Acoustic estimates of southern blue whiting from the Campbell Island Rise, August–September 2009

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EXECUTIVE SUMMARY

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The ninth acoustic survey of southern blue whiting (SBW) on the Campbell Island Rise was carried out from 27 August to 23 September 2009 (voyage TAN0907). A first snapshot of the spawning grounds was completed between 2 and 11 September, while a second snapshot was performed between 11 and 20 September. Distribution of SBW was widespread throughout the survey, with dense aggregations often observed at or beyond stratum boundaries. Consequently, additional strata (with modified boundaries) were surveyed to the north (strata 9 and 8E in both snapshots, as well as stratum 8S in snapshot 1). In the southern area, boundaries of stratum 7S were extended to the south (as in 2006) and to the west. A large spawning aggregation was encountered outside these boundaries during snapshot 2 and a new "adaptive" stratum was defined around it. Fourteen bottom trawls were carried out during the survey to collect data on species composition, length frequency, and spawning state of SBW.

Pre-spawning adult SBW were detected in the northern area in stratum 4, south of 3S, and north of 8N during snapshot 1 (4–8 September). In the south, pre-spawning adults were observed on the eastern side of stratum 7S, while spawning and post-spawning adults were recorded to the west (9–11 September). Dense spawning aggregations were observed in the northern area during snapshot 2 on the south-east boundary of stratum 8E, the northern section of strata 8N and 6N and stratum 4 (15–18 September). Immature marks were observed in strata 2, 4, 5, 7N, and 7S in both snapshots, with particularly extended aggregations in stratum 5 recorded during the second snapshot. No juvenile marks were observed during this survey.

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 9.4 dB km^{-1}. The estimate of adult SBW biomass for all strata was 148 321 t (c.v. 39%) in the first snapshot and 260 756 t (c.v. 36%) in the second snapshot, giving an average adult estimate of 204 539 t (c.v. 27%). The estimate of immature SBW biomass for all strata was 71 887 t (c.v. 30%) in the first snapshot and 124 309 t (c.v. 37%) in the second snapshot, giving an average immature estimate of 98 098 t (c.v. 26%).

These 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 estimate of 2 year olds (2007 year-class) was the highest ever recorded at 110 250 t. Estimate of 3 year olds (2006 year class) was also very high (115 944 t), being the second highest in the acoustic time series (after the very strong 1991 year-class). These results suggest that the 2006 and 2007 year-classes are well above average. Biomass estimate of age 4 and older fish was consistent with previous surveys.

1. INTRODUCTION

Southern blue whiting (*Micromesistius australis*) is the basis of one of New Zealand's largest volume fisheries, with annual landings averaging 30 000 t in the last 10 years (Ministry of Fisheries 2010). 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. 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. From 1992–93 to 1995–96 an annual catch limit of 32 000 t applied, but this was increased for the 1996–97 fishing year to 58 000 t as the stock assessment indicated higher yields were available. Southern blue whiting (SBW) was introduced into the QMS from 1 April 2000 with separate TACCs for each of the four main stocks in SBW6. The Campbell Island TACC for the 2009 season was 20 000 t.

Spawning occurs on the Bounty Platform from mid August to early September and 3–4 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 programme to estimate SBW spawning stock biomass on each fishing ground using acoustics began in 1993. The Bounty Platform, Pukaki Rise, and Campbell Island Rise were each surveyed annually between 1993 and 1995. After the first three annual surveys it was decided to survey these areas less frequently. The Campbell grounds were surveyed in 1998, 2000, 2002, 2004, 2006, and now in 2009. The results of these acoustic surveys form the basis for the stock assessment of SBW (e.g., Hanchet et al. 2006). An acoustic survey of the main SBW spawning aggregations on the Campbell Island Rise was also carried out from the commercial vessel *Aoraki* in 2003 (O'Driscoll & Hanchet 2004), but abundance estimates from this survey are not currently used for stock assessment.

The main aim of these surveys has been to develop a time series of relative abundance indices of recruited fish (i.e., fish that have recruited into the commercial fishery). Because the commercial fishery targets mainly the dense spawning aggregations, the recruited fish are mostly sexually mature. Additionally, the surveys provide estimates of biomass of pre-recruit fish (immature 1, 2, and 3 year olds) in the survey area, which are important in predicting recruitment in future years.

This report summarises the data collected during the ninth research acoustic survey of SBW on the Campbell Island Rise in August–September 2009 and presents biomass estimates, fulfilling the reporting requirements for Objective 1 of Ministry of Fisheries Research Project SBW2009/02:

1. To estimate pre-recruit and spawning biomass at Campbell Island during September 2009, using an acoustic survey, with a target coefficient of variation (c.v.) of the estimate of 30%.

2. METHODS

2.1 Survey design

The best time to acoustically survey SBW 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 2009 survey was carried out from 27 August to 23 September 2009 to maximise the chances of covering the spawning period. The 28-day booking of *Tangaroa* allowed for 21 days in the survey area, with 2 days for loading and unloading, and 5 days steaming to and from Wellington. Within the 21 days of survey time, allowance was made for one day for acoustic calibration, 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 of 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 for snapshot 1 (Figure 1) was based on that used in the most recent survey of the area in 2006 (O'Driscoll et al. 2007). 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 right angles to the depth contours during day and night. The original stratification for snapshot 1 was based on the historic commercial catch and effort data, and results from previous acoustic surveys. The core strata (2–7) have been included in all previous acoustic surveys.

Stratum 7 was split in 2004, following the recommendation of Hanchet et al. (2003), who noted that the southern spawning aggregation was usually confined to a small area in the southernmost part of this stratum. Originally, this stratum was split at 53ºS, but the division was shifted south to 53º 12' S for snapshot 2 of the 2004 survey (O'Driscoll et al. 2005), and this revised split was retained for 2006 and 2009. The southern boundary of stratum 7S was shifted south from 53º 25' to 53º 27' during the 2006 first snapshot because commercial vessels reported seeing SBW just south of stratum 7S just before commencing transects in this stratum (O'Driscoll et al. 2007). This change was also retained in the initial allocation of transects for the 2009 survey.

From 2000 to 2004, there was a trend of increased effort and increased catch east of 171º E and outside the core acoustic strata (Hanchet 2005). The eastern boundary of the survey area was extended to the east in 2004 with the addition of stratum 8. Stratum 8 was further divided (into 8N and 8S) during the 2004 survey, and a new stratum (8E) was added to the east of stratum 8N for snapshot 2 because fish were detected in this area (O'Driscoll et al. 2005). Strata 8N, 8S, and 8E were all retained for snapshot 1 of the 2006 survey, but the area of stratum 8E was reduced by shifting the southern boundary from 52º 12' S to 52º 04' S (O'Driscoll et al. 2007). In 2004 and 2005, there was fishing to the east of stratum 3S and a new stratum (stratum 9) was added in 2006 to cover possible aggregations in this area, but no SBW were detected in this stratum (O'Driscoll et al. 2007). These strata were all retained for the initial allocation of transects for the 2009 survey.

Optimal allocation of transects to strata in snapshot 1 was determined by examining the location of historical fishing effort and acoustic survey results. The phase 1 transect allocation for core strata in 2009 was similar to the allocation used for the last five surveys (Table 1).

During the first snapshot, strong pre-spawning aggregations were seen on the southeastern boundary of stratum 3S, so the southern section of stratum 9 was also surveyed (three most southern transects). Aggregations of SBW were also observed at the eastern boundary of stratum 8N, and south of the original boundary for stratum 8E, so the boundaries for 8E were shifted south to reflect this distribution.

In the south, the commercial fleet was fishing west of the initial 7S stratum boundary, and aggregations were observed all the way to 169˚ 40' E. The western boundary was thus shifted to this position and this change was retained for the second snapshot. A very dense spawning SBW aggregation was discovered to the south of the stratum on September 12, and four parallel transects were run across it from the southern boundary of stratum 7S (53˚27' S) to 53˚35' S (new "adaptive" stratum 7SWa, Figure 2).

2.2 Acoustic data collection

Acoustic data were collected with NIWA's Computerised Research Echo Sounder Technology (CREST) systems (Coombs et al. 2003). A towed CREST system (Towbody 3) was used for most acoustic data collection along survey transects. A second towbody (Towbody 4) was used on a few occasions (particularly towards the end of the voyage) due to an electronic fault in Towbody 3. In the CREST system, a four-channel echosounder with a 38 KHz split-beam transducer was mounted in a flat-nosed, torpedo-shaped, 'heavy weight' 3 m long towed body. The towed body was connected to *Tangaroa* via about 2000 m of Rochester type 301301 tow cable, which supplied power to the echosounder and allowed digital data from the receiver to be sent to a ship-mounted control computer. Data were also collected using the hull-mounted EK60 system with 18, 38, 70, 120, and 200 kHz transducers. The 38 kHz transducer was not transmitting during survey transects with the towed system to prevent interference. The 38 kHz hull system was switched on when the towbody was onboard. The hull system only was used to collect data while trawling, and for four transects (in strata 3S, 3N, and 2) towards the end of the survey because of electronic faults with the towbodies.

Towbody 3 was calibrated outside Banks Peninsula on our way to the survey ground on 29 August 2009. Towbody 4 was calibrated in Perseverance Harbour (Campbell Island) on 9 September 2009. The hull systems were not calibrated due to lack of time. These systems were calibrated in January 2010. Details of the acoustic systems and their calibrations are provided in Appendix 1.

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). Directions of the transects were slightly modified on a few occasions to minimise the effect of rough sea conditions. The minimum distance between transect midpoints varied between strata, and was calculated as follows:

$$m = 0.5 * L/n$$

where m is minimum distance, L is length of stratum, and n is 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 50–70 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 and to collect biological data. Marks were targeted using the orange roughy ('rough bottom') trawl with a modified 40 mm mesh codend. No fishing was carried out with the NIWA 119 hoki midwater trawl or mesopelagic trawl during this survey. 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 0.3 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 250 SBW and 50–200 of other important species from every tow was measured. In most tows the sex and macroscopic gonad stage (see Appendix 2) 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 Other data collection

A Seabird SM-37 Microcat CTD datalogger (serial number 2416) was mounted on the headline of the net during 10 bottom trawls to determine the absorption coefficient and speed of sound, and to define water mass characteristics in the area. CTD drops were also carried out at Banks Peninsula and in Perseverance Harbour in conjunction with the acoustic calibrations.

2.5 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 2009 fishery were extracted from the Ministry of Fisheries Observer database in December 2009. 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 system given by Hanchet (1998)) were summarised by date.

2.6 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 9.4 dB km^{-1} (Appendix 3).

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 2.7). 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).

2.7 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) for each category (adult, immature, and juvenile fish). The ratios for juvenile and immature categories were calculated from the scaled length frequency distributions 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. There were differences in the size distribution of fish caught by commercial vessels from the northern and southern aggregations (see Section 3.2) so two adult ratios were calculated based on trawls north and south of 52° 30’ S.

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

$$TS = 38 \log_{10} FL - 97 \tag{2}$$

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):

$$w = 0.00439 * FL^{3.133} \tag{3}$$

Mean weight and mean backscattering cross-section (linear equivalent of TS) for each category (northern adult, southern adult, immature, and juvenile) were obtained by transforming the scaled length frequency distribution for both sexes combined by Equations 3 and 1 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 in adult, immature, and juvenile categories 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 2009 following Hanchet et al. (2000b).

3. RESULTS

3.1 Data collection

Weather conditions were fair throughout most of the survey. Swell height rarely exceeded 10 m. Nevertheless, 126.5 h (5.3 days) of survey time were lost due to poor weather conditions. A particularly bad weather system was encountered right at the beginning of the survey and the vessel had to dodge for 49 h before commencing work. This was followed by good survey conditions for the following two weeks (2–13 September). Strong winds and swell further prevented work on 14 September (16 h), 16 September (15 h), and 18 – 19 September (46.5 h). A total of 632 acoustic data files (200 towbody and 432 hull) were recorded during the survey. Transects surveyed on the towbody covered a distance of 959.5 n. miles in snapshot 1 and 867.1 n. miles in snapshot 2. The total distance covered by the towbodies (including recorded steam between transects) was 2275.8 n. miles.

Due to the widespread nature of SBW marks during this survey, there was no time for the collection of in situ target strength (TS) data. Therefore, Objective 2 of Ministry of Fisheries Project SBW2009/02 will not be completed.

The amount of trawling was restricted during this survey due to some problems with the hydraulic system onboard *Tangaroa*, and also due to the larger area to survey as fish were often observed close to or outside stratum boundaries. Fourteen bottom trawls were made to identify targets and collect biological samples (Table 2). Tow length ranged from 0.51 to 1.37 n. miles at an average speed of 3.5 knots. The total trawl catch was 4291 kg. Trawls caught a wide range of species, but the catches were largely dominated by southern blue whiting (65% of total catch by weight, Figures 3-4). The next most abundant species were javelinfish (10.7%), ling (9.5%), and spiny dogfish (4.3%). In contrast to 2006, catches of oblique banded rattail were relatively low (only 0.7 % of the total catch).

Ten CTD profiles were obtained in conjunction with bottom trawls, and these were used to estimate the absorption coefficient during the survey (see Appendix 3). The water column was unstratified with surface temperatures ranging between 7.0 and 7.6 °C.

3.2 Commercial data

The first vessel began fishing on the Campbell Island grounds on 1 September. The location of commercial trawls from 2004 to 2009 is shown in Figure 5. Fishing effort was quite scattered within the survey area in 2009. Information gathered from the fleet during the survey suggested that fishing vessels were struggling to find fish of suitable size. Significant fishing efforts were made west of stratum 7S, and also east of 171° in the north.

The timing of spawning in 2009 appeared to be slightly later than in 2006 (Figure 6). The data also failed to capture the two spawning peaks observed in previous surveys, perhaps as the fleet was struggling to find larger fish outside of the main spawning areas. Another explanation is that there was only one (main) spawning peak in 2009.

There were differences in the size distribution of fish caught by commercial vessels from the northern and southern aggregations, so separate length frequencies were calculated for tows north and south of 52° 30’ S (Figure 7). The 2009 catch had two modes, centred roughly on 29 cm and 40 cm for males, and 32 cm and 43 cm for females (Figure 7). The smaller length mode was more pronounced for males. This mode was virtually absent for females in the south area. The mean length of fish caught in the north (35.3 cm) was 2 cm lower than in the south (mean length = 37.3 cm).

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 easy to identify by their appearance and location in the water column. Strong spawning marks were observed in the south during the first snapshot. Acoustic marks in the northern aggregation were characteristic of pre-spawning adult SBW (Figures 8–9), while those in the south consisted of spawning or post-spawning fish. These marks were also widespread in the southern area during snapshot 2, extending beyond the previous survey's strata boundaries. Spawning marks were close to the bottom during the day, but up to 200 m off the bottom at night (Figures 10–11). Large spawning aggregations were also observed in the north during snapshot 2 in strata 6N, 8N, 8E, and 4.

Large spawning aggregations were sampled in stratum 6N (tow 14), 8N (tow 4), and SWa (tows 10 and 11). Most mark identification work focused on the less dense aggregations where identity was less certain. These revealed lower densities of pre-spawning adults on a few occasions (in stratum 3S, 4, and 8S), and immature 2 year old SBW (with a mixture of 3 year old) caught between 320 and 425 m depth in stratum 5 and 7N. The shallowest of these tows was targeted on a mark typical of juveniles (1 year old), but yielded immature fish (tow 8 in stratum 7N). No juveniles were caught during this survey. Two 'background' trawls were made in deeper waters when the targeted marks had moved or were missed (tows 6 and 9). These yielded low catches of adult SBW with large proportions of javelinfish (see Table 2). The deepest of these tows yielded a large catch of ling (tow 9 at 619 m depth). Classification of immature marks was based on their similarity with marks seen while fishing and their similarity to marks observed in previous surveys (Figures 12–14). No juvenile marks were identified in 2009 due to their absence in the catch.

Mesopelagic fish were common throughout the survey area (Figure 15). During the day the marks usually appeared as a band of small schools 20–150 m above the seabed. At night this band of marks rose to form a layer within 100–300 m of the surface. No fishing on these marks was carried out during this survey due to lack of time.

In summary, the size distributions from the research trawls were used to assign the main SBW marks seen during the survey into the following categories.

- Characteristic moderately dense marks in 300–425 m depth were the immature SBW category (mainly 2 year old).
- Dense marks in water deeper than 450 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 SBW 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). This approach will lead to a positive bias. Further trawling on juvenile and immature SBW mark types with a variety of gears is required in future surveys to help improve estimates of species composition.

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 16–19). During the first snapshot, pre-spawning adult marks covered a wide area and were observed throughout stratum 4, with dense aggregations on the northeast corner of stratum 6N and the northwest corner of stratum 8N. Lower density but extensive aggregations of pre-spawning adults were also observed in stratum 3S, the northern section of stratum 9, and throughout stratum 8E and 8S to the east. Spawning and post-spawning aggregations were observed throughout stratum 7S, extending well beyond the previous western boundary. Immature marks were observed in the shallow end of stratum 2, 4, 7N, and 7S. Extensive marks were also observed across stratum 5. The densest of the immature marks was sampled in stratum 7N (tow 8).

At the beginning of snapshot 2, a large spawning aggregation was discovered just southeast of stratum 7S in deep water (600–750 m bottom depth). A series of parallel transects was carried out across this aggregation to delimit its distribution, and an adaptive stratum was defined as 7SWa. Spawning and post spawning fish were still present in stratum 7S, but their distribution was not as extensive as during the first snapshot. The densest adult marks observed during snapshot 2 were in the northern section of strata 6N and 8N. These spawning aggregations extended over a large area. Commercial vessels were fishing well beyond the core stratum boundaries, and a significant aggregation was observed on the southeast corner of stratum 8E. Another significant spawning plume was discovered in stratum 4. Distribution of immature SBW in snapshot 2 was similar to that observed during the first snapshot, with a noticeable increase in abundance to the south and in stratum 5.

As noted earlier, no juvenile marks were assigned in 2009 due to their absence in the catch. In previous surveys, juveniles were observed at the shallow ends of the acoustic transects. O'Driscoll et al (2007) noted that their distribution probably extended shallower than 300 m. Attempts to sample "juvenile-type" marks in 2009 yielded immature 2 year old fish.

3.5 SBW size and maturity

Length, sex, and gonad stage were determined for 2676 SBW during the survey. The scaled length frequencies from research tows on adult and immature marks are compared to data from the commercial fishery in Figure 7. The size distribution of fish from research tows on adult aggregations was generally similar to the commercial catch (see Section 3.2), but there was a higher proportion of 3 year old fish with a mode at 28–29 cm (2006 year-class) in research trawls. Nearly all fish caught in research tows on immature marks were 2 year olds from 23 to 27 cm (mean 25.4 cm), with more females than males caught.

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. All adult female SBW caught on the northern aggregation in snapshot 1 were pre-spawning (stages 2 and 3, with a couple of stage 4) (see Appendix 2 for description of research stages). In the south (stratum 7SWa), 30% of the fish were running ripe (stage 5) and more than 50% had already spawned once (stages 6–8) (Table 3). More than 99% of the females in the immature category (FL less than 30 cm) were stage 1, but almost 25% of the males in this category were in spawning condition (stages 3–7).

3.6 SBW biomass estimates

The values of *r* for each SBW category based on the length frequency distributions in Figure 7 are given in Table 4. SBW biomass estimates by snapshot and stratum are given in Table 5. These estimates were calculated using the TS-length relationship of Dunford & Macaulay (2006), the calculated sound absorption coefficient of 9.40 dB km^{-1} (see Appendix 3), and no towbody motion correction. Note that the estimates in Table 5 are not directly comparable with those from previous SBW acoustic survey which used the TS-length relationship of Monstad et al. (1992). Also note that before 2006 an absorption coefficient of 8.0 dB km^{-1} was used (e.g., Hanchet et al. 2003). O'Driscoll et al. (2007) indicated that using the old absorption (8.0 dB km^{-1}) decreased biomass estimates by 20–25%, with magnitude of the change dependent on the average depth of the SBW marks. On the other hand, implementing the motion correction increased biomass by only 3–10% in 2006. 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). Note that sea conditions in 2006 were much worse than those experienced in 2009. For comparison, Table 6 lists the 2009 results under a range of scenarios (using the two different TS-length relationships and absorption coefficients).

Using the updated TS-length relationship and absorption coefficient, the adult biomass estimate was 148 321 t (c.v. 39%) in snapshot 1 and 260 756 t (c.v. 36%) in snapshot 2. A significant proportion of the biomass was outside of the historical core area (strata 2–7), notably in stratum 8N and 8E, and to the southeast in stratum 7SWa (snapshot 2). Biomass of immature SBW was also particularly high in 2009, with 71 887 t (c.v. 30%) in snapshot 1 and 124 309 t (c.v. 37%) in snapshot 2. Immature marks were widespread but all within the historical core area.

The decomposed biomass estimates by age class are shown in Table 7. The 2009 biomass estimates for age 2, 3, and 4+ SBW (including all strata) were 110 250 t (c.v. 22%), 115 944 t (26%), and 92 598 t (27%) respectively. Note that no juvenile marks were observed during the 2009 survey, hence 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 8. Similarly, the estimates by category are given in Table 9. Values were derived using the new TS-length relationship of Dunford & Macaulay (2006) and a mean absorption coefficient of 9.39 dB km^{-1} (Grimes et al. 2007). Note that the total biomass (all age groups combined) for 2009 is the highest ever recorded and suggests strong age 2 and 3 year classes (2006 and 2007 recruits).

4. DISCUSSION

4.1 Timing of the survey

The timing of the 2009 survey was similar to that in the previous three surveys (2002, 2004, and 2006). Timing was about 1 week later for surveys before 2002 (see Figure 6). In 2009, spawning began on about 10 September in the south and the percentage of running ripe females from observer data peaked on 13 September. These data failed to capture a second spawning peak, but large spawning plumes were observed in the northern area on 15–18 September. Thus the timing of the survey in relation to the spawning season appeared similar to recent years.

4.2 Variability between snapshots

Adult and immature biomass estimates were significantly higher in the second snapshot. Adult biomass in the southern area was particularly high due to the discovery of a large spawning plume southeast of the stratum 7S extended boundaries. In the northern area, additional aggregations in strata 4, 6N, 8N, and to the east in 8E also contributed to this increase. There was noticeable straddling of aggregations on stratum boundaries throughout the survey. Fish were also often found near (or past) the edge of previous stratum boundaries. Immature marks were also widespread during both snapshots, but distribution was within the core area (strata 2–7). The large increase in immature biomass during the second snapshot was largely due to increased density in stratum 5 (see Figure 19).

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, and current surveys were modified accordingly. From 2005 to 2008, few commercial tows were made east of the core acoustic strata and in 2006 over 90% of the biomass was within the core acoustic strata. However in 2009 most of the fishing effort in the northern area was east of 171° E, and about 50% of the total biomass was recorded in strata 8N-8E-8S during the survey. This suggests a return to the distribution pattern seen in 2002 and 2004. Significant biomass of SBW within the core area (notably in strata 3S, 4, 7N, and 7S) and their movement indicate that it is unlikely that these 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 2009 due to the presence of fish to the west. The presence of a large spawning plume southwest of stratum 7S was also indicative of expanded SBW distribution this year. Distribution of adults between the two snapshots did not suggest movement to the north.

All fish recorded during the survey were used for the biomass estimates. In light of the distribution of SBW in 2009, we recommend that the stratification be revised for future surveys.

4.4 Comparison between years

The 2009 survey yielded the highest biomass estimate of SBW on the Campbell Island Rise to date (see Table 8). As in 1995, there was no estimate of age 1 SBW. The age 2 biomass estimate was the highest ever recorded (110 250 t), with all prior estimates being below 30 000 t, with the exception of the first survey in 1993 (107 192 t as a result of the strong 1991 year class). Similarly, the age 3 estimate of 115 994 t was higher than in most other surveys, where the biomass of this age group was previously below 40 000 t, with the exception of 1994 (168 006 t, again from the strong 1991 year class). These results suggest that 2006 and 2007 are relatively strong year classes. The biomass estimate of these fish (age 2 and 3) accounted for more than 70% of the total SBW biomass in 2009. The estimate of age 4+ was average.

5. ACKNOWLEDGMENTS

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Table 1: Summary of transects carried out during the 2009 acoustic survey of the Campbell Island Rise. Transect positions are plotted in Figures 6-9.

Snapshot 1 (2–11 Sep)			Snapshot 2 (11–20 Sep)		
Stratum	Area (km^2)	Transects	Stratum	Area (km^2)	Transects
2	3 154	4	2	3 154	3
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	5
6S	3 025	3	6S	3 025	1
7N	2 980	4	7N	2 980	4
7S*	1 995	10	7S*	1 995	9
8E^{+}	1 514	3	8E	1 232	4
8N	1 436	4	8N	1 436	5
8S	1 452	4	8S	-	0
9^{-}	947	3	9^{-}	798	2
			7SWa^{++}	326	4
Total	26 727	55	Total	25 170	52

* Stratum 7S western boundary was extended to 169°40' E.
$^{+}$ Boundaries of stratum 8E were shifted south during the first snapshot.
$^{-}$ Boundaries of stratum 9 were reduced in both snapshots to match the actual area surveyed.
$^{++}$ 7SWa denotes the aggregation of SBW surveyed southwest of stratum 7S in snapshot 2.

Table 2: Trawl station details and catch of the main species during the 2009 acoustic survey of the Campbell Island Rise. Tow positions are plotted in Figures 3 and 4. Trawl type: BT bottom. Species: SBW southern blue whiting; JAV javelinfish; LIN ling; SPD spiny dogfish; GSP pale ghost shark; HAK hake.

		Gear		Start	Start	Tow	Tow length			Catch (kg)				
Tow	Date	type	Stratum	latitude	longitude	depth (m)	(n. mile)	SBW	JAV	LIN	SPD	GSP	HAK	Total
1	4-Sep-09	BT	4	-51.7150	170.3617	442	1.37	464.5	0.3	0	0.9	0	0	467.1
2	4-Sep-09	BT	4	-51.6970	170.4418	458	1.08	502.6	15.2	25.4	3.0	17.1	11.3	604.4
3	5-Sep-09	BT	3S	-51.6807	170.9205	504	0.78	224.8	3.1	116.1	37.7	4.2	21.2	415.5
4	5-Sep-09	BT	8N	-51.8073	171.1080	504	0.54	273.3	2.7	25.4	43.9	0	16.1	366.8
5	6-Sep-09	BT	5	-52.1040	170.4955	364	0.90	111.6	0	1.2	0	0	0	115.6
6	6-Sep-09	BT	6N	-51.9897	171.0268	482	0.79	36.9	69.6	12.3	6.3	0.8	0	136.2
7	7-Sep-09	BT	8S	-52.5615	171.3075	502	0.83	379.3	40.4	9.9	2.0	5.4	0	447.7
8	8-Sep-09	BT	7N	-52.7317	170.1165	321	0.51	301.5	0	0	1.2	0	0	309.9
9	11-Sep-09	BT	7S	-53.3993	170.1812	619	1.04	13.6	61.2	192.9	9.1	16.1	0	314.7
10	12-Sep-09	BT	7SWa	-53.5652	169.8177	701	0.82	7.8	19.6	0	0	5.0	0	40.6
11	12-Sep-09	BT	7SWa	-53.5413	169.7978	655	1.11	182.3	36.5	29.1	19.8	8.3	35.1	337.6
12	13-Sep-09	BT	5	-52.3623	170.2610	374	0.87	381.4	0.7	7.2	3.6	0	0	402.0
13	13-Sep-09	BT	5	-52.3513	170.5288	424	0.85	12.7	0.6	0	2.2	0	0	19.7
14	15-Sep-09	BT	6N	-51.8662	170.8072	495	1.23	186.3	11.2	29.9	40.3	16.0	12.9	313.7

Table 3: Gonad stages of SBW caught in research trawls during the 2009 acoustic survey. Gonad stages are defined in Appendix 2.

				Males							Females							
Tow	Date	Stratum	Mark type	1	2	3	4	5	6	7	1	2	3	4	5	6	7	8
1	4-Sep-09	4	Adult	0	0	59	80	1	0	0	21	5	67	0	0	0	0	0
2	4-Sep-09	4	Adult	0	0	24	93	0	0	0	9	0	98	0	0	0	0	0
3	5-Sep-09	3S	Adult	0	0	28	81	1	0	0	3	1	71	17	1	0	0	0
4	5-Sep-09	8N	Adult	0	0	26	97	12	3	0	0	2	76	3	0	0	0	0
5	6-Sep-09	5	Immature	35	9	8	2	0	0	0	145	1	0	0	0	0	0	0
6	6-Sep-09	6N	Background	4	0	4	6	0	0	0	14	1	64	5	0	0	0	0
7	7-Sep-09	8S	Adult	0	1	19	66	0	6	0	29	0	155	7	0	0	0	0
8	8-Sep-09	7N	Immature	62	0	11	1	0	0	0	194	0	0	0	0	0	0	0
9	11-Sep-09	7S	Background	0	0	0	1	3	4	0	0	0	2	11	7	3	2	0
10	12-Sep-09	7SWa	Adult	1	0	9	11	3	1	0	0	1	0	7	1	0	2	0
11	12-Sep-09	7SWa	Adult	0	0	5	4	62	65	42	1	1	17	19	16	16	10	1
12	13-Sep-09	5	Immature	123	0	24	7	0	3	1	138	0	0	0	0	0	0	0
13	13-Sep-09	5	Immature	29	0	10	11	0	2	4	51	1	2	0	0	0	0	0
14	15-Sep-09	6N	Adult	6	1	6	6	3	3	0	138	3	33	8	7	0	0	0

Teble 4. Estimates of the ratio *r* used to convert SBW backscatter to biomass. Values are derived from the scaled length frequency distributions. Different ratios were used for adult marks north and south of 52° 30' S. 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	28	35.3	0.342	0.0001767	-37.5	1 933
Adult (south)	Commercial	25	37.3	0.403	0.0002156	-36.7	1 871
Immature	Research	4	25.4	0.112	0.0000441	-43.6	2 532

Table 5: Biomass estimates (t) and c.v. by stratum and snapshot of immature and adult SBW for the Campbell Island Rise in 2009.

	Immature		Adult	
Stratum	Biomass (t)	c.v.	Biomass (t)	c.v.
Snapshot 1				
2	8 570	39	0	-
3N	0	-	0	-
3S	0	-	24 776	85
4	5 519	46	12 991	34
5	26 447	32	0	-
6N	0	-	0	-
6S	0	-	0	-
7N	26 454	71	0	-
7S	4 897	56	29 285	29
8E	0	-	7 442	29
8N	0	-	69 770	76
8S	0	-	3 513	75
9	0	-	544	101
Total	71 887	30	148 321	39
Snapshot 2				
2	9 770	51	0	-
3N	0	-	0	-
3S	0	-	0	-
4	6 869	35	48 047	101
5	70 101	63	0	-
6N	2 918	100	20 422	92
6S	0	-	0	-
7N	16 208	33	0	-
7S	18 442	29	8 599	50
7SWa	0	-	58 192	84
8E	0	-	46 856	82
8N	0	-	78 640	57
8S	0	-	n/a	n/a
9	0	-	0	-
Total	124 309	37	260 756	36
Best estimate (average)	98 098	26	204 539	27

Table 6: Average biomass (t) of SBW between snapshots using different scenarios of TS-length relationships and sound absorption.

	Absorption (dB km^{-1})	Immature (t)	Adult (t)
NEW TS	9.4	98 098	204 539
	8.0	78 886	163 225
OLD TS	9.4	71 055	285 710
	8.0	57 140	227 983

NEW TS = 38 Log_{10}FL - 97 (Dunford & Macaulay 2006)
OLD TS = 21.8 Log_{10}FL - 72.8 (Monstad et al 1992)

Table 7: 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 2009. 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	8 143	232	5	
3N	0	0	0	0	
3S	0	1 974	12 794	11 362	
4	0	6 279	6 853	5 956	
5	0	25 133	717	15	
6N	0	0	0	0	
6S	0	0	0	0	
7N	0	25 075	719	15	
7S	0	7 253	18 516	11 584	
8E	0	593	3 842	3 412	
8N	0	5 558	36 012	31 981	
8S	0	302	2 133	1 343	
9	0	44	281	250	
Total	0	80 354	82 099	65 923	228 376
c.v.	-	26	37	40	
Snapshot 2					
	Age 1	Age 2	Age 3	Age 4+	
2	0	9 287	265	6	
3N	0	0	0	0	
3S	0	0	0	0	
4	0	10 355	25 015	22 053	
5	0	66 586	1 900	40	
6N	0	4 396	10 615	9 357	
6S	0	0	0	0	
7N	0	15 395	441	9	
7S	0	18 290	5 901	3 412	
7SWa	0	5 172	36 555	23 029	
8E	0	4 400	28 508	25 317	
8N	0	6 264	40 590	36 046	
9	0	0	0	0	
Total	0	140 145	149 790	119 269	409 204
c.v.	-	31	35	36	
Average					
	Age 1	Age 2	Age 3	Age 4+	
	0	110 250	115 944	92 598	318 792
	-	22	26	27	

Table 8: Decomposed biomass estimates (t) by survey and age group for the Campbell Island Rise derived using the new TS-length relationship (Dunford & Macaulay 2006) and the new absorption coefficient (9.40 dB km^{-1} for 2009, 9.47 dB km^{-1} for 2006, and 9.39 dB km^{-1} for other years). See Grimes et al. (2007) for details of the estimates before 2006.

	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

Table 9: Biomass estimates (t) by survey and mark category for the Campbell Island Rise derived using the new TS-length relationship (Dunford & Macaulay 2006) and the new absorption coefficient (9.40 dB km^{-1} for 2009, 9.47 dB km^{-1} for 2006, and 9.39 dB km^{-1} for other years). See Grimes et al. (2007) for details of the estimates before 2006.

	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

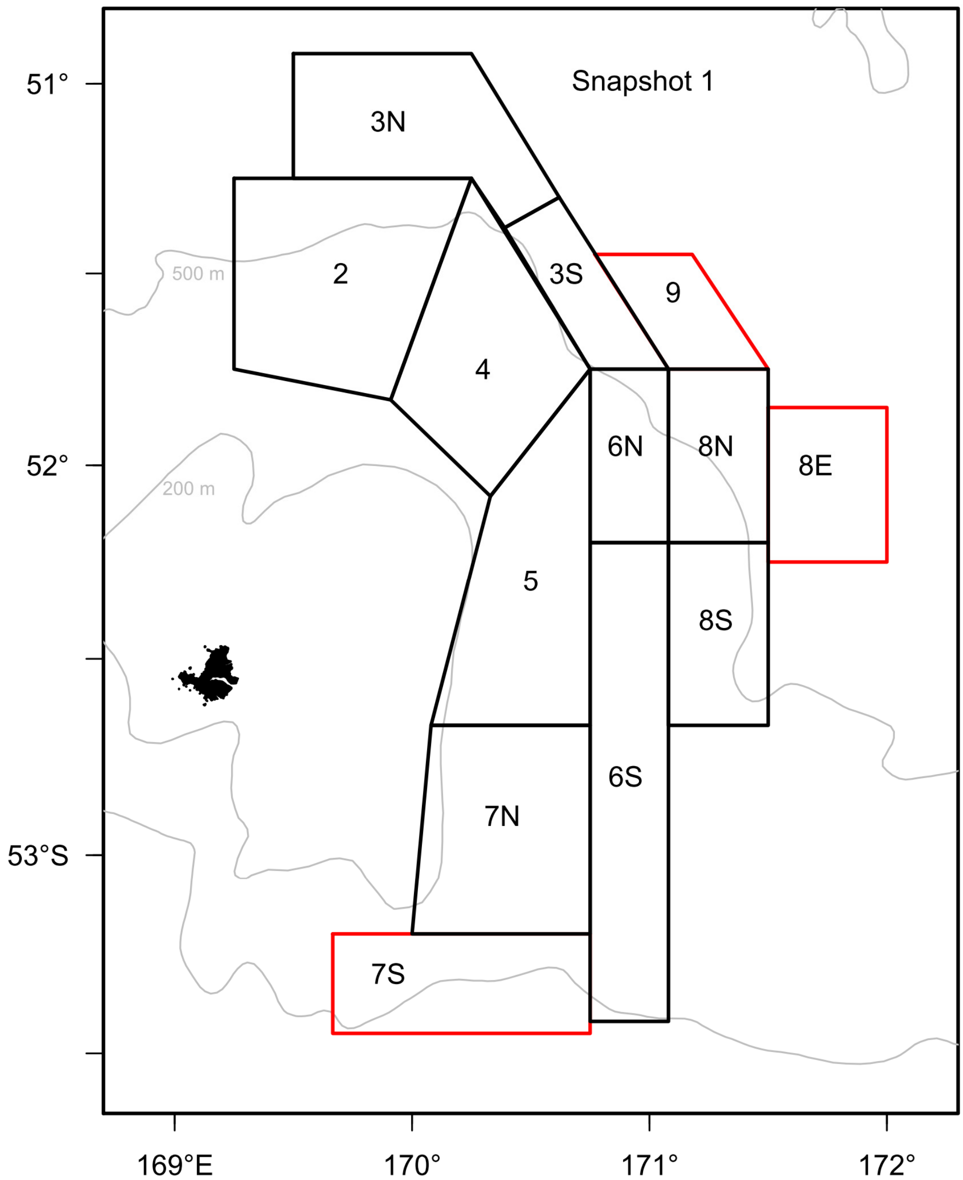

Figure 1: Stratum boundaries for snapshot 1 of the 2009 acoustic survey of the Campbell Island Rise. Red lines indicate modified boundaries.

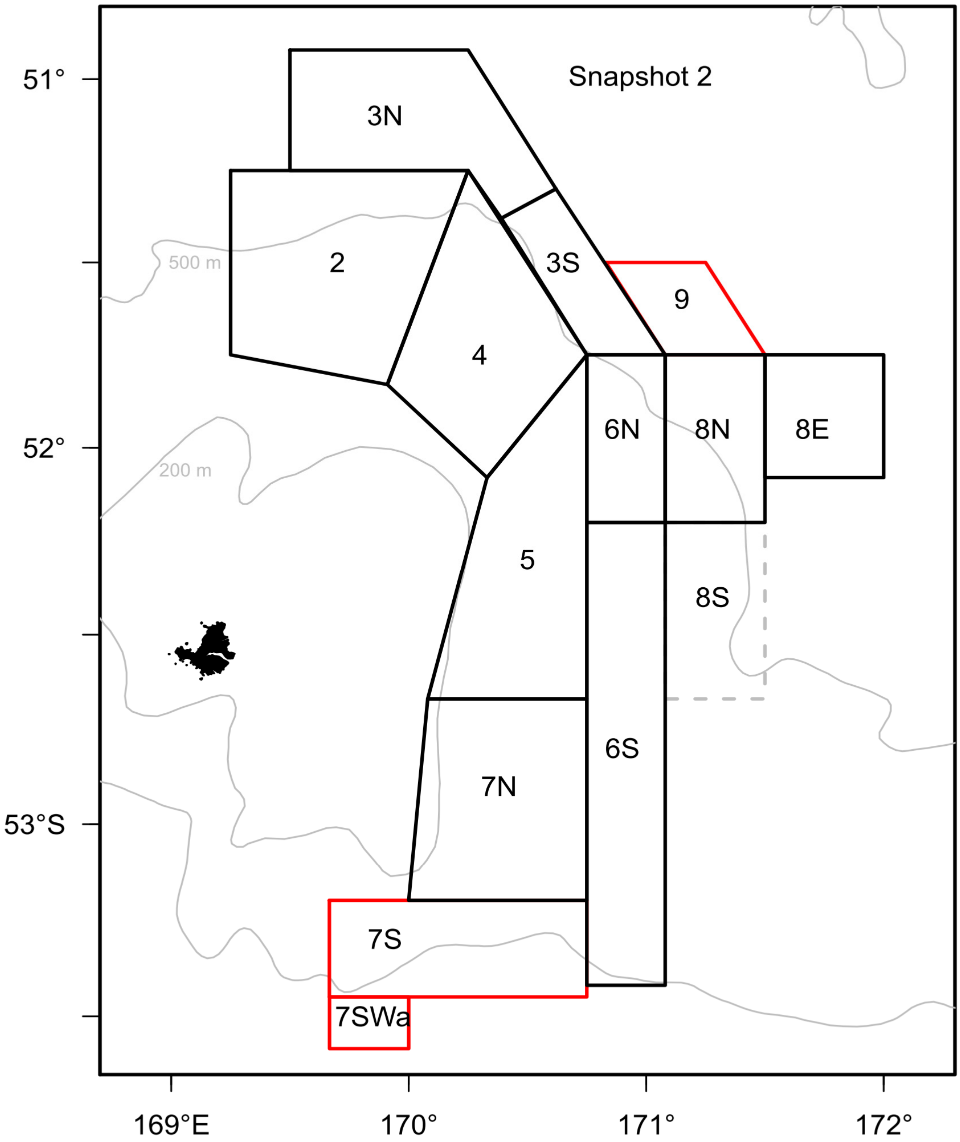

Figure 2: Stratum boundaries for snapshot 2 of the 2009 acoustic survey of the Campbell Island Rise. Red lines indicate modified boundaries or new stratum (7SWa). Stratum 8S (dashed line) was not surveyed.

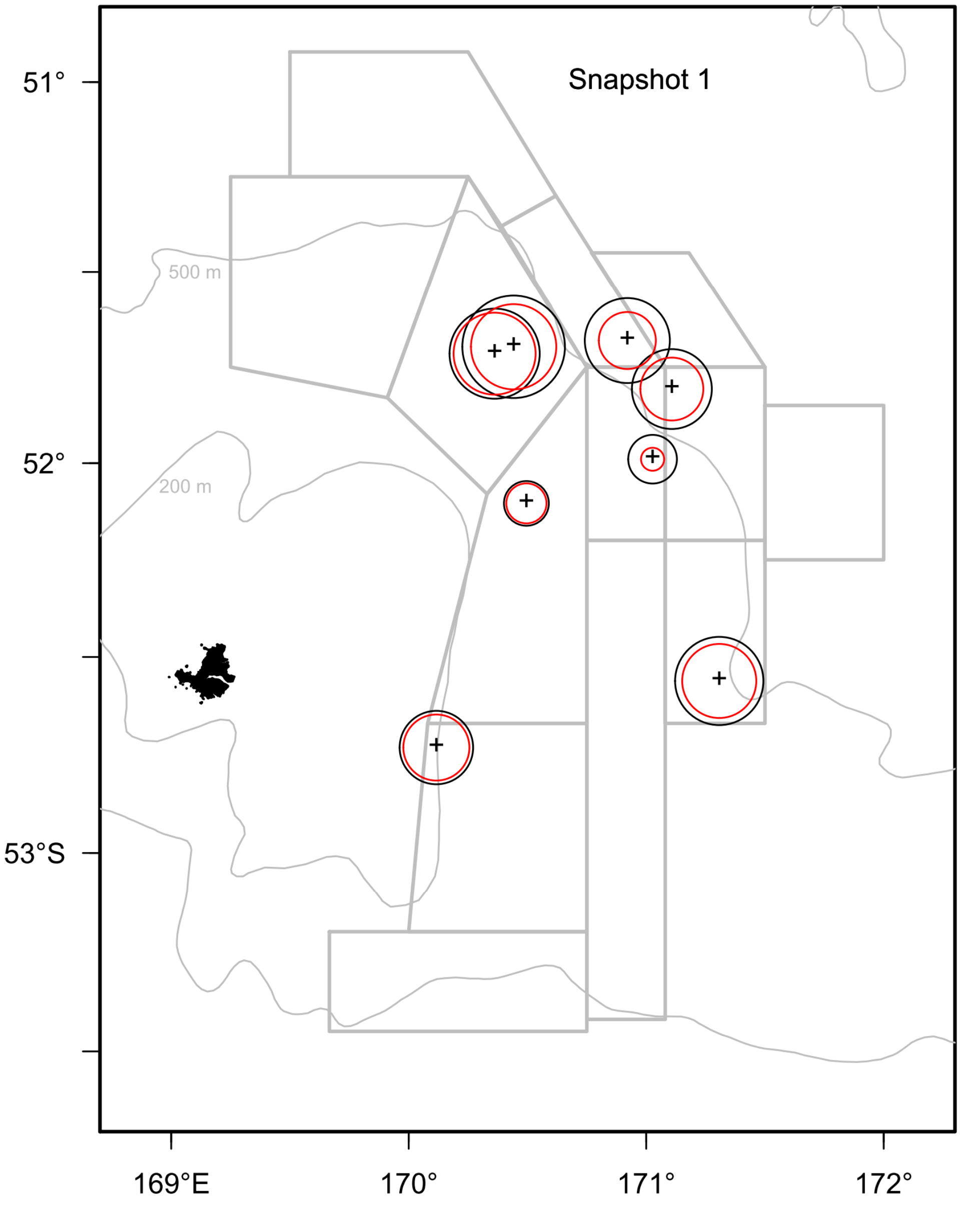

Figure 3: Catch rates of research trawls during snapshots 1 of the 2009 acoustic survey of the Campbell Island Rise. Circle area is proportional to the trawl catch. Maximum circle size is 604 kg. The + indicates the position of the trawl, the red circle the catch of SBW, and the black circle the total catch.

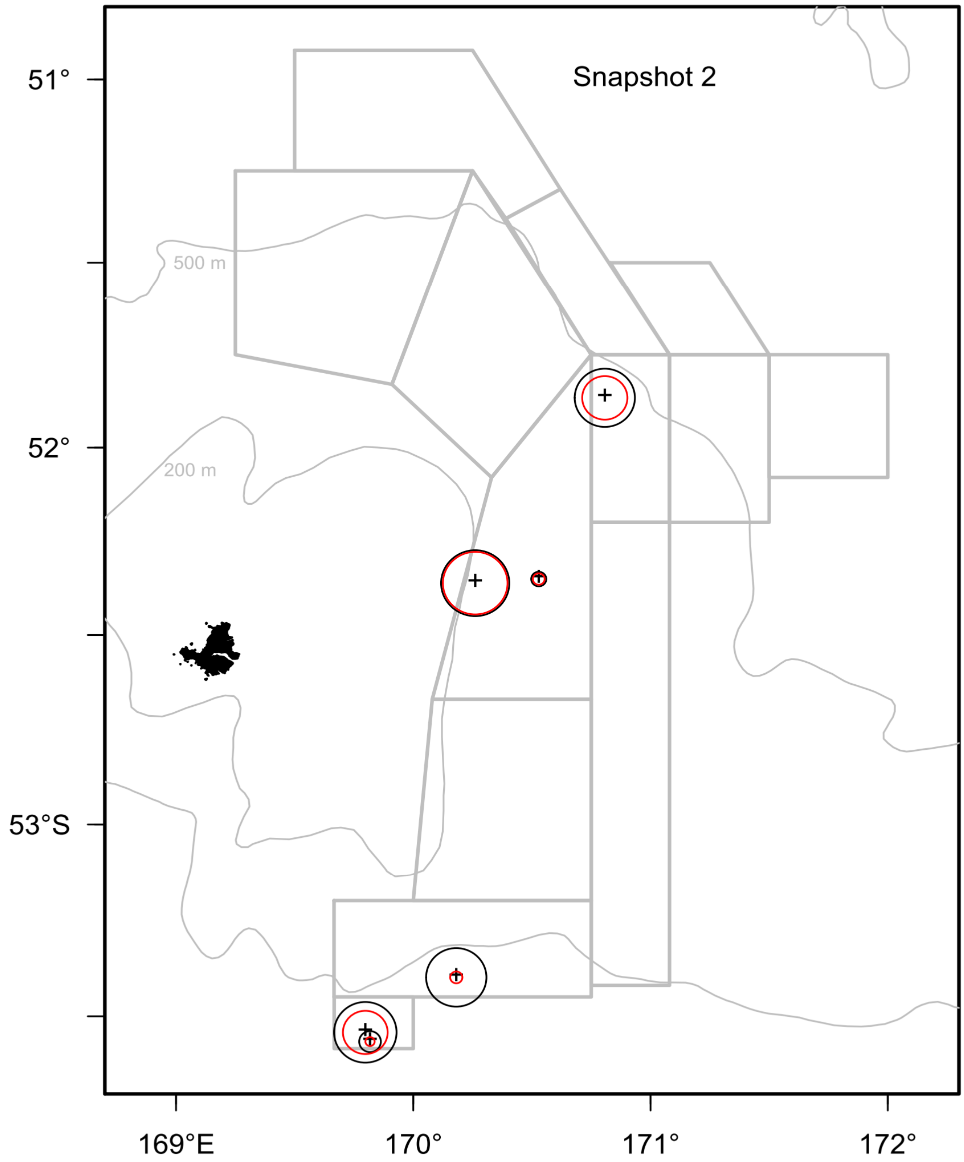

Figure 4: Catch rates of research trawls during snapshots 2 of the 2009 acoustic survey of the Campbell Island Rise. Circle area is proportional to the trawl catch. Maximum circle size is 402 kg (circle size on the same scale as figure 3). The + indicates the position of the trawl, the red circle the catch of SBW, and the black circle the total catch.

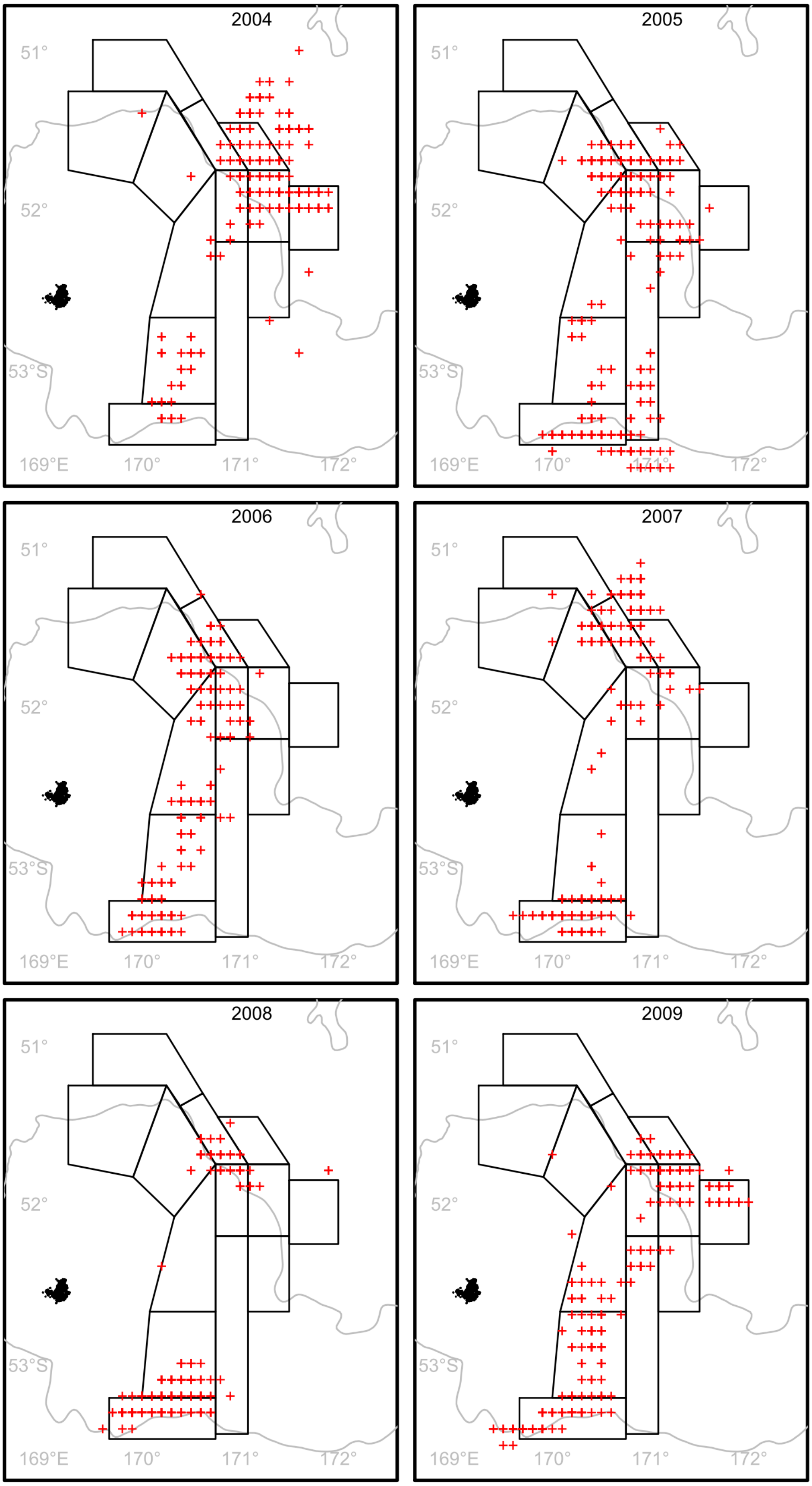

Figure 5: Start positions of commercial trawls carried out on the Campbell Island Rise from 2004 to 2009. Note that each cross may represent more than one tow. Snapshot 1 stratum boundaries are shown for reference.

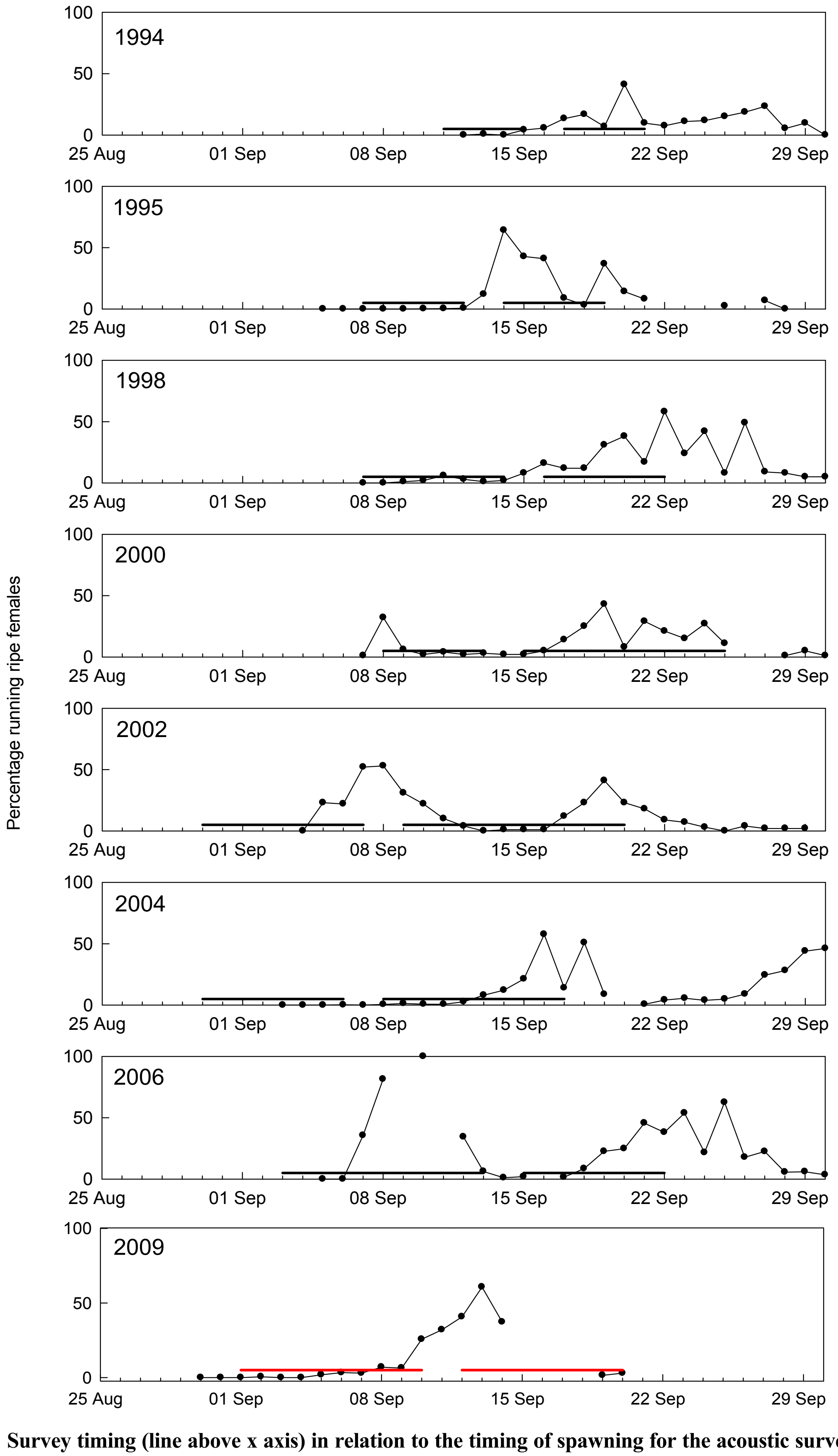

Figure 6: Survey timing (line above x axis) in relation to the timing of spawning for the acoustic survey time-series for SBW on the Campbell Island Rise. Percentage of running ripe females is from observer data.

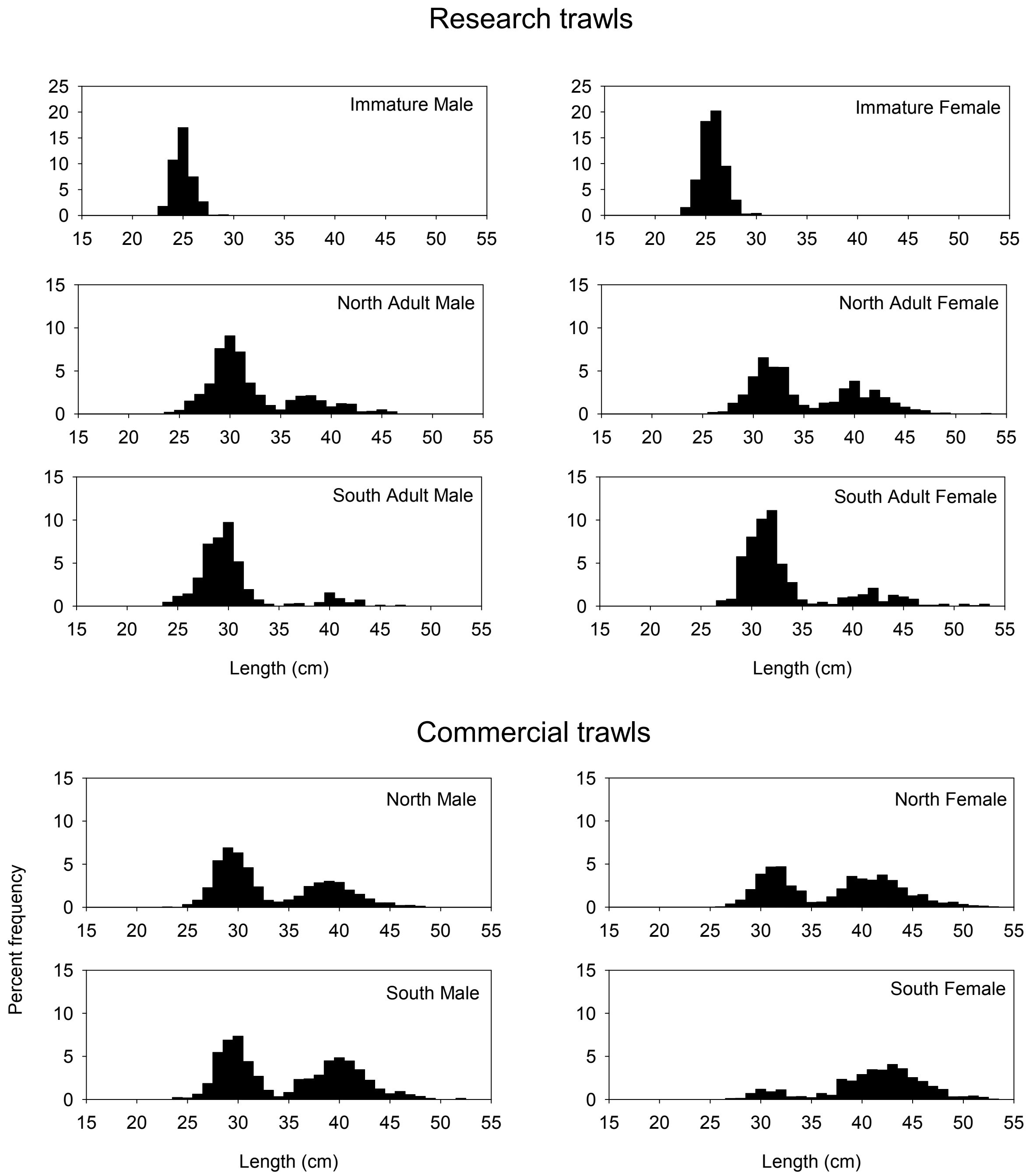

Figure 7: Catch-weighted length frequency distributions for southern blue whiting caught in research trawls by *Tangaroa* from immature and adult marks north and south of 52º 30' S and from commercial tows north and south of 52° 30' S during the spawning fishery. Research data were used in the acoustic survey analysis for decomposing immature marks and commercial data were used for adult marks.

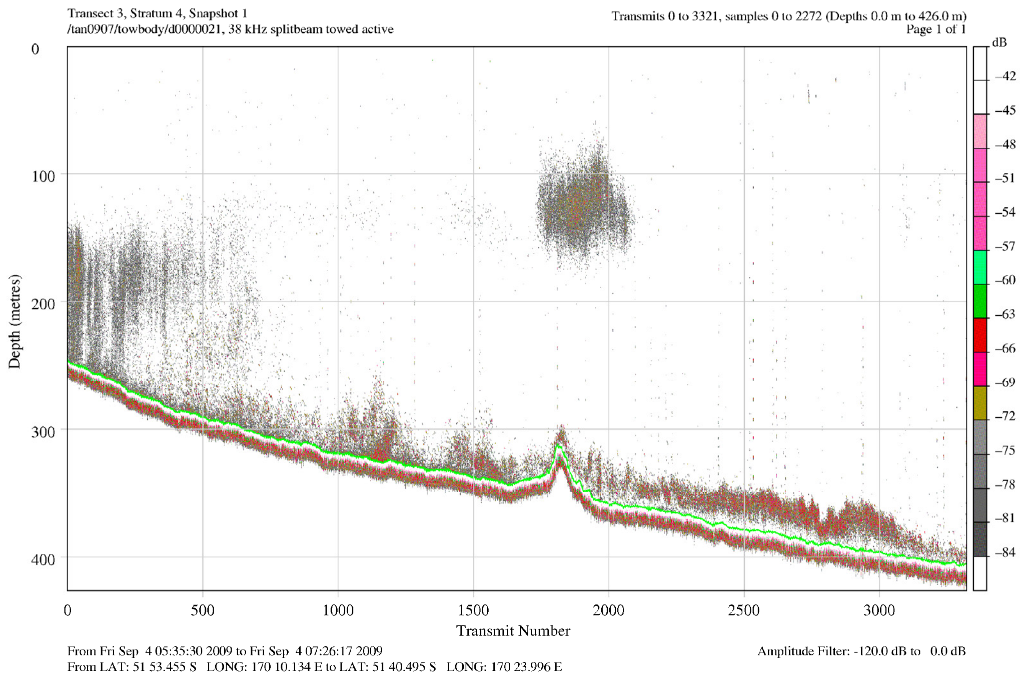

Figure 8: Adult pre-spawning mark close to the bottom in the morning in stratum 4 on 5 September 2009. Towbody depth was about 50 m. Marks in midwater are mesopelagic fish.

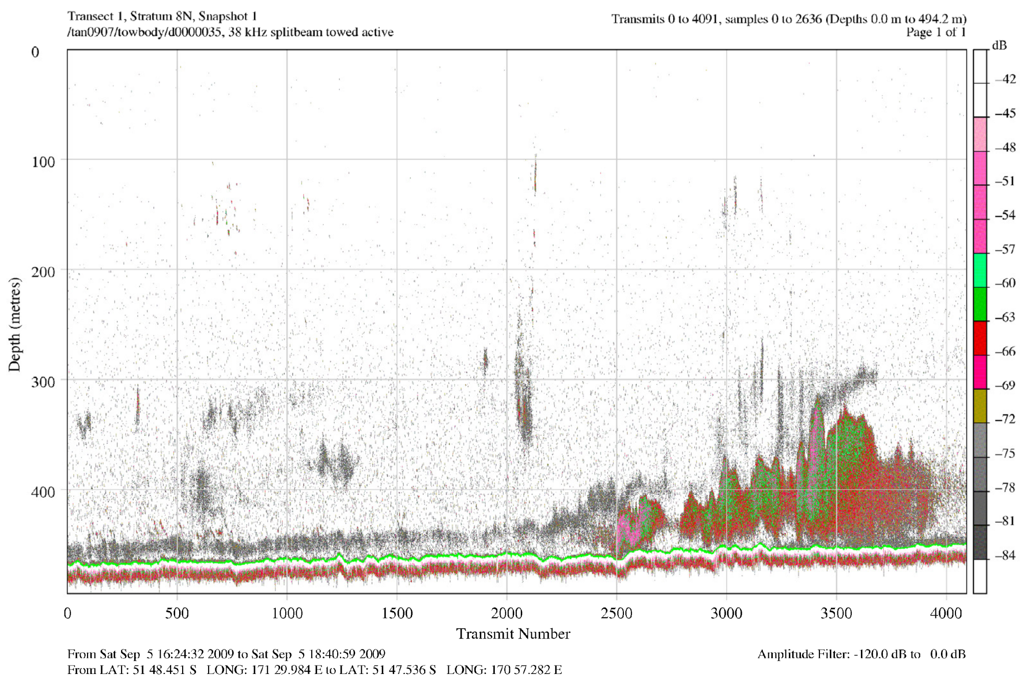

Figure 9: Large adult pre-spawning mark close to the bottom in the evening in stratum 8N on 5 September 2009. Towbody depth was about 50 m. Marks in midwater are mesopelagic fish.

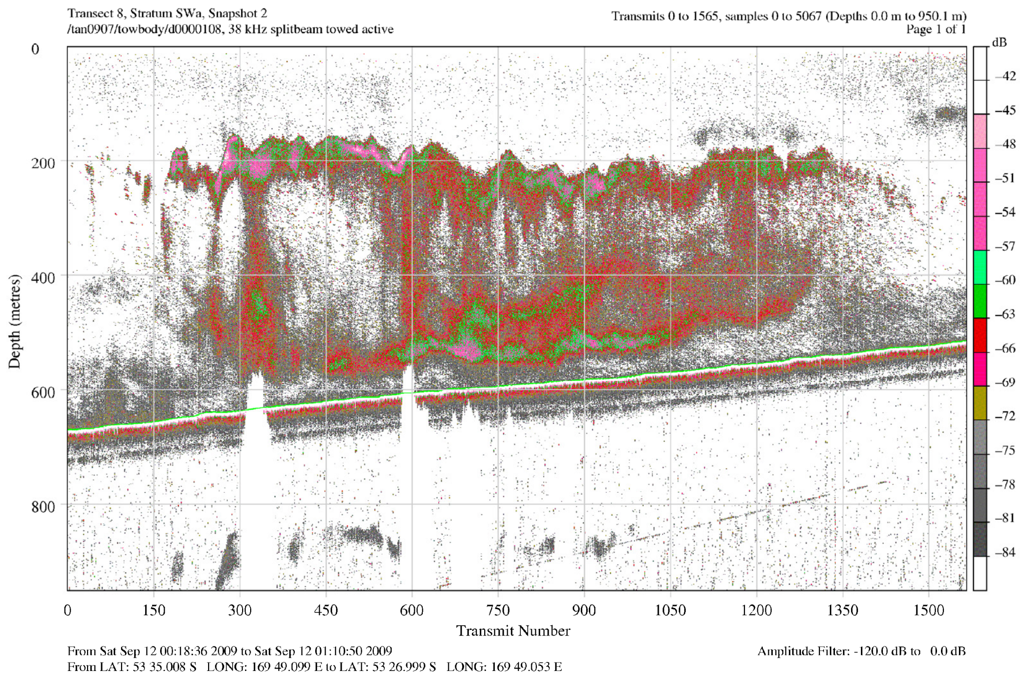

Figure 10: Extended adult spawning marks observed at night in stratum 7SWa on 12 September. Towbody depth was about 50 m.

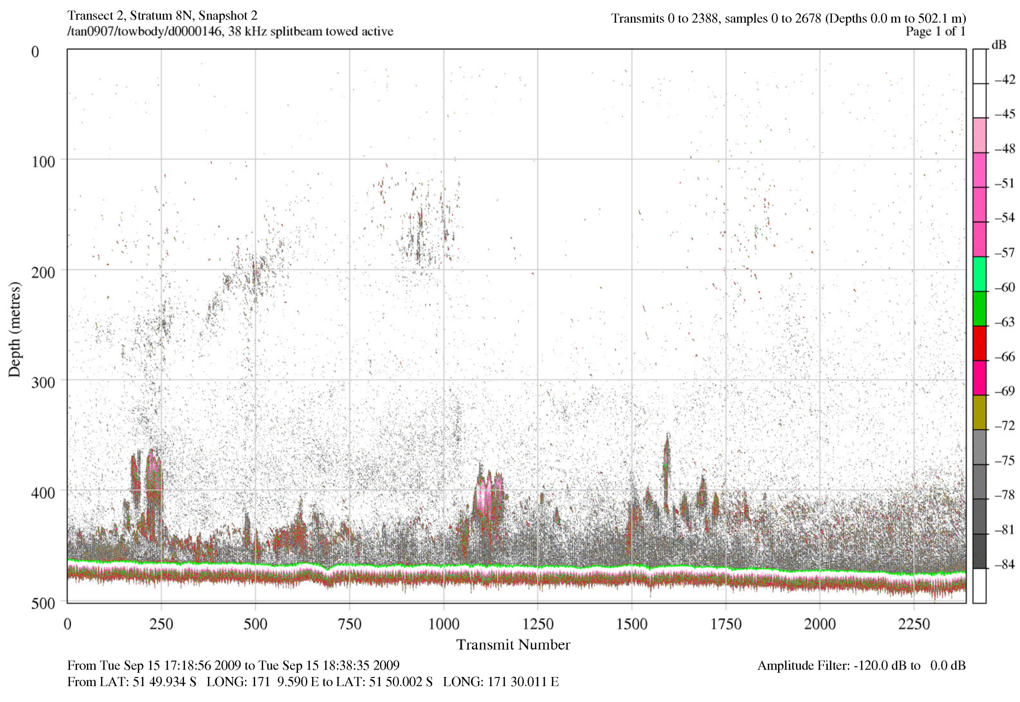

Figure 11: Very dense spawning marks (note the white cores) close to the bottom observed in the evening in stratum 8N on 15 September. Towbody depth was about 50 m.

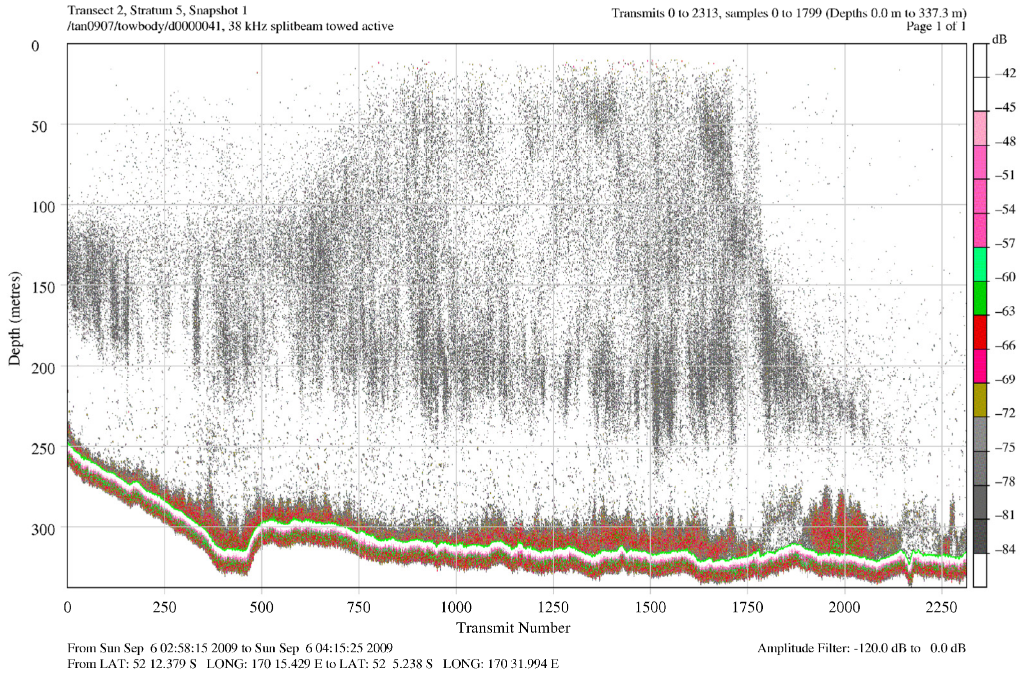

Figure 12: Immature marks close to the bottom observed at night in stratum 5 on 6 September. Towbody depth was about 50 m.

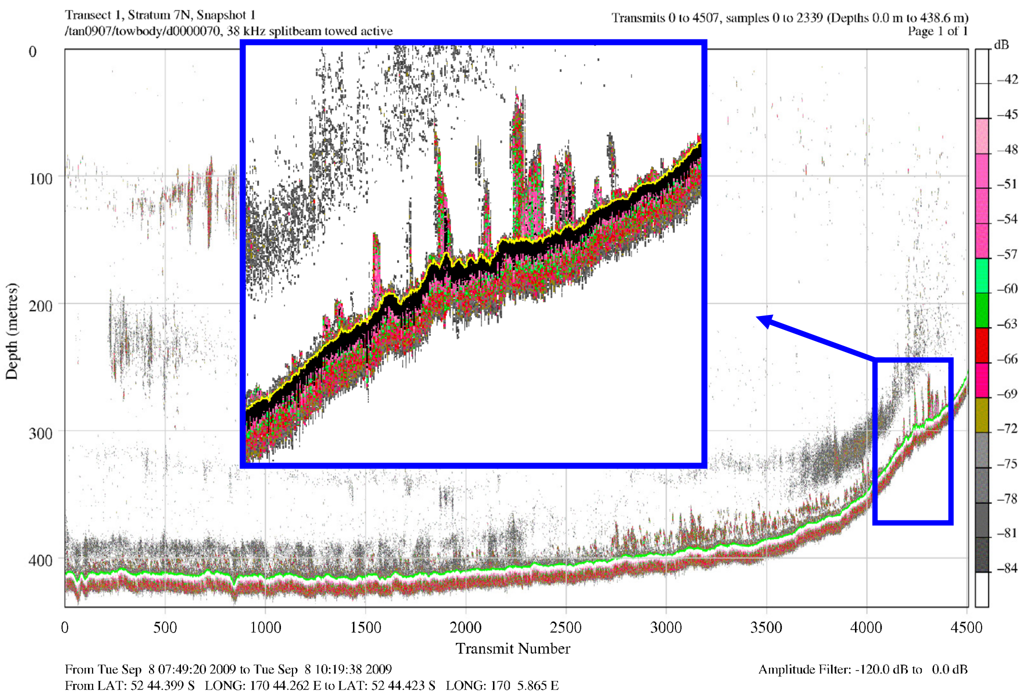

Figure 13: Immature marks close to the bottom observed at night in stratum 7N on 8 September. Towbody depth was about 50 m.

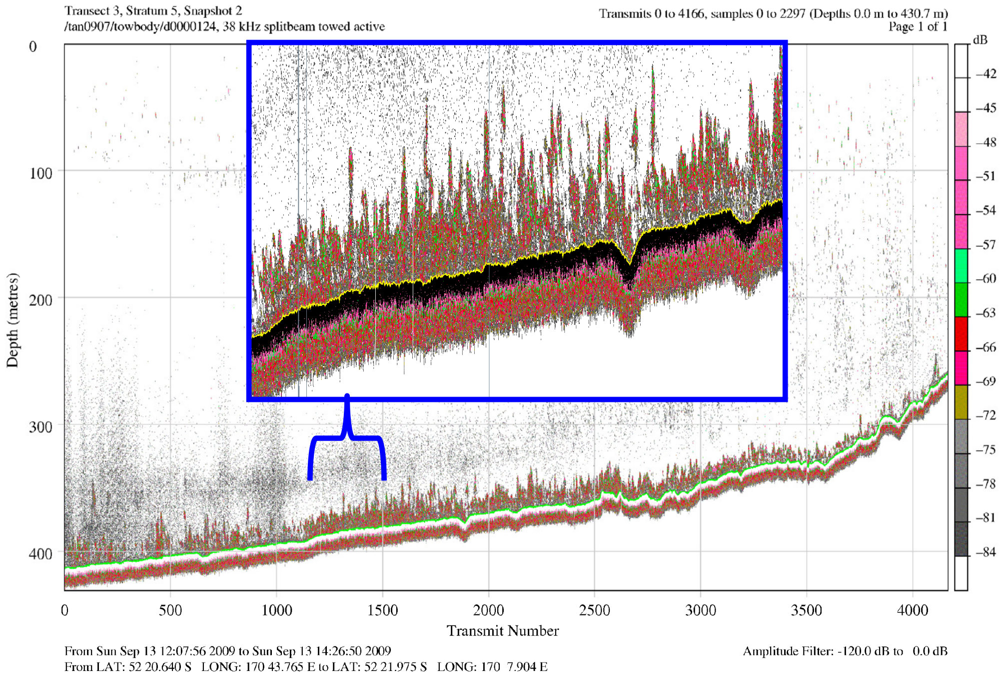

Figure 14: Immature marks close to the bottom observed during the day in stratum 5 on 13 September. Towbody depth was about 50 m.

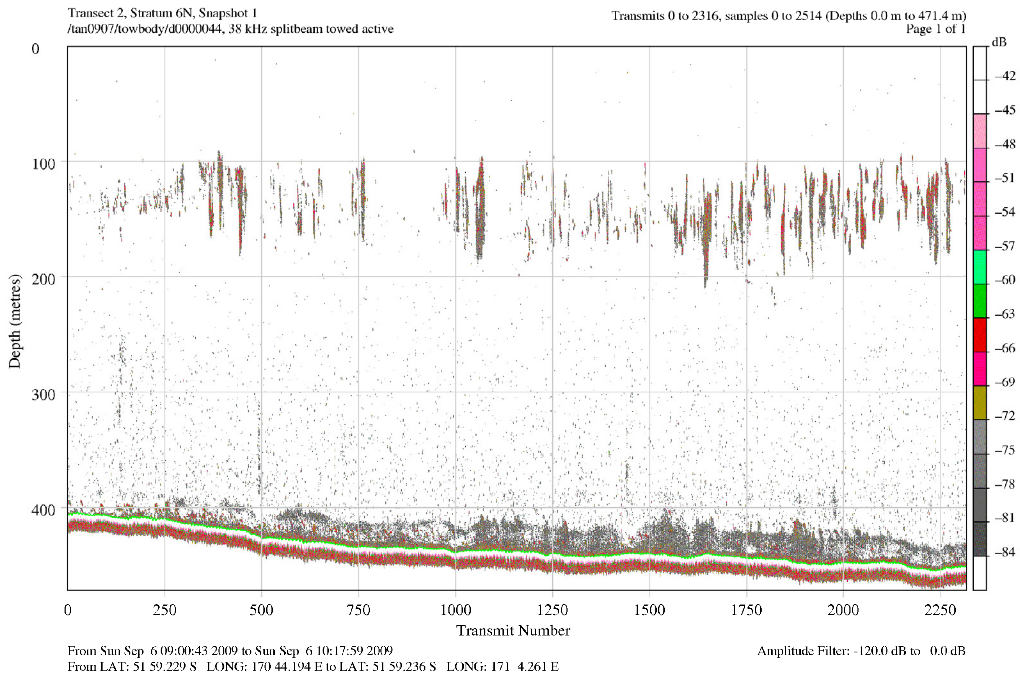

Figure 15: Mesopelagic marks (schools) up in the water column and background acoustic marks close to the bottom at night in stratum 6N on 6 September. Towbody depth was about 50 m.

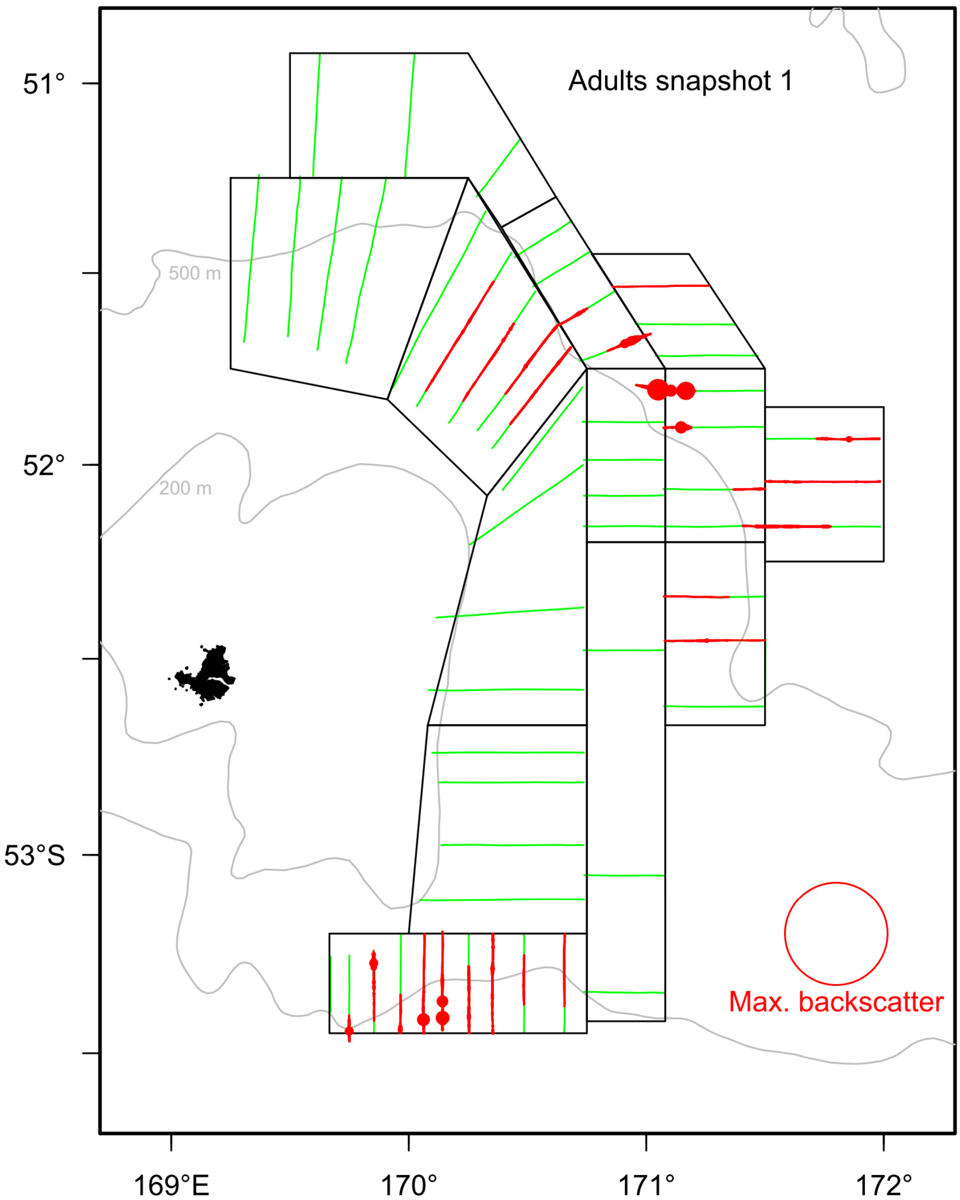

Figure 16: Spatial distribution of acoustic backscatter (in red) from adult SBW plotted in 10 ping bins for snapshot 1. Circle area is proportional to the log of the acoustic backscatter, scaled to the maximum SBW backscatter recorded in 2009.

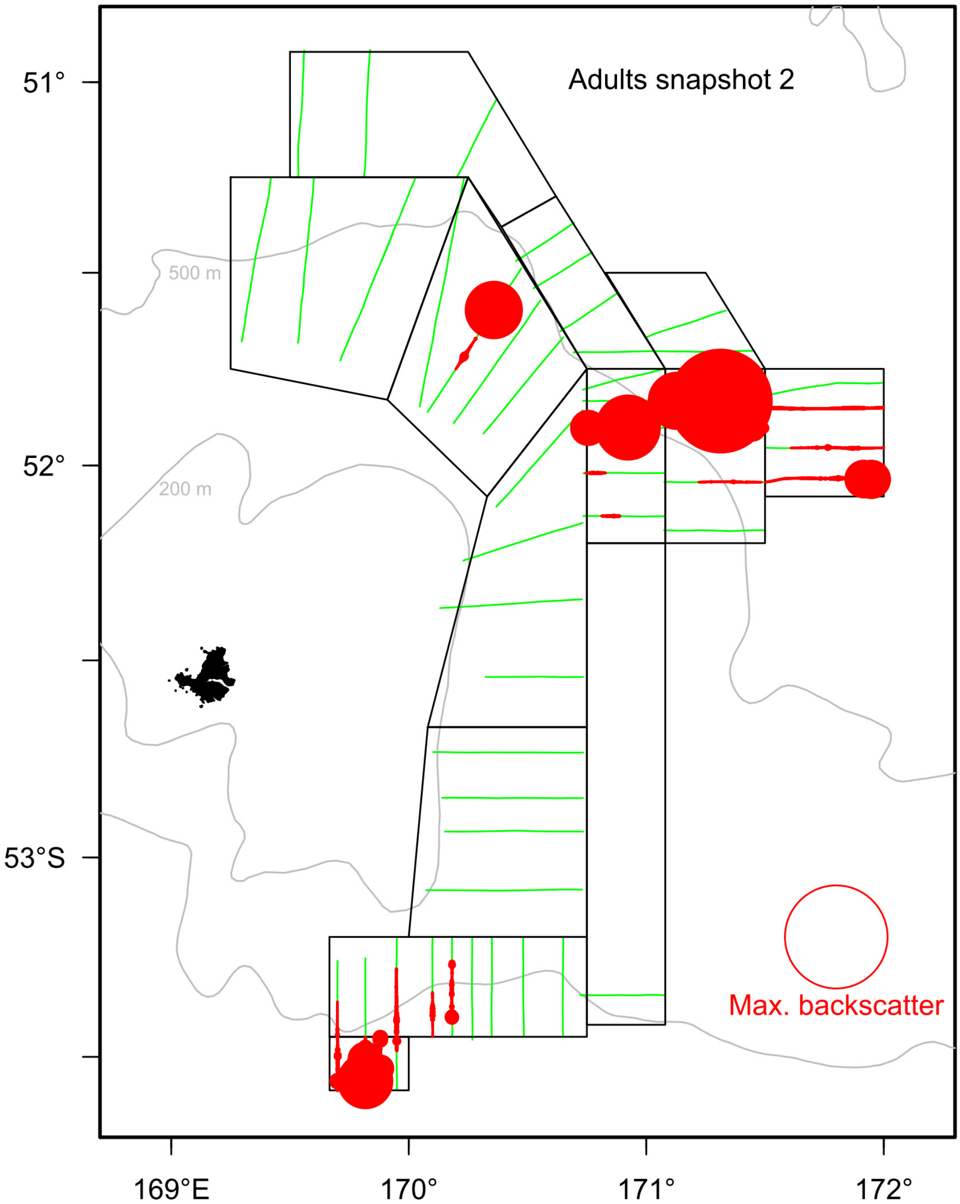

Figure 17: Spatial distribution of acoustic backscatter (in red) from adult SBW plotted in 10 ping bins for snapshot 2. Circle area is proportional to the log of the acoustic backscatter, scaled to the maximum SBW backscatter recorded in 2009.

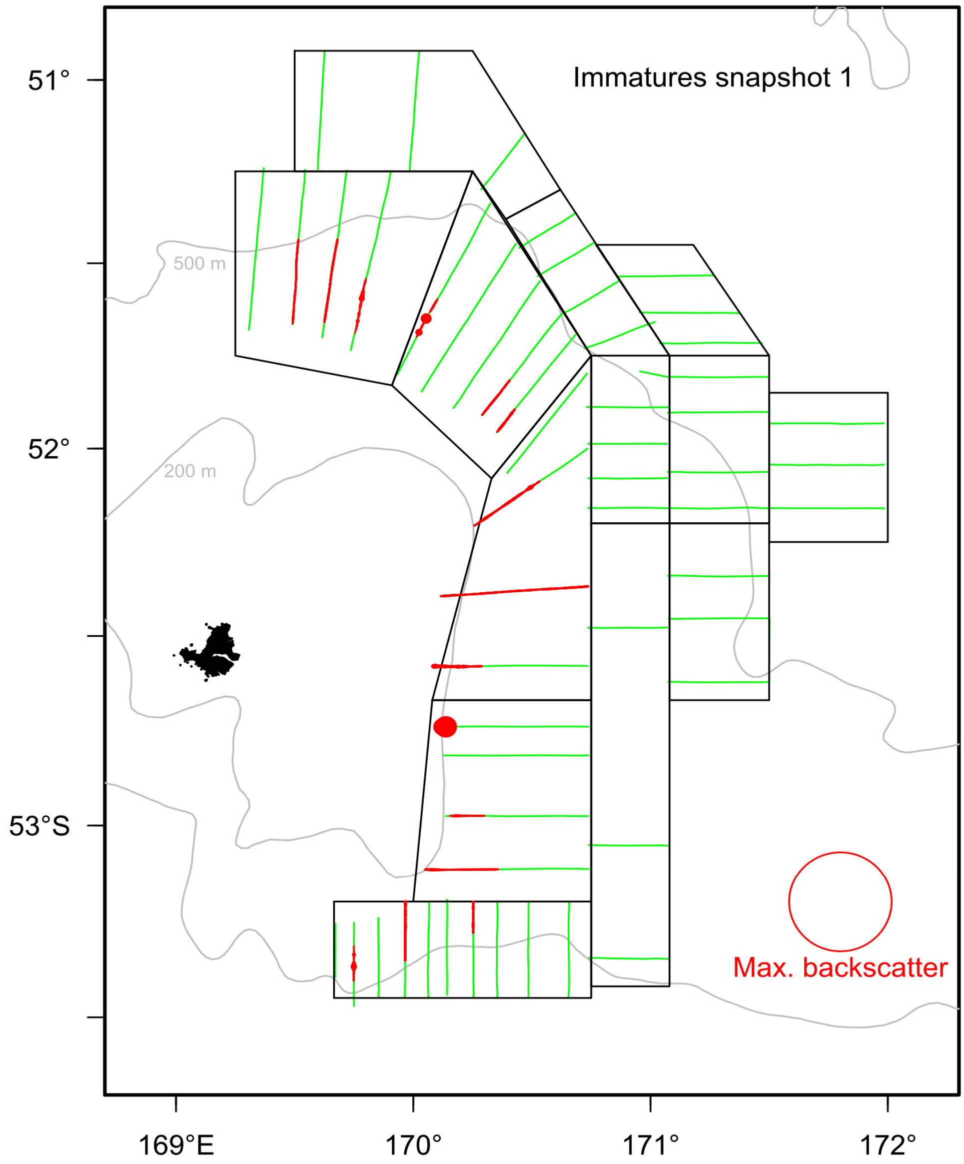

Figure 18: Spatial distribution of acoustic backscatter (in red) from immature SBW plotted in 10 ping bins for snapshot 1. Circle area is proportional to the log of the acoustic backscatter, scaled to the maximum SBW backscatter recorded in 2009.

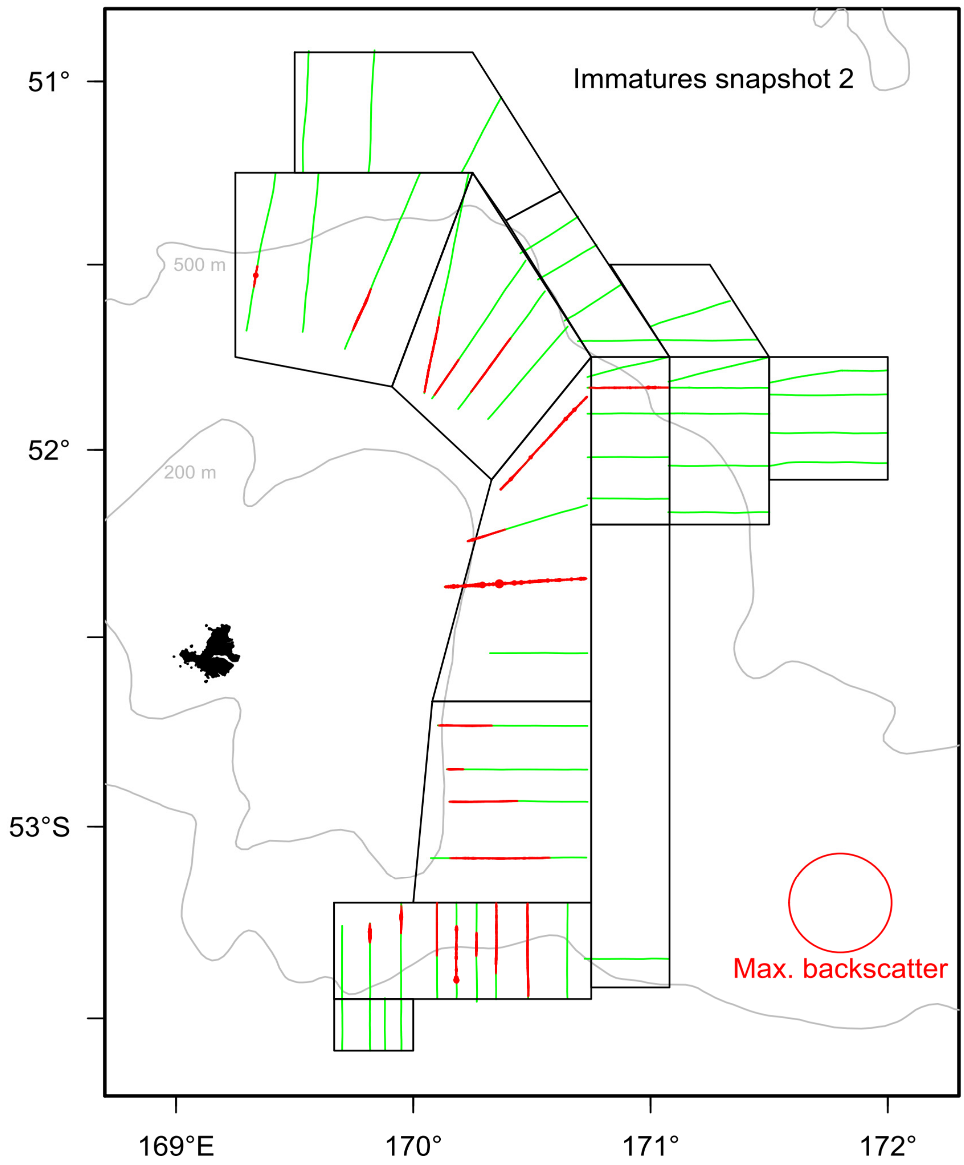

Figure 19: Spatial distribution of acoustic backscatter (in red) from immature SBW plotted in 10 ping bins for snapshots 2. Circle area is proportional to the log of the acoustic backscatter, scaled to the maximum SBW backscatter recorded in 2009.

Appendix 1: Acoustic equipment used for abundance estimation

Table A1.1 provides the system settings and calculated calibration coefficients used during the 2009 acoustic survey. Towbody 3 was used for most acoustic data collection along survey transects. Towbody 4 was used on a few occasions during the second snapshot. The hull system was used to collect data while trawling, and along four survey transects on 19 September because of faults with the towed systems. Table A1.2 provides the setting parameter for the hull systems during data collection, and table A1.3 provides the calibration parameters (systems calibrated in January 2010).

Table A1.1: System settings and calibration values for the 38 kHz CREST systems used for the 2009 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	Towed body 4
Transducer model	ES38DD	ES38DD
Transducer serial no.	28332	28327
3 dB beamwidths (˚) alongship/athwartship	7.0/6.9	7.0/6.9
Effective beam angle (sr)	0.0083	0.0083
Operating frequency (kHz)	38.16	38.16
Transmit interval (s)	2.00	2.00
Transmitter pulse length (ms)	1.00	1.00
Effective pulse length (ms)	0.78	0.78
Filter bandwidth (kHz)	1.5	1.5
Initial sample rate (kHz)	60	60
Decimated sample rate (kHz)	4	4
V_T (V)	1100	1035
G	12866	15212
Absorption (dB km^{-1})		
calibration	10.39	9.79
survey*	9.40	9.40

* See Appendix 3

Table A1.2: System settings for the EK60 hull systems used for the 2009 SBW survey.

Frequency (kHz)	18	38	70	120	200
GPT model	Q18(2)-S	Q38(4)-S	Q70(1)-S	Q120(1)-S	Q120(1)-S
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
Transducer draft setting (m)	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)	22.4	26.5	27.0	27.0	27.0
Sa correction (dB)	0.0	0.0	0.0	0.0	0.0
Bandwidth (Hz)	1570	2430	2860	3030	3090
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)	2.67	9.79	22.79	37.44	52.69
Speed of sound (m/s)	1494	1494	1494	1494	1494
Angle sensitivity (dB) along/ath	13.90/13.90	21.90/21.90	23.0/23.0	23.0/23.0	23.0/23.0
3 dB beamwidth (°) along/ath	11.0/11.0	7.10/7.10	7.0/7.0	7.0/7.0	7.0/7.0
Angle offset (°) along/ath	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0

Table A1.3: Calibration values for the EK60 hull systems used for the 2009 SBW survey. The hull system was calibrated on 27 January 2010 in Palliser Bay.

18 kHz	Transducer peak gain (dB)	23.00
	Sa correction (dB)	–0.76
	Beamwidth (°) alongship/athwartship	11.0/11.3
	Beam offset (°) alongship/athwartship	0.00/0.00
	RMS deviation (dB)	0.14
38 kHz	Transducer peak gain (dB)	25.95
	Sa correction (dB)	–0.59
	Beamwidth (°) alongship/athwartship	6.9/6.9
	Beam offset (°) alongship/athwartship	0.00/0.00
	RMS deviation (dB)	0.11
70 kHz	Transducer peak gain (dB)	26.72
	Sa correction (dB)	–0.30
	Beamwidth (°) alongship/athwartship	6.3/6.4
	Beam offset (°) alongship/athwartship	0.00/0.00
	RMS deviation (dB)	0.14
120 kHz	Transducer peak gain (dB)	26.74
	Sa correction (dB)	–0.35
	Beamwidth (°) alongship/athwartship	6.1/6.4
	Beam offset (°) alongship/athwartship	0.00/0.00
	RMS deviation (dB)	0.16
200 kHz	Transducer peak gain (dB)	25.03
	Sa correction (dB)	–0.36
	Beamwidth (°) alongship/athwartship	6.7/6.7
	Beam offset (°) alongship/athwartship	0.00/0.00
	RMS deviation (dB)	0.18

Appendix 2: 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 3: Calculation of sound absorption coefficients

Nine CTD casts were carried out as part of the 2009 survey. Average sound absorption was estimated using the formula of Doonan et al. (2003) (Table A3.1). The average absorption estimate of 9.40 dB km^{-1} was used when estimating SBW biomass (see Section 3.6).

Table A3.1: Estimates of acoustic absorption for the Campbell Island Rise acoustic survey area in 2009. 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})
1	502	34.33	7.09	9.45
4	499	34.34	7.10	9.47
5	358	34.33	7.02	9.49
6	484	34.34	7.08	9.47
9	630	34.40	7.52	9.32
10	695	34.40	7.44	9.21
11	648	34.40	7.39	9.26
12	369	34.34	7.11	9.49
14	474	34.33	7.12	9.42
Average	518	34.36	7.21	9.40