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EXECUTIVE SUMMARY

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This report summarises the results of the seventh acoustic survey of southern blue whiting (SBW) on the Campbell Island Rise. Two snapshots of the main acoustic survey area were carried out during the pre-spawning and spawning period from 30 August to 17 September 2004. Three "fleet strata" were also surveyed, encompassing areas of commercial fishing. A total of 25 trawls (17 bottom trawls and 8 midwater trawls) were carried out during the survey for mark identification, and to collect data on species composition, length frequency and spawning state of SBW.

During the first snapshot, pre-spawning adult SBW were detected on the northeastern (stratum 8) and southern grounds (stratum 7S), with highest densities in the south. A similar adult distribution pattern was observed during the second snapshot, but high densities of fish were also detected north and east of the survey area (strata 8E and 10). The northeastern aggregation began spawning during snapshot 2 on about 12 September. Immature SBW were widely distributed from 360 to 450 m depth in strata 4, 5, and 7N. Very 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 a sound absorption coefficient of 8 dB km^{-1} (which is the method used in previous SBW acoustic surveys). A high proportion of the adult biomass in 2004 was outside the usual acoustic survey area. The Middle Depth Working Group decided to use two acoustic biomass estimates for stock assessment: a best estimate from all strata (including strata 8, 8E, and 10, which were outside the core area), and an estimate based on core strata only (strata 2–7) as a sensitivity. The all strata estimate of adult SBW biomass was 98 483 t (c.v. 39%) and the core estimate was 39 096 t (c.v. 36%). All juvenile and immature marks were within the core strata. The average biomass estimate from the two snapshots was 12 977 t (c.v. 16%) for immature SBW and 1481 t (c.v. 69%) 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 (including strata 8, 8E, and 10) was 56 197 t, which was 37% of the estimate from the previous acoustic survey in 2002 and the lowest since 1994. The estimates of 2 and 3 year olds were the second highest in the acoustic time series (after the very strong 1991 year-class), suggesting the 2001 and 2002 year-classes are above average. The estimate of 1 year olds (2003 year class) was average.

1. INTRODUCTION

Southern blue whiting (*Micromesistius australis*) is the basis of one of New Zealand's largest volume fisheries, with landings averaging 30 000 t in the last six years (Annala et al. 2004). 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 25 000 for the 2004 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 results 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 (e.g., Hanchet & Ingerson 1996). After the first three annual surveys it was decided to survey these areas less regularly. The Campbell grounds were surveyed in 1998, 2000, and most recently in 2002 (Hanchet et al. 2003). The results of these acoustic surveys have been an important input into SBW stock assessments for the last decade (e.g., Hanchet 2002, 2005), providing a fishery-independent index of spawning SBW biomass on the major spawning grounds. 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 (Hanchet 2005).

The main aim of the acoustic surveys for SBW has been to develop a time series of abundance indices of recruited fish (i.e., fish that have recruited into the commercial fishery) for stock assessment modelling. Because the commercial fishery targets mainly the dense spawning aggregations, the recruited fish are mostly sexually mature. In addition to the spawning fish, pre-recruit fish (immature 1, 2, and 3 year olds) are also found in the survey area.

This report summarises the data collected during the seventh research acoustic survey of SBW on the Campbell Island Rise in August–September 2004 and presents biomass estimates (Objective 1 of Ministry of Fisheries Research Project SBW2003/02). Results of experimental work on SBW target strength (Objective 2) will be reported separately.

2. METHODS

2.1 Survey design

Various acoustic survey designs for SBW stocks were investigated by Dunn & Hanchet (1998) and Dunn et al. (2001). These two simulation studies showed that optimal survey design would use proportional sampling, where the underlying distribution of the fish is already known and the sampling effort is proportional to the fish density. In the absence of this information, they concluded that two-phase sampling strategies should be used, with up to 20% of transects assigned to the second phase. Information on the distribution of the fish at the time of the survey is available from the location of the fleet and/or the results of the first acoustic snapshot of the area. During recent surveys of the Campbell Island Rise, information from both sources has been used to redefine the survey strata and the associated sampling effort for snapshot 2 (e.g., Hanchet & Grimes 2001, Hanchet et al. 2003).

The success of this two-phase survey design in estimating adult SBW abundance on the Campbell Island Rise has been mixed. During the 1998 and 2000 surveys the design was very successful and resulted in biomass estimates with c.v.s of less than 20% (Hanchet et al. 2000b, Hanchet & Grimes 2001). However, the survey carried out in 2002 using the same design failed to meet the target c.v. (Hanchet et al. 2003). The main reason for the high c.v. in 2002 was that most of the backscatter in each snapshot came from a single transect. Hanchet et al. (2003) recommended the following modifications to the survey design to overcome this problem in the future.

- Where appropriate, the main aggregation should be repeatedly sampled using several snapshots (as in 1998).
- Real time estimates of transect densities should be calculated on board the ship at the time of the survey.
- Stratum 7 should be subdivided into two separate strata for snapshot 1.
- Future surveys continue to start in late August to allow for an early start of the spawning season on the Campbell grounds.

In 2004, we again used a two-phase survey design, but incorporated the modifications recommended by Hanchet et al. (2003). The initial stratification for snapshot 1 (Figure 1) was based on that used in previous surveys of the area (Hanchet & Grimes 2001, Hanchet et al. 2003) with two changes. In the past three surveys, the southern spawning aggregation had been confined to a small area in the southernmost part of stratum 7, so we split this stratum into two (at 53° S), as recommended by Hanchet et al. (2003). The eastern boundary of the survey area was also extended with the addition of a new stratum 8 because spawning aggregations were observed to the east of stratum 7 in 2002 and 2003 (Hanchet et al. 2003, O'Driscoll & Hanchet 2004).

We aimed to carry out two snapshots of the Campbell Island Rise. To achieve an overall target c.v. of 30% (as specified by MFish) required individual snapshot c.v.s of about 40%. Optimal allocation of transects to strata was determined by examining the location of historical fishing effort and acoustic survey results. The proposed phase 1 transect allocation for snapshot 1 in 2004 (Table 1) was similar to the allocation used for the last three surveys, but gave a slightly higher weighting to strata 4 and 7S, which were the most consistent areas of high SBW density in recent years.

Up to six transects were set aside for phase 2 in snapshot 1. Approximate transect density estimates were examined in real time during the survey, and phase 2 transects were allocated to strata with the densest marks. To minimise problems of fish movement between phases, and to avoid excessive steaming time, the phase 2 transects were carried out whilst phase 1 was still in progress. During the first snapshot, the densest marks in the northern area were seen in stratum 8, and so an additional three phase 2 transects were allocated there. A dense aggregation was also detected on two transects in the southern area (stratum 7S). Rather than add additional phase 2 transects in this stratum in snapshot 1, we revised the stratification (see below), and immediately began snapshot 2.

The stratification and allocation of transects in snapshot 2 (Figure 1, Table 1) was adapted to reflect both the fish distribution in snapshot 1 and the reported positions of the fishing fleet (Figure 2). In the southern area, the northern boundary of stratum 7S was shifted south from 53° 00' to 53° 12' S to better reflect the distribution of fish. Eight short (13 n. mile) north-south transects were allocated to the revised stratum 7S in snapshot 2. The other changes to the stratification for snapshot 2 were in stratum 8 (see Figure 1). The original stratum was divided into two (8N and 8S) by a line at 52° 12' S. A new stratum (8E) was also added to the east of stratum 8N because of reports that there were vessels fishing out to 172° E (Figure 2). Because we did not survey stratum 8E in snapshot 1, we carried out two snapshots of this stratum during snapshot 2. There were dense marks on one of the three transects in stratum 6N, and so an additional two phase 2 transects were added to this stratum in snapshot 2 (see Table 1).

Addition of phase 2 transects may not be sufficient to reduce c.v.s below target levels (as was the case in 2002). To reduce the possibility of this occurring again in 2004, we aimed to carry out additional acoustic snapshots of the main aggregation(s) from the industry vessel *Aoraki* fitted with a Simrad ES-60 echosounder and hull-mounted transducer, using the approach trialled successfully in 2003 (O'Driscoll & Hanchet 2004). Unfortunately, due to a tragic fatal accident involving one of the crew shortly after the vessel arrived on the fishing grounds, no acoustic data were collected from *Aoraki*. Instead, we surveyed three additional "fleet strata" from *Tangaroa* during snapshot 2 on 14–16 September (see Figure 1). The first (stratum 8F) was around the main area of commercial fishing on the northeastern aggregation (within strata 8E and 8N) and consisted of eight 8 n. mile north-south transects across the main tow-paths of the fleet (based on our observations on radar on 13–14 September). The second fleet stratum (stratum 9) was to the north of the main survey area at about 51° 30' S 171° 30' E (Figure 1). Three New Zealand vessels reported fishing in this area from about 4–8 September (Figure 2). The third fleet stratum (stratum 10) was a very small area adjacent to stratum 3S.

2.2 Acoustic data collection

All transects were carried out using NIWA's *CREST* 38 kHz towed body acoustic system (Coombs et al. 2003) deployed from *Tangaroa*. Only one towbody (Towbody 2) was used during the survey. The acoustic system was calibrated during the survey in Perseverance Harbour at Campbell Island on 10 September. A deep calibration of Towbody 2 was also carried out before this survey in July 2004. Details of the acoustic system and its calibration are provided in Appendix 1.

Transect locations were randomly generated (using NIWA's "rtran" program), 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. At times the direction of transects was altered to allow the survey to continue despite poor weather conditions.

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 8–10 knots 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. Midwater marks were targeted with one of two pelagic trawls: the NIWA 119 hoki midwater trawl (headline height, 40 m; codend mesh, 40 mm), or the new mesopelagic trawl purchased in 2003 (headline height, 18.5 m; codend mesh, 10 mm). Bottom marks were targeted using the orange roughy wing trawl (also called the 'ratcatcher'; headline height, 3.5 m; codend mesh, 32 mm).

Most target identification work was focused at:

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. separating the small schooling midwater fish such as the common lanternfish (*Lampanyctodes hectoris*) and pearlside (*Maurolicus muelleri*) from the moderately dense schools of pre-recruit SBW when they are in the shallower part of their depth range and close to the bottom;
5. obtaining a sample of adult SBW in areas which were not being fished by the commercial fleet.

Trawling was carried out only between 12:00 and 24:00 NZST to reduce staffing costs. 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 500 SBW and 50–200 of other important species from every tow was measured. In most tows the sex and macroscopic gonad stage 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 were constructed by scaling length frequencies from individual tows by the SBW catch in the tow.

2.4 Target strength data collection

In situ target strength (TS) data were collected from pre-spawning SBW in the southern aggregation (stratum 7S) on 7–8 September. The towbody was lowered as close as possible to the aggregation and 12 hours of acoustic data were collected from 23:00 to 11:00 NZST.

The aim was to collect multiple acoustic pings from each SBW target to determine the orientation (swimming angle) of individual fish. This information would help to resolve differences between in situ and swimbladder model estimates of SBW TS (Dunford 2003). To maximise the number of pings obtained from each SBW, the vessel speed was as slow as possible. However, weather conditions during the TS experiment were not ideal (20–35 knots of wind and a 2 m swell), and it was not possible to drift slowly over the aggregation as originally planned because the towbody pitched too much. Instead, we steamed slowly over the marks at speeds of 2.5–4 knots, running with the weather.

The size and species composition of the marks was confirmed by midwater trawling before and after the acoustic data collection.

2.5 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 2).

2.6 Commercial catch data

Additional information on the species composition, size, and spawning state of adult SBW in the survey area was obtained from commercial catch data collected by scientific observers. Data from the 2004 fishery were extracted from the Ministry of Fisheries Observer database in December 2005. 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.

2.7 Acoustic data analysis

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

Echograms were visually examined, and the bottom determined by a combination of an in-built bottom tracking algorithm and manual editing. Regions were then defined corresponding to different acoustic mark types. Following the approach used in previous years, SBW acoustic marks in the 2004 survey 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}). Acoustic density was output in two ways. First, average acoustic density over each transect was calculated. These values were used in biomass estimation (see Section 2.8). Second, acoustic backscatter was integrated over 10-ping bins (vertical slices) to produce a series of acoustic densities for each transect (typically 100–700 values per transect). These data had a high spatial resolution, with each value (10 pings) corresponding to about 100 m along a transect, and were used to produce plots showing the spatial distribution of acoustic density (see Section 3.3).

2.8 Biomass estimation

Acoustic density estimates were converted to SBW biomass using the ratio, *r*, of mean weight to mean backscattering cross-section (linear equivalent of target strength) 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 3.4) so two adult ratios were calculated based on trawls north and south of 53° S.

Acoustic target strength was derived using the target strength to fork length (TS-FL) relationship used in previous SBW acoustic surveys (e.g., Hanchet et al. 2003). This is the TS-FL relationship used for blue whiting in the northern hemisphere given by Monstad et al. (1992):

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

where TS is in decibels and FL is in centimetres.

Results from recent New Zealand swimbladder modelling studies and SBW in situ data suggest that this relationship is not appropriate for SBW (Dunford 2003). 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:

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

The TS-FL relationship used in previous years (Equation 1) was retained in the current analysis because the Middle Depth Working Group in 2004 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 2004 following Hanchet *et al. (2000c)*.

3. RESULTS

3.1 Data collection

A total of 96 acoustic transects was carried out during the two snapshots of the Campbell Island Rise and an additional 17 transects were completed in the three fleet strata (Table 1). *Tangaroa* arrived on the Campbell Island grounds before most of the commercial fishing fleet. The first acoustic snapshot was completed between 30 August and 6 September. The second snapshot started immediately after snapshot 1 on 7 September and finished on 17 September, but was interrupted to carry out a target strength experiment on the southern aggregation and to calibrate the acoustic equipment in Perseverance Harbour on Campbell Island. The loss of all of the final day on the survey grounds (18 September) because of bad weather meant that it was not possible to complete all transects in strata 2 and 3N in snapshot 2 (Table 1). The *CREST* acoustic system performed very well and no survey time was lost due to hardware or software faults.

There were 25 trawls to identify targets and collect biological samples (Table 2, Figure 3). Tow length ranged from 0.16 n. miles when targeting dense marks, to a maximum of 2.0 n. miles when targeting less dense marks or background layers (Table 2). The total trawl catch was 11 418 kg. Trawls caught a wide range of species, but the total catch was dominated by southern blue whiting (69% of total catch, see Table 2). The next most abundant species were javelinfish (9%), ling (6%), pale ghost shark (4%), and silverside (3%).

Thirteen acoustic files were recorded during 12 hours of in situ target strength (TS) data collection. There were up to three clear modes in the TS data (at about -32, -42, and -50) on the *CREST* display and the relative height of the modes varied between files. Midwater trawling (with bottom contact) before (tow 12) and after (tow 13) the TS experiment caught 700 and 900 kg of pre-spawning SBW respectively, with little bycatch (see Table 2). There was a broad length frequency distribution with two modes at about 32 cm and 44 cm. These data will be analysed to help refine the length-TS relationship for SBW.

Fifteen CTD profiles were obtained in conjunction with bottom trawls, and these were used to estimate the absorption coefficient during the survey (see Appendix 2). The water column was unstratified with surface temperatures ranging between 7.1 and 7.3 °C.

3.2 Mark identification

Marks 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. Marks in both the southern (stratum 7S) and northeastern (stratum 8) areas during snapshot 1 were characteristic of pre-spawning adult SBW (Figure 4). Spawning began during snapshot 2 about 14 September (see Section 3.4). Marks in strata 8F and 10 on 15–16 September were characteristic of spawning SBW (Figure 5), with night-time marks observed within 200 m of the surface (in 525 m water depth). Trawls on pre-spawning adult SBW marks were made in stratum 8 (tow 6), stratum 7S (tows 9–13), and stratum 8E (tows 20 and 21).

Most mark identification work focused on the less dense pre-recruit SBW marks and other light 'fuzz' marks seen in the survey area. Juvenile (1 year old) SBW were caught mainly in 300–360 m in stratum 2 (tows 1 and 25). Immature 2 year old SBW (with a mixture of 1, 3, and 4 year olds) were caught in 360–450 m in strata 4 and 5 (tows 2, 7, 8, 15, and 22).

Several trawls were targeted at marks that were not SBW. As in earlier surveys (Hanchet et al. 2002), dense marks in shallow water were found to contain mainly silverside (tow 14). Several 'background' trawls were made in 400–500 m. These generally yielded low catches of SBW (tows 3, 16, and 17). In several transects (particularly in strata 7 and 8) a continuous thin layer of fish marks was seen on the bottom in water deeper than 500 m. This layer consisted mainly of javelinfish, pale ghost shark, and ling (tows 5, 18, and 19).

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. We carried out two trawls (tows 23 and 24) on these marks using the mesopelagic trawl. These tows caught mainly myctophids from the genera *Lampanyctodes* and *Protomyctophum*, as well as smaller numbers of other myctophids and pearlsides (*Maurolicus australis*).

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 360–450 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.

3.3 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 6–8) and the distribution of adult SBW in the fleet strata (Figure 9). No immature or juveniles marks were observed in the fleet strata. Note that there were two snapshots of stratum 8E during snapshot 2 (see Table 1), but for analysis and plotting the first snapshot of stratum 8E was treated as part of snapshot 1.

During the first snapshot the main adult marks in the northern area were seen in stratum 8 (see Figure 6). A Russian vessel arrived on 2 September, as we were finishing the phase 2 transects, and started fishing this aggregation. Several other vessels (including *Aoraki*) arrived after we left the area and reported that there were also SBW marks north and east of the stratum 8 boundary (see Figure 2). No adult marks were seen in strata 5 and 6, but a dense aggregation was detected on two transects in the southern area (stratum 7S). Three Japanese vessels arrived and began fishing on the southern aggregation on 6 September.

The location of the southern aggregation was similar in snapshot 2. Fish were observed on five inner transects, but not on the outer transects, suggesting that the southern aggregation was fully encompassed within the revised stratum 7S boundaries (see Figure 6). Few adult SBW marks were found in stratum 8S, but there were scattered adult marks over a relatively wide area in strata 8N and 8E during snapshot 2. During our survey of this area on 13–15 September, a fleet of up to 10 vessels was fishing in stratum 8E. There were also dense marks on one of the three transects in stratum 6N and three commercial vessels were present when we surveyed this area on 12 September.

Adult SBW marks were observed along five of the eight transects in the fleet stratum 8F (Figure 9). Three New Zealand vessels reported fishing in stratum 9 from about 4 to 8 September (see Figure 2). However, we did not observe any SBW marks when we carried out three short transects on 15 September. Dense spawning marks were observed in stratum 10 on 16 September. Initially only three vessels were fishing on these marks, but the entire fleet moved to this area before we had completed our six transects and stayed until 20 September (see Figure 2).

Immature SBW marks were found in both snapshots in strata 4, 5, and 7N (see Figure 7). Some of the marks in stratum 4 during snapshot 2 were moderately dense. In contrast, very few juvenile (1 year old) SBW marks were seen during the survey (see Figure 8).

3.4 SBW size and maturity

Length, sex, and gonad stage were determined for 4109 SBW during the survey. The scaled length frequencies from research tows on adult, immature, and juvenile marks are shown in Figure 10 and compared to the scaled length frequency distribution of the commercial catch from observer data. There was a high proportion of males from 30 to 34 cm (2001 and 2002 year-classes), and of females from 34 to 37 cm (mainly 2001 year-class) in the research catch from adult aggregations. The commercial fleet also caught a high proportion of small fish during the spawning fishery in 2004, particularly south of 53° S. The average size of fish caught commercially from the northern aggregation (scaled mean length for both sexes combined = 40.3 cm) was 3.5 cm larger than fish caught in the south (mean length = 36.8 cm)

(Table 3). Most immature fish in research tows were from 27 to 35 cm, with almost all juveniles less than 25 cm (Figure 10).

The timing of spawning in 2004 was similar to that in 2003 and later than in 2002. The threshold of 10% running ripe females was first reached in research tows on 12 September (Figure 11) and in commercial tows on 14 September (Figure 12). Fish examined before 12 September had not already spawned because ovaries were still large and contained no residual ovulated eggs. Running ripe males were also observed in research tows from 12 September (see Figure 11). Inferences about spawning season based on research data must be treated with caution because of the small number of tows and also because much of the fishing was outside the main spawning aggregations. Data from observers on commercial vessels provide better information on the timing of spawning. There were two spawning events in 2004, with a high proportion of running ripe females recorded between 14 and 18 September and then again from 27 to 30 September (Figure 12).

3.5 SBW biomass estimates

The values of r for each SBW category based on the length frequency distributions in Figure 10 were 2954 kg m^{-2} for adults north of 53° S, 2727 kg m^{-2} for adults south of 53° S, 2199 kg m^{-2} for immature fish, and 1653 kg m^{-2} for juveniles (Table 3).

SBW biomass estimates by snapshot and stratum calculated using 'standard methods' (Monstad et al. (1992) TS, sound absorption coefficient of 8.0 dB km^{-1}, and no towbody motion correction) are given in Table 4. The estimates in Table 4 are comparable with those from previous SBW acoustic surveys on the Campbell Island Rise (e.g., Hanchet et al. 2003).

The adult biomass estimate was 66 048 t (c.v. 40%) in snapshot 1 and 46 284 t (c.v. 34%) in snapshot 2. A high proportion of the adult biomass in 2004 was outside the usual acoustic survey area. The average adult biomass in core acoustic strata (strata 2–7) was 39 096 t (c.v. 36%), which was only 27% of the estimate of 164 300 t (c.v. 70%) from the previous survey in 2002 (Hanchet et al. 2003). Including strata 8 and 8E, which were surveyed in both snapshots in 2004, increased the adult biomass estimate to 56 166 t (c.v. 28%).

The fleet stratum 8F was within the extended survey area (see Figure 1) and the biomass estimate for this stratum of 6836 t was similar to the two snapshot estimates for 8E of 3835 and 8656 t. Therefore, it was not necessary to include this fleet stratum in the biomass estimate. However, there was significant adult biomass of 42 317 t (c.v. 83%) during snapshot 2 in fleet stratum 10, which was outside the survey area (see Figure 1). Commercial vessels also reported SBW aggregations outside the survey area during snapshot 1 in the area of fleet stratum 9 (see Figure 2). We did not observe adult marks in this area during snapshot 2 (see Figure 9) and it is possible that the fish had moved west into strata 10 and 6N. Adding the single estimate for stratum 10 to the average biomass from the two acoustic snapshots increased the adult biomass estimate to 98 483 t (c.v. 39%). Treatment of fish outside the survey area is discussed in more detail in Section 4.2.

Biomass estimates for immature SBW in snapshots 1 and 2 were 11 720 t (c.v. 24%) and 14 233 t (c.v. 21%) respectively. Biomass estimates for juvenile SBW were 1371 t (c.v. 74%) and 1592 t (c.v. 65%). All juvenile and immature marks were within the core strata (strata 2–7). The average biomass estimate from the two snapshots was 12 977 t (c.v. 16%) for immature SBW and 1481 t (c.v. 69%) for juveniles (Table 4).

The effect on biomass of increasing the sound absorption from 8.0 to 9.39 dB km^{-1} (which was the value calculated from CTD casts in Appendix 2), and also of implementing a correction for towbody motion is shown in Table 5. Changing the absorption increased biomass estimates by 9–33%. 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 towbody motion correction further increased biomass by 5–15%. The magnitude of the change due to motion correction was related to mark depth (larger effect with increasing depth) and weather and sea conditions (larger effect in poor weather when there was greater towbody motion).

The decomposed biomass estimates by age class are shown in Table 6. The 2004 biomass estimates for age 1, 2, 3, and 4+ SBW (including strata 8, 8E, and 10) were 1512 t, 17 327 t, 34 527 t, and 56 197 t respectively. No estimates of c.v. were available for estimates of biomass by age. A statistical method to calculate c.v.s for decomposed biomass estimates is currently being investigated.

4. DISCUSSION

4.1 Timing of the survey

The timing was shifted forwards by about a week in 2002 to try to ensure that the fish were surveyed before and during spawning (Hanchet et al. 2003), and this earlier timing was retained in 2004. Spawning began on about 14 September, midway through snapshot 2. Thus, the survey timing in relation to the spawning season was consistent with previous surveys (Figure 12).

4.2 Variability between snapshots

Biomass estimates were relatively consistent between the two snapshots (see Table 4). There was a drop in adult biomass in stratum 7S from 39 793 t in snapshot 1 to 22 759 t in snapshot 2. This was largely due to the refinement of the stratum boundaries for the second snapshot, which decreased the stratum area and reduced the c.v. from 61% to 43%. Adult SBW marks were observed in the northern part of stratum 8 in snapshot 1, but few fish were observed in stratum 8N in snapshot 2. It seems likely that at least some of the fish in this area moved west, where they were detected in stratum 6N in snapshot 2. Similarly, there were vessels fishing northeast of stratum 8 during snapshot 1 (see Figures 1 and 2), but we did not observe marks in stratum 9 during snapshot 2. These fish may also have moved west into stratum 10.

There was only one snapshot of the spawning aggregation in stratum 10. In hindsight, this was unfortunate as the biomass estimate from this stratum was high (42 317 t) despite the very small stratum area (124 km^2). In the initial survey design, we intended that aggregations such as that in stratum 10 would be surveyed repeatedly from a commercial vessel. The loss of the *Aoraki* due to unforeseeable circumstances early in the survey period meant that this was not possible, and the c.v. for the adult biomass estimate including stratum 10 exceeded the MFish target of 30% (see Table 4).

4.3 Treatment of fish outside the survey area

As in 2002 (Hanchet et al. 2003) and 2003 (O'Driscoll & Hanchet 2004), SBW aggregations were observed east of the core survey area (strata 2–7) in 2004. Stratum 8 was added before the 2004 survey in an attempt to encompass the eastern aggregation, and this was extended with the addition of stratum 8E during the survey. Fish were also observed east of stratum 3S in stratum 10.

There are two possibilities regarding the observed distribution of fish outside the core area: (1) the northern aggregation had moved further east and was spawning outside the survey area; (2) the fish which previously had spawned in the northern area had been depleted and the fish observed outside of the core area represent a new unsurveyed part of the population. Under hypothesis 1, the biomass estimate used in the assessment model should include all fish surveyed because it implies that the proportion of the surveyed population within the core area has changed. Hypothesis 2 implies that the proportion of the total biomass within the core area has remained unchanged and that the biomass estimate used in the assessment model should include only those fish surveyed in the core area.

Hanchet (2005) examined recent commercial catch/effort and length frequency data from 1997–2004 to assess which hypothesis was more likely. This analysis showed that the distribution of the fishery has clearly changed since 2002, with the fleet fishing further east in 2002–04. 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. If the northern aggregation had experienced high exploitation while the eastern aggregation had experienced little or no exploitation, the size or age structures of the two aggregations should differ. Since this was not the case, the results provided support for hypothesis 1, but did not rule out hypothesis 2 (Hanchet 2005).

The Middle Depth Working Group agreed that two estimates of biomass from the 2004 survey should be carried forward for assessment of the Campbell SBW stock: the estimate including strata 8, 8E, and 10 as the base case; and the estimate for the core acoustic strata only (strata 2–7) as a sensitivity. Hanchet (2005) presents the stock assessment results.

4.4 Comparison between years

The time series of decomposed biomass estimates at age for the Campbell Island grounds are summarised in Table 7. The best estimate of age 4+ fish in 2004 (including strata 8, 8E, and 10) was 56 197 t, which was only 37% of the estimate from the previous acoustic survey in 2002 and the lowest since 1994. If only core strata were considered, the estimate of age 4+ fish (17 283 t) was only 12% of the 2002 estimate. The best estimates of 2 and 3 year olds were the second highest in the acoustic time series (after the very strong 1991 year-class), suggesting the 2001 and 2002 year-classes are above average. The estimate of 1 year olds (2003 year class) was average.

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Table 1: Summary of transects carried out during the 2004 acoustic survey of the Campbell Island Rise. Stratum boundaries are shown in Figure 1. Number of additional phase 2 transects are shown in parentheses.

Snapshot 1 (30 Aug – 6 Sep)			Snapshot 2 (7–17 Sep)			Fleet strata (14–16 Sep)		
Stratum	Area (km^2)	Transects	Stratum	Area (km^2)	Transects	Stratum	Area (km^2)	Transects
2	3 154	5	2	3 154	1	8F	584	8
3N	2 342	3	3N	2 342	1	9	290	3
3S	1 013	4	3S	1 013	4	10	124	6
4	2 690	5	4	2 690	4			
5	3 029	4	5	3 029	5			
6N	1 150	3	6N	1 150	3 (2)			
6S	3 025	3	6S	3 025	3			
7N	1 899	4	7N	2 980	5			
7S	2 273	5	7S	1 192	8			
8	2 888	3 (3)	8N	1 436	5			
			8E	1 739	5 + 5*			
			8S	1 452	3			
Total		42			54			17

* Two snapshots of stratum 8E, each with 5 transects, were carried out on 13–14 September during snapshot 2.

Table 2: Trawl station details and catch of the main species during the 2004 acoustic survey of the Campbell Island Rise. Tow positions are plotted in Figure 3. Trawl type: BT, bottom; MW, midwater; MP, mesopelagic. Species: SBW, southern blue whiting; JAV, javelinfish; LIN, ling; GSP, pale ghost shark; SSI, silverside; CAS, oblique banded rattail; HAK, hake.

		Gear		Mark	Start	Start	Max tow	Tow length								Catch (kg)
Tow	Date	type	Stratum	type	latitude	longitude	depth (m)	(n. mile)	SBW	JAV	LIN	GSP	SSI	CAS	HAK	Total
1	30-Aug-04	BT	2	Juvenile	51 40.39	169 35.36	331	2.00	22.5	2.1	3.2	-	57.7	23.3	-	171.8
2	1-Sep-04	BT	4	Immature	51 43.57	170 08.33	397	1.02	141.0	82.9	6.3	4.2	12.1	14.8	5.6	306.2
3	1-Sep-04	BT	4	Background	51 38.93	170 15.31	443	1.50	55.4	204.8	82.1	31.8	40.7	17.1	-	523.2
4	1-Sep-04	BT	4	Background	51 33.96	170 21.39	479	1.99	10.4	191.4	46.6	40.7	60.3	16.7	-	436.0
5	1-Sep-04	BT	3S	Background	51 26.68	170 35.54	517	1.51	2.3	98.8	20.8	127.1	12.8	2.5	-	306.3
6	3-Sep-04	BT	8	Adult	52 00.91	171 24.44	515	1.65	234.9	92.5	17.7	42.3	6.4	2.3	-	416.2
7	4-Sep-04	BT	5	Immature	52 23.24	170 31.67	432	1.32	98.3	9.2	2.5	28.4	6.5	7.0	-	171.4
8	4-Sep-04	BT	5	Immature	52 21.91	170 17.02	396	1.95	74.0	0.5	7.5	-	14.2	16.4	-	151.4
9	6-Sep-04	BT	7S	Adult	53 19.74	170 19.59	559	1.67	344.0	38.0	18.4	2.3	10.5	10.8	-	454.9
10	6-Sep-04	MW	7S	Adult	53 17.42	170 27.76	520	0.88	21.9	-	-	-	-	-	-	22.1
11*	6-Sep-04	MW	7S	Adult	53 17.74	170 29.87	519	1.26	4 656.9	-	4.5	-	-	-	24.7	4 686.1
12	7-Sep-04	MW	7S	Adult	53 22.06	170 17.22	588	0.79	959.3	-	-	-	-	-	-	963.5
13	8-Sep-04	MW	7S	Adult	53 21.99	170 14.22	584	0.16	773.1	0.6	-	-	-	-	5.3	829.1
14	12-Sep-04	BT	4	Silverside	52 00.72	170 21.09	283	0.70	-	-	-	-	36.0	16.9	-	64.4
15	12-Sep-04	BT	5	Immature	52 01.67	170 37.99	416	1.11	64.3	3.8	25.6	12.6	37.6	15.3	-	230.8
16	12-Sep-04	BT	6N	Background	52 04.85	170 58.55	485	1.51	4.7	50.3	2.2	50.7	14.2	1.9	-	146.3
17	12-Sep-04	BT	6N	Background	51 59.71	171 04.21	494	1.50	10.9	29.2	3.4	56.0	6.6	7.5	13.1	161.0
18	13-Sep-04	BT	8E	Background	51 54.81	171 36.32	520	1.02	50.3	60.6	108.4	27.5	19.2	3.2	9.3	320.7
19	13-Sep-04	BT	8E	Background	51 54.85	171 49.53	529	0.99	25.3	70.7	137.0	27.5	12.2	2.0	-	321.6
20	14-Sep-04	MW	8E	Adult	51 58.21	171 39.83	524	1.59	199.9	33.2	165.8	-	2.7	-	33.8	441.2
21	14-Sep-04	MW	8E	Adult	51 58.04	171 39.60	524	1.72	67.7	13.0	38.6	-	9.8	0.7	11.8	145.2
22	16-Sep-04	BT	4	Immature	51 51.38	170 20.62	385	0.67	84.0	0.1	-	-	1.6	3.1	-	111.6
23	16-Sep-04	MP	4	Mesopelagic	51 23.59	170 22.15	214	1.65	-	-	-	-	-	-	-	5.9
24	16-Sep-04	MP	4	Mesopelagic	51 23.91	170 20.47	110	1.91	-	-	-	-	-	-	-	3.2
25	17-Sep-04	BT	2	Juvenile	51 40.94	169 49.20	357	0.59	0.1	0.1	-	-	0.6	4.6	-	27.7

* *Net window burst.*

Table 3: Estimates of the ratio, *r*, used to convert SBW backscatter to biomass (see Section 2.8 for details). Values are derived from the scaled length frequency distributions in Figure 10. Different ratios were used for adult marks north and south of 53° 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	110	40.3	0.504	0.000171	-37.7	2 954
Adult (south)	Commercial	9	36.8	0.382	0.000140	-38.5	2 727
Immature	Research	5	30.5	0.200	0.000091	-40.4	2 199
Juvenile	Research	2	22.7	0.079	0.000048	-43.2	1 653

Table 4: Biomass estimates (t) and c.v. by stratum and snapshot of juvenile, immature, and adult SBW, for the Campbell Island Rise in 2004. The italicised entries in snapshot 2 were obtained from snapshot 1 because only one transect was completed in each of these strata in snapshot 2.

		Juvenile		Immature		Adult	
Stratum	Area (km^2)	Biomass (t)	c.v. (%)	Biomass (t)	c.v. (%)	Biomass (t)	c.v. (%)
Snapshot 1							
2	3 154	1 371	74	150	97	186	97
3N	2 342	0		0		0	
3S	1 013	0		0		0	
4	2 690	0		1 329	40	0	
5	3 029	0		2 518	69	0	
6N	1 150	0		2 380	61	0	
6S	3 025	0		0		1 157	100
7N	1 899	0		1 622	36	0	
7S	2 273	0		3 722	41	39 793	61
8	2 888	0		0		21 077	50
8E*	1 739	0		0		3 835	60
Total	**25 202**	**1 371**	**74**	**11 720**	**24**	**66 048**	**40**
Snapshot 2							
2	3 154	*1 371*	*74*	*150*	*97*	*186*	*97*
3N	2 342	*0*		*0*		*0*	
3S	1 013	0		0		0	
4	2 690	0		4 766	32	0	
5	3 029	0		1 584	30	0	
6N	1 150	0		0		14 298	70
6S	3 025	0		0		0	
7N	2 980	221	101	7 733	34	0	
7S	1 192	0		0		22 759	43
8N	1 436	0		0		571	88
8S	1 452	0		0		0	
8E	1 739	0		0		8 656	87
Total	**25 202**	**1 592**	**65**	**14 233**	**21**	**46 470**	**34**
Fleet							
10	124	0		0		42 317	83
8F	584	0		0		6 836	31
9	290	0		0		0	
Mean estimate							
Strata 2–7		1 481	69	12 977	16	39 096	36
Strata 2–8E		1 481	69	12 977	16	56 166	28
Add stratum 10		1 481	69	12 977	16	98 483	39

* Both snapshots of stratum 8E were carried out during snapshot 2 but for this analysis the first snapshot of stratum 8E was treated as part of snapshot 1

Table 5: Effect of using the sound absorption coefficient calculated from the survey (see Appendix 2), and then the towbody motion correction, on biomass estimates (t) by snapshot of juvenile, immature, and adult SBW. 'Standard' values are from Table 4, but exclude strata 2 and 3N for snapshot 2.

				Biomass (t)
Snapshot	Category	Standard	New absorption	Add motion correction
1	Adult	66 048	88 114	101 059
	Immature	11 720	14 618	16 132
	Juvenile	1 371	1 662	1 752
2	Adult	46 284	61 212	69 702
	Immature	14 083	17 367	19 420
	Juvenile	221	254	292
Fleet stratum 10	Adult	42 317	45 683	47 845

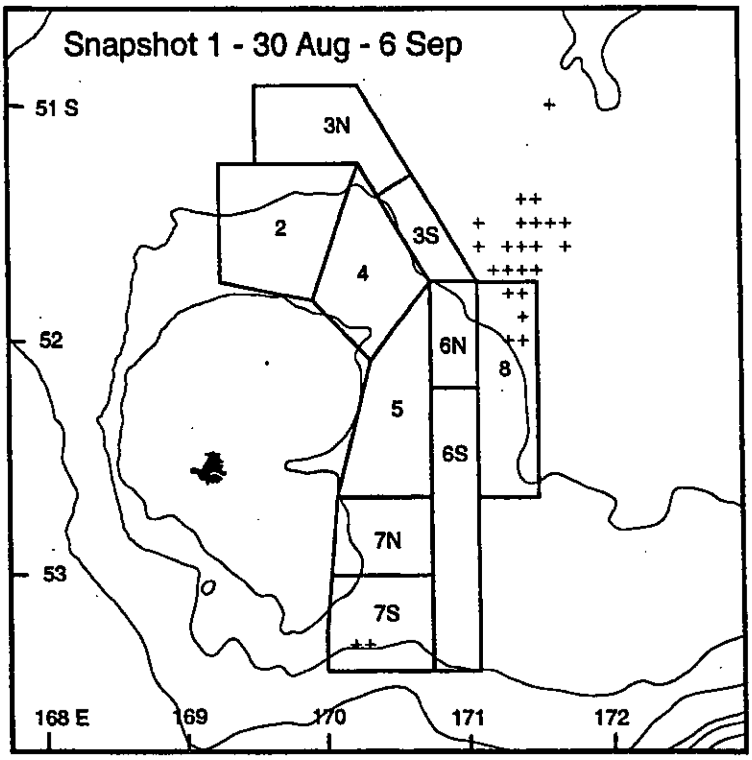
Table 6: Decomposed biomass estimates (t) by stratum and snapshot of 1, 2, 3, and 4 year old and over SBW for the Campbell Island Rise in 2004. The italicised entries were obtained from the previous snapshot.

					Ages
Stratum	Area (km^2)	1	2	3	4+
Snapshot 1					
2	3 154	1 328	163	82	124
3N	2 342	0	0	0	0
3S	1 013	0	0	0	0
4	2 690	8	1 002	300	22
5	3 029	16	1 905	570	43
6N	1 150	14	1 792	536	40
6S	3 025	0	153	511	446
7N	1 899	10	1 223	360	27
7S	2 273	22	8 081	18 370	15 395
8	2 888	0	1 035	5 557	13 815
8E*	1 739	0	188	1 011	2 512
Total	**25 202**	**1 398**	**15 542**	**27 297**	**32 424**
Snapshot 2					
2	3 154	*1 328*	*163*	*82*	*124*
3N	2 342	*0*	*0*	*0*	*0*
3S	1 013	0	0	0	0
4	2 690	28	3 595	1 076	81
5	3 029	10	1 196	358	27
6N	1 150	0	700	3 761	9 348
6S	3 025	0	0	0	0
7N	2 980	260	5 840	1 717	129
7S	1 192	0	3 011	10 022	8 759
8N	1 436	0	28	151	374
8S	1 452	0	0	0	0
8E	1 739	0	425	2 282	5 673
Total	**25 202**	**1 626**	**14 958**	**19 449**	**24 515**
Fleet					
10	124	0	2 077	11 154	27 727
Mean estimate					
Strata 2–7		**1 512**	**14 412**	**18 873**	**17 283**
Strata 2–8E		**1 512**	**15 250**	**23 373**	**28 470**
Add stratum 10		**1 512**	**17 327**	**34 527**	**56 197**

* Both snapshots of stratum 8E were carried out during snapshot 2 but for this analysis the first snapshot of stratum 8E was treated as part of snapshot 1

Table 7: Decomposed biomass estimates (t) by survey and age group for the Campbell Island Rise. Values in parentheses for 2002 and 2004 include biomass from strata outside the core acoustic survey area (i.e., stratum 8F in 2002, and strata 8, 8E, and 10 in 2004). All other values are for the core area (strata 2–7).

	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) 4 704	(3 829) 3 732	(11 842) 11 549	(152 184) 148 189
2004	(1 512) 1 512	(17 327) 14 412	(34 527) 18 873	(56 197) 17 283



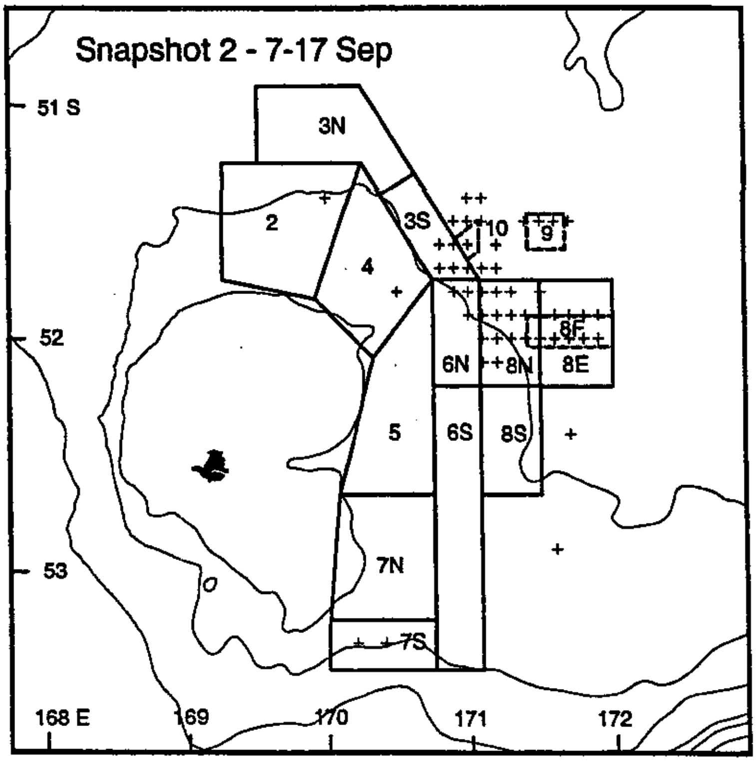


Figure 1: Stratum boundaries for snapshots 1 and 2 of the 2004 acoustic survey of the Campbell Island Rise. Fleet strata (dashed lines) were surveyed from 14–16 September during snapshot 2. Crosses show the start positions of commercial trawls carried out during the period of the snapshot (see Figure 2). Note that each cross may represent more than one tow. Thin lines are 250, 500, and 750 m depth contours.

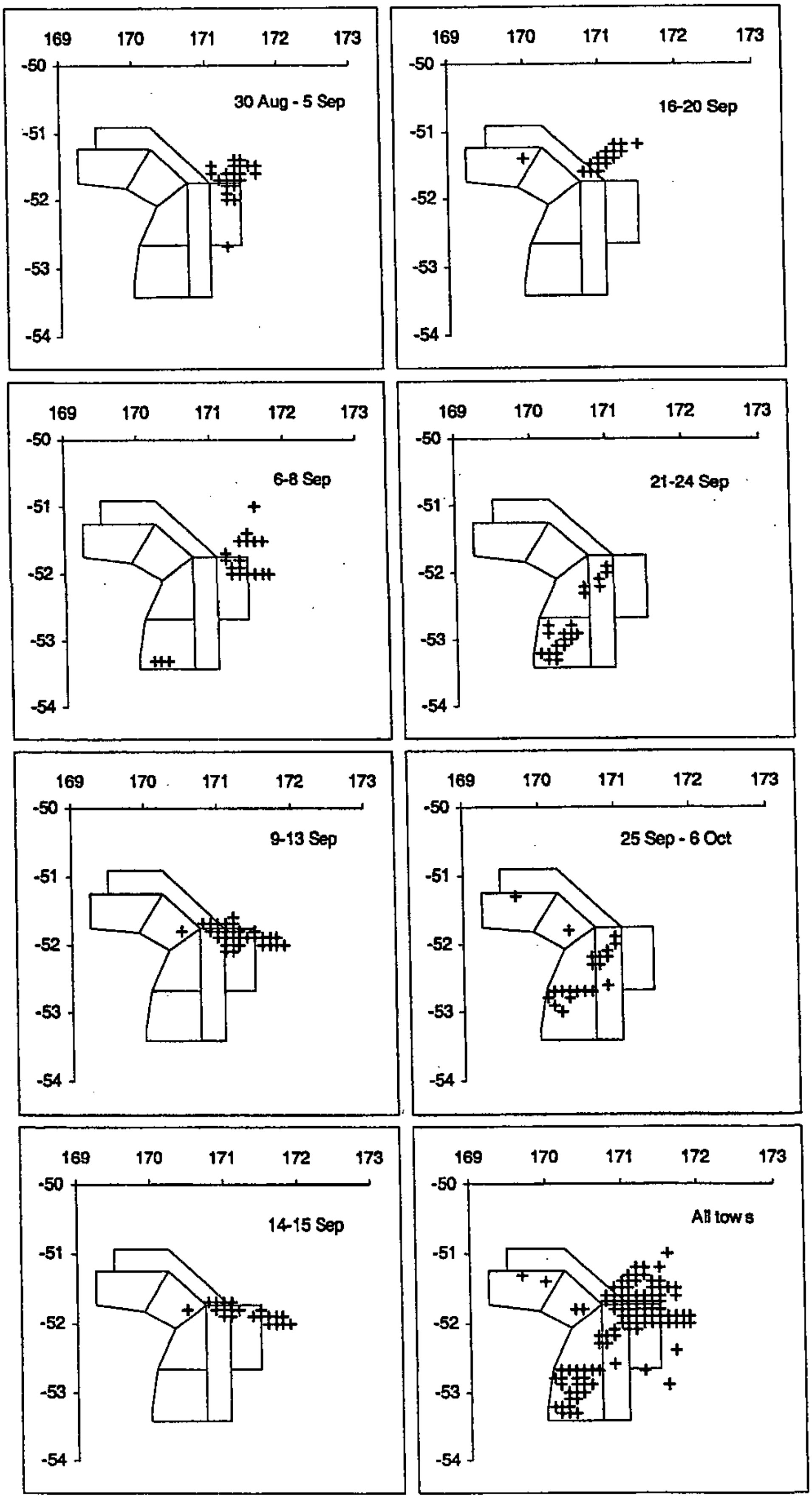


Figure 2: Start positions of commercial trawls carried out on the Campbell Island Rise during the 2004 SBW season. Note that each cross may represent more than one tow. Snapshot 1 stratum boundaries are shown for reference. Acoustic snapshot 1 was from 30 August to 6 September, and snapshot 2 was from 7 to 17 September (see Figure 1).

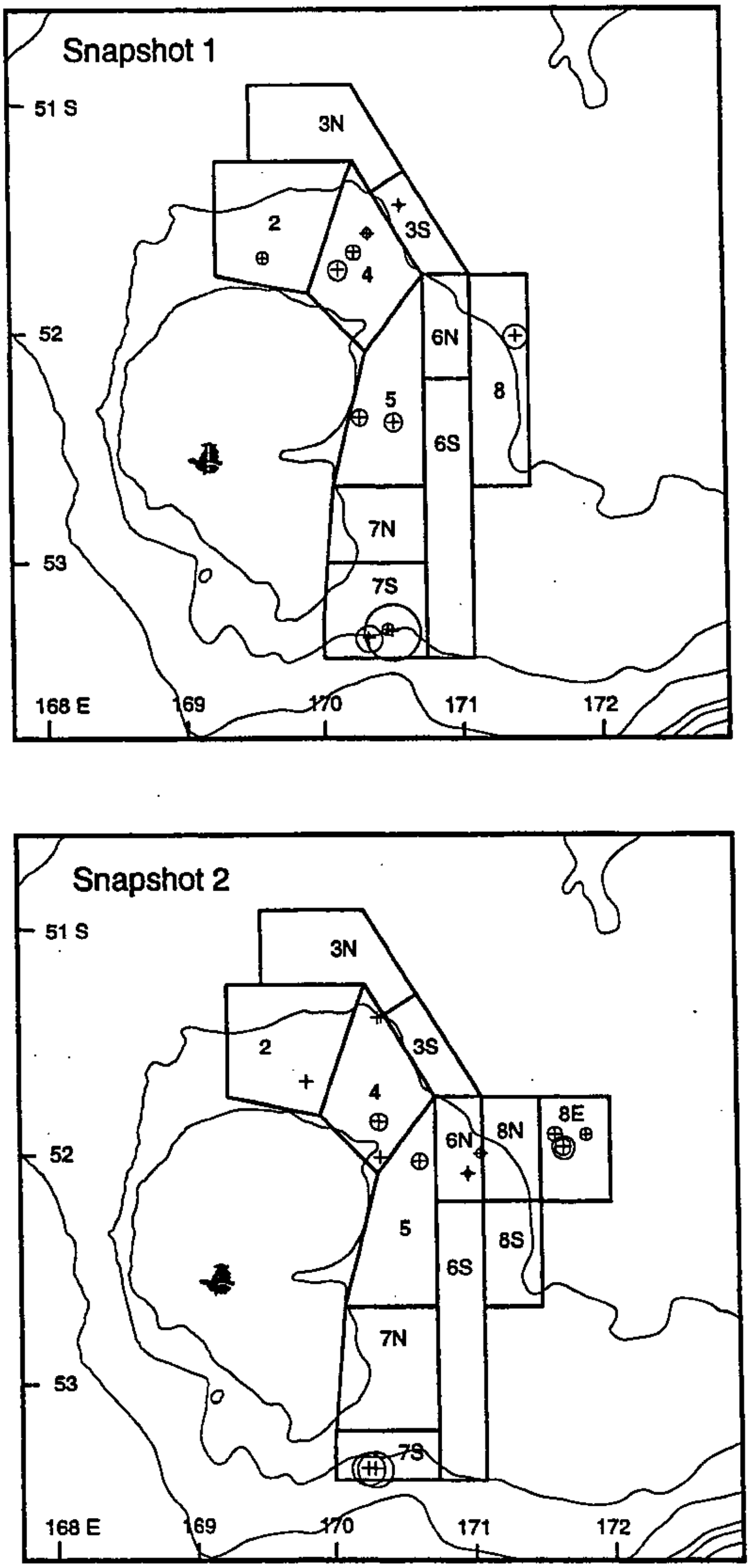


Figure 3: Catch rates of trawls during snapshots 1 and 2 of the 2004 acoustic survey of the Campbell Island Rise. Circle area is proportional to the log of the trawl catch. Maximum circle size is 4 700 kg. Thin lines are 250, 500, and 750 m depth contours.

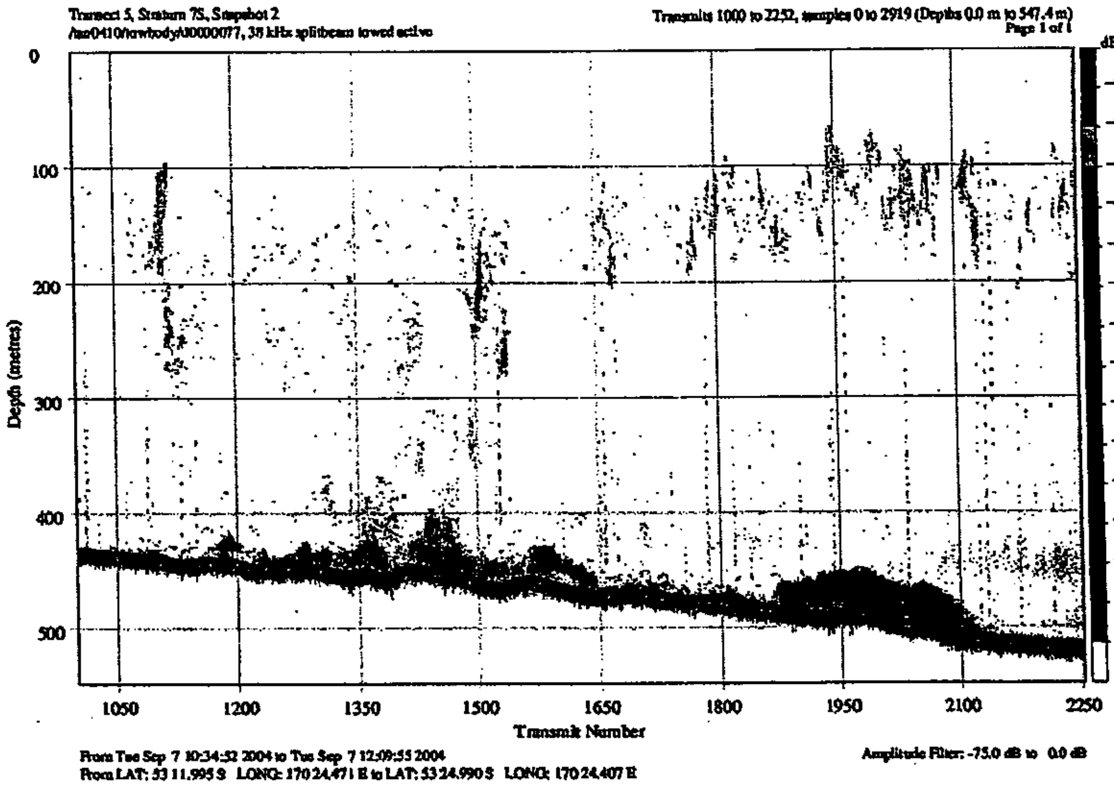


Figure 4: Dense adult daytime pre-spawning mark close to the bottom surveyed in stratum 7S on 7 September 2004. Towbody depth was about 50 m.

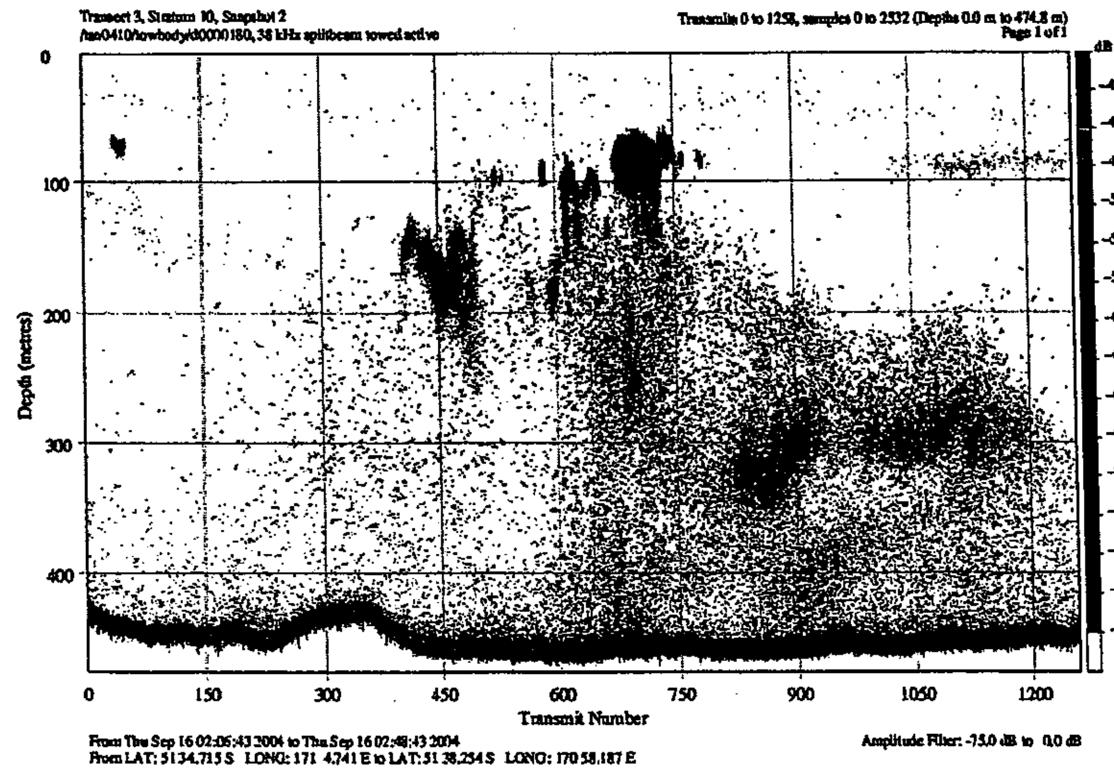
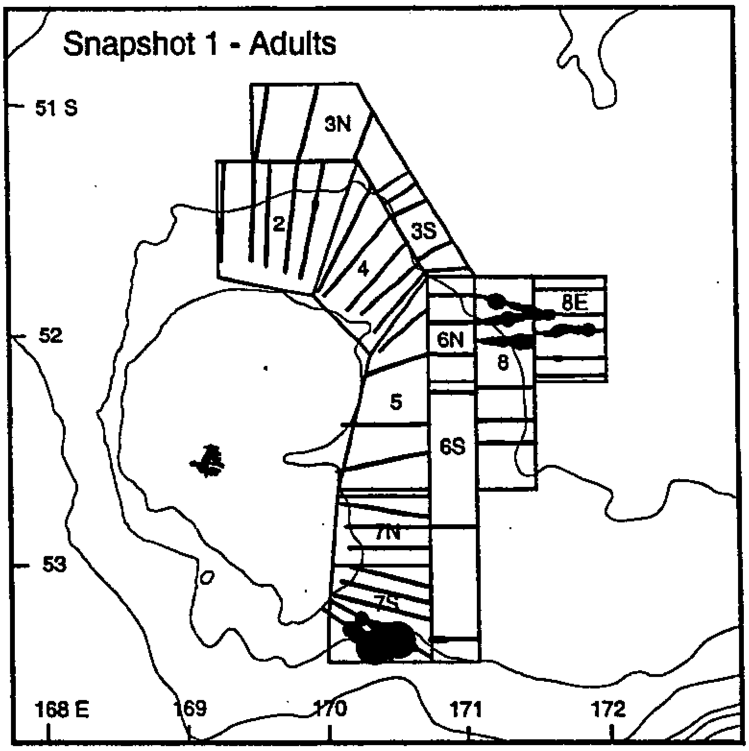


Figure 5: Very dense adult nightime spawning mark surveyed in stratum 10 on 16 September 2004. Towbody depth was about 50 m.



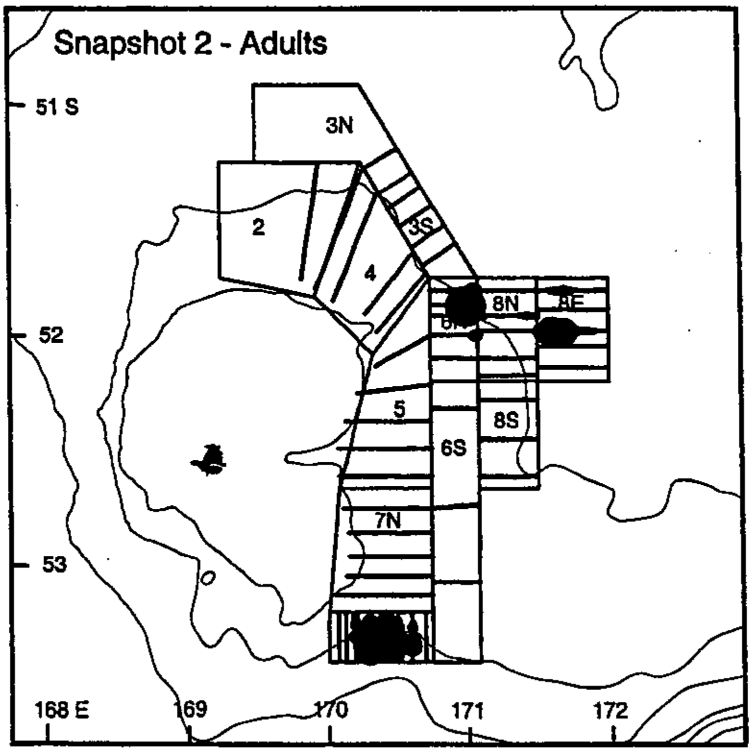
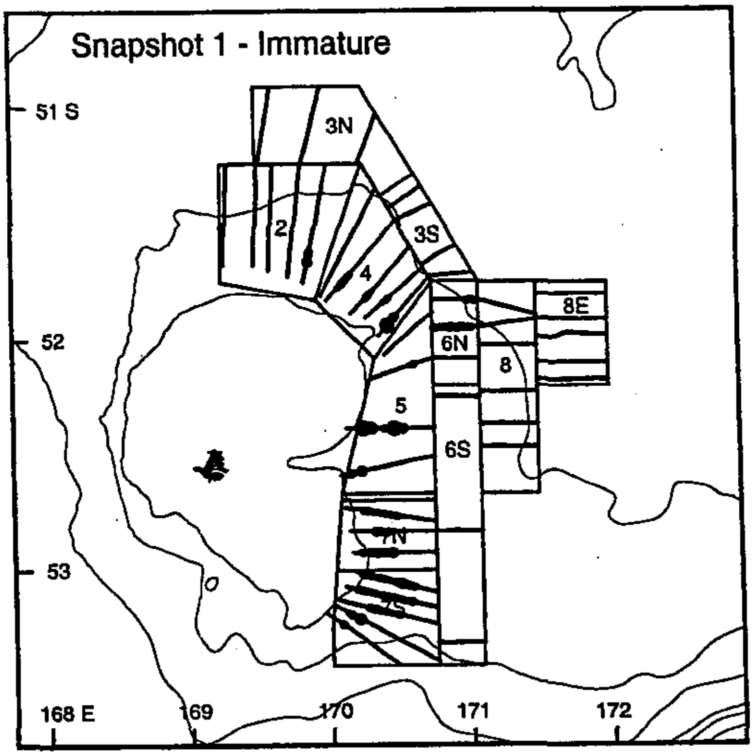


Figure 6: Spatial distribution of acoustic backscatter from adult SBW plotted in 10 ping (~100 m) bins for snapshots 1 and 2. Symbol size is proportional to the log of the acoustic backscatter. Both snapshots of stratum 8E were carried out during snapshot 2, but for plotting and analysis the first snapshot of stratum 8E was treated as part of snapshot 1.



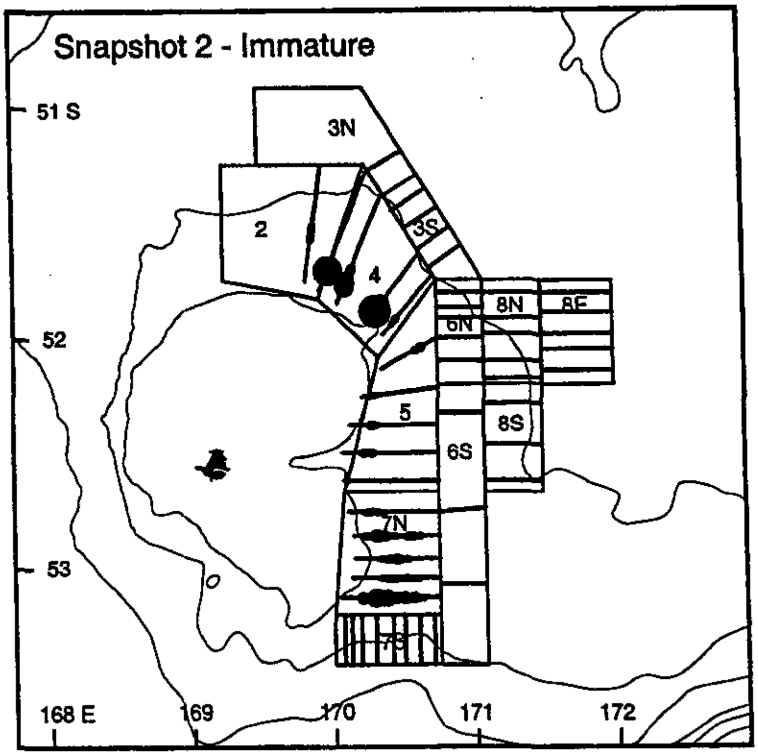
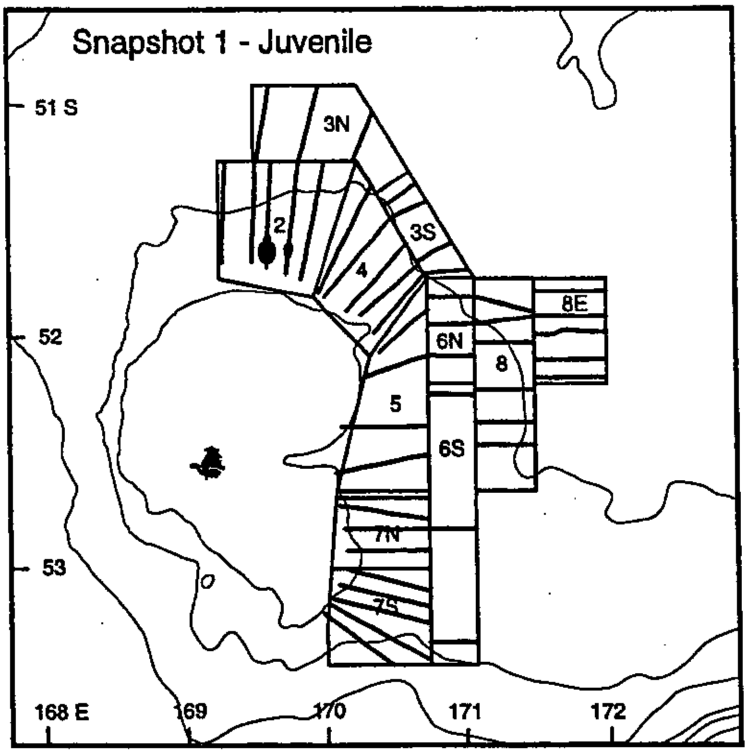


Figure 7: Spatial distribution of acoustic backscatter from immature SBW plotted in 10 ping (~100 m) bins for snapshots 1 and 2. Symbol size is proportional to the log of the acoustic backscatter. Both snapshots of stratum 8E were carried out during snapshot 2, but for plotting and analysis the first snapshot of stratum 8E was treated as part of snapshot 1.



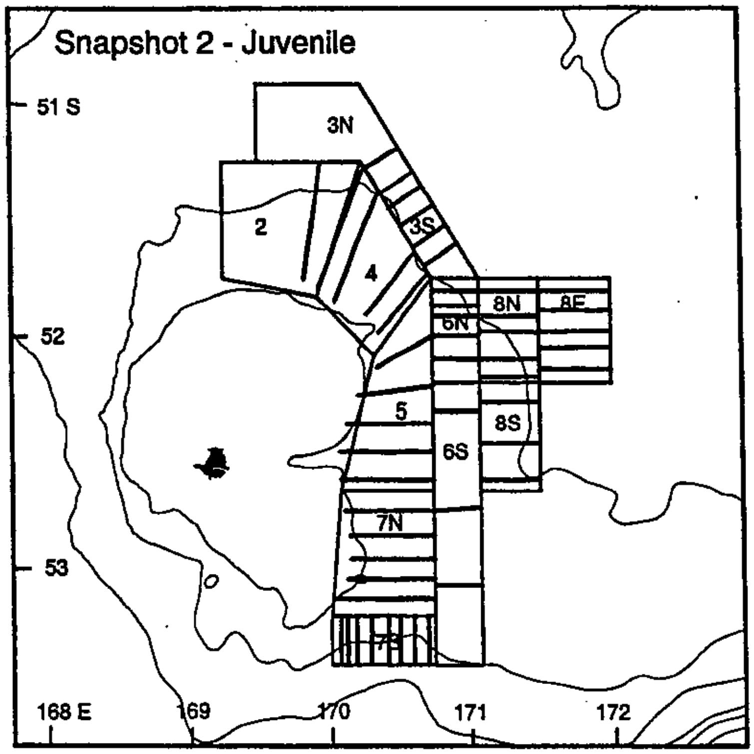


Figure 8: Spatial distribution of acoustic backscatter from juvenile SBW plotted in 10 ping (~100 m) bins for snapshots 1 and 2. Symbol size is proportional to the log of the acoustic backscatter. Both snapshots of stratum 8E were carried out during snapshot 2, but for plotting and analysis the first snapshot of stratum 8E was treated as part of snapshot 1.

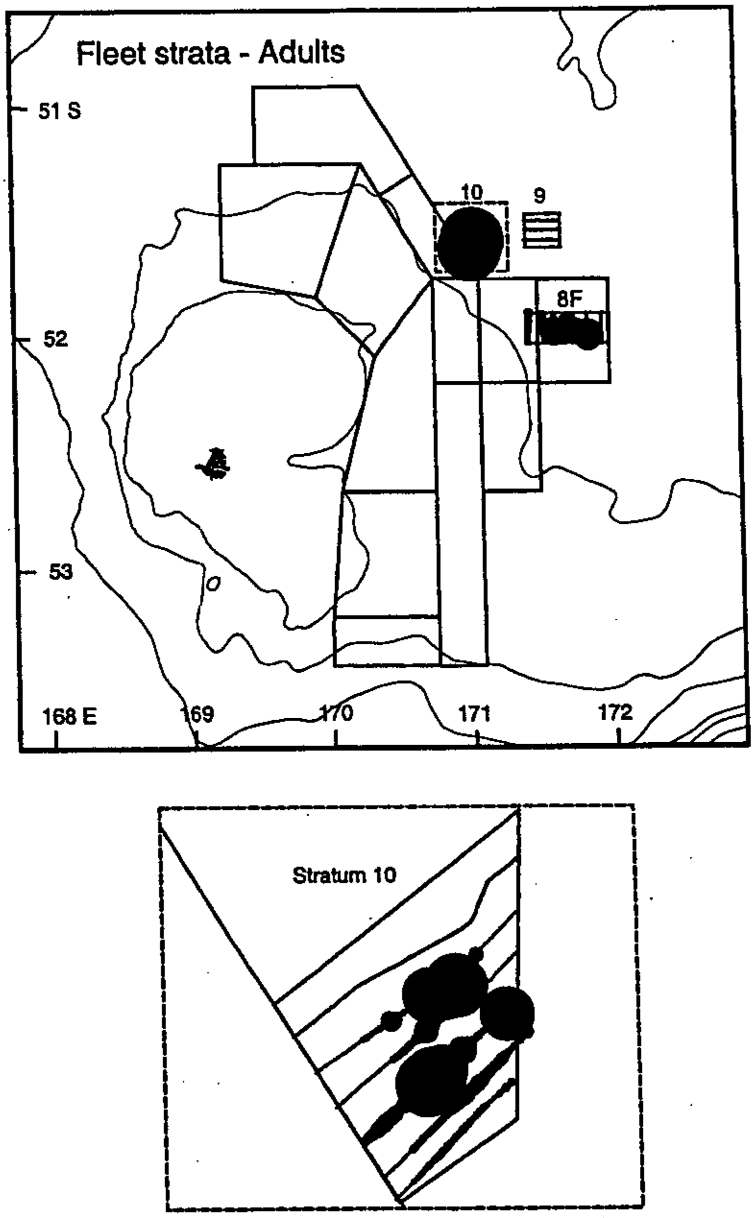


Figure 9: Spatial distribution of acoustic backscatter from adult SBW plotted in 10 ping (~100 m) bins for fleet strata. Lower panel is an enlargement of stratum 10. Symbol size is proportional to the log of the acoustic backscatter.

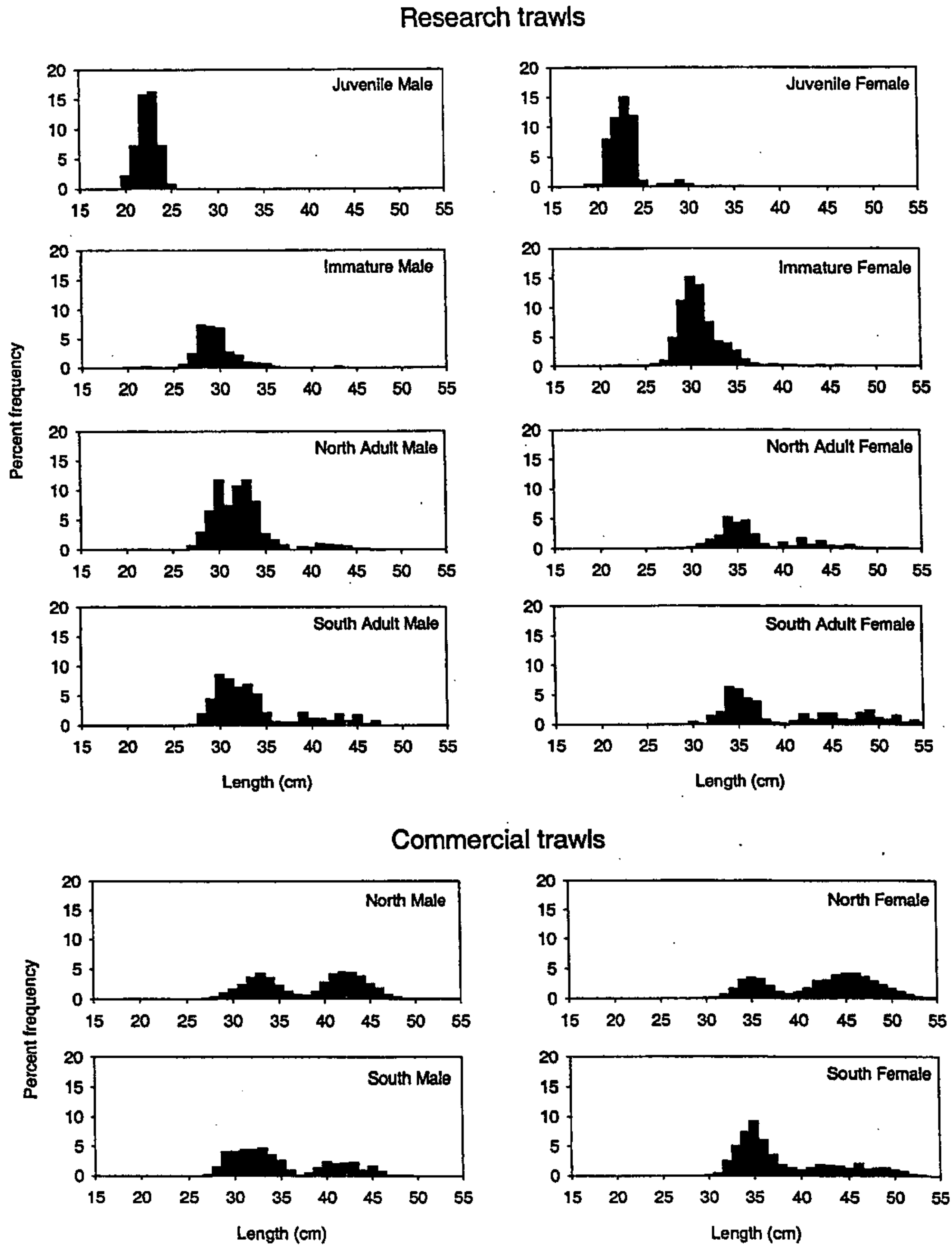
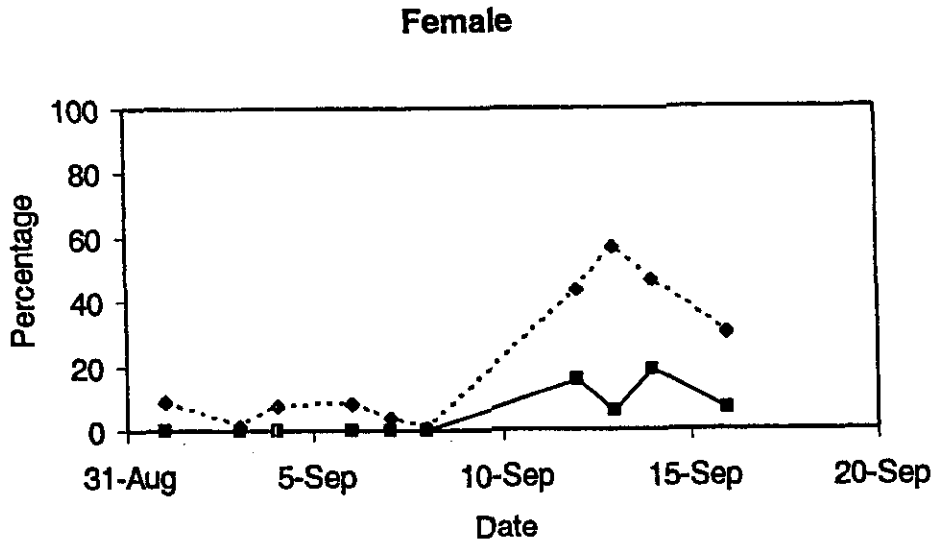


Figure 10: Catch-weighted length frequency distributions for southern blue whiting caught in research trawls by *Tangaroa* from juvenile, immature, and adult marks north and south of 53° S and from commercial tows north and south of 53° S during the spawning fishery. Research data were used in the acoustic survey analysis for decomposing juvenile and immature marks and commercial data were used for adult marks.



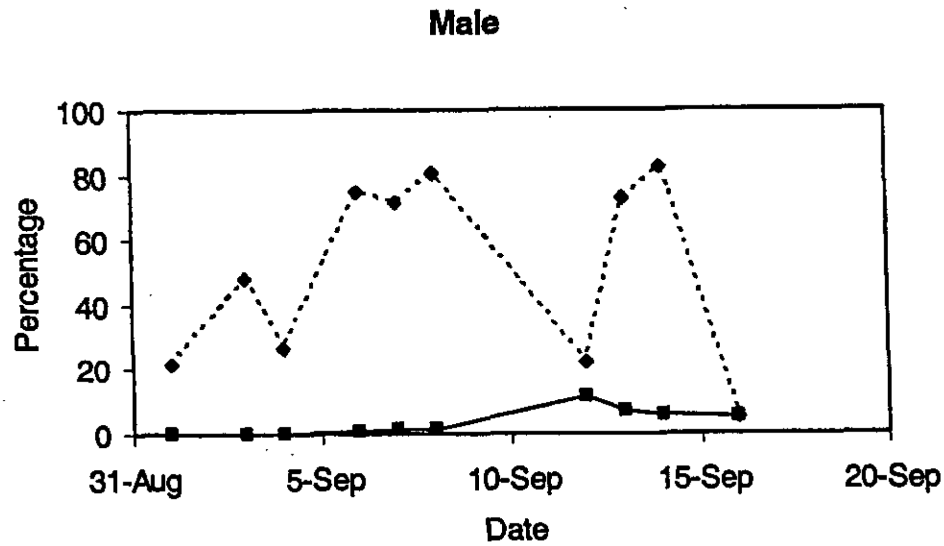


Figure 11: Percentage of ripe (dotted line) and running ripe (solid line) SBW by date from research trawls. Immature (stage 1) fish were excluded when calculating percentages.

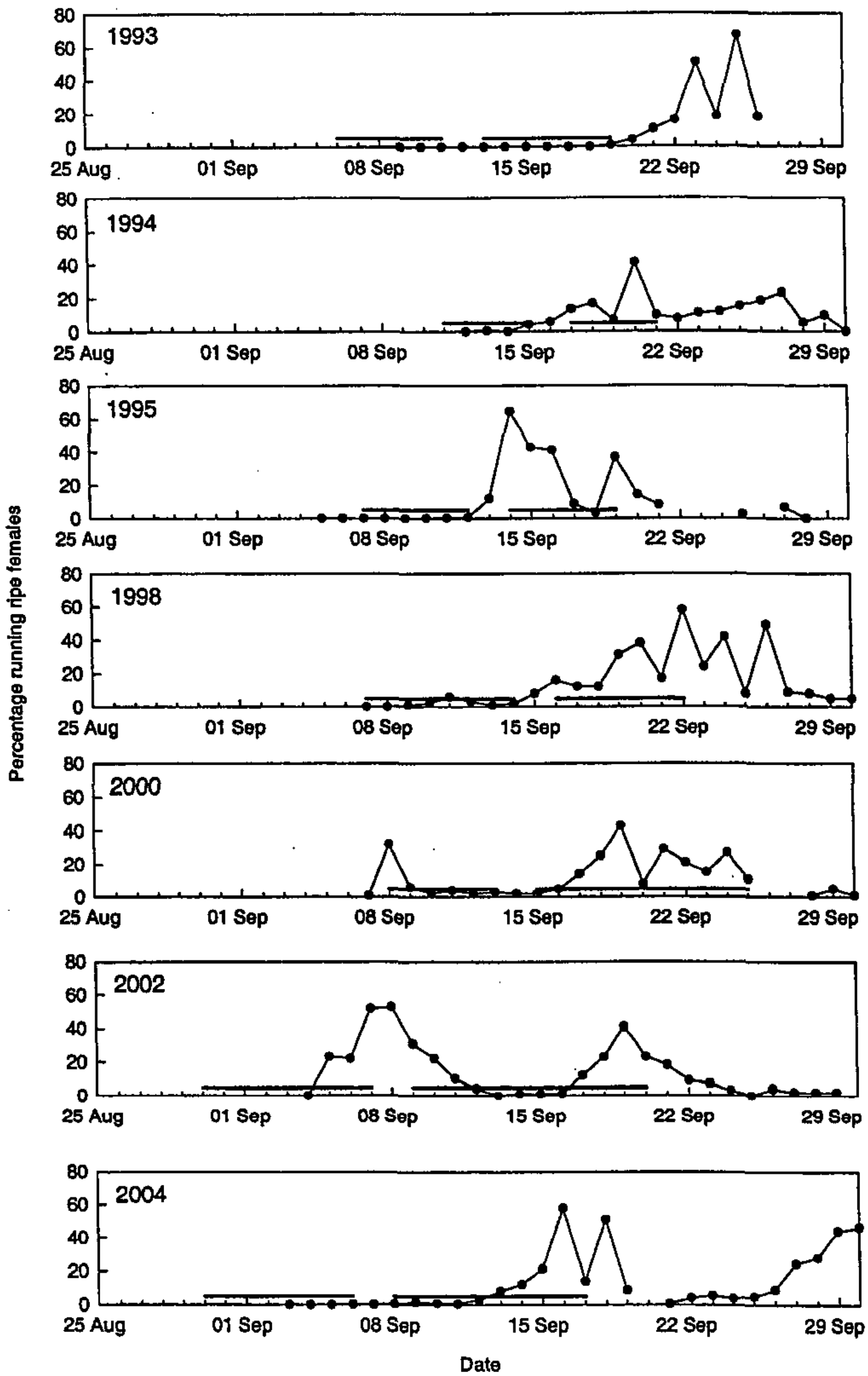


Figure 12: Survey timing (thick line above x axis) in relation to the timing of spawning for the acoustic survey time-series for SBW on the Campbell Island Rise. Percentage of running ripe females is from observer data.

Appendix 1: Acoustic equipment used for abundance estimation

This appendix describes the system used to collect acoustic data during the 2004 Campbell Island Rise SBW survey. Features of the general system are covered as well as details of the specific system.

Data for abundance estimation were collected with NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs et al. 2003). *CREST* is computer based, using the concept of a 'software echo sounder'. It supports multi-channels, each channel consisting of at least a receiver and usually also a transmitter. The receiver has a broadband, wide dynamic range pre-amplifier and serial analog-to-digital converters (ADCs), which feed a digital signal processor (DSP56002). The ADCs have a conversion rate of 60 kHz and the data from these are complex demodulated, filtered, and decimated. The filter was a 100 tap, linear-phase finite impulse response digital filter. For the abundance survey work this had a bandwidth of 1.6 kHz and the data were decimated to 4 kHz. Following decimation, a 20 log R time-varied gain was applied. The results were shifted to give 16 bit resolution in both the real and imaginary terms and the complex data stored for later processing.

The transmitter was a switching type with a nominal power output of 2 kW rms. It will operate over a wide range of frequencies (12–200 kHz). For the survey the transmitted pulse length was 1 ms (38 cycles at 38 kHz), and the effective pulse length was 0.78 ms. Time between transmits was 2 s.

One towed *CREST* system was used on all transects in this survey. This system consisted of a split-beam 38 kHz *CREST* echosounder connected to a towed Simrad split-beam transducer via about 2000 m of Rochester type 301301 tow cable. The towed body was a 3 m long flat-nosed, torpedo-shaped, 'heavy weight' design. Digital data from the receiver were sent to a control computer where they were combined with position and transect information and stored.

Calibration followed the standard procedures set out by Foote et al. (1987). Calibrations were carried out during the survey in Perseverance Harbour at Campbell Island (shallow calibration) and at sea in July 2004, during an orange roughy acoustic survey (deep calibration). Calibration data are provided in Table A1.1.

Table A1.1: Calibration data for the 38 kHz CREST systems used for the 2004 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
Transducer model	ES38DD
Transducer serial no.	28327
3 dB beamwidths (°)	7.0 × 6.9
Effective beam angle (sr)	0.0083
Operating frequency (kHz)	38.156
Transmit interval (s)	2.00
Transmitter pulse length (ms)	1.00
Effective pulse length (ms)	0.78
Filter bandwidth (kHz)	1.5
Initial sample rate (kHz)	60
Decimated sample rate (kHz)	4
V_T (V)	1 366
G	14 491
Absorption (dB km^{-1})*	8.0 & 9.39

* See Appendix 2

Appendix 2: Calculation of sound absorption coefficients

As sound travels through water, acoustic energy is lost due to absorption and spreading. This effect must be taken into account when estimating fish abundance (e.g., MacLennan & Simmonds 1992). The absorption of sound by seawater is related to the depth, temperature, and chemical composition (related to salinity) of the water. Previously, there were two sets of equations available to calculate absorption: for SBW surveys, the standard procedure has been to use an absorption of 8.0 dB km^{-1}, which was based on the formula of Fisher & Simmons (1977) from laboratory measurements of artificial seawater. Most recent fisheries acoustic work has used the alternative sound absorption formula of Francois & Garrison (1982a, 1982b), which was based on in situ measurements. This formula gives higher estimates of absorption. The Francois & Garrison (1982a, 1982b) formula was not adopted by NIWA because the data on which the equations were based did not include measurements at 38 kHz (Coombs & Cordue 1995, Doonan et al. 2003).

Doonan et al. (2003) reviewed the absorption of sound in seawater, focusing on the frequencies used in fisheries acoustics and published a new formula based on a statistical reanalysis of existing data. This new formula has been adopted for surveys of New Zealand deepwater fish species and O'Driscoll & McMillan (2004) used the new absorption to update the time series of acoustic estimates for Cook Strait hoki.

In this report we calculated sound absorption for the Campbell Island Rise survey areas from CTD data using the formula of Doonan et al. (2003).

Calculation of sound absorption

Fifteen CTD casts were carried out as part of the 2004 survey. We estimated average sound absorption for each temperature, salinity, and depth profile. Estimates of sound absorption by area are given in Table A1. We used the average absorption estimates of 9.39 dB km^{-1} as a sensitivity when estimating SBW biomass (see Section 3.5).

Table A1: Estimates of acoustic absorption for the Campbell Island Rise acoustic survey areas in 2004. Absorption was calculated from CTD profiles made during the surveys using the formula of Doonan et al. (2003).

Trawl station	Max. depth of cast (m)	Mean temperature (° C)	Mean salinity (PSU)	Mean absorption (dB km^{-1})
1	305	7.14	34.38	9.50
2	394	7.11	34.38	9.37
3	437	7.15	34.38	9.41
4	476	7.14	34.37	9.34
5	512	7.14	34.37	9.32
6	507	7.20	34.39	9.30
7	425	7.18	34.40	9.41
8	375	7.19	34.41	9.44
9	551	7.35	34.42	9.27
14	261	7.18	34.41	9.53
15	411	7.16	34.39	9.39
16	481	7.17	34.39	9.33
17	487	7.17	34.39	9.32
18	517	7.19	34.39	9.31
19	224	7.23	34.39	9.60
average	424	7.18	34.39	9.39

Appendix 3: Description of gonad development used for staging SBW

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