**MINISTRY OF FISHERIES**
Te Tautiaki i nga tini a Tangaroa

# Diel variation in fish density estimates during acoustic surveys of southern blue whiting

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## EXECUTIVE SUMMARY

Diel variation in acoustic backscattering of southern blue whiting (SBW) was investigated by analysing previous surveys for (i) diel differences in mean transect density, (ii) diel differences in day/night comparisons (primarily of adaptive strata), and (iii) evidence of daytime signal reduction.

There was a drop in transect densities in mid-afternoon and an increase in adult biomass and density estimates at night on all three fishing grounds, but the effects range in size and significance. The diel effect was strongest on Bounty Platform. On this ground, five of the seven day/night comparisons showed significantly higher biomass estimates at night, and transect densities were significantly lower during the afternoon.

There was only weak evidence for diel differences in adult acoustic biomass estimates or transect densities on Campbell Island Rise. All three day/night comparisons gave higher biomass estimates at night than during the day, but the differences were not statistically significant. Transect densities appeared to show a decline in mid-afternoon, but the analysis suffered through low sample sizes and high variability and the result was not statistically significant. Observations from the fishery suggested that diel effects may become more marked as spawning approaches, but this effect was also not found to be significant. No diel differences or trends were observed for immature (2 year old) SBW.

There was no evidence for diel differences in transect densities on the Pukaki Rise. Although transect densities again showed a decline in mid-afternoon, the analysis suffered from low sample sizes and high variability and the effect was not significant.

We propose two explanations for diel differences. Firstly, that they result from differences in density distribution caused by changing light levels. During the day the fish form a number of very dense schools of various sizes, leading to variable biomass and density estimates. At night the fish form a few very large aggregations of lower and more uniform density, leading to more consistent biomass and density estimates. Secondly, that they result from the effect of bottom shadowing during the day (i.e., fish are hard down on the bottom and not available to acoustics). Bottom shadowing is especially problematic on Bounty, where fish are very difficult to detect during the day, even with considerable searching.

The 1998 Campbell data were analysed for evidence of acoustic and bottom shadowing and saturation which would result in a daytime signal reduction. Evidence for acoustic shadowing was inconclusive. We calculated that the effect of the bottom blind zone would be to underestimate the daytime biomass by 1–25%. We believe the upper bound is an overestimate as (i) not all daytime schools are hard down on the bottom, (ii) the estimate uses the minimum depth extent of a SBW school as observed in this survey, and (iii) this estimate assumes a uniform density of fish within a school. Daytime signal saturation occurred infrequently in the densest marks observed and this would have led to a minor underestimate of the daytime biomass estimates.

We recommend that acoustic survey transects continue to be carried out during both day and night on the Campbell and Pukaki grounds and during the night only on Bounty. We recommended that diel differences on Campbell and Pukaki should be further investigated by carrying out additional day/night comparison experiments. These experiments should survey single aggregations for at least 24 hours, and if possible be extended to 36 hours or longer.

# 1. INTRODUCTION

A programme to estimate southern blue whiting (SBW) spawning stock biomass on each fishing ground using acoustic techniques began in 1993. The Bounty, Pukaki, and Campbell grounds were each surveyed annually between 1993 and 1995, and the Auckland grounds were surveyed in 1995, and the results 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), Campbell was surveyed in September 1998 (Hanchet et al. 2000), and Bounty was surveyed in August 1999 (NIWA, unpublished data).

The random parallel transect design of Jolly & Hampton (1990) was used in most strata with transects being run perpendicular to the depth contours, i.e., from shallow to deep water or vice versa. Additionally, on some occasions aggregations were surveyed more intensively by drawing a boundary around the location of dense adult marks and completing a number of shorter random parallel transects in this area. These 'adaptive' strata were sometimes surveyed both during the day and night to test for diurnal differences in biomass (see below).

Diel differences in fish density estimates were first noticed in 1993 on Bounty. An area containing spawning SBW was surveyed during the day and night using replicate transects (Hanchet et al. 1994). The biomass estimate from the night transects was about 20 times higher than from the day transects. In 1994, a series of three further day/night experiments was carried out on Bounty. In each experiment the biomass was higher at night, although not all the differences were statistically significant (Hanchet & Ingerson 1996). Two day/night comparisons were also carried out on Campbell in 1993 and 1994. Again, in both years the biomass estimate was higher at night, but neither result was significant (Hanchet & Ingerson 1996). During the biomass surveys, few marks were seen on Bounty during the day, despite considerable searching, whereas on both Campbell and Pukaki large dense adult SBW marks were clearly visible both during the day and at night.

The results of the non-adaptive survey transects completed during the 1993 and 1994 surveys were also examined for diel differences in fish density (NIWA, unpublished data). All non-adaptive transects were divided into day or night and the mean transect densities compared for each area and year using 2-sample randomisation tests (Manly 1997). Mean transect densities were significantly higher at night on Bounty (P<0.01). Mean transect densities tended to be higher during the day on Pukaki and Campbell, but the differences were not significant (P>0.05). As a result of these analyses it was decided to only survey Bounty at night. It was also decided to continue to survey the other grounds during both day and night and to further investigate diel differences if the opportunity arose.

In 1998, a target strength/detectability experiment was carried out on Campbell (Hanchet et al. 2000). A dense aggregation of adult SBW was surveyed on five separate occasions between 20:00 and 16:00 the following day. The biomass estimates peaked between 00:00 and 08:00, and were lowest between 20:00 and 24:00. There was concern amongst members of the Middle Depths Working Group that there might be a diel effect on biomass and density estimates on Campbell. Therefore a piece of work was commissioned with the following three objectives.

1.    To analyse the mean transect density and density distribution of acoustic backscattering from day and night transects in each area at different time periods of the day.
2.    To review the results of the day/night comparisons carried out in each area during acoustic surveys in all previous years.
3.    To examine dense daytime marks for evidence of daytime signal reduction.

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## 2. METHODS

### 2.1 Transect densities

The following surveys were included in the analysis: TAN9308, TAN9408, TAN9510 (Bounty, Campbell, and Pukaki), TAN9710 (Bounty and Pukaki only), and TAN9811 (Campbell only).

The acoustic data were extracted from NIWA records. For each transect there is a measurement of mean acoustic backscatter per unit area or transect density ('abscf'). The transect density was calculated for marks categorised as 'adult' (1997, 1998 surveys) or as 'definite and probable adults' (1993–1995 surveys). The transect densities used in this work are the same as the transect densities used in the original analyses of the acoustic surveys (e.g., Grimes & Hanchet 1999), and in subsequent simulation analyses (e.g., Dunn & Hanchet 1998). The exception is that when a single transect was recorded in two files we have not combined the two to produce a single transect density, as is usually done. As a result we have two measurements instead of one and better temporal resolution.

Reliable transect densities for immature fish were also available for Campbell from 1993 to 1995. Transect densities for immature fish for Pukaki and Bounty will be changed substantially as a result of a current study under way on a re-analysis of earlier acoustic surveys (milestone 108 of project SBW9801), so data from these two areas were not analysed.

The transect densities cover a wide range, with occasional very high values. Preliminary analysis showed a very skewed distribution of residuals when analyses were carried out without a log-transformation. The $\log_e(\text{abscf}+10^{-8})$ transformation was used in regression analyses to reduce the influence of high values and allow the assumption of normally distributed residuals. ($10^{-8}$ was selected arbitrarily as a small constant.)

Behavioural changes over time in SBW could be expected to be driven by light levels, so the clock time is not as important as the time relative to sunrise and sunset. We calculated sunrise and sunset times for all transects. Since the surveys started on 14 August and continued until 22 September, and covered a range of longitudes from 169.1° E to 179.7° W, there was substantial variation in sunrise and sunset times. A new 'time' variable was made, taking the values 0 at midnight, 0.25 at sunrise, 0.5 at noon, 0.75 at sunset, and 1 at midnight. The value of the time variable for a given transect was based on the time of the midpoint of the transect.

A 'day/night' variable was made based on the 'time' variable: transects were classified as 'day' if their midpoint was between sunrise and sunset (i.e., their time value was from 0.25 to 0.75). 'Time' was categorised as a 'time category' for regression analyses by dividing it for convenience into 12 equal bands (6 between sunrise and sunset and 6 between sunset and sunrise).

Transect 1, stratum 2, snapshot 2, Campbell, 1998 is shown below as an example. The transect started at 14:03 and finished at 16:27, and so the midpoint is at 15:15. Sunrise was calculated as 06:23 and sunset as 18:44, and hence midnight was 00:33 and noon was 12:33. The transect midpoint is 44% of the distance between noon (12:33) and sunset (18:44). So the "corrected" value for the midpoint was 0.61 (which is 44% of the distance between 0.5 and 0.75). This value lies in time category 8.
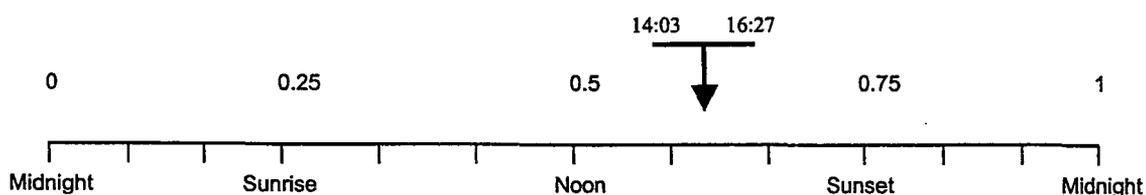
Strata were excluded if they had not already been acoustically analysed, if they were adaptive strata on SBW aggregations, or if all their transects had zero transect densities (Table 1). Transects were excluded if their time or position was not available. Strata with different names in the same geographical location during the same survey were pooled. That left 440 transects in 41 strata (Tables 1, 2). In the analyses of time effects, we indicate the location of a transect by a categorical 'stratum' variable which takes a different value for each of the 41 survey/stratum combinations. In 1995 and 1997 most transects on Bounty were carried out only at night so the number of daytime transects there is low compared to the other grounds (Table 2).

**Table 1: Strata included in the analysis of adult and immature (2 year old) fish**

|      |        |          | Adults | Immature |
|------|--------|----------|--------|----------|
|      | Bounty | Campbell | Pukaki | Campbell |
| 1993 | 1,2 | 2,4,7 | 1,2,3 | 2,4,5,7 |
| 1994 | 1,2,3 | 2,4,5,7 | 1,2,3,4,5 | 2,4,5,7 |
| 1995 | 1,2 | 3,4,7 | 1,2,3 | 2,4,5,7 |
| 1997 | 1,2,3,4 |  | 2,3,4,5 |  |
| 1998 |  | 2,3,4,5,6 |  |  |

**Table 2: Number of non-zero and total adult transects in each time category**

| Time category | Bounty | | Campbell | | Pukaki | |
|---------------|--------|------|----------|------|--------|------|
|  | Non-zero | Total | Non-zero | Total | Non-zero | Total |
| 1 | 16 | 21 | 9 | 15 | 10 | 11 |
| 2 | 14 | 16 | 9 | 15 | 8 | 9 |
| 3 | 11 | 13 | 6 | 11 | 9 | 13 |
| 4 | 9 | 9 | 11 | 18 | 11 | 14 |
| 5 | 4 | 5 | 7 | 13 | 12 | 15 |
| 6 | 4 | 5 | 6 | 11 | 10 | 11 |
| 7 | 1 | 2 | 6 | 12 | 6 | 6 |
| 8 | 3 | 6 | 6 | 16 | 6 | 8 |
| 9 | 6 | 8 | 2 | 8 | 6 | 9 |
| 10 | 14 | 17 | 7 | 17 | 12 | 15 |
| 11 | 12 | 16 | 6 | 13 | 12 | 14 |
| 12 | 11 | 17 | 9 | 17 | 13 | 14 |
| Total | 105 | 135 | 84 | 166 | 115 | 139 |

It was also hypothesised that the relationship between transect densities and time of day may change as the spawning season progressed, due to changes in fish behaviour. We used the variable 'day relative to spawning' to indicate progress through the spawning season, defined as the current date minus the spawning date. The spawning date is defined as the date when at least 10% of the SBW being caught are running ripe (Hanchet 1998). The spawning date varies between areas, years, and strata (Table 3). Spawning dates are available for Campbell and Bounty only.

**Table 3: Spawning dates by area, year, and strata (Hanchet 1998, NIWA, unpublished data)**

| Year | Bounty | Campbell | |
| | all strata | strata 1–4 | strata 5–7 |
| --- | --- | --- | --- |
| 1993 | 21/8 | 21/9 | 25/9 |
| 1994 | 22/8 | 17/9 | 22/9 |
| 1995 | 24/8 | 13/9 | 17/9 |
| 1997 | 29/8 | - | - |
| 1998 | - | 12/9 | 17/9 |

## 2.2   Day/night comparisons

Over the course of the survey series several adaptive strata were surveyed during both day and night to investigate possible diel differences in transect density and biomass. The details of these comparisons are given in the reports of those particular surveys. Some occurred where the fleet were fishing and were designated fleet strata; others occurred where dense adult SBW marks were seen during the acoustic transects and were designated high density strata. In fleet strata, a boundary was drawn around the area that the fleet had been fishing over the previous 12–24 h. This stratum was then surveyed using the random parallel design. In high density strata, three of the boundaries of the aggregation were ascertained from preliminary zig-zag transects going from shallow to deep water along the shelf, until no more dense marks were seen. Next a group of five parallel transects was randomly drawn so that the mean distance between transects was about 0.5 n. mile. These transects were then surveyed acoustically, continuing shallower or deeper if marks extended beyond the stratum boundaries. The groups of transects were repeated until no more dense marks were seen.

The results of all the comparisons are tabulated and tested for significance (*see* below).

## 3.   ANALYSIS

## 3.1   Transect densities

### 3.1.1   Comparisons between times of day

The transect densities were plotted against the 'time' variable for each area. The plots were repeated using the log-transformed transect densities, so as to reduce the visual emphasis on high transect density values.

Transect densities were compared between day and night for each area, and for all areas pooled, by regressing the log-transformed transect densities on 'day/night'. We also included 'stratum' as an explanatory variable to control for the effects of differences between strata and/or differences between years. (The regression analyses effectively calculate differences between times *within* each stratum of each survey, and pool the results across strata and surveys. Direct comparisons are not made between distinct strata or between years.) The regression equation was

$$\log_e(abscf + 10^{-8}) = \beta_0 + \beta_1 \text{ 'stratum'} + \beta_2 \text{ 'day/night'} + \beta_e$$

The effect of time on transect densities was investigated in more detail by regressing the log-transformed transect densities on 'time category' and 'stratum' and plotting the 'time category' effect, again for each area and for all areas pooled:

$$\log_e(abscf + 10^{-8}) = \beta_0 + \beta_1 \text{ 'stratum'} + \beta_2 \text{ 'time category'} + \beta_e$$

This regression was repeated excluding transects with zero transect densities. For Campbell only, this regression was repeated using transect densities for immature fish.

### 3.1.2 Changes in the transect density/time relationship as spawning progresses

It was hypothesised that the relationship between transect densities and time of day would change as the spawning season progressed, due to changes in fish behaviour. We tested this hypothesis by a regression including an interaction term between 'time category' and 'day relative to spawning':

$$\log_e(abscf + 10^{-8}) = \beta_0 + \beta_1 \text{ 'stratum' } + \beta_2 \text{ 'time category' } + \beta_3 \text{ 'day relative to spawning'}$$
$$+ \beta_4 \text{ ('time category' } * \text{ 'day relative to spawning') } + \beta_e$$

## 3.2 Day/night comparisons

The day-night difference in each experiment was tested for significance using the Z statistic (Snedecor & Cochran 1982), assuming estimates were independent and log-normally distributed with *c.v.*s as published. For each test the null hypothesis was no difference between day and night. The entire series of 10 comparisons was also analysed using a sign test (Snedecor & Cochran 1982) to test the statistical significance of the proportion of the comparisons which showed higher densities during the day. A sign test was used because of the non-normal nature of the data.

## 3.3 Daytime signal reduction

The 1998 Campbell Island Rise data were analysed for evidence and/or effects of several possible causes of the reduced biomass estimates calculated during the daytime. These included:
(i)      evidence of acoustic shadowing within the fish schools;
(ii)     effects of the fish distributed within the bottom blind zone;
(iii)    effects of signal saturation within the dense schools of fish.

## 4.      RESULTS

## 4.1     Non-adaptive transects

### 4.1.1   Comparisons between times of day

Plots of log-transformed and raw transect densities against 'time' are shown in Figures 1 and 2 respectively. There is a drop in transect densities during the early morning and day on Bounty. The highest densities on Bounty were all observed during the night. No trend is apparent in the other two areas.

The regression analyses of log-transformed transect density for day/night differences indicated that for all areas mean transect density was higher at night than during the day. This 'day/night' effect approached significance for Bounty (P = 0.07) but not for Campbell (P = 0.84), Pukaki (P = 0.23), or all areas combined (P = 0.15). Given that the day/night difference for Bounty is clearly visible in Figures 1 and 2, it is surprising that it is not statistically significant. However, the graph shows only unstandardised transect densities (i.e., it does not correct for differences between strata and between years). Also, the sample of daytime transects on Bounty is fairly small and comes mostly from the first two surveys, and the variability in the data is substantial (the residual standard deviation is 1.5 on the $\log_e$ scale).

The estimated time effects for each area, and for all areas combined, from the regression analysis using the 'time category' variable are shown in Figure 3. The time effects are not significant for any individual area (Bounty P = 0.49, Campbell P = 0.31, Pukaki P = 0.37). In all three areas there is a consistent decline in transect density from time categories 6 or 7 to category 9 followed by an increase to category 12. This represents a decline during the afternoon from midday until 18:00 (shortly before sunset) followed by an increase through until midnight. Transect densities tend to be more variable during the day on Bounty than in other time categories or areas. No other clear patterns are visible in the results. When the data from all three areas are pooled the time effect is significant (P = 0.029) (Figure 3). The $R^2$ value is 0.29, compared to 0.25 with the 'stratum' effect only.

When the analysis was repeated excluding transects with zero transect densities, the results for Bounty did not change substantially except that the time effect became statistically significant (P = 0.001). The dip at category 9 is still consistent in each of the other two areas although the adjacent time categories 8 and 10 are closer to the average, and the time effects are not significant (Campbell P = 0.30, Pukaki P = 0.84). The time effects are shown in Figure 4. When the data from all three areas are pooled the time effect is again significant (P = 0.03) (Figure 4).

The transect densities of immature fish on Campbell showed no obvious day/night trends (Figure 5), and the time effect was not significant (P = 0.10).

### 4.1.2 Changes in the transect density/time relationship as spawning progresses

For Campbell and Bounty, the interactions between 'time category' and 'day relative to spawning' were not significant (Campbell P = 0.15, Bounty P = 0.26). The 'day relative to spawning' main effect was significant for Campbell (P = 0.005) but not for Bounty (P = 0.66). The effect indicated an increase in transect densities over time. This result is driven by the 1998 survey, where the Campbell biomasses were much higher in the second snapshot than in the first. The main effect is no longer significant if the 1998 data are excluded from the analysis.

## 4.2 Day/night comparisons

The results of all the day/night comparisons of the adaptive strata are summarised in Table 4. In every experiment in both areas the biomass at night was higher than the biomass during the day. The sign test indicates this result is statistically significant (P = 0.002). Biomass at night on Bounty was 2 to 25 times greater than during the day and five of the seven paired comparisons were significantly different (P<0.05). In contrast, biomasses at night on Campbell were 1.2 to 4.7 times greater than biomasses during the day, but none of the individual paired comparisons were significant.

## 4.3 Daytime signal reduction

### 4.3.1 Acoustic shadowing

Indirect evidence of acoustic shadowing within the fish school during the daytime transects was examined in two ways. The first involved analysis of the bottom reflection. This method was preferable to directly examining signal attenuation within the school of fish, as any attempt to do so would require assumptions about the fish density distribution within the school, possibly prejudicing any results that might be obtained. In contrast, in areas where the bottom is relatively flat, one can assume that the bottom reflection will not change significantly over short distances. If the concentration of the fish within the upper part of the school is sufficiently dense to

attenuate the signal reaching fish at greater depths, then this concentration of fish should also attenuate the signal reaching the bottom. Thus, selected data were examined to determine if the echo from the bottom beneath dense schools of fish varied significantly from the bottom echo at places above which the fish marks were weak. This analysis proved inconclusive as the bottom signal was found to be saturated at all times. Had there been a decrease in the bottom echo due to acoustic shadowing by the overlying fish school, it could not be detected using the system gains as set during the transects analysed.

In the second of the attenuation studies, backscatter coefficients for adjacent vertical columns in which the depth to the bottom appeared to vary significantly were analysed. Echoes due to scattered energy arrive later than those due to direct reflected energy. This causes the bottom to appear artificially deep. If an artificially deep bottom corresponds to a portion of the water column in which a dense concentration of fish shadows the bottom, there might be a significant difference in the backscattered energy between these columns and water columns in which the bottom appears at a "normal" depth. Backscattering coefficients were calculated for transmits showing relatively deep bottom and adjacent transmits. There were no significant differences in the backscattering coefficients obtained for any of these transmits.

**Table 4: Summary of day-night comparisons of biomass estimates. S, spawning; P, pre-spawning**

| Year | Day/ Night | S/P | Snap-shot | Stratum area (km$^2$) | No. of transects | Biomass (t) | c.v. (%) | Z statistic | P |
|---|---|---|---|---|---|---|---|---|---|
| **Bounty** | | | | | | | | | |
| 1993 | D | S | 2 | 774 | 5 | 1 700 | 24) | 4.35 | <0.001 |
| 1993 | N | S | 2 | 774 | 5 | 46 600 | 83) | | |
| | | | | | | | | | |
| 1994 | D | S | 3 | 107 | 14 | 1 700 | 52) | 5.70 | <0.001 |
| 1994 | N | S | 3 | 49 | 14 | 40 600 | 27) | | |
| | | | | | | | | | |
| 1994 | D | S | 4 | 1 462 | 18 | 6 100 | 72) | 2.53 | 0.011 |
| 1994 | N | S | 4 | 1 462 | 22 | 48 800 | 54) | | |
| | | | | | | | | | |
| 1994 | D | S | 5 | 1 831 | 14 | 8 900 | 94) | 0.88 | 0.38 |
| 1994 | N | S | 5 | 1 831 | 12 | 20 300 | 53) | | |
| | | | | | | | | | |
| 1995 | D | P | 1 | 1 466 | 4 | 1 200 | 99) | 0.69 | 0.49 |
| 1995 | N | P | 1 | 1 466 | 5 | 2 200 | 31) | | |
| | | | | | | | | | |
| 1995 | D | P | 1 | 475 | 11 | 4 700 | 36) | 2.67 | 0.008 |
| 1995 | N | P | 1 | 475 | 11 | 20 200 | 44) | | |
| | | | | | | | | | |
| 1997 | D | P | 2 | 193 | 7 | 1 300 | 63 | 4.02 | <0.001 |
| 1997 | N | P | 2 | 1 308 | 11 | 25 044 | 48 | | |
| | | | | | | | | | |
| **Campbell** | | | | | | | | | |
| 1993 | D | P | 1 | 306 | 4 | 7 700 | 66) | 0.31 | 0.75 |
| 1993 | N | P | 1 | 306 | 7 | 9 700 | 44) | | |
| | | | | | | | | | |
| 1994 | D | S | 2 | 180 | 11 | 4 300 | 86) | 1.52 | 0.13 |
| 1994 | N | S | 2 | 158 | 12 | 20 400 | 80) | | |
| | | | | | | | | | |
| 1998 | D | P | 1 | 69 | 5 | 81 220 | 54) | | |
| 1998 | D | P | 1 | 95 | 5 | 67 982 | 29) | 0.35 | 0.73 |
| 1998 | N | P | 1 | 61 | 5 | 61 997 | 32) | | |
| 1998 | N | P | 1 | 69 | 5 | 113 064 | 21) | | |

### 4.3.2 Blind zone

The occurrence of fish in the bottom blind zone has also been suggested as an explanation for diel differences in biomass estimates. During the 1998 Campbell Island Rise SBW survey, daytime bottom fish aggregations were found to be 30–50 m in vertical extent. For the Simrad ES38DD transducer used in NIWA's tow body, for a flat sea bottom, the equivalent height of the acoustic dead zone at 500 m range, the approximate depth to the bottom in this survey, is about 0.61 m (Doonan et al. 1999). Assuming a uniform density of fish within the aggregation, this would account for an error of at most 1–2% in fish biomass. However, for bottom slopes of 5–10°, slopes typical of those of stratum 7DN of this survey, the equivalent height of the acoustic dead zone increases to 2.5–7 m, respectively (Doonan et al. 1999). Again assuming a uniform density of fish within the aggregation, and following the procedure in Doonan et al. (1999) for calculating the backscatter correction, if all schools were hard down on the bottom and had a depth extent of only 30 m, the maximum error in the biomass would be about 23%. The true error would be less than this as (i) not all schools are hard down on the bottom, (ii) many of the schools have a depth extent of greater than 30 m, and (iii) the fish density may not be uniform throughout the school.

This correction is of the same order of magnitude as that obtained by Ona & Mitson (1996) for fish hard down on the bottom in a shallow water survey off Norway. Note, however, that Ona & Mitson's procedure for calculating the backscatter correction differs from that of Doonan et al. (1999). Ona & Mitson calculated separate corrections for the equivalent lost volume, the backstep region, and the partial integration zone and then scaled the sum of the corrections by the area backscattering coefficient of the lowest layer to obtain the backscatter correction. In contrast, Doonan et al. (1999) calculated only an equivalent lost height, but scaled it differently. Doonan et al. (1999) stated that as their scaling method involved linear regression of the backscatter in the lowest layers, it provided a better estimate of the lost backscatter than that of Ona & Mitson (1996).

### 4.3.3 Signal saturation

While analysing the bottom echo signals, it was determined that the signal within the dense marks was saturated on several of the daytime transects. Signal saturation occurred for depth ranges of up to about 0.5 m on a few transmits of several of the daytime transects. As the echo level changed rapidly before and after the signal saturated, it is not possible to estimate a corrected value for these depth ranges. However, as the signal saturation occurred in only a few depth bins on a few transmits, the accumulated error resulting from this saturation is unlikely to be more than a few percent. Signal saturation was not observed on any of the night time transects examined. Thus, daytime signal saturation, although not likely to have greatly contributed to an underestimation of the biomass, would have contributed at least in a minor way to the difference in the daytime and night time biomass estimates. In future surveys, the equipment gain needs to be set so as to ensure that the echo signal does not saturate.

## 5. DISCUSSION

The results provide strong evidence for diel differences in acoustic biomass estimates and transect densities on Bounty. On this ground, five of the seven day/night comparisons showed significantly higher biomass estimates at night, and transect densities were significantly lower during the afternoon. Although the 'day/night' effect was not significant in the regression analysis of transect densities for Bounty, the analysis is weak because of the few transects carried out between 10:00 and 18:00. Furthermore, the result is consistent with observations made during the surveys. In each survey considerable amounts of time have been spent searching for marks during the day and few large dense marks have been seen.

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The results for the Campbell ground are less conclusive The analyses of the day/night comparisons and transect densities suggest that SBW are more acoustically visible at night, but none of the results were statistically significant. The regression analysis of transect densities suggested a drop during the afternoon and early evening. However, the analysis is weakened by the high variability in transect densities and by low sample sizes (in the analysis excluding zero transects there were only two transects in time category 9 (late afternoon)). Although most of the day/night comparisons involved only one survey of the aggregation at night and one in the daytime, in 1998 an aggregation was surveyed five times over a 20 hour period from 20:00 to 16:00. The results from this experiment are compared to those of the regression analysis shown in Figure 6, and show a similar trend to the regression analysis, peaking between 04:00 and 08:00, although the two were not statistically significantly correlated (P = 0.17). The large drop between 12:00 and 16:00 was not seen during the experiment. Unfortunately the experiment was not conducted over the critical 16:00 to 20:00 period when transect densities were at their lowest in all areas. Future comparisons should ensure that at least the full 24 hours is covered.

Fewer data are available from Pukaki than from the other two areas as no day/night comparisons have been carried out in this area. As with the other two areas, the time category effect again suggested a decline at time category 9 (late afternoon). However, transect densities in the two adjacent categories (8 and 10) were close to average for all data and well above average when zero transects were excluded. The time category effects had high error bars and again had low sample sizes during the afternoon. The results for the Pukaki Rise should therefore be regarded as inconclusive. If possible, day/night comparisons should be attempted on the Pukaki ground.

Diel differences in acoustic density and biomass estimates have been recognised as a problem in acoustic surveying for a number of years (e.g., Rose 1992, Aglen 1994). A number of possible reasons for the diel differences have been proposed, including changes in target strength, bottom shadowing, lateral avoidance, acoustic shadowing through signal attenuation, and changes in density distribution (Aglen 1994). It is likely that different effects are important for different species and for different areas. For example, Appenzeller & Leggett (1992) found that acoustic estimates of lacustrine pelagic fish abundance in Quebec were significantly lower during the day when the fish were aggregated in dense schools. They attributed the lower daytime estimates to acoustic shadowing, and suggested the bias may have been as large as 50%. Freon et al. (1993) also found large diel differences in acoustic backscattering from a large database comprising mainly small, coastal (continental shelf), tropical pelagic species (mainly Clupeidae and small Carangidae). They attributed the lower daytime backscattering values mainly to lateral avoidance of the vessel by these schools, but also believed that changes in density distribution and fish occurring in the bottom blind area were important. Misund & Aglen (1992) estimated that 35% of midwater schools of herring and sprat, seen ahead of a vessel using a multibeam sonar, avoided the vessel and were not seen on the ship's echosounder.

The reasons for day/night differences in surveys of southern blue whiting have been discussed by Hanchet & Ingerson (1996), Ingerson & Hanchet (1996), and Hanchet et al. (2000). Macaulay (1999) showed that there was no difference in target strength between day and night for southern blue whiting so diel changes in target strength are not an issue. Lateral avoidance is considered to be a problem for some small coastal shallow pelagic species (e.g., Freon et al. 1993), but the avoidance reaction by fish at depths greater than 200 m has been shown to be negligible (Ona & Godo 1990). Ingerson & Hanchet (1996) concluded that lateral avoidance was unlikely to be the main problem on Bounty because diel differences were still found at depths of 400–450 m where the effect of ship's noise would be minimal.

The effect of signal reduction through bottom shadowing on daytime biomass estimates was examined in the present study using data from the target strength/detectability experiment carried out in 1998 on Campbell. The results suggest that the effect of the bottom blind zone would be to underestimate the daytime biomass by 1–25%. We believe the upper bound is an overestimate as (i) not all daytime schools are hard down on the bottom, (ii) the estimate uses the minimum depth

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extent of a SBW school as observed in this survey; many schools had a greater depth extent, and, consequently, the percentage of fish occurring in the bottom zone would decrease; and (iii) this estimate assumes a uniform density of fish within a school. However, a similar range of underestimates (7–24%) were obtained for demersal cod and haddock in the north-east Atlantic (Ona & Mitson 1996).

Although bottom shadowing is undoubtedly important at certain times of the year and in certain areas it cannot explain the low values seen between 20:00 and 24:00 in the target strength/detectability experiment on Campbell, or the diel trend in transect density estimates on the Campbell and Pukaki grounds. Hanchet *et al.* (2000) suggested that changes in the distribution of fish over the 24-hour period meant that the detection probability of the fish became lower at certain times of the light cycle. 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 was therefore quite different in the night/dawn snapshots to the day snapshots. The day transects had a highly skewed distribution, whereas the night/dawn transects had a bimodal distribution with one peak at low densities and a second peak at moderate to high densities. They concluded that the trend in biomass observed during the experiment was simply a function of the distribution of transect densities. During the 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 day the fish were aggregated into a large number of dense schools of different sizes. The size frequency distribution of these schools and hence of transect densities is right-skewed, and the chance of hitting a large school is low. They hypothesised that during the first night snapshot (20:00 to 24:00) the fish were still merging together from individual densely aggregated schools into a single large aggregation and that this accounted for the lower and more variable biomass estimate observed at this time.

There is some evidence that on Campbell this phenomenon is caused by fish aggregating to spawn. Firstly, the time effect in immature (2 year old) fish showed no trend with time of day. Secondly, the differences between the biomass estimates from the day/night comparisons were larger when fish were closer to spawning. The comparisons were carried out 12 days before spawning in 1993, 2–3 days before spawning in 1998 and during spawning in 1994. However, when the transect density data were examined for an interaction effect between 'time category' and 'day relative to spawning' this was not significant.

On Bounty the diel effect is much more marked. Unlike on Campbell, dense daytime marks are rarely seen during the day (*see* Table 1). During searching on Bounty, very dense day time marks have been seen on only two or three occasions and never during one of the surveys or day/night comparisons, suggesting that density distribution is a problem. It may be that bottom shadowing is also more of a problem on Bounty. The slope tends to be steeper than on Campbell, and the bottom tends to be harder and rougher, typically granite, whereas Campbell/Pukaki is softer and smoother, and typically mud. During the day marks are usually seen as small blobs or bobbles hard down on the bottom, whereas on Campbell marks typically have a higher vertical extent and are also seen 'carpeting' the bottom. On one occasion on Bounty, whilst the vessel was stationary carrying out a camera drop, it appeared that fish marks could be seen actually rising up off from the bottom blind layer at dusk. For whatever reason, it appears that a large proportion of the biomass is acoustically invisible on the Bounty. At present, changes in fish density distribution and bottom shadowing are the most likely reasons for the diel differences on Bounty.

It is difficult to reconcile the largely non-significant results of the transect density analysis with the highly significant day/night comparisons. Apart from the dip in transect densities in time band 9 (16:00–18:00) in most analyses, the transect data showed no strong day/night differences in any of the areas. In contrast, the day/night comparisons, particularly those on the Bounty Platform, were strongly significant. Part of the reason for this difference may be the low numbers of

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transect densities on the Bounty Platform during the day, and also the low numbers at time band 9 in each area. Also many of the transect densities had zero or low values and this led to high variability at all times of day and night. In contrast, the day/night experiments were carried out only in areas of high density and therefore should have been more powerful tests of diel differences.

An effort should be made to try and understand the reasons for the results obtained during this study. Where possible, more data should be collected at time band 9 in each area to determine if this decline in transect density is real or if it is just an artefact of low sample sizes. More day/ night experiments should be carried out in each area, and they should cover at least a 24–36 hour period. Further work to try and detect the fish during the day should be carried out on the Bounty Platform. Some success was achieved during the TAN9910 survey of the Bounty Platform. The towbody was lowered to within 150 m of the seabed to reduce the depth of the blind bottom zone, and fish were seen close to the seabed which had not been seen on the ship's sounder. This now needs to be tested in a proper experiment. Lastly, if the analysis were redone, transects from the adaptive strata should be included in the data set, and if possible the transects should be cut into shorter lengths (ca. 0.5 n. mile) so that transect densities can be related to time more precisely.

Further work should also be carried out to determine the effects of acoustic shadowing because analysis of the data to determine these effects in the present study proved inconclusive. Without knowledge of the density distribution of fish within a school, indirect means to estimate the effects of acoustic shadowing must be considered. Examination of the echos from a strong reflector beneath the fish school appears to be a viable method of extracting this information. Furthermore, a likely candidate for this reflector is the bottom. Thus, it might be useful to design a survey across a dense school with gain settings such that the bottom echo remains on scale in order to look for acoustic shadowing. Potential reasons for the diel differences between areas also warrant further examination. The detectability of known targets close to the seabed could be examined between the two areas to determine whether this is a reason for the observed difference.

## 6. CONCLUSIONS AND RECOMMENDATIONS

- There is a strong diel effect on Bounty, with adult transect density and biomass estimates being significantly greater at night. Transects are currently carried out only at night in this area, and it is recommended that this practice be continued.
- The results from the Campbell ground are less conclusive. There is some evidence for a diel effect because adult transect densities and biomass estimates tend to be higher at night, and transect densities lower during the late afternoon, but the results were not significant. It is recommended that transects continue to be carried out during both day and night on this ground.
- The results from Pukaki were also inconclusive. There is some evidence for a diel effect because adult transect densities tend to be higher at night, and lower during the late afternoon, but the results were not significant. It is recommended that transects continue to be carried out during both day and night on this ground.
- It is recommended that further day/night comparisons are carried out to further investigate diel differences on Campbell and Pukaki. These comparisons should survey aggregations for at least 24 hours and if possible be extended to 36 hours or longer.
- It is also recommended that the potential effects of acoustic and bottom shadowing be examined experimentally.

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## Bounty Platform



## Campbell Island Rise



## Pukaki Rise
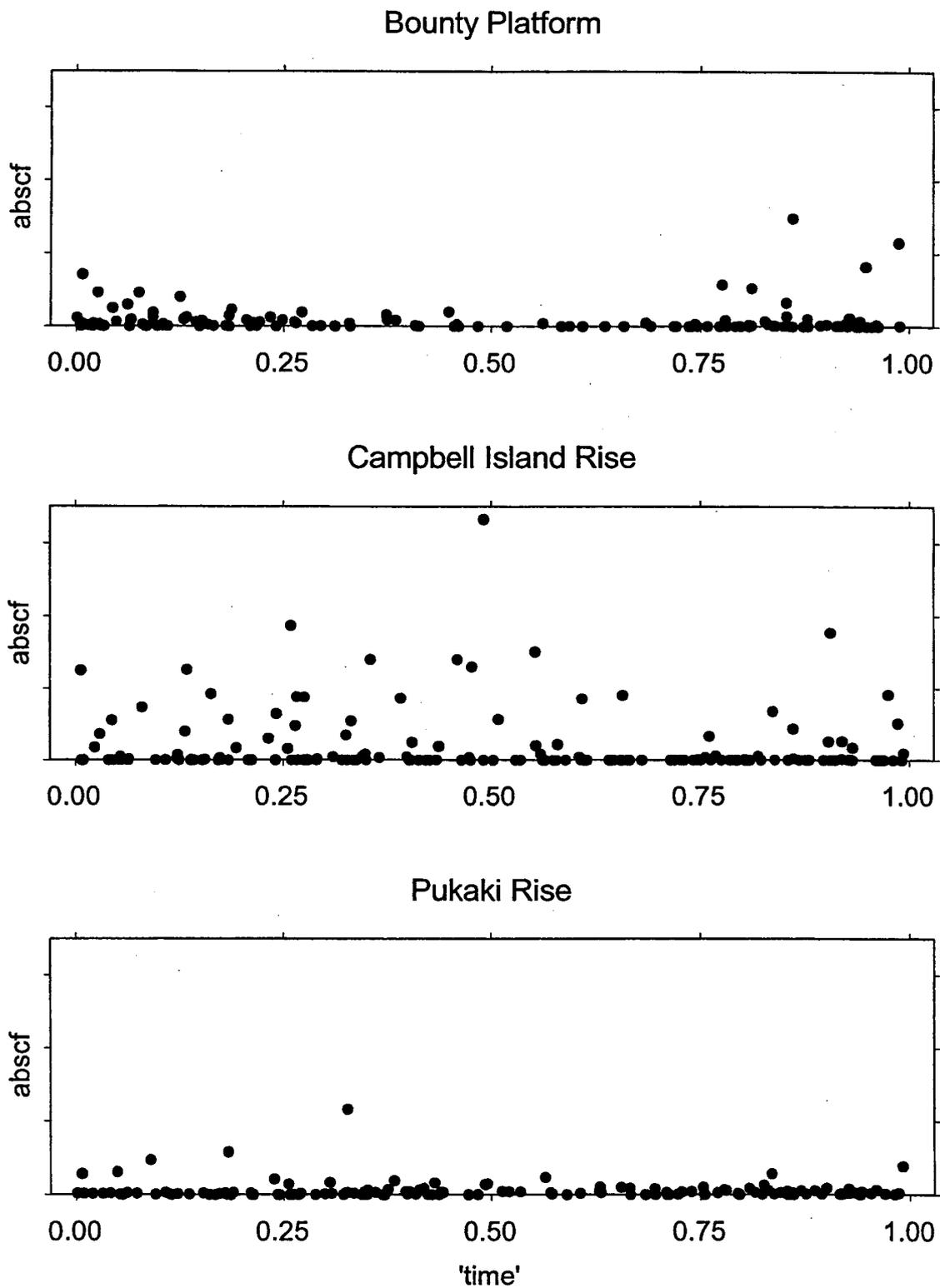


'time'

Figure 1: Transect densities against time of day (0 = midnight, 0.25 = sunrise, 0.5 = noon, 0.75 = sunset, 1 = midnight). All plots have the same vertical scale.
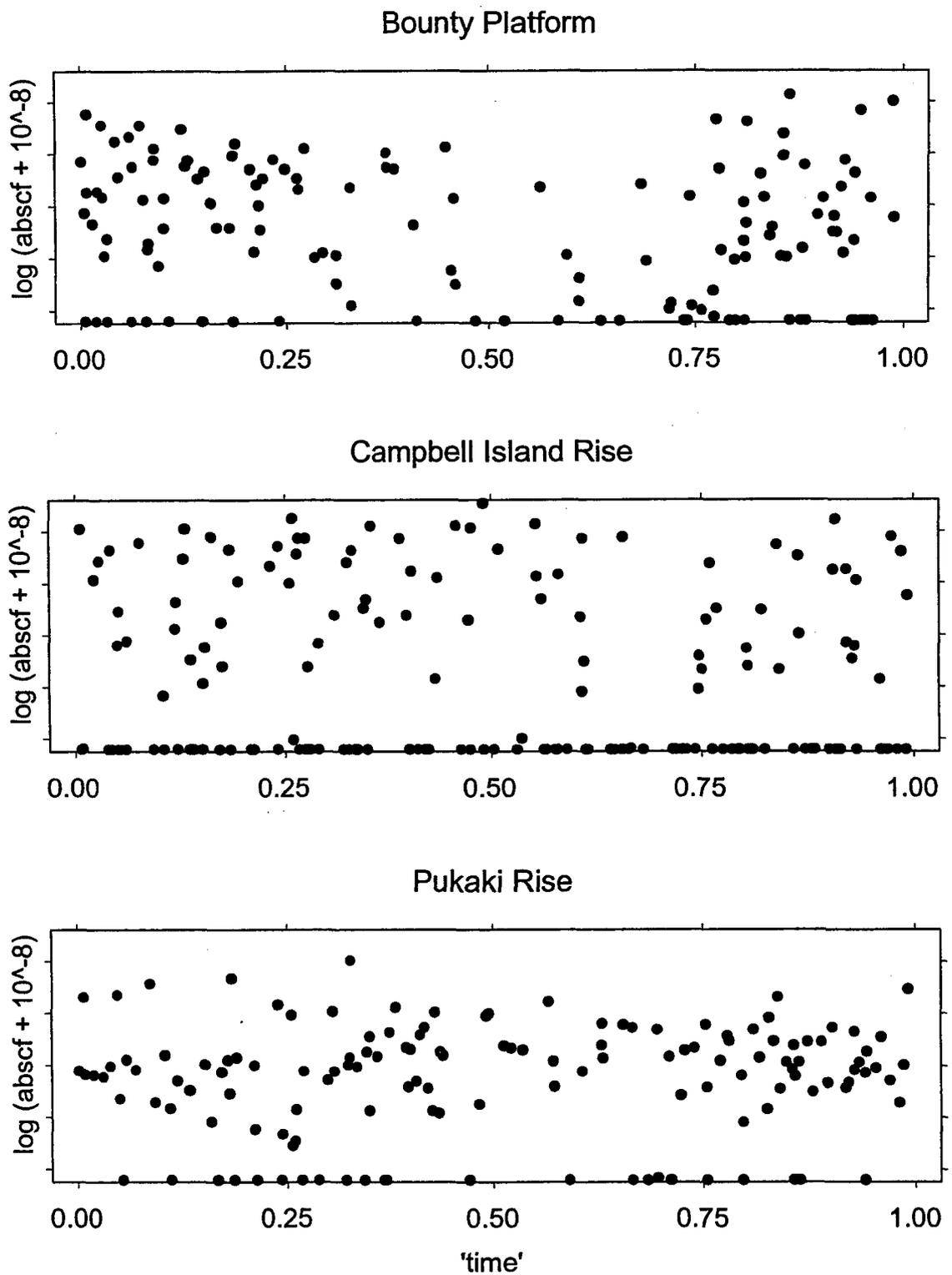
Figure 2: Log-transformed transect densities against time of day (0 = midnight, 0.25 = sunrise, 0.5 = noon, 0.75 = sunset, 1 = midnight). All plots have the same vertical scale. The points along the bottom of each graph have abscf < $10^{-8}$.
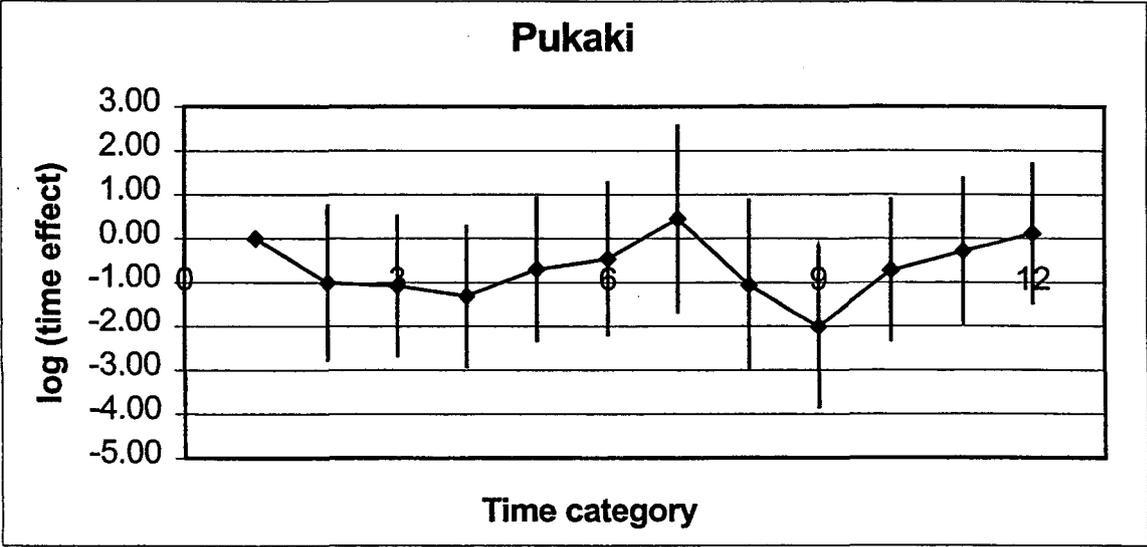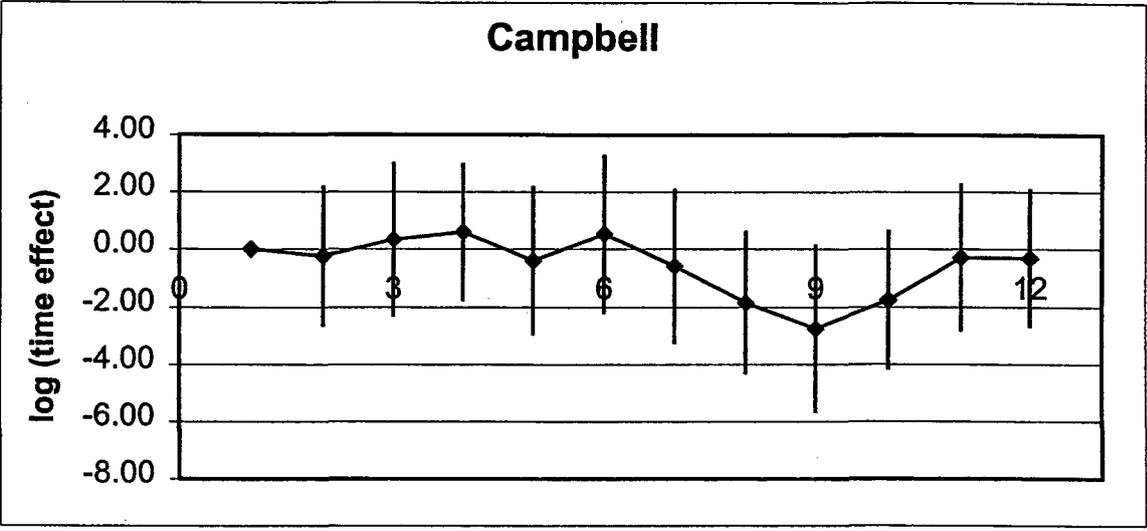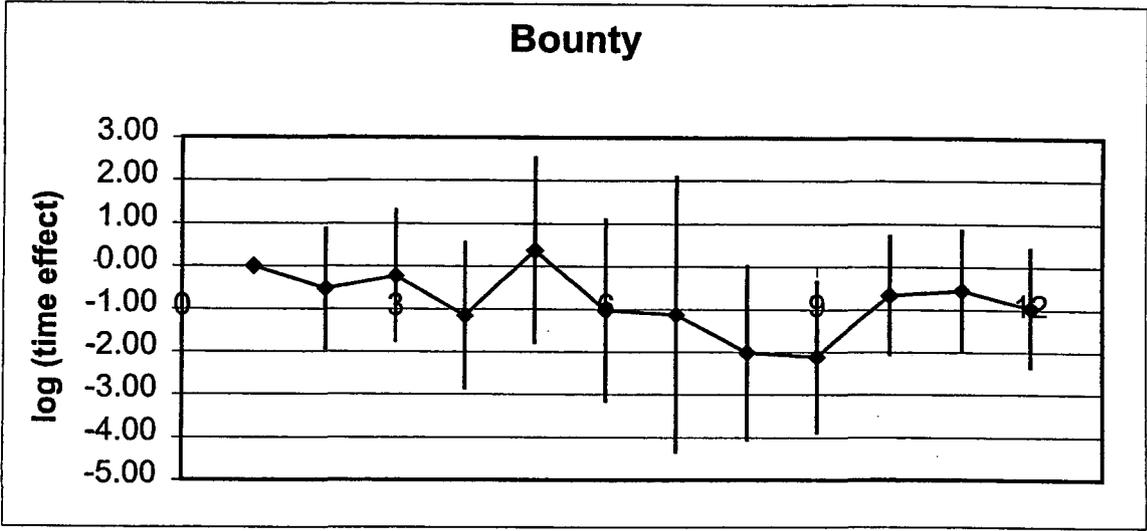
**Figure 3:** Effect of time on transect densities, standardised for stratum/year. Error bars indicate 95% confidence intervals. Values for all time bands are relative to time band 1. Sunrise is between bands 3 and 4: sunset is between bands 9 and 10.
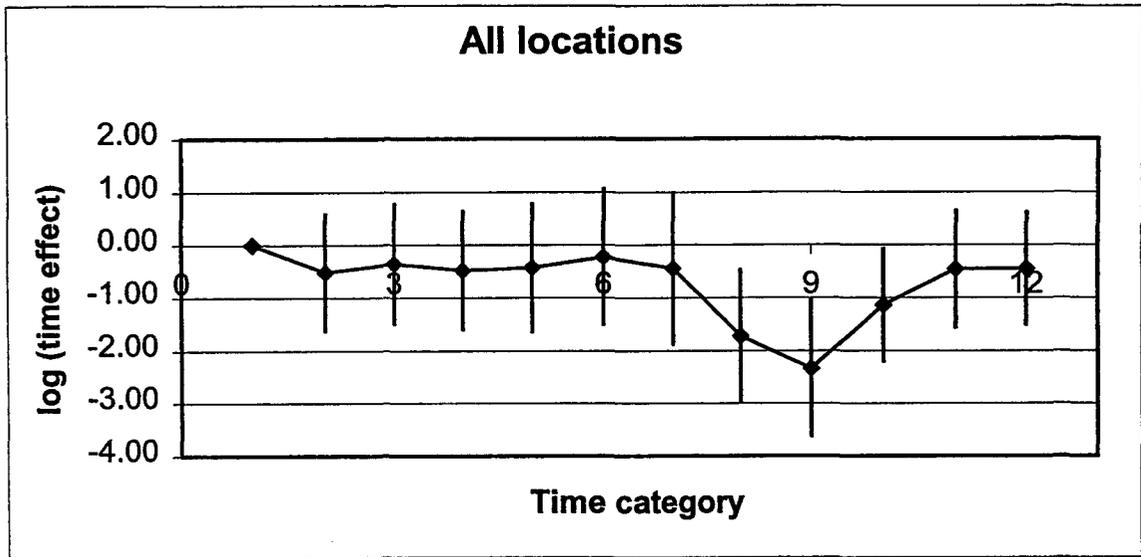
**Figure 3:** *continued*
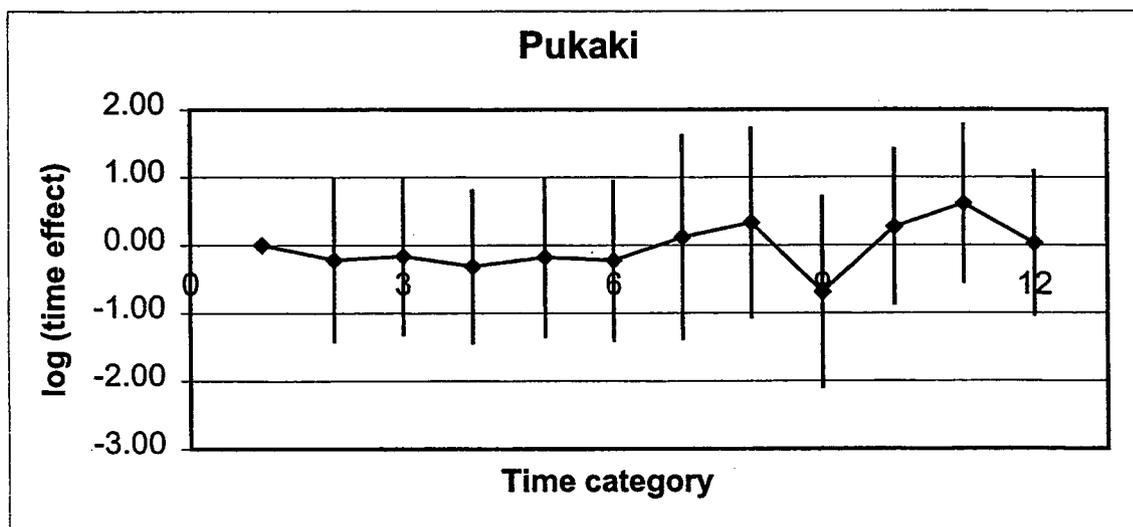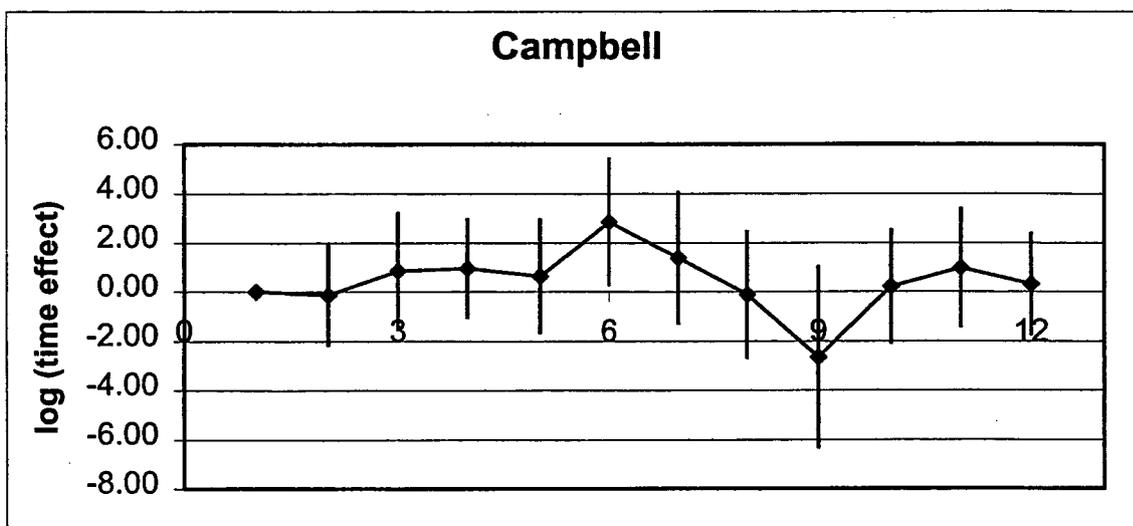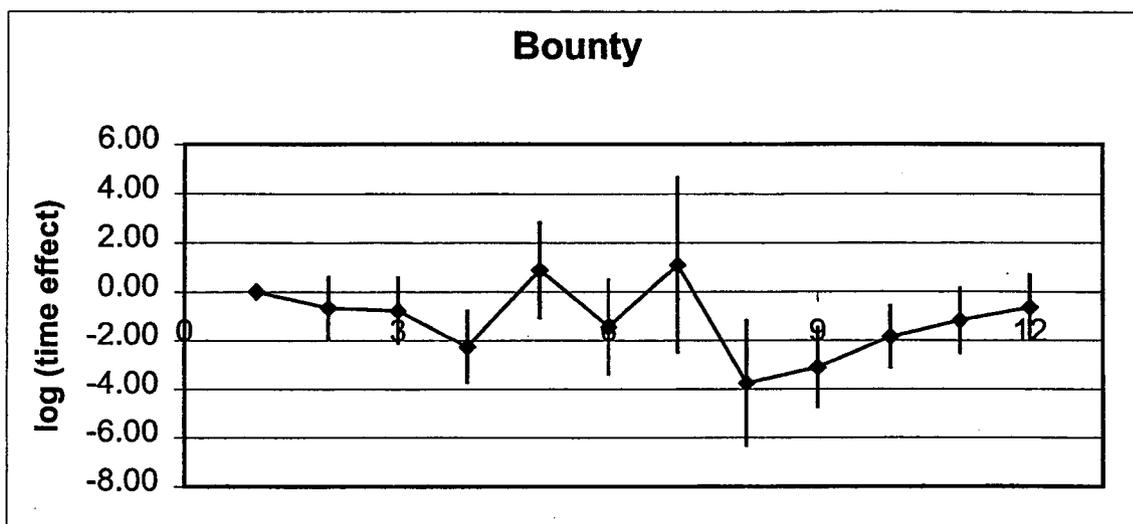
**Figure 4: Effect of time on transect densities, standardised for stratum/year, excluding zero transects. Error bars indicate 95% confidence intervals. Values for all time bands are relative to time band 1. Sunrise is between bands 3 and 4: sunset is between bands 9 and 10.**

**All locations**
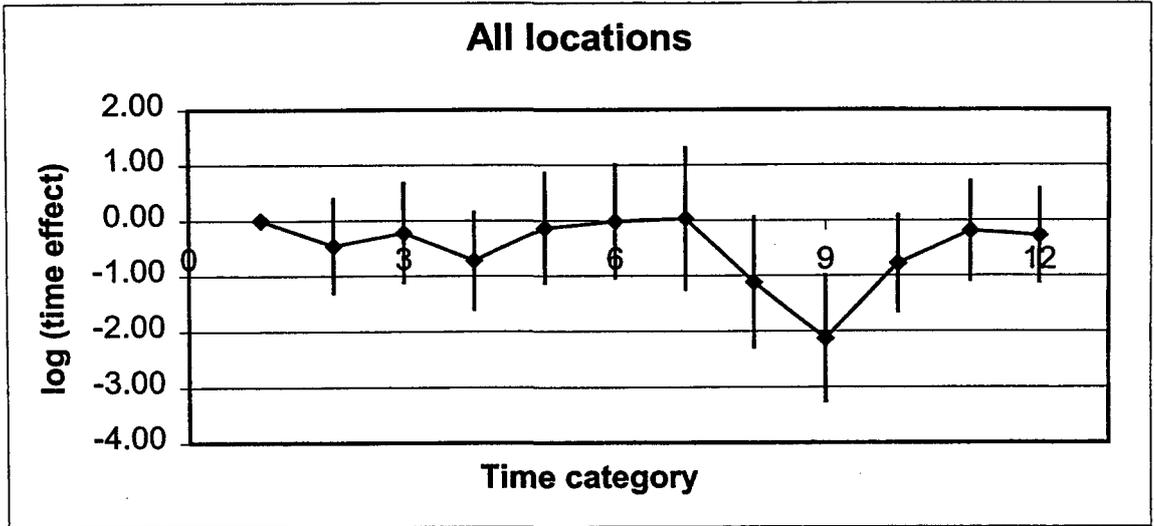
Figure 4: *continued*



**Immatures on Campbell**
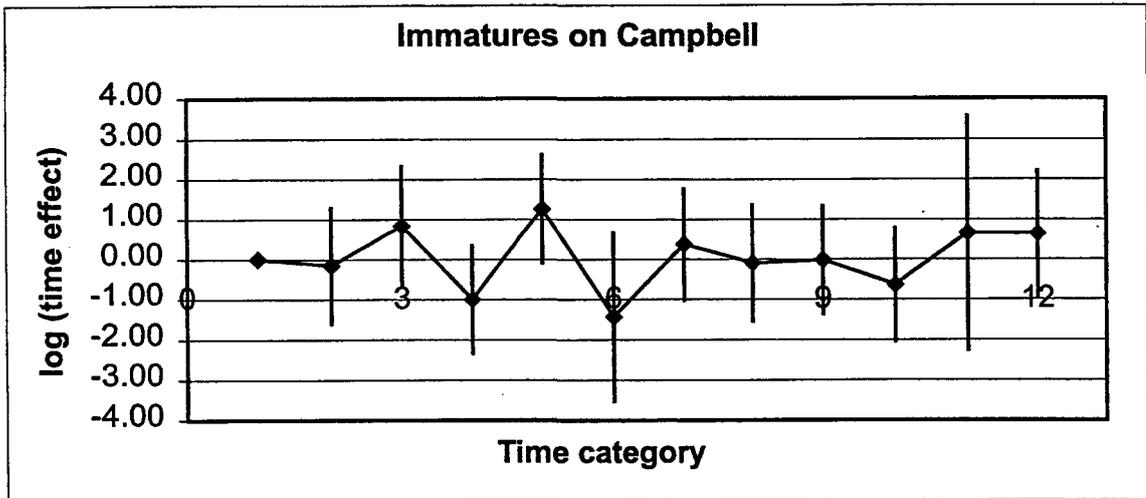
Figure 5: Effect of time on immature transect densities, standardised for stratum/year. Error bars indicate 95% confidence intervals. Values for all time bands are relative to time band 1. Sunrise is between bands 3 and 4: sunset is between bands 9 and 10.
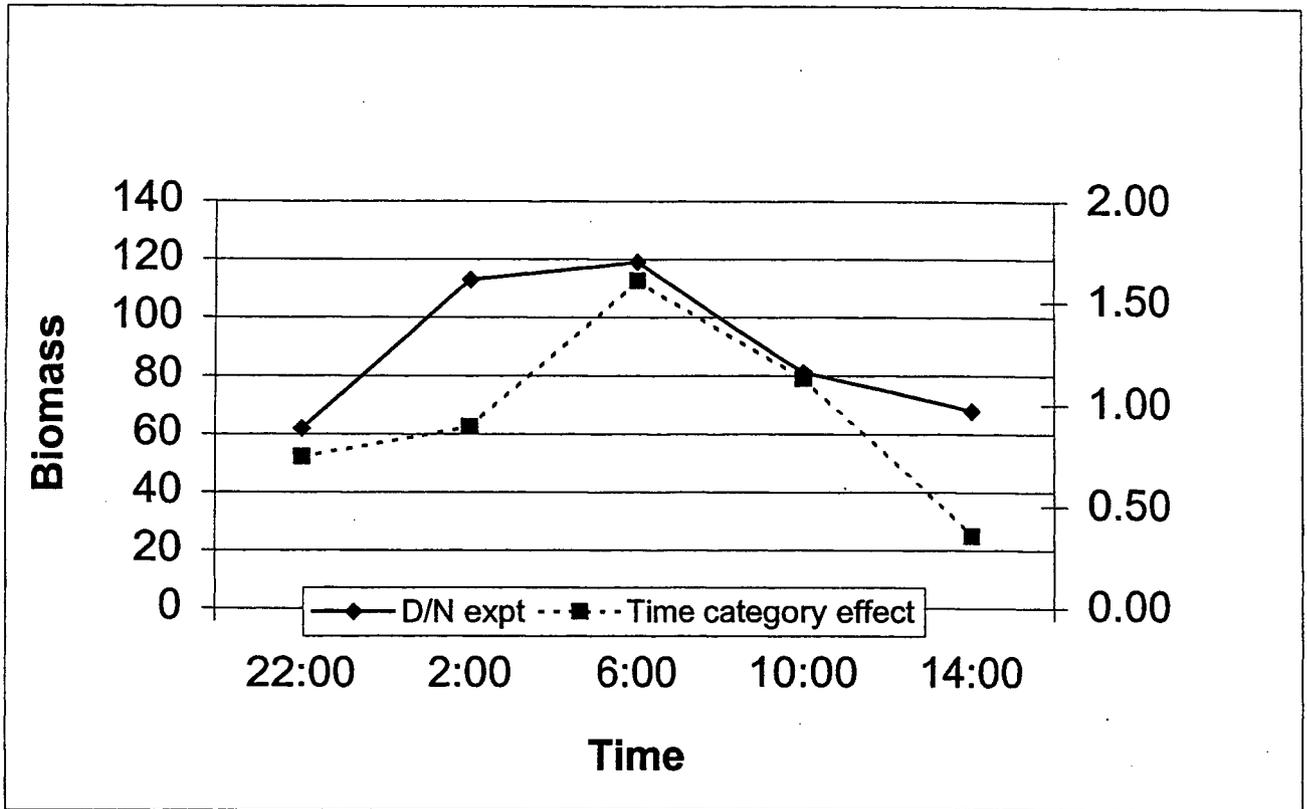
**Figure 6:** Comparison of 1998 day/night target strength/detectability experiment with time effect from regression analysis of non-adaptive transects (1993 to 1998) for Campbell Island Rise.