Ministry for Primary Industries
Manatū Ahu Matua

Acoustic and trawl estimates of orange roughy (*Hoplostethus atlanticus*) biomass on the southwest Challenger Plateau, June/July 2011

New Zealand Fisheries Assessment Report 2013/48

I. Hampton,
D.C. Boyer,
R.W. Leslie,
J.C. Nelson,
M.A. Soule,
R.L. Tilney

ISSN 1179-5352 (online)
ISBN 978-0-478-42007-4 (online)

August 2013

New Zealand Government

Growing and Protecting New Zealand

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries websites at:
http://www.mpi.govt.nz/news-resources/publications.aspx
http://fs.fish.govt.nz go to Document library/Research reports

Table of Contents

EXECUTIVE SUMMARY

Hampton, I.; Boyer, D.C.; Leslie. R.W.; Nelson, J.C.; Soule, M.A.; Tilney, R.L. (2013). Acoustic and trawl estimates of orange roughy (*Hoplostethus atlanticus*) biomass on the southwest Challenger Plateau, June/July 2011.

***New Zealand Fisheries Assessment Report 2013/48.* 44 p.**

This paper summarises the results of a combined stratified random trawl and acoustic survey of the southwest Challenger Plateau carried out from a commercial vessel, FV *Thomas Harrison*, between 25 June and 11 July 2011, in the course of a commercial fishing trip. The trawl survey was carried out in two phases using trawl gear identical to that used from the same vessel in trawl and acoustic surveys of the area in 2005, 2006, 2009 and 2010. The 10 strata in the survey, all but two of which (surrounding the Pinnacles and the Westpac hills) were on flat ground, were the same as those in the 2009 and 2010 trawl surveys, except for an additional stratum created within Stratum 22 in the course of the current survey, and within Stratum 24 in 2009. 58 random trawls were conducted in Phase 1 and six in Phase 2, of which all but two (on the Pinnacles) were on the flat ground surrounding the Pinnacles. No random trawls were done on the Westpac Bank, outside the EEZ, because of time lost due to weather, which was exceptionally poor for much of the survey. The acoustic survey was carried out with the vessel's 38 kHz Simrad ES60 fishing echo sounder, as in the previous acoustic surveys. It consisted of five snapshots within Stratum 22, one snapshot of Stratum 24, five snapshots of the Pinnacles (four of Megabrick and one of Twintits) and two snapshots each of Dork and Volcano on the Westpac Bank. The snapshots were executed at various times during the voyage. Acoustic targets were identified by 12 target-identification trawls, supplemented where appropriate by random trawl survey and commercial trawls.

The trawl and acoustic surveys both showed orange roughy to be concentrated on the flat ground northeast of the Pinnacles (particularly in Stratum 22) and on the hills, although there were too few trawls on any of the hills for a reliable trawl estimate of biomass on them. The trawl estimates were 19 717 t (sampling c.v. 31.2%) or 17 899 t (sampling c.v. 31.9%), depending on whether the length of one trawl, shortened in anticipation of an excessive catch, was taken as the actual tow length, or the standard distance of 1.5 n.miles. These estimates are significantly (at the 95% level) higher than the comparable estimate from the 2010 survey (12 190 t), but are significantly lower than the equivalent estimate in 2009 (46 480 t). The acoustic estimate of the aggregated component on flat ground (9481 t with a sampling c.v. of 23.8 %, almost all of which was found in Stratum 22) is 1.57 times the equivalent estimate in 2010, but only 58 % of that in 2009. These differences are also significant at the 95% level, the former barely so. The acoustic estimate for the Pinnacles (Megabrick and Twintits) was 3476 t with a c.v. of 15.6%, which is about four times greater than the acoustic estimate for these hills in 2010, but less than half that in 2009 (7246 t). We consider the estimate for Megabrick (1241 t; c.v. 17.5%) to be more reliable than the Twintits estimate (2235 t; c.v. 22.2%) since there were four snapshots of Megabrick and four trawls used for target identification, as opposed to one of each on Twintits, and the proportion of orange roughy in the trawls was higher (99.4 compared with 96.4%) than in the single trawl used to identify targets on Twintits. The estimate for the Westpac hills (2900 t; c.v. 28.6%) is considered the least reliable since it is based on a single identification trawl (on Dork) in which there was a significant proportion (12.6%) of other species, mainly spiky oreo *Neocyttus rhomboidalis.*

Orange roughy females tended to be larger than the males in all areas (mean standard length 33.4 compared with 31.4 cm), as has been observed in the previous trawl and acoustic surveys of this area. The largest fish were recorded in the single trawl on the Westpac Bank, where the mean length was 2.0 cm greater than the mean for all other areas. The maturation of females during the survey, which was similar to that in the two previous surveys, but a few days later than in 2005 and 2006, showed that the timing of the survey was appropriate for assessing the spawning biomass.

The paper concludes with recommendations for improving the effectiveness and efficiency of the surveys, and a discussion on possible ways of combining the trawl and acoustic estimates into a single

absolute estimate of the orange roughy spawning biomass on flat ground (at least), which we believe is likely to be the estimate most useful for management.

1. INTRODUCTION

The fishery for orange roughy on the southwestern part of the Challenger Plateau west of New Zealand started in 1981. Catches increased rapidly for the next three years with the discovery of spawning aggregations, mainly on the Challenger Flats to the northwest of the Pinnacles, and outside the EEZ on the Westpac Bank (Figure 1). The fishery has been managed as a single straddling stock through the setting of TACCs which were increased progressively from 4950 t in 1984–85 to a maximum of 12 000 t in the 1987–88 season. TACCs were subsequently progressively reduced to 1900 t in 1989–90 when stock assessments suggested that the stock had been fished down to below B_{MSY} (Clark & Francis 1990). For the next eight years the TACC was kept at this level, during which time about 1500 t of orange roughy were caught per year on average. Because of concerns that the stock was not rebuilding at this level the TACC was reduced to 1425 t in the 1998–99 season. In 2000, reassessment of the stock using standardized CPUE indices in a stock reduction model (Field & Francis 2001) suggested that the stock was at about 10% of B_{MSY}. In consequence, the fishery was closed to fishing from 1 October 2000 with a nominal TACC of 1 t in an attempt to rebuild the stock at the maximum rate.

Trawl surveys of the area were started with an exploratory survey in 1983, leading to more restricted and focused surveys between 1984 and 1986, followed by a time series of stratified random trawl surveys between 1987 and 1990 (Clark & Tracey 1994).

The first combined acoustic and stratified random trawl survey on the southwestern Challenger plateau (including the Westpac Bank) was conducted in 2005 (Clark et al. 2005) from a commercial vessel FV *Thomas Harrison*, followed by similar surveys from the same vessel in 2006 (Clark et al. 2006), 2009 (Doonan et al. 2009) and 2010 (Doonan et al. 2010). The surveys covered the same core area which was expanded to the east of the Pinnacles in 2006 and further east in 2009 in response to the finding of significant concentrations of orange roughy on the eastern extremities of the survey area in the 2005 and 2006 surveys.

The survey described here covered the same areas as in 2009 and 2010, using the same vessel, equipment and methods as in those surveys. Its chief purpose was to produce relative trawl and acoustic estimates of orange roughy spawning biomass in the area for comparison with those from the earlier surveys, with a target sampling c.v. of 30% for the trawl survey and 15% for the acoustic survey. The survey was conducted between 25 June and 11 July; a period which, based on earlier surveys, was expected to co-incide with peak spawning.

2. METHODS

2.1 Overall survey design

The survey design was similar to that used during the 2005, 2006, 2009 and 2010 surveys, involving a combination of trawling and acoustics. The general survey area, which included the Pinnacles, the flat area to the east and west of them (Pinnacles Flat), the Central Flat and Westpac Bank (outside the EEZ), are shown in Figure 1. No new areas were added, but provision was made for the alteration of the trawl strata to isolate any aggregations found on flat ground from low densities in the rest of these strata. The planned division of effort between the trawl and acoustic surveys was similar to that in the previous surveys, with approximately 50 % of the survey time (7 days) allocated to the trawl survey and approximately 30% (4–5 days) to the acoustic survey. Time also had to be allowed for commercial fishing since the trip was primarily a commercial fishing trip with some dedicated time for the random trawling component. Further design considerations were the need to take advantage of the best weather for the acoustic snapshots, and the fact that surveys of hills, whether by acoustics or trawl, were accorded lower priority than acoustic and trawl surveys of the flat areas because it was expected that there would be greater difficulty in interpreting the data from them (e.g. Clark 1994, Hampton et al. 2007).

2.2 Trawl survey

2.2.1 Equipment

The trawl gear consisted of a four-panel "Arrow" trawl with cutaway lower wings, a single lengthener and two codends; rubber and steel bobbins; 50 m bridles and 70 m sweeps, towed on high-aspect 7 m^2 2300 kg Super-Vee trawl doors. It was anticipated that the door-spread at 3 knots would be 135–140 m, the wing-spread 17 m and the average headline height 6.0–6.5 m. The net was the same as that used in the 2005, 2006, 2009 and 2010 surveys, and in previous trawl surveys during the 1980s. The door spread and headline height was measured for every trawl in the trawl survey. A wireless Furuno CN 22 net monitor and temperature sensor was fitted to the headline, and catch sensors to the cod-end, to monitor fish in the vicinity of the trawl, net depth, water temperature and catch size in real time. After 2 July, more accurate measurements of water temperature throughout the water column were provided by a Star-ODI DST temperature/depth data storage tag fitted to the net.

2.2.2 Survey design

A two-phase stratified random design, as recommended by Francis (1984), incorporating aspects of previous hill surveys (Clark 1994) was applied. This design is comparable with that used in the 1987–1990 series of trawl surveys, and in the trawl component of the surveys between 2005 and 2010. The prescribed strata were the same as in the 2009 survey, but were slightly different from those employed in the 2010 survey, in which a number of the strata were subdivided after that survey in an attempt to improve precision (Doonan et al. 2010). The 2010 re-stratification was not repeated since it was considered that the fine-scale distribution which prompted it would not necessarily recur in the current survey. As in the 2010 survey, it was stipulated that there be at least three trawls in each stratum, and that any aggregations found on the flat grounds would be excluded from the trawl survey and surveyed acoustically instead in new ad hoc acoustic strata created specifically for this purpose.

The strata ultimately adopted are specified in Table 1, which also lists their areas and the number of first and second-phase random trawls carried out in each stratum. The only departure from the prescribed strata was the addition of Stratum 22A. This stratum was created during the course of the survey to isolate a single large catch in Stratum 1 (otherwise a low-density stratum), close to the boundary of Stratum 22 which would have greatly inflated the biomass and variance estimates in Stratum 1 and directed practically all Phase-2 trawls to this stratum, had it been included in it. The creation of Stratum 22A avoided this problem, but required the addition of two extra trawls in this stratum to satisfy the requirement of at least three trawls per stratum, and the addition of an additional trawl in Stratum 1 to replace the one removed.

The Phase 1 allocations were initially based on the mean of the biomass estimates in each of the strata in the 2009 and 2010 surveys, but were revised in the course of the survey to adjust for the amount of time ultimately available for the trawl survey and, to some extent, the catch rates in the first phase. The chief adjustment, apart from that resulting from the creation of Stratum 22A, was the omission of all but three of the planned random trawls on the hills (Strata 10 and 11), which was necessitated by loss of time due to poor weather. The allocation of the few trawls in the second phase, which had to be severely curtailed due to the shortage of time, was loosely based on the estimates of biomass in the first phase. The trawls, which were designed to cover 1.5 n.miles at a speed of 3.0 knots, were randomly placed within the strata with the restriction that no tracks could overlap. The positions and tow directions were generated by I.J. Doonan, NIWA, Wellington, through NIWA's "Rand_Stn" program, which has been used for placing stations in previous random trawl surveys of the Challenger Plateau.

2.2.3 Trawling strategy

The trawling strategy was based on that used in the previous trawls surveys of the area. The gear was shot such that the vessel (rather than the net) was at the stipulated position at touch-down, which may be different to the way in which this was done in some of the previous surveys. In some cases, to save time or avoid crossing a stratum boundary, the trawl was towed in a direction opposite to that stipulated in the design. All trawls were designed to cover the standard distance of 1.5 n.miles, with the provision that a trawl in which the catch sensors were triggered before the end of the trawl could be terminated early to avoid an excessively large catch.

2.2.3 Analysis of trawl data

B_j, the biomass in stratum j, was estimated from the expression:

$$B_j = A_j \Sigma[(C_{orh})_{ji} / n_j d_{ji} w_{ji}] \qquad ,$$

where:

A_j = Area of stratum j,
$(C_{orh})_{ji}$ = orange roughy catch in the *ith* trawl in stratum j,
d_{ji} = distance towed in *ith* trawl in stratum j,
w_{ji} = wing spread in *ith* trawl in stratum j,
n_j = number of trawls in stratum j in Phases 1 and 2 combined.

The summation runs over all trawls in the stratum, in both phases. The expression assumes that there is no herding by the sweeps and bridles, or fish passing over the top of the net. It was evaluated in two ways: a) using the measured d_{ji} values throughout, and b) taking d_{ji} as 1.50 n.miles wherever a trawl was terminated prematurely in anticipation of a large catch. The former in effect assumes that the density along the untrawled section of track was the same as that along the trawled section, and the latter that it was zero.

The coefficient of variation (c.v.) of the estimate was estimated from the standard error, giving equal weight to all trawls irrespective of trawl length or wing spread. The total biomass for the survey was obtained by summing the B_j estimates, and the overall c.v. by summing the stratum variances.

2.3 Acoustic survey

The acoustic survey was aimed at producing unbiased estimates of orange roughy biomass, together with estimates of sampling error, in a number of areas where dense aggregations, suitable for acoustic surveying, had been found in recent acoustic and trawl surveys of the southwest Challenger Plateau. It was planned that the snapshots be done in areas where large commercial catches were made in these surveys, and that they be mainly executed during breaks in commercial fishing while large catches were being processed prior to shooting the next trawl. This strategy has been effectively used for surveying orange roughy from commercial vessels elsewhere in New Zealand in the past 10 years, particularly in the Spawning Plume and on various hills on the north Chatham Rise and the western Puysegur Bank (e.g. Hampton & Soule 2003, Hampton et al. 2007). It was anticipated that there would be sufficient time for 10 snapshots in trawl strata 22 and 24 on Pinnacles Flats, seven on the Pinnacles themselves (Megabrick and Twintits) and seven on the Westpac hills (Dork and Volcano). Allowance was also made for 20 target-identification trawls, to be split equally between the hills and the flat areas. In the event, due primarily to time lost because of poor weather, only five snapshots of the flats and seven of the hills, and 12 identification trawls, could be completed in the time available.

2.3.1 Acoustic equipment

The survey was conducted using the vessel's SIMRAD ES60 [2] fishing echo-sounder firing at 2 kW into a sphere-calibrated ES 38B 38-kHz split-beam transducer mounted in the hull. Further details of the equipment settings are given in Table A-1, Appendix A. Concerns about the use of the ES60 for scientific work were allayed in an orange roughy survey from FV *San Waitaki* in 2002 when it was shown that at this power setting (i.e. below the cavitation threshold), there was very little difference between the performance of the vessel's ES60 sounder and a Simrad EK60 Scientific sounder operating into the same transducer and sphere-calibrated to the same accuracy (Hampton & Soule 2003). The effect of the "triangular wave" fluctuation in system sensitivity discovered in the ES60 by Ryan & Kloser (2004) was removed from both the survey and the calibration data through ES60Adjust: a software program developed by CSIRO, Hobart (Keith et al. 2005) specifically to remove this error.

Myriax ECHOVIEW software (Version 4.90.70) was used to view and process ES60 raw (power and angle) data files, which were logged and transferred via Myriax ECHOLOG60 (Version 4.90.47.16715) software. Raw data files were also periodically transferred and stored to disk for post processing and analysis.

A Honeywell HMR3000 attitude sensor, interfaced to the logging PC, monitored vessel pitch, roll and heading throughout the survey, enabled echo returns to be corrected for vessel pitch and roll on a ping-by-ping basis through ECHOVIEW's motion-compensation software, which implements correction algorithms developed by Dunford (2005).

The sphere calibration was carried out at the start of the survey, in Nelson Bay on 25 June, according to standard procedures (Foote et al. 1987), using a 60 mm copper sphere. A repeat calibration attempt, on return to port on 9 July, although generally supporting the earlier calibration, was regarded as inconclusive because of the poor weather conditions at the time. The system was calibrated again on 15 August by NIWA at the start of a hoki survey in the Cook Strait, in this case with a 38.1 mm tungsten carbide sphere. The calibration constant for the survey was taken as the geometric mean of the constants from the calibrations on 25 June and 15 August.

2.3.2 Acoustic survey design

Snapshots of flat areas were done using a parallel transect design, in which transects were equally spaced, on average approximately 0.5 n.miles apart running either E/W or, in one snapshot, N/S. In a number of cases, every second transect was surveyed in the first pass through the grid, and the remainder on a second pass through the grid in the opposite direction. This was done to counter the effects of fish movement in the direction normal to the transects during the course of the snapshot. In such cases the biomass was estimated from the geometric mean of the estimates from the two passes, as recommended by MacLennan & Simmonds (1992). Survey speed was maintained at between 8 and 10 knots, depending on weather.

The snapshots of the hills were done at between 4 and 6 knots on four or five radial transects intersecting at the centre of the hill, as recommended by Doonan et al. (2003a). Transects were equally spaced in angle, starting from a random bearing.

2.3.3 Snapshots

The general location of the snapshots is shown in Figure 2. Details of those from which acoustic estimates of orange roughy biomass could be extracted are given in Table 2. Not shown in Table 2 are two reconnaissance snapshots in Stratum 22, conducted early in the survey to locate the areas of

[2] ES70 software was initially installed, but due to a fault early in the survey, it was removed. The original ES60 software (used in all previous surveys) was re-installed and used for the remainder of the survey.

highest abundance, and the southernmost snapshot in Stratum 22 (see Figure 2) in which no significant orange roughy aggregations were detected. Note that Snapshot 2 of Stratum 22 consisted of two consecutive surveys (2A and 2B), in which the grid of the second survey was created by extending each transect of the first survey to the south on the supposition (confirmed in the event) that the first survey had not covered the southern extremity of the distribution.

2.3.4 Mark identification

Orange roughy aggregations were primarily identified as such by aimed trawling with the Arrow trawl in so-called identification trawls, supported in places by large orange roughy catches in nearby commercial or random trawls. The physical characteristics of an aggregation and its depth and proximity to other similar aggregations and orange roughy catches were also used extensively as identification and classification criteria.

2.3.5 Analysis of acoustic data

For each snapshot on which there were discernable orange roughy-like aggregations, estimates of orange roughy biomass were derived from the acoustic data through the following steps:

- Marks identified directly or indirectly as orange roughy aggregations were isolated from other biological targets, and their mean area back-scattering strengths estimated through ECHOVIEW. Those where the identification was regarded as positive were classified as A-category targets, and those where the identification was less certain, but where the aggregations were believed to be more likely orange roughy than not, were classified as B. Biomass estimates were made excluding and including the B-category targets as a test of the sensitivity to the uncertainty in identification. All B-category targets were included in the final biomass estimates.

- $(\overline{S_a})_j$, the mean area back-scattering strength from isolated orange roughy targets along transect j , were estimated from the relationship;

$$(\overline{S_a})_j = 10 \, Log \, (\overline{(NASC)}_j / 4\pi \, (1852)^2)$$

  where $(\overline{NASC})_j$ is the mean nautical area scattering cross-section (NASC) of the aggregation on transect j, as defined by MacLennan et al. ((1995). In the hill snapshots $(\overline{S_a})_j$ was computed from the NASC values for 10 ping segments along it, with weighting by distance from the hilltop, as recommended by Doonan et al. (2003a) to compensate for over-sampling of the centre by radial transects. As in Doonan et al. (2003a), the sampling variance was computed from the variation between the $(\overline{S_a})_j$ estimates. For the parallel-transect surveys, (i.e. those over flat ground), $(\overline{S_a})_j$ was calculated from the mean NASC for the transect.

- On the hills, the NASC for each 10-ping segment of the transect was corrected for negative bias arising from the inability to detect roughy in the near-bottom dead-zone, using Barr's polynomial expression (in Doonan et al. 1999) to estimate the equivalent dead-zone height, viz:

$$h_{eq} = 0.001d \, (1.264 - 0.216\alpha + 0.262\alpha^2 - 1.382 \times 10^{-3}\alpha^3 + 2.686 \times 10^{-4}\alpha^4) \quad ,$$

  where d is the distance between the transducer and the target and α the slope of the bottom beneath the aggregation in degrees. For each 10-ping segment the proportion of the back-scatter from the aggregation lost in the dead-zone was estimated from heq and the mean back-scatter from the aggregation in the 10m channel immediately above the dead-zone. The same method was used to correct the NASC values in the snapshots over flat ground, except that in this case a single correction was applied to each transect, based on a single value for the mean slope of the bottom beneath the aggregation.

- For each snapshot, the orange roughy biomass was estimated from $\overline{S_a}$, the mean back-scattering strength for the snapshot, which was obtained by averaging the $(\overline{S_a})_j$ values with weighting by transect length in the case of the parallel snapshots, where the transect lengths were variable. The biomass for the snapshot, B , was estimated from the expression:

$$B = P_{orh}\, A\, \overline{w}\, 10^{\,0.1\,(\overline{S_a} - \overline{TS})} \quad ,$$

where $\overline{TS}$ is the mean orange roughy target strength for the snapshot, A the snapshot area, and $\overline{w}$ the estimated mean weight of orange roughy in the snapshot, obtained from the trawl samples. For radial snapshots, A was taken as the area of a circle of diameter equal to the transect length, while for parallel surveys it was estimated from the mean transect length and spacing. P_{orh}, the partitioning factor, is the proportion of the back-scatter from the aggregation which is attributable to orange roughy rather than to any other species in it.

$\overline{TS}$ was estimated by applying the following expression of Macaulay et al. (2008) to pooled length distributions of orange roughy in samples taken from the identification trawls:

$$TS = 16.15 \, Log\, L - 76.81$$

where L is the standard length in cm. This expression was obtained from experiments in the Spawning Plume area in 2007, in which an integrated optical and acoustic system mounted on the headline (Ryan et al. 2009) was used. It has been accepted by the Deep Water Fisheries Assessment Working Group as the most appropriate target strength expression for orange roughy on the Chatham Rise during the spawning period, and has also been used in the analysis of acoustic data from the 2009 and 2010 surveys of the Challenger Plateau (Doonan et al. 2009, 2010).

P_{orh}, the partitioning factor for the snapshot, was estimated from the species composition in the identification trawls and estimates of the mean back-scattering cross sections of the major species present through the expression:

$$P_{orh} = \frac{\overline{c}_{orh}\ \overline{\sigma}_{orh}}{\sum \overline{c}_i\ \overline{\sigma}_i}$$

where $\overline{c_i}$ is the mean proportion by weight of species i in the snapshot, and

$$\overline{\sigma_i} = 10^{\,0.1\,\overline{TS_i}} \,/\, \overline{w_i}$$

is the mean back-scattering cross-section per unit weight of species i in the snapshot. The summation runs over all of the major species caught. Where there was more than one identification trawl in the snapshot, the catch proportions by number were averaged, with weighting by the square root of catch weight for consistency with the partitioning in the 2009 and 2010 surveys (Doonan et al. 2009, 2010). The $\overline{TS}$ values for species other than orange roughy were estimated from the mean length and weight of the fish sampled in the stratum, and target strength/length relationships in Clark et al. (2005, 2006), which in most cases were based on relationships in Macaulay et al. (2001). They are listed in Table B-1, Appendix B.

- For the hill snapshots, the standard error (and hence the c.v.) in the biomass estimate was estimated from the variation between the $(\overline{S}_a)_j$ values, as in Doonan et al. (2003a). For the parallel snapshots it was estimated from the following expression, derived from Jolly & Hampton's (1990) estimator of the sampling variance for randomly-spaced parallel transects of unequal length:

$$Var(\overline{S}_a) = \frac{n}{(n-1)} \frac{\sum_{j=1}^{n} L_j^{\,2}[(\overline{S}_a)_j - \overline{S}_a]^2}{(\sum_{i=1}^{n} L_j)^2}$$

where L_j is the length of transect j and n the number of transects in the snapshot.

- Corrections to the biomass estimates for inaccuracy in the absorption coefficient used in the ES60's internal range compensation software were applied at the stratum level, by applying the temperature/depth profiles from the temperature monitors mounted on the net to the expression of Doonan et al. (2003b) for the absorption coefficient at 38 kHz as a function of temperature, depth and salinity (assumed to be 34.5 ppt throughout).

- Biomass estimates and corresponding c.v.s for various combinations of the snapshots were obtained by summing the estimates of biomass and sampling variance for the selected snapshots.

3. RESULTS

3.1 Size and reproductive state of orange roughy

Size structure
Figure 3 shows the length distributions of orange roughy males, females and both sexes combined taken from trawls used for target identification in Stratum 22, Stratum 24, Megabrick, Twintits and the Westpac hills. The distributions are broadly similar, with the females tending to be larger than the males throughout. The mean lengths and weights in each of the areas, which were the values used in making the acoustic estimates, are listed in Table 3. Figures 4 and 5 show the length distributions for both sexes combined in each stratum of the trawl survey, based on all the random trawls in the stratum, with weighting by catch size, and Table 4 the mean lengths and weights in each stratum. The latter were estimated from the weighted length frequencies and the length/weight relationship in Figure 6, which was based on measurements during the survey.

Reproductive state
The percentages of female orange roughy in Stages 3 to 6 (maturing to spent) on the gonad maturity scale for females of Pankhurst & Conroy (1987) are plotted against date in Figure 7, with no discrimination by area. The trend lines were obtained by polynomial regression. It can be seen that when the survey started on 27 June, almost all females were either maturing (Stage 3) or ripe (Stage 4), but that by the end of the survey on 9 July, most of the females were either running (Stage 5) or spent (Stage 6). From this it is clear that spawning was well underway at the start of the survey, but not yet complete by the end of it, from which it is evident that the survey was well timed in relation to the spawning cycle.

3.2 Distribution and biomass

3.2.1 Trawl survey

Catches of orange roughy and other common species in the random, identification and commercial trawls are listed in Table C-1, Appendix C, while Table D-1 in Appendix D lists the occurrence and catch of every species caught by trawl during the survey. Catch rates of orange roughy in the random, identification and commercial trawls are plotted in Figures 8, 9 and 10 respectively. It can be seen from Table C-1 that catches in the random trawls were highly variable, ranging from a few kilograms to a maximum of over 22 t in Stratum 22 and over 25 t on the Pinnacles (Stratum 10). Catches in the identification and commercial catches tended to be higher, particularly in Strata 22 and 24 (Table C-1).

Figures 8 to 10 show that the highest orange roughy catch rates in all three types of trawl were on the Pinnacles and the flat areas to the east of them, particularly in Strata 22 and 24. The single trawl on the Westpac Bank (on Dork) yielded a relatively high catch (over 5 t), but cannot be taken as an indication of orange roughy density on the Bank because of the lack of further trawls there, and the fact that it was an aimed (i.e. identification) rather than a random trawl.

Table 5 shows the estimates of orange roughy biomass and c.v.s for each stratum in the trawl survey for both phases combined, using the actual tow distance for all trawls. The biomass estimates are given for all fish and for those at least 27 cm; the length used in previous surveys to partition the biomass between immature and mature fish (Clark et al. 2005, 2006, Doonan et al. 2009, 2010). The size partitioning was done on the basis of the length distributions in Figures 4 and 5 and the length/weight relationship in Figure 6. The figures in parenthesis in Table 5 show the estimates obtained if the tow distance in the one trawl which was shortened in anticipation of an excessively large catch (Station BT24, in Stratum 22) was taken as 1.5 n.mile rather than the actual distance of 0.67 n.mile. The high proportion of the biomass in Strata 10 and 22 and the large c.v.s in some of the strata will be noted.

Table 6 summarises the orange roughy estimates and c.v.s for the whole survey and Table 7 the corresponding estimates for other species which were common in the catches (including stratum 10), taking the actual tow distances throughout. The low biomass estimates for all other species compared to orange roughy will be noted.

3.2.2 Acoustic survey

Calibration
The constants from the calibrations on 25 June and 15 August, and from the three previous calibrations of the system, which were all performed by NIWA, are shown in Table A-2, Appendix A. The results indicate a decline of about 50% in sensitivity since the calibrations in 2009, with comparatively little change between 2010 and 2011.

Nature of marks
The most distinctive orange roughy-like aggregations were detected in Stratum 22 and on the hills. The marks in Stratum 22 were reasonably well defined and extended to more than 100 m off the bottom in places (e.g. Figure 11). On Megabrick, Twintits and Dork they were well defined, concentrated on the top of the hill and in contact with the bottom, but on Volcano they were well off the bottom and concentrated on the rim of the crater (see examples in Figures 12 to 15).

Mark identification
Mark identification in Stratum 22 was based on two identification trawls (Stations BT35 and BT67 in Table C-1) and four commercial trawls (Stations BT16, BT17, BT68 and BT75). The average catch in these trawls was 14.3 t of which 98.8 % on average was orange roughy. In Stratum 24, although several large clean catches of orange roughy were made, both in the identification trawls and the commercial trawls (Table C-1), in no cases could these be associated with acoustically-detected aggregations which, in the single snapshot of this stratum, were extremely scarce and small. Mark identification in this snapshot was therefore based solely on the nature of the marks. Two

identification trawls (BT55 and BT64) and one random trawl (BT33) were combined for mark identification and backscatter partitioning in the four snapshots of Megabrick. One identification trawl (BT34) was used to identify targets in the single snapshot of Twintits, and the single trawl on Dork on 6 July (Table C-1) for the two snapshots of Dork and Volcano. Details of the catches in all these trawls are given in Table 8, and of the partitioning factors for the hills, derived from the catches, in Table 9.

Distribution

A composite track chart of all snapshots in Stratum 22 and the single snapshot in Stratum 24, showing the distribution of detected orange roughy aggregations is shown in Figure 16, and more detail of the snapshots in Stratum 22 (including the tracks of the trawls used in target identification), is in Figure 17. Cruise tracks and distributions for the individual snapshots in this stratum, and for the single snapshot of Stratum 24 (including the tracks of the trawls used for target identification there) are given in Figures 18 to 23. These figures show that orange-roughy aggregations on flat ground were largely concentrated between the 880 and 900 m contours to the northeast of the Pinnacles at the time of the acoustic survey. A comparison between the distribution in Figure 18 (Snapshot 1) and those in Figures 21 and 22 (Snapshots 3 and 4), suggests that there was a shift in distribution to the east, away from the Pinnacles, over the 3 to 4-day period of those snapshots.

Figure 24 shows the tracks and locations of orange roughy-like marks for the snapshots of the hills. The marks covered all sides of the hill on Megabrick and Dork, but were concentrated on the northern and eastern sides of Twintits and Volcano, in the latter case over the rim of the crater rather than the crater itself (see Figure 15), as in previous surveys of Volcano (e.g. Doonan et al., 2009, 2010).

Biomass estimates

Biomass and c.v. estimates for all of the snapshots of Stratum 22 from which estimates could be extracted, and for the single snapshot of Stratum 24, are shown in Table 10. This table also shows the percentage of the estimate contributed by B-category targets, which was particularly large for Snapshots 2A and 2B in Stratum 22 and 100% in the snapshot of Stratum 24, and the dead zone corrections, which were small throughout. Note that the sum of the estimates for Snapshots 2A and 2B has been used in computing the mean for Stratum 22 on the assumption that the two snapshots covered different parts of the population – i.e. that the fish had not simply moved from one survey area to the other during the course of the two snapshots. The c.v. in parenthesis was calculated from the variation between the snapshot estimates, rather than from the c.v.s in the individual snapshots.

Table 11 sets out the biomass estimates, c.v.s, dead-zone corrections and partitioning factors for all snapshots of the hills (there were no Category-B targets in these snapshots). The c.v. in parenthesis for the mean of the Megabrick estimates was calculated from the variation between the snapshot estimates, rather than from the c.v.s in the individual snapshots, as in all other entries. The parentheses around the partitioning factor for Volcano indicate that it was based on a trawl on a nearby hill (Dork), there being no trawls on Volcano itself during this survey. Aspects to note are the consistency of the different estimates for the same hill, and the relatively low dead-zone corrections throughout, which is a consequence of the densities being generally low close to the bottom, and zero on Volcano. The lower partitioning factors on Dork and Twintits compared to that on Megabrick is largely due to the higher proportion of spiky oreo *Neocyttus rhomboidalis* in catches on these two hills (12.6 and 3.4% by number respectively) compared to that in the catches on Megabrick (0.6%). Note that the lack of trawls on Volcano makes the partitioning factor for this hill, and therefore the biomass estimate derived using it, the least reliable of those in Table 11.

4. DISCUSSION

4.1 Biology

Table 3 and Figure 3 indicate that the orange roughy sampled in the different acoustic strata of the Pinnacles area were of similar size, whereas the single trawl on Dork suggests that the fish on the

Westpac Bank were somewhat larger. The modes in the male and female distributions are consistent with those in the four previous trawl surveys, which for the whole southwest Challenger Plateau ranged between 28–30 cm and 29–32 cm for males and between 29–31 and 31–33 cm for females (Doonan et al. 2010). The length distributions in Figures 4 and 5 and the mean lengths and weights in Table 4 suggest that orange roughy on the Central Flats (Strata 1, 3 and 4) and in Stratum 25 were somewhat smaller than on the Pinnacles and the Pinnacle Flats, although note from Figures 4 and 5 the relatively small number of fish in the length distributions from these strata.

The maturation of females in the survey is compared with that in previous years in Table 12, which gives the dates in each survey by which the percentage of females in Stage 3 (maturing) had dropped to 35% and the spent (Stage 6) percentage risen to 20%. The data for 2011 were taken from Figure 7, and those for the earlier years from figures in Doonan et al. (2010) for the Pinnacles area.

From this it would appear that in terms of the timing of the spawning cycle in the Pinnacles area (where all but one of the trawls in 2011 were carried out), 2011 was more similar to the two previous years than to 2005 and 2006, when spawning appears to have started and ended a few days earlier. It also appears from Table 12 that the duration of the spawning in 2011 was unusually long compared to that in the other four years.

4.2 Distribution

The fact that the trawl and the acoustic survey both recorded highest densities of orange roughy in much the same area (i.e. on the Pinnacles and over flat ground to the northeast of them) is corroborative evidence that orange roughy, whether aggregated or not, were concentrated in this area at the time of the survey, as has been found in the trawl and acoustic surveys of the southwest Challenger Plateau since 2005 (Clark et al. 2005, 2006, Doonan et al. 2009, 2010). The finding of orange roughy on all four of the hills surveyed (assuming that the unidentified marks on Volcano were indeed orange roughy) is also consistent with the earlier surveys, as is the fact that there was a larger proportion of spiky oreo on Dork than on Twintits and Megabrick.

The acoustic marks over both the flat areas and on the hills were also similar in nature and location to those detected in the previous surveys, with reasonably well-defined aggregations in Stratum 22, strong marks covering the top of Megabrick, Twintits and Dork and the crater rim of Volcano, and weak marks barely discernable above the bottom in places elsewhere. Examples from previous surveys are shown as figures 5 to 8 in Clark et al. (2005), figure 2 in Clark et al. (2006), figures 6 and 7 in Doonan et al. (2009) and figures 6 to 8 in Doonan et al. (2010).

It would therefore appear as if both the distribution and behaviour of orange roughy in the area during the spawning season have been consistent in recent years, an exception being the lack of aggregated orange roughy in Stratum 24 in the current survey as opposed to 2009, when about 39% of the acoustically-estimated biomass on the Challenger Flats was found in this stratum (from table 14 in Doonan et al. 2009). Note however, from Table C-1 and Figures 8 and 10 that a number of large orange roughy catches were made in this stratum in the current survey, and from Table 5 that the biomass estimate from the trawl survey of Stratum 24 is relatively high compared to most of the other strata.

4.3 Biomass estimates

Trawl survey

In that all the flat strata in the trawl survey of the Challenger Flats were sampled at least three times (the prescribed minimum) by trawls which in almost all cases ran for the prescribed length of 1.5 n.miles and were classified as good (see Table C-1), the trawl survey of this area can be judged to have been successfully executed. This is borne out by the c.v.s, which are only slightly above the target of 30%. In contrast, the two random trawls in Stratum 10 (one on Megabrick and the other on Twintits) and the single identification trawl on Dork are too few in number for the estimation of biomass on the hills, even had they been unbiased and random (which is unlikely given the practical restrictions on towing direction, and difficulties in controlling and estimating the effective swept area in trawl surveys of orange roughy on hills, see e.g. Clark 1994). We have therefore discarded these trawls for biomass estimation purposes, while noting the large effect that removing Stratum 10 has on the estimates of total biomass in Table 6.

The biomass estimates in Table 6 of 19 769 or 17 951 t for the Challenger Flats (depending on the length assumed for trawl BT24) are regarded as the most defensible of the estimates from the trawl survey, and the most comparable with estimates of dispersed orange roughy from the previous trawl surveys (see later discussion).

Acoustic survey

The acoustic estimate of aggregated orange roughy biomass in Stratum 22 shown in Table 10 is well founded, being based on four snapshots in which the aggregations and the areas which they occupied were reasonably well defined, and their identity satisfactorily confirmed by the six trawls used in target identification. The c.v. estimate based on the difference between the snapshot estimates (14.2%) reflects the consistency of the estimates and is within the target of 15%. Note however, that the estimator itself is poor, being based on only four estimates, and that the estimate based on the c.v.s of the individual snapshots (22.3%) is considerably higher. It must also be appreciated that the sampling c.v., however estimated, greatly underestimates the uncertainty of the survey since it excludes the uncertainties in target strength, partitioning factors, calibration corrections and errors in corrections for dead zone, weather and sound absorption.

The low estimate for Stratum 24 (108 t) is more questionable because of the high c.v. (56.1 %) and the fact that it is based on a single snapshot. Nonetheless there seems little doubt that the aggregated biomass in this stratum was probably insignificant compared to that in Stratum 22, despite the number of large orange roughy catches in the random, commercial and identification trawls there (Table C-1 and Figures 8 and 10).

The acoustic estimates in Table 11 for the hill strata are generally of less value than those for the flat strata, primarily because of the species mixture in the catches used for target identification, which leads to considerable uncertainty in the partitioning factor, which is particularly sensitive to errors in species composition because of the low target strength per unit weight of orange roughy compared to that of most of the other species present (e.g. Boyer & Hampton 2001, Macaulay et al. 2001, Clark et al. 2005, 2006). The estimate of most quantitative value appears to be that for Megabrick because of the fact that there were four snapshots there, yielding estimates which did not differ greatly (note the c.v. of 18.8% in Table 11), and the relatively high proportion of orange roughy in the catches used for target identification (99.4 %). At the other extreme, the estimate for Volcano must be regarded as of least quantitative value due primarily to the lack of an identification trawl on this hill, exacerbated by the high c.v.s of the individual snapshots and the relatively high proportion (12.6 %) of other species in the trawl used to calculate the partitioning factor.

Comparison with previous estimates

In Table 13 the trawl and acoustic estimates of orange roughy biomass on the Pinnacle Flats are compared with previous estimates there. It is assumed in comparing the trawl estimates that the performance of the net in the current survey was the same as that in the previous surveys, which seems reasonable from comparison of the gear parameters recorded in Table E-1, Appendix E. Comparison with the trawl estimate in 2005 was not attempted since the trawl survey in that year did not cover Stratum 24, where 76% of the biomass in 2006 was found (Clark et al. 2006). For the purposes of comparison the trawl estimates have been standardised on the strata surveyed in 2006, which required removal of Stratum 25 from the three most recent surveys. The reduction in the estimates was less than 1% in all cases. The acoustic estimates for 2005 and 2006 have been re-calculated using the target strength expression of Macaulay et al. (2008) rather than the expression;

$$TS = 16.15 \, Log \, L - 74.34$$

used by Clark et al. (2005, 2006), on the assumption that the aggregations contained no species other than orange roughy. The effect was to increase all estimates by a factor of 1.77.

The 2011 trawl estimate is significantly higher at the 95% level than the corresponding estimate in 2010 (t value 2.02) and significantly lower than the 2009 estimate (t=1.98). The difference between the 2011 and 2006 estimates is not significant at this level (t= 0.70). There is a similar pattern in the acoustic estimates of the aggregated component between 2009 and 2011, although in this case the difference between the 2010 and 2011estimates is barely significant at the 95% level (t= 1.63) whereas the differences between the 2011 estimate and the acoustic estimates in 2005 and 2006 are both highly significant (t = 3.1 and 3.6 respectively).

It is important to appreciate that comparison of the trawl estimates is compromised to some extent by the fact that prior to 2010 there was no requirement that trawls which were believed to have sampled an aggregation be rejected. While there is no conclusive evidence that any of the random trawls in these surveys had in fact done so, it appears possible that this may have happened in 2009 (at least) when three trawls, all of which made large catches, had to be shortened to avoid even larger catches. Removal of these trawls (which is proper if the trawl survey is to estimate only the dispersed component of the population), reduces the biomass estimate for the 2006 strata to 35 545 t (from data in table 7 of Doonan et al. 2009), demonstrating the need for a consistent protocol for handling these situations. In particular, criteria for deciding on whether or not the trawl entered an aggregation at any stage need to be agreed upon and rigorously implemented in future surveys.

In Table 14 the estimates of the biomass of other common species taken in the trawl survey and the c.v.s are compared with the estimates from the previous four surveys. It will be seen that most of the species taken in the 2011 survey were caught in the earlier surveys too, and that the species composition in the surveys is broadly similar, particularly regarding the prevalence of various species of dogfish in all of the surveys. A noticeable exception is the comparatively low abundance of spiky oreo in the current survey, but this could be because there were far fewer tows on the hills than in previous years because of the poor weather. It should also be noted that the comparability between the years is compromised to some extent by the fact that the trawl strata were not identical in all the years.

In Table 15 the acoustic estimates on the Pinnacles are compared with those from the two previous surveys, as reported in Doonan et al. (2009, 2010). We have not attempted a comparison with the estimates from the surveys in 2005 and 2006 since the partitioning factors used in those surveys, which were calculated using the earlier target strength expression, would have had to have been re-calculated from the species compositions in all the identification trawls using the new expression, which is beyond the scope or purpose of this report. It can be seen that the 2011 estimates are considerably higher than those for the previous year (t=6.36), and are on a similar level to the 2009 estimates. The latter difference is barely significant at the 95% level (t= 1.65).

It should be noted that none of the acoustic estimates in this report have been corrected for the loss of signal due to aeration of the near-surface water, which is unlikely to have been negligible in any of the surveys. For example, in eight surveys of orange roughy in the spawning plume on the North Chatham Rise from FV *San Waitaki* between 2002 and 2009, the average negative bias from this source was estimated through modeling studies based on the reduction in the strength of the bottom signal in poor weather at between 20 and 40% (Cordue 2010). The bias could well have been even greater on FV *Thomas Harrison*, which is a considerably smaller vessel than FV *San Waitaki* (length: 42 m compared with 64 m) and is therefore probably a less stable platform for acoustic work.

Total population size

Given that, with the possible exception of the acoustic estimate on Megabrick, neither the trawl nor the acoustic estimates of orange roughy biomass on the hills are regarded as of much quantitative value, the question arises as to whether the much better-founded trawl and acoustic estimates on the flats can be used in any way to yield an absolute estimate of spawning biomass there. In principle, if the trawl and acoustic estimates can be regarded as absolute estimates of the dispersed and aggregated components respectively, the two estimates could simply be added to estimate the total biomass. In practice, uncertainty about the catchability coefficient (*q*) for orange roughy has precluded the use of this approach in combined trawl and acoustic surveys of orange roughy in New Zealand and elsewhere (e.g. Boyer & Hampton 2001, Hampton et al. 2007, Doonan et al. 2010). A way forward has recently been proposed by P. L. Cordue, Innovative Solutions, Wellington, New Zealand (pers. comm.) who has developed a model-based approach for estimating q indirectly by comparing trawl and acoustic estimates of the orange roughy density in layers on the bottom which are both well enough defined to be assessable acoustically but sufficiently dispersed to be assessed by trawl. Uncertainty in the acoustic estimates (which are treated as absolute) arising from uncertainty in target strength and sampling error is included in the model to fix error bounds on the estimate of q. The model is currently being tested on trawl and acoustic data from the surveys of the Challenger Plateau between 2005 and 2010. Alternatively, or perhaps in addition, experiments using a combination of optical and acoustic sensors mounted on the net could be conducted on suitably concentrated layers to observe herding and escapement, and so estimate q and the uncertainty in it directly.

A further problem in combining estimates of the dispersed and aggregated components arises from the fact that the proportion of population that is aggregated could vary substantially during the survey. This could introduce a significant bias if the trawl and acoustic surveys do not cover the same time period, and could inflate the c.v. in the trawl estimate and any c.v.s in the acoustic estimate based on the variation between snapshot estimates. However, provided the aggregated proportion remains constant during the relatively short span of each snapshot, c.v.s based on the c.v.s in the individual snapshot estimates should not be affected.

Considering the particular difficulties of estimating orange roughy biomass on the hills, whether by trawl or acoustic survey, we recommend that future trawl and acoustic surveys of this area be concentrated on the flat ground, particularly Stratum 22, where the trawl and acoustic estimates on flat ground have been highest in all surveys since 2005, and where there is the greatest chance of obtaining reliable trawl and acoustic estimates. By devoting considerably less survey time (if any) to the hills, it should be possible to conduct sufficient acoustic snapshots of the key flat areas to estimate the c.v. from the variation between the estimates (the more robust estimator provided there are enough snapshots), and perhaps obtain a measure of the stability of the aggregated component of the population in these areas as well. Note that it would be important from the point of view of combining the estimates in some way that the trawl and acoustic surveys cover the same time period. Time could also be allowed to collect data for model-based estimates of q or for experiments to estimate it directly, although such studies need not necessarily be done in the same area or at the same time, as long as the same vessel and gear are used, and the orange roughy layers in the experiments are similar to those in the survey area.

5. CONCLUSION

Overall, it is concluded that the survey was successful in generating relative trawl and acoustic estimates of orange roughy biomass in the flat areas within the EEZ during the spawning period which are comparable with previous estimates for this area, and that have sampling c.v.s within, or close to, the targets set for these surveys. The trawl estimate of the dispersed component of the population is significantly higher than the comparable estimate from the 2010 survey, as is the acoustic estimate. Both estimates are significantly lower than the equivalent estimates from the 2009 survey. The acoustic estimate of aggregated orange roughy on the hills within the EEZ (Megabrick and Twintits) is about four times greater than the equivalent estimate in 2010, and is closer to the high estimate in 2009. We caution however that 64% of the biomass comes from Twintits where there was only one snapshot and one mark-identification trawl, as opposed to the much better-founded estimate on Megabrick. Nothing quantitative can be concluded from this survey about the biomass of dispersed or aggregated orange roughy outside the EEZ, since all but one of the planned trawls on the Westpac Bank, and most of the snapshots, had to be abandoned due to the exceptionally poor weather.

We consider that future trawl and acoustic surveys of the southwest Challenger Plateau should concentrate on the flat areas because of the difficulties in obtaining defensible estimates of biomass on the hills by either method. We recommend that future surveys of the flats should aim to a) improve the c.v. in the acoustic estimate by increasing the number of snapshots, b) quantify the relative stability of the dispersed and aggregated components of the population during the spawning period, and c) collect data for improving estimates of q, either through modeling or direct observation. All these activities would improve the prospects of ultimately being able to combine the trawl and acoustic estimates into a single absolute estimate of population size which, if sufficiently accurate, is likely to be the estimate of most value for management purposes.

6. ACKNOWLEDGEMENTS

This survey posed exceptional challenges in that for the first time commercial catching was part of the voyage plan, and indeed was considered to be the most important objective. Managing the sometimes conflicting requirements of surveying and commercial fishing, which was severely aggravated by bad weather and the consequent loss of survey time during the voyage, was a difficult task. The fact that so much was achieved in spite of this is a tribute to the excellent co-operation and helpfulness of the officers and crew of FV *Thomas Harrison*, whom we thank most sincerely. We also wish to acknowledge the excellent assistance from the MAF (now MPI) Observer (Ben Dillon) who was interested, keen to learn and fitted in seamlessly as part of the scientific team.

7. REFERENCES

Boyer, D.C.; Hampton, I. (2001). Development of acoustic techniques for assessment of orange roughy (*Hoplostethus atlanticus*) biomass off Namibia, and of methods for correcting for bias. *South African Journal of Marine Science 23:* 223–240.

Clark, M.R.; Francis, R.I.C.C. (1990). Revised assessment of the Challenger Plateau (QMA 7A) orange roughy fishery for the 1989–90 fishing year. New Zealand Fisheries Assessment Research Document 90/1. (Unpublished report held by NIWA library, Wellington.) 17p.

Clark, M. (1994). Aspects of trawl survey design for deepwater species on pinnacle and drop-off features. MAF Fisheries Greta Point Internal Report No. 227.

Clark, M.R.; Tracey, D.M. (1994). Changes in a population of orange roughy (*Hoplostethus atlanticus*) with commercial exploitation on the Challenger Plateau, New Zealand. *Fishery Bulletin 92:* 236–253.

Clark, M.; O'Driscoll, R.L.; Macaulay, G. (2005). Distribution, abundance, and biology of orange roughy on the Challenger Plateau: results of a trawl and acoustic survey, June–July 2005 (THH0501). NIWA Client Report WLG2005-64 prepared for The Orange Roughy Management Company Limited, October 2005. 60p.

Clark, M.; O'Driscoll, R.L.; Macaulay, G.; Bagley, N.W.; Gauthier, S. (2006). Distribution, abundance, and biology of orange roughy on the Challenger Plateau: results of a trawl and acoustic survey, June–July 2006 (THH0601). NIWA Client Report WLG2006-83 prepared for the Deepwater Group Limited, October 2006. 63p.

Cordue, P.L. (2010). Linear-model derived bottom-referenced corrections for the Chatham Rise ORH plume acoustic transects. Presentation to New Zealand Deep Water Fisheries Assessment Working Group, 23 April 2010. (Unpublished presentation held by Ministry for Primary Industries, Wellington.)

Doonan, I.; Coombs, R.; Barr, R.; McClatchie, S.; Grimes, P.; Hart, A.; Tracey, D.; McMillan, P. (1999). Estimation of the absolute abundance of orange roughy on the Chatham Rise. Final Research Report for Ministry of Fisheries Project ORH9701. (Unpublished report held by Ministry for Primary Industries, Wellington.) 68 p.

Doonan, I.; Bull, B.; Coombs, R. (2003a). Star acoustic surveys of localized fish aggregations. *ICES Journal of Marine Science 60:* 132–146.

Doonan, I.; Coombs, R.; McClatchie, S. (2003b). The absorption of sound in seawater in relation to the estimation of deep-water fish biomass. *ICES Journal of Marine Science 60:* 1047–1055.

Doonan, I.; Boyer, D.; Hampton, I.; Macaulay, G.; Nelson, J.C.; Parkinson, D. (2009). Abundance, distribution and biology of orange roughy on the southwest Challenger Plateau (area ORH7A): results of a trawl and acoustic survey, June-July 2009. Client Report by National Institute of Water and Atmospheric Research, Wellington, and Fisheries Resource Surveys, Cape Town to Sealord Group Ltd, Nelson, New Zealand. 79p.

Doonan, I.J.; Parkinson, D.; Gautier, S. (2010). Abundance, distribution and biology of orange roughy on the southwest Challenger Plateau (area ORH7A): results of a trawl and acoustic survey, June-July 2010. NIWA Client Report: Deep Water Working Group 2010-63. 64 p.

Dunford, A.J. (2005). Correcting echo-integration data for transducer motion. *Journal of the Acoustical Society of America 118(4):* 2121–2123.

Field, K.D.; Francis, R.I.C.C. (2001). CPUE analysis and stock assessment of the Challenger Plateau orange roughy stock (ORH 7A) for the 2000–01 fishing year. *New Zealand Fisheries Assessment Report 2001/25.* 19 p.

Foote, K.G.; Knudsen, H.P.; Vestnes, G.; MacLennan, D.N.; Simmonds, E.J. (1987). Calibration of acoustic instruments for fish density estimation: a practical guide. *ICES Cooperative Research Report 144.* 68 p.

Francis, R.I.C.C. (1984). An adaptive strategy for stratified random trawl surveys. *New Zealand Journal of Marine and Freshwater Research 18:* 59–71.

Hampton, I.; Soule, M.A. (2003). Acoustic survey of orange roughy biomass on the North East Chatham Rise, 9–22 July 2002. Deep Water Fisheries Assessment Working Group paper 03/02. (Unpublished paper held by Ministry for Primary Industries, Wellington.) 63p.

Hampton, I.; Soule, M.A.; Leslie, R.W. (2007). Acoustic and trawl survey of orange roughy on Puysegur Bank, and in the Spawning Plume and Northeast hills on the North Chatham Rise, New Zealand, July 2006. Report by Fisheries Resource Surveys to the New Zealand Deepwater Group. 91p.

Jolly, G.M.; Hampton, I. (1990). A stratified random transect design for acoustic surveys of fish stocks. *Canadian Journal of Fisheries and Aquatic Sciences 47:* 1282–1291.

Keith, G.J.; Ryan, T.E.; Kloser, R.J. (2005). ES60Adjust.jar. Java software utility to remove a systematic error in Simrad ES60 data. CSIRO Marine and Atmospheric Research. Castray Esplanade, Hobart, Tasmania. Australia.

Macaulay, G.; Hart, A.; Grimes, P. (2001). Estimation of the target strength of orange roughy by-catch species. Final Research Report for Ministry of Fisheries Research Project ORH1999/01A Objective 2. (Unpublished report held by Ministry for Primary Industries, Wellington). 10 p.

Macaulay, G.; Kloser, R.; Ryan, T. (2008). Visually verified *in situ* target strength measurements of orange roughy from the Chatham Rise, July 2007. Final Research Report (by NIWA and CSIRO) for Ministry of Fisheries Research Project ORH2006-01A Objective 2. (Unpublished report held by Ministry for Primary Industries, Wellington). 43 p.

MacLennan, D.N.; Simmonds, E.J. (1992). Fisheries Acoustics, Chapman and Hall, London, Fish and Fisheries Series 5. 325 p.

MacLennan, D.N.; Fernandes, P.G.; Dalen, J. (1995). A consistent approach to definitions and symbols in fisheries acoustics. *ICES Journal of Marine Science 59:* 365–369.

Pankhurst, N.W.; Conroy, A.M. (1987). Size-fecundity relationships in the orange roughy (*Hoplostethus atlanticus*). *New Zealand Journal of Marine and Freshwater Research 21:* 295–300.

Ryan, T; Kloser, R. (2004). Quantification and correction of a systemic error in Simrad ES60 echosounders. Technical note presented at the ICES WGFAST 2004, Gdynia, Poland. 9 p.

Ryan, T.E.; Kloser, R.J.; Macaulay, G.J. (2009). Measurement and visual verification of fish target strength using an acoustic-optical system attached to a trawlnet. *ICES Journal of Marine Science 66:* 1238–1244.

TABLES

Table 1: Strata in trawl survey, and number of first and second-phase random trawls in each stratum.

Stratum	Description	Area (km^2)	No. Phase 1 tows	No. Phase 2 tows
1	800-900 m, around Central Flat	371	3	0
3	Guard stratum around Central Flat and Pinnacles	945	3	0
4	Central Flat	149	3	0
10	Twin Tits and Megabrick (pinnacles and trenches)	8	2	0
21	Western side of Pinnacles	121	3	0
22	Pinnacles Flats	83	12	1
22A	High-density stratum	107	3	1
23	Eastern Pinnacles Flat	93	10	2
24	Eastern Pinnacles extension	305	15	2
25	Eastern Pinnacles guard stratum	438	3	0
Total		2 619	58	6

Table 2: Dates, number of transects, transect pattern and identification trawls for each of the snapshots used in biomass estimation.

Stratum	Snapshot	Date	No. transects	Transect direction	No. id. trawls
22	1	1-Jul-11	10	E/W	0
22	2A	1-Jul-11	8	N/S	1
22	2B	1-Jul-11	8	N/S	
22	3	4-Jul-11	12	E/W	0
22	4	5-Jul-11	4	E/W	2
24	1	3-Jul-11	14	E/W	3
Megabrick	1	30-Jun-11	4	Radial	0
Megabrick	2	30-Jun-11	5	Radial	1
Megabrick	3	3-Jul-11	5	Radial	1
Megabrick	4	4-Jul-11	5	Radial	2
Twintits	1	30-Jun-11	4	Radial	1
Volcano	1	5-Jul-11	5	Radial	0
Volcano	2	5-Jul-11	5	Radial	0
Dork	1	6-Jul-11	4	Radial	0
Dork	2	6-Jul-11	4	Radial	1

Table 3: Mean length, weight and estimated mean target strength of orange roughy in areas where greatest catches were made, taken from trawls used in acoustic estimation of biomass.

				Mean length	Mean weight	Mean TS
				(cm)	(kg)	(dB)
Area	No. of trawls	Males	Females	All fish	All fish	
Stratum 22	8	30.4	32.6	30.9	1.04	-52.7
Megabrick	4	31.7	34.1	33.0	1.21	-52.3
Twintits	1	31.5	32.6	31.8	1.12	-52.5
Mean: Pinnacles (Flats and hills)	16	31.0	32.9	32.0	1.14	-52.5
Wespac Hills	1	32.8	35.2	34.0	1.31	-52.1

Table 4: Mean length and weight of orange roughy, all trawl strata.

Stratum	1	21	22	22A	23	24	25	3	4	10
Mean length (cm)	28.9	31.8	31.7	32.0	30.9	31.3	29.8	28.7	30.2	31.9
Mean weight (kg)	0.74	1.14	1.12	1.15	1.04	1.07	0.96	0.89	1.00	1.15

Table 5: Number of trawls, biomass estimates for fish 27 cm or more and of all fish, and c.v.s for each stratum in the trawl survey (both phases combined). The figures in parenthesis show the effect of taking the tow distance for Station B24 in Stratum 22 as 1.5 n.miles rather than the actual tow distance of 0.64 n.miles.

Stratum	No. of trawls	Biomass ≥ 27 cm (t)	Biomass (total) (t)	c.v. (%)
1	3	57	72	48.2
21	3	420	525	94.7
22	13	11 646	13 180	43.1
		(10 039)	(11 361)	(45.8)
22A	4	981	1 012	57.1
23	12	1 118	1 143	68.1
24	17	3 155	3 231	64.6
25	3	49	51	52.9
3	3	272	280	77.2
4	3	233	274	26.6
10	2	20 327	20 532	97.6

Table 6: Estimates of total orange roughy biomass and c.v.s from the trawl survey for various analysis variants.

Strata	Variant	Biomass (t)	c.v. (%)
All	Actual tow length for all trawls	40 301	52.0
	Length of trawl BT24 = 1.5 n.mile	38 483	54.1
Stratum 10 removed	Actual tow length for all trawls	19 769	31.1
	Length of trawl BT24 = 1.5 n.mile	17 951	31.9

Table 7: Total biomass and c.v. estimates for other common species in the trawl survey (including stratum 10). Actual tow distances used throughout.

Common name	Code	Biomass (t)	c.v. (%)
Seal shark	BSH	33	37.9
Mahia rattail	CMA	21	33.8
Serrulate rattail	CSE	14	16.5
Leafscale gulper shark	CSQ	194	29.9
Owston's dogfish	CYO	235	20.8
Longnose velvet dogfish	CYP	114	12.8
Deepsea cardinalfish	EPT	32	67.2
Baxters lantern dogfish	ETB	5	37.3
Hake	HAK	246	56.8
Johnson's cod	HJO	66	35.2
Hoki	HOK	107	17.5
Plunkets shark	PLS	31	80.2
Widenosed chimaera	RCH	54	36.8
Ribaldo	RIB	153	20.0
Slickhead, bigscaled brown	SBI	193	63.1
Shovelnose dogfish	SND	324	10.1
Spiky oreo	SOR	79	24.0
White rattail	WHX	373	19.7

Table 8: Catch of major species in trawls used for mark identification in acoustic survey. ID = Identification trawl, CO = Commercial trawl, R = Random trawl.

				Catch (kg)								
Stratum	Station	Type	Total	DOG	EPT	HAK	HJO	HOK	ORH	RIB	SOR	SSO
22	16	CO	11 064	64	0	0	4	7	10 972	13	3	0
	17	CO	10 435	97	0	19	8	0	10 289	11	1	0
	35	ID	8 361	79	0	0	3	0	8 267	11	1	0
	67	ID	17 993	307	0	6	22	8	17 606	18	1	0
	68	CO	17 947	99	0	0	25	5	17 759	14	4	0
	75	CO	20 261	31	0	44	16	2	20 138	10	0	0
24	6	CO	5 185	102	0	9	1	10	5 022	9	3	0
	57	ID	4 866	134	3	22	0	11	4 645	27	5	0
	63	CO	17 113	259	0	17	9	4	16 678	42	1	0
Megabrick	33	R	25 619	0	59	0	8	58	25 380	12	103	0
	55	ID	4 245	34	0	0	3	3	4 163	8	4	0
	64	ID	5 666	6	0	0	3	0	5 536	34	57	1
Twintits	34	R/ID	2 597	18	3	0	3	1	2 462	11	74	3
Dork	69	ID/R	5 784	32	0	0	2	0	5 150	0	599	0

Table 9: Partitioning of backscatter between species in snapshots of Megabrick, Twintits, Dork and Volcano, based on species compositions in Table 8.

Stratum/ Species code	Catch (kg)	Proportion of numbers in catch (%)	Mean length (cm)	Mean target strength (dB)	Proportion of backscatter (%)
Megabrick					
DOG	40	0.048	88.3	-38.1	0.8
HJO	14	0.076	45.2	-33.1	4.1
HOK	61	0.089	84.5	-40.0	1.0
ORH	35 080	98.722	33.0	-52.3	64.3
PLS	48	0.012	141.0	-34.0	0.5
RIB	54	0.190	50.3	-29.8	22.0
SOR	164	0.579	34.0	-39.4	7.2
SSO	1	0.006	33.0	-44.8	0.0
Twintits					
EPT	2	0.044	66.0	-23.6	12.1
HJO	3	0.262	43.5	-33.5	7.4
HOK	1	0.044	80.0	-40.3	0.3
ORH	2 462	95.589	31.8	-52.5	34.1
PLS	21	0.087	141.0	-34.0	2.2
RIB	10	0.306	50.4	-29.8	20.7
SOR	74	3.451	32.7	-39.9	22.8
SSO	3	0.087	40.5	-42.6	0.3
Dork_Volcano					
DOG	32	0.111	94.8	-37.5	1.0
HJO	2	0.089	44.5	-33.3	2.0
ORH	5 150	87.147	34.0	-52.1	26.0
SOR	599	12.608	34.5	-39.3	71.1

Table 10: Acoustic estimates of orange roughy biomass, c.v.s, dead zone corrections and % of biomass classified as Category B in Strata 22 and 24. The estimate for Snapshot 2 was obtained by summing the estimates for Snapshots 2A and 2B. The c.v. in parenthesis was calculated from the variation between the snapshot estimates.

Snapshot	Biomass (t)	c.v. (%)	B-category (%)	Dead zone correction
Stratum 22				
1	11 723	60.5	17	1.08
2A	2 319	41.6	47	1.09
2B	3 277	27.8	25	1.03
3	9 554	28.3	3	1.07
4	10 618	30.7	15	1.06
Mean	9 373	22.3		
		(14.2)		
Stratum 24				
1	108	56.1	100	1.00
Strata 22 and 24 combined	9 481	23.8		

Table 11: Acoustic estimates of orange roughy biomass, c.v.s, dead zone corrections and partitioning factors for hill strata. The c.v. in parenthesis was calculated from the variation between the snapshot estimates.

Snapshot	Biomass (t)	c.v. (%)	B-category (%)	Dead zone correction
Stratum 22				
1	11 723	60.5	17	1.08
2A	2 319	41.6	47	1.09
2B	3 277	27.8	25	1.03
3	9 554	28.3	3	1.07
4	10 618	30.7	15	1.06
Mean	9 373	22.3		
		(14.2)		
Stratum 24				
1	108	56.1	100	1.00
Strata 22 and 24 combined	9 481	23.8		

Table 12: Comparison of orange roughy spawning state in current survey with that in the Pinnacles area on previous surveys.

	2005	2006	2009	2010	2011
Date 35 % Stage 3	26-27 Jun	27-Jun	1-Jul	2-3 Jul-11	29-Jun
Date 20% Spent	3-Jul	29-Jun	4-Jul	5 or 8 Jul	7-Jul

Table 13: Estimates of orange roughy biomass on the Pinnacle Flats from trawl and acoustic surveys between 2005 and 2011. The acoustic estimates for 2005 and 2006 have been re-calculated from the values given in Clark et al. (2005, 2006) using the target strength expression of Macaulay et al. (2008). The trawl estimates have been standardised on the conditions of the 2006 survey, as explained in the text. Values in parenthesis were obtained by taking the length of Trawl BT24 as 1.5 n.miles rather than the actual tow length of 0.67 n.miles.

Survey	2005 Biomass (t)	2005 c.v. (%)	2006 Biomass (t)	2006 c.v. (%)	2009 Biomass (t)	2009 c.v. (%)	2010 Biomass (t)	2010 c.v. (%)	2011 Biomass (t)	2011 c.v. (%)
Trawl	-	-	16 010	27	46 480	30	12 190	19	19 717 (17899)	31 (32)
Acoustic	3 356	49	2 296	72	16 164	26	6 043	13	9 481	24

Table 14: Comparison of biomass estimates (B) and c.v.s for other species in the trawl surveys between 2005 and 2011.

		2005		2006		2009		2010		2011	
Common name	Code	B (t)	c.v. (%)	B (t)	c.v. (%)	B (t)	c.v. (%)	B (t)	c.v. (%)	B (t)	c.v. (%)
Seal shark	BSH	107	44	11	46	61	53	112	42	33	37.9
Mahia rattail	CMA	17	21	24	22	44	34	13	20	21	33.8
Serrulate rattail	CSE	1	48	29	12	26	24	31	13	14	16.5
Leafscale gulper shark	CSQ	342	24	415	18	457	25	308	26	194	29.9
Owston's dogfish	CYO	604	16	451	19	503	24	389	23	235	20.8
Longnose velvet dogfish	CYP	51	30	82	16	176	14	225	15	114	12.8
Deepsea cardinalfish	EPT	3	100	3	100	9	91	20	81	32	67.2
Baxters lantern dogfish	ETB	49	38	59	22	31	14	65	24	5	37.3
Hake	HAK	126	25	90	31	161	17	164	22	246	56.8
Johnson's cod	HJO	39	19	64	16	80	23	133	29	66	35.2
Hoki	HOK	15	69	18	41	146	42	93	43	107	17.5
Plunkets shark	PLS	3	76	41	52	85	36	0	0	31	80.2
Widenosed chimaera	RCH	138	21	102	27	84	27	264	23	54	36.8
Ribaldo	RIB	297	18	339	14	499	20	217	18	153	20.0
Slickhead, bigscaled brown	SBI	140	54	197	22	29	37	367	45	193	63.1
Shovelnose dogfish	SND	306	17	235	16	654	10	239	25	324	10.1
Spiky oreo	SOR	135	48	174	33	272	46	342	43	79	24.0
White rattail	WHX	211	18	317	16	385	32	333	20	373	19.7

Table 15: Acoustic estimates of orange roughy biomass on the Pinnacles (Megabrick and Twintits) in 2009, 2010 and 2011. Estimates for 2009 and 2010 from Doonan et al. (2009, 2010).

Hill	2009 Biomass (t)	2009 c.v. (%)	2010 Biomass (t)	2010 c.v. (%)	2011 Biomass (t)	2011 c.v. (%)
Megabrick	6 114	51.4	664	33	1 241	17.5
Twintits	1 132	45	190	28	2 235	22.2
Megabrick + Twintits	7 246	43.9	854	26	3 476	15.6

FIGURES

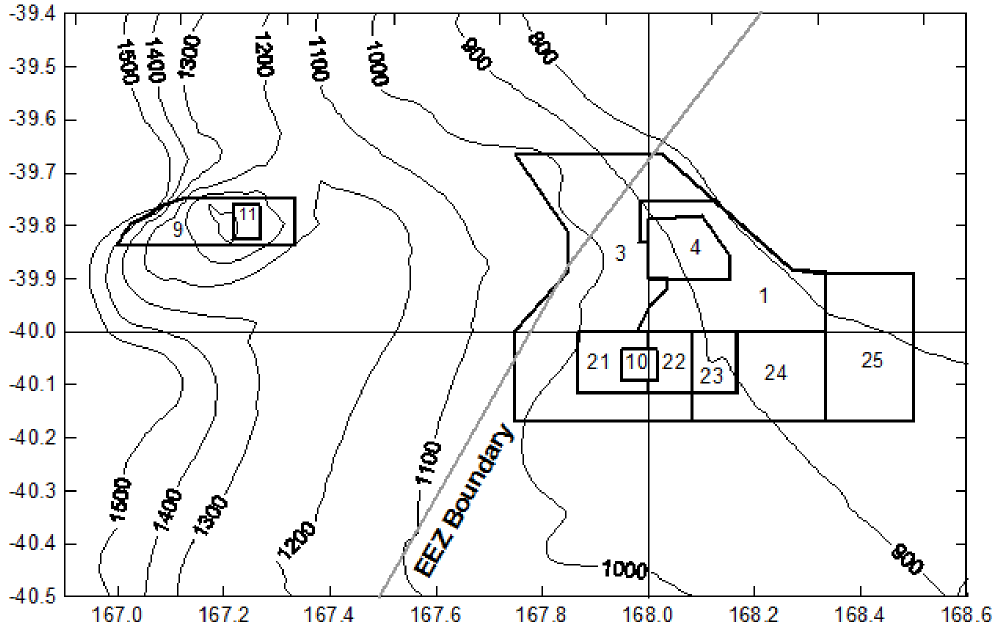

Figure 1: Survey area showing strata in trawl survey.

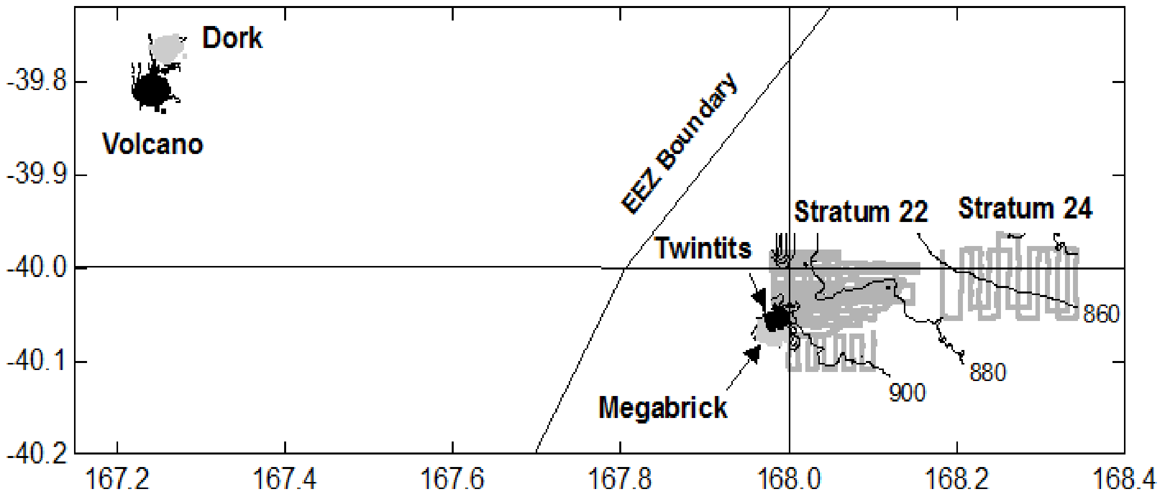

Figure 2: Locations and tracks of acoustic snapshots.

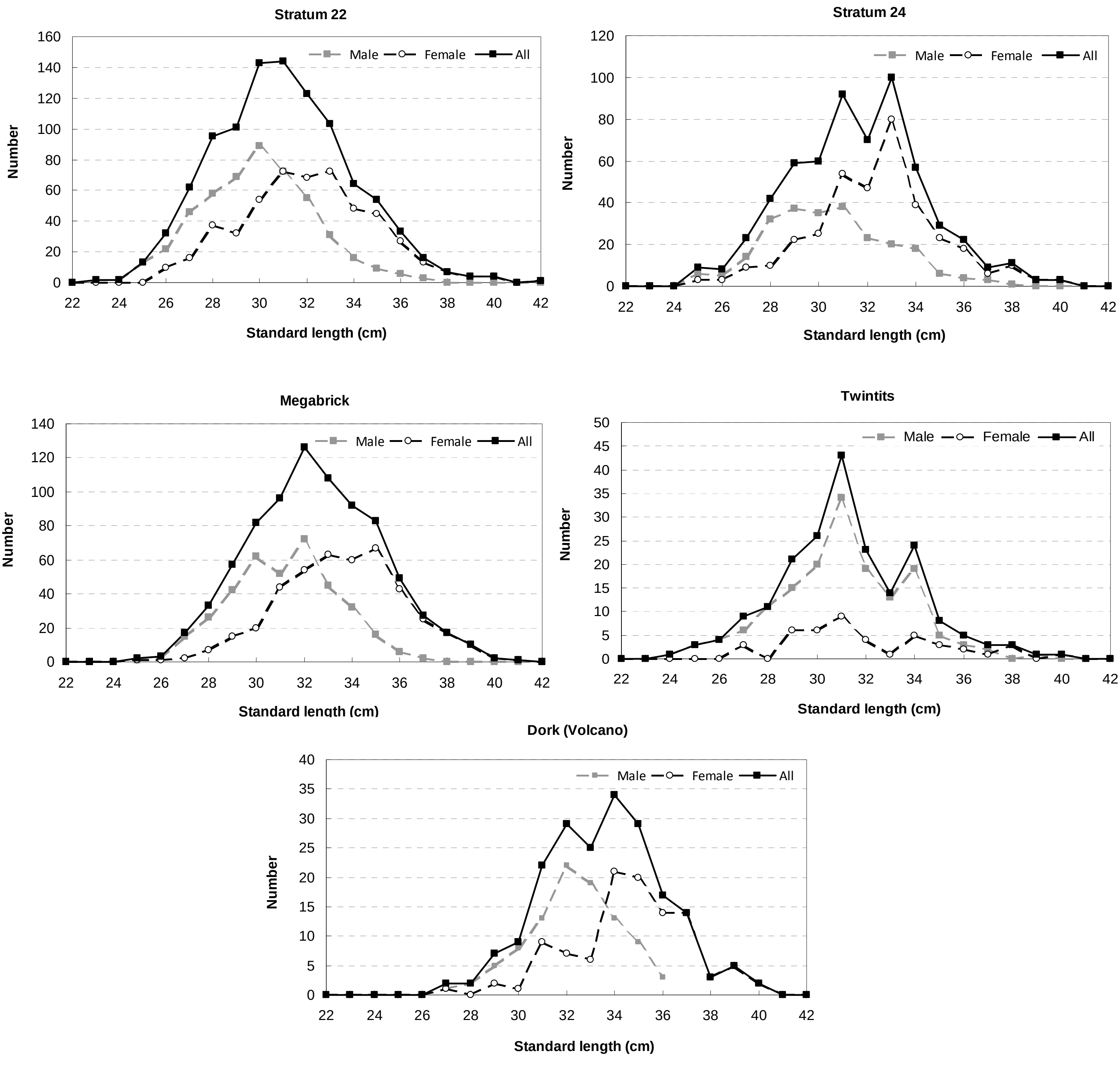

Figure 3: Length distribution of orange roughy in trawls used for mark identification in Strata 22 and 24, and on Megabrick, Twintits and Dork (Volcano).

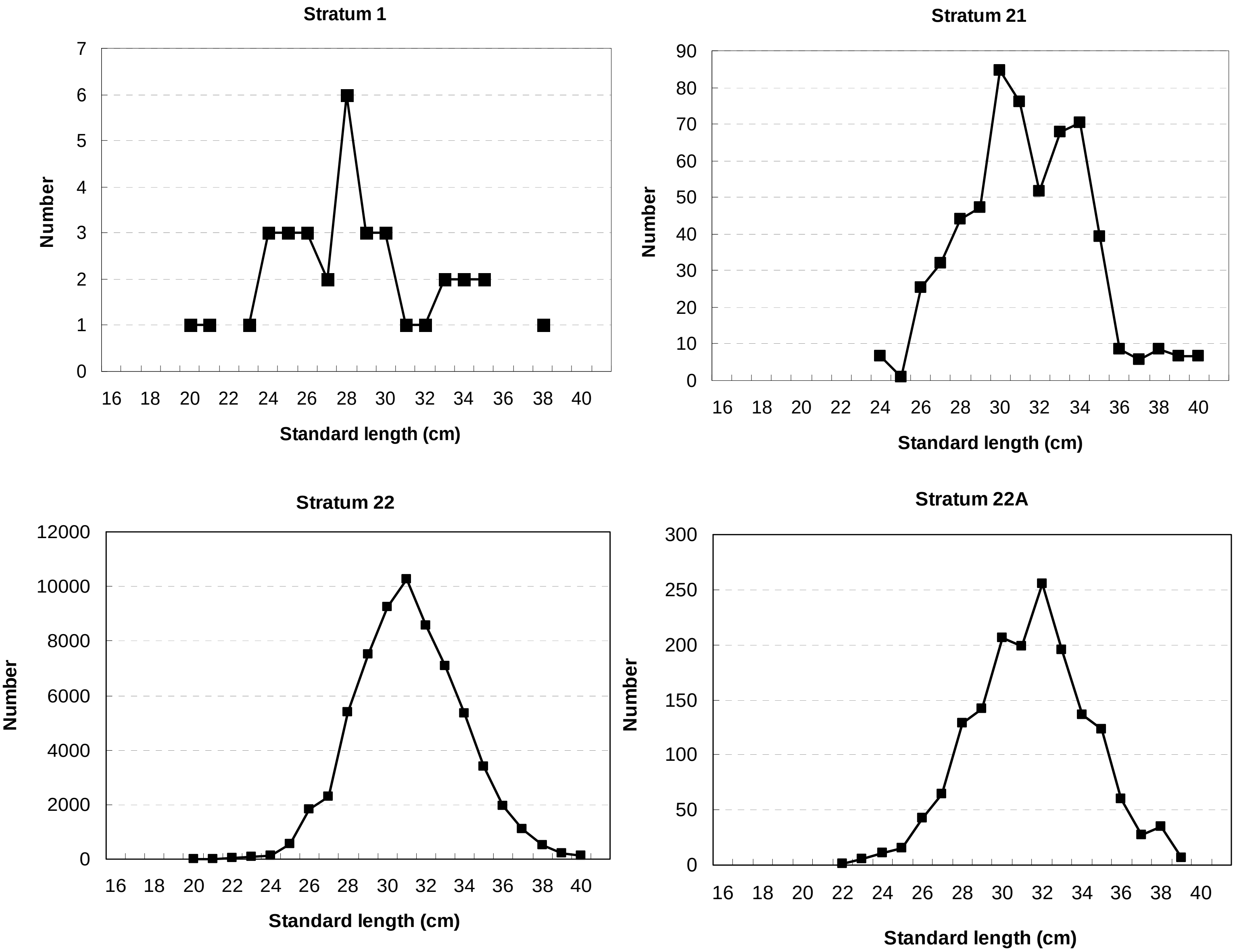

Figure 4: Length distribution of orange roughy in random trawls in Strata 1, 21, 22 and 22A of trawl survey.

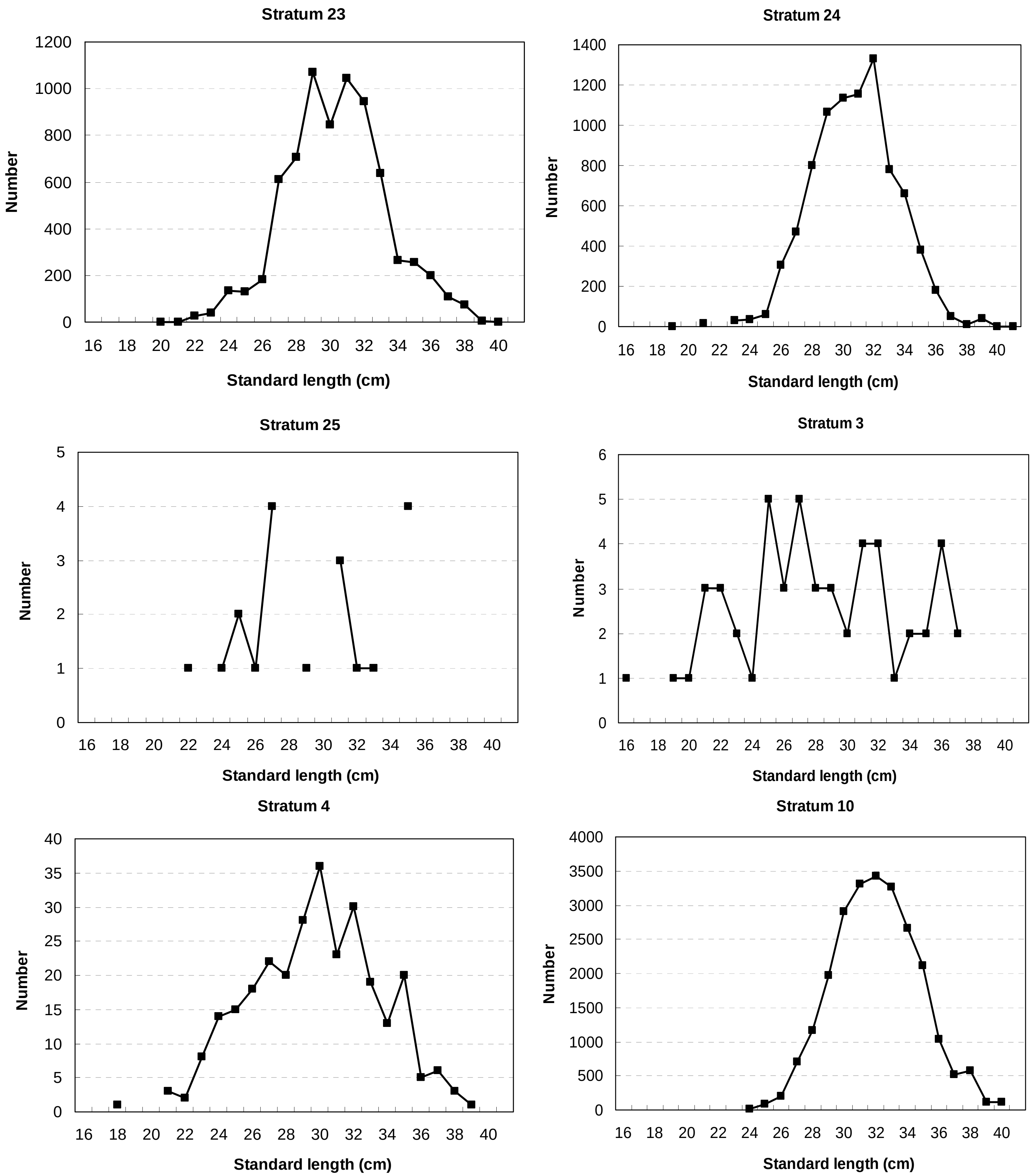

Figure 5: Length distribution of orange roughy in random trawls in Strata 23, 24, 25, 3 and 10 of trawl survey.

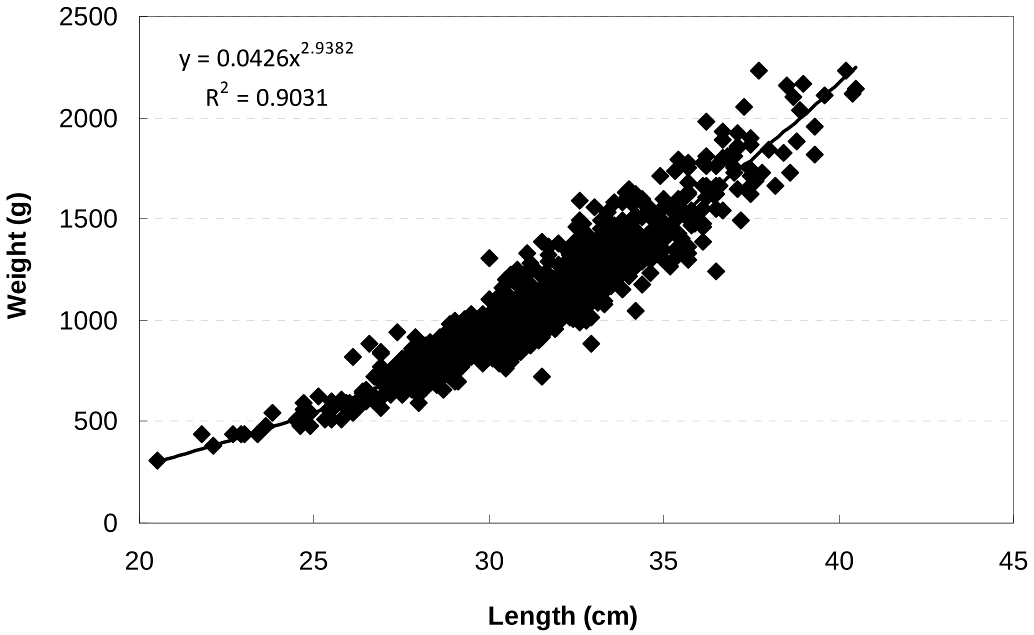

Figure 6: Orange roughy length/weight relationship from measurements during survey.

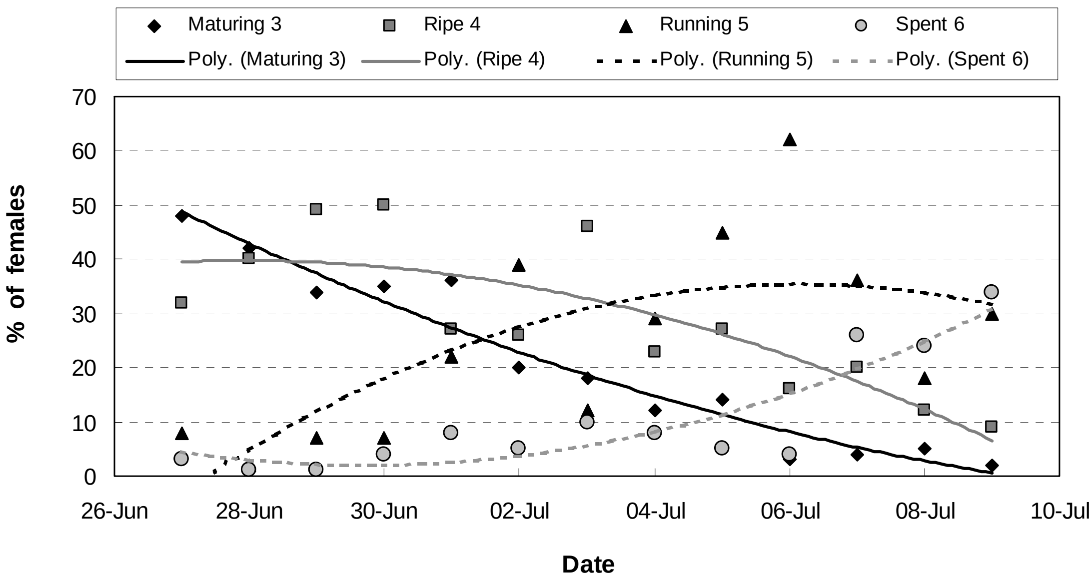

Figure 7: Progression of female gonad maturity stages by date (all strata). Curves from polynomial fit to data.

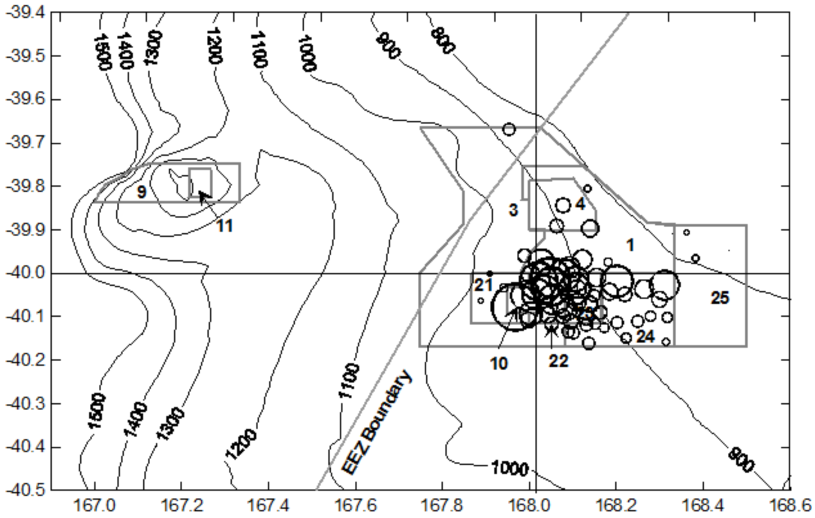

Figure 8: Catch rates in the random stratified trawl survey. Circle diameter is proportion to log of catch rate. Maximum catch rate (in Stratum 10)was 85.6 t km^{-1}.

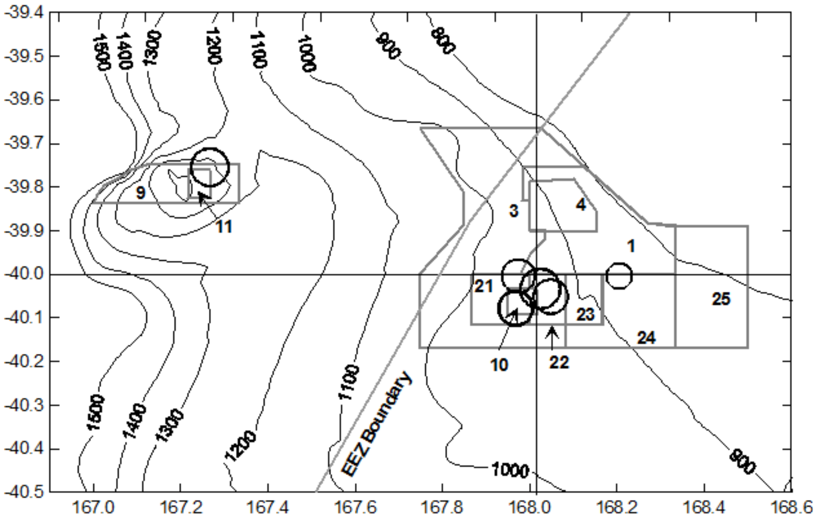

Figure 9: Catch rates in identification trawls in the acoustic survey. Circle diameter is proportion to log of catch rate. Maximum catch rate 15.4 t km^{-1}.

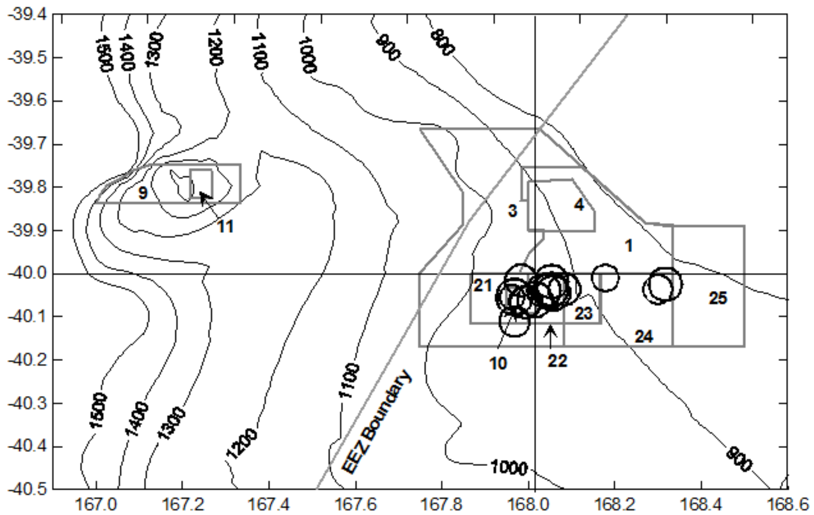

Figure 10: Catch rates in commercial trawls used in the acoustic survey. Circle diameter is proportion to log of catch rate. Maximum catch rate 6.63 t km^{-1}.

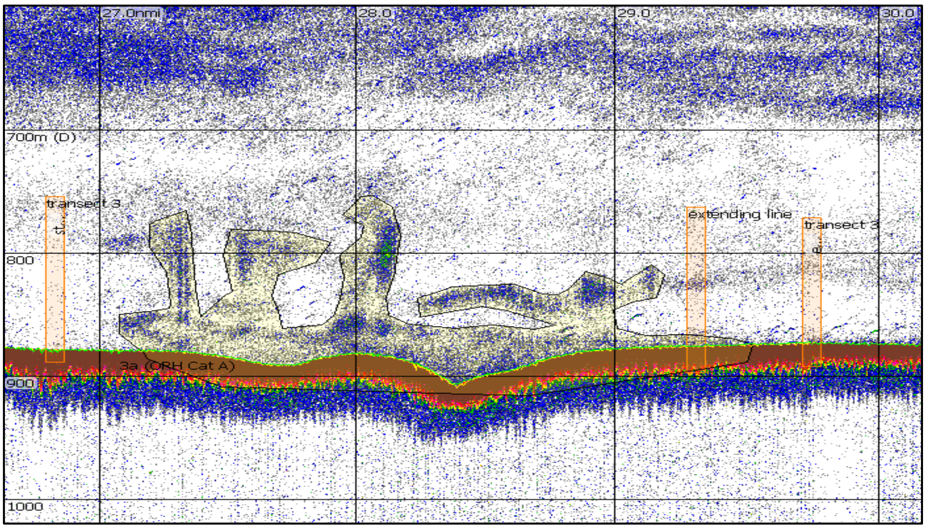

Figure 11: Orange roughy marks during Snapshot 3 of Stratum 22. The vertical lines are 1 n.mile apart.

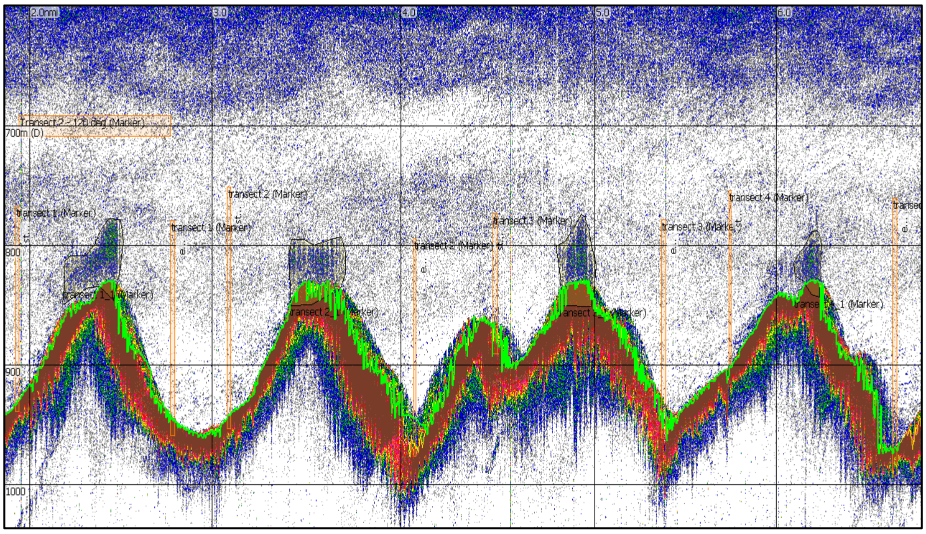

Figure 12: Orange roughy marks during Snapshot 1 of Megabrick. The vertical lines are 1 n.mile apart.

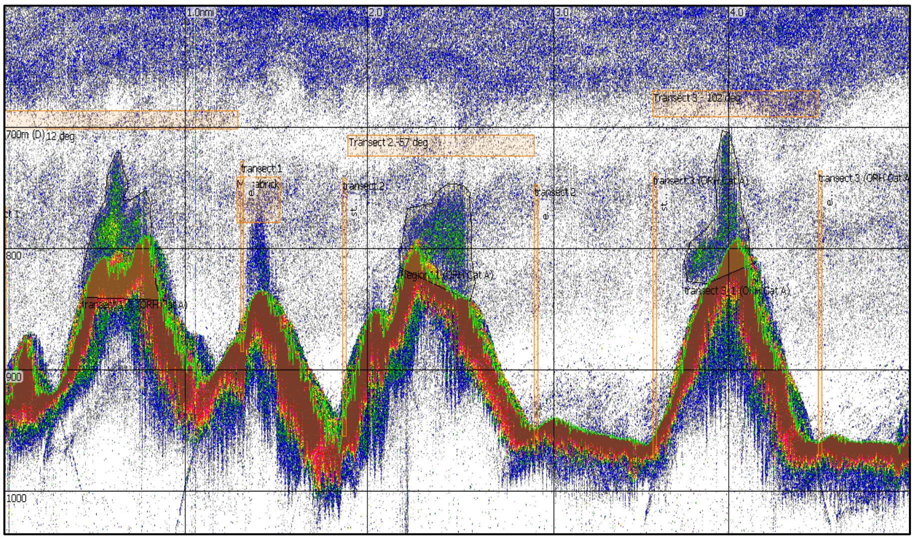

Figure 13: Orange roughy marks during Snapshot 1 of Twintits. The vertical lines are 1 n.mile apart.

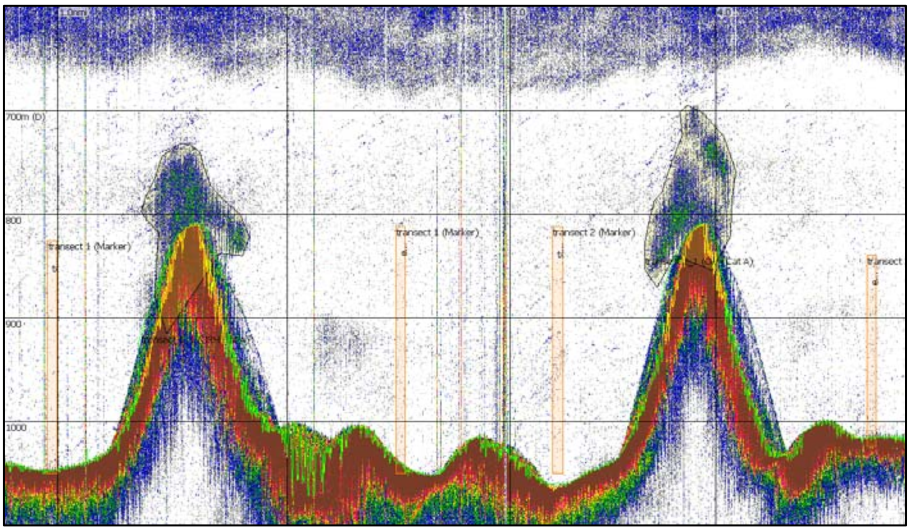

Figure 14: Orange roughy marks during Snapshot 2 of Dork. The vertical lines are 1 n.mile apart.

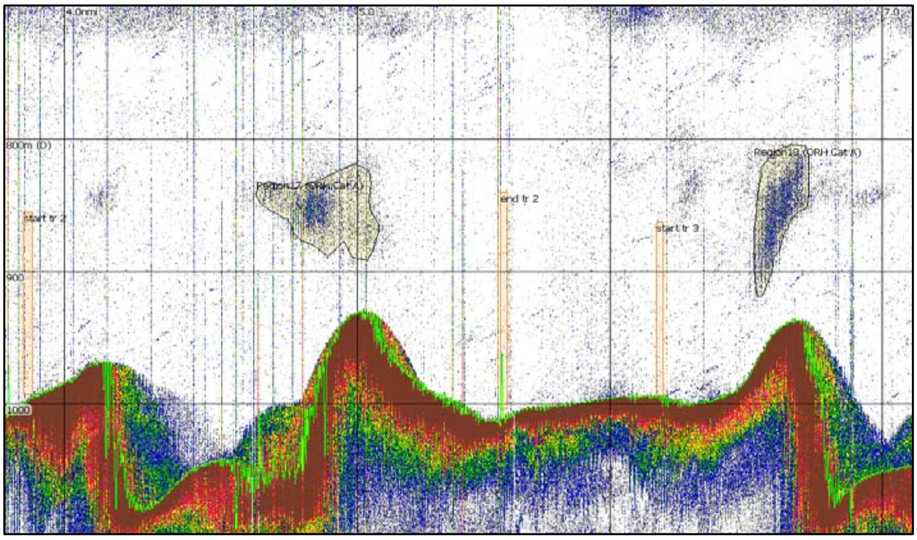

Figure 15: Orange roughy-like marks during Snapshot 1 of Volcano (not identified by trawl). The vertical lines are 1 n.mile apart.

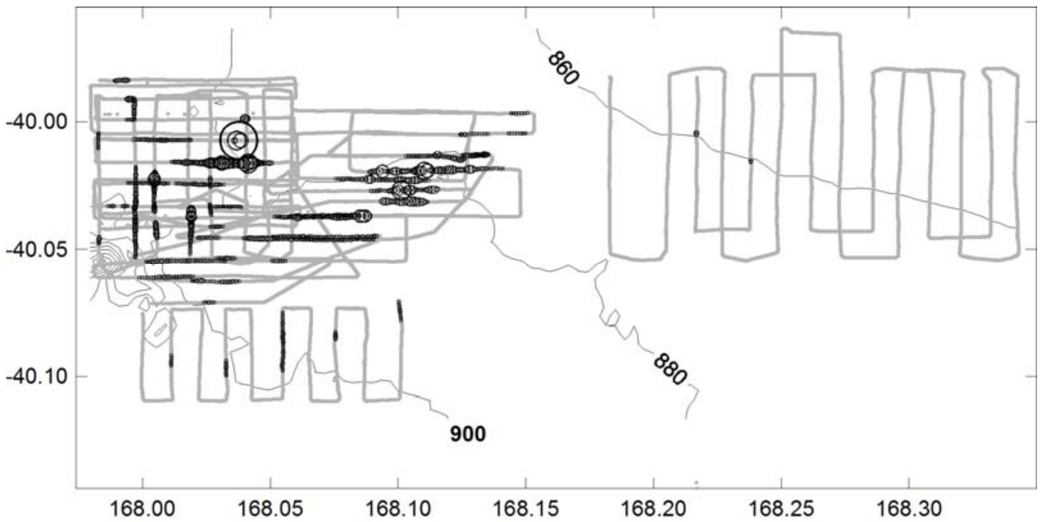

Figure 16: Tracks and orange roughy distribution in all snapshots of Strata 22 and 24. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Maximum 950 m^2 n.mile^{-2}.

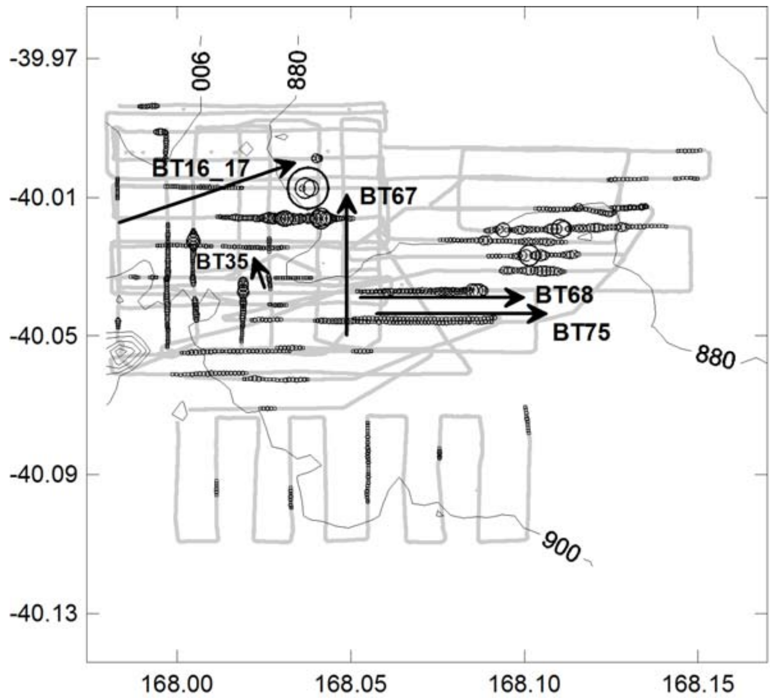

Figure 17: Detail of survey grids, orange roughy marks and tracks of trawls used for mark identification in Stratum 22. The arrows mark the ship's position during the trawls. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Maximum is 950 m^2 n.mile^{-2}.

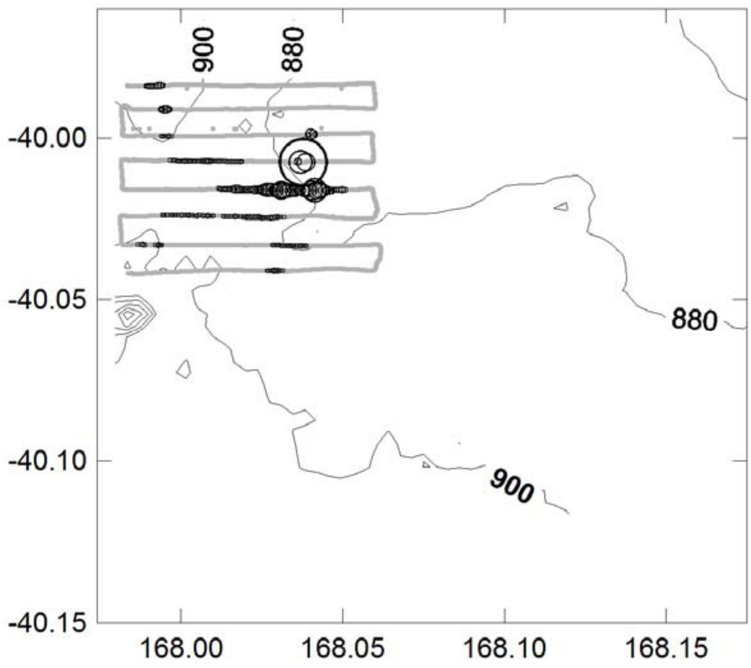

Figure 18: Survey tracks and orange roughy distribution, Snapshot 1, Stratum 22. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Maximum is 950 m^2 $n.mile^{-2}$.

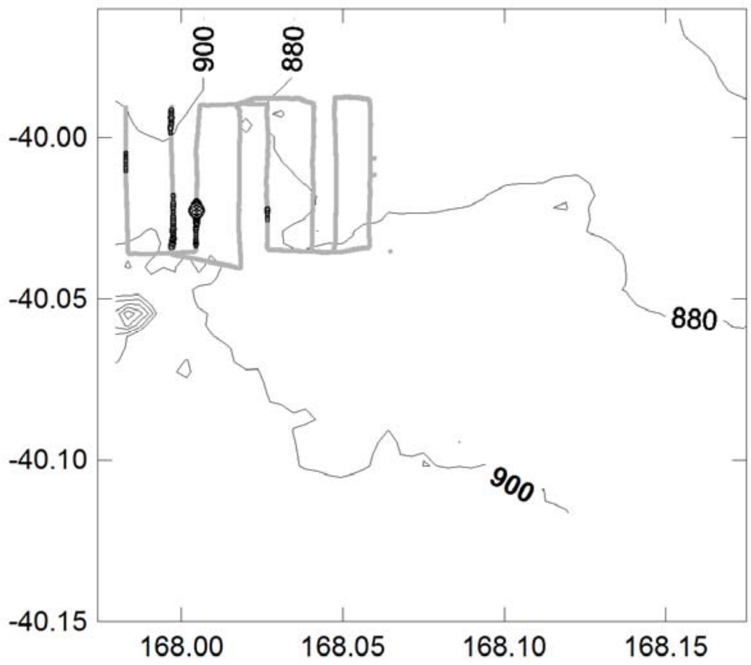

Figure 19: Survey tracks and orange roughy distribution, Snapshot 2A, Stratum 22. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Maximum is 950 m^2 $n.mile^{-2}$.

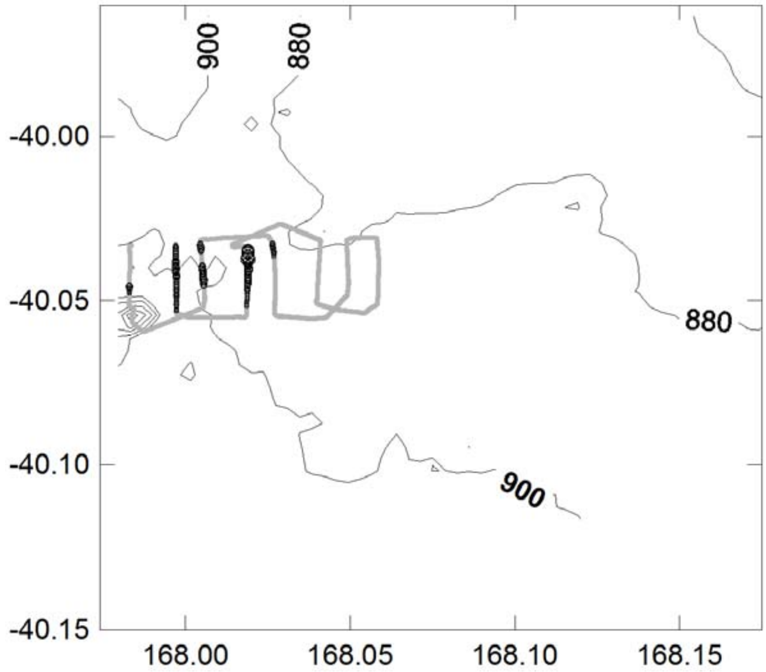

Figure 20: Survey tracks and orange roughy distribution, Snapshot 2B, Stratum 22. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Maximum is 950 m^2 $n.mile^{-2}$.

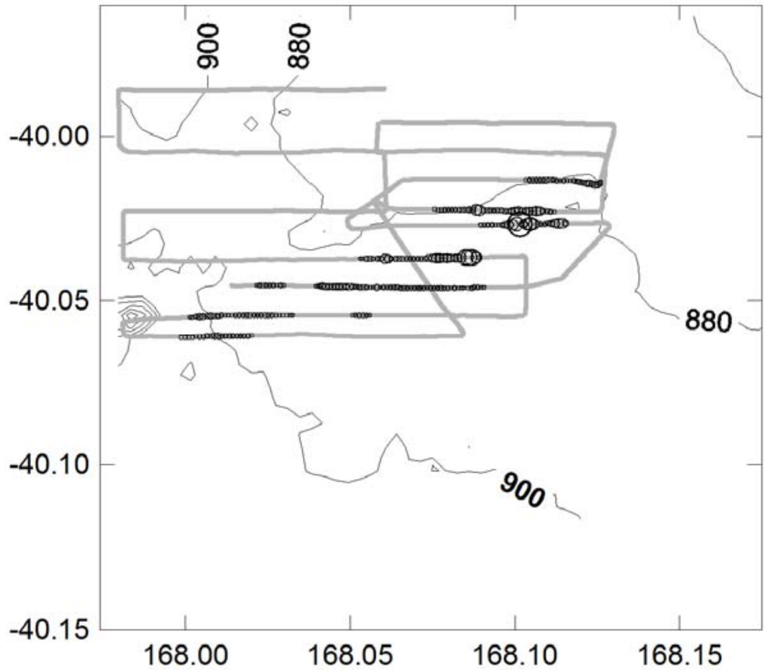

Figure 21: Survey tracks and orange roughy distribution, Snapshot 3, Stratum 22. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Maximum is 950 m^2 $n.mile^{-2}$.

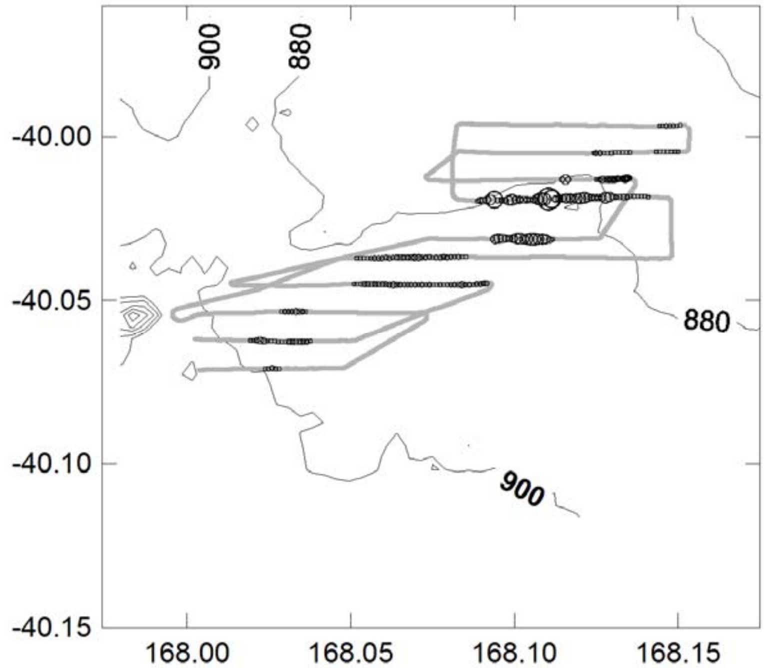

Figure 22: Survey tracks and orange roughy distribution, Snapshot 4, Stratum 22. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Maximum is 950 m^2 n.mile^{-2}.

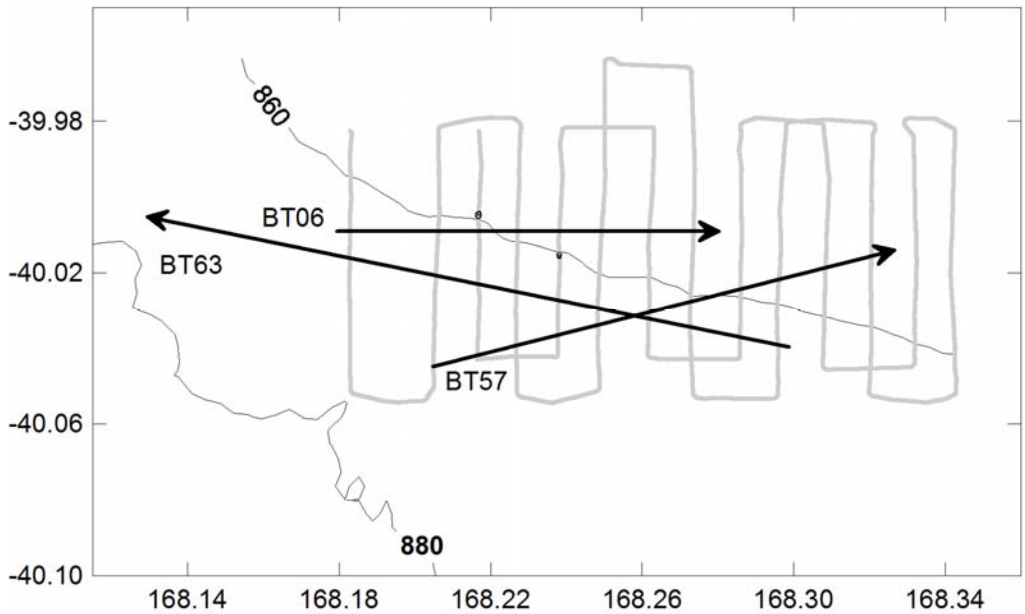

Figure 23: Survey tracks and tracks of trawls used for mark identification in Stratum 24. The arrows mark the ship's position during the trawls. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Maximum is 950 m^2 n.mile^{-2}.

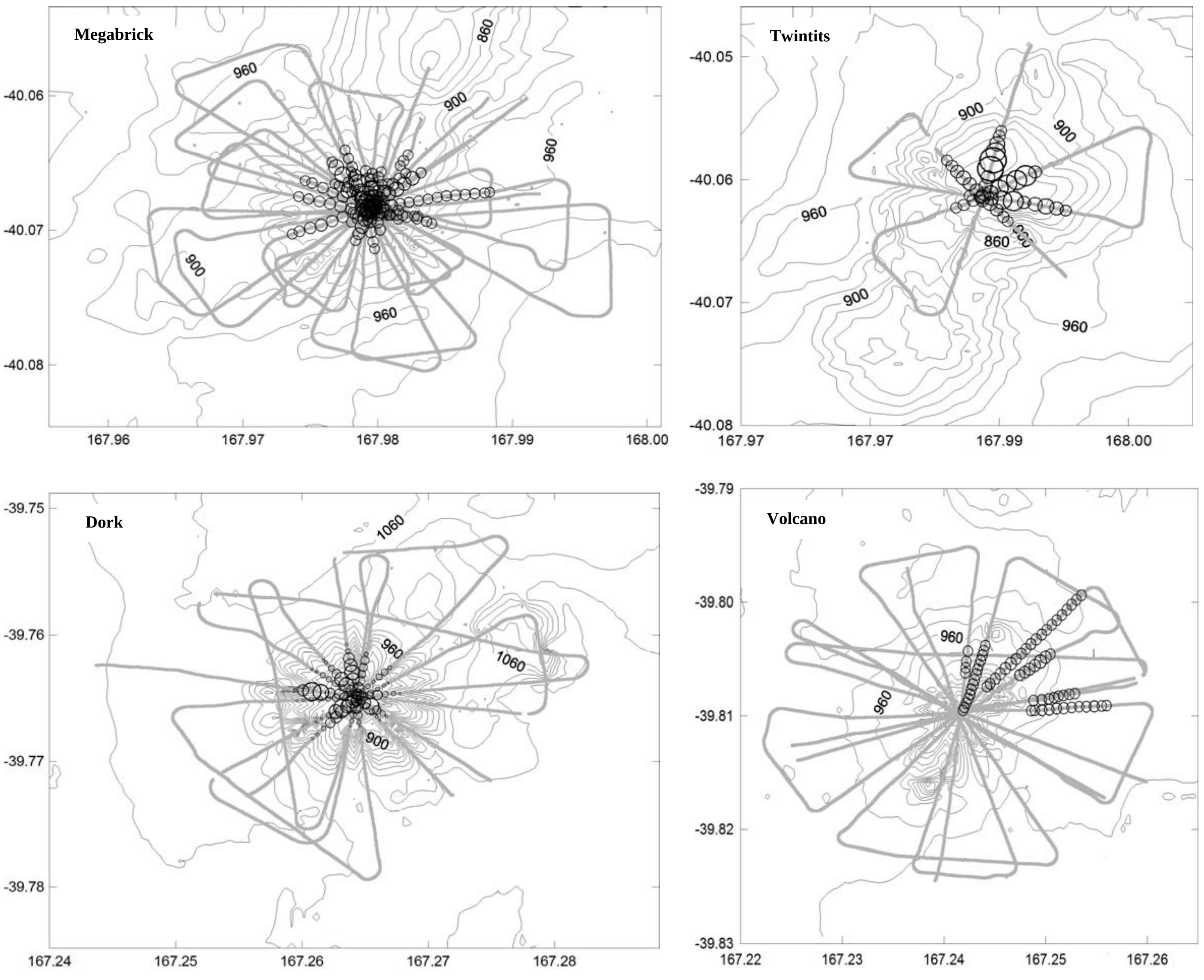

Figure 24: Survey tracks and distribution of orange roughy-like marks for snapshots of Megabrick, Twintits, Dork and Volcano. Circle diameter is proportional to area back-scattering strength. Same scale for all plots; maximum is 1360 m^2 $n.mile^{-2}$.

8. APPENDIX A

Table A-1: Details and settings of acoustic equipment.

Echosounder	Simrad ES-70
Transducer	ES38B
Operating frequency	38 000 Hz
Bandwidth	2 425 Hz
Transmit power	2 000 W
Pulse length	1.024 ms
2-way beam angle	-20.6 dB re 1 steradian
Gain	26.5 dB
Sa correction	0.0
Absorption (α)	9.43 dB km^{-1}
Sound velocity	1 500 m s^{-1}
3 dB beam width	
Alongship	7.1°
Athwartship	7.1°
Angle sensitiviy	
Alongship	21.9
Athwartship	21.9
Angle offset	
Alongship	0.0
Athwartship	0.0

Table A-2: Results of calibrations of ES60 sounder; June 2009 to August 2011.

Date	Contractor	G_o (dB)	S_A correction (dB)	Correction (dB)	Correction factor
June-2009	NIWA	25.48	-0.64	3.32	2.15
August-2009	NIWA	25.24	-0.60	3.72	2.36
June-2010	NIWA	24.68	-0.59	4.82	3.03
June-2011	FRS	24.38	-0.57	5.38	3.45
August-2011	NIWA	24.62	-0.52	4.80	3.02
Mean (2011)	FRS + NIWA	24.50	-0.54	5.08	3.22

9. APPENDIX B

Table B-1: Target strength/length relationships used in partitioning of back-scatter between species. All expressions are of the form *$TS = a\ Log_{10} L + b$*.

Species	Specific name	Code	a	b	Reference
Deepwater dogfish		DOG	20	-77	Clark et al. (2006)
Deepsea cardinalfish	*Epigonus telescopus*	EPT	34.6	-66	Clark et al. (2006)
Johnsons cod	*Halargyreus johnsonii*	HJO	24.7	-33.3	Clark et al. (2006)
Hoki	*Macruronus novaezelandiae*	HOK	13.4	-65.8	Clark et al. (2006)
Orange roughy	*Hoplostethus atlanticus*	ORH	16.2	-76.8	Macaulay et al. (2008)
Ribaldo	*Mora moro*	RIB	21.7	-66.7	Clark et al. (2006)
Spiky oreo dory	*Neocyttus rhomboidalis*	SOR	25.2	-78.1	Clark et al. (2006)
Smooth oreo dory	*Pseudocyttus maculatus*	SSO	24.6	-82.2	Clark et al. (2006)

10. APPENDIX C

Table C-1: Tow positions and station details for all trawls (random, identification and commercial). R= Random trawl, ID=Identification trawl, CO=Commercial trawl. Gear performance code: 1= Good, 2=Acceptable, 3= Dubious.

Stn	Type	Date	Lat	Long		Stratum	Min Depth (m)	Max Depth (m)	Length of tow (n.miles)	Gear Perf.	ORH	DOG	EPT	HAK	HJO	HOK	RIB	SOR	SSO	Total (kg)
BT01	R	26-Jun-11	40 01.56	168 18.71	E	24	863	875	1.5	2	2 944	8	0	0	0	0	5	0	0	2 958
BT02	R	27-Jun-11	40 00.20	168 04.80	E	22	876	881	1.6	1	5 177	32	0	0	0	2	5	3	0	5 232
BT03	R	27-Jun-11	39 58.41	168 01.62	E	22A	881	887	1.5	1	1 211	20	0	9	3	0	11	1	0	1 269
BT04	R	27-Jun-11	39 53.40	168 03.80	E	4	880	894	1.5	1	63	18	0	0	3	1	6	2	2	109
BT05	R	27-Jun-11	39 53.73	168 08.32	E	4	847	849	1.5	1	142	41	0	4	1	10	9	2	0	276
BT06	CO	27-Jun-11	40 00.52	168 10.79	E	24	861	872	4.6	1	5 022	102	0	9	1	10	9	3	0	5 185
BT07	ID	27-Jun-11	40 00.20	167 58.41	E	22	878	898	2.6	1	13 750	136	0	27	6	6	15	5	0	13 976
BT08	R	28-Jun-11	39 40.11	167 57.23	E	3	863	887	1.5	1	39	36	3	22	4	0	3	1	0	132
BT09	R	28-Jun-11	39 49.00	167 54.81	E	3	974	989	1.5	1	2	18	0	0	0	0	0	0	0	71
BT10	R	28-Jun-11	39 50.54	168 04.65	E	4	853	859	1.6	1	78	17	0	1	0	3	7	4	0	130
BT11	R	28-Jun-11	39 58.37	168 10.81	E	1	854	856	1.6	1	19	31	0	5	0	10	11	2	0	110
BT12	R	28-Jun-11	40 01.07	168 12.18	E	24	864	870	1.6	1	5 580	101	4	0	1	1	6	0	0	5 675
BT13	R	28-Jun-11	40 02.62	168 11.11	E	24	873	878	1.5	1	125	25	0	4	1	0	4	2	0	173
BT14	R	28-Jun-11	40 02.93	168 13.26	E	24	863	877	1.7	1	81	11	0	1	0	0	6	0	0	112
BT15	R	28-Jun-11	40 02.10	168 15.95	E	24	858	871	1.5	1	210	17	0	2	0	0	5	0	0	265
BT16	CO	29-Jun-11	40 01.00	167 59.00	E	22	890	891	2.5	1	10 972	64	0	0	4	7	13	3	0	11 064
BT17	CO	29-Jun-11	40 01.00	167 59.00	E	22	885	892	2.5	1	10 289	97	0	19	8	0	11	1	0	10 435
BT18	R	29-Jun-11	40 02.11	168 02.15	E	22	882	887	1.5	1	1 763	68	0	0	0	6	1	2	0	1 886
BT19	R	29-Jun-11	40 00.52	168 02.91	E	22	871	882	1.0	1	22 164	86	0	18	0	0	5	0	0	22 318
BT20	R	29-Jun-11	40 06.39	167 59.82	E	22	910	916	1.6	1	104	12	0	0	2	0	3	0	0	132
BT21	R	29-Jun-11	40 05.67	168 02.59	E	22	897	904	1.6	1	112	22	0	10	4	0	7	0	0	177
BT22	R	29-Jun-11	40 05.97	168 04.61	E	22	904	907	1.4	1	64	13	0	8	0	0	4	1	0	111
BT23	R	30-Jun-11	40 04.48	168 04.65	E	22	895	897	1.5	1	590	16	0	4	1	0	4	2	0	619
BT24	R	30-Jun-11	40 01.18	168 01.37	E	22	883	884	0.6	1	10 672	4	0	0	3	2	4	2	0	10 709
BT25	R	30-Jun-11	40 02.95	168 01.21	E	22	888	898	1.4	1	3 945	57	0	11	1	0	8	3	0	4 031
BT26	R	30-Jun-11	40 03.60	168 03.40	E	22	894	894	1.5	1	4 018	8	0	1	2	0	12	1	0	4 084
BT27	R	30-Jun-11	40 06.92	168 03.11	E	22	910	911	1.5	1	55	37	0	0	0	0	6	0	0	121
BT28	R	30-Jun-11	40 01.82	168 03.01	E	22	887	887	1.2	1	20 434	63	0	12	5	3	0	0	0	20 520

Stn	Type	Date	Lat	Long		Stratum	Min Depth (m)	Max Depth (m)	Length of tow (n.miles)	Gear Perf.	ORH	DOG	EPT	HAK	HJO	HOK	RIB	SOR	SSO	Total (kg)
BT29	R	30-Jun-11	40 08.30	168 06.15	E	24	908	916	1.5	1	39	4	0	4	0	0	11	0	0	71
BT30	R	30-Jun-11	40 08.03	168 05.32	E	24	910	914	1.5	1	39	10	0	3	0	0	1	1	0	66
BT31	R	30-Jun-11	40 06.57	168 05.75	E	23	902	906	1.5	1	93	27	0	3	1	0	8	0	0	143
BT32	R	1-Jul-11	40 04.39	168 08.38	E	23	887	893	1.6	1	115	34	0	2	1	0	9	0	0	171
BT33	R	1-Jul-11	40 04.64	167 58.13	E	10	842	848	0.2	1	25 380	0	59	0	8	58	12	103	0	25 619
BT34	R/ID	1-Jul-11	40 03.05	167 59.59	E	10	788		1.2	1	2 462	18	3	0	3	1	11	74	3	2 597
BT35	ID	1-Jul-11	40 02.07	168 01.46	E	22	881	887	0.3	1	8 267	79	0	0	3	0	11	1	0	8 361
BT36	R/ID	1-Jul-11	40 07.55	168 10.32	E	24	900	908	1.5	1	23	29	0	0	0	0	2	0	0	79
BT37	R	2-Jul-11	40 08.97	168 13.38	E	24	906	911	1.5	1	26	20	0	7	0	0	6	0	0	71
BT38	R	2-Jul-11	40 06.83	168 12.21	E	24	886	896	1.5	1	58	26	0	0	0	0	6	1	0	77
BT39	R	2-Jul-11	40 06.58	168 14.95	E	24	892	900	1.5	1	16	14	0	2	0	0	2	0	0	68
BT40	R	2-Jul-11	40 09.50	168 18.95	E	24	903	908	1.5	1	12	12	0	7	0	3	1	0	0	50
BT41	R	2-Jul-11	40 06.09	168 18.98	E	24	881	888	1.6	1	28	10	0	0	0	0	8	1	0	59
BT42	R	2-Jul-11	40 05.84	168 16.70	E	24	885	887	1.5	1	27	20	0	0	0	0	1	0	0	55
BT43	R	2-Jul-11	40 03.55	168 18.04	E	24	863	877	1.6	1	107	11	1	5	0	0	3	1	0	136
BT44	R	2-Jul-11	40 00.50	168 09.36	E	23	869	876	1.6	1	205	53	0	0	1	0	4	1	0	273
BT45	R	2-Jul-11	40 00.73	168 06.39	E	23	867	911	1.5	1	955	44	0	6	2	2	13	0	0	1 034
BT46	CO	2-Jul-11	40 03.56	168 00.97	E	10	833	932	0.5	1	4 438	0	0	6	7	0	27	27	2	4 542
BT47	CO	2-Jul-11	40 03.17	167 57.75	E	10	850	959	0.2	1	156	2	0	0	0	0	0	0	0	158
BT48	CO	2-Jul-11	40 03.98	167 59.63	E	10	818	967	0.5	1	2 100	3	68	2	14	2	29	114	0	2 333
BT49	R	2-Jul-11	40 06.02	168 07.94	E	23	890	901	1.4	1	84	22	0	2	0	0	4	2	0	124
BT50	R	2-Jul-11	40 05.45	168 09.78	E	23	887	897	1.5	1	53	26	0	0	0	0	9	2	0	96
BT51	R	3-Jul-11	40 03.08	168 08.93	E	23	882	882	1.5	1	40	10	0	0	0	0	0	0	0	53
BT52	R	3-Jul-11	40 02.23	168 06.67	E	23	885	890	1.6	1	176	18	0	2	0	2	8	1	0	218
BT53	R	3-Jul-11	40 03.96	168 06.57	E	23	890	895	1.5	1	154	26	0	0	1	3	8	1	0	198
BT54	R	3-Jul-11	40 05.04	168 05.20	E	23	887	895	1.5	2	356	11	0	0	2	0	1	1	0	387
BT55	ID	3-Jul-11	40 04.68	167 58.07	E	10	853	950	0.7	1	4 163	34	0	0	3	3	8	4	0	4 245
BT56	CO	3-Jul-11	40 03.22	167 58.04	E	Twintits	834	942	0.3	1	4 051	5	2	0	2	0	9	152	0	4 220
BT57	ID	3-Jul-11	40 00.26	168 12.28	E	24	860	864	5.7	1	4 645	134	3	22	0	11	27	5	0	4 866
BT58	CO	4-Jul-11	40 01.50	168 19.01	E	24	858	862	2.8	1	15 803	0	0	0	0	0	0	0	0	15 803
BT59	R	4-Jul-11	39 56.80	168 27.51	E	25	818	822	1.5	1	0	14	0	4	0	2	2	2	0	34
BT60	R	4-Jul-11	39 54.53	168 19.78	E	1	812	815	1.5	1	1	2	0	0	0	6	3	1	0	17
BT61	R	4-Jul-11	39 54.27	168 21.70	E	25	807	808	1.5	1	7	3	0	0	0	6	1	4	0	27
BT62	R	4-Jul-11	39 57.92	168 23.04	E	25	829	839	1.5	1	11	9	5	3	1	5	2	4	0	68

Stn	Type	Date	Lat	Long		Stratum	Min Depth (m)	Max Depth (m)	Length of tow (n.miles)	Gear Perf.	ORH	DOG	EPT	HAK	HJO	HOK	RIB	SOR	SSO	Total (kg)
BT63	CO	4-Jul-11	40 02.12	168 17.91	E	24	868	874	7.9	1	16 678	259	0	17	9	4	42	1	0	17 113
BT64	ID	5-Jul-11	40 04.58	167 58.17	E	Megabrick	830	928	0.7	1	5 536	6	0	0	3	0	34	57	1	5 666
BT65	CO	5-Jul-11	40 03.93	167 59.54	E	Twintits	812	931	0.4	1	1 587	0	0	0	0	0	0	0	0	1 587
BT66	CO	5-Jul-11	40 06.60	167 58.19	E	Megabrick	835	928	1.3	2	3 802	0	0	0	0	0	0	0	0	3 802
BT67	ID	5-Jul-11	40 02.98	168 02.83	E	22	883	887	2.4	1	17 606	307	0	6	22	8	18	1	0	17 993
BT68	CO	5-Jul-11	40 02.38	168 03.14	E	22	880	887	2.1	1	17 759	99	0	0	25	5	14	4	0	17 947
BT69	ID/R	6-Jul-11	39 45.30	167 15.98	E	10 (Dork)	801	1000	0.3	1	5 150	32	0	0	2	0	0	599	0	5 784
BT70	CO	6-Jul-11	40 02.18	168 03.25	E	22/23	882	884	2.8	1	16 134	0	0	0	0	0	0	0	0	16 134
BT71	R	6-Jul-11	40 05.48	168 00.17	E	21	911	913	1.4	2	628	13	0	0	2	0	2	0	0	658
BT72	R	6-Jul-11	40 03.72	167 53.28	E	21	905	930	1.5	1	7	9	0	12	0	0	1	2	0	35
BT73	R	7-Jul-11	40 02.08	167 56.57	E	21	891	904	1.5	2	18	11	0	0	0	0	3	2	0	64
BT74	CO	7-Jul-11	40 02.34	168 02.24	E	22	890	891	2.2	1	12 816	67	0	13	18	0	16	0	0	12 949
BT75	CO	7-Jul-11	40 02.76	168 03.44	E	22	885	885	2.2	1	20 138	31	0	44	16	2	10	0	0	20 261
BT76	R	7-Jul-11	39 48.36	168 08.13	E	1	808	811	1.5	2	10	11	0	12	1	3	0	8	0	65
BT77	R	7-Jul-11	39 59.22	168 05.49	E	22	871	873	1.5	2	381	12	0	1	1	3	2	0	0	408
BT78	R	7-Jul-11	39 58.08	168 07.31	E	22A	863	870	1.5	2	227	11	0	0	0	6	6	0	0	259
BT79	R	8-Jul-11	39 59.98	167 54.55	E	3	934	939	1.6	2	6	13	0	0	4	0	0	0	0	50
BT80	R	8-Jul-11	40 00.18	168 00.18	E	22	886	905	1.6	2	203	31	0	0	4	3	12	4	0	271
BT81	R	8-Jul-11	40 02.15	168 06.20	E	23	887	894	1.4	3	5 068	134	0	0	5	0	3	1	0	5 222
BT82	R	8-Jul-11	40 09.70	168 08.18	E	24	911	922	1.4	3	38	26	0	1	0	0	1	2	0	95
BT83	R	8-Jul-11	40 07.12	168 07.92	E	24	900	907	1.5	1	36	38	0	2	0	0	1	0	0	91
BT84	R	8-Jul-11	40 07.01	168 09.19	E	23	897	904	1.5	1	27	0	0	3	0	0	6	2	0	53
BT85	CO	9-Jul-11	40 02.13	168 05.01	E	22	870	883	2.0	2	8 107	0	0	0	0	0	0	0	0	8 107
BT86	R	9-Jul-11	39 57.47	167 59.43	E	22A	900	947	1.5	2	54	29	0	1	4	0	11	0	0	109
BT87	CO	9-Jul-11	40 01.13	168 03.23	E	22	878	886	3.2	1	18 933	0	0	0	0	0	0	0	0	18 933
All											87 296	3 024	147	360	214	198	605	1 224	7	351 851

11. APPENDIX D

Table D-1: Catch and occurrence of all species taken in random, identification and commercial trawls.

Code	Phylum	Species	Common name	Catch (kg)	No. of stations	% presence
PED	Arthropoda:Crustacea	*Aristaeopsis edwardsiana*	Scarlet prawn	0.5	3	3.7
LHO	Arthropoda:Crustacea	*Lipkius holthuisi*	Lipkius holthuisi	0.9	9	11.1
LMU	Arthropoda:Crustacea	*Lithodes murrayi*	Lithodes murrayi	0.7	1	1.2
PLY	Arthropoda:Crustacea	*Polycheles suhmi*	Polychelidae	0.4	3	3.7
SPI	Arthropoda:Crustacea	*Spider crab*	Spider crab	24.4	3	3.7
VIT	Arthropoda:Crustacea	*Vitjazmaia latidactyla*	Deep sea spider crab	1.6	3	3.7
CRB	Arthropoda:Crustacea		Crab	0.4	2	2.5
BPD	Brachiopoda	*Brachiopoda*	Lamp shells	0.1	1	1.2
SLK	Chordata:Actinopterygii	*Alepocephalidae*	Slickhead	16.8	3	3.7
SSM	Chordata:Actinopterygii	*Alepocephalus australis*	Slickhead, smallscaled brown	64	16	19.8
SBI	Chordata:Actinopterygii	*Alepocephalus sp.*	Slickhead, bigscaled brown	146.8	28	34.6
BOE	Chordata:Actinopterygii	*Allocyttus niger*	Black oreo	0.6	1	1.2
TOP	Chordata:Actinopterygii	*Ambophthalmos angustus*	Pale toadfish	6.4	4	4.9
AGI	Chordata:Actinopterygii	*Argyropelecus gigas*	Giant hatchetfish	0.1	1	1.2
AST	Chordata:Actinopterygii	*Astronesthidae*	Snaggletooths	0.6	3	3.7
AVO	Chordata:Actinopterygii	*Avocettina spp.*	Snipe eel	0.1	1	1.2
SCO	Chordata:Actinopterygii	*Bassanago bulbiceps*	Swollenhead conger	5.7	10	12.3
HCO	Chordata:Actinopterygii	*Bassanago hirsutus*	Hairy conger	2.3	7	8.6
BFE	Chordata:Actinopterygii	*Bathysaurus ferox*	Deepsea lizardfish	0.2	1	1.2
RBM	Chordata:Actinopterygii	*Brama brama*	Rays bream	9.8	4	4.9
BCR	Chordata:Actinopterygii	*Brotulotaenia crassa*	Blue cusk eel	1.7	2	2.5
RUD	Chordata:Actinopterygii	*Centrolophus niger*	Rudderfish	10.4	4	4.9
CYL	Chordata:Actinopterygii	*Centroscymnus coelolepis*	Centroscymnus coelolepis	156.4	22	27.2
CCR	Chordata:Actinopterygii	*Cetonurus crassiceps*	Globosehead rattail	0.8	1	1.2
CHA	Chordata:Actinopterygii	*Chauliodus sloani*	Viper fish	1.6	11	13.6
CHX	Chordata:Actinopterygii	*Chaunax pictus*	Pink frogmouth	1.8	4	4.9
CHP	Chordata:Actinopterygii	*Chimaera sp.*	Chimaera, brown	13.9	2	2.5
CBO	Chordata:Actinopterygii	*Coelorinchus bollonsi*	Bollons rattail	16.4	9	11.1
CFA	Chordata:Actinopterygii	*Coelorinchus fasciatus*	Banded rattail	1.1	6	7.4
CIN	Chordata:Actinopterygii	*Coelorinchus innotabilis*	Notable rattail	7.3	39	48.1
CKA	Chordata:Actinopterygii	*Coelorinchus kaiyomaru*	Kaiyomaru rattail	0.2	1	1.2
CMA	Chordata:Actinopterygii	*Coelorinchus matamua*	Mahia rattail	73.8	64	79
CDX	Chordata:Actinopterygii	*Coelorinchus maurofasciatus*	Dark banded rattail	0.3	2	2.5
CJX	Chordata:Actinopterygii	*Coelorinchus mycterismus*	Upturned snout rattail	0.9	2	2.5
CHY	Chordata:Actinopterygii	*Coelorinchus trachycarus*	Roughhead rattail	2.7	4	4.9
CKX	Chordata:Actinopterygii	*Coelorinchus trachycarus & C acanthiger*	Spottyfaced rattails (roughhead)	3.8	8	9.9
COM	Chordata:Actinopterygii	*Coryphaenoides armatus*	Cosmopolitan rattail	0.5	1	1.2
CBA	Chordata:Actinopterygii	*Coryphaenoides dossenus*	Humpback rattail (slender rattail)	12.9	10	12.3
CMU	Chordata:Actinopterygii	*Coryphaenoides murrayi*	Abyssal rattail	0.3	1	1.2
CSE	Chordata:Actinopterygii	*Coryphaenoides serrulatus*	Serrulate rattail	87.1	71	87.7
CVY	Chordata:Actinopterygii	*Coryphaenoides spp.*	Rattail	0.2	1	1.2
CSU	Chordata:Actinopterygii	*Coryphaenoides subserrulatus*	Four-rayed rattail	31.6	54	66.7
SDE	Chordata:Actinopterygii	*Cryptopsaras couesi*	Seadevil	0.2	1	1.2
LDO	Chordata:Actinopterygii	*Cyttus traversi*	Lookdown dory	1.5	1	1.2
BEE	Chordata:Actinopterygii	*Diastobranchus capensis*	Basketwork eel	61.3	17	21
RSK	Chordata:Actinopterygii	*Dipturus nasutus*	Rough skate	0.4	1	1.2
SFN	Chordata:Actinopterygii	*Diretmoides parini*	Spinyfin	9.1	8	9.9
DIS	Chordata:Actinopterygii	*Diretmus argenteus*	Discfish	9.2	11	13.6
EPL	Chordata:Actinopterygii	*Epigonus lenimen*	Bigeye cardinalfish	0.1	1	1.2
EPT	Chordata:Actinopterygii	*Epigonus telescopus*	Deepsea cardinalfish	206.6	16	19.8
GAO	Chordata:Actinopterygii	*Gadomus aoteanus*	Filamentous rattail	1.2	5	6.2
GST	Chordata:Actinopterygii	*Gonostomatidae*	Gonostomatidae	0.1	1	1.2

Code	Phylum	Species	Common name	Catch (kg)	No. of stations	% presence
HJO	Chordata:Actinopterygii	*Halargyreus johnsonii*	Johnson's cod	465.4	73	90.1
HAL	Chordata:Actinopterygii	*Halosauropsis macrochir*	Abyssal halosaur	3.4	6	7.4
HPE	Chordata:Actinopterygii	*Halosaurus pectoralis*	Common halosaur	2.4	7	8.6
SPE	Chordata:Actinopterygii	*Helicolenus spp.*	Sea perch	45.6	23	28.4
HIA	Chordata:Actinopterygii	*Himantolophus appelii*	Prickly anglerfish	3.8	6	7.4
FHD	Chordata:Actinopterygii	*Hoplichthys haswelli*	Deepsea flathead	0.3	1	1.2
ORH	Chordata:Actinopterygii	*Hoplostethus atlanticus*	Orange roughy	439644	81	100
RAG	Chordata:Actinopterygii	*Icichthys australis*	Ragfish	4.8	3	3.7
STA	Chordata:Actinopterygii	*Kathetostoma giganteum*	Giant stargazer	3.4	2	2.5
NBU	Chordata:Actinopterygii	*Kuronezumia bubonis*	Bulbous rattail	11.1	19	23.5
NPU	Chordata:Actinopterygii	*Kuronezumia leonis*	Kuronezumia leonis	0.2	1	1.2
LAE	Chordata:Actinopterygii	*Laemonema spp.*	Laemonema spp	0.2	1	1.2
LPI	Chordata:Actinopterygii	*Lepidion inosimae*	Giant lepidion	87.8	6	7.4
SMC	Chordata:Actinopterygii	*Lepidion microcephalus*	Small-headed cod	2.4	1	1.2
LPS	Chordata:Actinopterygii	*Lepidion schmidti*	Giant lepidion	2.7	1	1.2
JAV	Chordata:Actinopterygii	*Lepidorhynchus denticulatus*	Javelin fish	29.1	14	17.3
ROC	Chordata:Actinopterygii	*Lotella rhacinus*	Rock cod	16.5	1	1.2
RAT	Chordata:Actinopterygii	*Macrouridae*	Rattails	0.3	2	2.5
HOK	Chordata:Actinopterygii	*Macruronus novaezelandiae*	Hoki	257.4	43	53.1
MEL	Chordata:Actinopterygii	*Melanonus gracilis*	Melanonus gracilis	0.1	1	1.2
MST	Chordata:Actinopterygii	*Melanostomiidae*	Melanostomiidae	1.6	1	1.2
HAK	Chordata:Actinopterygii	*Merluccius australis*	Hake	472.6	61	75.3
BJA	Chordata:Actinopterygii	*Mesobius antipodum*	Black javelinfish	0.4	2	2.5
RIB	Chordata:Actinopterygii	*Mora moro*	Ribaldo	1401.3	79	97.5
LAN	Chordata:Actinopterygii	*Myctophidae*	Lantern fish	0.1	1	1.2
SOR	Chordata:Actinopterygii	*Neocyttus rhomboidalis*	Spiky oreo	4351.5	79	97.5
SBK	Chordata:Actinopterygii	*Notacanthus sexspinis*	Spineback	0.8	3	3.7
OMI	Chordata:Actinopterygii	*Opostomias micripnus*	Opostomias micripnus	1.1	1	1.2
PHO	Chordata:Actinopterygii	*Photichthys argenteus*	Lighthouse fish	0.1	1	1.2
SSO	Chordata:Actinopterygii	*Pseudocyttus maculatus*	Smooth oreo	56.8	14	17.3
PSY	Chordata:Actinopterygii	*Psychrolutes microporos*	Psychrolutes	0.7	3	3.7
WIN	Chordata:Actinopterygii	*Pteraclis velifera*	Wingfish	0.2	1	1.2
PYR	Chordata:Actinopterygii	*Pyrosoma atlanticum*	Pyrosoma atlanticum	0.1	1	1.2
BAT	Chordata:Actinopterygii	*Rouleina sp.*	Large headed slickhead	5	2	2.5
SUH	Chordata:Actinopterygii	*Schedophilus huttoni*	Schedophilus huttoni	13.5	7	8.6
SAW	Chordata:Actinopterygii	*Serrivomer sp.*	Sawtooth eel	0.1	1	1.2
HAT	Chordata:Actinopterygii	*Sternoptychidae*	Hatchetfish	0.1	1	1.2
SYN	Chordata:Actinopterygii	*Synaphobranchidae*	Synaphobranchidae	0.1	1	1.2
TAL	Chordata:Actinopterygii	*Talismania longifilis*	Talismania longifilis	46.7	15	18.5
BSP	Chordata:Actinopterygii	*Taratichthys longipinnis*	Big-scale pomfret	0.7	1	1.2
DEA	Chordata:Actinopterygii	*Trachipterus trachypterus*	Dealfish	23.5	3	3.7
TVI	Chordata:Actinopterygii	*Trachonurus villosus*	Trachonurus villosus	0.6	2	2.5
WHX	Chordata:Actinopterygii	*Trachyrincus aphyodes*	White rattail	622.8	66	81.5
TRS	Chordata:Actinopterygii	*Trachyscorpia capensis*	Trachyscorpia capensis	61.9	33	40.7
TUB	Chordata:Actinopterygii	*Tubbia tasmanica*	Tubbia tasmanica	9.8	8	9.9
VNI	Chordata:Actinopterygii	*Ventrifossa nigromaculata*	Blackspot rattail	0.2	1	1.2
BSL	Chordata:Actinopterygii	*Xenodermichthys spp.*	Black slickhead	112.3	55	67.9
BAF	Chordata:Actinopterygii		Black anglerfish	2.8	5	6.2
APR	Chordata:Elasmobranchii	*Apristurus spp.*	Catshark	1.7	1	1.2
CSQ	Chordata:Elasmobranchii	*Centrophorus squamosus*	Centrophorus squamosus	2489.4	49	60.5
CYP	Chordata:Elasmobranchii	*Centroscymnus crepidater*	Centroscymnus crepidater	322.3	68	84
CYO	Chordata:Elasmobranchii	*Centroscymnus owstoni*	Smooth skin dogfish	1316.4	68	84
BSH	Chordata:Elasmobranchii	*Dalatias licha*	Seal shark	245.4	20	24.7
SND	Chordata:Elasmobranchii	*Deania calcea*	Shovelnose spiny dogfish	987.1	72	88.9
SSK	Chordata:Elasmobranchii	*Dipturus innominatus*	Smooth skate	28.9	1	1.2
ETB	Chordata:Elasmobranchii	*Etmopterus baxteri*	Baxters lantern dogfish	164.6	43	53.1
ETL	Chordata:Elasmobranchii	*Etmopterus lucifer*	Lucifer dogfish	3.1	7	8.6
ETP	Chordata:Elasmobranchii	*Etmopterus pusillus*	Etmopterus pusillus	0.9	2	2.5

Code	Phylum	Species	Common name	Catch (kg)	No. of stations	% presence
BTA	Chordata:Elasmobranchii	*Notoraja asperula*	Smooth deepsea skate	1.3	3	3.7
BTS	Chordata:Elasmobranchii	*Notoraja spinifera*	Prickly deepsea skate	0.3	1	1.2
BTH	Chordata:Elasmobranchii	*Notoraja spp.*	Bluntnose skates deepsea skates	0.8	2	2.5
PLS	Chordata:Elasmobranchii	*Proscymnodon plunketi*	Plunkets shark	439.9	24	29.6
ERA	Chordata:Elasmobranchii	*Torpedo fairchildi*	Electric ray	11.3	1	1.2
LCH	Chordata:Holocephali	*Harriotta raleighana*	Long-nosed chimaera	26.2	17	21
GSP	Chordata:Holocephali	*Hydrolagus bemisi*	Pale ghost shark	60	29	35.8
GSH	Chordata:Holocephali	*Hydrolagus novaezealandiae*	Ghost shark	1.3	2	2.5
RCH	Chordata:Holocephali	*Rhinochimaera pacifica*	Widenosed chimaera	299.3	53	65.4
SAL	Chordata:Thaliacea	*Salpida*	Salps	21.6	15	18.5
ACS	Cnidaria	*Actinostolidae*	Deepsea anemone	0.2	1	1.2
ANT	Cnidaria	*Anthozoa*	Anemones	0.3	1	1.2
COB	Cnidaria	*Antipatharia (Order)*	Black coral	1.3	2	2.5
BOC	Cnidaria	*Bolocera spp.*	Deepsea anemone	0.8	1	1.2
COE	Cnidaria	*Coelenterata*	Coelenterata	3	2	2.5
EPZ	Cnidaria	*Epizoanthus sp.*	Epizoanthus sp.	0.6	4	4.9
HMT	Cnidaria	*Hormathiidae*	Deepsea anemone	0.3	1	1.2
COU	Cnidaria		Coral (unspecified)	0.1	1	1.2
GOC	Cnidaria		Gorgonian coral	1.5	3	3.7
JFI	Cnidaria		Jellyfish	188.6	41	50.6
ASR	Echinodermata	*Asteroid (starfish)*		0.1	1	1.2
SFI	Echinodermata	*Asteroidea & ophiuroidea*	Starfish	0.7	1	1.2
BRG	Echinodermata	*Brisingida*	Brisingida	0.9	4	4.9
CPA	Echinodermata	*Ceramaster patagonicus*	Pentagon star	0.2	2	2.5
DHO	Echinodermata	*Dermechinus horridus*	Sea urchin	0.7	1	1.2
TAM	Echinodermata	*Echinothuriidae*	Tam o shanter urchin	5.2	22	27.2
SUR	Echinodermata	*Evechinus chloroticus*	Kina	0.1	1	1.2
GOR	Echinodermata	*Gorgonocephalus sp.*	Gorgonocephalus sp	0.4	1	1.2
GRM	Echinodermata	*Gracilechinus multidentatus*	Sea urchin	1.2	2	2.5
HTH	Echinodermata	*Holothurian unidentified*	Sea cucumber	54.9	29	35.8
PLT	Echinodermata	*Plutonaster spp.*	Plutonaster spp	0.2	1	1.2
ZOR	Echinodermata	*Zoroaster spp.*	Rat-tail star	2.2	14	17.3
CHQ	Mollusca	*Cranchiidae*	Cranchiid squid	0.1	1	1.2
GAS	Mollusca	*Gastropods*	Gastropoda	0.1	1	1.2
DWO	Mollusca	*Graneledone spp.*	Deepwater octopus	1.4	2	2.5
VSQ	Mollusca	*Histioteuthis spp.*	Violet squid	84.9	38	46.9
MIQ	Mollusca	*Moroteuthis ingens*	Warty squid	8.9	4	4.9
MRQ	Mollusca	*Moroteuthis robsoni*	Warty squid	13.1	3	3.7
WSQ	Mollusca	*Moroteuthis spp.*	Warty squid	5.9	2	2.5
OSQ	Mollusca	*Octopoteuthiidae*	Octopoteuthiidae	10.3	5	6.2
RSQ	Mollusca	*Ommastrephes bartrami*	Ommastrephes bartrami	4.4	4	4.9
OMQ	Mollusca	*Ommastrephidae*	Ommastrephidae	9.9	1	1.2
OPI	Mollusca	*Opisthoteuthis*	Umbrella octopus	3.7	3	3.7
PSQ	Mollusca	*Pholidoteuthis boschmai*	Pholidoteuthis boschmai	26.8	6	7.4
SQX	Mollusca	*Teuthida*	Squid	75.2	11	13.6
TSQ	Mollusca	*Todarodes filippovae*	Todarodes filippovae	13.5	13	16
GLS	Porifera	*Glass sponges*	Hexactinellida (Class)	4.9	1	1.2
ONG	Porifera	*Porifera (phylum)*	Sponges	1.4	5	6.2
PDL	Priapulida	*Priapulida*	Penis worms	0.1	1	1.2
ROK		Geological specimens	Rocks stones	12.5	1	1.2

12. APPENDIX E

Table E-1: Comparison between net performance in random trawl surveys of Challenger Plateau by FV *Thomas Harrison* between 2005 and 2011.

	Number	Minimum	Maximum	Mean
THH0501				
Speed (kts)	44	2.7	3.5	3.1
Distance (n.miles)	44	0.27	1.81	1.40
Doorspread (m)	39	118	146.5	138
Headline height (m)	44	5.4	9.5	5.9
THH0601				
Speed (kts)	54	3	3.5	3.2
Distance (n.miles)	54	0.23	1.83	1.43
Doorspread (m)	47	119	145	134
Headline height (m)	54	3.4	8.4	5.5
THH0901				
Speed (kts)	64	2.8	3.5	3.09
Distance (n.miles)	64	0.28	1.58	1.40
Doorspread (m)	64	120	147.1	137
Headline height (m)	64	4.7	7.1	5.5
THH1001				
Speed (kts)	68	2.8	3.4	3.1
Distance (n.miles)	68	0.18	1.63	1.40
Doorspread (m)	67	117.6	153.3	143
Headline height (m)	68	4.3	7.1	5.3
THH1101				
Speed (kts)	61	2.8	3.4	3
Distance (n.miles)	61	0.16	1.66	1.46
Doorspread (m)	61	133	155.3	144
Headline height (m)	61	4.5	5.9	5.4