Acoustic estimates of southern blue whiting from the Campbell Island Rise, August–September 2006

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The eighth acoustic survey of southern blue whiting (SBW) on the Campbell Island Rise was carried out from 29 August to 25 September 2006 (TAN0611). The weather and sea conditions during the survey were very poor and nearly half of the available time on the grounds was unsuitable for acoustic data collection. Because of the poor conditions, only one full acoustic snapshot of the Campbell Island Rise was completed, between 3 and 14 September. A second snapshot, which covered the two main adult aggregations, started immediately after snapshot 1 on 14 September and finished on 22 September. One 'fleet stratum' was also surveyed in the northern region, encompassing the main area of commercial fishing. Eleven bottom trawls were carried out during the survey for mark identification, and to collect data on species composition, length frequency, and spawning state of SBW.

Pre-spawning adult SBW were detected in the northern area on 7–8 September, and post-spawning fish were observed on the southern grounds on 13–14 September. The northern aggregation began spawning during snapshot 2, and spawning marks were observed on 20–22 September. Immature SBW were widely distributed from 360 to 450 m depth, but few juvenile SBW marks were observed.

Biomass estimates were calculated for adult, immature, and juvenile SBW using the target strength (TS) to fork-length (FL) relationship of $TS = 21.8 \log_{10}FL - 72.8$, length frequency information from commercial and research trawls, and the calculated sound absorption coefficient of 9.47 dB km^{-1}. The estimate of adult SBW biomass for all strata was 102 234 t (c.v. 43%) in the first snapshot and 155 192 t (c.v. 46%) in the second snapshot, giving an average adult estimate of 128 713 t (c.v. 32%). The second snapshot did not cover the shallower northern strata, so estimates of immature and juvenile SBW were from the first snapshot only. The biomass estimates were 9968 t (c.v. 24%) for immature SBW and 1457 t (c.v. 38%) for juveniles.

These categories were decomposed to provide estimates of age 1, 2, 3, and 4+ fish. The best estimate of age 4 and older fish was 102 186 t (c.v. 32%), which was 43% higher than the estimate from the previous acoustic survey in 2004. The estimate of 2 year olds (2004 year-class) was similar to the 2002 year-class, and the second highest in the acoustic time series (after the very strong 1991 year-class), suggesting that this year-class is above average. Conversely, the estimate of 3 year olds (2003 year-class) was the second lowest in the time series. The estimate of 1 year olds (2005 year class) was average.

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 eight years (Ministry of Fisheries 2006). 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. Fish from the four spawning grounds are treated as separate stocks for stock assessment (Hanchet 1998). The largest stock spawns on the Campbell Island Rise, with a TACC for this area of 20 000 t for the 2006 season.

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 regularly. The Campbell grounds were surveyed in 1998, 2000, 2002, 2004, and now in 2006. The results of these acoustic surveys form the basis 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 eighth research acoustic survey of SBW on the Campbell Island Rise in August–September 2006 and presents biomass estimates, fulfilling the reporting requirements for Objective 1 of Ministry of Fisheries Research Project SBW2005/02:

1. To estimate pre-recruit and spawning biomass at Campbell Island during September 2006, 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 2006 survey was carried out from 29 August to 25 September 2006 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 MFish) 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 2004 (O'Driscoll et al. 2005). 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 53° S, but the division was shifted south to 53° 12' S for snapshot 2 of the 2004 survey (O'Driscoll et al. 2005), and this revised split was retained for snapshot 1. The southern boundary of stratum 7S was shifted south from 53° 25' S to 53° 27' S during snapshot 1 because commercial vessels reported seeing SBW just south of stratum 7S before we started transects in this stratum.

From 2000 to 2004, there was a trend of increased effort and increased catch east of 171° 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 52° 12' S to 52° 04' S. In 2004 and 2005, there was fishing to the east of stratum 3S and a new stratum (stratum 9) was added in snapshot 1 to cover possible aggregations of SBW in this area.

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 2006 (Table 1) was similar to the allocation used for the last four surveys. Either 3 or 4 phase 1 transects were allocated to each of the new strata (8N, 8S, 8E, 9). Approximate transect density estimates were examined in real time during the survey, and an additional phase 2 transect was allocated to each of strata 6N, 6S, and 8S (Table 1), where the densest marks were seen during phase 1. To minimise problems of fish movement between phases and to avoid excessive steaming time, the phase 2 transects were carried out while phase 1 was in progress, as soon as it was apparent that there were dense marks in these strata. No marks were seen on two transects in stratum 8E, so the third phase 1 transect in this stratum was dropped to save time.

The stratification and allocation of transects in snapshot 2 (Figure 1, Table 1) was adapted to reflect the significant loss of time due to bad weather, the fish distribution in snapshot 1, and the reported positions of the fishing fleet. There was only time to cover parts of the six strata (3S, 4, 5, 6N, 7N, 7S) which we believe encompassed the two main adult aggregations at the time of the second snapshot. To adapt to the apparent northward movement of the southern aggregation, the split between strata 7N and 7S was shifted north from 53° 12' to 53° 05' S, and the southern boundary of stratum 7S was also shifted north, from 53° 27' to 53° 20' S. Commercial vessels reported that the northern aggregation had moved northwest since snapshot 1, so we did not survey strata 6S, 8N, and 8S, where marks were detected in the first snapshot. Instead, we focused our limited effort on the areas where vessels were actively fishing from 18 to 22 September (strata 3S, 4D, 5N, 6N). The southern boundary of stratum 6N was shifted south from 52° 12' to 52° 20' S. Stratum 5N was defined as the part of stratum 5 north of 52° 20' S. Stratum 4D was the deeper (northeastern) part of stratum 4. There were no phase 2 transects in snapshot 2.

In addition to the main acoustic snapshots we also surveyed one "fleet stratum" around the main area of commercial fishing on the northern aggregation on 20–21 September (Figure 1). This consisted of six 4 n. mile north-south transects across the main tow-paths of the fleet (based on our observations on radar on 20 September). Two additional snapshots of the fleet stratum in the northern area were carried out from the industry vessels FV *Prof. M. Aleksandrov* and FV *Meridian 1* on 19–24 September.

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 2) was used for most acoustic data collection along survey transects. In this system, a four-channel CREST 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 a hull-mounted CREST system with single-beam 12 and 38 kHz transducers. Only the 12 kHz transducer was transmitting during survey transects with the towed system to prevent interference. Both frequencies of the hull system were switched on when the towbody was onboard. The hull system only was used to collect data while trawling, and along survey transects on 21 September when a series of incidents meant that both tow cables required repairs. Both the towbody and hull systems were calibrated following standard procedures (MacLennan & Simmonds 1992). Towbody 2 was calibrated before this voyage, in the Marlborough Sounds, on 3 August. A further calibration was attempted in poor conditions in Perseverance Harbour on Campbell Island on 10–11 September. The data from Perseverance Harbour were low quality, but confirmed the results of the previous calibration. The hull 38 kHz CREST system was calibrated south of Banks Peninsula on 24 September, during the transit to Wellington. 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). 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 50–100 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 wing trawl (also called the 'ratcatcher') with headline height 3.5 m, and codend mesh 40 mm. Two pelagic trawls were carried (NIWA 119 hoki midwater trawl and fine-mesh mesopelagic trawl), but were not used during this survey.

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. Acoustic recordings were made of all trawls using the 12 kHz and 38 kHz hull-mounted CREST acoustic system, but these data were not analysed quantitatively.

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: 2958) was mounted to the headline of the net during most bottom trawls to collect temperature and salinity data, which were then used to estimate the acoustic absorption coefficient during the survey (Appendix 3).

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 2006 fishery were extracted from the Ministry of Fisheries Observer database in December 2006. 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. Two values of sound absorption were applied. The calculated sound absorption for the area based on CTD data was 9.47 dB km^{-1} (Appendix 3). An assumed absorption coefficient of 8.0 dB km^{-1} was also used so that comparisons could be made with biomass estimates from previous

SBW acoustic surveys which also used a sound absorption of 8.0 dB km^{-1}. A correction for towbody motion (Dunford 2005) was also applied in some runs. All corrections were carried out within the ESP2 software, and were done iteratively to allow the effect of each correction to be assessed.

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 used in previous SBW acoustic surveys (e.g., O'Driscoll et al. 2005). This is the TS-FL relationship used for blue whiting in the northern hemisphere given by Monstad et al. (1992):

$$TS = 21.8 \log_{10}FL - 72.8 \qquad (1)$$

where TS is in decibels and FL is in centimetres.

Results from recent New Zealand swimbladder modelling studies (Dunford & Macaulay 2006) and SBW in situ data (Dunford 2006) suggest that this relationship is not appropriate for SBW. A preliminary estimate of a new TS-FL relationship was proposed by Dunford (2003), which has a steeper slope and gives a higher target strength:

$$TS = 40 \log_{10}FL - 99 \qquad (2)$$

The TS-FL relationship used in previous years (Equation 1) was retained in the current analysis because the Middle Depth Working Group did not accept the new relationship proposed by Dunford (2003) (Equation 2). Because the abundance indices are used only in a relative sense in modelling, a change in the intercept would not affect the relative indices (although it would affect the acoustic *q*). However, if there were a different slope this would affect the use of the indices even in a relative sense.

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 (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 2006 following Hanchet et al. (2000b). For the first time in 2006, c.v.s on the estimates at age were calculated directly, rather than derived from the estimates for juvenile, immature, and adult marks.

3. RESULTS

3.1 Data collection

The weather and sea conditions during this survey were amongst the worst ever encountered by the crew of *Tangaroa*. Wind speeds on most days were between 35 and 60 knots, and sometimes exceeded 80 knots. Swell height exceeded 10 m on several occasions. The towbody was usually retrieved when wind speeds exceeded 45 knots and swells exceeded 4 m. There were 9.3 days when no acoustic transects were possible (dodging or sheltering). This included two days immediately after the vessel arrived in the survey area on 1–3 September, and six days from 10 to 19 September, when we sought shelter at Campbell Island twice (10–12 and 16–18 September). Additional time was lost because of slow ship speed when heading into the weather. There were about 2 days when it was possible to collect acoustic data but was too rough to trawl.

A total of 315 acoustic data files (139 towbody and 176 hull) were recorded during the survey. There were 81 acoustic transects during the two snapshots of the Campbell Island Rise and an additional 6 transects in the three fleet stratum (Table 1). The CREST towed acoustic system performed very well and only 4 hours of survey time was lost due to hardware repairs. However, there were 12 hours on 21 September when acoustic data were collected on the hull system only as both towbody cables required retermination. Because of the loss of time and the poor weather and sea conditions during the survey, there was no opportunity for the collection of in situ SBW target strength (TS) data.

The amount of trawling was also severely restricted by the poor conditions. For example, it was too rough to fish on 10 of 13 days from 10 to 22 September. Eleven bottom trawls were made to identify targets and collect biological samples (Table 2, Figure 2). Tow length ranged from 0.35 to 2.39 n. miles at an average speed of 3.5 knots (Table 2). The total trawl catch was 2854 kg. Trawls caught a wide range of species, but the catches were dominated by southern blue whiting (52.4% of total catch, see Table 2). The next most abundant species were oblique banded rattail (21.1%), javelinfish (8.9%), silverside (4.7%), and pale ghost shark (2.8%).

Eight 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 7.3 °C.

3.2 Commercial data

The first vessel began fishing on the Campbell Island grounds on 31 August. The location of commercial trawls is shown in Figure 3. Effort was split between the southern and northern areas up until 12 September, with most tows (64%) south of 53° S. Between 13 and 17 September, vessels in the south tracked the (post-spawning) southern aggregation to the northeast, but by 18 September all the effort had shifted to the northern area, where the northern aggregation was beginning to spawn. Fishing continued in the north until the end of the season on 3 October, but from 26 September some of the vessels returned to the southern aggregation which was spawning for a second time east of Campbell Island at about 52° 40' S.

The timing of spawning in 2006 was very similar to that in 2005 (Hanchet et al. 2006), with the southern aggregation beginning spawning about 10 days earlier than the northern aggregation. In 2006, the threshold of 10% running ripe females was first reached in the southern area on 7 September, and then in the northern area on 19 September (Figure 4). A second spawning of the southern aggregation started on about 26 September. The timing of spawning was similar to that during previous surveys in 2000 and 2002 and earlier than in 2004 (Figure 4).

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 5). The 2006 catch had three modes, centred on 30 cm, 38 cm, and 45 cm for males, and 32 cm, 40 cm, and 48 cm for females (Figure 5). The larger and smaller length modes were more pronounced for the northern area and the mean length of fish caught in the north (39.6 cm) was slightly higher than in the south (mean length = 39.1 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 adult marks were easy to identify by their appearance and location in the water column. No strong spawning marks were observed during the first snapshot. Acoustic marks in the northern aggregation were characteristic of pre-spawning adult SBW (Figure 6), while those in the south consisted of post-spawning fish. Post-spawning marks were also widespread in the southern area during snapshot 2. These marks were close to the bottom during the day (Figure 7), but up to 150 m off the bottom at night (Figure 8). We observed similar post-spawning adult marks in strata 5N and 6N on 20–21 September. As in the south, marks were close to the bottom in small schools during the day, but extended well up into the water column at night. Dense marks in strata 3S and 4 on 21–22 September were characteristic of spawning SBW, with night-time marks observed within 200 m of the surface (Figure 9). Trawls on adult SBW marks were made in stratum 6N (tow 8), stratum 5N (tow 11), and stratum 7S (tows 9 and 10). An unusual feature this year was the large numbers of oblique banded rattail caught when fishing on post-spawning SBW marks in the southern area (see Table 2).

Most mark identification work focused on the less dense pre-recruit SBW marks and other light 'fuzz' marks seen in the survey area during snapshot 1. Juvenile (1 year old SBW) were caught in 300–320 m in stratum 2 (tow 1). Immature 2 year old SBW (with a mixture of 1, 2, and 3 year olds) were caught in 360–400 m in strata 2 and 4 (tows 3 and 5). Several 'background' trawls were made in 450–510 m, either deliberately (tows 2 and 4), or when the targeted marks had moved or were missed (tows 6 and 7). These generally yielded relatively low catches of adult SBW (see Table 2). Classification of juvenile and immature marks in snapshot 2 was based only on their similarity with marks seen in previous surveys and is uncertain because there was no trawling to verify mark composition.

Mesopelagic fish were common throughout the survey area. During the day the marks usually appeared as a band of small schools 20–150 m above the sea-bed. 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 300–360 m depth were the juvenile SBW category (1 year old).
- Characteristic light marks in 360–420 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). This approach will lead to a positive bias, particularly in the estimates of juvenile and immature SBW because the trawls targeted at juvenile and immature marks caught a high proportion of other species (see Table 2). In previous surveys, even trawls on dense juvenile marks caught as little as 60% SBW (Hanchet et al. 2002). 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, immature, and juvenile SBW along each transect during the two acoustic snapshots of the main survey area (Figures 10–12) and the distribution of adult SBW in the fleet strata (Figure 13).

During the first snapshot the densest adult marks in the northern area were seen across four strata (southern parts of strata 6N and 8N and the northern parts of strata 6S and 8S) (see Figure 10). Up to seven vessels were searching and fishing in the northern area (mostly in stratum 6N) while we were running acoustic transects on 7–8 September (Figure 3). Adult marks were also detected in the southern area (stratum 7S). Commercial vessels were fishing on this southern aggregation from 3 to 14 September (see Figure 3). Several vessels reported that there were dense spawning marks with good catch rates at about 53° 25' S 170° 05' E in the southwestern corner of stratum 7S before the storm on 10–12 September. It seems likely that peak spawning occurred during the storm, when most vessels were unable to trawl (see Figure 4). After the storm, the marks had dispersed and were further north. We caught post-spawning fish in the northern part of stratum 7S on 14 September. On the same date a Japanese vessel reported good catches in the south of stratum 7N.

Adult marks were also widespread in the southern area (in the re-defined stratum 7S) during snapshot 2 from 14 to 19 September. The northern aggregation had moved north and slightly west between snapshots, with the densest marks in strata 3S and 4D on 21–22 September. Post-spawning adult marks were also observed in strata 5N and 6N. Most of the commercial fleet was fishing on the northern aggregation, primarily in strata 3S and 4D, during snapshot 2 (see Figure 3). Dense adult SBW marks were observed along five of the six transects in the fleet stratum (see Figure 14).

Immature SBW marks were found in strata 2, 4, 5, and 7N during snapshot 1 and in strata 4D, 5N, and 7N during snapshot 2 (see Figure 11). Juvenile-like SBW marks were seen in strata 2, 4, and 7N during snapshot 1 and in strata 5N, 7N, and 7S during snapshot 2 (see Figure 12). Snapshot 2 did not cover the shallower northern strata, so provides only partial information on the distribution of immature and juvenile SBW. Transects in stratum 4D did not run shallower than 400 m, and immature marks were concentrated along the inner boundary (see Figure 11). Juveniles were observed at the shallow ends of the acoustic transects in both snapshots (see Figure 12) and their distribution probably extended shallower than 300 m

3.5 SBW size and maturity

Length, sex, and gonad stage were determined for 1808 SBW during the survey. The scaled length frequencies from research tows on adult, immature, and juvenile marks are compared to data from the commercial fishery in Figure 5. 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 2-year old males from 28 to 32 cm (2004 year-classes) and the average fish size was 3–4 cm smaller in the research catch. Nearly all fish caught in research tows on immature marks were 2-year olds from 27 to 32 cm (mean 29 cm), with more females than males caught. A few 2-year old SBW were also caught in the single tow on juvenile marks, but most fish were 1-year olds between 20 and 25 cm (see Figure 5).

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 SBW (greater than 34 cm) caught during tow 8 on the northern aggregation on 8 September were pre-spawning (stages 3 and 4) (see Appendix 2 for description of research stages), whereas 76% of SBW from tow 10 on the southern aggregation on 14 September had already spawned once (stages 6–8) (Table 3). Post-spawning SBW were also recorded in the northern area from tow 11 on 20 September (Table 3). All SBW less than 25 cm were immature (stage 1). Almost all (98.4%) female SBW from 27–32 cm were immature, but 77% of male SBW in this length range 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 5 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 Monstad et al. (1992), the calculated sound absorption coefficient of 9.47 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 reports (e.g., Hanchet et al. 2003), which used an absorption coefficient of 8.0 dB km^{-1}. The effects on biomass of decreasing the sound absorption from 9.47 to 8.0 dB km^{-1}, and also of implementing a correction for towbody motion are shown in Table 6. Using the old absorption (8.0 dB km^{-1}) decreased biomass estimates by 20–25%. The magnitude of the change was dependent on the average depth of the SBW marks: there was a larger effect when marks were deeper. Implementing the motion correction increased biomass by 3–10%. The magnitude of the change due to motion correction was related to mark depth (larger effect with increasing depth) and sea conditions (larger effect in poor conditions when there was greater towbody motion).

The adult biomass estimate was 102 234 t (c.v. 43%) in snapshot 1 and 155 192 t (c.v. 46%) in snapshot 2. Most of the adult biomass in 2006 was within the core acoustic survey area, with only 17 670 t (17% of the total biomass) outside the core area, in strata 8N and 8S, during snapshot 1. The best estimate of adult biomass from the average of both snapshots was 128 713 t (c.v. 32%). The biomass from the fleet stratum was low (4367 t). As this covered only a small part of the northern aggregation (see Figures 10 and 13) and was fully encompassed by the main survey area, the fleet stratum did not provide any additional information.

Snapshot 2 was designed to estimate only adult biomass, and did not include stratum 2 or the area of stratum 4 shallower than 400 m, where juvenile and immature SBW were observed in snapshot 1. The mark identification of immature and juvenile marks was also less certain in snapshot 2 because no trawling was possible. This was particularly true for juveniles. Almost all of the juvenile biomass came from two transects in strata 5N and 7N (see Table 5). There were no trawls in less than 450 m water depth in these strata and the classification of these marks as SBW was based only on their similarity with juvenile SBW marks seen in previous surveys. For these two reasons (incomplete coverage and uncertain mark identification), the best estimates for juvenile and immature SBW were from snapshot 1 only. The biomass estimates were 9968 t (c.v. 24%) for immature SBW and 1457 t (c.v. 38%) for juveniles.

The decomposed biomass estimates by age class are shown in Table 7. The 2006 biomass estimates for age 1, 2, 3, and 4+ SBW (including all strata) were 1284 t (c.v. 32%), 24 848 t (23%), 12 606 t (34%), and 102 186 t (32%) respectively. Note that the estimates of 1, 2, 3, and 4+ SBW for snapshot 2 were derived from the combination of decomposed biomass from juvenile and immature marks in snapshot 1 and adult marks only in snapshot 2. The contribution from juvenile and immature marks in snapshot 2 was not included for the reasons outlined above.

4. DISCUSSION

4.1 Timing of the survey

The timing of the 2006 survey was similar to that in 2002 (Hanchet et al. 2003) and 2004 (O'Driscoll et al. 2005) and about one week earlier than previous surveys (see Figure 4). Spawning began on about 7 September in the southern area and about 19 September in the northern area. Thus the timing of survey in relation to the spawning season was similar to previous years (see Figure 4)

4.2 Variability between snapshots

Adult and immature biomass estimates were fairly consistent between the two snapshots (see Table 5). The adult biomass in the southern area (strata 7N and 7S) increased slightly from 19 000 t in snapshot 1 to 24 000 t in snapshot 2, while the adult biomass in the northern area increased from 83 000 t to 131 000 t. The stratification of the northern area was not very appropriate in either snapshot, with the aggregation straddling a number of stratum boundaries (strata 6N, 6S, 8N, and 8S in snapshot 1, and strata 3S, 4D, 5N, and 6N in snapshot 2). Both aggregations tended to move north between snapshots, and the highest densities in the northern aggregation also moved west.

Unlike in some previous surveys (e.g., Hanchet et al. 2003), adult SBW were spread over a relatively wide area in both snapshots in 2006, so the overall survey c.v. for adult SBW (32%) was close to the MFish target of 30%. The fleet strata carried out by *Tangaroa* and the two industry vessels FV *Prof. M. Aleksandrov* and FV *Meridian 1* only covered parts of the northern aggregation within the main survey area and provide no useful information towards the acoustic abundance index.

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. During the 2005 season, most catch and effort was once again west of 171° E, with only about 60 tows (8%) east of 171° E, which yielded low catch rates (Hanchet et al. 2006). Furthermore, this pattern continued in 2006 where no commercial tows were made east of the core acoustic strata and over 90% of the biomass was within the core acoustic strata.

Given this return to the more normal (pre-2002) fish distribution patterns, it seems likely that the unusual fish distribution seen during the 2002 and 2004 acoustic surveys was because of a shift in the fish distribution during that period. The alternative hypothesis, that the fish within the core area had been depleted and that the fish outside the core area represented the occurrence of a new (previously unsurveyed) aggregation, postulated by Sullivan et al. (2005) can therefore be rejected. Therefore, the biomass estimates for 2002, 2004, and 2006 used in the assessment model should include all fish surveyed rather than only those from the core area. There is further support for this hypothesis from Hanchet (2005), who 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.

4.4 Comparison between years

The time series of decomposed biomass estimates at age for the Campbell Island grounds are summarised in Table 8. Note that all these estimates (including 2006) were derived using the old absorption coefficient (8.0 dB km^{-1}) because not all previous surveys had been corrected for the new absorption at the time of writing. The best estimate of age 4+ fish in 2006 (including all strata) was 43% higher than the estimate from the previous acoustic survey in 2004, but lower than estimates from 1995 to 2002. The best estimate of 2 year olds (2004 year-class) was similar to the 2002 year-class, and the second highest in the acoustic time series (after the very strong 1991 year-class), suggesting that this year-class is above average. Conversely, the estimate of 3 year olds (2003 year-class) was the second lowest in the time series, and was probably below average. The estimate of 1 year olds (2005 year class) was average.

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Table 1: Summary of transects carried out during the 2006 acoustic survey of the Campbell Island Rise. Stratum boundaries are shown in Figure 1. Number of phase 2 transects are shown in parentheses.

Snapshot 1 (3–14 Sep)			Snapshot 2 (14–22 Sep)		
Stratum	Area (km²)	Transects	Stratum	Area (km²)	Transects
2	3 154	4			
3N	2 342	3			
3S	1 013	4	3S	1 013	4
4	2 690	5	4D+	1 735	4
5	3 029	4	5N+	1 416	3
6N	1 150	5 (1)	6N+	1 477	5
6S	3 025	4 (1)			
7N	2 980	4	7N+	2 326	3
7S*	1 371	6	7S+	1 385	6
8E	1 232	2			
8N	1 436	4			
8S	1 452	4 (1)			
9	1 287	4			
Total	26 161	53 (3)	Total	9 352	25
			Fleet	111	6

* Area of stratum 7S in snapshot 1 is greater than that used in snapshot 2 of the 2004 survey (1192 km²) because the southern stratum boundary was shifted from 53° 25' S to 53° 27' S.

+ Stratum boundaries of 4D, 5N, 6N, 7N, and 7S were re-defined for snapshot 2 (see text for details).

Table 2: Trawl station details and catch of the main species during the 2006 acoustic survey of the Campbell Island Rise. Tow positions are plotted in Figure 2. Species: SBW, southern blue whiting; JAV, javelinfish; LIN, ling; GSP, pale ghost shark; SSI, silverside; CAS, oblique banded rattail; HAK, hake.

Tow	Date	Stratum	Mark type	Start latitude (°S)	Start longitude (°E)	Max tow depth (m)	Length (n. mile)	Catch (kg) SBW	JAV	LIN	GSP	SSI	CAS	HAK	Total
1	3-Sep-06	2	Juvenile	51.6713	169.5877	329	1.18	25.8	-	-	-	18.9	14.3	-	80.1
2	5-Sep-06	4	Background	51.5553	170.1768	475	1.07	65.6	16.1	5.8	16.9	28.6	4.1	-	148.6
3	5-Sep-06	2	Immature	51.6890	169.9088	380	1.11	227.4	0.1	5.0	-	17.2	10.6	-	273.8
4	6-Sep-06	3S	Background	51.5057	170.6692	513	1.15	2.7	24.1	0.7	16.6	5.7	1.7	-	73.1
5	6-Sep-06	4	Immature	51.8103	170.2253	382	0.85	102.5	0.3	-	-	10.4	30.7	-	166.0
6	7-Sep-06	8N	Background	52.0612	171.2347	504	1.51	43.4	20.0	4.1	17.4	5.6	2.3	8.6	123.2
7	7-Sep-06	6N	Background	52.0175	171.0215	491	1.46	20.8	21.8	0.8	10.8	7.8	9.9	-	89.9
8	8-Sep-06	6N	Adult	52.0753	170.7632	466	1.22	187.0	64.7	18.3	14.9	7.5	13.4	28.0	366.9
9	14-Sep-06	7S	Adult	53.1980	170.1675	456	2.59	655.0	80.4	-	-	22.6	310.0	-	1 088.3
10	14-Sep-06	7S	Adult	53.2138	170.1092	446	1.94	107.0	25.7	-	-	8.9	203.1	-	370.3
11	20-Sep-06	5	Adult	52.1937	170.6257	458	0.35	57.7	0.6	2.9	3.8	1.6	1.8	-	73.9

Table 3: Gonad stages of SBW caught in research trawls during the 2006 acoustic survey. Data are not presented for tow 9 because of inconsistent staging. 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	3-Sep-06	2	Juvenile	110	3	0	0	0	0	0	97	0	0	0	0	0	0	0
2	5-Sep-06	4	Background	2	5	65	23	1	0	0	12	5	59	0	0	0	0	0
3	5-Sep-06	2	Immature	28	6	3	0	0	0	0	175	0	0	0	0	0	0	0
4	6-Sep-06	3S	Background	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0
5	6-Sep-06	4	Immature	38	4	4	0	0	0	0	160	0	0	0	0	0	0	0
6	7-Sep-06	8N	Background	0	0	32	0	0	0	0	2	0	48	0	0	0	0	0
7	7-Sep-06	6N	Background	0	0	31	9	0	0	0	2	3	17	1	0	0	0	0
8	8-Sep-06	6N	Adult	0	0	36	145	0	0	0	4	0	80	1	0	0	0	0
10	14-Sep-06	7S	Adult	0	12	19	7	20	53	3	11	0	19	2	3	69	10	0
11	20-Sep-06	5	Adult	0	1	0	9	27	33	4	1	0	7	8	0	57	6	0

Table 4: Estimates of the ratio, *r*, used to convert SBW backscatter to biomass (see Section 2.7 for details). Values are derived from the scaled length frequency distributions in Figure 5. 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	75	39.6	0.474	0.0001635	-37.9	2 898
Adult (south)	Commercial	35	39.1	0.444	0.0001574	-38.0	2 822
Immature	Research	2	29.3	0.175	0.0000832	-40.8	2 104
Juvenile	Research	1	23.1	0.087	0.0000505	-43.0	1 730

Table 5: Biomass estimates (t) and c.v. by stratum and snapshot of juvenile, immature, and adult SBW, for the Campbell Island Rise in 2006. Note that the best estimates of juvenile and immature SBW biomass were from snapshot 1 only. Snapshot 2 covered only the adult areas and there was no trawling to verify the identity of juvenile or immature marks observed in this snapshot.

		Juvenile		Immature		Adult	
Stratum	Area (km^2)	Biomass (t)	c.v. (%)	Biomass (t)	c.v. (%)	Biomass (t)	c.v. (%)
Snapshot 1							
2	3 154	1 142	43	2 765	53	0	
3N	2 342	0		0		0	
3S	1 013	0		0		0	
4	2 690	90	91	3 583	38	0	
5	3 029	0		3 043	39	0	
6N	1 150	0		0		26 510	55
6S	3 025	0		0		39 352	100
7N	2 980	225	99	576	100	0	
7S	1 371	0		0		18 702	39
8E	1 232	0		0		0	
8N	1 436	0		0		10 134	59
8S	1 452	0		0		7 536	100
9	1 287	0		0		0	
Total	**26 161**	**1 457**	**38**	**9 968**	**24**	**102 234**	**43**
Snapshot 2							
3S	1 013	0		0		70 118	94
4D	1 735	0		5 446	31	22 803	107
5N	1 416	2 172	109	269	98	26 364	31
6N	1 477	0		0		11 652	51
7N	2 326	3 598	97	1 182	53	0	
7S	1 385	74	100	0		24 255	25
Total	**9 352**	**5 845**	**72**	**6 896**	**26**	**155 192**	**46**
Best estimate							
Core strata 2–7		**1 457**	**38**	**9 968**	**24**	**119 878**	**35**
All strata		**1 457**	**38**	**9 968**	**24**	**128 713**	**32**
Fleet	111					4 367	38

Table 6: Effect of using the old absorption coefficient (8.0 dB km^{-1}), and the towbody or vessel motion correction (with standard absorption 9.47 dB km^{-1}), on biomass estimates (t) by snapshot of juvenile, immature, and adult SBW. 'Standard' values are from Table 5.

				Biomass (t)
Snapshot	Category	Standard	Old absorption	Motion correction
1	Adult	102 234	78 178	112 035
	Immature	9 968	8 125	10 786
	Juvenile	1 457	1 215	1 551
2	Adult	155 192	124 318	170 024
	Immature	6 896	5 502	7 525
	Juvenile	5 845	4 853	6 152
Fleet stratum	Adult	4 367	3 525	4 480

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 2006. Only adult marks were decomposed for snapshot 2. The italicised entries were obtained from juvenile and immature marks from strata 2, 4, 5, and 7N in the first snapshot.

					Ages
Stratum	Area (km^2)	1	2	3	4+
Snapshot 1					
2	3 154	932	2 907	16	0
3N	2 342	0	0	0	0
3S	1 013	0	0	0	0
4	2 690	122	3 508	15	0
5	3 029	44	2 965	13	0
6N	1 150	0	3 339	2 759	20 463
6S	3 025	2	4 955	4 096	30 373
7N	2 980	184	604	3	0
7S	1 371	0	1 189	1 221	16 930
8E	1 232	0	0	0	0
8N	1 436	0	1 276	1 055	7 820
8S	1 452	0	948	784	5 816
9	1 287	0	0	0	0
Total	**26 161**	**1 284**	**21 691**	**9 962**	**81 402**
c.v.		**32**	**27**	**45**	**42**
Snapshot 2					
3S	1 013	2	8 825	7 295	54 094
4D	1 735	0	2 867	2 370	17 572
5N	1 416	0	3 318	2 743	20 340
6N	1 477	0	1 466	1 212	8 988
7N	2 326	0	0	0	0
7S	1 385	0	1 544	1 584	21 975
Total adult marks	**9 352**	**2**	**18 020**	**15 204**	**122 969**
+ Snap 1 imm and juv		*1 282*	*9 984*	*47*	*0*
Total		**1 284**	**28 004**	**15 251**	**122 969**
c.v.		**32**	**33**	**48**	**45**
Best estimate					
Core strata 2–7		1 284	23 736	11 687	95 368
All strata		**1 284**	**24 848**	**12 606**	**102 186**
c.v.		**32**	**23**	**34**	**32**

Table 8: Decomposed biomass estimates (t) by survey and age group for the Campbell Island Rise derived using the old absorption coefficient (8.0 dB km^{-1}). Values in parentheses for 2002, 2004, and 2006 represent biomass from only the core acoustic survey area (strata 2–7) where they differ from the total.

	Age 1	Age 2	Age 3	Age 4+
1993	1 817	71 902	14 781	24 033
1994	329	12 259	139 552	28 841
1995	0	11 176	23 228	130 535
1998	2 283	13 142	28 022	167 668
2000	961	10 460	8 421	135 612
2002	4 704	(3 732) 3 829	(11 549) 11 842	(148 189) 152 184
2004	1 512	(14 412) 17 327	(18 873) 34 527	(17 283) 56 197
2006	1 065	(18 969) 19 808	(9 206) 9 900	(75 194) 80 342

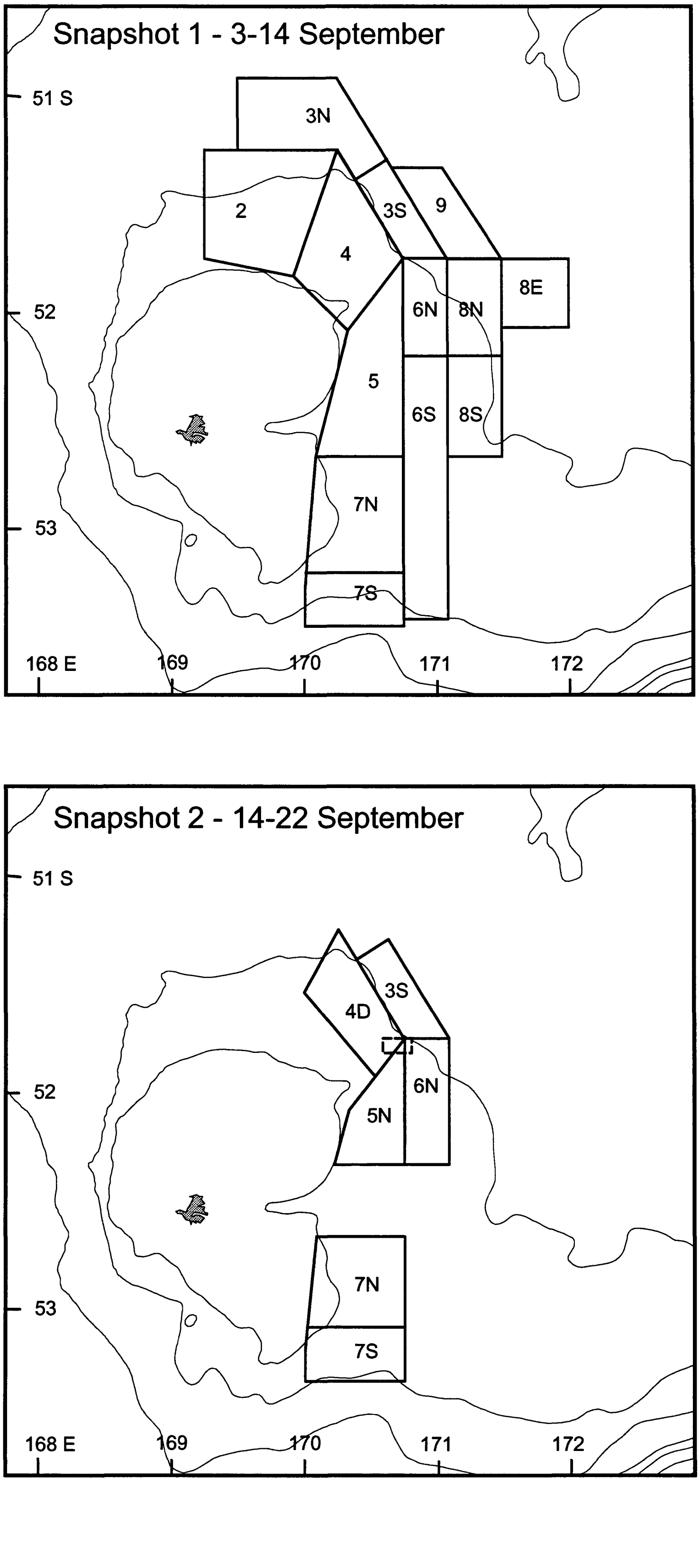
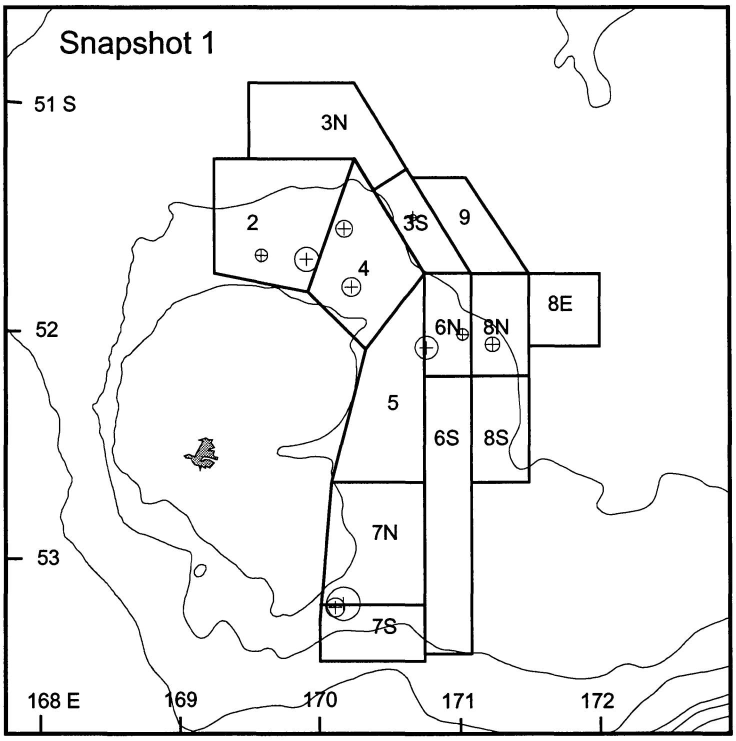


Figure 1: Stratum boundaries for snapshots 1 and 2 of the 2006 acoustic survey of the Campbell Island Rise. A fleet stratum (dashed line) was surveyed on 20–21 September during snapshot 2. Depth contours are 250, 500, and 750 m.



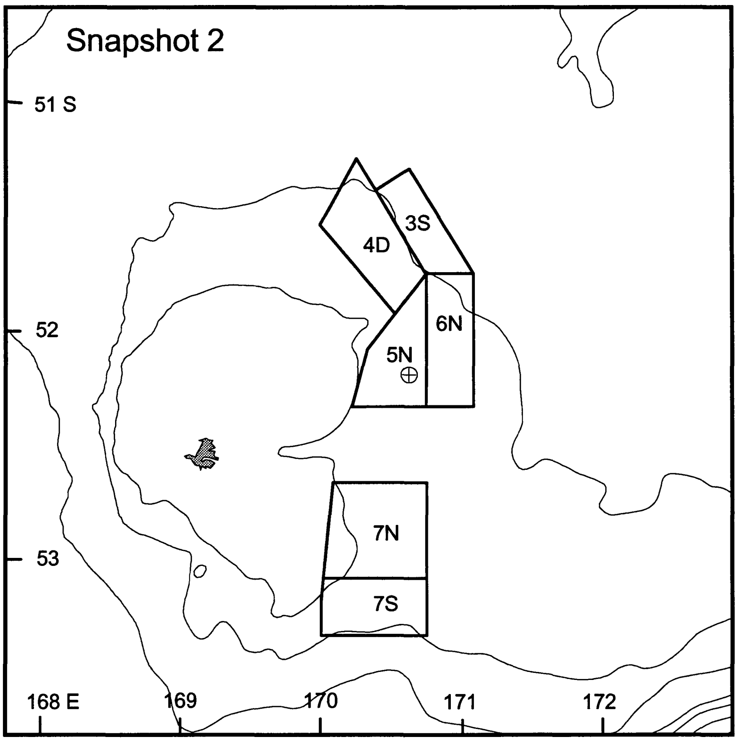


Figure 2: Catch rates of trawls during snapshots 1 and 2 of the 2006 acoustic survey of the Campbell Island Rise. Circle area is proportional to the log of the trawl catch. Maximum circle size is 655 kg. Depth contours are 250, 500, and 750 m.

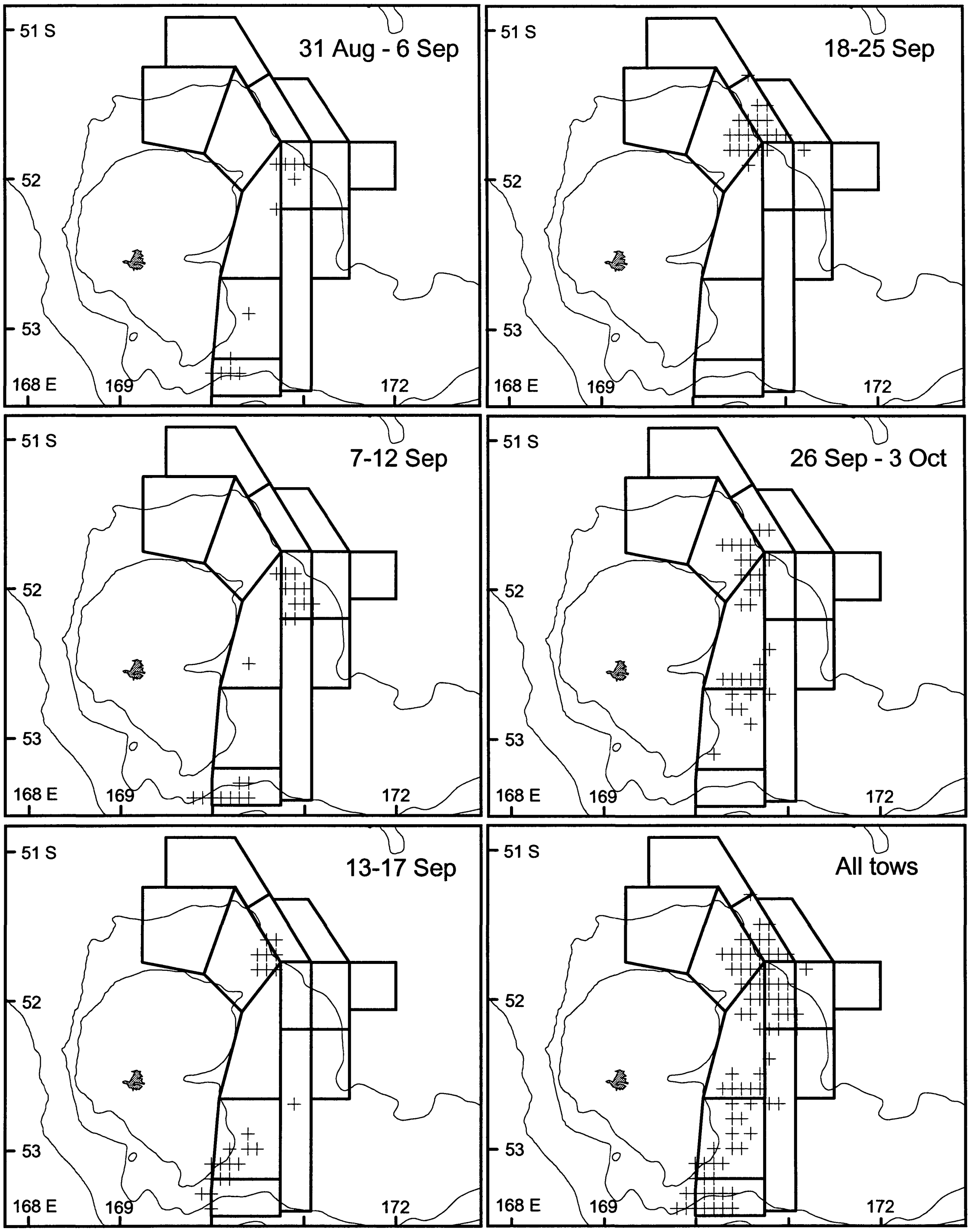


Figure 3: Start positions of commercial trawls carried out on the Campbell Island Rise during the 2006 SBW season. Note that each cross may represent more than one tow. Snapshot 1 stratum boundaries are shown for reference. Acoustic snapshot 1 was 3–14 September, and snapshot 2 was 14–22 September (see Figure 1).

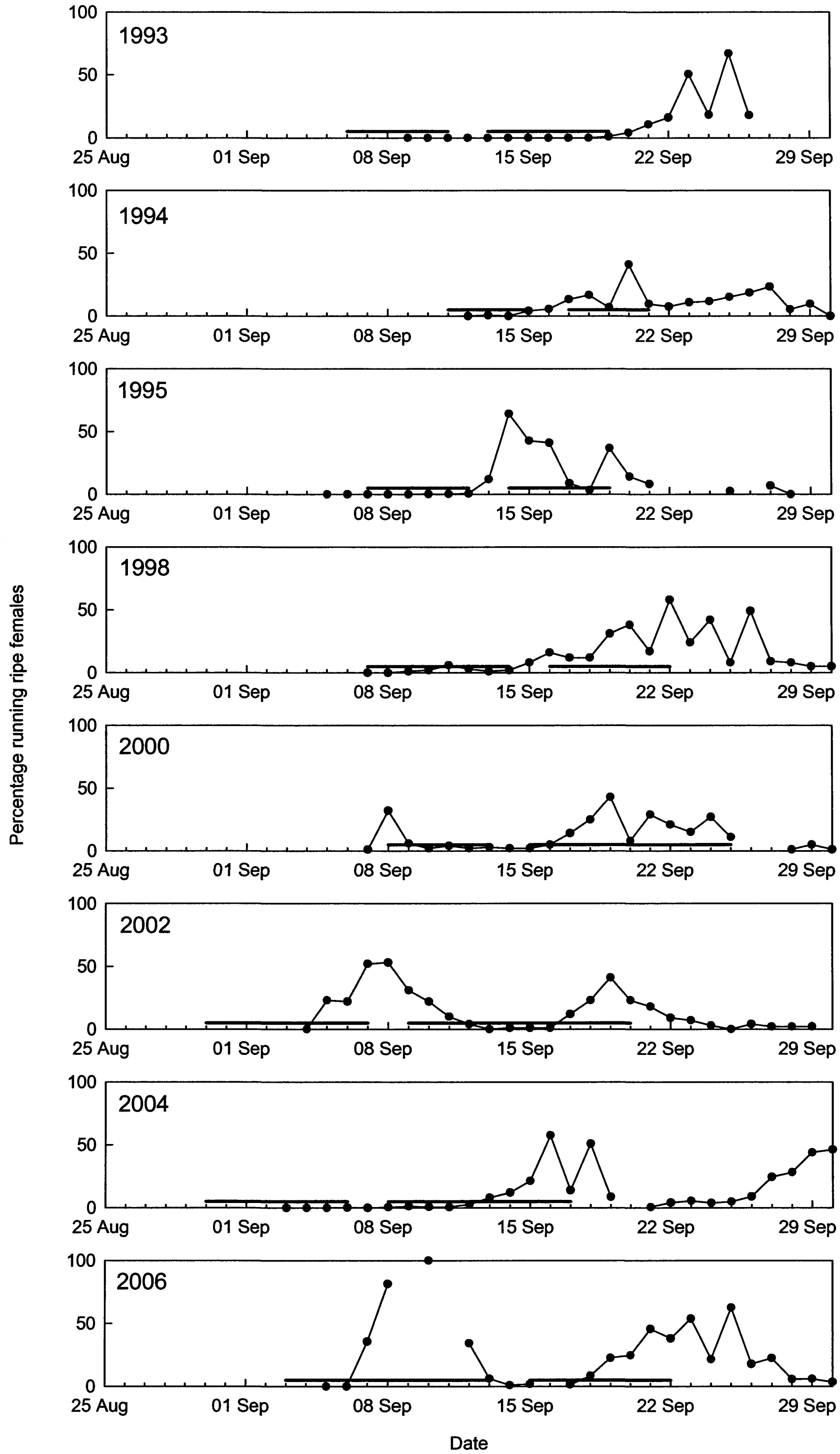


Figure 4: Survey timing (line above x axis) in relation to the timing of spawning for the acoustic survey time-series for SBW on the Campbell Island Rise. Percentage of running ripe females is from observer data.

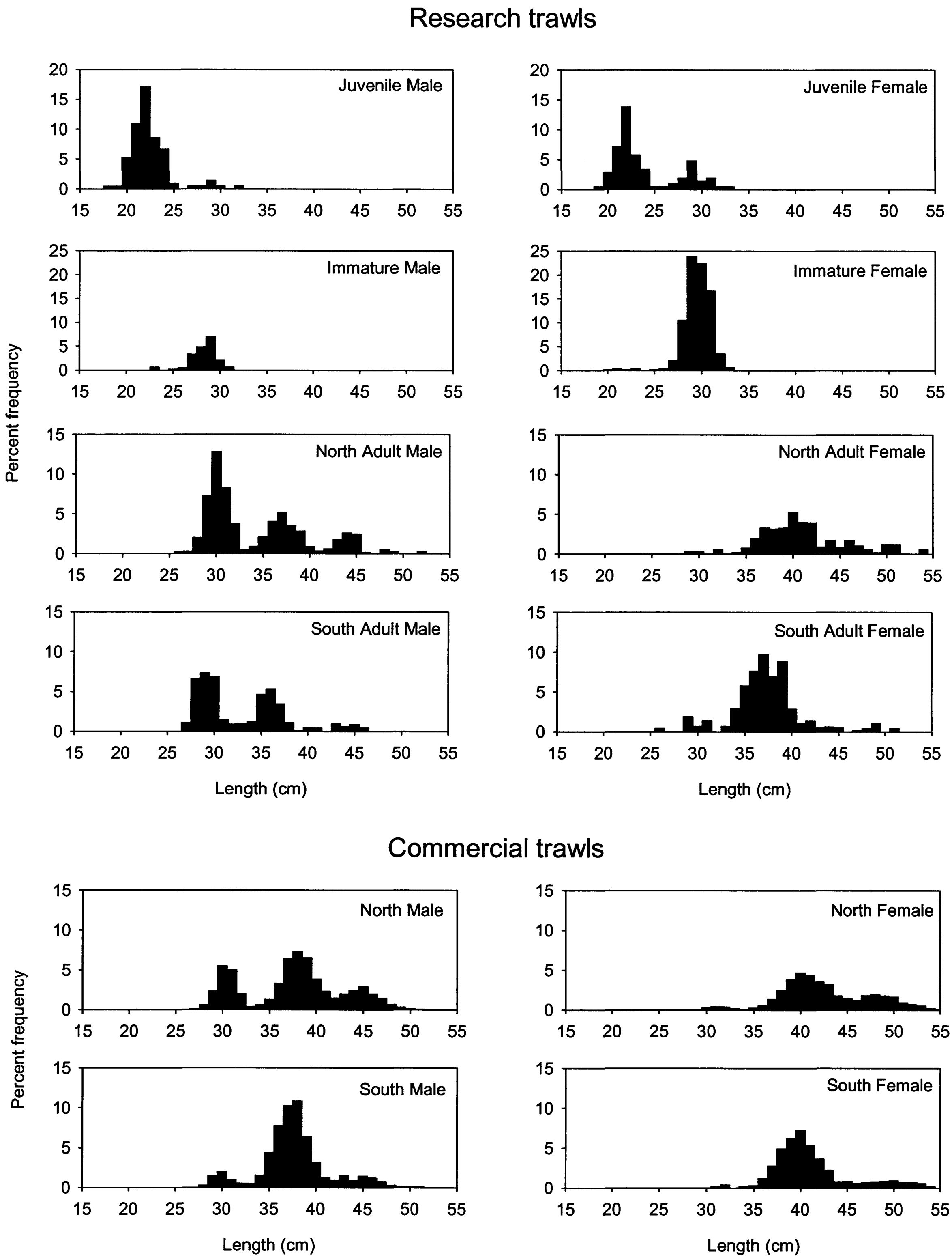


Figure 5: Catch-weighted length frequency distributions for southern blue whiting caught in research trawls by *Tangaroa* from juvenile, immature, and adult marks north and south of 52° 30' S and from commercial tows north and south of 52° 30' S during the spawning fishery. Research data were used in the acoustic survey analysis for decomposing juvenile and immature marks and commercial data were used for adult marks.

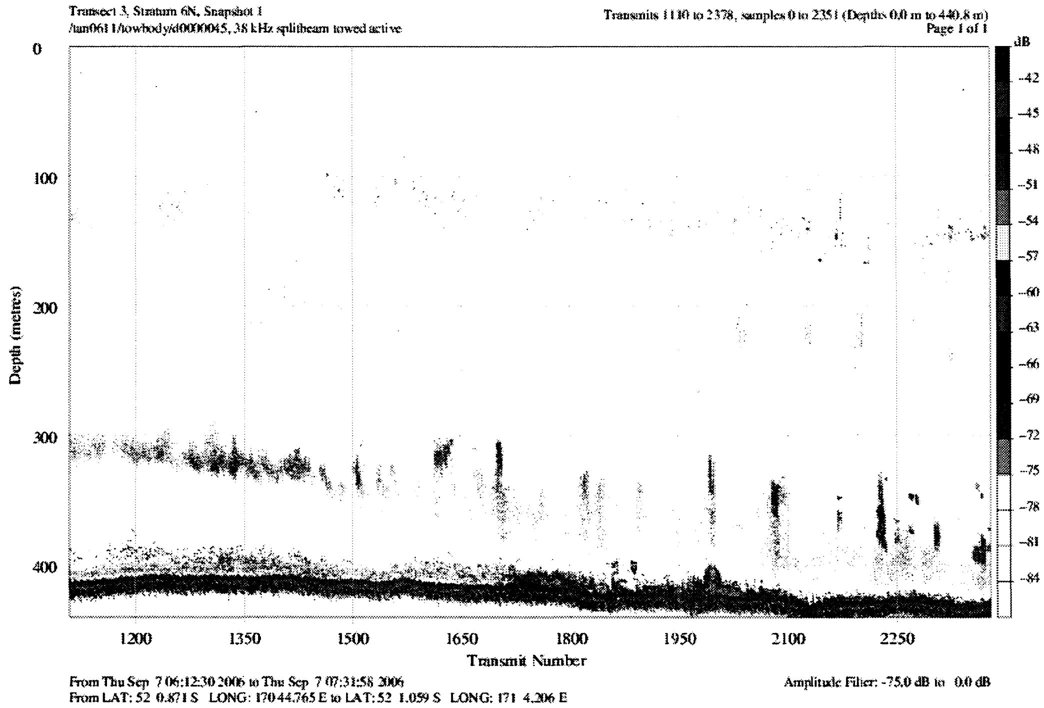


Figure 6: Adult pre-spawning mark close to the bottom at dawn in stratum 6N on 7 September 2006. Towbody depth was about 50 m. Marks from 300–400 m are mesopelagic schools descending.

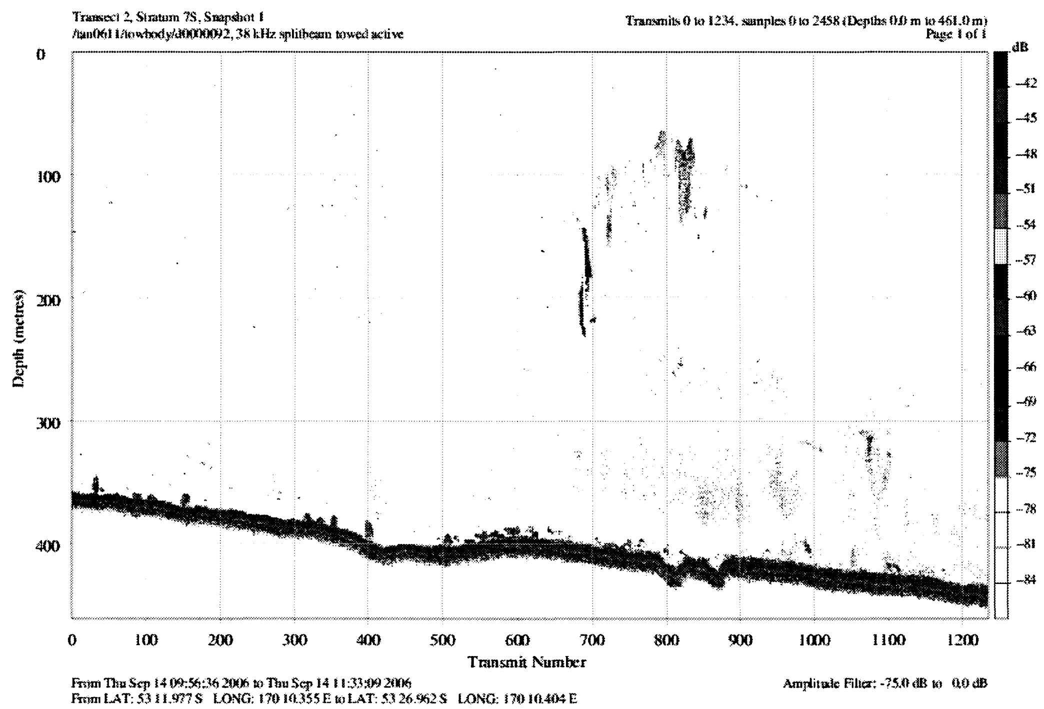


Figure 7: Adult post-spawning marks within 20 m of the bottom during the day in stratum 7S on 14 September 2006. Towbody depth was about 50 m.

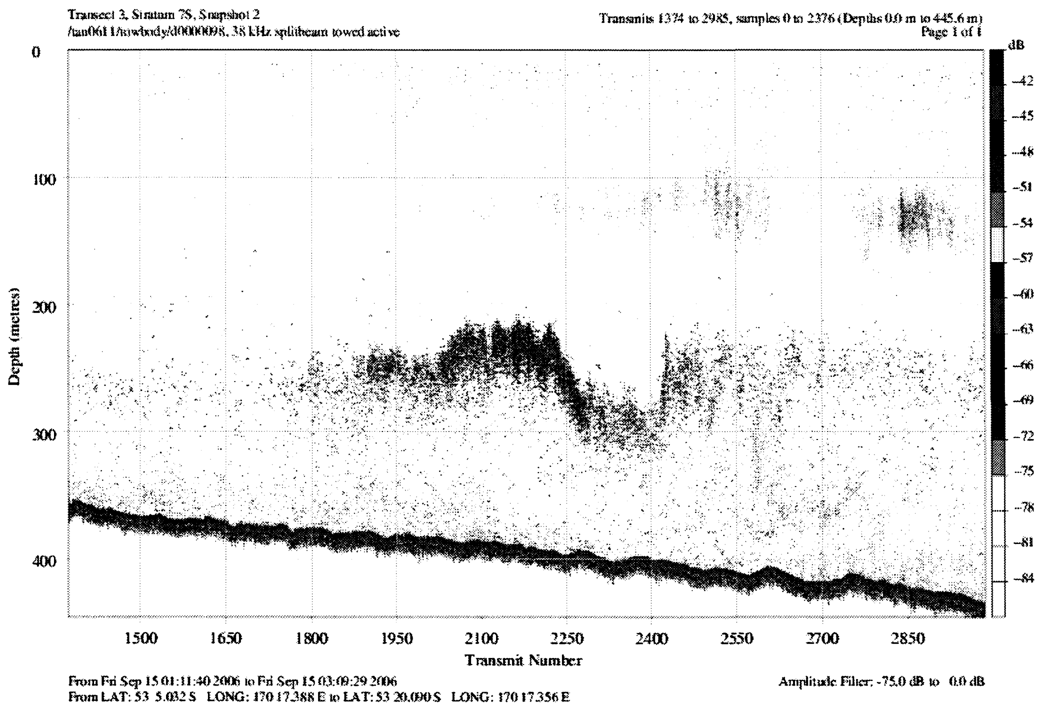


Figure 8: Adult post-spawning marks (layer between 200 and 300 m) at night in stratum 7S on 15 September 2006. Towbody depth was about 50 m.

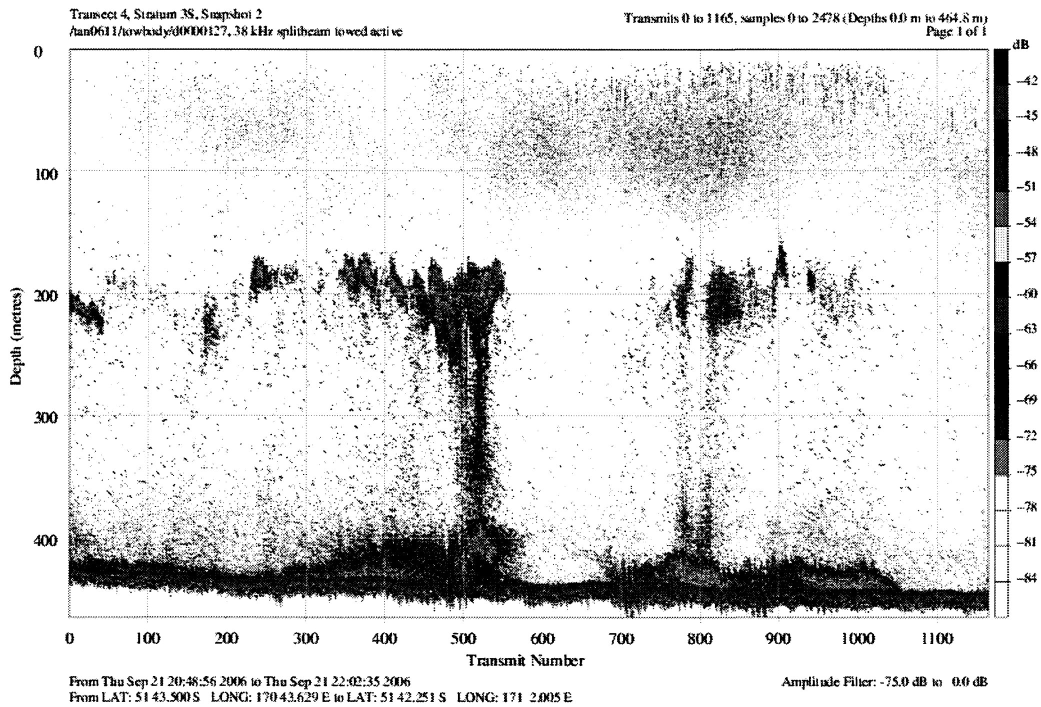
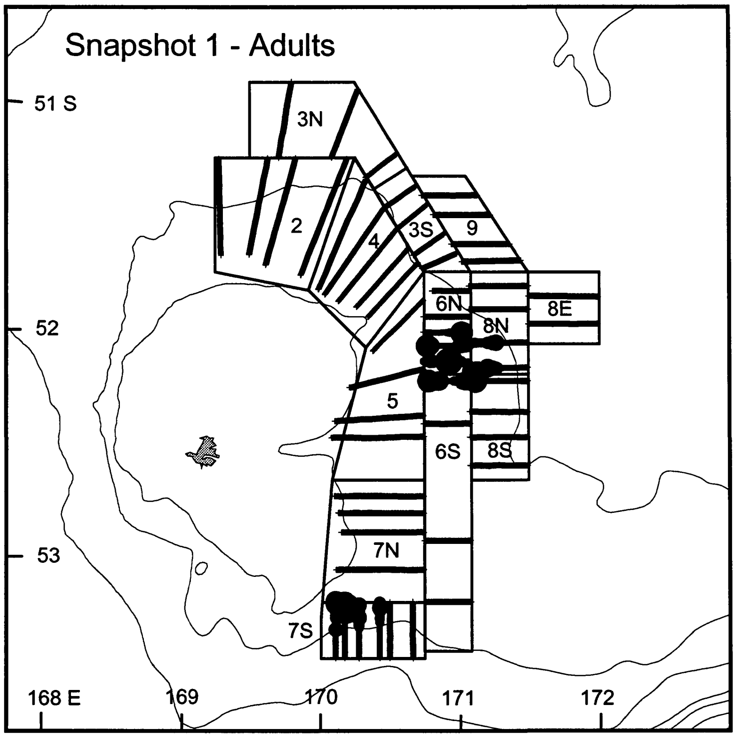


Figure 9: Very dense adult spawning marks at night in stratum 3S on 21 September 2006. Towbody depth was about 50 m.



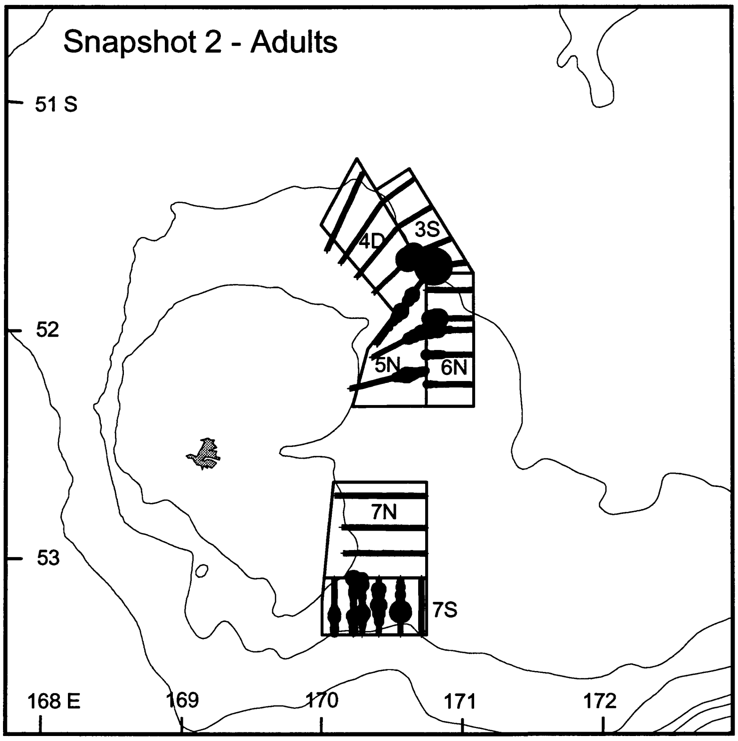
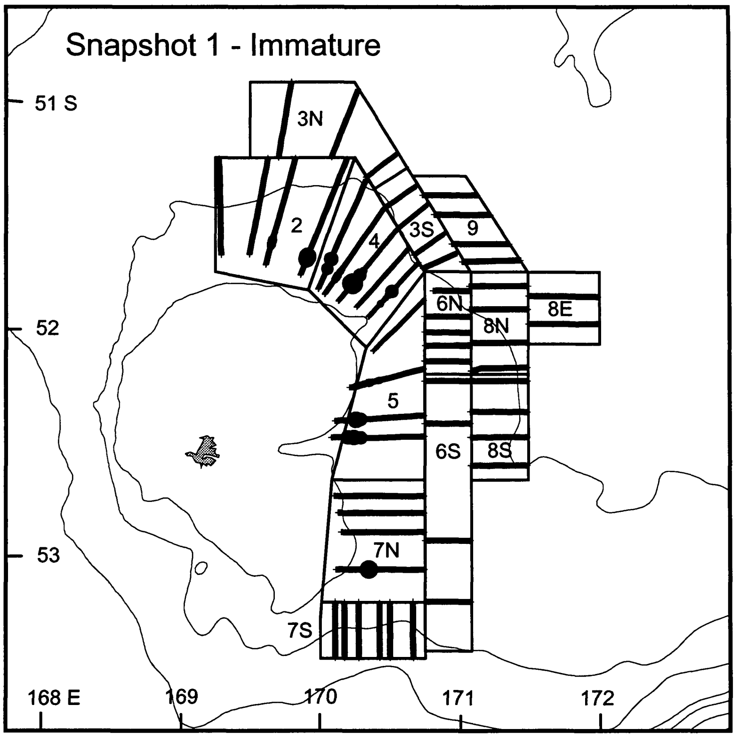


Figure 10: Spatial distribution of acoustic backscatter from adult SBW plotted in 10 ping (~100 m) bins for snapshots 1 and 2. Circle area is proportional to the log of the acoustic backscatter.



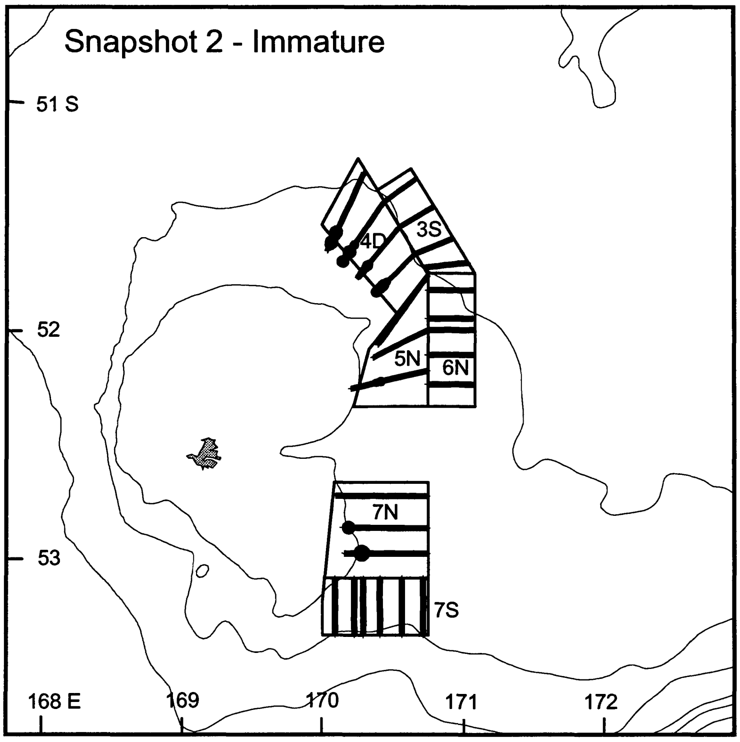
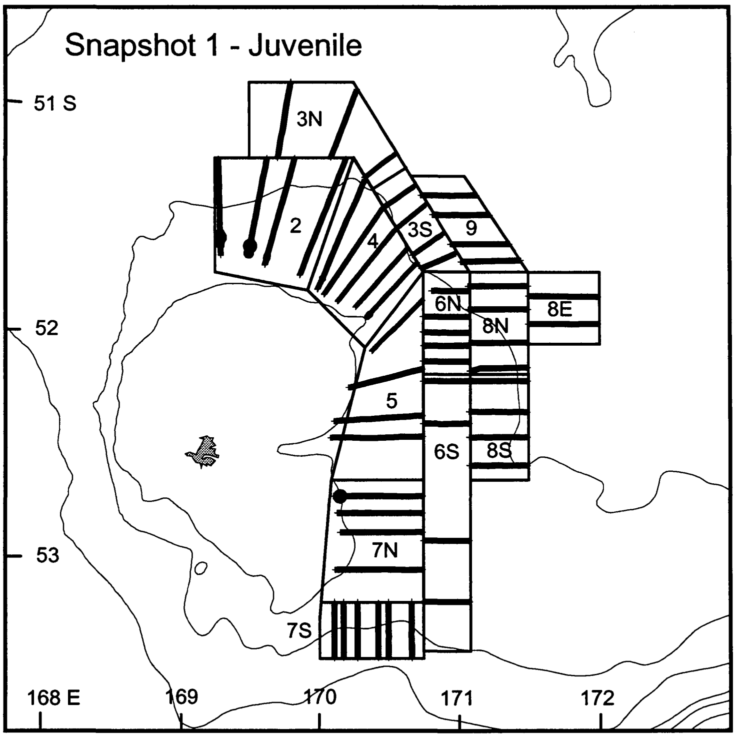


Figure 11: Spatial distribution of acoustic backscatter from immature SBW plotted in 10 ping (~100 m) bins for snapshots 1 and 2. Circle area is proportional to the log of the acoustic backscatter.



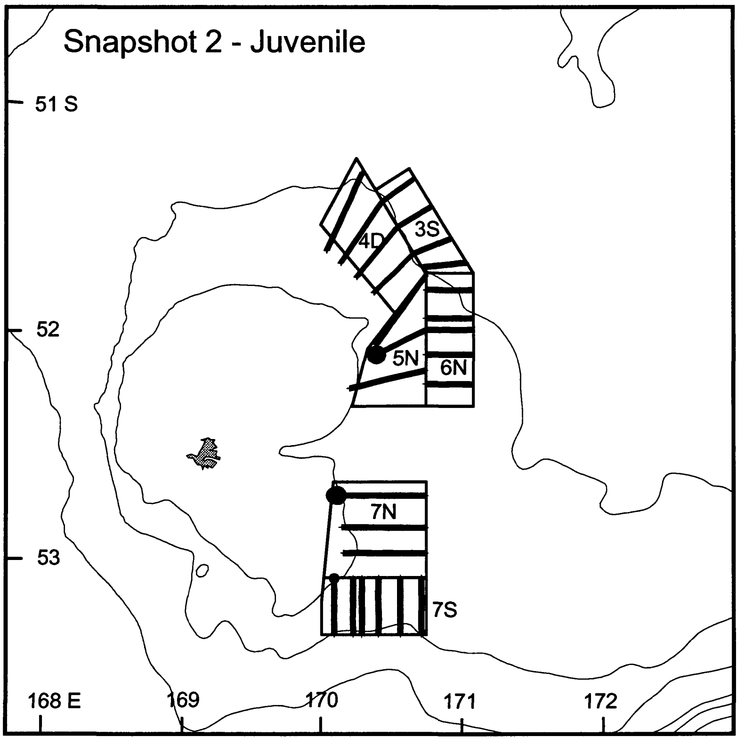


Figure 12: Spatial distribution of acoustic backscatter from juvenile SBW plotted in 10 ping (~100 m) bins for snapshots 1 and 2. Circle area is proportional to the log of the acoustic backscatter.

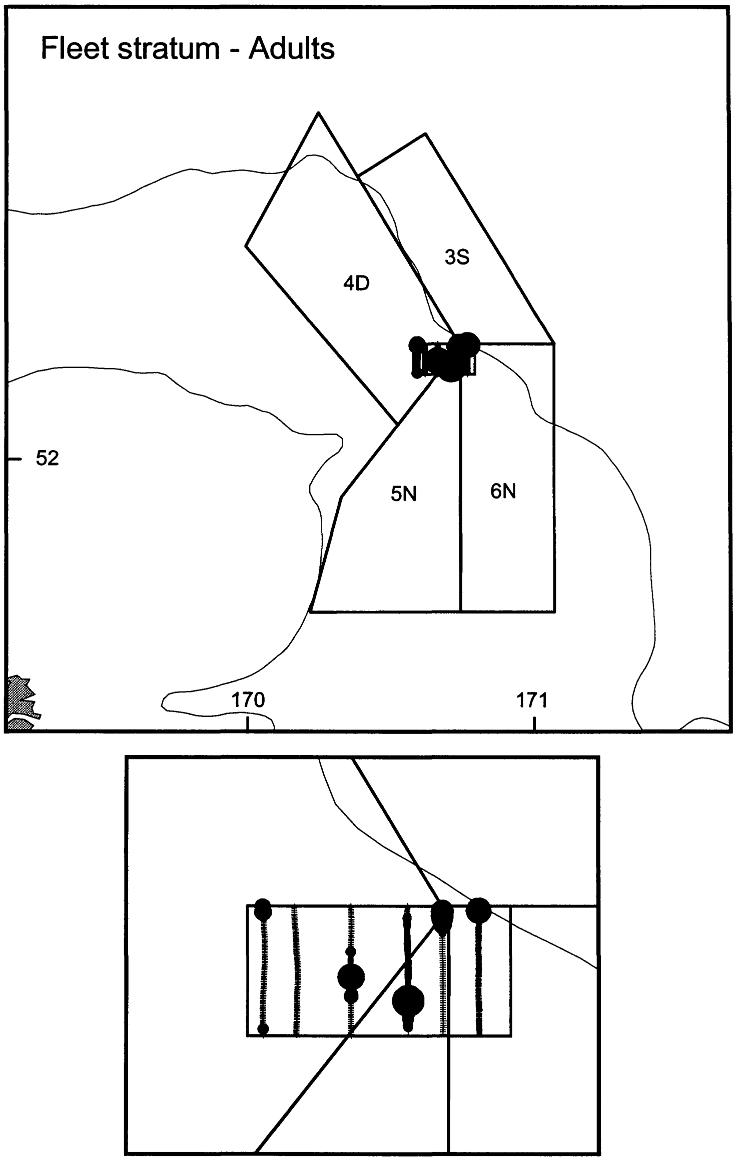


Figure 13: Spatial distribution of acoustic backscatter from adult SBW plotted in 10 ping (~100 m) bins for the fleet stratum. Upper panel shows stratum location and lower panel is an enlargement. Circle area is proportional to the log of the acoustic backscatter.

Appendix 1: Acoustic equipment used for abundance estimation

Table A1.1 provides the system settings and calculated calibration coefficients used during the 2006 acoustic survey. Towbody 2 was used for most acoustic data collection along survey transects. The hull system was used to collect data while trawling, and along survey transects on 21 September when a series of incidents meant that both tow cables required repairs.

Table A1.1: System settings and calibration data for the 38 kHz CREST systems used for the 2006 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 2	Hull
Transducer model	ES38DD	38-7
Transducer serial no.	28327	23421
3 dB beamwidths (°) alongship/athwartship	7.0/6.9	7.2/7.3
Effective beam angle (sr)	0.0083	0.0091
Operating frequency (kHz)	38.16	38.00
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	1.6
Initial sample rate (kHz)	60	100
Decimated sample rate (kHz)	4	4
V_T (V)	1323.6	292.0
G	14490.8	36689.6
Absorption (dB km^{-1})		
calibration	9.35	9.46
survey*	9.47	9.47

* See Appendix 3

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

Eight CTD casts were carried out as part of the 2006 survey. Average sound absorption for each temperature, salinity, and depth profile was estimated using the formula of Doonan et al. (2003) (Table A3.1). The average absorption estimate of 9.47 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 2006. Absorption was calculated from CTD profiles made during the survey using the formula of Doonan et al. (2003).

Trawl station	Max. depth of cast (m)	Mean salinity (PSU)	Mean temperature (° C)	Mean absorption (dB km^{-1})
2	469	34.37	7.15	9.48
4	505	34.37	7.14	9.40
6	495	34.37	7.13	9.46
7	482	34.36	7.13	9.46
8	451	34.37	7.13	9.45
9	416	34.39	7.26	9.47
10	411	34.38	7.24	9.52
11	450	34.36	7.01	9.49
average	460	34.37	7.15	9.47