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Stock management areas for orange roughy (*Hoplostethus atlanticus*) in the Tasman Sea and western South Pacific Ocean

New Zealand Fisheries Assessment Report 2016/19

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EXECUTIVE SUMMARY

Clark, M.R.; McMillan, P.J.; Anderson, O.F.; Roux, M-J. (2016). Stock management areas for orange roughy (*Hoplostethus atlanticus*) in the Tasman Sea and western South Pacific Ocean

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The stock structure of orange roughy in fishing areas outside the EEZ is regarded as uncertain, and in a number of areas has been assumed based on the distribution of fishing effort. This report describes and updates the available information for fisheries in the western region of the SPRFMO area. The report adopts an holistic approach, where multiple observational data sets were examined in order to maximise the likelihood of correctly defining stocks, given that no single data set would provide complete and unequivocal information.

The observational data that were summarised and/or analysed included catch distribution, the location of spawning grounds, differences in life history characteristics including patterns in length frequencies, length/age at maturity, genetic studies using allozymes or mitochondrial DNA, and a variety of other data including otolith composition and shape, morphometric parameters, and parasite composition and load.

No individual data set provided complete information on stock structure, and few individual data sets were in complete agreement on stock numbers and boundaries. However, the review supports the retention of existing assessment boundaries for fisheries in the Tasman Sea:

Lord Howe Rise
Northwest Challenger Plateau
Southwest Challenger Plateau
West Norfolk Ridge
South Tasman Rise

The Louisville Seamount Chain was previously divided into 3 sub-areas for catch description and analysis. The concept of three sub-areas is retained, but the boundaries were revised based on timing of spawning.

It is recommended that consideration be given to carrying out more genetic and age-based analyses for the Louisville and West Norfolk Ridge fisheries.

This work was carried out under Ministry for Primary Industries project DEE2014-10: Objective 1, “To evaluate options for assessing and managing ET (outside the EEZ) orange roughy in the SPRFMO Convention Area, on the basis of stock structure or spatial criteria”.

1. INTRODUCTION

Orange roughy fisheries in the New Zealand region outside the EEZ developed in the mid-1980s on the southwest Challenger Plateau, and increased further 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 (Clark 2008). These fishing grounds are now in the area covered by the South Pacific Regional Fisheries Management Organisation (SPRFMO).

New Zealand has limited the annual catch of orange roughy by its vessels in the SPRFMO Convention Area to 1852 t, which is based on the average annual catch during the reference period 2002–2006. Fishing is further restricted to those areas of the SPRFMO Convention Area that are open to bottom fishing, as described in the New Zealand bottom fishery impact assessment (MFish 2008). The current approach, however, does not provide for management of separate stocks, or prevent serial depletion. New Zealand is required to propose effective management measures for orange roughy to SPRFMO by 2016, and the intention of MPI in contracting the work reported here, is to split the SPRFMO Convention Area into several regions based on either stock structure or spatial criteria, and then evaluate stock assessment and management options for each region.

Five main fishing grounds were defined by Clark (2008), and used in a number of fishery characterisations for fisheries outside the EEZ (Figure 1):

a) Lord Howe Rise: The main region of the fishery is 35°00’ S – 36°45’ S and 164°00’ E – 167°00’ E

b) Northwest Challenger Plateau: The main target fishery (referred to as the “Core Area”), is on the northern slopes of the Plateau, between 36°50’ S – 38°00’ S, and 166°00’ E – 170°00’ E.

c) West Norfolk Ridge: 32°30’ S – 34°30’ S, 166°30’ E – 168°10’ E.

d) Louisville Ridge: There are three general areas:

- North: 35°00’ S – 39°54’ S, 165°00’W – 172°00’ W.
- Central: 40°00’ S – 44°54’ S, 157°00’ W – 167°00’ W.
- South: 45°00’ S – 50°00’ S, 148°00’ W – 159°00’ W.

e) Three Kings Ridge: 28° 00.0’ S – 31° 00.0 S, 172° 20.0’ E – 175° 40.0’ E

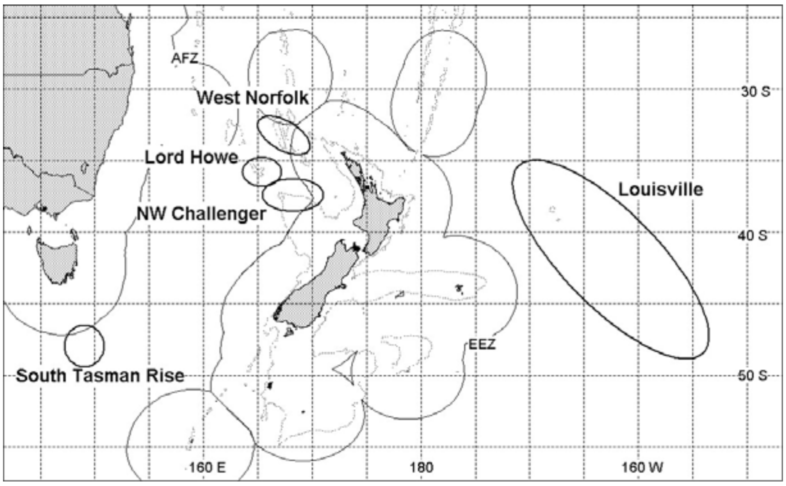

Figure 1: The distribution of major orange roughy fisheries outside the EEZ in the New Zealand region of the SPRFMO Area (after Clark 2004).

These areas were based largely upon geographical separation of major topographic features, breaks in the distribution of fishing effort, and previously published biological data on stock structure for some Tasman Sea areas.

The stock structure of orange roughy has been a major issue for fisheries science and management in New Zealand waters for many decades. Initially it was assumed that fisheries operating on spawning orange roughy in areas such as Ritchie Banks, Cook Canyon, Challenger Plateau and Chatham Rise exploited separate stocks. As more fishing grounds were developed, however, including areas outside the EEZ, the identification of separate stocks became both more important, but also more complex as additional sources of information became available (Clark 1990).

Methods for stock identification in marine capture fisheries were reviewed by Pawson and Jennings (1996) who listed a number of potential sources of information to inform a stock identity decision: distribution and abundance of various life-history stages, marks and tags, both natural and artificial, meristics and morphometrics, calcified structures, genetics and life-history parameters. An holistic approach to fish stock identification, involving a broad spectrum of techniques was advocated by Begg and Waldman (1999), who considered a suite of biological parameters and qualitative characters that could be considered for defining stocks including: mark-recapture, catch data, life history characteristics, parasites (faunal composition and load), otolith microchemistry, morphology (meristics, morphometrics), scale and otolith analyses, genetics, protein variation, mitochondrial DNA and nuclear DNA.

There have been numerous stock discrimination studies carried out on orange roughy at a range of spatial scales, from global (e.g., Smith 1986, to sub-regional (e.g., east coast New Zealand, Smith & Benson 1997). A variety of methods were employed in the New Zealand-Australia region that are relevant to evaluation of stock structure for fisheries outside the EEZ:

- Genetic markers (e.g., Elliot & Ward 1992, Smolenski et al. 1993, Smith et al. 1997)
- Age at maturity (e.g. Horn et al. 1998)
- Morphometrics (e.g., Haddon & Willis 1995)
- Parasite (e.g., Lester et al. 1998)
- Otolith chemistry (e.g., Edmonds et al. 1991, Thresher & Proctor 2007)
- Spawning distributions (Pankhurst 1988, Francis and Clark 1998)

- Fishery and fishing effort distribution (e.g., Clark et al. 2002)

For orange roughy fisheries outside the EEZ in the New Zealand region, there were several summaries, or studies where multiple techniques were applied, and combining all available relevant data (following Begg & Waldman 1999). Clark (1990) summarised information on size, spawning period, biochemical studies, fish movement and parasite composition; Clark & Tilzey (1996) evaluated information from the Lord Howe Rise and Northwest Challenger Plateau on size structure, spawning time, fishery distribution, and geographical distance; and Smith et al. (2002) applied five techniques-life history traits, size structure, otolith shape, genetic markers, and spawning time. Dunn & Devine (2010) examined data solely from the Chatham Rise, but also included aspects of CPUE trends, nursery ground location, migration, habitat structure, fish condition, and growth rates.

More data have become available to update an assessment of stock structure of orange roughy outside the New Zealand EEZ, and extend it to fishing grounds throughout the SPRFMO region. In this report, we evaluate all relevant data to best define the stock structure of orange roughy outside the EEZ, as a basis for complementary work under the project to apply a range of assessment methods to estimate stock parameters.

1.1 Project objectives:

The specific objective defined by MPI was “To evaluate options for assessing and managing ET (outside the EEZ) orange roughy in the SPRFMO Convention Area, on the basis of stock structure or spatial criteria”

2. METHODS

The project was principally a desk-top study. The approach taken was to summarise the available information, and update it where new studies, or more recent data, were available. There were five key aspects investigated, which covered the main techniques, and were most likely to give useful, and cost-effective, results:

2.1 Genetics

This was solely a literature summary and review.

2.2 Life history parameters

This was solely a literature summary and review. Age and length at maturity were examined by Horn et al. (1988) and Smith et al. (2002).

2.3 Size structure

Data from the MPI Observer Programme (OP) were extracted from the *cod* database up to the 2013–14 fishing year for all areas outside the EEZ. Length frequency distributions, and mean length statistics by sex, were analysed. Observed samples of orange roughy length were weighted by the total catch of orange roughy in the trawl, and the sample weight was estimated (where necessary) using published length weight-functions. Sex averaged mean lengths were calculated for each seamount and year, and overall.

2.4 Spawning information

The location, and timing, of spawning has shown variability by area. Biological data collected by research and OP trips have regularly been updated for individual fishing years (e.g., Anderson 2006), but there has not been a recent complete collation and analysis. Hence, data were extracted from the MPI *cod* database up to 2013–14, and new analyses carried out to derive the location of orange roughy catches with advanced gonad stages (female: ripe/running and spent). Where data were available from a similar location over several days or weeks, temporal changes were examined to compare the likely timing of spawning.

Observers recorded the macroscopic gonad condition (see Table 1) of female orange roughy only, using the following definitions:

Table 1: Observer orange roughy gonad stage definitions.

Stage	Description
F1	Immature to early maturation
F2	Maturing
F3	Ripe
F4	Running ripe
F5	Spent

2.5 Fishery distribution

Orange roughy aggregations often show a strong spatial structure, separated geographically. In the past this has proven an important factor in defining the boundaries of management units (e.g., Clark 2004, 2008).

Trawl catch data on a tow-by-tow basis were obtained from the Ministry for Primary Industries (MPI) for all bottom and midwater fishing events by New Zealand vessels outside the EEZ from 1989–90 to 2013–14 (up to June 2015). Full effort details and catch by species information were provided, totalling about 50 000 records.
A number of checks and grooming procedures were carried out.

- Tows with either start or finish positions within the EEZ were deleted (about 3000 records).
- Tows with missing positional data were deleted.
- East-West topographical mistakes were corrected by checking the position of tows by the particular vessel in the same week. That enabled assignment to Lord Howe/Challenger Plateau (east longitude) or Louisville Ridge (west longitude).
- Tows greater than 20 n. miles based on either start-finish positions, or speed multiplied by duration were deleted.
- Median imputation procedures based on tows by the same vessel in the same area and time periods were used to fill in gaps in some data fields (e.g., tow duration, depth, target species).

Following automated grooming analyses, manual checks were done on tows in certain areas that may have been logically consistent but were errors due to incorrect locations. These were checked for depth, area, and species (either target or catch) and deleted when they were obvious errors (e.g., scampi or snapper target species, tows over unfishable depths away from the axis of the ridge, rise or seamount chain).

The final dataset totalled 48 500 tows, of which 48 000 were bottom trawl. There were 500 midwater trawls or tows that targeted midwater species such as alfonsino and bluenose (the latter being the working definition used by SPRFMO).

2.6 Other data

Several other data sources were summarised from published papers and reports:

- Otolith chemistry, and otolith shape
- Morphometrics and meristics
- Parasite composition and loading

3. RESULTS

The results of the various summaries and analyses are described and assessed individually, and then together. As noted by Smith et al. (2002) and Dunn & Devine (2010), no individual technique is likely to provide complete and unequivocal results. Some parameters will show patterns and trends, others may be uninformative; and what might discriminate some areas, may not do so in other areas. Hence, we initially summarised each result, and then integrated them to draw conclusions based either on the weight of data most relevant for showing biological stock structure, or fishery/habitat criteria that may realistically separate fish distributions.

3.1 Genetic studies

Twelve key papers were reviewed (Table 2). These studies used allozymes, mitochondrial DNA, or microsatellites. The papers covered a number of orange roughy grounds within and outside the EEZ, but no samples were examined to date from the West Norfolk Ridge or Louisville Seamount Chain. The main findings of these studies are briefly described below:

- Smith (1986) conducted the first study of genetic variation in orange roughy and found little genetic differentiation at seven polymorphic enzyme loci in samples from the western (Challenger Plateau) and eastern (Chatham Rise, Wairarapa and Kaikoura) coasts of New Zealand and from the north-eastern Atlantic Ocean (Rockall Trough). The Tasman Sea, western Pacific and Atlantic Ocean samples differed significantly in allele frequency at only two loci, while at a third locus a rare allele was found only in the Atlantic Ocean (Smith 1986, Elliott and Ward 1992).
- Allozyme techniques were again used by Black & Dixon (1989) comparing samples from around New Zealand and Australia. They identified three subpopulations: NZ (Chatham Rise), eastern Australia/Tasmania, and South Australia.
- Elliot & Ward (1992), however, examined a wider range of samples from around southern Australia and Tasmania, and found no evidence of genetic subdivision.
- Mitochondrial DNA analyses were carried out by Ovenden et al. (1989), and they reported differences between western and eastern Tasmania grounds. However, a similar analysis from spawning grounds west and east of New Zealand found no differences (Baker et al. 1992).
- An extensive study of New Zealand, Australian, and South African samples was carried out by Smolenski et al. (1993), with partial genetic separation of fish from New South Wales, South Australia, and Tasmania. However, the mitochondrial samples taken from the same site off South Australia in consecutive years were distinct.
- Mitochondrial DNA from six spawning grounds around New Zealand showed significant heterogeneity, although two southern grounds were similar (Smith et al. 1996). Significant

heterogeneity in allozyme loci from several New Zealand locations was also found by Smith & Benson (1997), although this varied with area. The Chatham Rise demonstrated spatial and temporal heterogeneity at two loci, but samples from the east coast of the North Island showed no heterogeneity (Smith & Benson 1997).

- Multiple genetic methods were applied by Smith et al. (1997) to four spawning grounds off New Zealand. Three genetic stocks were recognised: east coast North Island (Ritchie Banks, Chatham Rise), southeast coast of the South Island (Waitaki), and southern New Zealand (Puysegur Bank).
- A major effort was made by Smith et al. (2002) to identify genetic stocks in the Tasman Sea fisheries. Four grounds on the Lord Howe Rise and Challenger Plateau were analysed. Mitochondrial DNA was homogeneous between areas, whereas restriction digests of the whole mitochondrial genome indicated differences between Lord Howe Rise and the Challenger Plateau (both northwest and southwest Challenger).
- Varela et al. (2012) undertook global analyses using mitochondrial DNA, and found that there was no significant differentiation between New Zealand, Australia, Namibia and Chile. COI results showed low, but significant, differentiation between the northeast Atlantic and the southern hemisphere locations. Microsatelite methods showed genetic homogeneity between New Zealand and Australia, and no temporal variation in repeat sampling in areas off the North Island of New Zealand (Varela et al. 2013).

Table 2: Summary of genetic analyses of orange roughy samples from the SPRFMO Convention Area, arranged chronologically. NZ, New Zealand; Chatham, Chatham Rise; GAB, Great Australian Bight; NSW, New South Wales.

Areas	Method	Reference
NZ (Challenger, Chatham, Kaikoura, Wairarapa), northeast Atlantic Ocean	Enzyme loci	Smith (1986)
NZ (Chatham) and Australia	Enzyme loci	Black and Dixon (1989)
East and west Tasmania	Mitochondria1 DNA	Ovenden et al. (1989)
Australia (West Australia, GAB, south Tasmania, east Tasmania, Cascade Plateau), NZ (Chatham)	Enzyme loci	Elliott and Ward (1992)
Two spawning grounds east and west of New Zealand	DNA fingerprint	Baker et al. (1992)
Australia (GAB, South Australia, east Tasmania, west Tasmania, NSW) NZ, South Africa	Mitochondria1 DNA	Smolenski et al. (1993)
Six spawning sites around New Zealand and one site off Tasmania	Restriction fragment-length polymorphisms of mitochondrial DNA	Smith et al. (1996)
NZ (east coast and Chatham Rise)	Allozyme loci	Smith and Benson (1997)
Four NZ spawning sites (Ritchie Bank, North Chatham, Waitaki, Puysegur)	Compared three methods: Allozyme loci, mitochondrial DNA, polymorphic DNA	Smith et al. (1997)
Lord Howe Rise, Northwest Challenger, Southwest Challenger, Westpac Bank	Mitochondrial DNA, restriction digests of the whole mitochondrial genome	Smith et al. (2002)
Global: NZ, Australia, Namibia, Chile, northeast Atlantic	Mitochondrial DNA (COI and cytochrome b)	Varela et al. (2012)
Global: NZ (eight north sites sampled in two different years), Australia, Namibia, Chile, northeast Atlantic Ocean	Microsatellite DNA loci	Varela et al. (2013)

<u>Conclusion</u>: Genetic techniques have shown contradictory results at different geographical and temporal scales with few unambiguous results that would suggest clear stock boundaries for SPRFMO fisheries. There is reasonable evidence from mitochondrial genome studies for differences between orange roughy from the Lord Howe Rise and Northwest Challenger Plateau.

3.2 Life history parameters

Two studies have reported analyses of mean age and length at maturity of orange roughy (Table 3). However, these show contrasting results. Horn et al (1998) reported significant between-area differences in both parameters. Within New Zealand fish formed three groups for length at maturity: Challenger Plateau (smallest), Ritchie Banks/Chatham Rise/Puysegur Bank (intermediate), and Bay of Plenty (largest). For age at maturity three different groups were suggested: Challenger Plateau (youngest), Bay of Plenty/Ritchie Banks/Puysegur Bank (intermediate), and Chatham Rise (oldest). Smith et al. (2002) used the same techniques to examine four areas in the Tasman Sea, but found no differences between fish from the Lord Howe Rise and Challenger Plateau. There were no available samples from the West Norfolk Ridge or the Louisville Seamount Chain.

Table 3: Summary of studies of orange roughy life history parameters from samples collected in the SPRFMO Convention Area.

Areas	Parameters	Reference
New Zealand, Namibia, North Atlantic Ocean	Age and length at maturity	Horn et al. (1998)
Lord Howe Rise, Northwest Challenger, Southwest Challenger, and Westpac Bank	Age and length at maturity	Smith et al. (2002)

A small sample (18) of otoliths from the East Pacific Rise were examined to estimate age at maturity, based on zone counts to the transition zone (NIWA unpublished data). Counts ranged from 31 to 45, with a mean age estimated at 36.9 years. While acknowledging the small sample size we note that these ages are greater than the range of mean ages from 23 to 33 years reported by Horn et al. (1998) and Smith et al. (2002).

Conclusion: The published studies showed inconsistent results, and do not appear to provide usable evidence for stock boundaries for orange roughy fisheries in the SPRFMO area.

3.3 Size structure

There are two published papers (Table 4) that have compared length frequency distributions of orange roughy from Tasman Sea locations. Clark & Tilzey (1996) noted that fish from the Lord Howe Rise (mean standard length 36 cm) were consistently larger than those from the Northwest Challenger Plateau (32 cm). Smith et al. (2002) compared the four main fishing grounds in the Tasman Sea, and found, like Clark & Tilzey (1996) that there were significant size differences between Lord Howe Rise and Northwest Challenger Plateau. They also reported that Lord Howe fish were larger than those on the Southwest Challenger Plateau, and the Westpac Bank.

Table 4: Summary of findings from studies of orange roughy length frequency parameters from samples collected in the SPRFMO Convention Area within the New Zealand region, arranged chronologically.

Areas	Parameters	Reference
Lord Howe Rise, Northwest Challenger, Southwest Challenger, and Westpac Bank	Length frequency analysis	Smith et al. (2002)
Lord Howe Rise, Northwest Challenger	Length frequency analysis	Clark & Tilzey (1996)

There were regular analyses of data collected by the MPI Observer Programme (OP). Mean lengths were calculated annually for each fishing area (Table 5).

Table 5: Summary of studies of orange roughy mean lengths from fish samples collected by the MPI Observer Programme in the SPRFMO Convention Area, arranged chronologically.

Area	Parameters	Mean length (year)	Reference
Lord Howe Rise	Mean length of all sampled fish (cm SL)	35 (1989)	Anderson (2006)
		34 (1990)	
		35 (1992)	
		37 (1993)	
		36 (1994)	
		36 (1999)	
		36 (2000)	
		36 (2001)	
		34 (2008)	Anderson (2011)
		35 (2009)	
NW Challenger	Mean length of all sampled fish (cm SL)	32 (1989)	Anderson (2006)
		34 (1992)	
		34 (1993)	
		33 (1994)	
		34 (1996)	
		34 (1998)	
		33 (1999)	
		33 (2000)	
		31 (2001)	
		31 (2002)	
		33 (2009)	Anderson (2011)
West Norfolk Ridge	Mean length of all sampled fish (cm SL)	41 (2002)	Anderson (2006)
		41 (2003)	
		41 (2008)	Anderson (2011)
		42 (2009)	
Louisville Seamount Chain	Mean length of all sampled fish (cm SL)	40 (1994)	Anderson (2006)
		39 (1995)	
		44 (1996)	
		40 (2001)	
		39 (2002)	
		38 (2003)	
		40 (2004)	

In order to help identify patterns in size structure, overall mean lengths sorted into 2 cm intervals were plotted for each seamount in the Tasman Sea fisheries (Lord Howe, West Norfolk Ridge, and Northwest Challenger) (Figure 2), and on the Louisville Seamount Chain (Figure 3).

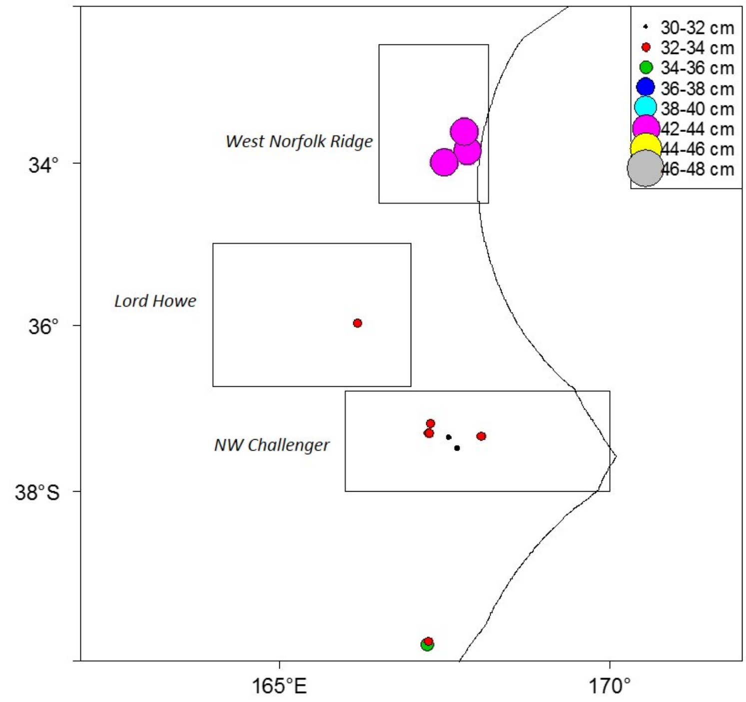

Figure 2: Scaled orange roughy mean lengths (all years, average of male and female means) by seamount for Lord Howe, West Norfolk Ridge, NW Challenger, and Westpac Bank fisheries pooled into 2 cm intervals. Fishery areas plotted are those defined by Clark (2008).

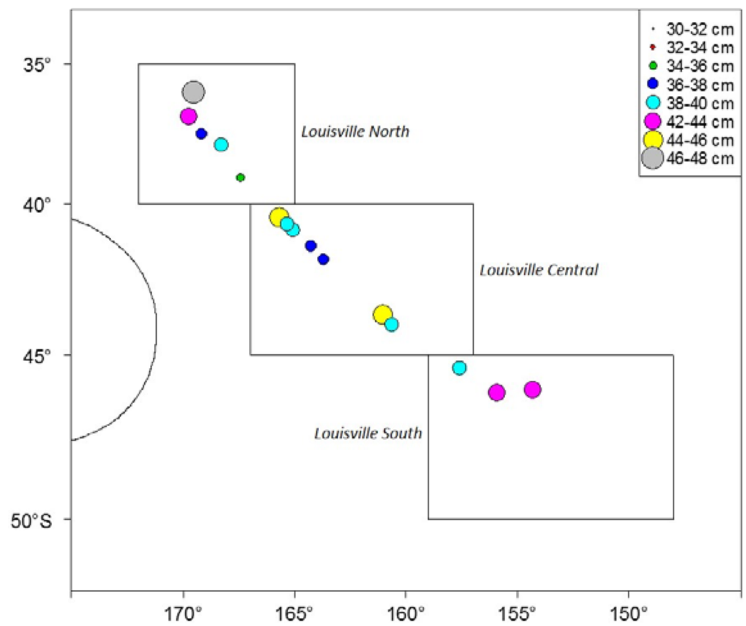

Figure 3: Scaled orange roughy mean lengths (all years, average of male and female means) by seamount on the Louisville Seamount Chain in 2 cm intervals. Fishery areas plotted are those defined by Clark (2008).

Mean sizes of fish from NW Challenger and Lord Howe (and Westpac Bank) were smaller than those from the West Norfolk Ridge. The latter was similar to the Louisville Seamount Chain. No pattern in mean lengths with location (i.e., latitude or fishery area) is discernible with Louisville seamounts.

The overall patterns and trends in mean length are relatively consistent when examined for individual seamounts. Although fish differ in size between some features, there are few large changes in size structure over time. This applies to both Tasman Sea fishing grounds (Figure 4), and Louisville seamounts (Figure 5).

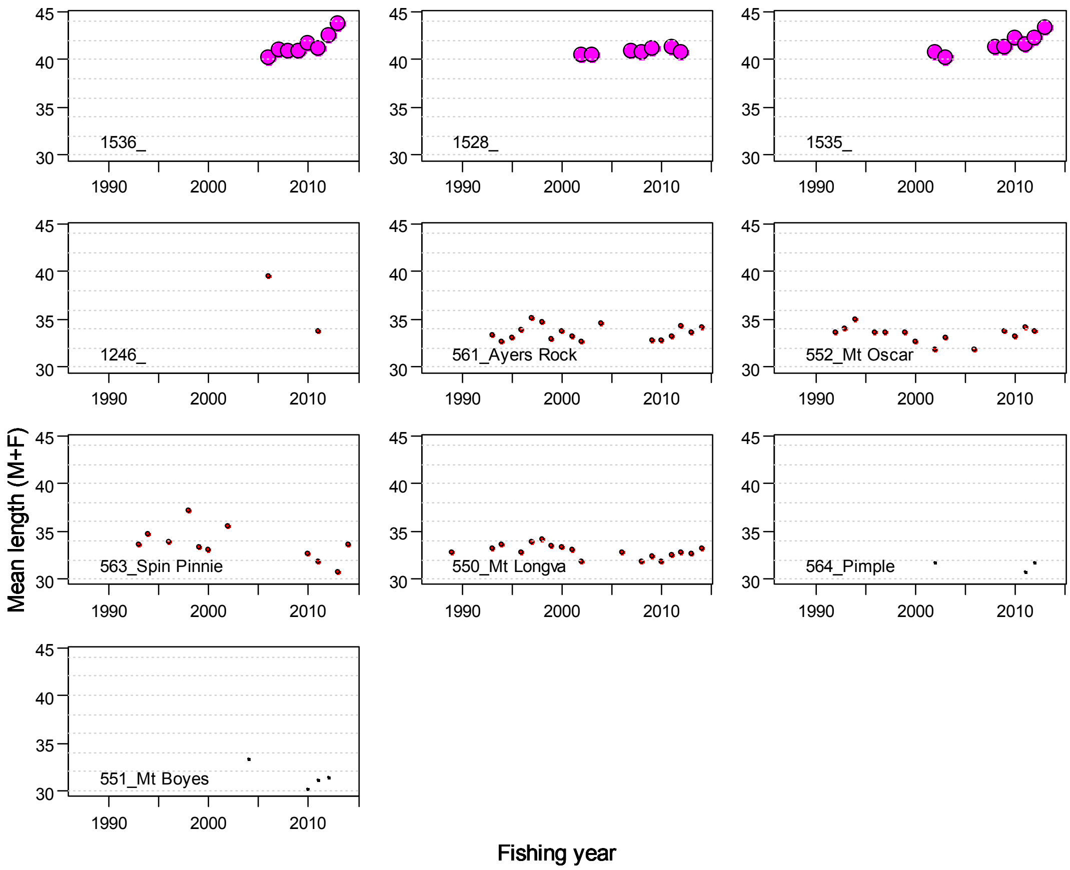

Figure 4: Scaled mean lengths (average of male and female) by fishing year for each seamount sampled from the Lord Howe, West Norfolk Ridge, NW Challenger, and Westpac Bank fisheries (see Figure 2 for symbol codes). Plots are ordered by latitude (north to south) across and down from top left to bottom right.

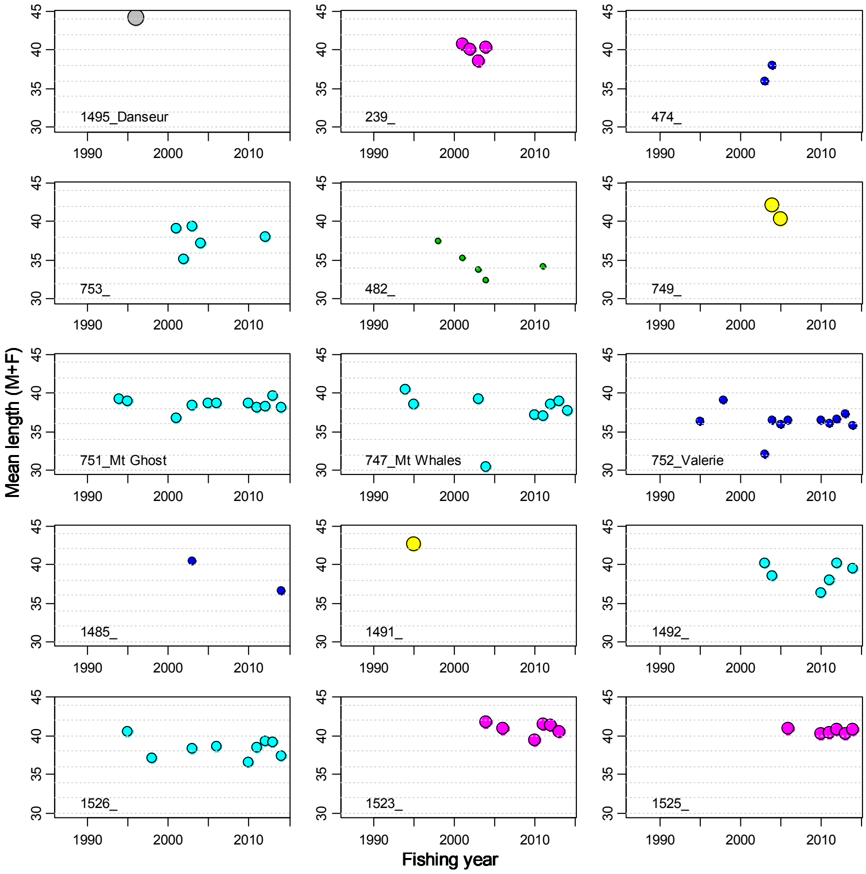

Figure 5: Scaled mean lengths (average of male and female) by fishing year for each seamount sampled on the Louisville Seamount Chain (see Figure 3 for symbol codes). Plots are ordered by latitude (north to south) across and down from top left to bottom right.

Conclusion: There is clear variability between areas, but generally a high level of consistency between years within an area. Orange roughy from the Norfolk Ridge and Lord Howe Rise were generally larger than those from the NW Challenger Plateau, but other patterns are less consistent.

3.4 Timing of spawning

The majority of data on timing of spawning for fisheries outside the EEZ was from gonad staging by Observers on commercial vessels. Smith et al. (2002) evaluated four areas in the Tasman Sea, including the SW Challenger Plateau and Westpac Bank. They found high between-year variation in timing of spawning in these two areas (up to 3 weeks and 4 weeks respectively), as well as noting a shift to earlier spawning in the late 1990s. However, the timing was relatively consistent within the Lord Howe Rise and NW Challenger areas (Table 6). 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 taken from the West Norfolk Ridge and Louisville Seamount Chain areas.

Table 6: Summary of orange roughy spawning times from Observer Programme data. Peak spawning – the highest proportion of ripe/running ripe or when 20% of fish are spent (default).

Area	Parameters	Spawning date	Reference
Lord Howe Rise	Peak of spawning	4 July 1993	Clark & Tilzey (1996)
		11 July 1989	Anderson (2006)
		17 July 1990	
		15 July 1992	
		10 July 2008	Anderson (2011)
		13 July 2009	
NW Challenger	Peak of spawning	22 June 1993	Clark & Tilzey (1996)
		20/21 Jun 1999	Anderson (2006)
		26 June 2000	
		30 June 2009	Anderson (2011)
West Norfolk Ridge	Peak of spawning	29 June 2008	Anderson (2011)
Louisville Seamount Chain	Peak of spawning	6 July 2002	Anderson (2006)
		28 Jun 2003	

The high likelihood of the presence of some stock structure on the Louisville Seamount Chain (because its length extends for several hundred kilometres) made that area a priority for more detailed analysis. Major spawning locations can be inferred from catch sizes and spawning condition of sampled fish reported by the OP (see Appendix 1). The location of orange roughy catches greater than 10 t and with over 20% of female fish in ripe or running ripe condition are shown in Figure 6. This indicates that large aggregations of spawning fish occur throughout the Chain, but were limited to a single seamount (239) in the northern area; five seamounts in the central area (Ghost, Whales, Valerie, 1485, 1492); and three seamounts in the southern area (1526, 1523, 1525). Aggregations of spawning fish were found entirely within June in the northernmost seamount (239), but appeared progressively later for more southern seamounts, to between July 27 and August 24 for the southernmost four seamounts.

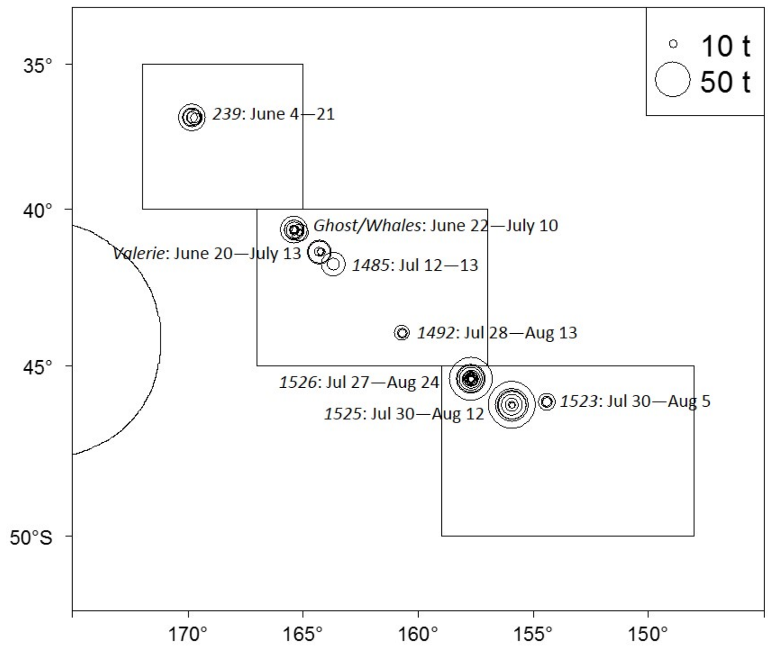

Figure 6: Location and dates of spawning orange roughy on the Louisville Seamount Chain. The expanding circles are proportional to the total catch weight; only locations where the catch was greater than 10 t and the percentage of ripe/running ripe female fish was greater than 20% are shown.

The existing boundaries for the Louisville fisheries (as defined by Clark, 2008) were adjusted to match the observed latitudinal gradient in the timing of spawning. This was done by identifying seamounts that constitute "timing of spawning boundaries" along the chain, based on the available data. This included the southern-most June spawning seamount in the northern area, the northern- and southern-most July spawning seamounts in the central area, the southern-most August spawning seamount in the central area, and the northern-most August spawning seamount in the southern area. An average distance hierarchical clustering algorithm was applied to the matrix of summit positions for all seamounts located in-between "boundary seamounts" in order to split them into groups characterized by their proximity to the nearest June/July or July/August spawning seamounts.

All seamounts located north of the northern-most June spawning seamount in the northern area were assumed to belong to the June-spawning "stock". Similarly, all seamounts located south of the southern-most August spawning seamount in the southern area were assumed to belong to the August-spawning "stock". This resulted in three spatially continuous sets of seamounts, characterised by their proximity and differences in the timing of spawning: the northern June-spawning seamounts; the central July-spawning seamounts; and the southern August-spawning seamounts (Figure 7).

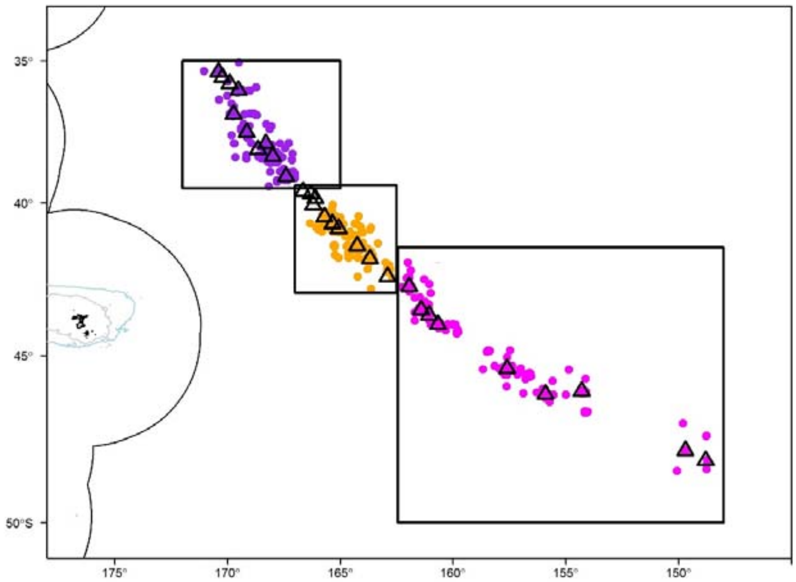

Figure 7: Adjusted boundaries for the Louisville fisheries. The northern June-spawning stock (northern box, purple dots); the central July-spawning stock (central box, orange dots); and the southern August-spawning stock (southern box, pink dots) are distinguished. Triangles represent individual seamounts within the orange roughy distribution range (summit depth between 500 and 1600 m). Coloured dots are effort (individual tows).

<u>Conclusion:</u> Differences in spawning time appear to be useful indicators of potential stock structure, and separate Lord Howe Rise and Northwest Challenger Plateau. The gradient in spawning times on the Louisville Seamount Chain also strongly suggests that there is spatial structure between various seamounts, and although not definitive, this has given information on which to suggest a revision of potential management boundaries.

3.5 Other biological studies

A variety of other miscellaneous studies have used various techniques that are relevant to distinguishing separate stocks of fish. These include parasites, otolith chemistry, otolith shape, morphometrics, and various combinations of these (Table 7). The main findings are briefly summarised below:

- Lester et al. (1988) found differences in parasite composition and loading that they inferred discriminated five Australian and three New Zealand stocks. Australia: (1) Great Australian Bight (2) South Australia/west Victoria/west and south Tasmania, (3) Cascade Plateau/Tasman Rise, (4) north-east Tasmania, (5) New South Wales. New Zealand: (1) north-east New Zealand, (2) south-east New Zealand, (3) west New Zealand.
- A total of 38 morphometric measurements were used by Elliot et al. (1995) who documented significant variation in orange roughy morphology. They felt there were at least seven morphologically distinguishable stocks of orange roughy in southern Australia, despite genetic data indicating appreciable levels of gene flow.
- Haddon & Willis (1995) also used body measurements (17) to compare two areas off New Zealand. They found significant differences (males and females separately) in shape between sites when linear relations between eight body measures and standard length were compared. The eight measures were: head length, snout length, orbit diameter, maxilla width, premaxilla length, caudal peduncle, gill raker count, and anal fin count.
- Trace element analysis of otoliths was examined by Edmonds et al. (1991). Patterns of element concentrations were specific to the areas where fish were captured. This suggested that there was little movement of fish between the three areas. Otolith elements were also used by Thresher & Proctor (2007) who reported that differences in primordium composition for all five elements (Strontium (Sr), Lead (Pb), Copper (Cu), Zinc (Zn) and Mercury (Hg)) among sites were slight, but significant. This was principally between the North Atlantic and SW Pacific Ocean fish, and location assignment was poor within the SW Pacific Ocean: less than 25% of fish were successfully assigned to source location. Nevertheless, mean Sr weight-fractions at the primordium showed similar latitudinal variation across sites in Australia, New Zealand and the Tasman Sea, indicating a degree of spatial structure to orange roughy populations. Ontogenetic variability of Sr from juveniles and young adults within and between sites in the SW Pacific fish was believed to strongly support the hypothesis that variability in some elements (e.g., Sr) could be site-specific and environmentally sensitive.
- Otolith shape was analysed by Smith et al. (2002) for the four Lord Howe Rise and Challenger Plateau areas. This analysis separated out two groups: Lord Howe-NW Challenger, and SW Challenger-Westpac Bank.
- A combination of parameters was studied by Gauldie & Jones (2000). They concluded that (1) parasite load was not related to region (on the scale of New Zealand Quota Management Area); (2) parasite load was weakly related to both otolith shape and fish growth rate; (3) there were differences in growth rate between regions; and (4) there was a significant variation in the shape of the otolith by region.
- Dunn & Devine (2010) examined data from within the Chatham Rise off New Zealand. They looked at catch distribution, CPUE trends, location of spawning and nursery grounds, inferred migrations, differences in life history parameters (patterns in length frequency distributions, length at maturity, fish condition), genetic studies using allozymes or mitochondrial DNA, and habitat structure and natural boundaries. They concluded that no individual analysis provided complete information on stock structure, and no two

individual analyses seemed to completely agree. The overall analysis favoured the assumption of two stocks on the Chatham Rise: northwest, and east/south.

Table 7: Summary of other stock discrimination analyses of orange roughy samples from the SPRFMO Convention Area, arranged chronologically.

Area	Method	Reference
Southern Australia (8 sites) New Zealand (3 sites)	Parasite fauna of the viscera	Lester et al. (1988)
Three areas (off Adelaide, off east and west coasts of Tasmania)	Trace elements in sagittal otoliths	Edmonds et al. (1991)
Southern Australia (7 non-spawning, 2 spawning [St Helens], 1 sample south of Tasmania)	38 morphometric measurements from 1300 fish, size-standardized, analysed by univariate and multivariate statistics	Elliott et al. (1995)
Puysegur Bank, Lord Howe Rise	17 body measurements and counts. Discriminant functions used to compare sites and sexes	Haddon and Willis (1995)
Geographically separated NZ populations (regional fisheries - Ritchie Bank, the North Chatham Rise, and the Challenger Plateau)	Parasite load, otolith shape, growth rate, depth of capture, sex and date of capture	Gauldie and Jones (2000)
Lord Howe Rise, Northwest Challenger, Southwest Challenger, and Westpac Bank	Otolith shape	Smith et al. (2002)
Australia (6 sites), New Zealand (4 sites), Tasman Sea (2 sites), and North Atlantic	Sr, Pb, Cu, Zn and Hg in otolith primordium and Sr ontogenetic variability	Thresher and Proctor (2007)
Chatham Rise	Catch, CPUE, location of spawning and nursery grounds, migrations, life history parameters, fish condition, genetic studies, habitat structure, oceanography.	Dunn and Devine (2010)

Conclusion: Some techniques indicated spatial structure (parasites, morphology, otolith chemistry) although patterns were inconsistent. These types of studies could be responsive to differing environment conditions by region.

3.6 Fishery distribution

Fishing effort for orange roughy has focussed on six main regions outside the EEZ: Lord Howe Rise (two areas), Challenger Plateau (northwest and southwest), West Norfolk Ridge, Louisville Seamount Chain, and the South Tasman Rise, with sporadic exploratory fishing in areas to the north along the Three Kings Rise (Figure 8).

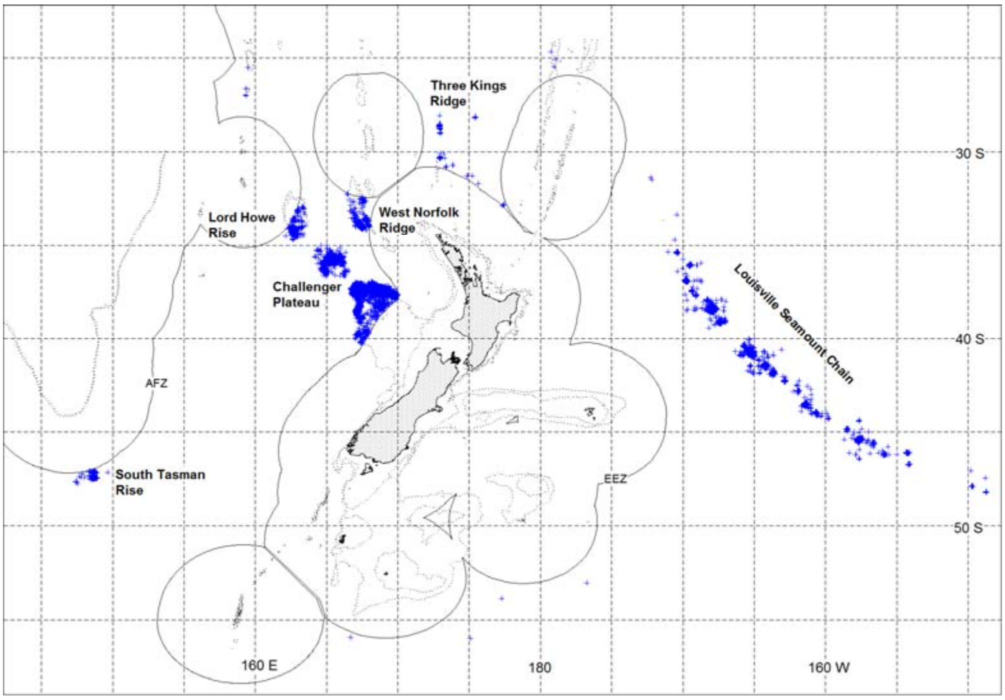

Figure 8: Distribution of tows where orange roughy was targeted or caught by New Zealand registered vessels from 1990 to 2014.

Fisheries outside the EEZ started on the Lord Howe Rise in 1988 (Clark & Tilzey 1996), but early data were incomplete until reporting requirements were formalised in the 1990s. The initial focus of fishing was on grounds of the Lord Howe Rise and Challenger Plateau, with the Louisville fishery developing in 1994 (Figure 9). The next five years saw the Lord Howe fishery decrease, the Louisville fishery develop further and expand its distribution, and a new fishery develop on the South Tasman Rise. The distribution changed again in the period from 2005 to 2009, with the South Tasman Rise fishery closed by the New Zealand and Australian governments, a new fishery developed on the West Norfolk Ridge, and catches became patchier and general smaller on the Louisville seamounts and Challenger Plateau. The last five year period (including incomplete catch data from 2015) saw effort reduce in coverage on the Louisville Seamount Chain, and also became more restricted on the Challenger Plateau. The fishery distribution was affected by the New Zealand bottom trawl standard adopted in the SPRFMO area, which has open-move-on areas, and areas closed to fishing (MFish 2008).

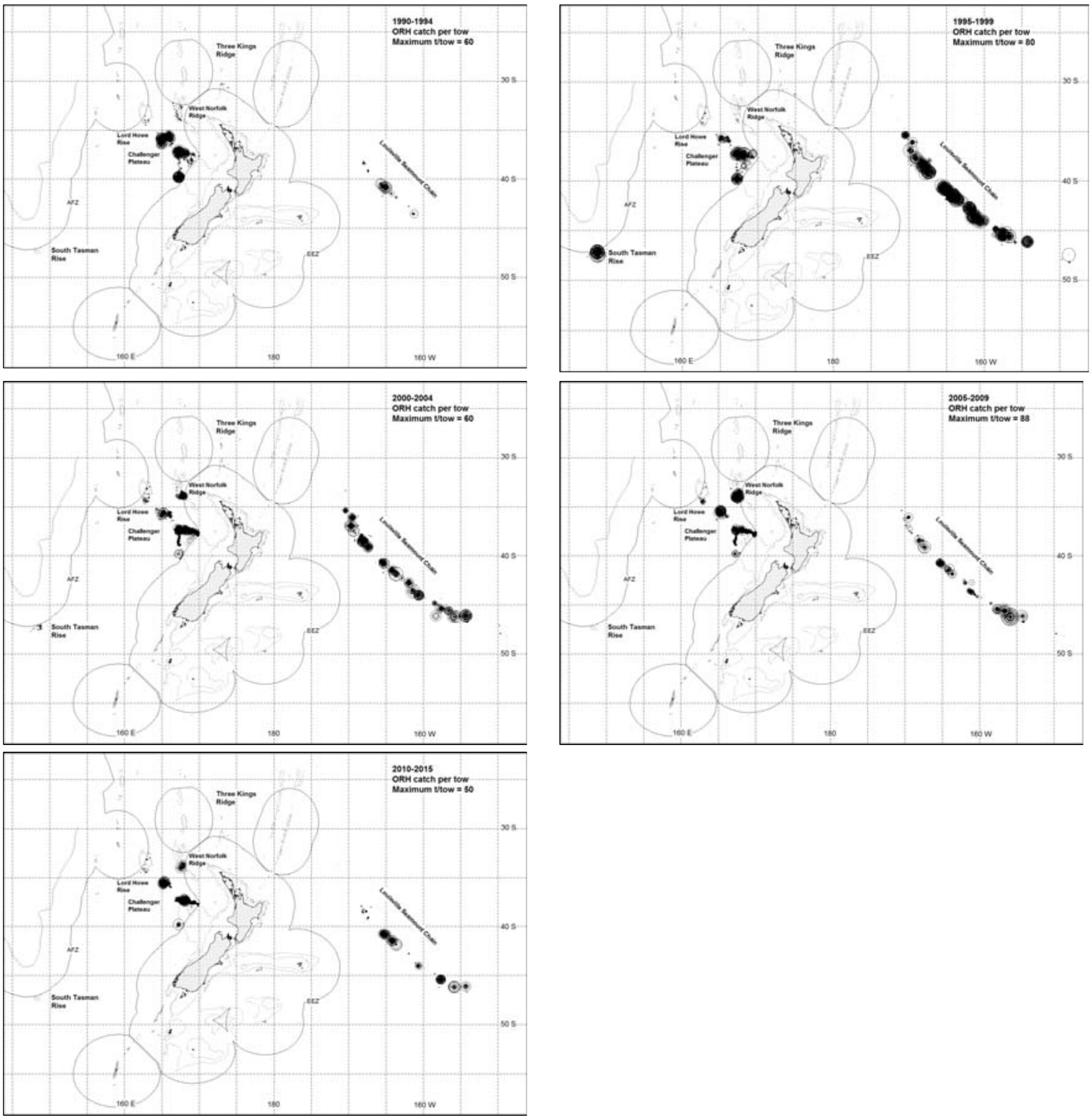

Figure 9: Distribution of catch rates by New Zealand vessels of orange roughy (catch per tow) in 5 yearly blocks from 1990 to 2015 (calendar year). The area of each circle is proportional to catch rate, with a maximum size of 90 t.

The location of orange roughy fisheries and high catch rates to the west of New Zealand was consistent over time, and match the existing divisions used for stock assessments on the Lord Howe Rise, NW Challenger Plateau, and the West Norfolk Ridge. However, catch and effort was more variable on the Louisville Seamount Chain (Clark et al. 2010), and the fishery distribution has varied between seamounts with area over time. The distribution of catch rates for all years combined, plotted against the existing and revised boundaries (for Louisville) are shown in Figure 10.

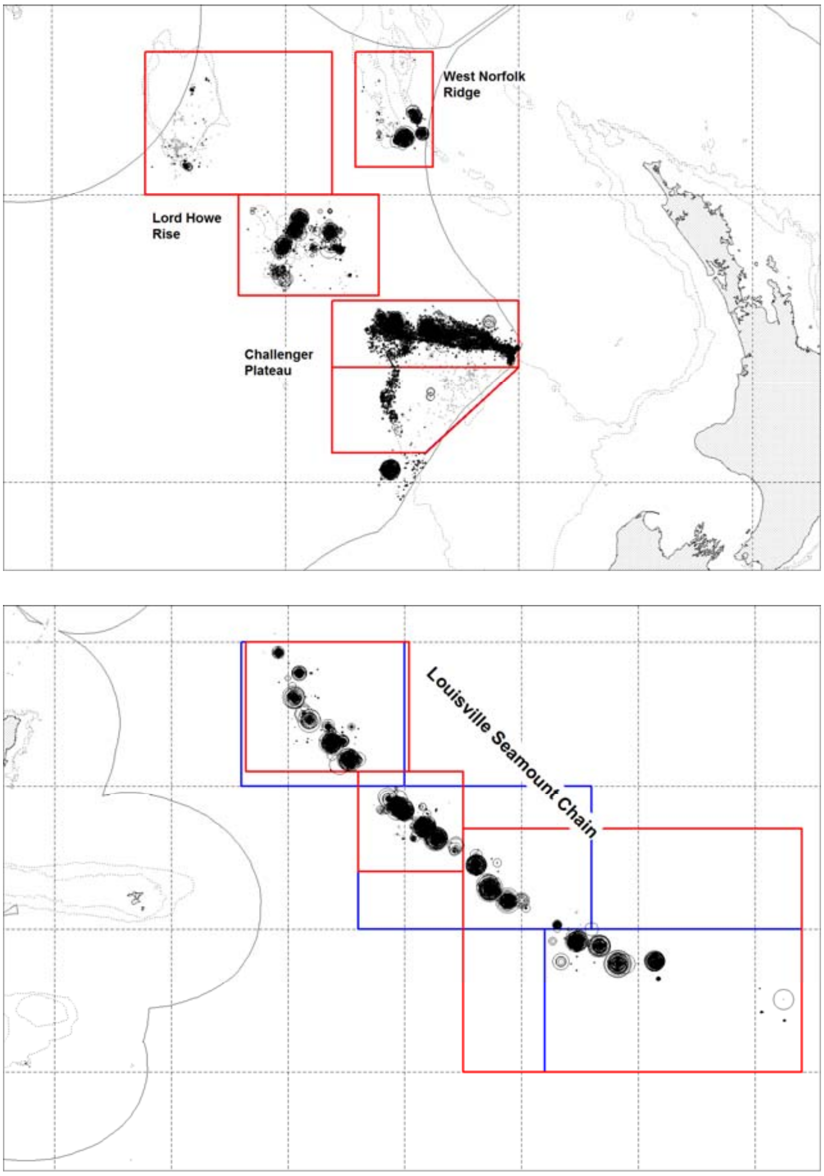

Figure 10: distribution of New Zealand bottom trawl fisheries for orange roughy (black bubbles) relative to the existing (blue), and new (red) sub-areas). Where both sub-areas are coincident, red boxes overlie blue boxes

4. 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 11).

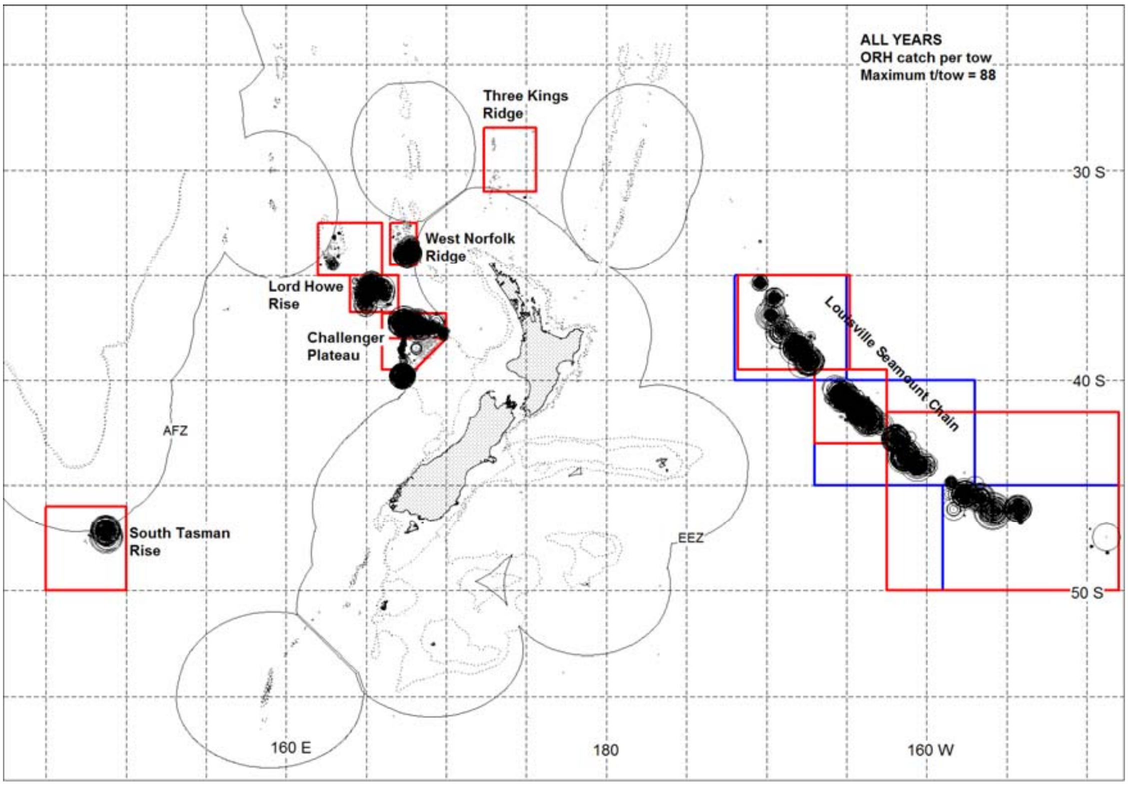

Figure 11: Comparison of new areas assumed for stock assessment purposes (in red) and previous areas (in blue) overlaid on the total distribution of catch rates for orange roughy. Where both areas are coincident, red boxes overlay blue boxes

The various sources of data described in this report were variable in quantity and quality. Often, there were contradictory or produced conflicting results, but overall a combination of data provided useful guidance for the management boundaries plotted above. The information that is central to the divisions applied to these areas is given in Table 8 below, which enables the reader to refer back to the key results. It is beyond the scope of this report to go through each data source and discuss the pros and cons in detail. For that exercise, we refer the reader to Dunn & Devine (2010).

Table 8: Summary of existing fishery areas, whether they are supported by this review, and the data sources used to reach conclusions.

"Fishery" area	Separate stock	Data
Lord Howe	Yes	Genetics Size Time of spawning Fishery discrete
NW Challenger	Yes	Genetics Size Time of spawning Fishery discrete
West Norfolk	Yes	Size Fishery discrete (but likely straddling stock with ORH 1)
SW Challenger (Westpac)	Yes (ORH 7A)	Genetics Size Timing of spawning Fishery discrete
Louisville Seamount Chain	Yes (North-Central-South)	Time of spawning Fishery seamount driven, but geographic groupings

The greatest uncertainty in stock structure, as it applies to management of orange roughy fisheries in the western part of SPRFMO, is the distribution of fish along the Louisville Seamount Chain. The changes suggested here based on spawning time are an improvement on the previous divisions which were largely driven by the geographical distribution of the fishery, and breaks in the seamount chain. However, our analyses suffered from the lack of samples or worked-up data from West Norfolk Ridge and the Louisville Seamount Chain. In particular there have been no genetic analyses, or examination of otoliths for potential changes in the age at maturity along the chain. We recommend strongly that Observer data collection is increased to include the sampling of tissues for genetic study, as well as continuing otolith collection (with subsequent analysis of age data).

5. ACKNOWLEDGMENTS

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Appendix 1: Percentage of each gonad stage for female orange roughy samples, by seamount and month (all years combined). Bold: seamounts are those where spawning (stages 3 and 4) was observed.

Seamount	Area	Month	Immature	Maturing	Ripe	Running ripe	Spent	N.staged
1246_	Lord Howe	Mar	0	13	88	0	0	8
		May	86	13	1	0	0	70
1472_	Kermadec Ridge	Apr	0	94	0	0	6	18
1485_	Louisville Central	Jul	11	8	2	54	25	121
1491_	Louisville Central	Mar	17	83	0	0	0	6
1492_	Louisville Central	Jul	0	8	65	26	0	263
		Aug	1	6	33	45	15	193
1495_Danseur	Louisville North	Apr	6	93	1	0	0	82
1523_	Louisville South	Jul	0	7	71	21	2	200
		Aug	0	4	43	39	13	524
1525_	Louisville South	Jul	1	49	38	12	0	100
		Aug	1	12	40	38	10	511
1526_	Louisville South	Jan	0	100	0	0	0	7
		Jul	0	48	31	21	0	271
		Aug	1	9	37	44	9	1194
		Sep	29	0	0	4	68	28
1528_	West Norfolk Ridge	Jan	25	70	5	0	0	394
		Feb	0	100	0	0	0	16
		Mar	10	80	10	0	0	163
		May	2	98	0	0	0	43
		Jun	0	20	34	38	7	441
		Jul	8	1	0	15	76	168
		Aug	11	0	0	0	89	18
		Oct	30	59	10	1	0	108
		Nov	11	79	4	1	5	124
1535_	West Norfolk Ridge	Feb	3	97	0	0	0	32
		May	1	98	1	1	0	181
		Jun	0	22	50	23	4	2079
		Jul	0	0	1	71	28	112
		Aug	37	0	0	0	63	93
		Oct	6	6	0	0	89	36
		Nov	0	62	38	0	0	26
1536_	West Norfolk Ridge	Mar	4	8	88	0	0	26
		May	0	87	13	0	0	52
		Jun	3	37	36	21	3	264
		Oct	2	0	0	0	98	58
		Nov	0	2	0	0	98	55
		Dec	0	75	25	0	0	79
239_	Louisville North	Jun	0	13	53	31	2	707

Seamount	Area	Month	Immature	Maturing	Ripe	Running ripe	Spent	N.staged
		Jul	7	0	0	4	89	46
474_	Louisville North	Jun	0	13	80	7	0	15
		Jul	69	0	0	14	17	29
482_	Louisville North	Feb	5	93	2	0	0	42
		Jun	7	10	55	24	5	165
		Jul	21	0	8	25	46	24
550_Mt Longva	NW Challenger	Jan	33	67	0	0	0	36
		Feb	0	0	100	0	0	1
		Mar	22	78	0	0	0	78
		Apr	17	77	0	0	6	285
		May	16	79	1	0	3	434
		Jun	5	26	38	22	9	3002
		Jul	16	2	10	30	42	756
		Aug	44	2	0	0	54	106
		Oct	72	20	4	0	4	132
551_Mt Boyes	NW Challenger	Jan	27	73	0	0	0	51
		Mar	0	0	100	0	0	3
		May	0	100	0	0	0	12
		Jun	1	53	43	3	0	140
		Jul	0	12	88	0	0	17
		Aug	24	53	0	0	24	34
552_Mt Oscar	NW Challenger	Jan	0	100	0	0	0	3
		Feb	0	88	13	0	0	8
		Mar	22	73	4	0	2	51
		May	7	69	18	0	6	375
		Jun	2	23	22	44	8	1575
		Jul	2	13	16	8	61	353
		Aug	57	0	0	0	43	7
561_Ayers Rock	NW Challenger	Jan	36	63	1	0	0	123
		Feb	55	39	6	0	0	33
		Mar	8	36	33	4	19	159
		Apr	27	68	1	1	4	196
		May	18	54	26	1	1	782
		Jun	5	37	39	16	3	2461
		Jul	19	4	6	28	43	1057
		Aug	95	0	0	0	5	62
		Sep	100	0	0	0	0	126
		Oct	97	0	3	0	0	37
563_Spin Pinnie	NW Challenger	Jan	38	56	6	0	0	16
		Feb	29	71	0	0	0	38
		May	2	31	67	0	0	64
		Jun	3	15	29	45	9	661
		Jul	0	0	0	40	60	42
		Sep	0	40	8	0	52	25

Seamount	Area	Month	Immature	Maturing	Ripe	Running ripe	Spent	N.staged
564_Pimple	NW Challenger	Jan	86	14	0	0	0	7
		Mar	0	0	100	0	0	1
		May	29	71	0	0	0	21
		Jun	0	42	48	10	0	162
581_Volcano	Westpac (Chall)	May	19	74	7	0	0	162
		Jun	7	63	10	18	2	562
		Jul	8	12	6	43	30	694
		Aug	5	5	0	40	50	62
		Sep	100	0	0	0	0	32
582_The Dork	Westpac (Chall)	May	22	38	40	0	0	72
		Jun	11	40	24	21	5	638
		Jul	14	21	13	31	21	1089
		Aug	0	41	11	26	22	46
		Sep	100	0	0	0	0	38
747_Mt Whales	Louisville Central	Jan	0	100	0	0	0	181
		Mar	8	47	17	3	24	274
		May	15	52	10	0	22	201
		Jun	8	61	12	16	3	978
		Jul	8	7	6	12	67	222
		Aug	6	69	0	0	26	54
		Sep	0	2	0	0	98	62
749_	Louisville Central	Jun	12	3	82	3	0	33
751_Mt Ghost	Louisville Central	Jan	6	94	0	0	0	82
		Feb	3	97	0	0	0	152
		May	11	87	1	0	0	211
		Jun	2	22	24	46	6	827
		Jul	3	4	10	59	22	1308
		Sep	6	1	0	0	93	138
752_Valerie	Louisville Central	Jan	0	100	0	0	0	13
		Mar	4	72	22	1	1	134
		Apr	75	25	0	0	0	8
		May	10	86	5	0	0	21
		Jun	4	62	26	7	0	1059
		Jul	5	7	16	23	48	598
		Aug	58	0	0	0	42	55
753_	Louisville North	Feb	0	100	0	0	0	33
		Jun	24	6	18	35	18	17
		Jul	17	1	8	25	49	76