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## EXECUTIVE SUMMARY

**Hanchet, S.M., Grimes, P.J., & Bull, B. 2000: Acoustic biomass estimates of southern blue whiting (*Micromesistius australis*) from the Campbell Island Rise, September 1998.**
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This paper summarises the results of the fifth acoustic survey of southern blue whiting (SBW) stocks in subantarctic waters. Two complete acoustic snapshots were carried out on the Campbell Island Rise. A further five acoustic snapshots were completed of a pre-spawning aggregation of adult SBW on the southern ground.

Commercial trawl data were used to help determine the main fishing locations in each area and to assist in the identification of marks. Based on these data, investigative target trawling from *Tangaroa*, and previous experience, SBW marks were identified as adult (mature fish which have recruited to the commercial fishery), immature (mainly 2 year olds, but including some immature 1 and 3 year old fish), or juvenile (1 year old fish).

The main aggregation in the northern grounds was surveyed twice, and the biomass increased four-fold between the first and second snapshots. The reason for this large difference is unclear, but may be associated with the change in fish distribution. During snapshot 1, the fish were still tightly aggregated in small dense pre-spawning and spawning aggregations. By the start of snapshot 2 the fish had finished spawning their first batch of eggs and had moved shallower and become dispersed over a much larger area. The average of the two snapshots was taken to be the best estimate, and equalled 70 300 t (*c.v.* = 22%).

The main aggregation on the southern ground was surveyed on seven separate occasions and all were used for final biomass estimation. The biomass estimates ranged from 60 000 t to 144 000 t and averaged 101 200 t (*c.v.* = 26%).

The final estimate of adult biomass on both Campbell grounds was 171 500 t (*c.v.* = 18%). This is similar to the 1994 estimate, but higher than the 1995 estimate. The *c.v.* in the current survey was the lowest recorded in any SBW survey and was partly because of the intensive sampling of the southern aggregation, and partly because of the dispersed nature of the fish on the northern ground. This is the first time that post-spawning SBW have been surveyed in this area.

The mean biomass estimates of immature and juvenile fish were taken as the average of the two snapshots and equalled 13 000 t and 1289 t respectively. The estimates of "immature" biomass and number of 2 year old fish were the lowest that have been recorded on the Campbell Island Rise. This is the first time that 1 year old SBW have been surveyed on the Campbell Island Rise.

The results of a 24-hour detectability/target strength experiment are presented and discussed. Although there was no significant difference in biomass between day and night, biomass appeared to peak (and had lowest *c.v.*s) between midnight and 8 a.m. The most likely explanation for this trend in biomass and *c.v.*s is a change in the distribution of fish schools and hence transect densities. During the late night and dawn snapshots the fish covered a large area and were distributed reasonably evenly across the aggregation so that most transects had similar densities. During the two day snapshots the fish were aggregated into many large dense schools. The distribution of the size of these schools and hence transect densities was lognormal, and the chance of hitting a large school was low. During the early night snapshot the fish were merging together from the individual dense schools into a single large aggregation, and this may account for the lower and more variable biomass estimate observed at this time.

## 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, and the results were documented by Hanchet *et al.* (1994), Hanchet & Ingerson (1996), and Ingerson & Hanchet (1996). After the first three annual surveys it was decided to survey these areas biannually. The Bounty and Pukaki spawning grounds were surveyed in August and September 1997 (Grimes & Hanchet 1999).

The current report stems from an objective carried out under contract to MFish: "To estimate pre-recruit and recruited biomass on Campbell Island Rise during September 1998 using an acoustic survey (SBW9701)."

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 mainly sexually mature, and for modelling purposes the maturity and selectivity ogives are assumed to be synonymous. Modelling of the stocks suggests that less than 10% of the fish recruit to the fishery at age 2, a larger but variable proportion (averaging about 50%) recruit at age 3, and that fish are fully recruited at age 4 (Annala *et al.* 1999). In addition to the spawning fish, pre-recruit fish (immature 1, 2, and 3 year olds) are also found in the survey area. Attempts to quantify pre-recruit biomass in previous surveys by separation into an "immature" (mainly 2 year old fish) category has been problematic due to the occurrence in some years of 2 and 3 year old fish in mixed schools (Hanchet & Ingerson 1996).

As in previous years, SBW acoustic marks in the current survey were initially classified into adult (recruited fish), immature (mainly 2 year olds), and juvenile (1 year olds). After the biomass estimates of the "immature" category were calculated the biomass was decomposed to provide estimates of 1, 2, and 3 year old immature fish. This was the first year that 1 year old fish have been caught during the Campbell Island surveys.

In a review of the SBW acoustic surveys, Rose (1998) recommended an experiment be carried out to determine whether there were diurnal differences in acoustic biomass. He proposed carrying out replicate transects during day and night across an aggregation to measure acoustic backscatter, and then collecting target strength data from day and night. By analysing the results of both data sets, he reasoned, it would be possible to determine the reasons for any diurnal differences.

## 2. SURVEY DESIGN

### 2.1 Survey area and transect allocation

#### 2.1.1 Main survey

Various acoustic survey designs for SBW stocks were investigated by Dunn & Hanchet (1998). They showed that the 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 1998 survey of the Campbell Island Rise, information from both sources was used to redefine the survey strata and the associated sampling effort.

The initial stratification used in previous surveys of Campbell Island Rise was reviewed by examining the spatial distribution of SBW from historical catch effort data and from previous acoustic surveys. Based on this information, stratum boundaries were changed slightly to better reflect recent fishing effort and acoustic survey results.

Initial allocation of phase 1 transects was carried out based on the stratification given by Dunn & Hanchet (1998), using the following equation:

$$n_i = NA_iV_i \Big/ \sum_{i=1}^{m} A_iV_i \qquad \text{for } m = \text{total number of strata}$$

where:

$n_i$ is the number of samples allocated to stratum $i$ of area $A_i$ and variability $V_i$, and $N$ is the total number of stations in the snapshot. The proportion of the total number of commercial tows (from 1983 to 1996, and 1990 to 1996) which had been made in each stratum, and also the mean acoustic transect density estimates from previous surveys, were used separately as estimates of variability. (The mean was used because this is generally thought to be more precisely known than the variance (Francis 1984).)

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 optimal allocation using these two data sets therefore gave somewhat conflicting results. Optimal allocation using the acoustic survey results suggested a higher weighting for strata 2, 3, and 7, but these were based on only three years' data. The final allocation schedule chosen gave most weighting to strata 7 and 2, which have been the most consistent areas of high density, with a slightly higher weighting to stratum 7 on the basis of recent fish distribution.

During the first few days of the survey, the fleet located spawning adult SBW in deeper water in stratum 4 and the adjacent part of stratum 3. Therefore, to improve the survey design, stratum 3 was split into two strata (3N and 3S), and stratum 4 was split into two strata (4D and 4S) at the 450 m depth contour (Figure 1). In addition, sampling effort was increased in strata 4D and 3S because this was where the fleet was fishing. A large mark was also surveyed on a single transect at the southern end of stratum 7.

Before snapshot 2 was started a detectability/target strength experiment (*see* Section 2.1.2) was carried out in stratum 7 which delineated the boundaries of this southern aggregation. During snapshot 2 this aggregation was surveyed as a separate stratum (7F) (*see* Figure 1). The stratum 7F boundaries extended beyond the boundaries of the aggregation to allow for possible movement of fish (Figure 2). Changes made to the northern strata for snapshot 1 were retained for snapshot 2. In addition, the southern parts of strata 6 and 3N were not surveyed. The final allocation schedule is shown in Table 1.

During snapshot 1 transects were carried out into 330 m. On some transects fish marks extended shallower, so in snapshot 2 transects were extended into 300 m. In addition, transects in stratum 2 were surveyed only out to 500 m due to time constraints.

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 (Ingerson & Hanchet 1996, Grimes & Hanchet 1999). At times the direction of transects was altered to allow the survey to continue despite poor weather conditions. Minimum distances of 2 n. mile between the end of one transect and the start of the next reduced spatial correlation between transects in such instances.

### 2.1.2 Detectability/target strength experiment

During the routine transects an aggregation was located to the south of the survey area, at the southern end of stratum 7. During the initial run through the mark it was estimated to be about 6 n.mile long. An experiment was carried out on this aggregation to determine whether there were diurnal differences in backscatter. A series of night, dawn, and day snapshots, each comprising several transects, were completed over a 20 hour period. Transects were spaced at approximately 1 n.mile intervals. Six or seven transects were made across the aggregation during each snapshot (*see* Figure 2). The final transect in each snapshot extended beyond the aggregation to ensure no fish were moving into or away from the experimental area. (The final transects were not included in the biomass estimation and are not plotted.) The boundaries of the aggregation to the west and east were then obtained by taking the midpoint between the last transect with fish and the final transect (with no fish), whilst the boundaries to the north and south were obtained by joining up the ends of the transects (*see* Figure 2). This design allowed for at least five useable transects from each snapshot for density and biomass estimation. Five snapshots were completed, two at night, one at dawn, and two during the day.

## 2.2 Acoustic mark identification and SBW categories

Acoustic mark identification was based on targeted research trawls using *Tangaroa,* on an examination of the location of trawls made by the commercial fleet, and on experience gained from earlier acoustic surveys.

### 2.2.1 Research trawls

Eight bottom trawls and five midwater trawls were carried out to determine species and size composition of the marks (Table 2). Midwater trawls were made using the P/159A Ymuiden pelagic trawl (with 16 m foremeshes), and bottom trawls were made using the fine mesh orange roughy wing trawl. All trawls were made with a 40 mm mesh liner in the codend. The location of these trawls is shown in Figure 3 and the size distribution in Figure 4.

The first three bottom trawls were carried out in stratum 7 in 30–330 m, 350–380 m, and 400–420 m. These provided the size composition of the SBW marks in the shallow waters in stratum 7. Although trawls 2 and 3 were dominated by 2 year old fish, there were significant numbers of 1 and 3 year old fish in each trawl.

Trawls 5 to 7 were midwater trawls targeted at the very dense adult marks at the southern end of stratum 7. Trawl 5 was not sampled because the codend burst and only meshed fish were retained. Trawls 6 and 7 yielded similar size distributions to trawl 5, comprising mainly large fish. Both trawls were made on marks where target strength data had been collected.

Trawls 8 to 12 were bottom trawls made during snapshot 2 in strata 4D, 4S, and 5. Trawls 8 to 10 targeted marks at depths ranging from 430 to 470 m, near where Russian and Polish commercial vessels were fishing. These marks were dominated numerically by mainly mature SBW (*see* Figure 4). The tows also caught significant numbers of silverside (*see* Table 2). Trawl 11 was made in a depth of 400 m and caught immature 1, 2, and 3 year old fish (similar to trawls 2 and 3). Trawl 12 was made in 325–335 m and caught only 1 year old fish. Trawl 13 was a midwater trawl made in stratum 2 over depths of 420–430 m, and yielded a similar result to trawls 8 to 10.

### 2.2.2 Commercial trawls

Vessels started fishing on the Campbell Island Rise on 2 September and continued through until late October. Vessels fished several discrete aggregations in depths of 480–520 m on the northern ground (strata 4D and 3S) until mid September, each at different stages of gonad development. Significant numbers of spent fish were caught on 11 September. However, most running ripe fish were caught from 16 to 18 September. After the initial spawning was completed, some vessels moved into shallower water (430–460 m) on the northern ground (strata 2, 4S, 4D, 5, and 6N), whilst others moved to the southern ground. A second spawning event was taking place on the northern ground on 23 and 26 September, after the acoustic survey was completed. Several vessels fished the southern aggregation between 19 September and 15 October. Spawning was already in progress on 19 September and continued until 26 September. The size distribution of SBW from each of these grounds is shown in Figure 5.

### 2.2.3 Acoustic marks and categories

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:
(i) juvenile (1 year olds),
(ii) immature (mainly 2 year olds, but including some immature 1 and 3 year olds),
(iii) adult (mainly mature 3 to 10 year old fish which have recruited into the commercial fishery).

Distinctive marks in depths of 300–350 m in several strata were assumed to comprise juvenile (1 year old) fish. This is the first time that substantial numbers of 1 year old SBW have been surveyed on the Campbell Island Rise.

As in previous years reasonably extensive marks were found throughout the survey area in depths of 350–420 m. Trawling showed that these marks comprised immature SBW, but, unlike previous years they included 1, 2 and 3 year old fish.

Two areas of adult fish were found. Dense marks located on the northern ground in strata 3S and 4D in depths of 480–520 m during snapshot 1 were being fished by the commercial vessels at the time and so were assigned adult SBW. During snapshot 2, adult SBW marks were located in shallower depths (430–460 m), throughout the northern strata. This apparent change in depth distribution of the fish was consistent with the movement of the fleet into the shallower waters during snapshot 2. However, these marks were more dispersed than the dense pre-spawning marks seen in snapshot 1, and research trawling using *Tangaroa* showed that they comprised a mixture of SBW and other species including silverside, hoki, ling, etc (*see* Table 2). To take account of the proportion attributable to other species, the backscatter from marks in the 430–460 m depth range during snapshot 1 was calculated and turned into biomass using the SBW target strength–fish length relationship (*see* below). This value was then subtracted from the total biomass estimated for the mixed SBW/other marks in snapshot 2.

Dense adult SBW marks were also seen in the southern end of stratum 7, in snapshots 1 and 2. This was confirmed by research trawls 5, 6, and 7, and by the commercial fleet.

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.

## 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.

The abundance indices in previous surveys were turned into absolute estimates using the target strength-fish length relationship used for blue whiting in the Northern Hemisphere by Monstad *et al.* (1992). Recent studies on gadoids in the Northern Hemisphere (Rose 1998) have suggested a higher target strength (similar slope but higher intercept) (Figure 6). *In situ* target strength data collected during the 1998 southern blue whiting acoustic survey agrees with the recent Northern Hemisphere relationship (Macaulay 1999). However, *in situ* data from the 1994 survey agree with the old Northern Hemisphere relationship (McClatchie *et al.* 1998). Regressions fitted to the *in situ* data collected from both New Zealand surveys, and also swimbladder modelling studies (McClatchie *et al.* 1998), suggest a steeper slope than the Northern Hemisphere studies (Figure 6). 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.

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 in decibels and FL is fork length in centimetres (*see* Grimes & Hanchet 1999 for further details).

Adult SBW were assumed to have the length distribution caught by the commercial fishery on the northern and southern grounds (*see* Figure 5). The length frequency distributions for immature and juvenile fish were taken from the *Tangaroa* tows (*see* Figure 4). No allowance has been made for the contribution of other species to the backscattering assigned to the immature and juvenile SBW categories.

In the acoustic analysis the mean SBW stratum density 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 in Cordue (1991).

## 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 therefore examined 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 hadn't 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 7 and 8. During snapshot 1, adults on the northern ground were mainly confined to strata 3S and 4D, and the biomass was 29 000 t (*c.v.* = 52%). Adults on the southern ground were confined to a single transect in stratum 7, and the biomass was 144 000 t (*c.v.* = 101%). The combined snapshot biomass was 172 000 t (*c.v.* = 85%). Few adult SBW were seen in the rest of the survey area. Less dense marks of immature fish were seen around much of the survey area with the densest marks in stratum 7, resulting in an immature biomass estimate of 11 200 t (*c.v.* = 29%). Few marks of only juvenile fish were encountered and these were mainly in strata 4S and 5.

In snapshot 2 the adults were far more widespread in the northern ground occurring in all the strata in the 430–460 m depth range. The highest biomass was in stratum 5, but fish were also seen in strata 2, 4S, 4D, and 6N. The biomass of the marks on the northern ground was 112 000 t (*c.v.* = 24%). Of this, about 8200 t was attributable to other species such as silversides, hoki, etc (Table 3). The final estimate for the northern ground was therefore 103 800 t, which is considerably higher than in snapshot 1. The densest marks were again seen in the small area on the southern ground (stratum 7F) (*see* Figure 2). The estimated biomass in stratum 7F was 121 000 t (*c.v.* = 47%). The combined snapshot biomass was 224 800 t (*c.v.* = 26%). Slightly more immature fish were encountered in the second snapshot and these were mainly in strata 5 and 7, resulting in an immature biomass estimate of 14 900 t (*c.v.* = 28%). Again, few juvenile fish were seen and these were mainly in stratum 5.

## 3.2 Detectability/target strength experiment

The results of the detectability/target strength experiments are given in Table 4 and Figures 2 and 9. The biomass estimates ranged from 60 000 to 120 000 t. Biomass was low during the first night snapshot (7DN1), peaked during the second night and dawn snapshots (7DN2 and 7DN3), and declined during the two daytime snapshots (7DN4 and 7DN5). The two highest snapshot estimates had high densities on most transects (*see* Figure 2) and had the lowest *c.v.*s (20–21%). The other three snapshots had more variable transect densities and higher *c.v.*s (29–54%). The mean of the day and night snapshots were similar (75 000 t and 88 000 t respectively), and because of the high *c.v.*s would not be significantly different. However, the estimates from snapshots 7DN2 and 7DN3 were similar to the estimate obtained from stratum 7F, which was carried out over a similar time period (02:00–10:00) 24 hours later, and the situation may be more complex than simply a day-night difference.

The SBW schools undergo a marked diurnal change in their distribution. During the night the schools appear to combine into a very large single aggregation extending 250–550 m in the water column (over a bottom depth of 600 m), and covering a distance of over 2 n.mile on most transects. Towards dawn this aggregation descends towards the bottom, still as a single layer. As it gets closer to the bottom it breaks up into a number of smaller, denser schools. These schools extend up to about 50 m above the bottom, and, although denser, cover less than 0.5 n.mile of any one transect in total. Although the highest transect densities recorded during day and night were similar (*see* Figure 2). However, the distribution of transect densities between the night/dawn snapshots and day snapshots was quite different. The day transects had a highly skewed lognormal distribution, whereas the night/dawn transects had a bimodal distribution with a peak of low densities, and a second peak of moderate to high densities (Figure 10).

## 3.3 Gonad data

The timing of spawning could not be well defined on the northern Campbell Island Rise (Table 5). Although 10% of fish were spent on 11 September, most running ripe fish were not caught until 16 to 18 September, and the first spawning was not completed until 19 September. It appears that in the 1998 season the fleet fished several different aggregations which were slightly out of phase with one another. A second spawning event occurred on 23 and 26 September.

Spawning appeared to occur slightly later on the southern ground (*see* Table 5). Although fish were still maturing on 15 and 16 September when sampled by *Tangaroa*, spawning was already in progress by 19 September, when the fish were first sampled by the fleet, and continued until 26 September. A second spawning event could not be identified from commercial data on the southern ground.

The data were examined to determine whether there was evidence of turnover. On the northern ground there was a low level of spent fish (5–10%) through most of the survey period. The southern ground was surveyed before spawning took place. There was therefore no evidence of fish spawning and leaving either ground before or during the survey period. Although there was an increase in the proportion of maturing fish during late September and early October on both grounds, observers reported that these fish had already spawned. There was therefore no evidence of turnover on either ground from the gonad data.

## 3.4 Previous acoustic surveys

The results of the decomposition of the "immature" fish marks into numbers at age from previous surveys are shown in Table 6.

## 4. DISCUSSION

### 4.1 Biomass estimation

The main aggregation in the northern grounds was surveyed twice, and the biomass increased four-fold between the first and second snapshots. The reason for this large difference is unclear, but may be associated with the change in fish distribution. During snapshot 1, the fish were still tightly aggregated in small dense pre-spawning and spawning aggregations. By the start of snapshot 2 the fish had finished spawning their first batch of eggs and had moved shallower and become dispersed over a much larger area. The resulting biomass was considerably higher and its *c.v.* much lower than in snapshot 1. It could be argued that the second snapshot was a better estimate of the total biomass of the northern aggregation. However, there is no reason to believe that either estimate is biased, therefore, to be consistent with other years, the average of the two snapshots was taken to be the best estimate, and equalled 70 300 t (*c.v.* = 22%) (*see* Table 6).

The main aggregation on the southern ground was surveyed twice as part of the main survey (strata 7 and 7F respectively), and five times during the detectability/target strength experiment (*see* Section 4.2) (*see* Table 6). Although the snapshots carried out as part of the experiment were not part of the original survey design, they provide additional estimates of the biomass in the southern aggregation. The biomass estimates were variable, but there was no significant difference between day and night. Therefore, the biomass estimates from all seven snapshots were averaged, which equalled 101 200 t (*c.v.* = 26%).

The final estimate of adult biomass from both Campbell grounds was 171 500 t. This is similar to the 1994 estimate, but higher than the 1995 estimate (Table 7). This is the most precise biomass estimate (*c.v.* = 18%) that has been obtained for the Campbell Island area. This low *c.v.* is partly because of the intensive sampling of the southern aggregation and partly because of the dispersed nature of the fish on the northern ground. This is the first time that post-spawning SBW have been surveyed on the Campbell Island Rise.

When the 1999 southern blue whiting stock assessment was first carried out, the results of the detectability/target strength experiment were not available. The acoustic survey estimate was taken as the average of the two snapshots, after subtracting the "other" category, and equalled 198 000 t (Annala *et al.* 1999). When the additional modelling work was carried out, a value of 175 200 t was used for the 1998 acoustic survey estimate. Since then a minor error was found in the calculation, and the revised estimate is now 171 500 t.

Biomass estimates of immature fish were similar between snapshots. The mean biomass estimate of immature fish was taken as the average of the two snapshots and equalled 13 000 t (*c.v.* = 20%). The estimates of "immature" biomass and number of 2 year old fish were the lowest that have been recorded on the Campbell Island Rise (*see* Table 7).

The biomass estimate of juvenile fish was slightly higher in snapshot 2. This may have been partly due to the extension of transects into 300 m depth in snapshot 2. The mean biomass estimate of juvenile fish was taken as the average of the two snapshots and equalled 1290 t (*c.v.* = 52%). This is the first time that 1 year old SBW have been surveyed on the Campbell Island Rise (*see* Table 7).

This is the first time that allowance has been made for the contribution of other species to the backscattering assigned to the adult SBW category. Generally speaking, the bycatch of other species in the commercial fishery is negligible (Hanchet *et al.* 1994), and it is considered that the contribution of other species to the acoustic backscattering from the dense adult SBW marks in the northern and southern aggregations is negligible. Similarly, in previous years SBW have been surveyed during the pre-spawning and spawning period when the fish are still tightly aggregated, and backscatter from other species has probably not been significant. Species mix is likely to be a greater problem for the less dense juvenile and immature marks. However, these are used as relative abundance indices in the modelling (Hanchet unpublished results).

### 4.2 Target strength

There is additional uncertainty over these biomass estimates due to uncertainty over target strength. The abundance indices were turned into absolute estimates by using the target strength-fish length relationship derived for blue whiting in the Northern Hemisphere (Monstad *et al.* 1992). However, recent studies on gadoids in the Northern Hemisphere (Rose 1998) have suggested a higher target strength (similar slope but higher intercept) (*see* Figure 6). Using this relationship would reduce all survey estimates by about 30%. This would affect the absolute estimate of biomass, but indices within a series would still be comparable.

*In situ* target strength work carried out during the 1994 and 1998 southern blue whiting acoustic surveys and theoretical modelling studies suggest a steeper slope than the Northern Hemisphere studies (*see* Figure 6). This would affect the use of the surveys in a relative sense because the biomass of smaller fish (in the 1994 and 1995 surveys) would have been underestimated whilst the biomass of larger fish (in the 1993 and 1998 surveys) would have been overestimated. It is planned to collect further *in situ* target strength data in the 1999 survey of the Bounty Platform.

### 4.3 Detectability/target strength experiment

A detectability/target strength experiment was carried out to determine whether there were diurnal differences in SBW acoustic biomass on the Campbell Island Rise following the recommendations of Rose (1998). Although there was no significant difference in biomass between day and night, biomass estimates appeared to peak (and had lowest *c.v.*s) between midnight and 08:00. There is strong evidence of diurnal differences in adult SBW biomass on the Bounty Platform, where biomass estimates have been up to 20 times higher during the night (Hanchet & Ingerson 1996). Because of this, since 1994 only night transects have been used for biomass estimation on the Bounty Platform. On the Campbell Island Rise, two day/night comparisons of biomass have been carried (*see* also Hanchet & Ingerson 1996). In 1993, a pre-spawning aggregation biomass was estimated to be 7700 t (*c.v.* = 66%) during the day and 9700 t (*c.v.* = 44%) at night. In 1994, a spawning aggregation biomass was estimated to be 4300 t (*c.v.* = 86%) during the day and 20 400 t (*c.v.* = 80%) at night. Because of the high *c.v.*s these biomass estimates were not significantly different.

A number of possible reasons for diurnal differences in acoustic transect densities and biomass have been proposed, including changes in target strength, bottom shadowing (fish in bottom blind layer), lateral avoidance, acoustic shadowing (through signal attenuation), and changes in density distribution (Aglen 1994). Hanchet & Ingerson (1996) were unable to determine which of these was most likely to be a problem on the Bounty Platform. Additional data collected during this survey and other observations made during this and previous surveys are summarised below.

Target strength data were collected from 15:00 to 20:00 during six passes across the aggregation surveyed during the detectability experiment (Macaulay 1999). During that time the top of the aggregation rose up from a depth of 550 m to 250 m (over a bottom depth of 600 m). The results of this work were summarised by Macaulay (1999), who showed that there was no difference in target strength between day and night. These findings are in agreement with the physiology of blue whiting, which has a well developed *rete mirabile*, a gas gland, and also an oval through which the gas resorption takes place (Egil Ona, Marine Fisheries Centre, Norway, pers. comm).

Bottom shadowing was also investigated during the survey and analysis. During the daytime target strength work, the towbody was lowered to within 50 m of the seabed both in, and adjacent to, the dense aggregation. A clear separation was always observed between the fish and the seabed, which was consistent with the observations from the EK500 echosounder on the bridge. It was therefore concluded that no significant amounts of fish occurred in the blind layer close to the seabed.

Lateral avoidance would not appear to be an issue for SBW on the Campbell Island Rise, at least during the current experiment. The fish were located in over 550 m depth of water during the day, and at this depth the effect of vessel noise is unlikely to be significant (Aglen 1994). Attenuation of the marks through the dense daytime schools does not appear to be a problem from examining the echotraces, but this probably needs further investigation.

The last factor considered is the distribution of transect densities between day and night. Adult SBW schools underwent a marked diurnal change in their distribution. During the night the schools appeared to combine into a very large single midwater aggregation. At dawn, this aggregation descended towards the bottom, still as a single layer. As it got closer to the bottom, after dawn, it broke up into a number of smaller, denser schools. The distribution of transect densities between the night/dawn snapshots and day snapshots was therefore quite different. The day transects had a highly skewed lognormal distribution, whereas the night/dawn transects had a bimodal distribution with a peak of low densities, and a second peak of moderate to high densities. The highly skewed distribution of daytime transects was demonstrated further by carrying out a starburst of four transects during the day on one of the densest daytime marks. On two of these transects the amount of backscatter was similar to that obtained from the densest day or night transects. On the other two transects the marks were longer and the amount of backscatter was more than double that from the densest day or night transects.

The trend in biomass observed during the experiment could therefore simply be a function of the density distribution of the transect densities. During the night and dawn snapshots, the fish cover a large area and are distributed reasonably evenly across the aggregation so that most transects will have similar densities. During the day the fish are aggregated into many dense schools. The distribution of these schools and hence transect densities is lognormal, and the chance of hitting a large school is quite low. During the first night snapshot (7DN1) the fish were merging together from individual densely aggregated schools into a single large aggregation and this may account for the lower and more variable biomass estimate observed at this time. Furthermore, this is the only hypothesis that can account for the low snapshot estimate observed between 20:00 and midnight.

It is recommended that transect data collected from each area should be examined for diurnal differences. Future surveys on the Campbell Island Rise should continue to be carried out during the day and night. However, the results from these surveys may need to be treated differently if the preliminary findings from this experiment are confirmed. It is recommended that further 24 hour experiments on both pre-spawning and spawning aggregations are carried out to further examine diurnal variation.

### 4.4 Mark identification

With four surveys now completed, there is a great deal of certainty to the positive identification of the very dense adult SBW marks that contain most of the SBW biomass. Good scientific observer coverage of the commercial fleet also helped to confirm the depths and areas of fish distribution. Trawling is likely to remain an important tool in the acoustic programme for the following reasons:

1. distinguishing less dense adults marks from pre-recruit marks in areas where they occur in similar depths;

2. identifying the size and age composition of SBW in the less dense pre-recruit marks including 1, 2, and immature 3 year old fish;
3. separating the small schooling midwater fish such as the common lanternfish (*Lampanectodes hectoris*) and pearlside (*Maurolicus muelleri*) from the moderately dense schools of pre-recruit SBW when they are in the shallower part of their depth range and close to the bottom;
4. establishing species mix proportions away from the dominant heavy SBW marks.

## 5. ACKNOWLEDGMENTS

We thank the scientific staff who assisted on the survey and also the officers and crew of *Tangaroa* for their helpful co-operation. We also thank Roger Coombs for constructive comments on the MS and Brent Wood for estimating stratum areas for each of the grounds. This project was funded by the Ministry of Fisheries projects SBW9701 and MOF804.

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**Table 1: Transect allocation during voyage TAN9811 in snapshots 1 and 2**

| | Snapshot 1 | | Snapshot 2 | |
|---|---|---|---|---|
| | 7/9/98 - 14/9/98 | | 16/9/98 – 22/9/98 | |
| Stratum | Stratum area ($km^2$) | No. of transects | Stratum area ($km^2$) | No. of transects |
| 2 | 2 912 | 7 | 1 912 | 5 |
| 3N | 2 342 | 3 | 2 342 | – |
| 3S | 1 013 | 6 | 1 013 | 6 |
| 4D | 1 341 | 10 | 1 341 | 6 |
| 4S | 1 200 | 4 | 1 350 | 4 |
| 5 | 2 893 | 4 | 3 029 | 4 |
| 6 | 4 711 | 5 | – | – |
| 6N | – | – | 1 570 | 6 |
| 7 | 3 879 | 9 | 3 769 | 6 |
| 7F | – | – | 186 | 10 |
| Total | | 46 | | 47 |

**Table 2: Trawl station and catch details for TAN9811. Trawl type: BT, bottom; MW, mid-water; Age, age of SBW in years; A, adults (>3 years old); SSI, silverside; SCD, smallscaled nototheniid; MIX, mixture of various other species including hoki, ling, ghost shark, and deepsea pigfish**

| | | Start position | | Trawl | Stra- | Gear depth(m) | | Bottom depth(m) | | Age | SBW | SSI | SCD | MIX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stn | Start date | Latitude | Longitude | type | tum | start | finish | start | finish | | (kg) | (kg) | (kg) | (kg) |
| 1 | 13-Sep-98 | 52 58.11 | 170 09.90 | BT | 7 | 320 | 323 | 321 | 323 | 1/2 | 0.3 | 0 | 25 | 13 |
| 2 | 13-Sep-98 | 53 00.38 | 170 12.10 | BT | 7 | 334 | 372 | 334 | 372 | 1/2/3 | 1000 | 0 | 25 | 4 |
| 3 | 13-Sep-98 | 53 01.94 | 170 20.22 | BT | 7 | 401 | 414 | 401 | 414 | 1/2/3 | 20 | 2 | 4 | 30 |
| 4 | 13-Sep-98 | 53 00.70 | 170 14.05 | MW | 7 | 323 | 352 | 358 | 376 | 1/2/3 | 6 | 0 | 0 | 0 |
| 5 | 15-Sep-98 | 53 22.53 | 170 17.56 | MW | 7 | 258 | 220 | 600 | 588 | Adult | 30 | 0 | 0 | 0 |
| 6 | 16-Sep-98 | 53 22.14 | 170 21.84 | MW | 7 | 240 | 232 | 588 | 592 | Adult | 5000 | 0 | 0 | 0 |
| 7 | 16-Sep-98 | 53 21.39 | 170 19.61 | MW | 7 | 273 | 228 | 577 | 591 | Adult | 2200 | 0 | 0 | 0 |
| 8 | 20-Sep-98 | 51 46.78 | 170 32.25 | BT | 4D | 447 | 447 | 447 | 447 | 2/3/A | 640 | 58 | 0 | 100 |
| 9 | 20-Sep-98 | 51 49.29 | 170 33.03 | BT | 4 | 434 | 437 | 434 | 437 | 2/3/A | 1020 | 15 | 8 | 100 |
| 10 | 20-Sep-98 | 52 05.06 | 170 45.53 | BT | 6 | 456 | 464 | 459 | 464 | 2/3/A | 203 | 12 | 0 | 247 |
| 11 | 20-Sep-98 | 51 56.06 | 170 28.67 | BT | 4 | 400 | 395 | 400 | 395 | 1/2/3 | 287 | 55 | 20 | 17 |
| 12 | 20-Sep-98 | 51 54.43 | 170 19.50 | BT | 4 | 326 | 352 | 326 | 352 | 1 | 5 | 57 | 35 | 100 |
| 13 | 22-Sep-98 | 51 36.00 | 169 57.33 | MW | 2 | 422 | 425 | 447 | 453 | 2/3/A | 51 | 0.4 | 0 | 15 |

**Table 3: Preliminary biomass estimate and c.v. by stratum and snapshot of adult, immature (1, 2, and 3 year old), juvenile (1 year old) SBW, and other species (including silverside, hoki, ling, etc) for the Campbell Island Rise in 1998**

| | Adult | | Immature | | Juvenile | | Other species | |
|---|---|---|---|---|---|---|---|---|
| Stratum | Biomass (t) | *c.v.* (%) | Biomass (t) | *c.v.* (%) | Biomass (t) | *c.v.* (%) | Biomass (t) | *c.v.* (%) |
| Snapshot 1 | | | | | | | | |
| 2 | 312 | 99 | 2 142 | 23 | 122 | 100 | 0 | – |
| 3N | 0 | – | 0 | – | 0 | – | 0 | – |
| 3S | 13 733 | 43 | 0 | – | 0 | – | 0 | – |
| 4D | 14 719 | 93 | 0 | – | 0 | – | 1 709 | 41 |
| 4S | 0 | – | 1 053 | 54 | 321 | 101 | 4 443 | 90 |
| 5 | 0 | – | 1 183 | 77 | 224 | 64 | 1 089 | 110 |
| 6 | 0 | – | 0 | – | 0 | – | 975 | 99 |
| 7 | 143 617 | 101 | 6 794 | 44 | 79 | 71 | 0 | – |
| **Total** | **172 381** | **85** | **11 172** | **29** | **746** | **51** | **8 215** | **53** |
| Snapshot 2 | | | | | | | | |
| 2 | 21 420 | 27 | 1 540 | 45 | 65 | 94 | | |
| 3N | 0 | | 0 | | 0 | | | |
| 3S | 846 | 100 | 0 | | 0 | | | |
| 4D | 5 060 | 63 | 0 | | 0 | | | |
| 4S | 22 944 | 17 | 668 | 90 | 72 | 102 | | |
| 5 | 44 586 | 54 | 8 203 | 46 | 1 134 | 105 | | |
| 6N | 17 044 | 62 | 0 | | 0 | | | |
| 7 | 0 | | 4 488 | 31 | 560 | 88 | | |
| 7F | 120 562 | 47 | 0 | | 0 | | | |
| **Total** | **232 462** | **27** | **14 900** | **28** | **1 831** | **71** | | |
| **Average of snapshots 1 and 2** | | | | | | | | |
| **Mean** | **202 422** | **38** | **13 036** | **20** | **1 289** | **52** | | |
| **Mean (exc. other)** | **198 314** | **38** | | | | | | |

**Table 4: Preliminary biomass estimate and c.v. by snapshot for the detectability/target strength experiment carried out on adult SBW in 1998. (Dawn and dusk were at 06:30 and 18:00.)**

| Snapshot | Stratum area ($km^2$) | Time | Biomass (t) | *c.v.* (%) |
|---|---|---|---|---|
| 7DN1 | 61 | 20:00 – 23:40 | 61 997 | 32 |
| 7DN2 | 69 | 23:50 – 04:10 | 113 064 | 21 |
| 7DN3 | 65 | 04:20 – 08:30 | 119 992 | 20 |
| 7DN4 | 69 | 08:40 – 11:50 | 81 220 | 54 |
| 7DN5 | 95 | 12:00 – 16:10 | 67 982 | 29 |

**Table 5: 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)**

| Date | n | Gonad stage | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| **Northern Campbell Island Rise** | | | | | | |
| 7-Sep-98 | 477 | 3 | 95 | 1 | 0 | 0 |
| 8-Sep-98 | 1158 | 2 | 97 | 1 | 0 | 0 |
| 9-Sep-98 | 796 | 4 | 94 | 1 | 1 | 0 |
| 10-Sep-98 | 853 | 6 | 88 | 4 | 2 | 0 |
| 11-Sep-98 | 540 | 5 | 71 | 9 | 6 | 10 |
| 12-Sep-98 | 688 | 6 | 66 | 18 | 3 | 7 |
| 13-Sep-98 | 704 | 2 | 80 | 8 | 1 | 8 |
| 14-Sep-98 | 1424 | 4 | 79 | 7 | 2 | 8 |
| 15-Sep-98 | 1280 | 4 | 71 | 12 | 8 | 5 |
| 16-Sep-98 | 1159 | 4 | 58 | 16 | 16 | 5 |
| 17-Sep-98 | 1103 | 3 | 64 | 13 | 12 | 8 |
| 18-Sep-98 | 906 | 7 | 63 | 9 | 12 | 8 |
| 19-Sep-98 | 494 | 12 | 75 | 4 | 2 | 7 |
| 20-Sep-98 | 676 | 15 | 74 | 5 | 3 | 4 |
| 21-Sep-98 | 614 | 15 | 74 | 3 | 1 | 7 |
| 22-Sep-98 | 338 | 13 | 50 | 28 | 4 | 6 |
| 23-Sep-98 | 840 | 8 | 27 | 30 | 31 | 4 |
| 26-Sep-98 | 1156 | 2 | 8 | 8 | 51 | 32 |
| 27-Sep-98 | 787 | 13 | 17 | 5 | 9 | 56 |
| 28-Sep-98 | 753 | 16 | 12 | 6 | 8 | 57 |
| 29-Sep-98 | 342 | 25 | 11 | 3 | 5 | 56 |
| 30-Sep-98 | 345 | 19 | 29 | 3 | 7 | 43 |
| 1-Oct-98 | 82 | 26 | 34 | 0 | 4 | 37 |
| 2-Oct-98 | 259 | 68 | 13 | 1 | 1 | 17 |
| 3-Oct-98 | 298 | 45 | 26 | 1 | 0 | 27 |
| 4-Oct-98 | 122 | 70 | 24 | 1 | 2 | 3 |
| 5-Oct-98 | 126 | 88 | 11 | 0 | 1 | 0 |
| 6-Oct-98 | 131 | 69 | 24 | 2 | 1 | 5 |
| 7-Oct-98 | 66 | 59 | 29 | 8 | 5 | 0 |
| 8-Oct-98 | 173 | 88 | 9 | 0 | 2 | 1 |
| 14-Oct-98 | 91 | 78 | 7 | 2 | 4 | 9 |
| **Southern Campbell Island Rise** | | | | | | |
| 19-Sep-98 | 809 | 0 | 1 | 49 | 49 | 0 |
| 20-Sep-98 | 645 | 0 | 4 | 20 | 75 | 2 |
| 21-Sep-98 | 582 | 0 | 2 | 45 | 33 | 20 |
| 22-Sep-98 | 749 | 0 | 4 | 4 | 82 | 10 |
| 23-Sep-98 | 457 | 0 | 57 | 1 | 11 | 31 |
| 24-Sep-98 | 157 | 1 | 12 | 10 | 42 | 36 |
| 25-Sep-98 | 40 | 5 | 18 | 0 | 8 | 70 |
| 26-Sep-98 | 61 | 13 | 16 | 7 | 20 | 44 |
| 30-Sep-98 | 194 | 68 | 14 | 1 | 1 | 16 |
| 1-Oct-98 | 178 | 37 | 38 | 3 | 0 | 22 |
| 2-Oct-98 | 60 | 0 | 28 | 3 | 3 | 65 |
| 4-Oct-98 | 121 | 36 | 30 | 4 | 7 | 23 |
| 5-Oct-98 | 160 | 0 | 16 | 1 | 6 | 77 |
| 6-Oct-98 | 210 | 33 | 19 | 1 | 0 | 46 |
| 8-Oct-98 | 112 | 0 | 18 | 1 | 2 | 79 |
| 9-Oct-98 | 68 | 13 | 12 | 1 | 6 | 68 |
| 15-Oct-98 | 43 | 58 | 14 | 7 | 7 | 14 |

**Table 6: Revised adult biomass estimate and c.v. for the northern and southern aggregations for the Campbell Island Rise in 1998**

| Snapshot | Biomass (t) | *c.v.* (%) |
|---|---|---|
| Northern aggregation | | |
| 1 | 28 764 | 52 |
| 2 | 111 900 | 24 |
| **Mean** | **70 332** | **22** |
| | | |
| Southern aggregation | | |
| 1 | 143 617 | 101 |
| 2 | 120 562 | 47 |
| 7DN1 | 61 997 | 32 |
| 7DN2 | 113 064 | 21 |
| 7DN3 | 119 992 | 20 |
| 7DN4 | 81 220 | 54 |
| 7DN5 | 67 982 | 29 |
| **Mean** | **101 205** | **26** |
| | | |
| **Sum of aggregations** | ***171 537** | **18** |

* A slight error was found in this calculation after the earlier value of 175 200 had already been used for modelling.

**Table 7: Adult (recruited), immature (mainly 2 year old), and juvenile (1 year old) mid-season biomass estimates (and % c.v.s), and decomposed number of 1 and 2 year old fish from the surveys of the Campbell Island Rise. –, not estimated**

| | Biomass estimates | | | Decomposed numbers | |
|---|---|---|---|---|---|
| Year | Adult ('000 t) | Immature ('000 t) | Juvenile ('000 t) | 2 year olds (millions) | 1 year olds (millions) |
| 1993 | 18.5 (21) | 89.6 (23) | – | 739.9 | – |
| 1994 | 161.4 (36) | 22.4 (38) | – | 109.2 | – |
| 1995 | 121.1 (30) | 19.8 (20) | – | 121.1 | – |
| 1998 | *171.5 (18) | 13.0 (20) | 1.3 (52) | 84.2 | 56.2 |
| 1998 | **198.3 (38) | 13.0 (20) | 1.3 (52) | 84.2 | 56.2 |

* A slight error was found in the calculation after the earlier value of 175.2 had already been used for modelling. (Hanchet unpublished results).
** Value from Table 3 originally used in modelling for 1999 assessment of Campbell Island stock (Annala *et al.* 1999)

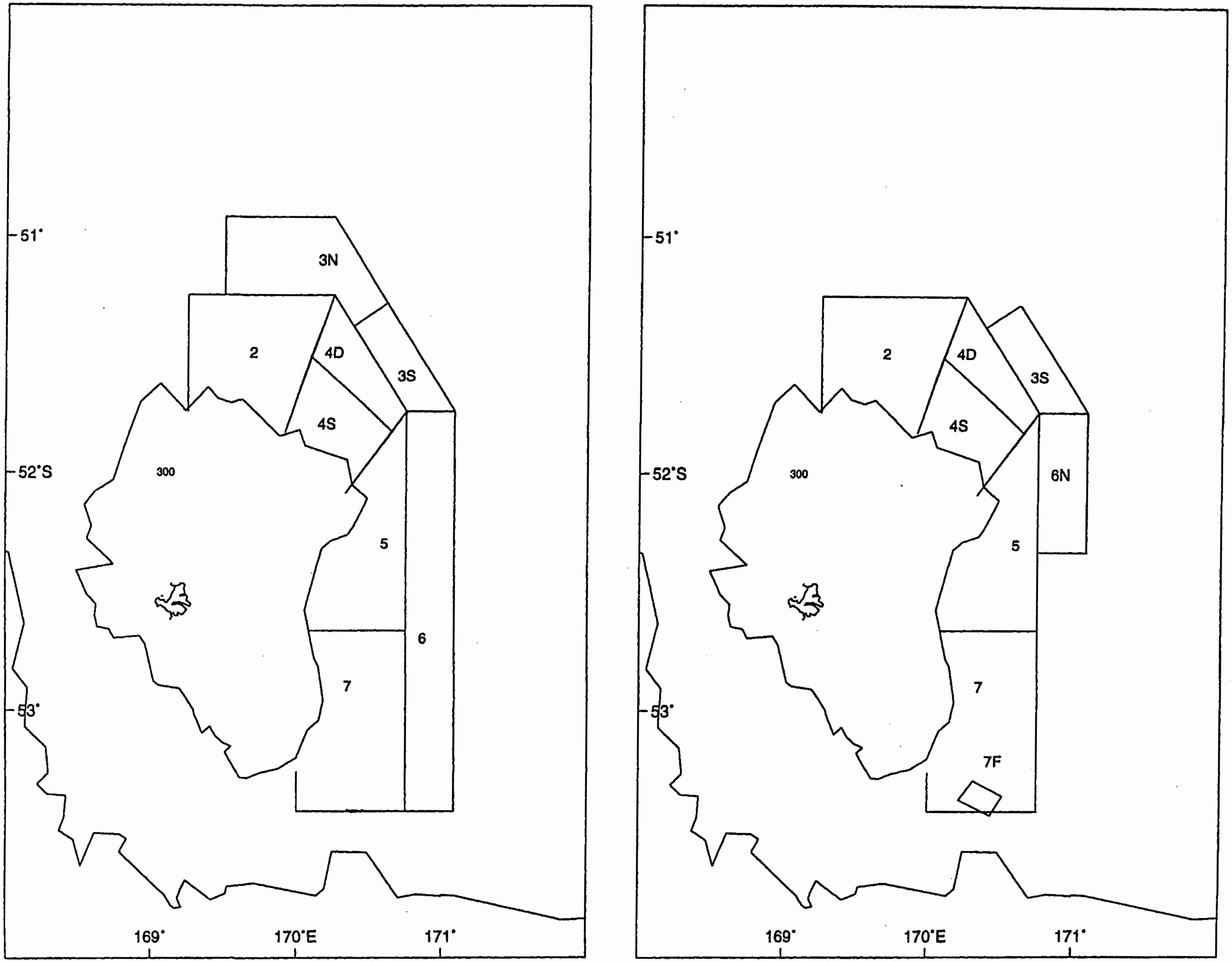



**Figure 1: Survey area and stratum boundaries for snapshots 1 (left) and 2 (right) for TAN9811.**

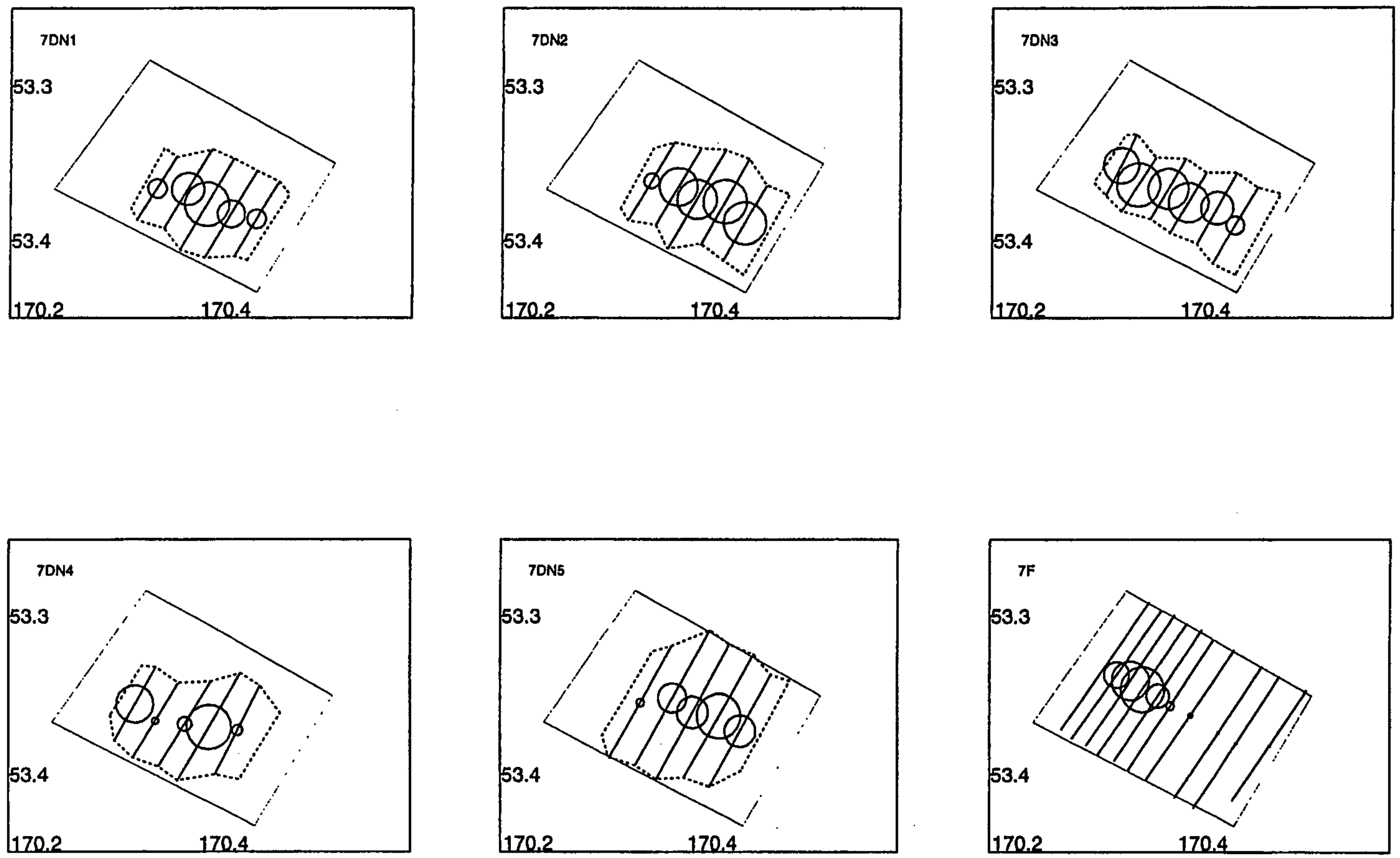



**Figure 2: Density estimates of adult southern blue whiting (t. km$^{-2}$) by transect for detectability/target strength experimental snapshots 7DN1–5, and for snapshot 2 stratum 7F, on the Campbell Island Rise.**

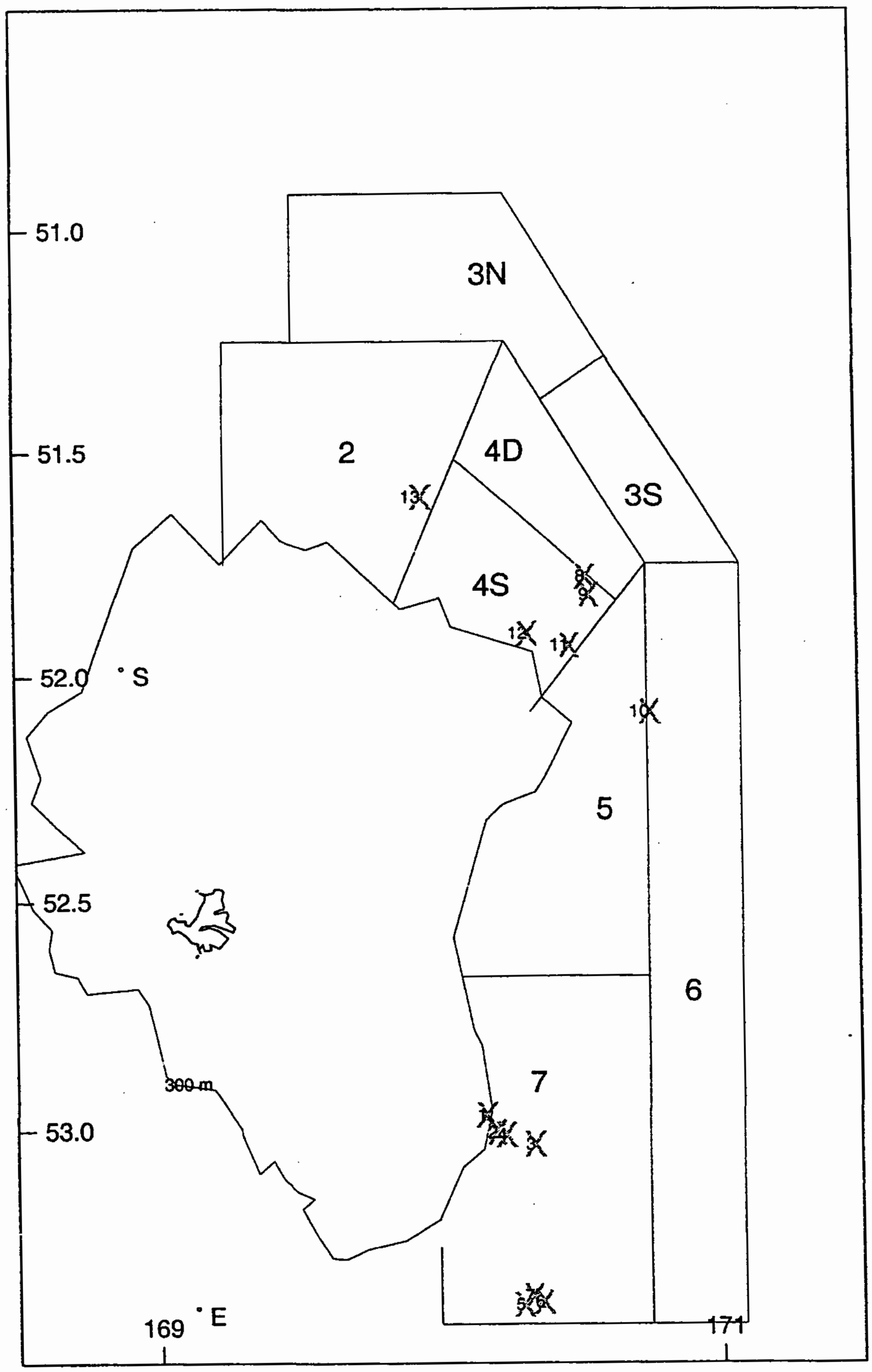



**Figure 3: Location of trawls made during TAN9811, snapshots 1 and 2.**

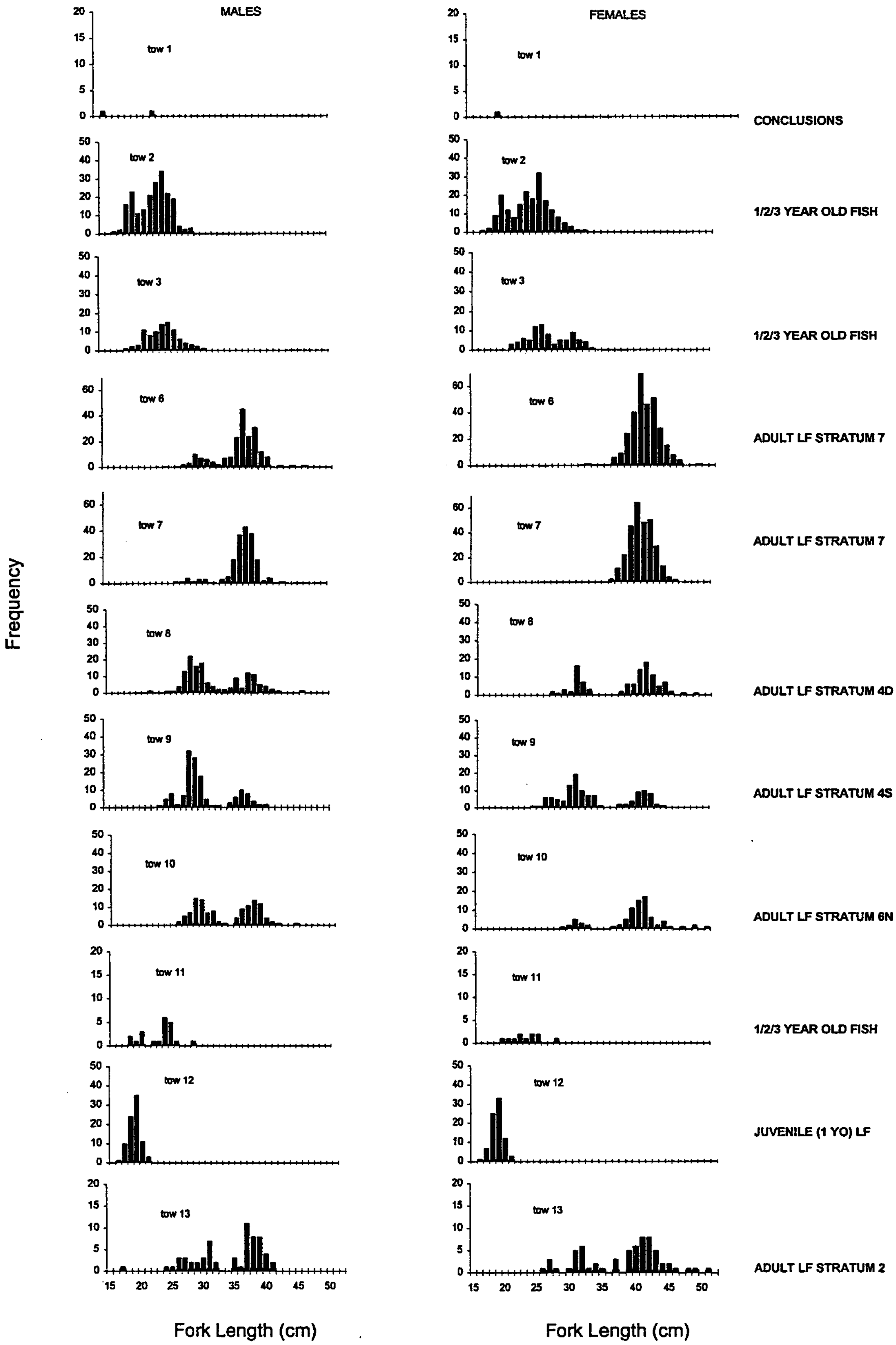



**Figure 4: Raw length frequency distributions of southern blue whiting for each *Tangaroa* trawl station**

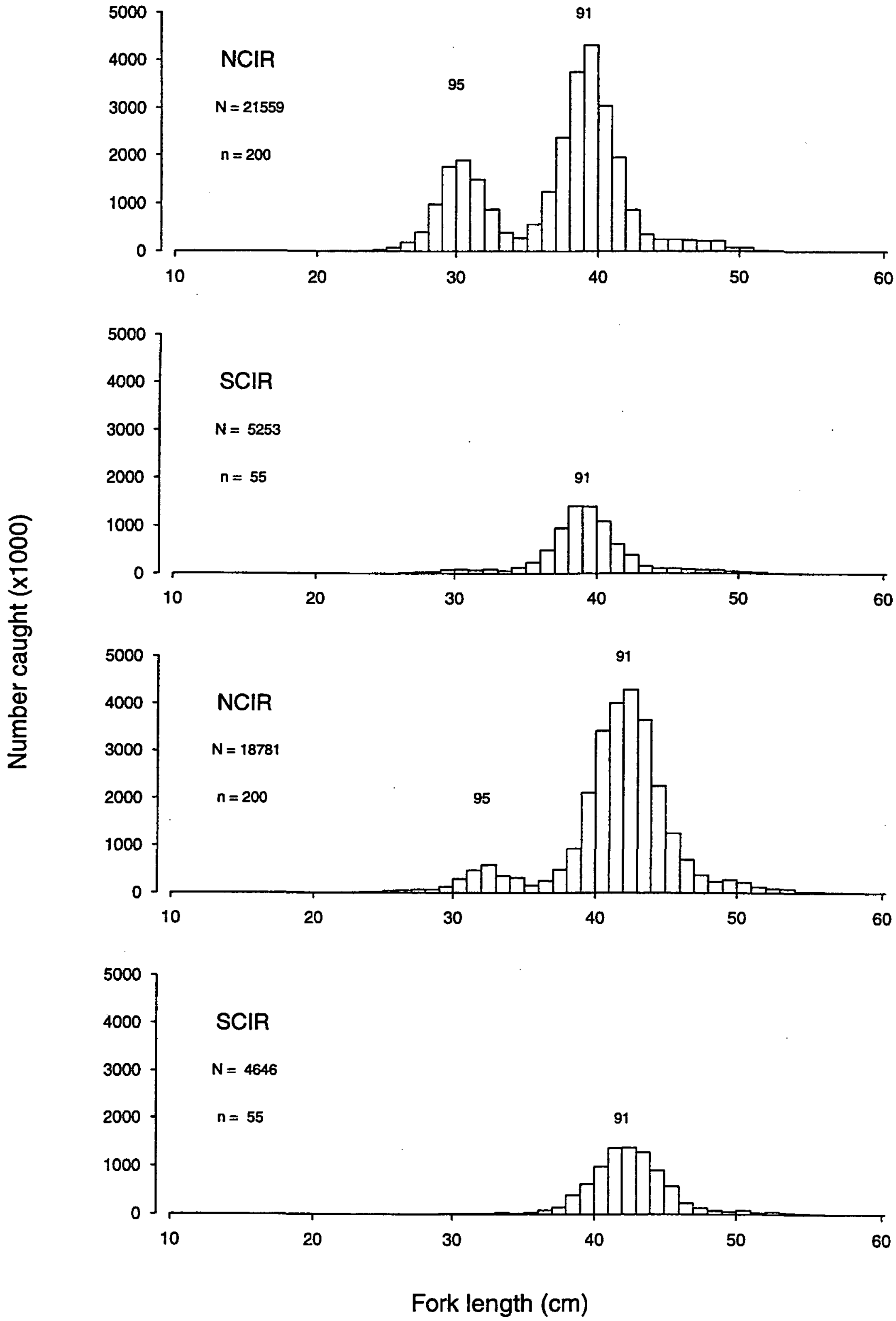



**Figure 5: Weighted length frequency distribution of males and females in the 1998 catch from the northern Campbell Island Rise (NCIR), and southern Campbell Island Rise (SCIR). (N, number of fish measured; n, number of samples). Modal lengths of strong year classes determined from otolith readings are shown.**

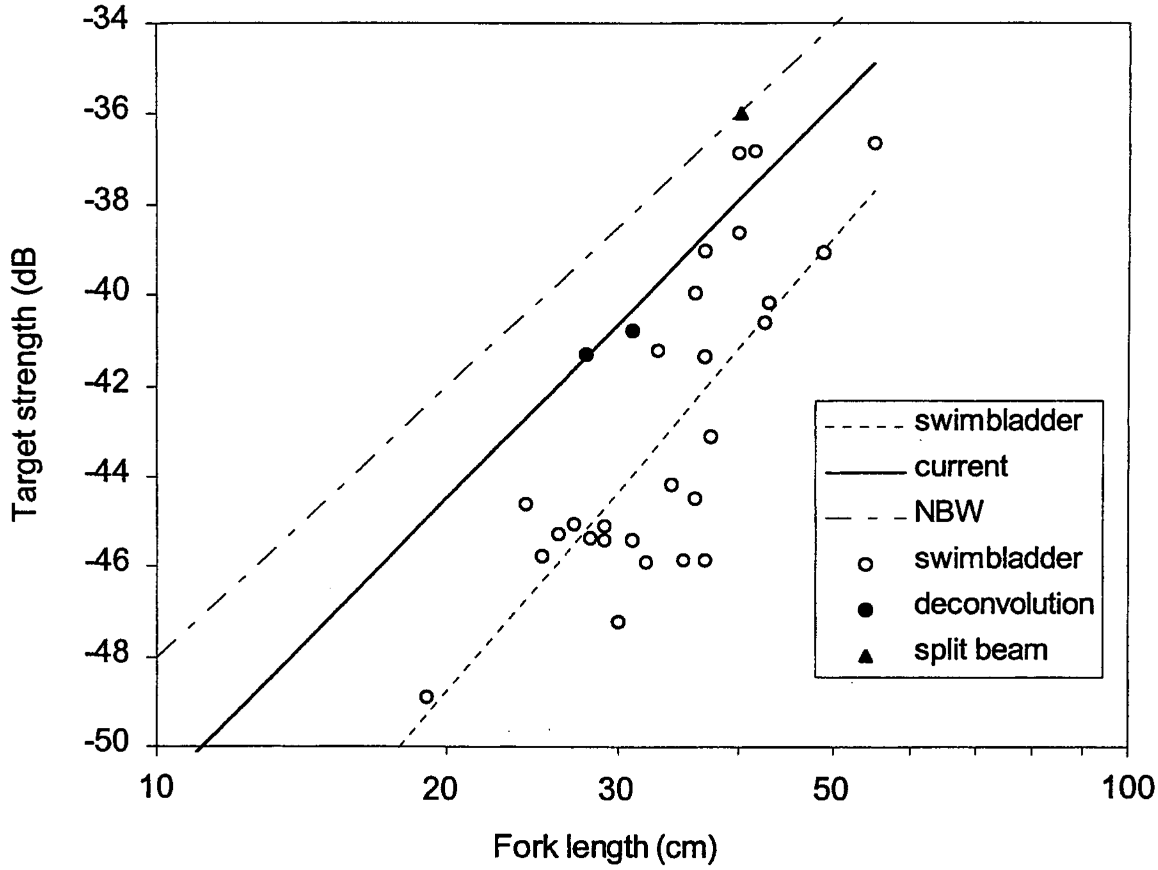



**Figure 6: Target strength – fish length relationship for SBW. The solid line is the existing regression used for biomass estimation. The solid symbols are estimates of target strength from *in situ* studies. The open circles are estimates from swimbladder casts, and the dashed line labelled swimbladder is a regression fit to these points from McClatchie *et al.* (1998). The dashed line labelled NBW is the relationship currently assumed for Northern Hemisphere gadoids (Rose 1998).**

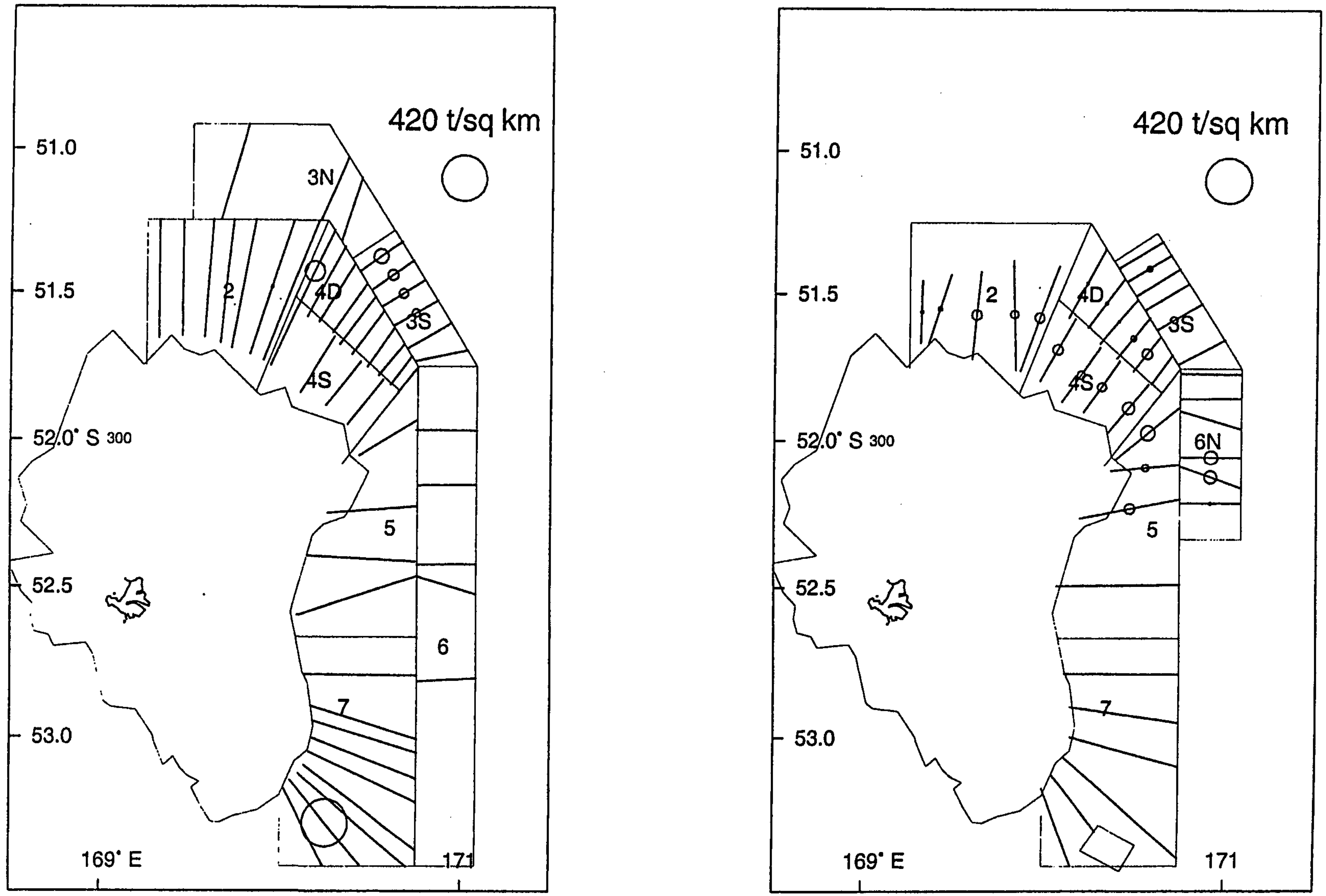
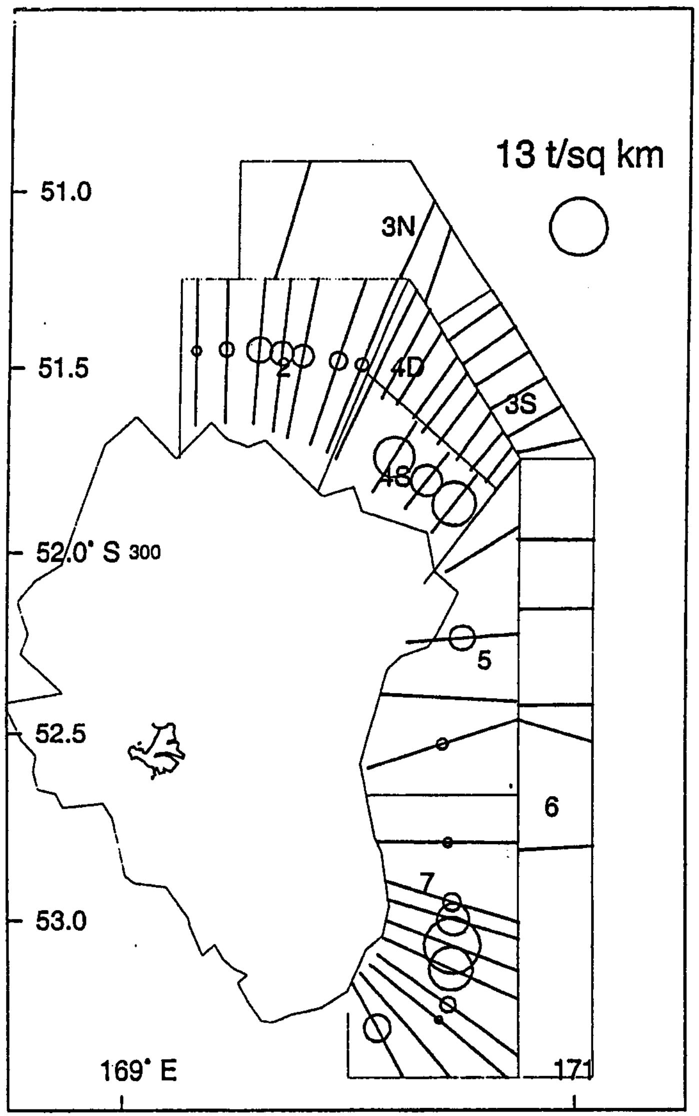



**Figure 7: Density estimates of adult southern blue whiting (t. km-2) by transect for snapshots 1 (left) and 2 (right) on the Campbell Island Rise.**



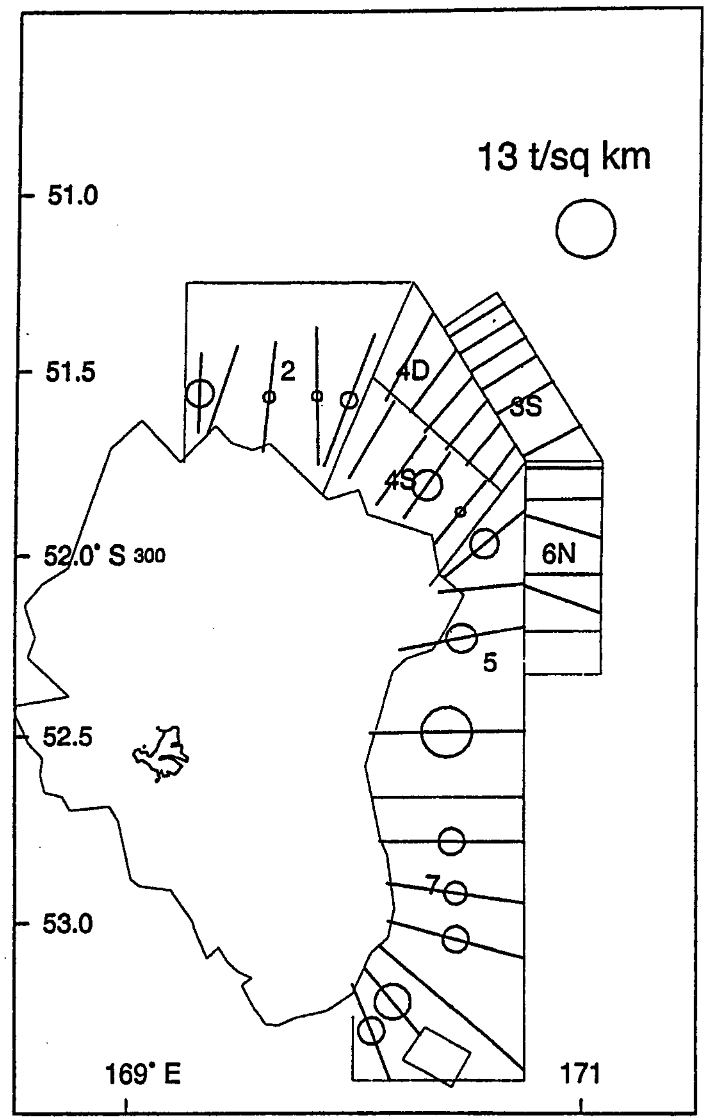




**Figure 8: Density estimates of immature southern blue whiting (t. km-2) by transect for snapshots 1 (left) and 2 (right) on the Campbell Island Rise.**

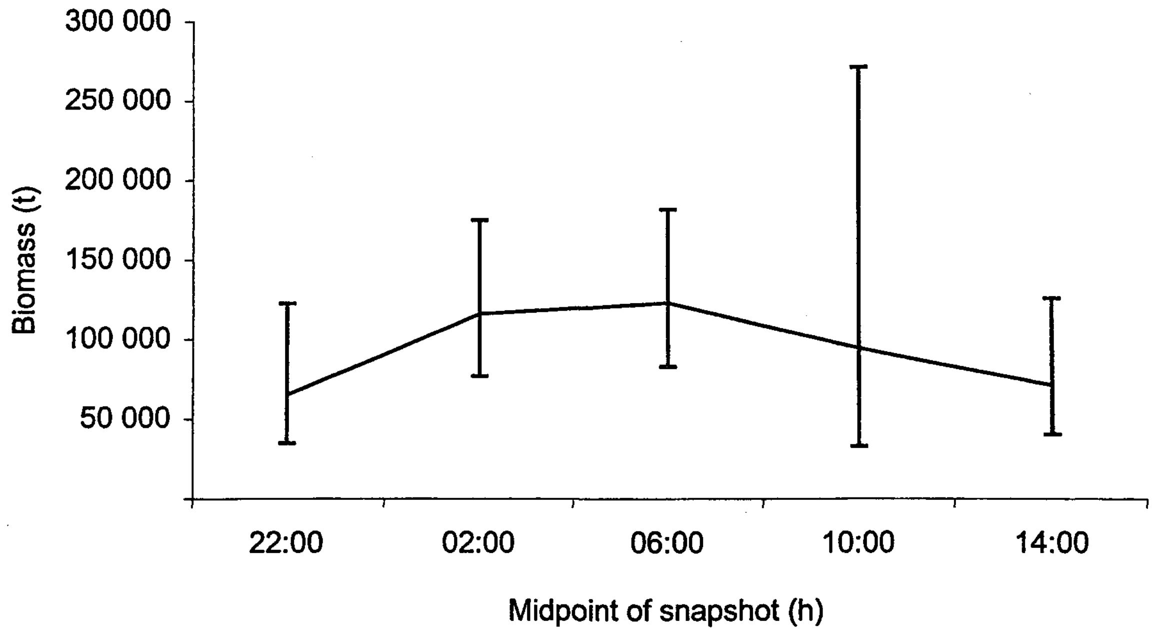



**Figure 9: Biomass estimates (with lognormal error bars) for snapshots 7DN1 to 7DN5.**

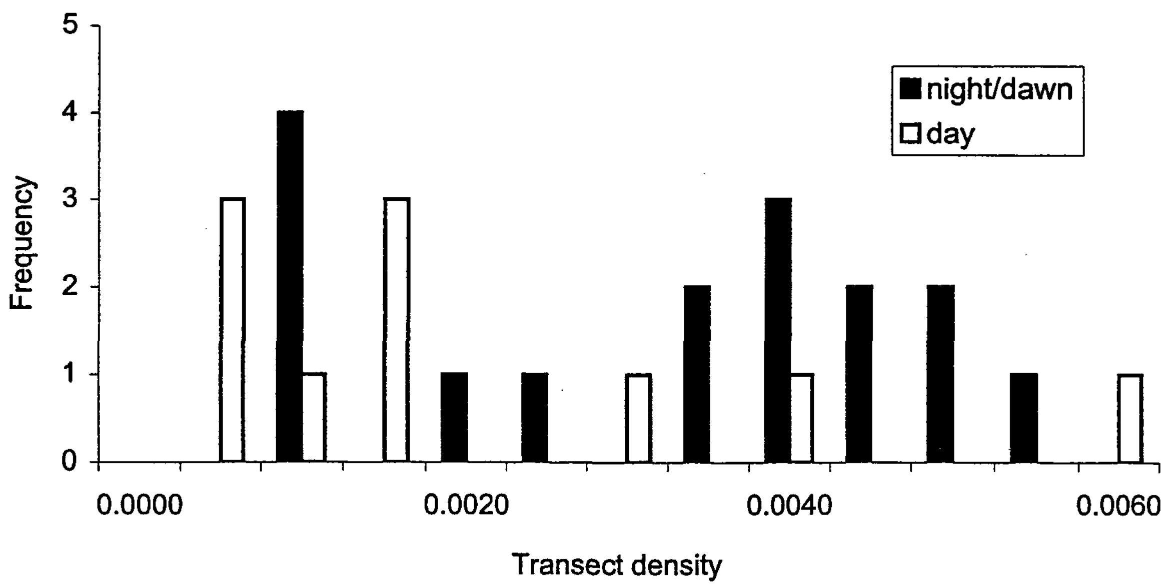



**Figure 10: Distribution of transect densities during day and night/dawn snapshots.**