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EXECUTIVE SUMMARY

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An acoustic survey of spawning southern blue whiting (SBW) on the Campbell Island Rise was carried out from FV *Aoraki* from 1 to 20 September 2003. The survey was conducted between routine commercial fishing operations using the vessel's Simrad ES-60 echosounder with hull-mounted 38-kHz transducer. Two main spawning aggregations of SBW were located, in the northeast and the south, and there was adequate time during fish processing to carry out 18 acoustic mark mapping exercises. These exercises provided the equivalent of seven acoustic snapshots of the northeastern area and two snapshots of the southern area, where each snapshot consisted of five or more parallel transects across the area containing marks. Forty-four commercial trawls were carried out during the survey, providing biological data and information for mark identification.

Spawning was relatively late in 2003, with the threshold of 10% running ripe females reached on 16 September. Low densities of pre-spawning adult SBW marks were observed in the northeastern area from 7 to 10 September. Marks schooled up and became denser as spawning approached from 11 to 18 September. Spawning aggregations typically consisted of a number of dense SBW schools within a region of about 300 km^2.

Absolute acoustic biomass estimates were calculated for the two spawning aggregations. Estimates were 54 000 t for the northeastern aggregation and 48 000 t for the southern aggregation using the target strength (TS) to fork-length (FL) relationship of $TS = 21.8 \log_{10}FL - 72.8$ (which is the relationship used in all previous SBW acoustic surveys), and 23 000 t and 21 000 t using an updated TS-FL relationship ($TS = 40 \log_{10}FL - 99$). The biomass estimate for both areas combined had a sampling c.v. of 20–26%.

The survey from FV *Aoraki* showed that industry vessels with hull-mounted acoustic systems could be used to collect acoustic data on SBW in good weather (less than 25 knots of wind). Although it is unlikely that a survey of the entire Campbell Island Rise area (more than 21 000 km^2) could be undertaken from one or more commercial vessels without seriously compromising fishing success, snapshots of the main spawning aggregations could be carried out using the processing time between commercial trawls. This type of collaborative survey may provide estimates of minimum SBW spawning biomass, or could be used in conjunction with a wider area research survey to improve survey precision.

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 five years (Annala et al. 2003). 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 2003 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 main aim of the acoustic surveys 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. The results of these acoustic surveys of spawning SBW have been an important input into SBW stock assessments for the last decade (e.g., Hanchet 2002), providing a fishery-independent index of spawning SBW biomass in the major spawning grounds.

No MFish-funded acoustic survey of SBW was scheduled in 2003. However, SBW stakeholder groups were interested in knowing whether it was feasible to use industry vessels with ES-60 echosounders and hull-mounted transducers to survey spawning SBW. As part of a collaborative initiative between these stakeholders and NIWA, a pilot acoustic survey was carried out on the Campbell Island Rise from FV *Aoraki* in September 2003. This work was funded by the Hoki Fishery Management Company.

The aims of this survey work were to: a) determine the feasibility of using industry vessels with ES-60 echosounders and hull-mounted transducers to survey spawning SBW on the Campbell Island Rise; b) determine the number, relative size, and location of the main spawning SBW aggregations on the Campbell Island Rise; c) obtain estimates of the absolute biomass of the main spawning aggregations in 2003; and d) collect data to improve the design for a Campbell Island Rise acoustic survey in winter 2004. It is important to note that the objective was not to provide a 2003 acoustic biomass index consistent with the existing Campbell Island Rise time-series, but instead to investigate alternative survey designs using industry vessels.

2. METHODS

2.1 Survey design

The survey was adaptive, with the aim of mapping the spatial extent and assessing the within and between transect variability of the main SBW aggregations. Significant aggregations were located by searching on FV *Aoraki* and by communication with other vessels.

Two alternative survey designs were used. In the first design, marks were covered with a regular zig-zag pattern, turning when we ran out of fish marks. Transect spacing between turning points on adjacent legs was 0.5–2.0 n. mile. Once the approximate boundaries of the mark had been determined using the zig-zag design or by mapping the location of the commercial fleet, a second design was employed consisting of a series of random parallel transects across the mark, following the methods of Jolly & Hampton (1990). This second design was analogous to the "fleet strata" method used in previous SBW surveys (e.g., Hanchet et al. 2003). Transect spacing and orientation were dependent on the size and shape of the aggregation and the prevailing weather and sea conditions.

2.2 Acoustic data collection

Acoustic surveys were carried out from the 68 m factory/freezer stern trawler FV *Aoraki* from 1 to 20 September 2003 using a commercial Simrad ES-60 echosounder with a hull-mounted 38-kHz split-beam transducer. This echosounder is essentially identical to the EK-60 scientific echosounder commonly used by fisheries research institutes worldwide and provides data of scientific quality (but see Appendix 1). The acoustic system was calibrated before the survey on 31 May 2003 off Nelson, and again, following the survey, off Dunedin on 24 October 2003 using standard scientific methods (Foote et al. 1987). Details of the acoustic system and its calibration are provided in Table 1.

Survey work was conducted between routine fishing operations using the approach used successfully for hoki in 2002 and 2003 (O'Driscoll 2003, O'Driscoll et al. 2004). While processing between trawls, FV *Aoraki* was able to carry out acoustic transects without compromising fishing success. Processing time was typically 6–12 h for catches of 10–20 t. All transects were run at 7–10 knots.

2.3 Trawling

Commercial trawls were used for mark identification and collection of biological data. The positions of tows were determined by the fishing officers (captain and first mate) and were usually targeted on relatively dense SBW marks.

Both midwater and bottom trawls were used during the survey. The bottom trawl had 140 m sweeps, 25 m bridles, and 37 m groundrope, with an average headline height of 3.5 m. The midwater trawl had a combined sweep and bridle length of 200 m with an average headline height of 45 m. Doorspread for both trawls was about 200 m (range 172–233 m). Codend mesh size was 60 mm, except for one midwater trawl with 100 mm codend mesh carried out on 10 September.

Trawl catch weights and species' composition were estimated from the vessel processing returns. A random sample of 100–200 SBW from every tow was measured, and the sex and macroscopic gonad stage determined. Estimated SBW length frequencies 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 some trawls to collect temperature and salinity data, which were then used to estimate the acoustic absorption coefficient during the survey (Appendix 2).

2.5 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). ESP2 was modified in January 2004 to correct for a systematic error in the ES-60 data (see Appendix 1) and this correction was applied during the analysis.

Echograms were visually examined, and the bottom determined by a combination of an in-built bottom tracking algorithm and manual editing. Regions corresponding to SBW were then identified. Marks were classified subjectively, based on their appearance on the echogram (shape, structure, depth, strength, etc.), and using information from commercial trawls into categories developed by Hanchet et al. (2002).

Backscatter from marks (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 2.6). Second, acoustic backscatter was integrated over 10-ping bins (vertical slices) to produce a series of acoustic densities for each transect (typically 30–100 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.

2.6 Biomass estimation

Acoustic density estimates were converted to SBW biomass using a ratio, *r*, of mean weight to mean backscattering cross section (linear equivalent of target strength) for SBW. This ratio was calculated from the scaled length frequency distribution of SBW from commercial trawls by FV *Aoraki* during the survey.

Acoustic target strength was derived using two target strength to fork length (TS-FL) relationships. The first was the 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:

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

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

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

Biomass estimates and variances were obtained from transect density estimates using the formulae of Jolly & Hampton (1990). Biomass estimates were calculated only for marks for which there were five or more parallel random transects across the mark area. Stratum areas were calculated from transect start and finish positions using MapInfo mapping software. Biomass estimates were not calculated for the zig-zag mapping surveys which were used to define the extent of the marks.

3. RESULTS

3.1 Data collection

FV *Aoraki* was among the first vessels to arrive on the Campbell Island grounds, on 3 September 2003. We began searching in the northern and eastern areas and located reasonable marks between 51° 40' S, 170° 40' E and 52° 15' S, 171° 20' E on 7 September (Figure 1). These marks were close to the bottom and widely spread, consisting of pre-spawning adult SBW (see Section 3.2). Six mark mapping exercises were carried out on these marks (Table 2), but acoustic survey work was problematic because the marks were dispersed and fast moving. Seven vessels arrived on 7–10 September and began fishing on these marks. Three Japanese vessels passed through the northern area on 3–4 September but did not fish.

On 8 September we were notified that the Japanese vessels had located, and were fishing on, a large aggregation to the south at 53° 20' S, 170° 30' E. We steamed south to this area on 10 September, arriving around 22:30 NZST. There were a number of dense midwater schools scattered over a small area of about 10 n. miles by 10 n. miles (Figure 1). Schools contained pre-spawning adult SBW of similar gonad stages to those in the northeastern area. We carried out three mark mapping exercises in this area on 11–12 September. Only one or two vessels were fishing on the southern marks during this period.

We returned to the northeastern grounds on 13 September. A fleet of up to 10 vessels was concentrated around 52° 5' S, 170° 55' E and reported good catch rates. We carried out nine mark mapping exercises around the fleet, finding midwater schools similar to those observed in the southern area. Fish began spawning on 16 September (see Section 3.4).

A total of 274 acoustic data files was recorded. Acoustic data were recorded while searching as well as along survey transects and during all trawls. Some of the data collected while searching and trawling were not suitable for quantitative analysis because of interference from the vessel's sonar. The sonar was turned off for all survey transects. Because the ES-60 transducer was hull-mounted, data quality was strongly dependent on sea conditions. Sea and weather conditions were excellent from 7 to 15 September, with less than 15 knots of wind and swells under 2 m. Conditions were less favourable at the start and end of the survey. No noise trials were carried out during the survey, but our experience indicated that data collection was seriously compromised when wind speeds exceeded 25 knots.

We completed 117 acoustic transects in 18 separate adaptive mark mapping exercises during the survey (Table 2). From these, we have the equivalent of two biomass snapshots of the southern area and seven snapshots of the northeastern area, where each snapshot consisted of five or more parallel transects across the area containing marks.

Seven bottom trawls and 37 successful midwater trawls were carried out from FV *Aoraki* when NIWA staff were aboard (Table 3). The total catch of 606 t was predominantly (99.3%) adult SBW, with low levels of bycatch of ling (0.3%), rattails (0.2%), hake, pale ghost shark, and silversides (all less than 0.1%). The CTD was mounted on four trawls to obtain measurements of temperature and salinity in the area (Appendix 2).

3.2 Mark identification

Visual examination of echograms in association with trawl catches indicated that there was a wide range of mark types associated with adult SBW. Some examples are given below. Marks types were generally similar to those described for pre-spawning and spawning adult SBW on the Campbell Island Rise by Hanchet et al. (2002).

As mentioned in Section 3.1, pre-spawning adult SBW marks were observed in the northeastern area from 7 to 10 September, usually on or close to the seabed during the day (Figure 2). At night, the densest part of the mark moved off the bottom, with fish extending into midwater up to 100 m from the bottom (Figure 2). Pre-spawning SBW marks observed in the southern area between 11 and 12 September and in the northeastern area from 13 to 15 September were close to the bottom during the day, but rose higher in the water column at night (Figure 3). This is typical behaviour as spawning approaches (Hanchet et al. 2002). Spawning began on 16 September (see Section 3.4), with SBW forming characteristic 'thunder cloud' schools at night (Figure 4). During the day, fish were found in very dense midwater schools which were typically tall (large vertical extent) and narrow (Figure 4). No post-spawning SBW were observed during the 2003 survey.

Acoustic backscatter from regions corresponding to dense SBW marks was integrated to obtain acoustic density estimates and all backscatter from these marks was assumed to be from SBW. This is a reasonable assumption because midwater trawls on these marks caught almost 100% SBW (see Table 3). Lower density bottom-referenced marks which sometimes occurred surrounding SBW marks (e.g., Figure 4) were not integrated. Although these marks might contain some SBW, bottom trawls on these marks also caught a mix of other species (see Table 3), especially ling and rattails.

3.3 Distribution of SBW backscatter

Expanding symbol plots show the spatial distribution of SBW along each random parallel transect during the seven snapshots of the northeastern area (Figure 5) and the two snapshots of the southern area (Figure 6).

In the first three snapshots of the northeastern area from 7 to 10 September (mark exercises 3, 5, and 6), densities of SBW were quite low and relatively evenly distributed over the surveyed area (Figure 5). Our observation from the zig-zag transects was that the marks were also quite fast moving. These two factors made defining mark boundaries difficult and we were not confident that these first three snapshots encompassed all of the marks. SBW became more schooled up as spawning approached, making it easier to define the extent of the high density area. The location of the SBW aggregations was also more stable, and the area surveyed in the four snapshots between 13 and 18 September (mark exercises 10, 12, 16, and 17) was more consistent, although mark boundaries and transect orientation did vary between snapshots (Figure 5). Spawning in the northeastern area in 2003 did not occur in a single large aggregation, but rather as several small dense schools within a region of about 300 km^2 (Figure 5). Typically 2–4 transects in each of the Snapshots 4–7 crossed SBW schools, with relatively low densities on the other transects (Figure 5).

There was a single dense aggregation which was crossed by two transects in the first snapshot of the southern area on 10–11 September (mark exercise 7) (Figure 6). Skippers of Japanese vessels reported that an aggregation was also present in this area on 8–9 September. The southern aggregation had dispersed somewhat during our second snapshot on 11–12 September (mark exercise 9) and peak densities were lower (Figure 6). This change in spatial distribution did not appear to be related to the onset of spawning, as SBW caught in this area from 10 to 12 September were almost all pre-spawning fish (Table 4).

3.4 SBW size and maturity

Length, sex, and gonad stage were determined for 4300 SBW. The scaled length frequencies by sex and area are given in Figure 7. There were differences in fish size between areas. In the northeastern area, most adult fish were in a single mode with the peak at 43 cm for females and 40 cm for males. In the southern area there were three clear adult modes: at 37, 42, and 47 cm for females; and 36, 40, and 44 cm for males. There was a mode of smaller males at 28 cm in both areas. The sex ratio was similar in both areas with about 60% females to 40% males.

Spawning was later in 2003 than in 2002. In 2002, the first spawning occurred from 5 to 11 September (Hanchet et al. 2003). In 2003, no running ripe female SBW were observed before 12 September (Table 4, Figure 8). The threshold of 10% running ripe females was reached on 16 September. Fish examined before 12 September had not already spawned because ovaries were still large and contained no residual ovulated eggs. Running ripe males were observed from 8 September, with a peak on 16–17 September (Figure 8).

3.5 SBW biomass estimates

Mean weight and mean backscattering cross-section were obtained by transforming the scaled length frequency distributions (see Figure 7) for both areas and both sexes combined, and then calculating the means of the transformed distributions (Table 5). The choice of TS-FL relationship had a large effect on mean backscattering and the ratio, r, used to convert SBW backscatter to biomass. This ratio was 2.3 times higher using the old TS-FL relationship (Table 5), and consequently biomass estimates using the new TS-FL relationship of Dunford (2003) were less than half of those estimated using the old relationship (Table 6).

SBW biomass estimates by snapshot and area using both TS-FL relationships and the estimated sound absorption coefficient of 9.45 dB km^{-1} (see Appendix 2) are given in Table 6. Estimates are also given using the TS-FL relationship of Monstad et al. (1992) and an absorption coefficient of 8.0 dB km^{-1}, so that comparisons can be made with biomass estimates from previous SBW acoustic surveys on the Campbell Island Rise (e.g., Hanchet et al. 2003), which also used a sound absorption of 8.0 dB km^{-1}. The correction in the sound absorption from 8.0 to 9.45 increased biomass estimates by about 20% (Table 6).

Biomass estimates for the northeastern area were lower in Snapshots 1–3 than in Snapshots 4–7 (Table 6). Because of our concerns about defining the mark area in the first three snapshots (see Section 3.2), we chose to average estimates only from Snapshots 4–7 to obtain an overall estimate of SBW biomass in this area. Snapshots of the southern area were less than 24 h apart, and both estimates were averaged to obtain the southern biomass estimate.

Biomass estimates for the northeastern and southern aggregations were similar (Table 6). Because both aggregations were present at the same time, estimates from the two areas were summed to obtain an overall spawning biomass estimate.

Sampling precision (c.v.) of individual snapshots ranged between 13 and 84% (Table 6). The c.v.s were lowest in the first three snapshots of the northeastern area, where the SBW were relatively dispersed, and increased as fish became more aggregated and densities became more variable (see Section 3.2).

The sampling precision of the mean biomass estimates for each area can be calculated in two ways (Cordue & Ballara 2001). The first method is to average the variances from each snapshot. The second method assumes the snapshot biomass estimates are independent and identically distributed random variables. The sample variance of the snapshot estimates divided by the number of snapshots is therefore an unbiased estimator of the variance of the mean estimate. The two methods gave overall survey c.v.s of 26% and 20% respectively (Table 6). 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).

4. DISCUSSION

This acoustic survey was conducted successfully from an industry vessel during routine commercial fishing operations. The weather was excellent, data quality was high, and there was sufficient processing time between fishing operations to allow the main spawning aggregations to be surveyed. The research requirements did not appear to seriously compromise fishing success on FV *Aoraki*.

Two main spawning aggregations were surveyed. Biomass estimates from these aggregations using the 'old' method (Monstad et al. (1992) TS-FL relationship, and an absorption coefficient of 8.0 dB km^{-1}) were 44 000 t for the northeastern aggregation and 40 000 t for the southern aggregation (see Table 6). The combined estimate of 84 000 t for 2003 was about half of the "best estimate" for ages 3+ SBW (160 000 t) in the wide-area acoustic survey of the Campbell Island Rise in 2002 (Hanchet et al. 2003). Clearly, the biomass estimate from 2003 is not comparable as an index of abundance with the previous acoustic surveys on the Campbell Island Rise because of the very different survey design. The survey in 2003 only aimed to estimate biomass in the small areas around main spawning aggregations. The proportion of the adult SBW population occurring outside of the surveyed area is unknown.

It is not possible to include the 2003 acoustic biomass estimate in the current stock assessment for SBW. However, results of this, and any similar, survey could potentially be incorporated in a new assessment model as an estimate of minimum biomass. This is currently being proposed for the orange roughy spawning plume on the Chatham Rise. Such an approach would not provide an estimate of abundance for pre-recruit SBW, which typically occur outside the area being fished by the commercial fleet.

The success of the 2003 survey was due largely to the weather conditions. Acoustic research from commercial vessels such as FV *Aoraki* is limited by the use of a hull-mounted transducer to periods of relatively good weather. Our results indicated that data quality deteriorated considerably when there was more than about 25 knots of wind and 2 m of swell, although transect direction could be manipulated to avoid pitching when running into the swell. We lost only three days due to bad weather in 2003. Wind data from the Campbell Island meteorological station indicated that we were fortunate during this survey (Figure 9). The mean daily wind speed in the survey period from 3 to 19 September 2003 was 20 knots, with mean daily wind speeds exceeding 25 knots on only three days. During the same period in September 2002, mean daily wind speed at Campbell Island was 27 knots and was greater than 25 knots on 10 days (Figure 9). Previous SBW acoustic surveys have used a CREST towed body acoustic system (e.g., Hanchet et al. 2003). The advantage of a towed system is that the acoustic transducer can be deployed below the bubble layer created by bad weather, and partially isolated from vessel motion, increasing the number of days on which acoustic data can be collected.

The collaborative fishing and research approach described in this report works well for small-scale acoustic surveys of spawning aggregations where catch rates are high. A major limitation is that the boundaries of the survey area are determined by the time available during the processing 'window'. The length of the processing window depends on the size of the preceding catch (which in turn is related to market-driven product requirements) and also the time required to locate a suitable mark for the next commercial trawl. In this survey, the processing window was typically 6–12 h. This was sufficient to survey a total area of about 2250 km^2 over the two aggregations (see Figure 1). It is unlikely that a survey of the entire Campbell Island Rise area (more than 21 000 km^2) could be undertaken from one or more commercial vessels without seriously compromising fishing success.

Although surveys from industry vessel are unlikely to replace the need for large scale research surveys of SBW on the Campbell Island Rise, survey designs which include industry vessels should be considered. Various acoustic survey designs for SBW stocks were investigated by Dunn & Hanchet (1998) and Dunn et al. (2001). These two simulation studies concluded that 2-phase sampling strategies should be used, with up to 20% of transects assigned to the second phase. However, addition of phase 2 transects may not be sufficient to reduce c.v.s below target levels, as was the case in 2002 (Hanchet et al. 2003). To reduce this possibility of this occurring, Hanchet et al. (2003) recommended that the main spawning aggregation(s) should be repeatedly sampled using several snapshots. These snapshots of the aggregation substrata could be carried out by industry vessels, thereby reducing the number of days of research vessel time required.

The 2003 survey has also provided information on the recent distribution of SBW on the Campbell Island Rise, which will be useful in defining stratum boundaries for future surveys. For example, the northeastern aggregation in 2003 extended east to about 171° 20' E (see Figure 1), which was beyond the original boundary of the 2002 acoustic survey area (Stratum 6 boundary at 171° 5' E from Hanchet et al. 2003).

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Table 1: Set-up and calibration data of the acoustic system used in the 2003 Campbell Island Rise SBW survey.

Echosounder	Simrad ES-60
Transducer model	ES38B
Transducer serial no.	29945
Operating frequency	38 000 Hz
Bandwidth	2 425 Hz
Transmit power	2 000 W
Pulse length	1.024 ms
Ping interval	2.0 s
Sample interval	0.192 m
2-way beam angle	-20.6 dB re 1 steradian
Gain	25.98
Sa correction	-0.66
Absorption (α)*	*9.45 & 8.0 dB km^{-1}*
Sound velocity	1 500 m s^{-1}
3 dB beam width	
Alongship	7.2°
Athwartship	7.4°
Angle sensitivity	
Alongship	21.9
Athwartship	21.9
Angle offset	
Alongship	0.6°
Athwartship	0.2°
Time-varied gain	20logR + 2αR

* See Appendix 2

Table 2: Summary of acoustic transects carried out on the Campbell Island Rise during September 2003. Areas are shown in Figure 5. An asterisk indicates exercises with five or more parallel transects across the marks which were used as 'snapshots' for biomass estimation.

Area	Exercise	Type	Start time	End time	No. of transects
Northeast	1	Zig-zag	6 Sep 02:26	6 Sep 10:44	8
Northeast	2	Zig-zag	7 Sep 10:00	7 Sep 18:14	17
Northeast	3*	Parallel random	7 Sep 19:12	8 Sep 11:56	6
Northeast	4	Parallel random	8 Sep 15:38	8 Sep 19:35	3
Northeast	5*	Parallel random	9 Sep 09:07	9 Sep 15:33	7
Northeast	6*	Parallel random	9 Sep 19:07	10 Sep 02:58	5
South	7*	Parallel random	10 Sep 23:46	11 Sep 05:07	5
South	8	Zig-zag	11 Sep 11:08	11 Sep 14:22	6
South	9*	Parallel random	11 Sep 20:36	12 Sep 07:10	6
Northeast	10*	Parallel random	13 Sep 12:07	13 Sep 17:55	5
Northeast	11	Zig-zag	13 Sep 19:25	14 Sep 00:07	11
Northeast	12*	Parallel random	15 Sep 07:23	15 Sep 22:01	7
Northeast	13	Zig-zag	15 Sep 22:53	16 Sep 01:19	7
Northeast	14	Zig-zag	16 Sep 03:45	16 Sep 04:25	4
Northeast	15	Zig-zag	16 Sep 05:58	16 Sep 08:47	5
Northeast	16*	Parallel random	16 Sep 13:22	16 Sep 23:16	5
Northeast	17*	Parallel random	17 Sep 14:57	18 Sep 02:03	7
Northeast	18	Parallel random	18 Sep 06:39	18 Sep 10:29	4

Table 3: Catch summary for commercial trawls carried out by FV *Aoraki* during the acoustic survey on Campbell Island Rise in 2003. Estimated catch weights are from the vessel processing records. Trawl positions are shown in Figure 1.

Area	Trawl type		Tow length (n. mile)			SBW catch (t)			% SBW in catch		
		n	mean	min	max	mean	min	max	mean	min	max
Northeast	Midwater	32	8.6	0.6	25.9	15.6	0.2	60.0	99.9	96.7	100.0
	Bottom	7	10.9	5.7	18.5	1.8	0.2	3.3	71.5	50.0	82.5
South	Midwater	5	9.7	2.5	14.6	18.0	8.0	30.0	100.0	100.0	100.0
	Total	44	9.1	0.6	25.9	13.7	0.2	60.0	95.4	50.0	100.0

Table 4: Gonad stages of SBW caught in commercial trawls on the Campbell Island Rise by FV *Aoraki* during the 2003 acoustic survey. Data are arranged by date. Gonad stages are defined in Appendix 3.

		Gonad stage							
Sex	Date	1	2	3	4	5	6	7	8
Male	4 Sep	0	1	61	7	0	0	0	
	5 Sep	2	6	116	52	0	0	0	
	6 Sep	0	3	22	15	0	0	0	
	7 Sep	0	0	28	14	0	0	0	
	8 Sep	0	1	20	85	5	0	0	
	9 Sep	0	0	22	59	6	0	0	
	10 Sep	0	0	8	47	5	0	0	
	11 Sep	0	1	20	49	10	0	0	
	12 Sep	0	3	23	120	31	0	0	
	13 Sep	0	0	8	24	4	0	0	
	14 Sep	0	7	22	103	72	0	0	
	15 Sep	1	2	4	53	62	0	0	
	16 Sep	0	1	1	24	92	15	1	
	17 Sep	0	0	0	9	86	23	1	
	18 Sep	0	1	1	7	96	85	25	
	19 Sep	0	1	0	6	28	55	20	
Female	4 Sep	1	1	128	1	0	0	0	0
	5 Sep	3	4	210	6	0	0	0	0
	6 Sep	0	0	60	0	0	0	0	0
	7 Sep	0	0	58	0	0	0	0	0
	8 Sep	0	2	186	1	0	0	0	0
	9 Sep	0	1	111	1	0	0	0	0
	10 Sep	0	0	135	5	0	0	0	0
	11 Sep	1	1	108	10	0	0	0	0
	12 Sep	0	2	211	7	2	0	1	0
	13 Sep	0	0	57	7	0	0	0	0
	14 Sep	3	0	139	148	6	0	0	0
	15 Sep	0	0	5	164	9	0	0	0
	16 Sep	0	0	13	52	91	8	0	2
	17 Sep	3	2	1	132	44	93	0	6
	18 Sep	1	1	1	24	116	39	1	2
	19 Sep	0	0	1	2	4	46	4	33

Table 5: Estimates of the ratio, r, used to convert SBW backscatter to biomass for two alternative TS-FL relationships (see Section 2.5 for equations). Values are derived from the scaled length frequency distributions in Figure 6. σ is the acoustic backscattering coefficient.

		Monstad et al. (1992)			Dunford (2003)		
Mean length (cm)	Mean weight (kg)	Mean σ (m^2)	Mean TS (dB)	r (kg m^{-2})	Mean σ (m^2)	Mean TS (dB)	r (kg m^{-2})
42.7	0.583	0.000191	-37.2	3 058	0.000445	-33.5	1 311

Table 6: SBW acoustic biomass estimates from the 2003 Campbell Island Rise survey by snapshot and area. **Only snapshots 4–7 in the northeastern area were averaged to obtain the biomass estimate for this mark area (see text for details). Estimates are given using the alternative TS-FL relationships of Monstad et al. (1992) and Dunford (2003) (see Table 5) and the estimated absorption coefficient of 9.45 dB km^{-1} (see Appendix 2). 'Old' biomass estimates using the TS-FL relationship of Monstad et al. (1992) and an absorption coefficient of 8.0 dB km^{-1} and are comparable with estimates from previous SBW acoustic surveys on the Campbell Island Rise. The c.v.s of the mean biomass estimates were calculated in two ways: either by averaging the snapshot c.v.s; or by calculating the variance of the snapshot biomass estimates (in parentheses).**

				Biomass ('000 t)			
Area	Snapshot	Mark exercise	Stratum area (km^2)	Monstad et al. TS	Dunford TS	Old	c.v.
Northeast	1	3	303	16	7	12	13
	2	5	407	22	9	16	17
	3	6	579	30	13	23	24
	4	10	342	53	23	40	55
	5	12	332	46	20	40	84
	6	16	330	40	17	34	57
	7	17	276	75	32	63	49
	mean			**54**	**23**	**44**	**30 (14)**
South	1	7	393	67	29	55	60
	2	9	330	29	13	24	39
	mean			**48**	**21**	**40**	**43 (39)**
Both	**mean**			**102**	**44**	**84**	**26 (20)**

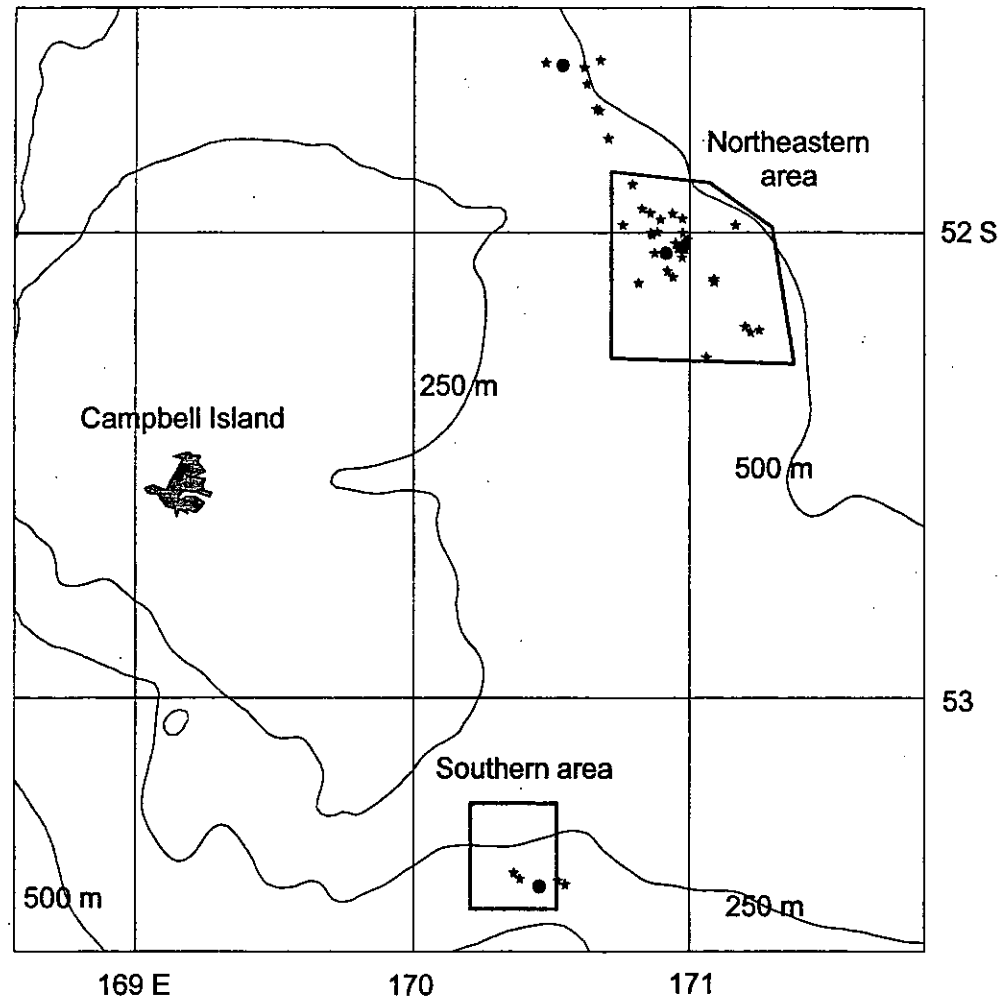


Figure 1: Survey area showing start positions of commercial trawls (stars) and CTD profiles (circles) carried out by FV *Aoraki* during the 2003 acoustic survey. Boxes show the approximate boundaries of the northeastern and southern acoustic survey areas (see Figures 5 and 6).

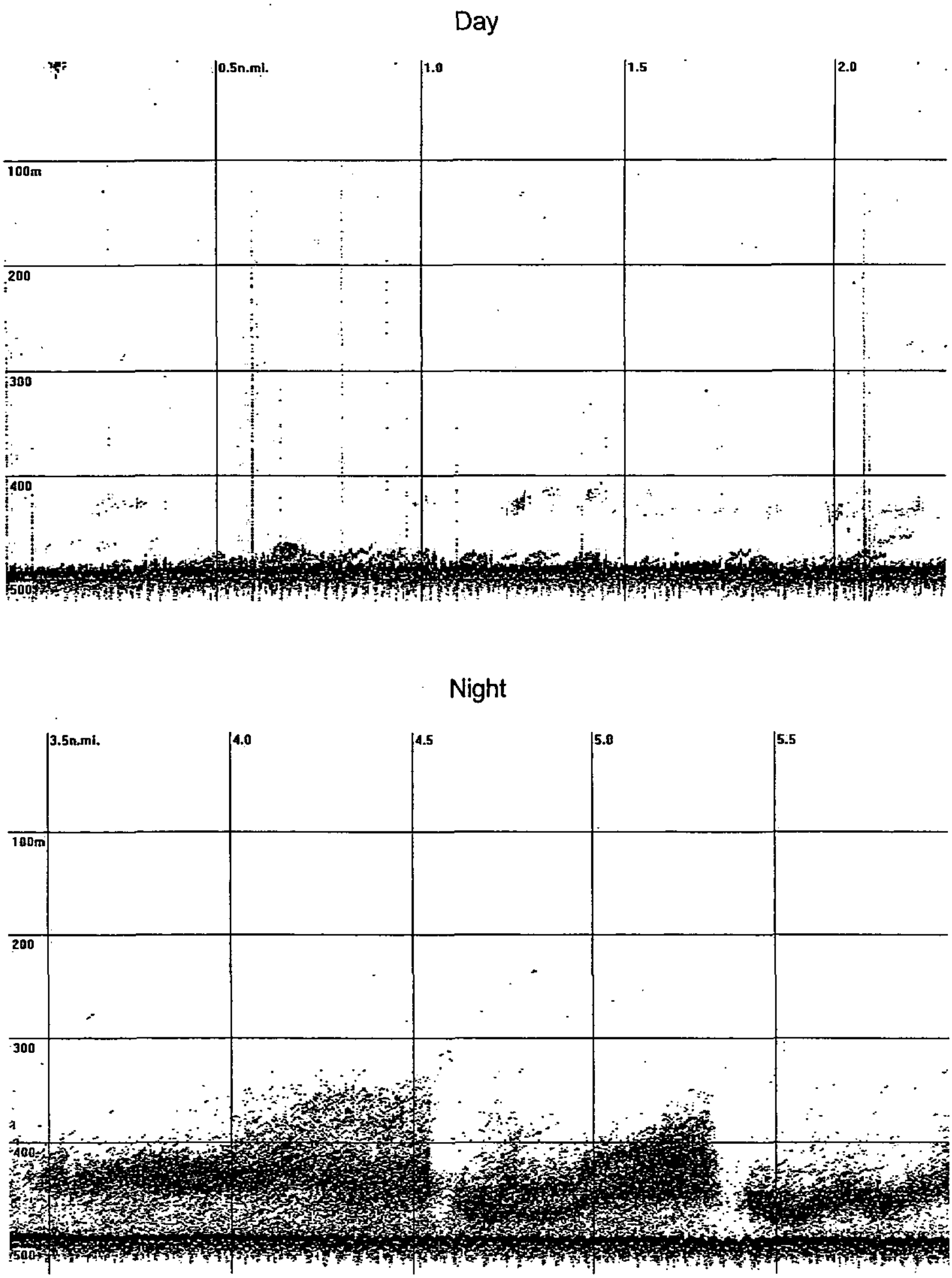


Figure 2: Echograms showing pre-spawning adult SBW in northeastern area (around 52° S, 171° E) on 7 September 2003. Upper echogram was recorded at 15:30 NZST and lower echogram at 22:30 NZST.

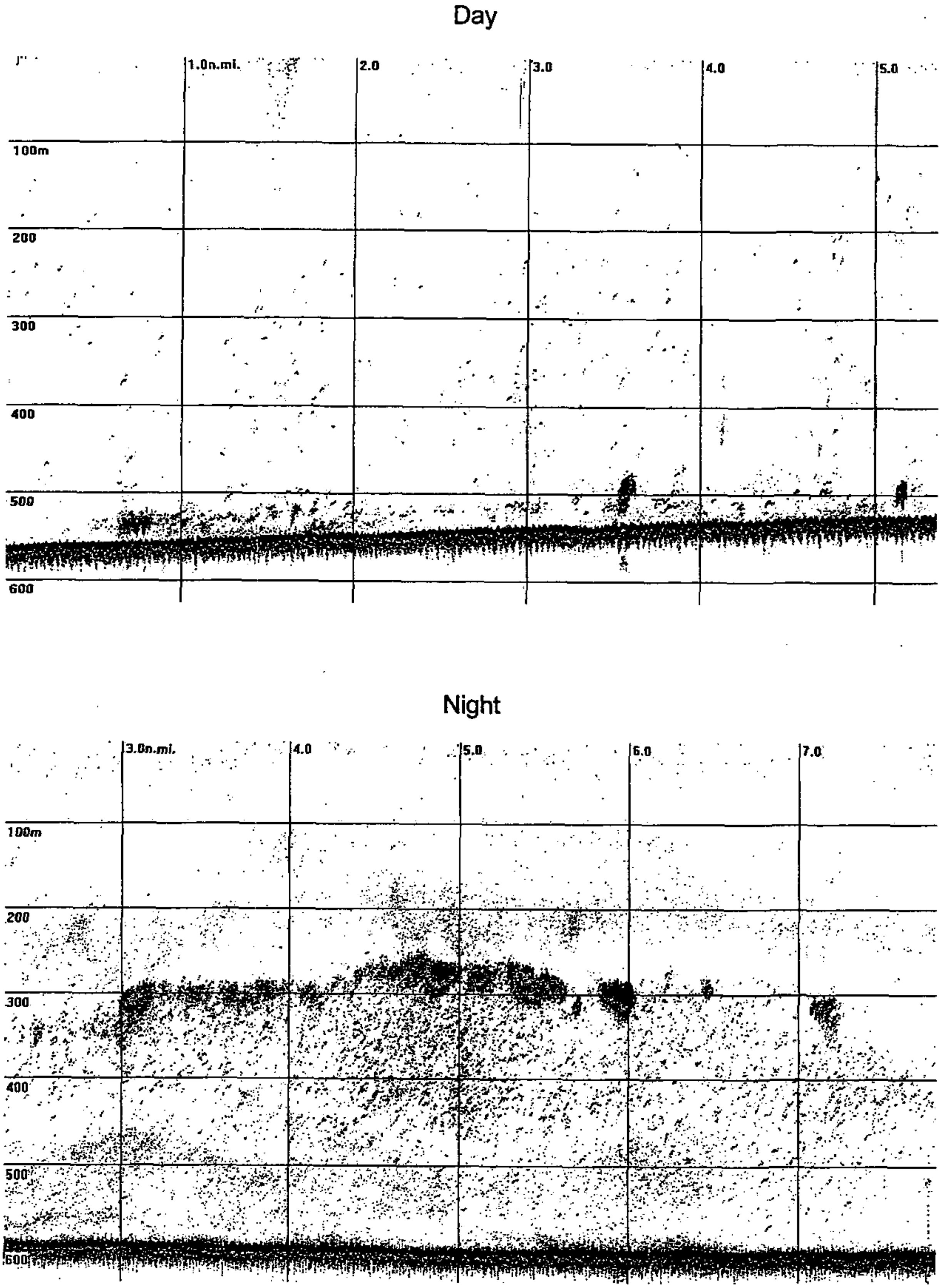


Figure 3: Echogram showing pre-spawning adult SBW in southern area (around 53° 20' S, 170° 30' E) on 11 September 2003. Upper echogram was recorded at 13:30 NZST and lower echogram at 01:30 NZST.

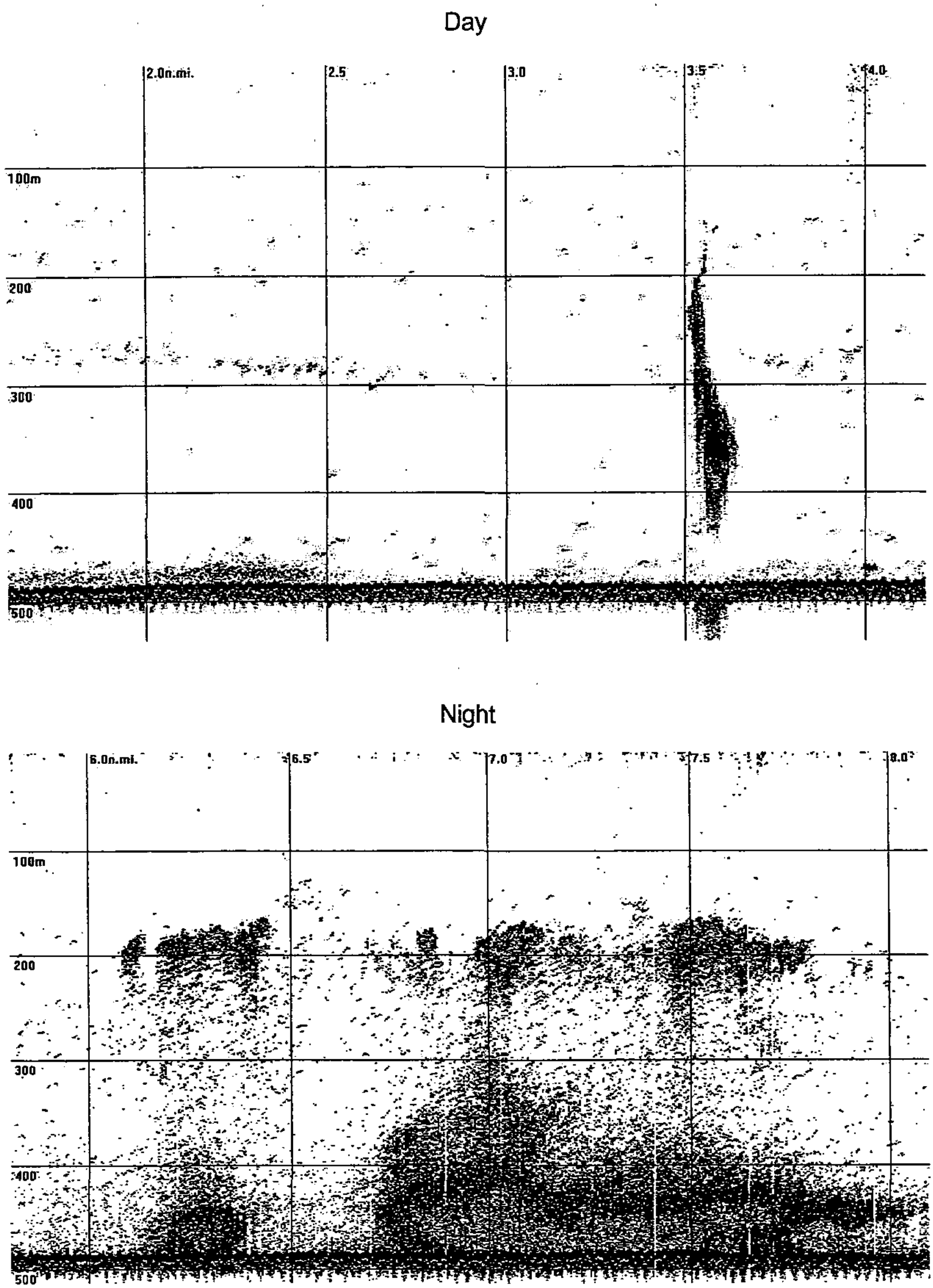
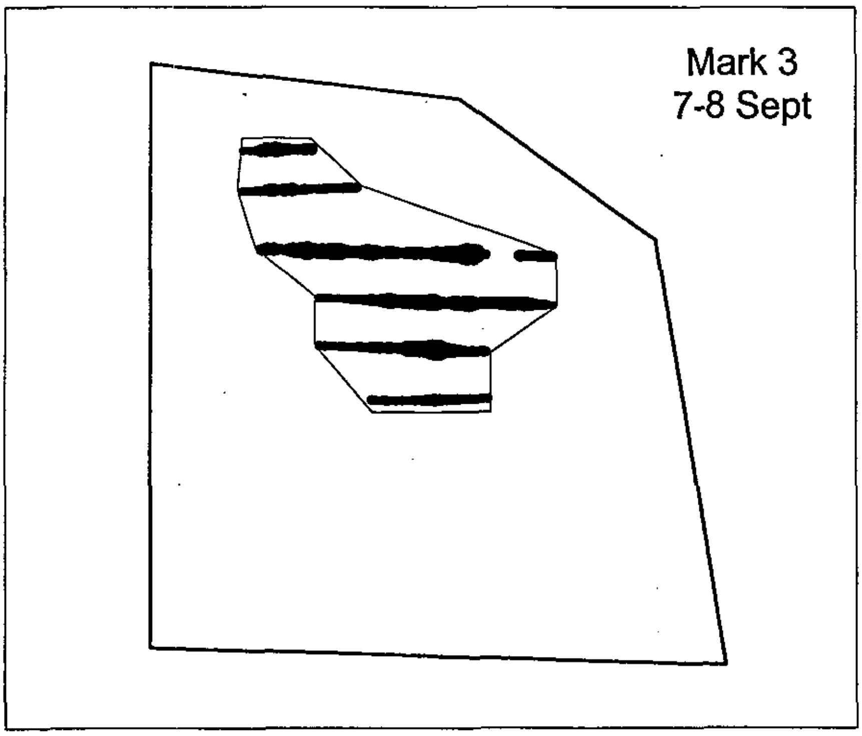


Figure 4: Echogram showing spawning SBW in the northeastern area on 16–17 September 2003. Upper echogram was recorded at 16:50 NZST and lower echogram at 20:15 NZST. A weak bottom-referenced mark is also visible at the start of the daytime echogram. This mark type was not integrated when estimating SBW biomass.



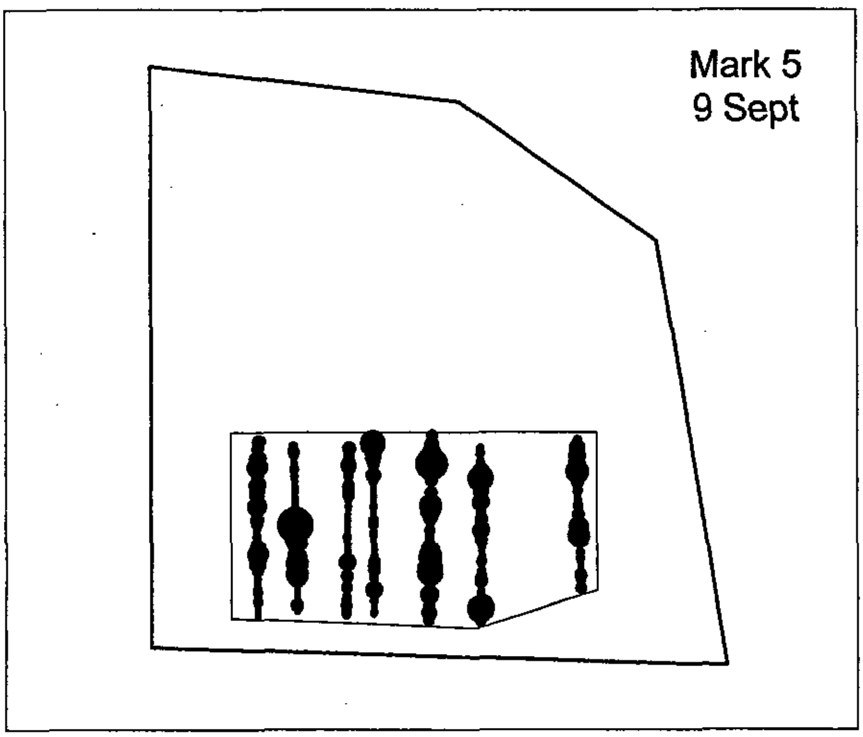
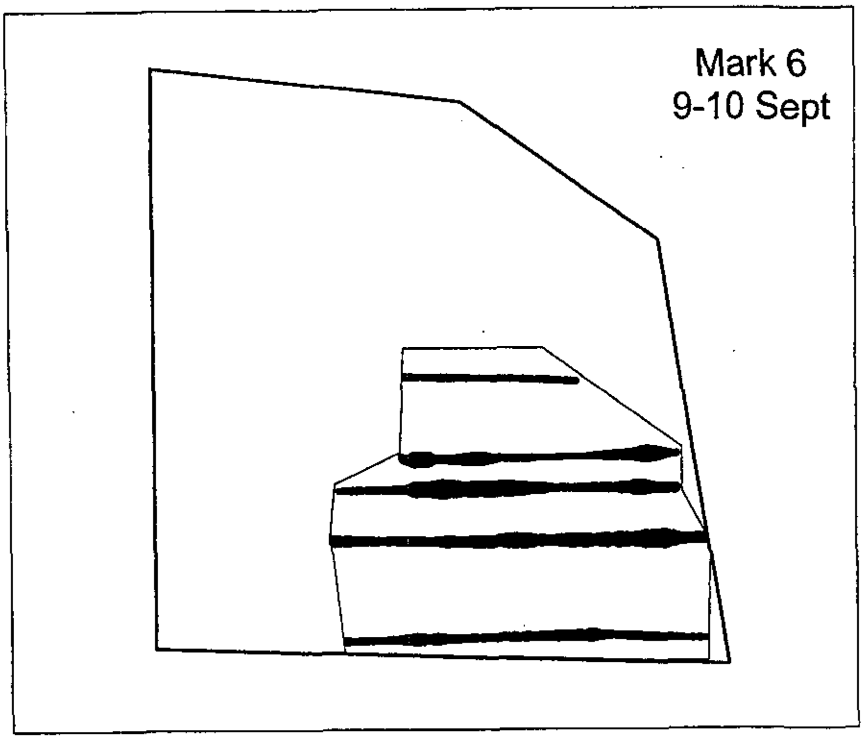


Figure 5: Spatial distribution of SBW acoustic backscatter plotted in 10 ping (~100 m) bins for Snapshots 1 and 2 of the northeastern area. Circle area is proportional to the log of the acoustic backscatter. Thin line is the mark boundary used to estimate stratum area. Bold line is the area boundary (see Figure 1).



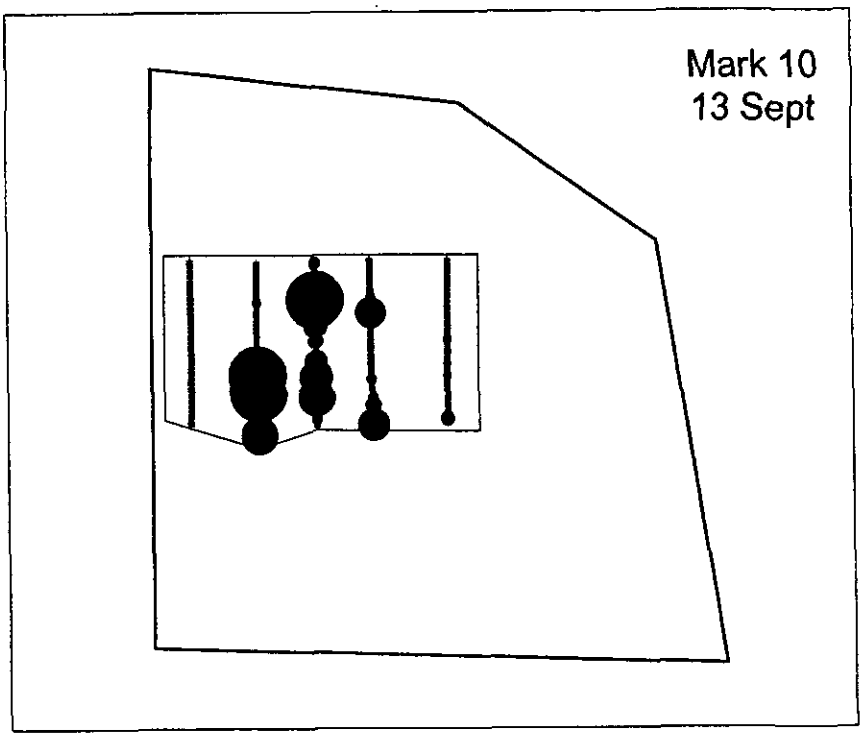
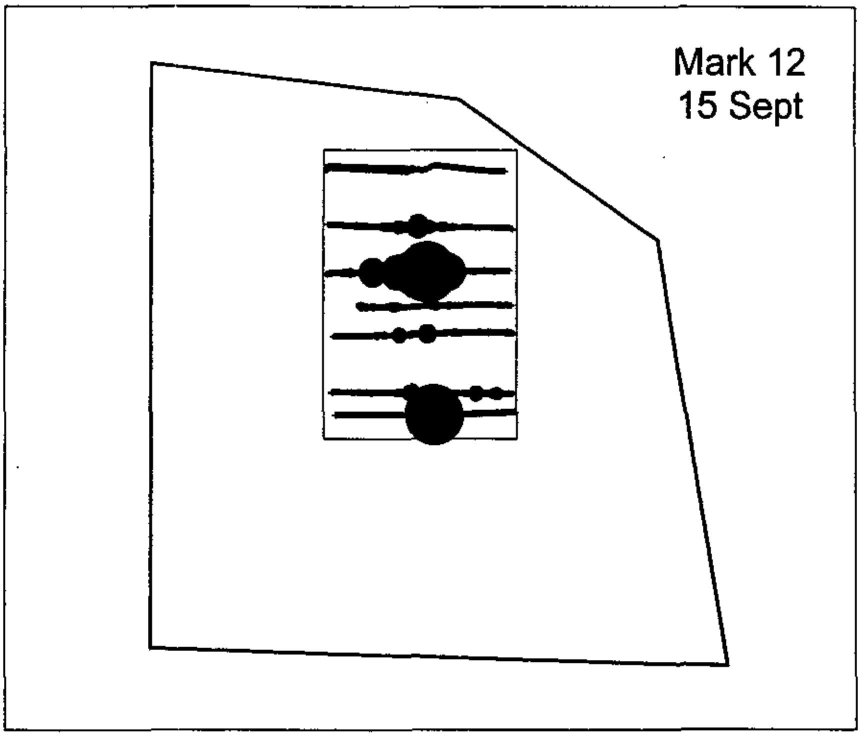


Figure 5 cont: Spatial distribution of SBW acoustic backscatter plotted in 10 ping (~100 m) bins for Snapshots 3 and 4 of the northeastern area. Circle area is proportional to the log of the acoustic backscatter. Thin line is the mark boundary used to estimate stratum area. Bold line is the area boundary (see Figure 1).



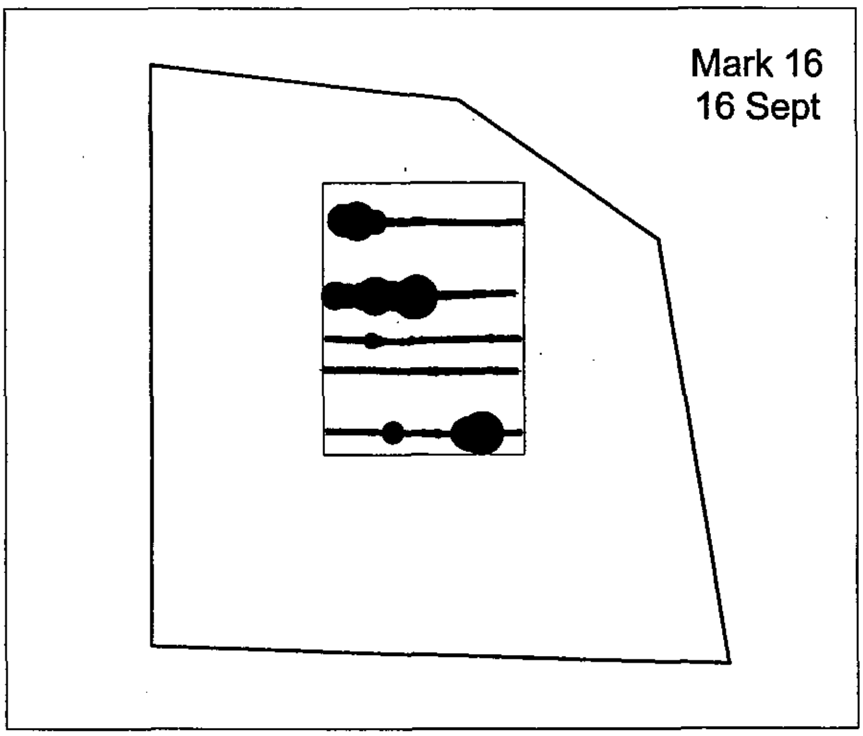


Figure 5 cont: Spatial distribution of SBW acoustic backscatter plotted in 10 ping (~100 m) bins for Snapshots 5 and 6 of the northeastern area. Circle area is proportional to the log of the acoustic backscatter. Thin line is the mark boundary used to estimate stratum area. Bold line is the area boundary (see Figure 1).

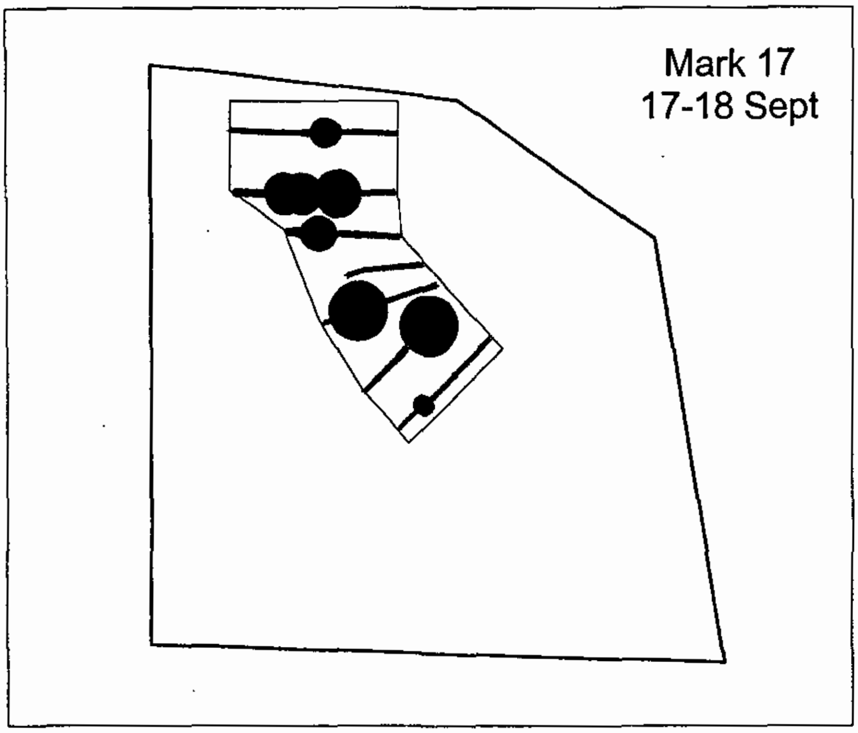
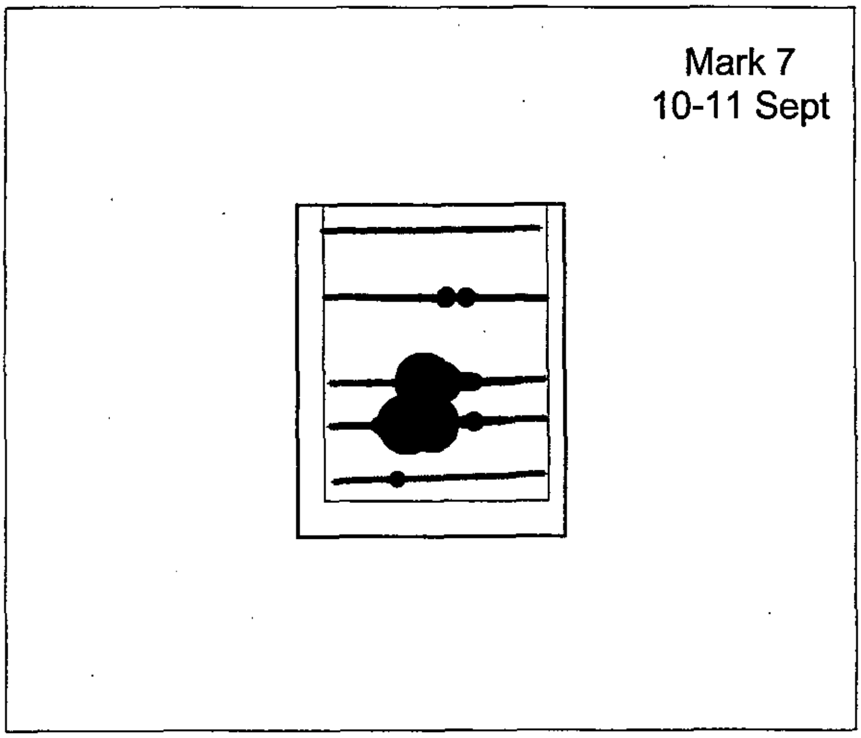


Figure 5 cont: Spatial distribution of SBW acoustic backscatter plotted in 10 ping (~100 m) bins for Snapshot 7 of the northeastern area. Circle area is proportional to the log of the acoustic backscatter. Thin line is the mark boundary used to estimate stratum area. Bold line is the area boundary (see Figure 1).



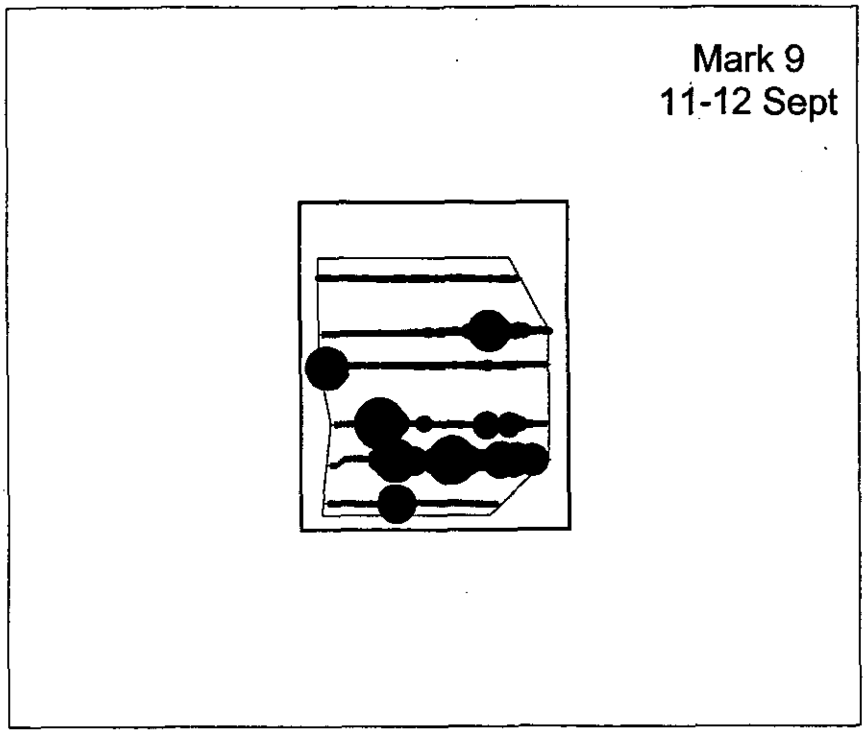


Figure 6: Spatial distribution of SBW acoustic backscatter plotted in 10 ping (~100 m) bins for Snapshots 1 and 2 of the southern area. Circle area is proportional to the log of the acoustic backscatter. Thin line is the mark boundary used to estimate stratum area. Bold line is the area boundary (see Figure 1). Scale is the same as that for Figure 5.

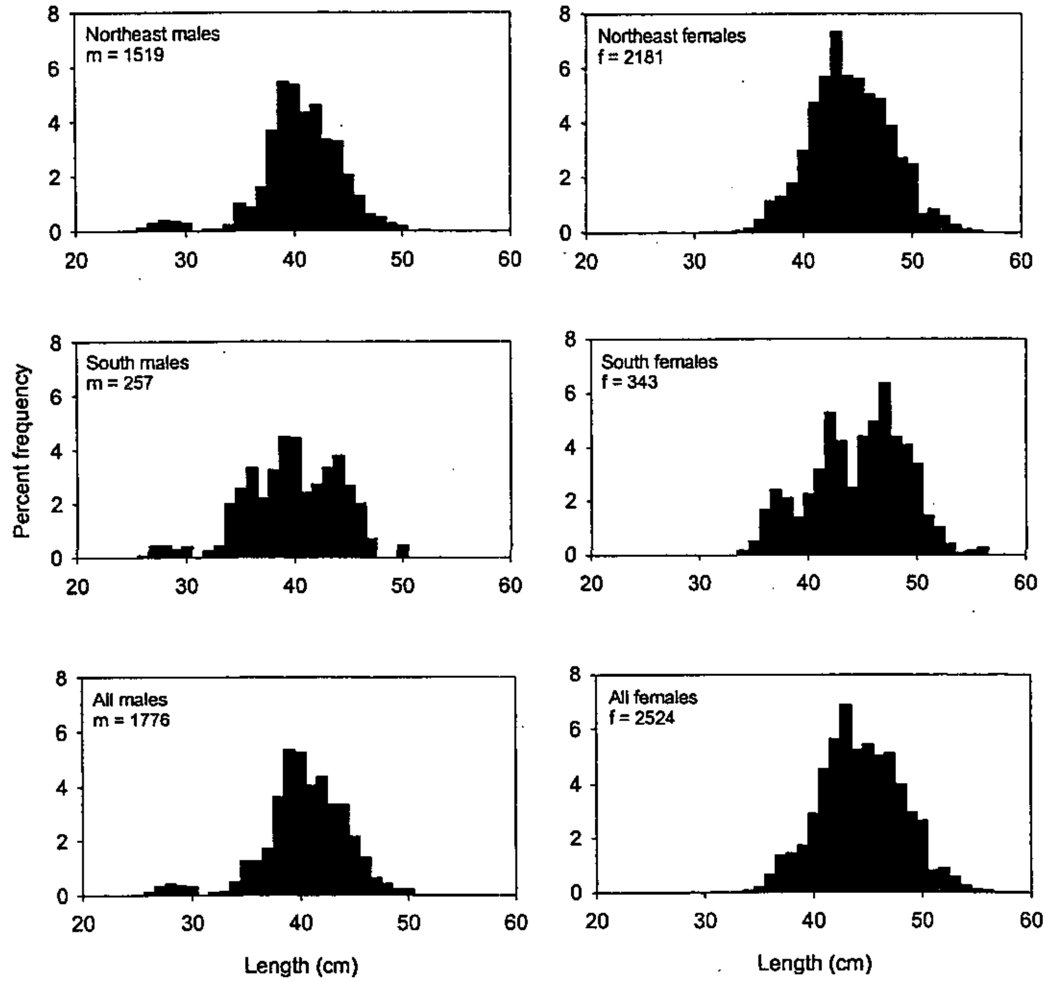
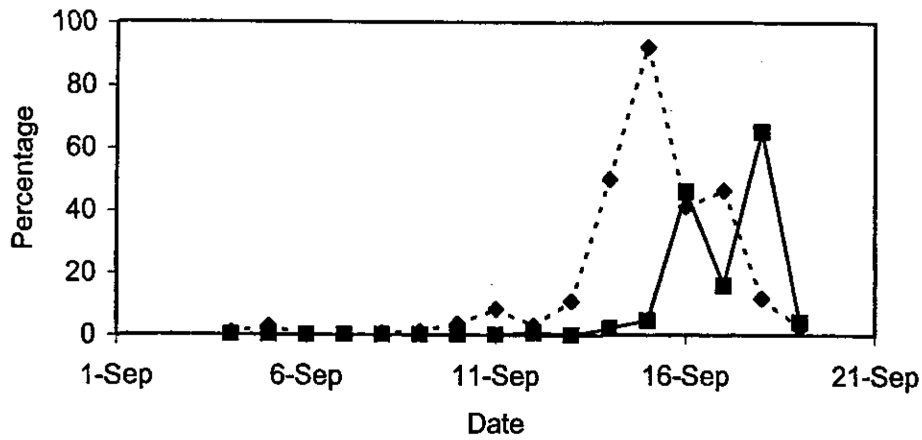


Figure 7: Scaled length frequencies of male and female SBW by area caught in commercial tows on the Campbell Island Rise by FV *Aoraki* during the acoustic survey in September 2003. m (male) and f (female) values refer to numbers of fish measured.

Female



Male

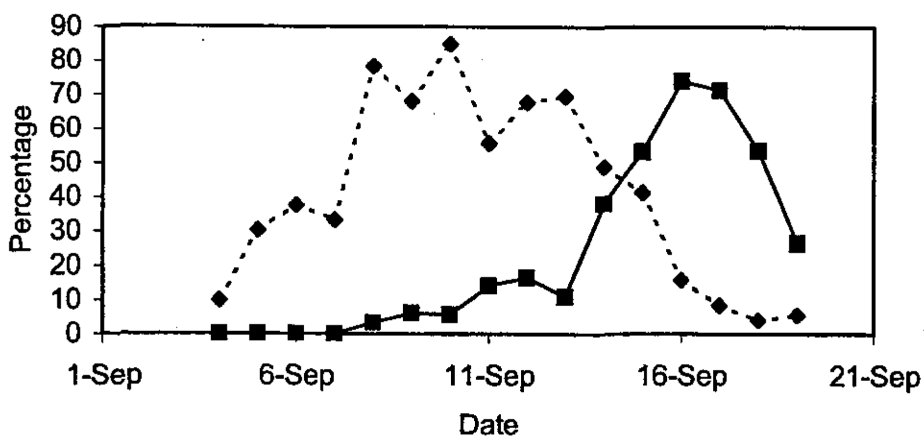


Figure 8: Percentage of ripe (dotted line) and running ripe (solid line) SBW by date. Data are given in Table 4.

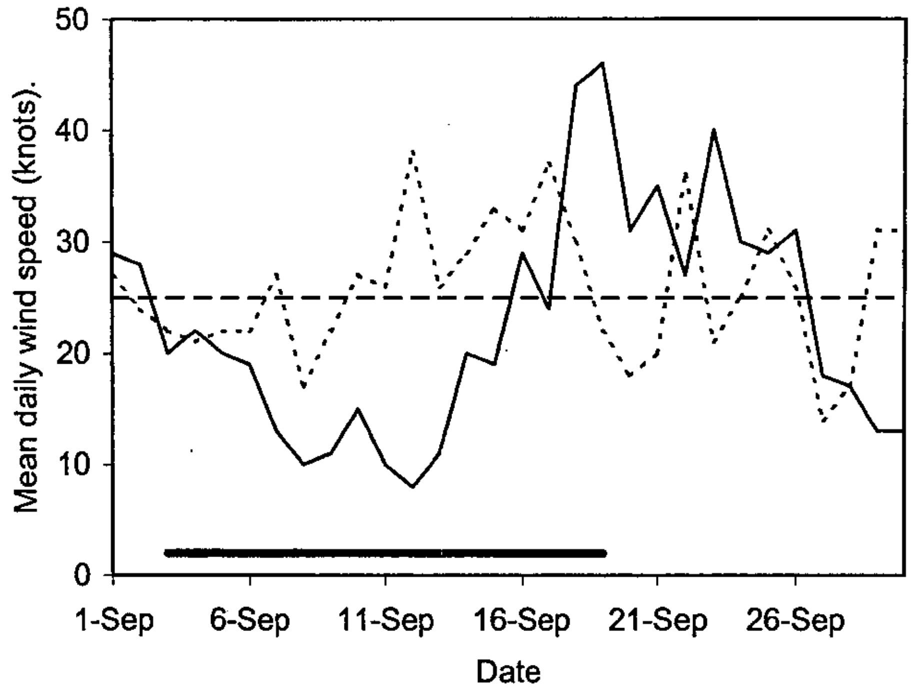


Figure 9: Mean daily wind speed at the Campbell Island meterological station in September 2002 (dotted line) and 2003 (solid line). Dashed line indicates approximate upper boundary for acoustic data collection with a hull-mounted transducer (mean wind speed of 25 knots). Bar above the x-axis shows the period of the 2003 acoustic survey.

Appendix 1: Description of systematic error in Simrad ES-60 echosounder system

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Preliminary measurements of systematic errors in the Simrad ES60 echosounder system

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1st September 2003

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Summary

The wide usage of the Simrad ES60 echosounder within the fishing industry makes it a valuable source of qualitative and potentially quantitative data. Initial investigations into the quantitative properties of the Simrad ES60 echosounder have revealed an underlying systematic ping indexed variation (1dB) in the digitised echogram data. At any given depth the variation can be described by a triangular wave of 1dB amplitude with a period of exactly 2721 pings, Figure A1.

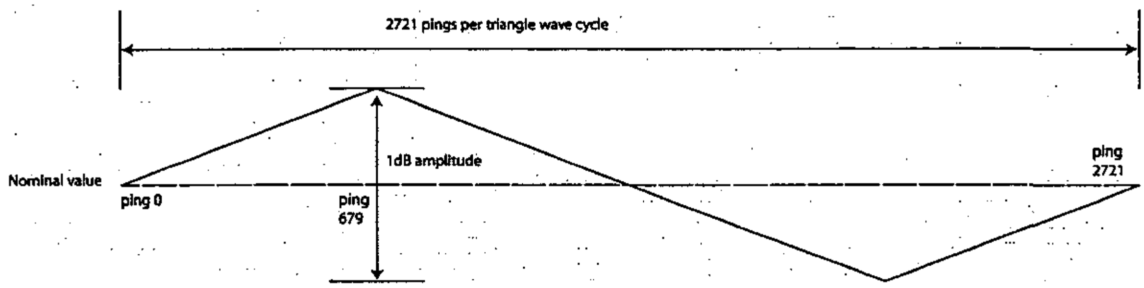

Figure A1. Diagram of the underlying triangle wave error that exists in ES60 echogram data.

Our findings show that the triangle wave metrics of amplitude and period are the same regardless of:

- Ping rate
- Power level
- Pulse repetition rate
- Echosounder mode (i.e. active, test)
- Frequency
- GPT model
- Inspection of Sv or TS data
- Depth of signal

The triangular amplitude error wave resets to the zero crossing after hardware reset. Conversely, the error wave amplitude continues from where it left off after the ES60 software was stopped and restarted; this suggests that the amplitude of the error is directly related to the ping number count. With the appropriate settings the variation in the ES60 data can be readily observed in the on-screen display by setting the sounder to a fast ping rate in test mode and a surface referenced display range to 5 meters.

A key finding is that the error wave can be observed in the tail of the transmit pulse. Therefore, sufficient information is contained within the raw echogram data to allow post-processing corrections, either on a ping by ping basis or to an echo integration interval after it has been exported. This greatly improves the Simrad ES60 for quantitative use and further tests are being carried out on other aspects of the ES 60 quantitative capabilities.

The above summary of findings is based on a CSIRO report that details the various tests and methods used, which is available upon request.

The systematic ping indexed bias in the raw data shows that it could be easily removed in software and Simrad Kongsberg were informed of this result in July 2003. We look forward to a firmware fix to this problem in the near future.

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 about 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

Four CTD casts were carried out as part of the 2003 survey (see Figure 1). 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 9.45 dB km^{-1} when estimating SBW biomass.

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

CTD station	Depth of cast (m)	Mean temperature (° C)	Mean salinity (PSU)	Mean absorption (dB km^{-1})
3	474	7.06	34.36	9.44
15	457	7.06	34.37	9.44
22	467	7.45	34.42	9.42
27	325	7.06	34.37	9.50
average	431	7.16	34.38	9.45

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 amall (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 in colour 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.