratified with surface temperatures ranging between 7.0 and 7.2 °C (Appendix 4).

3.2 Commercial data

The first vessel began fishing on the Campbell Island grounds on 17 August. The location of commercial trawls in 2011 is shown in Figure 6. Fishing effort was concentrated in the east before the survey and during most of snapshot 1, with the first vessel arriving in the southern area on 10 September. During the second snapshot, most effort was in the east and south. There was significant effort southwest of stratum 7S at the end of snapshot 1 and south and west of stratum 7SW during snapshot 2 (Figure 6). Fishing effort shifted northwest after the *Tangaroa* had left the area and notified vessels about the location of the northern aggregation. The final SBW target tow in the area was reported on 6 October.

Commercial data were divided into three sub-areas: north (strata 2 and 4); east (strata 3S, 6N, 8N, 8S, and 8E); and south (stratum 7S), corresponding to the locations of the three adult aggregations detected during the acoustic survey (see Section 3.4). A total catch of 29 204 t of SBW was recorded from 976 tows on TCEPR. Of this, 15 205 t was taken from 507 tows in the east; 7439 t from 234 tows in the north; and 6560 t from 235 tows in the south. About 22% of the southern catch (1429 t) was taken in 50 tows outside the (adjusted snapshot 2) 2011 acoustic survey boundary.

Spawning appeared to occur over a very short period from about 12–16 September (Figure 7), while *Tangaroa* was in the southern area, with a second peak after we had left the survey area from 23–29 September. The timing of spawning in 2011 appeared to be slightly later than in 2006 or 2009 (Figure 7).

The length of fish caught by commercial vessels from the northern, eastern, and southern aggregations was similar, with the main mode at 32–35 cm for males and 34–39 cm for females (Figure 8). A mode of larger fish, with a peak at 41 cm for males and 45 cm for females was also present. The southern area showed a higher proportion of fish larger than 40 cm than in the northern and eastern areas.

3.3 Mark identification

Mark types were generally similar to those described for SBW on the Campbell Island Rise by Hanchet et al. (2002). As in previous years, most of the main adult marks were relatively easy to identify by their appearance and location in the water column. However, mark identification in snapshot 2 was more challenging than usual because the post-spawning marks encountered were more diffuse and widespread than the stronger, pre-spawning and spawning, marks observed in snapshot 1 and in previous surveys (e.g., Gauthier et al. 2011).

Pre-spawning adult marks were detected during snapshot 1 in stratum 2 on 4 September (e.g., Figure 9) and in stratum 8E on 7 September (e.g., Figures 10 and 11). Adult marks were also recorded at the end of snapshot 1 and the start of snapshot 2 in stratum 7S and 7SW on September 11–13. These marks were in midwater and were characteristic of weak spawning aggregations (e.g., Figure 12). Vessels in the vicinity reported catching spawning fish. Post-spawning fish were widely distributed in strata 2, 4, 3S, 6N, 8N, and 8E on 18–21 September. These fish formed a dispersed layer up to 250 m of the bottom during the day which descended to within 50 m of the bottom during the day (e.g., Figure 13). Strongest marks were in 390 to 420 m depth north of Campbell Island in stratum 2 (e.g., Figure 14). Half of the 10 trawls on adult marks caught a high proportion of SBW (more than 80–100% by weight), and catch rates in these trawls was high (see Table 2). The other five trawls on adult marks had lower catch rates with a smaller proportion of SBW (8–50% by weight). In some of these tows it was clear that the ratcatcher bottom trawl did not adequately sample the mark, which was often away from the bottom (e.g., Figure 12).

Immature SBW marks were abundant and widespread during this survey, occurring in depths shallower than 420 m in strata 2, 4, 5, 7N, and 7S. Marks were in characteristic "plumes" or clumps during the day (e.g., Figures 14 and 15) which dispersed at night (e.g., Figure 16). Seven trawls on immature marks all had moderate catch rates with a high proportion (mean 81% by weight) of 20–27 cm SBW (see Table 2, Figure 8). Ageing later showed that these were slow growing two year-olds from the 2009 year-class. No attempt was made to distinguish immature and juvenile marks in this survey as no juvenile (1 year-old) SBW were caught. As in 2009 (Gauthier et al. 2011), attempts to sample "juvenile-type" marks in 2011 yielded immature 2 year old fish.

Weak background demersal marks (bottom "fuzz") was widespread throughout the survey area (e.g., in the deeper part of the transect shown in Figure 15), but four trawls on this mark type indicated that this contained a low proportion of SBW (mean 16% by weight, see Table 2). Mesopelagic fish marks were common, particularly in the south. During the day mesopelagic marks were observed as series of schools between 50 and 300 m depth. These schools tended to disperse at night. No fishing on mesopelagic marks was carried out during this survey.

In summary, the main SBW marks seen during the survey were assigned into the following categories.

- Characteristic moderately dense marks in 300–420 m depth were the immature SBW category (mainly 2 year old).
- Dense marks in water deeper than 380 m were the adult SBW category.

There was some overlap between the depth range of immature and adult marks, particularly in the northern area (strata 2 and 4) in snapshot 2 when marks were almost continuous (e.g., see Figure 14). A depth boundary of 380 m was used to separate adult and immature marks in these strata, based on a transition in mark type (from layers to clumps) at about this depth, and results from trawling which caught adults as shallow as 390 m, but exclusively immature fish at 300–350 m.

No species decomposition of acoustic backscatter was attempted because of the small number of trawls and uncertainty associated with the relative catchabilities of different species. All backscatter from adult and immature marks was assumed to be from SBW, which was consistent with mark identification in previous years (Hanchet et al. 2003, O'Driscoll et al. 2007, Gauthier et al. 2011). The acoustic contribution of SBW in the background demersal fuzz marks was ignored.

Because of some uncertainty associated with subjective classification of post-spawning marks in eastern areas (strata 3S, 6N, 6S, 8N, 8S, 8E, and 9) in snapshot 2, we carried out a sensitivity analysis by integrating all bottom-referenced backscatter (i.e., excluding mesopelagic marks) in these strata in snapshot 2 and subtracting the background backscatter from the same strata in snapshot 1 (where SBW marks were easily distinguished). This sensitivity assumes the increase in backscatter in bottom layers in snapshot 2 was entirely due to the presence of post-spawning SBW. This was the same method used to partition post-spawning marks in 1998 (Hanchet et al. 2000b).

3.4 Distribution of SBW backscatter

Expanding symbol plots show the spatial distribution of adult and immature SBW along each transect during the two acoustic snapshots (Figures 17–20). As noted in Section 3.3, adults were detected in three areas during snapshot 1: in the north (stratum 2); east (stratum 8E); and south (stratum 7S). Extensive, but weaker, marks were also detected in eastern (strata 3S, 6N, 8N, and 8E) and northern areas (strata 2 and 4) during snapshot 2.

Immature SBW marks were abundant and widespread in both snapshots, occurring in depths shallower than 430 m in strata 2, 4, 5, 7N, and 7S. The densest immature marks were in strata 7N and 7S in the first snapshot and strata 2 and 5 in snapshot 2. Consistent with previous surveys, the western (inner) survey boundary was at 300 m depth. Immature marks occurred close to this boundary (Figures 19–20) and may have extended shallower than 300 m, but the survey priority was to estimate abundance of adult SBW so there was insufficient time to fully explore the likely distribution of immature SBW.

3.5 SBW size and maturity

Length, sex, and gonad stage were determined for 4041 SBW during the survey (see Table 3). The scaled length frequencies from research tows on adult and immature marks are compared to data from the commercial fishery in Figure 8. The size distributions of fish from research tows on adult aggregations in the north and east was generally similar to the commercial catch (see Section 3.2), with most fish between 30 and 40 cm with a modal length of 33–35 cm. Like the commercial catch, adult fish from research tows in the south showed a broader size distribution, with a higher proportion of fish larger than 40 cm than in the northern and eastern areas, but research sample sizes in this area were small. As noted in Section 3.3 above, fish caught from immature marks had a single mode between 20 and 27 cm, and were two-year olds from the 2009 year-class.

Inferences about timing of spawning cannot be made from research data because of the small number of tows and also because much of the fishing was outside the main spawning aggregations. Almost all adult females SBW caught in snapshot 1 were pre-spawning (stages 2 and 3), and almost all adult SBW caught in snapshot 2 were post-spawning (stages 6–8) (see Appendix 3 for description of research stages). Running ripe fish were seldom observed in research trawls, except in tow 16 in stratum 8S on 16 September (Table 4). Both males and females in the immature category were almost exclusively stage 1.

3.6 SBW biomass estimates

The values of *r* for each SBW category based on the length frequency distributions in Figure 8 are given in Table 5. SBW biomass estimates by snapshot and stratum are given in Table 6. These estimates were calculated using the TS-length relationship of Dunford & Macaulay (2006) and a calculated sound absorption coefficient of 9.44 dB km^{-1} (see Appendix 4). Note that the estimates in Table 6 are not directly comparable with those from previous SBW acoustic survey reports which used older estimates of sound absorption (typically 8.0 dB km^{-1}) and TS (Monstad et al. 1992). No towbody motion correction (Dunford 2005) was applied, as measurements of towbody pitch and roll are not available for all surveys in the time-series. O'Driscoll et al. (2007) indicated that compensating for motion correction increased biomass by only 3–10% in 2006. As expected, the magnitude of the change due to motion correction was related to mark depth (larger effect with increasing depth) and sea conditions (larger effect in poor conditions when there was greater towbody motion).

The adult biomass estimate was 103 346 t (c.v. 44%) in snapshot 1 and 132 897 t (c.v. 18%) in snapshot 2. Nearly 70% of the adult biomass in both snapshots was outside of the historical core area (strata 2–7), notably in stratum 8N and 8E, and to the south-west of the original boundary of stratum 7 (stratum 7SW in snapshot 2). The estimated adult biomass in 2011 (average of both snapshots) was 118 122 t (c.v. 22%), which was only 58% of the adult biomass estimated in 2009 (204 539 t), but higher than adult biomass estimated in 2004 and 2006, and similar to that in 2002 (Table 7).

The estimate of SBW in the eastern aggregation (strata 3S, 6N, 6S, 8N, 8S, 8E, and 9) in snapshot 2 based on subjective classification of post-spawning marks was 94 730 t (c.v. 23%) (see Table 6). In the sensitivity analysis, where we assumed that all of the increase in backscatter in bottom layers from snapshot 1 to snapshot 2 was due to post-spawning SBW, the biomass estimate in these strata in snapshot 2 increased to 101 542 t (c.v. 18%). These estimates are very similar, and we concluded that the subjective classification was doing an adequate job of distinguishing post-spawning SBW from other species.

Biomass of immature SBW was also lower than in 2009, but still the third highest estimate in the time-series (Table 7) with 55 937 t (c.v. 16%) in snapshot 1 and 73 273 t (c.v. 27%) in snapshot 2, giving an average estimate of 64 605 t (c.v. 17%). Immature marks were widespread, but all within the historical core area.

The decomposed biomass estimates by age class are shown in Table 8. The 2011 biomass estimates for age 2, 3, and 4+ SBW (including all strata) were 61 512 t (c.v. 17%), 1668 t (22%), and 116 396 t (22%) respectively. Because no juvenile marks were observed during the 2011 survey, there are no estimates of biomass for 1 year old SBW. The time series of decomposed biomass estimates at age for the Campbell Island grounds are summarised in Table 9. The biomass estimate of age 4 and older fish was the highest since 1998, following the recruitment of the strong 2006 and 2007 year-classes into the fishery. The estimate of 2-year-olds was also relatively high, suggesting that the 2009 year-class is above average. Few 3-year-old fish were observed, indicating a weak 2008 year-class.

4. DISCUSSION

4.1 Timing of the survey

The timing and duration of the 2011 survey were similar to that in the previous four surveys (2002, 2004, 2006, and 2009). The survey was about one week earlier than before 2002 (see Figure 7). In 2011, spawning appeared to occur over a very short period from about 12 to 16 September, with a second peak in the northern area after *Tangaroa* had left the survey area from 23–29 September (see Figure 7). The timing of the survey relative to spawning was therefore appropriate, with snapshot 1 surveying pre-spawning fish, and snapshot 2 primarily surveying post-spawning fish. However, unlike in other recent surveys, no very dense spawning aggregations were observed in either snapshot in 2011.

4.2 Variability between snapshots

Adult and immature biomass estimates were higher in the second snapshot, but there was more consistency between snapshot estimates than in many of the previous surveys. For example in 2009, the adult estimate from snapshot 2 was nearly double that from snapshot 1 (Gauthier et al. 2011). Estimates of adult and immature SBW in both snapshots had relative low c.v.s (less than 44%), and the Ministry of Fisheries target c.v. of 30% for the average estimate was achieved (Table 6). The estimated adult c.v. of 22% was the lowest since the 2000 survey (Table 7). The relatively precision of the 2011 survey estimate reflects the good spatial coverage of the survey area and the absence of very dense, tightly concentrated, aggregations.

4.3 Treatment of fish outside the core survey area

Between 2002 and 2004, there was an increased effort and increased catch east of 171° E and outside the core acoustic strata (Hanchet 2005), so the acoustic survey boundaries for the 2002, 2004, 2006, 2009, and current surveys were modified accordingly. From 2005 to 2008, few commercial tows were made east of the core acoustic strata (see Figure 2) and in 2006 over 90% of the SBW biomass was within the core acoustic strata (O'Driscoll et al. 2007). However in 2009–11 much of the fishing was east of 171° E (see Figures 2 and 6). In 2009, about 50% of the total biomass was recorded outside the core area in strata 8N-8E-8S during the acoustic survey (Gauthier et al. 2011), and the contribution from these strata increased to 68% of the total adult biomass in 2011 (see Table 6). This suggests a return to the distribution pattern seen in 2002 and 2004. It is unlikely that these eastern fish represent a new (previously unsurveyed) aggregation. Hanchet (2005) examined commercial length frequency data from 1997 to 2004 and found that SBW caught from the eastern aggregation (outside of the core area) had a similar size distribution to those caught in the north within the core area. Boundaries of stratum 7S were also extended in both 2009 (Gauthier et al. 2011) and in this survey due to the presence of fish to the south and west. Few adult SBW were detected within the old (core) boundaries of stratum 7, and it seems likely that this aggregation has shifted in recent years. Despite the expansion of the survey area, the estimate of SBW from the southern aggregation was relatively small in 2011, and there is a concern that we may have missed detecting SBW in this area. However, the revised survey boundaries did encompass 80% of the commercial catch and effort in the south (see Figure 6).

The observation of a third, apparently separate, aggregation of spawning fish north of Campbell Island in 2011 in stratum 2 was unexpected. Recently there has been little commercial fishing effort in this area (e.g., Figure 2), and few adult SBW were detected in this stratum during previous surveys. The size distribution of fish from the northern aggregation in both commercial and research tows was similar to that from the eastern aggregation (see Figure 8), so it is possible the fish that historically spawned in a single aggregation in the northeast have split into two distinct aggregations in the north and east in 2011.

All fish recorded during the survey were used for the biomass estimates. In light of the distribution of SBW in 2011, we recommend that the survey area and stratification continues to be reviewed before future surveys.

4.4 Comparison between years

Although the acoustic biomass estimate for SBW 4 years and older on the Campbell Island Rise increased by 26% in 2011, this increase was lower than that expected given the very high biomass of 2 and 3 year-old fish (2007 and 2006 year-class) detected in the 2009 survey (see Table 9). These year-classes should now be fully recruited to the adult spawning population, and length frequency data suggest that fish from these year-classes dominate the commercial catch (see Figure 8).

The acoustic biomass estimate for adult fish (which includes spawning 3 year-olds) decreased by 42% from 2009 (see Table 7). This decrease was driven primarily by the much lower contribution of the southern aggregation. In 2009, adult estimates from this aggregation (stratum 7S and 7SW) were 29 285 t (c.v. 29%) and 66 791 t (c.v. 73%) from snapshots 1 and 2 respectively (Gauthier et al. 2011). In 2011, the average adult biomass estimate from the two snapshots of the equivalent southern strata was only 4027 t (c.v. 41%) (see Table 6), which was lower than the commercial catch from the south of 6560 t.

The largest aggregation in 2011 was in the east with an average biomass estimates of 87 077 t (c.v. 27%) from the two snapshots. This was similar to the adult biomass estimates from the eastern strata (8N, 8E, and 8S) of 77 000 t and 125 000 t in the 2009 survey (Gauthier et al. 2011). Three industry vessels also collected acoustic data along 54 transects in 8 aggregation-based snapshots of the eastern SBW aggregation (within research stratum 8E) from 8–13 September 2010 (O’Driscoll 2011). Biomass estimates from the 2010 industry surveys ranged from 12 081 t (c.v. 65%) to 69 423 t (c.v. 38%). The two best estimates based on survey execution and coverage gave an average of 65 737 t (c.v. 38%) (O’Driscoll 2011). This was lower than the estimate of the eastern aggregation from this survey, but generally consistent, given the much smaller spatial coverage of the aggregation-based surveys (surveyed area 168–171 km^2 in 2010 compared to about 4 600 km^2 in strata 8N, 8S, and 8E in the 2011 research survey).

Biomass of immature SBW was also lower than in 2009, but the estimate of age-2 fish was still the third highest in the time-series (see Table 9), which suggests relatively good recruitment of the 2009 year-class.

4.5 SBW target strength

Very recent work on the acoustic target strength (TS) of the closely related blue whiting (*Micromesistius poutassou*) raises concern that acoustic estimates based on the TS-length relationship of Dunford & Macaulay (2006) may overestimate SBW biomass. Pedersen et al. (2011) carried out *in situ* measurements and found that blue whiting TS was considerably higher than that observed and modelled for SBW. They provide a TS-to-total length (TL) relationship for blue whiting of:

$$TS = 20 \log_{10} TL - 65.2 \qquad (3)$$

If we apply this equation in place of Equation (1) in calculating the ratio of mean weight to mean backscattering cross section (after converting fork length to total length using the relationship $TL = 1.06\ FL - 0.28$), estimates of adult SBW biomass in the northern, eastern, and southern areas would be only 41%, 39%, and 44% of the estimates in Table 6. Because of the very different slopes of the alternative TS-length relationships in Equations (1) and (3), the effect on biomass is length-dependent, with a greater difference at smaller fish lengths (Figure 21). If the relationship proposed by Pedersen et al (2011) is correct, we may be overestimating immature SBW abundance in 2011 by a factor of 5.5. This would lead to a bias within the relative time-series where acoustic surveys overestimate fish at younger ages relative older ages. Target strength experiments on SBW carried out using the acoustic-optical system (AOS) on this voyage should help to reconcile the very large difference in TS estimates for SBW and the new estimates for blue whiting, but results will not be available until June 2012.

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7. TABLES

Table 1: Summary of transects carried out during the 2011 acoustic survey of the Campbell Island Rise. Approximate transect positions are plotted in Figures 3–4.

Snapshot 1 (4–12 Sep)			Snapshot 2 (12–22 Sep)		
Stratum	Area (km^2)	Transects	Stratum	Area (km^2)	Transects
2	3 154	4	2	3 154	4
3N	2 342	3	3N	2 342	3
3S	1 013	4	3S	1 013	4
4	2 690	5	4	2 690	4
5	3 029	4	5	3 029	4
6N	1 150	4	6N	1 150	4
6S	3 025	3	6S*	755	3
7N	2 980	4	7N	2 980	4
7S	1 995	10	7SE**	933	3
8N	1 436	4	7SW**	1 623	5
8S	1 452	3	8N	1 436	4
8E	1 730	4	8S^{+}	945	3
9	798	3	8E^{++}	2 253	5
			9	798	3
Total	26 794	55		25 101	53

* Stratum 6S southern boundary was shifted north from 53˚ 25’S to 52˚ 30’S.
** Stratum 7S was divided into two and boundaries were adjusted.
$^{+}$ Stratum 8S southern boundary was shifted north from 52˚ 40’S to 52˚ 30’S.
$^{++}$ Stratum 8E southern boundary was shifted south from 52˚ 12’S to 52˚ 20’

Table 2: Trawl station details and catch of the main species during the 2011 acoustic survey of the Campbell Island Rise. Tow positions are plotted in Figures 1 and 2. Mark type: Trial, gear trial; Adult; Imm, immature; Back, background. Species: SBW, southern blue whiting; LIN, ling; JAV, javelinfish; SSI, silverside; CAS, oblique banded rattail; GSP, pale ghost shark. *Tows with codend open.

		Mark	AOS		Start	Start	Tow	Tow length	Catch (kg)						
Tow	Date	type	(Y/N)	Stratum	Latitude (°S)	Longitude (°E)	depth (m)	(n. mile)	SBW	LIN	JAV	SSI	CAS	GSP	Total
1*	30-Aug-11	Trial	N	-	41 06.19	174 32.27	251	2.85	-	-	-	-	-	-	-
2	4-Sep-11	Adult	N	2	51 27.09	169 42.09	480	1.43	810.8	3.2	22.1	62.2	2.5	65.8	1 027.6
3	4-Sep-11	Adult	N	2	51 31.33	169 39.97	419	0.80	2 169.7	30.9	2.1	7.2	4.9	20.8	2 303.8
4	6-Sep-11	Imm	N	2	51 49.92	170 04.87	328	0.81	76.2	0.0	0.0	3.3	2.9	0.0	92.3
5	6-Sep-11	Imm	N	4	51 54.93	170 23.75	354	0.41	161.2	0.8	0.1	4.6	0.9	0.0	178.5
6	7-Sep-11	Back	N	5	51 55.97	170 37.14	422	1.16	13.0	0.0	1.2	9.3	1.7	9.6	442.6
7	8-Sep-11	Imm	N	5	52 07.96	170 33.43	418	0.90	142.3	0.7	2.3	6.5	2.7	9.3	170.4
8	10-Sep-11	Imm	N	7N	52 53.84	170 11.98	370	0.88	195.7	0.3	1.8	4.4	52.0	0.0	285.5
9	10-Sep-11	Imm	N	7S	53 12.84	169 57.28	322	0.84	103.8	0.0	0.9	6.9	88.4	0.0	210.5
10	10-Sep-11	Back	N	7S	53 17.55	170 03.11	434	0.92	3.4	0.0	1.4	2.4	6.6	0.0	15.3
11	11-Sep-11	Adult	Y	7S	53 23.58	170 02.73	572	0.80	32.2	33.0	16.1	0.9	6.5	15.2	145.8
12	11-Sep-11	Adult	Y	7S	53 27.14	169 47.86	550	1.73	28.8	23.0	14.8	1.4	1.4	8.6	123.6
13	15-Sep-11	Imm	Y	7N	52 42.15	170 11.29	397	1.10	648.5	0.5	1.9	0.5	2.4	0.0	681.9
14*	15-Sep-11	Imm	Y	7N	52 42.12	170 11.63	396	0.58	-	-	-	-	-	-	-
15	16-Sep-11	Imm	Y	5	52 26.29	170 13.83	386	1.40	178.6	0.0	0.1	0.6	0.1	0.0	182.8
16	16-Sep-11	Adult	N	8S	52 13.69	171 22.57	519	1.12	26.3	61.1	62.1	5.5	10.6	64.8	337.5
17	17-Sep-11	Adult	N	8E	51 51.79	171 42.44	519	0.88	396.6	292.9	20.3	5.1	2.0	7.9	836.4
18	18-Sep-11	Adult	Y	6N	51 53.87	170 59.95	492	2.22	286.9	32.4	1.5	2.6	0.1	12.6	345.0
19	18-Sep-11	Adult	N	8N	51 51.86	171 12.86	504	0.62	30.7	89.6	31.5	7.2	2.8	16.8	276.0
20	19-Sep-11	Back	Y	9	51 29.74	170 52.32	524	1.84	44.7	8.8	8.0	5.6	0.4	33.4	119.3
21	20-Sep-11	Adult	Y	2	51 36.42	169 51.30	399	1.07	1 992.7	2.6	0.5	6.7	1.3	12.2	2 021.9
22*	20-Sep-11	Adult	Y	2	51 36.60	169 51.30	396	2.28	-	-	-	-	-	-	-
23	20-Sep-11	Adult	Y	4	51 36.78	170 08.61	424	1.69	5 944.8	0.0	0.8	2.3	0.4	6.6	5 962.4
24	21-Sep-11	Back	N	3N	51 07.68	170 14.09	551	1.75	8.4	38.7	119.9	10.9	3.4	40.1	299.6
Total									13 295.3	621.3	309.4	156.1	194.0	323.7	16 095.3

Table 3: Total numbers of fish measured for length frequency distributions and biological samples. The total number of fish measured is sometimes greater than the sum of males and females because some fish were unsexed.

Species	Species code	Number measured Males	Number measured Females	Number measured Total	Number of biological samples
Oblique banded rattail	CAS	18	58	1047	162
Banded rattail	CFA	0	0	463	10
Olivers rattail	COL	0	1	207	0
Dwarf cod	DCO	0	0	28	28
Ghost shark	GSH	12	6	18	18
Pale ghost shark	GSP	109	47	156	156
Hake	HAK	1	22	23	23
Hoki	HOK	27	27	54	54
Javelin fish	JAV	0	38	1 491	63
Lookdown dory	LDO	1	2	3	3
Ling	LIN	70	144	215	215
NZ southern arrow squid	NOS	3	3	6	6
Rough skate	RSK	1	2	3	3
Southern blue whiting	SBW	1 967	2 072	4 041	466
Spiny dogfish	SPD	1	40	41	41
Silverside	SSI	5	3	1 066	161
Smooth skate	SSK	0	2	2	2
White warehou	WWA	12	1	13	13
Total		2 227	2 468	8 877	1 424

Table 4: Gonad stages of SBW caught in research trawls during the 2011 acoustic survey. Gonad stages are defined in Appendix 3.

				Males							Females							
Tow	Date	Stratum	Mark type	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
2	4-Sep-11	2	Adult	0	1	82	7	0	0	0	1	0	148	0	0	0	0	0
3	4-Sep-11	2	Adult	0	1	89	28	0	0	0	1	0	119	0	0	0	0	0
4	6-Sep-11	2	Imm	112	0	5	0	0	0	0	150	0	0	0	0	0	0	0
5	6-Sep-11	4	Imm	140	5	4	0	0	0	0	133	0	0	0	0	0	0	0
6	7-Sep-11	5	Back	47	0	9	0	0	0	0	45	0	2	0	0	0	0	0
7	8-Sep-11	5	Imm	102	6	1	0	0	0	0	117	0	1	0	0	0	0	0
8	10-Sep-11	7N	Imm	110	0	26	0	0	0	0	134	0	0	0	0	0	0	0
9	10-Sep-11	7S	Imm	108	7	6	0	0	0	0	130	0	0	0	0	0	0	0
10	10-Sep-11	7S	Back	5	0	1	1	0	0	0	10	0	3	0	0	0	0	0
11	11-Sep-11	7S	Adult	0	7	19	4	1	1	0	0	0	37	3	0	0	0	0
12	11-Sep-11	7S	Adult	0	4	24	16	4	0	0	1	0	31	6	1	0	0	0
13	15-Sep-11	7N	Imm	118	5	4	1	0	0	0	100	0	0	0	0	0	0	0
15	16-Sep-11	5	Imm	98	0	15	0	0	0	0	112	0	0	0	0	0	0	0
16	16-Sep-11	8S	Adult	3	3	12	9	34	2	3	3	0	6	6	14	3	2	0
17	17-Sep-11	8E	Adult	0	1	2	4	7	28	56	0	0	5	7	3	52	60	0
18	18-Sep-11	6N	Adult	0	1	0	0	3	29	76	2	0	3	0	0	41	52	0
19	18-Sep-11	8N	Adult	0	0	0	0	7	15	32	0	0	0	0	4	21	30	0
20	19-Sep-11	9	Back	3	2	0	0	3	12	79	2	0	0	0	0	20	47	0
21	20-Sep-11	2	Adult	3	0	2	0	2	57	22	5	5	13	10	7	20	126	1
23	20-Sep-11	4	Adult	1	0	0	1	25	62	133	5	0	10	4	8	93	76	0
24	21-Sep-11	3N	Back	0	0	0	0	0	1	5	2	0	1	0	0	3	15	0

Table 5: Estimates of the ratio *r* used to convert SBW backscatter to biomass Values are derived from the scaled length frequency distributions in Figure 8. Different ratios were used for adult marks from northern, eastern, and southern areas. σ is the acoustic backscattering coefficient.

Category	Data source	No. of trawls	Mean length (cm)	Mean weight (kg)	Mean σ (m^2)	Mean TS (dB)	*r* (kg m^{-2})
Adult (north)	Commercial	32	36.5	0.356	0.0001821	-37.4	1 955
Adult (east)	Commercial	158	35.9	0.338	0.0001708	-37.7	1 980
Adult (south)	Commercial	56	37.7	0.399	0.0002104	-36.8	1 898
Immature	Research	7	23.6	0.089	0.0000334	-44.8	2 651

Table 6: Biomass estimates (t) and c.v. by stratum and snapshot of immature and adult SBW for the Campbell Island Rise in 2011.

	Immature		Adult	
Stratum	Biomass (t)	c.v.	Biomass (t)	c.v.
Snapshot 1				
2	1 553	54	18 310	86
3N	0	-	0	-
3S	0	-	0	-
4	11 207	48	0	-
5	18 206	17	0	-
6N	0	-	0	-
6S	0	-	0	-
7N	16 556	29	0	-
7S	8 415	56	5 613	56
8E	0	-	79 254	54
8N	0	-	0	-
8S	0	-	169	100
9	0	-	0	-
Total	55 937	16	103 346	44
Snapshot 2				
2	19 284	92	27 656	37
3N	0	-	0	-
3S	0	-	5 041	28
4	1 148	88	8 069	41
5	32 031	23	934	101
6N	0	-	7 042	51
6S	0	-	320	100
7N	19 742	20	0	-
7SE	0	-	0	-
7SW	1 068	41	2 442	41
8E	0	-	43 734	33
8N	0	-	27 402	55
8S	0	-	9 408	50
9	0	-	849	100
Total	73 273	27	132 897	18
Best estimate (average)	64 605	17	118 122	22

Table 7: Biomass estimates (t) by survey and category for the Campbell Island Rise. Updated from Gauthier et al. (2011) (see Grimes et al (2007) for details of the estimates prior to 2006). Values represent best estimates for all areas surveyed.

	Juvenile	c.v.	Immature	c.v.	Adult	c.v.	Total
1993	0	–	129 380	0.25	28 649	0.24	158 029
1994	0	–	26 280	0.38	180 439	0.34	206 719
1995	0	–	48 844	0.29	123 124	0.30	171 968
1998	2 103	0.45	26 987	0.20	171 199	0.14	200 289
2000	2 468	0.39	6 074	0.24	138 196	0.17	146 738
2002	13 228	0.39	681	0.76	116 178	0.68	130 087
2004	3 090	0.67	16 833	0.16	79 074	0.35	98 997
2006	2 200	0.38	10 892	0.24	81 628	0.32	94 720
2009	0	–	98 098	0.28	204 539	0.27	302 637
2011	0	–	64 605	0.17	118 122	0.22	182 727

Table 8: Decomposed biomass estimates (t) by stratum and snapshot of 1, 2, 3, and 4 year old and over SBW for the Campbell Island Rise in 2011. Note that no 1 year old fish were observed during the survey or caught by the commercial fleet.

Snapshot 1					
stratum	Age 1	Age 2	Age 3	Age 4+	Total
2	0	1 650	185	18 067	
3N	0	0	0	0	
3S	0	0	0	0	
4	0	10 540	14	4	
5	0	17 124	22	7	
6N	0	0	0	0	
6S	0	0	0	0	
7N	0	15 571	20	6	
7S	0	7 933	67	5 572	
8E	0	414	1 166	78 027	
8N	0	0	0	0	
8S	0	1	3	166	
9	0	0	0	0	
Total	0	53 233	1 477	101 849	156 559
c.v. (%)	0	16	44	44	

Snapshot 2					
stratum	Age 1	Age 2	Age 3	Age 4+	Total
2	0	18 424	301	27 297	
3N	0	0	0	0	
3S	0	27	74	4 963	
4	0	1 163	82	7 962	
5	0	30 135	48	923	
6N	0	37	104	6 933	
6S	0	1	3	304	
7N	0	18 567	24	7	
7SE	0	0	0	0	
7SW	0	1 012	26	2 423	
8E	0	229	644	43 057	
8N	0	143	404	26 977	
8S	0	49	138	9 262	
9	0	5	12	836	
Total	0	69 792	1 860	130 944	202 596
c.v. (%)	0	27	18	18	

	Age 1	Age 2	Age 3	Age 4+	Total
Average	0	61 512	1 668	116 396	179 576
c.v. (%)	0	17	22	22	

Table 9: Decomposed biomass estimates (t) by survey and age group for the Campbell Island Rise. Updated from Gauthier et al. (2011) (see Grimes et al (2007) for details of the estimates prior to 2006). Values represent best estimates for all areas surveyed.

	Age 1	c.v.	Age 2	c.v.	Age 3	c.v.	Age 4+	c.v.	Total
1993	206	1.76	107 192	0.28	13 396	0.23	16 784	0.25	137 578
1994	699	0.57	19 634	0.29	168 006	0.32	23 213	0.28	211 552
1995	0	–	17 269	0.27	27 952	0.21	124 892	0.25	170 113
1998	8 678	0.25	20 895	0.15	35 579	0.12	139 388	0.18	204 540
2000	2 443	0.38	15 606	0.16	8 785	0.16	110 931	0.17	137 765
2002	13 436	0.38	4 609	0.65	10 632	0.64	103 422	0.68	132 099
2004	3 144	0.65	24 380	0.15	36 683	0.30	39 007	0.39	103 214
2006	2 230	0.32	27 933	0.23	10 199	0.34	56 206	0.32	96 568
2009	0	–	110 250	0.22	115 944	0.26	92 598	0.27	318 792
2011	0	–	61 512	0.17	1 668	0.22	116 396	0.22	179 576

8. FIGURES

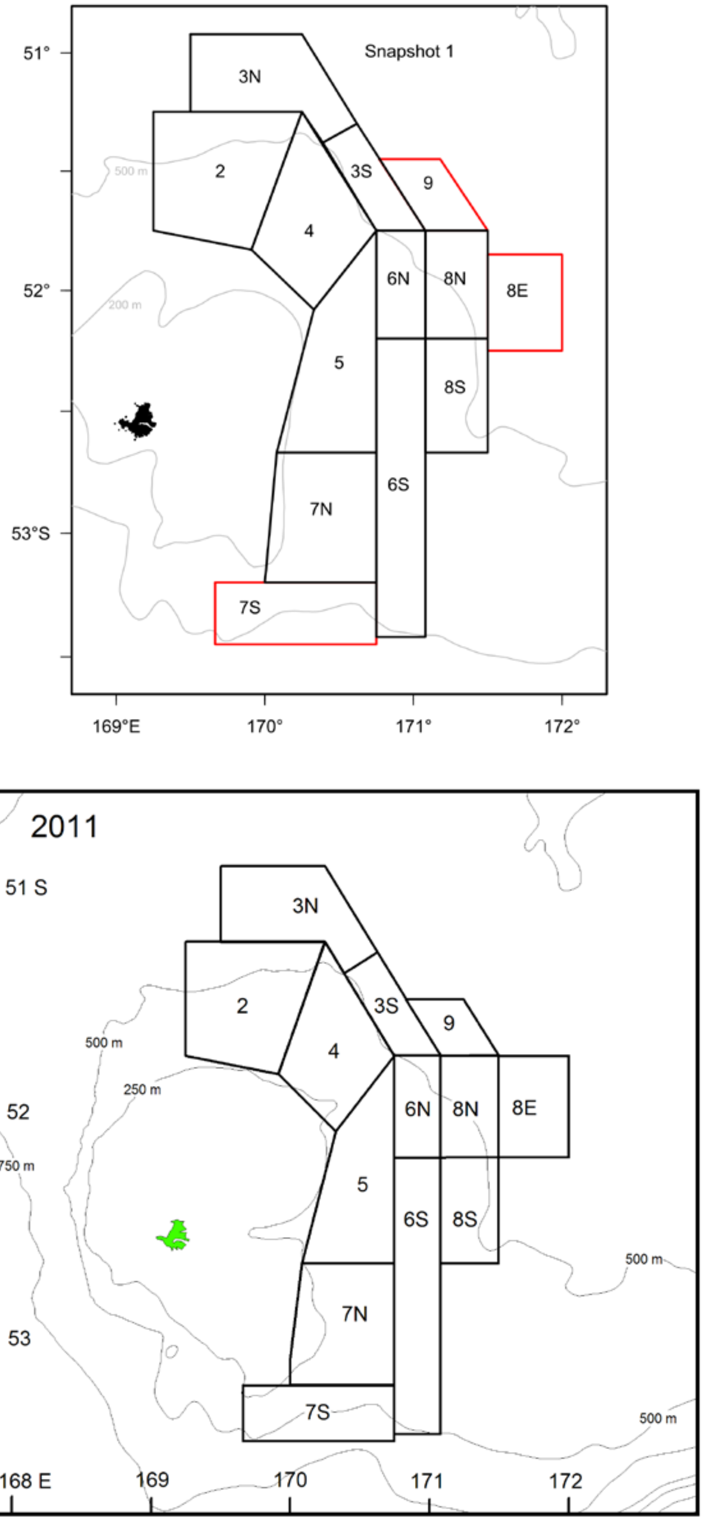

Figure 1: Stratum boundaries for snapshot 1 of the 2009 acoustic survey of the Campbell Island Rise (upper panel) and proposed stratum boundaries for 2011 (lower panel). Strata 2–7 are the core acoustic strata which have been covered in all previous surveys. Strata 8, 9 and 7S (red lines in upper panel) were adjusted based on the fish distribution during the 2009 survey and the revised stratum boundaries were retained for 2011 with minor modifications (see text for details).

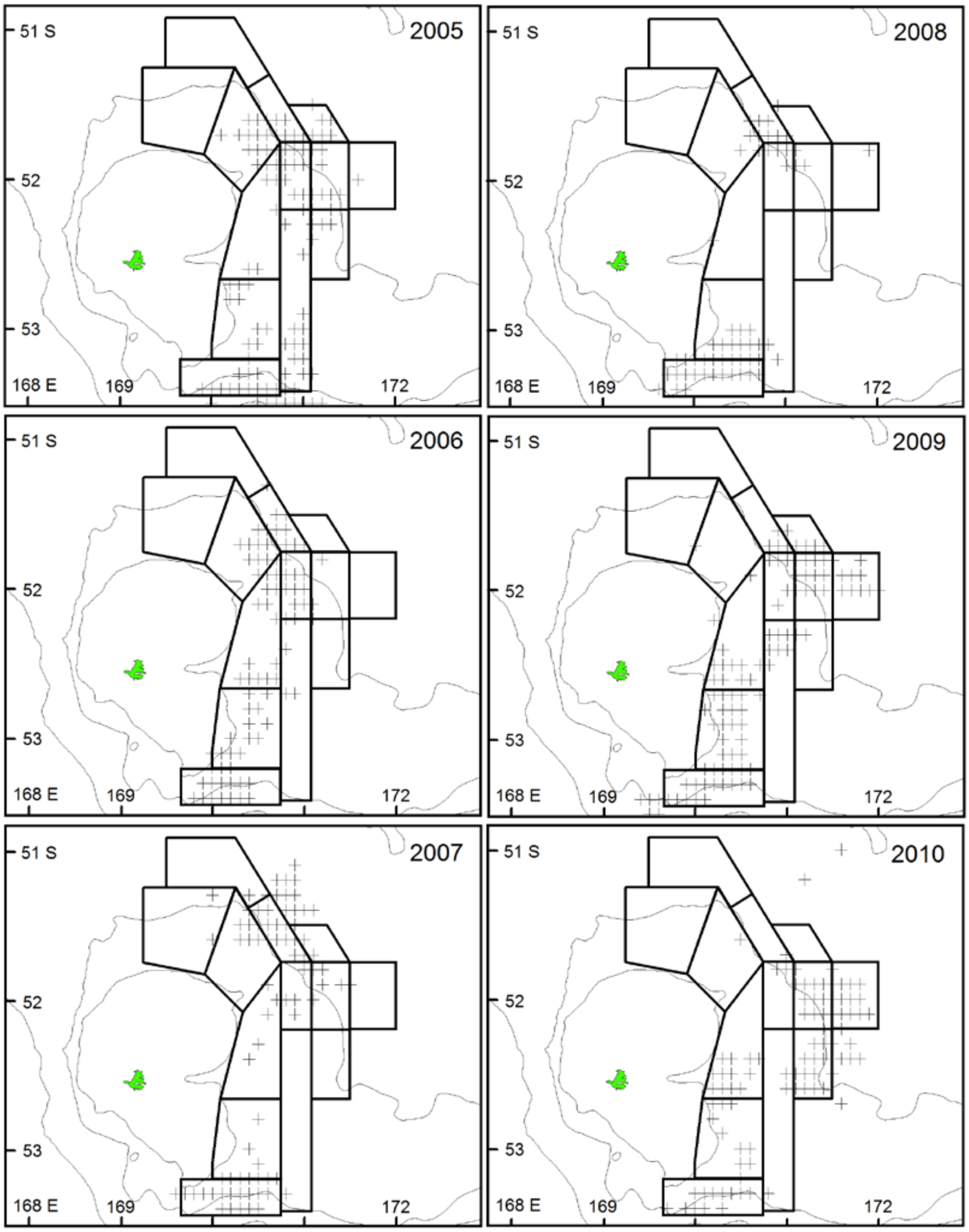

Figure 2: Proposed stratum boundaries for snapshot 1 with crosses indicating the start positions of all commercial tows within the survey period (29 August – 25 September) in the previous six seasons. Data are aggregated at 0.1º resolution, and each cross may represent multiple tows.

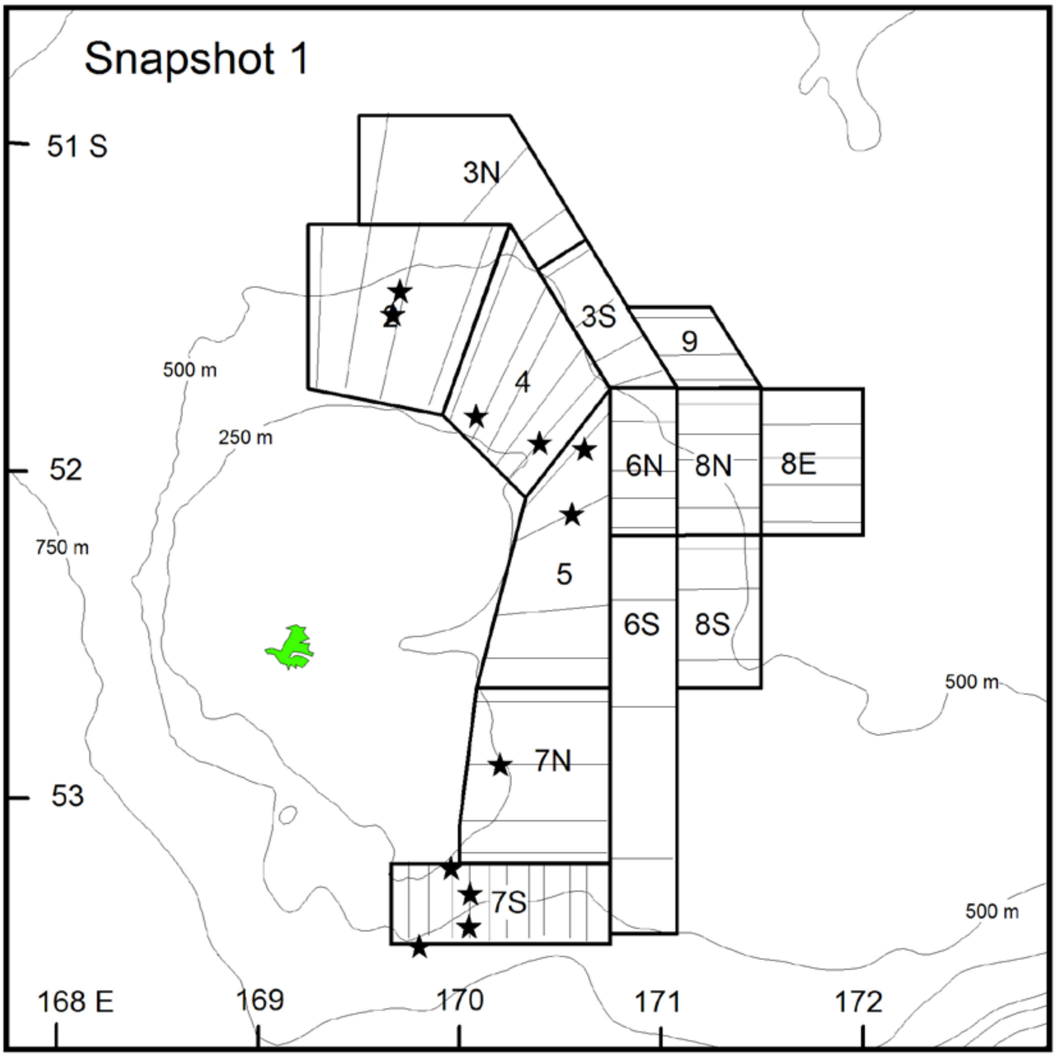

Figure 3: Final stratum boundaries and approximate positions of transects (lines) and trawls (stars) during snapshot 1 of the 2011 acoustic survey of the Campbell Island Rise (4–12 September). Note that the western survey boundary was defined by the 300 m depth contour. Actual transect positions are shown in Figures 17–20.

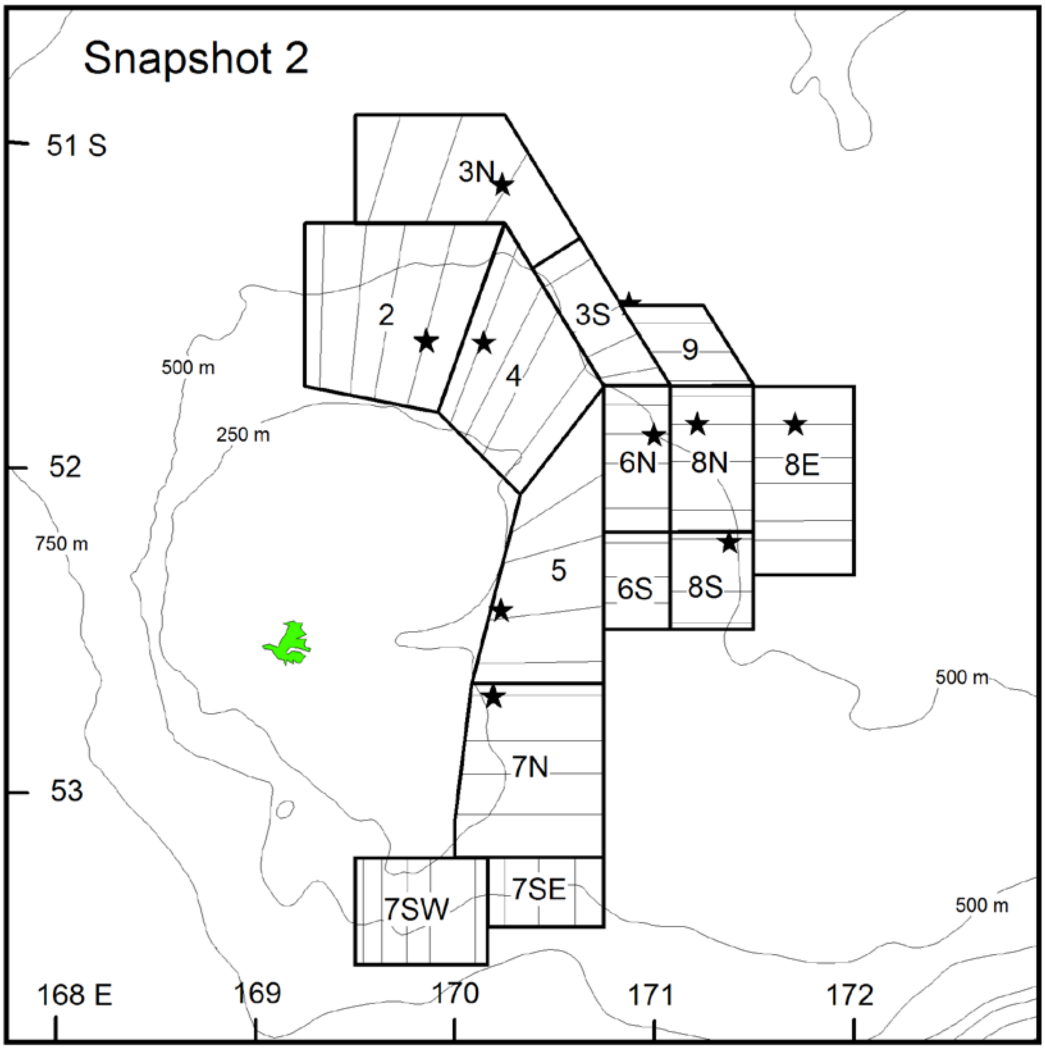

Figure 4: Stratum boundaries and approximate positions of transects (lines) and trawls (stars) during snapshot 2 of the 2011 acoustic survey of the Campbell Island Rise (12–22 September). Note changes to stratum boundaries in strata 6S, 7S, 8S, and 8E from snapshot 1.

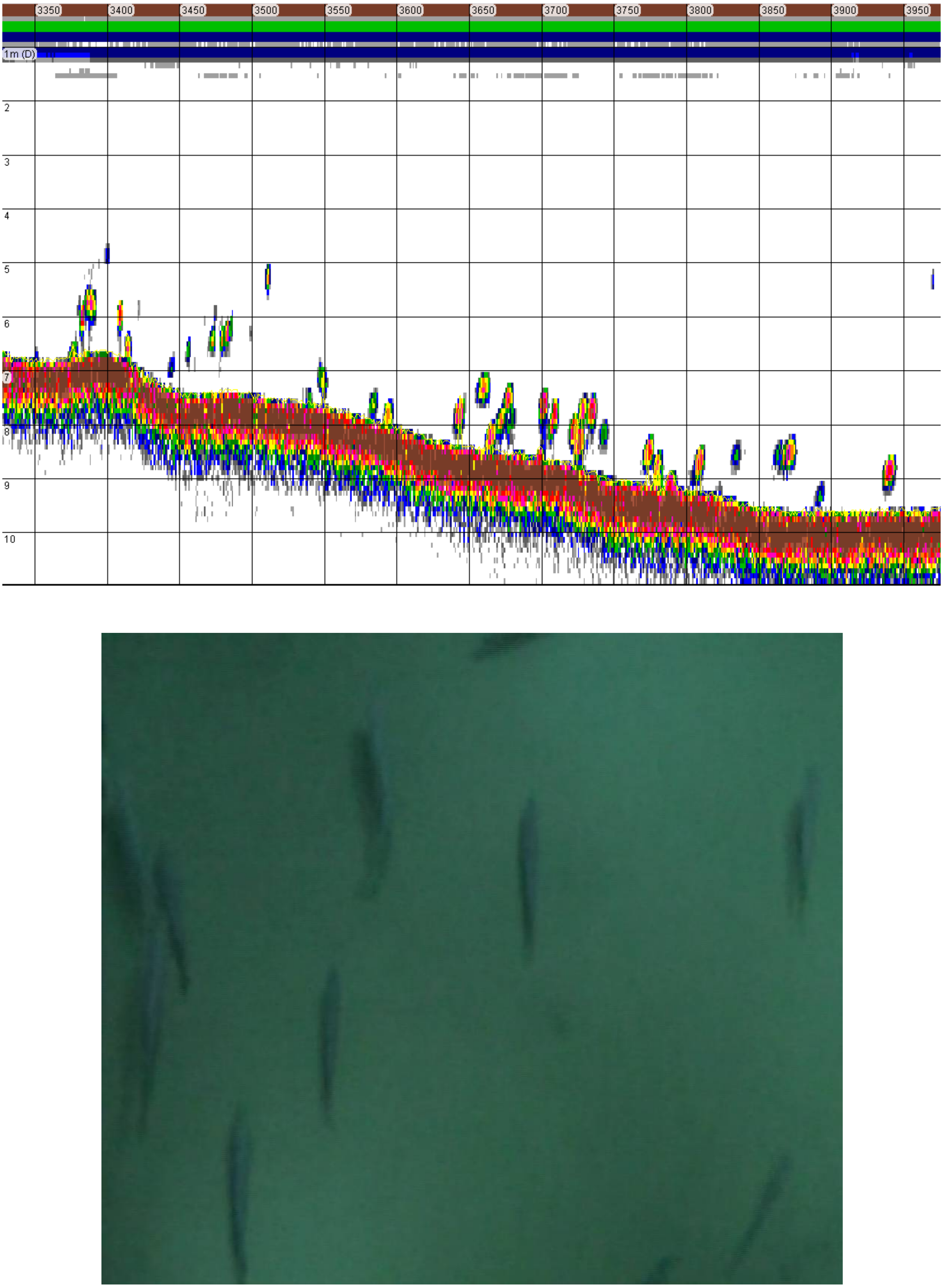

Figure 5: Acoustic echogram (upper picture) and screen-grab from video (lower picture) from AOS on tow 23 on 20 September, showing adult southern blue whiting in the mouth of the trawl.

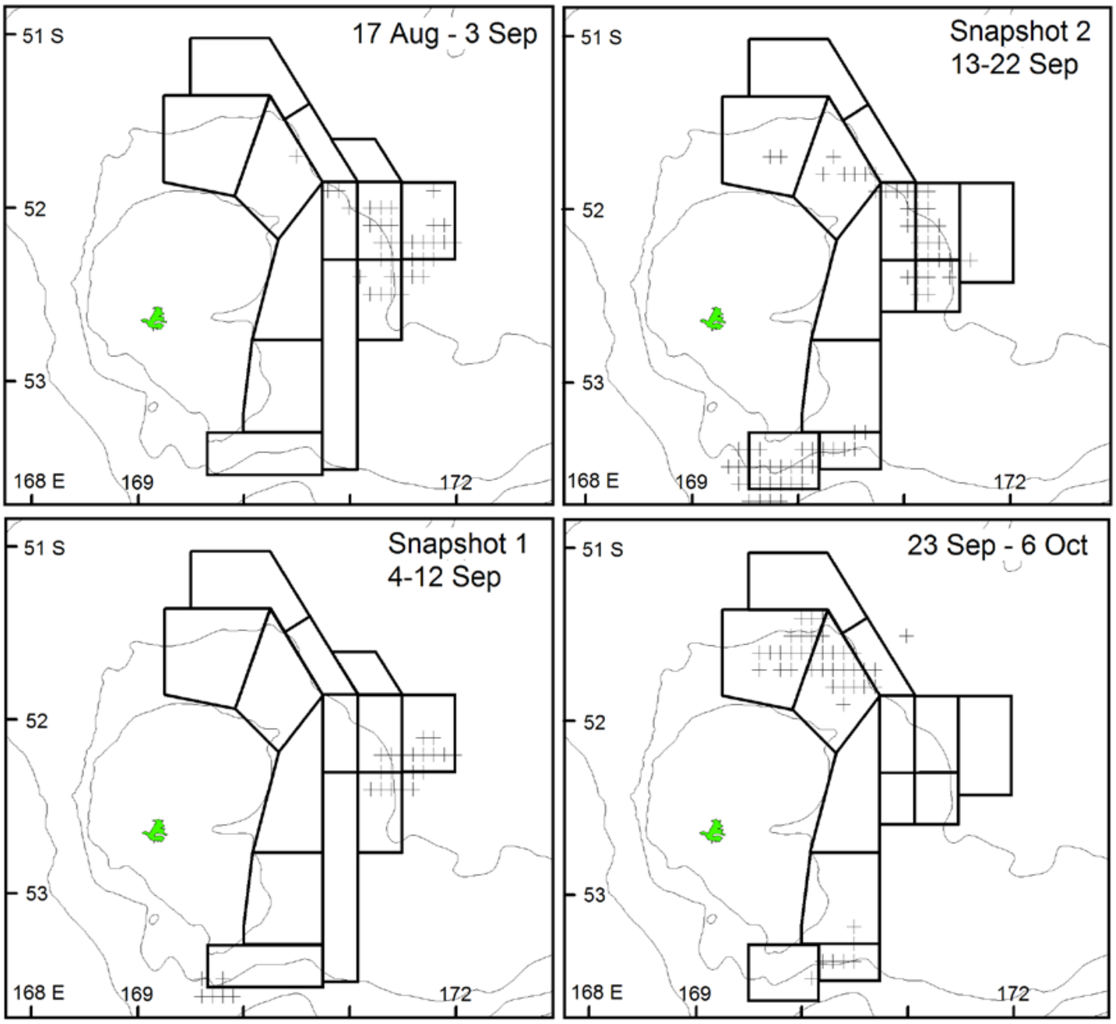

Figure 6: Location of commercial tows by date in 2011. Crosses indicate the start positions of all commercial tows within periods corresponding to snapshots 1 and 2, and periods before and after the survey. Data are aggregated at 0.1º resolution, and each cross may represent multiple tows.

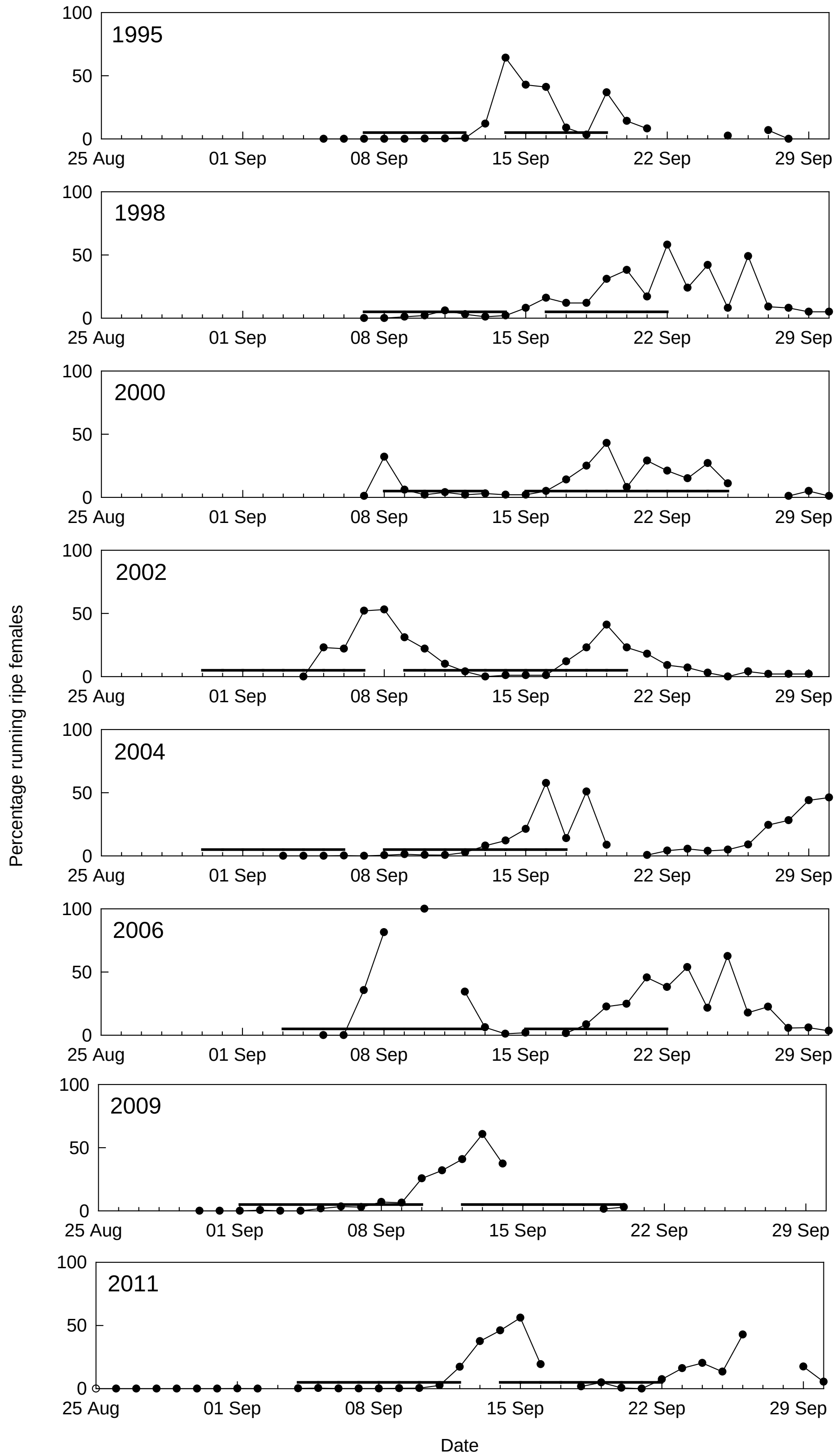

Figure 7: Survey timing (line above x axis) in relation to the timing of spawning for the acoustic surveys from 1995 to 2011 on the Campbell Island Rise. Percentage of running ripe females is from observer data.

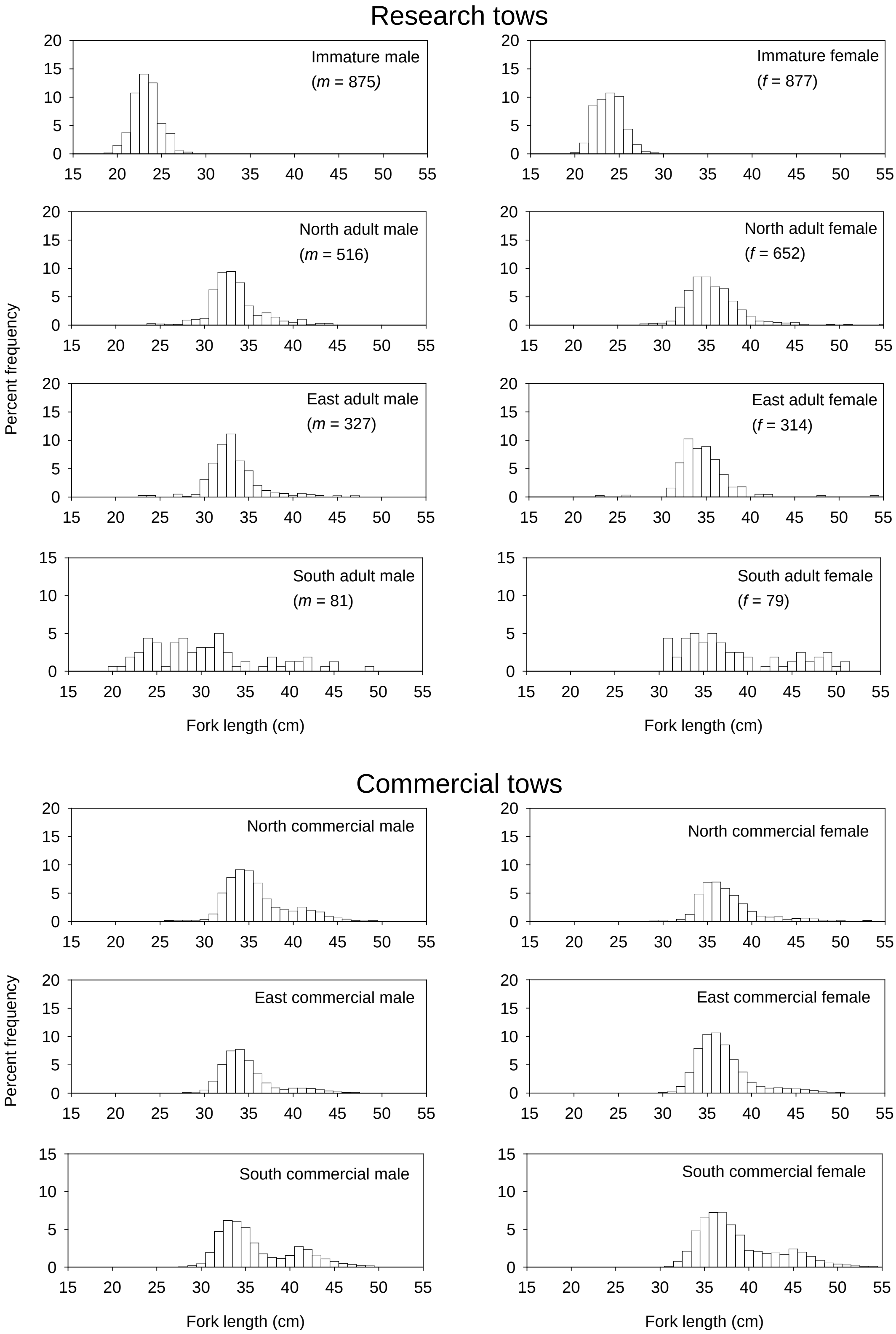

Figure 8: Catch-weighted length frequency distributions for southern blue whiting caught in research trawls by *Tangaroa* from immature and adult marks and from commercial tows during the spawning fishery. Size distributions for adults were separated into northern, eastern, and southern areas (see text for details). Research data were used in the acoustic survey analysis for decomposing immature marks and commercial data were used for adult marks. *m* and *f* values for research tows show number of males and females measured.

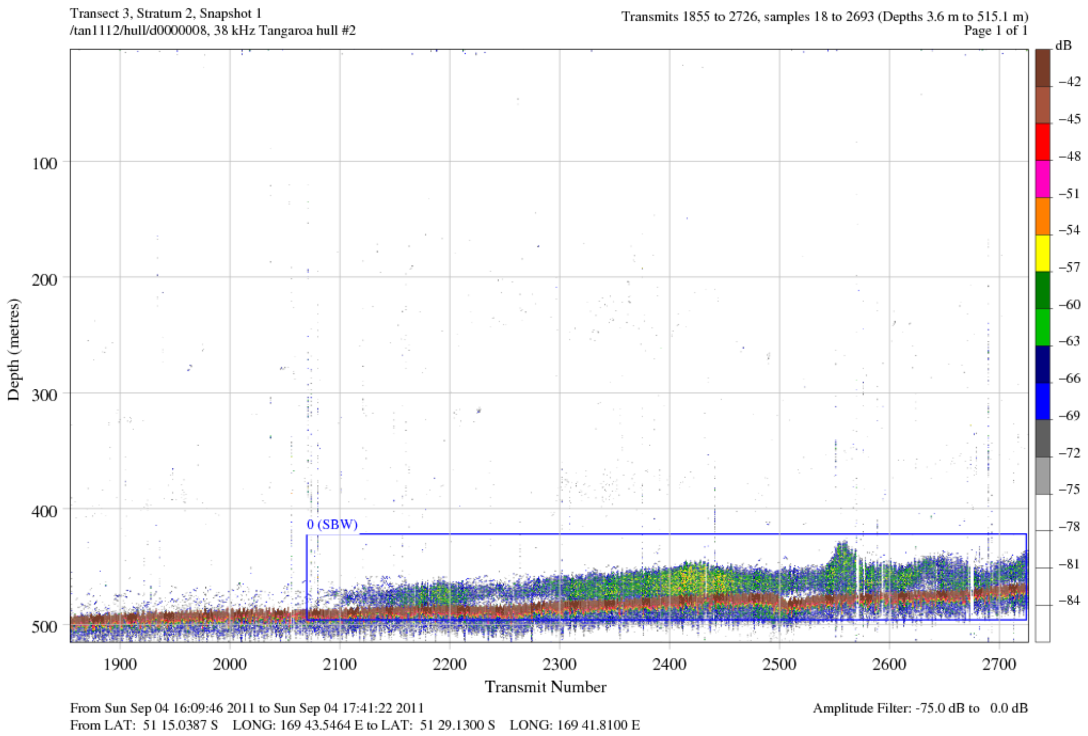

Figure 9: Adult pre-spawning mark close to the bottom in the afternoon in stratum 2 on 4 September 2011. Towbody depth was about 50 m.

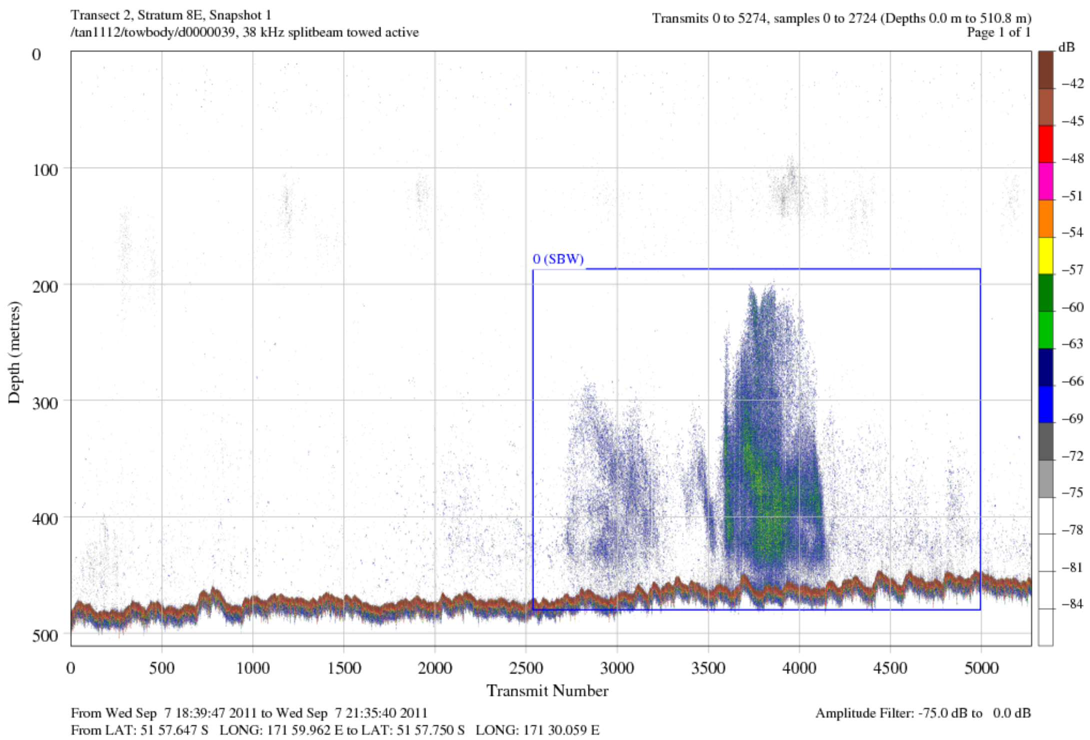

Figure 10: Adult pre-spawning mark up to 250 m off the bottom at night in stratum 8E on 7 September 2011. Towbody depth was about 50 m.

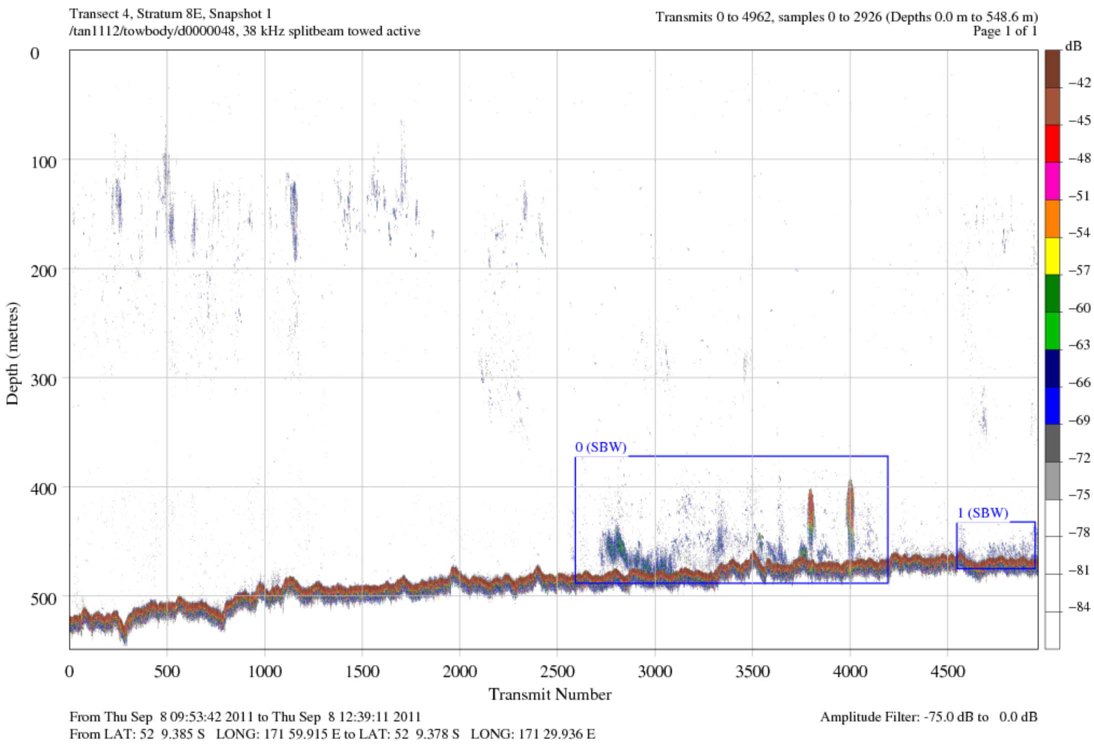

Figure 11: Strong pre-spawning marks during the day in stratum 8E on 8 September 2011. Towbody depth was about 50 m.

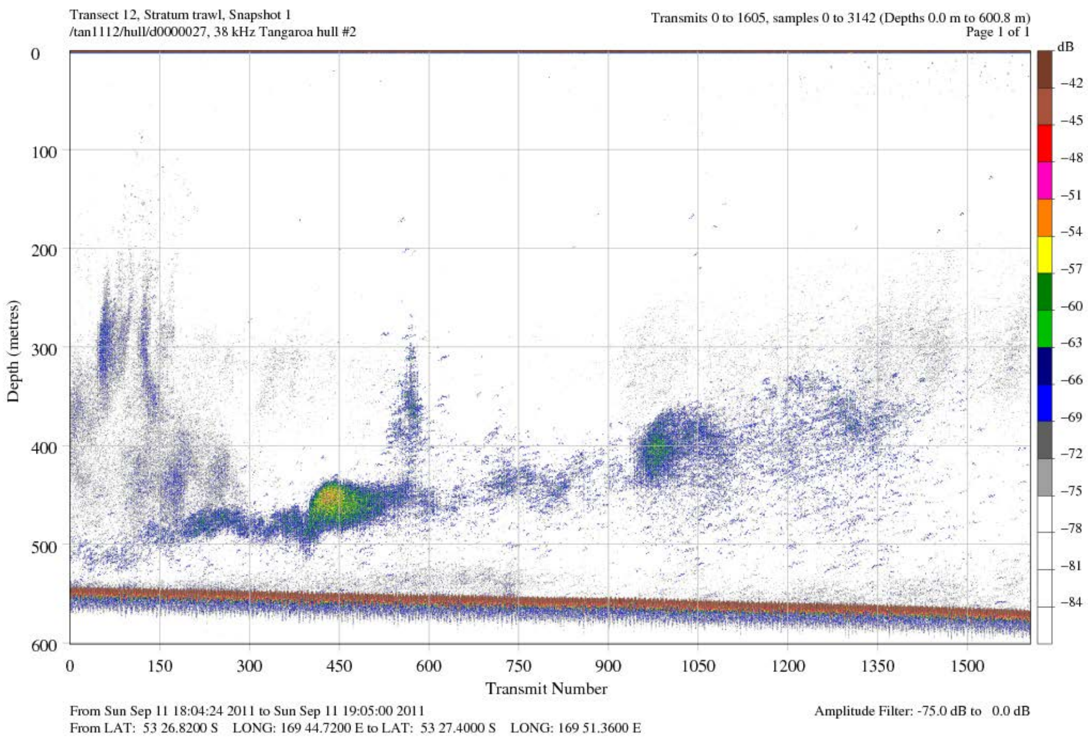

Figure 12: Marks from pre-spawning or spawning SBW ascending at dusk in stratum 7SW on 11 September 2011. Echogram is from a hull recording during trawl 12.

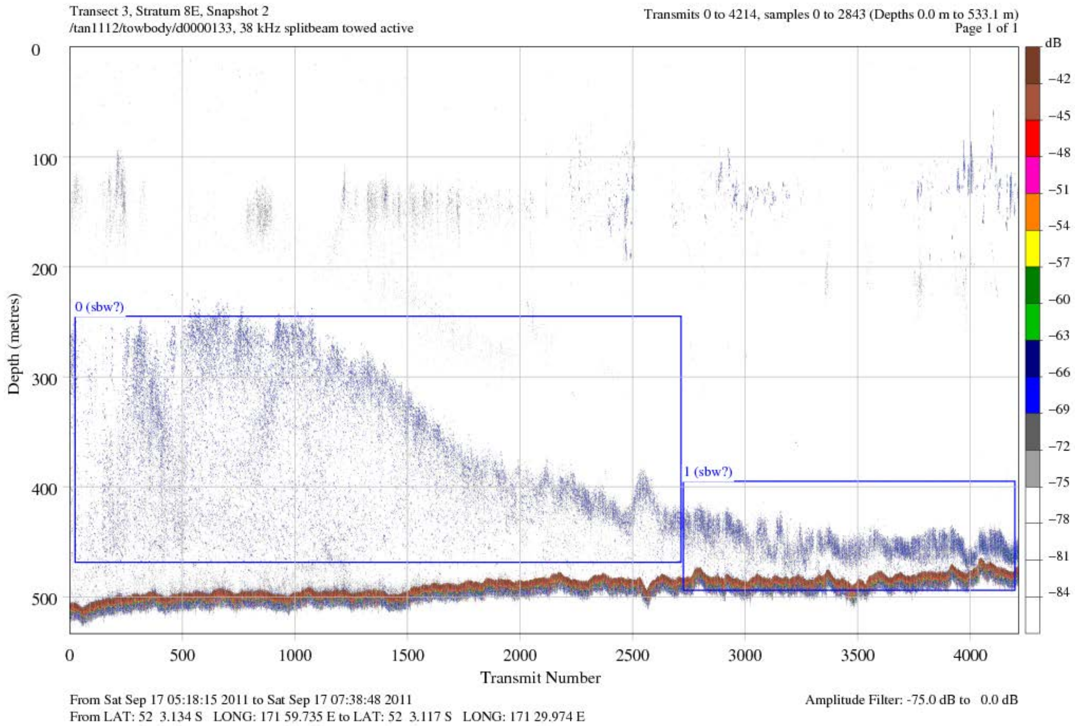

Figure 13: Post-spawning marks descending at dawn in stratum 8E on 17 September 2011. Towbody depth was about 50 m.

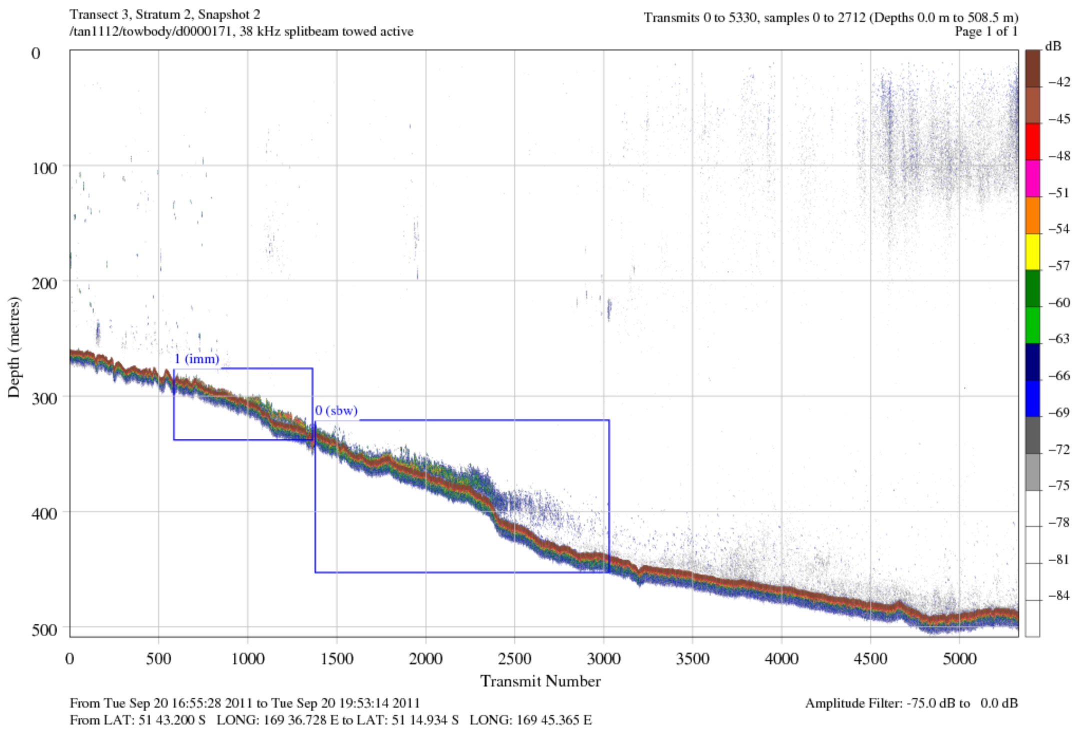

Figure 14: Post-spawning adult marks and immature marks during the day in stratum 2 on 20 September 2011. Towbody depth was about 50 m. Depth separation between adult and immature marks was estimated to be at 380 m (see text for details).

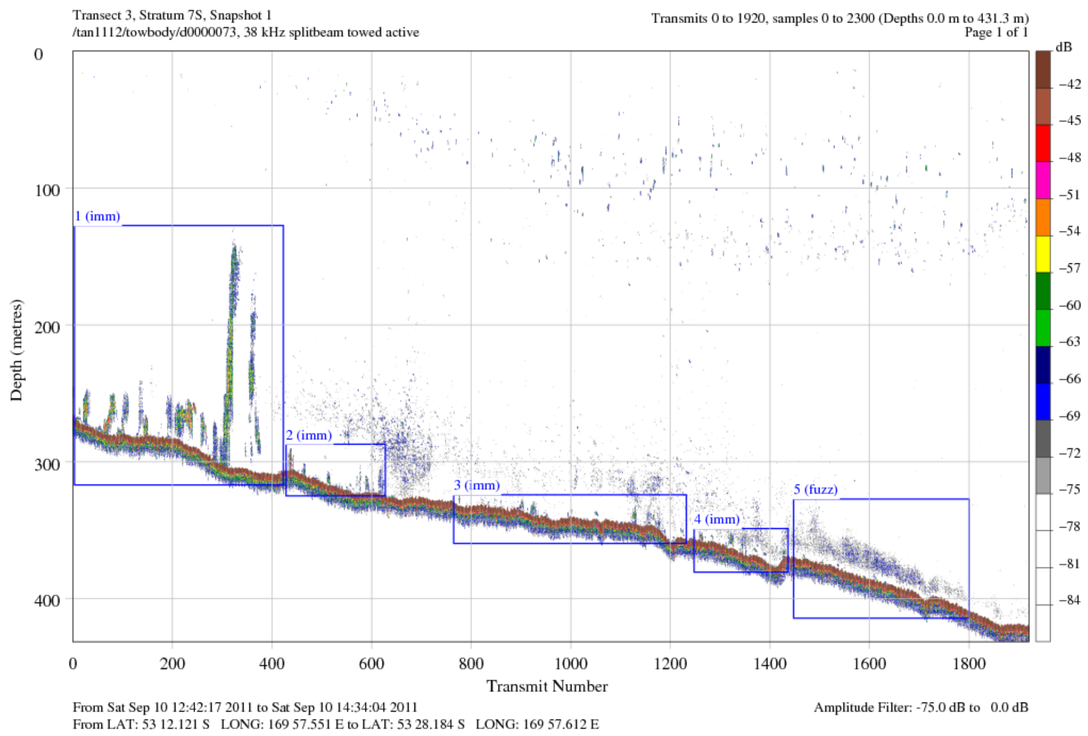

Figure 15: Immature marks during the day in stratum 7S on 10 September 2011. Towbody depth was about 50 m. Marks were strongest at depths shallower than 400 m.

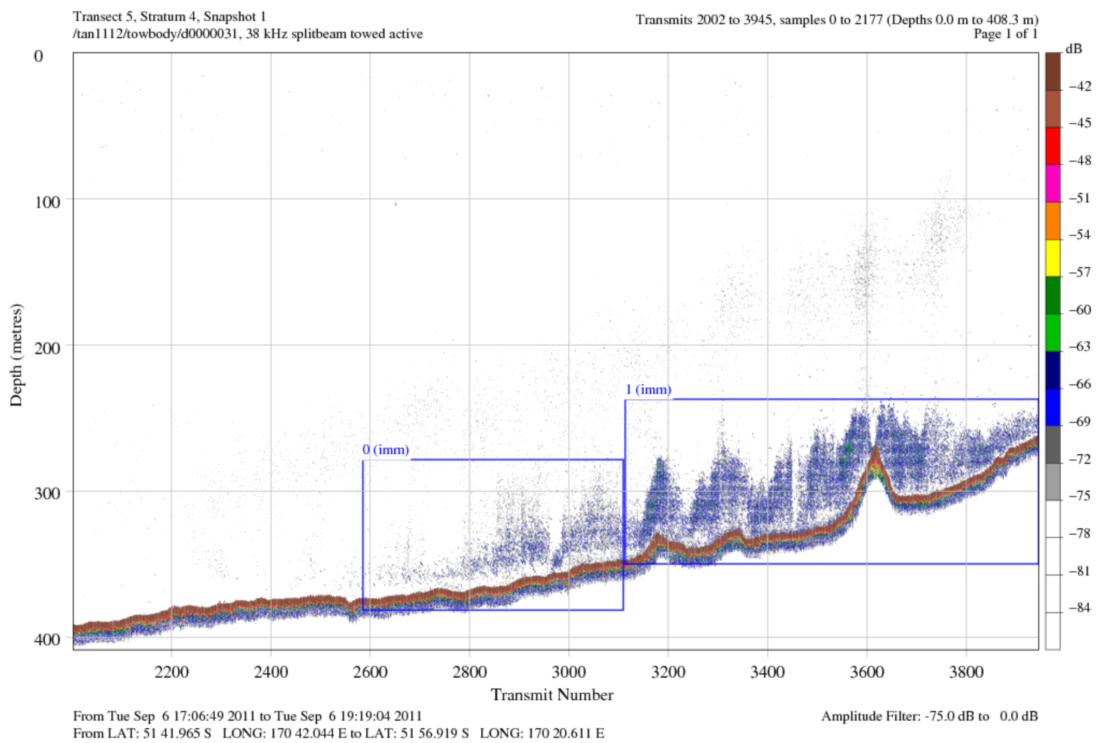

Figure 16: Immature marks at night in stratum 4 on 6 September 2011. Towbody depth was about 50 m.

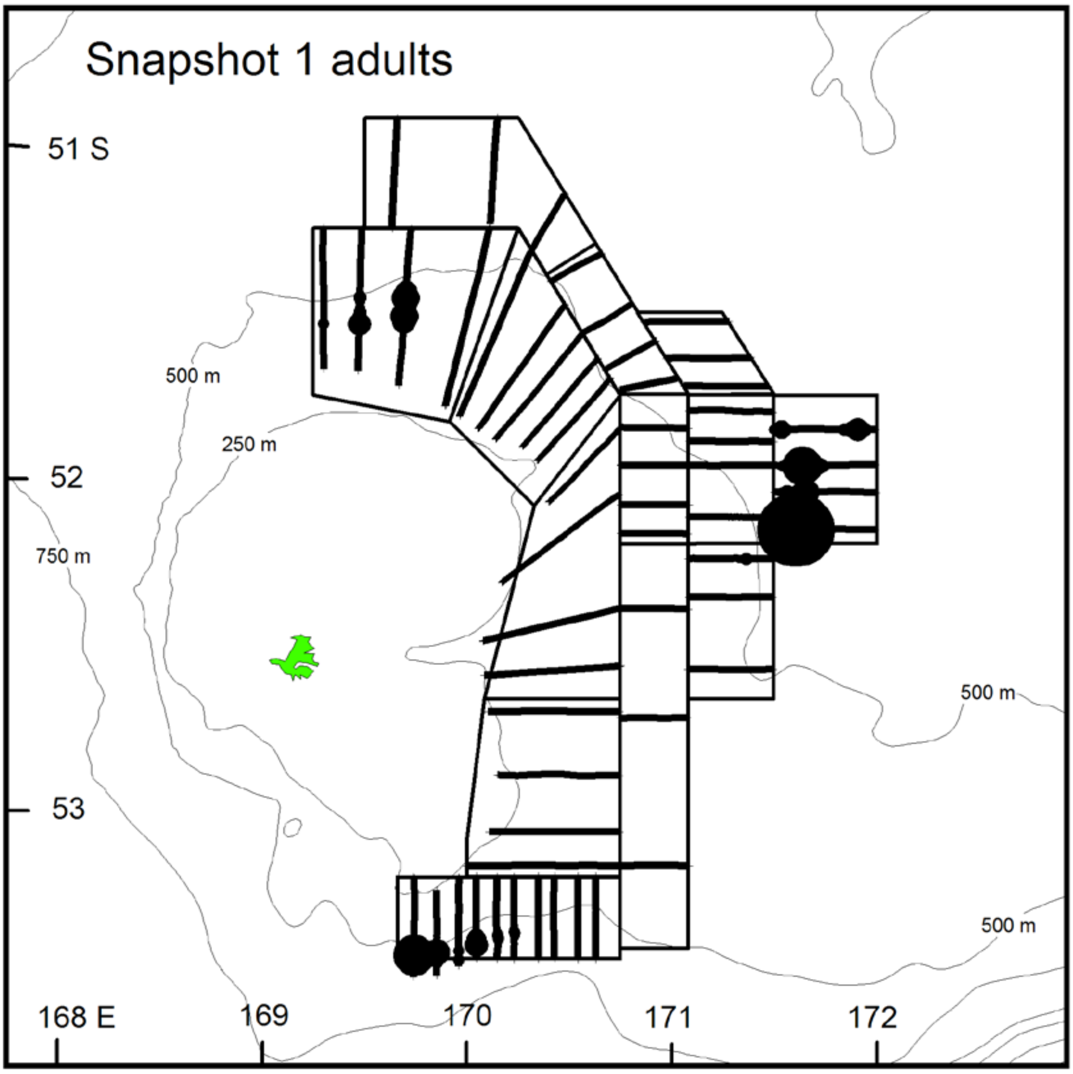

Figure 17: Spatial distribution of acoustic backscatter from adult SBW plotted in 10 ping (approximately 100 m) bins for snapshot 1. Circle area is proportional to the log of the acoustic backscatter, scaled to the maximum SBW backscatter recorded in 2011.

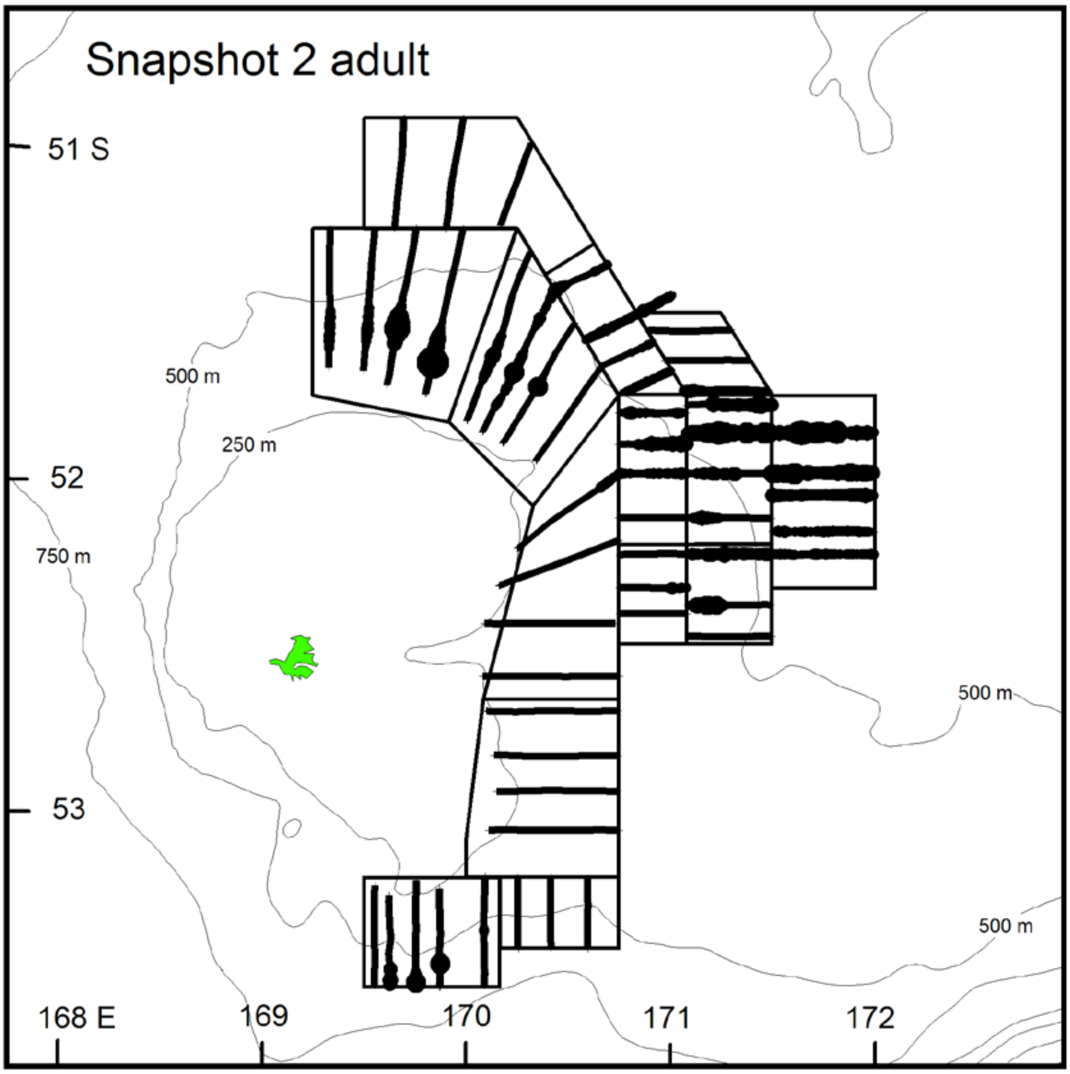

Figure 18: Spatial distribution of acoustic backscatter from adult SBW plotted in 10 ping (approximately 100 m) bins for snapshot 2. Circle area is proportional to the log of the acoustic backscatter, scaled to the maximum SBW backscatter recorded in 2011.

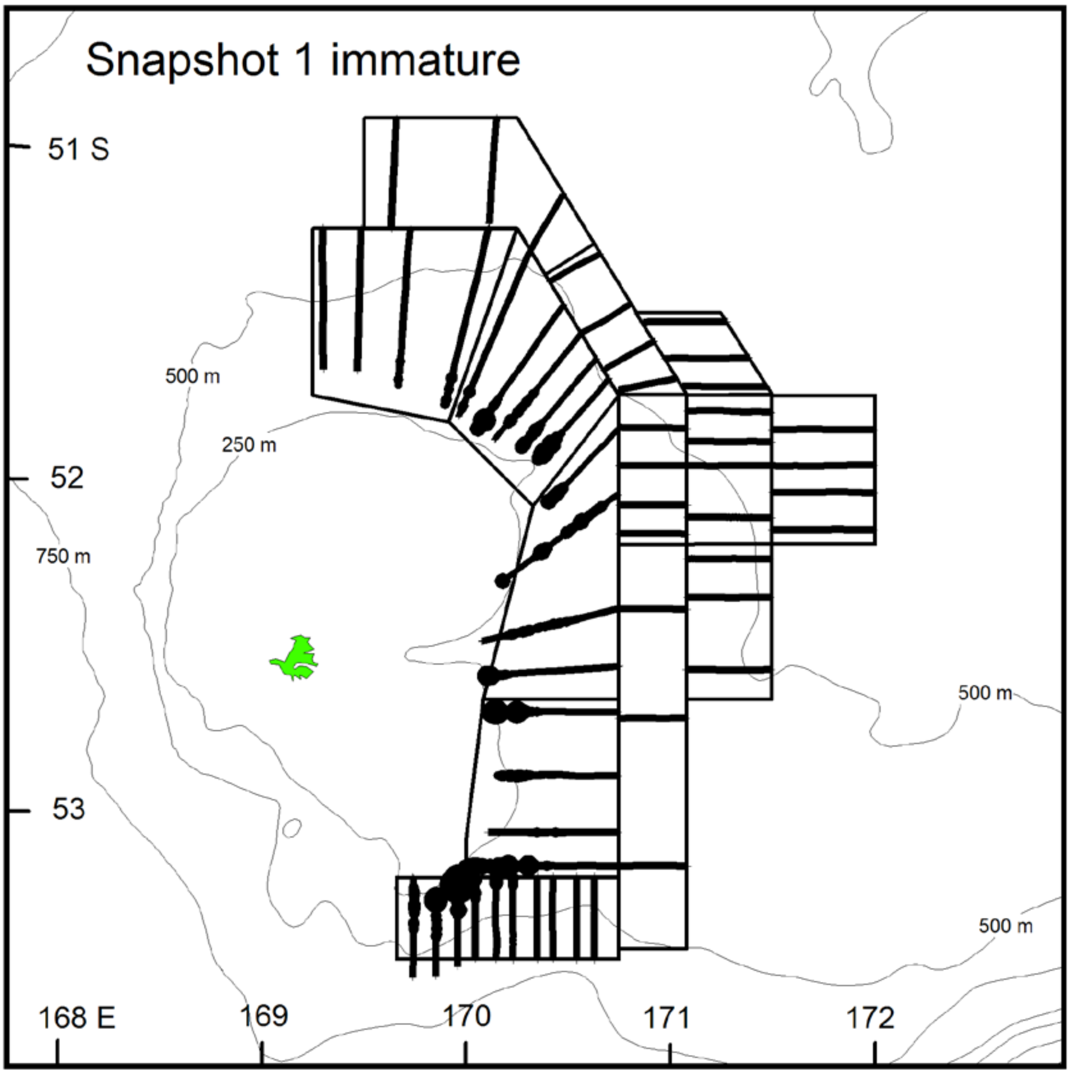

Figure 19: Spatial distribution of acoustic backscatter from immature SBW plotted in 10 ping (approximately 100 m) bins for snapshot 1. Circle area is proportional to the log of the acoustic backscatter, scaled to the maximum SBW backscatter recorded in 2011.

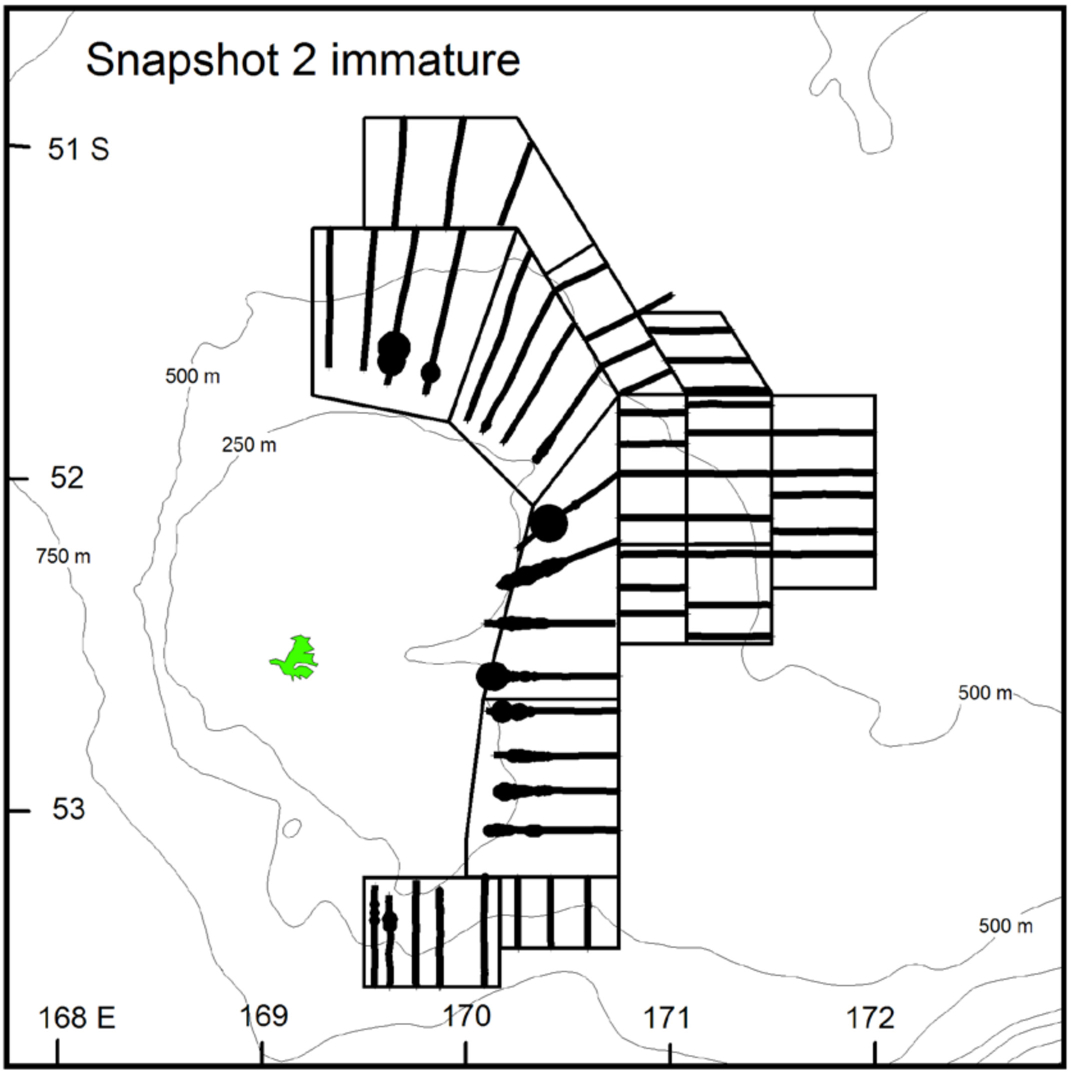

Figure 20: Spatial distribution of acoustic backscatter from immature SBW plotted in 10 ping (approximately 100 m) bins for snapshot 2. Circle area is proportional to the log of the acoustic backscatter, scaled to the maximum SBW backscatter recorded in 2011.

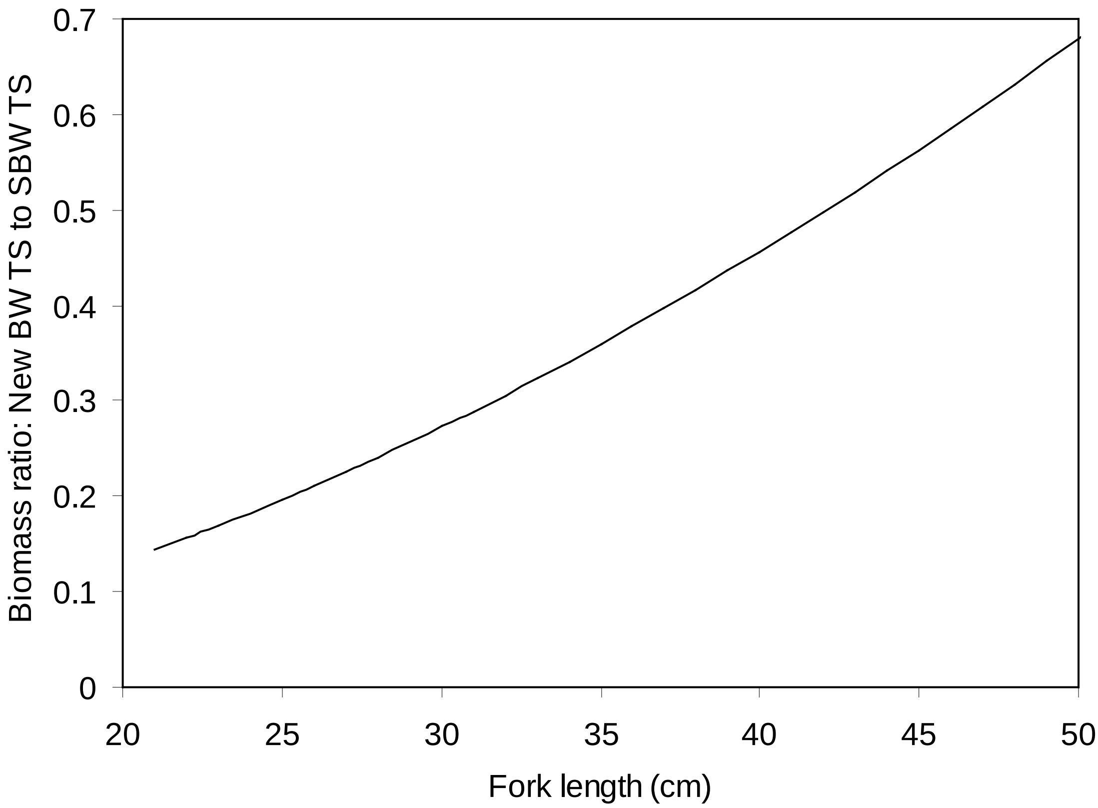

Figure 21: Ratio of biomass estimates for SBW calculated using recently published (Pedersen et al. 2011) TS-length regression for blue whiting (new BW TS) to estimates calculated using the TS-length relationship of Dunford & Macaulay (2006) (SBW TS). The ratio varies with fish length.

APPENDIX 1: TAN1112 EK60 calibration

The 18, 38, 70, 120, and 120 kHz EK60 echosounders on *Tangaroa* were calibrated on 30 August 2011 in Resolution Bay, Marlborough Sounds, at the start of the Campbell Island southern blue whiting acoustic survey. The calibration was conducted broadly as per the procedures in MacLennan & Simmonds (1992).

Because of difficulties with calibrating *Tangaroa* in the past and uncertainty about whether the installation of the dynamic positioning system would affect our ability to drag a line from the bow of the vessel, divers were used to assist with the set-up. The Diving Services vessel *Topside* was chartered as a support vessel, and Bruce Lines was the chief diver.

The vessel was anchored in about 40 m of water in Resolution Bay (41˚ 07.64’ S, 174˚ 13.52’ E) at 10:40 NZST. The divers located the transducer, attached the lines, and made sure these were not fouled. Long (3.8 m) fibreglass calibration poles were also used in place of our standard 1 m poles to help keep the calibration lines clear of the hull. Because of changes to the vessel during the refit in 2010, including the installation of a monkey island on the starboard side of the bridge, we had to use different starboard pole locations from those used in previous calibrations. 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 weather during the calibration was good, with 15 knots of northerly wind and no swell or waves. The vessel was swinging slowly (0.1 knots) at anchor.

The calibration started at 10:58 NZST, the sphere was located in the beam at 11:04, and the divers and support boat returned to Picton at 11:19. The sphere was first centred in the beam of the 38 kHz transducer to obtain data for the on-axis calibration. It was then moved around to obtain data for the beam shape calibration. Due to the close proximity of all five transducers, a number of echoes were recorded across all frequencies. After the 38 kHz calibration, the sphere was moved to ensure on-axis calibration of the other frequencies.

The calibration data were recorded in two EK60 raw format files (TAN1112-D20110829-T225749.raw and TAN1112-D20110829-T234736.raw). These data are stored in the NIWA *acoustics* database. The EK60 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). Estimates of acoustic absorption were calculated using the formulae in Doonan et al. (2003). The formula from Francois & Garrison (1982) was used at 200 kHz. Estimates of seawater sound speed and density were calculated using the formulae of Fofonoff & Millard (1983). The sphere target strength was calculated as per equations 6 to 9 in MacLennan (1981), using longitudinal and transverse sphere sound velocities of 6853 and 4171 m s^{-1} respectively and a sphere density of 14 900 kg m^{-3}.

Analysis

The data in the raw EK60 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 S_a correction was calculated from:

$$Sa, corr = 5\log 10\left(\frac{\sum P_i}{4P_{\max}}\right),$$

where P_i is sphere echo power measurements 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 overall sphere echoes is used to determine the final $S_{a,corr}$.

Results

The results from the CTD cast are given in Table A1.2, along with estimates of the sphere target strength, sound speed, and acoustic absorption for 18, 38, 70, 120, and 200 kHz.

The calibration parameters resulting from the calibration are given in Table A1.3, along with results from previous calibrations. It is important to note that the 38 kHz and 70 kHz systems were calibrated in the Ross Sea in February 2008, where the water temperature was -1.44 °C, considerably colder than during the subsequent calibrations. The effect of water temperature on transducer parameters and performance is not precisely known, but has been reported to have a significant effect at some frequencies (Demer & Renfree 2008) and any large differences between the two sets of results should not be taken as a permanent shift in system performance. Also, the 70 kHz transducer was in a different location during the voyage to the Ross Sea and this can also affect transducer performance. Despite this, results for all frequencies are relatively consistent (within 0.5 dB) across all calibrations. The linear change (which can be interpreted as the percentage change in estimated biomass) between the calibration in May 2008 used for default settings and the calibration in August 2011 ranged between -11% (for 200 kHz) and +12% (for 120 kHz). The calibration coefficients for the 38-kHz echosounder most often used for abundance estimation differed by less than 3% between calibrations in 2008 and 2011, and by less than 11% across all four calibrations (Table A1.3). The calibration coefficients from the January 2010 calibration were consistently higher than those in May 2008 and August 2011 (Table A1.3). However, the beam coverage in the 2010 calibration was not complete, particularly at the 18, 120, and 200 kHz frequencies.

The estimated beam patterns, as well as the coverage of the beam by the calibration sphere, are given in Figures A1.1–A1.10. The symmetrical nature of the beam patterns and the centering on zero indicates that the transducers and EK60 transceivers were operating correctly. The RMS of the difference between the Simrad beam model and the sphere echoes out to the 3 dB beamwidth was less than 0.1 dB for 18, 38, and 70 kHz, was 0.17 dB for 120 kHz, and 0.21 dB for 200 kHz (Table A1.3), indicating good or excellent quality calibrations on all frequencies (less than 0.4 dB is acceptable, less than 0.3 dB good, and less than 0.2 dB excellent).

Table A1.1. EK60 transceiver settings and other relevant parameters in effect during the calibration. These were derived from the May 2008 calibration (see Table A1.3).

Parameter					
Frequency (kHz)	18	38	70	120	200
GPT model	GPT-Q18(2)-S 1.0 00907205c476	GPT-Q38(4)-S 1.0 00907205c463	GPT-Q70(1)-S 1.0 00907205ca98	GPT-Q120(1)-S 1.0 009072058148	GPT-Q120(1)-S 1.0 009072058148
GPT serial number	652	650	674	668	692
GPT software version	050112	050112	050112	050112	050112
ER60 software version	2.1.2	2.1.2	2.1.2	2.1.2	2.1.2
Transducer model	ES18-11	ES38	ES70-7C	ES120-7C	ES200-7C
Transducer serial number	2080	23083	158	477	364
Sphere type/size	tungsten carbide/38.1 mm diameter (same for all frequencies)				
Transducer draft setting (m)	0.0	0.0	0.0	0.0	0.0
Transmit power (W)	2000	2000	1000	500	300
Pulse length (ms)	1.024	1.024	1.024	1.024	1.024
Transducer peak gain (dB)	22.96	25.81	26.43	26.17	24.96
Sa correction (dB)	-0.81	-0.57	-0.35	-0.36	-0.25
Bandwidth (Hz)	1574	2425	2859	3026	3088
Sample interval (m)	0.191	0.191	0.191	0.191	0.191
Two-way beam angle (dB)	–17.0	–20.60	–21.0	–21.0	–20.70
Absorption coefficient (dB km^{-1})	2.67	9.79	22.79	37.44	52.69
Speed of sound (m s^{-1})	1494	1494	1494	1494	1494
Angle sensitivity (dB) alongship/athwartship	13.90/13.90	21.90/21.90	23.0/23.0	23.0/23.0	23.0/23.0
3 dB beamwidth (º) alongship/athwartship	10.8/10.8	7.0/7.0	6.6/6.6	6.5/6.6	6.8/6.9
Angle offset (º) alongship/athwartship	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0

Table A1.2. CTD cast details and derived water properties. The values for sound speed, salinity and absorption are the mean over water depths 6 to 30 m.

Parameter	
Date/time (NZST, start)	30 August 2011 12:18
Position	41˚ 07.64 S 174˚ 13.52 E
Mean sphere range (m)	23.9 (18 kHz), 23.8 (38), 23.9 (70), 23.8 (120), 23.8 (200)
Mean temperature (ºC)	11.1
Mean salinity (psu)	34.7
Sound speed (m/s)	1493.7
Water density (kg/m^3)	1026.6
Sound absorption (dB/km)	2.42 (18 kHz) 9.36 (38 kHz) 22.72 (70 kHz) 38.60 (120 kHz) 56.30 (200 kHz)
Sphere target strength (dB re $1m^2$)	–42.67 (18 kHz) –42.40 (38 kHz) –41.35 (70 kHz) –39.49 (120 kHz) –39.17 (200 kHz)

Table A1.3. Estimated calibration coefficients for all calibrations of *Tangaroa* hull EK60 echosounders. Note that the February 2008 measurements were conducted in –1.4°C seawater and the 70 kHz was at a different location. For the latest calibration, linear percent difference from the May 2008 calibration values used as default (see Table A1.1) are shown in parentheses.

		Aug 2011	Jan 2010	May 2008	Feb 2008
18 kHz					
	Transducer peak gain (dB)	22.78 (+3%)	23.36	22.96	
	Sa correction (dB)	-0.69	-0.76	–0.81	
	Beamwidth (°) alongship/athwartship	10.9/11.1	11.1/11.3	10.8/10.8	
	Beam offset (°) alongship/athwartship	-0.02/0.08	0.00/0.00	0.00/0.00	
	RMS deviation (dB)	0.08	0.14	0.26	
38 kHz					
	Transducer peak gain (dB)	25.75 (+3%)	25.98	25.81	25.85
	Sa correction (dB)	-0.58	-0.58	–0.57	–0.53
	Beamwidth (°) alongship/athwartship	6.8/6.9	6.9/7.0	7.0/7.0	7.0/7.0
	Beam offset (°) alongship/athwartship	0.00/0.00	0.00/0.00	0.00/0.00	–0.04/0.04
	RMS deviation (dB)	0.08	0.10	0.16	0.13
70 kHz					
	Transducer peak gain (dB)	26.23 (+8%)	26.78	26.43	26.58
	Sa correction (dB)	-0.32	-0.30	–0.35	–0.28
	Beamwidth (°) alongship/athwartship	6.5/6.6	6.3/6.4	6.6/6.6	6.7/6.6
	Beam offset (°) alongship/athwartship	-0.00/0.00	0.00/0.00	0.00/0.00	–0.03/0.00
	RMS deviation (dB)	0.10	0.14	0.25	0.15
120 kHz					
	Transducer peak gain (dB)	25.96 (+12%)	26.79	26.17	
	Sa correction (dB)	-0.39	-0.35	–0.36	
	Beamwidth (°) alongship/athwartship	6.4/6.6	6.1/6.4	6.5/6.6	
	Beam offset (°) alongship/athwartship	-0.13/0.11	0.00/0.00	0.00/0.00	
	RMS deviation (dB)	0.17	0.17	0.35	
200 kHz					
	Transducer peak gain (dB)	25.25 (-11%)	25.35	24.96	
	Sa correction (dB)	-0.29	-0.36	–0.25	
	Beamwidth (°) alongship/athwartship	6.3/6.7	6.7/6.7	6.8/6.9	
	Beam offset (°) alongship/athwartship	0.00/0.00	0.00/0.00	0.00/0.00	
	RMS deviation (dB)	0.21	0.18	0.39	

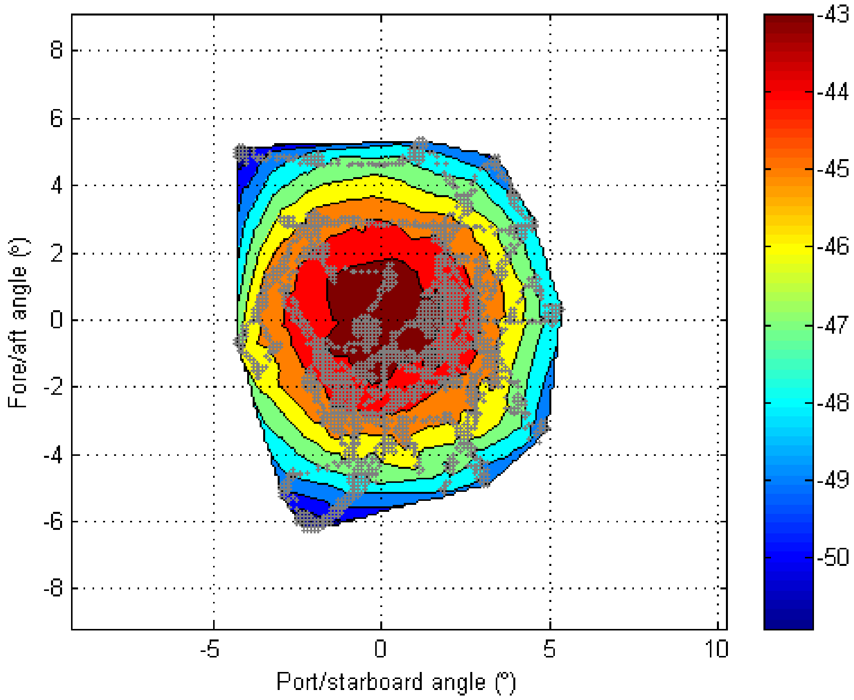

Figure A1.1. The 18 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

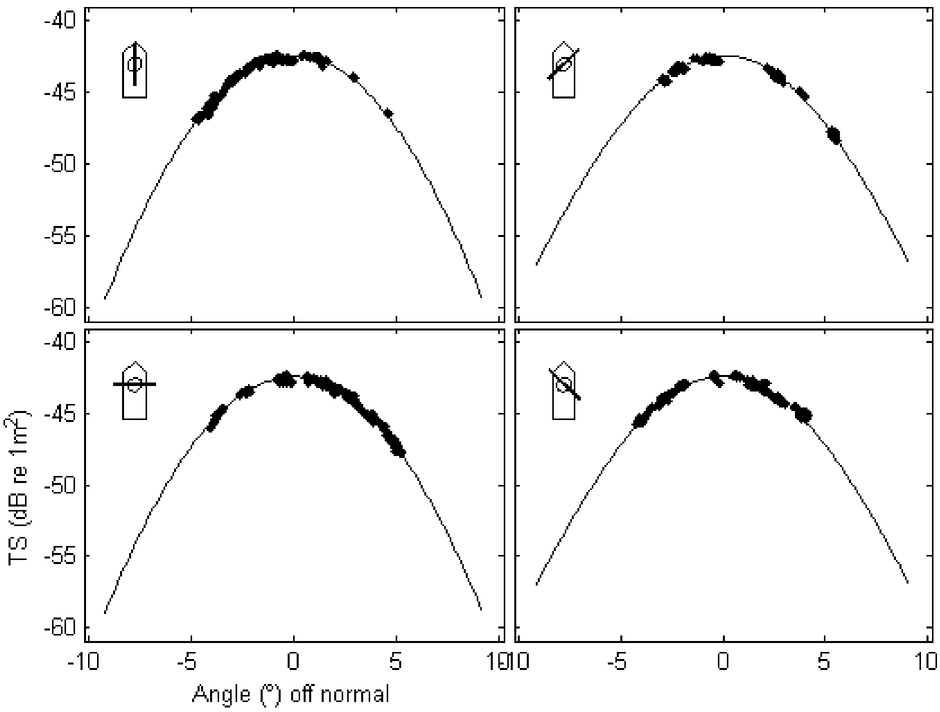

Figure A1.2. Beam pattern results from the 18 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

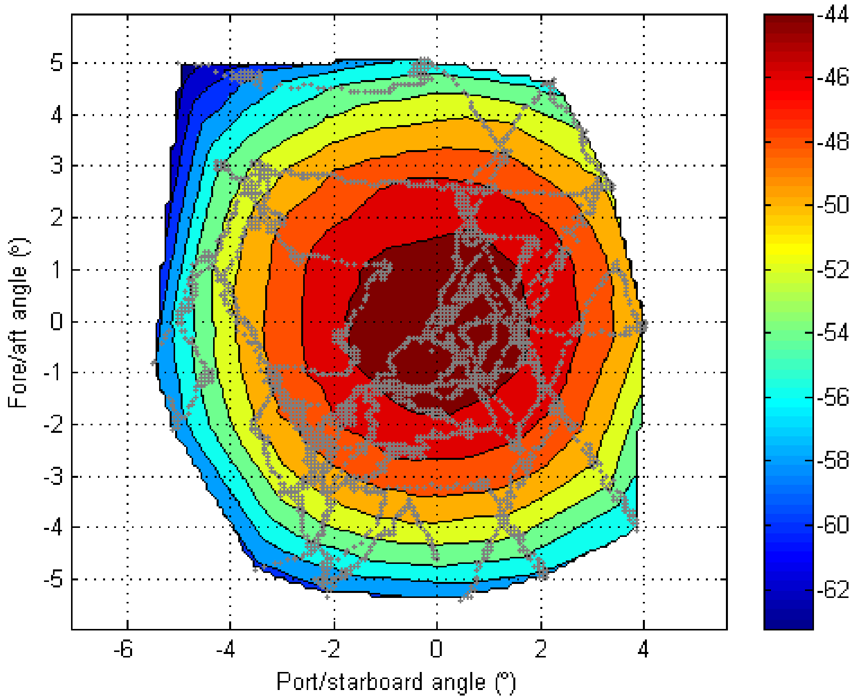

Figure A1.3. The 38 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

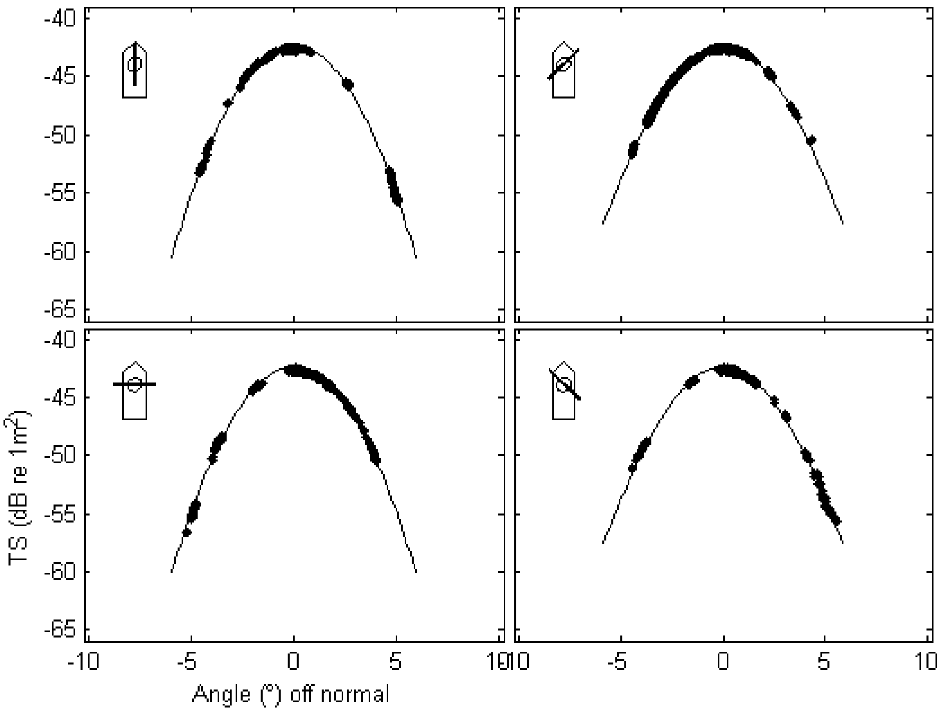

Figure A1.4. Beam pattern results from the 38 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

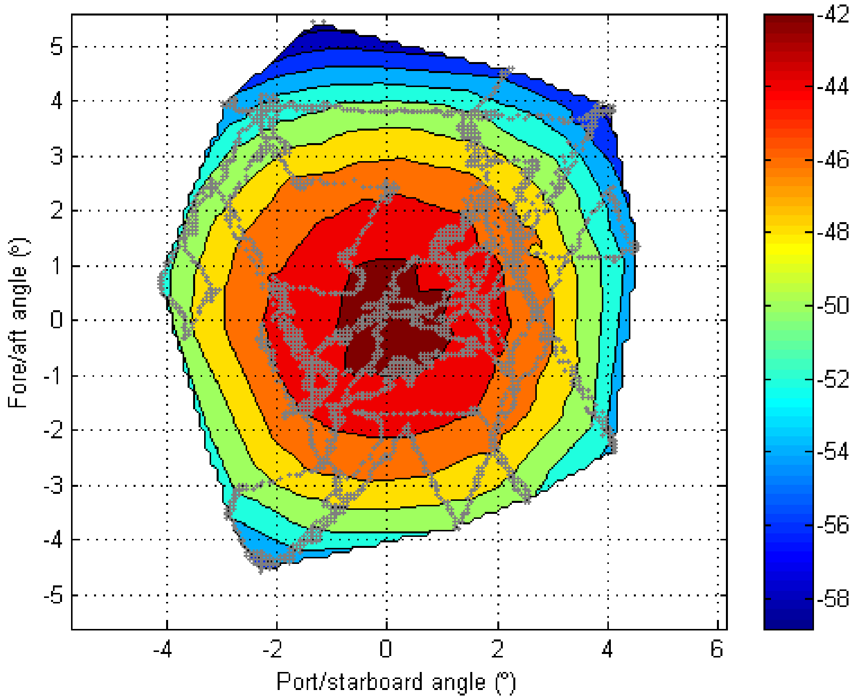

Figure A1.5. The 70 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

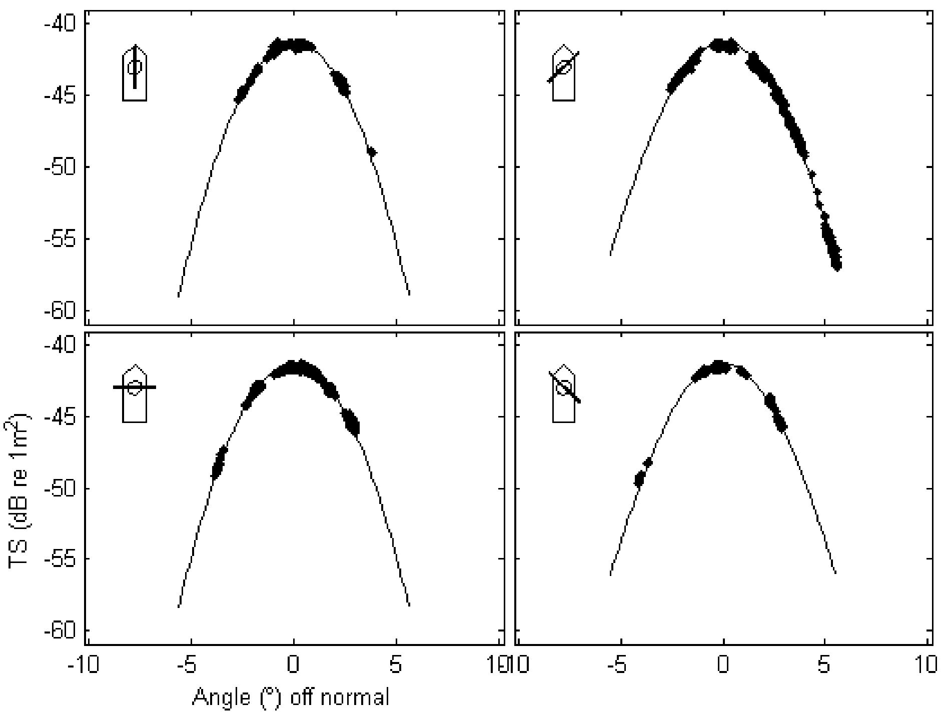

Figure A1.6. Beam pattern results from the 70 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

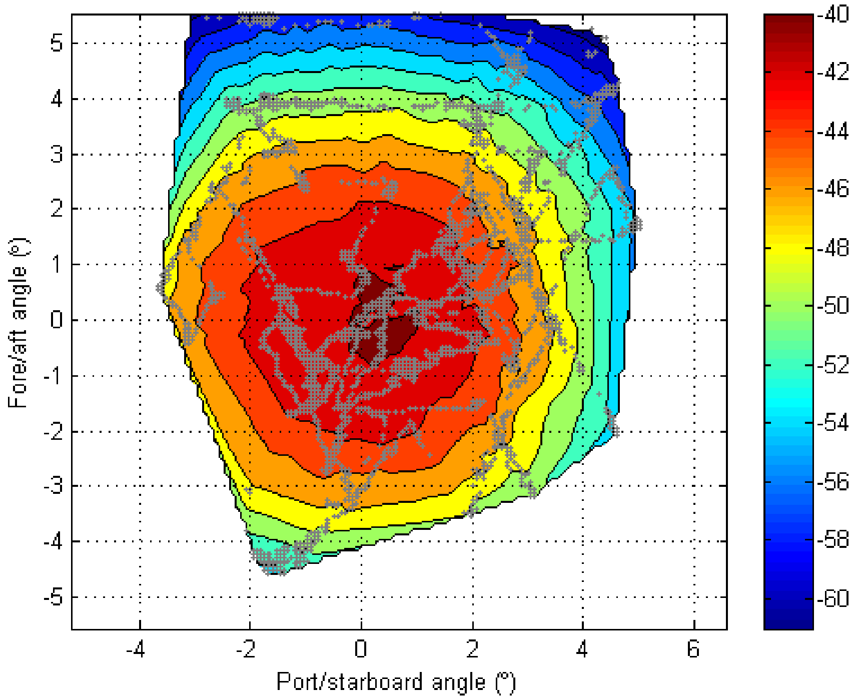

Figure A1.7. The 120 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

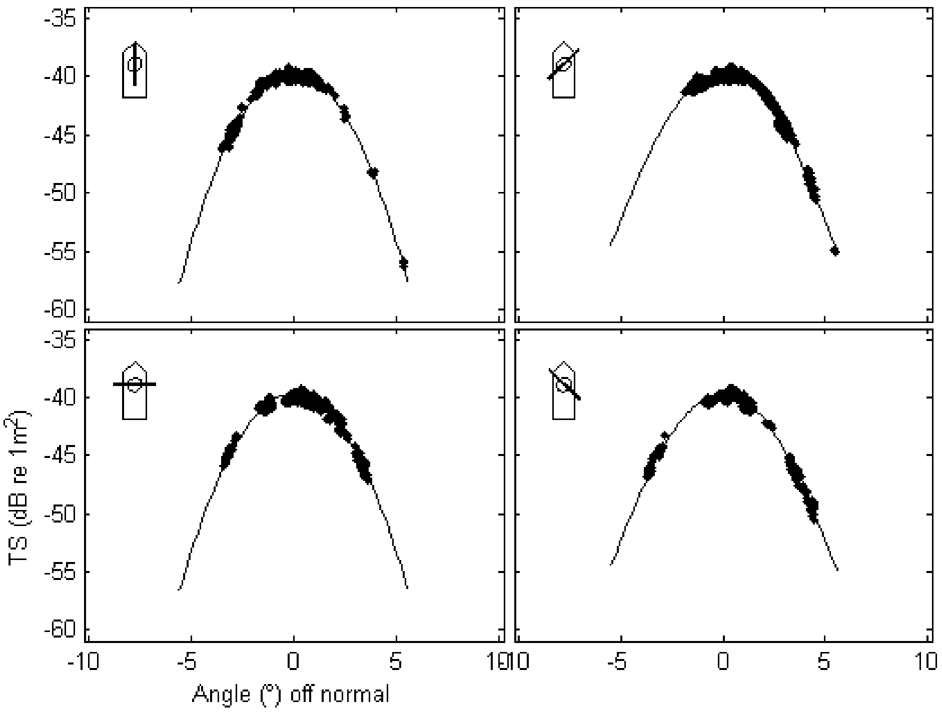

Figure A1.8. Beam pattern results from the 120 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

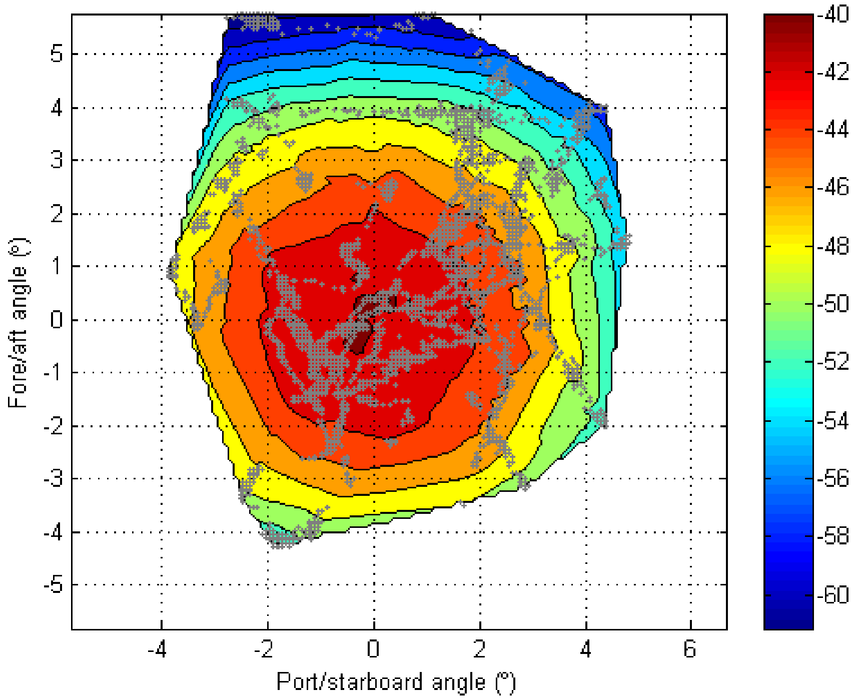

Figure A1.9. The 200 kHz estimated beam pattern from the sphere echo strength and position. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

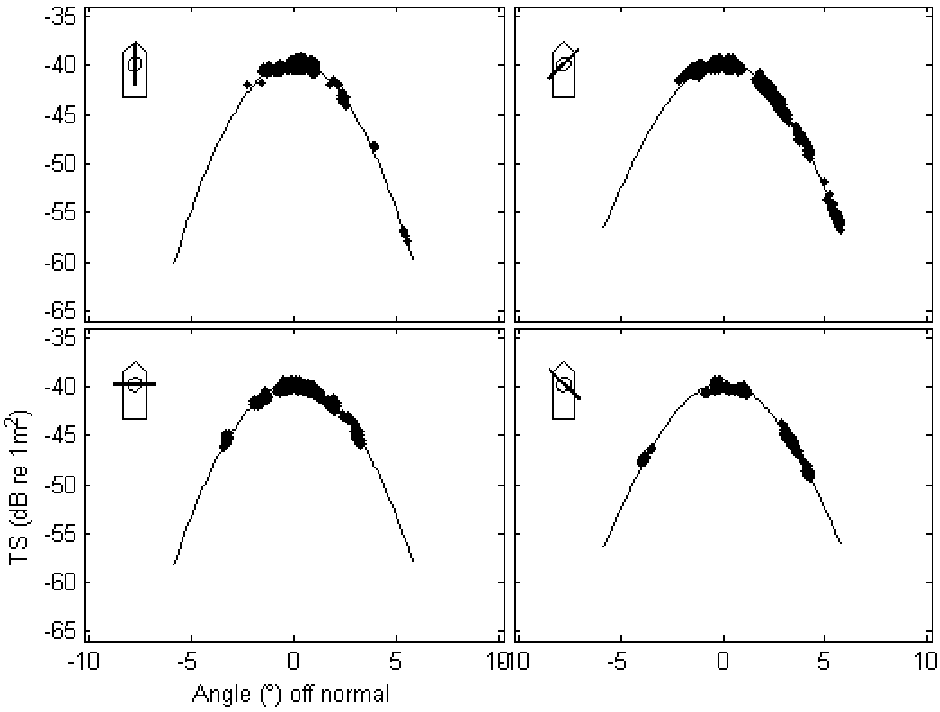

Figure A1.10. Beam pattern results from the 200 kHz analysis. The solid line is the ideal beam pattern fit to the sphere echoes for four slices through the beam.

APPENDIX 2: Towbody 3 calibration.

Table A2.1 provides the system settings and calculated calibration coefficients for towbody 3 used during the 2011 acoustic survey.

Table A2.1: System settings and calibration values for the 38 kHz CREST systems used for the 2011 SBW survey. V_T is the in-circuit voltage at the transducer terminals for a target of unit backscattering cross-section at unit range. *G* is the voltage gain of the receiver at a range of 1 m with the system configured for echo-integration (‘20 Log R’).

	Towed body 3
Transducer model	ES38DD
Transducer serial no.	28332B
3 dB beamwidths (˚) alongship/athwartship	7.3/7.4
Effective beam angle (sr)	0.0093
Operating frequency (kHz)	38.16
Transmit interval (s)	2.00
Transmitter pulse length (ms)	1.00
Effective pulse length (ms)	0.78
Filter bandwidth (kHz)	1.5
Initial sample rate (kHz)	100
Decimated sample rate (kHz)	25
V_T (V)	1168
G	12866
Absorption (dB km^{-1})	
calibration	9.83
survey*	9.44

* See Appendix 4

APPENDIX 3: Description of gonad development used for staging SBW

Research gonad stage		Males	Females
1	Immature	Testes thin translucent ribbons, almost undetectable.	Ovaries translucent, white and small (about 2 cm). No eggs present.
2	Resting	Testes partially lobed, but still threadlike.	Ovaries elongate and pale in colour. No eggs visible to naked eye.
3	Maturing	Testes multilobed, opaque to white with no milt extrudable.	Ovaries creamy white and firm with opaque eggs.
4	Mature	Testes with large creamy white lobes. Only small amount of milt extrudable.	At least one clear hyaline egg visible through ovary wall. Ovary considerably enlarged and speckled.
5	Running-ripe	Milt easily extrudable and free-running when pressed.	Clear (ovulated) eggs freely extrudable either from vent or cut ovary. At least 10% of the eggs in the ovary should be in this stage.
6	Partially spent	Testes brownish at edges, bloodshot and thin. Some milt extruded with pressure.	Ovary bloodshot and partially deflated. Vitellogenic, hyaline, and some ovulated eggs present.
7	Spent	Testes usually brownish, thin and straggly with no extrudable milt.	Ovary bloody, flaccid, and dark red/purple. Ovary wall often thickened. A few residual opaque or ovulated Eggs may be present.
8	Reverted		Ovary bloodshot and partially deflated. Mainly vitellogenic eggs, but a few ovulated eggs also present.

APPENDIX 4: Calculation of sound absorption coefficients

Nineteen CTD casts were carried out as part of the 2011 survey. Average sound absorption was estimated using the formula of Doonan et al. (2003) (Table A4.1). The average absorption estimate of 9.44 dB km^{-1} was used when estimating SBW biomass (see Section 3.6).

Table A4.1: Estimates of acoustic absorption (at 38 kHz) for the Campbell Island Rise acoustic survey area in 2011. Absorption was calculated from CTD profiles made during the survey using the formula of Doonan et al. (2003).

Station number	Max depth (m)	Mean salinity (ppt)	Mean temperature (˚C)	Absorption (dB km^{-1})
2	486	34.38	7.17	9.46
4	335	34.39	7.03	9.65
5	372	34.39	7.04	9.56
7	361	34.39	7.07	9.56
8	400	34.41	7.12	9.49
9	333	34.42	7.20	9.56
10	444	34.42	7.25	9.38
12	554	34.42	7.22	9.30
13	408	34.41	7.09	9.40
15	388	34.40	7.03	9.47
16	528	34.39	7.02	9.38
17	523	34.39	7.08	9.39
18	493	34.39	7.07	9.35
19	511	34.39	7.05	9.46
20	525	34.39	7.08	9.40
21	404	34.39	7.06	9.39
22	404	34.39	7.06	9.40
23	433	34.39	7.10	9.38
24	556	34.38	7.18	9.42
Average	445	34.40	7.10	9.44