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EXECUTIVE SUMMARY

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An acoustic survey of the Mid-East Coast orange roughy fishery was carried out between 16 and 27 June 2003 from *Tangaroa* (voyage TAN0310) and *Ocean Ranger* (ORA0301). The survey was based on the one carried out in 2001 but with sole emphasis on the area where plumes occur (main strata), whilst the outer background areas were not surveyed at all. Combinations of star and parallel transects were used depending on the nature of the terrain and fish distribution. The number of snapshots varied between one and four depending on the area. The acoustic mark-types used in the analysis were simplified from those used in 2001.

The total spawning abundance for the main strata was 3800 t (c.v. 22%). Adding the 2001 estimate of 6900 t (c.v. 64%) for the outer background strata and adjusting for the proportion of mature fish not present on the spawning grounds gives an estimate for total abundance of 18 200 t (c.v. 43%).

1. INTRODUCTION

The Mid-East Coast (MEC) of the North Island is the largest orange roughy fishery in the Cape Runaway to Banks Peninsula (ORH 2A, 2B and 3A) management area. The MEC fishery has decreased in size in recent years, as quota levels have been reduced from over 6000 t in the early 1990s to the present limit of 800 t. These reductions have been associated with strong declines in CPUE, and a contraction of the periods of the year when high catch rates can be taken. The fishery has also tended to become spread over a wider geographical area. Stock size and yields have been estimated using data from egg surveys carried out in 1993 and 1995, an acoustic survey in 2001, standardised CPUE analyses for the entire stock area as well as the Ritchie Banks region (Statistical reporting area 013), and length data applied in a stochastic stock assessment (Francis & Field 2000).

Acoustic surveys have become established as the main fishery-independent method for estimating the abundance of orange roughy aggregations. The first acoustic survey of the MEC was carried out in 2001. In view of the continuing uncertainty about the status of this stock, a second survey was carried out in 2003. This second survey was based on the first, but for cost reasons a number of compromises were made and there was a tighter focus on the areas where plumes were found. This report describes the 2003 survey and its results.

2. METHODS

The survey design was similar to that of the 2001 survey (Doonan et al. 2003c), except for the following changes.

- The number of snapshots was reduced.
- The search carried out at the start of the survey was limited to ground not covered in 2001, and to finding the main plume.
- The mark classification used for the 2001 survey was used for this survey, except for the Rock Garden, reducing the trawling required. The 2001 mark classification had a large subjective element so there remains an unquantifiable uncertainty in the analysis that was not able to be addressed.
- The survey was restricted to the main strata (Figure 1), and the 2001 result was used for the outer background. Note that the main strata also contains background strata, or large areas of background marks (light layers close to the bottom), but they are surveyed here since they surround the known spawning aggregations.

As in all previous orange roughy acoustic surveys, the overall approach was to measure acoustic backscatter together with information on the size structure of the roughy and the mix of species present in acoustic marks, which was obtained by trawling. Survey timing was based on analysis of reproductive data from past abundance surveys of the area and from commercial fishing vessels. A stratified random approach was used (Jolly & Hampton 1990) and the strata were allocated based on the 2001 survey results. Stratum boundaries were not tightly defined in advance and it was envisaged that they would be reviewed in the light of experience at the start of the survey. To expedite this review, a rapid preliminary survey was carried out to locate spawning aggregations and finalise strata and transect allocations. Two vessels were used, NIWA's 70 m research vessel *Tangaroa,* which carried out all of the acoustic work, and Talley's 43 m stern trawler *Ocean Ranger*, which carried out the trawl sampling.

2.1 Acoustic principles

The conventional approach of echo-integration was used to estimate areal backscatter of acoustic energy by fish (Burczynski 1982, Do & Coombs 1989, Doonan et al. 2001), which was then apportioned using species composition derived from trawling. Areal backscatter is converted into total numbers of fish over all species per square metre by using a weighted (by number) average of the target strength over the species composition. The number of orange roughy per square metre is the total number times the fraction (in numbers) of orange roughy in the species composition. Abundance is obtained by converting numbers into weight per square metre using the average weight and multiplying up to the stratum area. Average weight is estimated from the trawl catches.

The detailed mathematical analysis used to estimate abundance from the survey results is the same as that used by Doonan et al. (1999) and a generic derivation is given in Appendix 1. Corrections were made to the backscatter for shadowing, towed body motion, and absorption of sound by seawater.

2.2 Acoustic equipment

The acoustic backscatter data were collected by *Tangaroa* with NIWA's Computerised Research Echo Sounder Technology (*CREST*) (Coombs et al. 2003). The configuration used was essentially the same as in previous deepwater acoustic surveys (Doonan et al. 2001, Coombs et al. 2003). A single split-beam system towed at between 100 and 600 m deep was used. This was calibrated in the large tank at Greta Point before and after the survey, and a deep-drop calibration to 500 m was carried out during the survey. The calibrations followed the approach described in Coombs et al. (2003) which in turn is based on Foote et al. (1987). A 38.1 mm ± 2.5 µm diameter tungsten carbide sphere with a nominal target strength of –42.4 dB was used as a calibration standard. The transducer 3 dB beamwidths were 7.0° (alongship) and 6.9° (athwartship) and its effective beam angle for integration was 0.0083 sr. The effective pulse length was 0.78 ms and the sample rate was 4 kHz. The in-circuit voltage at the transducer terminals for a target of unit backscattering cross-section at unit range (the linear equivalent of "SL+SRT", see Coombs et al. (2003)) was 1168 V when the towed body was shallower than 250 m and 1195 V when it was deeper. The voltage gain of the receiver at 1 m with the system configured for echo-integration was 14 788.

Information on acoustic mark shapes and intensities was collected from *Ocean Ranger*'s Furuno sounders by taking digital photographs of the display screens.

Salinity, temperature, and depth (CTD) data were collected on two drops using a Seabird 37-SM MicroCAT CTD to allow the transducer temperature correction to be measured and to estimate sound absorption using the new relationship derived by Doonan et al. (2003b). The Seabird was attached to the trawl headline for 15 tows. Two Guildline CTD drops were also made during the survey.

2.3 Survey design

As noted above, the survey covered only the main strata of the 2001 survey (Figure 1). These are centred on Ritchie Hill, but also included the Rock Garden to the south. The design within the main strata was based on the 2001 survey (Doonan et al. 2003c) (Figure 2).

Rapid preliminary surveys using a hull-mounted acoustic system were carried out to identify aggregations and to establish whether any extension of the 2001 strata was needed. Two different transect patterns were used, depending upon the characteristics of the ground being surveyed. Hill features were surveyed using a radial star pattern (Doonan et al. 2003a) where each star included two to four transects, centred on the top of the main mark, at approximately equally spaced angles. In each snapshot, an initial search was carried out on the hills with the hull system and only hills with marks were surveyed. This procedure freed time to concentrate on a thorough survey of the known aggregations. More extensive areas of slope and elongated features were surveyed using systematically positioned parallel transects, usually oriented east-west with the position of the first transect randomly assigned.

The area within the main strata covered was more or less the same as in 2001, but the coverage of the area where plumes were expected (DB) was much more intense and the survey was more efficient as a result. The following six main strata (see also Figure 3) were established:

- Ritchie A (RA), Ritchie B (RB), and Rock Garden (RG) were surveyed with parallel transects.
- North Hill, and HR were surveyed with stars.
- DB which contained two plumes (plume 1 and plume 2) and was surveyed with two stars.

Strata RA and RB were background strata that surrounded the spawning aggregations, but they were not a part of the outer background strata used in 2001. The main differences between this survey and the 2001 main area strata was that DB was split out of the 2001 RB stratum and that HR was surveyed as a ridge and not at just one point (Hill 814 in 2001).

2.4 Biological sampling

All trawling to estimate species and size composition and other biological parameters was carried out by *Ocean Ranger* using a standard six-panel wingless "rockhopper" orange roughy trawl. The codend mesh size was 100 mm for all but the trawls in the background strata, where it was 60 mm.

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 (i.e., frequency by gonad stage, standard length to the nearest centimetre below, and sex) 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.

2.5 Estimating absolute abundance

The overall procedure for estimating abundance was essentially the same as in previous orange roughy surveys (Bull et al. 2000, Doonan et al. 2001) (Appendix 1), except that the proportions of species (by number) from each catch were weighted by the square root of the catch size rather than catch size alone. The same weighting was used in the 2001 estimate. Square root weighting was used because the small number of trawls means that the proportion estimates are not robust to a large catch with an atypical composition; square root weighting gives a more robust estimate. 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 abundance of spawning orange roughy in the areas surveyed. Spawning abundance was then scaled up to estimate mature biomass using the factor given in Section 2.6.3. Spawning roughy were defined as those with a gonad stage of 3 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.

2.5.1 Mark-types

The character of the MEC fishery differs from that of the bigger fisheries on the Chatham Rise where a substantial proportion of the biomass is in large aggregations which are almost exclusively orange roughy. In the MEC other aggregating species are also present (e.g., alfonsino and cardinalfish) and roughy aggregations are smaller and more scattered. A specific mark classification scheme was developed for the 2001 survey (Hart et al. 2003) which identified seven mark-types. However, most of the roughy abundance in the main strata came from only two of the mark-types, ORANGE ROUGHY and RED MARKS GREY LAYER (Doonan et al. 2003c). For this survey we amalgamated these two into a single ORANGE ROUGHY mark type containing mainly spawning orange roughy. Two 2001 mark-types that related to midwater layers, and to alfonsino and cardinal were dropped, since these were not included in the integrations. Everything else was included in a BACKGROUND mark type containing small amounts of orange roughy and a mixture of other species. The catch data for the ORANGE ROUGHY mark-type were split by stratum.

2.5.2 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 target strength and length are shown in Table 1. For orange roughy these are based on measurements of live fish in a tank (McClatchie et al. 1999) combined with in situ results from Barr & Coombs (2001). The target strengths for oreos were derived from a Monte-Carlo analysis of in situ and swimbladder data (Macaulay et al. 2001, Coombs & Barr in press) and the relationships used were:

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

for smooth oreos and

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

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).

2.5.3 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 abundance to total abundance. 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 abundance and B_{Sf} is the abundance 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 the estimated abundance of spawning fish (both sexes) from the acoustic survey of the spawning area.

The data to calculate *Smat* need to come from the total area from which spawners are drawn, and to be collected during the months leading up to spawning. For MEC, appropriate data are from Ritchie Bank (TAN9203, March–April 1992; TAN9303, March–April 1993; and TAN9403, March-April 1994). These data produced three estimates and the value used was the average of these, i.e., 1.70 with a c.v. of 7% (Doonan et al. 2003c). The same value was used for the abundance estimate from the 2001 survey.

2.5.3 Estimating variance and bias

Analysis of variation 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 that reflected how the data were collected and combined to form the relationships (see Doonan et al. (1999) for details). Abundance estimates were then recalculated. The process was repeated for 500 bootstrap iterations and c.v.s of the bootstrapped abundance estimates were calculated.

3. RESULTS

The survey took place between 16 and 27 June 2003 with *Tangaroa* (voyage TAN0310) present for the whole period and *Ocean Ranger* (voyage ORA0301) from 18 to 25 June.

3.1 Strata

No aggregations were seen in the preliminary survey outside the strata established in 2001 and so the area covered was more or less the same as in 2001. As the survey progressed it was clear that the behaviour of the roughy differed from that in previous years. In particular, few roughy marks were evident during the day with small plumes forming only at night, particularly in the main spawning plume stratum, DB. Spawning timing was similar to that in 2001. The survey was modified to accommodate these factors with the result that although 2–3 snapshots were carried out in each stratum these were not synchronised and no overall snapshots can be defined. Numbers of acoustic transects and snapshots are shown in Table 2.

3.2 Trawls

Fourteen satisfactory trawls were completed on the hills on spawning marks and 10 random trawls were carried out in the flat strata (Table 3). Here, satisfactory hill tows means that not only was the gear performance code 1 or 2, but that the tow also went through the intended mark. In 2001, 8 satisfactory trawls were completed on the hills on spawning marks and 21 random trawls were carried out in the flat strata (Table 3). Both data sets were combined and they show that the ORANGE ROUGHY mark-type is from 89% to 99% orange roughy, by weight, while BACKGROUND contains few roughy (Table 3). Because of cost cutting in the survey, not enough trawls were planned to give adequate results on their own, so data from both surveys were combined. Also, the mark-types were derived as combinations of the mark-types used in the 2001 estimate, so combining data was straightforward.

3.3 Gonad stages

Gonad staging results are shown in Table 4 and in Figure 4 together with the results from 2001 and the trawl survey in 1993. Only two effective points were obtained, but these showed that most females were spawning (ripe and running ripe) in the latter part of the survey period at DB which was also the case in 2001. The ripe and running ripe proportions for 2003 do not fit the smooth curves from the earlier years particularly well, but the data from the main plume area (DB) fits better with the 1993 data (Figure 4), mainly because of the sample on 24 June. Thus, spawning in 2003 seems to have been similar to that in previous years although it may have been slightly later than in 2001.

3.4 Abundance estimates

The snapshots used to estimate abundance in the main area around Ritchie Hill are shown in Table 5. Where there was more then one snapshot, they were averaged by stratum. The two snapshots over plume 1 in DB were averaged and added to the results for plume 2.

The estimates of abundances of spawning orange roughy from the survey are shown in Table 6. These include corrections for the shadow zone, towed body motion, and sound absorption as described in Section 2.1. The weather was good for most of the survey, so motion corrections were insignificant. The shadow zone correction was generally low, except for North Hill where it was 26% (Table 7). Non-spawning orange roughy were estimated to be 17 t (North Hill), 16 t (HR), 5 t (DB), 13 t (Rock Garden), 20 t (RA), and 69 t (RB). Sources of variance are summarised in Table 8.

The transects and distribution of backscatter by mark-type are shown in Figures 5 and 6.

The total spawning abundance for the main strata was 3800 t (c.v. 22%). To estimate the mature abundance in MEC, the main strata spawning abundance was added to the 2001 outer background strata value of 6900 t, c.v. 64% (Doonan et al. 2003c), and then the total adjusted for the proportion of mature fish not present on the spawning grounds (i.e., *Smat* of 1.7) to give an estimate of 18 200 t, c.v. 43%.

3.5 Sensitivity

The sensitivities of the main strata abundance estimates to changes in the values of the contributing parameters are presented in Table 9. 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).

The abundance estimate was sensitive to changing the intercepts of the target-strength length relationships by ±2 dB for orange roughy and by ±3 dB for other species (Table 9). The 3 dB used in the sensitivities was only a guess at the range for future revisions. The 2 dB change in the roughy case is about the difference between the target strength given in Table 1 and the estimate used by Kloser et al. (2000). The abundance estimate was also sensitive to changes in the catchabilities of other species relative to orange roughy. These are unknown, and it is also not known if orange roughy are more or less catchable than other species. The sensitivities used should be viewed as a mean change for all the other species because each species would be expected to have it's own values.

When individual species were excluded from the catch (Table 9), the exclusion of Johnson's cod or ribaldo produced a change in abundance of 17%.

4. DISCUSSION

The 2003 survey provided a good estimate of roughy abundance in the main strata with a c.v. of 22%, well within the target range of 20–30%. This c.v. is far lower than the 61% obtained for the same area in the 2001 survey. The main omission in the 2003 survey is that the outer background strata were not surveyed because the decline in the value of the fishery meant that the funds available for the survey were limited and it was therefore focussed on areas where the main concentrations of roughy were found in 2001. The outer background area was not surveyed because it would have been very time consuming, but the outer background accounted for nearly 40% of the abundance in 2001. The same outer background abundance is used in the present estimate in which it accounts for over 64%. The outer background has a high c.v. of 64%, and because it is used in this abundance estimate contributes a large part of the overall uncertainty.

To obtain a total abundance for the MEC, the main strata results for 2003 can be combined with the 2001 outer background value in two ways: by adding them together (chosen here) or by expanding the 2003 main strata value on the basis of the distribution of the 2001 proportion of the main strata abundance in the total, p_2001 (Deepwater Working Group's choice). A third way, because the two main strata results are not statistically different, would be to average them and add the result to the outer background value.

We chose the first way because we believe that the 2001 main strata value was more likely to be an overestimate through a sampling artefact. In 2003, we adopted a more efficient design by splitting the 2001 RB stratum into a background and a plume stratum (DB). Although the survey design for the 2001 RB was technically unbiased, it gave a high c.v. and a large abundance so that this c.v. was propagated into the main strata variance. This situation arose because the spawning plumes situated in RB were encountered on one transect in each snapshot (there were three snapshots) which gave rise to a high abundance on this transect, but low ones on all others. Thus, both the c.v. and the total abundance were high in RB. The distance between the two transects that clearly encountered the plumes was about 2 km, which was about the length of a spawning fish mark seen by the *Tasman Viking* in 2000 and implied in some reports from them when fishing as a catcher vessel in the 2001 survey. However, extensive searching in 2003 in DB area and its surrounds failed to locate a 2 km long plume, but two plumes were found, each about 100 to 200 m in diameter. Perhaps fortuitously, the positions of these two plumes were very close to those passed over in 2001, one in each of the first two 2001 RB snapshots. Most of the difference between 2003 and the first two snapshots in 2001 (the highest estimates) are due to the abundance difference in the ORH mark-type for the 2001 RB value and the 2003 DB plumes values. This suggests, but not conclusively, that the 2001 survey was unlucky and generated a large positive error.

The significance of a large positive error is that it biases the scaling factor, F_2001 = 1/p_2001, used to adjust the 2003 survey for the outer background strata as used in the second method, i.e., MEC abundance = 1.7 • B_main_2003 * F_2001, where 1.7 scales up the spawning abundance to mature and B_main_2003 is the estimated spawning abundance for the main strata in 2003. The estimation of F_2001 can be re-arranged to be given by

{B_main_2001 *(1+ξ) + B_back_2001)}/{ B_main_2001 *(1+ξ)},

where B_main_2001 is the true estimated abundance for the main strata in 2001 (i.e., B_main_2001 *(1+ξ) is the estimated value), B_main_2001 is the estimated abundance for the outer background strata in 2001, and ξ is the fractional bias in the main strata estimate. The estimated value of F_2001 is (7900 + 6900)/7900 = 1.9. For illustrative purposes, if ξ was 1.0, i.e., the true value in the 2001 main strata was about the same as in 2003, then the true F_2001 would be about 3. Thus a large positive error in the 2001 abundance for the main strata biases the scaling factor down. Another way to look at it is to use the estimated F_2001 of 1.9 to see what the projected abundance in the outer background strata is in 2003. Thus, the 2003 MEC spawning abundance would be 1.9*3800 = 7200 so the outer background spawning abundance is 3400 t; a decline of one-half over 2 years, which seems to be a rather large fractional decrease.

Further, the 2001 abundance c.v.s on both the outer background and main strata are high so the c.v. on F_2001 is also high and the resultant c.v. on the 2003 MEC abundance using the second method is 76% (A. Hicks, NIWA, pers. comm.). The c.v. for the first method is 43%, but it needs to be inflated by the bias caused by the changes over two years, if any, i.e., a root-mean-square-error (RMSE) approach. The bais is unknown, but to produce a RMSE equivalent of a 76% c.v., the bias would have to be 7000 t, i.e., a true 2003 outer background abundance of zero or 14 000 t. To get an RMSE equivalent of a 50% c.v., the bias would have to be 2800 or 40% of the 2001 value. We think that the total error is less using the first approach than the second.

Given the above, we prefer adding the 2001 outer background estimate to the 2003 main strata estimate for the 2003 MEC abundance (first approach).

Surprisingly, the two methods gave almost the same MEC abundance, the real differences being in the c.v.s. The estimate by expanding the 2003 main strata value on the basis of the distribution of the 2001 proportion of the main strata abundance in the total, p_2001, was 18 500 t, c.v. 76% (Hicks, pers. comm.). In comparison, adding the 2003 main strata estimate to the 2001 outer background estimate gave 18 300 t (c.v. 43%). The result appears to be a consequence of the method used to generate the MEC abundance via a p_2001 sampling distribution obtained by bootstrapping the 2001 survey results (Hicks, pers. comm). For each bootstrap, one of the main strata snapshots was chosen and a random value generated using the survey estimated mean and c.v. in a lognormal distribution. Similarly, a random value was generated for the outer background strata using the survey estimated mean and c.v. in a lognormal distribution. These two random values were combined to give a bootstrap p_2001. The bootstrap distribution was then applied to the 2003 survey results to give a distribution of MEC mature abundance, which had a mode in the 5000–10 000 t range and a very long tail out to 100 000 t or more. The MEC estimate is the mean of this distribution and the long tail means that it shifted away from the estimate using the survey values (these would give F_2001 = 1.9, MEC abundance = 1.7*(3800 *1.9) = 12 300 t, i.e., 50% lower than the bootstrap distribution method).

The aggregating behaviour of the orange roughy in most of the strata differed in this survey from that in 2001, and indeed all other orange roughy surveys in that, with the exception of Plume I in the DB stratum, the fish only formed distinct plumes at night. The significance of this is not clear.

In other recent acoustic abundance estimates of orange roughy an alternative target strength relationship based on the in situ results of Kloser et al. (2000) has also been used to derive an alternative abundance estimate and the average of the two has been used for stock assessment (e.g., Anderson et al. 2002). For comparison, the Kloser target strength gives an overall abundance of 19 800 t. However, recent work (Coombs 2004) shows that Kloser included targets that were not orange roughy in their analysis and their target strength estimate is too low as a consequence.

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Table 1: 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			
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 (*Caelorinchus 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 robustus*)	EPR	-70.0	23.2			
Serrulate rattail (*Coryphaenoides serrulatus*)	CSE	-135.0	59.7			
Smooth oreo (*Pseudocyttus maculatus*)	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 2: Numbers of transects and snapshots by stratum. "Design" is "S" for star and "P" for parallel transects. Search snapshots used the hull transducer only. Biomass estimation used data from the towed system.

Area	Total number of transects	Number of snapshots	Design
RITCHIE			
DB			
Searches	43	4	P
Towed system	8	3	S
North Hill			
Searches	7	3	S
Towed system	4	2	S
HR ridge			
Searches	7	4	S
Towed system	9	2	S
RA (includes HR)			
Searches	12	1	P
Towed system	17	2	P
RB			
Searches	12	1	P
Towed system	8	1	P
ROCK GARDEN			
Searches	23	3	P
Towed system	17	3	P

Table 3: **Median catch (kg) of all orange roughy (ORH) and spawning orange roughy (ORH_SR), the percentage of orange roughy in the total catch and the number of trawls by stratum and mark-type (ORANGE ROUGHY, BACKGROUND).**

Strata	Mark-type	Catch		Proportion	Number of trawls		
		ORH	ORH-SR	ORH(%)	2001	2003	Total
All	BACKGROUND	21	13	16	21	10	31
North Hill	ORANGE ROUGHY	10795	9732	99	1	1	2
DB	ORANGE ROUGHY	5106	4783	99	3	5	8
HR	ORANGE ROUGHY	1910	1737	98	1	3	4
RA, RB	ORANGE ROUGHY	1995	1812	89	2	0	2
Rock Garden	ORANGE ROUGHY	1846	1705	96	1	5	6

Table 4: **Percentage gonad stages for female orange roughy in stratum DB.**

Date	Gonad stage				
	Immature or resting	Mature	Ripe	Running ripe	Spent or partially spent
June 20	0.7	13.5	69.9	13.8	1.7
June 24	0.2	6.4	67.8	18.9	6.8

Table 5: **Snapshots used to estimate abundance by strata for the 2003 acoustic survey (all using the towed system).**

Stratum	Snapshot	Design	Area (km^2)	Number of transects	Date (June 2004)
North Hill	1	S	21	2	22
	2		16	2	23
HR	2	S	63	2	22
DB-plume1	1	S	2	3	24
	2		30	3	24
DB-plume2	1	S	4	3	24
Rock Garden	1	P	14	6	19
	2	P	14	6	20
	3	P	14	5	23
RA	1	P	72	9	20–21
	2	P	74	8	22–23
RB	1	P	225	6	21

Table 6: **Estimated spawning orange roughy abundance by 2003 strata and snapshot. "-", no data.**

Stratum	Stratum abundance		Snapshot abundance (t)		
	(t)	c.v. (%)	1	2	3
North Hill	253	26	439	68	-
HR	743	69	743	-	-
DB	669	23	223†	284†	-
			415‡	-	-
Rock Garden	1179	40	375	1529	1633
RA	219	34	274	164	-
RB	710	49	710	-	-
Total	3773	22			

† plume 1, ‡ plume 2

Table 7: **Mean shadow zone correction for each stratum over the snapshots used in the biomass estimation.**

Stratum	Correction
RA	1.11
RB	1.08
HR	1.11
DBplume1	1.02
DBplume2	1.04
North Hill	1.26
Rock	1.12

Table 8: **Coefficient of variation of the spawning orange roughy estimate for the total 2003 strata by each source alone. The total c.v. from all sources was 0.22. The individual sources combine in an approximate multiplicative way so they can be combined using $\sqrt{\prod_i\left(1+c_i^2\right)-1}$ which gives a total c.v. of 0.22.**

Source	c.v.
Catch	0.10
Backscatter	0.16
Target strength of other species	0.09
Target strength of orange roughy	0.06

Table 9: **Sources of bias for the acoustic survey abundance estimates, spawning orange roughy, in the main strata. †, magnitude exceeds c.v. of the estimated abundance (22%). TS, target strength.**

Source	**Abundance change (%)**
TS estimate, other species	
Lower intercepts by 3 dB	136†
Increase intercepts by 3 dB	-72†
TS estimate of target orange roughy	
Lower intercept by 2 dB	128†
Increase intercept by 2 dB	-77†
Catchability of other species	
Twice that for target roughy	131†
Half that for target roughy	-74†
Excluding one species at a time	
Johnson's cod	17
Ribaldo	17
Four-rayed rattail	6

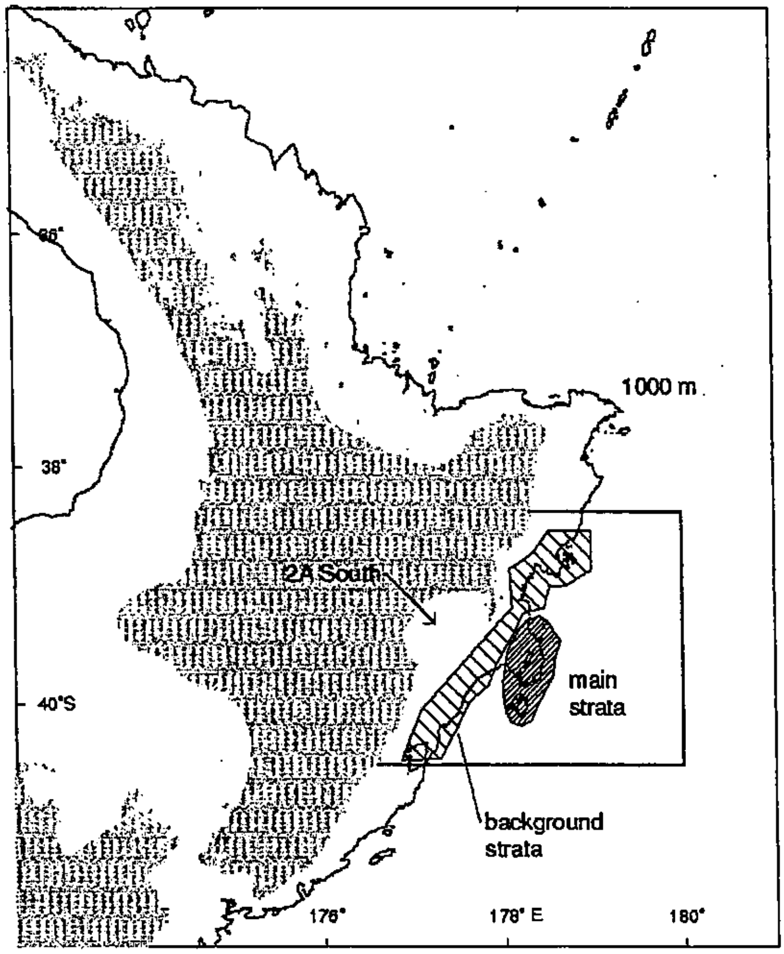


Figure 1: The MEC survey area showing the main strata, which were surveyed in both 2001 and 2003, and the outer background strata (coded as "background strata" on plot) which were only surveyed in 2001. The main strata surround Ritchie Hill and contain the only known spawning schools in this area.

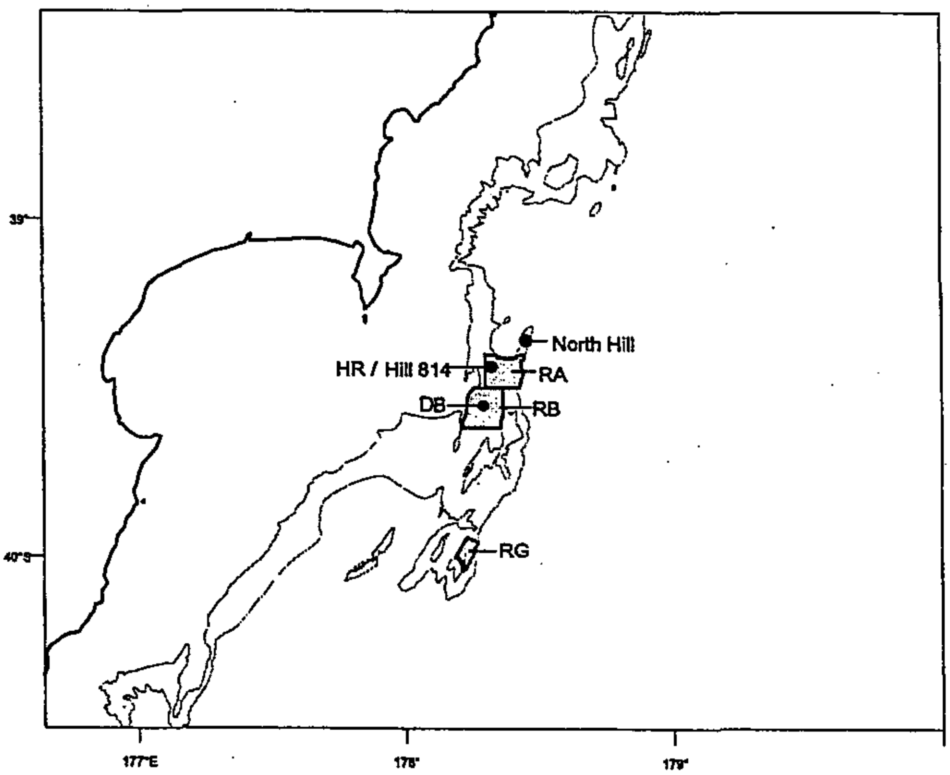


Figure 2: Map of the main strata in the 2001 survey area showing the two strata (RA, RB), minor aggregations (HR, North Hill), and the Rock Garden stratum (RG). The main spawning aggregation (DB) was part of the RB stratum.

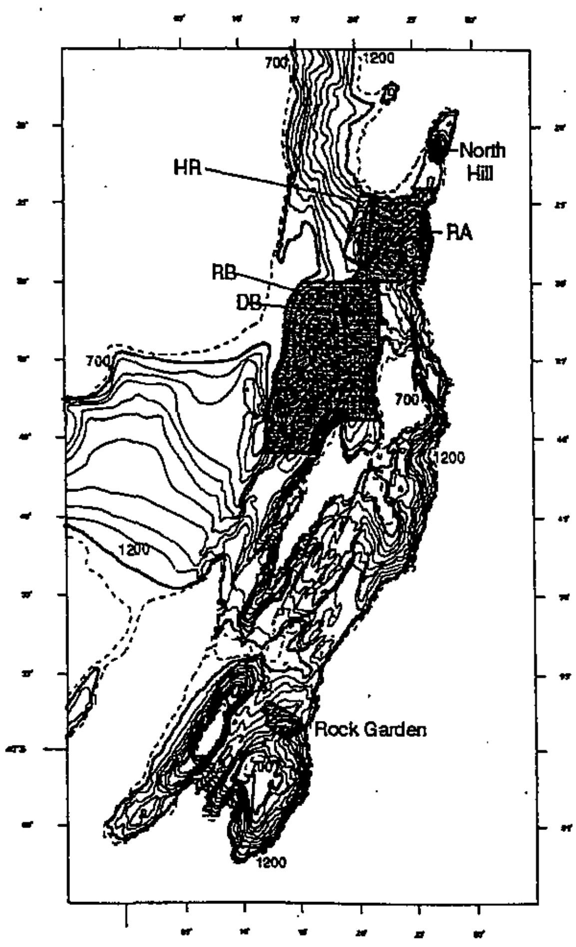
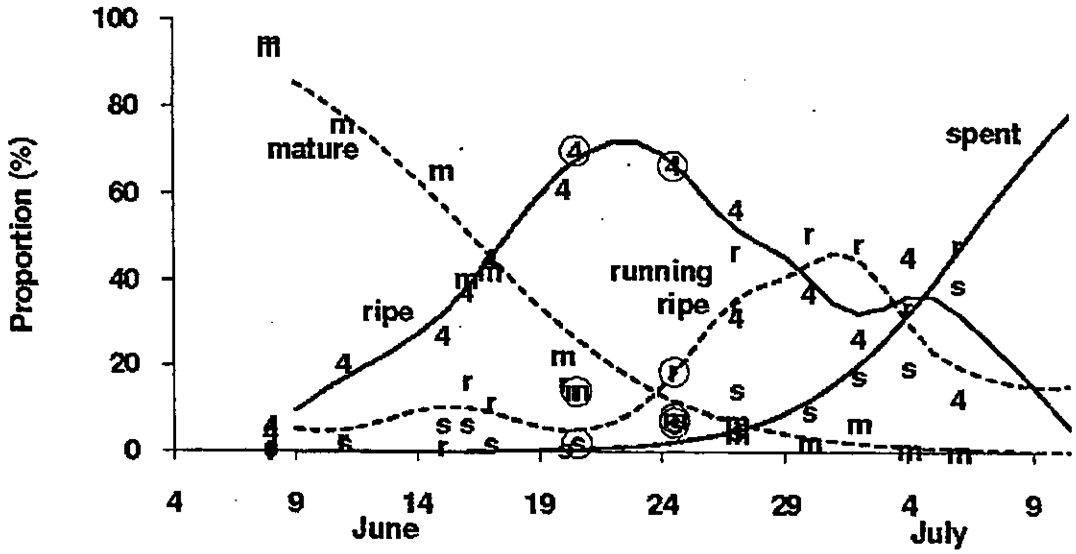


Figure 3: Map of the strata in the 2003 survey area showing the two background strata (RA, RB), Rock Garden (surveyed with parallel transects) and the "aggregation" (DB, HR, North Hill), surveyed with stars.

1993



2001

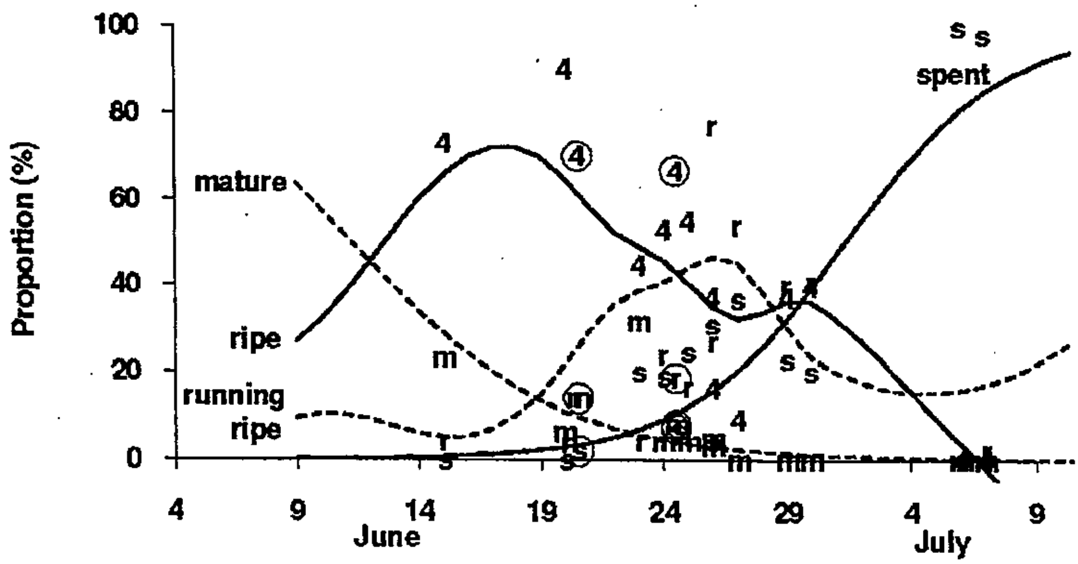


Figure 4: Percentage of each gonad stage from samples on each day from the 1993 and 2001 survey with the DB plume area in 2003 survey (symbols in circles). m, mature; 4, ripe gonads; r, running ripe; s, spent. Only data from tows where 1 t or more of roughy were used. The first two 2001 points were from market sampling. Smooth lines were fitted to both the 1993 and 2001 data, but with the 2001 spawning estimated to be 5 days earlier than that in 1993.

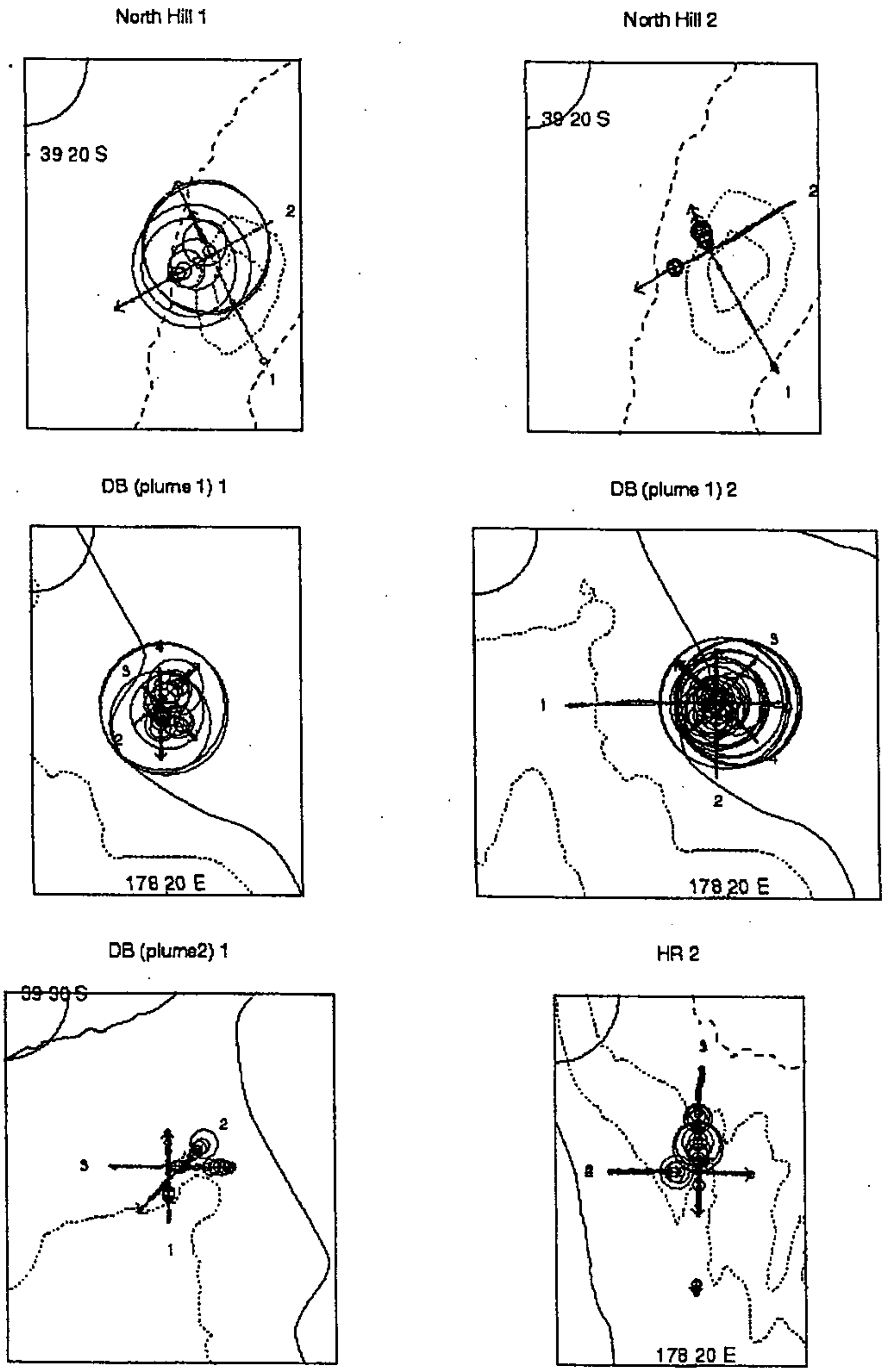


Figure 5: Star surveys (stratum-snapshot): average total backscatter over 10 pings (proportional to the diameter of the circle, a reference quarter circle (=0.5x10^{-5}) is given in the top left hand corner). Transects are numbered and have been adjusted so that they are shown at the approximate position of the towed body. The largest backscatter in each plot comes from orange roughy schools.

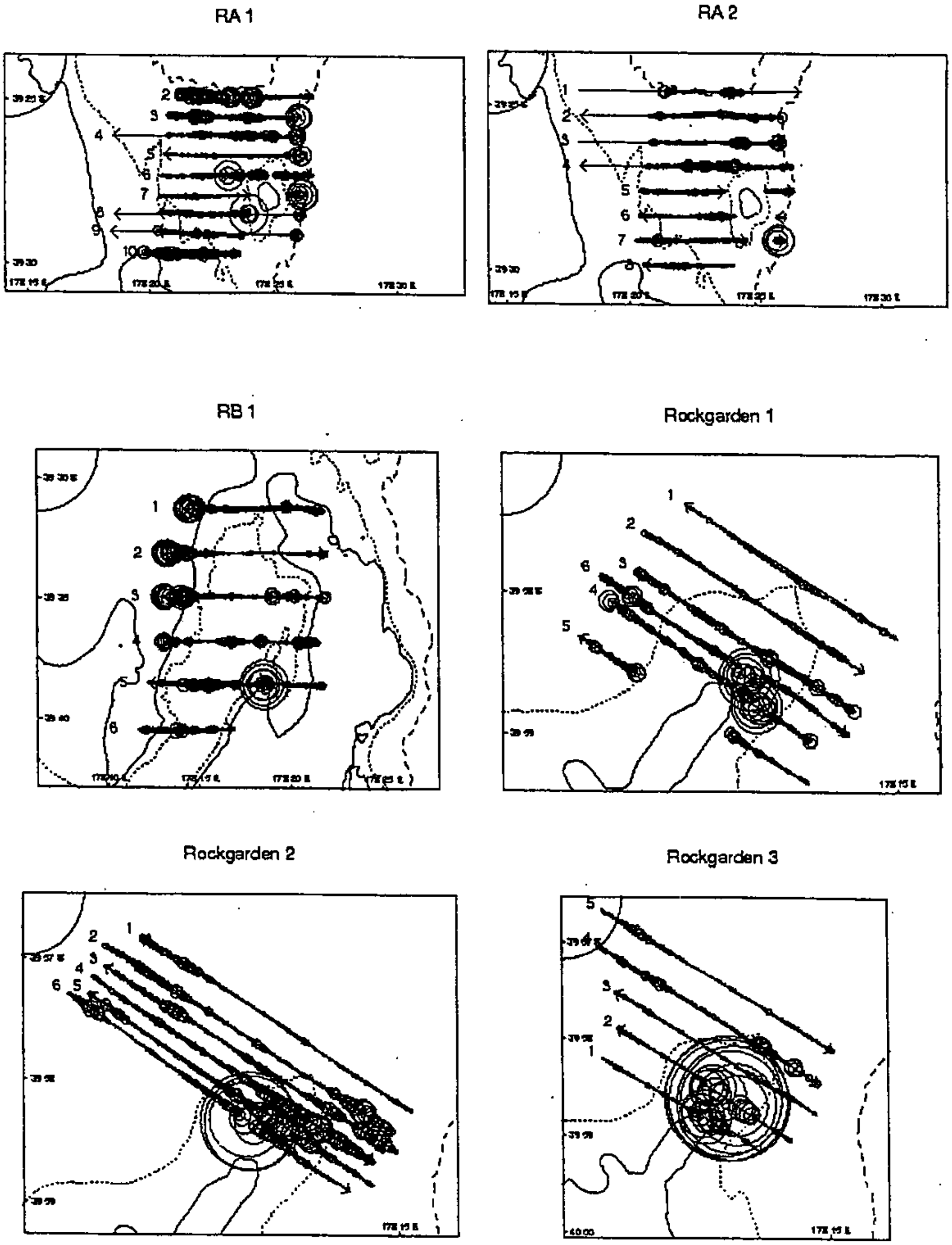


Figure 6: **Parallel transect surveys (stratum-snapshot): average total backscatter over 10 pings (proportional to the diameter of the circle, a reference quarter circle (=0.5x10-5) is given in the top left hand corner). Transects are numbered and have been adjusted so that they are shown The largest backscatter in strata RA and RB are from the BACK mark-type. For the Rockgarden, the largest backscatters are from orange roughy schools.**

Appendix 1: Generic mark-stratum analysis for acoustic surveys

The following gives an account of the estimation of abundance when using mark-classes and strata for a generic deepwater species, called DEEPWATER in what follows, with code XXX. In general, biomass is estimated separately for the flat and seamounts. For the former, the acoustic data are classified into mark-types where marks equate approximately to echogram images. The mark classification schemes are a result of analyses of concurrent data collection from trawling and the echogram of the mark trawled on. The biomass of DEEPWATER in each mark-type is estimated from the backscatter for each mark, the proportion by number of DEEPWATER in that type (estimated by trawling), the mean acoustic cross-section (target strength) for the mix of species in that mark-type, and the mean weight of the DEEPWATER in that mark-type. These are then summed over each stratum, scaled up by the stratum area, and the results are then summed over all strata.

Most seamounts (or isolated plumes) are surveyed using star transects and the biomass on each mount is estimated using the method of Doonan et al. (2003). If there are too many seamounts to survey, then seamounts are grouped into classes and a random selection within each is surveyed. The mean biomass is calculated for each seamount class, multiplied by the total number of seamounts in that class, and summed over all classes to give total biomass for all seamounts in the trawl survey area.

Flat

For the flat ground, the acoustic data are classified into types of 'marks' (mark-type). For stratum, i, the abundance of DEEPWATER in mark-type m, is given by:

$$B_{i,m} = \frac{\overline{abscf_{i,m}}}{\overline{\overline{\sigma}}_{bs,m}} \times p_{XXX,m} \times area_i \times \overline{w_m} \qquad (1)$$

where $area_i$ is the area of the stratum, $abscf_{i,m}$ is the mean backscattering (fish.m^{-2}), $\overline{\overline{\sigma}}_{bs,m}$ is the mean tilt-averaged acoustic cross-section for the species mix, $p_{XXX,m}$ is the proportion of DEEPWATER by number, and $\overline{w_m}$ is the mean weight of a DEEPWATER. The mean tilt-averaged acoustic cross-section for the species mix is given by:

$$\overline{\overline{\sigma}}_{bs,m} = \sum_{j}^{species} p_{jm} \overline{\overline{\sigma}}_{bs,jm}$$

where j indexes each species, p_{jm} is the proportion in numbers of species j in the mix; and $\overline{\overline{\sigma}}_{bs,jm}$ is the mean tilt-averaged cross-section for species j (which depends on the length distribution of that species in mark-type m).

Mean cross-section, $\overline{\overline{\sigma}}_{bs,jm}$, is given by $\sum_l f_{XXX,m,l} 10^{\frac{\langle TS \rangle_{XXX}(l)}{10}}$ for DEEPWATER and by $\sum_l f_{j,m,l} 10^{\frac{\langle TS \rangle_j(L_{jm})}{10}}$ for other species, where $f_{XXX,m,l}$ is the fraction of DEEPWATER in mark-type m with length l and $f_{j,m,l}$ is a similar fraction for the j^{th} species, $\langle TS \rangle_j(l)$ is the tilt-averaged or in situ target strength-to-length function for species j, L_{jm} is the mean length of species j in mark-type m, $\langle TS \rangle_j(l) = a_j + b_j \times \log_{10} l$ and a_j and b_j are constants.

The mean tilt-averaged acoustic cross-section is given by:

$$\overline{\sigma}_{bs} = \int \sigma_{bs}(\theta) g(\theta) d\theta$$

where θ is the tilt angle (in the pitch plane only), $\sigma_{bs}(\theta)$ is the acoustic cross-section as a function of θ, and $g(\theta)$ is the probability of a fish being at an angle θ. Tilt-averaged target strength, $\langle TS \rangle$, is given by $10 \log_{10} \overline{\sigma}_{bs}$.

The lengths, mean weights, species composition, and proportion of DEEPWATER in the population are obtained by trawling during the survey.

For several strata (*strata*) and mark-types (*marks*) the total abundance, B_{Flat}, is given by:

$$\sum_{i}^{strata} \sum_{m}^{marks} B_{i,m}$$

Seamounts

The total abundance for all seamounts (*Hills*), B_{Hills}, is given by:

$$\sum_{h}^{Hill-classes} N_h \overline{B}_h ,$$

where $\overline{B}_h$ is the mean DEEPWATER abundance on seamounts in the h-th seamount class, and N_h is the number of seamounts in the class. Each seamount abundance is estimated using Eequation 1 above, where i indexes the seamount and there is only one mark-type used (plume = m). A 'star' transect pattern is used to survey most seamounts, and for this method the mean backscatter, $abscf_{i,plume}$ in $B_{i,plume}$ is over-sampled in the centre of the star and under-sampled at the edges. As most marks are usually entered in the middle of the star with relatively large sections of the transect outside the mark, the mean is biased high in relation to the area (taken from the two ends of the transects). To compensate for this effect, the mean backscatter for each transect is a weighted mean over all segments (10 pings in length) of the transect where the weights are proportional to the distance from the fifth ping in the segment to the centre of the star.