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EXECUTIVE SUMMARY

Hanchet, S.M.; Grimes, P.J.; Coombs, R.F.; Dunford, A. (2003). Acoustic biomass estimates of southern blue whiting (*Micromesistius australis*) from the Campbell Island Rise, August–September 2002.

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This paper summarises the results of the sixth acoustic survey of southern blue whiting (SBW) on the Campbell Island Rise. Two snapshots of the Campbell Island Rise were carried out between 28 August and 24 September 2002. A total of 22 research trawls was made by *Tangaroa* to determine species and size composition of the marks seen during the survey. Commercial trawl data were also used to help to determine the main fishing locations. Based on these data and previous experience, SBW marks were initially identified as adult, immature, and juvenile fish. These categories were then decomposed to provide estimates of age 1, 2, 3, and 4 plus fish.

During both snapshots, adult SBW were found on both the northern and southern grounds. In snapshot 1 they were found in strata 3S and 4 in the north, and in stratum 7 to the south. However, most of the backscatter came from a single transect in stratum 7, and this resulted in a high c.v. The adult biomass estimate for snapshot 1 was 239 600 t (c.v. = 93%). In snapshot 2, the adults were found in strata 5 and 6N in the north, and in stratum 8 (a subset of stratum 7) to the south. However, most of the backscatter again came from a single transect in stratum 7, which again resulted in a high c.v. The adult biomass estimate for snapshot 2 was 89 100 t (c.v. = 65%). In snapshot 2 a small aggregation being fished by the commercial vessels to the east of the usual survey area was also surveyed twice. The two estimates of adult biomass for this aggregation averaged 4400 t (c.v. = 62%).

Before deciding on how the acoustic estimates should be treated the timing of the survey, the treatment of the fish outside the survey area, and the variability between snapshots were considered. The timing of the survey in relation to spawning was similar to that of previous years. The biomass surveyed outside the usual survey area was not included in the time series of abundance indices to be consistent with previous surveys. Although there was a large difference in biomass between the two snapshots, the Middle Depths Working Group agreed that both snapshots should be averaged. Therefore, the average of the two snapshots was used to provide the best estimate of adult biomass from this survey and equalled 164 300 t (c.v. = 70%). The decomposed estimate of age 4 and older fish was 148 200 t.

The adult biomass estimate from the 2002 survey had a very poor precision. The main reason for this is that most of the backscatter in both snapshots came from single acoustic transects. Although there was high uncertainty associated with the biomass estimates from the 2002 survey, it seems premature to reject the acoustic surveys as a method of monitoring SBW biomass. Surveys in 1998 and 2000 obtained reliable estimates of biomass with c.v.s of less than 20%. We believe that the implementation of the following relatively minor changes to the survey design would overcome these problems in future surveys. We recommend that future surveys continue to start in late August to allow for an early start of the spawning season on the Campbell grounds; that real time estimates of transect densities be calculated on board the ship at the time of the survey; that stratum 7 be subdivided into two separate strata for snapshot 1; and that, where appropriate, the main aggregation should be repeatedly sampled using several snapshots.

The estimates of 2 and 3 year olds are almost the lowest in the time series, which suggest the 1999 and 2000 year classes are relatively weak. In contrast, the estimate of 1 year olds (the 2001 year class) is the highest on record.

1. INTRODUCTION

The four known spawning grounds for southern blue whiting (SBW) are on the Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise. Spawning occurs on the Bounty Platform from mid August to early September and 3–4 weeks later in the other areas (Hanchet 1998).

A programme to estimate SBW spawning stock biomass on each fishing ground using acoustic techniques began in 1993. The Bounty Platform, Pukaki Rise, and Campbell Island Rise were each surveyed annually between 1993 and 1995, and the Auckland Islands Shelf was surveyed in 1995 (Hanchet et al. 1994, Hanchet & Ingerson 1996, Ingerson & Hanchet 1996). After the first three annual surveys it was decided to survey these areas less regularly. The Bounty spawning grounds were surveyed in 1997, 1999, and 2001 (Grimes & Hanchet 1999, Hanchet & Grimes 2000, Hanchet et al. 2002a), the Campbell grounds were surveyed in 1998 and 2000 (Hanchet et al. 2000b, Hanchet & Grimes 2001), and the Pukaki grounds in 1997 and 2000 (Grimes & Hanchet 1999, Hanchet & Grimes 2001).

The current report stems from an objective carried out under contract to MFish: "To estimate pre-recruit and spawning biomass on the Campbell Island Rise during August and September 2002, using an acoustic survey, with a target coefficient of variation (c.v.) of the estimate of 30% (SBW2001/02)."

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 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 areas. Attempts to quantify pre-recruit biomass in previous surveys by separation into an "immature" (mainly 2 year old fish) category was problematic due to the occurrence in some years of 2 and 3 year old fish in mixed schools (Hanchet & Ingerson 1996). The problem was resolved by decomposing the SBW categories into numbers at age (Hanchet et al. 2000c).

As in previous years, SBW acoustic marks in the 2002 survey were initially classified into adult (recruited fish), immature (mainly 2 year olds), and juvenile (1 year olds). These categories were then decomposed to provide estimates of 1, 2, 3, and age 4 plus fish following Hanchet et al. (2000c).

2. METHODS

2.1 Acoustic survey

2.1.1 Acoustic survey design

Various acoustic survey designs for SBW stocks were investigated by Dunn & Hanchet (1998) and Dunn et al. (2001). These two 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 (see also Thompson & Seber 1998). In the absence of this information, they concluded that two-phase sampling strategies should be used, with up to 20% of stations 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 the 2002 survey of the Campbell Island Rise, information from both sources was used to redefine the survey strata and the associated sampling effort for snapshot 2.

2.1.2 Stratification and transect allocation

The stratification and allocation used in previous surveys of the Campbell Island Rise were reviewed by examining the spatial distribution of SBW from historical catch effort data and from previous acoustic surveys. Stratification for the 1998 and 2000 surveys had proved successful and so the stratification was retained for snapshot 1 of the 2002 survey (Figure 1).

It was proposed to carry out two snapshots of the Campbell Island Rise. To achieve an overall target c.v. of 30% would require individual snapshot target c.v.s of about 40%. Transects were allocated to strata by examining the location of historical fishing effort and previous acoustic survey results. During the 1980s most fishing effort tended to be focused on the northern strata (particularly 2 and 4), whereas in the 1990s it has been focused more on the southern strata (particularly 5 and 7). The transect allocation using these two data sets therefore gave somewhat conflicting results.

In previous years we have also run optimisation programmes on the previous acoustic survey results (Hanchet et al. 2001). However, in recent acoustic surveys strata containing the fish have often been subdivided to improve sampling precision. For example, in 1998 and 2000 strata 3, 4, 6, and 7 were all subdivided for one or both snapshots. It has therefore become difficult to use these transect density estimates in transect optimisation simulations. Instead we visually examined the acoustic results of all five surveys. During these five surveys most fish were surveyed in snapshot 1 in the region of strata 3S and 4 and in stratum 7. The final allocation schedule shown in Table 1 was almost identical to that used for the 1998 and 2000 surveys. It gave most weighting to stratum 3S followed by strata 4 and 7, which have been the most consistent areas of high density.

Seven phase 2 transects were set aside for allocation during each snapshot to strata which recorded high densities in the first phase. Because of potential problems with fish movement, and to avoid excessive steaming time, the phase 2 transects were carried out whilst phase 1 was in progress. Because density estimates were not available during the survey, the allocation of phase 2 transects was made on an *ad hoc* basis to the stratum where the densest marks were seen during phase 1.

2.1.3 Acoustic snapshots

During the first snapshot the main marks in the northern area were seen in stratum 4, and so an additional seven transects were allocated there. Several Japanese vessels arrived just after the phase 2 transects were finished and started fishing the area. Observers reported that the fish started spawning shortly after we left the area (see also Section 3.2). Few marks were seen in strata 5 and 6, but one very dense spawning mark was found in a single transect in stratum 7. This stratum already had nine transects, and the phase 2 transects had already been used up, so no further phase 1 transects were completed there.

Snapshot 2 was begun immediately after snapshot 1 had finished, and surveyed the area from south to north (i.e., from stratum 7 through to stratum 3S). The stratification and allocation of transects in snapshot 2 was adapted to reflect both the fish distribution in snapshot 1 and the predicted post-spawning fish distribution. The main change to the stratification was in stratum 7 (Figure 2). The area where the fish had been found in snapshot 1 was divided off as a separate stratum (stratum 8), and 10 short (10 n. mile) transects were completed there. The other changes to the stratification were in stratum 7 which was divided into two strata (7N and 7S) by a line at 53°S, and stratum 6 which was divided into two strata (6N and 6S), at 52°40'S (see Figure 2). Few SBW marks were found in the southern strata.

A commercial vessel told us that they had been fishing an aggregation outside the survey area to the east of stratum 6N since early September (see also Section 2.2.1 and Figure 3). Although this was outside the survey area, we considered it was important to survey this aggregation to determine its approximate size. By the time we reached the area on 13 September all the commercial fleet had moved from the northern aggregation in stratum 4 to this new area. We made contact with one of the commercial vessels and found the approximate boundary of the area being fished by the vessels. We then surveyed this area (stratum 8F1) (see Figures 2 and 3) with six transects during the night of 13–14 September. During the night and early morning we kept track of the vessel positions and then repeated the exercise and surveyed a smaller area (stratum 8F2) (see Figure 2) with a further seven transects during the day on 14 September.

We surveyed strata 3S, 4, 5, and 6N over the next week and found adult marks only in strata 5 and 6N. During this time the weather conditions worsened and two days were lost to bad weather. In previous years the fleet has usually moved into strata 5 and 6N after the fish have finished spawning their first batch of eggs. Previous acoustic surveys have also mainly found post-spawning adult fish in these two strata. We therefore decided not to survey strata 2 and 3N, but instead to focus the remaining survey time on phase 2 for the adults, on further target identification, and on target strength work. The main marks were seen in stratum 5, so a further four phase 2 transects were placed in this stratum. The acoustic transects were completed on 20 September.

2.1.4 Acoustic transects

The random parallel transect design of Jolly & Hampton (1990) was used in all strata with transects being run perpendicular to the depth contours, i.e., from shallow to deep water or vice versa. The mid position of each transect was randomised for each snapshot. The minimum distance between transects varied amongst 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.

Thus, the minimum distance was large enough to ensure that no large areas were left unsurveyed within each stratum, as in previous surveys (Hanchet & Grimes 2001). At times the direction of transects was altered to allow the survey to continue despite poor weather conditions. Minimum distances of 2 n. miles between the end of one transect and the start of the next reduced spatial correlation between transects in such instances.

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. 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.

2.1.5 Acoustic equipment and calibration

The acoustic data were collected with NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs 1994) and the configurations used were closely similar to those described in detail by Hanchet et al. (2002a). The backscatter data were collected with one of two split-beam, towed systems ('Towbody1' or 'Towbody3') towed at between 50 and 100 m depth. A hull-mounted single beam system was used for four transects at the end of the survey. The towed systems were calibrated in the large tank at Greta Point before the survey. Towbody1 has had several 'deep drop' calibrations during oreo and orange roughy surveys (e.g., Doonan et al. 2001) and the constants used for biomass estimation were derived from these with the tank measurements providing confirmation. Towbody3 was calibrated at anchor in Perseverance Harbour, Campbell Island, during the voyage and also on orange roughy and hoki surveys immediately before this survey. For the hull system, calibrations from previous years were used.

The calibrations generally followed the approach described by Foote et al. (1987). A 38.1 mm ± 2.5 μm diameter tungsten carbide sphere with nominal target strength of –42.4 dB was used as a calibration standard. This was suspended on a single nylon line about 20 m below the transducer for towed body calibrations, and depending on the location, the whole assembly was lowered down the water-column. For hull calibrations the sphere was suspended on three lines about 30 m below the transducer as described by Foote et al. (1987).

The effective pulse length for all systems was 0.78 ms and the sample rate 4 kHz. The transmitted frequency was 38.156 kHz for the towed bodies and 38.000 kHz for the hull. The interval between transmissions was 2 s for the towed systems and 3 s for the hull. Effective beam angles, gains, combined transmitter and receiver responses and other parameters are shown in Appendix 1.

Data were also collected at 12 kHz on the hull system, but this was not calibrated nor used in the biomass estimate.

2.2 Acoustic mark identification and SBW categories

Acoustic mark identification was based on an examination of the location of trawls made by the commercial fleet, on the results of targeted research trawls using *Tangaroa*, and on experience gained from earlier acoustic surveys (e.g., McClatchie et al. 1998, Hanchet et al. 2002b).

2.2.1 Commercial trawls

The first vessel started fishing on Campbell Island Rise in mid July, and for the next six weeks most trawls were made to the east of the acoustic survey area (Figure 3). The vessel returned to port just as the acoustic survey started but returned to the eastern area and continued to fish a small area at about 172° E from 4 to 11 September. At the same time most of the other commercial vessels arrived on the Campbell grounds and fished on the boundary between strata 3S and 4 from 4 to 11 September (Figure 3). The vessels moved from the northern ground to the eastern aggregation on 12 September. They caught about 3000 t from this aggregation over 3 days and by 15 September they had all moved south to stratum 7. They remained fishing the southern area from 16 to 20 September, when the second acoustic snapshot finished. Over the next week the vessels gradually moved north and east through stratum 7N, 5, and 6N. Very little fishing was carried out after 29 September, but the last vessel did not leave the grounds until 13 October.

2.2.2 *Tangaroa* trawls

A total of 22 trawls were made to identify targets and collect biological samples (Table 2). The size distribution of the trawls is shown in Figure 4. Midwater trawls were made using the NIWA 119 midwater trawl (headline height ca. 40 m), whilst bottom trawls were made using the orange roughy 'ratcatcher' wing trawl (headline height ca. 4.5 m). All trawls were made with a 40 mm mesh liner in the cod end. Trawls ranged from 10 to 20 minute duration when targeting dense marks, to a maximum of 60 minutes when targeting less dense marks or background layers. The trawls caught a wide range of species, but the catches were largely dominated by southern blue whiting (Table 2). The next most abundant species were ling, banded rattail, arrow squid, javelinfish, and silverside.

Most target identification work focused on the less dense pre-recruit SBW marks and other light marks seen in the survey area. However, several trawls were also targeted at dense marks, which were suspected of being adults (trawls 3, 9, 10). These trawls generally contained a high proportion of adult SBW, and confirmed that the dense marks in strata 4 and 7 comprised mainly pre-spawning and spawning SBW. Several trawls in snapshot 2 confirmed the presence and extent of post-spawning SBW in moderately dense marks in stratum 5 (trawls 15, 16, 18). The high catch of ling and javelinfish on trawls 3 and 11 is probably due to the use of a bottom trawl for these tows, and is not representative of the true species composition of the spawning schools.

Several background trawls (trawls 5, 6, 7, 12) were made on less dense marks at depths of 400–450 m in strata 4 and 5. These trawls contained a mix of SBW and other species. The proportion of SBW was low, ranging from 10 to 30%, and they were dominated by 2 year old fish (with a mixture of 1, 3, and 4 year olds). There also appeared to be a trend in the size distribution with depth in this depth range with a higher proportion of smaller fish shallower and larger fish out deeper (Figure 4).

We also carried out 10 trawls in water of less than 400 m bottom depth (Table 2). Trawls that targeted moderately dense marks made quite large catches of juvenile (1 year old) SBW, such as trawl 2 which caught 250 kg and trawl 4 which caught 100 kg. (Note that a 1 year old SBW weighs only about 30 g, so a catch of 100 kg is over 3000 fish). Both trawls were made in areas where moderately dense marks were seen on the acoustic transects. However, trawls in other areas in this depth range sometimes made reasonable catches of squid, silverside, and oblique banded rattail.

Two other trawls provided useful identification of two moderately dense areas of marks seen during the survey. Trawl 8 was a midwater trawl targeting a series of pelagic marks, which were about 20–50 m above the seabed in a depth of about 500 m. These marks were part of a dominant mesopelagic fish layer seen in most transects around the Rise over bottom depths of 400–600 m. The trawl had large numbers of myctophids (mainly *Lampanyctodes hectoris*) caught in the meshes throughout the length of the trawl and codend. Trawl 11 was a bottom trawl carried out at a depth of 600 m on moderately dense marks at the south of the survey area. This layer appeared to comprise mainly javelinfish and ling (Table 2).

Separate acoustic recordings were made for all trawls using the 12 kHz and 38 kHz hull-mounted transducers. The categories assigned to the various marks are considered in the next section.

2.2.3 Acoustic marks and SBW categories

As mentioned above, very dense acoustic marks were seen in deep water (over 450 m) in strata 3S, 4, and 7 in snapshot 1 and at the beginning of snapshot 2 (Figure 5). These marks were classed as adult SBW both because of their high density and also because of the distinctive characteristics of the marks. Their identity was confirmed by several *Tangaroa* trawls and by the location of the commercial trawls.

Moderately dense marks were seen on the bottom during the day in several strata during snapshot 2. These marks occurred sporadically in some sections of most transects in stratum 5 between depths of 400–460 m (Figure 6). In places they also extended out to strata 6N, 8F1, and 8F2. In general the marks formed a series of small relatively dense marks on or close to the seabed during the day and a less dense diffuse layer in the bottom 100 m at night. Several trawls by *Tangaroa* showed that the fish in stratum 5 were post-spawning adult SBW, and this was confirmed by the location of tows by commercial vessels for this and the other strata during mid–late September.

Light marks were seen at times in depths of 400–450 m in snapshot 1. These were similar to the moderately dense marks above but the marks tended to be shorter and more discrete. On the basis of several background trawls made by *Tangaroa*, these marks were assigned an 'immature' SBW category. This is consistent with trawls carried out in previous surveys of the Campbell grounds marks at this depth (Hanchet et al. 2002b). No such marks were identified in snapshot 2, probably because the adults had moved into shallower water by then.

There was a range of marks in depths of 300–400 m in the inshore strata. Although 10 trawls were carried out in this depth range, there was still considerable uncertainty over the mark identification. Large catches of juvenile (1 year old) SBW were caught in areas where moderately dense marks were seen (Figure 7). However, other trawls on less dense marks made reasonable catches of squid, silverside, and oblique banded rattail. For the analysis, the moderately dense marks were assumed to comprise 100% juvenile (1 year old) SBW. This is probably an overestimate because even the trawls dominated by juvenile SBW still comprised as much as 40% of other species. The less dense marks were assumed to be other species.

Three other areas of fish marks were seen during the survey. A very extensive area of moderately dense mesopelagic fish marks were seen on almost every transect in the survey area in bottom depths of 400–600 m. During the day they were usually located in a band 20–50 m above the seabed. The marks appeared as a series of small schools, rather than a continuous layer, and were usually off the bottom. However, at dusk and dawn the marks appeared to broaden and almost touch the seabed before rising up into midwater (Figure 8). At night these marks broadened into a band located within 150–300 m of the surface. The marks were identified as *Lampanyctodes hectoris* by *Tangaroa.* A second mesopelagic layer was seen in shallower water (less than 350 m) around much of the Rise. This showed similar characteristics to the deeper *Lampanyctodes* layer and based on trawls from previous surveys probably comprised mainly pearlside (*Maurolicus australis*).

The third area of moderately dense marks occurred at the southern edge of the survey area in 500–600 m. The mark was identified as javelinfish by *Tangaroa* and from previous experience. No dense marks were observed which could not be identified. Less dense marks covering a large part of the survey area were generally classified as non-SBW in line with previous acoustic surveys.

The size distributions used to decompose the biomass from the SBW categories into numbers at age were taken from the *Tangaroa* trawls for the juvenile and immature categories, and from the observer data for the adult category (Figure 9). All trawls made shallower than 400 m caught only 1 year old SBW, and so these trawls were summed to represent the size of the juvenile category. The four background trawls made on the light marks in 400–450 m were used to decompose the 'immature' SBW category. These trawls were dominated by 2 year old SBW, but included a mixture of 1, 3, and 4 year old fish (Figure 9). The commercial length frequency data were used to decompose the adult category. Firstly the data were examined to determine whether there were size differences between the aggregations seen in the north, east and south. There was little difference in the size distribution of fish from commercial vessels between the northern and eastern aggregations but the fish from the southern aggregation were consistently larger. Adult biomass from the northern strata (3S, 4, 5, 6N, and 8F) was therefore decomposed using the scaled LF distribution from trawls taken north of 52° 30'S, whilst adults from the southern strata (7, 7N, 7S, 6S, 8) were decomposed using the scaled LF distribution from trawls south of 52° 30'S.

In summary the size distributions from the research and commercial tows were used to assign the main SBW marks seen during the survey into the following categories:

- Characteristic moderately dense marks in 300–400 m were the juvenile SBW category (1 year old).
- Characteristic light marks in 400–450 m were the immature SBW category (mainly 2 year old).
- Dense marks deeper than 450 m in snapshot 1 and in 400–460 m in snapshot 2 were the adult SBW category and divided into:
  - Fish in the northern strata (3S, 4, 5, 6N, and 8F) decomposed using the northern LF.
  - Fish in the southern strata (7, 7N, 7S, 6S, 8) decomposed using the southern LF.

2.3 Analysis of acoustic data

The average areal acoustic backscattering on each transect was calculated using standard echo integration (Burczynski 1979) of the SBW marks identified from echograms. To calculate the mean SBW density for each stratum, the mean areal backscattering was multiplied by the mean weight per fish and divided by the mean backscattering cross section (per fish). Target strength-fish length and fish weight-fish length relationships (male, female, and average) were used together with the length frequencies to estimate the mean weight and mean backscattering cross section in each area.

In previous surveys the target strength-fish length relationship for blue whiting in the northern hemisphere given in Monstad et al. (1992) was used for the analysis. Recent studies on gadoids in the northern hemisphere (Rose 1998) have suggested a higher target strength (similar slope but higher intercept). *In situ* target strength data collected during the 1998 and 2000 southern blue whiting acoustic surveys agree moderately well with the recent northern hemisphere relationship (Dunford 2001). However, preliminary results from recent New Zealand swimbladder modelling studies suggest a higher target strength, and possibly also steeper slope, than the recent Northern Hemisphere studies (Dunford 2001). The target strength-fish length relationship used in previous years was retained in the current analysis because it is not yet known which alternative relationship is most likely. 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. Target strength data collected during the 2002 survey will be presented in a separate document (Dunford et al. unpubl. results).

The weight-length relationships, which apply to spawning fish, were taken from Hanchet (1991). The target strength–fish length relationship

$$TS = 21.8 \log_{10} FL - 72.8$$

was used, where TS is target strength (dB re 1 μPa at 1m) and FL is fork length in centimetres (see Grimes & Hanchet (1999) for further details).

The mean SBW stratum density for each SBW category was multiplied by the area of the stratum to obtain biomass estimates for each stratum which were then summed over all strata to produce an estimate for the snapshot, from the formulae given by Cordue (1991). Biomass estimates were also decomposed into numbers at age 1, 2, 3, and 4 years and older using the length frequency data given in Figure 9 together with the age-length key derived from the commercial and research tows on the Campbell Island Rise following Hanchet et al. (2000c).

No allowance has been made for the contribution of other species here. However, as stated above it is only likely to be significant for the 1 year old SBW marks.

2.4 Gonad data

Staging data for female fish (using the five stage system given by Hanchet (1998)) were recorded by scientific observers on each ground during the season. Data were examined to define spawning times on each ground and to determine whether there was any evidence of turnover. Turnover would be occurring if large numbers of fish had spawned and left the area during the survey or before it began, or if new fish arrived on the ground during the survey or after it had ended. The gonad data were used to determine whether large numbers of spent fish were present in the area before or during the survey, or if there was a large increase in spent fish followed by an increase in ripening fish (i.e., fish which had not already spawned that year) during the survey or after it had been completed.

3. RESULTS

3.1 Acoustic biomass estimates

The results of the two snapshots completed on the Campbell Island Rise are shown in Table 3 and Figures 10–12. During snapshot 1, adults were found on both the northern and southern grounds (Figure 10). The most important stratum on the northern ground was stratum 4 with a biomass of 12 200 t (c.v. = 53%). The most important stratum on the southern ground was stratum 7. However, the fish were seen only on one transect, and this resulted in a biomass of 220 600 t with a very high c.v. of 101%. The overall adult snapshot biomass was 239 600 t (c.v. = 93%). Immature fish marks were only seen on a few transects in strata 4 and 7 (Figure 11), resulting in an immature biomass estimate of 1150 t (c.v. = 76%). Juvenile fish were found in several transects in strata 2, 4, and 5 (Figure 12). The juvenile biomass estimate was 7200 t (c.v. = 48%).

During snapshot 2, the adults were again confined to a small area in the southern ground occurring on three transects in stratum 8 (see Figure 10). However, most of the backscatter again came from a single transect, and this resulted in a biomass of 63 500 t with a c.v. of 88% (Table 3). The small dense spawning aggregation measured about 4 n.miles long by about 2.5 n.miles wide. Few fish were found in the rest of the southern strata 7S, 7N, or 6S. In the northern strata adult SBW were found in most transects in stratum 5 and two transects in stratum 6N. The adult biomass estimate for snapshot 2 was 89 100 t (c.v. = 65%). No marks, which could be classed as immature fish, were found in snapshot 2. Small numbers of juvenile fish were seen in the second snapshot, but these were again in strata 4, 5, and 7 (Figure 12). The juvenile biomass estimate was 2400 t (c.v. = 41%).

In snapshot 2 we also surveyed an aggregation being fished by the commercial vessels outside the usual survey area. Adult SBW were seen on two transects in stratum 8F1 and four transects in stratum 8F2 (see Figure 10). No particularly dense marks were found in either fleet stratum, although fish densities were comparable to those seen in strata 5 and 6N. Estimates of adult biomass from the two strata were 6900 t (c.v.=78%) and 1900 t (c.v. = 44%) respectively and averaged 4400 t (c.v. = 62%).

The decomposed biomass estimates by age class are shown in Table 4.

3.2. Gonad data

Spawning started early this year on the Campbell Island Rise. Observers sampled the first fish on the northern ground on 4 September, and by 5 September the fish had started spawning (Table 5a). The first spawning was finished by 11 September. Data collected by *Tangaroa* from 7 to 9 September showed that fish in the southern aggregation were spawning at a similar time (Table 5b). A commercial vessel was also fishing out to the east on a third aggregation in early September. Although no gonad staging data were collected, the echotraces recorded by the vessel from this aggregation over the same period had typical SBW spawning marks. The commercial vessels then moved south and recorded fish spawning their second batch of eggs from 18 to 22 September. By late September most fish were spent or resting.

Data were also examined for evidence of turnover. Fish examined at the beginning of the survey had not spawned because ovaries were still large and contained no residual ovulated eggs. The first spawning took place during snapshot 1 and was over by 11 September. At this stage about 20% of the fish were spent. The percentage of spent fish dropped slightly between 15 and 18 September, but then increased again as the second spawning started. It is possible that a small proportion of the spent fish left the main spawning schools at this time, but data from *Tangaroa* suggested that the spent fish had not left the survey area (Table 5b).

A higher percentage of maturing fish in the observer data between 10 and 18 September was associated with the second spawning event, which started on 18 September (see Table 5a). It appears that these fish would have already spawned one batch of eggs because this increase coincided with an increase in stage 6 and 8 fish from the *Tangaroa* samples (Table 5b). (Note stage 6 fish are defined as fish with maturing, mature, and residual ovulated eggs in the ovary, whilst stage 8 fish are defined as fish with maturing and residual ovulated eggs in the ovary.) As in 2000, there appeared to be sporadic spawning continuing through September into October. It is unclear if these fish had spawned previously in the 2002 season. However, the catches from these schools were small, suggesting they would not contribute a lot to the overall biomass. There was therefore no evidence of significant turnover from the gonad data.

4. DISCUSSION

4.1 Treatment of acoustic snapshots

The Middle Depths Working Group (MDWG) discussed the treatment of the biomass estimates from the two acoustic snapshots at some length. In previous years the biomass estimates from the two acoustic snapshots have been averaged to provide a 'best estimate' (e.g., Hanchet & Grimes 2001). Before deciding on how the acoustic snapshots should be treated, a number of issues such as the timing of the survey, the variability between snapshots, and the treatment of the fish outside the survey area were considered.

Timing of the survey

The timing of the 2002 survey was shifted forwards by about a week to try to ensure that the fish were surveyed before and during spawning. The timing of this survey and previous surveys in relation to spawning is summarised in Figure 13. The first snapshot in 2003 was carried out during the pre-spawning and spawning period, finishing at peak spawning on both grounds. The second snapshot covered the tail end of the first spawning, the period between spawning, and the start of the second spawning. The timing in relation to the spawning season was therefore very consistent with previous surveys.

Variability between snapshots

Despite the large (2.5 fold) difference in biomass between the two snapshots in the 2002 survey there is no *a priori* reason why the estimate from one snapshot should be better than the other. Both snapshots were carried out at a time when most of the spawning biomass was on the grounds and should have got similar results. So why were the biomass estimates so different?

The main reason for the large difference in biomass between the two snapshots was the different areas used to scale up the mean transect densities to the stratum biomass. The absolute backscatter from the two transects with the highest densities was similar (in fact, that from snapshot 2 was slightly higher). However, when the densities from all the transects in the strata were averaged and the mean scaled up to the total stratum area, the much larger area in stratum 7 (4217 km^2 compared to only 550 km^2 in stratum 8) resulted in a much higher estimate for snapshot 1. It could be argued that the second snapshot was a more accurate reflection of the biomass in the southern aggregation because the area of the aggregation was better defined in snapshot 2. However, both snapshots provide unbiased estimates of the biomass, and the MDWG therefore agreed both snapshots should be averaged to provide the 'best estimate'.

Treatment of fish outside the survey area

The 2002 survey was the first where an aggregation had been surveyed outside the main survey area. We considered two possible hypotheses regarding the eastern aggregation and hence how it should be treated. The first hypothesis is that some fish always spawn outside the survey area (in which case the biomass of the aggregation should be excluded from the 'best estimate'). The alternative hypothesis is that in most years all fish spawn inside the survey area but that for some reason the 2002 season was unusual and a proportion of fish spawned outside the survey area (in this case the biomass of the aggregation should be included in the 'best estimate').

The commercial catch data were examined to determine whether they provide evidence for either hypothesis. (This analysis was actually carried out as part of project SBW 2001/01 (Hanchet & Blackwell unpubl. results), but the results are considered here.) Commercial vessels usually arrive in early September and routinely search the northern grounds at the beginning of the season for marks. Once they have found the main aggregation they tend to remain on that aggregation until the fish have finished spawning and then move to the south. Although they have occasionally fished outside the survey area, this has usually been at the end of the spawning season when the vessels follow fish schools leaving the area. The 2002 season was the first time that a vessel had consistently fished the Campbell grounds from mid July through to early September. Coincidentally, the 2002 season was also the first time that a spawning aggregation had been seen and fished outside the survey area. So it could be that in every spawning season some fish spawn outside the area but they have never been found before because nobody has ever looked. The commercial catch data therefore do not provide evidence to support or reject either hypothesis. However, the MDWG agreed that for consistency with previous years the biomass outside the survey area should be excluded for stock assessment purposes. The 'best estimate' of adult biomass from the 2002 survey was therefore 164 300 t (c.v. = 70%). The decomposed estimate of age 4 plus fish was 148 200 t.

4.2 Variability within snapshots

The objective of the survey was to estimate the spawning stock biomass on the Campbell grounds with a target c.v. of 30%. In previous years with a similar survey design the target c.v. has been easily reached, in fact, in the past two surveys adult c.v.s have been less than 20% (Hanchet & Grimes 2001). In contrast, the c.v. from the 2002 survey was 70%, so what went wrong?

The fundamental reason for the high c.v. was that most of the backscatter in each snapshot came from a single transect. In the first snapshot it was part of a stratum where the remaining eight transects had zero SBW backscatter, whilst in the second snapshot it was part of a stratum with seven zero transects and two transects with only relatively small amounts of SBW backscatter. The resulting stratum c.v.s were 101% and 88% respectively (see Table 3). However, this level of within stratum variability is not unusual for SBW surveys. For example, in the 1998 and 2000 surveys the c.v.s for the biomass estimates of stratum 7 in snapshot 1 were 101% and 75% respectively (Hanchet et al. 2000b, Hanchet & Grimes 2001).

In the 2000 survey a low overall c.v. was achieved for snapshot 1 because a large proportion of the biomass was located in several other strata in the survey area, and the c.v.s of those strata were much lower. In the 1998 survey the resulting biomass estimate for snapshot 1 had a high c.v of 85%. In snapshot 2 the biomass estimate and c.v. was again high for stratum 7. However, in that year we continued to survey the aggregation as part of a day-night detectability experiment. Using this approach we eventually had seven estimates of the southern aggregation, which combined together to give a low c.v. on the final biomass estimate.

In contrast to the earlier surveys there were two factors that gave rise to the high c.v. in the 2002 survey. The first was that most of the biomass in both snapshots came from a single stratum, so that although the c.v.s from the other strata were improved by the use of the phase 2 transects, this did not significantly improve the overall c.v. The second factor was that the isolation of the aggregation into stratum 8 failed to provide a significant improvement to the overall c.v. Although 10 transects were placed in the reduced stratum, only one hit very dense fish marks due to the small size of the aggregation. The transect densities in the other two transects were an order of magnitude less than the densest transect. The magnitude of the difference between transects was not apparent at the time, and so the resulting high c.v. was not anticipated.

So how could the survey have been improved?
We have identified three improvements that could be made in future surveys. The first is to have real time estimates of transect densities available on board the ship at the time of the survey. This would enable us to estimate c.v.s whilst at sea and hence target the phase 2 transects into those strata where the largest gains in precision could be made. The ESP2 software has now been developed to a stage where these data could be made available, and given extra resources estimates of the transect densities could be made at sea.

A second improvement would be to divide stratum 7 into two separate strata for snapshot 1. Then if a single high transect density was obtained on one transect, the additional phase 2 transects could be surveyed in that sub-stratum. This should not only lead to a gain in precision, but should also reduce the between snapshot variability. The disadvantage of this sub-stratification is that the fish could be straddling the boundary and could therefore give rise to high c.v.s in both substrata. However, in the last three surveys fish have been surveyed only in the southernmost part of the stratum (i.e., in 7S) in snapshot 1.

The third improvement would be to repeatedly sample the main aggregation – as in the 1998 survey. This was not really an option in the 2002 survey because the fish were close to the end of spawning, and once they finish spawning the fish typically start to disperse. If we had repeatedly surveyed the aggregation in stratum 8 then we would have run the risk of double counting, as the fish moved north and east into strata 7S and 6S. We therefore elected to survey stratum 7S and 6S as soon as possible to reduce the risk of any double counting. However, in years when the fish are either pre-spawning (as in 1998), or have just started spawning, there would be time to carry out several snapshots of the aggregation.

4.3 Comparison between years

The time series of decomposed biomass estimates at age for the Campbell grounds are summarised in Table 6. The adult (4+) biomass estimate is similar to estimates from the last three acoustic surveys, suggesting the adult biomass has remained relatively stable since 1995. The estimates of 2 and 3 year olds are almost the lowest in the time series, which suggest the 1999 and 2000 year classes are relatively weak. In contrast, the estimate of 1 year olds (the 2001 year class) is the highest on record. The distribution of 1 year olds this year was slightly unusual, as they extended slightly deeper than in previous surveys, and they were occasionally found in quite high densities.

These decomposed biomass estimates were used in modelling the Campbell stock (Hanchet et al. 2003). In previous assessments these estimates have been assigned a weighting equivalent to a c.v. of about 0.35. However, during the 2003 assessment the MDWG wanted to use a specific c.v. for each data point. Because c.v.s for the decomposed estimates were not available, the MDWG agreed to use the estimates from the SBW categories to approximate the decomposed c.v.s. It is therefore recommended that c.v.s for the decomposed estimates be calculated before the next assessment.

5. RECOMMENDATIONS

Although there was high uncertainty associated with the biomass estimates from the 2002 survey, it seems premature to reject the acoustic surveys as a method of monitoring SBW biomass. Previous surveys obtained reliable estimates of biomass with c.v.s of less than 20% in 1998 and 2000. We believe that the implementation of the following relatively minor changes to the survey design would overcome these problems in future surveys. We recommend the following:

- Future surveys continue to start in late August to allow for an early start of the spawning season on the Campbell grounds.
- 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.
- Where appropriate, the main aggregation should be repeatedly sampled using several snapshots.

We also recommend that c.v.s be calculated for the decomposed biomass estimates before the next assessment.

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Table 1: Transect allocation for voyage TAN0212. Number of additional phase 2 transects shown in parentheses.

	Stratum area (Km^2)	Snapshot 1	Snapshot 2
Date		30/8/02-8/9/02	8/9/02-20/9/02
Stratum number			
2	3 154	5	0
3N	2 342	3	0
3S	1 013	6	3
4	2 690	6 (7)	4
5	3 029	4	5(4)
6	4 711	3	–
6N	2 550	–	4
6S	2 161	–	4
7	4 217	9	–
7N	1 899	–	4
7S	1 916	–	5
8	550	–	10
8F1	2 041	0	6
8F2	265	0	7
Total		43	56

Table 2: Trawl station details for TAN0212 with catch (kg) of the main species. Time, duration of tow in minutes, Trawl type: BT, bottom, MW, mid-water, * MW trawl on or near bottom, #MW trawl in midwater. Age, age of SBW in years, Ad = adults. LIN, ling; CAS, oblique banded rattail; NOS, arrow squid; JAV, javelinfish, SSI, silverside; Total, total catch of all species.

Stn	Date	Lat	Long	Time mins	Trawl type	Stratum	Min depth	Max depth	Age (yrs)	Catch (kg) SBW	LIN	CAS	NOS	JAV	SSI	Total
1	31-Aug-02	51 40	169 29	14	BT	2	307	312	1	<1	0	5	252	0	4	270
2	1-Sep-02	51 40	169 45	26	BT	4	340	356	1	258	6	18	1	0	19	365
3	2-Sep-02	51 35	170 36	21	BT	4	491	492	Ad	2 601	497	3	0	82	4	3 258
4	2-Sep-02	51 48	170 07	16	BT	4	350	367	1	98	0	26	0	0	18	162
5	3-Sep-02	51 45	170 30	16	BT	4	442	454	2	52	17	5	0	7	0	147
6	4-Sep-02	51 45	170 25	30	BT	4	426	440	2	25	59	16	0	66	9	235
7	4-Sep-02	51 50	170 26	36	BT	4	398	419	2	27	33	40	<1	31	67	254
8	7-Sep-02	53 22	170 33	20	MW	7	*551	560	-	0	0	0	0	0	0	14
9	7-Sep-02	53 24	170 27	20	MW	7	#607	619	Ad	3 258	0	0	0	0	0	3 258
10	9-Sep-02	53 24	170 34	21	MW	7	*579	611	Ad	244	17	0	0	2	0	263
11	9-Sep-02	53 26	170 34	29	BT	7	604	633	Ad	52	342	<1	1	264	0	733
12	16-Sep-02	52 04	170 38	62	BT	5	421	427	2	19	16	49	4	5	9	133
13	18-Sep-02	52 03	170 33	21	BT	5	362	373	-	0	<1	7	10	<1	0	23
14	18-Sep-02	52 03	170 32	13	BT	5	373	374	-	0	0	6	5	0	4	40
15	19-Sep-02	52 22	170 44	15	BT	5	458	460	Ad	874	21	3	1	3	2	953
16	19-Sep-02	52 32	170 13	17	BT	5	414	426	Ad	961	0	40	1	<1	2	1 017
17	19-Sep-02	52 21	170 21	18	BT	5	394	395	1	35	5	48	3	2	9	163
18	20-Sep-02	51 60	170 36	17	BT	5	406	418	Ad	626	2	5	0	5	1	677
19	20-Sep-02	51 47	170 03	17	BT	4	342	347	-	0	0	2	23	0	8	52
20	21-Sep-02	51 40	169 49	33	BT	2	335	368	1	2	0	36	1	<1	119	186
21	21-Sep-02	51 43	169 59	22	BT	4	364	375	1	2	0	52	2	<1	21	97
22	21-Sep-02	51 48	170 11	18	BT	4	375	376	-	0	0	5	54	<1	32	160
Total catch										9 132	1 016	468	367	356	326	12 459

Table 3: Biomass estimates (t) and c.v. by stratum and snapshot of juvenile, immature, and adult SBW, for the Campbell Island Rise in 2002. The italicised entries were obtained from the previous snapshot. Best estimate is the mean of snapshots 1 and 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	1 080	71	0	–	435	100
3N	2 342	0	–	0	–	0	–
3S	1 013	0	0	0	–	6 356	99
4	2 690	3 347	48	271	48	12 196	53
5	3 029	2 682	110	0	–	0	–
6	4 711	0	–	0	–	0	–
7	4 217	124	97	876	99	220 640	101
Total	**21 156**	**7 233**	**48**	**1 147**	**76**	**239 627**	**93**
Snapshot 2							
2	3 154	*1 080*	71	0	–	0	–
3N	2 342	0	–	0	–	0	–
3S	1 013	0	–	0	–	0	–
4	2 690	337	63	0	–	0	–
5	3 029	604	70	0	–	10 506	36
6N	2 550	0	–	0	–	13 410	82
6S	2 161	0	–	0	–	1 491	101
7N	1 899	346	102	0	–	0	–
7S	1 916	0	–	0	–	188	93
8	550	0	–	0	–	63 457	88
Total	**21 304**	**2 367**	**41**	**0**	–	**89 052**	**65**
8F1	1 705	0	–	0	–	6 929	78
8F2	400	0	–	0	–	1 947	44
Mean 8F		0	–	0	–	4 438	62
Best estimate		**4 800**	**37**	**574**	**76**	**164 340**	**70**

Table 4: 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 2002. The italicised entries were obtained from the previous snapshot. Best estimate, mean of snapshots 1 and 2.

					Ages
Stratum	Area (km^2)	1	2	3	≥ 4
Snapshot 1					
2	3 154	1042	6	41	386
3N	2 342	0	0	0	0
3S	1 013	0	87	595	5 651
4	2 690	3 264	318	1 172	10 847
5	3 029	2 588	0	0	0
6	4 711	0	0	0	0
7	4 217	228	5 302	14 709	199 186
Total	21 156	**7 122**	**5 713**	**16 517**	**216 070**
Snapshot 2					
2	3 154	*1042*	*6*	*41*	*386*
3N	2 342	*0*	*0*	*0*	*0*
3S	1 013	0	0	0	0
4	2 690	326	0	0	0
5	3 029	584	143	980	9 303
6N	2 550	0	182	1251	11 876
6S	2 161	0	33	99	1 343
7N	1 899	334	0	0	0
7S	1 916	0	4	13	170
8	550	0	1 383	4 197	57 230
Total	21 111	**2 286**	**1 751**	**6 581**	**80 308**
8F1	1 705	0	150	458	6 237
8F2	400	0	43	129	1 754
Mean 8F		0	97	293	3 995
Best estimate		**4 704**	**3 732**	**11 549**	**148 189**

Table 5a: Percentage of females at each gonad stage from observer data by area and date. N, number of fish examined. Gonad stages: 1, immature/resting; 2, ripening; 3, ripe; 4, running ripe; 5, spent (see also Hanchet 1998).

		Gonad stage				
Date	N	1	2	3	4	5
Northern Campbell						
4-Sep-02	266	0	77	23	0	0
5-Sep-02	91	0	34	43	23	0
6-Sep-02	237	1	29	48	22	0
7-Sep-02	657	0	3	44	52	0
8-Sep-02	604	0	2	43	53	2
9-Sep-02	764	1	7	58	31	4
10-Sep-02	1042	1	26	43	22	8
11-Sep-02	362	1	36	40	10	14
12-Sep-02	1008	0	53	17	4	26
13-Sep-02	1044	2	47	31	0	20
24-Sep-02	336	22	1	8	8	60
26-Sep-02	66	42	17	2	0	39
27-Sep-02	187	40	4	9	4	44
28-Sep-02	329	39	5	10	2	44
29-Sep-02	334	59	4	4	2	31
30-Sep-02	100	73	3	2	2	20
9-Oct-02	129	67	17	14	2	0
10-Oct-02	73	86	12	1	0	0
Southern Campbell						
14-Sep-02	948	3	58	16	1	22
15-Sep-02	1086	2	63	21	1	13
16-Sep-02	764	2	74	19	1	5
18-Sep-02	1336	7	30	34	12	17
19-Sep-02	1068	6	12	39	23	21
20-Sep-02	894	7	2	19	41	30
21-Sep-02	602	5	4	21	23	47
22-Sep-02	492	18	3	11	18	50
23-Sep-02	440	16	5	1	9	70
24-Sep-02	110	11	21	0	3	65
25-Sep-02	152	27	24	6	3	41
7-Oct-02	79	86	10	4	0	0
8-Oct-02	112	43	37	20	0	1
11-Oct-02	170	89	4	6	0	0
12-Oct-02	131	92	5	2	0	0
13-Oct-02	65	94	0	6	0	0
14-Oct-02	134	85	3	12	0	0

Table 5b: Percentage of females at each gonad stage in *Tangaroa* trawls by date for northern and southern Campbell. N, number of fish examined. Gonad stages: 3, ripening; 4, ripe; 5, running ripe; 6, partially spent; 7, spent; 8, reverted (spawned one batch and reverted to ripening stage). (Note immature fish not shown.)

		Gonad stage					
Date	N	3	4	5	6	7	8
Northern Campbell							
2-Sep-02	216	96	4	0	0	0	0
3-Sep-02	46	87	9	4	0	0	0
4-Sep-02	9	89	0	11	0	0	0
16-Sep-02	16	0	0	0	50	31	19
19-Sep-02	361	0	0	1	54	36	9
20-Sep-02	90	0	0	12	16	63	9
Southern Campbell							
7-Sep-02	313	0	18	27	55	0	0
9-Sep-02	299	0	2	27	65	4	2

Table 6: Decomposed biomass estimates (t) by survey and age group for the Campbell Island Rise.

	1yo	2yo	3yo	4yo+
1993	1 817	71 902	14 781	24 033
1994	329	12 259	139 552	28 841
1995	0	11 176	23 228	130 535
1998	2 283	13 142	28 022	167 668
2000	961	10 460	8 421	135 612
2002	4 704	3 732	11 549	148 189

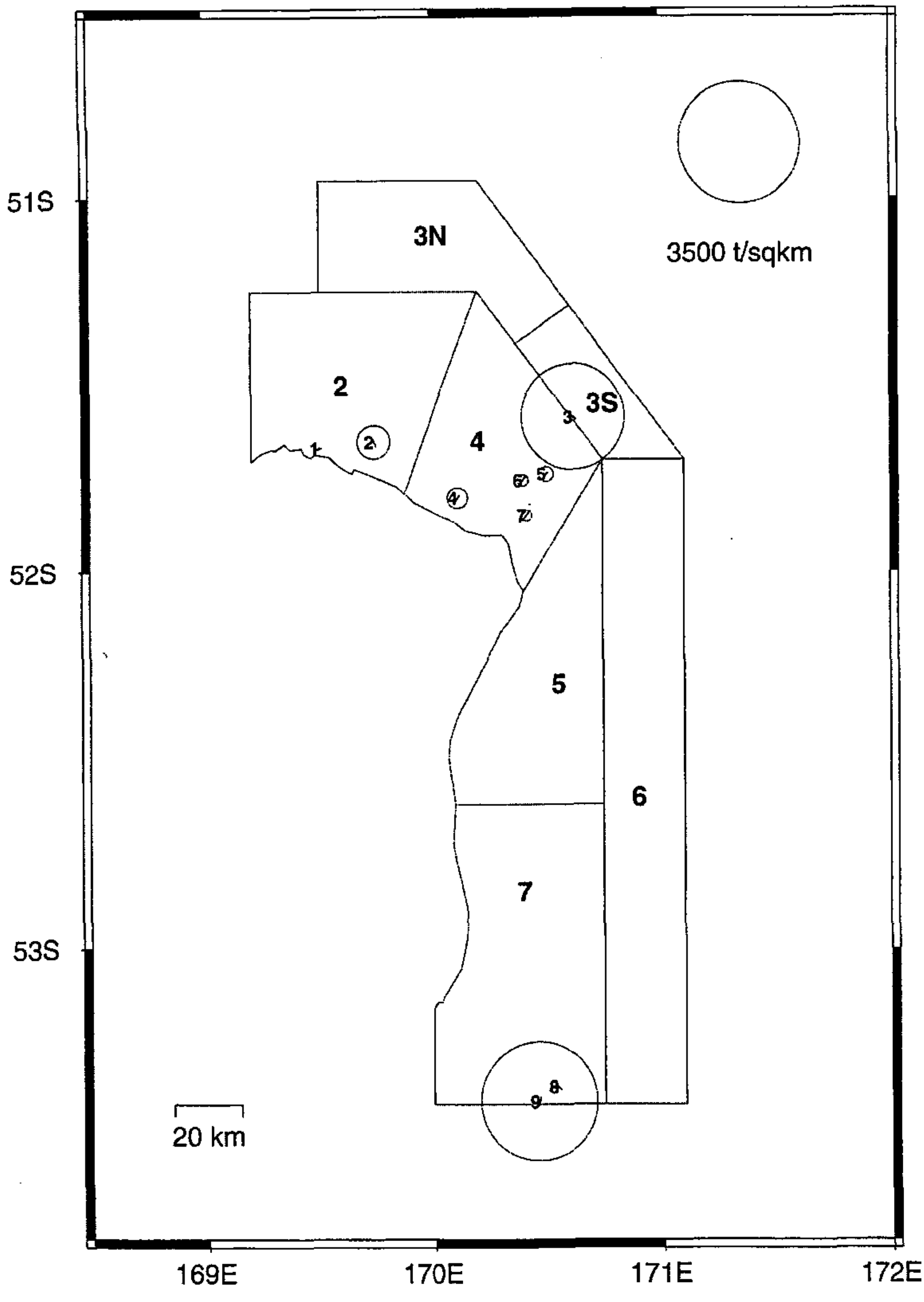

Figure 1: Survey area, stratum boundaries, and location and catch rates of trawls in snapshot 1 on Campbell Island Rise during TAN0212.

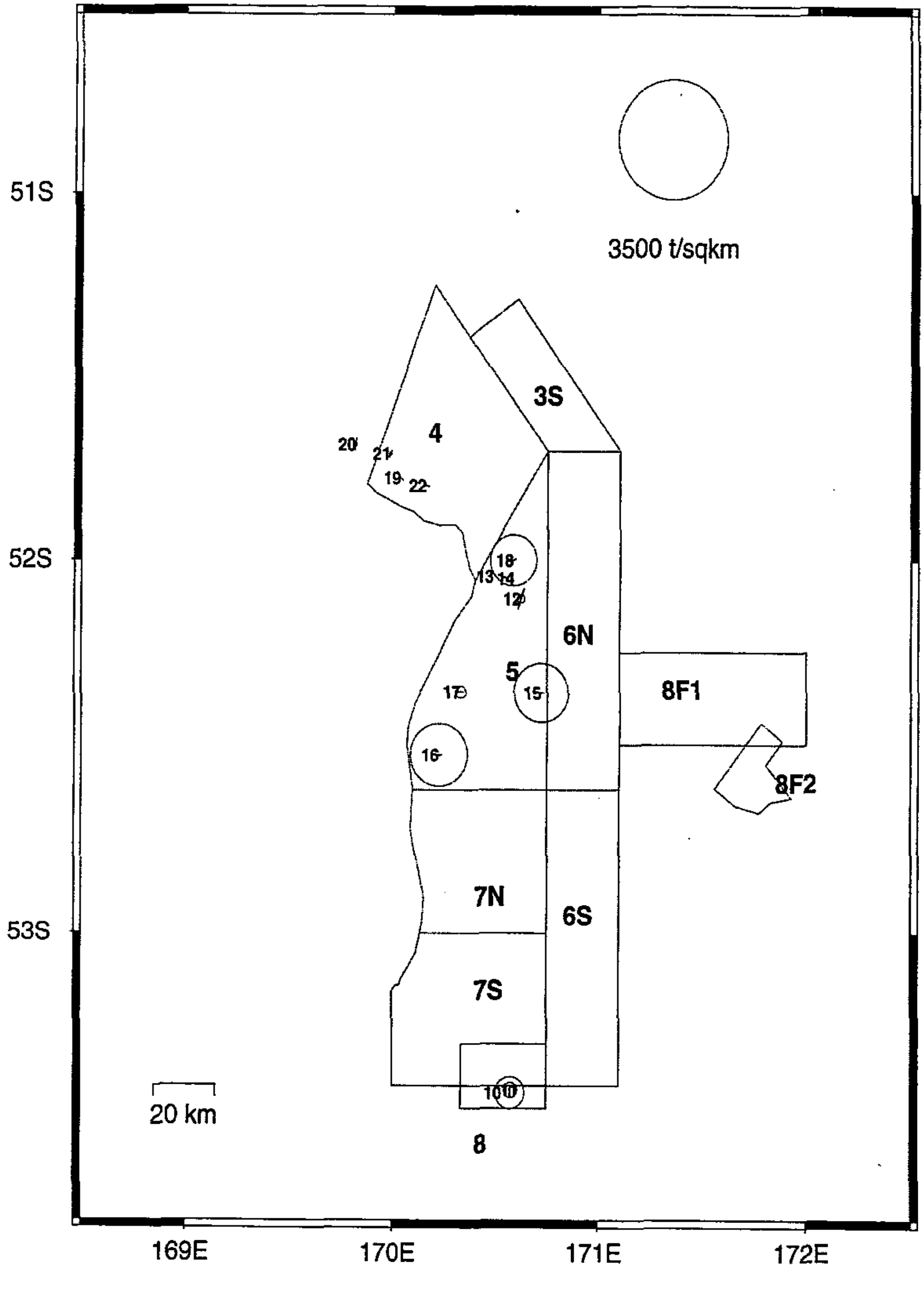

Figure 2: Survey area, stratum boundaries, and location and catch rates of trawls in snapshot 2 on Campbell Island Rise during TAN0212.

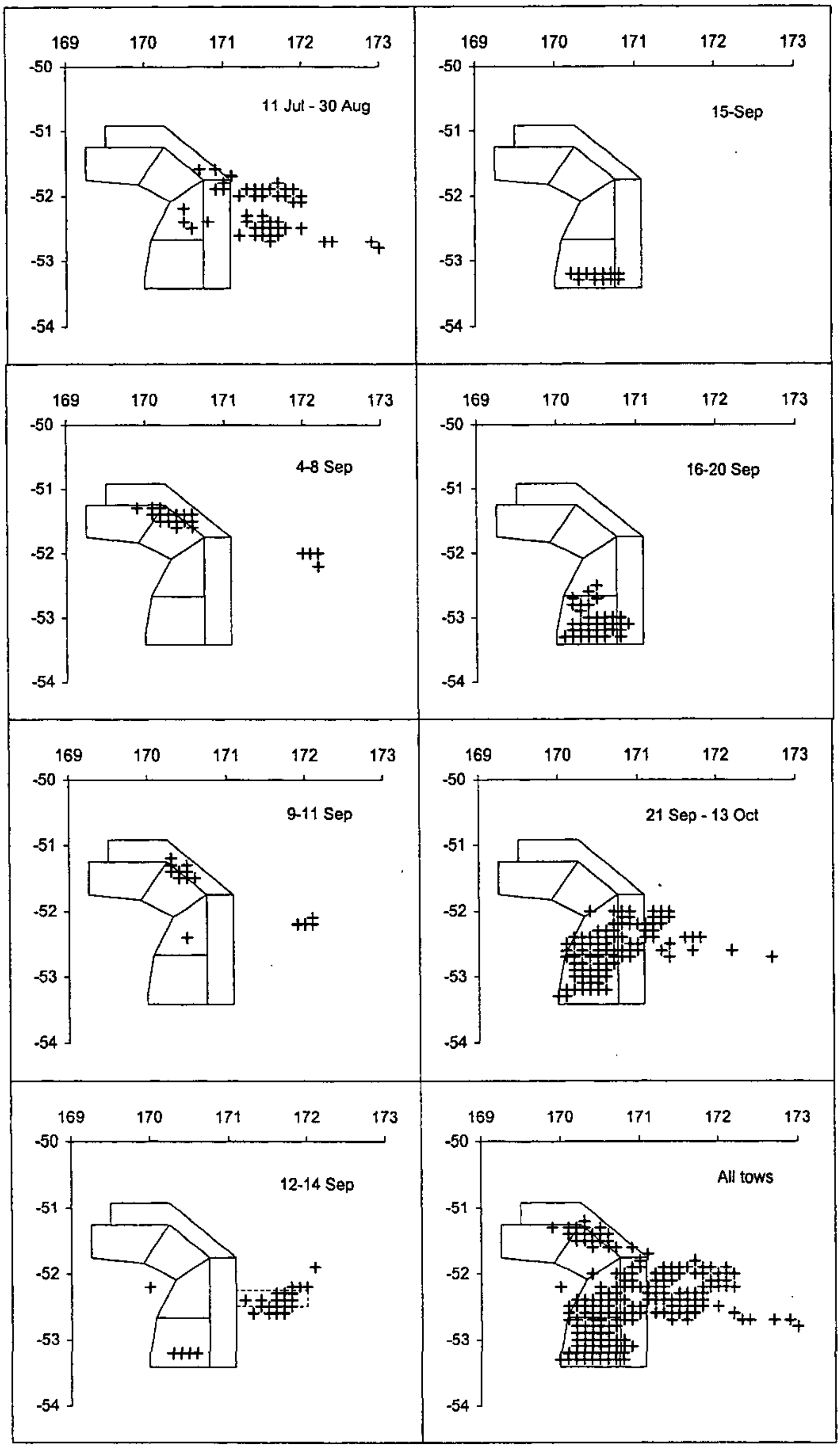

Figure 3: Trawls carried out on Campbell during the 2002 season. Acoustic snapshot 1 was from 30 Aug to 8 Sep, and snapshot 2 was from 9 to 20 Sep. Note each symbol may represent more than one trawl. Commercially sensitive data have been removed.

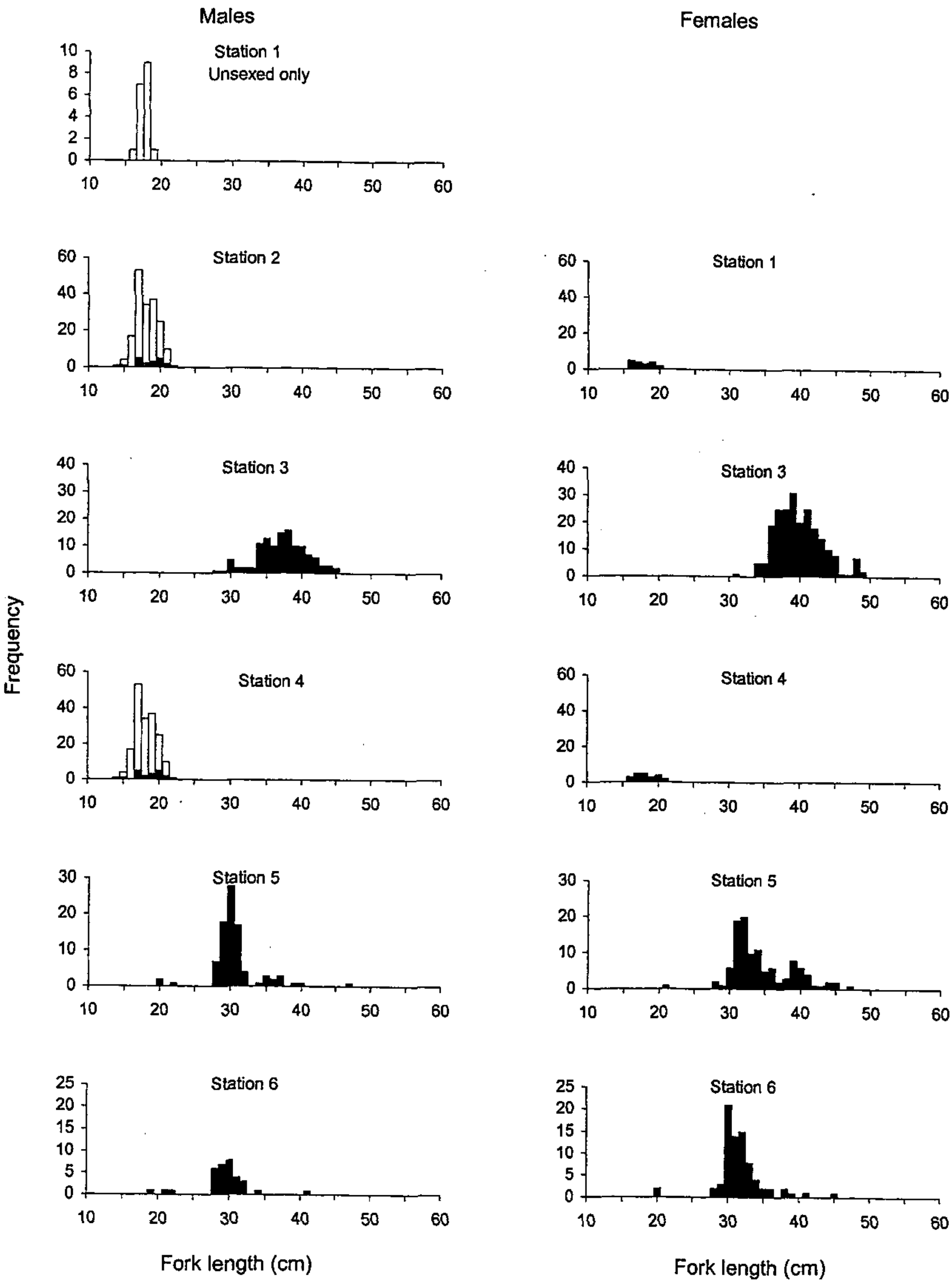

Figure 4: Unscaled length frequency distributions of male and female SBW for each trawl station. Unfilled columns are unsexed fish.

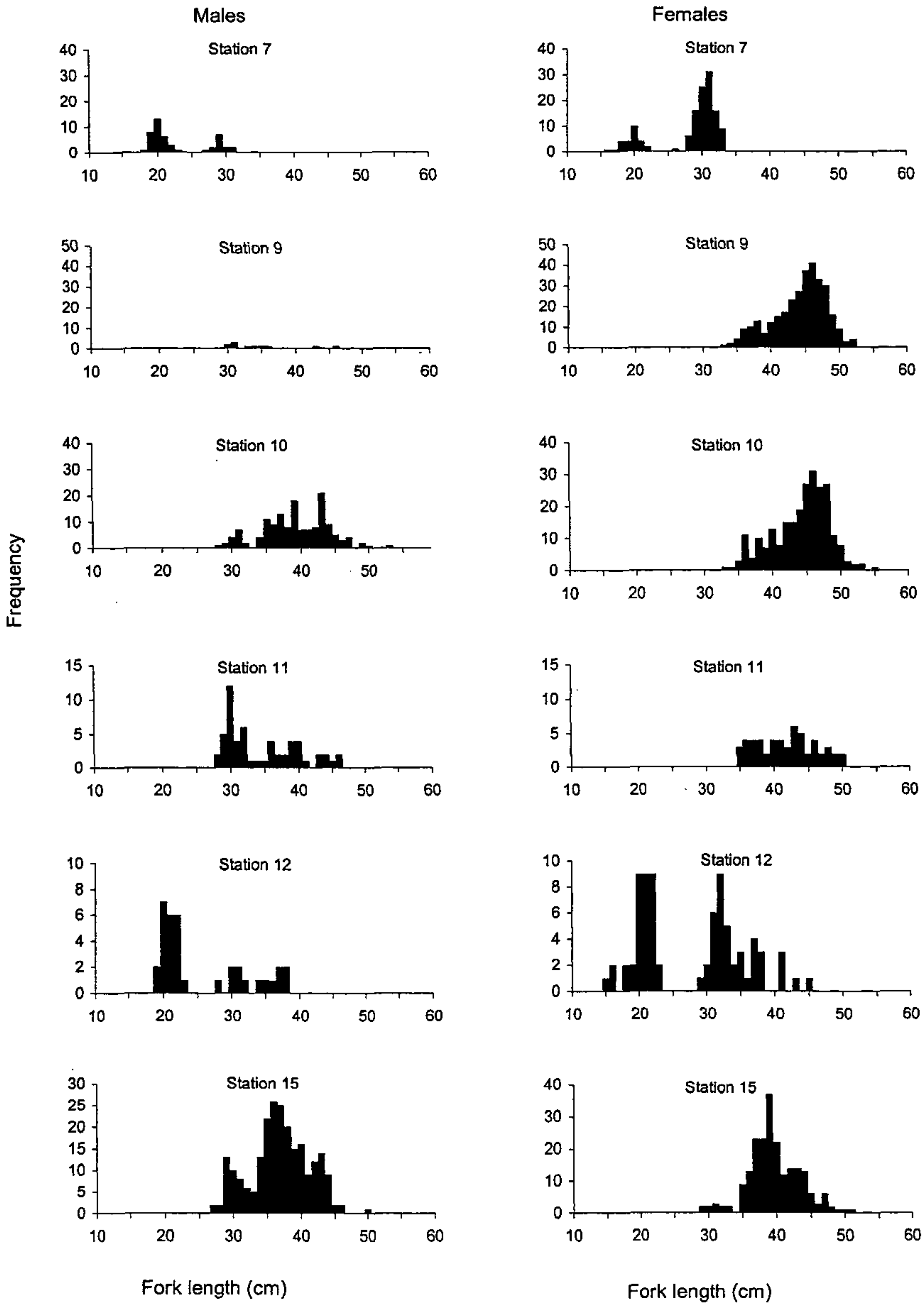

Figure 4 continued :

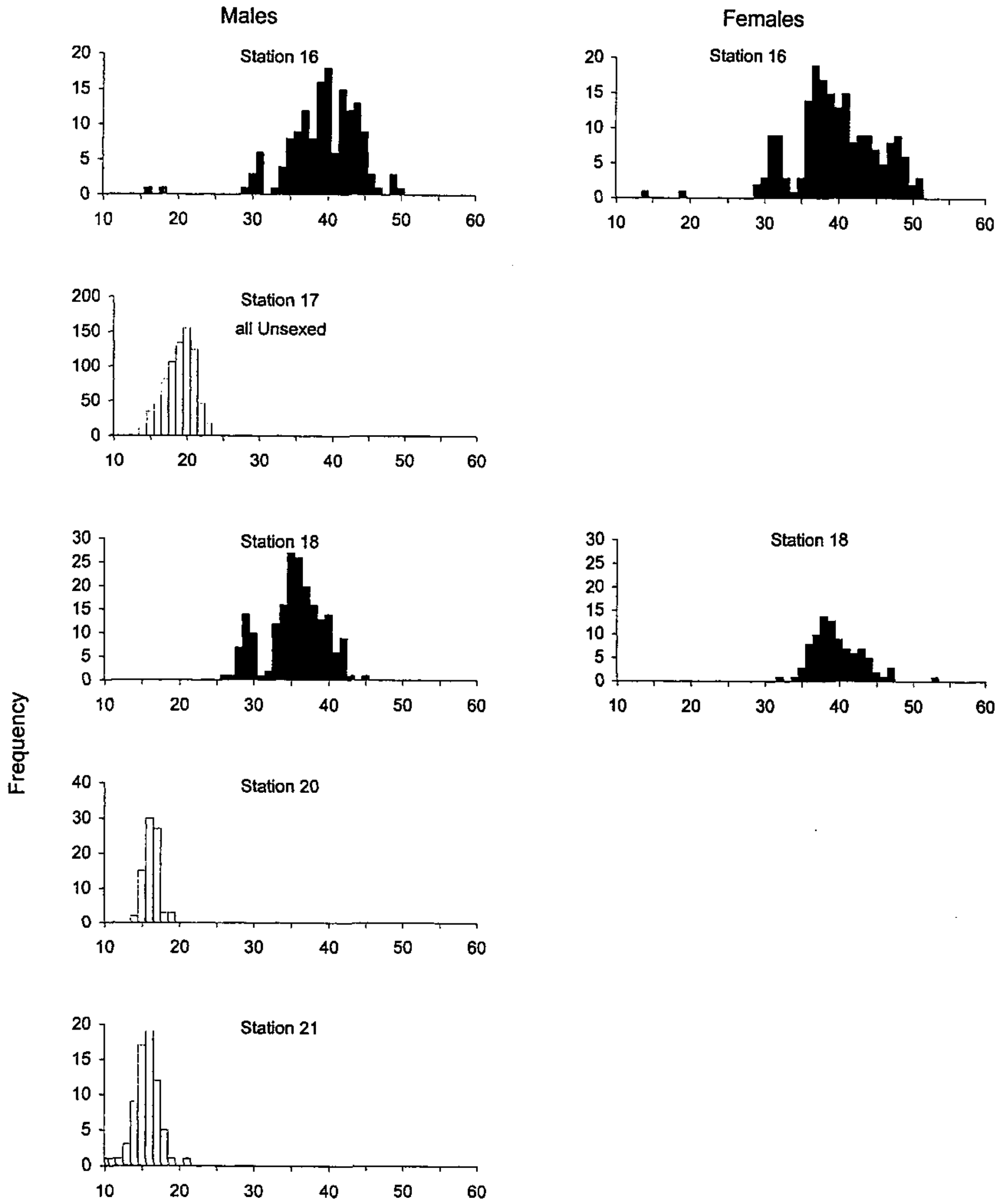

Figure 4 continued :

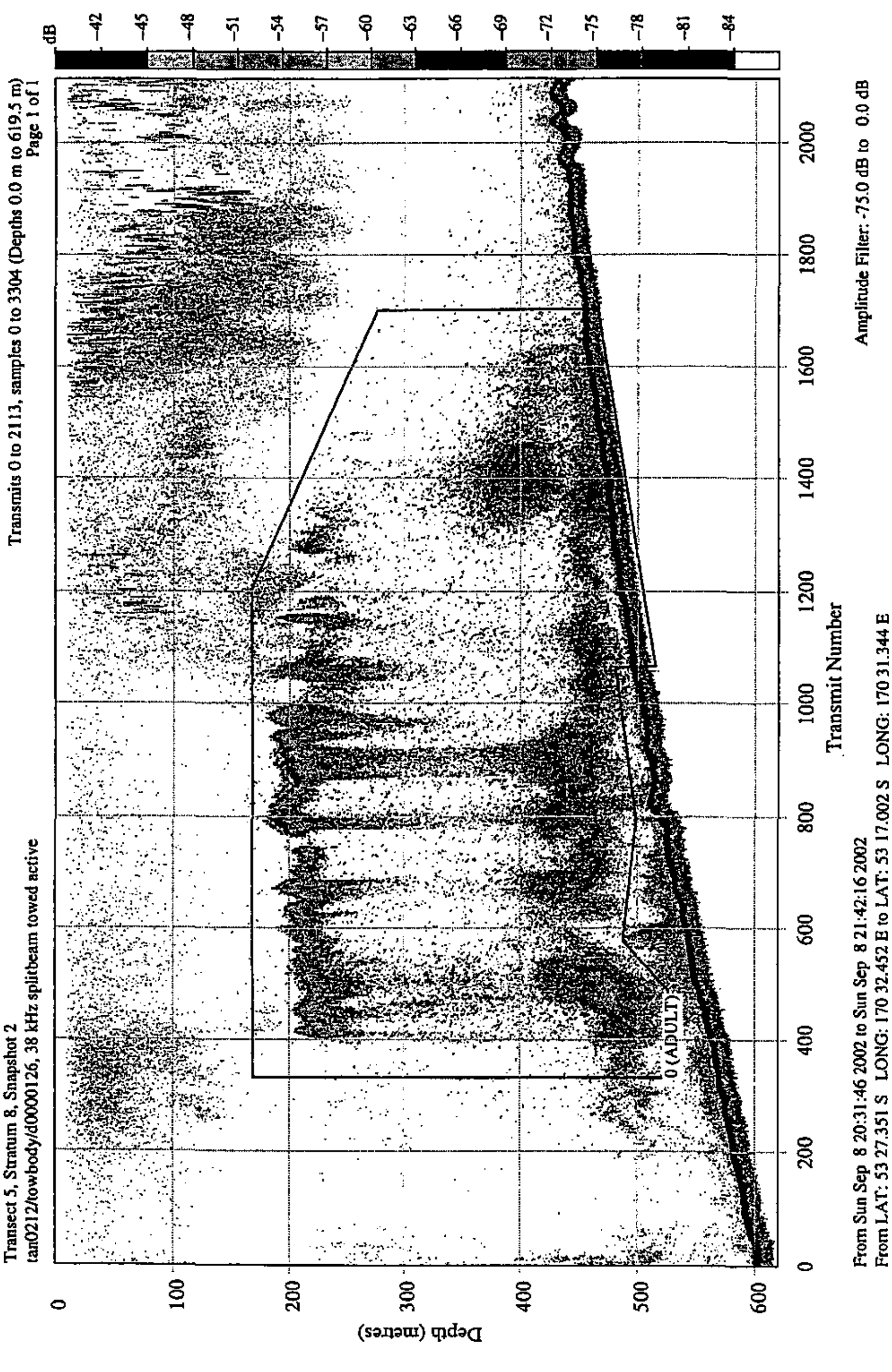

Figure 5: The very dense adult spawning mark surveyed in stratum 8 in snapshot 2. The boundary of the adult marks is identified. The bottom layer in deeper water from TX 0–800 is javelinfish.

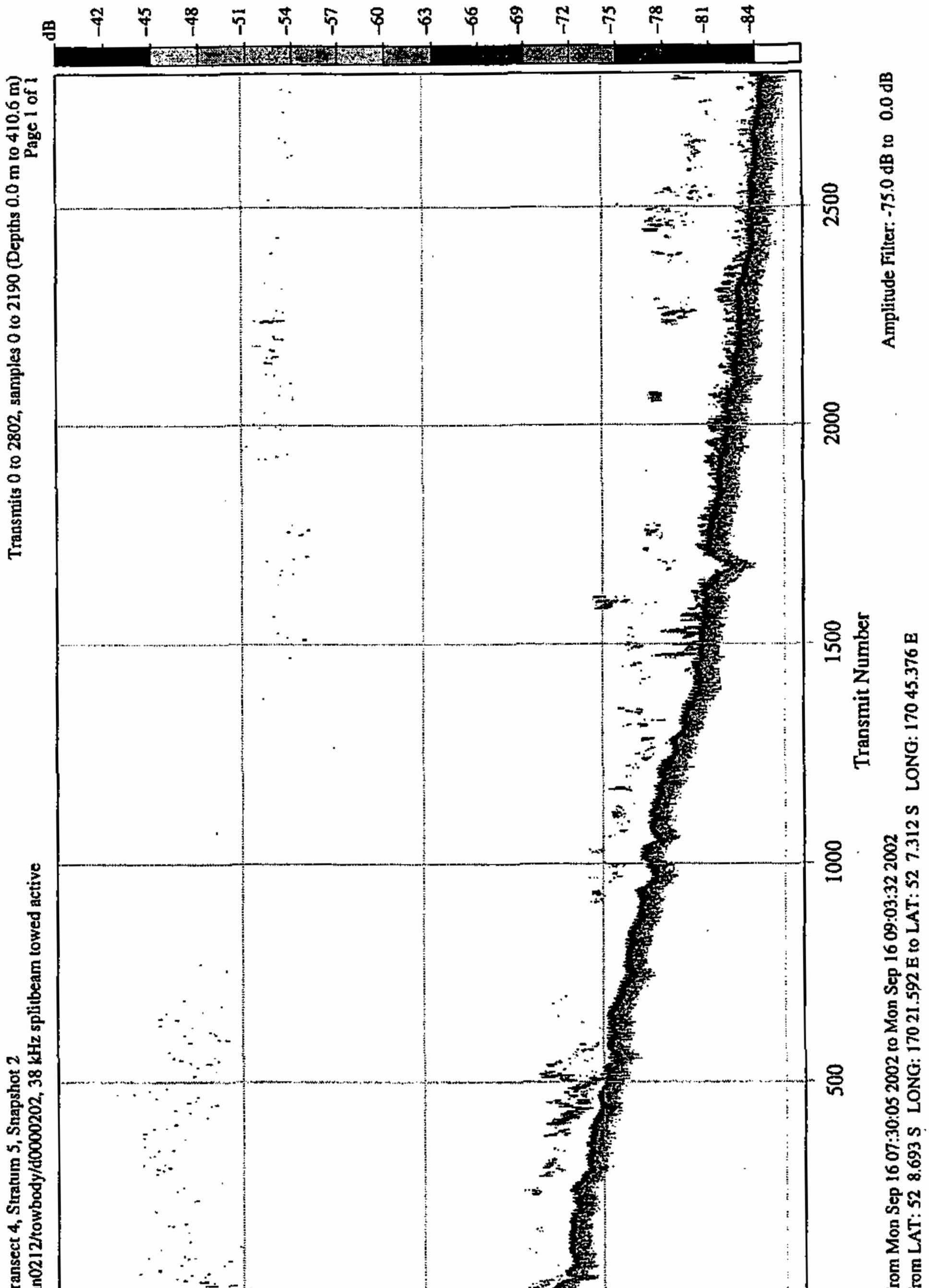

Figure 6: A typical daytime adult SBW post-spawning bottom mark surveyed in stratum 5 in snapshot 2 extending from TX 1400–2800. Towbody at 30 m depth.

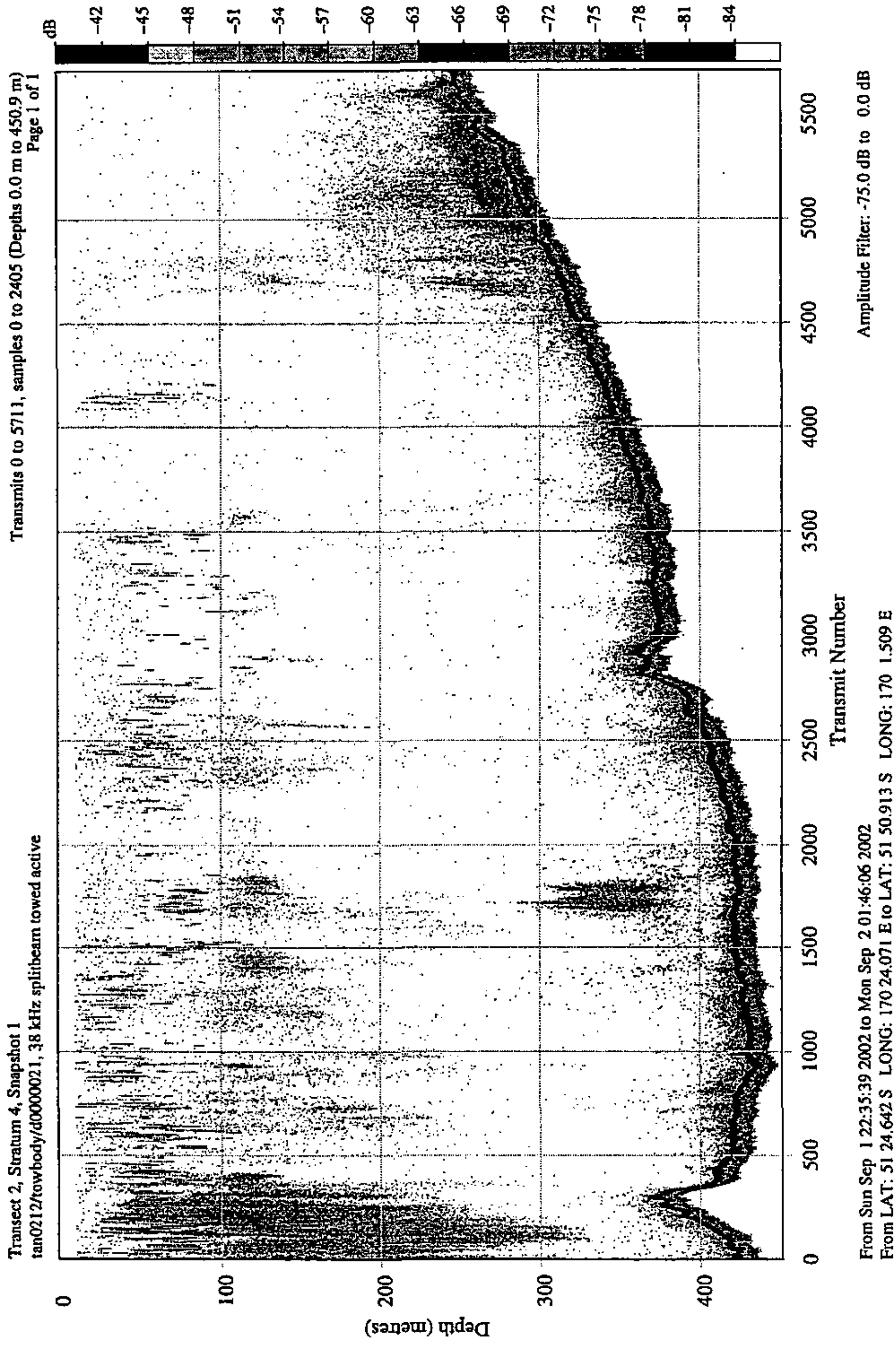

Figure 7: A moderately dense juvenile (1 year old) SBW mark surveyed at night in stratum 4 in snapshot 1. Also shown is an adult pre-spawning mark in deeper water.

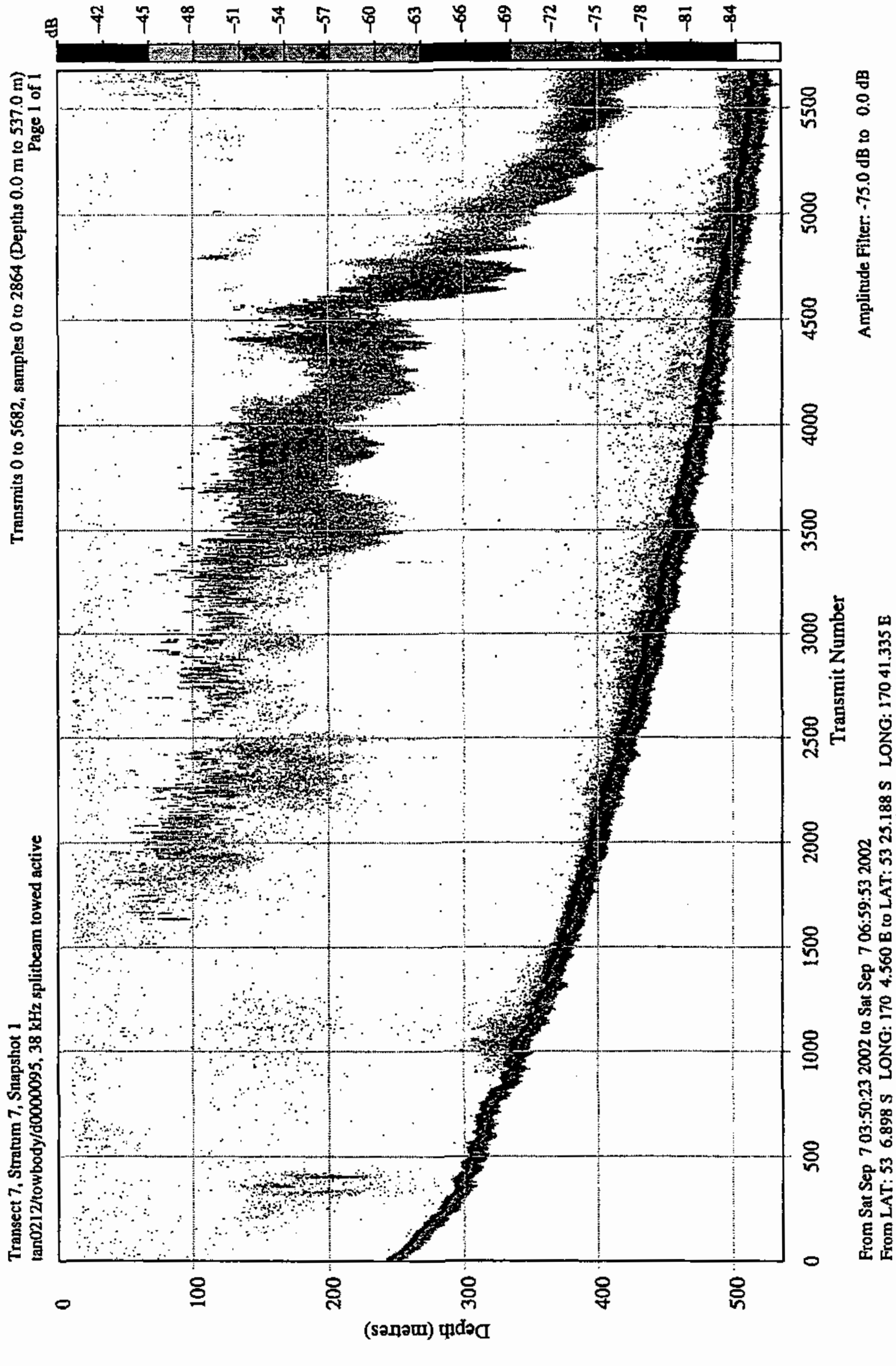

Figure 8: A moderately dense mesopelagic fish layer descending from about 150 m down towards the seabed at dawn. Also shown is a light juvenile bottom mark at TX 1000.

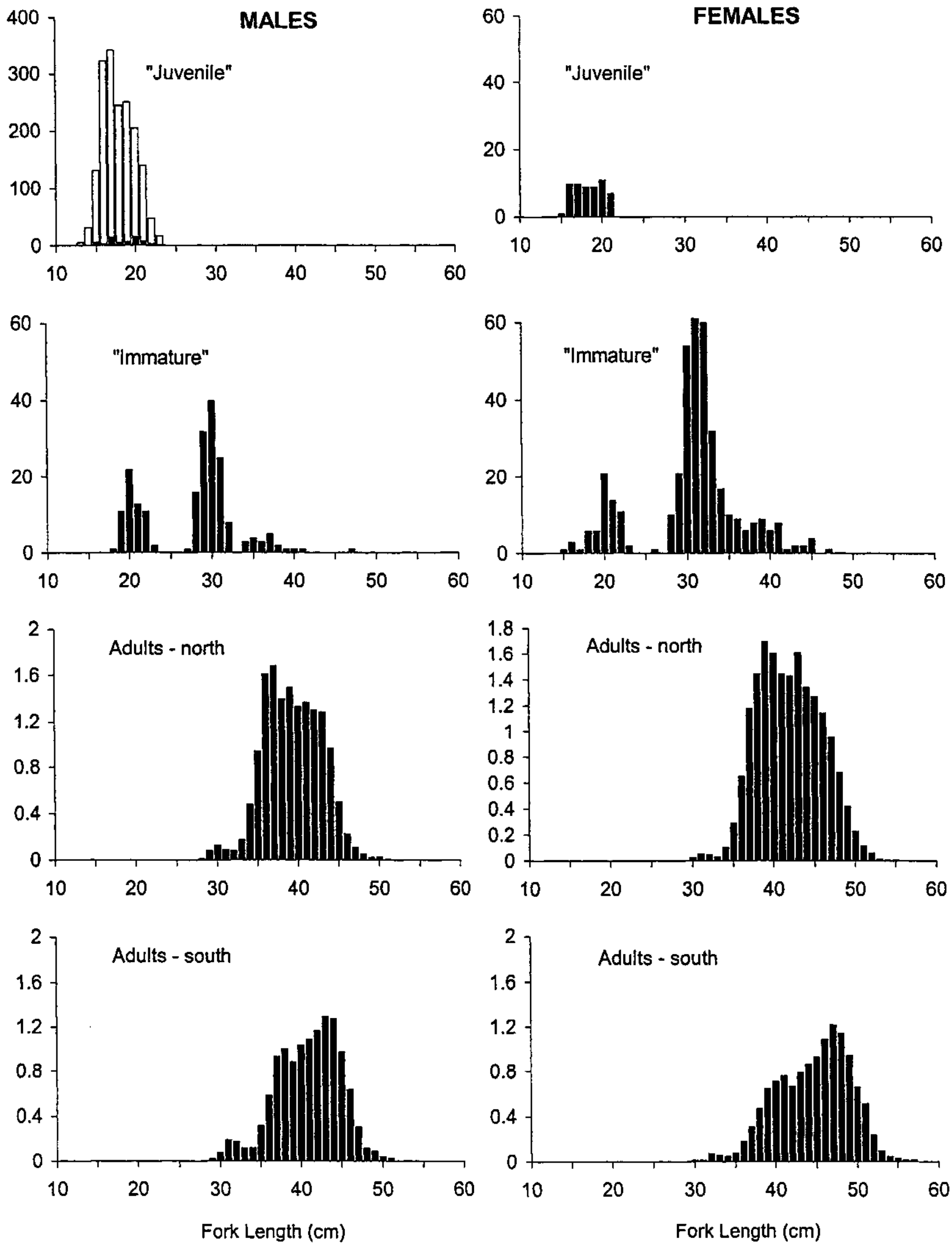

Figure 9: Length frequency distributions of SBW categories used for the acoustic survey analysis Juvenile and immature categories from TAN0212, adults are scaled commercial data (in millions). Unfilled columns are unsexed fish.

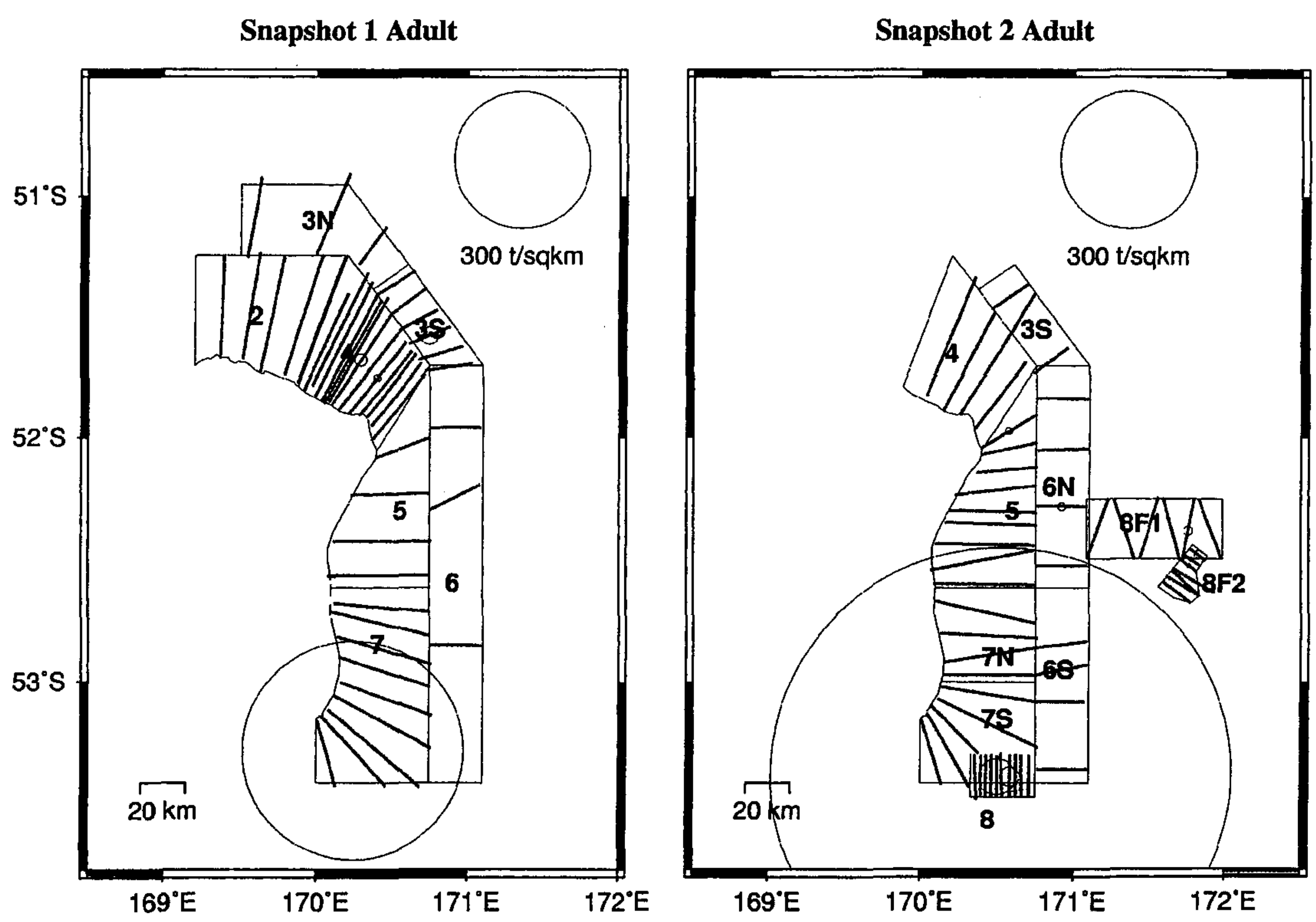

Figure 10: Density estimates of adult southern blue whiting (t/km^2) by transect for snapshots 1 (left) and 2 (right) on the Campbell Island Rise.

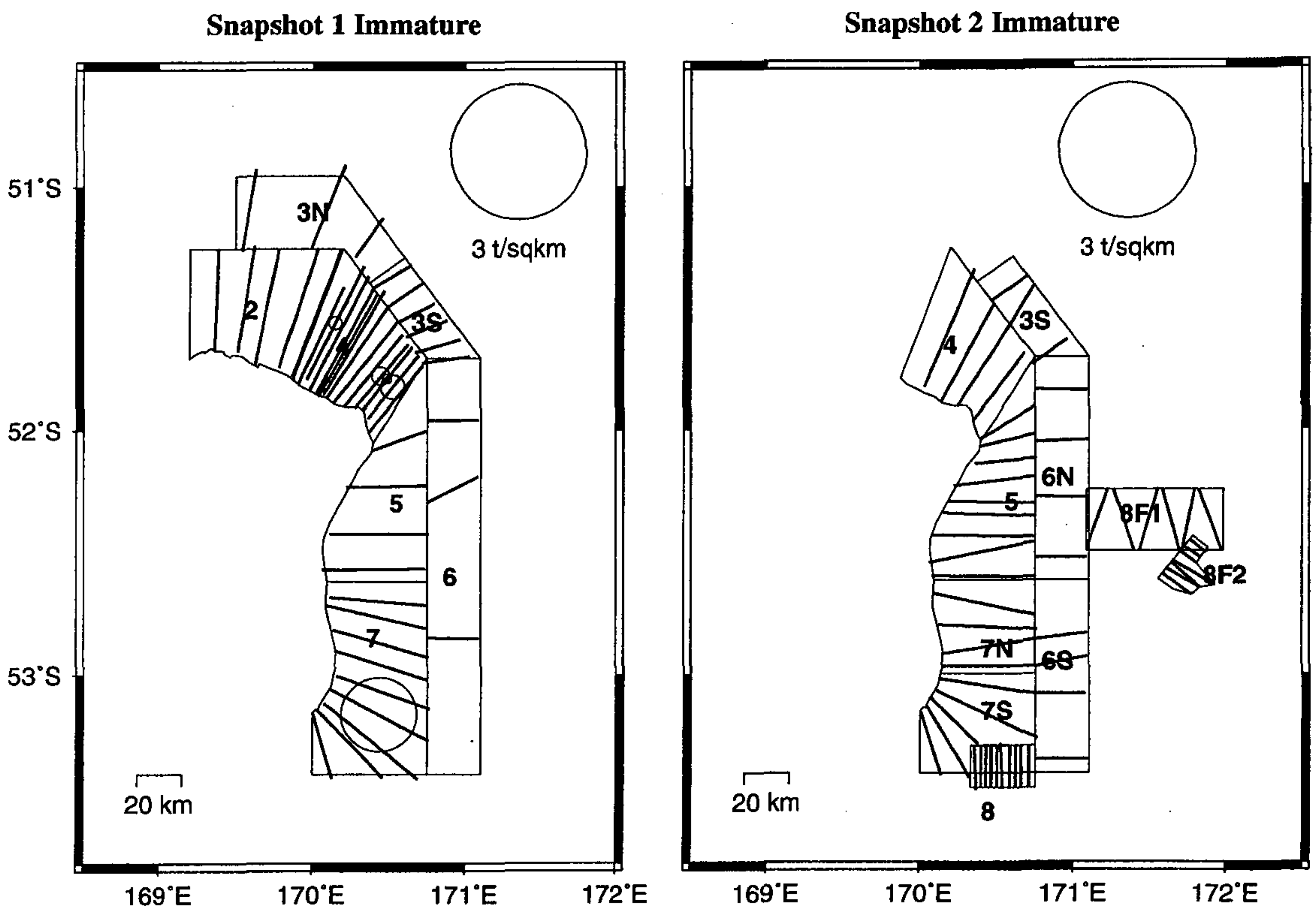

Figure 11: Density estimates of immature southern blue whiting (t/km^2) by transect for snapshots 1 (left) and 2 (right) on the Campbell Island Rise.

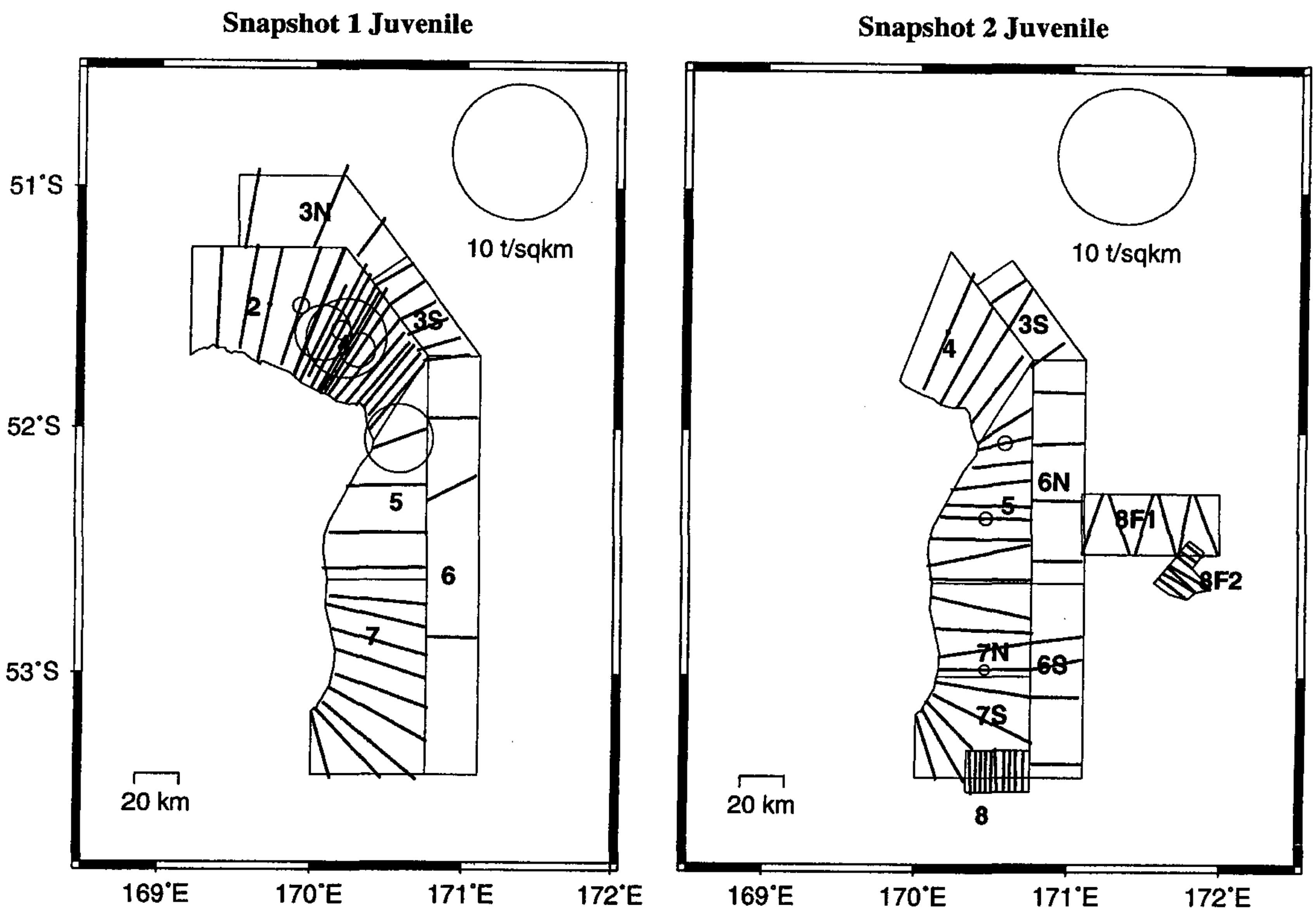

Figure 12: Density estimates of juvenile southern blue whiting (t/km^2) by transect for snapshots 1 (left) and 2 (right) on the Campbell Island Rise.

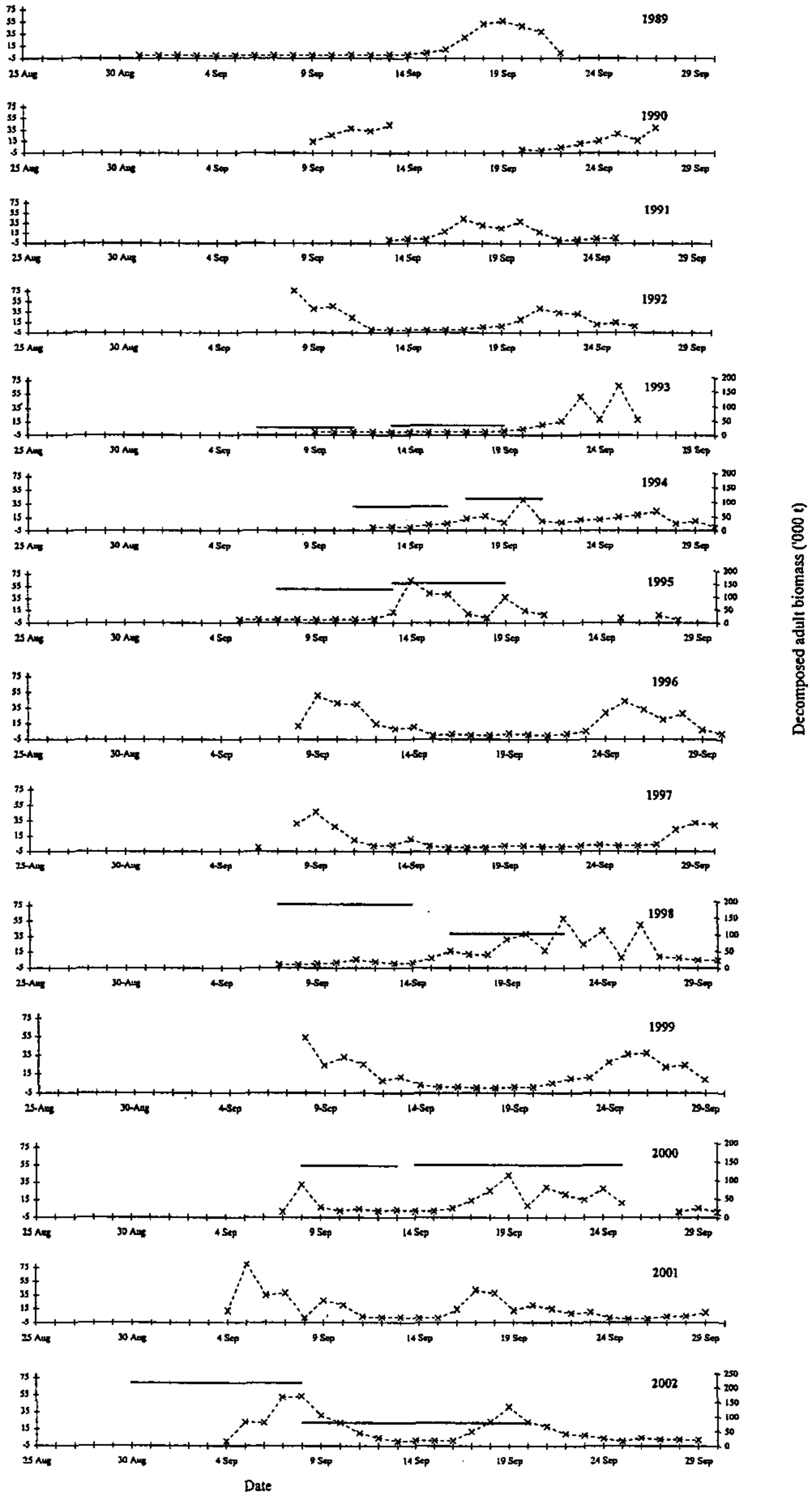

Figure 13: Timing of spawning in relation to the timing and biomass estimates of each acoustic sna Percentage running ripe females (x) and decomposed spawning stock biomass estimates (solid line)

Appendix 1: Calibration data for the systems used. V_T is the in-circuit voltage at the transducer terminals for a target of unit backscattering cross-section at unit range and G is the voltage gain of the receiver at 1 m with the system configured for biomass measurements. C is the overall calibration constant.

System	**Towbody1**	**Towbody3**	**Hull**
Transducer serial no.	28326	28332B	23421
3dB beamwidth (°)	6.8×6.9	7.3×7.4	7.2×7.3
Effective beam angle (sr)	0.0081	0.0093	0.0091
V_T	1240	1005	331
G	12604	12866	18327
C	2484520	1022570	1022570