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New Zealand research relevant to the assessment of stocks of orange roughy

M. Clark, M-J. Roux & M. Cryer

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New Zealand research relevant to the assessment of stocks of orange roughy (*Hoplostethus atlanticus*)

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Contents

1. Purpose of paper

This paper updates the Scientific Committee on New Zealand research on stocks of orange roughy (*Hoplostethus atlanticus*) within the SPRFMO Area and, where relevant, straddling New Zealand's EEZ and the SPRFMO Area.

2. Historical summary

Orange roughy (*Hoplostethus atlanticus*) fisheries in the New Zealand region but outside New Zealand's EEZ developed in the mid-1980s on the southwest Challenger Plateau, and increased in the late 1980s and early-1990s on the Lord Howe Rise, Northwest Challenger Plateau and the Louisville Ridge. In the late 1990s, areas on the South Tasman Rise and West Norfolk Ridge were fished. Many of these fishing grounds are in the SPRFMO Area.

Fishing for deepwater commercial species outside the New Zealand EEZ is to a large extent focused on seamounts[1]" in this report (after Pitcher et al. 2007), where orange roughy (ORY, *Hoplostethus atlanticus*) and oreos (black oreo, BOE, *Allocyttus niger*, and smooth oreo, SSO, *Pseudocyttus maculatus*) often aggregate. In the general New Zealand region it is estimated that over 60% of orange roughy catch, and 50% of oreo catch has been taken off seamounts (O'Driscoll & Clark 2005). However, in many areas the populations were rapidly depleted and most orange roughy fisheries on seamounts declined (e.g., Clark 2009, Clark et al. 2010a, Pitcher et al. 2010). Seamounts are also widely regarded as supporting fragile habitats (Althaus et al. 2009, Clark et al. 2010b), and susceptible to both overfishing and benthic habitat damage. Designing and carrying out appropriate abundance surveys on seamounts can be lengthy, expensive, and complicated. In addition, fish stocks on seamounts may be small and localised and dedicated research surveys are typically not cost-effective. Catch-per-unit effort analyses can be useful, but have proven of limited statistical value given the variable nature of the fisheries outside the EEZ (Clark et al. 2010a).

Meta-analysis and associated predictive modelling, which examine trends in existing and historical seamount fisheries around New Zealand, together with information on their physical characteristics, have shown promise as a method for estimating original (unfished) orange roughy biomass on seamounts (Clark et al. 2001). Clark et al. (2001) compiled physical attributes and catch data of deepwater fisheries for 77 seamounts in the New Zealand region. Characteristics of location, depth, size, elevation above the seafloor, age, continental association, geological origin, distance offshore, distance from surrounding seamounts, and degree of spawning were defined for each seamount. These data were then regressed as independent variables against the minimum orange roughy population size estimated from the historical catch to investigate whether they could be useful predictors of likely long-term catch from newly found seamounts.

Region (related to latitude and continental/oceanic association), depth of the peak, and slope of the seamount were significant predictors of biomass. The method was applied to a section of the Louisville Ridge (Clark 2003), and more broadly to seamounts on the Lord Howe Rise, Northwest

[1] The term "seamount" includes knolls and hills with an elevation of 100 m or more

Challenger Plateau, West Norfolk Ridge, and Louisville Ridge (Clark et al. 2010a, SWG-09-INF-01, Penney 2010, SWG-09-DW-02).

Catch per unit effort analyses have been carried out for most of the New Zealand fisheries outside the EEZ (e.g., Clark & Anderson 2001, O'Driscoll (2003), Clark et al. (2010a) with limited success.

Figure 1 shows a recent application of this work (Penney 2010), with the trends in orange roughy catch (t), CPUE (t/tow, with standard errors) and estimated Maximum Constant Yield (MCY, a static interpretation of MSY), Maximum Average Yield (MAY, a dynamic interpretation of MSY), ½MB0, and 2002-2006 average catch reference levels from Clark et al. (2010a) shown for the main fishing areas.

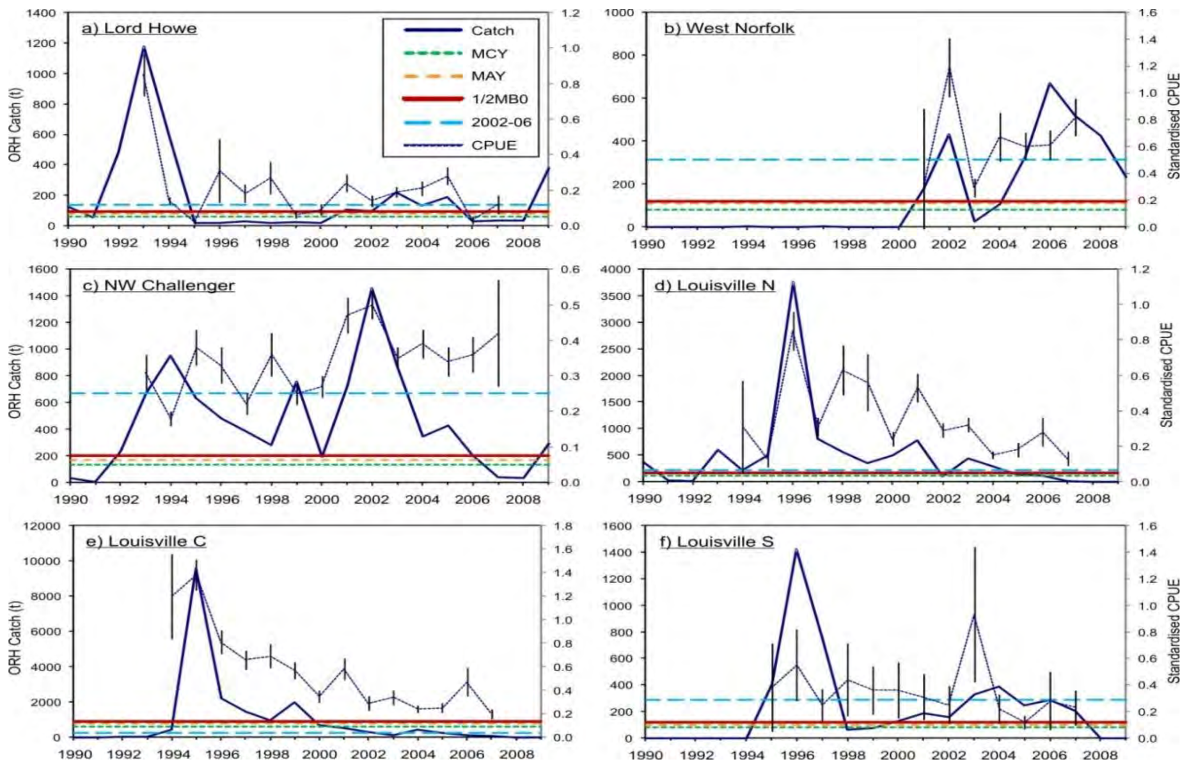


Figure 1: Summary of trends in total orange roughy catch (t), CPUE (t/tow, with standard errors) and estimated MCY, MAY, ½MB$_0$ and 2002–2006 average catch reference levels for each fishing area (from Penney 2010).

Penney (2010) concluded it was unlikely that fishery-independent surveys of low-productivity, high-seas bottom fishery resources would occur, so predictive, model-based approaches to estimate abundance would be required (citing the seamounts meta-analyses of Clark et al. (2001, 2010 as an example). He considered that short-term (2–5 year) sustainable fishing levels for orange roughy could lie somewhere between the yield estimates (MCY / MAY / MSY) for each area and recent average catches at that time. However, Penney (2010) noted that the 2002–2006 average catches exceed the estimated long-term sustainable yields (MCY, MAY or MSY) determined using predicted unfished biomass in each area for all SPRFMO areas analysed except the Central Louisville Ridge. He concluded that, for the longer-term, sustainable catch limits would probably be set close to the estimated MCY (total 1,040 t) or MAY (total 1,380 t) levels for each fishing area and below the average for the 2002–2006 reference period (1,852 t). The average catch of orange roughy by New Zealand vessels for the 8 years since the reference period has been 1,008 t.

3. Recent work to estimate initial stock size

Indices of catch per unit effort have proven poor indices of initial abundance for several orange roughy fisheries in the SPRFMO Area (section 2), prompting New Zealand to explore a different approach. This work builds on previous studies of seamount fisheries that used regression modelling to relate virgin biomass (estimated from the catch history for orange roughy) to physical characteristics of individual seamounts (section 2). A total of 120 seamounts throughout the New Zealand region (New Zealand's EEZ plus parts of the SPRFMO Area to the west of approximately 150^{o} W) were analysed, after selection by location and depth, as being suitable for orange roughy. A set of 23 physical characteristics for each seamount was compiled.

A Generalised Additive Modelling approach was used and, for the final model, the physical variables selected were latitude, summit depth, SST anomaly (an indication of frontal zones) and the level of spawning activity. Together these variables explained 83% of the deviance for the logarithm of virgin biomass. These physical variables are considered to be biologically sensible and are readily available for new seamounts from either exploratory fishing activities or widespread oceanographic data. Spawning level may initially be unknown, but this was the least important of the model variables, and contributed only 5% of the deviance.

Model fits were broadly aligned with actual catch values for most seamounts. Orange roughy biomass is estimated to be concentrated on seamount features of the Chatham Rise, with other major sites along the east coast of the North Island, Challenger Plateau, and Louisville Seamount Chain. Predicted abundance decreases rapidly in northern areas and matches the known distribution of orange roughy relatively well. This model indicates that low levels of biomass are expected on the West Norfolk Ridge. The model substantially underestimated biomass on three seamounts on the Chatham Rise, where it is thought that migration of orange roughy from other seamounts in the cluster, and from the nearby slope, may result in higher historical catch levels than the model is able to predict for a single seamount.

Overall the study suggests that the physical characteristics of a seamount can be informative as a general guide to the likely level of orange roughy biomass on a broad scale, although the predictions were sometimes very inaccurate for some individual seamounts. The study is currently in press (Clark et al. 2015).

4. Stock discrimination in the SPRFMO Area

4.1. Introduction

The National Institute of Water & Atmospheric Research (NIWA) undertook this research under contract to MPI. The overall project objective relevant to this area of work was specified as:

- *To evaluate options for assessing and managing orange roughy in the SPRFMO Convention Area, on the basis of stock structure or spatial criteria*

The key task of the work was to assess whether the existing working areas for stock assessment (Figure 2) remained appropriate and, if not, to identify suitable biological and/or management boundaries prior to conducting stock assessment (see section 5).

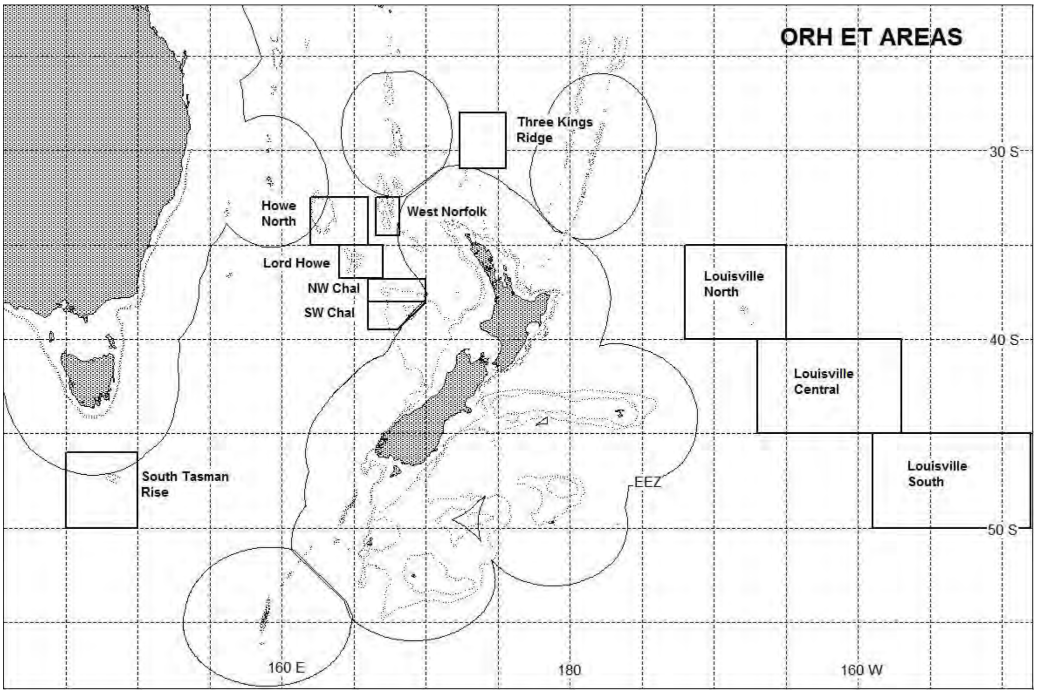


Figure 2: Existing stock areas used for fishery summaries by New Zealand for orange roughy in the SPRFMO Area and outside New Zealand's EEZ (after Clark 2008).

For the purpose of this review, "Stock" was defined as "an assessment or management unit, even if there is some mixing between areas" and included five key aspects (noted below with an indication of what new information has become available since the last review:

- Genetics (published reports and papers)
- Life history parameters (review age at maturity including new samples)
- Size structure (review new observer data by area and sex)
- Spawning time (review new observer data)
- Fishery distribution (review new catch and effort data extract for New Zealand vessels)

Other information was included if likely to improve stock discrimination:

- Otolith chemistry
- Morphometrics or meristics
- Oceanography

4.2. Genetics

Twelve key papers have been reviewed (with studies using allozymes, M-DNA, or microsatellites). However, no samples have been examined to date from the West Norfolk Ridge or Louisville Seamount Chain. In general, genetic techniques have shown contradictory results at different geographical and temporal scales with few unambiguous results that would suggest stock boundaries for SPRFMO fisheries. There is reasonable evidence from mitochondrial genomes for differences between orange roughy from the Lord Howe Rise and NW Challenger.

4.3. Life history parameters

Two studies have reported analyses of mean age and length at maturity, but they show contrasting results. One found differences for areas within the New Zealand EEZ (i.e., between Challenger Plateau fisheries and those on the Ritchie Bank, in the Bay of Plenty, on the Chatham Rise, and in the Puysegur area), but the other found no differences between fish from the Lord Howe Rise and Challenger Plateau. There were no samples from the West Norfolk Ridge or the Louisville Seamount Chain. Overall, these published studies do not provide usable evidence for stock boundaries for orange roughy fisheries in the SPRFMO area[2].

4.4. Size structure

A variety of published and new information was analysed, including regular observer data summaries (published by MPI) and observer length data collected between 1986 and 2014, mostly from tows conducted on seamounts. There is clear variability between areas, but generally a high level of consistency between years within an area. Orange roughy from the Lord Howe Rise are generally substantially larger than those from the NW Challenger Plateau, but other patterns are less consistent (Figure 3).

[2] A preliminary analysis of transition zone age estimates from a small sample (n=18) of fish from the central Pacific suggested fish from there had a high mean age (~37 years) relative to New Zealand fish (23-33 years).

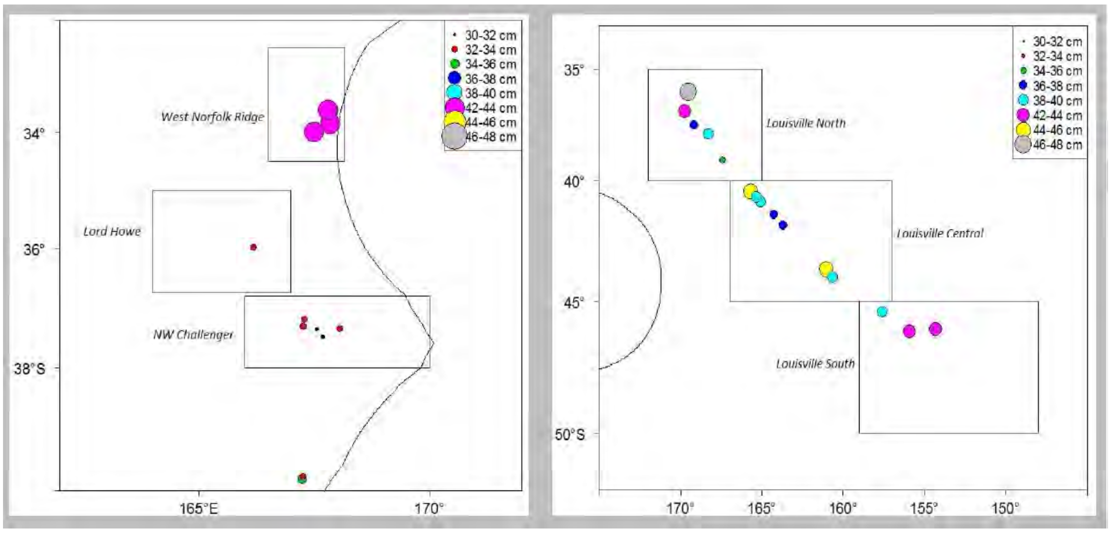


Figure 3: Plot of mean size of orange roughy taken in each of the existing sub-areas used for stock assessment purposes

4.5. Timing of peak spawning

Regular biological sampling and published summaries indicates that there are differences in the seasonal timing of peak spawning in the Lord Howe Rise and the Northwest Challenger fisheries (Anderson 2006, 2011). Peak spawning was estimated to occur between 20–30 June in the NW Challenger fishery, but substantially later, about 10–17 July, in the Lord Howe fishery. There were few samples from the West Norfolk Ridge and Louisville fisheries. The high likelihood of the presence of some stock structure on the Louisville Seamount Chain (because of its length extending for several hundred km) made that area a priority for more detailed analysis. That analysis indicated that spawning occurs earliest (in June) on the north of the Louisville Ridge and progressively later with increasing latitude (Figure 4). The distribution of seamounts with different timing of orange roughy spawning was used to assign non-sampled seamounts to the nearest spawning break, using an average distance hierarchical clustering algorithm.

4.6. Distribution of fisheries

There has been consistency over time in the location of orange roughy fisheries to the west of New Zealand in the SPRFMO Area and the locations, plus clustering of catch rates, match the existing divisions used for stock assessments on the Lord Howe Rise, NW Challenger Plateau, the West Norfolk Ridge, and the South Tasman Rise (Figure 5). However, catch and effort focussed on individual seamounts, is highly variable on the Louisville Ridge.

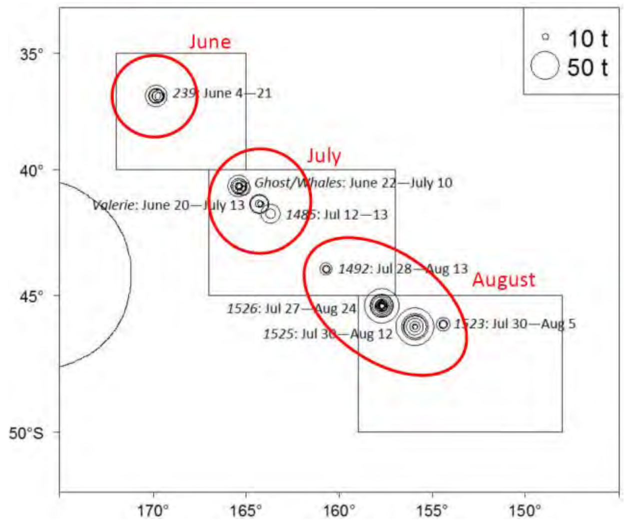


Figure 4: progression of timing of peak spawning of orange roughy along the Louisville Ridge.

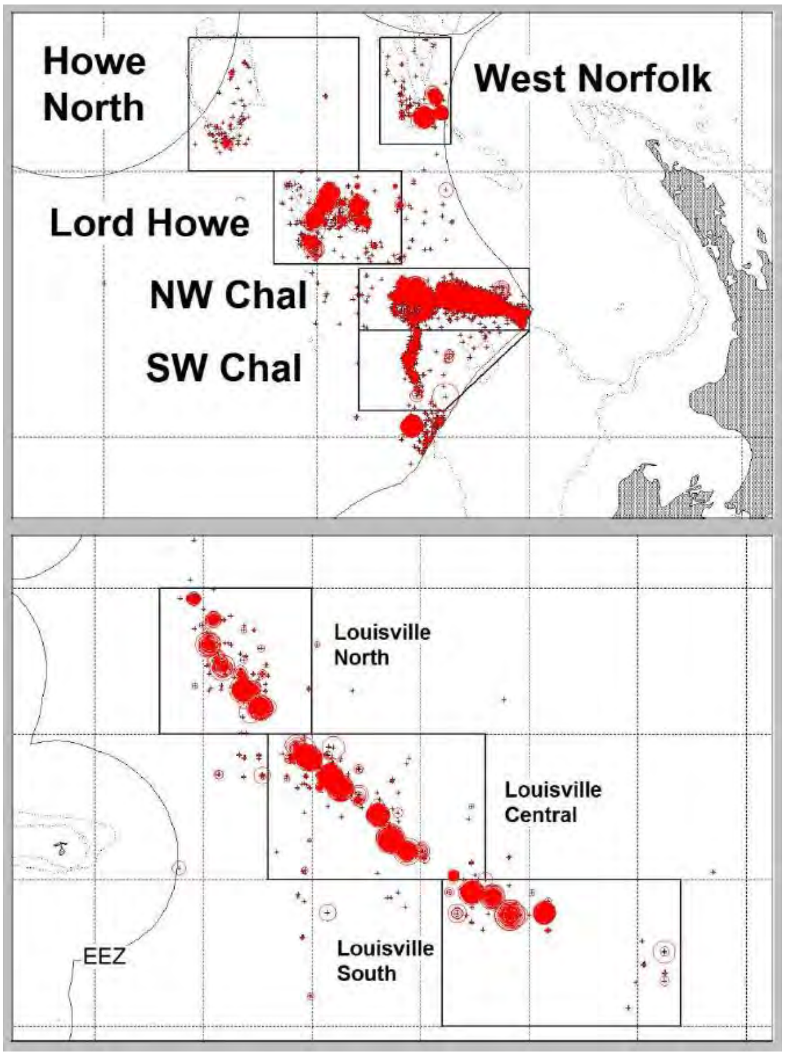


Figure 5: distribution of New Zealand bottom trawl fisheries for orange roughy (red bubbles) relative to the existing sub-areas used for stock assessment purposes (black boxes).

4.7. Other studies

A study of parasite fauna indicated there could be five Australian and three New Zealand stocks, but another suggested parasite load by itself may not be a viable tool for discriminating stocks. Overall, parasite analysis seems an uncertain approach to stock discrimination.

Morphological studies suggest multiple differences in some areas, but show inconsistent patterns and there is uncertainty around the extent to which differences stem from phenotypic expression caused by different environmental conditions in local areas or from stock differences.

Analysis of otolith microchemistry showed that strontium composition varied by latitude for fish sampled from off Australia, New Zealand and the Tasman Sea, and implied some spatial-structure to orange roughy populations.

4.8. Overall conclusions and recommendations

The work conducted to date suggests that the stock assessment and management areas for orange roughy in the SPRFMO Area to the west of New Zealand remain appropriate and need not be changed. Areas to the east of New Zealand, on the Louisville Ridge should be refined. Three areas, termed Louisville North, Central, and South, should be retained but the boundaries modified between North and Central components and Central and South components. (Figure xx).

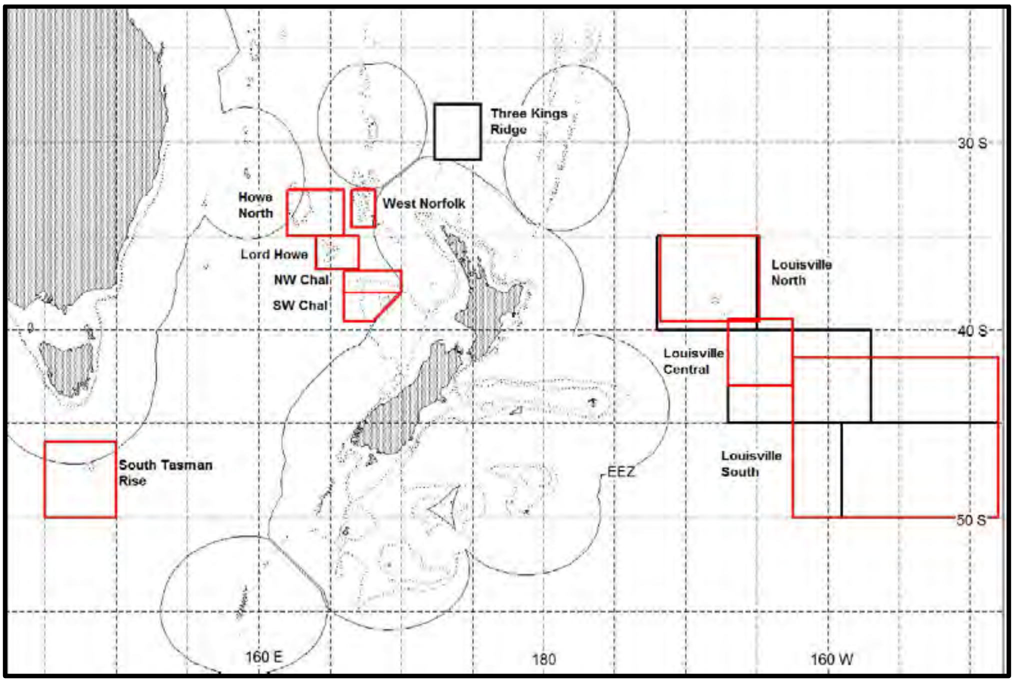


Figure 6: Comparison of new areas assumed for stock assessment purposes (in red) and previous areas (in black). Where both are coincident, red boxes overlie black boxes.

5. Progress on stock assessments in the SPRFMO Area.

5.1. Introduction

NIWA also undertook this research under contract to MPI. The overall project objective relevant to this area of work was specified as:

- *To apply a range of low-information stock assessments for each stock or management area for ET orange roughy in the SPRFMO Convention Area.*
- *Based on these management boundaries and catch-effort data, estimate abundance trends and undertake stock assessment using biomass dynamic modelling approaches*

Commercial catch and effort (CPUE) data are the only information source available to evaluate stock status of orange roughy in the SPRFMO Area. These data tend to be spatially and temporally dispersed and are thus uninformative as raw indicators of stock abundance (Clark et al. 2010).

Non-random temporal changes in the spatial distribution of fishing effort (i.e. fleet movements between subareas within the fishing grounds), can lead to important bias in the abundance trend or year effects (Walters 2003, Campbell 2004, Carruthers et al. 2011). This is because data from subareas actually fished in one year are not necessarily representative of changes in abundance in subareas that were not fished. Ignoring missing year-subareas data can cause 'hyper stability' if the fishery progressively moves to new subareas having higher fish densities and the total number of subareas that are fished decreases over time. Alternatively, 'hyper depletion' may occur if fishing activities spread across an increasing number of subareas having lower fish densities over time. Such bias phenomena are well established (Hilborn and Walters 1992) and have been demonstrated using real data or in simulation exercises (Walters 2003, Campbell 2004, Carruthers et al. 2010, 2011).

Table 1: Summary of recommendations from the stock discrimination analysis

Area	**Stock (sub-area for analysis)**	**Rationale**
Three Kings Ridge	No	Small fishery, no data
Lord Howe North	No	Small fishery, no data
Lord Howe	Yes	Separate stock (existing)
NW Challenger	Yes	Separate stock (existing)
SW Challenger (west flank)	No	No catch
SW Challenger (Westpac)	No	Straddling ORH 7A
West Norfolk	Yes	Separate stock (existing)
Louisville	Yes	Subdivision into North Subdivision into Central Subdivision into South (new boundaries)
South Tasman Rise	No	Straddling AFZ

A set of alternative methods, namely spatial CPUE analyses and cohort-aggregated biomass dynamics models, were applied and tested as potential means to evaluate stock status of orange roughy stocks in the SPRFMO Area, whilst minimizing bias. Six management areas or potential biological stocks are considered for assessment: the Lord Howe Rise; Northwest Challenger Plateau; West Norfolk Ridge; and the adjusted Louisville areas (North, Central and South) along the Louisville Ridge (Figure 6, Table 1).

5.2. Methods

Commercial catch and effort data from all fishing events that targeted or caught orange roughy outside the New Zealand EEZ within the SPRFMO Area boundaries between 1 October 1989 and 30 September 2014, were extracted from the fishery statistics database managed by the Ministry for Primary Industries (MPI, Replog no. 10009) and used for analyses. These data include all fishing effort from New Zealand vessels for that time period, and tow-by-tow information on fishing location, fishing patterns (i.e. trawl depth, speed, tow duration, etc.), estimated catch and vessel specifications. Standard error checking and grooming procedures were applied (see Clark et al. 2010 for details). The final dataset was restricted to bottom trawl effort (a small number (<1%) of tows that used midwater trawl gear were excluded). The NZ fishing year runs from 1 October to 30 September of the following year. Thus, the fishing year starting on 1 October 2000 and ending on 30 September 2001 is referred to as the 2001 fishing year. The term 'year' is used in reference to the NZ fishing year in this report, and distinguished from the calendar year (January 1st to December 31st).

The spatial CPUE approach assumes that overall population abundance is contributed from several strata or subareas *a* within the fishing grounds, which can be weighted to reflect their respective contributions to total abundance (Walters 2003). Thus for a given stock in year *y*:

$$CPUE_y = \sum_{a}^{subareas} cr_{a,y} w_a$$

The annual abundance index ($CPUE_y$) is calculated as the weighted sum (w_a= subarea weight) of subarea catch rates in that year ($cr_{a,y}$). Subarea weights w_a are deemed proportional to subarea-specific catchability q_a:

$$w_a \propto \frac{n_{a,y}}{N_y} \propto \frac{1}{q_a}$$

The approach assumes limited dispersal and/or slow mixing/redistribution of fish between subareas, which appears to be a valid assumption in slow-growing, deepwater fish stocks (Roux and Doonan 2015). Subareas need to be small enough to allow for random fishing within subareas boundaries (Walters 2003).

For orange roughy assessment, the hybrid GLM-imputation method described by Carruthers et al. (2011) is used to calculate standardized, spatial CPUE indices of abundance. This method consists in fitting an interaction GLM with year-subarea interactions and significant covariates to predict standardized CPUE in each year-subarea strata in which fishing occurred. Walters (2003) imputation methods are then used to estimate CPUE in year-subareas strata with no data.

Fishing activities for orange roughy can occur primarily on underwater topographic features (UTFs) (e.g. Louivilles stocks), on the continental slope (i.e. Lord Howe Rise), or both (i.e. Northwest Challenger Plateau and West Norfolk Ridge fisheries). Subareas were defined by first assigning individual tows to UTFs (where UTF fishing occurred) and/or by performing hierarchical distance clustering on non-UTF tows.

UTF data were extracted from the Seamounts (SEAMOUNT V2) database managed by NIWA (Rowden et al. 2008). Only UTFs within the orange roughy distribution range (summit depth between 500-1500 m) were retained for analyses. Three criteria were used to assign individual tows to UTFs: 1)tTow start position (at the vessel) relative to UTF summit position; 2) UTF category, as distinguished by UTF elevation (100-499 m = hill; 500-999 m = knoll; ≥ 1000 m= seamount); and 3) tow duration. Tows were assigned to UTFs if their duration was equivalent or less than 30 minutes and their start position was located within 3 nm of the summit position (hills); 5 nm (knolls) and 8 nm (seamounts). For the Louisville areas, the third criteria (tow duration) was ignored and all tows were assigned to the nearest seamount by minimizing the distance between tow start positions and summit positions. A few tows located further than 50 nm from the nearest summit position were excluded from the analyses.

Hierarchical cluster analyses consisted in calculating the average distance between tows that were not assigned to a seamount, and applying the average linkage clustering algorithm (Sneath and Sokal 1973) to the distance matrix in order to group tows into subareas.

In all management areas, spatial CPUE analyses were restricted to catch and effort data contributed from subareas that had a minimum of 50 tows over the entire time series, and to fishing years in which total effort was at least 20 tows. A core vessels selection was performed that retained only data from vessels that fished for a minimum of 2 years with at least 5 tows per year.

A lognormal, interaction GLM (Generalised Linear Model (Chambers & Hastie 1991)) was fitted to log-transformed, non-zero catch-effort data (t per tow). A forward stepwise multiple regression procedure implemented in R code (R Development Core Team 2015) was used to select among explanatory variables offered in the saturated model (Table 1). *Fishing year* was included as the first term and the algorithm added variables based on changes in residual deviance. Variables were added to the model up to a 1% improvement in explained residual deviance. Selected variables (hereinafter referred to as *significant covariates*) were included in the final model, along with fishing year, subarea, and the fishing year-subarea interaction term. The explanatory power of the final model was described by the reduction in residual deviance relative to the null deviance defined by a simple intercept model (R^2).

Table 2. Summary of explanatory variables offered in the saturated interaction GLM CPUE models. Continuous variables were offered as third order polynomials.

Variable	Type	Description
fyear	Factor	Fishing year (Oct 1-Sep 30)
subarea	Factor	Subareas within the fishing grounds/management area
fyear:subarea	Interaction term	year-subarea interaction
vessel	Factor	Unique vessel identifier
target sp.	Factor	Target species as reported on a tow by tow basis
month	Factor	Calendar month
day of year	Continuous	Day of calendar year
fweek	Factor	Fishing week (relative to fyear)
trawl.depth	Continuous	Average trawl depth (m)
trawl.speed	Continuous	Average trawl speed (kn)
tow duration	Continuous	Average tow duration (in hours)

Model fits were investigated using standard residuals diagnostics (i.e., plots of residuals against fitted values and quantiles of the standard normal distribution; plots of fitted versus observed values; and residuals density plots). This was done to check for departures from the regression assumptions of homoscedasticity and normality of errors in log-space (i.e., log-normal errors). Year effects and year-subarea interaction effects were extracted from the final model and used to predict standardised CPUE values for year-subareas strata in which fishing occurred.

For each stock/management area, a space-time table of standardized catch rates was constructed that contained a row for every fishing year and a column for each subarea. A minimum effort threshold (at least 5 tows per year) was applied, meaning that for a given subarea, standardized catch rates predicted for years with less than 5 tows were not considered representative of local abundance and were included in the table as missing data. Missing year-subarea data were populated using Walters (2003) imputation methods. The following imputation criteria were applied to all stocks/management areas:

- Backward imputation (prior to the start of the fishery) was carried out by assigning the maximum catch rate recorded during the first three years of fishing to earlier years.
- Forward imputation (following the cessation of fishing) was carried out by assigning the mean catch rate from the last three years of data to subsequent years.
- Linear interpolation was used to populate missing data in-between adjacent years.

The CPUE time series within each of the subareas were normalised to have a geometric mean of 1 (canonical form (Francis 1999)), weighted, and the results were summed across subareas in each year to derive the annual indices. An equal weight (w_a =1) was applied to all subareas during the initial runs, meaning that subareas were assumed to have constant catchability (or equally contribute to total stock abundance).

A bootstrap re-sampling procedure (with replacement) was applied to the selected catch-effort data (including significant covariates) in order to estimate variability in the annual indices and calculate an annual coefficient of variation (cv). GLM standardisation, imputation, subareas-weighting and summation procedures were iterated 500 times for this purpose.

A cohort-aggregated biomass dynamics model (BDM) was fitted to the catch histories and standardized spatial CPUE indices for each stock. The model describes changes in exploited biomass (B) over time *t* in response to a particular harvest regime (catch C) and according to the production function g():

$$B_{t+1} = B_t + g(B_t) - C_t$$

The generalized production function described by McAllister et al. (2000) is assumed, which consists in a hybrid model that combines the logistic function (Shaefer 1954, 1957) with the Fletcher (1978) model:

$$g(B_t) = \begin{cases} rB_t\left(1 - \dfrac{B_t}{2B_{MSY}}\right) & B_t \leq B_{MSY} \\ \gamma m\left(\dfrac{B_t}{K} - \left(\dfrac{B_t}{K}\right)^n\right) & B_t > B_{MSY} \end{cases}$$

$$\gamma = \frac{n^{(n/(n-1))}}{n-1}$$

$$m = MSY$$

The function has three parameters: the maximum intrinsic growth rate r (corresponding to the maximum rate of population increase as the biomass approaches zero); the arithmetic mean biomass at unexploited equilibrium or carrying capacity K, and a shape parameter *n* that defines the inflection point of the production function relative to K. In the deterministic case, useful reference points can be obtained from the parameter estimates:

$$MSY = \frac{rB_{MSY}}{2}$$

$$B_{MSY} = K\left(\frac{1}{n}\right)^{1/(n-1)}$$

The shape parameter *n* determines the value of B_{MSY}/K and is most intuitively understood via the parameter $\varphi = B_{MSY}/K$. A symmetric production function, for example, has $n = 2$ and $\varphi = 0.5$. During initial runs, φ was fixed on input and given a value of 0.25, meaning that B_{MSY} was assumed to occur at 25% of the biomass at unexploited equilibrium *K* (whereby $K \approx B_0$).

Parameters were estimated within a Bayesian state-space framework that re-formulates the process equation to include a time-dependent, multiplicative error term (the process error, $\varepsilon_{[p]}$) and a parallel observation process that relates an abundance index *I* to the unobserved biomass state with some degree of error (the observation error, $\varepsilon_{[o]}$), according to an estimated catchability scalar *q*:

$$B_{t+1} = (B_t + g(B_t) - C_t).\,\varepsilon_{[p]t}$$

$$I_{it} = (q_i B_t).\,\varepsilon_{[o]it}$$

where the *i* subscript refers to the index. The inclusion of process error allows the model to account for inter-annual variability in stock biomass due to temporal changes in biological processes that are not explicitly modelled (e.g., variability in recruitment, growth or the rate of natural mortality). The model therefore partitions the fishery variability in a way that allows stochastic components of the dynamics to be included when the stock is projected forward in time. This is important for precautionary or risk based management (Harwood and Stokes 2003).

The catchability scalar was calculated as a "nuisance" parameter, meaning that it was derived analytically as the maximum posterior density (MPD) estimate, assuming a uniform prior on the natural scale (Bull et al. 2012). A uniform prior was assumed for *ln(K)*, which is proportional to *1/K* and therefore gives lower weight to higher *K* values. This is both intuitively appealing and improves performance of the estimator by discouraging extremely large *K* values (McAllister 2013). Because for this class of model *r* and *K* are highly correlated, estimation is helped through the use of an informative prior for the intrinsic growth. An informative log-normal prior for *r* was constructed from available life-history data using methods described in McAllister et al. (2001). This involved estimating *r* numerically based on iterated solving of the Euler-Lotka equation (x1000 iterations). Life history data used to construct an *r* prior for orange roughy stocks are summarized in table 2. The priors for *r* and *K* were therefore:

$$r \sim LN(\mu_r, \sigma_r^2)$$

$$\ln(K) \sim U(3.0{,}30.0)$$

The upper and lower bounds for *ln(K)* were chosen subjectively so as to not impinge on the parameter space explored during estimation.

Table 3. Orange roughy life history data used in the construction of an informative prior for *r* in BDM modelling. All parameters values were given a cv of 0.2.

Life history trait	Parameter	Value	Reference(s)
Maximum age (Amax)	A_{max}	91	Andrews et al. 2009
Natural Mortality	*M*	0.045	Doonan et al. 2015, Doonan 1994
Age at maturity	A_{mat}	38	Doonan et al. 2015
Growth (von Bertalanffy)	L_{inf}	37.63	Doonan et al. 2015
	k	0.065	
	t_0	-0.5	
Length-weight	*a*	0.0921	Doonan et al. 2015
	b	2.71	
Recruitement steepness (Beverton and Holt)	*h*	0.75	Doonan et al. 2015, Francis 1992

Bayesian estimation of parameters was achieved in R using the rstan package, which implements a Markov Chain Monte Carlo routine (Stan Development Team 2014). For preliminary runs, process error was fixed on input and given a value of 0.10 in all stocks. Annual coefficients of variations calculated for the standardized spatial CPUE abundance indices were included as observation error. Model convergence was assessed by comparing posterior distributions of the estimated parameters (*r*, *K*, and q) and plots of cumulative parameters values among chains. Whether or not the abundance indices were informative in the BDM process was assessed by conducting separate model runs with and without the index and comparing the posterior distributions for *K* and current status between the runs.

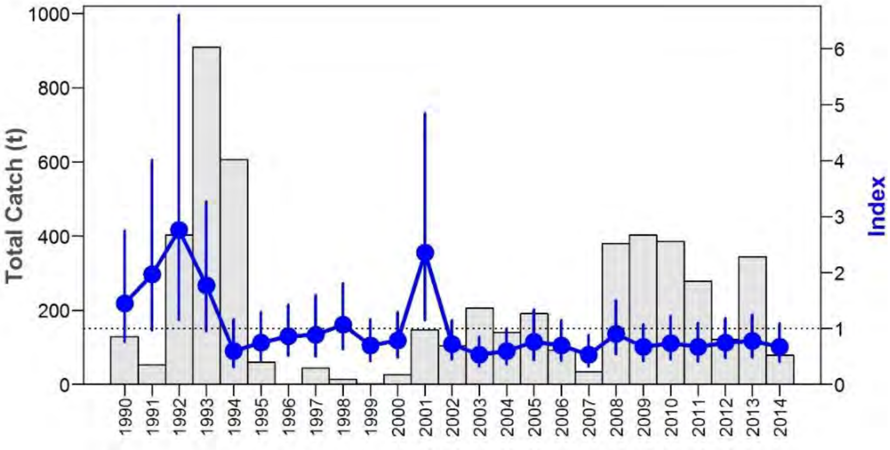
5.3. Preliminary results

Standardized, spatial CPUE abundance indices are summarized for each stock in Table 3, and plotted together with catch series in Figure 2. Stock-by-stock information and detailed results are discussed in the following sections.

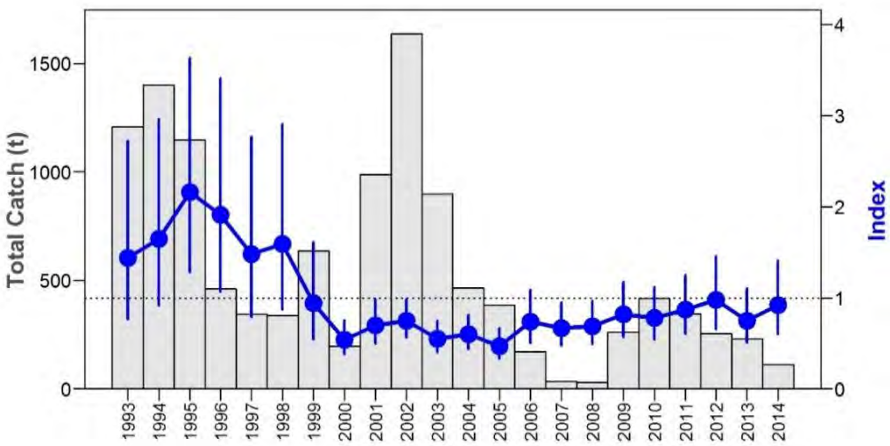
Table 4. Lognormal, standardized annual spatial CPUE abundance indices and coefficients of variation (cv) for orange roughy stocks in the SPRFMO Area.

Fishing year	LHR		NWC		WNR		LOUIS-N		LOUIS-C		LOUIS-S	
	index	cv	index	cv	index	cv	index	cv	index	cv	index	cv
1989-90	1.45	0.51	-	-	-	-	-	-	-	-	-	-
1990-91	1.97	0.66	-	-	-	-	-	-	-	-	-	-
1991-92	2.76	1.14	-	-	-	-	-	-	-	-	-	-
1992-93	1.77	0.46	1.44	0.50	-	-	-	-	-	-	-	-
1993-94	0.60	0.56	1.65	0.41	-	-	-	-	4.76	0.31	-	-
1994-95	0.75	0.35	2.16	0.31	-	-	1.98	0.22	2.69	0.16	2.73	0.51
1995-96	0.86	0.30	1.91	0.40	-	-	1.76	0.22	0.88	0.22	2.12	0.54
1996-97	0.89	0.41	1.48	0.48	-	-	0.87	0.26	0.95	0.20	0.72	0.63
1997-98	1.07	0.32	1.59	0.44	-	-	1.47	0.29	0.87	0.24	2.08	0.57
1998-99	0.70	0.30	0.94	0.34	-	-	1.49	0.24	0.63	0.20	1.85	0.78
1999-00	0.79	0.28	0.54	0.12	-	-	0.69	0.27	0.76	0.24	1.78	0.50
2000-01	2.36	0.68	0.70	0.12	-	-	1.08	0.22	0.54	0.21	1.32	0.41
2001-02	0.72	0.25	0.75	0.08	2.70	0.24	1.19	0.21	0.50	0.27	0.95	0.56
2002-03	0.53	0.26	0.55	0.10	1.58	0.26	0.69	0.17	0.50	0.36	0.75	0.73
2003-04	0.60	0.30	0.60	0.10	1.44	0.31	0.53	0.15	0.48	0.26	0.49	0.36
2004-05	0.76	0.38	0.47	0.13	1.18	0.20	0.62	0.18	0.51	0.24	0.23	0.27
2005-06	0.70	0.28	0.74	0.16	0.95	0.25	0.84	0.14	0.98	0.34	0.32	0.49
2006-07	0.53	0.31	0.67	0.13	0.76	0.23	0.60	0.18	0.67	0.39	0.40	0.33
2007-08	0.90	0.30	0.69	0.12	0.91	0.29	-	-	-	-	-	-
2008-09	0.67	0.25	0.82	0.14	0.58	0.30	-	-	-	-	-	-
2009-10	0.74	0.29	0.78	0.14	0.67	0.50	0.78	0.18	0.86	0.19	0.55	0.34
2010-11	0.67	0.28	0.87	0.14	0.24	0.58	0.97	0.28	0.50	0.28	0.55	0.43
2011-12	0.75	0.24	0.98	0.17	0.43	0.43	0.79	0.18	0.68	0.26	0.32	0.29
2012-13	0.78	0.25	0.75	0.16	0.55	0.49	0.65	0.14	0.44	0.24	0.39	0.32
2013-14	0.67	0.27	0.92	0.20	-	-	-	-	0.81	0.27	0.44	0.42

A) Lord Howe Rise



B) Northwest Challenger Plateau



C) West Norfolk Ridge

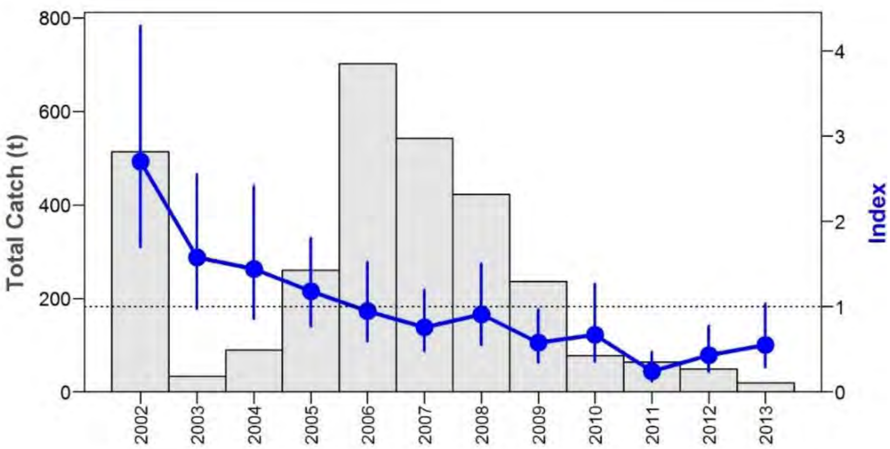
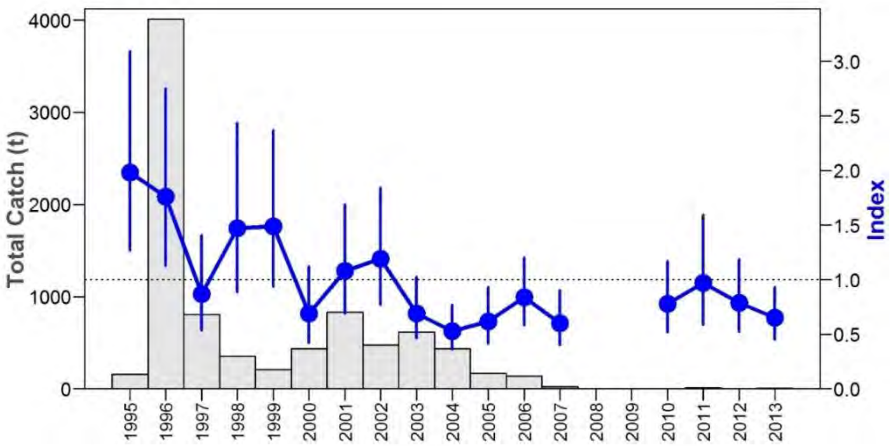
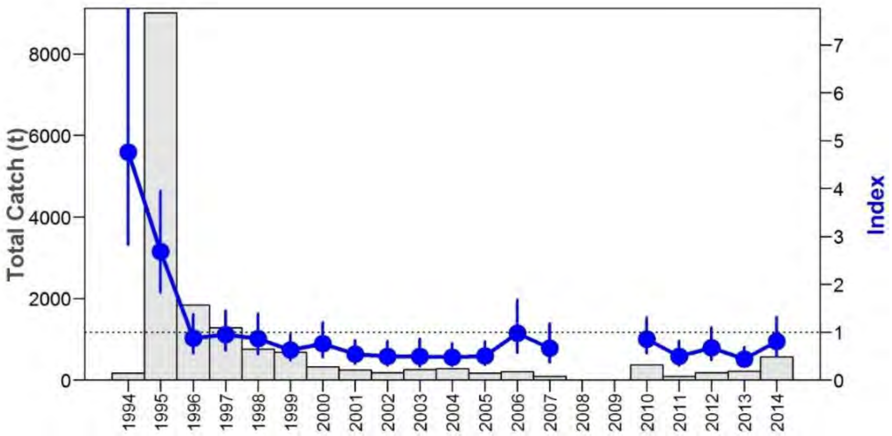


Figure 7. Catch series (grey bars, left axes) and normalised, standardized spatial CPUE abundance indices (blue line/full circles, right axes) for orange roughy stocks within the SPRFMO Area. Error bars are ±1 standard deviation.

D) Louisville-North



E) Louisville-Central



F) Louisville-South

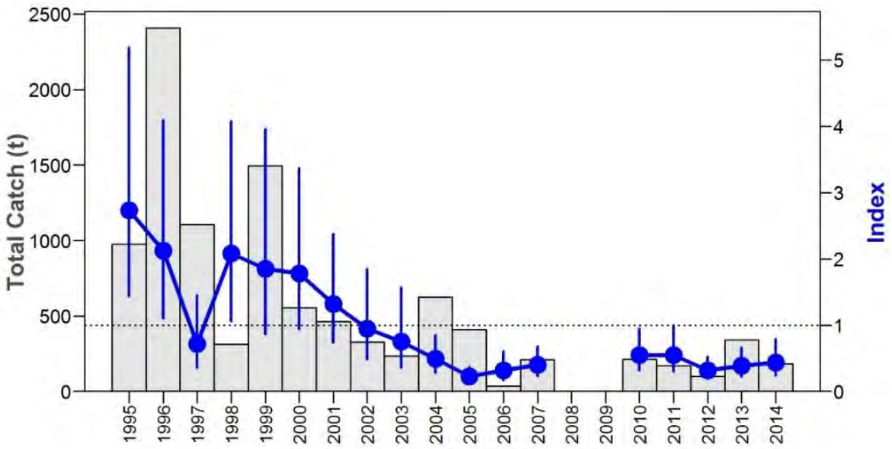


Figure 7 (continued). Catch series (grey bars, left axes) and normalised, standardized spatial CPUE abundance indices (blue line/full circles, right axes) for orange roughy stocks within the SPRFMO Area. Error bars are ±1 standard deviation.

Spatial CPUE analyses – Lord Howe Rise

The final dataset for the Lord Howe Rise area consisted in 2578 tows contributed from five subareas between 1990 and 2014 (Figure 3). Vessel, fishing week, month and trawl depth were selected as significant covariates in the interaction-GLM for the stock, which explained a 23% reduction in residual deviance (Table 4). Time series of standardized and imputed CPUE indices by subareas (space-time table) are presented in Table 5. The final index suggests relative stability in stock abundance since the late 1990s/early-2000s (Table 3, Figure 2A). An exception to this trend is an improbably high peak in 2001, which appears to result from a single (of few) large catch events in subarea E in that year (Table 5).

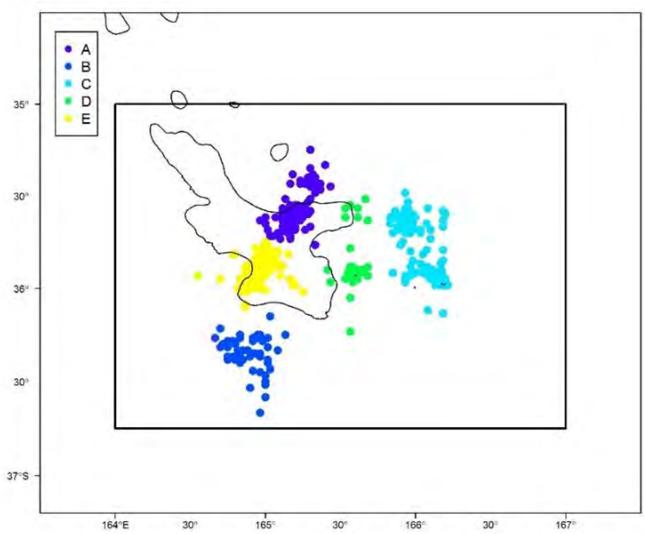


Figure 8. Lord Howe Rise management area, showing total effort (n=2578 tows=coloured dots) by subareas (n=5) considered for spatial CPUE analyses of orange roughy.

Table 5. Summary of the final lognormal, interaction-GLM model for catch rates of orange roughy in the Lord Howe Rise area. df=degrees of freedom; Resid=residual.

	df	Deviance	Resid. df	Resid. Dev	R2
Null Model			2577	14020.19	
fyear	23	1008.01	2554	13012.18	7.19
subarea	4	307.97	2550	12704.21	9.39
vessel	23	711.53	2527	11992.68	14.46
fweek	50	663.87	2477	11328.82	19.20
month	9	138.77	2468	11190.05	20.19
poly(trawl.depth, 3)	3	84.17	2465	11105.88	20.79
fyear:subarea	56	312.12	2409	10793.75	23.01

Table 6. Space-time table of standardized and imputed catch rates of orange roughy on the Lord Howe Rise. Columns are subareas defined based on hierarchical distance clustering of tows (See Figure 3 for subareas location).

	A	B	C	D	E
1990	1.56	0.47	3.39	1.59	2.32
1991	1.56	0.49	3.39	1.59	5.63
1992	1.56	2.25	3.39	1.59	8.93
1993	1.56	0.08	3.39	1.59	4.74
1994	0.37	1.16	0.77	1.13	0.42
1995	1.12	1.16	0.94	1.13	0.43
1996	1.61	1.16	1.17	1.13	0.43
1997	1.61	1.16	1.40	1.13	0.43
1998	1.61	1.16	2.51	1.13	0.43
1999	1.61	1.16	0.18	1.13	0.44
2000	1.61	1.16	0.28	1.13	0.89
2001	2.10	1.16	1.77	1.13	8.99
2002	0.41	1.16	0.85	1.13	1.05
2003	0.43	1.16	0.64	0.67	0.52
2004	0.52	1.16	0.58	0.78	0.78
2005	0.82	1.16	1.23	0.90	0.78
2006	0.55	1.16	1.23	0.78	0.78
2007	0.41	1.16	0.25	0.78	0.78
2008	2.63	1.16	0.44	0.78	0.78
2009	0.94	1.16	0.63	0.78	0.78
2010	1.36	1.16	0.67	0.78	0.78
2011	0.90	1.16	0.71	0.78	0.78
2012	0.86	1.16	1.20	0.78	0.78
2013	0.62	1.16	1.69	0.78	0.78
2014	0.67	1.16	0.90	0.78	0.78

Spatial CPUE analyses – Northwest Challenger Plateau

The final dataset for Northwest Challenger orange roughy consisted in 10302 tows contributed from twelve subareas (five UTFs and seven locations on the slope) between 1993 and 2014 (Figure 4). Data from two adjacent UTFs (no. 562 and no.563) were pooled for analyses due to low sample sizes.

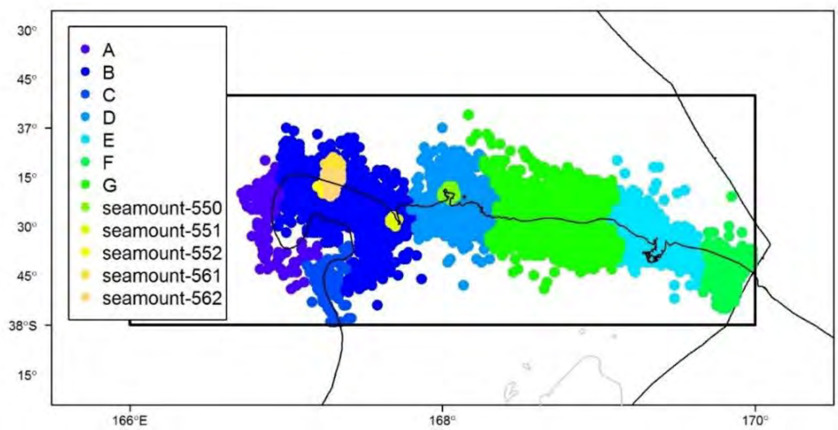


Figure 9. Northwest Challenger Plateau management area, showing total effort (n=10302 tows=coloured dots) by subareas (n=12) considered for spatial CPUE analyses of orange roughy.

Vessel, fishing week and tow duration were selected as significant covariates in the interaction-GLM for the stock, which explained a 24% reduction in residual deviance (Table 6). Time series of standardized and imputed CPUE indices by subareas are presented in Table 7. The final index shows higher and highly variable relative abundance from 1993 to 1998, followed by a brief decline in 1999-2000, and relatively stable abundance since 2001, with a slight increase over the last 5-6 years (Table 3, Figure 2B).

Table 7. Summary of the final lognormal, interaction-GLM model for catch rates of orange roughy in the Northwest Challenger area. df=degrees of freedom; Resid=residual.

	df	Deviance	Resid. df	Resid. Dev	R2
NULL model			10301	28022.96	
fyear	21	1009.26	10280	27013.7	3.60
sub-area	11	628.96	10269	26384.74	5.85
vessel	33	2290.18	10236	24094.56	14.02
fweek	52	890.75	10184	23203.8	17.20
poly(duration, 3)	3	596.48	10181	22607.33	19.33
fyear:sub-area	185	1367.28	9996	21240.05	24.20

Table 8. Space-time table of standardized and imputed catch rates of orange roughy on the Northwest Challenger Plateau. Columns are subareas defined by assigning tows to UTFs and performing hierarchical distance clustering on non-UTF tows (See Figure 4 for subareas location).

	A	B	C	D	E	F	G	UTF-550	UTF-551	UTF-552	UTF-561	UTF-562
1993	1.24	0.58	0.98	0.20	18.37	1.19	0.30	0.45	1.91	0.95	0.22	0.38
1994	1.24	1.17	0.98	0.78	18.37	1.19	0.51	0.63	0.52	0.82	3.44	1.05
1995	1.24	2.04	0.98	2.89	18.37	1.19	0.67	3.37	0.52	5.17	3.41	0.26
1996	0.25	0.70	0.98	1.59	18.37	1.19	0.67	0.16	0.52	7.83	1.90	1.42
1997	0.42	0.58	0.98	0.29	18.37	1.19	0.67	0.90	0.52	0.51	2.14	0.90
1998	0.42	1.11	0.98	1.39	18.37	1.19	0.67	2.33	0.52	0.53	1.19	0.90
1999	0.59	0.59	0.98	1.03	9.28	1.19	0.84	0.54	0.51	0.43	0.54	0.90
2000	0.92	1.04	0.98	0.68	0.19	1.19	1.08	0.63	1.21	0.46	0.79	0.90
2001	1.24	2.31	0.98	1.19	0.21	0.70	1.60	0.81	1.91	0.22	1.03	0.90
2002	1.66	1.31	0.98	0.98	0.30	0.98	2.08	1.74	1.21	0.70	1.06	0.90
2003	1.09	0.95	0.83	0.61	0.20	1.19	1.31	1.36	1.21	0.80	0.22	0.37
2004	0.95	1.62	0.66	0.73	0.20	1.35	1.12	1.35	1.21	1.06	0.67	0.31
2005	0.69	1.24	0.94	0.50	0.18	1.17	1.20	0.67	1.21	0.17	0.47	0.25
2006	0.99	1.24	1.23	0.55	0.24	1.03	1.17	2.03	1.21	1.17	1.03	1.94
2007	1.36	0.62	1.08	0.74	0.27	1.53	1.10	0.41	1.21	1.17	1.03	1.97
2008	1.36	0.62	1.08	1.25	0.20	0.92	1.10	0.92	1.21	1.17	1.03	1.97
2009	1.36	0.62	1.08	1.76	0.13	0.92	1.10	1.41	1.21	2.16	1.58	1.97
2010	1.73	1.39	1.08	1.38	0.47	0.31	1.03	0.95	1.21	1.37	1.62	2.01
2011	1.36	1.61	1.08	2.70	0.29	0.74	1.62	2.04	1.21	0.60	0.99	1.97
2012	1.36	0.67	1.08	1.97	0.67	1.17	1.32	1.21	1.21	2.09	3.46	1.97
2013	1.36	1.33	1.08	1.26	0.48	0.74	1.32	0.65	1.21	2.16	0.45	1.97
2014	1.36	0.78	1.08	2.29	0.48	0.74	1.32	3.12	1.21	2.13	0.56	1.97

Spatial CPUE analyses – West Norfolk Ridge

The final dataset for West Norfolk Ridge orange roughy consisted in 1420 tows contributed from five subareas (two UTFs and three locations on the slope) between 2002 and 2013 (Figure 5). Fishing week and variables related to fishing patterns (trawl depth, trawl speed and tow duration) were selected as significant covariates in the interaction-GLM for the stock, which explained a 21% reduction in residual deviance (Table 8). Time series of standardized and imputed CPUE indices by subareas are presented in Table 9. The final index suggests an overall decline in the relative abundance of orange roughy on the West Norfolk Ridge during the assessment period (Table 3, Figure 2c). No fishing took place on the ridge in 2014 (Appendix 1).

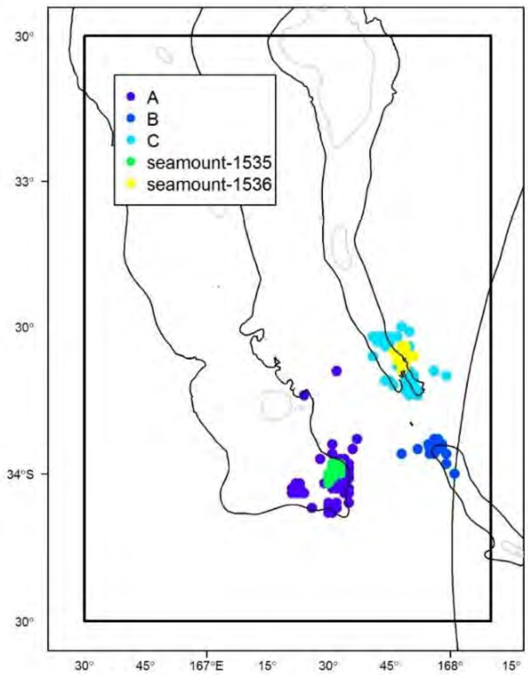


Figure 10. West Norfolk Ridge area showing total effort (n=1420 tows=coloured dots) by subareas (n=5) considered for spatial CPUE analyses of orange roughy.

Table 9. Summary of the final lognormal, interaction-GLM model for catch rates of orange roughy in the West Norfolk Ridge area. df=degrees of freedom; Resid=residual.

	df	Deviance	Resid. df	Resid. Dev	R2
Null Model			1419	6895.92	
fyear	11	442.61	1408	6453.32	6.42
subarea	4	68	1404	6385.31	7.40
fweek	45	464.75	1359	5920.56	14.14
poly(trawl.depth, 3)	3	117.25	1356	5803.31	15.84
poly(speed, 3)	3	60.53	1353	5742.79	16.72
poly(duration, 3)	3	20.94	1350	5721.85	17.03
fyear:sub-area	40	263.93	1310	5457.92	20.85

Table 10. Space-time table of standardized and imputed catch rates of orange roughy on the West Norfolk Ridge. Columns are subareas defined by assigning tows to UTFs and performing hierarchical distance clustering on non-UTF tows (See Figure 5 for subareas location).

	A	B	C	UTF-1535	UTF-1536
2002	4.38	6.42	2.41	3.11	2.65
2003	0.70	2.28	2.41	3.11	2.65
2004	1.39	0.56	2.41	3.11	2.65
2005	0.88	0.67	1.00	3.11	2.65
2006	1.23	0.94	0.82	3.11	0.62
2007	0.97	1.33	1.18	0.81	1.04
2008	0.62	2.13	1.78	1.02	0.86
2009	0.53	0.57	2.37	0.18	0.43
2010	1.80	0.40	0.57	0.76	1.21
2011	0.68	0.23	0.20	0.12	0.49
2012	0.48	1.54	0.39	0.25	0.35
2013	1.15	0.88	0.39	1.06	0.42

Spatial CPUE analyses – Louisville North

The final dataset for orange roughy in the Louisville North area consisted in 3343 tows contributed from seven UTFs between 1995 and 2013 (Figure 6). Vessel and timing of fishing (as fishing week) were significant covariates in the interaction-GLM for the stock, which explained a 33% reduction in residual deviance (Table 10).

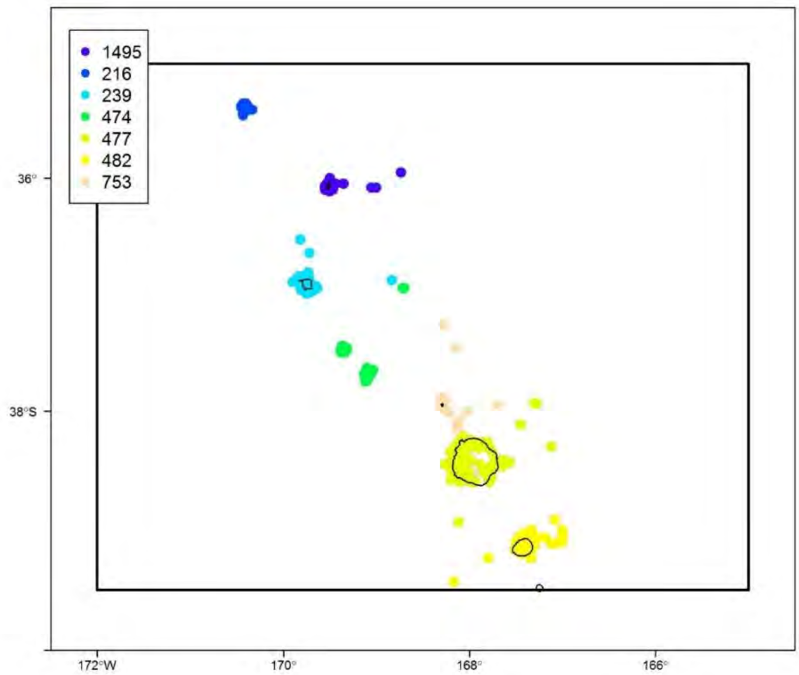


Figure 11. North Louisville Ridge area showing total effort (n=3343 tows=coloured dots) by UTF subareas (n=7) considered for spatial CPUE analyses of orange roughy.

Time series of standardized and imputed CPUE indices by subareas are presented in Table 11. The final index demonstrates a progressive decline in relative abundance from 1995 to 2007, followed by stable-low catch rates from 2010 to 2013 (Table 3, Figure 2D). Total catches were low (< 15 t) from 2010 to 2013 (see Appendix 1), and are thus barely visible in Figure 2D. No fishing took place on Louisville North UTFs in 2008-2009. A single tow performed in 2014 was not considered in CPUE analyses.

Table 11. Summary of the lognormal, interaction-GLM model for catch rates of orange roughy in the Louisville North area. df=degrees of freedom; Resid=residual.

	df	Deviance	Resid. df	Resid. Dev	R2
Null Model			3342	12997.46	
fyear	14	1411.1	3328	11586.37	10.86
subarea	6	33.63	3322	11552.74	11.12
vessel	24	1604.57	3298	9948.17	23.46
fweek	47	805.59	3251	9142.57	29.66
fyear:sub-area	59	377.01	3192	8765.56	32.56

Table 12. Space-time table of standardized and imputed catch rates of orange roughy in Louisville North. Columns are UTF-subareas defined by assigning individual tows to UTFs (see Figure 6 for UTFs and tows locations).

	UTF-1495	UTF-216	UTF-239	UTF-474	UTF-477	UTF-482	UTF-753
1995	2.43	2.18	2.18	4.65	0.49	1.07	3.57
1996	0.51	1.34	1.19	4.65	1.88	1.57	3.57
1997	1.23	2.18	0.72	0.73	0.41	0.73	1.30
1998	2.43	1.40	1.45	1.60	1.66	2.67	1.07
1999	1.57	1.40	2.18	1.60	1.14	3.52	1.07
2000	0.71	0.63	0.59	1.60	0.62	0.78	0.85
2001	1.33	0.88	1.71	1.60	0.50	1.96	1.08
2002	0.94	1.43	1.21	2.47	1.91	0.69	1.31
2003	0.77	0.55	0.77	0.39	1.29	1.00	1.02
2004	0.45	1.09	0.47	0.98	0.35	0.56	0.58
2005	1.48	0.82	0.86	0.32	0.43	0.54	0.73
2006	0.81	0.82	1.25	0.65	0.95	1.67	0.89
2007	0.96	0.82	0.86	0.65	0.53	0.51	0.73
2008	NA	NA	NA	NA	NA	NA	NA
2009	NA	NA	NA	NA	NA	NA	NA
2010	0.89	0.82	0.86	0.65	1.81	0.79	0.73
2011	0.89	0.82	0.86	0.65	3.08	1.06	0.73
2012	0.89	0.82	0.86	0.65	1.88	0.79	0.73
2013	0.89	0.82	0.86	0.65	0.68	0.79	0.73

Spatial CPUE analyses – Louisville Central

The final dataset for orange roughy in the Louisville Central area consisted in 5874 tows contributed from six UTFs between 1994 and 2014 (Figure 7). As for Louisville North, vessel and timing of fishing (as fishing week) were significant covariates in the interaction-GLM for the stock, which explained a 23% reduction in residual deviance (Table 12). Time series of standardized and imputed CPUE indices by subareas are presented in Table 13. The final index indicates a sharp, initial decline in stock abundance from 1994 to about 2001, followed by a relatively stable, lower abundance since a decade (Table 3, Figure 2E). No fishing took place on Louisville North UTFs in 2008-2009.

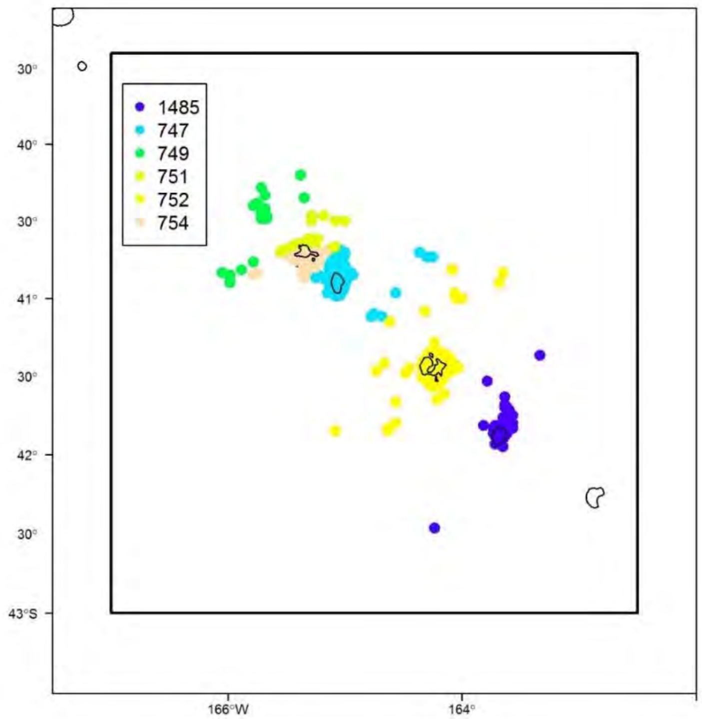


Figure 12. Central Louisville Ridge area showing total effort (n=5874 tows=coloured dots) by UTF subareas (n=6) considered for spatial CPUE analyses of orange roughy.

Table 13. Summary of the final lognormal, interaction-GLM model for catch rates of orange roughy in the Louisville Central area. df=degrees of freedom; Resid=residual.

	Df	Deviance	Resid. Df	Resid. Dev	Rsqr
NULL	NA	NA	5857	22544.88	0
fyear	18	1389.53	5839	21155.35	6.16
subarea	5	36.62	5834	21118.73	6.33
vessel	26	1811.44	5808	19307.29	14.36
fweek	51	1130.84	5757	18176.45	19.38
fyear:subarea	81	900.69	5676	17275.76	23.37

Table 14. Space-time table of standardized and imputed catch rates of orange roughy in Louisville Central. Columns are UTF-subareas defined by assigning individual tows to UTFs (see Figure 7 for UTFs and tows locations).

	UTF-1485	UTF-747	UTF-749	UTF-751	UTF-752	UTF-754
1994	4.16	3.51	1.97	4.46	7.37	21.51
1995	4.16	3.87	1.97	4.46	7.37	2.47
1996	0.80	1.32	1.03	2.18	1.05	1.56
1997	3.36	0.70	0.68	1.32	1.42	1.12
1998	1.94	1.71	0.93	0.73	2.04	0.55
1999	1.01	0.70	0.93	0.61	1.85	0.57
2000	1.92	0.33	0.93	1.91	1.29	0.51
2001	0.17	0.53	0.93	0.66	1.60	1.01
2002	0.25	0.53	0.93	1.03	0.87	0.87
2003	0.10	0.53	0.93	1.39	0.13	1.40
2004	0.05	0.73	1.18	0.87	0.61	0.92
2005	1.39	1.15	0.93	0.23	0.46	0.42
2006	1.87	1.84	0.93	3.26	0.38	0.56
2007	1.39	0.76	0.93	1.55	0.29	1.11
2008	NA	NA	NA	NA	NA	NA
2009	NA	NA	NA	NA	NA	NA
2010	1.39	2.34	0.93	0.81	1.00	1.30
2011	1.39	0.49	0.93	0.81	0.56	0.31
2012	1.39	0.80	0.93	0.81	1.79	0.46
2013	1.39	0.50	0.93	0.08	0.49	0.63
2014	0.91	1.04	0.93	0.81	2.26	1.33

Spatial CPUE analyses – Louisville South

The final dataset for orange roughy in Louisville South consisted in 2169 tows contributed from six UTFs between 1995 and 2014 (Figure 8). Vessel, timing of fishing (as both fishing week and calendar month) and target species were significant covariates in the interaction-GLM for the stock, which explained a 36% reduction in residual deviance (Table 14). Time series of standardized and imputed CPUE indices by UTFs are presented in Table 15. The final index indicates a progressive decline in relative abundance from 1995 to 2002, followed by stable-low catch rates (Table 3, Figure 2F). Similar to other Louisville areas, no fishing took place in Louisville South in 2008-2009 (Appendix 1).

Table 15. Summary of the final lognormal, interaction-GLM model for catch rates of orange roughy in the South Louisville area. df=degrees of freedom; Resid=residual.

	df	Deviance	Resid. df	Resid. Dev	R2
Null model	NA	NA	2168	12712.58	0
fyear	17	1271.28	2151	11441.3	10
subarea	5	69.55	2146	11371.76	10.55
vessel	24	1476.62	2122	9895.14	22.16
fweek	39	898.28	2083	8996.86	29.23
target_sp	4	87.43	2079	8909.43	29.92
month	5	64.23	2074	8845.2	30.42
fyear:subarea	68	768.5	2006	8076.7	36.47

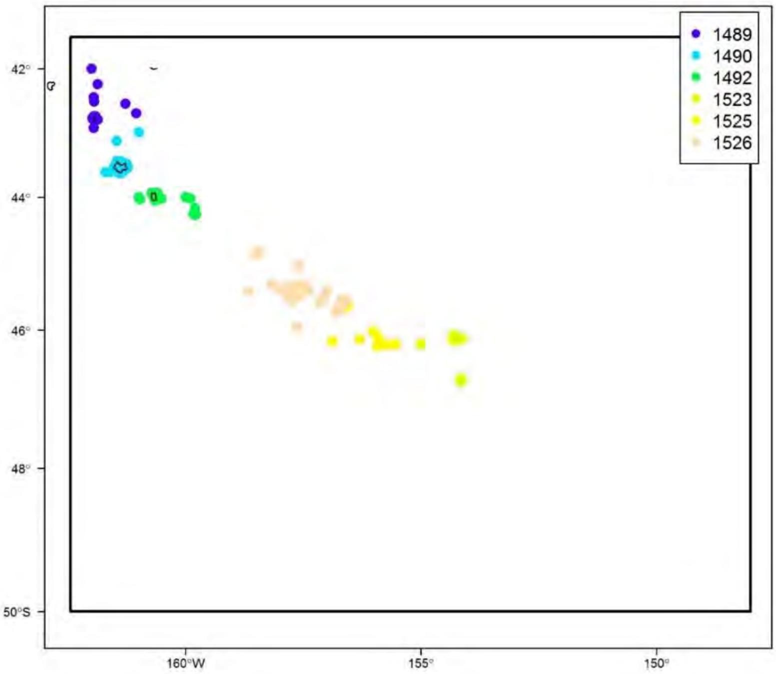


Figure 13. South Louisville Ridge area showing total effort (n=2169 tows=coloured dots) by UTF subareas (n=6) considered for spatial CPUE analyses of orange roughy.

Table 16. Space-time table of standardized and imputed catch rates for orange roughy in Louisville South. Columns are UTF-subareas defined by assigning individual tows to UTFs (see Figure 8 for UTFs and tows locations).

	UTF-1489	UTF-1490	UTF-1492	UTF-1523	UTF-1525	UTF-1526
1995	4.98	6.90	2.38	9.68	3.65	0.49
1996	4.98	3.35	2.38	5.57	3.65	1.87
1997	1.33	0.37	0.78	1.68	2.39	0.83
1998	4.98	1.24	1.58	9.68	2.39	1.54
1999	1.94	2.42	2.38	9.58	2.39	0.28
2000	0.33	2.42	1.95	9.48	2.39	1.69
2001	1.31	3.60	3.09	1.81	2.39	1.41
2002	1.38	2.08	1.33	1.41	2.39	1.16
2003	0.87	2.08	0.19	1.01	2.39	1.14
2004	0.87	0.56	0.19	1.58	1.13	0.72
2005	0.36	0.51	0.23	0.28	0.21	0.80
2006	0.88	0.54	1.05	0.26	0.33	0.24
2007	0.62	0.54	1.05	0.23	0.33	1.39
2008	NA	NA	NA	NA	NA	NA
2009	NA	NA	NA	NA	NA	NA
2010	0.62	0.54	1.87	0.20	0.33	2.07
2011	0.62	0.54	1.52	0.17	0.46	2.32
2012	0.62	0.54	0.31	0.71	0.70	0.38
2013	0.62	0.54	0.73	0.26	0.93	0.94
2014	0.62	0.54	1.16	0.67	0.57	0.98

5.4. Ongoing work

Biomass dynamic models (BDM) are currently being fitted and initial indications are that useful models can be fitted to four of the six areas examined here. These models will be reviewed by New Zealand's domestic working group where base cases, fine-tuning of the methods, and sensitivity analyses will be considered. The methods development and testing phase completed so far consisted in applying a similar set of methods across all stocks. Preliminary results underline the need for refining spatial CPUE analyses on a stock-by-stock basis, owing to important differences in data availability, spatial structure and fishing patterns among stocks. Reliable abundance indices are required for predicting biomass trajectories and achieving stock status evaluation relative to reliable K estimates and/or MSY-reference points in BDM. The use of stock-specific life history data to construct an r prior for each stock would also serve to better inform future BDM runs and improve model performance.

It is expected that the results of BDM stock assessments will be available before the SPRFMO Scientific Committee meets in late September 2015.

6. Recommendations

It is recommended that the Scientific Committee:

- **notes** New Zealand's work on stock assessment of demersal species, specifically orange roughy
- **notes** that New Zealand will likely have preliminary revised estimates of initial biomass, productivity, and stock status for some orange roughy stocks before the committee meets in 2015
- **agrees** that this work should contribute to the development of a revised CMM for bottom fisheries in the SPRFMO Area

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