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Acoustic and trawl estimates of orange roughy (*Hoplostethus atlanticus*) biomass on the southwest Challenger Plateau, June/July 2012

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.EXECUTIVE SUMMARY

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This paper summarises the results of a combined stratified random trawl and acoustic survey of orange roughy abundance on the southwest Challenger Plateau, carried out from a commercial vessel, FV *Thomas Harrison*, between 25 June and 10 July 2012 in the course of a commercial fishing trip. The trawl survey was conducted 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, 2010 and 2011. The nine strata in the survey, all of which were on flat ground surrounding the Pinnacles (Megabrick and Twintits), were the same as those on flat ground in the 2009, 2010 and 2011 trawl surveys, except for an additional stratum created within Stratum 22 in the 2011 survey, and within Stratum 24 in 2009. 43 random trawls were conducted in Phase 1 and seven in Phase 2. Unlike in the previous surveys, no random trawls were done on the Westpac Bank, outside the EEZ, because of a reduction in the amount of time available for surveying. The acoustic survey was carried out with the vessel's 38 kHz fishing echo sounder, as in the previous acoustic surveys of this area from *Thomas Harrison*. It consisted of five snapshots within Stratum 22, seven straddling Strata 23 and 24, and six on the Pinnacles to investigate whether there was an unusually high biomass there, as explanation for the unusually low biomass found within the adjacent Stratum 22. The snapshots were executed at various times during the voyage between 29 June and 8 July. Seven additional trawls were carried out in these strata to assist in target identification.

The trawl and acoustic surveys both showed orange roughy to be concentrated on the flat ground east and northeast of the Pinnacles, particularly in Strata 23 and 24. Notable differences in distribution in this survey compared to the previous ones were the relatively small amount of orange roughy taken in the trawls in Stratum 22, the almost total absence of orange roughy aggregations there, and the relatively high trawl estimate in Stratum 25, all of which indicate that the fish were more to the east and in slightly shallower water than in previous years. The estimates from the snapshots of the Pinnacles were relatively low, from which it was concluded that the unusually low biomass in Stratum 22 was not due to the fish having moved onto the Pinnacles at the time.

The trawl estimate of total orange roughy biomass (26 043 t, with a CV of 27 %) is significantly (at the 95 % level) higher than the comparable estimates from the 2006, 2010 and 2011 surveys, but is significantly lower than the highest estimate in the time series (i.e. 46 480 t in 2009). In contrast, the acoustic estimate of the aggregated component on flat ground (3439 t with a CV of 17 %), which is based on five snapshots in Strata 23 and 24, is significantly lower than the acoustic estimate of this component in 2011, and somewhat lower than the mean of the acoustic estimates in the previous five surveys.

In the identification trawls on the Pinnacles, orange roughy were only caught in significant amounts in the single trawl on Megabrick, unlike in previous surveys when they have been found on both hills. The estimate from the three snapshots there (3364 t; CV 22 %) is close to the estimate of total orange roughy biomass on Megabrick and Twintits in the 2011 survey, although in that year 64 % of the estimate was contributed by Twintits.

Orange roughy females tended to be larger than the males in all areas (mean standard length 33.4 compared to 31.4 cm), as has been observed in the previous trawl and acoustic surveys of this area. 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.

We conclude that the survey was successful in generating relative trawl and acoustic estimates of orange roughy biomass in the flat areas on the southwest Challenger Plateau within the EEZ during the spawning period. The estimates are comparable with previous estimates there at this time of the year, and have acceptably low sampling CVs, but the large variability in the individual snapshot estimates, which we consider is most likely due to inconsistent aggregating behavior, is an additional source of uncertainty which appears to have been particularly severe in this survey.

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 tons of 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), 2010 (Doonan et al. 2010) and 2011 (Hampton et al. 2013). 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.

Apart from the Westpac Bank, which was not surveyed, the survey described here covered the same areas as in 2009, 2010 and 2011, 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 CV of 30% for the trawl survey and 15% for the acoustic survey. The survey was conducted between 25 June and 10 July; a period which, based on earlier surveys, was expected to coincide with peak spawning.

2. METHODS

2.1 Overall survey design

The survey design was similar to that used during the 2005, 2006, 2009, 2010 and 2011 surveys, involving a combination of trawling and acoustics, although unlike in all the previous years, no trawls were allocated to any of the hill features because of the greater difficulty in interpreting the data from them compared to trawls on flat ground (e.g. Clark 1994). It was initially intended not to survey any of the hills acoustically either for similar reasons (e.g. Hampton et al. 2007), but in the event a number of such surveys were done for reasons explained in Section 2. 3.2.

The general survey area is shown in Figure 1. It included the Pinnacles, the flat area to the east and west of them (Pinnacles Flat), the Central Flat and the Westpac Bank (outside the EEZ). No new areas were added, but provision was made in the design 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 2/3 of the survey time (7 days) being allocated to the trawl survey and approximately 1/3 (5 days) to the acoustic survey. Time had also to be allowed for commercial fishing since the trip was primarily a commercial fishing trip with some dedicated time for the random trawling component. A further design consideration was the need to take advantage of the best weather for the acoustic snapshots because of their greater sensitivity to adverse weather effects.

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 surveys between 2005 and 2011 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.

2.2.2 Survey design

An adaptive two-phase stratified random design, as recommended by Francis (1984) was used. 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 2011. The prescribed strata were the same as in the 2009 and 2011 surveys, which were slightly different from those employed in 2010, when a number of the strata were subdivided after the survey in an attempt to improve precision (Doonan et al. 2010). (The 2010 re-stratification was not followed since it was considered that the fine-scale distribution which prompted it would not necessarily recur in the current survey). As in the 2010 and 2011 surveys, it was stipulated that there be at least three trawls in each stratum, and that any aggregations found on the flat grounds should be excluded from the trawl survey, and surveyed acoustically instead in new *ad hoc* acoustic strata ("plume" strata) created specifically for this purpose.

The strata ultimately adopted were as designed, the size and intensity of the acoustic marks detected being insufficient to justify the creation of any new "plume" strata to encompass them. They are specified in Table 1, which lists their areas and the number of first and second-phase random trawls carried out in each one. The Phase 1 allocations were initially based on the mean of the biomass estimates in each of the strata in the 2009, 2010 and 2011 surveys, but were revised in the course of the survey to adjust for the reduced amount of time ultimately available for the trawl survey. It was initially intended to carry out 50 trawls in Phase 1, but this was reduced to 42 by omitting all four planned tows on Westpac, three tows from Stratum 22 and one from Stratum 23. An extra Phase 1 tow was added to Stratum 23 to achieve the minimum of three tows in the southern part of the stratum, so that if desired, the stratum could be split latitudinally to adjust to a marked difference in the catch rates in the northern and southern halves. The allocation of the trawls in the second phase, which had to be reduced from seven to five due to the shortage of time, was based as far as practically possible on the estimates of biomass in each stratum in the first phase.

Tow positions were randomly selected with the restriction that their starting points were a minimum of 3 n.miles apart to ensure that no trawl tracks would overlap. Note that in some strata (e.g. in Stratum 22) it was not physically possible to separate all the tows by this amount. In these cases the minimum spacing was reduced, as has been done in previous surveys.

2.2.3 Trawling strategy

The trawling strategy was similar to that 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.

2.2.4 Analysis of trawl data

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

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

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 by using the measured d_{ji} values throughout, there being no trawls which were terminated prematurely in anticipation of a large catch.

The coefficient of variation (CV) 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 CV by summing the stratum variances.

2.3 Acoustic survey

2.3.1 Acoustic and environmental monitoring equipment

The survey was conducted using the vessel's SIMRAD ES70 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 echo-sounder for scientific work were allayed in an orange roughy survey from FV *San Waitaki* in 2002 using a SIMRAD ES60 echo-sounder, when it was shown that at this power setting (i.e. below the cavitation threshold), there was very little difference between the performance of this echo-sounder and a SIMRAD EK60 scientific echo- 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 Ver.5.2.60.21114) was used to view and process ES70 raw (power and angle) data files, which were logged and transferred via Myriax ECHOLOG60 (Version 4.70.0.14275) software. Raw data files were also periodically transferred and stored to disc for post processing and analysis.

Due to poor conditions and the vessel's commercial schedule, the echo sounder could not be calibrated at the start or end of the survey, as had been intended. However, a successful calibration of the system by the standard sphere method (Foote et al. 1987) was carried out by CSIRO off Tasmania on 23 July, using a 38.1 mm tungsten carbide sphere. The data were analysed independently by CSIRO and Fisheries Resource Surveys, and a calibration correction for the survey agreed upon through correspondence.

Pitch and roll data were recorded at a rate of 300 samples min^{-1} during all snapshots and trawls using a Honeywell HMR3000 Compass Module attitude sensor. The clocks of the echo-sounder computer and laptop on which the pitch and roll data were logged were synchronized daily. The pitch and roll data were used to correct the echo return from each ping for transducer motion through an ECHOVIEW routine based on the algorithm developed by Dunford (2005).

A Furuno F1-501 wind angle anemometer was used to measure true wind speed and direction, which was recorded periodically during acoustic surveys and several times during each tow. A temperature/depth profile was recorded manually for every trawl from the Furuno CN 22 net monitor.

2.3.2 Acoustic survey design

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, suitably formed for acoustic surveying, have been found in acoustic and trawl surveys of the southwest Challenger Plateau since 2005. It was planned that the snapshots be done in areas where large commercial catches have been made in these surveys, and that they be mainly executed during breaks in commercial fishing during the processing of large catches 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).

The design called for as many snapshots and target-identification trawls as possible to be carried out on the flat ground within the EEZ, but none on any of the hills because of difficulties in estimating the proportion of the back-scatter from non-homogeneous aggregations on hills which is attributable to orange roughy (e.g. Hampton et al. 2007).

On the basis of the previous acoustic surveys, it was anticipated that most of the orange roughy aggregations, and therefore most of the survey effort, would be concentrated in Strata 22, 23 and 24, particularly Stratum 22. The search effort at the beginning of the survey was therefore concentrated in these strata.

Snapshots of flat areas were done using a parallel transect design, in which transects were spaced on average approximately 0.5 n.miles apart, running either E/W or N/S, depending on the direction of the wind and swell. All of the snapshots in Stratum 22 and the first two in Strata 23 and 24 were primarily searching snapshots. The grids in these snapshots were worked in one direction only and the transects equally spaced 0.5 n.miles apart. In the later snapshots in Strata 23 and 24, which were intended for biomass estimation, the transect spacing was randomized to ensure unbiased estimates of biomass and precision (see Jolly & Hampton 1990), between limits of 0.25 and 0.75 n.miles. In these snapshots every second transect was surveyed in the first pass through the grid, and the remainder on a second pass in the opposite direction. This was done, following recommendations by Simmonds & Maclennan (2005), to counter the effects of fish movement in the direction normal to the transects during the course of the snapshot. Survey speed was maintained at between 8 and 10 knots, depending on weather.

Although not in the original design, a number of snapshots were done on the Pinnacles (Megabrick and Twintits) to investigate whether the unusually low biomass found in the adjacent Stratum 22 was explicable in terms of an unusually high biomass on these hills. Each of these snapshots was done at between 4 and 6 knots on four radial transects intersecting at the centre of the hill, as recommended by Doonan et al. (2003a). The transects were equally spaced in angle, starting from a random bearing.

2.3.3 Snapshots

Survey tracks of all the snapshots are shown in Figure 1. Details of those from which acoustic estimates of orange roughy biomass could be extracted are given in Table 2. Not listed in Table 2 are two reconnaissance snapshots; one in Stratum 22 and the other straddling Strata 23 and 24, which were conducted early in the survey to locate the areas of highest abundance. Also omitted are two later snapshots in Stratum 22 in which no clear orange roughy marks were detected, and one (Snapshot 10) straddling Strata 23 and 24 in which the marks were too indistinct for a credible acoustic estimate of orange roughy biomass. Note that Snapshot 3, which straddled Strata 22 and 23, was subdivided for analysis purposes into Snapshots 3A in Stratum 22, in which no clear orange roughy marks were detected, and 3B in Stratum 23, where a number of distinct aggregations, suitable for surveying acoustically, were detected.

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 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 h_{eq} and the mean back-scatter from the aggregation in the 10-m 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 these cases 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 acoustic and optical system (AOS) 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

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

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 and 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 CV) 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 CVs 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 2 shows the pooled length distribution of orange roughy males, females and both sexes combined taken from trawls used for target identification in the snapshots from which acoustic estimates of biomass were extracted (i.e. Snapshots 3, 4, 11, 12 and 16 on the flats and Snapshots 6, 8 and 14 of Megabrick). The distributions are broadly unimodal, with the females tending to be larger than the males in both areas. The mean length, weight and target strength in each of the snapshots used for biomass estimation are listed in Table 3. Figures 3 and 4 show the length distributions for both sexes combined in each stratum of the trawl survey, based on all the random trawls in the stratum, and Figure 5 the same information for Stratum 10, taken from all target-identification trawls on the Pinnacle hills. Table 4 lists the mean lengths and weights in each stratum. The latter were estimated from the stratum length frequencies and the length/weight relationship for the entire survey, shown in Figure 6.

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 28 June, most of the females were either maturing or ripe (Stages 3 and 4), but that by the end of the survey on 8 July roughly half of them were spent. 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 concluded 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 and identification 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 and identification trawls are plotted in Figures 8 and 9 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 10 t in Stratum 24. Catches in the identification trawls, the largest of which (33.9 t) was in Stratum 23, tended to be higher than in the random trawls (mean 9.38 t compared to 1.46 t). Less than 1 t of orange roughy was caught in the three identification trawls on the Pinnacles (Stratum 10), unlike in previous years, when a number of large catches of orange roughy were made there (e.g. Doonan et al. 2010, Hampton et al. 2013).

Figures 8 and 9 show that the highest orange roughy catch rates in both the random and the identification trawls were made in the flat areas to the east of the Pinnacles, particularly in Strata 22, 23 and 24. Table 5 shows the estimates of orange roughy biomass and CVs for each stratum in the trawl survey for both phases combined, and the estimates of total biomass in the survey area. The estimates are given for all fish and for those 27 cm and over; 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 3 and 4 and the length/weight relationship in Figure 6. The high proportion of the biomass in Strata 23, 24 and 25 and the large CVs in some of the strata will be noted.

Table 6 summarises the estimates of biomass and the CVs for other species which were common in the random trawl catches. Note the low biomass estimates for all these species compared to the orange roughy estimates in Table 5.

3.2.2 Acoustic survey

Calibration

The echo sounder gain factors agreed upon by CSIRO and FRS from the CSIRO calibration on 23 July are given in Table A-2, Appendix A, where they are compared against the results from previous calibrations of this system by NIWA and FRS. The results indicate that the system sensitivity has declined by some 3 dB (i.e. that it has approximately halved) between 2009 and the present. A correction factor of 3.92 was applied to all biomass estimates from the survey on the basis of the 2012 calibration.

Nature of marks

The most distinctive orange roughy-like aggregations were detected in Strata 23 and 24. These were reasonably well defined and extended to a maximum of about 70 m off the bottom in places (e.g. Figures 10 to 13). No marks which could be attributed to orange roughy with sufficient confidence to serve as a basis for an acoustic estimate of biomass were detected in Stratum 22. On Megabrick and Twintits the marks were small and in places off the bottom (e.g. Figures 14 and 15), unlike typical marks on these hills in previous surveys which were often large, dense and connected to the bottom (e.g. Doonan et al. 2009, 2010, Hampton et al. 2013).

Mark identification

Biological information for mark identification and the conversion of back-scatter to density in the snapshots used for biomass estimation was taken from the catches listed in Table 3, which shows the mean percentage of orange roughy, and mean length, weight and target strength of the orange roughy in each of these catches. The average catch in the trawls on the flats was 11.07 t, of which 98.9 % on average was orange roughy. The catch in the single trawl used for target identification and partitioning of the back-scatter on Megabrick was only 0.74 t, 93.9 % of which was orange roughy. The two target identification trawls on Twintits yielded a total of 60 kg of orange roughy, which comprised only 2 % of the total catch on this feature.

Although, as can be seen from Table C-1, a number of sizeable, clean catches of orange roughy were made in the trawls used for target identification (particularly trawl BT30, in which over 33 t of orange roughy were caught), in no case could the catch be attributed to specific acoustically-detected aggregations, which were generally small and scattered. Mark identification was therefore based as much on the nature of the marks as on the identification catches.

Distribution

A composite track chart of all snapshots, whether used for biomass estimation or not, is shown in Figure 1, while Figure 16 shows the track charts, mark locations and vessel tracks in the trawls used for mark identification and signal conversion in the snapshots on the flats from which biomass estimates were extracted. These figures show that orange roughy aggregations on flat ground at the time of the acoustic survey were largely concentrated in a narrow depth range (between 860 and 880 m) about 10 n.miles east/northeast of the Pinnacles. A comparison between the distributions in the individual snapshots in Figures 17 to 21 suggests that there was little meridional or zonal movement of the core of the distribution over the one week period of these snapshots (1 to 8 July).

Figure 22 shows the snapshot grids, locations of orange roughy-like marks and the vessel track in the single trawl on Megabrick, which was the only one of the two Pinnacle hills on which orange roughy dominated the catch. It can be seen that the marks were concentrated on the top of the hill and extended down all sides of it. Figure 15 suggests that the marks on Twintits (which contained very little orange roughy) were similarly concentrated, although they were generally further off the bottom than the marks on Megabrick.

Biomass estimates

Biomass and CV estimates for all of the snapshots on the flats from which biomass estimates could be extracted, are shown in Table 7. Note that the CV in parenthesis is CV_2 (e.g. Hampton & Soule 2003), which is calculated from the variation between the snapshot estimates rather than from the CVs in the individual snapshots. The Table also shows the percentage of the estimate contributed by B-category targets, which was particularly large for Snapshot 4 and 100 % for Snapshot 16, and the dead zone corrections, which were small throughout. Table 8 shows the catch of species other than orange roughy in the trawls used in target identification.

Table 9 sets out the biomass estimates, CVs dead-zone corrections and partitioning factors for the three snapshots of Megabrick. (There were no Category-B targets in these snapshots). Note the relatively large dead zone corrections and the low partitioning factor, which is a result of the presence of other species with high target strengths in the identification haul linked to these snapshots (Table 10).

4. DISCUSSION

4.1. Biology

Table 3 indicates that the mean lengths of orange roughy sampled in the various areas where most of the aggregations were found in the acoustic survey were similar. The mean lengths of males and females in the various strata in the trawl survey (Table 4) are consistent with those in the same strata in the 2011 trawl survey (see table 12, Hampton et al. 2013) and the modes 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 3 and 4 and the mean lengths and weights in Table 4 suggest that orange roughy on the Central Flats (Strata 3 and 4) were somewhat smaller than on the Pinnacle Flats, although note in Figure 4 the relatively few fish in the length distribution from Stratum 3.

The maturation of females in the survey is compared with that in previous years in Table 11, 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 Hampton et al. (2013) and those for the earlier years from figures in Doonan et al. (2010) for the Pinnacles area.

From the above it would appear that in terms of the timing of the spawning cycle in the Pinnacles area, 2012 was more similar to the three previous years than 2005 and 2006, when spawning appears to have started and ended a few days earlier. It also appears from Table 11 that the duration of the spawning in 2012 was similar to that in all previous years except 2011, when the cycle seems to have been substantially longer.

4.2 Distribution

Figures 8 and 9 and Table 5 indicate that the highest catches of orange roughy in the trawl survey of the flats were recorded to the east and northeast of the Pinnacles, south of 40.0^{o} S. This is broadly similar to the distribution found in all previous trawl surveys of the southwest Challenger Plateau since 2005 (Clark et al. 2005, 2006, Doonan et al. 2009, 2010, Hampton et al. 2013). Note however that the proportion of the biomass estimate contributed by Stratum 22 (adjacent to the Pinnacles) was substantially lower than in the previous surveys. For example, the estimate for this stratum in Table 5 amounts to less than 5% of the total compared to 62 % in the 2011 survey (from table 5, Hampton et al. 2013).

A comparison between Figures 8, 9 and 16 indicates that the aggregations detected acoustically were mostly found where high catch rates were recorded in the trawl survey (i.e. in Strata 23 and 24), except in Stratum 22, where no such aggregations were detected acoustically despite significant (albeit atypically low) catches there in the trawl survey. The lack of aggregations in Stratum 22 is in sharp contrast to the situation in previous years, when most of the aggregated biomass (61 % in 2010 and 99.8 % in 2011) was found in this stratum.

The comparatively low catch rates in Stratum 22 in the trawl survey, the absence of acoustically-detectable aggregations there, and the small marks on the Pinnacles (on only one of which was a significant proportion of orange roughy found) all indicate that the fish in this survey were less concentrated on and adjacent to the Pinnacles that has been the case in the surveys since 2005, and that they were further east and in slightly shallower water (ie. less than 880 m compared to 900 m) than in the previous surveys. A further indication is that the proportion of the biomass estimate contributed by Stratum 25 in the current survey (15%) is high compared to the average in the trawl surveys between 2006 and 2011 (approximately 1%).

Overall, the surveys since 2005 have shown that the distribution of orange roughy on the southwest Challenger Plateau over this period has been reasonably consistent and site-specific. Notable exceptions are the low aggregated biomass in Stratum 22 in the current survey and the lack of aggregated orange roughy in Stratum 24 in 2011 (Hampton et al. 2013) as opposed to the current survey and in 2009, when some 39% of the acoustically-estimated biomass on the Challenger Flats was found in this stratum (from table 14 in Doonan et al. 2009). Notwithstanding the low biomass estimate in Stratum 22 in the current trawl survey compared to the previous years, there has been less variation in the distribution of the catch rates in the random trawls than in the distribution of the aggregations. This suggests that the variation in the distribution of the aggregations is at least partly due to temporal and spatial variability in aggregating behavior rather than solely to variations in overall distribution.

4.3 Biomass estimates

Trawl survey
In that all the strata in the trawl survey of the Challenger Flats were sampled at least three times (the prescribed minimum) by trawls which in all cases ran for the prescribed length of 1.5 n.miles and were classified as either "good" or "acceptable" (see Table C-1), the trawl survey can be judged to have been successfully executed. This is borne out by the CV, which at 26.7 % (Table 5) is below the target of 30 % . It can be seen from Table 5 that more than half (57 %) of the biomass estimate of 26 039 t was contributed by the estimate for Stratum 24, and 88 % by the estimates for Strata 23, 24 and 25.

Acoustic survey
The acoustic estimate of aggregated orange roughy biomass in Strata 23 and 24 shown in Table 7 is in principle well founded, being based on five snapshots in which the aggregations and the areas which they occupied were reasonably well defined, and their identity satisfactorily confirmed by the seven trawls used in target identification. Note that the CV estimate based on the CVs of the individual snapshots (CV_1) is considerably smaller than that based on the variation between the snapshot estimates (CV_2). This is unlike the situation in multiple-snapshot acoustic surveys of orange roughy aggregations in the Chatham Rise Spawning Plume, where CV_2 estimates over a period of 10 years have consistently been either similar to or lower than the corresponding CV_1 estimates (e.g. Hampton et al. 2010). Even allowing for the fact that the CV_2 estimator is poor, being based on only five biomass estimates, the large difference between the two CV estimates suggests that the variation in the individual snapshot estimates is not solely due to sampling error. Possibilities include a variation in the degree of aggregation from one snapshot to the next, and horizontal movement in and out of the survey area between snapshots. The former appears the more likely considering the trawl and acoustic evidence from Stratum 22 that orange roughy in the area may not be detectable acoustically even if present in reasonable abundance, and the lack of evidence of significant lateral movement of the aggregations detected in the snapshots in Strata 23 and 24 during the survey period.

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It must be appreciated that the sampling CV, however estimated, greatly underestimates the uncertainty in the estimates since it excludes the uncertainties in target strength, partitioning factors, calibration corrections and errors in corrections for dead zone, weather and sound absorption.

Although the CV of the acoustic estimate in Table 9 of orange roughy biomass on Megabrick from the three snapshots and single identification trawl there (3364 t) is relatively low (22.1 %), we consider this estimate to be less reliable than those for the flat strata. This is primarily because of 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). Nonetheless, the Megabrick estimate, and the finding of insignificant quantities of orange roughy on Twintits, are of value in that they indicate that the unusually low abundance in the adjacent Stratum 22 was not due to an unusually high abundance on the Pinnacles; a question which the acoustic survey of these hills was designed to investigate in an *ad hoc* adjustment to the original survey design.

Comparison with previous estimates
In Table 12 and Figure 23 the trawl and acoustic estimates of orange roughy biomass on the Pinnacle Flats are compared with estimates there in the previous surveys. 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. This seems reasonable from a comparison between the gear parameters in Table E-1, Appendix E, although we note that the mean headline height of 4.5 m is the lowest in the time series and the mean speed (3.6 knots) the highest. 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 entailed removal of Stratum 25 from the four most recent surveys. (The reduction in the estimates was less than 1% in all years except 2012, when 15% of the biomass was found there). 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 2012 trawl estimate is close to the average in the previous four years (21 589 t), significantly higher at the 95% level than the corresponding estimates in 2006 and 2010, but significantly lower than the 2009 estimate. In contrast, the acoustic estimate of aggregated biomass from the current survey is significantly lower than the acoustic estimate of this component in 2011, and somewhat lower than the mean of the acoustic estimates in the previous five surveys (6961 t).

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 13 the estimates of the biomass of other common species taken in the trawl survey and the CVs are compared with the estimates from the previous five surveys. It can be seen that most of the species taken in the 2012 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 sharks and dogfish in all of the surveys. It should however 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 14 the acoustic estimates on the Pinnacles are compared with those from the three previous surveys, as reported in Doonan et al. 2009 and 2010 and Hampton et al. 2013. 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 estimate of total biomass on the two hills is similar to that in 2011, although in this case all of the biomass was found on Megabrick, as opposed to 2011, when 64 % of the biomass estimate was contributed by Twintits.

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 compared to 64 m) and is therefore probably more affected by aeration in poor weather.

Total population size
The question arises as to whether the 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). As noted by Hampton et al. (2013) a way forward has 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. No such layers were encountered during the current survey, but it is hoped that data collected from previous surveys, supplemented by new data in future, will ultimately lead to useful estimates of q through this or similar modeling exercises. 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 the estimate directly.

Hampton et al. (2013) point out that a further problem in combining estimates of the dispersed and aggregated components arises from the fact that the aggregated proportion may vary substantially during the survey, which could introduce significant biases and inflate CVs in both the trawl and acoustic estimates. As noted earlier, the large variability in the acoustic estimates in Table 7 and the large difference between the CV_1 and CV_2 estimates may well be evidence of this effect, which should be minimized by ensuring that the trawls and acoustic snapshots in an area are as closely matched in time as is possible.

5. CONCLUSION

We conclude that the survey was successful in generating relative trawl and acoustic estimates of orange roughy biomass in the flat areas on the Challenger Flats during the spawning period which are comparable with previous estimates there at this time, and that have acceptably low sampling CVs. The trawl estimate of the dispersed component of the population is above the comparable estimate from the 2011 survey, but the acoustic estimate of the aggregated component is significantly lower than that from the 2011 survey and is below the mean of the estimates from the previous five acoustic surveys. Both estimates are significantly lower than the equivalent estimates from the 2009 survey, when orange roughy appear to have been particularly abundant in the area.

A notable difference in this survey compared to the previous ones was the relatively small amount of orange roughy taken in the trawls in Stratum 22 and the almost total absence of aggregations there, both of which indicate a more easterly and slightly shallower distribution than in previous years. The six *ad hoc* snapshots on the Pinnacles, immediately to the west of Stratum 22, and particularly the zero estimate on Twintits, suggest that the unusually low biomass in Stratum 22 was not due to the fish having moved onto the Pinnacles at the time.

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As before (Hampton et al. 2013), we recommend that future surveys of the Challenger Flats should aim to a) improve the CV 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 on the Flats which, if sufficiently accurate, is likely to be the estimate of most value for management purposes. We emphasise, as in Hampton et al. (2013), that much lower priority should be given to both trawl and acoustic sampling of the hills because of deficiencies in both methods when attempting to sample non-homogeneous orange roughy aggregations on sloping ground, even to the extent of restricting the survey to flat ground, as in the current survey.

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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
21	Western side of Pinnacles	121	3	0
22	Pinnacles Flats	192	12	0
23	Eastern Pinnacles Flat	93	6	1
24	Eastern Pinnacles extension	305	11	3
25	Eastern Pinnacles guard stratum	438	3	1
Total		2 619	44	5

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

Stratum	Snapshot	Date	No. transects	Transect direction	No. id. trawls
23/24	3B	2-Jul-12	11	N/S	1
23/24	4	4-Jul-12	19	N/S	1
23/24	11	6-Jul-12	8	E/W	1
23/24	12	6-Jul-12	7	E/W	1
23/24	16	8-Jul-12	11*	N/S	0
Megabrick	6	5-Jul-12	4	Radial	0
Megabrick	8	5-Jul-12	4	Radial	1
Megabrick	14	8-Jul-12	4	Radial	0
Twintits	7	5-Jul-12	4	Radial	0
Twintits	9	5-Jul-12	4	Radial	1
Twintits	15	8-Jul-12	4	Radial	1
			* includes extentions		

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

						Mean length (cm)	Mean weight (kg)	Mean TS (dB)
Area	Snapshot no.	Trawl no.	% orange roughy	Males	Females	All fish	All fish	All fish
Stratum 23/24		22	98.9	29.9	31.6	30.5		
	3B	23	98.4	31.1	31.9	31.5	1.09	-52.80
		30	99.7	30.4	32.7	31.4		
	4	33	97.6	31.1	32.2	31.8	1.16	-52.43
	11	48	98.7	31.3	31.6	31.6	1.14	-52.48
	12	49	99.4	30.8	31.8	31.0	1.01	-52.59
	16	56	97.7	29.77	32.3	32.1	1.15	-52.36
Megabrick	6							
	8	35	93.9	31.7	34.0	32.9	1.17	-52.43
	14							

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

Stratum	1	21	22	23	24	25	3	4
Mean length (cm)	31.7	31.1	31.8	31.3	31.2	31.9	29.2	30.4
Mean weight (kg)	1.15	1.11	1.17	1.12	1.11	1.19	0.97	1.04

Table 5: Number of trawls, biomass estimates for fish 27 cm or more, and for all fish, and CVs for each stratum in the trawl survey (both phases combined).

Stratum	No. of trawls	Biomass ≥ 27 cm (t)	Biomass (total) (t)	CV (%)
1	3	1 456	1 476	86.2
21	3	114	121	87.9
22	12	1 231	1 259	35.9
23	7	4 003	4 154	52.1
24	14	14 424	14 858	41.2
25	4	3 760	3 908	52.4
3	3	81	96	22.4
4	3	155	171	54.4
All	49	25 224	26 043	26.7

Table 6: Total biomass and CV estimates for other common species in the random trawl survey.

Common name	Code	Biomass (t)	CV (%)	% of stations
Seal shark	BSH	285	55.5	20
Black slickhead	BSL	57	15.0	76
Humpback rattail	CBA	8	49.2	20
Notable rattail	CIN	3	39.6	65
Mahia rattail	CMA	21	29.5	82
Serrulate rattail	CSE	29	15.9	94
Leafscale gulper shark	CSQ	647	22.5	37
Four-rayed rattail	CSU	1	70.3	22
Owston's dogfish	CYO	479	13.3	67
Longnose velvet dogfish	CYP	54	30.9	59
Baxters lantern dogfish	ETB	54	30.9	39
Pale ghost shark	GSP	37	25	47
Hake	HAK	154	41.3	45
Johnson's cod	HJO	110	24.0	82
Hoki	HOK	120	33.0	31
Javelin fish	JAV	21	59.7	14
Widenosed chimaera	RCH	58	49.4	29
Ribaldo	RIB	330	18.8	98
Spinyfin	SFN	12	63.5	22
Shovelnose dogfish	SND	337	13.9	86
Spiky oreo	SOR	118	21.3	88
Trachyscorpia capensis	TRS	42	30.1	59
Violet squid	VSQ	53	49.5	35
White rattail	WHX	271	21.1	76

Table 7: Acoustic estimates of orange roughy biomass, CVs, dead zone corrections and % of biomass classified as Category B in Strata 23 and 24. The CV in parenthesis is CV_2, calculated from the variation between the snapshot estimates.

Snapshot	Biomass (t)	CV (%)	B-category (%)	Dead zone correction
3B	4 095	34.9	17	1.05
4	1 445	27.7	75	1.09
11	3 566	11.8	39	1.05
12	6 659	36.9	2	1.05
16	1 430	22.9	100	1.13
Mean	3 439	17.0	46.5	1.06
		(28.2)		

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

			Catch (kg)							
Stratum	Station	Type	Total	DOG	HAK	HJO	HOK	ORH	RIB	SOR
23/24	22	ID	9 208	6	0	1	0	9 180	11	1
	23	ID	3 479	12	16	2	0	3 423	12	2
	30	ID	34 274	8	33	3	2	33 886	27	4
	48	R	8 455	14	2	1	8	3 395	3	6
	49	R	15 651	0	5	0	0	8 347	12	10
	56	R	2 964	5	4	1	2	15 556	0	2
Megabrick	35	ID	787	0	1	0	3	739	11	32

Table 9: Acoustic estimates of orange roughy biomass, CVs, dead zone corrections and partitioning factor for snapshots of Megabrick.

Snapshot	Biomass (t)	CV (%)	Dead zone correction	Partitioning factor
6	4 096	35.4	1.340	0.22
8	3 033	42.1	1.370	0.22
14	2 962	37.4	1.500	0.22
Mean	3 364	22.1	1.400	0.22

Table 10: Partitioning of backscatter between species in snapshots of Megabrick, based on species composition in Trawl 35.

Stratum/ Species code	Catch (kg)	Proportion by number in catch (%)	Mean length (cm)	Mean target strength (dB)	Proportion of backscatter (%)
HOK	3	0.15	95.0	-39.30	0.70
ORH	739	93.23	32.9	-52.28	22.47
RIB	11	1.33	50.0	-29.83	56.05
SOR	32	4.86	33.0	-39.78	20.78

Table 11: Comparison of orange roughy spawning state in current survey with that on the southwest Challenger Plateau in previous surveys.

	2005	2006	2009	2010	2011	2012
Date 35 % Stage 3	26-27 Jun	27-Jun	1-Jul	2-3 Jul-11	29-Jun	02-Jul
Date 20% Spent	3-Jul	29-Jun	4-Jul	5 or 8 Jul	7-Jul	08-Jul

Table 12: Estimates of orange roughy biomass on the Pinnacle Flats from trawl and acoustic surveys between 2005 and 2012. 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 strata of the 2006 survey, as explained in the text.

Survey	2005		2006		2009		2010		2011		2012	
	Biomass (t)	CV (%)	Biomass (t)	CV (%)	Biomass (t)	CV (%)	Biomass (t)	CV (%)	Biomass (t)	CV (%)	Biomass (t)	CV (%)
Trawl	-	-	16 010	27	46 480	30	12 190	19	19 717	31	22 145	27
Acoustic	3 356	49	2 296	72	16 164	26	6 043	13	9 481	24	3 439	17

Table 13: Comparison of biomass estimates (B) and CVs for other species in the trawl surveys between 2005 and 2012.

		2005		2006		2009		2010		2011		2012	
		B	CV	B	CV	B	CV	B	CV	B	CV	B	CV
Common name	Code	(t)	(%)	(t)	(%)	(t)	(%)	(t)	(%)	(t)	(%)	(t)	(%)
Seal shark	BSH	107	44	11	46	61	53	112	42	33	38	285	56
Mahia rattail	CMA	17	21	24	22	44	34	13	20	21	34	21	30
Serrulate rattail	CSE	1	48	29	12	26	24	31	13	14	16	29	16
Leafscale gulper shark	CSQ	342	24	415	18	457	25	308	26	194	30	647	23
Owston's dogfish	CYO	604	16	451	19	503	24	389	23	235	21	479	13
Longnose velvet dogfish	CYP	51	30	82	16	176	14	225	15	114	13	54	31
Deepsea cardinalfish	EPT	3	100	3	100	9	91	20	81	32	67	0	0
Baxters lantern dogfish	ETB	49	38	59	22	31	14	65	24	5	37	54	31
Hake	HAK	126	25	90	31	161	17	164	22	246	57	154	41
Johnson's cod	HJO	39	19	64	16	80	23	133	29	66	35	110	24
Hoki	HOK	15	69	18	41	146	42	93	43	107	18	120	33
Plunkets shark	PLS	3	76	41	52	85	36	0	0	31	80	0	0
Widenosed chimaera	RCH	138	21	102	27	84	27	264	23	54	37	59	49
Ribaldo	RIB	297	18	339	14	499	20	217	18	153	20	330	19
Slickhead, bigscaled brown	SBI	140	54	197	22	29	37	367	45	193	63	0	0
Shovelnose dogfish	SND	306	17	235	16	654	10	239	25	324	10	337	47
Spiky oreo	SOR	135	48	174	33	272	46	342	43	79	24	118	21
White rattail	WHX	211	18	317	16	385	32	333	20	373	20	270	21

Table 14: Acoustic estimates of orange roughy biomass on Megabrick and Twintits between 2009 and 2012. Estimates for 2009 and 2010 from Doonan et al. (2009, 2010) and for 2011 from Hampton et al. (2013).

Hill	2009		2010		2011		2012	
	Biomass (t)	CV (%)	Biomass (t)	CV (%)	Biomass (t)	CV (%)	Biomass (t)	CV (%)
Megabrick	6 114	51.4	664	33	1 241	18	3 364	22
Twintits	1 132	45	190	28	2 235	22	0	0
Megabrick + Twintits	7 246	43.9	854	26	3 476	16	3 364	22

FIGURES

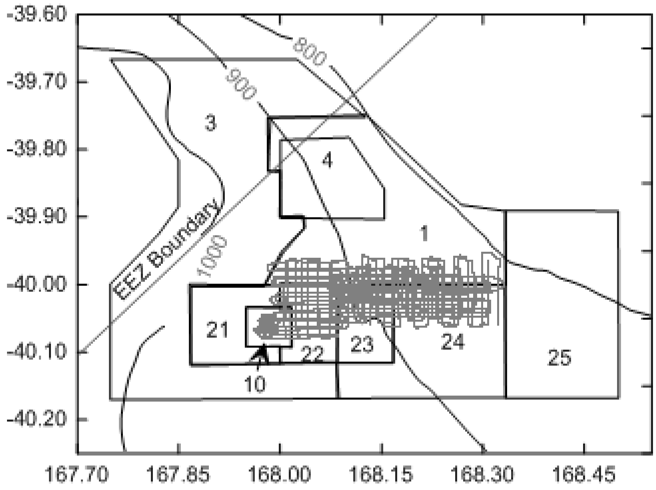
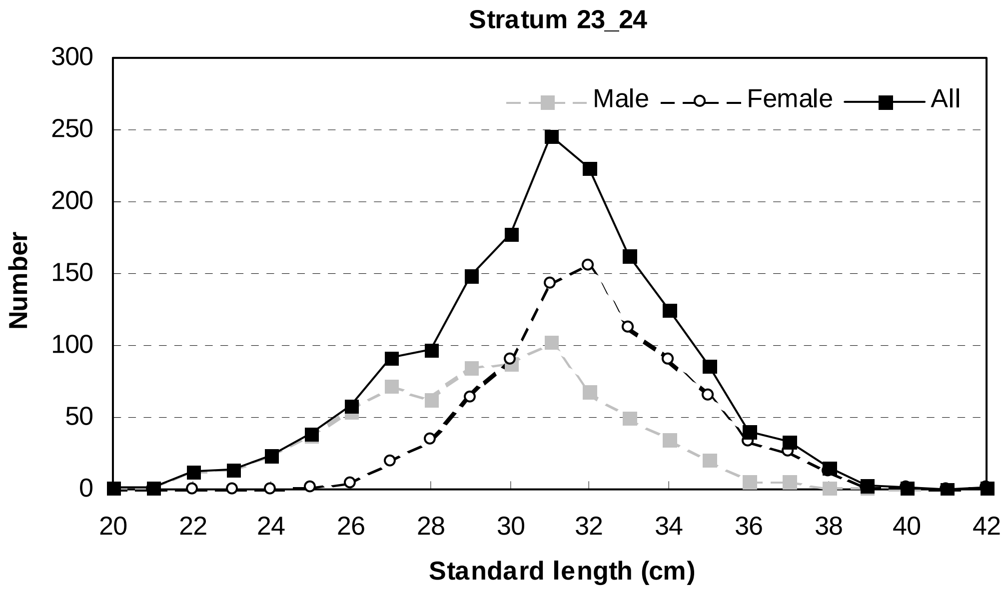


Figure 1: Survey area showing strata in trawl survey.



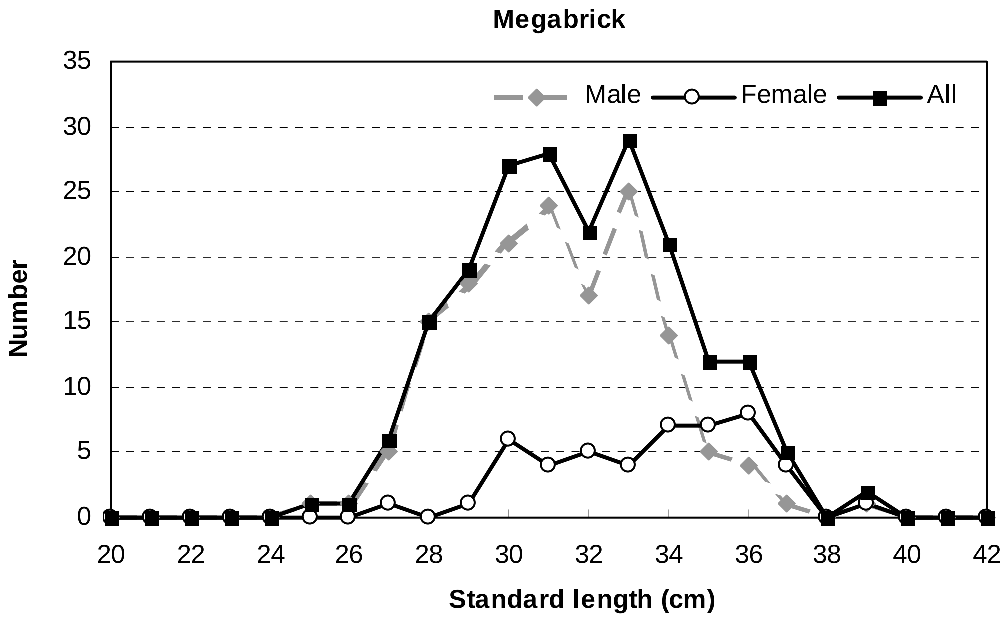


Figure 2: Length distribution of orange roughy in trawls used for mark identification in Strata 23_24 and on Megabrick.

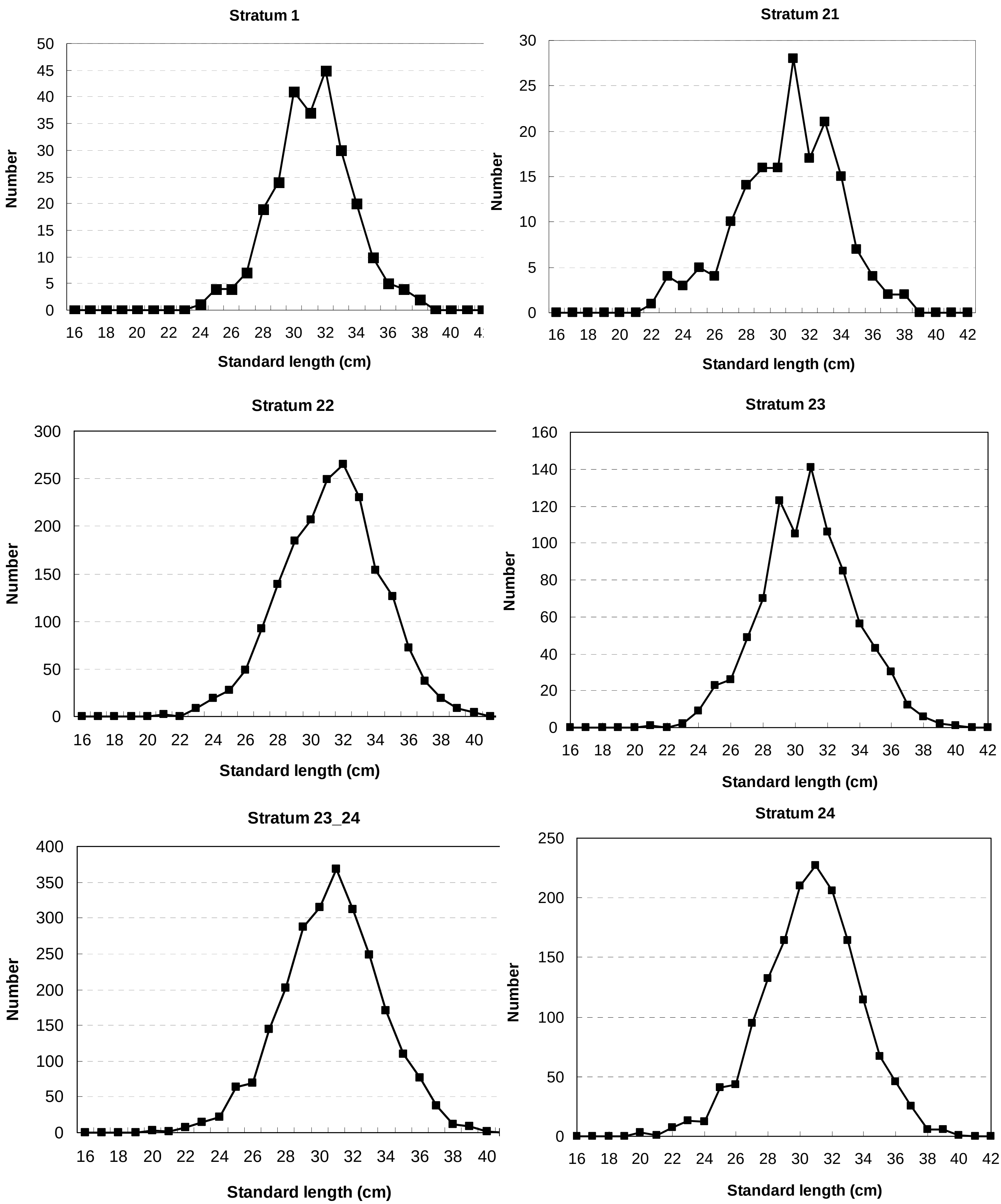


Figure 3: Length distribution of orange roughy in random trawls in Strata 1, 21, 22, 23, 23_24 and 24 of trawl survey.

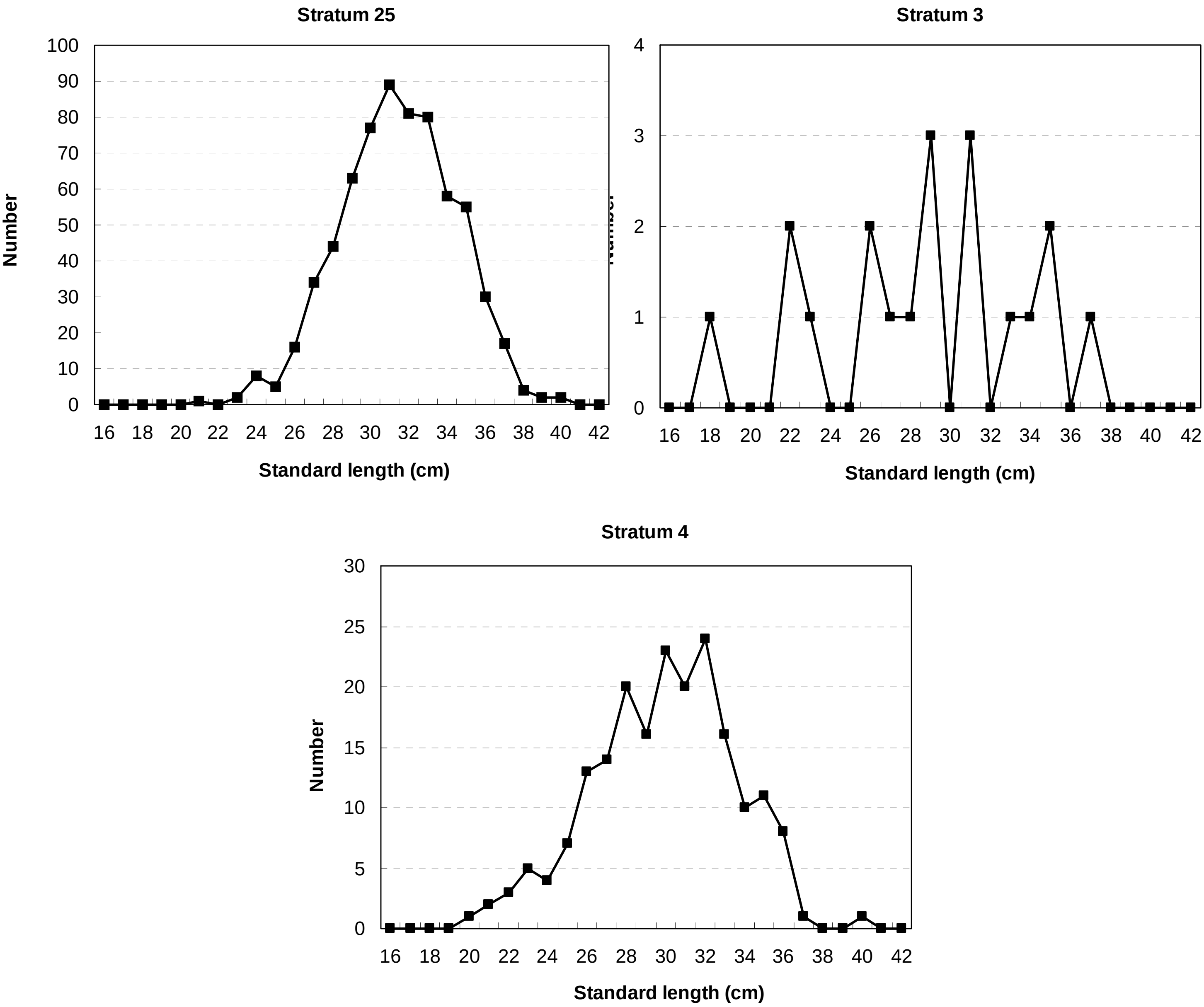


Figure 4: Length distribution of orange roughy in random trawls in Strata 25, 3 and 4 of trawl survey.

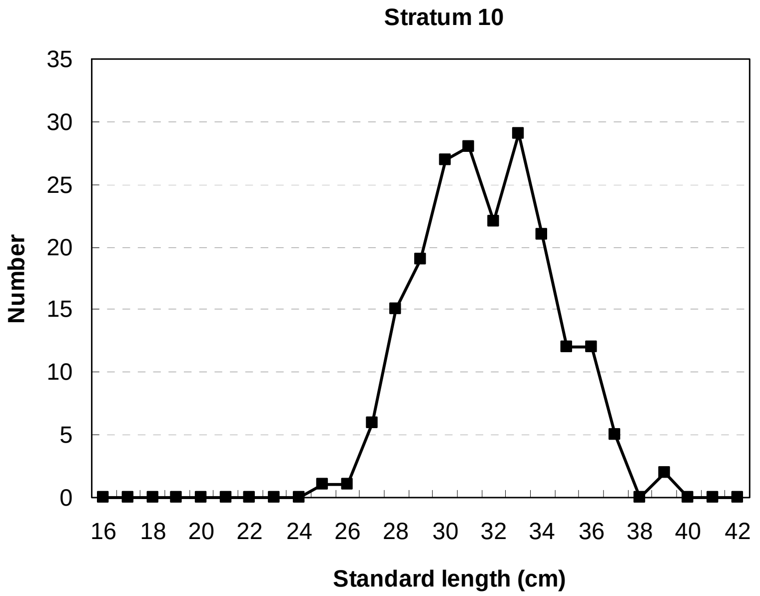


Figure 5: Length distribution of orange roughy in ID trawls in Stratum 10.

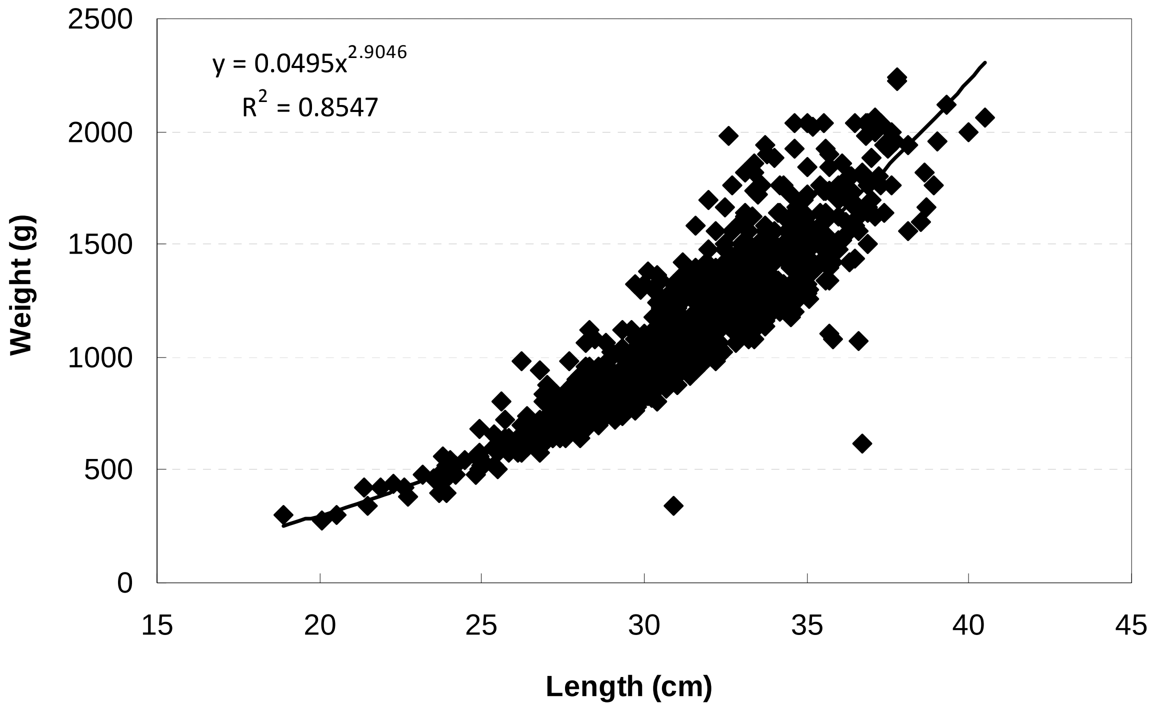


Figure 6: Orange roughy length/weight relationship from measurements during survey.

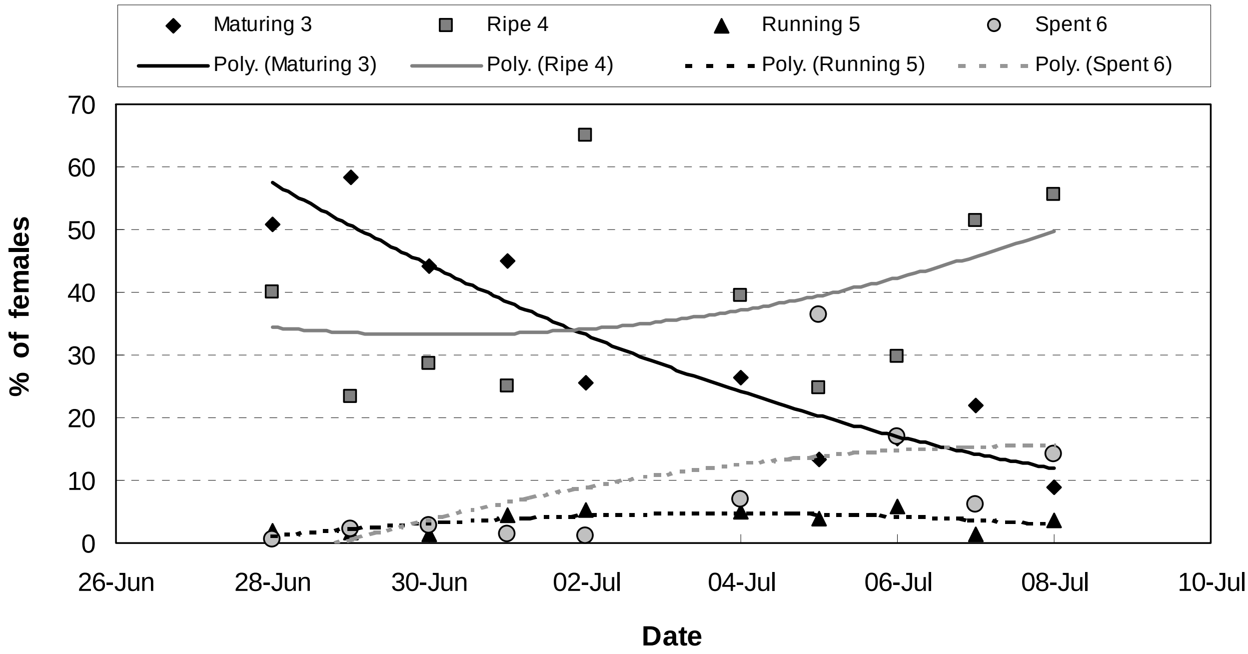


Figure 7: Progression of female gonad maturity stages by date (all strata). Curves from polynomial fit to data.

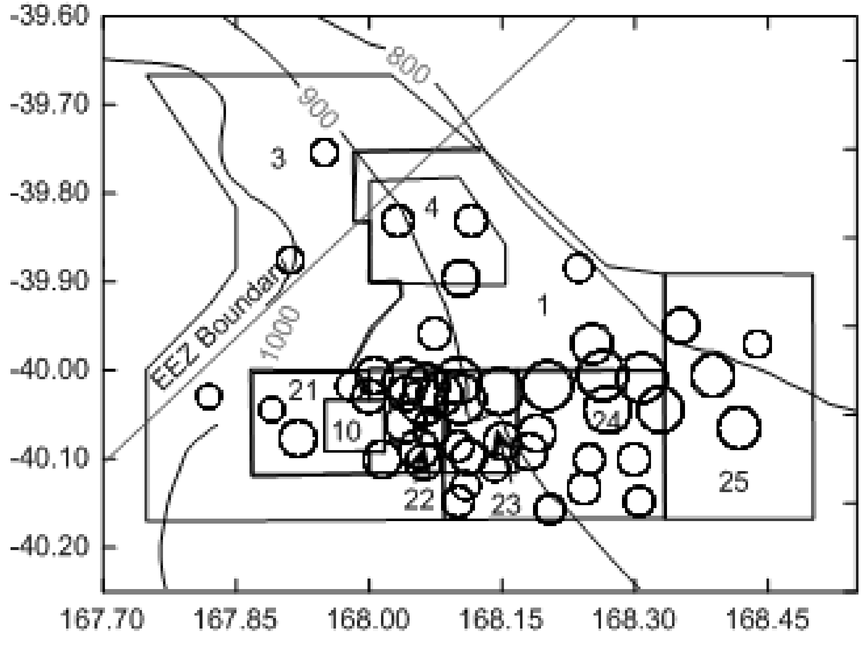


Figure 8: Catch rates in the random stratified trawl survey. Circle diameter is proportion to log of catch rate. Maximum catch rate (Stratum 24) = 3.44 t km^{-1}.

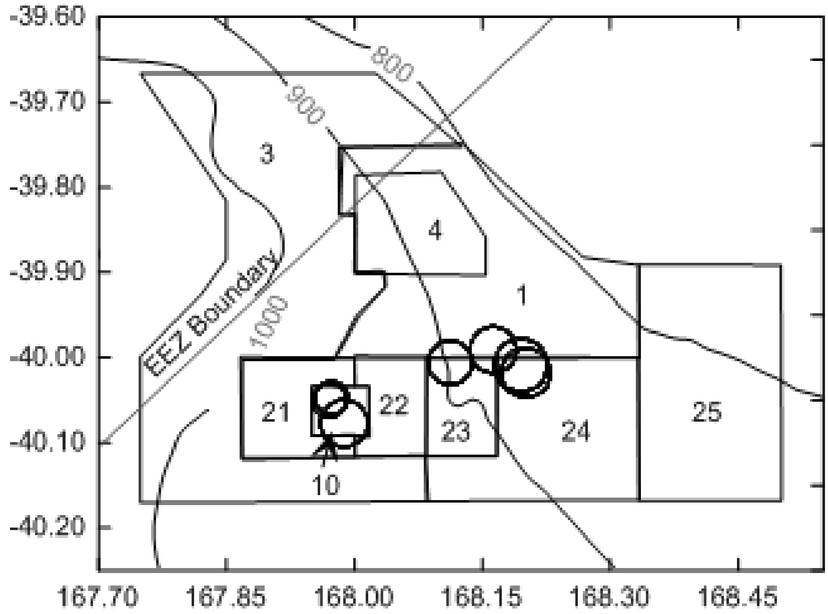


Figure 9: Catch rates in the identification trawls in the acoustic survey. Circle diameter is proportion to log of catch rate. Maximum catch rate (Stratum 24) = 20.0 t km^{-1}.

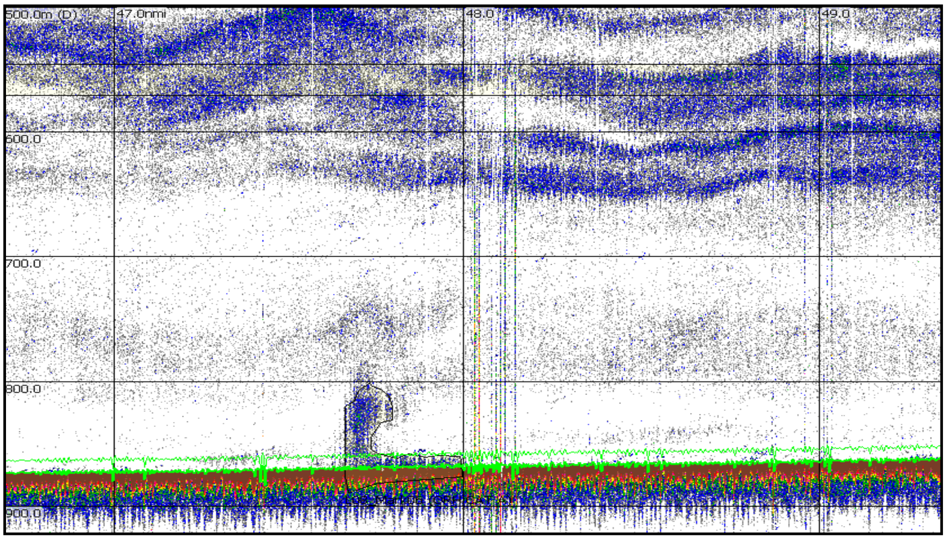


Figure 10: Orange roughy mark during Snapshot 3B of Strata 23_24. The vertical lines are 1 n.mile apart.

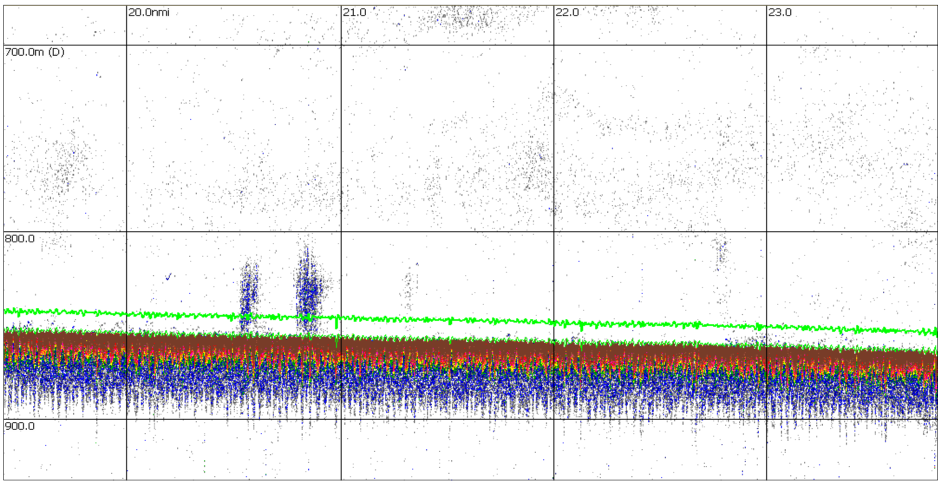


Figure 11: Orange roughy marks during Snapshot 11 of Strata 23_24. The vertical lines are 1 n.mile apart.

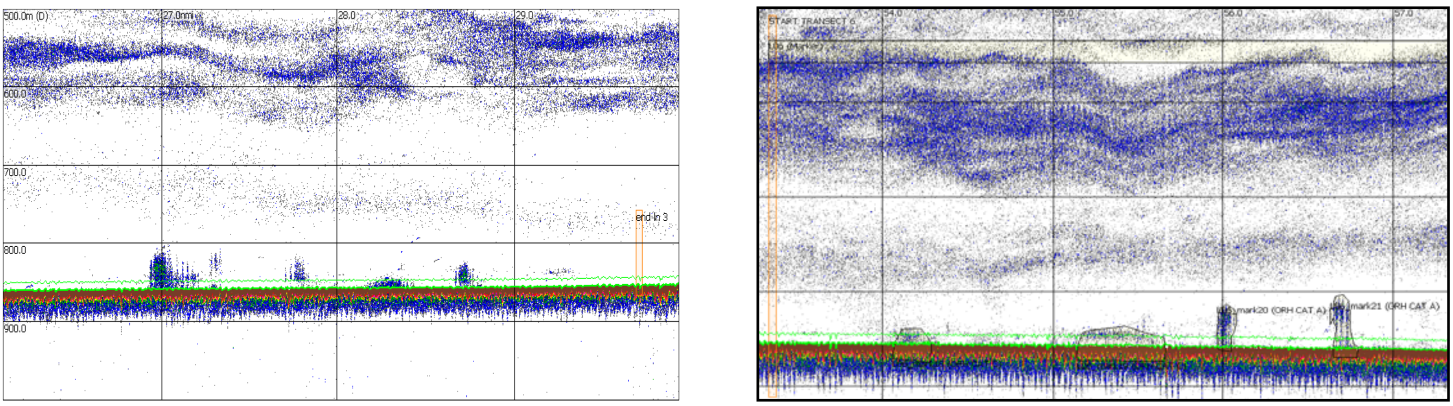


Figure 12: Orange roughy marks during Snapshot 12 of Strata 23_24. The vertical lines are 1 n.mile apart.

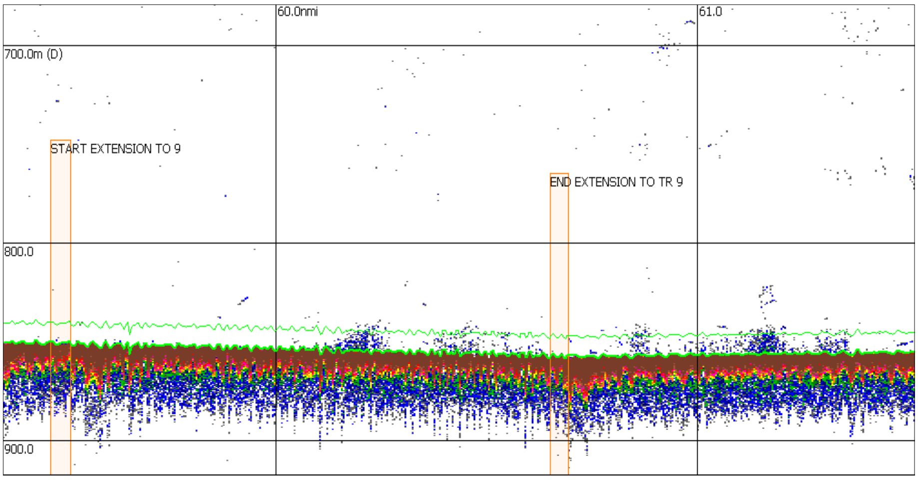


Figure 13: Orange roughy marks during Snapshot 16 of Strata 23_24. The vertical lines are 1 n.mile apart.

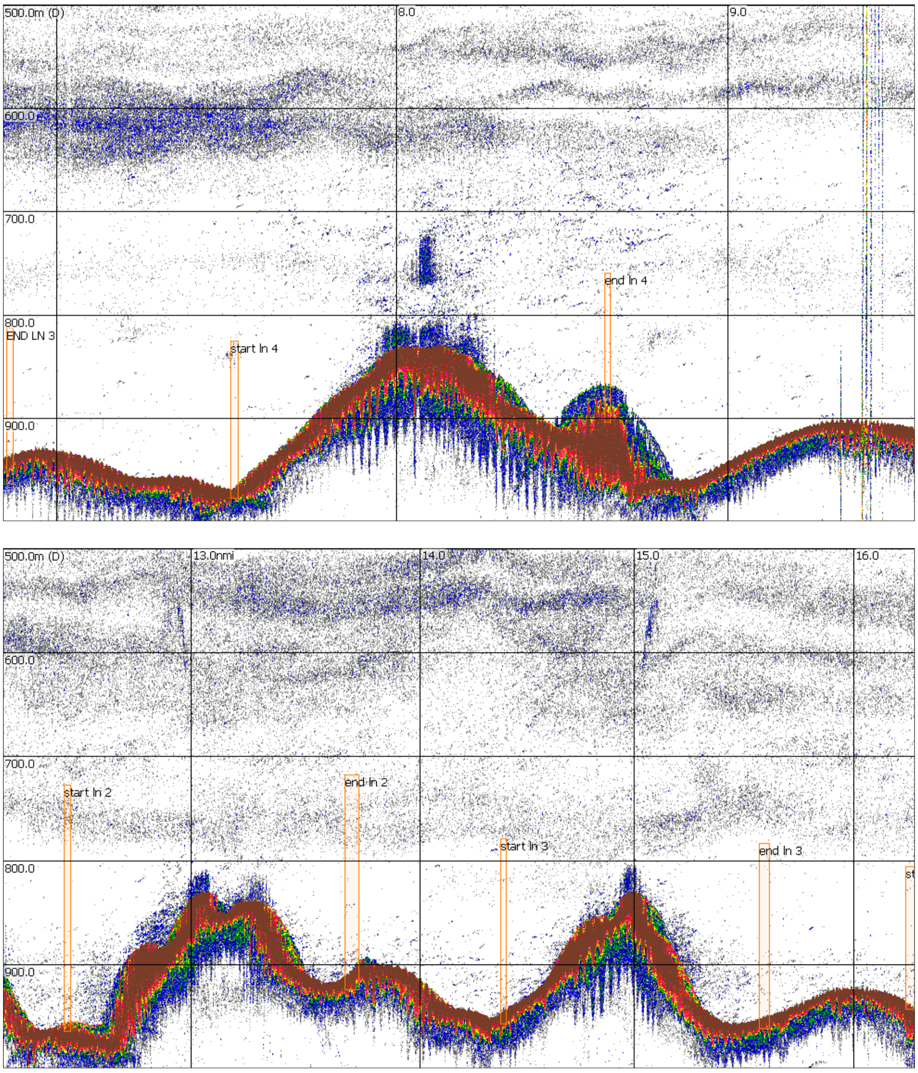


Figure 14: Orange roughy marks during Snapshots 6 & 14 of Megabrick. The vertical lines are 1 n.mile apart.

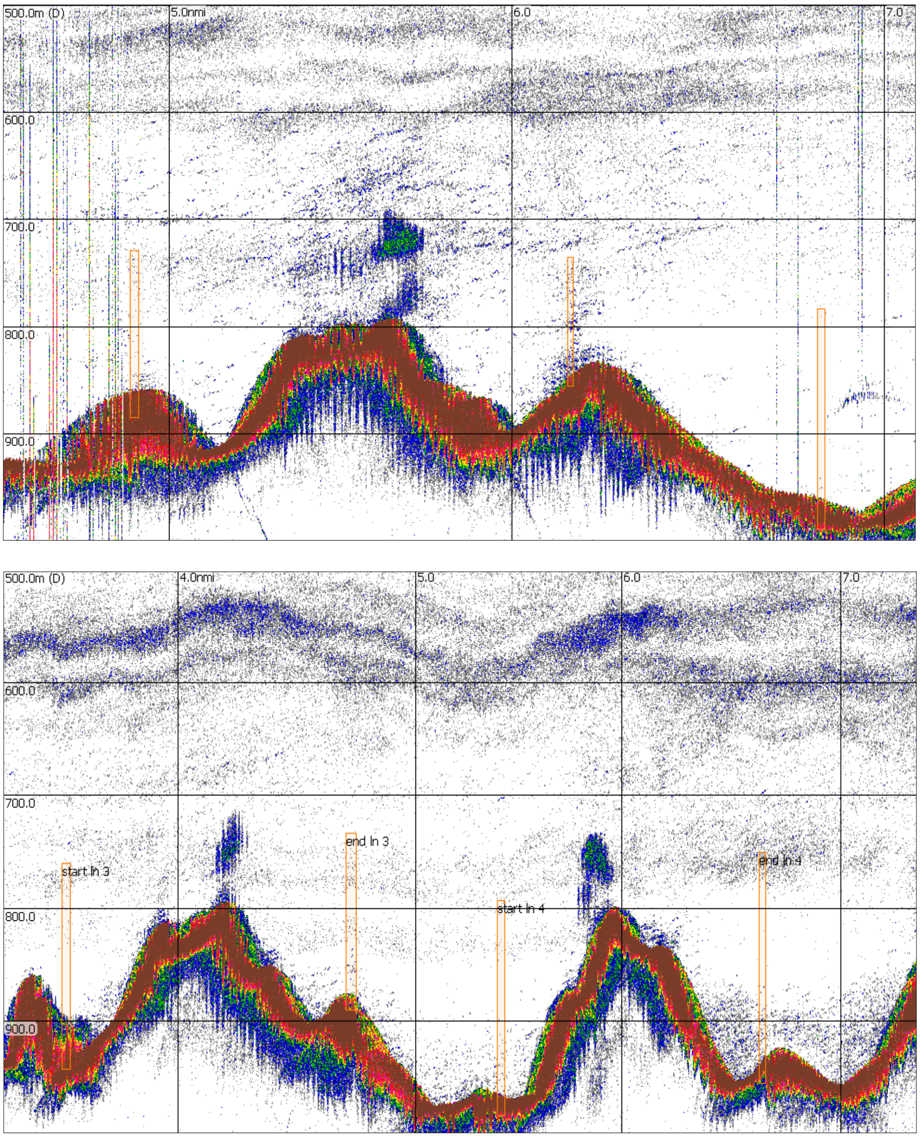


Figure 15: Orange roughy marks during Snapshots 7 & 15 of Twintits. The vertical lines are 1 n.mile apart.

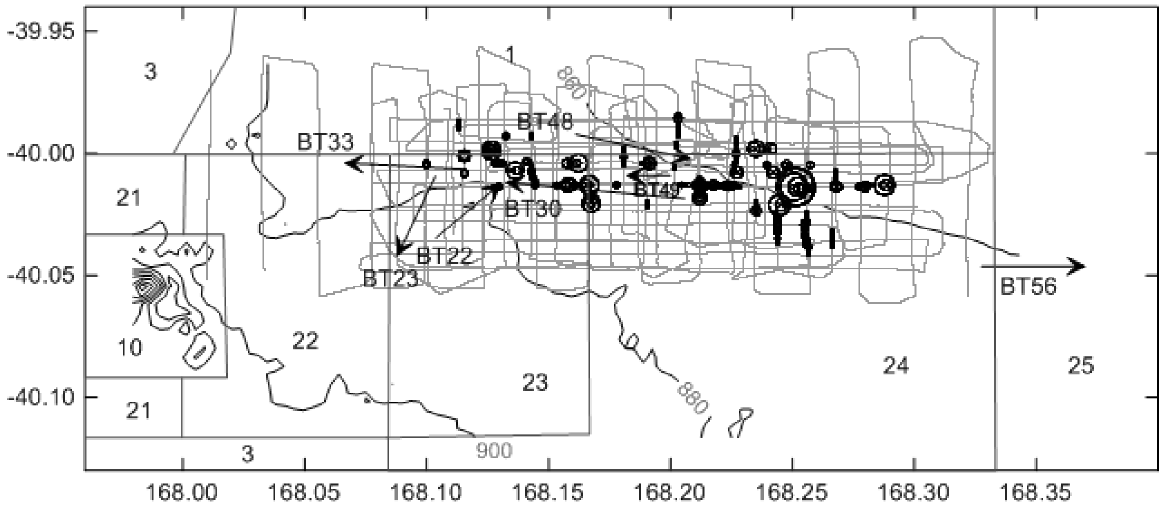


Figure 16: Tracks and orange roughy distribution in all snapshots of Strata 23_24. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Max = 600 m^2 $n.mile^{-2}$.

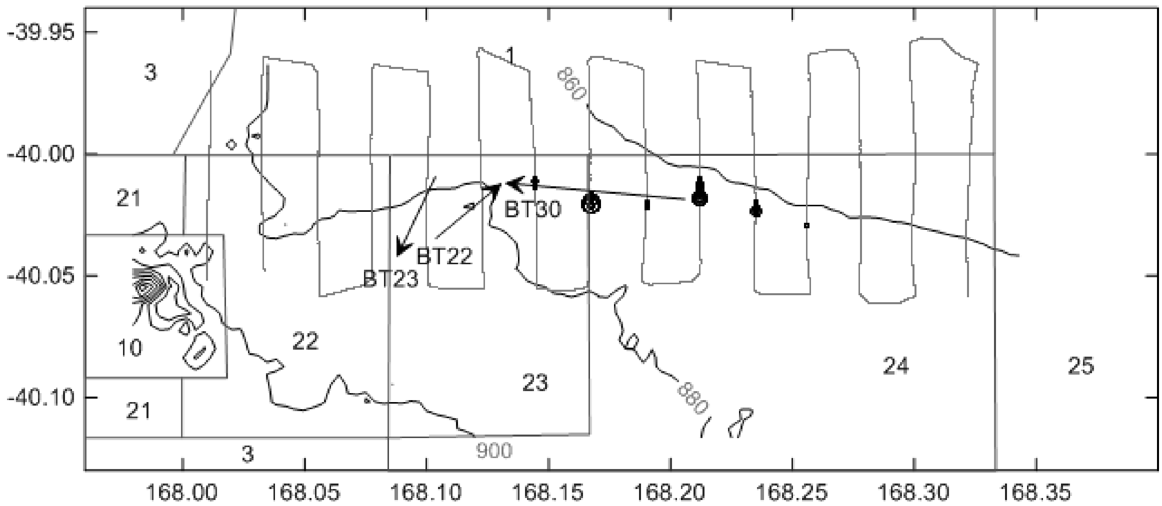


Figure 17: Survey tracks and orange roughy distribution, Snapshot 3 (A & B), Strata 22, 23_24. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Max = 600 m^2 $n.mile^{-2}$.

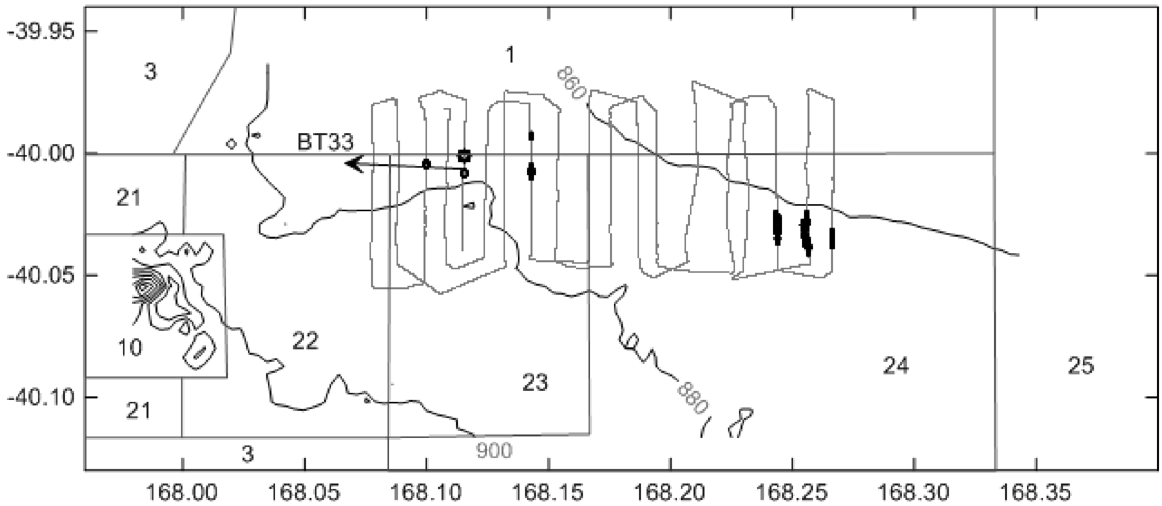


Figure 18: Survey tracks and orange roughy distribution, Snapshot 4, Strata 23_24. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Max = 600 m^2 n.mile^{-2}.

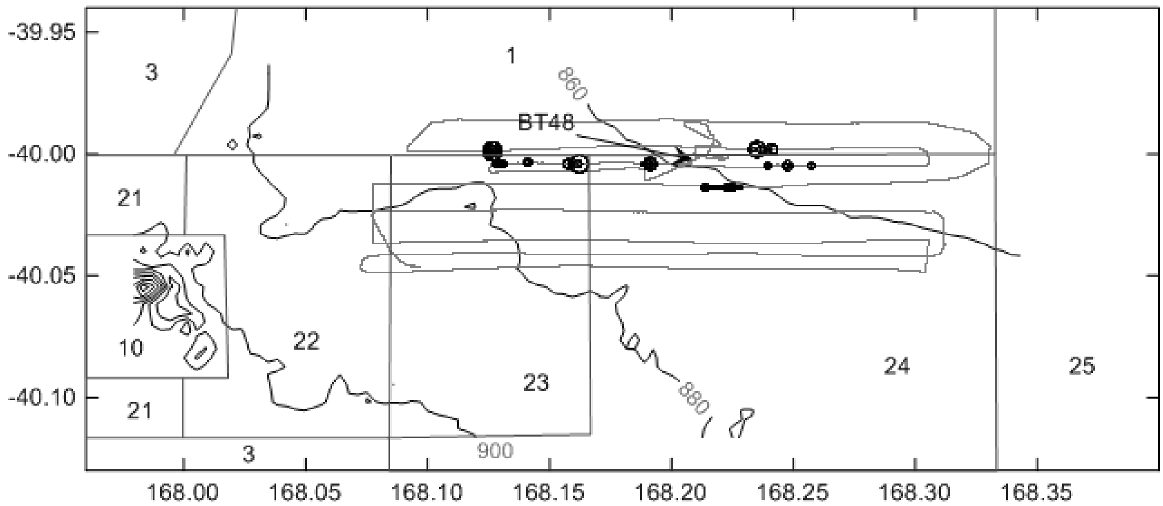


Figure 19: Survey tracks and orange roughy distribution, Snapshot 11, Strata 23_24. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Max = 600 m^2 n.mile^{-2}.

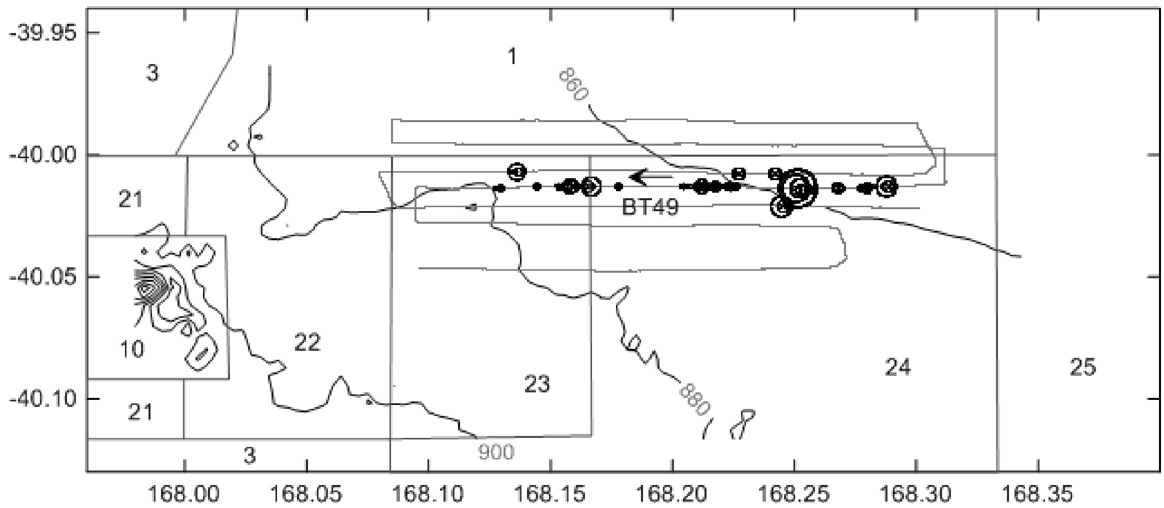


Figure 20: Survey tracks and orange roughy distribution, Snapshot 12, Strata 23_24. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Max = 600 m^2 $n.mile^{-2}$.

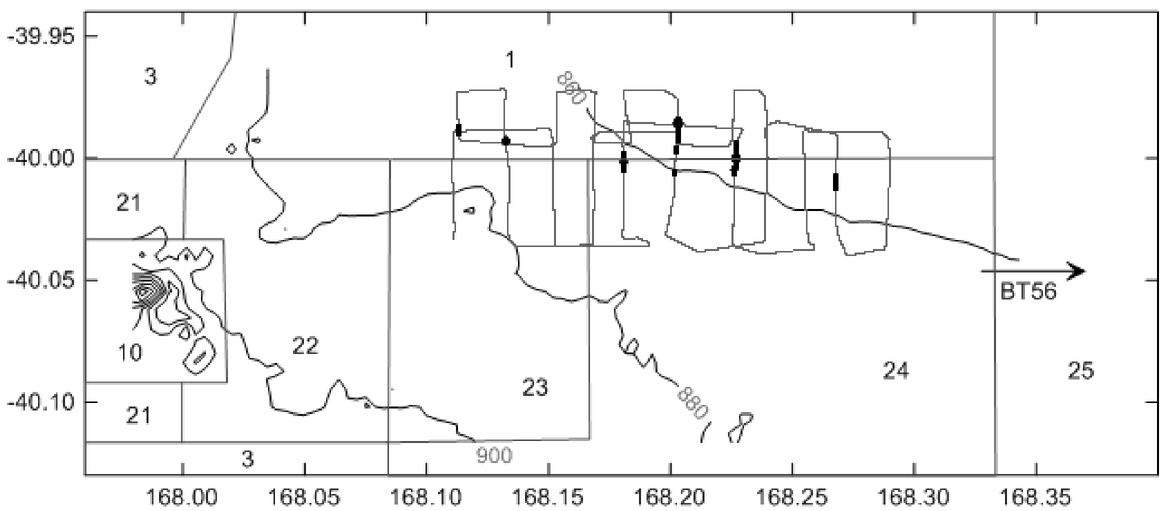


Figure 21: Survey tracks and orange roughy distribution, Snapshot 16, Strata 23_24. Circle diameter is proportional to area back-scattering strength. Same scale as in all other surveys of flats. Max = 600 m^2 $n.mile^{-2}$.

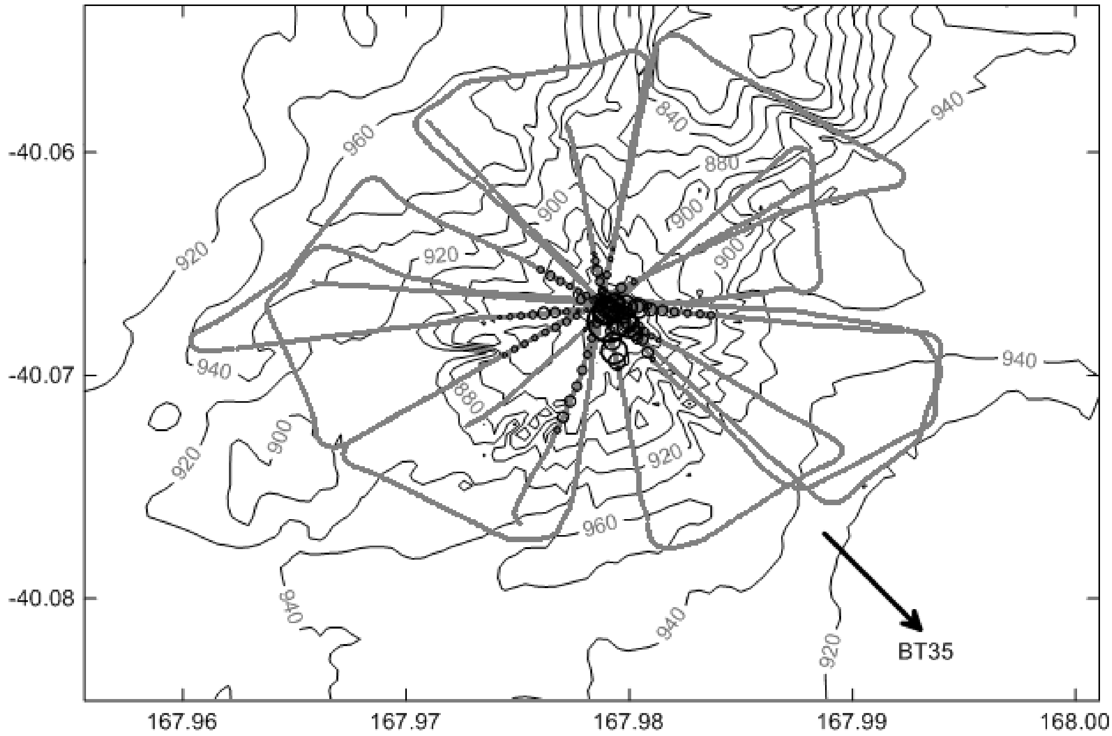


Figure 22: Survey tracks and orange roughy-like marks for Megabrick, Snapshots 6, 8 and 14. Circle diameter is proportional to area back-scattering strength. Same scale for all plots; max = 600 m² n.mile⁻².

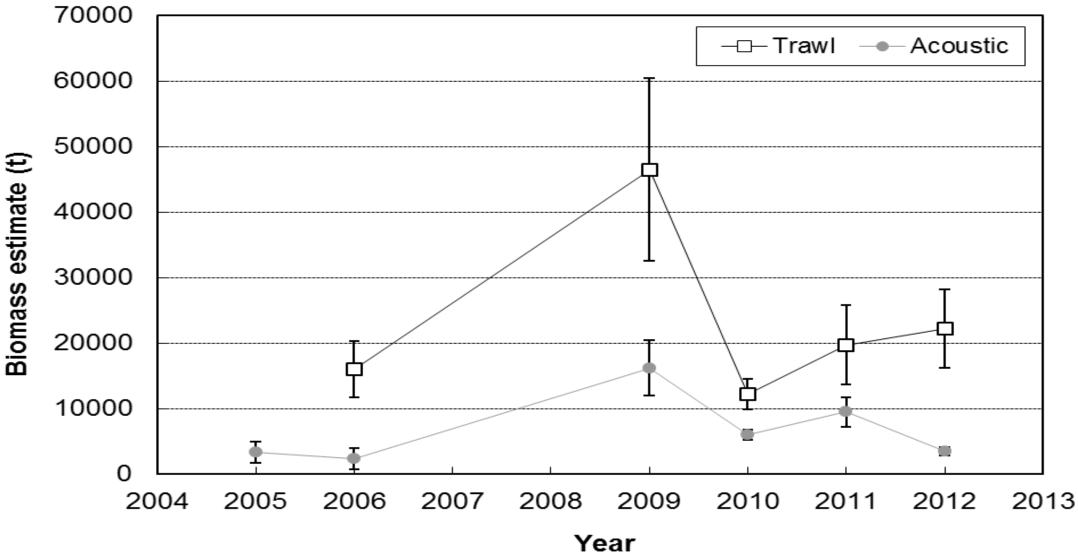


Figure 23: Trawl and acoustic survey estimates of orange roughy biomass on the Pinnacle Flats, 2005 to 2012, standardised on the trawl strata surveyed in 2006. The error bars show the standard sampling error.

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 (□)	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 FV *Thomas Harrison* sounder; June 2009 to July 2012.

Date	Contractor	G_o	S_A correction	Correction	Correction factor
		(dB)	(dB)	(dB)	
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
July-2012	CSIRO+FRS	24.05	-0.52	5.93	3.92

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
Johnsons cod	*Halargyreus johnsonii*	HJO	24.7	-33.3	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)

Appendix C

Table C-1: Tow positions and station details for all trawls. R = Random trawl, ID = identification 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	B1	28-Jun-12	40 04.00	168 25.00	E	25	862	875	1.8	2	1 017	14	0	0	3	5	17	0	0	1 129
BT02	B1	28-Jun-12	40 00.37	168 23.18	E	25	841	850	1.9	2	1 246	9	0	2	1	6	13	3	0	1 404
BT03	B1	28-Jun-12	39 56.91	168 21.14	E	25	826	833	1.6	2	95	30	0	9	0	8	5	4	0	175
BT04	B1	28-Jun-12	40 00.61	168 18.44	E	24	850	859	1.7	2	9 329	9	0	0	0	0	7	1	0	9 674
BT05	B1	28-Jun-12	40 00.42	168 15.77	E	24	855	861	1.7	2	10 761	5	0	0	0	0	8	1	0	11 002
BT06	B1	29-Jun-12	40 01.09	168 12.04	E	24	863	869	1.5	2	9 031	11	0	0	1	0	14	1	0	9 120
BT07	B1	29-Jun-12	40 05.26	168 03.42	E	22	893	899	1.6	2	437	17	0	0	4	4	5	0	0	474
BT08	B1	29-Jun-12	40 02.17	168 03.65	E	22	884	885	1.6	2	3 199	15	0	3	4	0	3	4	0	3 233
BT09	B1	29-Jun-12	40 06.06	168 00.93	E	22	906	913	1.7	1	234	45	0	0	11	0	4	2	0	311
BT10	B1	29-Jun-12	40 01.56	168 02.40	E	22	882	884	1.8	1	81	49	0	0	4	2	6	4	0	189
BT11	B1	29-Jun-12	40 01.52	168 08.93	E	23	867	881	1.7	1	5 022	14	0	0	0	3	5	2	0	5 129
BT12	B1	29-Jun-12	39 58.32	168 15.03	E	1	841	848	1.6	2	484	5	0	0	1	5	5	3	0	530
BT13	B1	30-Jun-12	40 02.64	168 16.24	E	24	867	870	1.7	1	4 539	0	0	19	2	4	7	2	0	4 606
BT14	B1	30-Jun-12	40 06.01	168 17.94	E	24	881	889	1.5	1	40	11	0	2	1	0	7	2	0	88
BT15	B1	30-Jun-12	40 08.86	168 18.24	E	24	896	905	1.6	1	16	33	0	0	0	0	6	0	0	79
BT16	B1	30-Jun-12	40 09.36	168 12.17	E	24	907	914	1.6	1	20	55	0	1	3	0	2	0	0	111
BT17	B1	30-Jun-12	40 06.04	168 14.89	E	24	886	895	1.6	1	25	8	0	2	0	0	12	0	0	68
BT18	B1	30-Jun-12	40 05.59	168 10.82	E	24	885	891	1.8	1	174	13	0	0	1	0	17	0	0	216
BT19	B1	30-Jun-12	40 08.82	168 06.05	E	24	908	915	1.6	1	29	6	0	1	2	0	6	0	0	67
BT20	B1	30-Jun-12	40 05.92	168 06.77	E	23	893	900	1.7	2	94	53	0	0	4	0	15	0	0	195
BT21	B1	1-Jul-12	40 04.78	168 09.14	E	23	883	892	1.6	2	194	3	0	3	0	0	5	2	0	235
BT22	B1	1-Jul-12	40 02.04	168 06.28	E	23	887	909	1.7	2	9 180	6	0	0	1	0	11	1	0	9 208
BT23	B1	1-Jul-12	40 00.70	168 06.12	E	23	876	886	1.7	2	3 423	12	0	16	2	0	12	2	0	3 479
BT24	B1	1-Jul-12	40 01.15	168 03.92	E	22	878	884	1.7	2	1 637	23	0	3	2	0	16	7	0	1 709
BT25	B1	1-Jul-12	40 00.78	168 02.49	E	22	878	886	1.8	2	1 767	39	0	2	3	0	11	13	0	1 862
BT26	B1	1-Jul-12	40 00.36	168 00.34	E	22	879	894	1.6	2	155	39	0	0	6	0	1	31	0	275
BT27	B1	1-Jul-12	40 01.75	168 00.03	E	22	885	895	1.3	2	51	14	0	2	3	4	3	14	1	99
BT28	B1	1-Jul-12	40 03.58	168 02.47	E	22	886	897	1.7	2	502	9	0	0	7	0	5	6	0	538

BT29	B1	1-Jul-12	40 01.62	168 04.81	E	22	880	886	1.7	2	2 204	22	0	0	5	0	7	1	0	2 248
BT30	ID	2-Jul-12	40 01.07	168 12.01	E	23	863	876	2.9	2	33 886	8	0	33	3	2	22	4	0	34 274
BT31	B1	4-Jul-12	40 06.24	168 03.74	E	22	902	903	1.6	2	116	12	0	0	4	0	10	0	0	156
BT32	Dis	4-Jul-12	40 05.25	168 01.63	E		899	911	1.6	2	131	14	0	0	5	2	5	1	0	173
BT33	ID	4-Jul-12	40 00.36	168 06.72	E	10	875	876	1.9	1	3 395	45	0	1	11	0	3	4	0	3 476
BT34	ID	5-Jul-12	40 02.77	167 58.46	E	10	795	923	0.2	3	10	0	2	0	0	0	7	826	1	847
BT35	ID	5-Jul-12	40 04.63	167 59.32	E	10	829	900	0.2	3	739	0	0	0	0	3	11	32	0	787
BT36	B1	5-Jul-12	40 03.98	168 04.26	E	22	889	894	1.6	1	130	22	0	3	11	0	5	1	0	224
BT37	B1	5-Jul-12	40 04.59	167 55.16	E	21	896	902	1.6	1	156	7	0	0	7	3	7	3	0	202
BT38	B1	5-Jul-12	40 01.73	167 49.08	E	3	975	999	1.7	1	3	21	0	1	7	0	1	0	0	122
BT39	B1	5-Jul-12	40 02.69	167 53.51	E	21	903	931	1.7	1	4	13	0	1	5	0	4	0	0	32
BT40	B1	5-Jul-12	40 01.06	167 58.84	E	21	891	892	1.6	1	10	19	0	0	7	0	13	8	0	70
BT41	B1	5-Jul-12	39 52.47	167 54.65	E	3	990	991	1.7	1	7	27	0	10	4	0	0	2	0	92
BT42	B1	6-Jul-12	39 45.26	167 57.06	E	3	910	917	1.6	1	7	30	0	0	1	5	10	2	0	90
BT43	B1	6-Jul-12	39 49.8	168 01.87	E	4	882	891	1.7	1	31	54	0	50	0	0	8	0	0	166
BT44	B1	6-Jul-12	39 53.71	168 06.22	E	4	845	869	1.7	1	143	11	0	12	0	0	3	1	0	188
BT45	B1	6-Jul-12	39 49.96	168 06.99	E	4	823	824	1.6	1	30	50	0	2	0	16	25	2	0	194
BT46	B1	6-Jul-12	39 52.99	168 14.27	E	1	802	813	1.7	1	13	17	0	0	1	8	11	5	0	134
BT47	B1	6-Jul-12	39 57.60	168 04.38	E	1	866	870	1.7	1	39	20	0	0	2	0	9	12	0	106
BT48	ID	6-Jul-12	39 59.56	168 09.74	E	23	857	859	1.9	1	8 347	14	0	2	1	8	12	10	0	8 455
BT49	ID	7-Jul-12	40 00.51	168 11.76	E	24	857	859	0.4	1	15 556	0	0	5	0	0	0	2	0	15 651
BT50	B2	7-Jul-12	40 04.24	168 11.44	E	24	872	882	1.8	1	216	17	0	0	3	0	7	1	0	293
BT51	B2	7-Jul-12	40 08.08	168 14.61	E	24	892	900	1.6	1	43	9	5	0	0	0	1	0	0	89
BT52	B1	8-Jul-12	40 06.60	168 08.60	E	23	896	898	1.8	1	13	16	0	0	2	0	3	0	0	49
BT53	B2	8-Jul-12	40 05.10	168 06.10	E	23	891	895	1.7	1	27	3	0	0	5	0	9	2	0	61
BT54	B2	8-Jul-12	40 07.80	168 06.50	E	24	900	908	1.7	1	12	33	0	0	1	0	8	0	0	94
BT55	ID	8-Jul-12	40 03.10	167 58.18	E	10	789	958	0.7	2	49	6	3	0	11	7	31	2 075	8	2 194
BT56	B2	8-Jul-12	40 02.76	168 19.75	E	24	860	860	1.8	1	2 896	5	0	3	1	2	2	10	1	2 964
BT57	B2	8-Jul-12	39 58.24	168 26.35	E	25	820	830	1.8	1	10	5	0	2	0	1	13	1	0	92
All											131 000	1 045	10	190	163	98	480	3 111	13	138 722

Appendix D

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

Code	Species	Common name	No. of stations	% presence	Catch (kg)
	Invertebrates				
ACS	Actinostolidae	*Deepsea anemone*	1	1.75	0.62
BNO	Benthoctopus spp.	*Deepwater octopus (2 rows)*	4	7.02	1.66
BRG	Brisingida	*Brisingida*	2	3.51	0.05
CHQ	Cranchiidae	*Cranchiid squid*	2	3.51	0.02
CJA	Crossaster multispinus	*Sun-star*	2	3.51	0.06
EEX	Enypniastes eximia	*Pelagic Sea Cucumber*	29	50.88	20.65
EPZ	Epizoanthus sp.	*Epizoanthus sp.*	17	29.82	0.70
GOR	Gorgonocephalus spp.	*Gorgonocephalus sp*	2	3.51	0.26
HEC	Henricia compacta	*Henricia compacta*	1	1.75	0.04
HTH	Holothurian unidentified	*Sea cucumber*	4	7.02	0.20
JFI	Jellyfish	*Jellyfish*	12	21.05	47.84
LHO	Lipkius holthuisi	*Omega prawn*	11	19.30	0.34
MIQ	Moroteuthis ingens	*Warty squid*	2	3.51	13.26
MSL	Mediaster sladeni	*Mediaster sladeni*	1	1.75	0.04
NEB	Neolithodes brodiei	*Brodie's king crab*	1	1.75	2.46
OCO	Octopodidae	*Unidentified Octopus*	1	1.75	0.06
OPI	Opisthoteuthis	*Umbrella octopus*	3	5.26	9.20
OSQ	Octopoteuthiidae	*Octopoteuthiidae*	5	8.77	34.12
PAM	Pannychia moseleyi	*Sea Cucumber*	1	1.75	0.10
PAO	Pillsburiaster aoteanus	*"Cussion" Star*	4	7.02	0.25
PED	Aristaeopsis edwardsiana	*Scarlet prawn*	1	1.75	0.04
PKN	Plutonaster knoxi	*Abyssal star*	1	1.75	0.04
PLY	Polycheles suhmi	*Deepsea blind lobster*	1	1.75	0.02
PSQ	Pholidoteuthis boschmai	*Large red scally squid*	2	3.51	6.78
PYR	Pyrosoma atlanticum	*Pyrosoma atlanticum*	6	10.53	0.8
SAL		*Salps*	1	1.75	0.1
SDM	Sympagurus dimorphus	*Hermit crab*	1	1.75	0.02
STP	Stephanocyathus platypus	*Solitary bowl coral*	1	1.75	0.02
TAM	Echinothuriidae	*Tam o shanter urchin*	11	19.30	0.89
TSQ	Todarodes filippovae	*Todarodes filippovae*	3	5.26	3.76
VSQ	Histioteuthis spp.	*Violet squid*	20	35.09	31.92
WSQ	Moroteuthis spp.	*Warty squid*	2	3.51	3.44
ZOR	Zoroaster spp.	*Rat-tail star*	4	7.02	0.38
	Sharks, Rays and Chimeara				
BSH	Dalatias licha	*Seal shark*	11	19.30	323.72
BTS	Notoraja spinifera	*Prickly deepsea skate*	1	1.75	0.7
BWS	Prionace glauca	*Blue shark*	1	1.75	10.5
CSQ	Centrophorus squamosus	*Centrophorus squamosus*	21	36.84	1145
CYL	Centroscymnus coelolepis	*Centroscymnus coelolepis*	1	1.75	11.2
CYO	Centroscymnus owstoni	*Smooth skin dogfish*	35	61.40	485.82
CYP	Centroscymnus crepidater	*Centroscymnus crepidater*	31	54.39	96.61
ETB	Etmopterus baxteri	*Baxters lantern dogfish*	22	38.60	71.74
ETL	Etmopterus lucifer	*Lucifer dogfish*	1	1.75	0.4
GSP	Hydrolagus bemisi	*Pale ghost shark*	24	42.11	41.17
LCH	Harriotta raleighana	*Long-nosed chimaera*	3	5.26	5.68
PLS	Proscymnodon plunketi	*Plunkets shark*	7	12.28	44.98
RCH	Rhinochimaera pacifica	*Widenosed chimaera*	15	26.32	88.72
RSK	Dipturus nasutus	*Rough skate*	1	1.75	29.6
SND	Deania calcea	*Shovelnose spiny dogfish*	45	78.95	391.15
SQA	Squaloid shark	*Unknown Shark*	1	1.75	1.2
	Fish				
ASE	Astronesthes spp.	*Snaggletooths*	1	1.75	0.08
BCA	Magnisudis prionosa	*Giant barracudina*	1	1.75	0.16
BCR	Brotulotaenia crassa	*Blue cusk eel*	2	3.51	3.88
BEE	Diastobranchus capensis	*Basketwork eel*	3	5.26	3.7
BSL	Xenodermichthys copei	*Black slickhead*	41	71.93	63.8
CBA	Coryphaenoides dossenus	*Humpback rattail (slender rattail)*	11	19.30	15.62

CFA	Coelorinchus fasciatus	*Banded rattail*	7	12.28	1.6
CHA	Chauliodus sloani	*Viper fish*	5	8.77	0.22
CHX	Chaunax pictus	*Pink frogmouth*	4	7.02	0.48
CHY	Coelorinchus trachycarus	*Roughhead rattail*	1	1.75	0.4
CIN	Coelorinchus innotabilis	*Notable rattail*	37	64.91	7.14
CMA	Coelorinchus matamua	*Mahia rattail*	44	77.19	26.12
CSE	Coryphaenoides serrulatus	*Serrulate rattail*	53	92.98	48.88
CSU	Coryphaenoides subserrulatus	*Four-rayed rattail*	12	21.05	1.56
DCO	Notophycis marginata	*Dwarf cod*	2	3.51	0.2
EPT	Epigonus telescopus	*Deepsea cardinalfish*	3	5.26	10.26
GAO	Gadomus aoteanus	*Filamentous rattail*	1	1.75	0.06
HAK	Merluccius australis	*Hake*	26	45.61	189.64
HCO	Bassanago hirsutus	*Hairy conger*	1	1.75	0.16
HIA	Himantolophus stewarti	*Prickly anglerfish*	1	1.75	0.28
HIM	Himantolophus spp.	*Prickly anglerfishes*	1	1.75	0.34
HJO	Halargyreus johnsonii	*Johnson's cod*	45	78.95	162.9
HOK	Macruronus novaezelandiae	*Hoki*	20	35.09	98.1
HPE	Halosaurus pectoralis	*Common halosaur*	6	10.53	3.02
JAV	Lepidorhynchus denticulatus	*Javelin fish*	7	12.28	11.75
MAU	Malacosteus australis	*Southern loosejaw*	2	3.51	0.06
MEN	Melanostomias spp	*Scaleless black dragonfishes*	5	8.77	0.42
MST	Melanostomiidae	*Melanostomiidae*	1	1.75	0.24
NBU	Kuronezumia bubonis	*Bulbous rattail*	9	15.79	3.64
NET	Nettastoma parviceps	*Duckbill eel*	1	1.75	0.18
OAR	Regalecus glesne	*Oarfish*	1	1.75	7.8
OMI	Opostomias micripnus	*Giant dragonfish*	2	3.51	1.42
ORH	Hoplostethus atlanticus	*Orange roughy*	57	100.00	131000.25
PHO	Photichthys argenteus	*Lighthouse fish*	5	8.77	0.38
RIB	Mora moro	*Ribaldo*	55	96.49	479.85
RUD	Centrolophus niger	*Rudderfish*	9	15.79	24.82
SAW	Serrivomer spp.	*Sawtooth eel*	1	1.75	0.02
SBI	Alepocephalus australis	*Bigscaled brown slickhead*	6	10.53	83.66
SBK	Notacanthus sexspinis	*Spineback*	1	1.75	0.2
SCO	Bassanago bulbiceps	*Swollenhead conger*	3	5.26	0.58
SDE	Cryptopsaras couesi	*Seadevil*	2	3.51	0.94
SFN	Diretmichthys parini	*Spinyfin*	13	22.81	11.62
SMC	Lepidion microcephalus	*Small-headed cod*	1	1.75	0.22
SOR	Neocyttus rhomboidalis	*Spiky oreo*	51	89.47	3111.34
SPE	Helicolenus spp.	*Sea perch*	2	3.51	7.42
SSM	Alepocephalus antipodianus	*Smallscaled brown slickhead*	3	5.26	11.94
SSO	Pseudocyttus maculatus	*Smooth oreo*	5	8.77	10.42
TAL	Talismania longifilis	*Talismania longifilis*	1	1.75	2.48
TOP	Ambophthalmos angustus	*Pale toadfish*	2	3.51	7.14
TRS	Trachyscorpia capensis	*Trachyscorpia capensis*	34	59.65	52.08
TRX	Trachonurus gagates	*Velvet rattail*	3	5.26	0.84
UNI	Unid Fish	*Unidentified fish*	1	1.75	1.02
WHX	Trachyrincus aphyodes	*White rattail*	42	73.68	322.5

Appendix E

Table E-1: Comparison between net performance in random trawl surveys of Challenger Plateau by FV *Thomas Harrison* between 2005 and 2012.

	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	147	138
Headline height (m)	44	5.4	9.5	5.9
THH0601				
Speed (kts)	54	3.0	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	3.1
Distance (n.miles)	64	0.28	1.58	1.40
Doorspread (m)	64	120	147	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	118	153	143
Headline height (m)	68	4.3	7.1	5.3
THH1101				
Speed (kts)	61	2.8	3.4	3.0
Distance (n.miles)	61	0.16	1.66	1.46
Doorspread (m)	61	133	155	144
Headline height (m)	61	4.5	5.9	5.4
THH1201				
Speed (kts)	49	2.8	3.6	3.3
Distance (n.miles)	49	1.33	1.87	1.66
Doorspread (m)	46	126	156	147
Headline height (m)	49	3.7	4.8	4.5