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Diel variation in spawning orange roughy (*Hoplostethus atlanticus*) abundance over the Graveyard seamount on the Northwest Chatham Rise

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Final Research Report

Report Title:	Diel variation in spawning orange roughy *(Hoplostethus atlanticus)* abundance over a seamount feature on the Northwest Chatham Rise
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7. Executive Summary

The diel variation in abundance of an orange roughy *(Hoplostethus atlanticus)* spawning aggregation on the Graveyard seamount on the Chatham Rise was studied using acoustics. A four day survey was carried out using a Latin cube statistical design. The acoustic data was echo-integrated and analysis of variance was carried out to estimate the effects of day, time of day and transect path. The estimated biomass of the spawning aggregation did not display any significant diel variation. We conclude that this result validates the current practice of acoustically surveying orange roughy on this seamount without considering diel effects. The aggregation fluctuated in abundance over the survey period, suggesting that turnover of fish was occurring. Differences in roughy biomass with transect orientation indicate the importance of randomized radial transects for these surveys.

8. Objective

To investigate the temporal dynamics of orange roughy spawning aggregations.

9. Introduction

Orange roughy (*Hoplostethus atlanticus*) is one of New Zealand's most important commercial finfish species. It occurs throughout much of the 200-mile Exclusive Economic Zone (EEZ) in depths between 700 to 1500 m. Biological information collected on orange roughy indicates a slow-growing and long-lived species; studies indicate it can live to over 100 years (Tracey & Horn 1999).

Orange roughy form dense aggregations during spawning and for feeding purposes over areas of seamounts throughout the EEZ and on some flat slope areas adjacent to seamount features (Clark 1999). During spawning the aggregations are typically comprised of over 90% orange roughy. The aggregations are localized and have been observed to form at the same sites from year to year. These properties improve the potential applicability of acoustic surveys of spawning aggregations as a stock assessment tool for orange roughy. The National Institute of Water and Atmospheric Research (NIWA), under contract to the New Zealand Ministry of Fisheries, have used acoustic techniques to study orange roughy on the North Chatham Rise since 1986. Full acoustic abundance surveys were carried out in 1998 (Doonan *et al.* 1999) and 1999 (Bull *et al.* 2000). Acoustic surveys of orange roughy have also been carried out in Australia (Elliot and Kloser 1993, Kloser *et al.* 1996).

Diel variation in fish behavior has the potential to affect acoustic survey results through vertical migrations, levels of aggregation and fish orientation (Fréon *et al.* 1993). Fish migrating vertically may leave the range of the acoustic transducer or be concealed in the shadow zone near the seafloor; increases in aggregation can cause signal saturation; fish orientation can affect target strength. Changes in position and density of fish schools can also lead to misidentification of acoustic marks.

To demonstrate the accuracy of the acoustic techniques currently used to survey orange roughy, it is necessary to show that the above diel behaviors do not occur to a major extent in spawning orange roughy aggregations. In this report, we present results on the diel behavior of spawning orange roughy, based on an acoustic study carried out on the seamount known as Graveyard. We evaluate the effects of diel behavior in terms of fluctuations in acoustic biomass estimates carried out repeatedly over a period of five days. As secondary results of the experiment, we assess the presence and extent of systematic differences in observed orange roughy abundance between days and transect paths.

Acoustic techniques have been used over the last decade to observe and quantify diel behaviors of various marine organisms (Fréon *et al.* 1993, Luecke & Wurtsbaugh 1993, Fréon *et al.* 1996, Marchal & Lebourges 1996, etc.). Acoustics has not previously been used quantitatively to study diel variation in orange roughy. Spawning orange roughy acoustic marks have been observed to change shape, location and density over time (eg. Pankhurst 1988), and there is a perception amongst commercial fishers that time of day can influence catch rates of orange roughy. Pankhurst studied orange roughy spawning aggregations at three different locations around New Zealand, using acoustics and biological examinations of trawl catches. He did not detect diel changes in gonad stages, vertical distribution of fish or sex steroid levels, and concluded "once initiated, spawning proceeds on a 'runaway' basis and does not show diurnal periodicity of the type common among shallow water species". Clark (1994) studied temporal variation in orange roughy catch rates on seamounts on Puysegur Bank, to the south of New Zealand (Fig. 1) and found no clear relationship between catch rate and time of day, though noted considerable variability in catch rates over a time period of several days. Clark & Field (1998) and Clark & Anderson (1999) found no consistent pattern in catch rates with time of day on Mercury Knoll, Bay of Plenty.

9.1 The Graveyard seamount

The Graveyard seamount is located in the Northwest Hills at 180° longitude on the Chatham Rise to the east of New Zealand (Fig. 1). The Northwest Hills complex contains 28 known seamounts, with vertical elevations of up to 300 m and base depths of 900 to 1500 m. Graveyard is the largest seamount in the complex and the main orange roughy spawning site: its peak is 750 m deep and is located at 42° 45.59′ S, 179° 59.34′ W. The area supports the second largest fishery for orange roughy in the New Zealand EEZ.

The Graveyard seamount was acoustically surveyed and trawled two weeks prior to this experiment as part of a NIWA orange roughy abundance survey. An orange roughy biomass estimate of 2600 t was reported for a single snapshot of 4 transects (Bull *et al.* 2000). Research trawling continued intermittently on Graveyard for several weeks: catches consisted almost exclusively of orange roughy (typically over 99%) with small amounts of other species, mostly smooth oreo (*Pseudocyttus maculatus*) and Baxters lantern dogfish (*Etmopterus baxteri*).

10. Methods

10.1 Acoustic equipment

The experiment was carried out from NIWA's research vessel "Tangaroa", a 70 m, 2280 t stern trawler commissioned in 1991. Acoustic data were collected using NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs 1994).

CREST is computer based, using the concept of a 'software echo sounder'. It supports multi-channels, each channel consisting of at least a receiver and usually also a transmitter. The receiver has a broadband, wide dynamic range pre-amplifier and serial analog-to-digital converters (ADCs) which feed a digital signal processor (DSP56002). The ADCs have a conversion rate of 100 kHz and the data from these are complex (quadrature) demodulated, filtered and decimated. The filter was a 100 tap, linear-phase finite impulse response digital filter. For the biomass survey work this had a bandwidth of 1.5 kHz and the data were decimated to 4 kHz. Following decimation, a 20 Log R time-varied gain was applied. The results were shifted to give 16 bit resolution in both the real and imaginary terms and the complex data were stored for later processing.

The transmitter is a switching type with a nominal power output of 2 kW rms. It will operate over a wide range of frequencies (12-200 kHz). The transmitted pulse length was 1 ms (38 cycles at 38 kHz) and the effective pulse length 0.78 ms. The time between transmits was 4 s.

The experimental results are based on data from the towed body *CREST* system (there was also a dual frequency system mounted on the hull). This is a four channel system connected to a Simrad type ES38DD split beam transducer.

The digital data from the receiver are transmitted via the tow cable to a control computer on *Tangaroa* where they are combined with position and transect information and stored. All four transducer quadrants (beams) are energised simultaneously from a single transmitter but on receive, the system operates as four semi-independent echosounders. Data are processed independently on the four channels but operation is tightly synchronised by the transmit key and by using a common clock for all the ADCs. In subsequent analysis the four channels are summed to form a single beam.

The parameters of the calibrated CREST system are given in Table 1. Calibration generally followed the procedures set out in Foote *et al.* (1987) and Johanesson and Mitson (1983). The system was calibrated using a 38.1 mm ±2.5 μm diameter tungsten carbide sphere with a nominal target strength of –42.4 dB. Calibrations were carried out in the deep tank at Greta Point before and after the survey and at sea on the Chatham Rise. For the latter the sphere was suspended from the towed body, 14 m below the transducer, on fixed length nylon lines. The whole assembly was lowered to a depth of about 1050 m.

The acoustic towbody was towed at an speed typically ranging from 5 to 10 knots at a depth typically between 300–500 m, thus coming within 250–400 m of the top of the seamount.

10.2 Acoustic data processing

Acoustic data were checked for errors and inconsistencies before being imported into the Ministry of Fisheries Acoustic Database. The NIWA software packages ESP and ESP2 were used to carry out bottom definitions and echo-integrations and calculate mean acoustic backscatter. The echo-integrations were restricted to acoustic marks within 150 m of the seafloor, so as to exclude midwater layers of small fish and plankton. Transects were truncated at the top of the 'background layer' covering the flat area around the seamounts, which typically contains a relatively low proportion of orange roughy. The outputs were mean acoustic backscatter per unit area, for each section of each transect.

A weighting method was used to convert the mean backscatter data for each transect into an individual orange roughy relative biomass estimate. The naive way of analysing star designs is to assume that the mean backscatter per unit area in each transect is an unbiased estimate of the mean backscatter per unit area on the entire seamount. An acoustic backscatter estimate for the seamount is then calculated by averaging the mean backscatter per unit area across transects and multiplying by the area of the seamount. However this method can cause serious bias. If fish form a plume on the top of the seamount, then the transects all cross the plume and the area where the fish density is highest is oversampled. The resulting biomass estimate is biased high. We instead used a weighting method to produce biomass estimates without oversampling bias.

The weighting method used was based on the model assumption that the seamount is roughly circular, with the centre at the hilltop, and that the orange roughy density depends on the distance from the centre. A measurement of acoustic backscatter at a given distance from the hilltop is hence a sample from a circle of that radius around the hilltop. The area of these circles increases proportionally to the radius. Hence each measurement of acoustic backscatter was weighted proportionally to its distance from the hilltop. A measurement at the top of the seamount, in the plume, had low weight since it was representative of a small area, and a measurement down the side had higher weight.

Following the radial weighting, corrections were applied for sound absorption in water and for acoustic shadowing. The orange roughy density in the shadow zone was assumed to be equal to that in the 10 m immediately above, which was estimated by a separate echo-integration, and the biomass estimate was increased to include the estimated amount of fish in the shadow zone. The thickness of the shadow zone generally depends on the acoustic equipment, the bottom depth and the steepness of the nominal bottom. For the Simrad transducer used, the thickness of the shadow zone was computed using the formulation of Ona and Mitson (1996), adapted for the response of the Simrad transducer (Barr, *in* Doonan et al. 1999). The shadow zone was typically about 1 m thick on the flat and on the top of the seamount, but up to 30 m on the steeper parts of the sides of the seamount.

The output of the acoustic analysis was a single relative estimate of orange roughy abundance on Graveyard for each transect, based on a weighted, corrected measurement of acoustic backscatter per square kilometer ($m^{-2}.km^{-2}$). We justify the use of areal backscatter as a measure of orange roughy abundance on the basis that recent trawl catches on Graveyard were dominated by orange roughy (Bull *et al.* 2000). Any changes in acoustic backscatter were therefore considered to be indicative of changes in orange roughy abundance or behaviour.

10.3 Survey design and statistical analysis

Data were collected between 4 July and 8 July 1999. To minimize the disturbance caused by noise and intrusion, no other acoustic work or trawling was carried out on Graveyard during the experiment or in the preceding 36 hours.

The experiment was carried out over four days, with a 24-hour pause on July 6. Each day was divided into four 6-hour quarters, starting at midnight. One four-transect star was carried out in each quarter (this procedure took most of the 6 hours to complete). The four transect paths crossed the peak of the seamount at bearings of 0°, 45°, 90°, 135° (Fig. 2).

The experiment used 64 transects to study three variables, day, quarter, and path, each with four levels. The quarter effect was of primary interest since it indicated the extent of diel variation in orange roughy abundance estimates on Graveyard. The day and path effects were of secondary interest, indicating the day-to-day stability of the aggregation over the survey period and the extent of systematic differences between the four transect paths. A fourth variable was the position of each transect within the quarter (first to fourth), which was considered to be an uninformative block effect. (Ideally all four transects in each starburst would have been carried out simultaneously, but four vessels would have been necessary.)

The arrangement of the 64 transects was planned to follow a Latin Cube design (Cochran & Cox 1966). The Latin Cube design was employed to prevent statistical confounding between the three main effects and the block effect. It allows the individual effects of day, quarter and path on backscatter to be distinguished, while including every combination of the four levels of the three effects in the minimum possible 64 (4×4×4) transects. The Latin Cube design specifies that each transect path occurs exactly once in each quarter of each day, exactly once in each within-quarter position on each day, and exactly once in each within-quarter position of each quarter (Table 2).

The transect backscatter data were analysed by analysis of variance (ANOVA) on the log-scale. A forwards stepwise process was used to fit the ANOVA model, adding terms for which the ANOVA F-test indicated significant improvement in fit. Potential terms were day, quarter, and path (all categorical fixed effects with 4 levels) and their interactions. Note that with the Latin Cube design, the statistical significance of the main effects is not dependent on the order in which they occur in the model.

11. Results

An orange roughy spawning aggregation was found to be present over the top of Graveyard. The experiment proceeded largely according to plan. Of the 64 transects, one was discarded due to corrupted data and one was carried out on a path other than that intended. The echogram of one of the transects is shown in Figure 3.

There were no major differences between the general shapes of acoustic marks at different times of day, either in their vertical extent or their level of aggregation. However clear differences were seen between transect paths, apparently due to the topography of the seamount. Path D passes along the ridge at the top of Graveyard and hence covers the greatest amount of the flattened area of the hilltop. Path B is approximately perpendicular to the ridge and covers the least amount of the hilltop, and paths A and C cross the ridge at 45° angles (Figure 2). Consequently, orange roughy marks on path D typically had a long horizontal extent, and on path B typically short.

The ANOVA analysis showed significant path ($p < 0.0001$) and day ($p = 0.02$) effects. The quarter effect was not significant ($p = 0.43$), nor the path/day interaction ($p = 0.10$). The absence of a significant quarter effect indicates that there was no significant diel fluctuation in estimated orange roughy abundance. Quarter/path and quarter/day effects were not tested since the quarter main effect was not significant.

The path effects, converted to the linear scale and relative to path A, were A: 1.00, B: 0.76, C: 1.13, D: 1.60. In other words, it was estimated that orange roughy biomass estimates on path B were on average 0.76 times as high as those on path A, once between-day differences were allowed for. This result confirms the visual impression that marks on path D were relatively large and on path B relatively small, due to the lengths of their cross-sections across the flat part of the hilltop. The relative abundance estimates on the 4 transect paths, corrected for between-day differences by dividing each estimate by the appropriate day effect, are shown in Figure 4. There were clear differences between paths, despite a considerable degree of spread.

The day effects, converted to the linear scale and relative to the first day, were day 1: 1.00, day 2: 1.05, day 3: 1.46, day 4: 1.03. In other words, the first, second and fourth days had very similar average levels, but the third day had a mean level approximately 1.4 times higher. The relative abundance estimates across time (day and quarter), corrected for between-path differences by dividing each estimate by the appropriate path effect, are shown in Figure 5. The estimates on day 3 are shown to be consistently high, indicating that the estimated between-day difference was not due only to a single outlier, or particularly high values on a single path or in a single quarter, but to an overall increase in observed abundance on day 3. The plot suggests that a substantial amount of fish arrived during the 24 hour pause between day 2 and day 3, and that a similar number of fish left the aggregation late in day 3 and throughout day 4.

The residuals from the ANOVA analysis appeared linear on a normal probability plot, validating the ANOVA assumption of normality on the log-scale. The plot showed no outliers. An examination of the residuals by day and by path showed no disturbing patterns. The high level on the third day was not due to one or two isolated high points – in fact the range of residuals on the third day was less than on any other day.

12. Discussion

The experiment did not detect statistically significant diel variation in orange roughy backscatter on the Graveyard seamount. The experiment had adequate statistical power to detect moderate levels of variation since it was possible to distinguish variation between days and between transect paths. Diel variation was also not apparent in the appearance of acoustic marks. This finding validates the current survey methodology for the Graveyard seamount, in that there appear to be no diel effects on acoustic abundance estimates.

The shadow zone down the sides of the seamount, which was up to 30 m thick on steeper parts of the slope, could not be investigated by the acoustic gear. This could mask diel variation if orange roughy moved into the shadow zone in quantity at some times of day.

The result confirms our previous understanding that orange roughy aggregations are relatively stable. It contrasts with other New Zealand commercial fish species which have dramatic diel variation. Hoki (*Macruronus novaezelandiae*) have been shown to rise off the bottom and disperse through the water column at dusk (Cordue 1994). Southern blue whiting (*Micromesistius australis*) also disperse at dusk, and in some areas cannot be acoustically surveyed during the daytime because their schools are too close to the bottom (Hanchet *et al.* 2000). Published studies of diel variation in marine organisms usually documented diel cycles (Fréon *et al.* 1993, Luecke & Wurtsbaugh 1993, Fréon *et al.* 1996, Marchal & Lebourges 1996, etc.).

The lack of diel variation may possibly be explained in terms of the feeding behaviour of orange roughy. Fish species commonly migrate vertically to follow the diel vertical migrations of pelagic prey, which in turn follow the movements of zooplankton. However Rosecchi et al. (1998) found no evidence that orange roughy migrate vertically in search of prey. Rosecchi et al. (1998) also found that orange roughy feed less often during the spawning period, which further reduces the incentive for movement. Further, because of the low diel variation in light levels at orange roughy depths, it was expected that orange roughy would be less affected by changing light levels than fish inhabiting shallower depths. Orange roughy behavior is probably affected by diel variation in light levels to some extent. For example, Pankhurst (1988) suggested that the onset of the orange roughy spawning period might be controlled by light levels, on the basis of evidence indicating that it was not linked to the water temperature or the phase of the moon.

The systematic differences observed between transect paths demonstrate the effect of the seamount bathymetry on acoustic biomass estimates. The result shows the necessity of the current methodology of carrying out several transects on different bearings over the seamount and averaging the resulting biomass estimates; it also suggests that transect path directions should be randomized to avoid bias.

It appears that the spawning aggregation has some fluctuation in size on a day-to-day basis. A substantial amount of fish appear to have arrived on Graveyard in the 24 hour gap between days 2 and 3 of the experiment, and a similar amount seem to have left the aggregation during day 4. We theorize that the arrivals were ripe fish coming to spawn and the departures were spent fish, i.e. that turnover of spawning fish was occurring. Turnover has a major effect on the ability of a survey to measure stock size reliably. Investigations of turnover at orange roughy spawning sites around New Zealand have yielded mixed results. In some areas a consistent buildup of spent fish suggested little turnover was present (Clark & Tracey 1993): on others this buildup did not occur, and turnover (possibly due to disruption by fishing activity) was hypothesised (Zeldis *et al.* 1997). The presence of turnover on Graveyard is being investigated using a temporal sequence of microscopic spawning condition measurements collected over a longer time period on the same voyage. The results will be published in a future paper.

13. Acknowledgements

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Table 1: Parameters and calibration data for the 38 kHz CREST acoustic system. G is the gain of the system at a range of 1 m

Transducer model	Simrad ES38DD
Transducer serial no.	28327
Nominal 3dB beamwidth (°)	7.0
Effective beam angle (sr)	0.0083
Operating frequency (kHz)	38.156
Transmit interval (s)	4.000
Transmitter pulse length (ms)	1.000
Effective pulse length (ms)	0.78
Filter bandwidth (kHz)	1.5
Initial sample rate (kHz)	100.000
Decimated sample rate (kHz)	4.000
TVG	$20\log_{10}R + 2\alpha R$
SL+SRT (dB re 1 V)	61.8
Transducer depth (m)	400
$20 \log_{10} G$	82.4

Table 2: The Latin Cube design. The four transect paths are denoted by A, B, C, and D (Fig. 2). Each cell shows the order in which the four transects were carried out in that quarter of that day. The Latin Cube design specifies that each transect path occurs exactly once in each row of each table, exactly once in each column of each table, and exactly once in each row/column combination. The effect of the design is to prevent any statistical confounding while maintaining a relatively small sample size

	0000-0600 h	0600-1200 h	1200-1800 h	1800-2400 h
Day 1	A B C D	D A B C	B C D A	C D A B
Day 2	B C D A	A B C D	C D A B	D A B C
Day 3	C D A B	B C D A	D A B C	A B C D
Day 4	D A B C	C D A B	A B C D	B C D A

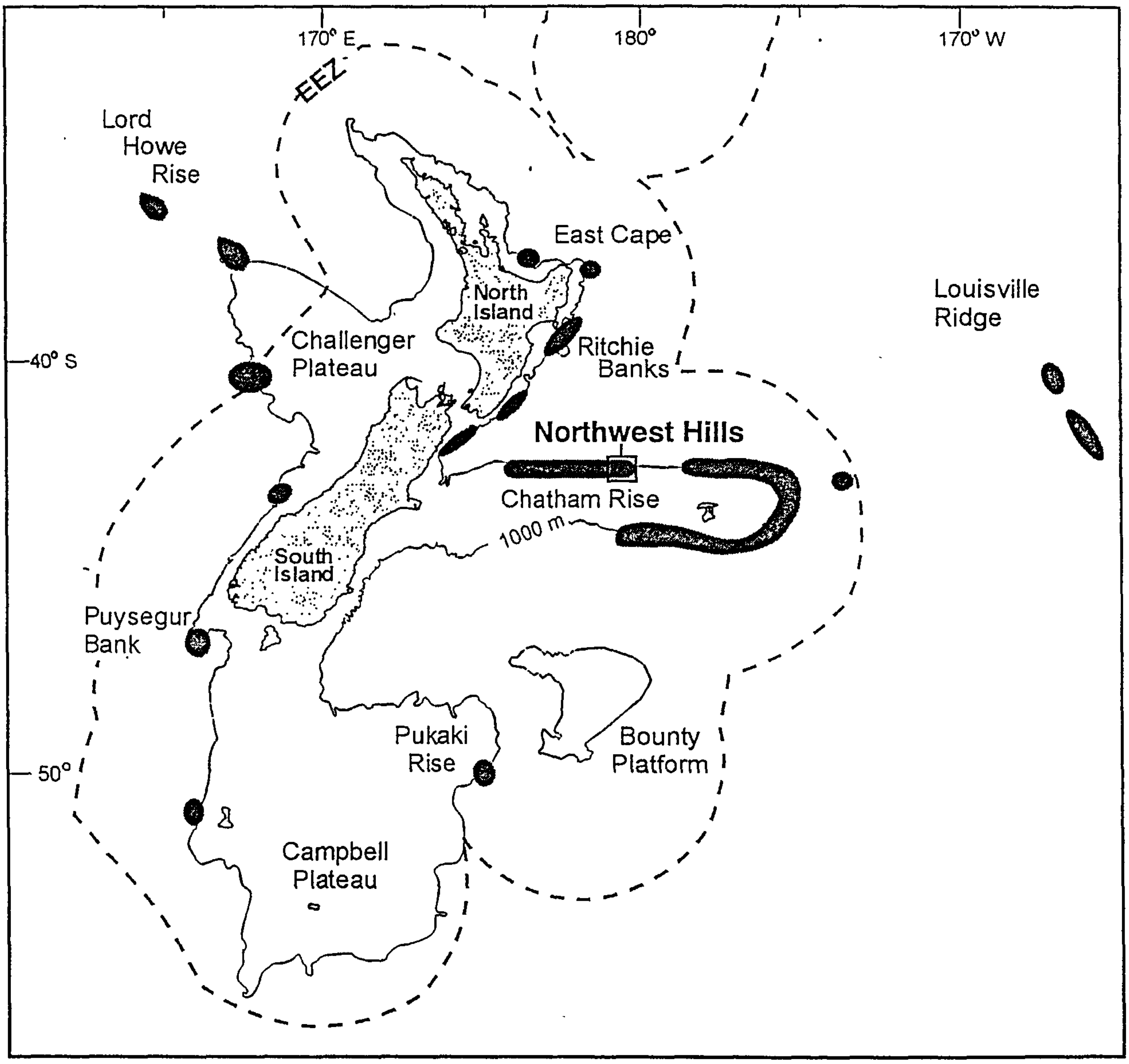

Figure 1. The New Zealand region, showing locations of main fishing grounds for orange roughy (shaded), including the Chatham Rise and the Northwest Hills. The experiment was carried out on the Graveyard seamount of the Northwest Hills.

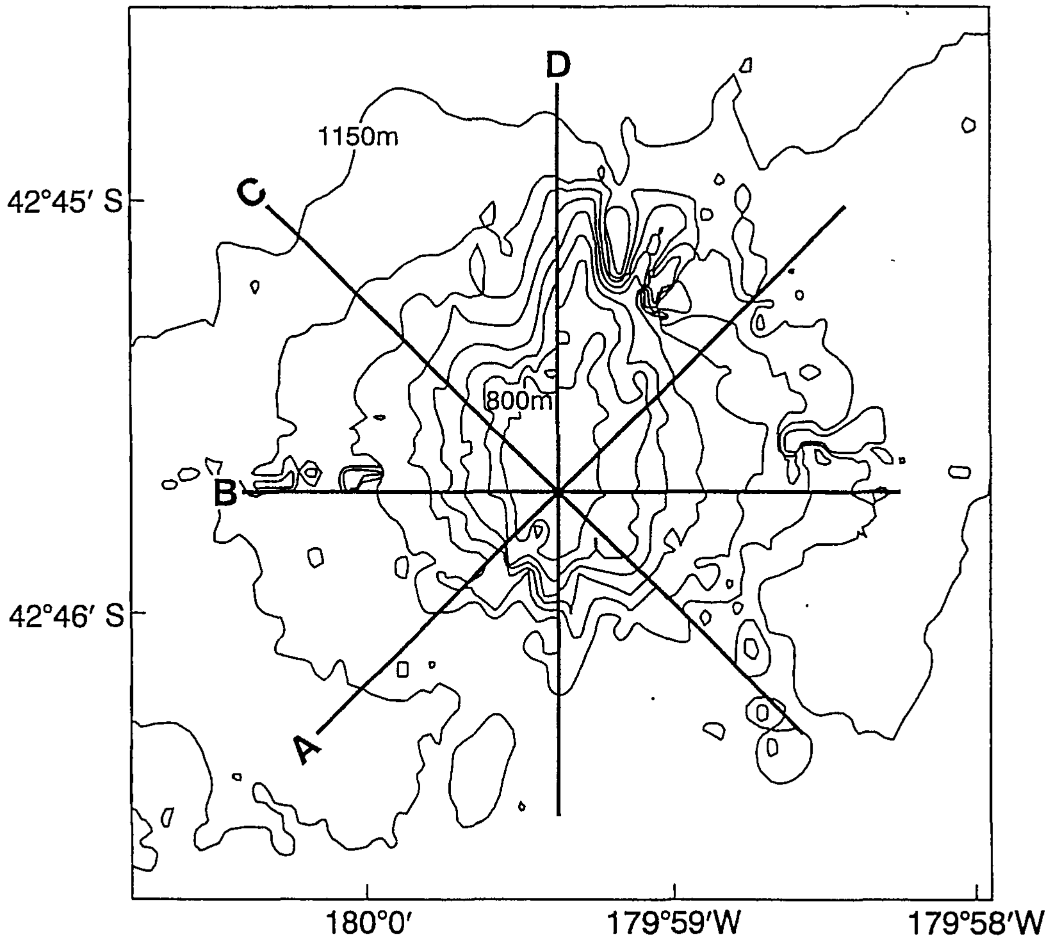

Figure 2. The four transect paths over the Graveyard seamount, A, B, C, and D. The experiment included 16 transects along each path. Transects extended well off the sides of the seamount in each direction, at least as far as indicated, and were truncated during the analysis to exclude non-orange roughy acoustic marks. Contours represent 50 m depth intervals.

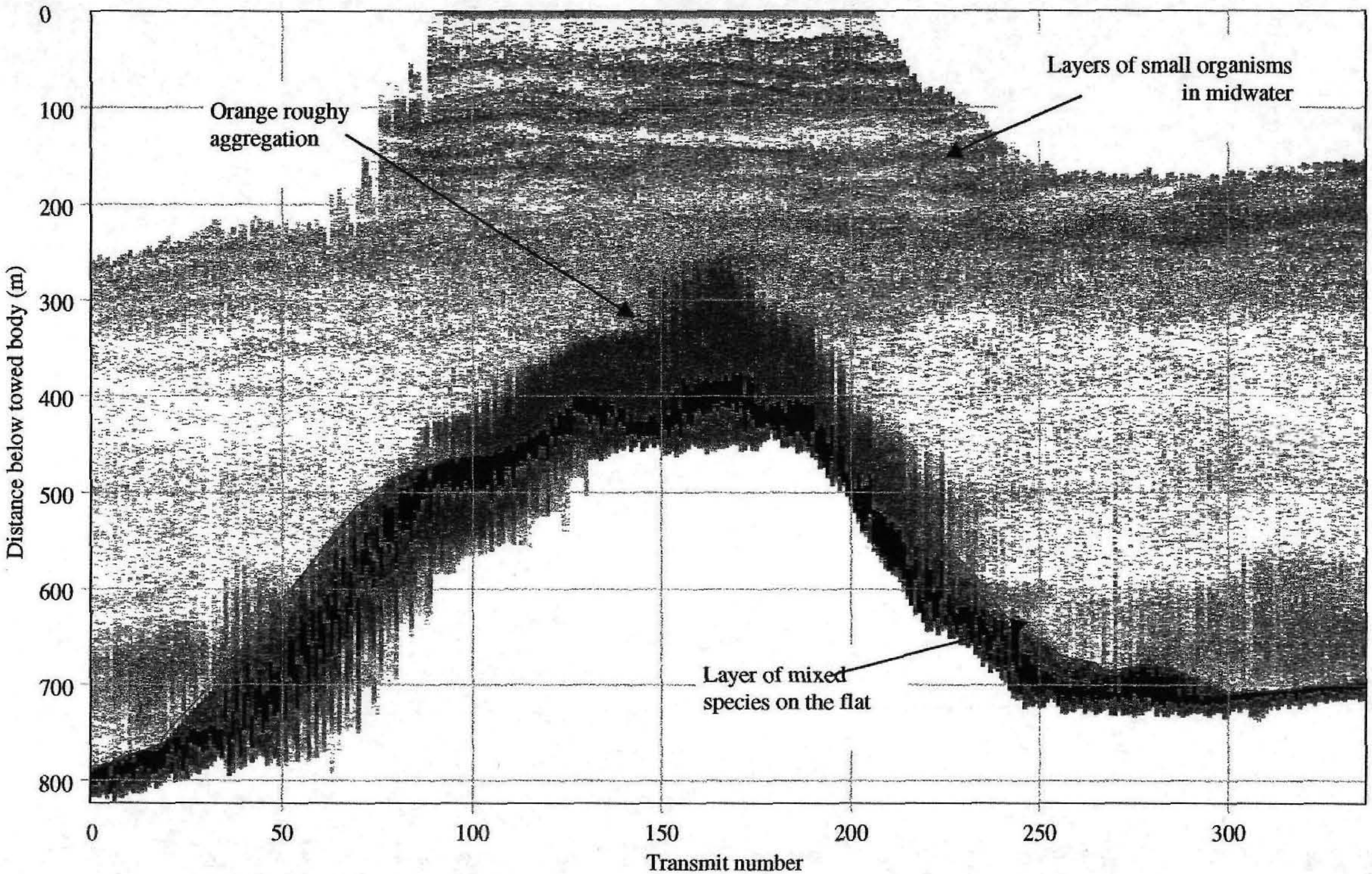

Figure 3. The echogram of one of the 64 transects carried out over the Graveyard seamount, extending onto the flat on both sides of the seamount. Acoustic transmits were spaced at intervals of 4 s; the average towing speed was 2.5 ms^{-1}. The vertical scale represents the distance (m) from the towed body (the towed body depth was about 380 m; the top of Graveyard, in the centre of the picture, is at 750 m depth). The heavy mark on the hilltop represents spawning orange roughy; the horizontal layers in midwater and the layer at the base of the seamount represent mixtures of species and were not echo-integrated. The blank patches around the margins denote truncation of data rather than the absence of echoes.

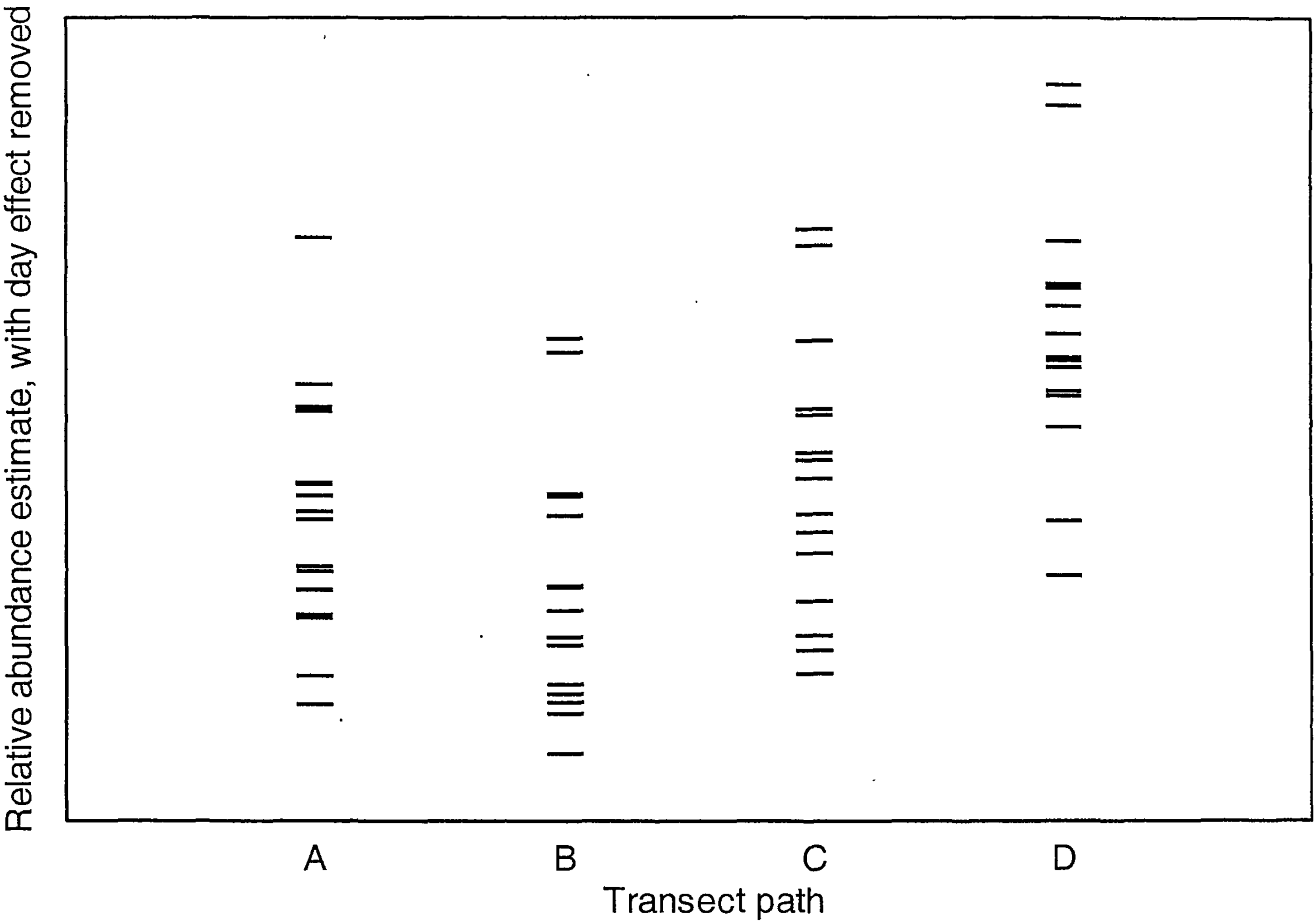

Figure 4. Relative abundance estimates by transect path, corrected for between-day differences by dividing each estimate by the appropriate day effect from the ANOVA analysis. Path D was parallel to the ridge on the hilltop (Figure 2) and hence had the longest cross-section across the flat top of the seamount and yielded the highest abundance estimates. Estimates are relative so no scale is given for the y-axis.

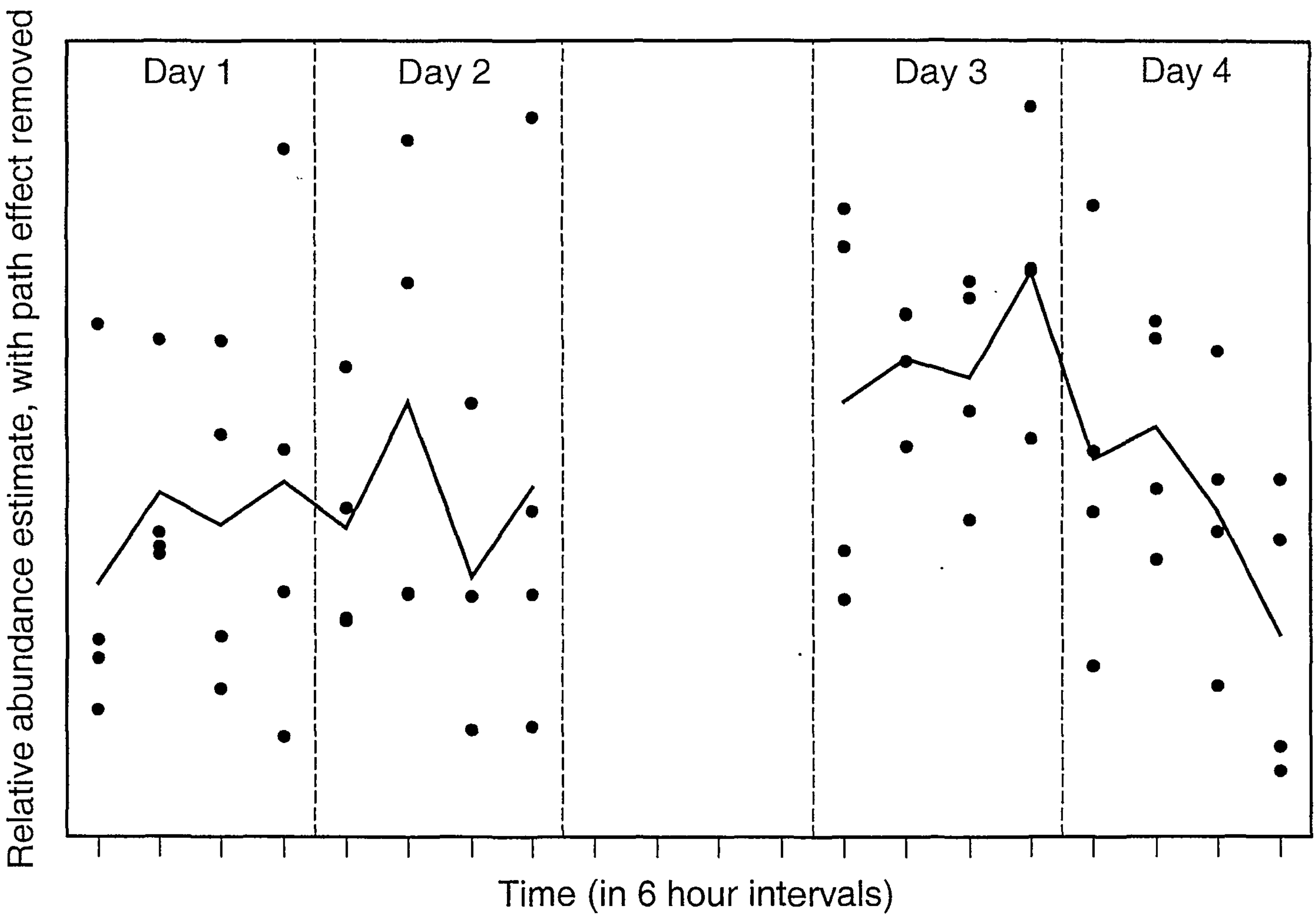

Figure 5. Relative abundance estimates by day and quarter, corrected for between-path differences by dividing each estimate by the appropriate transect path effect. The solid line shows the mean abundance. There was a 24 hour pause between days 2 and 3 of the experiment. Estimates are relative so no scale is given for the y-axis.