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Acoustic estimates of southern blue whiting from the Campbell Island Rise, August–September 2013 (TAN1309)

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The 11th acoustic survey of southern blue whiting (SBW) on the Campbell Island Rise was carried out from 27 August to 23 September 2013 (TAN1309). Two snapshots of the survey area were completed: on 30 August–8 September and 8–20 September respectively. Nineteen bottom trawls and four midwater 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 three of the bottom trawls to collect *in situ* data on the acoustic target strength (TS) of SBW.

Pre-spawning and spawning adult SBW were detected in the north (stratum 2) and east (stratum 8E) of the survey area during snapshot 1. Some SBW were detected east of the survey boundaries, so an additional stratum (stratum 10) was added to cover the full extent of the eastern aggregation. Stratum boundaries were then modified in snapshot 2, with some strata extended and others reduced, in an attempt to better reflect the distribution of fish. The first spawning occurred early in 2013, on 2–9 September, and post-spawning adult SBW were widely distributed in strata 2, 3S, 4, 5, 6N, 6S, 8N, and 8S during snapshot 2. A second spawning occurred immediately after the survey on 20–26 September. Despite extensive coverage in both snapshots, no adult SBW aggregations were detected in the south of the survey area. This is consistent with the low numbers observed in this region during the 2011 survey and the small catches there in recent years. Immature southern blue whiting marks were found at depths shallower than 410 m in strata 2, 4, 5, 7N, and 7S, but were not as abundant and widespread during this survey as in 2009 or 2011. Immature SBW were mainly 2-year old (2011 year-class) fish with lengths between 20 and 30 cm. No juvenile (1 year-old) SBW marks were observed.

Biomass estimates were calculated for adult and immature SBW using the new target strength (TS) to fork-length (FL) relationship of $TS = 22.06 \log_{10}FL - 68.54$, length frequency information from commercial and research trawls, and the calculated sound absorption coefficient of 9.45 dB km^{-1}. The estimate of adult SBW biomass for all strata was 52 349 t (CV 58%) in the first snapshot and 79 253 t (CV 14%) in the second snapshot, giving an average adult estimate of 65 801 t (CV 25%). Most of the biomass was from the northern aggregation (62% of total adult biomass averaged over both snapshots), with the remaining contribution from the eastern areas (38% of biomass). The estimate of immature SBW biomass for all strata was 9962 t (CV 85%) in the first snapshot and 6046 t (CV 40%) in the second snapshot, giving an average immature estimate of 8004 t (CV 55%). Adult SBW biomass in 2013 was 23% higher than the equivalent estimate from 2011, while immature SBW biomass was 45% lower.

1. INTRODUCTION

Southern blue whiting (*Micromesistius australis*) is one of New Zealand's largest volume fisheries, with annual landings of between 25 000 t and 40 000 t since 2000 (Ministry for Primary Industries 2013). 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 76 000 t in the 1991–92 fishing year, when almost 60 000 t was taken from the Bounty Platform stock (Ministry for Primary Industries 2013). 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 (SBW6I) was increased from 20 000 t in 2009 to 23 000 t in 2010, and further to 29 400 t since 2011. The most recent (2012) stock assessment suggests that the biomass of the stock is expected to increase over the next one to two years as strong recent year classes from 2006 and 2007 grow and enter the fishery (Ministry for Primary Industries 2013).

Spawning occurs on the Bounty Platform from mid-August to early-September and three to four weeks later in the other areas. 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 are used to measure relative abundance of adult SBW and also to predict pre-recruit numbers into the stock. The movement of fish during the survey period required the development of an adaptive survey design to increase efficiency. There were ten previous surveys of the Campbell grounds, in 1993, 1994, 1995, 1998, 2000, 2002, 2004, 2006, 2009, and 2011. The biomass estimate of SBW aged 4 years and older from 2011 was the highest since 1998, following the recruitment of the strong 2006 and 2007 year-classes into the fishery (O'Driscoll et al. 2012b). However, the 2011 survey suggested that these two year-classes are not as strong as indicated by the 2009 survey (Gauthier et al. 2011). The estimate of 2-year-olds was also relatively high in 2011, suggesting that the 2009 year-class was above average (O'Driscoll et al. 2012b).

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. The 10-year Research Programme for Deepwater Fisheries has surveys of SBW6I scheduled to be delivered every two years.

This report summarises the data collected during the 11^{th} research acoustic survey of SBW on the Campbell Island Rise in August–September 2013 and presents biomass estimates, fulfilling the reporting requirements for Objectives 1 and 2 of Ministry for Primary Industries Research Project SBW2010/04B.

1.1 Project objectives

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

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 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 that 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 2013 survey was carried out from 27 August to 23 September 2013 to maximise the chances of covering the spawning period. The 28-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 1 day for target strength work and 3 days for bad weather. The survey period was a day shorter than that in 2011 because the 2013 survey immediately followed the combined trawl and acoustic survey of hoki and middle depth fish abundance on the West Coast South Island (Ministry for Primary Industries Research Project HOK2010/04C), thus saving some time required for mobilising equipment.

We aimed to carry out at least two snapshots of the Campbell Island Rise spawning area with an overall target CV of 30% (as specified by the project objectives). 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 was based on that used in the most recent survey of the area in 2011 (O'Driscoll et al. 2012b). Stratum boundaries were re-evaluated by examining the location of the commercial fishing fleet up to and including 2012 (Figure 1). The location of the commercial catch has varied considerably over time and in many years, including the four most recent years, a high proportion of the catch has been taken from outside the core survey area (strata 2–7). For 2013, we made two changes to the stratum boundaries used for snapshot 1 of the 2011 survey to reflect the more easterly distribution of SBW observed in 2012 (Figure 2):

1. Stratum 8E was extended to the east (to 172° 10'E) and south (to 52° 30'S).
2. Stratum 9 was dropped as few fish had been caught in this stratum in the past three years and estimated biomass from this stratum in 2011 was very low (O'Driscoll et al. 2012b).

The proposed transect allocation for core strata in 2013 (Table 1) was similar to the allocation used for the last seven surveys.

During the first snapshot, all of the commercial fleet was within the survey area (in strata 2 and 4). However, while steaming, we observed adult SBW east of stratum 8E, so a small additional stratum (stratum 10) with 4 transects was added to encompass the full extent of this aggregation (Figure 3). We did not detect any SBW aggregations in the south of the survey area, so we extended the southern end of the western two transects in stratum 7S on 8 September from 53° 27'S to 53° 32'S in case fish were beyond the stratum boundaries (Figure 3).

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

1. Reducing stratum 6S by shifting the southern boundary north from 53˚ 25'S to 52˚ 30'S.
2. Modifying stratum 8E so that it extended from 52˚ 00'S to 52˚ 20'S and 171˚ 30'S to 172˚ 20'S and changing orientation of transects from east-west to north-south.
3. Enlarging stratum 7S by shifting the southern boundary south from 52˚ 27'S to 52˚ 33'S and western boundary from 169˚ 40'E to 169˚ 30'E to try to ensure that we were not missing any potential aggregations.

A brief search was carried out west and south of stratum 7S on 8 September (Figure 4). Due to poor weather in the latter part of the survey (11–18 September), and the resulting loss of time (see Section 3), it was not possible to survey stratum 3N during snapshot 2 (Table 1, Figure 4). The number of transects in strata 2, 4, 6N, and 8N was also reduced from the number originally planned (Table 1).

2.2 Acoustic data collection

NIWA's new Simrad EK60-based towed system (Towbody 3), with a 38-kHz split-beam transducer, was used for most acoustic data collection along survey transects in snapshot 1. A second towbody with a CREST 38 kHz echosounder (Towbody 4) was carried as a spare, and was used during snapshot 2 when the EK60 towbody required re-termination. Data were also collected using the hull-mounted EK60 system with 18, 38, 70, 120, and 200 kHz transducers 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 onboard. The 38 kHz hull system was also used for some survey transects when the weather conditions were suitable.

Both towed acoustic systems were successfully calibrated during the survey, in Perseverance Harbour at Campbell Island on 9 September, while sheltering from rough weather. The calibration of Towbody 3 is described in detail in Appendix 1. This was only the second at-sea calibration of the new towed EK60 echosounder. The calibration was of excellent quality and indicated that the transducer and transceiver were operating correctly. The estimated calibration coefficients were about 11% lower than those from the previous calibration of this system on 28 July 2013 (see Appendix 1). This was a greater difference than expected, but may be related to the different environmental conditions and towbody depths during the two calibrations. Calibration values for Towbody 4 (CREST) are provided in Appendix 2 and were comparable with those from previous calibrations. The multifrequency hull echosounders were calibrated on 28 July 2013 in Tasman Bay at the start of the combined trawl and acoustic survey of hoki and middle depth species on the west coast South Island (TAN1308). This calibration showed that all five frequencies were operating correctly, with estimated calibration coefficients given in O'Driscoll et al. (in prep).

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 650 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 (see Section 2.4). Midwater marks were targeted using the NIWA 119 hoki midwater trawl, which has a headline height of about 40 m, and was rigged with 150 m bridles. Bottom marks were targeted using the ‘ratcatcher’ wing trawl, with 50 m sweeps and 50 m bridles. An additional 1 m layback was added to increase the headline height of the bottom trawl to about 4 m. Both trawls had a cod-end mesh of 40 mm. 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 Marel 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 Acoustic target strength and moorings

The relationship between TS and fork length (FL) for SBW was revised based on *in situ* TS data collected during the 2011 Campbell survey using an acoustic optical system (AOS) mounted in the headline of the trawl (O’Driscoll et al. 2013). This new relationship gives TS values within 1 dB of those estimated using the relationship recently adopted by ICES for blue whiting (*Micromesistius poutassou*) obtained from *in situ* measurements (Pedersen et al. 2011), but higher values than those estimated from the previous relationship for SBW, which was based on swimbladder modelling (Dunford & Macaulay 2006). O’Driscoll et al. (2013) found that the steep slope in the previous model estimates of SBW TS (Dunford & Macaulay 2006) was likely to be due to an inappropriate application of the Kirchhoff-approximation model at small swimbladder sizes, but noted that further work is required to attempt to reconcile differences between SBW swimbladder modelling and *in situ* TS results.

During the 2013 survey, we collected additional *in situ* data using the AOS on some mark identification trawls. We also aimed to measure the tilt angle distribution of SBW *in situ* using moored underwater video (O’Driscoll et al. 2012a). Use of moored cameras is highly weather dependent (i.e., can only be done in good weather), and is more challenging for SBW than for orange roughy or hoki because of the mobility of the SBW aggregations. Because of fish movement, and also the risk of the mooring being caught by a commercial fishing vessel, moorings could only be attempted if a relatively stable aggregation was found away from the main fleet.

2.5 Other data collection

A Seabird SM-37 Microcat CTD datalogger (serial number 2416) 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). A CTD cast was also carried out in conjunction with the acoustic calibration in Perseverance Harbour.

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 2013 fishery were extracted from the Ministry for Primary Industries *cod* database in December 2013. 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) 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 9.45 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 ratio for adults was calculated using the length frequency distribution of the commercial catch from observer data.

Acoustic target strength was derived using the new target-strength-to-fork-length (TS-FL) relationship of O'Driscoll et al. (2013):

$$TS = 22.06 \log_{10}FL - 68.54 \qquad (2)$$

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):

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

Mean weight and mean backscattering cross-section (linear equivalent of TS) for each category (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 (CV) of the mean biomass estimate from the survey combined the variance from each snapshot, assuming that each snapshot was independent.

No towbody motion correction (Dunford 2005) was applied to biomass estimates, 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).

Acoustic biomass estimates are no longer decomposed to provide estimates of 1, 2, 3, and age 4+ fish (Hanchet et al. 2000b), as this is now done within the assessment model.

2.9 Target strength data analysis

Estimates of mean TS and confidence intervals (95% CI) from bootstrapping were calculated for all optically-verified SBW tracks using the methods of O'Driscoll et al. (2013). As the AOS has only a single camera, it was not possible to use stereo-photogrammetry to obtain fish lengths. However, by using accurate range derived from the acoustic track and component geometry, pixel counts from the video images were used to estimate fork length of the fish.

3. RESULTS

3.1 Data collection

All surveys objectives were achieved despite the loss of about 103 hours (4.5 days) of survey time due to poor weather conditions. Rough weather was encountered while steaming south at the beginning of the survey and our arrival in the survey area was delayed by 9 hours. Strong winds and large swells stopped work for 18 hours on 4–5 September, 28 hours on 11–13 September, and we were forced to seek shelter at Campbell Island for 48 hours on 15–17 September. Although weather and sea conditions allowed collection of acoustic data for the rest of the voyage, they were often marginal, with 25–40 knot winds (Figure 5) and 4–8 m swells. These conditions reinforced the value of using specialist towed acoustic systems, as data quality on the hull echosounders in these conditions was poor. The cumulative loss of time due to weather exceeded the allowance of 3 days provided for in the survey design (Section 2.1), and meant that there were fewer trawls than planned, little experimental work (only three AOS trawls and no moorings), and that snapshot 2 was reduced. A total of 428 acoustic data files (93 Towbody 3, 52 Towbody 4, and 283 hull) were recorded during the survey.

Nineteen bottom trawls and four midwater trawls were made to identify targets and collect biological samples (Table 2, Figures 3–4). Tow length ranged from 0.43 to 2.62 n. miles at an average speed of 3.5 knots (Table 2). The total trawl catch was 15 159 kg. This was made up of 74 species or species groups. Most tows were dominated by southern blue whiting (68.7% of total catch, Table 2). The most abundant bycatch species were spiny dogfish (6.8%), javelinfish (4.8%), ling (3.8%), hake, and pale ghost shark (both 3.3%). A total of 9887 fish and squid of 26 different species were measured (Table 3). Of these, 421 fish were also individually weighed (Table 3), and 358 sets of SBW otoliths were collected for ageing.

In situ target strength measurements were made on three mark identification bottom trawls (see Table 2) using the acoustic-optical system (AOS). Use of the AOS was limited by weather conditions as it could only be deployed at winds less than about 25 knots and swell less than 2 m to prevent damage to equipment. Suitable conditions only occurred on 31 August and 20 September (see Figure 5).

The poor weather also prevented deployment of moored cameras. The Exclusive Economic Zone and Continental Shelf (Environmental Effects – Permitted Activities) Regulations came into force on 28 June 2013, and the moored camera work fell under these new regulations ("fishing" activities are specifically excluded). The regulations required pre-activity notification to the Environmental Protection Agency (EPA) 40 working days prior to commencement of the activities and notification and consultation with iwi. NIWA did not provide pre-activity notification until 21 August 2013 (as soon as the process was defined and forms made available by EPA), so we required a waiver of the statutory timeframes. This waiver was provided by EPA on 6 September 2013, but the weather conditions were not suitable for a mooring deployment after this date.

The 19 CTD profiles showed that the water column was unstratified with surface temperatures ranging between 7.0 and 7.3 °C.

3.2 Commercial data

A total of 653 target SBW tows were reported on trawl catch effort processing return (TCEPR) forms from the Campbell Island grounds between 15 August and 1 October 2013, for a total estimated catch of 25 658 t of SBW. This was slightly lower than the reported (QMR) catch of 28 607 t for SBW6I. The catch rates from commercial trawls during the 2013 season are shown in Figure 6. Fishing effort was concentrated in the northern area throughout the season, with only 21 tows (543 t of SBW catch) in the east, and 5 tows (57 t catch) in the south. All fishing in the east and south was done early in the season (before 1 September). The fishing pattern in 2013 was strongly influenced by bycatch of sea-lions, which was perceived to be higher in the east (Richard Wells, Deepwater Group Ltd, pers. comm.). For this reason, vessels avoided the eastern SBW aggregation.

During the first snapshot, fishing effort was concentrated in stratum 2, but effort was more widespread in strata 2, 4, and 3S during snapshot 2 (Figure 7). The fleet moved further east, in strata 3S and 4, after the survey period (Figure 7).

Two distinct spawning periods (defined as when the proportion of running ripe females exceeded 10%) were recorded, from 2–9 September and from 20–26 September (Figure 8). The timing of the first spawning in 2013 was early compared to the timing in previous survey years (Figure 8).
The scaled length frequencies of fish caught by commercial vessels for the eastern area, and for the northern area in early and late periods (separated by 15 September to distinguish the first and second spawning) are shown in Figure 9. Length distributions were bimodal with two adult modes centred on about 33 cm and 38 cm for males, and 35 cm and 42 cm for females (Figure 9). Although there were very few trawls sampled in the east (SBW only measured from 5 commercial tows), there appeared to be a higher proportion of fish from the larger mode in the eastern area than in the north, and the mean length was higher in the east (Table 4). The proportion of SBW in the larger mode (Figure 9) and mean length (Table 4) were also slightly higher in the northern area during the late (second spawning) period than during the early (first spawning) period.

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.

Pre-spawning adult SBW marks were detected during snapshot 1 in stratum 2 at about 440–480 m bottom depth on 31 August (Figure 10). Very dense spawning marks were observed in stratum 8E and 10 on 4–5 September. These marks were in midwater at night, but closer to the bottom during the day (Figure 10). Post-spawning adult SBW were widely distributed in strata 5, 6N, 6S, 8N, and 8S during snapshot 2 on 13–18 September, and in strata 2, 3S, and 4 on 19–20 September. These fish formed layers up to 250 m off the bottom during the night which descended to within 50 m of the bottom during the day (Figure 11). Three midwater trawls on adult marks caught 98–100% SBW by weight, while five bottom trawls caught an average of 70% SBW (range 49–95%) (see Table 2).

Immature southern blue whiting marks were found at depths shallower than 410 m in strata 2, 4, 5, 7N, and 7S. Immature marks were in characteristic “plumes” or clumps during the day which dispersed at night (e.g. Figure 12). Five bottom trawls on immature marks all had moderate catch rates with an average of 58% SBW by weight (range 34–82%) (see Table 2). These were mainly 2-year old (2011 year-class) fish with lengths between 20 and 30 cm (see Figure 9). No attempt was made to distinguish immature and juvenile marks as very few juvenile (1 year-old) SBW were caught during the 2013 survey.

Other mark types are illustrated in Figure 13. Weak background demersal marks (bottom “fuzz”) were widespread throughout the survey area, but trawls indicated that this contained a low proportion of SBW –7 bottom trawls on background marks had mean 10% SBW by weight (range 0–33%). Near-bottom layers in shallow water (300–350 m bottom depth) were dominated by silverside (e.g., tows 4 and 7 in Table 2). Mesopelagic fish marks were common, particularly in the south. During the day mesopelagic marks were observed as a series of schools between 50 and 300 m depth. These schools tended to disperse at night. A midwater trawl on one of these marks (tow 15) caught pearlside (*Maurolicus australis*).

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

- Characteristic moderately dense marks in 300–410 m depth were the immature SBW category (mainly 2 year old).
- Dense marks in water deeper than 410 m were the adult SBW category.

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, 2012b, Gauthier et al. 2011). The acoustic contribution of SBW in the background demersal fuzz marks was ignored.

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 14–17). As noted in Section 3.3, adults were detected in two areas during snapshot 1: in the north (stratum 2); and east (strata 8E and 10). More extensive, but weaker, adult marks were detected in eastern (strata 5, 6N, 6S, 8N, and 8S) and northern areas (strata 2, 3S and 4) during snapshot 2. Despite extensive coverage in both snapshots, no adult SBW aggregations were detected in the south of the survey area.

Immature SBW marks occurred in depths shallower than 410 m in strata 2, 4, 5, 7N, and 7S. The densest immature marks were in stratum 5. Consistent with previous surveys, the western (shallow) survey boundary was at 300 m depth. Immature marks occurred close to this boundary (Figures 16–17) 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 3220 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 9. The size distributions of fish from research tows on adult aggregations in the north and east were generally similar to those from the commercial catch (see Section 3.2), with two adult modes in both areas, centred on about 33 cm and 38 cm for males, and 35 cm and 42 cm for females (see Figure 9). As in the commercial data, there appeared to be a higher proportion of fish from the larger mode in the eastern area than in the north, meaning that the average length was slightly higher in research catches in the east than that from research tows in the north (Table 4). As noted in Section 3.3, fish caught from immature marks had a single mode between 20 and 30 cm (see Figure 9), and were two-year olds from the 2011 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 female SBW caught in snapshot 1 were pre-spawning (stages 3–4), and almost all adult females caught in snapshot 2 were post-spawning (stages 6–8) (see Appendix 3 for description of research stages). Running ripe fish (stage 5) were seldom observed in research trawls, except in tow 10 in stratum 10 on 5 September (Table 5). 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 9 are given in Table 4. After discussion at its meeting on 9 December 2013, the Middle Depth Fisheries Assessment Working Group agreed to use the combined length frequency from all commercial tows to estimate the r for adult SBW.

SBW biomass estimates by snapshot and stratum are given in Table 6. These estimates were calculated using the TS-length relationship of O'Driscoll et al. (2013) and a calculated sound absorption coefficient of 9.45 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 (Fu et al. 2013).

The adult biomass estimate was 52 349 t (CV 58%) in snapshot 1 and 79 253 t (CV 14%) in snapshot 2. Only half (54%) of the adult biomass in the first snapshot was within the historical core area (strata 2–7), but most of the adult SBW (94%) had moved into the core area in snapshot 2. The estimated adult biomass in 2013 (average of both snapshots) was 65 801 t (CV 25%), which was 23% higher than the estimated adult biomass in 2011 (53 299 t), but lower than that in 2009 (99 521 t) (Table 7).

The estimate of immature SBW biomass for all strata was 9962 t (CV 85%) in the first snapshot and 6046 t (CV 40%) in the second snapshot, giving an average immature estimate of 8004 t (CV 55%). Biomass of immature SBW in 2013 was 45% lower than that in 2011 (14 454 t), and only a third of that observed in 2009 (24 479 t), but was about average for the time-series (Table 7).

3.7 Target strength estimates

The three AOS deployments provided only 11 optically-verified acoustic tracks from SBW (Figure 18). These covered a wide range of estimated FL from 22–51 cm and gave estimated mean TS between -53.0 and -32.0 dB. These estimates were within the range of TS values estimated from the much larger dataset (162 tracks) from 2011 (O'Driscoll et al. 2013), and are not inconsistent with the current TS-FL relationship (Equation 2) (Figure 18).

4. DISCUSSION

4.1 Timing of the survey

The timing and duration of the 2013 survey were similar to those in the previous five surveys (2002, 2004, 2006, 2009, and 2011). The survey was about one week earlier than those before 2002 (see Figure 8). In 2013, the first spawning occurred relatively early, from about 2–9 September, with a second peak from 20–26 September (see Figure 8). The timing of the survey relative to spawning was therefore appropriate, with snapshot 1 surveying pre-spawning and spawning fish, and snapshot 2 primarily surveying post-spawning fish.

4.2 Variability between snapshots

Both adult and immature SBW biomass estimates had higher CVs (see Table 6) in the first snapshot, reflecting highly aggregated distributions in this snapshot (see Figures 14 and 16). Fish were more dispersed during the second snapshot (see Figures 15 and 17) and CVs were correspondingly lower (see Table 6). The Ministry for Primary Industries target CV of 30% for adult SBW was achieved, with an average CV of 25% across the two snapshots. Adult biomass was 50% higher in the second snapshot, but, given their respective CVs, estimates from the two snapshots were relatively consistent. Much greater variability between snapshots has been observed in some previous surveys. For example in 2009, the adult estimate from snapshot 2 was nearly double that from snapshot 1 (Gauthier et al. 2011). The estimates of immature SBW in 2013 were also relatively consistent between snapshots, but had a relatively high average CV (55%) due to the occurrence of much of the biomass on a single transect in stratum 5 in the first snapshot (see Figure 16).

4.3 Treatment of fish outside the core survey area

Historically, the Campbell SBW fishery can be characterised as occurring on two distinct aggregations: northeastern, and southern (see Figure 1), which often have different fish length structure (Hanchet 1998, 2005). The location of the northeastern aggregation has varied, and, since 2002, there has been increasing commercial catch and effort outside the historical core survey area (see Figure 1). Hanchet (2005) examined commercial length frequency data from 1997 to 2004 and found that SBW caught east of the core area had a similar size distribution to those caught in the north within the core area, so changes in fish distribution were likely to be due to fish movement rather than appearance of previously unsurveyed fish. In 2011, the single aggregation in the northeast appeared to have split into two distinct aggregations in the north and east (O'Driscoll et al. 2012b), and commercial data from 2012 also supported the existence of separate aggregations in the north and east (see Figure 2). The size distribution of fish from the northern aggregation in both commercial and research tows in 2011 was similar to that from the eastern aggregation (O'Driscoll et al. 2012b).

Results from the 2013 acoustic survey again showed geographically separated adult aggregations in the north and east during snapshot 1 (see Figure 14), but the distribution was more contiguous in snapshot 2 (see Figure 15), as fish in the east had moved northwest, while those in the north moved north and east after first spawning. Length modes of SBW from research tows were similar in the north and east, but there was some evidence that the relative proportion of smaller fish was higher in the north, especially in the first half of the season (see Figure 9).

At the same time as the distribution of SBW has expanded in the north and east, the relative contribution of the southern aggregation has declined. In 2009, very dense spawning marks were detected in the south and the southern aggregation accounted for 24% of the estimated adult acoustic biomass on the Campbell Island Rise (Gauthier et al. 2011). This had declined to only 3% of the estimated adult biomass in 2011 (O'Driscoll et al. 2012b), and, despite extensive searching, no spawning SBW were detected in the south in 2013. Commercial catch rates in the south have also declined (see Figure 1), with only 5 trawls in this area in 2013 (see Figure 6). There is no clear explanation for the apparent disappearance of the southern aggregation. However, Hanchet (1998) noted that the strong 1991 year class first recruited to, and spawned in, the southern ground but thereafter returned in greater numbers to spawn in the northeast. There has also sometimes been a different size and age composition in the south to that in the northeast, and it is also possible that recent recruitment (see Section 4.4) has not fed into this aggregation.

All fish recorded during the 2013 survey were used for the biomass estimates. In light of continuing changes in the distribution of SBW, we recommend that the survey area and stratification continues to be reviewed before future surveys.

4.4 Comparison between years

The acoustic biomass estimate for adult SBW increased by 23% from the previous survey in 2011, which was consistent with relatively good recruitment of 4 year-old fish from the 2009 year-class into the spawning population. This year-class was reported as being strong as immature fish (age 2) in 2011 (O'Driscoll et al. 2012b). The 4-year-old fish were responsible for the left hand mode in observed adult length frequencies in 2013 (see Figure 9) with an average length of 33–35 cm. Ageing showed that fish in the larger mode (mean length 38–42 cm) were ages 5–12, with a peak at age 7 (2006 year-class). The 2006 year-class was estimated to be strong at age 3 in 2009 (Gauthier et al. 2009).

The 46% decline in acoustic biomass estimates for adult fish from 2009 to 2011 (see Table 7) was driven primarily by the much lower contribution of the southern aggregation in 2011 (O'Driscoll et al. 2012b). As noted in Section 4.3, the southern aggregation was not present in 2013, with the adult biomass split between the north and east. The northern aggregation (strata 2, 3S, and 4) accounted for 63% of the adult biomass averaged across the two snapshots, with the remaining 37% in the east (strata 5, 6N, 6S, 8N, 8S, 8E, and 10). Adult SBW biomass in 2013 was estimated to be similar to that in 2002 (see Table 7).

Biomass of immature SBW in 2013 was about average for the time-series, suggesting average recruitment of the 2011 year-class. Relatively few 1-year-old (2012 year-class) and 3-year-old (2010 year-class) were observed during the 2013 survey, suggesting that these year-classes may be weak.

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7. TABLES

Table 1: Summary of transects carried out during the 2013 SBW acoustic survey of the Campbell Island Rise. Transect positions are plotted in Figures 3–4. Values in parentheses for Snapshot 2 are the number of transects planned before time was lost due to bad weather. Note that the boundaries of strata 6S, 7S and 8E were modified for Snapshot 2.

	Snapshot 1 (30 Aug–8 Sep)			Snapshot 2 (8–20 Sep)	
Stratum	Area (km^2)	Transects	Stratum	Area (km^2)	Transects
2	3 154	5	2	3 154	4 (5)
3N	2 342	3	3N		0 (3)
3S	1 013	3	3S	1 013	3 (3)
4	2 690	5	4	2 690	4 (5)
5	3 029	4	5	3 029	4 (4)
6N	1 150	4	6N	1 150	3 (4)
6S	3 025	3	6S2	1 163	3 (3)
7N	2 980	4	7N	2 980	4 (4)
7S	1 995	10	7S2	3 045	4 (4)
8N	1 436	4	8N	1 436	3 (4)
8S	1 452	4	8S	1 452	3 (3)
8E	3 799	6	8E2	2 115	7 (7)
10*	253	4			
Total	28 318	59		23 227	42 (49)

* Stratum 10 was added during snapshot 1 because the eastern aggregation extended beyond the boundary of stratum 8E.

Table 2: Trawl station details and catch of the main species during the 2013 acoustic survey of the Campbell Island Rise. Tow positions are plotted in Figures 3 and 4. Mark type: Adult, adult SBW; Imm, immature SBW; SSI, silverside; Back, background fuzz; Meso, mesopelagic layer. Gear type: BT, bottom trawl; AOS, bottom trawl with AOS; MW, midwater trawl. Species: SBW, southern blue whiting; LIN, ling; JAV, javelinfish; SSI, silverside; SPD, spiny dogfish; GSP, pale ghost shark.

		Mark	Gear		Start	Start	Bottom	Tow length	Catch (kg)						
Tow	Date	type	type	Stratum	Latitude (°S)	Longitude (°E)	depth (m)	(n. mile)	SBW	LIN	JAV	SSI	SPD	GSP	Total
1	31-Aug-13	Adult	AOS	2	51 28.26	169 44.37	480	2.62	45.9	2.2	3.1	1.5	0.0	14.1	71.3
2	31-Aug-13	Adult	AOS	2	51 34.10	169 55.67	453	2.22	102.7	0.0	0.0	0.0	0.0	0.0	108.5
3	31-Aug-13	Adult	MW	2	51 32.76	169 55.85	276	0.43	5 078.7	0.0	0.0	0.0	0.0	0.0	5 099.9
4	1-Sep-13	SSI	BT	4	51 50.74	170 04.59	299	1.70	0.1	0.0	0.1	31.1	2.5	0.0	85.3
5	1-Sep-13	Back	BT	4	51 36.56	170 27.79	465	1.66	264.5	36.3	216.4	36.9	21.8	129.7	799.2
6	2-Sep-13	Back	BT	4	51 55.71	170 26.37	368	1.69	15.8	2.9	1.0	51.2	0.0	20.1	136.7
7	2-Sep-13	SSI	BT	5	52 03.75	170 25.62	312	0.88	0.0	0.0	0.1	48.2	1.2	0.0	101.4
8	2-Sep-13	Imm	BT	5	52 12.00	170 20.45	396	0.61	225.5	0.0	2.3	41.6	4.2	0.0	314.2
9	5-Sep-13	Back	BT	10	52 10.18	172 11.87	584	0.43	17.6	170.1	40.9	0.8	921.7	41.4	1 729.9
10	5-Sep-13	Adult	MW	10	52 10.65	172 12.75	500	0.98	2 819.3	0.0	0.0	0.0	0.0	0.0	2 867.3
11	7-Sep-13	Imm	BT	7N	53 09.41	170 02.30	312	1.18	232.2	0.0	0.4	20.6	0.0	0.0	354.3
12	8-Sep-13	Back	BT	7S	53 27.45	169 35.47	573	1.08	1.5	60.7	244.3	0.2	0.0	68.5	533.6
14	10-Sep-13	Imm	BT	7N	52 51.81	170 13.01	386	1.25	50.6	0.0	1.9	25.3	3.8	0.0	148.5
15	10-Sep-13	Meso	MW	7N	52 51.73	170 11.93	377	0.91	0.0	0.0	0.0	0.0	0.0	0.0	1.0
16	12-Sep-13	Adult	BT	6S	52 29.53	171 04.25	494	1.38	369.8	90.9	20.2	8.3	9.6	36.1	598.2
17	12-Sep-13	Adult	BT	5	52 25.51	170 35.58	448	1.11	481.4	20.1	37.4	3.5	25.4	21.7	608.9
18	14-Sep-13	Back	BT	8E	52 06.07	172 04.38	543	1.12	1.0	17.4	35.9	1.9	2.5	31.4	118.1
19	14-Sep-13	Back	BT	8E	52 18.35	171 34.17	543	1.10	29.4	87.8	75.3	9.1	5.2	17.3	294.2
20	15-Sep-13	Imm	BT	5	52 16.90	170 25.98	402	1.08	450.7	6.5	1.7	7.7	0.9	32.3	546.8
21	20-Sep-13	Imm	BT	4	51 42.59	170 08.87	395	0.85	40.7	20.0	0.2	14.9	0.0	17.1	117.6
22	20-Sep-13	Adult	MW	4	51 37.31	170 21.29	469	0.91	2.1	0.0	0.0	0.0	0.0	0.0	2.1
23	20-Sep-13	Back	BT	4	51 34.50	170 19.36	468	1.63	28.9	16.3	32.4	53.7	14.4	25.1	214.3
24	20-Sep-13	Adult	AOS	4	51 35.06	170 26.11	476	2.01	152.1	48.6	13.9	27.6	10.9	40.1	307.9
Total									10 410.5	579.8	727.5	384.1	1 024.1	494.9	15 159.2

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
Alert pigfish	API	0	2	11	0
Oblique banded rattail	CAS	127	59	1 420	0
Banded rattail	CFA	0	13	591	0
Olivers rattail	COL	0	2	31	0
Dwarf cod	DCO	0	13	393	0
Deepsea pigfish	DSP	0	9	248	0
Dark ghost shark	GSH	9	1	10	7
Pale ghost shark	GSP	180	91	271	16
Hake	HAK	2	47	49	2
Hairy conger	HCO	0	0	25	0
Hoki	HOK	16	60	76	0
Javelinfish	JAV	20	54	1 321	0
Long-nosed chimaera	LCH	0	3	3	0
Lookdown dory	LDO	1	1	2	1
Ling	LIN	99	182	281	5
Southern arrow squid	NOS	0	0	9	0
Opalfish	OPA	0	0	100	0
Red cod	RCO	1	3	4	1
Rough skate	RSK	1	1	2	0
Southern blue whiting	SBW	1 564	1 655	3 220	354
Smallscaled cod	SCD	29	33	62	35
Swollenhead conger	SCO	0	0	46	0
Spiny dogfish	SPD	14	171	195	0
Silverside	SSI	9	42	1 505	0
Variable spotted toadfish	VST	0	1	1	0
White warehou	WWA	6	5	11	0
	Total	2 078	2 448	9 887	421

Table 4: Estimates of the ratio *r* used to convert SBW backscatter to biomass. Values are derived from the scaled length frequency distributions in Figure 9. Abundance estimates (Table 6) were calculated using *r* from all observed commercial tows ('Adult (all)') for adult SBW, and from research tows on immature fish ('Immature') for immature SBW. σ is the acoustic backscattering coefficient.

Category	Data source	No. of trawls measured	Mean length (cm)	Mean weight (g)	Mean σ (m^2)	Mean TS (dB)	*r* (kg m^{-2})
Adult (north early)	Commercial	165	37.3	384	0.000417	-33.8	921
Adult (north late)	Commercial	129	37.8	403	0.000431	-33.7	935
Adult (east)	Commercial	5	38.8	436	0.000456	-33.4	956
Adult (all)	Commercial	299	37.5	392	0.000423	-33.7	927
Adult (north)	Research	6	36.6	363	0.000401	-34.0	906
Adult (east)	Research	8	38.8	432	0.000454	-33.4	951
Immature	Research	5	25.4	113	0.000177	-37.5	637

Table 5: Gonad stages of SBW caught in research trawls during the 2013 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
1	31-Aug-13	2	Adult	1	1	31	39	3	0	0	1	0	58	0	0	0	0	0
2	31-Aug-13	2	Adult	1	1	40	33	48	0	0	8	0	109	7	0	0	0	0
3	31-Aug-13	2	Adult	0	0	6	70	1	0	0	1	0	121	4	0	0	0	0
4	1-Sep-13	4	SSI	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
5	1-Sep-13	4	Back	5	13	26	5	0	0	0	4	1	169	0	0	0	0	0
6	2-Sep-13	4	Back	69	5	5	0	0	0	0	87	0	0	0	0	0	0	0
8	2-Sep-13	5	Imm	89	2	8	0	0	0	0	117	0	0	0	0	0	0	0
9	5-Sep-13	10	Back	0	1	2	5	1	0	0	0	2	8	3	1	6	6	0
10	5-Sep-13	10	Adult	0	1	14	37	17	2	19	0	2	7	35	30	36	28	0
11	7-Sep-13	7N	Imm	135	4	0	0	0	0	0	125	0	0	0	0	0	0	0
12	8-Sep-13	7S	Back	1	0	0	1	0	0	0	3	0	0	0	0	0	0	0
14	10-Sep-13	7N	Imm	87	7	0	0	0	0	0	107	1	0	0	0	0	0	0
16	12-Sep-13	6S	Adult	1	3	2	0	1	49	69	0	1	3	2	3	41	25	24
17	12-Sep-13	5	Adult	3	0	1	8	0	18	40	0	1	5	0	1	7	45	63
18	14-Sep-13	8E	Back	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
19	14-Sep-13	8E	Back	0	0	0	6	0	23	2	1	0	2	0	0	14	1	10
20	15-Sep-13	5	Imm	144	3	0	0	0	0	0	101	2	0	0	0	0	0	0
21	20-Sep-13	4	Imm	115	2	6	0	0	0	0	87	0	0	0	0	0	0	0
22	20-Sep-13	4	Adult	0	0	0	0	0	1	2	0	0	2	0	0	2	0	2
23	20-Sep-13	4	Back	6	4	0	2	6	35	28	4	3	5	0	0	8	7	3
24	20-Sep-13	4	Adult	0	0	1	4	14	94	33	0	1	3	0	7	43	4	27

Table 6: Abundance estimates (t) and CV by stratum and snapshot of immature and adult SBW for the Campbell Island Rise in 2013.

	Immature		Adult	
Stratum	Biomass (t)	CV	Biomass (t)	CV
Snapshot 1				
2	0	–	27 959	80
3N	0	–	0	–
3S	0	–	0	–
4	171	100	0	–
5	9 308	90	0	–
6N	0	–	207	100
6S	0	–	0	–
7N	459	95	0	–
7S	25	99	0	–
8E	0	–	1 792	63
8N	0	–	0	–
8S	0	–	0	–
10	0	–	22 392	93
Total	9 962	85	52 349	58
Snapshot 2				
2	571	68	4 156	69
3S	0	–	8 487	59
4	1 366	55	42 513	19
5	2 672	73	6 393	48
6N	0	–	9 360	34
6S	0	–	3 314	20
7N	1 437	77	0	–
7S	0	–	0	–
8E	0	–	0	–
8N	0	–	1 353	39
8S	0	–	3 679	37
Total	6 046	40	79 253	14
Best estimate (average)	8 004	55	65 801	25

Table 7: Biomass estimates (t) by survey and category for the Campbell Island Rise. Values for surveys from 1993–2011 are from Fu et al. (2013) and were re-calculated using estimates of TS from O'Driscoll et al. (2013). Values represent best estimates for all areas surveyed.

	Juvenile	CV	Immature	CV	Adult	CV
1993	0	–	35 208	25	16 060	24
1994	0	–	8 018	38	72 168	34
1995	0	–	15 507	29	53 608	30
1998	322	45	6 759	20	91 639	14
2000	423	39	1 864	24	71 749	17
2002	1 969	39	247	76	66 034	68
2004	639	67	5 617	16	42 236	35
2006	504	38	3 423	24	43 843	32
2009	0	–	24 479	26	99 521	27
2011	0	–	14 454	17	53 299	22
2013	0	–	8 004	55	65 801	25

8. FIGURES

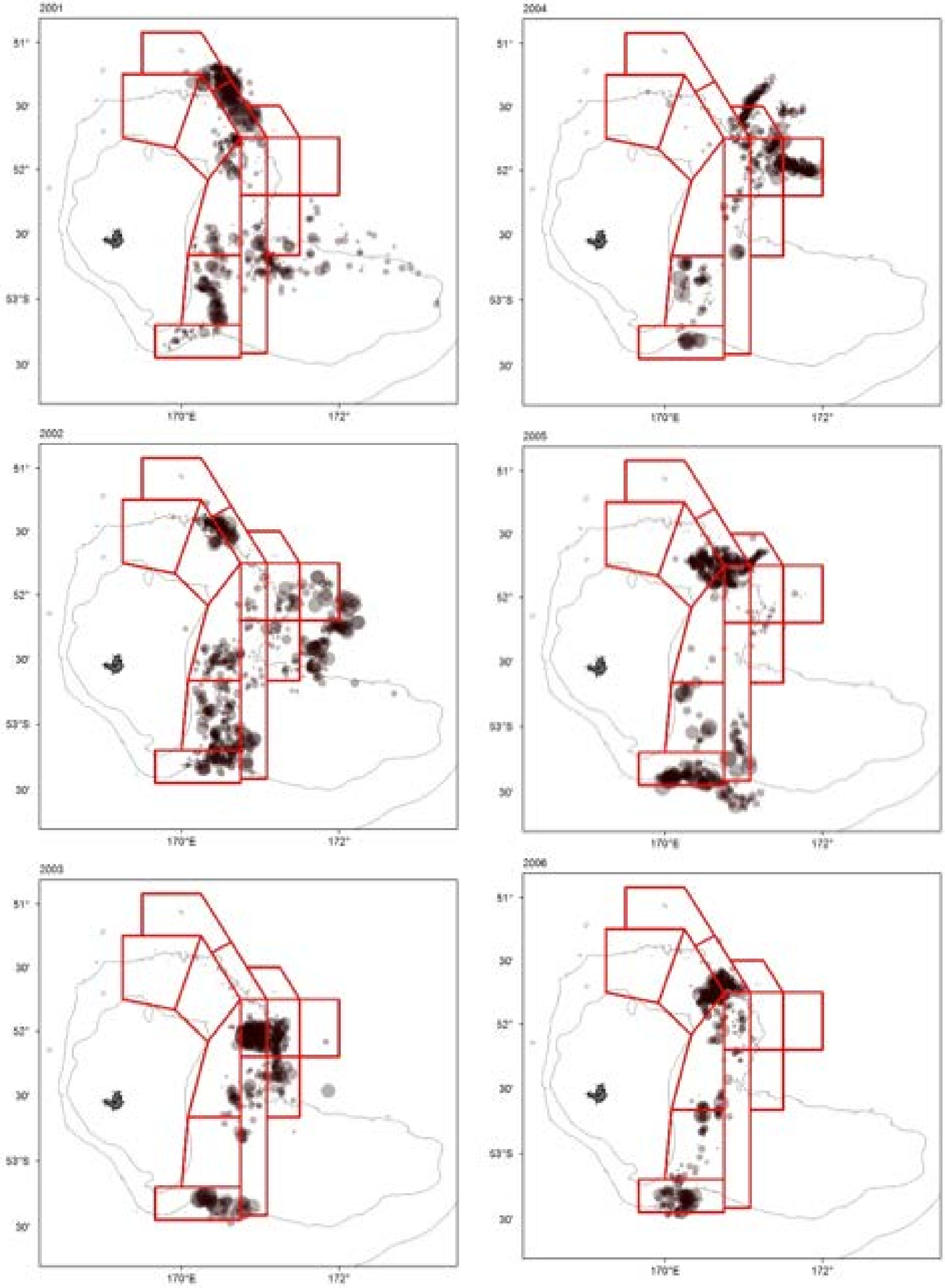

Figure 1: Stratum boundaries for Snapshot 1 of 2011 acoustic survey superimposed on plots of catch rates from commercial trawls on the Campbell Island Rise from 2001–06. Circle area is proportional to SBW catch rate.

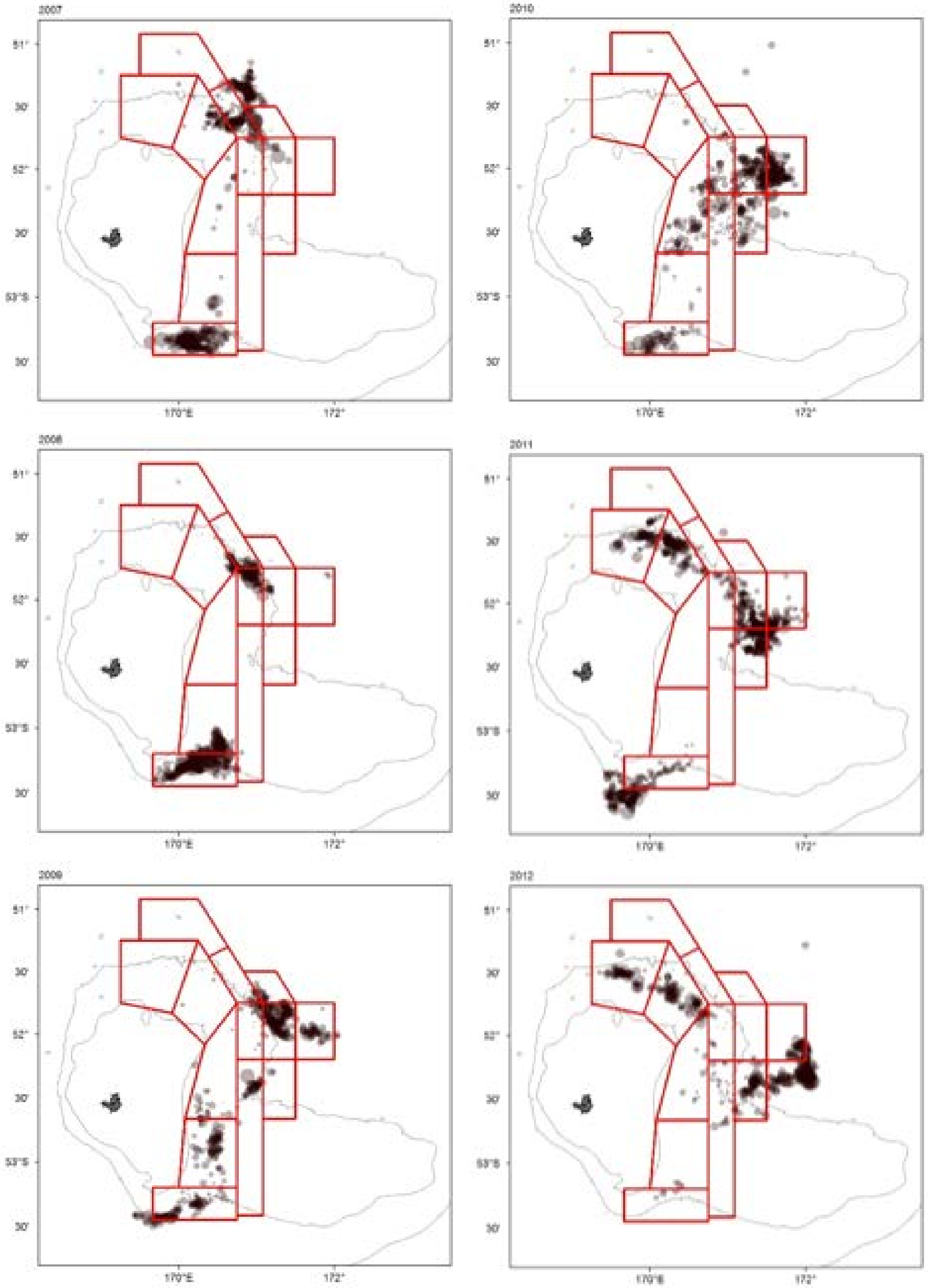

Figure 1 cont: Stratum boundaries for Snapshot 1 of 2011 acoustic survey superimposed on plots of catch rates from commercial trawls on the Campbell Island Rise from 2007–12. Circle area is proportional to SBW catch rate.

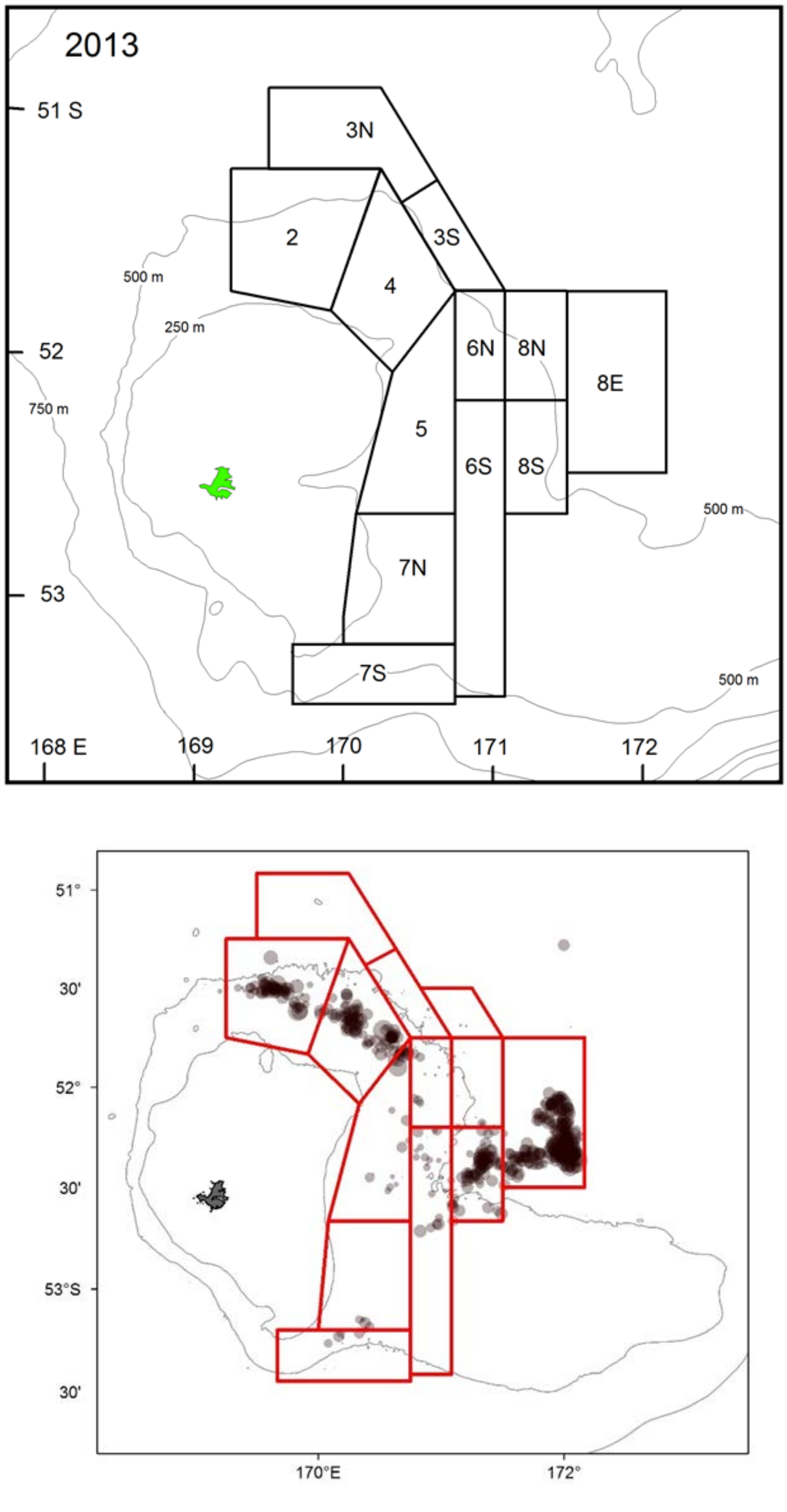

Figure 2: Proposed stratum boundaries for snapshot 1 of the 2013 acoustic survey of the Campbell Island Rise (upper panel) and commercial catch rates in 2012 (lower panel). Strata 2–7 are the core acoustic strata which have been covered in all previous surveys.

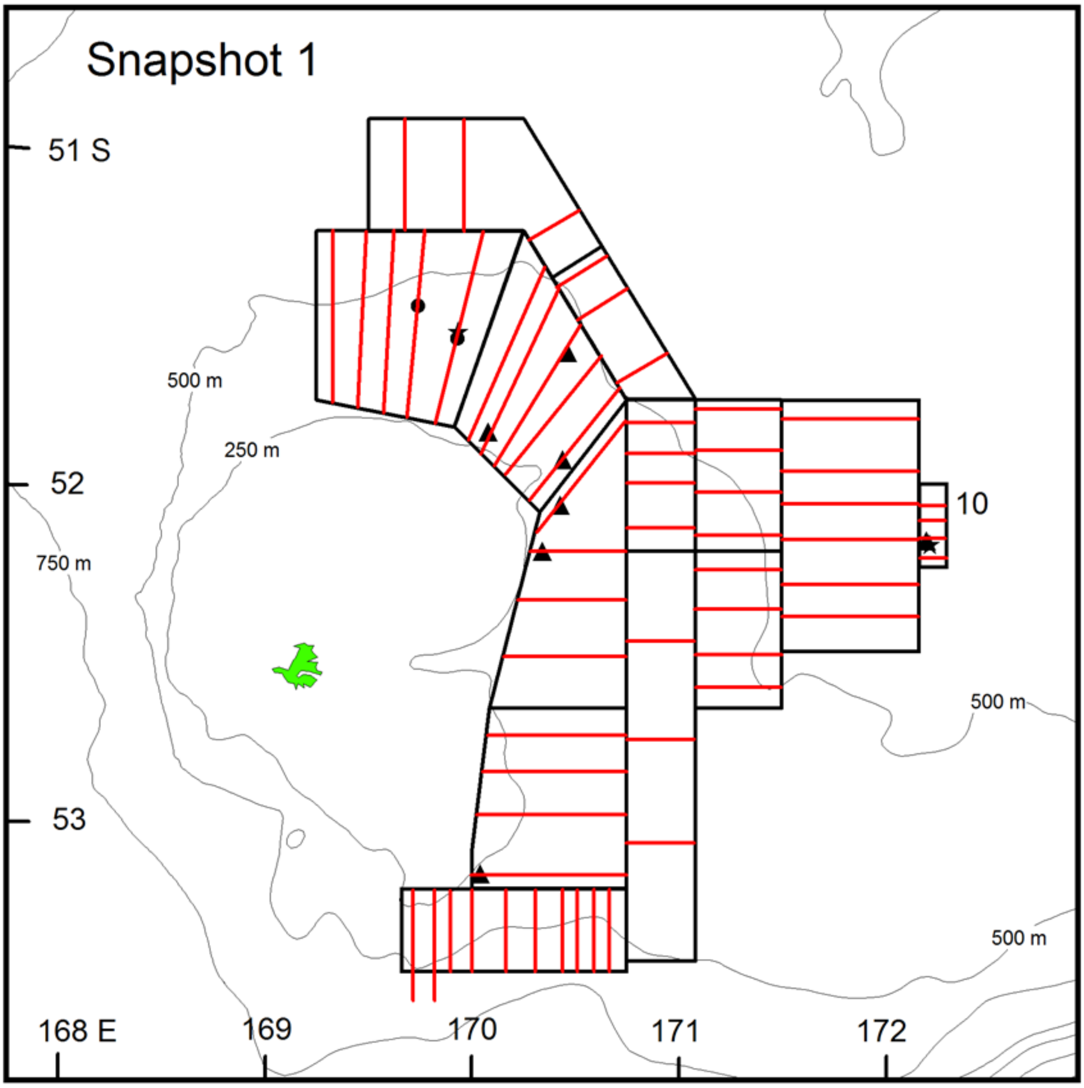

Figure 3: Location of acoustic transects (red lines) and mark identification trawls during snapshot 1 on 30 August to 8 September 2013. Circles are AOS trawls, triangles are bottom trawls, and stars are midwater trawls. Stratum labels are given in Figure 1, but note the addition of stratum 10 to the east of stratum 8E. The western two transects in stratum 7S were extended to the south.

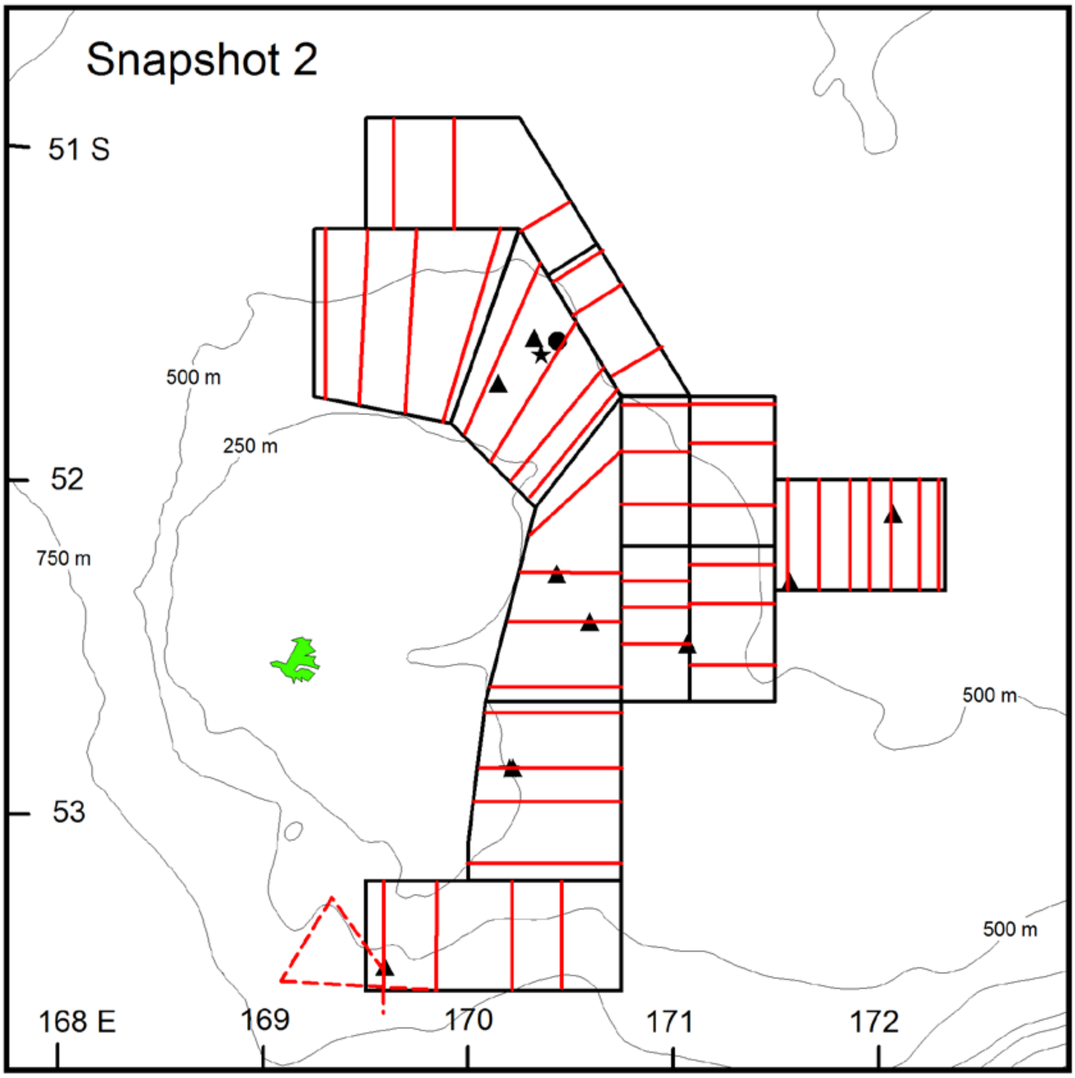

Figure 4: Location of acoustic transects (red lines) and mark identification trawls during snapshot 2 on 8–20 September 2013. Circles are AOS trawls, triangles are bottom trawls, and stars are midwater trawls. Stratum labels are given in Figure 1, but note changes to the boundaries of strata 8E, 6S, and 7S for snapshot 2. Dotted lines show lines searching for SBW aggregations west of stratum 7S.

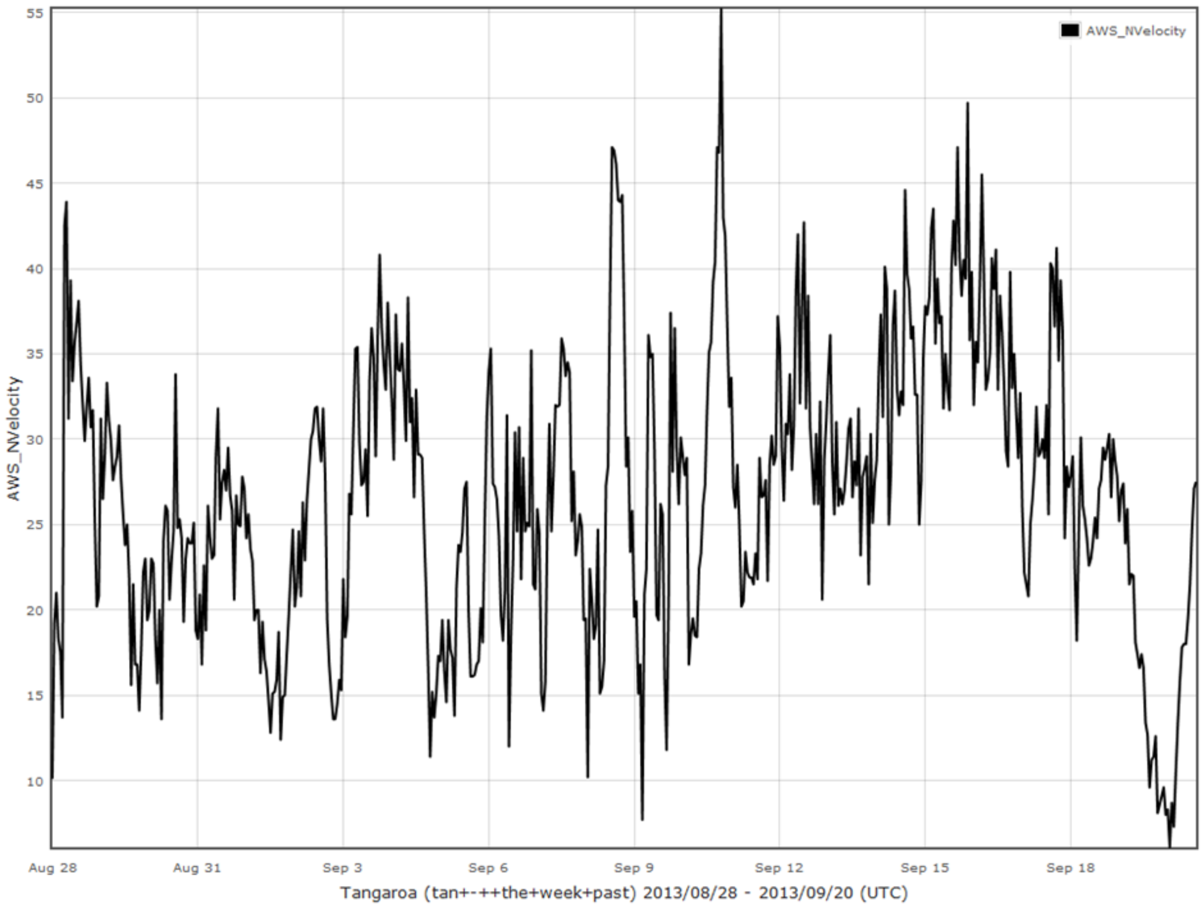

Figure 5: Output from *Tangaroa* data acquisition system (DAS) showing mean hourly wind speed (in knots) during the survey. Data are true wind speed, i.e., corrected for relative motion of ship.

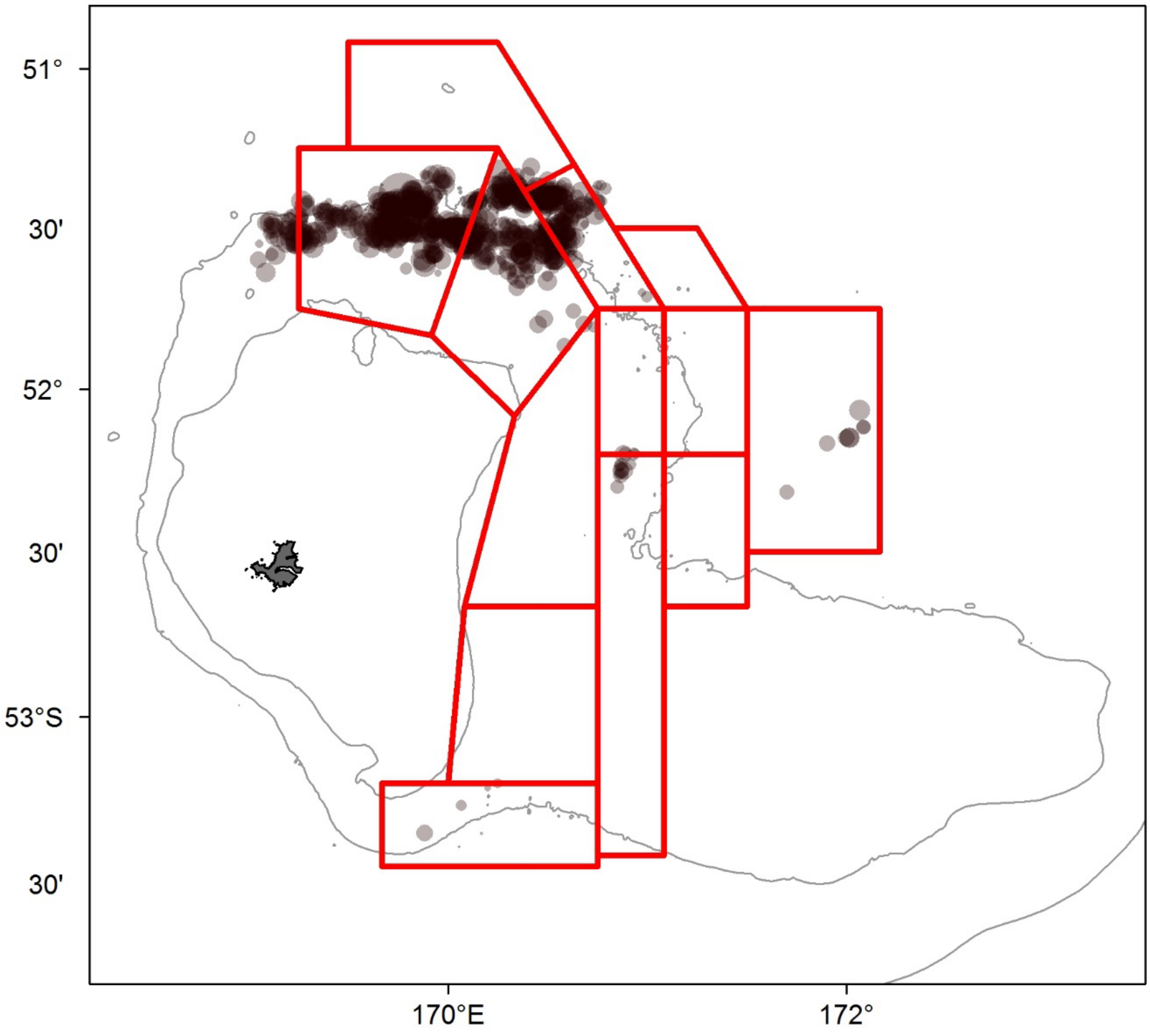

Figure 6: Commercial catch rates of SBW in 2013 Campbell Island fishery. Snapshot 1 stratum boundaries (excluding stratum 10) are shown in red. Circle area is proportional to SBW catch rate.

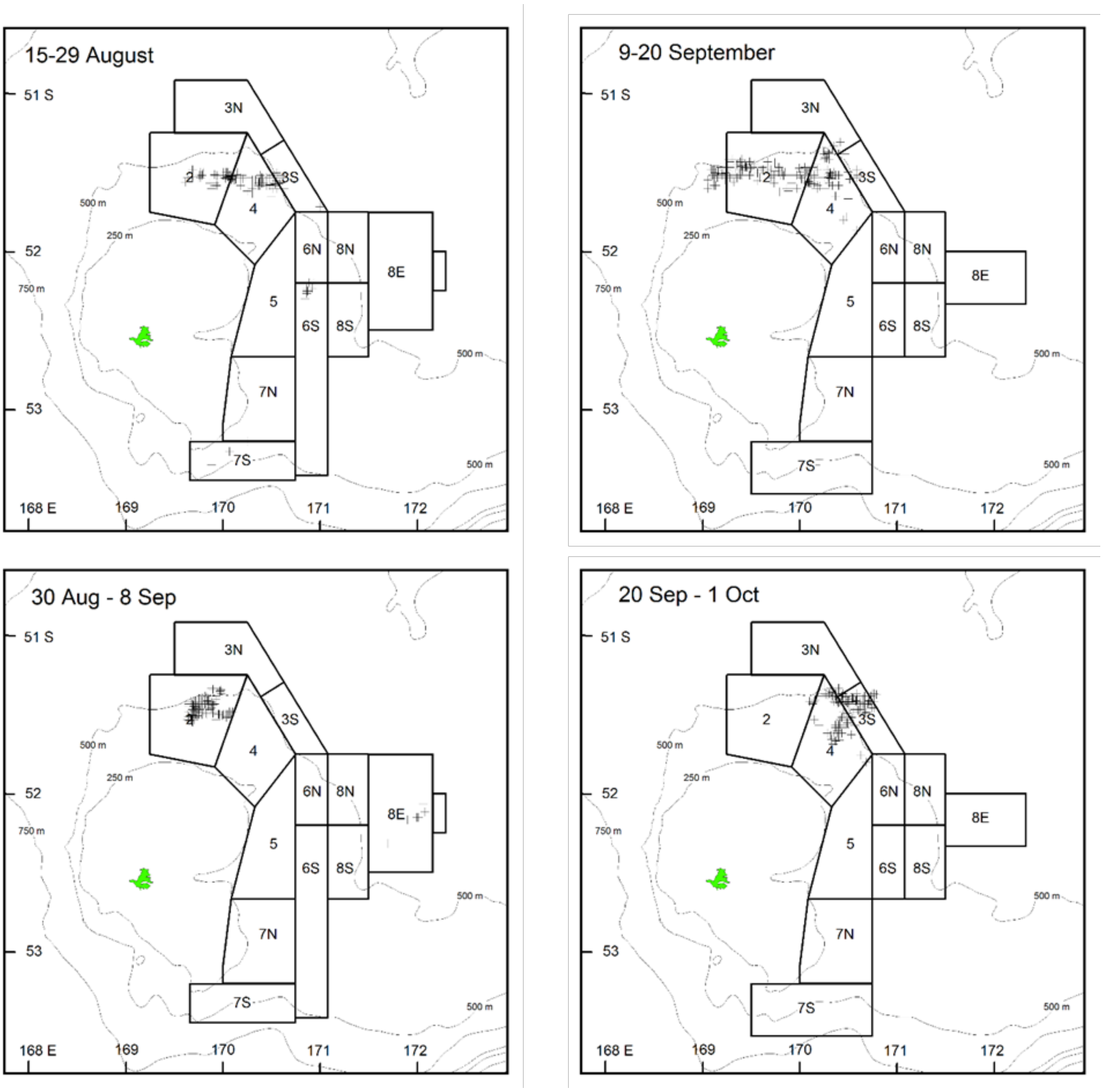

Figure 7: Location of commercial tows by date in 2013. Crosses indicate the start positions of all commercial tows within periods corresponding to snapshots 1 and 2, and periods before and after the survey.

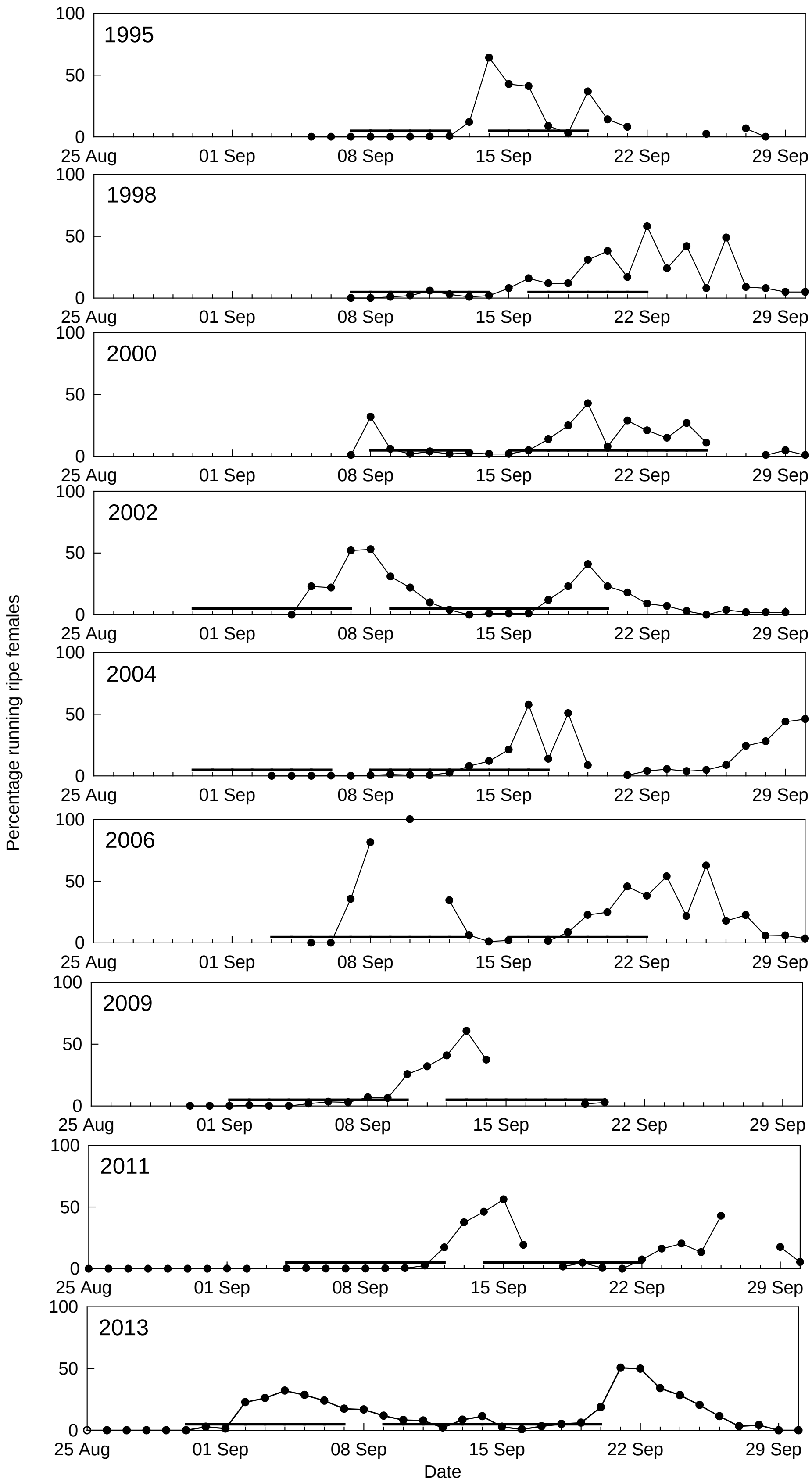

Figure 8: Survey timing (line above x axis) in relation to the timing of spawning for the acoustic surveys from 1995 to 2013 on the Campbell Island Rise. Percentage of running ripe females is from observer data.

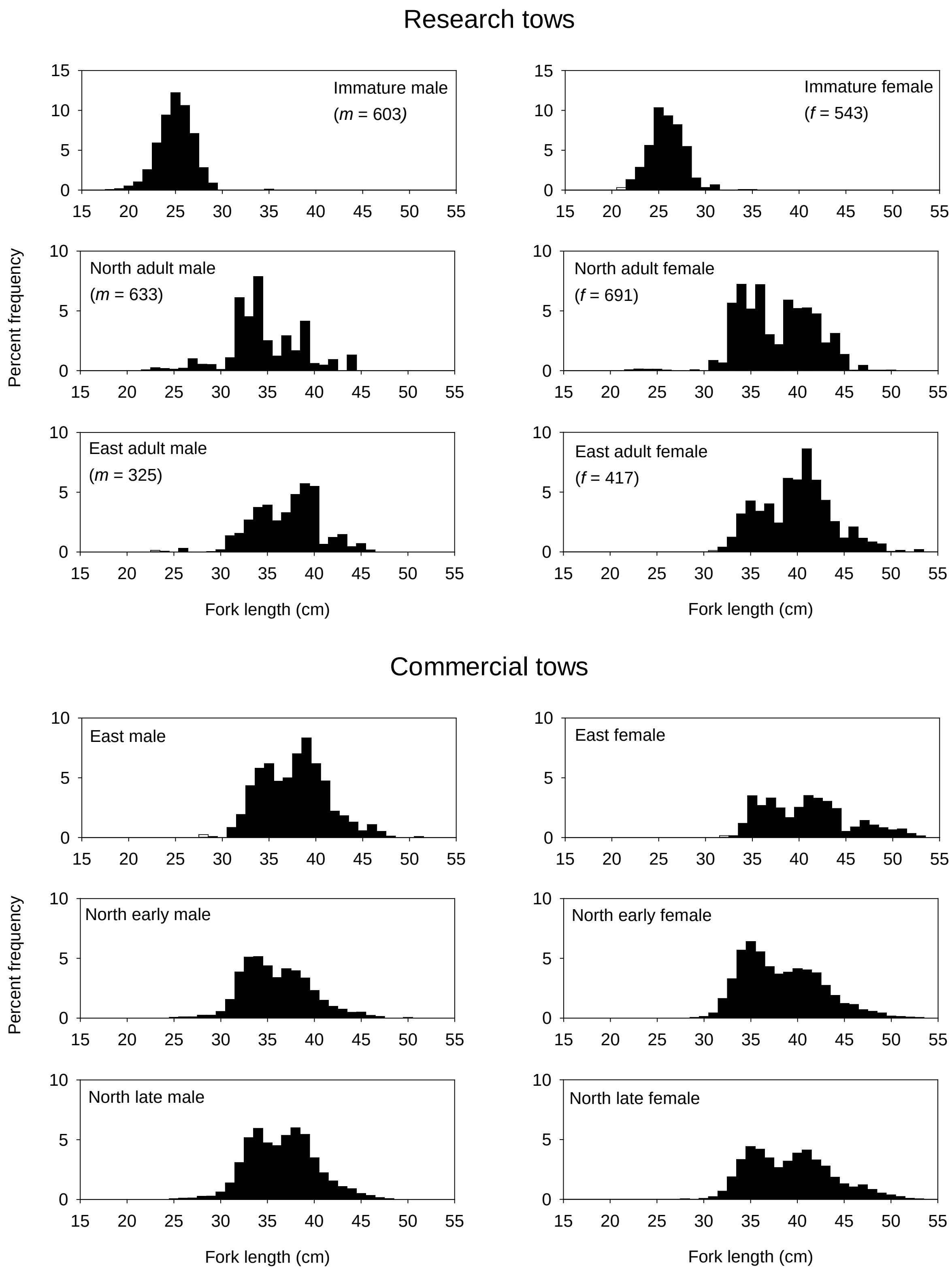

Figure 9: Catch-weighted length frequency distributions for southern blue whiting caught in research trawls by *Tangaroa* from immature and adult marks and from commercial tows during the spawning fishery. Size distributions for adults were separated into northern and eastern areas, and commercial tows were also separated into early (before 15 Sept) and late (after 15 Sept) periods (see text for details). All eastern commercial trawls were in the early period. *m* and *f* values for research tows show number of males and females measured.

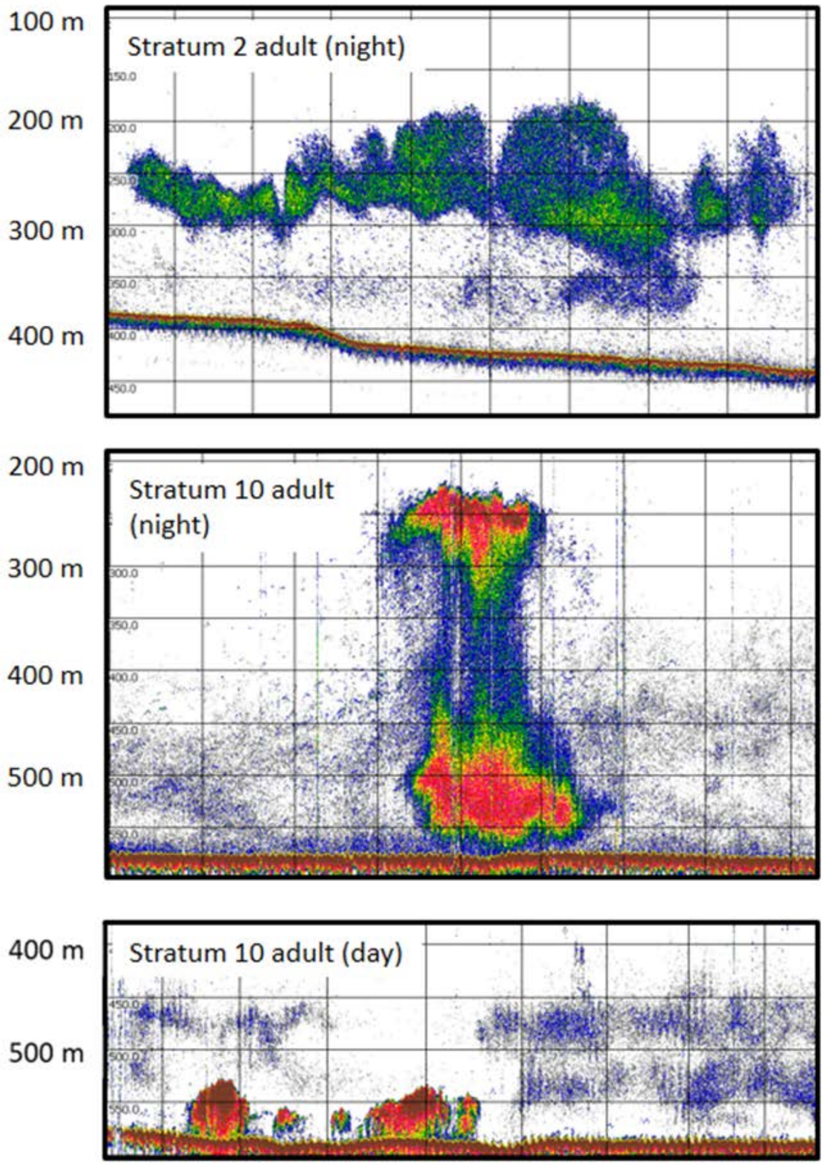

Figure 10: Examples of echograms showing pre-spawning (stratum 2) and spawning (stratum 10) adult SBW marks during snapshot 1. Each gridded cell is 0.5 nautical miles horizontally by 50 m vertically.

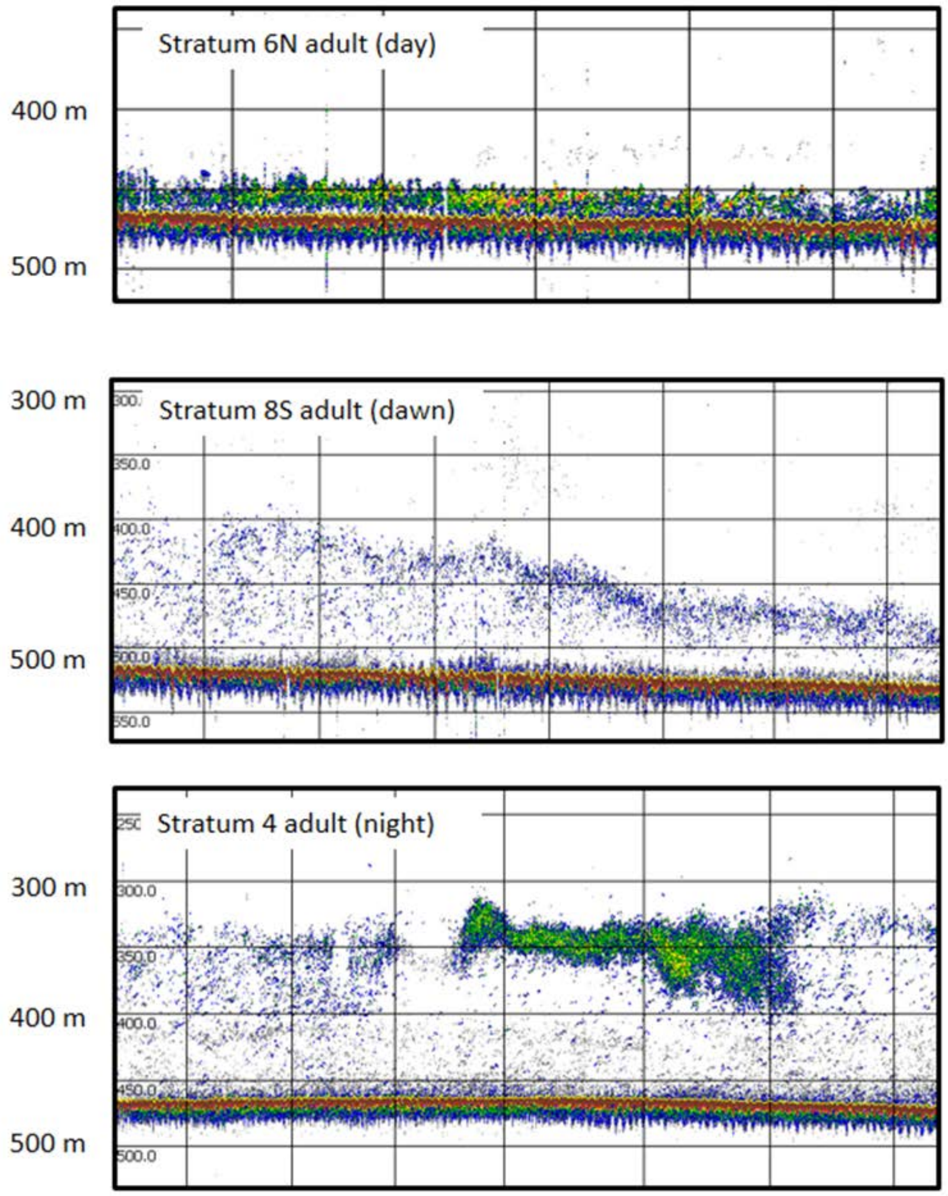

Figure 11: Examples of echograms showing post-spawning adult SBW marks during snapshot 2. Each gridded cell is 0.5 nautical miles horizontally by 50 m vertically.

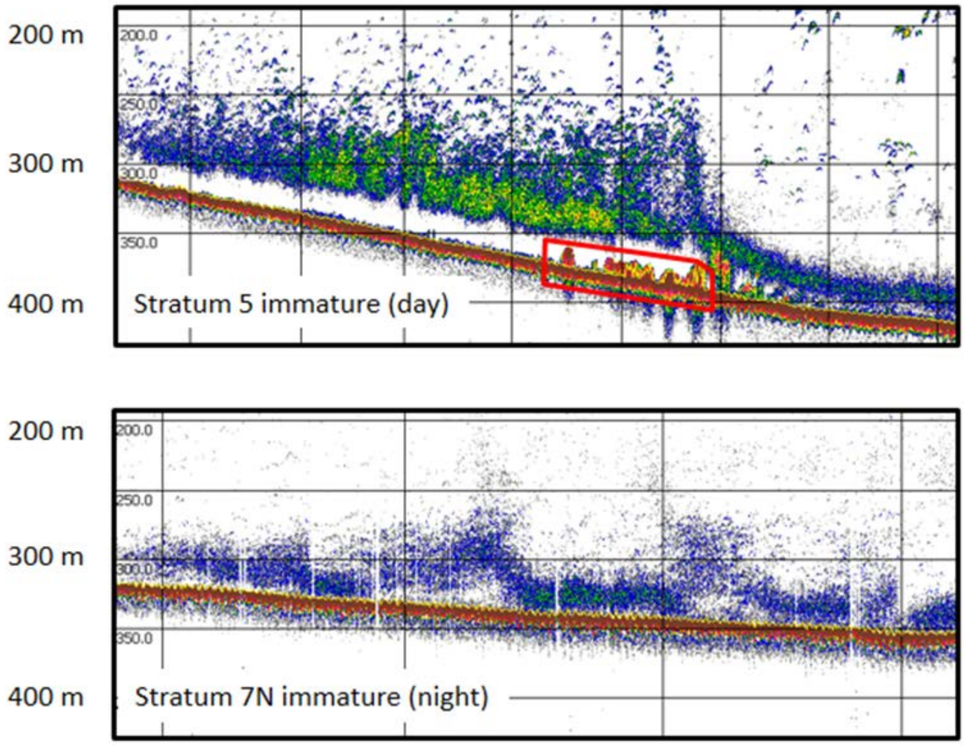

Figure 12: Examples of echograms showing immature SBW marks. Each gridded cell is 0.5 nautical miles horizontally by 50 m vertically. Red box highlights SBW marks in upper echogram.

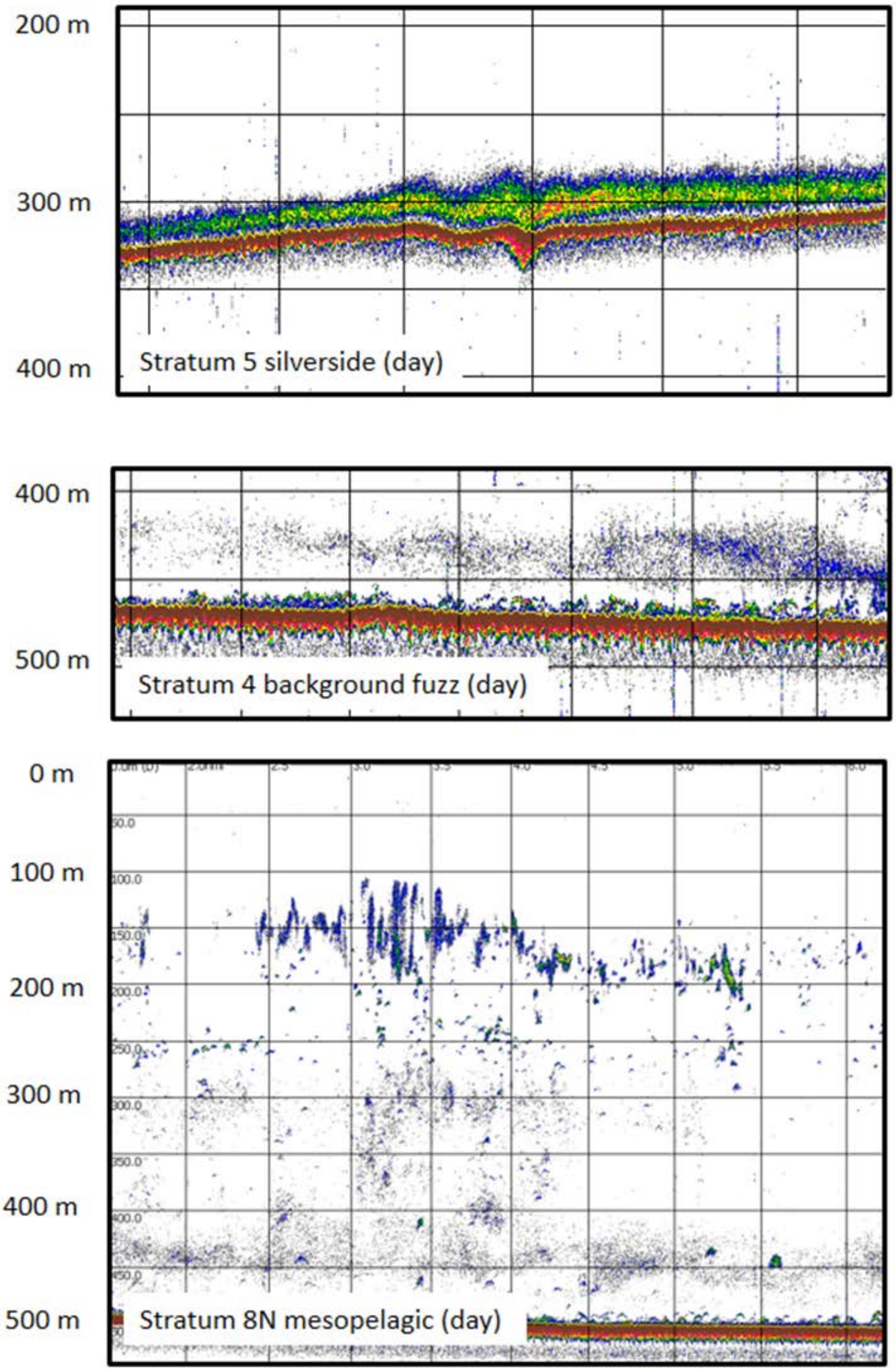

Figure 13: Examples of echograms showing other mark types. Each gridded cell is 0.5 nautical miles horizontally by 50 m vertically.

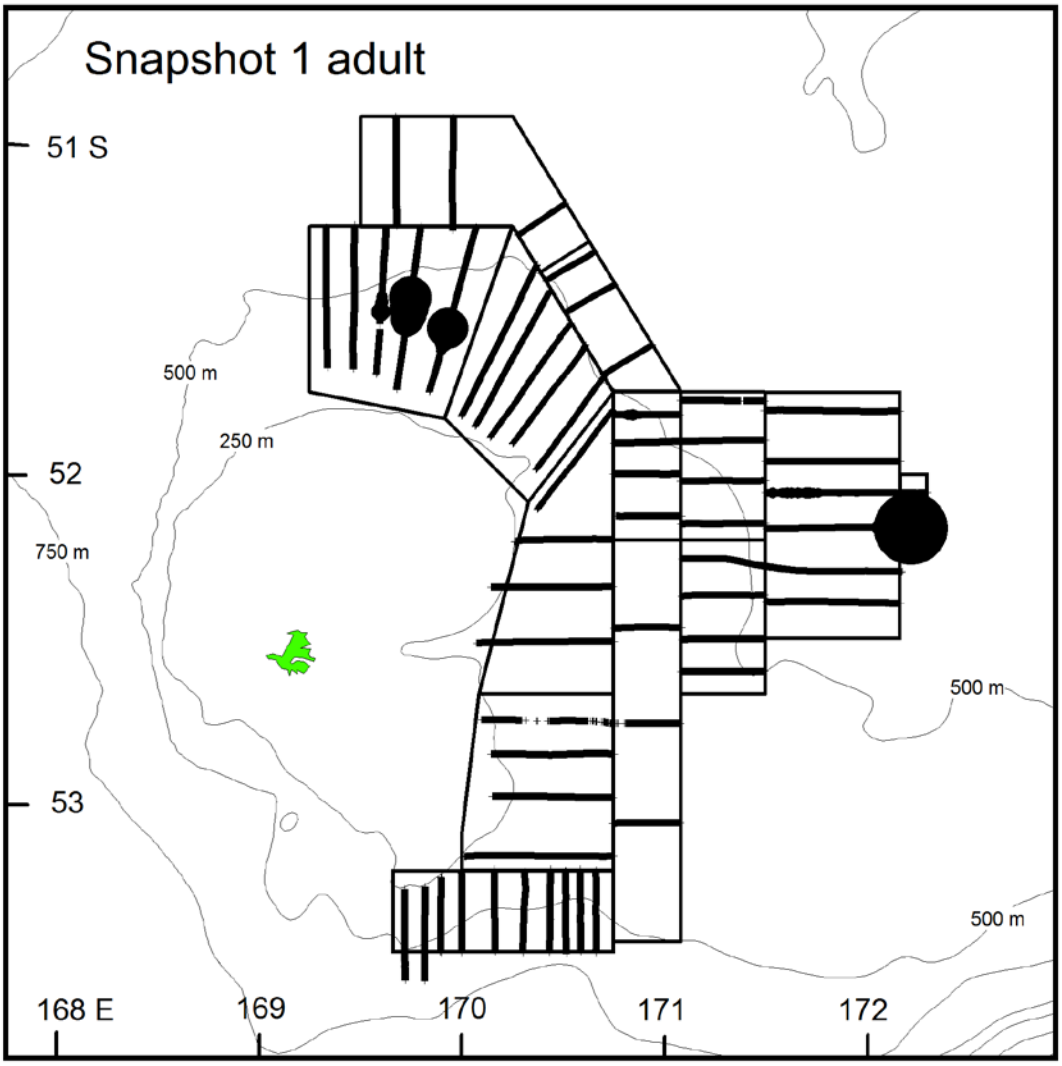

Figure 14: Spatial distribution of acoustic backscatter from adult SBW plotted in 10 ping (approximately 100 m) bins for snapshot 1. Circle area is proportional to the log of the acoustic backscatter.

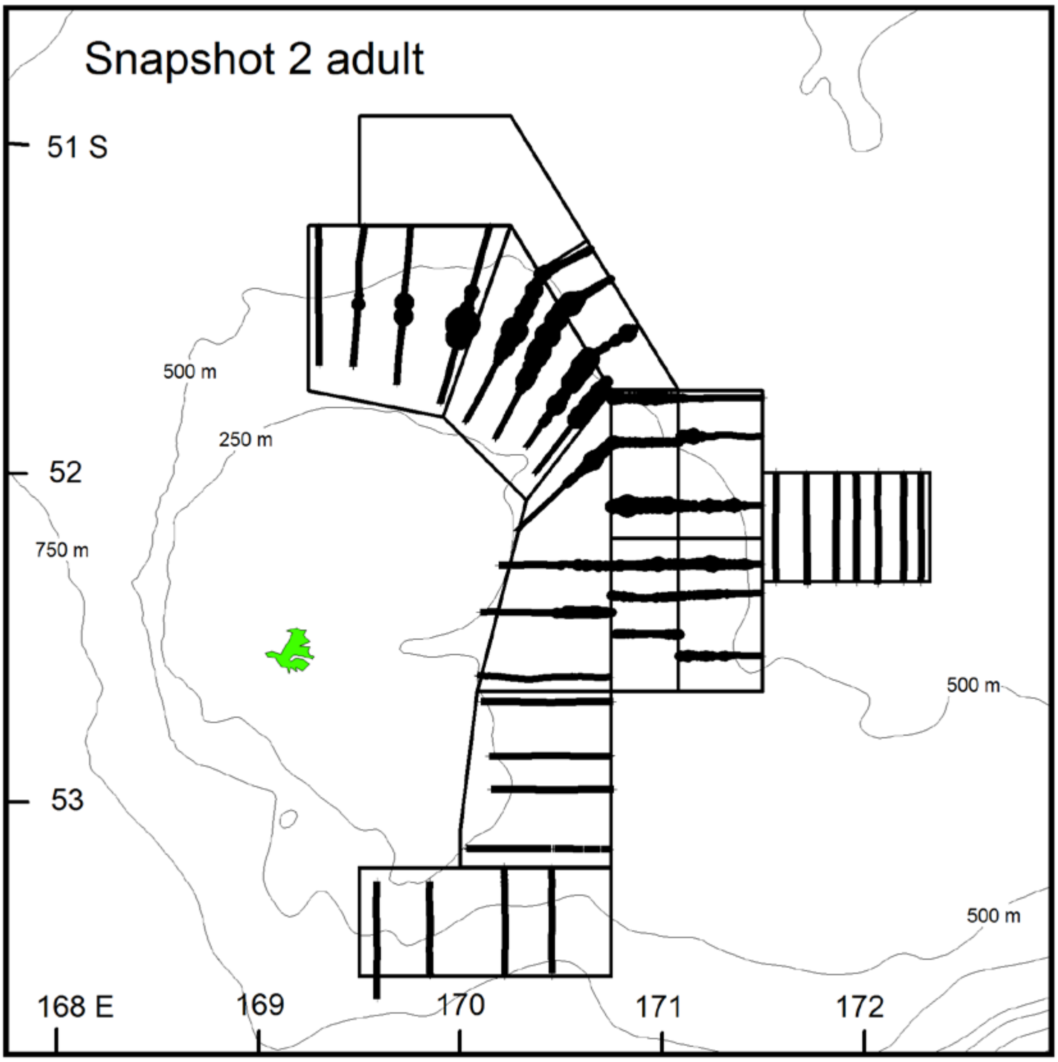

Figure 15: Spatial distribution of acoustic backscatter from adult SBW plotted in 10 ping (approximately 100 m) bins for snapshot 2. Circle area is proportional to the log of the acoustic backscatter.

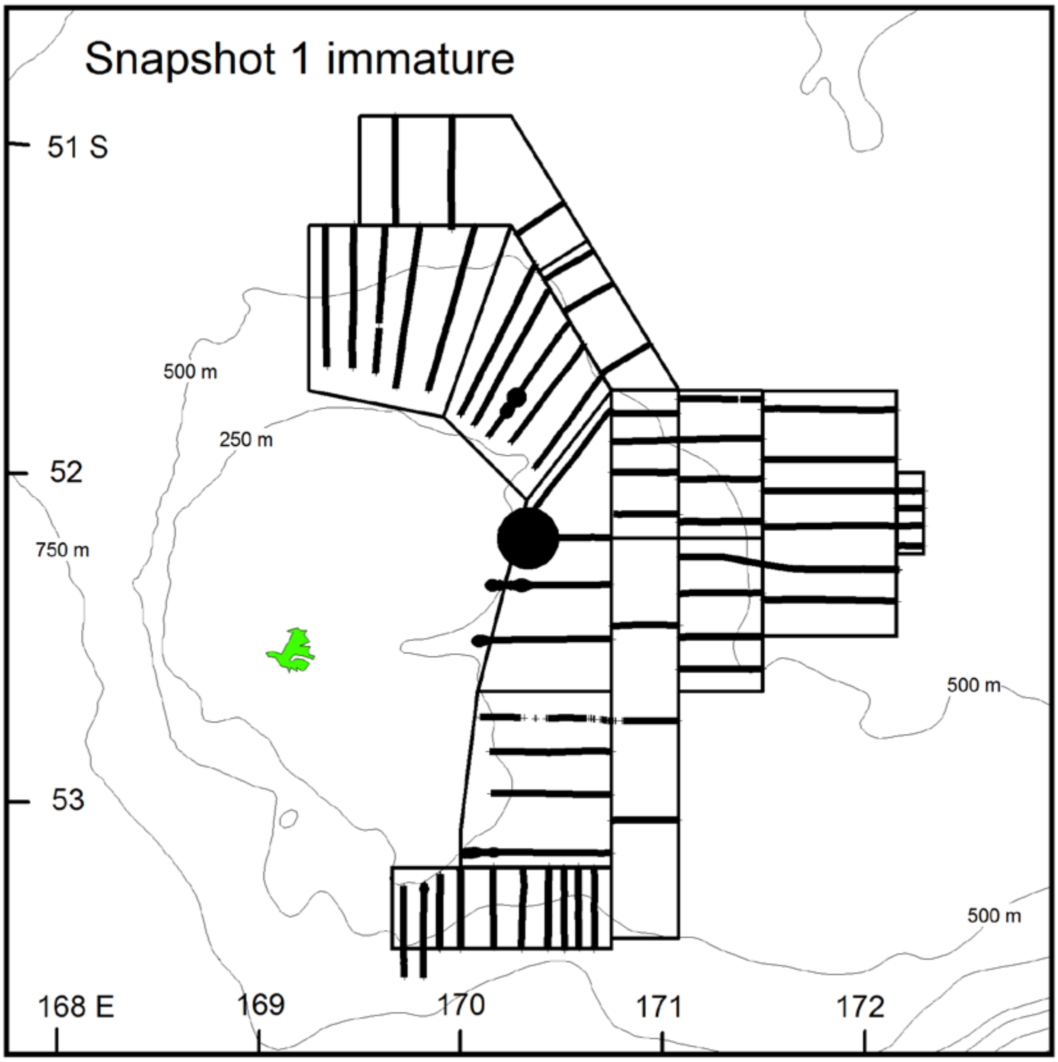

Figure 16: Spatial distribution of acoustic backscatter from immature SBW plotted in 10 ping (approximately 100 m) bins for snapshot 1. Circle area is proportional to the log of the acoustic backscatter.

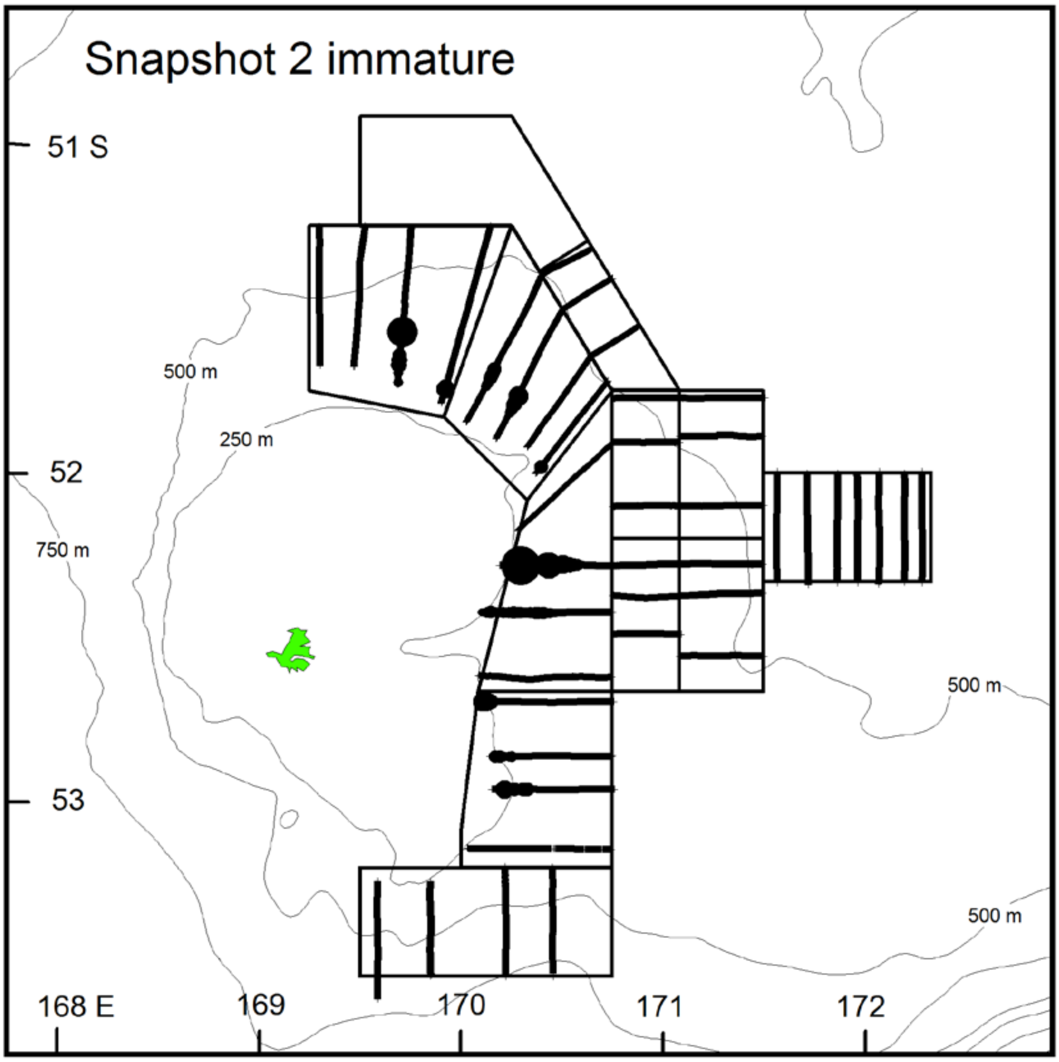

Figure 17: Spatial distribution of acoustic backscatter from immature SBW plotted in 10 ping (approximately 100 m) bins for snapshot 2. Circle area is proportional to the log of the acoustic backscatter.

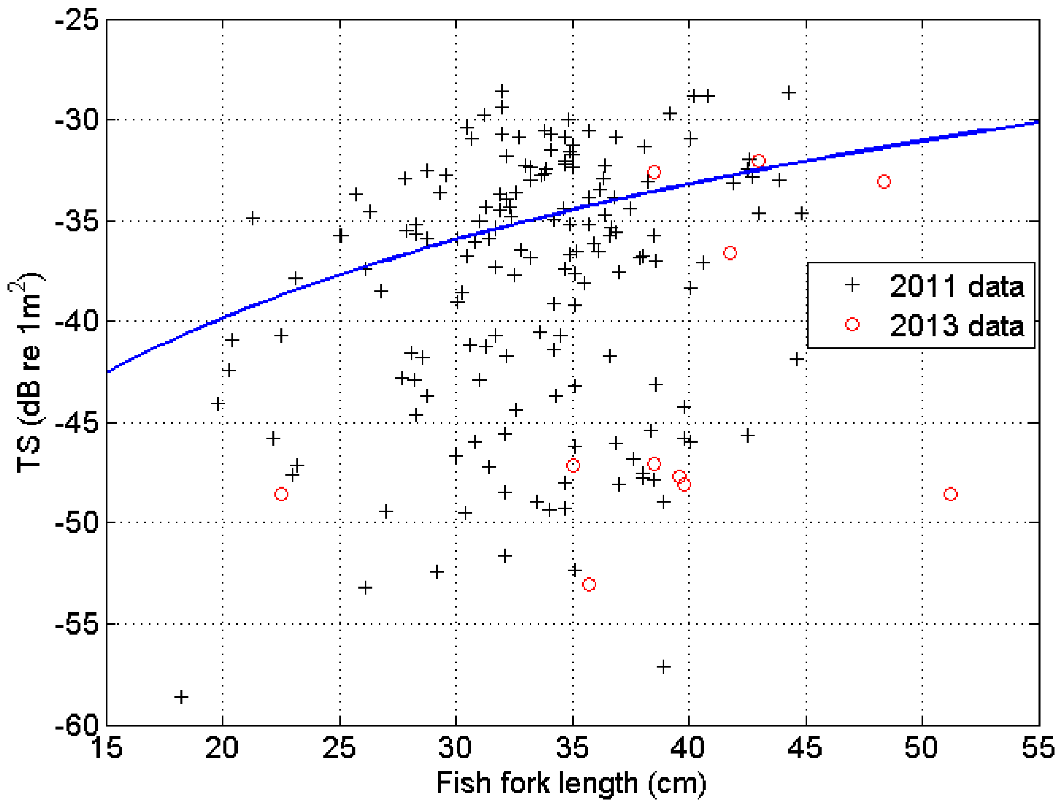

Figure 18: Estimates of mean target strength (TS) from 11 optically-verified SBW tracks in 2013 (open circles), compared with equivalent data from 2011 (crosses, from O'Driscoll et al. 2013), and the current TS-FL relationship (from Equation 2, blue line).

APPENDIX 1: Towbody 3 calibration

Calibration of the Simrad EK60 echosounder in Towbody 3 took place in Perseverance Harbour, Campbell Island (52˚ 33.12' S, 169˚ 12.14' E) on 9 September 2013, in the middle of the acoustic survey of spawning southern blue whiting on the Campbell Island Rise (TAN1309). This was the second at-sea calibration of the new EK60 echosounder in Towbody 3 (previously it was a CREST system). The previous calibration was carried out during the west coast South Island hoki survey on 28 July 2013 (TAN1308) and is described by O'Driscoll et al. (in prep).

The calibration started at 09:05 NZST. The towbody was lowered about 7 m below the surface, supported by the deployment wires and a nose rope to allow the pitch to be adjusted. A 38.1 mm tungsten carbide sphere was suspended by a single line about 20 m below the transducer. A weight was also deployed about 3 m below the sphere to steady the line. The transducer face, towbody window, sphere and associated lines were washed with a soap solution prior to entering the water.

The weather was fair with a 25 knot south-westerly wind and 0.5 m wind chop. The vessel was anchored, but was swinging on the anchor at speeds up to 0.5 knots. Vessel motion was enough to move the sphere around the beam with no manipulation of the supporting lines. The echosounder was run from a PC (ER60-3) onboard *Tangaroa* and calibration data were saved into one EK60 raw format file (tan1309-D20130908-T210540). Raw data are stored in the NIWA *acoustics* database. The EK60 transceiver settings in effect during the calibration are given in Table A1.1. The calibration was completed at 10:38 NZST.

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). 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:

$$Sa, corr = 5\log10\left(\frac{\sum P_i}{4P_{\max}}\right),$$

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 over all 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.

The calibration results are given in Table A1.3. The estimated beam pattern and sphere coverage are given in Figure A1.1. The symmetrical nature of the pattern and the zero centre of the beam pattern indicate that the transducer and EK60 transceiver were operating correctly. The fits between the theoretical beam pattern and the sphere echoes is shown in Figure A1.2 and confirms that the transducer beam pattern is correct. The estimated peak gain (G_0) of 24.34 dB and the Sa correction of -0.57 dB were estimated from 57 sphere echoes within 0.21° of the beam centre (Table A1.3). These values differed from the estimated G_0 and Sa correction estimated on the previous calibration on 28 July 2013 (Table A1.3). The linear difference between the two calibrations was about 11%, which was higher than expected, but may be related to the different environmental conditions and towbody depths during the two calibrations. The RMS of the difference between the Simrad beam model and the sphere echoes out to 3.6° off axis was 0.11 dB (Table A1.3), indicating that this calibration was of excellent quality (>0.3 dB is poor, <0.3 dB good, and <0.2 dB excellent).

Calibration coefficients estimated from this calibration were used for analysis of results from the Campbell Rise southern blue whiting survey (TAN1309).

Table A1.1: EK60 transceiver settings and other relevant parameters during the calibration.

Parameter	Value
Echosounder	Towbody 3 EK60
ER60 software version	2.4.3
Transducer model	ES38DD
Transducer serial number	28332B
EK60 GPT serial number	009072069o87
GPT software version	Not recorded
Sphere type/size	tungsten carbide/38.1 mm diameter
Operating frequency (kHz)	38
Towbody depth (m)	3
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 (º) alongship/athwartship	7.10/7.10
Angle offset (º) alongship/athwartship	0.0/0.0

Table A1.2: Auxiliary calibration parameters derived from conductivity, temperature and depth measurements.

Parameter	Value
Mean sphere range (m)	20.6
Mean temperature (°C)	7.1
Mean salinity (psu)	34.3
Sound speed (m/s)	1478.5
Mean absorption (dB/km)	9.79
Sphere TS (dB re 1 m^2)	–42.34

Table A1.3: Echosounder calibration values. Transducer peak gain was estimated from mean sphere TS using Matlab calibration code version 6818.

Parameter	Sep 13	July 13
Mean TS within 0.21° of centre	-46.65	-46.04
Std dev of TS within 0.21° of centre	0.16	0.12
Max TS within 0.21° of centre	-46.45	-45.86
No. of echoes within 0.21° of centre	57	124
On axis TS from beam-fitting	-46.50	-46.02
Transducer peak gain (dB)	24.34	24.69
Sa correction (dB)	-0.57	-0.69
Beamwidth (º) alongship/athwarthship	7.00/6.95	7.09/7.13
Beam offset (º) alongship/athwarthship	0.08/0.03	0.10/-0.02
RMS deviation	0.11	0.08
Echoes used to estimate the beam shape	23 886	9 460

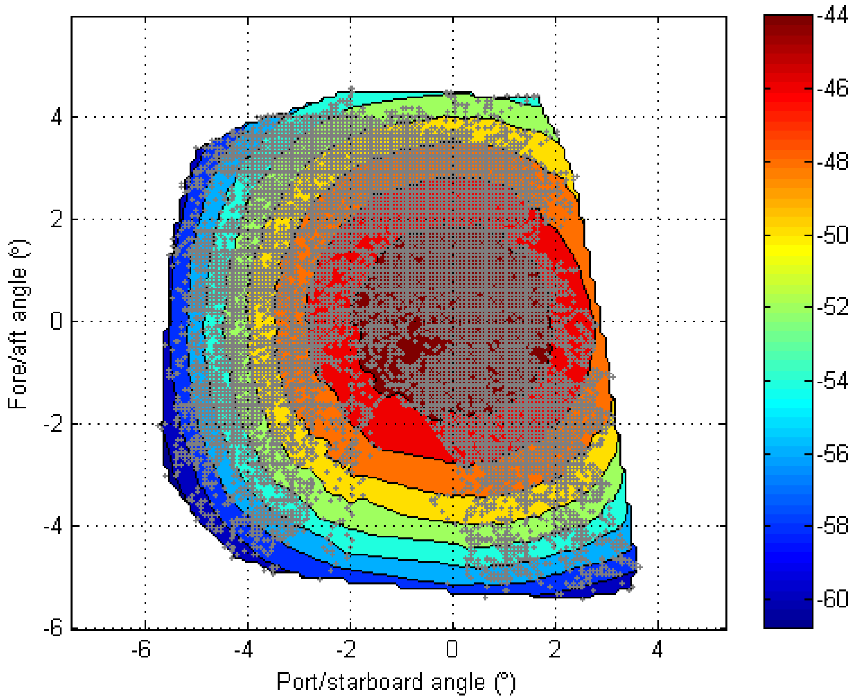

Figure A1.1: The estimated beam pattern from the sphere echo strength and position for the calibration. The '+' symbols indicate where sphere echoes were received. The colours indicate the received sphere echo strength in dB re 1 m^2.

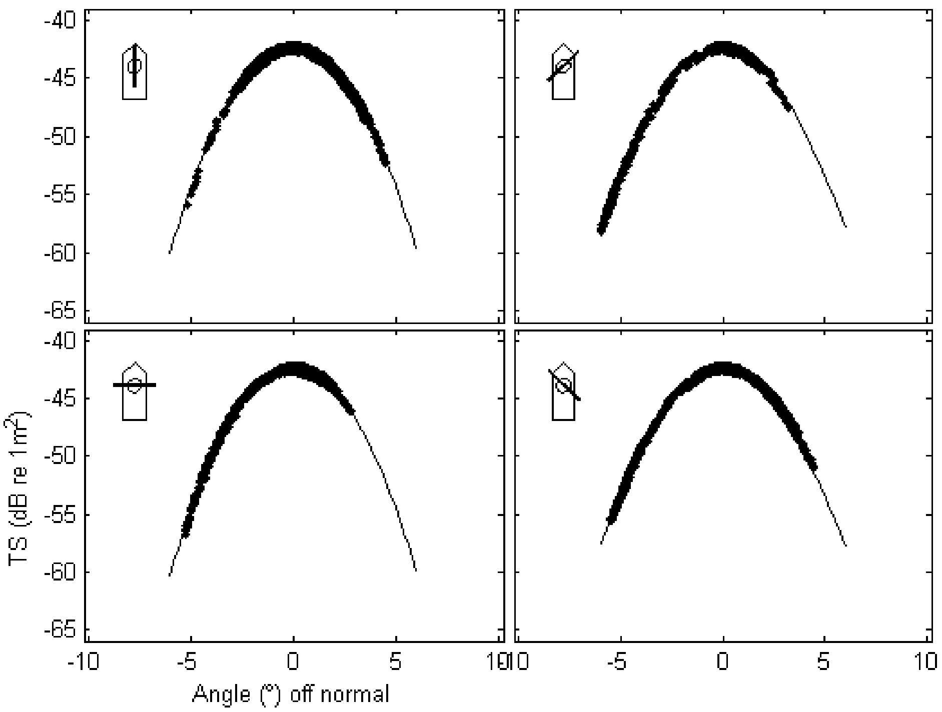

Figure A1.2: Beam pattern results from the calibration analysis. The solid line is the theoretical beam pattern fit to the sphere echoes for four slices through the beam.

APPENDIX 2: Towbody 4 calibration.

Towbody 4 was calibrated in Perseverance Harbour, Campbell Island on 9 September 2013 using the same set-up described in Appendix 1. Calibration analysis methodology for CREST towbodies is provided by Coombs et al. (2003).

Table A2.1 provides the system settings and calculated calibration coefficients for Towbody 4 used during the 2013 SBW acoustic survey.

Table A2.1: System settings and calibration values for the 38 kHz CREST system used for the 2013 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').

	Towbody 4
Transducer model	ES38DD
Transducer serial no.	28337
3 dB beamwidths (˚) alongship/athwartship	6.6/6.7
Effective beam angle (sr)	0.0076
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)	60
Decimated sample rate (kHz)	4
V_T (V)	1076
G	15 208
Absorption (dB km^{-1})	
calibration	9.77
survey*	9.45

* 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

The Seabird SM-37 Microcat CTD datalogger 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. Average sound absorption was estimated using the formula of Doonan et al. (2003) (Table A4.1). The average absorption estimate of 9.45 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 (PSU)	Mean temperature (˚C)	Absorption (dB km^{-1})
1	335	34.37	7.36	9.53
2	445	34.38	7.29	9.48
4	308	34.38	7.25	9.55
5	474	34.38	7.31	9.43
6	377	34.39	7.31	9.54
7	320	34.39	7.32	9.45
8	404	34.39	7.32	9.51
9	580	34.39	7.35	9.34
11	320	34.42	7.54	9.47
12	320	34.42	7.54	9.47
14	382	34.41	7.41	9.52
16	500	34.38	7.22	9.41
17	403	34.38	7.24	9.42
18	548	34.38	7.22	9.34
19	540	34.38	7.20	9.32
20	403	34.39	7.19	9.51
21	399	34.38	7.12	9.49
23	471	34.38	7.20	9.39
24	475	34.38	7.21	9.48
Average	421	34.39	7.30	9.45