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Review of Challenger Plateau orange roughy abundance surveys 2005–13 and survey design options for future abundance estimates.

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Abundance surveys of orange roughy on the Challenger Plateau (ORH 7A plus Westpac Bank) since 2005 used two approaches: a trawl survey of the wider spawning grounds, and an acoustic survey of the primary fish aggregations. Results from both survey series were reviewed and analysed, and recommendations are made for the design of future surveys.

For the trawl survey, a design with two central core strata surrounded by four guard strata is proposed based on the 2006–13 trawl survey results, i.e., excluding the 2005 data. We considered three options for the proposed guard strata (small, medium, and large areas). Compared to the reported survey abundance, the core plus small guard strata capture at least 85% of the spawning abundance (CV 15–65% per survey), core plus proposed medium strata capture at least 90% of the abundance (CV 15–60% per survey) and the core plus large guard strata capture at least 95% of the abundance (CV 15–55% per survey). The revised design is expected to achieve a biomass estimate with CV of 25% from about 50 tows.

For the acoustic survey, analysis of the number of snapshots and transects required to achieve a survey target CV of 20% for the three main orange roughy aggregations (northwest flat, northeast flat, and Volcano), showed that combinations of small numbers of snapshots (3–5) and modest numbers of transects (6–8) were required and that this level of sampling could be achieved in about one day of actual survey time (excluding transit and trawl time). However, there is a requirement to monitor the two aggregations on the flat area during the survey over consecutive days to ensure that the main spawning (peak abundance) is sampled. The important hill (Volcano) should be surveyed slightly later than previously i.e., from about 6 July onwards (past surveys were from 4–9 July) to cover peak abundance.

The mean weighted CVs (MWCVs) for orange roughy length frequency distributions from the Challenger Plateau series over 2006–13 were 18–57%, and four of the six surveys achieved a MWCV less than 30%. Simulations using orange roughy length frequency distribution data showed that measurements of about 100 fish per tow were required to achieve a MWCV of 30%. Only slight gains in MWCV were achieved for sample sizes greater than about 100 fish and, in fact, most of the reduction in CV was achieved after sampling 20 fish.

1. INTRODUCTION

The overall objective of this work was to:
Re-design the combined acoustic and trawl survey for orange roughy on the Challenger Plateau (ORH 7A), including the Westpac Bank.

Specific objectives were:

1. To evaluate the history of the trawl and acoustic survey on the Challenger Plateau (ORH 7A) and propose an improved design (or designs) that will ensure future surveys remain compatible with the existing survey time-series and support the current approach towards stock assessment.
2. To develop explicit statistical and operational guidance for delivery of the survey to inform future science providers.
3. To develop a biological sampling scheme to address sampling needs of the target and associated bycatch species.

The first time-series of Challenger Plateau (ORH 7A) orange roughy abundance and biology surveys (1984–1990) used the fishing vessels *Arrow, Amaltal Explorer, and Will Watch* and employed stratified random trawl survey designs, except for one which used a grid design (Clark & Tracey 1994). The second time-series started in 2005 and used the *Thomas Harrison* to conduct acoustic and trawl surveys (Clark et al. 2005). The second survey in this time-series (in 2006) covered a larger survey area (Clark et al. 2006), and was followed by a third survey in 2009 and then annual surveys up to 2014 (Doonan et al. 2009, Doonan et al. 2010, Hampton et al. 2013, Hampton et al. 2014, Boyer et al. 2013). Experimental work was conducted in 2014 on Volcano only using an AOS in the headline of the trawl net which confirmed that the aggregation over Volcano was orange roughy (Ryan et al. 2015). Since the work was structured in a series of star surveys, these data can be used in redesigning the Volcano survey. The distribution of spawning orange roughy on Challenger Plateau at the time of the 2005 survey had shifted from that surveyed in the 1980s and 1990s, so that the 2005 survey was thought to have missed most of the spawning fish, hence the expansion of the survey area in 2006. Because of this, data from the 2005 *Thomas Harrison* survey have not been used in stock assessments.

The main purpose of these surveys was to provide abundance estimates and biological data for stock assessments. The 2014 Challenger Plateau orange roughy stock assessment used three trawl survey indices from the earlier series (1987–89), five from the later series (2006, 2009–2012), two combined acoustic and trawl survey indices (2010, 2013), and one acoustic estimate of spawning plume abundance for a year that also had a trawl survey (2009) (Cordue, 2014, table 3). The assessment model used priors on catchability to account for slight stratification changes and different protocols used for each survey, and also for the different abundance types, i.e., acoustic or trawl abundance estimates. Surveying small, variable (in time and space) spawning plumes has proved to be difficult. The 2010 survey was designed to have separate acoustic and trawl survey abundance estimates that could be combined using an estimated vulnerability for the trawl survey relative to the acoustic survey. For the other surveys, Cordue (2014) assumed that the spawning plume was explicitly within the trawl survey area and therefore had a chance of being sampled during the trawl survey. However, for most of the trawl surveys this was not the case (or the spawning plumes had not formed sufficiently at the time of the survey). In 2013 the trawl survey had three large catches, which resulted in low precision for the estimated abundance (CV of 51%), reduced to 35% by using the acoustic survey abundance estimates for the spawning plume strata, i.e., a combined acoustic-trawl estimate (Cordue 2014).

It is likely that when spawning plumes are present on the flat and there are no survey tows on the spawning plume, the trawl survey CV and abundance estimate are biased low. Conversely, if there is a tow on the spawning plume, then the estimated CV is very large and the abundance estimate may be biased high. In addition, the trawl catchability in a spawning plume is likely to be different to that from areas of low density. For these reasons abundance estimates from trawl surveys alone are problematic.

Hills in the survey area have also confirmed orange roughy marks that are visible to acoustics, e.g., Volcano. Such hill aggregations are best surveyed using acoustic methods, and hill abundance estimates should be included into the overall acoustic abundance estimate.

The aim of this study was to produce a survey design that will form the basis of a future abundance series that is consistent between years, can be used in a stock assessment without requiring different yearly catchability priors, and has a tighter operational procedure so that *ad hoc* or on-the-spot survey decisions are avoided. The main problems with past surveys were the fluctuating distributions of the spawning plume(s) from year to year, and the high density layers that sometimes resulted in large catches during the trawl survey.

2. METHODS

2.1 Objective 1: Review of Challenger Plateau trawl and acoustic survey design

We considered separately the trawl survey, then the acoustic survey. Figure 1 shows the trawl survey strata and their codes, Figure 2 shows the known spawning plume aggregations and their approximate positions relative to the trawl survey in 2010.

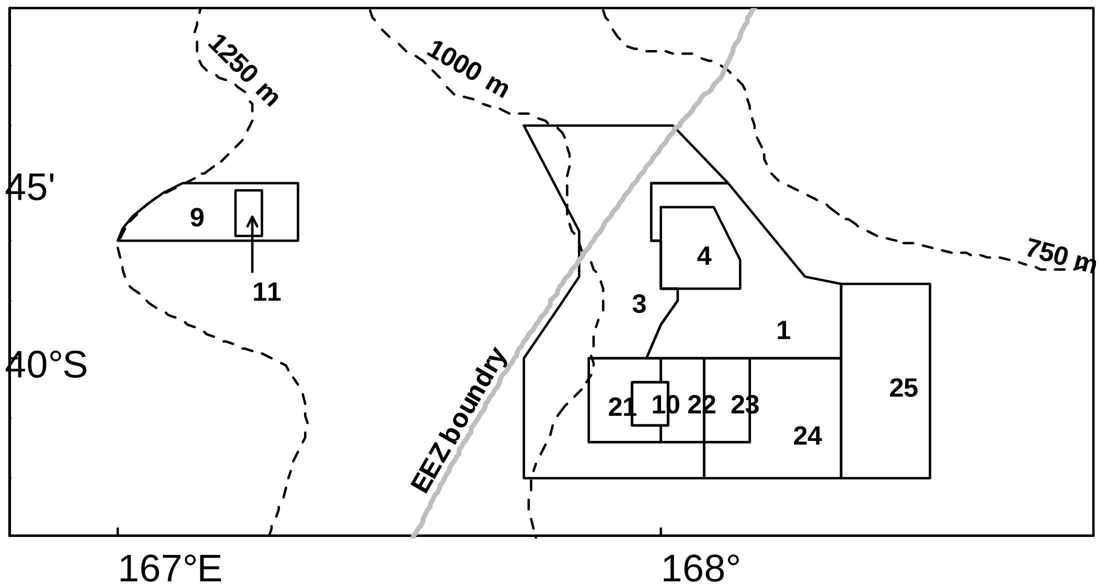

Figure 1: The survey area, showing the trawl survey strata and location of hills (Strata 10 and 11).

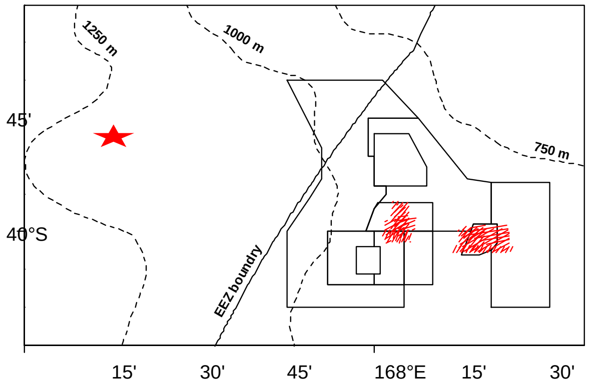

Figure 2: Trawl survey strata and the sites of the three spawning aggregations considered in this report, Volcano Hill (star), NW spawning aggregation (left stippled area), and NE spawning aggregation (right stippled area) as observed in 2010.

2.1.1 Trawl survey

The trawl strata are shown in Figure 1. Only surveys from 2005 on were considered. To identify key issues in performance, survey designs were reviewed with similarities and differences documented. Data were extracted from Fisheries New Zealand's *trawl* database.

The tender document stated that future abundance survey design be "…consistent with the current Challenger abundance time-series". In past assessments, slight differences in stratification and survey protocols between surveys in the time series from 2006 on (2005 was excluded from the assessments) were made consistent by the application of priors on catchability (and priors on ratios of catchabilities) in the stock assessment model (Cordue 2014). We envisage that this practice will continue into the future but the priors to use are not explicitly considered here. Future surveys will require their own prior which should be constant from year-to-year if the same design is used.

For the trawl surveys, the key survey design issues were the trawling protocol (net efficiency), the total area surveyed, and the movement of the spawning plume and its surrounding (high density) layer which results in large catches and inflated CVs (tows on this layer are included in the trawl survey abundance calculations, but tows on the spawning plume may or not be included depending on the survey). We propose to reduce the survey area to eliminate the lowest density areas and estimate the fraction of abundance this removes in each of the past surveys (where possible) so that this can be accounted for in any future trawl survey. To check net efficiency, we evaluated the trawl protocol over time including door spread, net height, towing speed, and distance towed. These measurements should remain within a defined range and future surveys should maintain their measurements within the same ranges.

The aim for the survey re-design was to find an alternative stratification that excluded perennially very low density areas and better delineated higher density areas so that large variations within a stratum were less likely to occur. It also needed to allow scope for disruptions caused by annual movement of high density fish layers associated with the spawning plumes. We propose to include buffer strata to ensure that future high density layers are always contained within the survey area regardless of year to year movement of their location. Reducing the survey area should lower cost, but this needs to be weighed against the fraction of excluded abundance. The analysis provided a range of options that restricted "lost" abundance to varying degrees (e.g., 5%, 10%, and 20%).

Random trawling on hills is problematic because there are limited tow angles available. Surveys of Pinnacles (stratum 10) and Westpac hills (stratum 11) were carried out in 2005, 2006, 2009, and 2010, but in 2011 only Pinnacles was surveyed and in 2012 and 2013 there was no trawl survey of hills. These hill strata were excluded from the stock assessment analyses (Ministry for Primary Industries, 2015).

We excluded these hill strata from the new design, i.e., strata 10 and 11, but kept stratum 9 (Westpac flat area outside the EEZ).

The re-design was completed in two parts: first, strata for the core areas (high density of orange roughy) were found using a catch rate map produced using kriging analysis (Krige 1951, Petitgas 1993, Liu et al. 2009) for each survey. Kriging predicts the value at a given point by computing a weighted average of the data in the neighbourhood of the point taking into account spatial correlation. The points are arranged onto a grid and used to generate contours. We used the ordinary kriging option in the R package Gstat (Pebesma & Wesseling 1998). The levels to use for contours were determined by inspection of the distribution of catch rates combined over all the contributing surveys. The area of high catch rates was delineated based on the contour maps, and proposed new strata within this were found by varying the stratum boundaries and number of core strata by hand, and then optimising the overall sums-of-squares of these strata for the density maps of the contributing surveys.

Secondly, four buffer strata were defined to the north, south, east, and west of the core strata. The analysis was carried out with three sizes of buffer strata (small, medium, and large). To find the percentage of abundance in the new stratification, for each of the 2006–13 trawl surveys, we assigned their tows into the proposed new strata and estimated relative abundance and associated CVs. These were compared to the published values

To complete the design, we found the optimal allocation of number of tows to the new strata. NIWA's R program *Allocate* was used to find the number of tows by stratum. *Allocate* apportions stations to strata to achieve a given CV, or to minimise the CV with a fixed number of stations. It does not consider phase 2 stations. A minimum number of stations must be set in each stratum (3 was used). The CV was calculated based on historical station data. In detail, for each stratum, a mean catch rate was calculated as an (un-weighted) average of the mean catch rates from each of the previous surveys in that stratum (by the current stratum boundary definitions). Simulated catch rates in that stratum, in each survey, were generated by multiplying the mean catch rate by a randomly chosen residual (with equal probabilities) from that stratum. Residuals were calculated by dividing the catch rate at a station by the mean catch rate in that stratum in that survey (current stratum boundaries). This produced an allocation which (under our assumptions about the catch rates) had a given CV. The number of tows required to achieve CVs of 15, 20, 25, and 30 % was then calculated.

2.1.2 Acoustic survey

Only surveys from 2006 onwards were considered. These surveys were reviewed, and similarities and differences documented, but there was no attempt to re-analyse past surveys.

Acoustic surveys on spawning aggregations are usually a series of mini-surveys (snapshots) over a number of days, with other survey work conducted between snapshots. Data on individual snapshot surveys were extracted from the relevant reports and compiled for analysis. The acoustic aggregations and hills surveyed by these snapshots are shown in Figure 2.

The abundance estimate from acoustic surveys used in assessments is calculated as the mean over the acceptable snapshots. Acceptable snapshots must meet a good weather threshold and be in a period of a stable abundance level (occasionally, the spawning plume abundance declines to a lower level for a number of snapshots or starts at a lower level). The CV for the overall mean comes from the between-snapshot variation (CV2) if there are enough snapshots (5 or more), or is constructed from the CV determined by transect variation within each snapshot (CV1).

The appropriate number of transects in a snapshot and the number of snapshots to carry out in a survey were investigated for the flat, and for hills with known orange roughy marks (i.e., Volcano). The key element is the CV for a single transect (pop-CV) from which the predicted CV can be found based on the number of transects/snapshot and the number of snapshots specified. The data used included the abundance estimates by snapshot, the number of transects per snapshot, and the year the data were collected.

A preliminary analysis of CV for individual snapshots showed that some snapshots included transects with large pop-CV estimates. Simulations with large pop-CV values showed that using the CV1 estimates poorly estimated pop-CVs and these generally did not follow the expected decline in CV with increasing sampling (1/√n pattern, n = number of transects). The simulations showed that better estimates of pop-CV came from CV2 estimates. Therefore, we used a method based on the between-snapshot CV estimates to estimate the pop-CV (*see* below) which meant that only years with two or more acceptable snapshots were considered.

The analysis focused on the three known spawning aggregation sites: Volcano (part of Westpac), the northwest, and the northeast flat aggregations (Figure 2). A snapshot, each with a series of transects, was treated as the base unit for the analyses.

Acoustic snapshot abundance estimates were assumed to be distributed as $B_{ji} \sim \mathrm{N}\left(\mu_j, \sqrt[2]{\frac{a_0}{m_{ji}}}\right)$, where *j* indexes year, *i* indexes snapshots within a year, m_{ji} is the number of transects on the mark (i.e., excluding the zero bounding transects), μ_j is the mean abundance, and pop-CV is given by $\sqrt[2]{a_0}$.
The likelihood from a series of snapshot estimates is

$$L = \prod_j^{years} \prod_i \frac{1}{\sqrt{2\pi\, {a_0}/{m_{ji}}}} e^{\left\{-\frac{(B_{ji}-\mu_j)^2}{2\mu_j^2 {a_0}/{m_{ji}}}\right\}}$$

and $\frac{d \log L}{d\, a_0}$ is given by

$$\sum_{ji} \left\{-\frac{1}{2a_0} + \left(B_{ji} - \mu_j\right)^2 \frac{m_{ji}}{2a_0^2 \mu_j^2}\right\}$$

$\widehat{a_0} = \frac{1}{N} \sum_{ji} \left(B_{ji} - \mu_j\right)^2 \frac{m_{ji}}{\mu_j^2}$, where *N* is the total number of snapshots and μ_j is replaced with the mean over snapshot estimates for year *j*. The term, $\left(B_{ji} - \mu_j\right)^2$, was replaced by, ${CV_j^2}/{m_j}$ where m_j is the number of snapshots in year *j*.

The population CV was assumed to apply for all years. CV was predicted for combinations of transects and snapshots. The number of transects considered was 1–12 and the number of snapshots was 2–15. For a target CV, combinations of numbers of snapshots and numbers of transects were searched for predicted CV values that were below, but within 2.5%, of the target CV. These were sorted by cost and the 10 lowest cost combinations reported.

Cost is measured as vessel time on each aggregation, ignoring search time, relocations, etc, based on a vessel speed of 9 knots. Indicative cost was used to rank candidates and make selection easier. For the northwest aggregation the median mark length was 6.5 km with a median parallel transect length of 5.1 km. For the northeast aggregation the median mark length was 6.1 km and median parallel transect length was 5.1 km. For the Volcano aggregation, we used 2.5 km long radial transects and a 7.9 km circumference at 4 knots, but an alternative version used a circumference twice as large.

We also estimated the designs for a combined abundance estimate of the three aggregations. To do this, we needed the relative abundance by aggregation so that effort could be assigned efficiently for the target CV. Three cases were chosen:

(1) The average abundance estimates from each aggregation (three aggregations: northwest flat [NW], northeast flat [NE], and Volcano).

(2) The average abundance estimates from two aggregations, NW and Volcano, and excluding the NE aggregation (the NE aggregation was absent in some years).
(3) The average abundance estimates for the two flat aggregations, but using a single year very high estimate for Volcano, which may potentially dominate the flat abundance.

Lists of the combination of the number of transects and snapshots required to achieve a target CV were generated, sorted by cost, and the best cost combinations presented.

2.2 Objective 2: Standard operations and statistical procedures for Challenger Plateau surveys

We reviewed all available survey documentation (both internal and external) for the later survey series, to analyse the operational practice used in past acoustic-trawl surveys. Standard NIWA Deepwater trawl survey procedures were documented by McMillan (1996) and are summarised in Section 3.2 below. Acoustic operations should follow the code of practice adopted for the spawning plume surveys on the north Chatham Rise (Doonan et al. 2012). Extra procedures are detailed for acoustic hill surveys where shadowing may be a problem (Doonan et al. 2003).

Statistical procedures were developed for tuning trawl and acoustic surveys to a required CV, based on past data, and adaptation of strata to dynamically meet needs, e.g., areas of thick layers (associated with large orange roughy catches) that extend across stratum boundaries.

This provided an operational guide that avoids having to make *ad hoc* decisions at sea covering situations such as what to do if a trawl survey tow encounters a spawning plume, or what to do when the spawning plume straddles two or more strata.

2.3 Objective 3: Review of catch and biological sampling for Challenger Plateau orange roughy and the main bycatch species

We used NIWAs biomass program, *SurvCalc* (Francis & Fu, 2012), to assess all bycatch species where surveys collected adequate trawl data. This analysis was repeated for the new stratification proposed from the above work for orange roughy (2.1 above). No adjustment was made to the proposed new strata to accommodate bycatch species since the areal availability of each by-catch species is likely to be very small in any orange roughy trawl survey area, i.e., the survey area is very small relative to the surrounding area of habitat.

A target list of species to consider was compiled. The list included species defined as vulnerable, e.g., elasmobranchs, or those that had a substantive catch (e.g., any species greater than 2% of the total weight of the catch across the Challenger Plateau orange roughy fishery as a whole). The cut-off value of 2% was determined from an analysis of data from the observer database. This target list was used to re-design the trawl survey to meet the target CV for bycatch. The target CV was set to 40% conditional on a minimum of three tows and a maximum of 20 tows in each stratum.

Estimates were made for the top 15 bycatch species (summed for all surveys combined). All 15 species were caught on every trip in the time series (except for no Plunket's shark on the 2010 survey). Distance between the doors in the original *SurvCalc* inputs was actually distance between the wings, but here we used distance between the doors with vulnerability set to 0.127 to effectively give distance between the wings (distance between the wings measured in 2006 was 17 m, and average distance between the doors was 134 m, so vulnerability was calculated as 17/134=0.127). Missing values (distance between the doors) were replaced with the mean distance between the doors from that stratum on that trip.

For some surveys there were differences between the calculated abundance estimates and the estimates from the corresponding survey reports. This is because there were differences between the analysed and reported numbers of stations for some of the surveys. For example, the analysis found 55 stations for THH0601 whereas the survey report (Clark et al. 2006) listed 54. Clark et al. (2006) for THH0601 excluded station 44, but there was no reason given for that exclusion, i.e., it was recorded as a biomass tow in the *Trawl* database. The analysis for THH1101 had 2 fewer stations than the survey report (Hampton et al. 2013). Analyses were performed for stations where the biomass flag was positive (i.e., a valid biomass tow) and gear performance was acceptable (<3).

Species that had a CV of 40% or less more than half the time were deemed to be sampled adequately and were ignored. This left just three species: seal shark (*Dalatias licha*) BSH, Plunket's shark (*Proscymnodon plunketi*) PLS, and Pacific spookfish (*Rhinochimaera pacifica*) RCH. *Allocate* was run on each survey, (target CV of 40%, a minimum of three tows, and a maximum of 20 tows in each stratum) rather than the complete time series, thus providing output tables for each survey and stratum, except where there were differences in strata between surveys (split strata, recombined strata, un-sampled strata etc.). The number of tows required to achieve specified values of target CV were tabulated. Note that this is for the current survey design, not the proposed one.

This work aimed to estimate the optimal sample size required for orange roughy and bycatch species measurements. NIWA's analysis program *CALA* (Francis et al. 2014) was used to analyse length data from past surveys, for species where data collection was deemed adequate, using a function of the software option to re-sample length frequency data to establish the sampling effort needed to reach a specified weighted CV of the length frequency. Results were tabulated and provided sample sizes (the number of tows required and the number of samples per tow) for a range of target weighted mean CVs for length frequencies.

The CVs for the scaled population length frequencies were calculated using *CALA* on 500 bootstrap samples and 300 simulations. For orange roughy, the sample sizes offered to the simulations were 50, 100, 150, 200 fish per tow. For most bycatch species there were only small amounts of length data so the simulation models were usually offered 2, 4, 6, 8, and 10 fish per tow. Length data for spiky oreo (*Neocyttus rhomboidalis)*, Johnson's cod (*Halargyreus johnsonii*) and ribaldo (*Mora moro*) were greater than data for other bycatch species so these models were offered 4, 8, 12, 16, and 20 fish per tow.

A recommended biological sampling regime for each survey type was developed for the Deepwater Fisheries Assessment Working Group to consider. This sampling regime is structured to ensure that a consistent time series of orange roughy catch, bycatch, and biological data are collected on every survey.

3. RESULTS

3.1 Objective 1: Review of Challenger Plateau trawl and acoustic survey design

3.1.1 Survey area and strata

The survey area is shown in Figure 1. The 2005 survey was considered to have missed fish aggregations on the flat so the area was extended east in 2006 by the addition of stratum 24, and further east and south in 2009 when stratum 25 was added. There were also smaller-scale changes, with stratum 22A (not shown in any figure), 241, and 242 created within previous strata in 2010, but no additions were made to the total survey area after 2009. Survey strata and area by survey (year) are given in Appendix A.

3.1.2 Trawl survey (flat)

Details of the late series of *Thomas Harrison* trawl surveys are given in Table 1, with details of strata in Table 2. All trawl surveys were of a stratified random trawl design, with one and sometimes two phases. Although not always well recorded, all surveys appeared to have used the same trawl gear specifications: a four-panel "Arrow" trawl net with cut-away lower wings (Appendix B), a single lengthener, two codends, 100 mm codend mesh, rubber and steel bobbin rig, 24 headline floats (1500 m rated), 0.5 m layback, 50 m bridles, 70 m sweeps, and high-aspect Super-Vee trawl doors (2300 kg, 7 m^2).

Trawl survey protocols required each tow to be carried out at about 3 knots for a distance of 1.5 n.miles (about a 30 minute tow duration) along the depth contour. i.e., keeping a similar depth to the random position depth. All tows were required to be a minimum of 3 n.miles apart although Hampton et al. (2014) stated for the 2012 survey 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." There also appeared to be inconsistency in how the random station position was applied, with either the boat being at the random position at the tow start or the gear settling on the bottom at the random position (Hampton et al. 2014). Both methods were used in past deepwater surveys (McMillan 1996) and the difference is probably not vital as a tow is acceptable if is carried out within 3 n.miles of the random position. The approach used in recent deepwater surveys has been to aim to tow the gear through the random position if possible, which means getting the gear on the bottom before or at the random position.

An important new trawl protocol addition for the 2010 survey was the exclusion of trawl abundance tows in the spawning plumes. Abundance tows that encroached into a spawning plume were abandoned and another random tow position substituted (Doonan et al. 2010). Tows from earlier surveys that sampled a spawning plume were discarded for biomass estimation and replaced (as in the 2010 survey) in the 2011, 2012, and 2013 surveys (Boyer et al. 2013). It appears difficult to predict beforehand whether a tow is likely to sample an aggregation because of the variability of spawning plume location and timing.

The trawl gear parameter measurements were consistent between surveys up to 2011, but the 2012 and 2013 surveys had slightly higher mean tow speeds, higher mean distance between the doors, and lower mean headline heights than the previous 4 surveys, (Table 3). Future surveys should aim to reduce tow speed to around 3 knots.

Table 1: Summary of the late series of *Thomas Harrison* trawl surveys of Challenger Plateau (ORH 7A). All surveys were stratified random trawl. New or altered strata in bold.

Date	Trawl survey	Strata	New trawl protocol	Reference
24 June to 6 July 2005	2 phases, flat plus hills	1, 3, 4, 9, 10, 11, 21, 22		Clark et al. (2005)
24 June to 5 July 2006	2 phase, flat plus hills	1, 3, 4, 9, 10, 11, 21, 22, **23, 24**		Clark et al. (2006)
26 June to 6 July 2009	2 phase, flat plus hills	1, 3, 4, 9, 10, 11, 21, 22, 23, 24, **25**		Doonan et al. (2009)
25 June to 8 July 2010	2 phase, flat plus hills	1, 3, 4, 9, 10, 11, 21, 22, **22A**, 23, **24**, 25, **241**, **242**	Excluded spawning plume tows	Doonan et al. (2010)
25 June to 11 July 2011	2 phase, flat plus hills	1, 3, 4, 10, 21, 22, 22A, 23, 24, 25	Survey of Pinnacles, not WestPac	Hampton et al. (2013)
25 June to 10 July 2012	2 phase, flat only	1, 3, 4, 21, 22, 23, 24, 25	No trawl survey on hills	Hampton et al. (2014)
27 June to 14 July 2013	2 phase SRT flat only	1, 3, 4, 9, 21, 22, 23, 24, 25	No trawl survey on hills	Boyer et al. (2013)

Table 2: Stratum names and areas used for the 2005–2013 series of ORH Challenger Plateau surveys.

Stratum	Description	Area (km^2)
1	800–900 m around the Central Flat	429
3	Irregular guard around Central Flat and Pinnacles	688
4	Central Flat	166
9	Westpac Bank general area excluding stratum 11	182
10	Pinnacles and trenches (Twin Tits and Megabrick)	8
11	Volcano and Dork hills on Westpac Bank	20
21	Western side of original stratum 2	121
22	Eastern side of original stratum 2	83
22A	North Pinnacles Flat/High density stratum, in stratum 1	107
23	Eastern Pinnacles Flat	93
24	Eastern Pinnacles guard	304
25	Guard east of stratum 24	437
241	Eastern Pinnacles guard, low density, replaced stratum 24	272
242	Eastern Pinnacles guard, high density, replaced stratum 24	49

Table 3: Trawl gear parameter measurements for the *Thomas Harrison* trawl surveys of Challenger Plateau (ORH 7A). –, no data. Distance between the wings was measured once in 2005 at 17 m (Clark et al. 2005).

Date	Mean tow speed (Knots)	Mean distance between doors (m)	Mean headline height (m)	Mean distance towed (n.miles)
24 June to 6 July 2005	3.1	138	5.9	1.4
24 June to 5 July 2006	3.2 (3.0–3.5)	134 (119–145)	5.5 (3.4–8.4)	1.4 (0.23–1.83)
26 June to 6 July 2009	3.1 (2.8–3.5)	137 (120–147)	5.5 (4.7–7.1)	1.4 (0.28–1.58)
25 June to 8 July 2010	3.1 (2.8–3.4)	144 (118–153)	5.3 (4.3–7.1)	1.4 (0.18–1.63)
25 June to 11 July 2011	3.0 (2.8–3.4)	143 (133–155)	5.4 (4.5–7.5)	1.5 (0.16–1.66)
25 June to 10 July 2012	3.3 (2.9–3.6)	148 (139–156)	4.5 (3.7–4.8)	1.7 (1.33–1.87)
27 June to 14 July 2013	3.5 (3.0–3.9)	147 (132–156)	4.5 (3.7–5.3)	1.5 (1.34–1.67)

3.1.3 Orange roughy relative abundance estimates

Estimates reported in published assessments are summarised in Table 4 and are provided by stratum by year in Appendix C.

Table 4: Summary of the orange roughy reported relative abundance estimates (t) for the trawl survey for the late series of *Thomas Harrison* trawl surveys of Challenger Plateau (ORH 7A). 95% CI in parentheses, CV in square brackets, – no data. NR, not reported.

Year	Area (km^2)	Number of tows	Total abundance (t)	Mature abundance (t)	Abundance used in stock assessment (t)
2005	1 697	44	19 776 (6 632–32 920)	18 107 (6 121–30 093)	–
2006	2 094	54	18 008 [25]	16 799 (8 366–25 232)	14 000
2009	2 837	64	54 092 [26]	51 894 [26]	34 900
2010	2 837	68	17 034 [16]	16 500 [16]	–
2011	2 619	64	40 301 [52]	–	18 400
2012	2 619	49	26 043 [27]	25 224 [NR]	22 500
2013	2 818	58	9 513 [61]	9 213 [62.3]	19 000

Analysis of the spatial distribution of orange roughy relative abundance

The distribution of catch rates from the 2006 to 2013 trawl surveys is shown in Figure 3. This shows a mode in catch rates at about 11 kg/ n. mile, with about 41% of tows having less than 75 kg/n. mile, about 28% having rates between 75–400 kg/ n. mile, and about 31% of tows with more than 400 kg/n. mile.

Krige analysis plots show the spatial distribution and density of catch rates (Figure 4). High density catch rates were in southern parts of the survey area for all surveys since 2006, although there is some inter-annual variation. Two aggregations were present in three of the surveys, but there was only one aggregation in the 2012 and 2013 surveys. The dense layer crept in to guard strata in the north (stratum 1) in five of the six surveys and to the east (stratum 25) in three of the surveys.

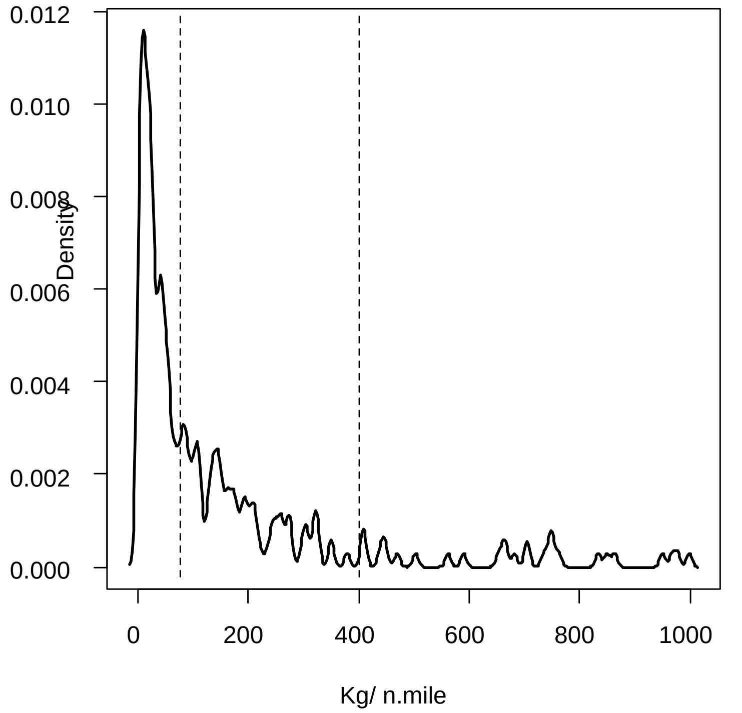

Figure 3: Distribution of orange roughy catch rates from the 2006 to 2013 trawl surveys. The left dashed line is where about 41% of the tows had catch rates less than about 75 kg/n. mile. About 28% of tows had catch rates between 75 (left) and 400 (right dashed line) kg/ n. mile.

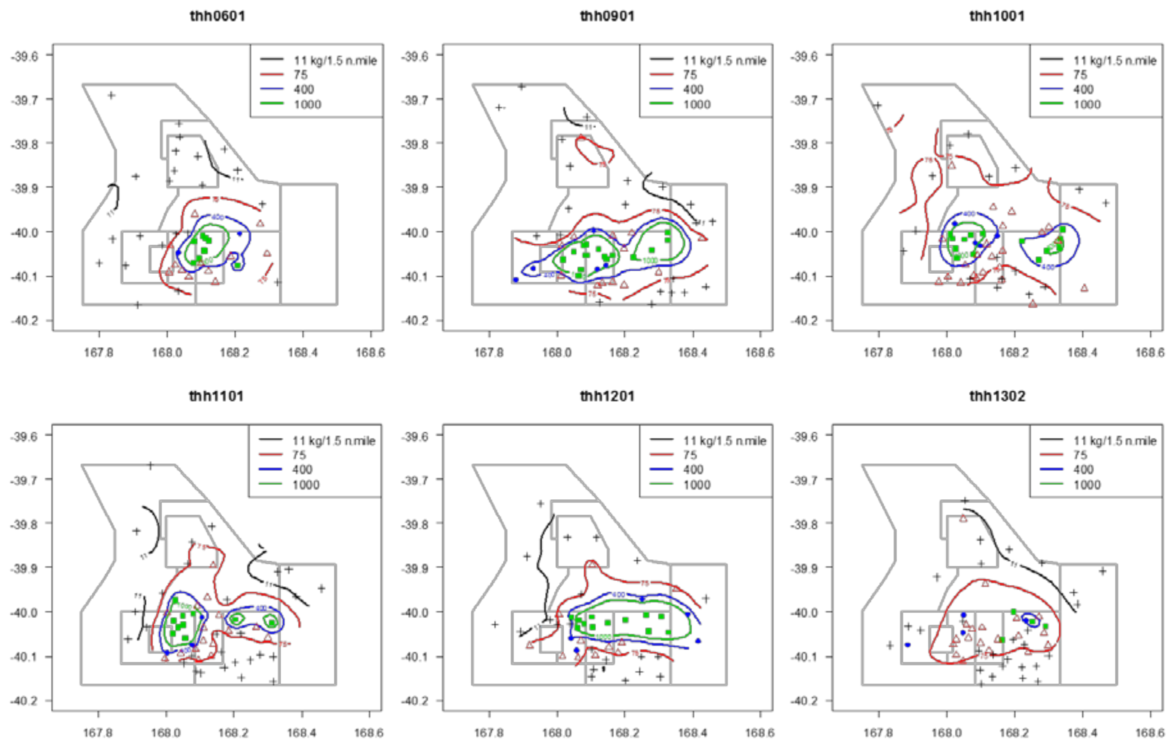

Figure 4: Krige analysis plots of orange roughy catch rates from the 2006 to 2013 trawl surveys of Challenger Plateau showing the spatial distribution of catch rate density.

Estimates of orange roughy relative abundance using proposed new strata

The Krige analysis identified a core southern region divided into two main strata to account for the east and west high density distributions. Four guard strata were defined around the two core strata to the north, south, east, and west, Figure 5. The abundance proportion estimated for the three sizes of guard strata is illustrated in Figure 6 and the effect on the estimated CV is shown in Figure 7.

Key results were that:

- The core strata contained at least 80% of the abundance in all surveys.
- Increased guard stratum size had a minimal effect (decrease) on CV.
- The three lowest core strata abundance estimates were from the last 4 surveys (2010–2013).
- The core plus medium-sized guard strata contained at least 90% of the abundance in all surveys.
- The core plus large-sized guard strata contained at least 95% of the abundance in all surveys.
- The precision of the abundance estimates was similar to those obtained using the 2009 stratification.

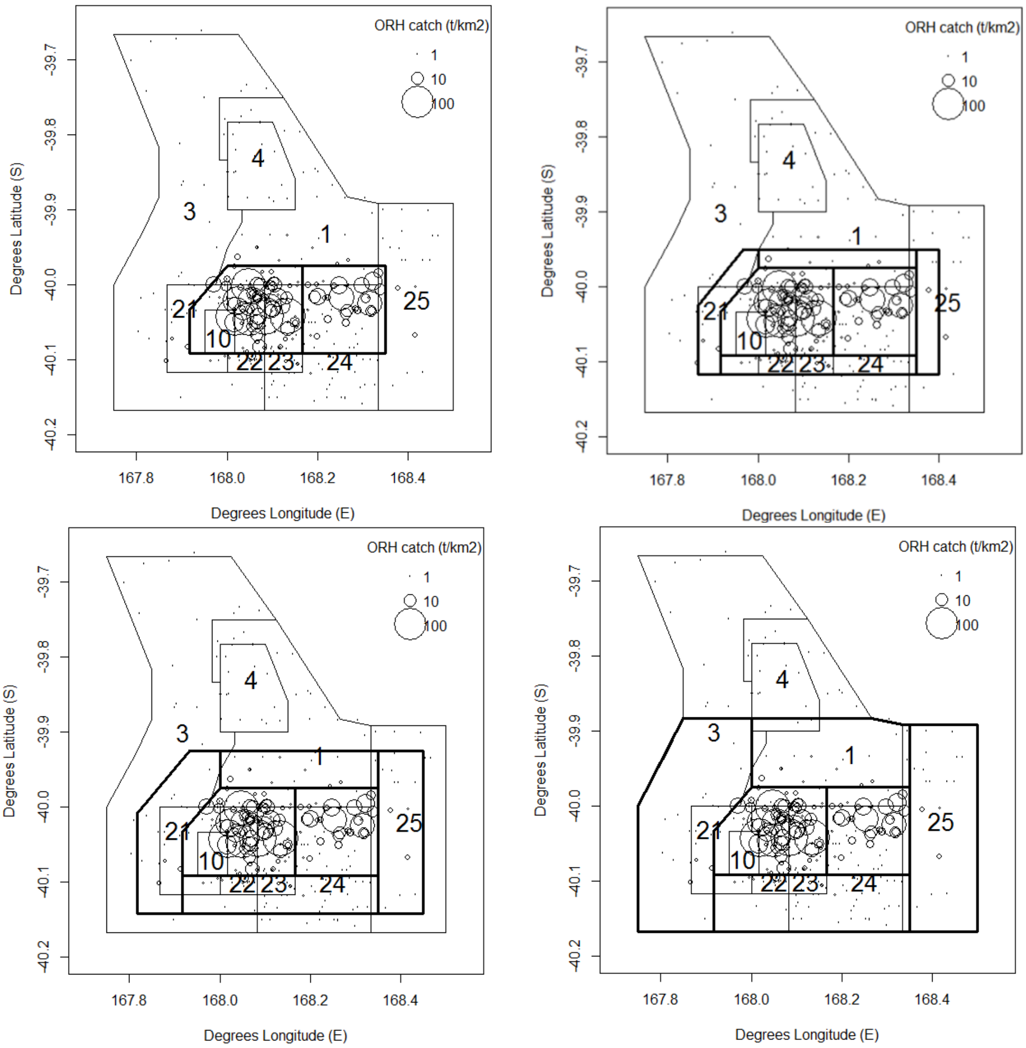

Figure 5: Orange roughy densities (t/km²) from the 2006 to 2013 trawl surveys plotted on the two proposed core strata with no guard strata (top left plot), and with the addition of small, medium and large guard strata (top right, bottom left, and bottom right plots respectively).

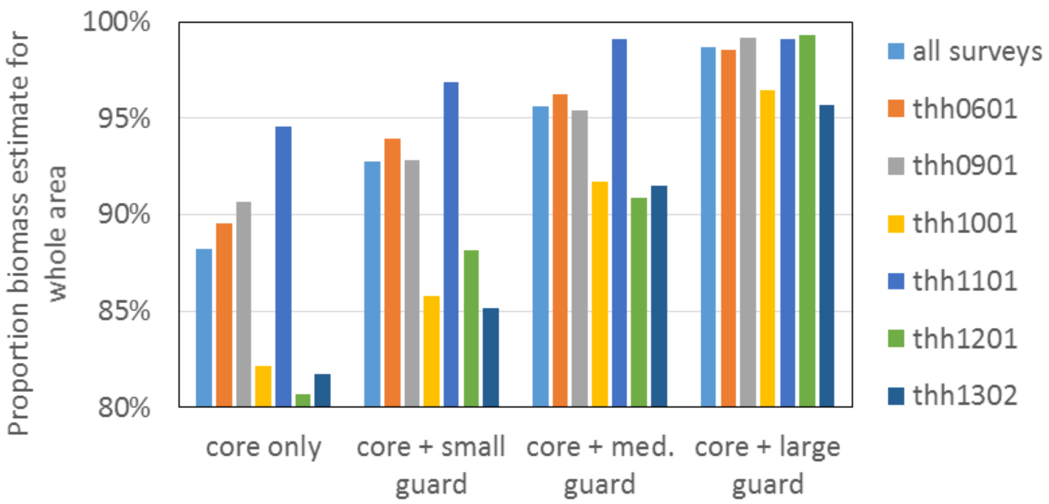

Figure 6: For the new strata, orange roughy abundance as proportions of the total area abundance from the 2006 to 2013 surveys. Trawl surveys plotted for the two proposed core strata and for core plus the small, medium and large guard strata.

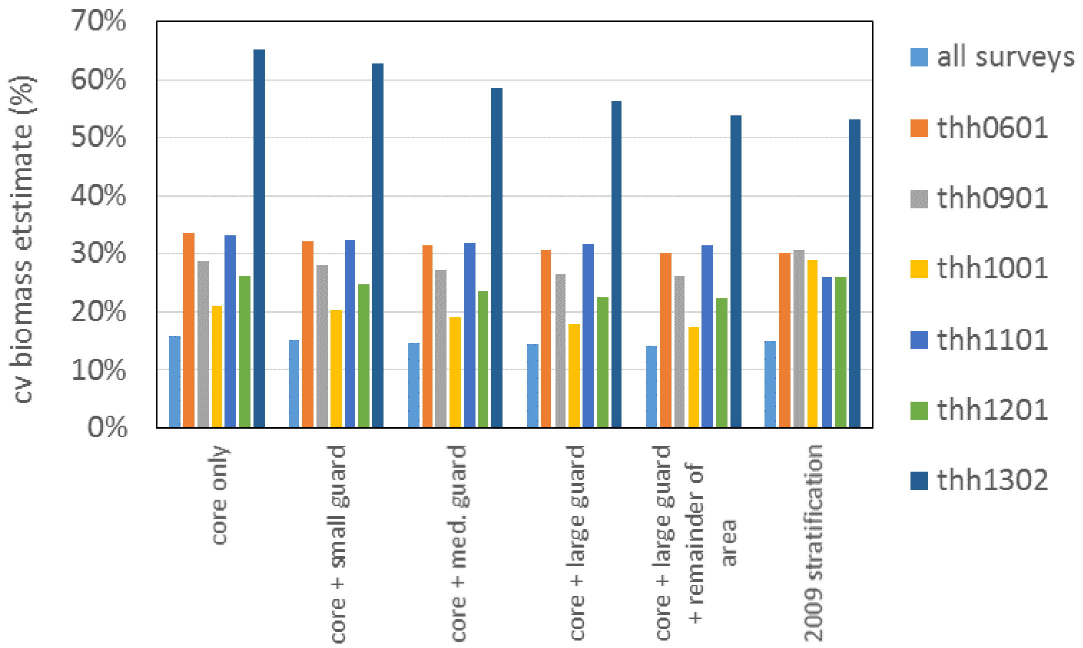

Figure 7: Orange roughy abundance CV from the 2006 to 2013 trawl surveys plotted for the two proposed core strata and for the core plus small, medium and large guard strata.

The number of tows for each target CV are presented in Table 5. This shows that a minimum of about 50 tows per survey is required to achieve a CV of 25%, and that a large increase in tows is required to achieve a decreased CV of 20% or 15% (70 or 110 tows)

Table 5: The number of tows required to achieve specific target orange roughy abundance CV values. Based on catch rates from tows from the 2006–2013 surveys where there was a minimum of 3 tows in each stratum and where data was applied to the core and medium-sized guard strata.

Stratum	Target CV (%)			
	30	25	20	15
	Number of tows for target CV			
Core west	15	21	33	60
Core east	10	14	22	38
Guard north	3	3	3	3
Guard east	3	3	3	3
Guard south	3	3	3	3
Guard west	3	3	3	3
Total	37	47	67	110

3.1.4 Acoustic survey – aggregations on the flat and on hills

The flat and hill acoustic surveys by year are summarised in Table 6 and details of the numbers of transects and strata covered by each survey are in Appendix D. Reported orange roughy relative abundance estimates (t) for the acoustic surveys of Challenger Plateau (ORH 7A) spawning plumes and hills are summarised along with the source of the estimates in Table 7. The 2014 results were from experimental work using an AOS in the headline of the trawl net to identify that marks over Volcano were orange roughy, i.e., no data were collected on the aggregations on the flats (Ryan et al. 2015). This work used a series of star surveys to collect data from which acoustic abundance estimate can also be made.

Table 6: Acoustic surveys of flat and hills carried out on *Thomas Harrison* surveys of Challenger Plateau (ORH 7A) and the 2014 experimental voyage on Volcano.

Date	Acoustic survey snapshots - flat	Acoustic snapshots - hills	Reference
24 June to 6 July 2005	1 stratum 4, 1 strata 21/22	3 stratum 10 (Pinnacles), 2 stratum 11 (Westpac)	Clark et al. 2005
24 June to 5 July 2006	1 strata 22/23	4 stratum 10 (Pinnacles), 3 stratum 11 (Westpac)	Clark et al. 2006
26 June to 6 July 2009	2 stratum 22, 4 stratum 22A, 1 each n-e and s-w corners of Pinnacles Flats	3 on each hill: Twin Tits, Megabrick, Volcano, and Dork. 1 Mt Yetch	Doonan et al. 2009
25 June to 8 July 2010	6 stratum 242, 7 stratum 1	5 Megabrick, & Volcano, 3 Twin Tits, 2 Dork	Doonan et al. 2010
25 June and 11 July 2011	5 stratum 22, 1 stratum 24	5 Pinnacles (4 on Megabrick and 1 on Twin Tits), 2 Westpac (2 each on Dork and Volcano)	Hampton et al. 2013
25 June and 10 July 2012	5 stratum 22, 7 strata 23/24	6 on Pinnacles (4 on Megabrick and 1 on Twin Tits)	Hampton et al. 2014
27 June 13 to July 2013	2 stratum 22, 12 stratum 23/1, 8 stratum 24/1, 1 stratum 25	2 Twin Tits, 4 Megabrick, 1 Dork, 3 Volcano	Boyer et al. (2013)
1–6 July 2014	Not attempted	5 Volcano	Ryan et al. (2015)

Table 7: Summary of the reported orange roughy relative abundance estimates (t) for the acoustic surveys of Challenger Plateau (ORH 7A) spawning plumes and hills. The 2014 hill estimate is for Volcano only.

Year	Spawning plumes (t)	Hills (t)	Total (% CV)	Reference
2005	1 649	1 086	2 734 (19)	Doonan et al. (2010), p. 15
2006	996	3 054	4 050 (22)	Doonan et al. (2010), p. 15
2009	5 617	16 876	22 493	Doonan et al. (2010), p. 15
2010	3 269	1 020	4 289	Doonan et al. (2010), p. 15
2011	9 481	3 476	12 957	Hampton et al. (2013), tables 13, 15
2012	3 439	3 364	6 803	Hampton et al. (2014), tables 12, 14
2013	13 376	6 596	19 972	Boyer et al. (2013)
2014	-	1 471$^{\xi}$ 5 653$^{\#}$	-	Ryan et al. (2015)

$^{\xi}$ 1-4 July average from AOS data; $^{\#}$ 5 July from AOS data

Analysis of acoustic data from the survey series

Analyses of the progression of orange roughy spawning on the flat (Pinnacles area) showed inter-annual variability of about 1 week, (Table 8), with substantial proportions of spent fish (20%) occurring anywhere from 19 June to 8 July. The dates (all during July) when the largest acoustic abundance estimates were made on the flat are in Table 9, and these suggest that the best time for a survey is from 2 to 8 July. For Volcano, the spawning state of fish is summarised in Table 10 where spawning appeared to be later than on the flat and so it should be surveyed after the flat aggregation, perhaps in the period 5–9 July.

Table 8: Annual comparison of the Pinnacles area orange roughy female spawning state between Challenger Plateau surveys. Gonad stage 3 – maturing ovary with large yolky oocytes.

	2005	2006	2009	2010	2011	2012	2013
Date when 35 % were stage 3	26–27 Jun	27 Jun	1 Jul	2–3 Jul	29 Jun	2 Jul	1 Jul
Date when 20 % were spent	3 Jul	29 Jun	4 Jul	5 or 8 Jul	7 Jul	> 8 Jul	2 Jul

Table 9: Comparison of dates of the largest orange roughy acoustic abundance estimates from the flat aggregations from Challenger Plateau surveys. All dates were in July.

Year	Dates of the largest snapshot abundances
2009	4 & 5
2010	2–4
2011	1, 4–5
2012	6
2013	middle snapshots (no date given)

Table 10: Annual comparison of the Volcano orange roughy female spawning state (% of all fish spawning). Data for 2014 was split into 2 parts based on 6 July to better show the potential progression of spawning. There were no data after 6 July in surveys carried out in other years so these data are not shown.

	2014	2009	2010	2014
Date	4–6 July	6 July	6 July	9 July
Spent	10	10	0	45
Ripe/running ripe	29	25	30	15
Resting/maturing	70	65	70	40

A summary of transects and snapshots used during previous acoustic orange roughy aggregation surveys of Challenger Plateau are in Table 11. The abundance estimates for the main flat aggregation (NW) were reasonably stable between surveys, but those for the NE aggregation and Volcano were variable. The median number of transects per snapshot was 9 for NW, 6 for NE, and 5 for Volcano.

The NW 2006 results were not used since they gave poor fits of the predicted survey CV from the pop-CV and the number of snapshots and transects used. The mean estimated pop-CV was 113% for NW, 134% for NE, and 157% for Volcano. The mean pop-CV can be used to predict the CV for each aggregation by year using the number of snapshots and transects used. Table 12 shows the comparisons and the predicted estimates matched the sample CV adequately for 8 of the 12 values and poorly in the remaining 4. Overall, this approach is adequate for planning, but, in practice, some years will have lower CVs (NE 2013, Volcano 2006, 2009) and higher CVs (NE 2012) than predicted.

Table 11: Summary of the number of transects and snapshots used for the acoustic surveys of orange roughy aggregations on Challenger Plateau and associated estimates of acoustic abundance (t) and CV (%). CV2, between-snapshot CV. NE, northeast flat; NW, northwest flat.

Aggregation area	Year	No. of snapshots	Median number of transects on the aggregation	Acoustic abundance	CV2
NE	2010	5	5	577	29
NE	2013	5	7	4 600	8
NW	2006	2	8	1 674	3
NW	2009	6	7	5 633	22
NW	2010	6	10	6 050	14
NW	2011	4	10	9 400	14
NW	2012	5	11	3 400	28
NW	2013	11	7	8 200	9
Volcano	2006	2	5	2 900	25
Volcano	2009	2	5	15 800	28
Volcano	2010	5	5	550	24
Volcano	2013	3	5	46 500	40
Volcano	2014	9	6	3 200	29

Table 12: Predicted and estimated orange roughy abundance CV by aggregation. Predicted mean pop-CV is based on the overall estimated pop-CV for each aggregation (NW 113%, NE 134%, and Volcano 157%) divided by the square-root of N, the number of snapshots.

Year	2006	2009	2010	2011	2012	2013	2014
NW aggregation							
N		6	6	4	5	11	
Predicted		21	15	20	17	12	
Estimated		22	14	14	28	9	
NE aggregation							
N			5			5	
Predicted			23			18	
Estimated			29			8	
Volcano							
N	2	2	5			3	9
Predicted	50	50	31			41	21
Estimated	25	28	24			40	29

Predicted orange roughy CV estimates for a combination of number of transects and snapshots.

Table 13 shows a list of the number of transects and snapshots required to achieve a target CV of 20% for the acoustic abundance estimate for the northwest orange roughy aggregation on the flat. Results show that the combination of small to moderate numbers of snapshots and moderate to high numbers of transects have relatively small cost, e.g., target CV of 20% with 3–5 snapshots and 6–10 transects per snapshot would require only 0.7–0.8 of a survey day. Similar results are found for the other two areas, northeast and Volcano aggregations, and results are given in Appendix E.

Table 13: Simulation analysis results showing the numbers of transects and snapshots needed to achieve predicted CV values (%) for acoustic surveys of the northwest orange roughy flat aggregation on Challenger Plateau. Total transects has two more transects to define the edge of the aggregations on the flat.

Target CV	Predicted CV	Number of snapshots	Number of transects on the aggregation	Total transects	Total survey time (days)
10	9.9	13	10	12	2.8
10	9.6	14	10	12	3.1
10	9.8	11	12	14	2.7
15	14.6	10	6	8	1.7
15	14.6	6	10	12	1.3
15	14.6	5	12	14	1.2
20	20.6	15	2	4	1.9
20	20.6	5	6	8	0.8
20	20	4	8	10	0.8
20	20.6	3	10	12	0.7
25	26.6	9	2	4	1.2
25	25.3	10	2	4	1.3
25	24.1	11	2	4	1.4
25	23.1	12	2	4	1.5
25	26.6	3	6	8	0.5
25	23.1	4	6	8	0.7
25	23.1	3	8	10	0.6
25	25.3	2	10	12	0.4
25	23.1	2	12	14	0.5
30	30.2	7	2	4	0.9
30	28.2	8	2	4	1
30	28.2	2	8	10	0.4

For a combined survey of aggregations, the relative abundance for the three main aggregations (two in one case) are shown in Table 14.

Table 14: Relative acoustic abundance to consider the relative importance of the three main orange roughy aggregations under three different scenarios. NW, northwest flat aggregation; NE, northeast flat aggregation; – no data.

Case	NW	NE	Volcano	Surveys used to estimate relative acoustic abundance
(1)	8	5	3	2013 flat, Volcano 2014 median from 4th July
(2)	9	–	3	2011 flat, Volcano 2014 median from 4th July
(3)	8	5	34	2013 flat, Volcano 2013 median

A list of the number of transects and snapshots required to achieve a target CV of 20% for the total acoustic abundance (up to three aggregations) estimate for each of the cases presented in Table 14 are shown in Tables 15–17. The implication is that only one day is required to survey all aggregations acoustically (not including steaming, searching time, and time for trawling). The time for surveying is not a bottleneck since the aggregations need monitoring over days to check the progress of spawning and to be sure that the survey is at peak spawning and size.

Table 15: Case (1) [see Table 14]. Numbers of transects and snapshots needed for a target CV of 20% for acoustic surveys of the 3 main orange roughy aggregations on Challenger Plateau. NW, northwest flat aggregation; NE, northeast flat aggregation; VOL, Volcano.

	Number of snapshots			Number of transects on mark				
Target CV (%)	NW	NE	VOL	NW	NE	VOL	Predicted CV (%)	Cost (days)
20	3	2	3	6	6	5	19.5	0.9
20	3	2	4	6	6	5	19.2	1
20	3	2	5	6	6	5	18.9	1
20	3	3	2	6	6	5	19.0	1
20	4	2	2	6	6	5	19.1	1
20	2	3	6	6	6	5	19.8	1.1
20	2	3	7	6	6	5	19.7	1.1
20	2	4	3	6	6	5	19.9	1.1
20	2	4	4	6	6	5	19.6	1.1
20	3	2	6	6	6	5	18.8	1.1

Table 16: Case (2) [see Table 14]. Numbers of transects and snapshots needed for a target CV of 20% for acoustic surveys of the 2 main orange roughy aggregations present on Challenger Plateau. NW, northwest flat aggregation; NE, northeast flat aggregation; VOL, Volcano.

	Number of snapshots		Number of transects on mark			
Target CV (%)	NW	VOL	NW	VOL	Predicted CV (%)	Cost (days)
20	4	4	6	5	19.4	0.8
20	4	5	6	5	19.0	0.8
20	5	2	6	5	19.8	0.8
20	4	6	6	5	18.7	0.9
20	4	7	6	5	18.5	0.9
20	5	3	6	5	18.5	0.9
20	5	4	6	5	17.8	0.9
20	4	8	6	5	18.4	1.0
20	4	9	6	5	18.3	1.0
20	6	2	6	5	18.8	1.0

Table 17: Case (3) [see Table 14]. Numbers of transects and snapshots needed for a target CV of 20% for acoustic surveys of the 3 main orange roughy aggregations on Challenger Plateau. NW, northwest flat aggregation; NE, northeast flat aggregation; VOL, Volcano.

	Number of snapshots			Number of transects				
Target CV (%)	NW	NE	VOL	NW	NE	VOL	Predicted CV (%)	Cost (days)
20	1	1	9	6	6	5	19.5	0.7
20	1	1	10	6	6	5	18.8	0.8
20	1	1	11	6	6	5	18.2	0.8
20	2	1	8	6	6	5	19.7	0.8
20	1	1	12	6	6	5	17.6	0.9
20	1	2	9	6	6	5	19.1	0.9
20	1	2	10	6	6	5	18.3	0.9
20	2	1	9	6	6	5	18.7	0.9
20	2	1	10	6	6	5	18.0	0.9
20	1	2	11	6	6	5	17.7	1.0

3.2 Objective 2: Standard operations and statistical procedures for Challenger Plateau surveys

3.2.1 Trawl survey standard procedure recommendations

The same vessel should be used for every survey in the time series, if possible. Long term, for succession planning of the operating vessel, it would be useful to investigate what are the most important factors driving differences in catchability between vessels.

A two-phase stratified random design should be applied (after Francis 1984), with about 10 to 20% of the total tows in Phase 2. This percentage should be kept relatively consistent between surveys since it affects the size of the bias (always negative). However, although the percentage of phase 2 tows affects bias, the changes are modest, e.g., 0.3% to 4% increases the magnitude of bias from 4% to 9% in a mackerel simulation (Francis 1984). Where possible, phase 1 tows in the core strata (22, 23, 24) should be carried out at one time and not split with a large time gap (i.e., days).

New tow start positions should be (randomly) generated for all phase 1 and 2 tows each year. An echosounder run can be made over each newly generated start position to determine if a trawl can be performed. On slope areas, tow direction should be parallel to the depth contour. An area within a specified radius, i.e., 3 n. miles, Doonan et al. (2009, p. 11) of the generated position may be surveyed to find suitable trawl ground. If the ground is not suitable, i.e., there is risk of serious gear loss or damage, the next random start position on the list is substituted. Doonan et al. (2009, p. 11) defined the random start position as “The position was used as the location of the gear-down” and this was specified more clearly for the 2010 survey “location for gear first settling on the seafloor”, Doonan et al. (2010, p. 4). In the 2011 and 2012 surveys the random position was where the “vessel (rather than the net) was at the stipulated position at touch-down”, Hampton et al. (2013, p. 4; 2014, p. 4). This slight difference is probably not critical but the method should be consistent throughout the time series of surveys. Other surveys ensure that the trawl passes through the random point at some time during the tow. The entire trawl path should be within the stratum area.

Some previous surveys included random tows that sampled a spawning aggregation, resulting in a large catch, and unacceptably high CV. The catchability of aggregation tows will be different from tows on lower densities. In the past there was debate about whether to include or exclude such a tow in the flat trawl survey abundance estimate. We recommend that if a random tow samples a spawning aggregation, it should be abandoned and another random position substituted, i.e., the aggregation area should be excluded from the trawl survey area. Spawning aggregations are best surveyed using acoustic methods.

Trawl gear

It is important that the trawl gear is the same, and is used in the same manner, for each trawl survey in a series, see 3.1 above for details of the gear used in previous Thomas Harrison surveys (2005–2013). The trawl gear includes all aspects of the net and its set-up (type, panel numbers and size, mesh size, twine type and size, ground-rope components, weight and dimensions, head-rope components, flotation and dimensions, net monitor, sweeps, bridles, trawl doors, and warps). Net construction is generally consistent, but headline flotation and sweep/bridle length, and arrangement of layback should be checked and specified for every trip.

Trawl parameters should be as similar as possible to the previous survey values, i.e., length of warp and tow speed should be similar, to give similar distance between the doors and headline height, see Table 3 above for values recorded from previous surveys. Trawl parameter measuring equipment should be used to measure distance between the doors (preferably every tow), distance between the wing ends (not as vital as distance between the doors), and the headline height of the net (every tow) whenever possible. These data are not captured electronically and consequently during a tow, readings of distance between the doors and headline height should be recorded every 10 minutes for flat tows and every 2 minutes (or less) for hill tows. An average reading should be entered as the "final" value for the tow.

Trawl procedure

The tow starts when the net is observed from the net monitor display to first touch and settle on the bottom, and finishes when the net leaves the bottom. Net monitors are therefore essential for deepwater surveys and trawls made without one are not valid for abundance estimation. The planned length of the tow should be 1.5 n. miles at 3 knots. The same tow length should be used for each survey series to enable comparison of catch rates. Actual tow length may be shortened because of the approach of bad terrain or because a large amount of fish has entered the net. Flying the net over an obstacle, e.g., a gully, during the tow, and recording only the distance when the net was on the bottom invalidates a tow.
, and recording only the distance when the net was on the bottom invalidates a tow.

Catch sampling
Catches should be sorted by species and all species (including bycatch) weighed and recorded. All organisms should be identified to species where possible. Fish should be identified using McMillan et al. (2011a, 2011b), and invertebrates using Tracey et al. (2011, 2014). Animals that cannot be identified or are rare or unusual should be labelled with a tow number and frozen and returned to NIWA or the Museum of New Zealand Te Papa Tongarewa for identification and later added to the trawl database. Other material, e.g., rocks, seaweed, plus rubbish such as cans, rope, etc, should also be recorded.

Small catches totaling less than about 1 t can often be weighed in full on motion compensated scales. For catches over about 1 t, the weight of the orange roughy can be back-calculated from the amount of fish processed on board, and all bycatch should be sorted and weighed. Back-calculating from processed weights requires the following information: the conversion factor (from unprocessed to headed and gutted state), estimated for most of the large catches from about 200 kg of unprocessed fish; the average frozen block (tray) weights estimated from samples weighed during the survey (and from each large catch if possible); and the number of frozen blocks of each species produced at each tow. The total catch of each species is then calculated from the product of the number of frozen blocks, the conversion factor, and the average block weight. These calculations are probably best carried out by the Factory Manager on board but if necessary research staff can also estimate conversion factors.

Sampling to estimate conversion factors can be done in two ways.
1. A sample of fish (about 200 individuals) are weighed before being processed and the product weighed.
2. If fish in the catch are homogeneous in size, a random sample of processed fish (about 200 individuals) can be taken, and the weight compared with a random sample of the same number of whole fish.

The first method enables a precise conversion factor from known fish to be calculated but has the problem of the machine operator[1] knowing that the experiment is taking place. Method two is preferred but requires more samples to be taken to ensure whole and cut fish are representative of the catch.

Biological sampling
Samples of about 100 individuals each of the target species i.e., orange roughy, and other quota and commercial non-quota species should be taken at each tow for length frequency (length to the nearest centimetre below), sex, and gonad stage. Length frequency samples of up to 50 individuals of all other species should also be taken as time permits, starting with the more abundant species. Length (to the nearest millimetre), weight (nearest 10 g), sex, gonad stage, gonad weight (nearest 1 g), otoliths, and stomach state and contents should be collected for 20 (or more) randomly selected individual specimens of the target or quota species at each tow. Larger samples should be taken for larger catches, i.e., 20 fish for catches of up to 5 t, 40 fish for catch up to 10 t, additional 20 fish for each 10 t thereafter. Reproductive state is assessed by macroscopic gonad staging using the NIWA standard definitions used on previous *Thomas Harrison* orange roughy surveys (Appendix F). When large catches are made, length (and age), and sex can vary in parts of the net so separate length frequency and biological samples should be taken from different parts of the codend for every 10 t of fish to give a more representative total sample.

3.2.2 Acoustic survey standard procedures

The acoustic survey design followed the adaptive design used for orange roughy surveys on the Chatham Rise spawning plume that use a hull transducer (Doonan et al. 2012).

[1] Research surveys typically process fish for resale which goes back to MPI.

Common requirements for surveys of flat and hill aggregations are:

1. Surveys to be carried out when the wind speed is less than 20 knots.
2. Define the boundaries of the aggregation as well as possible from a preliminary echosounder survey.
3. Ideally, the acoustic system should be calibrated before and after the survey. *See* Demer et al. (2015) for the procedures to follow. However, one calibration should be sufficient when there is a history of calibrations. Occasionally, calibrations can only be completed well outside of the survey time and this should be adequate given a stable transducer with a history of calibrations. Note that some series of echosounder calibrations have peak gain gradually declining over the long-term so regular calibrations are needed (Knudsen, 2009). For new transducers, a calibration is critical.
4. The aggregation should be surveyed before fishing on it so that it is undisturbed. After trawling, the aggregation should be 'rested' for several hours before another survey snapshot is undertaken.
5. Several tows over time are needed to record species composition and monitor the progression of spawning.
6. After each tow the net meshes should be carefully examined for left-over fish, to avoid contaminating subsequent tows and to provide information on small species that may have passed through the meshes during the tow but were not retained in the codend.
7. Acoustic data should also be recorded while trawling

Survey methods for aggregations using parallel transects.

1. Set up a grid of parallel lines which extend beyond the boundaries in both the along-track and cross-track directions. In a well-defined aggregation, there should be a clearly-defined start and end to the aggregation on all lines which intersect it, and at least one line on either side of it where no fish are detected (this is to demonstrate clearly that the survey properly covered the entire aggregation). On relatively flat ground the lines should run across the depth contours in the direction of greatest change in depth (and therefore greatest change in orange roughy density).
2. When surveying aggregations on flat ground the lines should be evenly spaced a minimum of 0.2 n. miles apart. The aim is for 8–10 transects that cross the aggregation, with the minimum average spacing of 0.2 n. miles. To counter bias from aggregation movement along the longest axis, transects should be split into two interleaving sets, with one set carried out in order going from right to left (or left to right) along the longest axis, and the other set done in the reverse direction.
3. Steam the grid at a constant speed of about 10 knots, or at normal steaming speed. Slow down if noise spikes start to appear on the record.
4. If there is enough time for further survey snapshots after completing the grid, repeat the grid as many times as possible in the time available, but do not simply repeat the previous grid, i.e., randomise the first transect.

Survey methods for aggregations on hills that require a 'star' design (after Doonan et al. 2003).

1. The centre of the star should be on the mark, not the top of the hill.
2. The survey speed should be slower than for flat surveys to get more pings on the mark, say 5–7 knots.
3. For hills, there is a problem with identifying the species composition by trawling so experimental work (an optical acoustic system fitted in the trawl net headline or similar) at some time is needed to confirm the species composition.
4. Trawling on the mark is needed to determine species composition and collect biological data.
5. If there is enough time for further survey snapshots after completing the grid, repeat the grid as many times as possible in the time available, but do not simply repeat the previous grid, i.e., randomise the first transect.

Associated data collected should include:

- True wind speed and direction on a regular basis, every 10 mins.
- Vessel pitch and roll data on a continuous basis.
- CTD data from the survey areas, by attaching a CTD unit to the trawl headline.
- Acoustic data during all trawls (both mark identification and random tows)

Standard procedures for acoustic survey mark identification trawls

Marks observed on the hills and during the spawning plume transect survey that are likely to contribute substantially to the acoustic abundance should be sampled to determine species composition and fish size. The trawl gear used should be similar to that used for the trawl survey tows, but this is not critical. The catch from a tow targeted at a mark needs to be at least 1 t to be certain that the tow has not missed the mark, and it is important that each tow only samples one mark, so tows may need to be short. Catch and biological data recording is the same as described above for trawl surveys. Catch composition is particularly important, so the catch weight of all species must be carefully recorded. Samples from each tow of 100 fish (*see* Section 3.2 for the recommendation of 100 fish rather than 200 used in the past) of each of the main (most abundant) species caught and up to 50 fish for other species should be measured for length and individual weight. Length (to the nearest millimetre), weight (nearest 10 g), sex, gonad stage, gonad weight (nearest 1 g), and otoliths, should be collected for 20 (or more) randomly selected individuals of the target and quota species for each tow.

Trawling on orange roughy aggregations is likely to break them up, making them unsuitable for acoustic surveys for some time afterward. The survey plan should allow for this by timing these trawls to follow an acoustic snapshot and then moving on to allow the aggregations to reform before carrying out further survey work on them.

3.3 Objective 3: Review of catch and biological sampling for Challenger orange roughy and the main bycatch species

Estimates of relative abundance for the top 15 bycatch species by weight caught in the Challenger Plateau trawl surveys are shown in Table 18.

Table 18: Relative abundance (distance between the wings, abd) estimates (t) and CVs (%) for the top 15 bycatch species in the Challenger Plateau trawl surveys.

	2006		2009		2010		2011		2012		2013	
Common name	Abd	CV	Abd	CV	Abd	CV	Abd	CV	Abd	CV	Abd	CV
Leafscale gulper shark	390	18	457	25	308	26	159	34	636	22	1005	19
Smooth skin dogfish	463	18	503	24	389	23	221	22	476	13	721	35
Shovelnose dogfish	236	15	654	10	239	25	309	10	336	14	375	14
Spiky oreo	176	33	272	46	342	42	166	46	118	22	136	26
Unicorn rattail	301	16	385	32	333	20	362	20	268	21	283	34
Hake	85	31	161	17	165	22	238	58	125	43	155	32
Longnose velvet dogfish	83	15	176	14	225	15	111	13	54	31	146	27
Seal shark	10	46	61	52	112	42	28	38	279	56	37	63
Hoki	17	41	146	42	93	43	147	34	119	33	214	23
Ribaldo	333	15	499	20	217	18	150	21	325	19	378	9
Widenosed chimaera	109	26	84	27	264	23	46	42	58	50	95	56
Johnsons cod	62	15	80	23	133	29	67	35	109	24	118	38
Plunket’s shark	51	47	85	36	0	0	34	74	54	85	6	86
Large scaled brown slickhead	197	22	29	37	368	45	193	64	433	70	173	40
Black slickhead	22	25	57	14	45	16	27	35	57	15	79	10

Station allocation for 'vulnerable' bycatch species

There were three species that had estimated CV values of more than 40%, more than half the time (Table 18): seal shark (BSH), Pacific spookfish (RCH), and Plunket's shark (PLS). The estimated number of stations required to estimate abundance with a specified CV of 40% for these three bycatch species is in Table 19. Only stratum 4 requires a significant increase in the number of stations from 3 to 15 over that normally used in the surveys.

Table 19: Station allocation by stratum required to estimate abundance with a specified CV of 40% for three vulnerable bycatch species: Seal shark (BSH), Pacific spookfish (RCH), and Plunket's shark (PLS). Also shown is the median number of tows by stratum over the 2006 to 2013 surveys

					Number of stations
Stratum	BSH	RCH	PLS	Maximum	Median surveys
1	5	3	3	5	3
3	3	6	3	6	3
4	3	3	15	15	3
10	3	3	3	3	3
21	3	3	3	3	3
22	12	3	3	12	11
23	3	3	3	3	10.5
24	3	3	6	6	15
25	3	3	3	3	3
Total				56	

Sample size and CV for length frequency sampling of orange roughy and bycatch species

A summary of the number of length/sex records per survey for the top 16 species in descending order of abundance (t) is shown in Table 20. A summary of orange roughy length/sex and biological record (length, weight, sex, and otolith taken) records is shown in Table 21. There were slightly fewer orange roughy length/sex and biological fish per tow measured in the later surveys.

The mean weighted CV (MWCV) for the Challenger survey series orange roughy length frequency samples was 18–57% (Table 22), but most of the surveys had values of about 30% with a median of 28%. It is unclear why the MWCV for the 2013 frequency was so high. Simulation analyses on the number of fish to sample per station showed that most of the reduction in MWCV was achieved by sampling 20 fish per station and that only minor gains in precision occurred when sample sizes were 100 or more, Figure 8.

Table 20: The number of fish measured for length and sex on each survey for the top 16 species (ranked by abundance estimate).

Species	2006	2009	2010	2011	2012	2013	Total
Orange roughy	6 413	10 204	9 712	5 768	5 501	5 642	43 240
Spiky oreo	449	429	496	391	215	282	2 262
Ribaldo	280	426	228	214	258	307	1 713
Hake	44	75	91	45	30	61	346
Hoki	11	51	81	68	31	68	310
Johnsons cod	141	33	43	16	0	64	297
Large scaled brown slickhead	107	4	0	0	0	69	180
Unicorn rattail	49	0	6	4	0	40	99
Black slickhead	4	0	10	1	0	56	71
Longnose velvet dogfish	0	3	25	3	0	34	65
Shovelnose dogfish	3	0	2	4	0	36	45
Smooth skin dogfish	0	2	8	2	0	29	41
Leafscale gulper shark	0	1	10	0	0	20	31
Widenosed Chimaera	0	0	5	1	0	17	23
Seal shark	0	0	1	0	0	3	4
Plunkets shark	0	1	0	0	0	0	1

Table 21: The number of orange roughy measured for length/ sex (LF) and biological record (Biols, length, weight, sex, and otoliths taken) on each orange roughy (ORH) Challenger Plateau trawl survey, using only valid abundance tows.

	Number of tows			Number of fish sampled	
Survey	Abundance	ORH caught	ORH length sample taken	LF	Biols
THH0601	55	55	55	6 413	1 118
THH0901	64	62	62	10 204	1 541
THH1001	68	67	67	9 712	1 404
THH1101	59	58	56	5 968	875
THH1201	49	49	49	5 501	883
THH1302	59	58	58	5 642	722

Table 22: Orange roughy mean weighted CV for length frequencies (%) from the Challenger Plateau survey series.

Survey	Female	Male	All
THH0601	29	31	26
THH0901	28	29	27
THH1001	18	22	18
THH1101	35	46	34
THH1201	35	31	28
THH1302	53	69	57

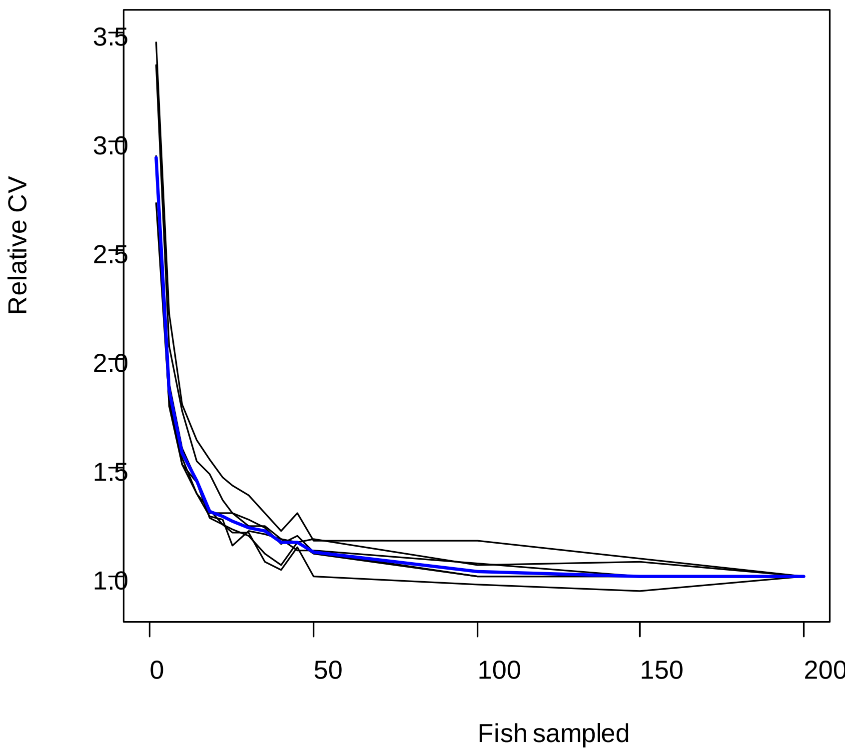

Figure 8: Orange roughy CV by number of fish sampled per station, relative to the CV using 200 fish per station. Black lines relate to individual surveys (*see* text) and the thick blue line is the median.

Bycatch species

More bycatch species measurements were made in the last two surveys of the series (Table 20) but most stations had fewer than 10 fish per station. We abandoned simulations to find the optimum level of sampling because the data were too sparse to be meaningful. However, the orange roughy results give some guidance. Orange roughy has a median MWCV of 28% for the survey series and we can read off the multiplier from Figure 8 to get an approximate CV, e.g. for 10 fish per tow the multiplier is 1.5. For species where 10 fish were sampled per tow, the MWCV may be around 1.5 * 28 = 42%. Most bycatch species had fewer than 10 fish per station and so MWCV estimates are likely to be large unless the fish samples from each tow are confined to a narrow length range.

4. DISCUSSION

Results of the work carried out and presented in this document were presented to a meeting of the Deepwater Fishery Assessment Working Group on 9 December 2014. The meeting favoured the continuation of the flat aggregation and hill aggregation acoustic surveys, but the flat area random trawl survey received less support. There was little or no support for the hill random trawl survey.

For the flat random trawl survey, this report proposed a simplified stratification comprising 2 core strata and 4 surrounding guard strata that potentially reduces the survey time required i.e., costs, and that ensures that the new survey area includes most of the orange roughy abundance estimated from the previous design. Any future trawl survey should follow the deepwater trawl survey sampling protocols summarised in this report to ensure compatibility with past surveys.

The main finding of an analysis of the flat aggregation acoustic survey data was that only small numbers (3–5) of snapshots and modest numbers of transects (6–8) were required to achieve a mean CV estimate of orange roughy abundance below 20%. Statistically, only one snapshot is needed to get a CV of 20% which potentially could be completed in about one day if 6–8 transects were used. More time would be required to locate and map the distribution of the aggregation prior to completing a snapshot and extra time would also be required to carry out one or more tows to confirm species identification and spawning status. However, a major requirement is monitoring the spawning aggregation for spawning progression, i.e., to ensure that the survey covers peak spawning, which can only be done over a number of days longer than the ship time required to complete these tasks and achieve the desired CV. There is also a requirement to monitor the abundance level from each snapshot to ensure that the mean level is consistent, as there have been cases where abundance has jumped up to a higher level (or down to a lower level on the Chatham Rise) in the past, confounding subsequent analyses. We recommend that future acoustic surveys monitor the spawning aggregations over at least 5 days.

Future acoustic surveys should follow the Deepwater acoustic survey sampling protocols summarised in this report. Hill aggregation acoustic surveys have indicated that relatively high abundance estimates could be estimated, e.g., from Volcano in 2013. It appears that aggregations form on that hill relatively late relative to the flat so the hill surveys should be delayed until that time, and this appears to be towards the end of the first week of July. Time to search and carry out one or more tows would also be required. Deepwater hill acoustic survey protocols should be followed. Mark identification and shadow zone issues could be informed by use of AOS equipment.

All biological sampling should follow the protocols summarised in this report but the simulation analysis suggests that orange roughy sample sizes greater than 100 fish contribute only minor improvements to the CV estimates. Sampling of the main bycatch species caught should continue but analysis results suggest that the CV estimates for length frequency distribution of many of the bycatch species will probably be relatively high, i.e., at least 40 %, because in most surveys fewer than 10 fish per tow of most species were caught.

5. ACKNOWLEDGMENTS

Thanks to Owen Anderson for a review of the manuscript. Thanks to M. Clark (NIWA) for copies of past Challenger Plateau survey reports and for the *Thomas Harrison* net plan. This work was completed under Objectives 1–3 of Ministry for Primary Industries project DEE201408.

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APPENDIX A: Survey area and strata for *Thomas Harrison* surveys of Challenger Plateau, 2005–2013.

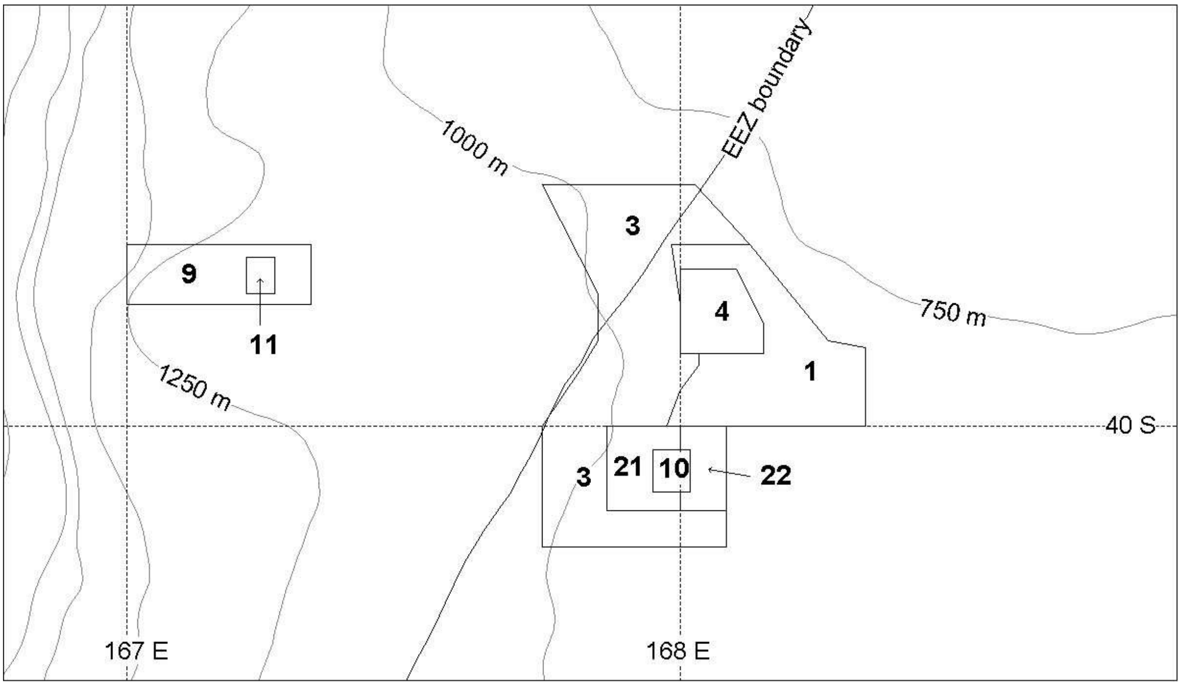


Figure A-1: Survey area and strata for 2005.

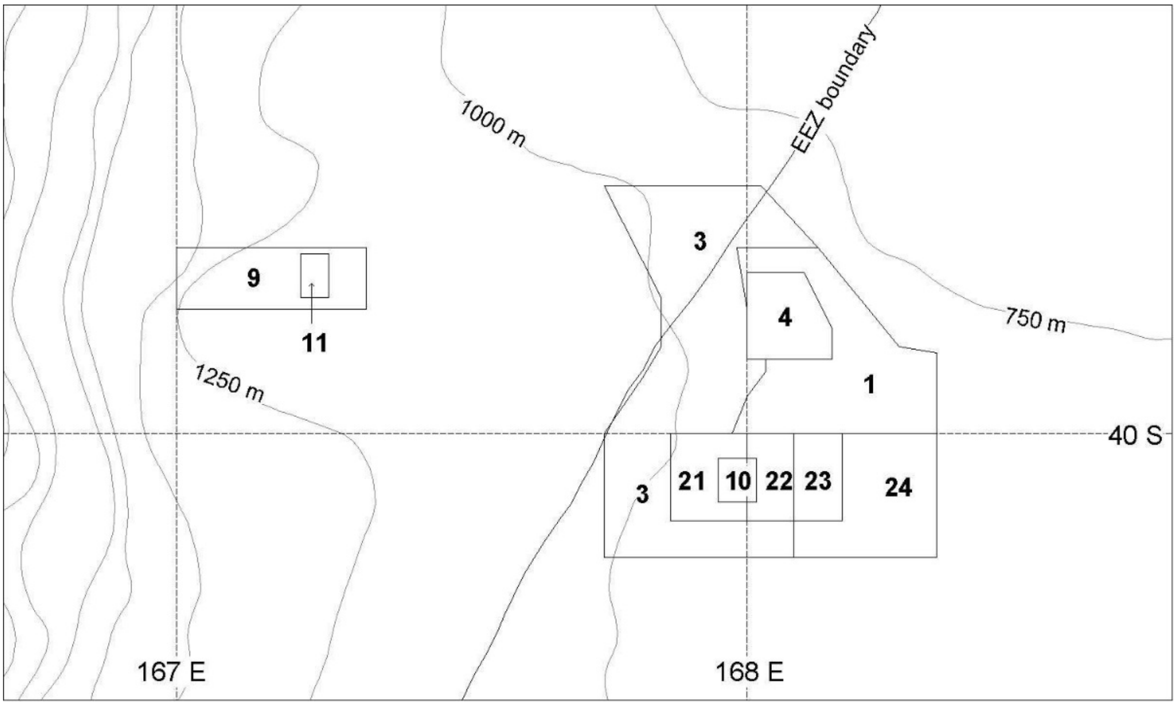


Figure A-2: Survey area and strata for 2006.

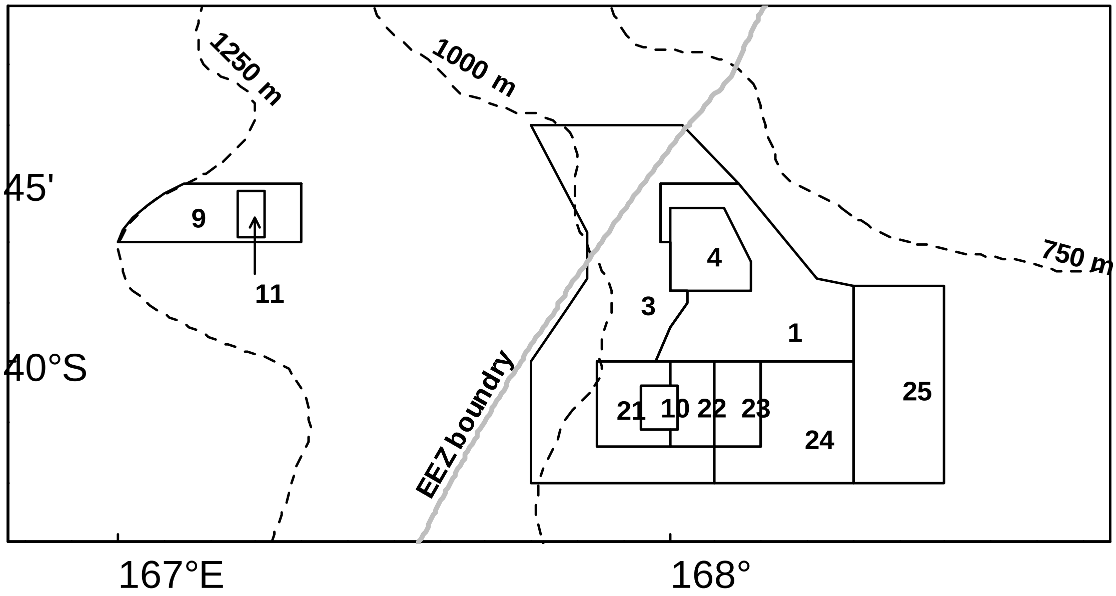


Figure A-3: Survey area and strata for 2009.

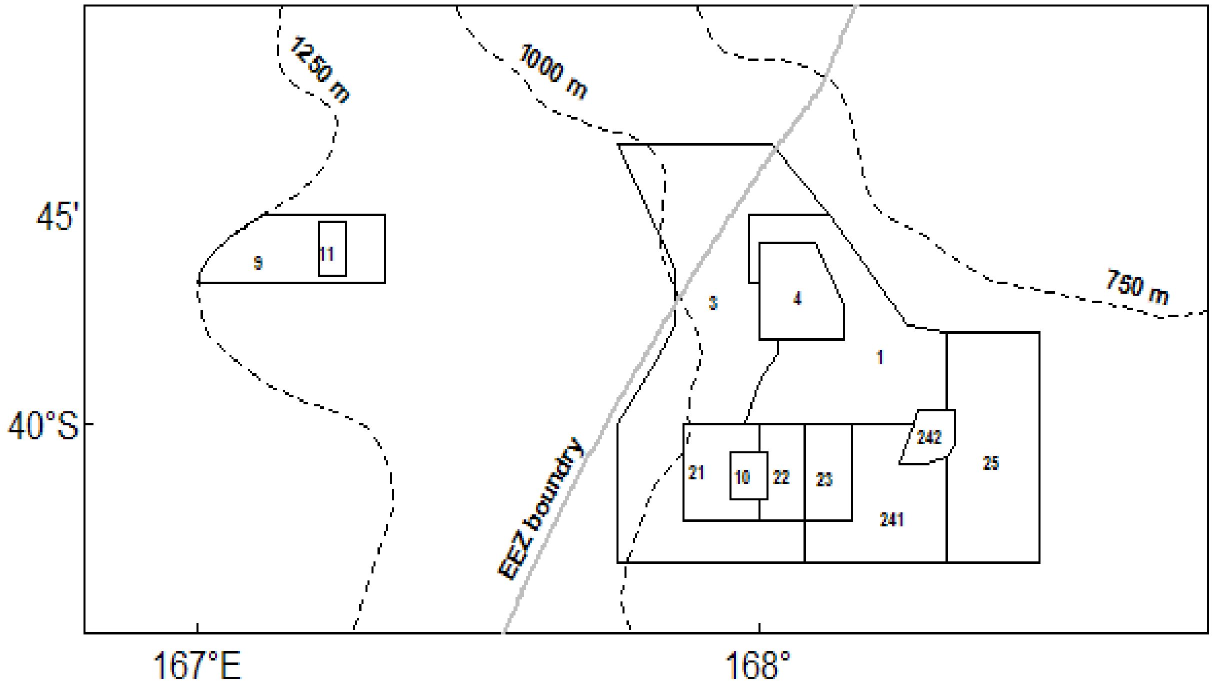


Figure A-4: Survey area and strata for 2010: Stratum 10 (Twin Tits and Megabrick), 11 (Westpac Volcano and Dork), Nth Pinnacles Flat (stratum 22A) and an area in stratum 242 were also surveyed acoustically.

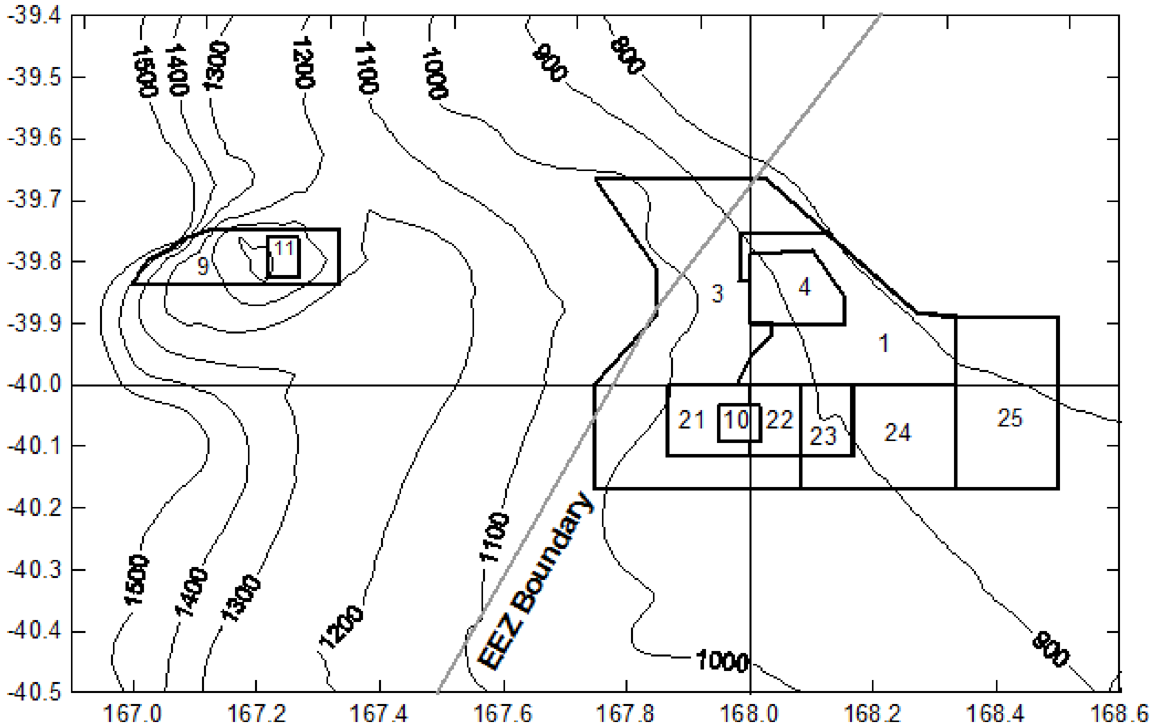


Figure A-5: Survey area and strata for 2011.

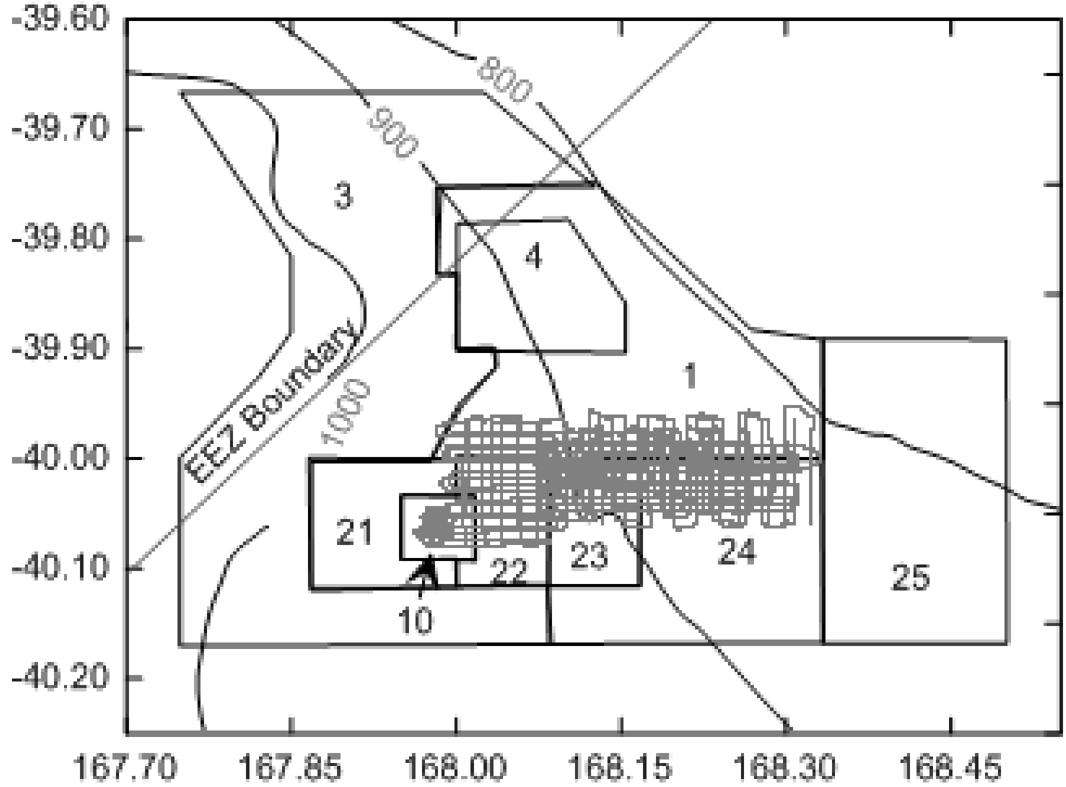


Figure A-6: Survey area and strata for 2012 and acoustic survey tracks.

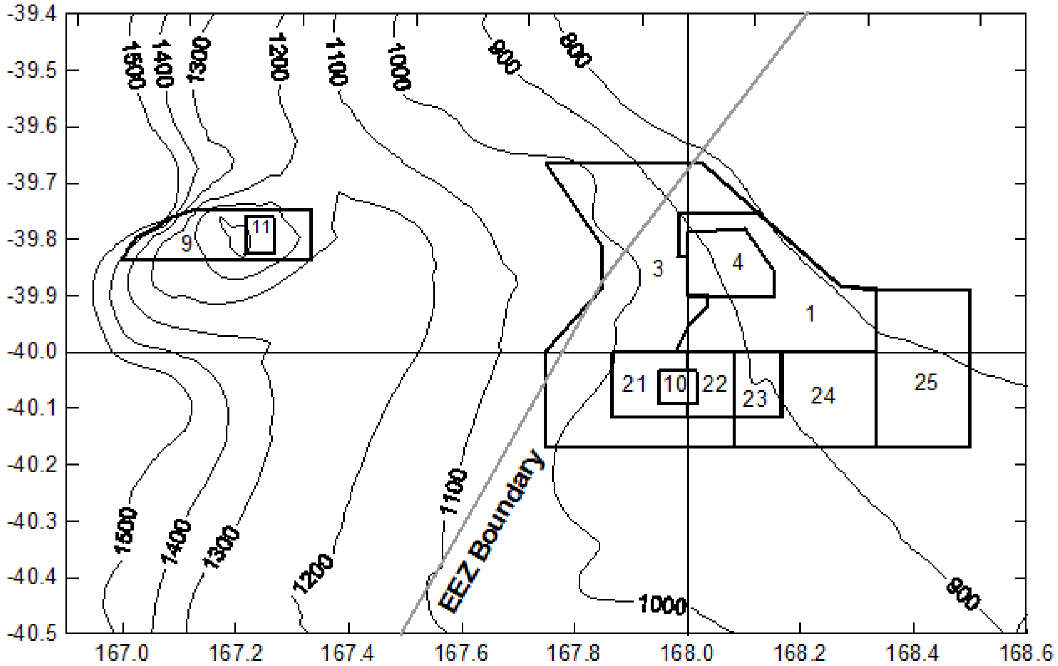
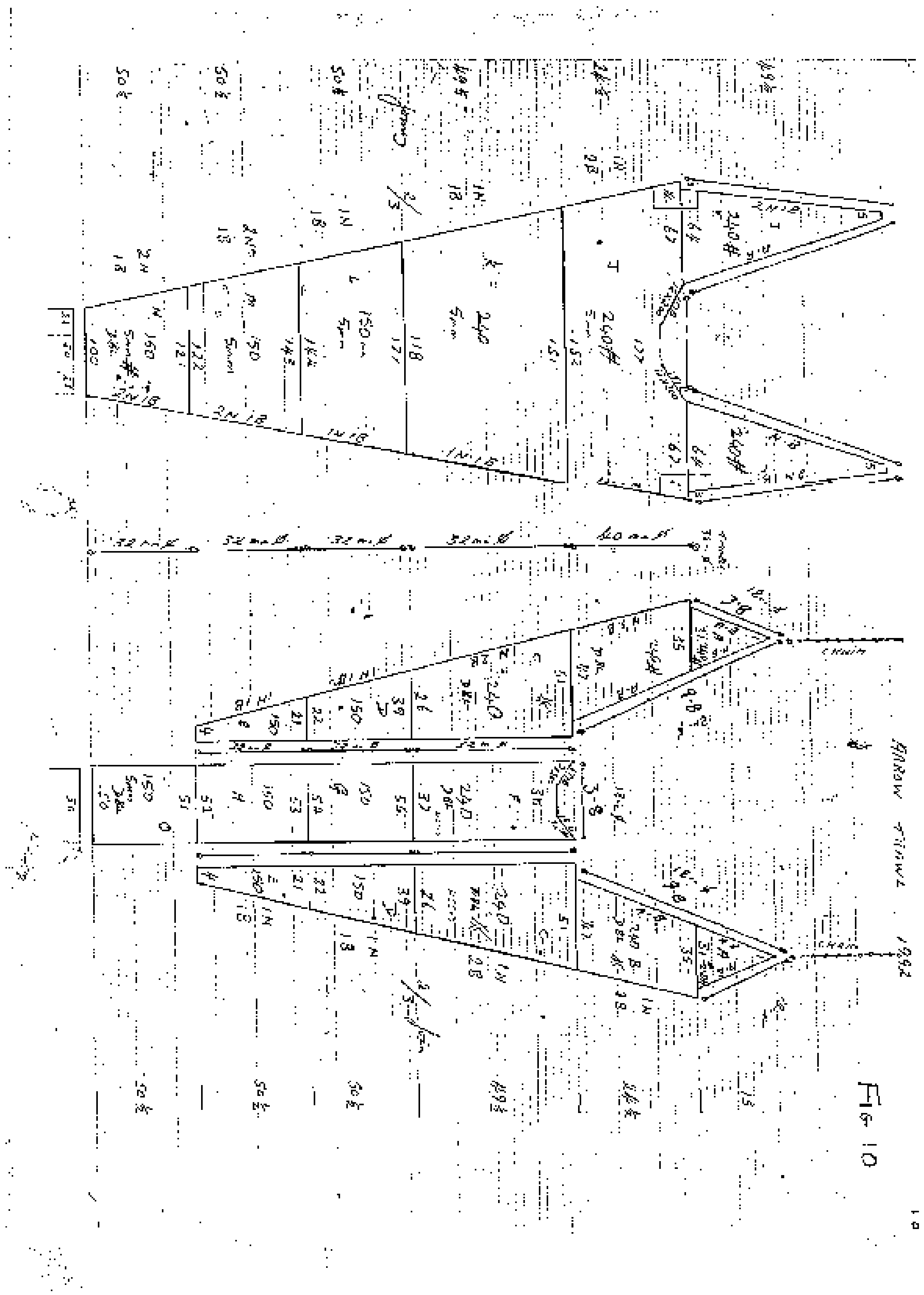


Figure A-7: Survey area and strata for 2013. From Boyer et al. (2013).

APPENDIX B: trawl net plan

Four seam orange roughy rough bottom gear (no lower wings) used for *Thomas Harrison* surveys of Challenger Plateau 2005–13.



APPENDIX C: Challenger Plateau orange roughy trawl survey abundance estimates, 2005–13.

Table C-1: Trawl survey design and reported abundance estimates and CV for the 2005 survey. †New strata in 2005.

Stratum	Area (km^2)	Number of tows	Abundance (t)	Mature abundance (t)
1	429	5	1 308	1 271
3	688	6	614	479
4	166	8	355	305
9	182	4	409	381
10	8	4	1 255	1 196
11	20	3	484	478
21†	121	3	77	65
22†	83	11	15 275	13 932
Total	1 697	44	19 776 (95% CI 6 632–32 920)	18 107 (95% CI 6 121–30 093)

Table C-2: Trawl survey design and reported abundance estimates and CV for the 2006 survey. * New strata in 2006.

Stratum	Area (km^2)	Number of tows	Abundance (t)	Mature abundance (t)
1	429	6	1 039	945
3	688	6	324	252
4	166	6	100	66
9	182	4	815	789
10	8	3	729	709
11	20	3	886	873
21	121	3	31	23
22	83	10	1 635	1 489
23*	93	9	8 988	8 538
24*	304	4	3 463	3 114
Total	2 094	54	18 008 (95% CI 9 144–26 873)	16 799 (95% CI 8 366–25 232)

Table C-3: Trawl survey design and reported abundance estimates and CV for the 2009 survey. †New stratum in 2009.

			Abundance		Mature abundance	
Stratum	Area (km^2)	Number of tows	(t)	CV (%)	(t)	CV (%)
1	478	4	166	32	124	31
3	945	3	352	83	265	86
4	149	3	233	69	216	73
9	199	3	1 480	54	1 407	53
10	8	4	1 761	62	1 735	62
11	20	2	3 863	66	3 787	66
21	121	3	1 029	50	982	50
22	83	10	10 672	49	10 211	49
23	93	12	15 966	50	15 336	51
24	304	12	18 171	55	17 454	55
25†	437	8	401	38	378	40
Total	2 837	64	54 092	26	51 894	26

Table C-4: Trawl survey design and reported abundance estimates and CV for the 2010 survey. † New strata in 2010.

			Abundance		Mature abundance	
Stratum	Area (km^2)	Number of tows	(t)	CV (%)	(t)	CV (%)
1	362	3	770	78	712	82
21	121	3	334	46	324	47
3	945	3	329	27	259	29
4	149	3	235	48	194	48
9	199	5	1 899	59	1 875	60
10	8	3	1 723	50	1 710	50
11	20	3	846	30	838	30
22	83	15	3 823	28	3 730	29
22A†	107	3	964	52	943	52
23	93	17	1 349	66	1 293	66
25	428	3	376	73	355	73
241†	272	8	2 530	60	2 452	60
242†	49	8	1 856	35	1 816	35
Total	2 837	68	17 034	16	16 500	16

Table C-5: Trawl survey design and reported abundance estimates and CV for the 2011 survey.

Stratum	Area (km^2)	Number of tows	Abundance (t)	Abundance CV (%)	Mature abundance (t)
1	371	3	72	48	57
3	945	3	280	77	272
4	149	3	274	27	233
10	8	2	20 532	98	20 327
21	121	3	525	95	420
22	83	13	13 180	43	11 646
22A	107	4	1 012	57	981
23	93	12	1 143	68	1 118
24	305	17	3 231	65	3 155
25	438	3	51	53	49
Total	2 619	64	40 301	52	

Table C-6: Trawl survey design and reported abundance estimates and CV for the 2012 survey.

Stratum	Area (km^2)	Number of tows	Abundance (t)	Abundance CV (%)	Mature abundance (t)
1	371	3	1 476	86	1 456
3	945	3	96	22	81
4	149	3	171	54	155
21	121	3	121	88	114
22	192	12	1 259	36	1 231
23	93	7	4 154	52	4 003
24	305	14	14 858	41	14 424
25	438	4	3 908	52	3 760
Total	2 619	49	26 043	26.7	25 224

Table C-7: Trawl survey design and reported abundance estimates and CV for the 2013 survey. *, assumed stratum area sizes same as reported for 2012 survey. From Boyer et al. (2013).

Stratum	Area (km^2)*	Number of tows	Abundance (t)	Abundance CV (%)	Mature abundance (t)	Mature abundance CV (%)
1	371	3	329	97	292	98
3	945	3	162	51	150	52
4	149	3	185	19	154	15
9	199	4	460	63	420	61
21	121	3	334	92	304	92
22	192	10	391	28	374	28
23	93	7	586	48	570	49
24	305	22	7 053	81	6 938	82
25	438	3	12	40	12	40
Total	2 818	58	9 513	60.7	9 213	62.3

APPENDIX D: Acoustic surveys survey design, Challenger Plateau, 2005–13.

Table D-1: Acoustic survey design for 2005 survey

		Snapshot 1		Snapshot 2		Snapshot 3	
Stratum	Area (km2)	Transects	Tows	Transects	Tows	Transects	Tows
Twin Tits	3.9	4	2 (2)	5	2 (2)	4	0
Megabrick	3.9	4	2 (2)	5	1 (1)	4	0
Volcano	19.0	5	4 (0)	5	1 (1)	–	–
Dork	1.6	3	2 (1)	–	–	–	–
Central Flat	162.3	10	5 (5)	–	–	–	–
Pinnacles	137.6	–	–	8	1 (1)	–	–
Pinnacles Flat	55.6	–	–	–	–	6	0

Acoustic survey protocols, 2005 survey

Surveys of the Pinnacles and Westpac Bank hill features employed star transects with 3–5 per hill (after Doonan et al. 2003). The Central Flat and the Pinnacles Flat were surveyed with 6–10 random parallel transects (after Jolly & Hampton 1990). Transects were run at 5 knots on the hills and 6–10 knots on the flat, depending on weather conditions.

Table D-2: Acoustic survey design for 2006 survey.

		Snapshot 1		Snapshot 2		Snapshot 3		Snapshot 4	
Stratum	Area (km2)	Transects	Tows	Transects	Tows	Transects	Tows	Transects	Tows
Twin Tits	3.9	6	1	5	3	5	1	5	0
Megabrick	3.9	5	0	5	1	5	1	5	0
Volcano	8.0	5	0	5	1	5	0	–	–
Dork	1.6	4	2	5	3	5	0	–	–
Central Flat	162.3		1	–	–	–	–	–	–
Pinnacles Flat	83.0	8	1	–	6	0	–	6	0

Table D-3: Acoustic survey design for 2009 survey.

	Snapshot 1				Snapshot 2				Snapshot 3				Snapshot 4			
Stratum	Date	Type	No. of lines	Trawl no.	Date	Type	No. of lines	Trawl no.	Date	Type	No. of lines	Trawl no.	Date	Type	No. of lines	Trawl no.
Twin Tits	28/6	Star	5		30/6	Star	5	35	4/7	Star	6	71,72, 73, 78				
Mega brick	28/6	Star	5		1/7	Star	5		5/7	Star	6	74				
Volcano	29/6	Star	5		30/6	Star	4		6/7	Star	5	76				
Dork	29/6	Star	4		30/6	Star	4		6/7	Star	4	77				
22	27-28/6	Par	8		1/7	Par	8									
22 Adaptive	28/6	Par	5		2/7	Par	6		4/7	Par	7	69, 70	5/7	Par	8	
NE Comer	5/7	Par	8	75												

Mt Yetch	29/6	Star	2
SW Comer	5/7	Par	4

Acoustic survey protocols, 2009

Surveys of aggregations on the flat in Stratum 22 had two designs, one using randomly placed parallel transects 0.9 n. mile apart, with a minimum spacing of 0.25 n. mile and a maximum of 1.25 n. mile (two surveys, code “22” in Table D-3); and another using equal spaced parallel transects with random starting positions (four surveys, code “22 Adaptive” in Table D-3). The latter had transect spacings of 0.3 n. mile for surveys using east/west transects, and approximately 0.25 n. mile for those surveys using north/south transects. The code “adaptive” means that the aggregations’ extent were found first and the survey grid dynamically laid over the aggregation. Equally spaced parallel transects with random starting positions was used for the snapshots of aggregations in the north-east and south-west corners, with transect spacing of 0.3 and 0.5 n. mile respectively. All transects were run at speeds of 8–10 knots.

For aggregations on hills, a star design was used that had with the same angle between transects, but with the first transect at a randomly-chosen bearing. Transects were run at a speed of 5–7 knots.

Table D-4: Acoustic survey design for 2010 survey. –, no data.

								....Abundance (t)
Snapshot	242 spawning plume	Stratum 1 spawning plume	Twin Tits	Megabrick	Volcano	Dork	Total Flat	Total Hills
1	603 (67)	5 327 (29)	206 (33)	372 (41)	622 (12)	59 (38)		
2	0 (100)	2 550 (17)	103 (30)	604 (31)	140 (45)	91 (25)		
3	411 (50)	6 161 (21)	261 (21)	449 (42)	459 (28)	–		
4	164 (100)	8 044 (11)	–	582 (12)	938 (22)	–		
5	1 177 (34)	11 128 (26)	–	1 311 (29)	588 (67)	–		
6	531 (100)	6 345 (39)	–	–	–	–		
7	–	7 852 (18)	–	–	–	–		
Mean	429	5 614	190	664	549	75		
Total							6 043 (13)	1 478 (15)
CV1	62	24	28	33	39	30		
CV2	42	14	24	25	24	21		
Mean if all ORH	619	6 046	1 722	766	891	1 698	6 665	5 077
Excluded snapshots	6	5						

Table D-5: Acoustic survey design for 2011 survey.

Stratum	Snapshot	No. of transects	Transect direction
Twin Tits	#1	4	Radial
Twin Tits	#1	4	Radial
Megabrick	#1	4	Radial
Megabrick	#2	5	Radial
Megabrick	#3	5	Radial
Megabrick	#4	5	Radial
Volcano	#1	5	Radial
Volcano	#2	5	Radial
Dork	#1	4	Radial
Dork	#2	4	Radial
22	#1	10	E/W
22	#2A	8	N/S
22	#2B	8	N/S

22	#3	12	E/W
22	#4	4	E/W
24	#1	14	E/W

Table D-6: Acoustic survey design for 2012 survey. *, includes extensions.

Stratum	Snapshot	No. of transects	Transect direction
Twin Tits	#7	4	Radial
Twin Tits	#9	4	Radial
Twin Tits	#15	4	Radial
Megabrick	#6	4	Radial
Megabrick	#8	4	Radial
Megabrick	#14	4	Radial
23/24	#3B	11	N/S
23/24	#4	19	N/S
23/24	#11	8	E/W
23/24	#12	7	E/W
23/24	#16	11*	N/S

Table D-7: Acoustic survey design for 2013 survey. From Boyer et al. (2013). ID, species identification in marks.

Stratum	Number of snapshots	Number of tows for ID	Number of random tows for ID
Twin Tits	2	2	0
Megabrick	4	3	0
Volcano	3	1	0
Dork	1	1	0
22	2	0	5
23/1 (NW Spawning plume)	12	5	6
24/1 (NE Spawning plume)	8	2	6
25	1	1	0
Total	32	14	17

APPENDIX E: Challenger Plateau acoustic survey design simulation results.

Table E-1: Simulation analysis results showing the numbers of transects and snapshots needed to achieve predicted CV values (%) for acoustic surveys of the northeast orange roughy flat aggregation on Challenger Plateau. NA, unknown.

Target CV	Predicted CV	Number of snapshots	Number of transects	Total transects	Total survey time (days)
10	10	15	12	14	NA
15	14.6	14	6	8	2.3
15	15	10	8	10	1.9
15	15	8	10	12	1.7
15	14.6	7	12	14	NA
20	20.7	7	6	8	1.2
20	19.3	8	6	8	1.3
20	19.3	6	8	10	1.1
20	19.3	4	12	14	NA
25	27.4	12	2	4	1.5
25	26.3	13	2	4	1.6
25	25.3	14	2	4	1.7
25	24.5	15	2	4	1.8
25	27.4	4	6	8	0.7
25	24.5	5	6	8	0.8
25	27.4	3	8	10	0.6
25	23.7	4	8	10	0.8
25	24.5	3	10	12	0.6
25	27.4	2	12	14	NA
30	31.6	9	2	4	1.1
30	30	10	2	4	1.2
30	28.6	11	2	4	1.3
30	31.6	3	6	8	0.5
30	30	2	10	12	0.4

Table E-2: Simulation analysis results showing the numbers of transects and snapshots needed to achieve predicted CV values (%) for acoustic surveys of the Volcano aggregation on Challenger Plateau.

Target CV	Predicted CV	Number of snapshots	Number of transects	Total transects	Total survey time (days)
15	15.7	20	5	5	0.9
20	20.8	19	3	3	0.6
20	20.3	20	3	3	0.6
20	21	14	4	4	0.6
20	20.3	15	4	4	0.6
20	19.6	16	4	4	0.6
20	19	17	4	4	0.7
20	20.3	12	5	5	0.6
20	19.5	13	5	5	0.6
25	27.3	11	3	3	0.4
25	26.2	12	3	3	0.4
25	25.1	13	3	3	0.4
25	24.2	14	3	3	0.4
25	23.4	15	3	3	0.5
25	22.7	16	3	3	0.5
25	26.2	9	4	4	0.4
25	24.8	10	4	4	0.4
25	23.7	11	4	4	0.4
25	22.7	12	4	4	0.5
25	26.5	7	5	5	0.3
25	24.8	8	5	5	0.4
25	23.4	9	5	5	0.4
30	32	8	3	3	0.3
30	30.2	9	3	3	0.3
30	28.7	10	3	3	0.3
30	32	6	4	4	0.2
30	29.7	7	4	4	0.3
30	27.8	8	4	4	0.3
30	31.4	5	5	5	0.2
30	28.7	6	5	5	0.3
35	37	6	3	3	0.2
35	34.3	7	3	3	0.2
35	35.1	5	4	4	0.2
35	35.1	4	5	5	0.2
40	40.5	5	3	3	0.2
40	39.2	4	4	4	0.2
40	40.5	3	5	5	0.1

APPENDIX F: Macroscopic orange roughy gonad stages

Macroscopic orange roughy gonad stages used by NIWA in the 2005 and 2006 *Thomas Harrison* surveys. Gonad stages are based on those of Pankhurst et al. (1987), with the addition of a further partially spent stage and one of mature-resting fish (Clark et al. 2005).

Gonad stages for orange roughy

Females

1 **Immature**
Ovary clear or pink, small. No eggs visible.

2 **Early Maturation/Resting**
Ovary pink, small eggs visible (as orange dots).
Ovary small.

3 **Mature**
Orange, yolk filled eggs obvious (diameter 0.5-1.5 mm), filling the ovary.
Ovary quite large, bright orange.

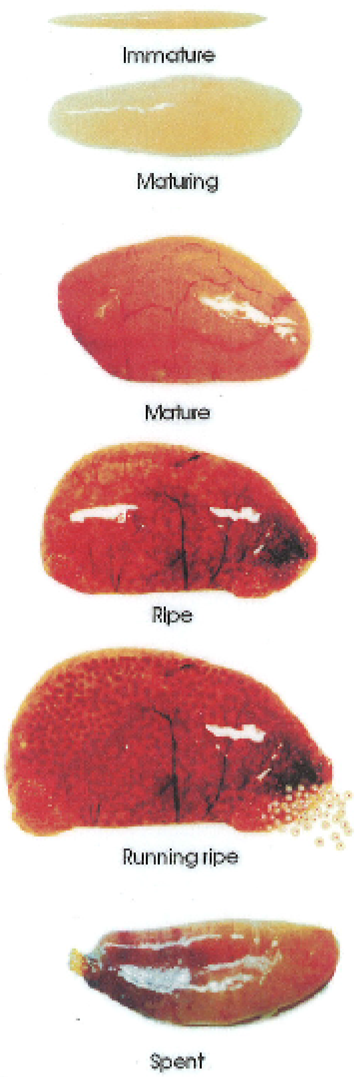
4 **Ripe**
Ovary large. Clear eggs are present (more than just one or two). Ovary has mottled orange appearance, with mixed orange and clear eggs.

5 **Running ripe**
Ovary large and thin walled, fragile.
Most eggs clear (hydrated).
Eggs flow freely when light pressure applied to the abdomen.

6 **Spent**
Ovary flaccid and bloody. Some residual eggs often present.

7 **Atretic**
Eggs yellow or blackish. Degenerating.

8 **Partially spent**
Ovary somewhat flaccid, slightly bloody.
Contains substantial numbers of clear freely flowing eggs, may have orange eggs also.
Some eggs lost.



Males

1 **Immature**
Testes small and threadlike when immature.
Hard and brown with no milt when resting.

Immature

2 **Early maturation/Resting**
Testes increased in size, but still small,
no milt expressible when cut.

Maturing

3 **Spermiated**
Viscous milt present when cut.
Testes can be relatively large.

Spermiated

4 **Spermiated, running**
Free-flowing milt. Testes shape and outline often not sharp like (3) because of milt. Flows freely with light pressure on the abdomen.

Running

5 **Spent**
Testes rather flaccid, and bloody.
Almost no milt is expressible.
Often has a 'glazed' brownish appearance.

Spent

8 **Partially spent**
Testes still quite large with some free flowing milt.
Brownish tinge, posterior end withered and bloody.

Partially spent