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EXECUTIVE SUMMARY

Doonan, I.J.; Coombs, R.F.; Hart, A.C. (2003). Acoustic estimates of the abundance of orange roughy on the Northwest Chatham Rise, ORH 3B, June-July 2002.

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An acoustic survey of orange roughy on the Northwest Chatham Rise was carried out between 20 June and 8 July 2002 using *Tangaroa* (voyage TAN0208) and *Ocean Ranger* (ORA0201). Strata on flat ground were surveyed once with a stratified random design and underwater hills were surveyed twice with a systematic 'star' design.

The biomass of spawning orange roughy, averaged over the snapshots, was estimated to be 30 000 t with a c.v. of 63%. Mature roughy biomass was estimated at 40 000 t with a c.v. of 63%. However, one tow in flat strata 3 had a disproportionate effect on the estimates, such that when excluded, the spawning abundance reduced to 17 000 t with a c.v. of 30%. For stock assessment, the mature biomass was taken to be 42 000 t, also with a c.v. of 63%. This was obtained by averaging estimates based on two independently derived values of orange roughy target strength.

1. INTRODUCTION

The Chatham Rise (management area ORH 3B) supports New Zealand's biggest fishery for orange roughy *(Hoplostethus atlanticus)*. For management purposes the Rise is divided into four sub-areas with more or less similar catches over the last decade; this report describes a survey of the Northwest area. During the spawning season the fishing in this area is focussed on the Graveyard complex of underwater hills where large roughy aggregations are found, particularly on Graveyard itself. These are the closest large roughy aggregations to the New Zealand mainland, and they have been used for several experimental investigations including an egg and larval survey in 1996 (Francis & Horn 1997), experimental acoustic surveys in 1995 and 1997, and investigation of variability in 1999 (Bull et al. 2000).

The large aggregations that spawning roughy form are ideal subjects for acoustic biomass estimation. However, outside these aggregations, when roughy are mixed with other fish species, particularly those with higher target strength, acoustic estimation, at least using the echo-integration technique, is problematic. Thus although acoustic techniques have become established as the fishery independent source of biomass information for roughy spawning aggregations, this is not the case for dispersed roughy. Accordingly, the survey described here had several aims in addition to estimating biomass using the established approach (see for example, Bull et al. 2000, Doonan et al. 2001). These included mapping movements of post-spawning fish by both acoustics and trawling, with joint aims of increasing understanding of roughy spawning behaviour and estimating trawl catchability. They also included estimating abundance of dispersed roughy using a random trawl survey and also by means of acoustic counting. This report covers the results of the established acoustic method and the trawl survey, the latter being used to apportion the acoustic results for dispersed roughy.

Dispersed roughy are widely spread in the area and occur mixed with other species in layers ('background' layers) over flat and undulating seabed (hereafter referred to as the 'flat'). Otherwise, roughy form large spawning aggregations on underwater hills, particularly on Graveyard. The survey aimed to estimate the biomass of mature orange roughy and used a stratified random design for the flat and stars for hills, the methods being similar to that used previously for roughy biomass on the Chatham Rise (Bull et al. 2000, Doonan et al. 2001).

2. METHODS

The overall approach to the survey was to measure acoustic backscatter together with information on the size structure of the roughy and the mix of species present obtained by trawling. Survey timing was based on analysis of reproductive data from the area from past biomass surveys. A stratified random approach was used (Jolly & Hampton 1990). Two vessels were used: NIWA's 70 m research vessel *Tangaroa* and Talley's 43 m stern trawler *Ocean Ranger*. *Tangaroa* carried out all the acoustic work and the trawling for most of the biomass survey. Apart from one tow on Deadringer, which was used in the biomass calculations, *Ocean Ranger* was used only to map the out-migration of roughy on to the flat after spawning (which is reported elsewhere).

2.1 Acoustic principles

The conventional approach of echo-integration was used to estimate areal backscatter of acoustic energy by fish (Burcznsky 1982, Do & Coombs 1989, Doonan et al. 2001), which was then apportioned using trawling results. Areal backscatter that has been apportioned to different species is converted to numbers of that species by dividing by its target strength and to biomass by multiplying by its average weight.

The detailed mathematical analysis used to estimate biomass from the survey results is the same as that used by Doonan et al. (1999).

A number of physical factors affect the accuracy of the estimates of backscatter, the most important for orange roughy surveys being shadowing, towed body motion, and absorption of sound by seawater.

Shadowing is a problem where the fish are on the sides of underwater hills or on sloping seafloors. The acoustic transducer projects a conical beam down through the water column with the wave-front forming part of the surface of a sphere. If the axis of the beam is perpendicular to a flat sea bottom, then the sea bottom reflection from the central part of the beam swamps the reflections from fish close to the bottom in the outer parts of the beam. There is thus a volume close to the sea bottom which is not visible to the acoustic gear, called the 'shadow zone'. The size of the shadow zone depends on the distance of the transducer from the bottom and particularly on the steepness of the nominal bottom. For the transducers used in this survey, on a flat seafloor it is typically about 1 m, but on steep hillsides it can be over 30 m. We estimated the thickness of the shadow zone using the method of Barr (in Doonan et al. 1999) and assumed that the orange roughy density in the shadow zone was the same as that in the 10 m immediately above. Corrections were calculated for groups of 10 pings and reported as the mean of these for a stratum and snapshot. The final biomass estimate includes shadow zone correction.

Transducer motion during a transmit results in the transducer pointing in different directions when transmitting and receiving. Corrections for the decrease in acoustic signal strength due to this motion were made using the method of Dunford (A. Dunford, NIWA, pers. comm.). Transducer movement data were collected synchronously with the acoustic data at 50 ms intervals. These data were interpolated to match the acoustic data, which were then corrected on a sample-by-sample basis. The corrections required are a function of the difference in pointing angle between transmission and reception and are therefore greatest at longer ranges and when transducer motion is most pronounced. Backscatter was calculated both with and without motion correction for each stratum and snapshot. The final biomass estimate includes motion correction.

The absorption of sound by seawater is not well known at 38 kHz (Do & Coombs 1989, Doonan et al. 2003b) and this uncertainty is a significant factor where long ranges are involved (e.g., flat background strata). The absorption coefficient was estimated from temperature and salinity data using the relationship derived by Doonan et al. (2003b) and was used to correct the data from the nominal absorption coefficient (8 dB.km^{-1}) applied by the receiver.

2.2 Acoustic equipment

The acoustic backscatter data were collected with NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs et al. 2003). The acoustic equipment used was essentially the same as in previous deepwater acoustic surveys (Doonan et al. 2001, Coombs et al. 2003). The backscatter data were collected with two split-beam systems towed at between 200 and 600 m depth. These were calibrated in the large tank at Greta Point before and after the survey and a deep-drop calibration of one (system 3) was carried out during the survey. Deep-drop calibrations from 2001 were used for the other system (system 2). The calibrations followed the approach described by Coombs et al. (2003). A 38.1 mm ± 2.5 µm diameter tungsten carbide sphere with nominal target strength of –42.4 dB was used as a calibration standard. The response of both transducers varies with ambient temperature (Coombs et al. 2003) and different calibration constants were used for different transects to accommodate this. Backup electronics were used in system 2 (mod) for some transects and this is also reflected in the calibration constants. The transducer in system 2 (Simrad ES38DD, serial number 28327) had 3 dB beamwidths of 7.0° x 6.9° (alongship and athwartship) and its effective beam angle for integration was 0.0083 sr. For the system 3 transducer (Simrad ES38DD, serial number 28332B), the values were 7.3° x 7.4° and 0.0093 sr. The transmit frequency was 38.16 kHz, the effective pulse length 0.78 ms, the time between transmits 2 s and the sample rate 4 kHz for all systems. Calibration constants and related parameters are summarised in Table 1 for all the configurations and temperatures used.

Additional acoustic data were collected using a hull-mounted system for target identification and particularly for an initial survey of the hills to locate marks. This was a dual-frequency *CREST* system operating at 12 and 38 kHz with the same characteristics for the latter as the towed systems except that the time between transmits was 4 s and the transmit frequency was 38.00 kHz. The 38 kHz transducer (Simrad 38-7, serial number 23421) beamwidth was 7.2° x 7.3° and effective beam angle 0.0091 sr. Other calibration data for the 38 kHz channel are shown in Table 1 (system 1). The 12 kHz transducer (Simrad 12-16-60, serial number 105) beamwidth was 15.8° x 15.8° and effective beam angle 0.043 sr. The transmit frequency was 12.00 kHz, but this channel was otherwise uncalibrated.

Salinity, temperature, and depth (CTD) data were collected using a Seabird 37-SM MicroCAT CTD to allow the transducer temperature correction to be measured and estimation of sound absorption. The Seabird was attached to the trawl headline for 15 tows. Two Guildline CTD drops were also made during the survey.

2.3 Trawl gear

Both vessels used similar 6-panel, rough-bottom orange roughy trawls for fishing on hills. These have cut-away lower wings, and are based on the development of the 'Arrow' style of trawl that is the industry standard. Codend mesh size was 100 mm. The net has a wing-spread of about 25 m. In addition, *Tangaroa* used a full-wing trawl ('ratcatcher') for fishing on flat ground in the trawl survey part.

2.4 Survey design

The location of the survey area is shown in Figure 1 and the design used was based on the 1999 survey of the same area (Bull et al. 2000). The survey was centred on Graveyard and covered both the hill complex and the flat areas to the west and east in the depth range 840–1150 m (Figure 2). The hills surveyed were those that had 97% of the spawning biomass of all hills surveyed in 1999. Hills that had little spawning roughy in 1999 (typically deep hills) were not surveyed. The flat strata were extended from 1999, based on the results of the latter survey and historic trawl survey data with the aim of better defining the limits of the distribution of roughy in the Northwest area of ORH 3B.

On the flat, trawling was structured as a stratified random trawl survey to yield a semi-independent estimate of roughy biomass in this area.

2.4.1 Hill strata

The hills selected are shown in Table 2 together with those that were excluded. Each hill was treated as a separate stratum and two snapshots were planned. A map of the selected hills is shown in Figure 3. The survey design was a radial star pattern (Doonan et al. 2003a) using 2–6 transects, centred on the top of the main mark, at approximately equally spaced angles. An initial search was carried out on the hills with the hull system and only hills with marks were surveyed during each snapshot.

In allocating trawl tows and acoustic transects to strata, three sources of variation were considered:

1. sampling error in the 1999 acoustic data,
2. sampling error in the proportions of spawning orange roughy in the species mix as measured by data from the 1999 trawling,
3. experimental error in the determination of the target strength of both orange roughy and other species.

Sources 1 and 2 above can directly be turned into the number of trawls and transects needed to reach the overall target c.v. (assuming no experimental error in the error estimates). Variation source 3 is part of the variance estimation for the abundance estimate, but it cannot be changed with survey design. It changes only when new experimental data are gathered. However, it does increase the overall variance and so the sampling error has to be reduced even more to reach the target c.v. and so it needs to be considered when determining the number of trawls and transects.

2.4.2 Flat strata

Data covering the spawning period (May–July) from trawl surveys carried out in the Northwest area in May, June, and July of 1992, 1994, 1996, 1997, and 1999 were used to establish the boundaries of the flat survey. The depth range in which most roughy occur in these data is 900–1050 m and the eastern and western boundaries were established from the longitude profile of catch rates (kg/km) in this depth range. Catch rate in this range depended only on longitude (Figure 4), whilst in deeper and shallower water, rates were much lower and showed a different relationship with longitude. The catch rate data were smoothed with respect to longitude giving the two profiles shown in Figure 4, one of which is somewhat over- and the other under-smoothed. Longitude limits were set such that they contained 80% of the area beneath the smoothed curves. Because catch rate is proportional to biomass, the limits equate to 80% of the biomass. The eastern boundary was about the same for both smoothed curves (178° 30' W), but differed between the two for the western boundary (178° 20' E and 179° 00' E. For planning purposes, 178° E was used for the western boundary, but both boundaries were checked by trawling during the survey.

Four flat strata were allocated (see Figure 2) and their boundaries were chosen to approximately minimise the sum-of-squares of the catch rates used above. In this allocation, stratum 1 had high, strata 2 and 3 medium, and stratum 4 low catch rates (Table 3). Depth limits for each stratum were those that separated out catch rates of less than 10 kg/km where they appeared as a continuous area. Isolated high catch rates were ignored. Stratum 1 was extended to 1150 m so that it surrounded the main spawning location of Graveyard (Table 3).

Parallel, north-south orientated transects were assigned randomly within each stratum. We assumed that all transects within a stratum had the same species and roughy spawning-stage mixture within 100 m of the bottom, and that the catches in tows within the stratum were representative of that mixture. This implies that all included species have equal catchability and we have therefore considered sensitivity cases where the catchability of roughy is doubled and halved relative to the other species.

2.5 Biological sampling

Trawl catches from each successful tow were sorted and weighed by species to the nearest 0.1 kg. For catches too large to be weighed, the orange roughy catch was estimated from the weighed, processed catch using a conversion factor. The estimated proportions of roughy and other species were used to apportion the acoustic backscatter in each stratum.

A random sample of 200 orange roughy was selected from each tow and staged length frequency measurements (standard length to the nearest centimetre below, sex, and gonad stage) were made. For large catches, at least three samples of 200 orange roughy were taken from different parts of the net to ensure sampling was representative of the catch. A further 20 roughy (more for large catches) were randomly selected for more detailed examination. Data collected were standard length (mm), weight (g), sex and gonad stage, and stomach fullness, digestion, state, and contents. Length measurements (to the nearest centimetre) and weights to the nearest gram were collected for samples of bycatch species.

Orange roughy mean lengths scaled by catch and sex ratio data were calculated for each stratum (i.e., each hill and each of the four flat strata). The length-weight relationship for all species was estimated from data collected during the survey.

2.6 Estimating absolute abundance

The overall procedure for estimating biomass was essentially the same as in previous orange roughy surveys (Bull et al. 2000, Doonan et al. 2001, 2003c), except that proportions of species from each catch were weighted by the square root of the catch size rather than catch size alone. The lowish number of trawls means that the proportion estimates are not robust to a large catch which has an untypical proportion in it, for which applying a square-root of catch size as weights makes for a more robust estimate. To account for the hills which were not surveyed, the hill abundance was increased by 3430/3320, the ratio of the abundances in the 1999 survey (Bull et al. 2000). The total recruited biomass of the stock is required for stock assessment and for roughy this is taken to be equal to the biomass of mature fish. However, this survey directly estimated only the biomass of spawning orange roughy in the areas surveyed. Spawning biomasses were then scaled up to estimate mature biomass. Spawning roughy were defined as those with a gonad stage of 3 or more that were 31 cm or more. The variability associated with each estimate was also estimated and a sensitivity analysis carried out.

The following sections expand on aspects of the overall analyses that are specific to this survey.

2.6.1 Target strength

The target strength relationships used in this assessment were the same as those used by Doonan et al. (2001), except for smooth and black oreos. The relationships between tilt-averaged target strength, <TS>, and length are shown in Table 4. For orange roughy these are based on measurements of live fish in a tank (McClatchie et al. 1999) corrected for depth (McClatchie & Ye 2000) and combined with in situ results from Barr & Coombs (2001) ("NIWA" in Table 4). An alternative relationship derived from Kloser et al. (2000) was used as a sensitivity case ("CSIRO" in Table 4). For oreos, the target strengths were derived from a Monte-Carlo analysis of in situ and swimbladder data (Macaulay et al. 2001, Coombs & Barr unpublished results) and the relationships used were:

$$TS_{SSO} = -82.16+24.63\log_{10}(L)+1.0275\sin(0.1165L-1.765)$$

for smooth oreos and

$$TS_{BOE} = -78.05+25.3\log_{10}(L)+1.62\sin(0.0815L+0.238)$$

for black oreos, where TS is the target strength and L the fish length.

For other common species we used relationships based on swimbladder modelling (Macaulay et al. 2001). Generic relationships were used for other species as detailed by Doonan et al. (1999).

2.6.2 Estimating spawning fraction

Because not all mature roughy spawn in any year, an estimate of the fraction, $Smat$, that do not spawn is required to convert spawning biomass to total biomass. Mature, but non-spawning, fish were incorporated into the acoustic estimate with the ratio $Smat = B_{mat}/B_S$ which was estimated with female data only, i.e., $B_{mat,f}/B_{Sf}$, where $B_{mat,f}$ is the female mature biomass and B_{Sf} is the biomass of females that spawned. Males were assumed to have the same ratio. Thus, the acoustic estimate of B_{mat} is $B_S \times Smat$, where B_S is estimated biomass of spawning fish (both sexes) from the acoustic survey of the spawning area.

Calculation of *Smat* was similar to that used by Doonan et al. (2003c) and the same definitions were used for maturity. The data used were from a survey of the Northwest area covering both hills and flat from 25 May to 6 June 1994 (TAN9406) and from these *Smat* was 1.35 with a c.v. of 4%.

2.6.3 Estimating variance and bias

Analysis of variability was based on the sampling variability of acoustic transects and trawl catches, and on the uncertainty in the target strengths of orange roughy and bycatch species. The three sources of variation were combined by a bootstrapping method. For each bootstrap iteration, the trawl catches and transect backscatter were resampled within each stratum. Target strength variations were treated in one of three ways. For orange roughy, the data used to estimate the target strength-length relationship were resampled and the relationship re-estimated. For species where the target strength was derived from swim-bladder data and for smooth oreo, the intercept of the target strength-length relationship was adjusted by a random amount that was drawn from a normal distribution with a zero mean and a standard deviation of 3 dB. For species that used a general target strength-length relationship, resampling was nested in a way which reflected the way the data were collected and combined to form the relationships (see Doonan et al. 1999 for details). Biomass estimates were then recalculated. The process was repeated for 500 bootstrap iterations and c.v.s of the bootstrapped biomass estimates were calculated.

3. RESULTS

The abundance survey was carried out between 20 June and 8 July 2002. The field work was constrained by the weather so that some trawls were not carried out immediately after the associated transects and there were fewer trawls and transects on the flat than had been planned. However, despite this, the survey coverage was adequate overall. There were two snapshots (Table 5) on the main hills (Graveyard, Scroll, Zombie, Deadringer, and Morgue). No trawls were carried out on Morgue in compliance with the Seamount Closure Regulations. Only a single snapshot of the flat strata was completed (Table 3).

3.1 Flat strata limits

Two tows to check catch rate levels and orange roughy spawning state were carried out beyond the eastern and western boundaries of the flat area. Catches of roughy in these tows were small compared to those within the planned boundaries (Table 3) and we consider the latter to be appropriate.

3.2 Trawls

Nine satisfactory trawls were completed on the hills on spawning marks (Table 5) and 19 random trawls were carried out in the flat strata (Table 3). Some hills proved difficult to fish, particularly Deadringer. On this hill, even the highly experienced fishing skipper on *Ocean Ranger* failed to make any fully satisfactory tows. However, two trawls each yielded about 0.7 t and these were used in the analysis.

3.3 Acoustic backscatter

Characteristic spawning orange roughy acoustic marks were seen on top of Graveyard (Figure 5) and on Morgue in both snapshots. There were smaller marks on Zombie and Scroll. The upper four panels of Figure 6 show the distribution of backscatter on the hill transects. The flat had no characteristic roughy marks, just the general background layer rising from the bottom that was expected. However, this was by no means uniform and varied considerably in thickness with areas of strong backscatter, particularly in strata 3 and 4 (see the lower 4 panels of Figure 6).

Trawls on the hill marks contained about 98% orange roughy, by weight. However, because Morgue is closed to fishing, there were no trawls on the large marks seen on this hill. Interpretation was based on catches from the 1999 survey (Bull et al. 2000) which had a significant proportion of smooth oreos and juvenile roughy. The higher target strength of the smooth oreos means that most of the backscatter is allocated to this species. The estimate of spawning orange roughy biomass is thus considerably lower than the alternative assumption, for example, that there was a similar proportion of roughy on Morgue to the other hills. This problem is considered further in the Discussion (Section 4).

The flat strata catches contained about 40% orange roughy by weight, with a mixture of other species present which have small air-filled swimbladders. Only some of the roughy were spawning fish. When the target strengths are factored in, backscatter from the flat strata was predominately from other species.

3.4 Biological sampling

Samples from catches on hills all showed the strongly unimodal length distributions typical of spawning orange roughy, and mean lengths ranged from 33.1 to 34.7 cm (median, 34.2 cm). Samples from the flat strata had high proportions of non-spawning roughy and showed broader distributions with smaller fish with mean lengths of 31.2–34.3 cm (median, 32.6) for catches over 12 kg.

Gonad stages for female orange roughy over the period of the survey are summarised in the top graph in Figure 7. Spawning females (ripe and running ripe) dropped to below 20% around 15 July. The gonad maturation progression in 2002 was similar to that in 1999 and 1996 (middle and bottom graphs in Figure 7). The data show that timing of the survey was appropriate for all areas and that the hill biomass estimates for this survey are comparable to those from 1999. In the latter, the hill survey was 23–25 June and the flat 25–29 June.

3.5 Biomass estimates

The estimates of biomass of spawning orange roughy from the survey are shown in Tables 6 and 7. These include corrections for the shadow zone, towed body motion, and sound absorption as described in Section 2.1. The latter were applied automatically by the analysis software, but shadow zone corrections were estimated explicitly by stratum as shown in Table 8. The largest corrections were on Graveyard because the aggregations there were over steep sea bottom. Average corrections for the other hills were factors of about 1.14 and for the flat about 1.02. The first orange roughy target strength relationship in Table 4 (NIWA) was used. The mean spawning biomass for the two hill snapshots plus the flat strata is 30 000 t. Using the 'sensitivity' (CSIRO) target strength relationship for orange roughy in Table 4 gives 34 000 t. Adjusting for the proportion of mature fish not present on the spawning grounds (i.e., *Smat* of 1.35) gives estimates of 40 000 and 44 000 t for the two target strength values with a c.v. of 63%. Sources of variance are summarised in Table 9.

The biomass of roughy on the flat was also estimated directly from the trawling. For this it was assumed that the catching area of the net is determined by the trawl width and headline height and the catching ability within this zone is 1. This gave a spawning biomass of 933 t with a c.v. of 26% which is only about 4% of the acoustic estimate.

3.6 Sensitivity

The estimates were very sensitive to the catch composition of one tow (45) in flat stratum 3 (see Tables 6 and 7). This stratum contained the highest spawning abundance (see Table 6) and when tow 45 was excluded from the analysis this reduced from 16 000 to 3800 t. The total spawning abundance dropped from 30 000 to 17 000 t, and the overall c.v. from 63% to 30%. The catch weight for tow 45 was unexceptional, but its species mix was very different from other flat trawls. It contained mostly orange roughy (125 fish), some sharks and dogfish (no swimbladders), and very few other species with air-filled swimbladders. Most catches from the flat are dominated numerically by species with air-filled swimbladders and the backscatter apportioned to orange roughy is severely down-weighted relative to these. The Deepwater Working Group discussed tow 45 at length and decided to use the results with it in.

The sensitivities of the flat abundance estimate to changes in the values of the contributing parameters are presented in Tables 10 and 11. Most sensitivities considered here do not represent truly likely changes, but are based on doubling and halving parameter values (e.g., a 3 dB change in target strength represents a factor of two in the fish-per-square-metre scale).

For the total abundance of orange roughy, the largest sensitivities occurred when the intercepts of the target-strength length relationships for other species were changed by ±3 dB (Table 10). The 3 dB used in the sensitivities was only a guess at the possible range of future revisions. The next most important sensitivities were changes in the catchabilities of other species relative to orange roughy. These are driven by the flat strata sensitivities. The hill estimates are sensitive only to the orange roughy target strength. Catchabilities of other species are unknown, and it is also not known if orange roughy are more or less catchable than other species.

When individual species were excluded from the catch (Table 11), Baxter's lantern dogfish produced a change in hill abundance of 10%. For the flat strata, and consequently for the total abundance, excluding the four-rayed rattail had a very large effect.

4. DISCUSSION

The abundance of all orange roughy on Graveyard is similar to that found in the last acoustic survey in the area in 1999. Using the NIWA target strength relationship (the first relationship in Table 4), the latter was 3587 t (c.v. 22%). The value for the present survey is 5600 t (c.v. 18%). A t-test of the two showed no statistically significant difference at the 5% level.

For stock assessment, an average of the two estimates of orange roughy target strength (NIWA and CSIRO: the 'sensitivity' value in Table 4) was used. The mature biomass reported above (NIWA) was 40 000 t. Using the CSIRO target strength estimate (Kloser et al. 2000) it is 44 000 t and these two estimates were averaged to give 42 000 t with a c.v. 63%.

The hill estimates are unambiguous, with only some debate about the value of roughy target strength. However, the flat estimates are much less certain and since, with tow 45, they are much larger than the hill biomass, they affect the accuracy of the total estimate. In addition, trawl catchability of all species is taken to be the same, and as Table 10 shows, the flat biomass estimates are quite sensitive to this. A further assumption is that the vertical distribution of roughy on the flat is similar to that on hills and backscatter is estimated (integrated) up to 100 m above the bottom. Flat biomass estimates are sensitive to this also (see Table 10). Reducing the integration height to 50 m reduces the total abundance by 62%. The actual distribution of dispersed roughy in the water column is unknown and is confounded with the catchability problem. When in large aggregations, roughy are found up to 100 m or more above the bottom and are known to be driven down by trawls. However, it is not known whether more dispersed roughy behave similarly and nothing at all is known about the behaviour of other species found well above the bottom. A further complication is that there are known to be other scatterers of similar target strength to roughy (for example myctophids) which are poorly sampled by the trawl or not caught at all.

If the above assumptions are correct, the effectiveness of trawling in catching dispersed roughy on the flat can be found by comparing the acoustic estimate with that from the trawl survey result (Section 3.5). The trawl estimated spawning biomass is 933 t which is equivalent to a trawl efficiency of about 4% (see Table 6). Considering the strata separately, for stratum 3, the trawl efficiency is 1.7% (4% if tow 45 is omitted), and for the other flat strata 10%. There are several possible explanations for these low trawl efficiencies. First, they may truly reflect low catchability: roughy are driven down but in low concentrations are able to avoid capture. Alternatively, they may be present but are not driven down and the trawl catches all the fish but only those in, say, the bottom 10 m (since this is about the headline height and it also represents 10% of 100 m). Secondly, there may actually be no roughy in the upper part of the water column and the backscatter attributed to roughy is entirely from other scatterers. Large biases would be introduced by all of these. In stratum 3 there were extensive scattering layers up to 100 m above the bottom, particularly at the deeper end (see Figure 6) and there were large catches of jellyfish, but not much roughy, in the trawl (46) in this position. In the other strata, the bottom scattering layers were lighter and less extensive and the catches of roughy higher. This suggests that much of the backscatter in stratum 3 may not have been from roughy.

Amongst the hills, Morgue presents a problem because although it had large marks, the Seamount Closure Regulations precluded fishing there. The analysis assumes that the species mix was the same in 2002 as in the 1999 survey (Bull et al. 2000). However, this is a strong assumption and little is known about the year-to-year variability of the species mix on these or any hills. Table 12 shows a comparison between the species mix for 1999 and 2002 on the main hills in the Graveyard complex, excluding Morgue. Orange roughy accounted for by far the main part of the catch (90–99% by weight) and the rest was made up of smooth oreos and Baxter's lantern dogfish. It can be seen that the proportion of roughy increased on Scroll and decreased on all the others sufficiently to affect the biomass estimate. Consequently, it seems unlikely that the mix on Morgue was the same as 1999, but it could have varied in either direction.

5. ACKNOWLEDGMENTS

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Table 1: Calibration data for the 38 kHz systems used for the survey. System 1 was hull-mounted, systems 2 and 3 were towed. V_T is the in-circuit voltage at the transducer terminals for a target of unit backscattering cross-section at unit range. G is the voltage gain of the receiver at a range of 1 m with the system configured for echo-integration and C is the overall calibration constant.

System	Temperature (°C)	G	V_T (V)	C
1	–	38 459	331	1 931 360
2	7.7	12 604	1 344	2 726 830
2	8.3	12 604	1 275	2 702 010
2	11.1	12 604	1 332	2 586 520
2 (mod)	11.1	12 097	1 275	2 482 450
3	8.0	12 866	1 009	2 210 430
3	12.0	12 866	1 045	2 291 250

Table 2: Hill strata

Hills surveyed

Name	Latitude and longitude of top		Depth of top (m)
Morgue	-42 43.02	179 57.56 W	890
Graveyard	-42 45.59	179 59.34 W	750
Zombie	-42 45.94	179 55.58 W	890
Scroll	-42 47.15	179 59.86 E	870
Deadringer	-42 44.14	179 41.42 W	820

Hills not surveyed

Name	Latitude and longitude of top		Depth of top(m)
Doom	-42 37.82	179 59.50 E	1263
Gloom	-42 36.49	179 58.85 E	1178
Crypt	-42 37.58	179 56.43 W	1145
Mummy	-42 38.72	179 52.97 W	1035
Headstone	-42 40.51	179 57.44 W	1000
Hartless	-42 39.92	179 55.25 W	1071
Diabolical	-42 47.39	179 59.23 W	894
RIP	-42 46.80	179 54.22 W	910
Gothic	-42 43.62	179 53.89 W	987
Pyre	-42 42.99	179 54.33 W	987
Casket/St Pauls	-42 50.09	179 59.19 E	792
Wecnec	-42 49.00	179 49.89 W	850
Hagar the Horrible	-42 43.75	179 45.57 W	1084
Ghoul	-42 47.83	179 59.16 E	935
Soul Destroyer	-42 41.34	179 59.69 W	1161
Solless	-42 40.74	179 59.38 W	1126
Coffin	-42 46.31	179 54.09 E	1007
Vampire	-42 43.22	179 57.27 E	>1100
Grendel	-42 42.57	179 50.43 W	1087
Ghost	-42 46.25	179 54.07 E	~1000
Phantom	-42 46.30	179 59.62 W	~950
Voodoo	-42 44.79	179 55.37 W	~1020
Gargoyle	-42 40.46	179 48.20 W	~1200

Table 3: Flat strata: location, area, and the number of transects and trawls

Stratum	Depth range	Longitude		Area (km^2)	Transects	Tows
1	840–1150	179 40 E	179 45 W	658	7	6
2	870–1100	179 45 W	178 31 W	1059	4	7
3	840–1075	178 51 E	179 40 E	512	3	4
4	840–1075	178 00 E	178 51 E	444	2	3

Table 4: Length–target strength relationships used where relationships are of the form <TS>=a + b $\log_{10}$(length) + c sin(c1 length – c2).

Species	Code	Intercept (a)	Slope (b)	Sin term used c	c1	c2
Orange roughy (*Hoplostethus atlanticus*) (NIWA)	ORH	-74.34	16.15			
Orange roughy sensitivity (CSIRO)	ORH	-76.15	16.15			
Basketwork eel (*Diastobranchus capensis*)	BEE	-76.7	23.3			
Black javelinfish (*Mesobius antipodum*)	BJA	-70.6	17.8			
Black oreo (*Allocyttus niger*)	BOE	-78.05	25.2	1.62	0.082	-0.24
Four-rayed rattail (*Coryphaenoides subserrulatus*)	CSU	-92.5	31.8			
Hoki (*Macruronus novaezelandiae*)	HOK	-74	18.0			
Javelinfish (*Lepidorhyncus denticulatus*)	JAV	-73.5	20.0			
Johnson's cod (*Halargyreus johnsonii*)	HJO	-74.0	24.7			
Notable rattail (*Coelorinchus innotabilis*)	CIN	-107.8	44.9			
Ribaldo (*Mora moro*)	RIB	-66.7	21.7			
Ridge scaled rattail (*Macrourus carinatus*)	MCA	-95.5	35.6			
Robust cardinalfish (*Epigonus telescopus*)	EPR	-70.0	23.2			
Serrulate rattail (*Coryphaenoides serrulatus*)	CSE	-135.0	59.7			
Smooth oreo (*Pseudocyttus maculates*)	SSO	-82.16	24.63	1.03	0.117	1.77
White rattail (*Trachyrincus aphyodes*)	WHX	-62.1	18.1			
Cod-like		-67.5	20.0			
Deep water swimbladdered		-79.4	20.0			
No swimbladder		-77.0	20.0			

Table 5: The two snapshots on the hills giving the number of transects and the number of trawls used in the analysis.

Name	Transects Snap1	Transects Snap2	Trawls Snap1	Trawls Snap2
Morgue	3	2	0	0
Graveyard	6	4	2	2
Zombie	3	3	1	1
Scroll	3	3	2	1
Deadringer	3	3	0	2

Table 6: Abundance of spawning orange roughy (t) by snapshot and stratum.

	Spawning abundance (t)		
Stratum	Snap 1	Snap 2	Stratum 3 tow 45 excluded
1	1 100	–	–
2	1 600	–	–
3	16 000	–	3 800
4	3 800	–	–
Deadringer	140	68	–
Graveyard	5 200	5 300	–
Morgue	450	1 600	–
Scroll	170	200	–
Zombie	490	200	–

Table 7: Overall abundance of spawning and mature orange roughy (t).

		Abundance	
			Tow 45 excluded
Spawning	Hill	7 200	7 200
	Flat	22 000	10 000
	Total	30 000	17 000
Mature		40 000	24 000
C.v. mature		63	30

Table 8: Mean correction factors for the shadow zone by stratum. The hills correction is over both snapshots. The values indicate the mean amount of backscatter after the correction is applied, compared to the original amount.

Stratum	Correction
Graveyard	1.25
Scroll	1.14
Zombie	1.13
Morgue	1.12
Deadringer	1.18
1	1.03
2	1.02
3	1.01
4	1.02

Table 9: Coefficient of variation (%) by source calculated when bootstrapping that source only. Catches, backscatter, and target strength (TS) of orange roughy were bootstrapped using available data. Target strengths of other species were varied by shifting the intercept up or down with a standard deviation of 3 dB.

Source	Stratum		
	All	Hills	Flat
Catches	57	8	72
Backscatter	5	14	4
TS of ORH	2	9	0
TS of other species	33	6	44

Table 10: Sources of bias for acoustic survey abundance estimates, orange roughy, snapshot 1 hill strata and background strata. †, magnitude exceeds c.v. of the estimated abundance when averaged over the 2 snapshots (all strata, 63%; hill strata, 19%; background, 80%). TS, target strength.

Source	Abundance change (%)		
		Strata	
	All	Hills	Flat
TS estimate, other species			
Lower intercepts by 3 dB	77†	11	96†
Increase intercepts by 3 dB	-41	-12	-49
TS estimate of target orange roughy			
Lower intercept by 2 dB	11	46†	1
Increase intercept by 2 dB	-8	-32†	-1
Catchability of other species			
Twice that for target roughy	64†	9	80†
Half that for target roughy	-38	-11	-46
Integrate flat backscatter from bottom to 50 m	-62	–	-68

Table 11: Bias from species mix used: effect of excluding one species at a time for background and the hill snapshot 1 surveys. Only species which cause a change of 5% or more in abundance are shown.

Species excluded	Abundance change (%)
Total abundance	
Four-rayed rattail	139
White rattail	8
Abundance in the hill strata	
Baxter's lantern dogfish	10
Smooth oreo	6
Abundance in the background strata	
Four-rayed rattail	179
White rattail	10
Notable rattail	6

Table 12: Precentage of orange roughy (ORH) and the two other main species, smooth oreos (SSO) and Baxters lantern dogfish (ETB) on the main hills (excluding Morgue) in 1999 and 2002

Hill	Year	% ORH	% SSO	% ETB	Total (t)
Morgue	99	70.9	7.7	20.0	20.7
Graveyard	99	99.0	0.4	0.6	245.9
	02	97.7	0.2	2.1	93.5
Scroll	99	96.1	3.7	0.1	149.0
	02	98.1	1.7	0.2	45.6
Zombie	99	94.3	5.2	0.5	17.7
	02	90.9	8.7	0.2	38.0
Deadringer	99	99.0	0.3	0.6	51.4
	02	94.2	2.8	2.8	1.7

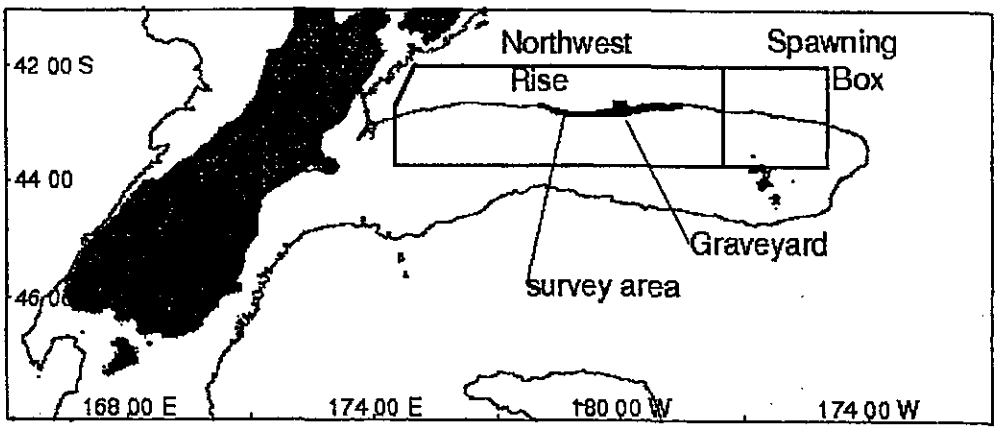

Figure 1: **Location of the survey area on the Northwest Chatham Rise.**

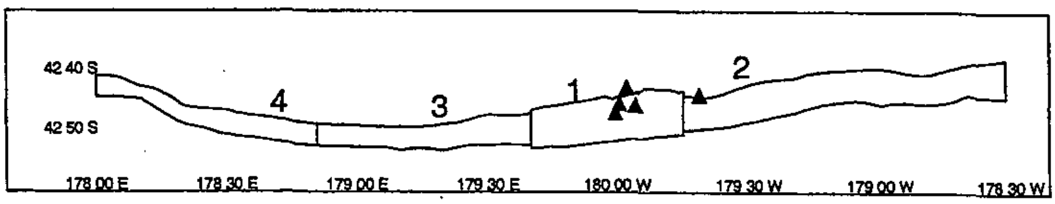

Figure 2: **Northwest Chatham Rise Hill survey, flat strata with positions of the hills to be surveyed (triangles).**

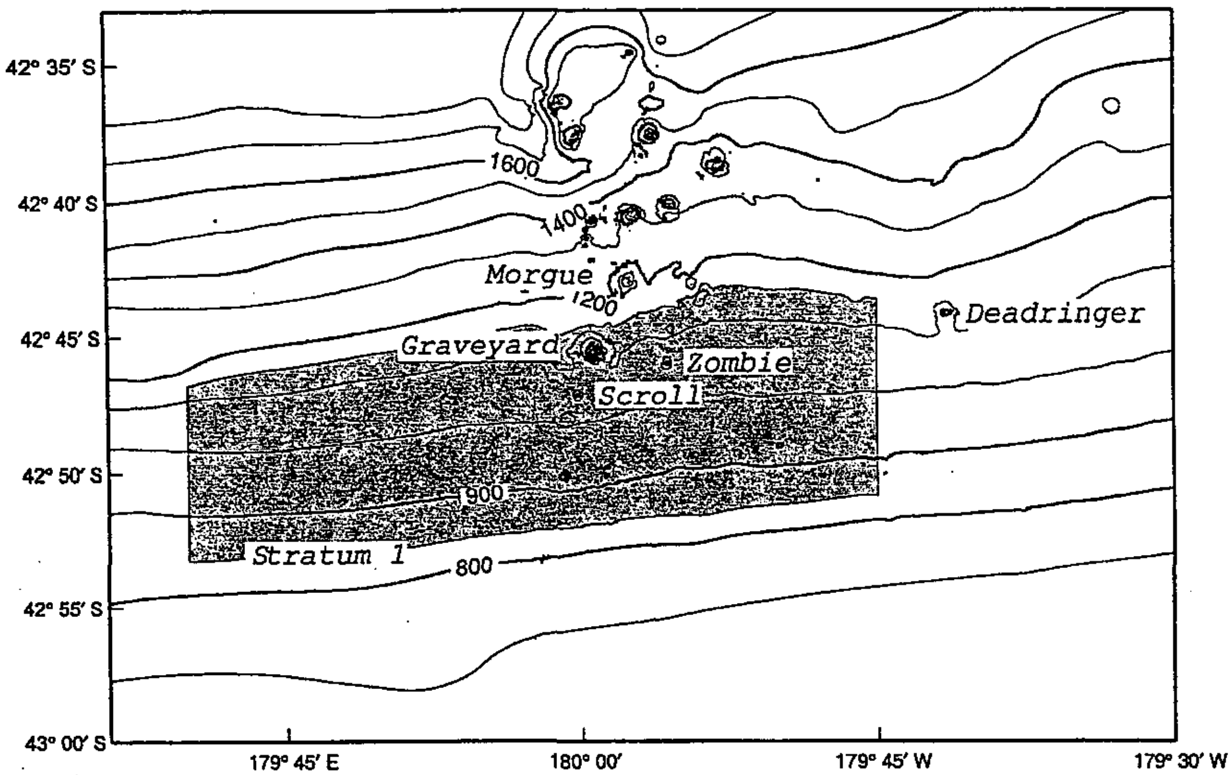

Figure 3: **Central flat stratum (stratum 1) and hills surveyed. Trawling was not carried out on Morgue.**

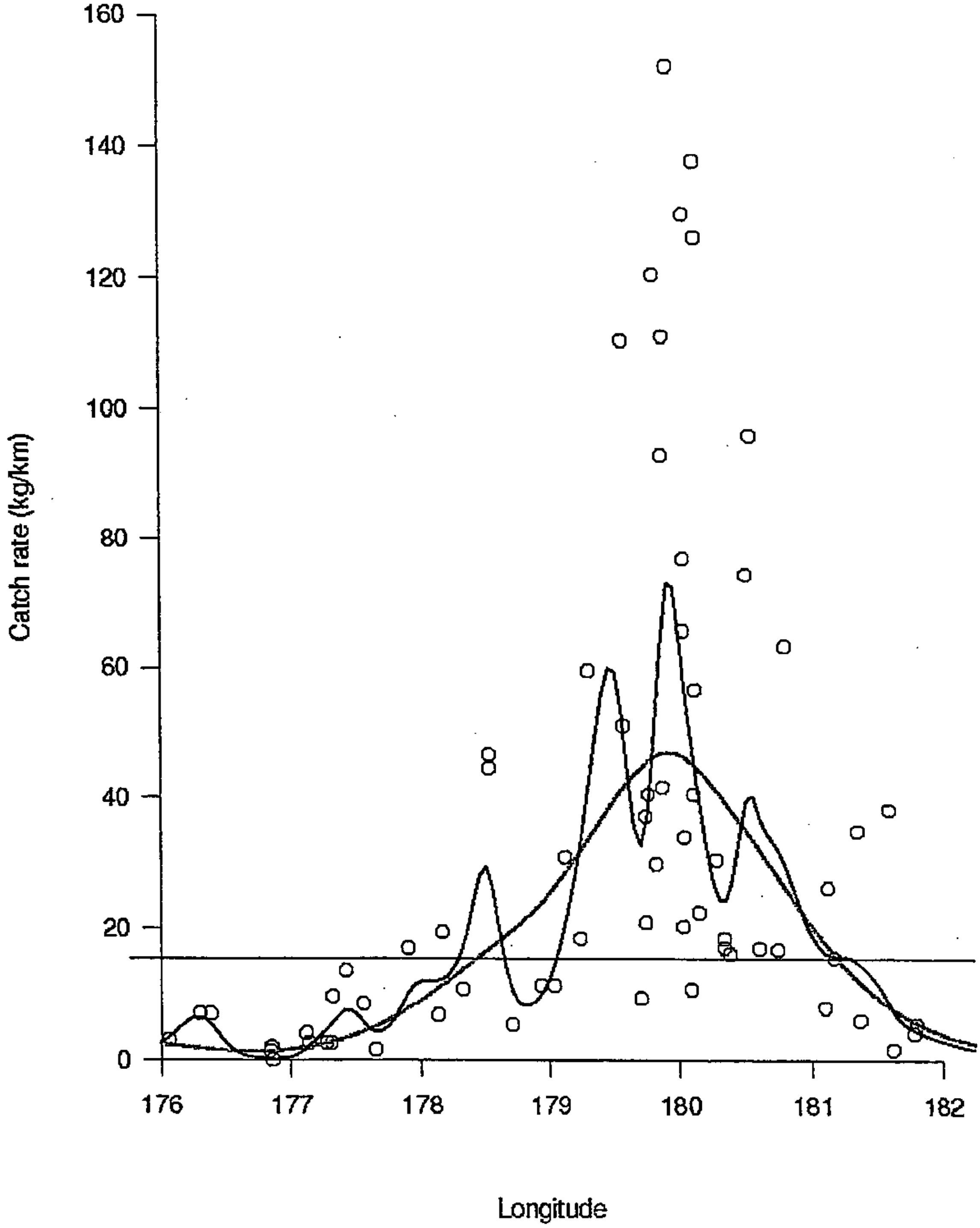

Figure 4: Catch rates of spawning orange roughy, 31 cm or more, along north Chatham Rise. Circles are catch rates (kg/km) in May to July from trawl surveys. The faded line is a smoothed curve through the data that over-smoothed the data somewhat. The dark curve is another smooth curve which has been under-smoothed. Where the horizontal line intersects the under-smoothed curve determines the interval that has 80% of the area

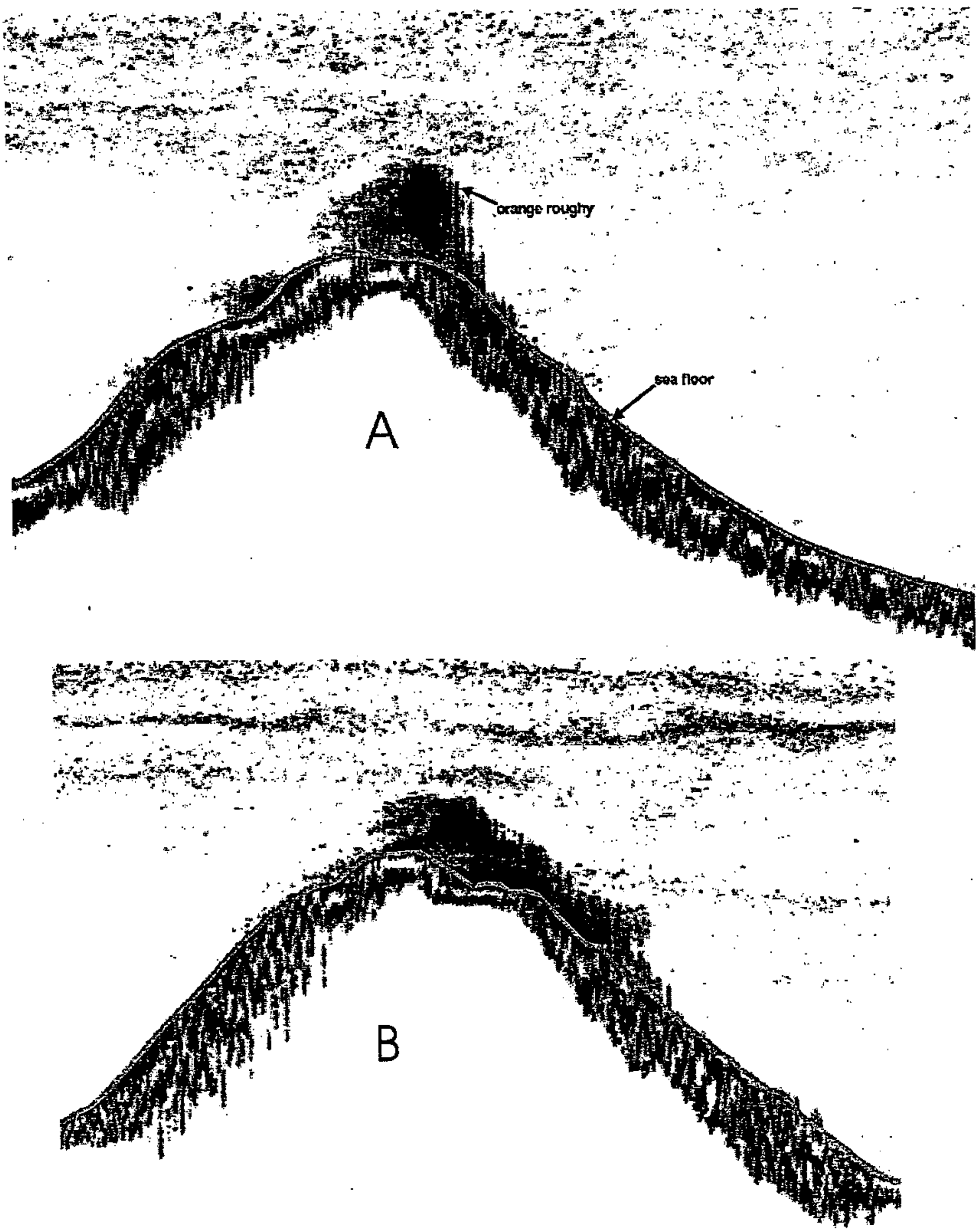

Figure 5: Echograms of spawning orange roughy on the Graveyard. A) transect 3, snapshot 1, heading 298°; school is about 100 m high. B) transect 3, snapshot 2, heading 340°; school is about 110 m high at the thickest part.

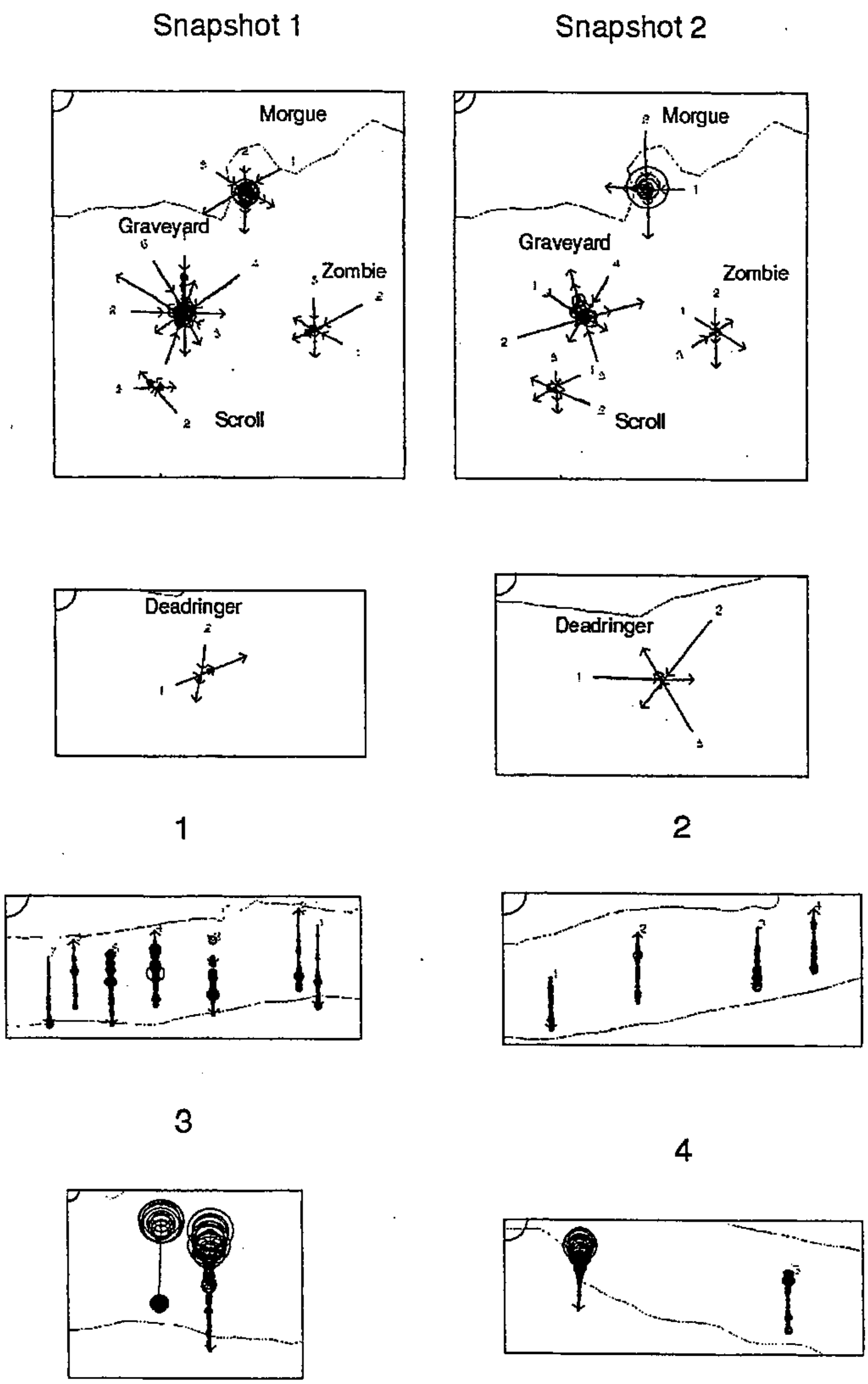

Figure 6: **Backscatter averaged over 10 ping groups (value proportional to circle diameter) by transect for the two snapshots on the hills (maximum 5×10^{-4} fish m^2) and the background strata 1, 2, 3, and 4 (maximum 5×10^{-5} fish m^2).**

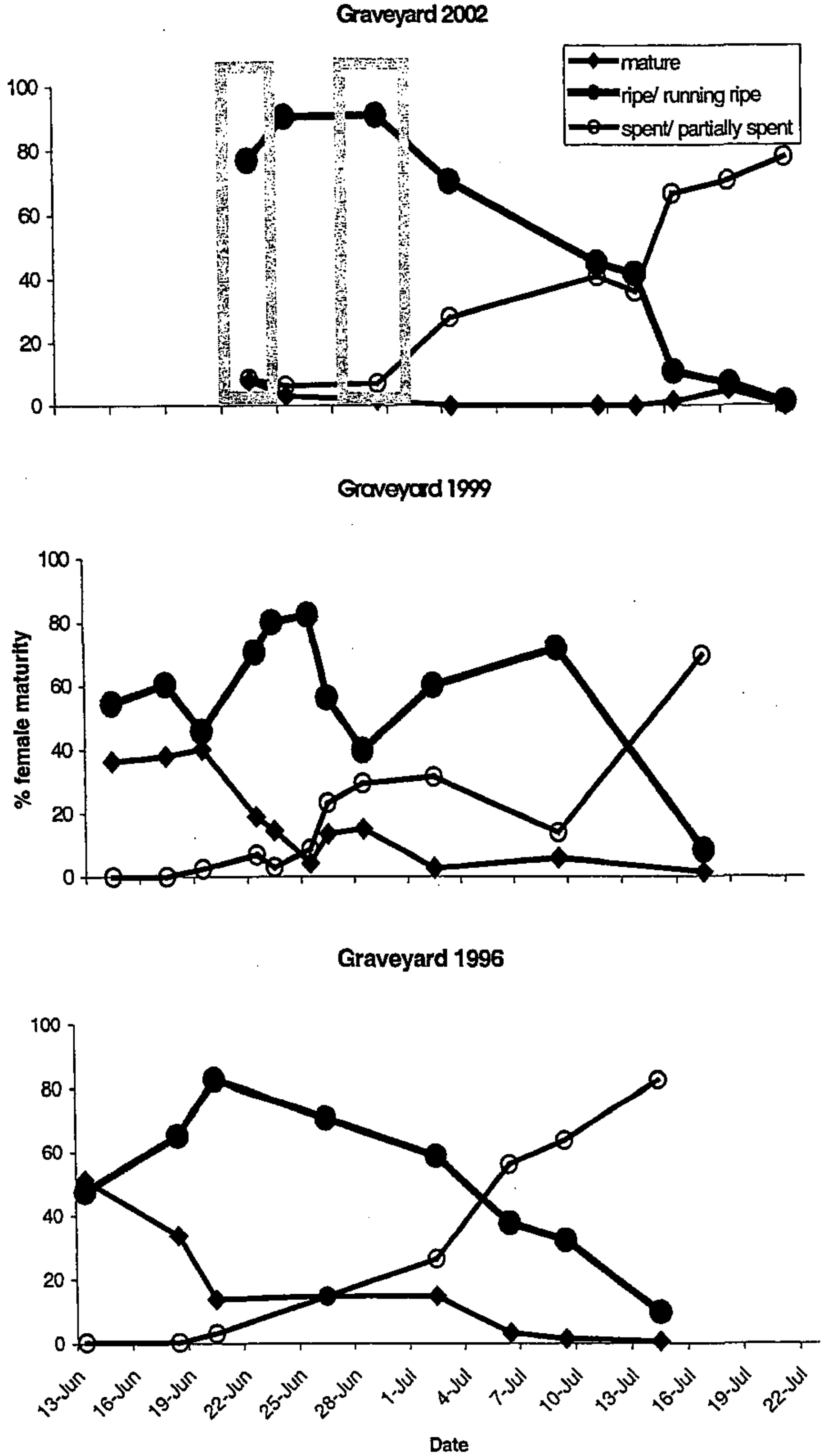

Figure 7: **Percentage of each female gonad stage from samples on each day for the Graveyard hill from trawls during the acoustic research surveys in 2002 and 1999, and the 1996 egg survey. Grey rectangles show the duration of acoustic biomass snapshots in 2002.**