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Target strength and counts of orange roughy in the background layer, Northwest Hills area, Chatham Rise, June–July 2002

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Final Research Report for
Ministry of Fisheries Research Project ORH2001/01
Objective 1

National Institute of Water and Atmospheric Research

20 January 2004

Final Research Report

Report Title Target strength and counts of orange roughy in the background layer, Northwest Hills area, Chatham Rise, June-July 2002

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1. **Date** 30 November 2003

2. **Contractor** NIWA

3. **Project title** Estimation of the abundance of orange roughy in selected areas

4. **Project code** ORH2001/01

5. **Project leader** Ian Doonan

6. **Duration of project**

   Start Date: 1 March 2002
   Completion date: 30 November 2003

7. **Executive Summary**

In this report, orange roughy in situ target strength data from 1999, 2000 and 2001 are re-analysed together with new data collected under this project on voyage TAN0208. In addition to rate-of-change-of-phase (RCP) as used in previous work, orange roughy behaviour and spatial distribution were also used to select echoes. The results support the current "NIWA" target strength relationship of target strength = $-74.34 + 16.15 \log_{10}$ (length) and show that the "CSIRO" relationship probably includes low target strength scatterers other than orange roughy.

The 2002 survey included a trial of an alternative approach to finding the biomass of orange roughy in the "background" outside of spawning aggregations using counts of individual targets to estimate number density. Altogether, 22 count transects were steamed with a mean length of 1.8 km. A trawl to collect orange roughy length and gonad stage data was made along each transect track. Target classification was based on target strength and RCP derived from the target strength study and the lengths of the orange roughy in the associated trawl catches. A statistically significant correlation was found between numbers of orange roughy caught in the trawls and the counts in the –200 to 0 deg/m RCP band, suggesting that a relative abundance estimate could be derived. The relative estimates are converted to tentative upper and lower estimates of absolute abundance. The results, which involve only a small number of short transects, show substantial promise for surveying dispersed roughy.

8. **Objectives**

This report updates and re-analyses orange roughy in situ target strength information and describes the outcome of the echo-counting survey on the flat, forming part of Objective 1 of Project ORH2001/01. Objective 1 was "To estimate the abundance, with a target coefficient of variation (c.v.) of the estimate of 20–30%, of orange roughy in the [Northwest hills and flat] area on the Chatham Rise (ORH 3B).

9. Introduction

All orange roughy ("roughy") acoustic estimates of biomass for New Zealand have been made using the echo-integration method and for this estimates of the target strength of roughy and species associated with roughy are essential. Although considerable progress has been made in estimating roughy target strength, particularly the introduction of rate-of-change-of-phase (RCP) (Barr et al. 2000, Barr & Coombs 2001, Barr & Coombs submitted), there remains significant uncertainty. The present project included collection of more in situ data and further target strength modelling work. The latter is a separate objective (Objective 3) and is documented elsewhere (Macaulay 2003).

Associated with target strength in this project is an attempt at an alternative way of estimating biomass by counting individual fish. The first acoustic surveys assumed that, during spawning, all roughy were in dense aggregations (Do & Coombs 1989). However, this has been found not to be true with estimates of roughy in "background" layers surrounding spawning aggregations of up to 30% of the total (Bull et al. 2000). Whilst the echo-integration method works well with large single species aggregations, in the background layers, where low-target strength roughy are mixed with high-target strength species such as Johnson's cod, echo-integration performs poorly (Kloser et al. 2000, McClatchie & Coombs 2003). Target strength studies on roughy and oreos showed that individual scatterers could usually be resolved outside of the dense aggregations (Kloser et al. 1997, McClatchie & Coombs 2000, Coombs & Barr 2002) and the work described here is an attempt to exploit this to estimate fish number density by counting individual targets using target strength as a classifier rather than directly in the biomass estimate. The survey formed part of a wider survey of the flat areas surrounding the Northwest Hills on the Chatham Rise, which combined echo-integration, trawl and echo-counting methods.

10. Methods

The target strength data were mostly collected during previous roughy and oreo surveys and the count data were collected during the survey of the Northwest hills area carried out in June and July 2002 with *Tangaroa* (voyage TAN0208) and *Ocean Ranger* (ORA0201).

10.1 Target strength

As noted in the introduction, there remains some uncertainty about roughy target strength. There are other scatterers of closely similar target strength in the same habitats as roughy and it has so far not been possible to clearly identify any particular echo. When seen from a great range, roughy form characteristic schools and those on hills often show striking "finger" (multiple parallel sinusoids in Cordue's 1996 terminology) structures (Figure 1). However, it is not possible to unambiguously resolve individual fish at long ranges and positioning a transducer close enough to achieve this affects the behaviour of the fish such that the schools become denser and the shape changes. Nevertheless, dense marks are often surrounded by separate echoes that show finger structures. Previous NIWA analyses of in situ target strength data have focussed on the selection of individual targets on the basis of characteristics such as the amplitude in the four beams of the transducer and phase relationships (Barr & Coombs 2001) but have not included fish-behaviours such as avoidance (diving) and position relative to aggregations or the seabed. In situ data from roughy and oreo surveys in 1999 (TAN9908), 2000 (TAN0008; TAN0011) and 2001 (TAN0109; TAN0117) were revisited and screened for large associated catches of roughy, the characteristic finger structures of Figure 1 and the heavy "column and sinusoid" marks (Cordue 1996) shown in Figure 2. Kloser et al. (2000) also screened for the latter in their analysis of target strength in the Spawning Box (see also Kloser et al. 2002). In addition they checked for signs of diving behaviour and that has also been included in this analysis. Some nominally non-roughy areas were also considered for comparison although roughy are ubiquitous on the Chatham Rise and along the East Coast in the 900–1200 m depth zone (Anderson et al. 1998). Otherwise, similar individual echo criteria to those used in Barr & Coombs (2001) were used and RCP extracted along with target strength corrected for position in the beam. Echoes were selected on width (3–9 samples), variability of angle of arrival between quadrant pairs (standard deviation of 0.25°) and position in the beam (±3.5°). New data collected during the survey (TAN0208) associated with the present project were analysed in the same way.

10.2 Acoustic equipment

All of the data were gathered using NIWA's Computerised Research Echosounder technology (*CREST*) (Coombs et al. 2003). The data from 1999 to mid-2000 (TAN9908; TAN0008) were collected with a standard *CREST* deep-towed body, as described in Barr & Coombs (2001), intended primarily for biomass survey work. After mid-2000 (TAN0011; TAN0109; TAN0117; TAN0208) data were collected with a deep-towed 'frame' system designed primarily for in situ target strength work. This system consists of an open, stainless steel structure with underwater electronics and a Simrad ES38DD split-beam transducer as described in Barr et al. (2002). Our standard target strength settings were used, the system transmitting a short single-frequency pulse (0.32 ms at 38.156 kHz) with the received data being filtered, complex demodulated, decimated, corrected for spherical spreading and sound absorption with a $40\log_{10}R+2\alpha R$ time varied gain and stored. The interval between transmissions was 1.4 s, the filter bandwidth 3.1 kHz, the initial sample rate 62.5 kHz. Two decimated sample rates were used: 12.5 kHz and 15.625 kHz. For target strength, the height of the towed body (or frame) above the sea floor varied with location between 50 and 150 m and the speed of the vessel between 0.5 and 2 knots. For counting, the frame was towed at about 1.5 knots and about 80 m above the sea floor at depths of between 800 and 1100 m.

The systems were calibrated in the large tank at Greta Point before and after the survey and several deep-drop calibrations were carried out during the various surveys. The calibrations followed the approach described in 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. For the present project, the gain of the target strength system at a range of 1 m, G_{ts}, was 1045; the in-circuit voltage at the transducer terminals for a target of unit backscattering cross-section at unit range, V_T, was 243 V and the overall calibration constant, C_{ts} was 254244. For the other surveys the calibration constants are listed in Table 1, which also includes references to more detailed calibration information.

Table 1: Target strength calibration constants, C_{ts}, for the in situ data used for target strength estimation and counts. The reference indicates where detailed calibration information can be found.

Voyage	C_{ts}	Reference
TAN9908	406269	Barr & Coombs (2001), Coombs et al. (2003)
TAN0008 (Plume)	406269	Barr & Coombs (2001), Coombs et al. (2003)
TAN0008 (Camerons)	730030	Barr & Coombs (2001), Coombs et al. (2003)
TAN0008 (Other hills)	365015	Barr & Coombs (2001), Coombs et al. (2003)
TAN0011	287906	Barr et al. (2002)
TAN0109	276000	Coombs & Barr (2002)
TAN0117	653858	Barr et al. (2002)
TAN0208	254244	This report, Section 10.2

10.3 Count survey design

A conventional stratified random design was used and each count run was coupled with a trawl over the same track. The count runs followed a randomly chosen section of an echo-integration transect. They were of an hour's duration and about 1.8 km long.

10.4 Count analysis

Analysis involved developing an approach to target classification followed by the actual process of counting.

When this project was first proposed, it was thought that the "roughy arc" in target strength–RCP plots (Barr et al. 2000) would be an adequate classifier on its own. However, subsequent work (Barr & Coombs submitted) has shown that other types of scatterers can generate similar patterns; consequently, other criteria have also been considered. Aggregations of roughy are known to be affected by the presence of towed vehicles and other objects (Koslow et al. 1995) and it was considered possible that any roughy would be more likely to be near the sea bed than higher up in the water column. Therefore position relative to the bottom was investigated.

For the target classification aspect of counting, targets were screened using the same criteria as for target strength estimation (Section 10.1), hereafter referred to as "selected" targets. However, whilst it is desirable to exclude possible multiple echoes from the analysis when estimating target strength, it is not when counting since this would underestimate the density. Consequently, for counting, a second set of counts was made in which targets were screened only for angle in the beam ("raw" targets). Counts were accumulated with reference to the sea floor in depth slices. The beam volume, V, for the slice was calculated from $V = \frac{2\pi}{3}(1-\cos\theta)(r_1^3 - r_2^3)$ where r_1 and r_2 are the two ranges from the transducer delimiting the slice and θ is the beam half-angle (3.5° in this case). Together with the counts, the volumes were used to estimate number density.

11. Results

11.1 Target strength

Over the voyages considered, more than 250 data files have been collected for in situ target strength analysis or with target strength settings. These contain around 20 GB of data and it has not been possible to screen all of them in an exhaustive fashion. Instead a representative selection of files meeting the criteria in Section 10.1 and covering all the roughy areas for which we have data has been made. The areas included are:

- Chatham Rise Spawning Box: plumes (flat).
- Chatham Rise Northwest Hills: Graveyard; Scroll; Morgue; Zombie; "out-migration" (flat).
- Chatham Rise Northeast Hills: Smiths City; Camerons; Erebus.
- Chatham Rise Eastern Hills: Cotopaxi.
- Mid-East Coast: Rock Garden (flat); Paul's Spot (flat).
- South Chatham Rise Hills: Hegerville.
- South Chatham Rise OEO 4A (flat).

The Spawning Box has the most extensive areas of roughy at high density and Figure 3 shows an echogram of characteristic roughy plume marks from a target strength run (TAN0008, file 7). The image has been corrected for the towed body depth and shows the true depth of echoes relative to the surface. In addition to the obvious heavy roughy marks, the echogram shows several layers of varying thickness that appear related to the roughy marks. In particular there is a distinct lower bottom-oriented scattering layer that extends up to about 70 m above the bottom. Figure 4 shows the relationship of target strength and height above the sea floor for the data in Figure 3. In the upper panel, targets were extracted with the criteria used for counting (position in the beam only) and in the lower, the criteria for target strength estimation. The plots are contour maps of $\log_{10}$ of numbers of targets based on 1 m height, and 0.5 dB target strength bins. The upper panel suggests a band of higher target density spanning a broad target strength range at around 40 m and high density spots of scatterers of about –53 dB target strength at 30 m and –50 dB close to the bottom. However, many of the targets are at considerable range from the transducer and represent responses from more than one scatterer and so their target strength will be over-estimated. This will tend to bias target strengths progressively to the right in the figure as they get closer to the bottom and there is some evidence of this happening. The plots do not compensate for the increasing beam volume in any way and so there will also be a steady increase in numbers from the top to the bottom of the figure. The lower panel has an order of magnitude fewer targets but more clearly shows –50 dB targets extending all the way up the water column with high density spots around 40 m and also a generally greater number of high target strength scatterers closer to the sea floor. In this case there is no bias in the target strength values but there certainly is in the numbers, which now get less, closer to the sea floor, because of increasingly overlapping echoes.

All the files selected show some equivalent to the bottom layer of Figure 3 and since this contains the majority of the –50 dB targets a height cut-off based on layer structure has been used in all subsequent analyses.

Target strength and RCP contour maps are shown for all the selected locations in Figure 5. The colour-bar is not shown in this or subsequent maps but the colours have a similar meaning to those in Figure 4 where white represents low numbers progressing through yellow, orange, red and black with increasing numbers of targets. The top row and the bottom row are from flat-seabed areas and all the rest are from hills. The bottom row had the smallest associated roughy catches. The patterns shown in Plume 2, Plume 7 and Graveyard are very similar and these all came from comparable column and sinusoid echograms (Figure 3). However, Graveyard and Morgue lack the strong mark at about –53 dB target strength. The other hills had less strongly defined roughy marks but usually some traces of fingers and strong marks close to the sea-floor. The out-migration mark close to Graveyard also featured fingers but was less compressed than a typical roughy mark, which allowed many individual echoes to be resolved. It has a much more consistent structure than any of the other plots which are quite different. Some plots feature high target strength scatterers, those around –42 dB are probably smooth oreos, which featured in most catches (Zombie, Hegerville, and OEO 4A flat). Paul's Spot had a high concentration of targets around –33 dB which were probably Johnson's cod.

All of the plots feature the roughy arc spanning an RCP range of –100 to +100 deg/m to a greater or lesser extent. The right-hand end usually shows some sign of a descending pattern tending back towards the left (the tail of the "question-mark" of Barr & Coombs submitted). Most show a strong target strength signal at between –54 and –52 dB which shows little lateral spread in RCP and hence is probably produced by something with an air-filled bladder such as a myctophid (Barr & Coombs submitted). The latter are hereafter referred to as "myctophids". Graveyard and Morgue are notable exceptions and do not have this signal. The Graveyard out-migration looks distinctly different from all the others. It shows a similar roughy-like signal in the RCP range –50 to +50 deg/m to Graveyard itself, but lacks the right-hand "lump" between –50 and –60 dB target strength and has gained one between –60 and –70 dB.

A representative subset of the data in Figure 5 is shown in Figure 6 and in these a quadratic function has been fitted to the peaks in the region of the roughy arc to try to capture the shape of the latter. In previous work (e.g., Barr & Coombs 2001) the target strength–RCP scatter was evaluated by eye and this is a first attempt at a more objective approach. The coefficients for these functions are shown in Table 2 together with the target strength and RCP at the maximum (or minimum in the case of Hegerville). Target strength histograms for these data sets are shown in Figure 7 in which Graveyard in particular shows a clear roughy mode. Matching length-frequency histograms are shown in Figure 8.

Table 2: Coefficients for the quadratic functions fitted to the roughy arc in Figure 6 together with the target strength (TS) and RCP at the maximum (minimum in the case of Hegerville).

Area/data set	Square$\times 10^{-3}$	Linear	Constant	TS	RCP
Plume 7	–0.0560	–0.0014	–49.3	–49.3	–12.1
Out-migration	–0.0111	–0.0106	–49.9	–47.4	–476.5
Graveyard	–0.0626	–0.0052	–49.5	–49.4	–41.3
Scroll	–0.0075	–0.0145	–49.6	–42.5	–966.6
Morgue	–0.0393	–0.0072	–49.3	–49.0	–91.2
Smiths	–0.0894	–0.0012	–49.6	–49.5	–6.7
Cotopaxi	–0.0915	–0.0051	–49.8	–49.7	–27.9
Hegerville	+0.0702	+0.0014	–50.6	–50.6	–9.9
Rock Garden	–0.7363	–0.0231	–48.6	–48.4	–15.7

The RCP values for the maximums of the quadratic functions for the out-migration and Scroll fall well outside the nominal range of the data but the others are all close to zero. However, for Hegerville the fitted arc is upside down and the function is a minimum. The pattern is more confused than in the others with more high-target strength species. The putative roughy target strength is lower than the others but higher than any of the myctophid signals. The target strength values from Table 2 excluding the out-migration and Scroll are plotted in Figure 9 together with the relationship currently used for roughy stock assessment, which is based on the live fish measurements of McClatchie et al. (1999) adjusted to the in situ analysis of Barr & Coombs (2001). As noted earlier, the data used by the latter overlap with the data used here. The relationship is $TS = -74.34 + 16.15 \log_{10}(\text{length})$ where TS is target strength. The points that lie furthest from the line are Rock Garden and Morgue, whilst Hegerville falls more or less on it. The target strengths in Table 2 are likely to be over-estimates since they are the maximums of the roughy arc. In principle a mean over some range of the arc would be better, but it is not clear what range to take. The large majority of the targets in Figure 6 have a RCP within ±100 deg/m and if the targets for Graveyard, for example, were uniformly spread within this range, the mean target strength would be –49.9 dB rather than –49.4 dB, a difference of only 0.5 dB. Given that the true distribution is poorly known and the differences are only likely to be small, the maximums have been taken as "reasonable" estimates. These values have not been used to update the length–target strength relationship since the in situ results used for this were based on means across the roughy arc and therefore account for the slight bias above.

11.2 TAN0208 data

The primary count survey took place between 26 June and 6 July 2002 and there were 18 transects covering strata 1, 2, 3 and 4 of the echo-integration survey (Doonan et al. 2004). A further 4 drops were made in the out-migration corridor to the west of Graveyard from 15–17 July 2002. Three target strength drops were made on Graveyard on 25 June but the hilltop was in view only briefly and there were no distinctive roughy marks.

11.3 Count classification

Initially, the count transects were taken in isolation and various classification schemes considered based on partitioning the combined RCP–target strength data for all transects into a number of somewhat arbitrary regions. However, with only limited ground-truth data this was abandoned in favour of an approach more directly derived from the target strength work and based on the roughy arc. The most clear-cut target strength data came from Graveyard and Morgue (Figures 6 and 7, Table 2) and were collected in the same general area as the count data. The linear term (Table 2) of most of the relationships is close to zero and a square term of -0.5×10^{-4} gives a curve midway between Graveyard and Morgue. Table 3 summarises the count transect and associated orange roughy trawl catch data. The minimum and maximum fish lengths from these were used to establish the constant term of the quadratics used to delimit the roughy arc. The equivalent target strengths for these were estimated from the length–target strength relationship in Section 11.1 above. RCP–target strength plots for all the Table 3 transects are shown in Figures 10 and 11 together with roughy arcs based on the fish lengths. The latter generally take in a broad swath of echoes including some of the descending part of the question mark of Barr & Coombs (submitted), which features prominently in all the transects except 118. The arcs also mostly include a very strong myctophid response. These arcs really only delimit a zone in which roughy may occur since the true "arc" is generated as roughy increase in size and the trajectory of this is more a curved zig-zag (Figure 10.8 in Barr & Coombs 2001), which "bounces" between RCP limits of around ±600 deg/m. This shape is based on a very simple model of roughy anatomy and real roughy may differ to an unknown degree. Further, the catches of roughy were mostly very small and the lengths may not be representative of the population. The classification is investigated further below with respect to the count results.

Table 3: Summary of the orange roughy catch and length data for the trawls associated with the count transects

Trawl number	Transect file number	Stratum	Catch weight (kg)	Catch number	Lengths (cm)			
					Mean	Standard deviation	Minimum	Maximum
Snapshot 1								
16	64	1	6.5	23	19.1	4.1	12.1	31.9
17	67	1	29.5	36	27.3	6.5	10.7	37.7
18	68	1	107.7	119	28.7	5.3	11.9	37.9
19	69	1	55.2	61	28.7	5.6	13.3	40.3
20	71	1	34.9	64	24.4	4.1	14.7	33.5
21	72	1	9.9	10	29.2	8.0	14.3	38.2
24	73	2	12.5	32	20.3	5.9	12.3	35.5
25	74	2	44.8	53	28.0	5.3	20.0	38.4
26	77	2	3.7	10	21.4	4.0	16.2	28.6
27	79	2	3.7	5	25.8	6.9	18.6	37.3
28	80	2	71.5	79	29.0	4.4	19.3	42.4
45	114	3	156.8	135	31.2	3.9	18.5	39.6
46	115	3	22.3	26	28.1	4.3	19.6	34.8
47	116	3	49.7	59	28.4	4.3	19.1	38.6
48	117	3	49.7	50	30.0	4.4	14.5	37.0
49	118	4	174.8	144	32.2	3.7	19.5	39.6
50	119	4	16.6	11	34.8	3.9	26.5	39.9
51	120	4	17.7	18	30.7	2.9	22.7	34.6
Snapshot 2								
105	163	out	32.5	31	30.5	4.6	21.3	38.1
106	165	out	45.4	52	28.3	6.1	14.1	37.3
122	167	out	212.5	158	34.3	4.0	17.8	42.4
125	168	out	419.6	301	34.6	2.8	25.8	41.4

11.4 Counts

The proposal for this work envisaged producing an absolute abundance estimate based on positively identifying all (or at least, most) targets. However, the target strength and classification results show that at present that is not practicable and a more indirect approach is necessary. Densities were first investigated using selected targets, mainly because both target strength and RCP are blurred by overlapping echoes for raw targets. The densities will therefore tend to underestimate the true roughy numbers but should be proportional to them (i.e., they will give an estimate of relative number density).

The average height of the towed body above the sea floor was about 70 m giving an effective data range of 60 m. Estimates of number density were made initially from targets selected using the target strength criteria. These all came from the roughy arc as outlined above but were broken down into 10 m height-above-bottom (hereafter "height") slices and 100 deg/m RCP bins with the aim of investigating the effects of height and the question mark echoes.

The densities estimated for the transects for each of the depth–RCP categories were correlated with the numbers of roughy caught in the associated trawls (Table 3). The resultant matrix of correlation coefficients is plotted as an image in Figure 12. The colour scheme is the same as that used for the contour maps and represents the absolute value of the correlation coefficient so that darker colours signify high correlations and light, low. The degrees of freedom are 20 for which a coefficient of greater than $|0.423|$ is statistically significant at the 5% level. The numbers in white in Figure 12 are significant positive correlations and the black, non-significant ones (there were no significant negative correlations). Assuming the high correlations indicate roughy, this shows a pattern of roughy extending through the whole water column with a particular focus at around 40 m (a similar height to that found in the target strength investigation, Figure 4). The RCP response suggests bands of strongly interfering, non-roughy targets between 0–100 and 100–200 deg/m. The former corresponds to the myctophid targets and the latter the question mark descending arm (see Figures 10 and 11) and there appear to be more interfering echoes in the –300 to –200 deg/m band. From Figures 10 and 11 the putative roughy targets can be seen to be to the left of the myctophid response where there is usually some trace of an arc. However, the myctophid target strength is the same or higher than the roughy.

Although the correlations are statistically highly significant, there is a great deal of scatter. The upper panel of Figure 13 shows a scatter plot for the whole water column and the –100 to 0 RCP band of Figure 12 whilst the lower panel shows a similar plot for the region around –40 dB (–42 to –38 dB). Echoes in this range are prominent in many of the transects in Figures 10 and 11 and are probably oreos and rattails. The correlation is not significant in this case.

The above results suggest that the count data can be used to derive a credible relative abundance index for roughy; can we derive an absolute measure? The relative index is based on heavily selected targets, which can be presumed to have a high proportion of roughy. Clearly many roughy targets in the roughy arc have been discarded, but the distribution in the arc will depend on the size distribution of the fish and almost certainly will not be uniform or random. The selection process also discards potential roughy marks in a way that is likely to depend on the behaviour of the fish. If dispersed roughy tend to keep their distance from each other and other fish, few roughy would have been discarded; on the other hand, if they associate closely, then most might have been.

The distribution of density across the arc with respect to RCP for the selected data is shown in Figure 14. This is dominated by the myctophids in the 0–100 deg/m band which presumably also occur to some extent in the roughy band. On the other hand there is no way of knowing what proportion of the 0–100 band is roughy, although, since there is no correlation with roughy catches, it is presumably small. Densities outside of the –200 to +200 deg/m range are very low so a reasonable assumption is that the selected targets in the –200 to 0 band give a minimum estimate of roughy numbers.

As noted earlier (Section 10.4) selection discards many targets and the intention was to use all (raw) targets for counting. Raw targets produce very similar (but fuzzier) patterns to those in Figures 10 and 11. They also produce comparable height–RCP responses as can be seen from Figure 15, which is the raw equivalent to the upper panel of Figure 12. In this case however, none of the correlation coefficients are statistically significant. Raw targets from the RCP band –200 to 0 deg/m are taken to be an upper estimate of roughy numbers. The raw densities are plotted against the selected densities in Figure 16. The correlation is statistically significant at the 1% level but there is clearly a lot of scatter.

The densities for the transects are converted to estimates of biomass in Table 4 for the four strata of snapshot 1. The densities are applied to a layer 0–60 m above the bottom and multiplied up by the area of the stratum. Numbers of spawning females are estimated from the numbers caught in each stratum. Numbers are converted to weights using the average fish weights for the stratum; for the "all" category all the weights of all the roughy caught were used to estimate biomass whilst for the spawning females only their own weights were used. The c.v.s reflect the between-transect variation in the density estimates only. Biomass estimates for spawning females from the echo-integration survey (Doonan et al. 2004) are included for comparison.

Table 4: Biomass estimates (t) based on number density for the four strata of snapshot 1. "All" is for all echoes counted in the selected and raw categories respectively. "SF" is for spawning females only for selected and raw categories and for the estimates made by echo-integration (note, the integration estimate for stratum 3 excludes trawl 45). The numbers in brackets are c.v.s (%) for the underlying density estimates.

Stratum	Area (km^2)	All selected	(c.v.)	All raw	(c.v.)	SF selected	(c.v.)	SF raw	(c.v.)	SF integrals
1	658	3 300	(71)	27 400	(69)	550	(71)	4 500	(69)	1 100
2	1059	5 200	(52)	20 500	(45)	900	(52)	3 500	(45)	1 600
3	512	4 200	(62)	22 500	(87)	620	(62)	3 300	(87)	3 800
4	444	5 000	(124)	13 500	(126)	1 900	(124)	5 100	(126)	3 800

12. Discussion

12.1 Target strength

The results described here support previous NIWA work and show that the current roughy length–target strength is consistent with in situ observations in and about roughy aggregations from a wide range of locations. Although the relationship is based on measurements made directly on roughy (McClatchie et al 1999), the intercept has been adjusted using in situ results from targets that cannot be individually positively identified as roughy, consequently some uncertainty remains. However, the results presented here further strengthen the circumstantial case.

In stock assessments in New Zealand, two alternative estimates of orange roughy target strength are generally used: one derived from the work of NIWA as above, and the other from CSIRO. The latter is usually included as a case in the sensitivity analysis but the working group takes a mean of the NIWA and CSIRO values in selecting the biomass estimate to use in stock assessment so that both are given equal weight. The CSIRO relationship is the same as the NIWA one except that the intercept is based on in situ data from the Spawning Box collected by CSIRO in 1998 and analysed as described in Kloser et al. (2000). CSIRO's analysis selects the area within an echogram from which targets are taken using their multifrequency capability but does not select individual targets in the manner available to NIWA by using RCP. They take a mean over quite a large target strength range (–60 to –46 dB), which includes the myctophid targets seen in Figures 5 and 6 in the Plume areas. There seems little justification for continuing to use the CSIRO target strength relationship in stock assessments and a better sensitivity case would be to use the range of values evident in Figure 7 reflecting a variation in the target strength–length relationship intercept of ±1 dB.

The re-working of past data in this report was by no means exhaustive and more insights would almost certainly be gained from further analysis. In particular, a profitable approach would be to combine the in situ data with simulated target strength distributions in the same way as for oreos (Coombs & Barr in press) using the results of Objective 3 of this project (Macaulay 2003). For roughy, the model will allow phase as well as target strength responses to be generated so the roughy arc could be explicitly included in the fit.

The result from the out-migration is worth following up in that the roughy were reasonably well separated rather than forming dense aggregations of overlapping echoes. The data here were not collected with target strength estimation in mind and there was no target trawling on marks. Future in situ target strength data should aim to exploit out-migration situations with appropriate trawl sampling.

12.2 Counts

The echo counting approach was proposed as a way of avoiding the problem of roughy being masked by higher target strength fish. However, without positive identification of individual roughy targets a new problem is apparent: the presence of scatterers of very similar target strength ("myctophids") whose identity is unknown, and whose numbers relative to roughy are known only indirectly (e.g., from Figure14).

Nevertheless, there is a positive correlation between roughy catches and the acoustic data. The correlation coefficients for all the transects and for snapshot 1 only, are statistically significant; for snapshot 2 the correlation is still quite high at 0.54 but there are only 2 degrees of freedom. The correlations could be fortuitous, but the fact that they are consistent over the two snapshots, which surveyed different phases of the roughy life cycle, suggests not. As noted earlier, roughy are the deep-water species most commonly caught on the Chatham Rise and they were present in all of the trawls in this survey. They are the only species for which this is true. Consequently, they must account for some proportion of the echoes recorded.

The density results yield a relative abundance index directly, however, turning this into an absolute estimate is much more difficult because of the unknown interfering targets. Even so, the results in Table 4 mostly bracket the echo integration results and are not inconsistent with them.

The analyses presented here are very much a first cut and could probably be improved upon. An alternative approach for example, might be to locate the "centre of gravity" of the interfering echoes in each transect and subtract them. Some of the target strength data collected from the Mid East Coast and the South Chatham Rise are comparable to the count data but show different patterns of interfering echoes (Figure 5). These could be treated in a similar fashion and might help to confirm the correlations.

This report has focussed on the target identification aspects of counting; however, it is worth commenting more broadly on the approach. Because the survey was essentially over flat bottom (the steepest bottom slope angle was less than 1.5° and that was for less than half of one transect, the rest was less than 0.3°) there was essentially no bottom shadowing. With a pulse of only 0.32 ms, the bottom effect from this source was only 0.24 m. With a short range

(70 m) the effects of the motion of the frame were negligible (between transmit and receive the transducer angle changed by less than 0.5° at worst) and in any case any effect would be indirect by underestimating the individual target strengths. With the transducer used, the diameter of the beam on the sea floor was about 9 m and the total volume sampled per ping about 1400 m^3, but the vertical distribution information was preserved. The beam vertical cross-section area (300 m^2) is similar to the wing tip area of the standard roughy trawl, except that is aligned vertically rather than horizontally, and of course, it does not have to be pulled up to empty the catch.

Better knowledge of the detailed scattering properties of roughy (e.g., from modelling) and identifying the "myctophids" would greatly improve target classification. The former should be possible as a desktop study using the methods developed under Objective 3 of this project (Macaulay 2003). The latter will require sampling at sea with a suitable fine-mesh net. Alternative ways of classifying echoes using broadband techniques such as chirps (Barr 2001, Barr & Coombs 2001) would potentially revolutionise the approach. Certainly, the results presented here which involve only a small number of short transects, show substantial promise for surveying dispersed roughy.

13. References

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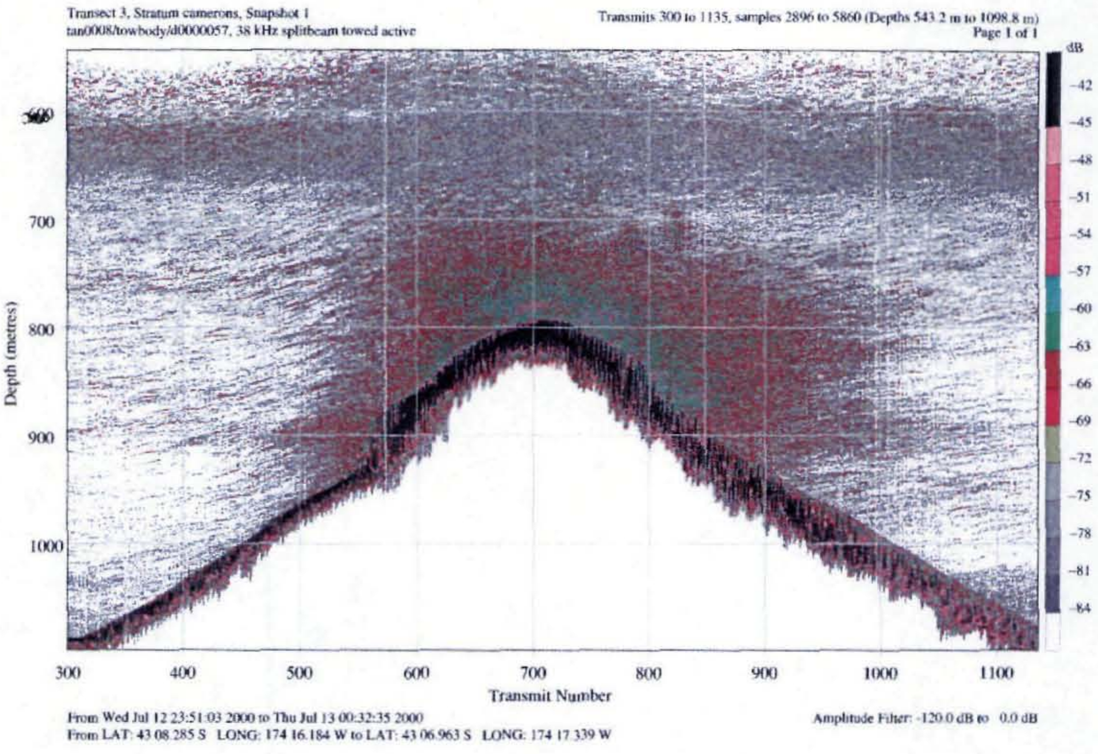

Figure 1: Large orange roughy aggregation on Camerons (Northeast Chatham Rise) showing horizontal "fingers". Towed body data at a range of 300–500 m from the bottom, recorded with survey settings ("20logR" TVG).

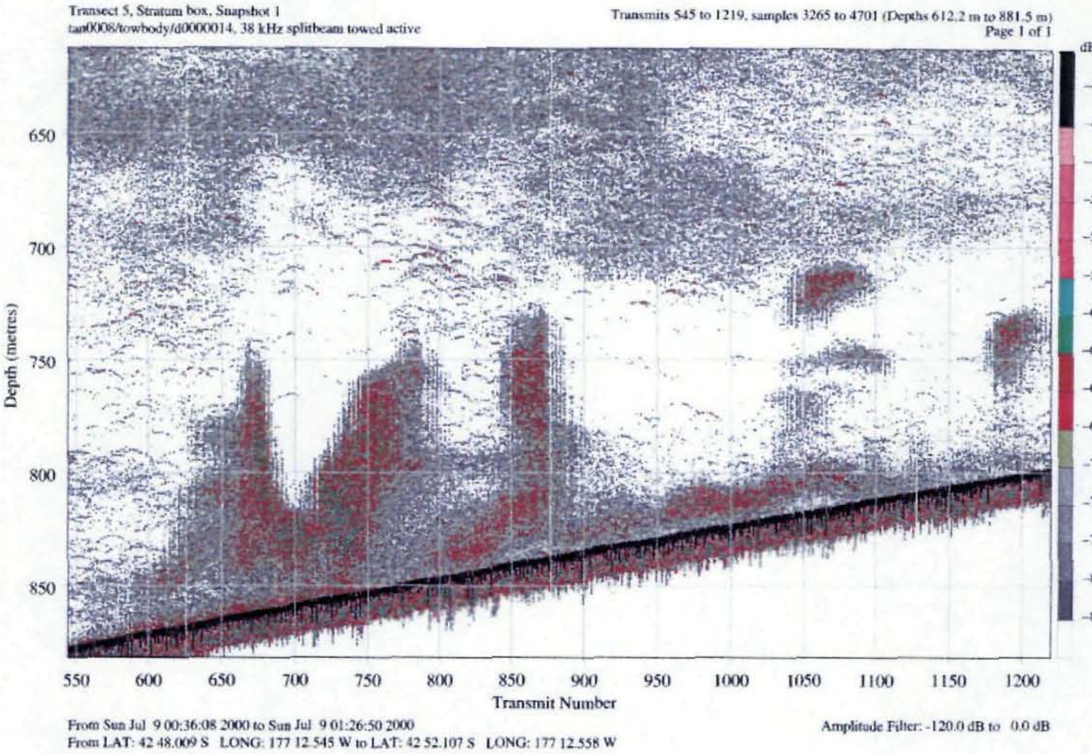

Figure 2: **Large orange roughy aggregations in the Spawning Box (Northeast Chatham Rise) showing "column and sinusoid" structures. Towed body settings as in Figure 1.**

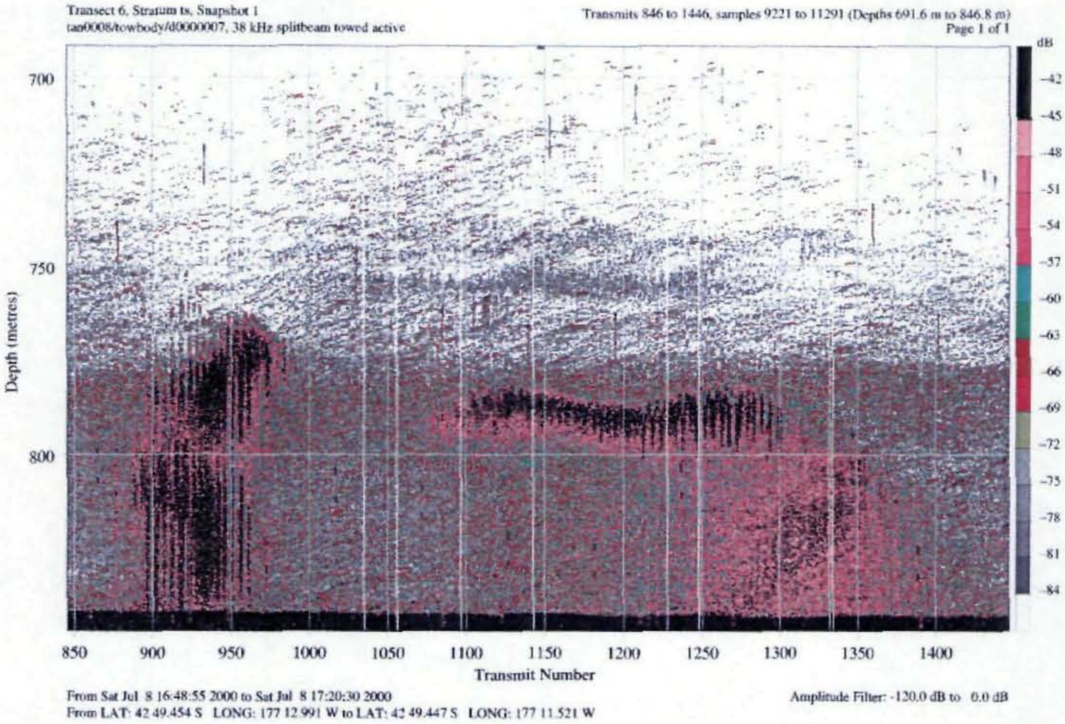

Figure 3: Large orange roughy aggregations in the Spawning Box showing "column and sinusoid" structures. Towed body about 150 m above the sea floor, which is the black line at the bottom of the figure. Recorded at close range with target strength settings ("40logR" TVG).

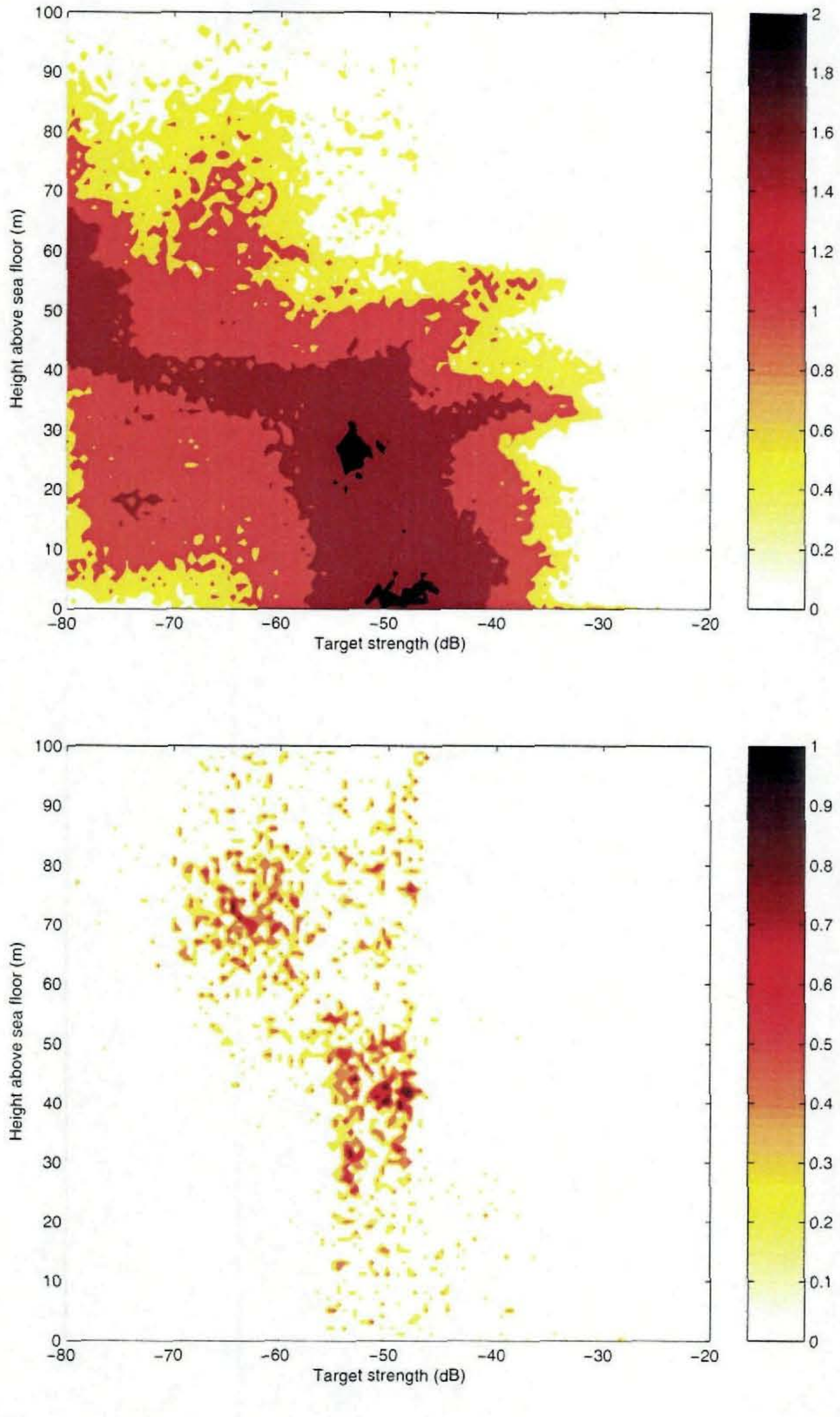

Figure 4: **The relationship of target strength and height above the sea floor for the data in Figure 3. In the upper panel targets were extracted with the criteria used for counting and in the lower the criteria for target strength estimation. The plots are contour maps of $\log_{10}$ of numbers of targets based on 1 m height, and 0.5 dB target strength bins.**

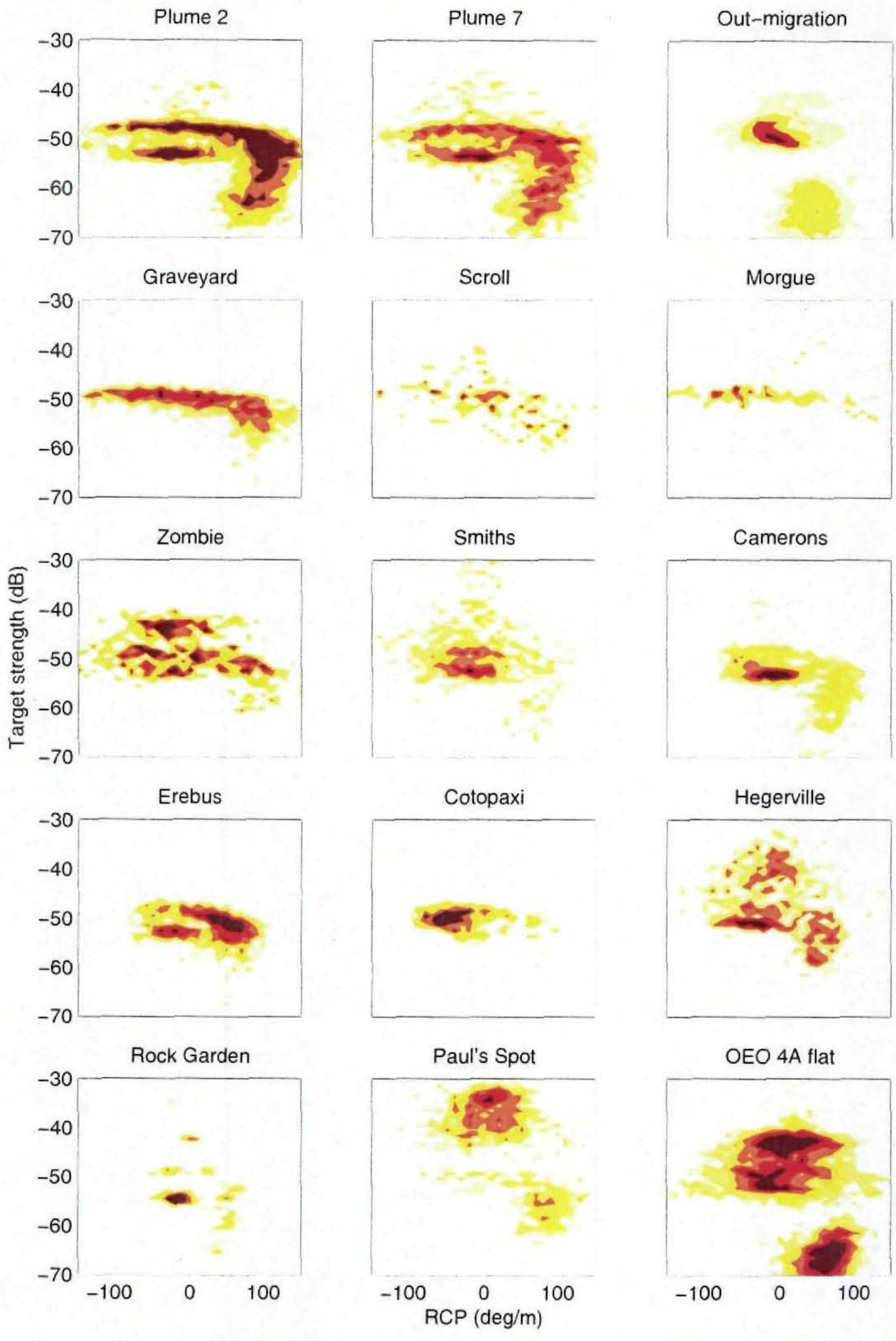

Figure 5: Target strength versus RCP for all the locations used in the target strength analysis. The relative colour scheme is the same as in Figure 4. The plots are contour maps of $\log_{10}$ of numbers of targets based on 1 dB target strength and 10 deg/m RCP bins.

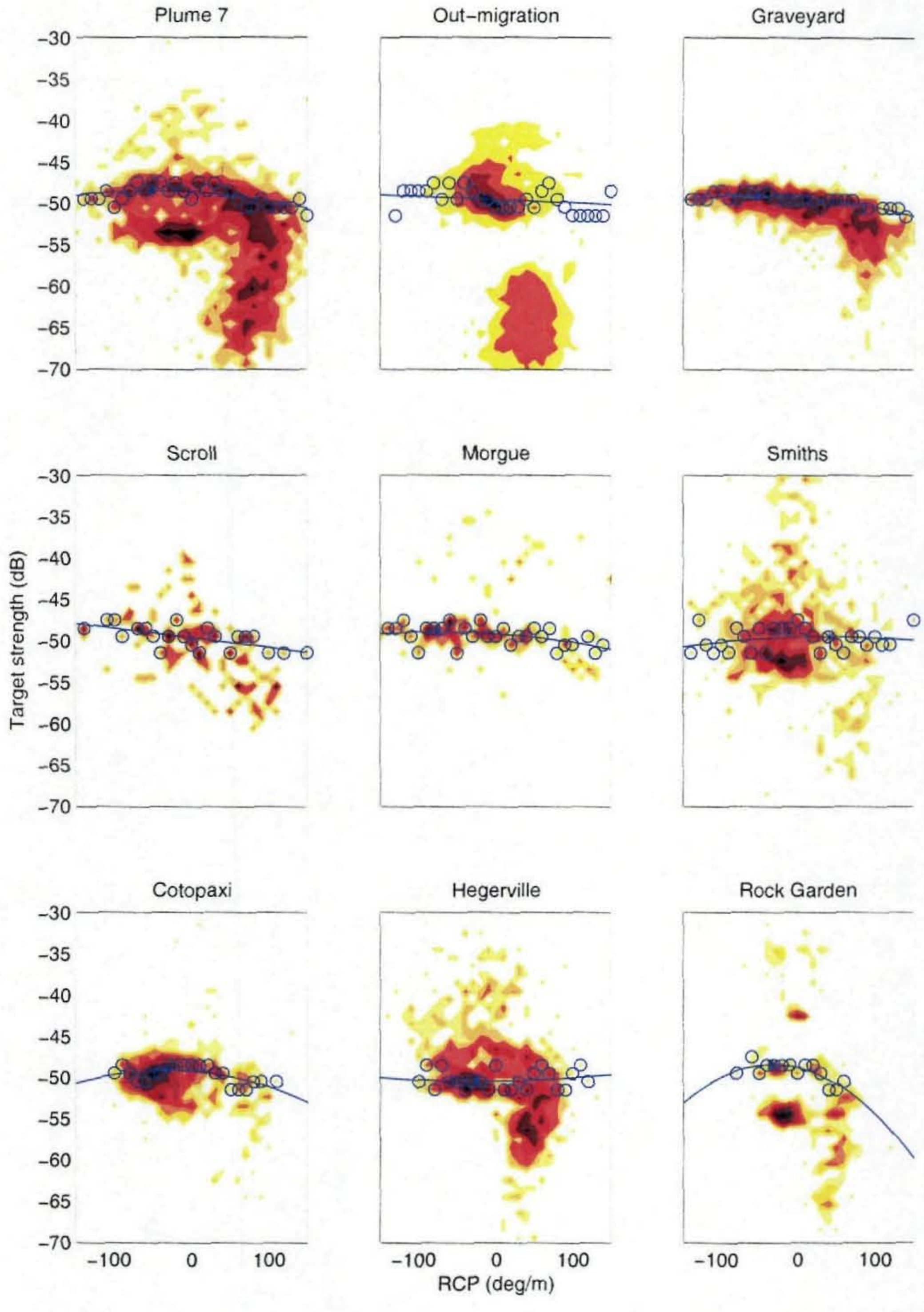

Figure 6: **Contour maps of target strength versus RCP for a sub-set of the locations in Figure 5. The contour plots are the same as in Figure 5 with the addition of points (open circles) and fitted curves in the roughy arc. The "*" marks the maximum of the fitted curve.**

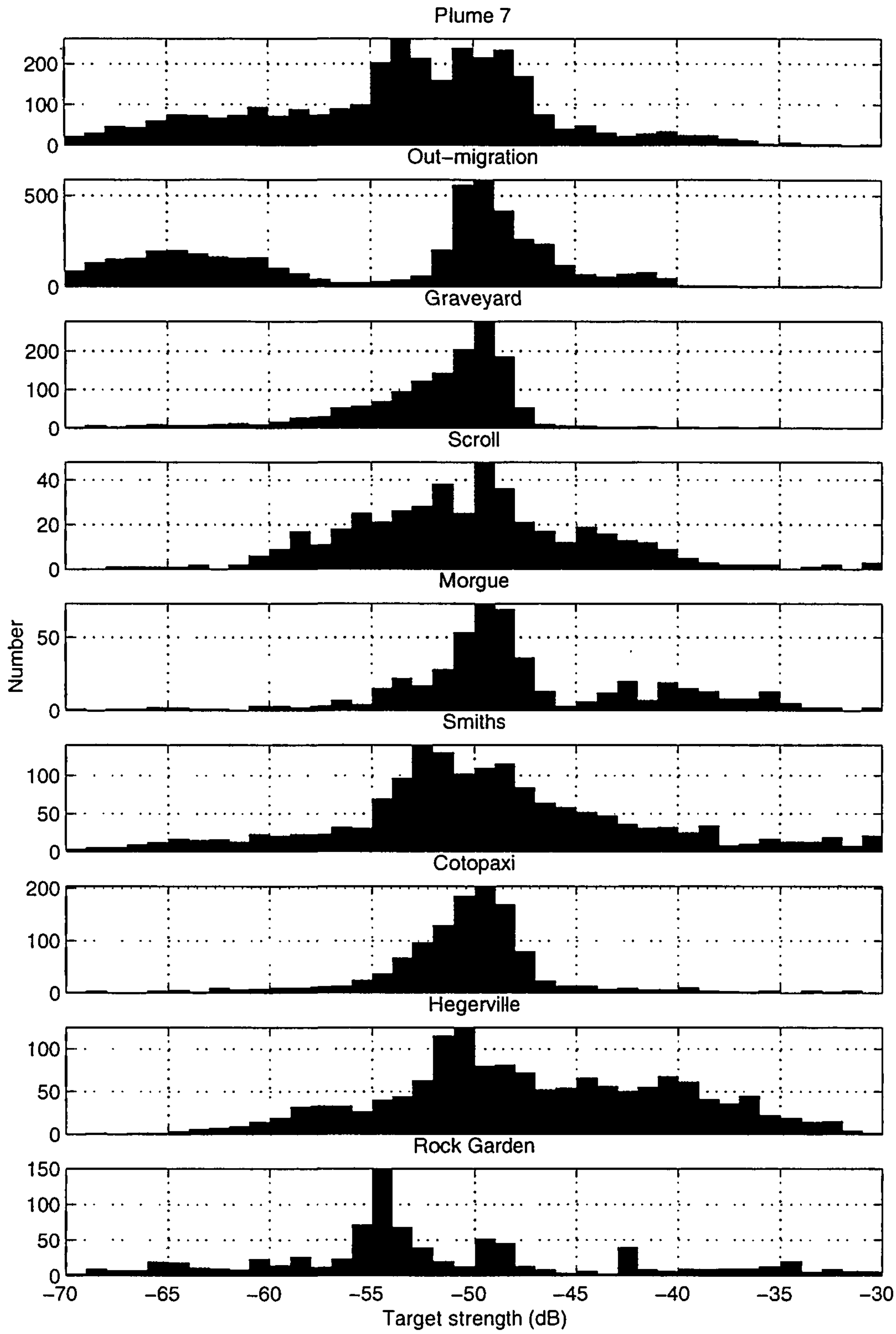

Figure 7: Histograms of target strength distributions for the locations in Figure 6.

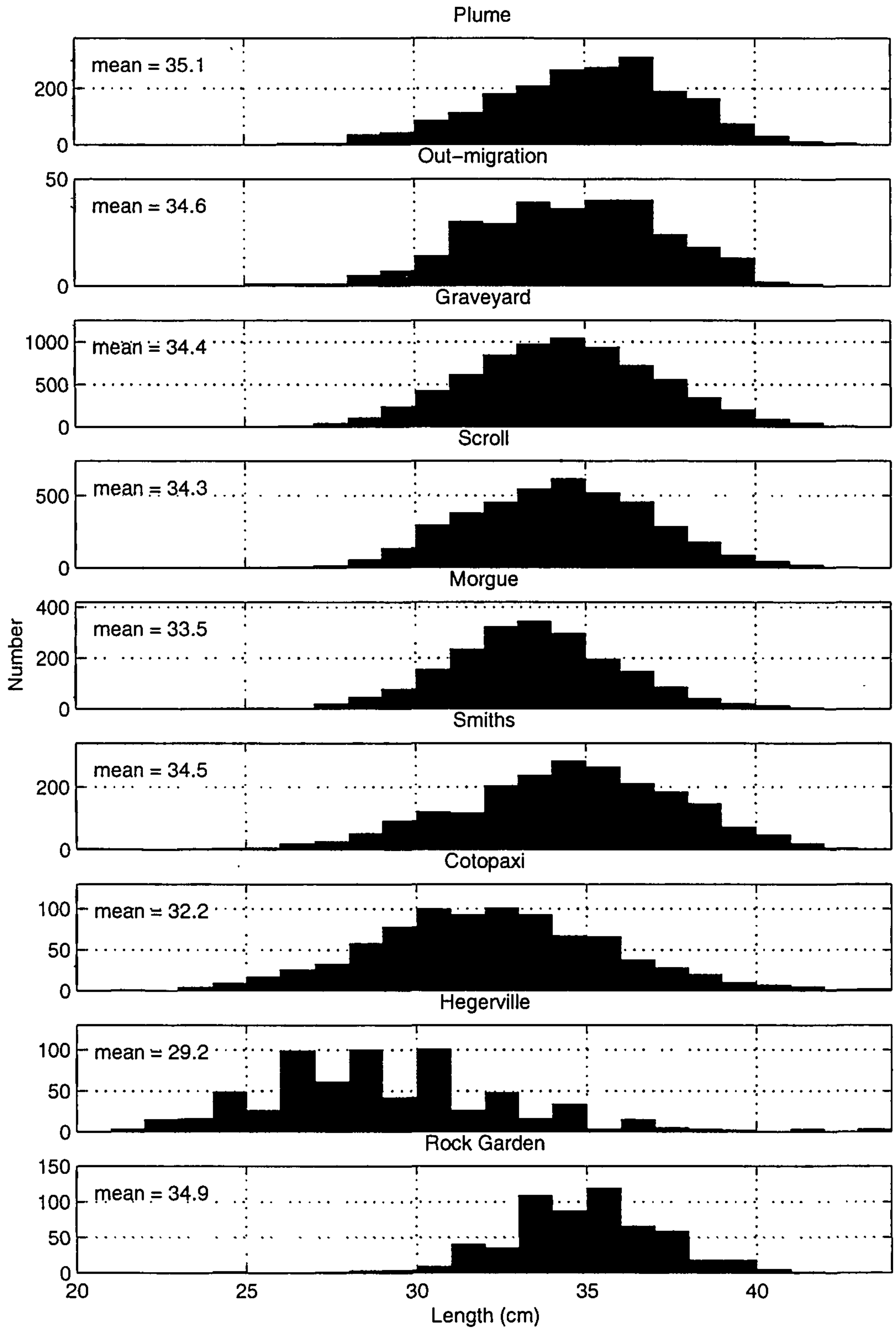

Figure 8: **Histograms of orange roughy length distributions for the locations in Figure 6.**

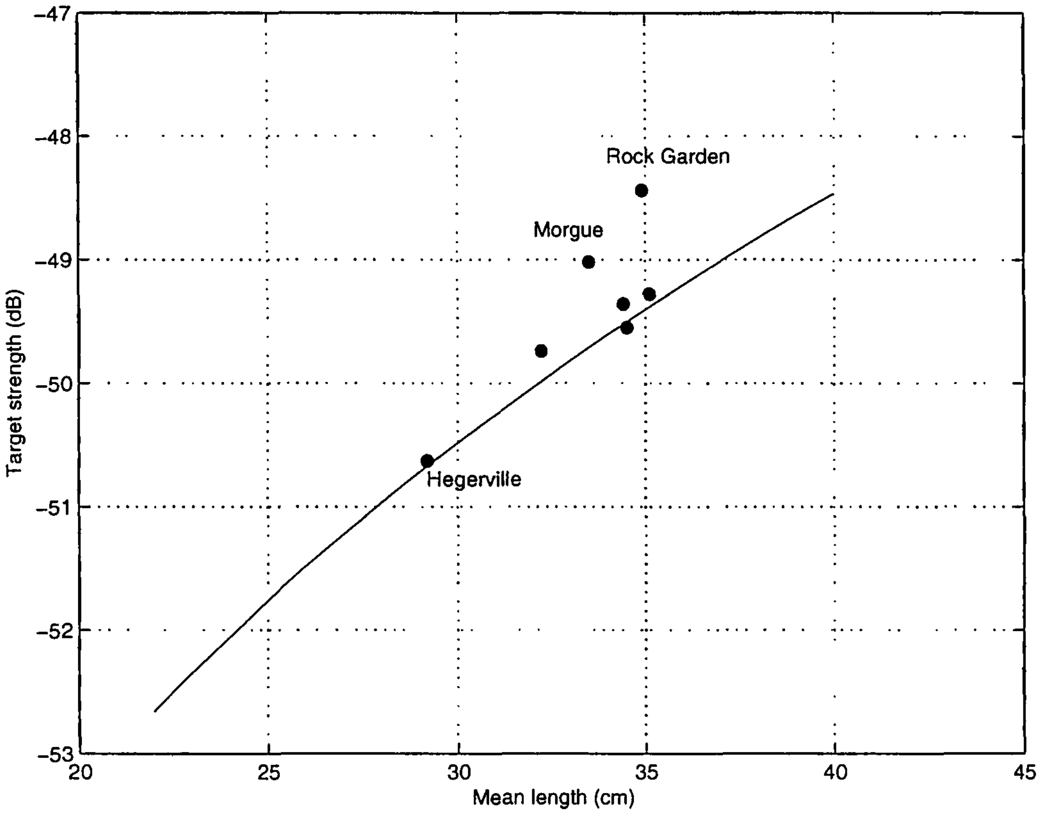

Figure 9: **Target strength estimates from Table2 plotted against mean length for the locations in Figure 6. The line is the relationship used for stock assessment TS = -74.34 + $\log_{10}$L where TS is target strength and L length.**

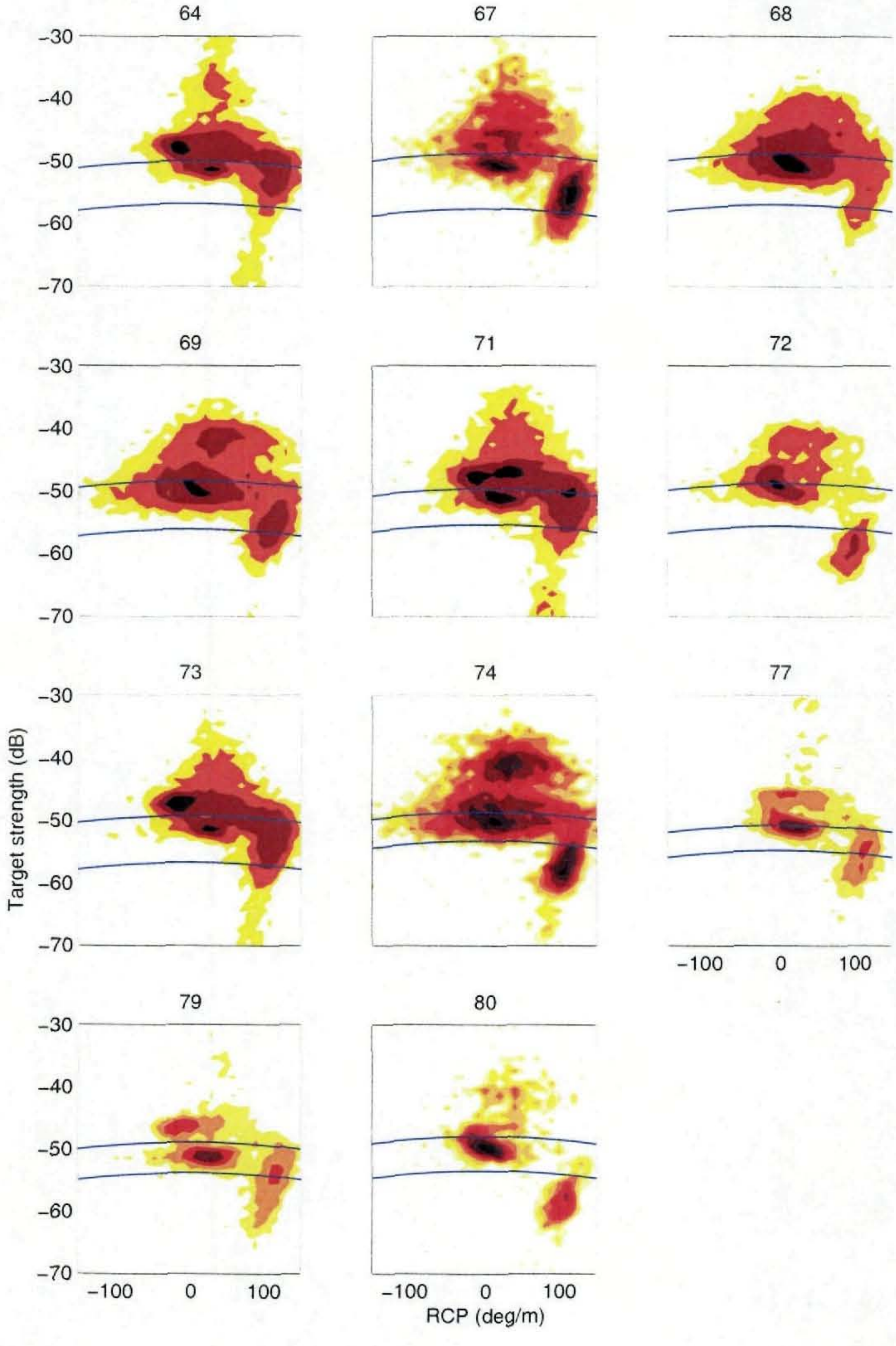

Figure 10: Contour maps of target strength versus RCP for files 64–80 in the count survey. The roughy arcs are based on the relationship for Graveyard and Morgue, together with the minimum and maximum lengths from the associated trawls.

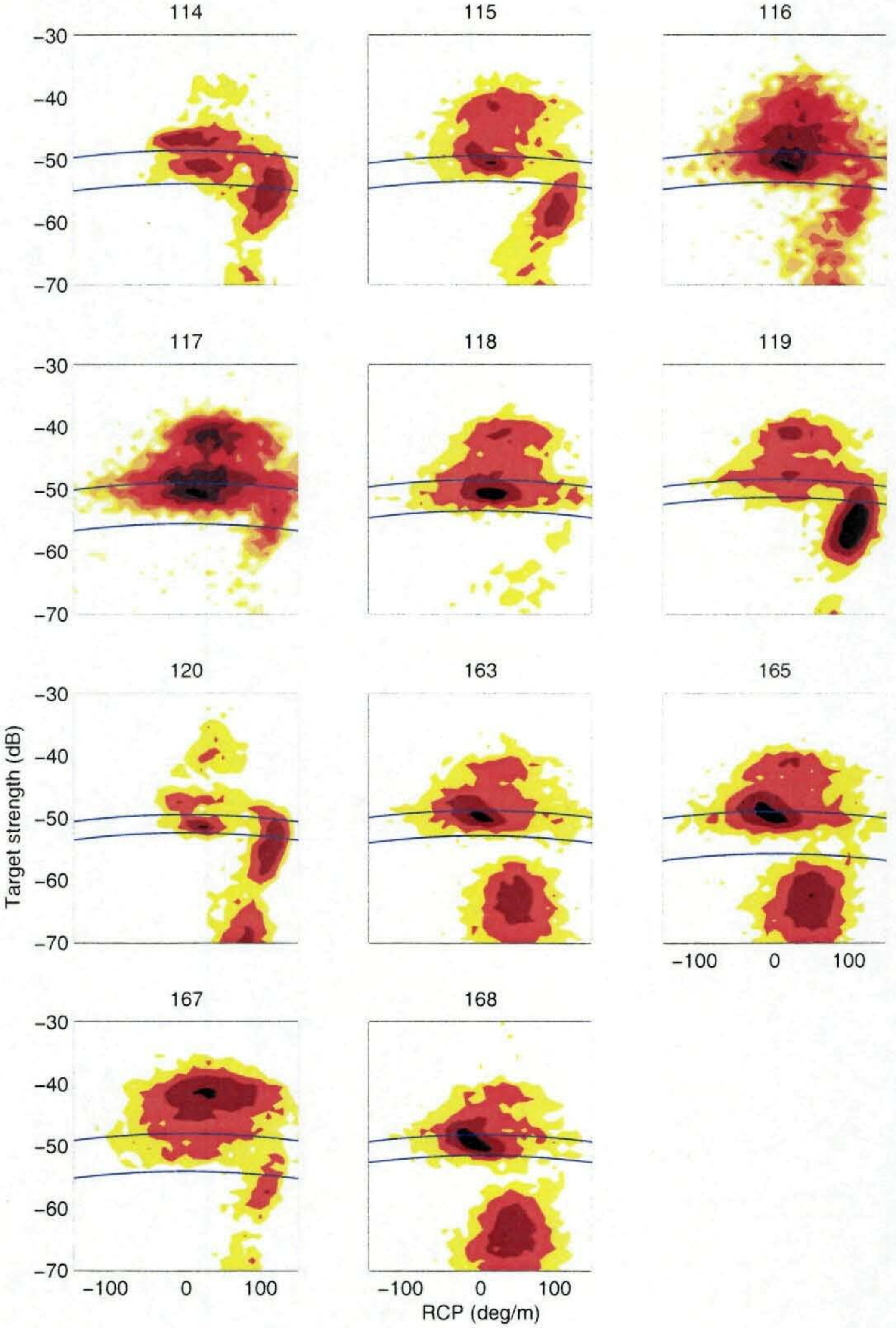

Figure 11: Contour maps of target strength versus RCP for files 114–168 in the count survey. The roughy arcs are based on the relationship for Graveyard and Morgue, together with the minimum and maximum lengths from the associated trawls.

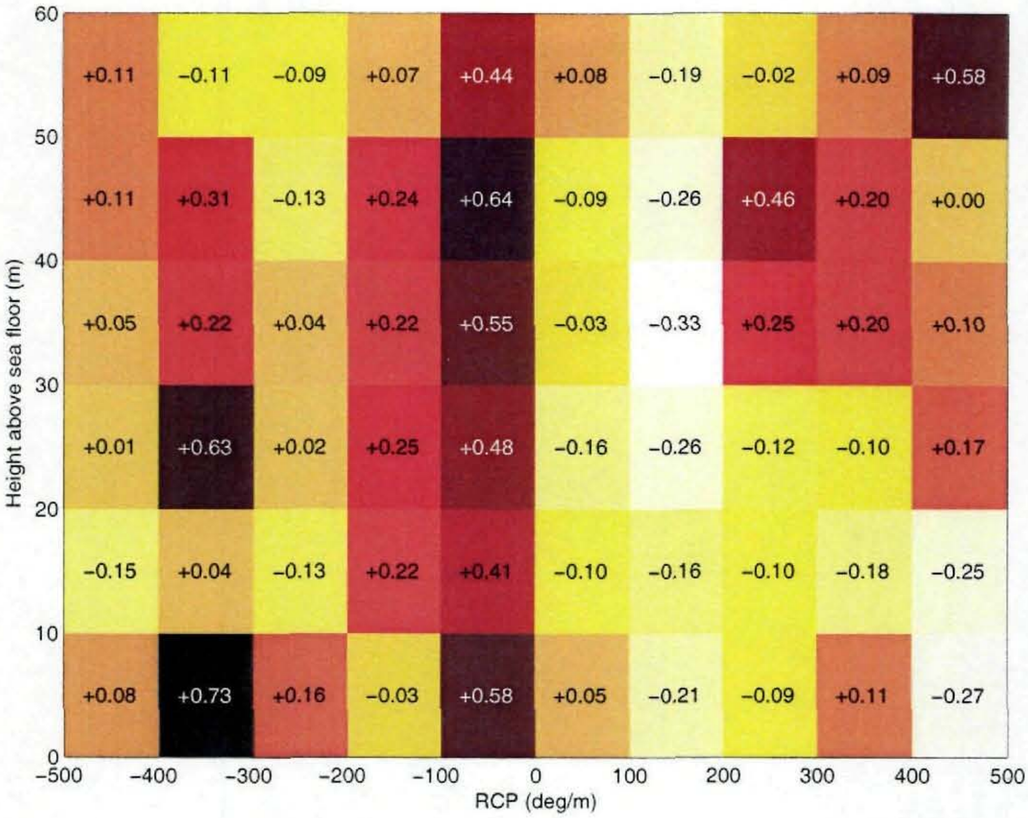

Figure 12: Image of matrix of correlation coefficients of acoustic number density with trawl catches of orange roughy for RCP versus depth for the data in Table 3. The colour scheme used is as in the previous map figures and represent the absolute value of the correlation coefficient so that darker colours signify high correlations and light, low. The numbers are the correlation coefficients and absolute values greater than 0.423 are statistically significant at the 5% level. The numbers in white are significant positive correlations and the black, non-significant ones

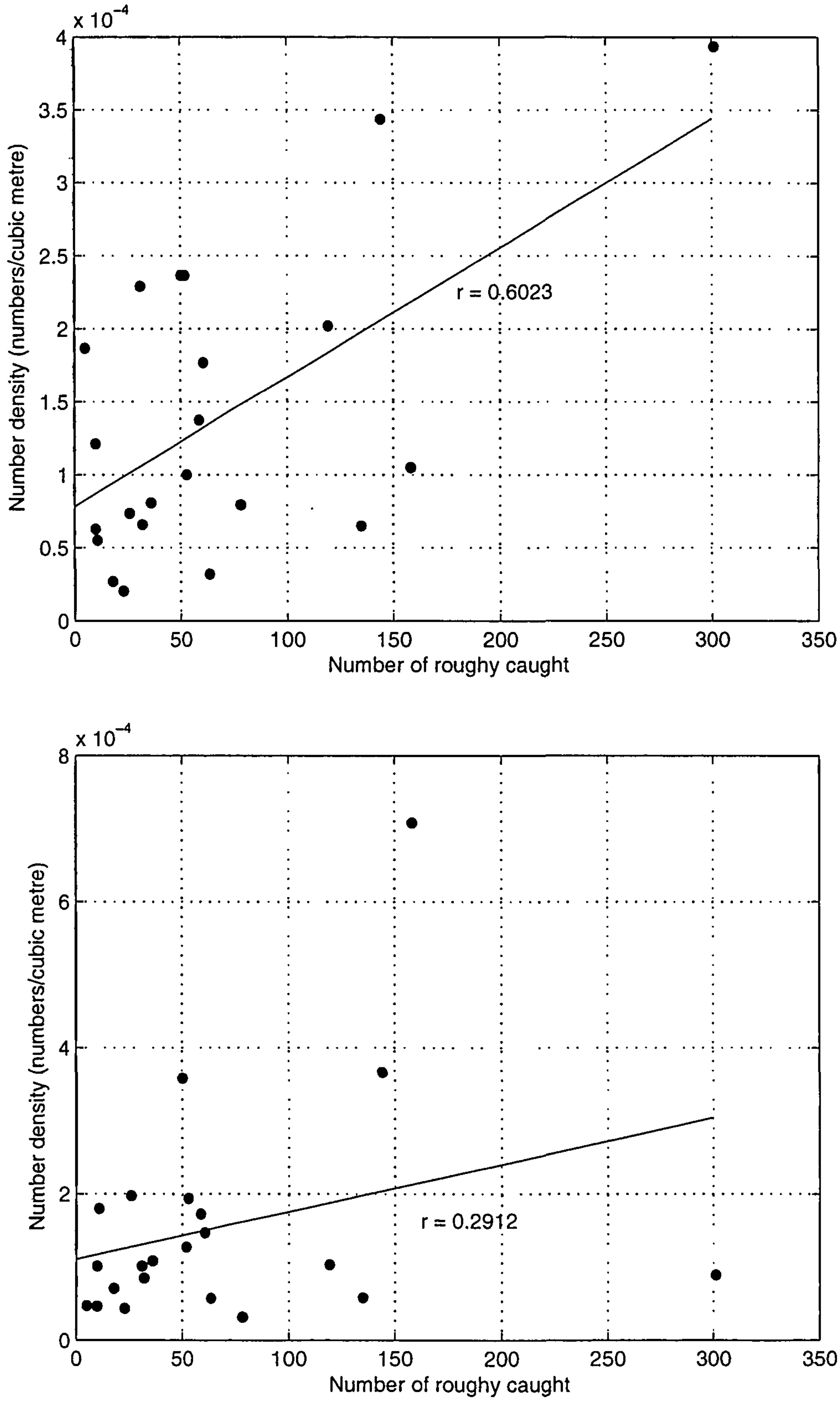

Figure 13: Scatter plots of number density from the acoustic data against numbers of roughy trawled. The upper plot is for targets in the –100 to 0 RCP band of the roughy arc and covers the whole water column. The correlation coefficient (r = 0.6023) is statistically significant at better than the 1% level. The lower plot is for targets above the roughy arc between –42 and –38 dB. The correlation (r = 0.2912) is not statistically significant.

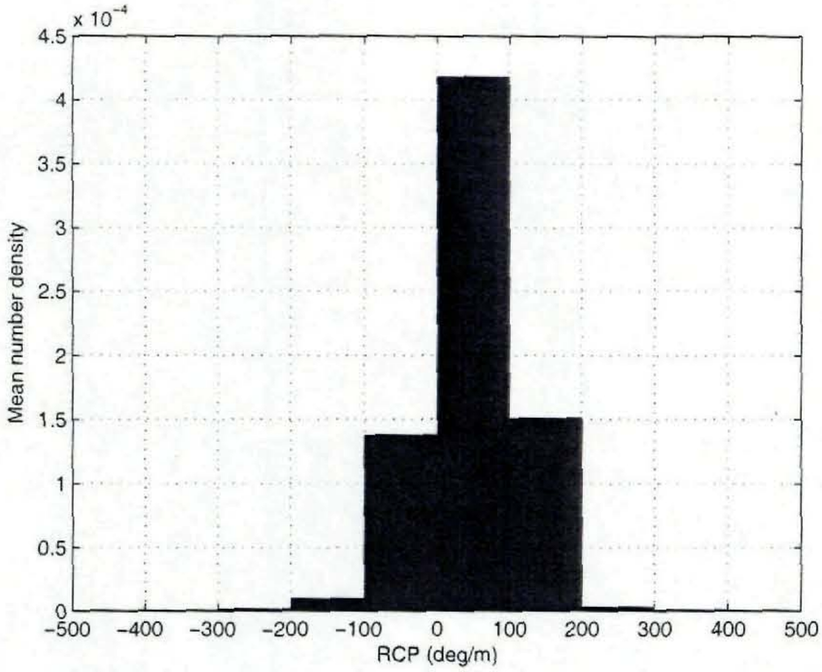

Figure 14: The distribution of density across the roughy arc with respect to RCP for the selected data.

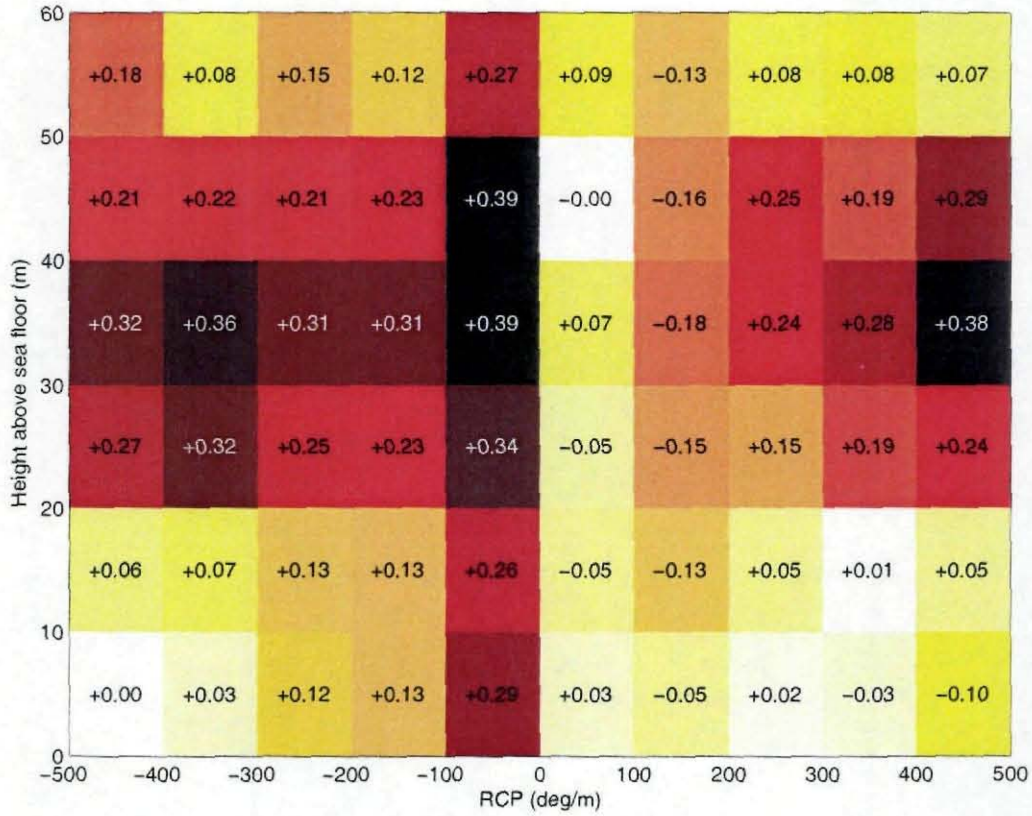

Figure 15: Image of correlations of acoustic number density with trawl catches of orange roughy for RCP versus depth for the raw targets. The colour scheme is the same as for Figure 12. The numbers are the correlation coefficients, none of which are statistically significant. However, the numbers for the higher (>0.3) positive correlations are shown white.

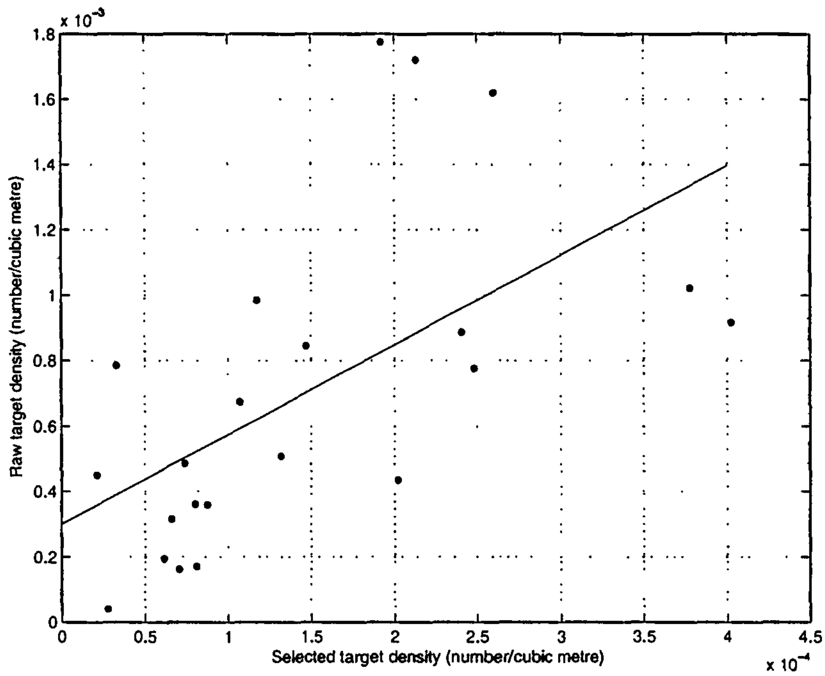

Figure 16: Scatter plot of raw against selected density estimates for all of the transects.