

New Zealand Fisheries
Assessment Report
2008/65
November 2008
ISSN 1175-1584

An evaluation of stock status for orange roughy
on the east and south Chatham Rise in 2008

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**Published by Ministry of Fisheries
Wellington
2008**

ISSN 1175-1584

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**Ministry of Fisheries
2008**

Dunn, M.R.; Anderson, O.F.; Doonan, I.J. (2008).
An evaluation of stock status for orange roughy on the
east and south Chatham Rise in 2008.
New Zealand Fisheries Assessment Report 2008/65. 30 p.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

Dunn, M.R.; Anderson, O.F.; Doonan, I.J. (2008). An evaluation of stock status for orange roughy on the east and south Chatham Rise in 2008.

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This evaluation of orange roughy stock status covers the area of Quota Management Area ORH 3B that includes that part of the northern Chatham Rise known as the Spawning Box, the eastern Chatham Rise including the Northeast Hills and the Andes hill complex, and the south Chatham Rise. Catches from the fishery developed and peaked in the 1980s, and since then have reduced following a series of catch quota reductions.

The work in this report is described as an ‘evaluation’ rather than ‘assessment’ of stock status in order to distinguish it from previous work using Bayesian population models. These models were not used in 2008, because of concerns about predicted biomass rebuilds for the Spawning Box and Eastern Flats sub-stock which seemed to be determined by productivity assumptions rather than observational data, and so were replaced by a more holistic evaluation of the observational data sets.

The data sets and analyses described here are for commercial catch and effort, research trawl surveys, acoustic biomass surveys, the proportion of non-spawning adults, the spatial extent of the commercial fishery in the Spawning Box, standardised catch-per-unit-effort, recruitment estimates, and other information (length frequency, fish condition, and mean length at first maturity).

The cumulative commercial catch, combined with the decline in trawl survey biomass indices and in standardised CPUE indices, indicated the biomass on the east and south Chatham Rise stock was substantially fished down during the 1980s. By the early 1990s, the spawning biomass in the Spawning Box was probably reduced to less than 30% of initial levels. Since the early 1990s there is no evidence of a biomass rebuild, despite the reduction in commercial catches. In fact, there is evidence from standard CPUE indices, and other information, that the vulnerable biomass has continued to decline.

1. INTRODUCTION

The orange roughy (*Hoplostethus atlanticus*) fishery on the northeast Chatham Rise has been the largest and most persistent in the world (Branch 2001, Anderson & Dunn 2008). The Chatham Rise falls within Quota Management Area ORH 3B (Figure 1).

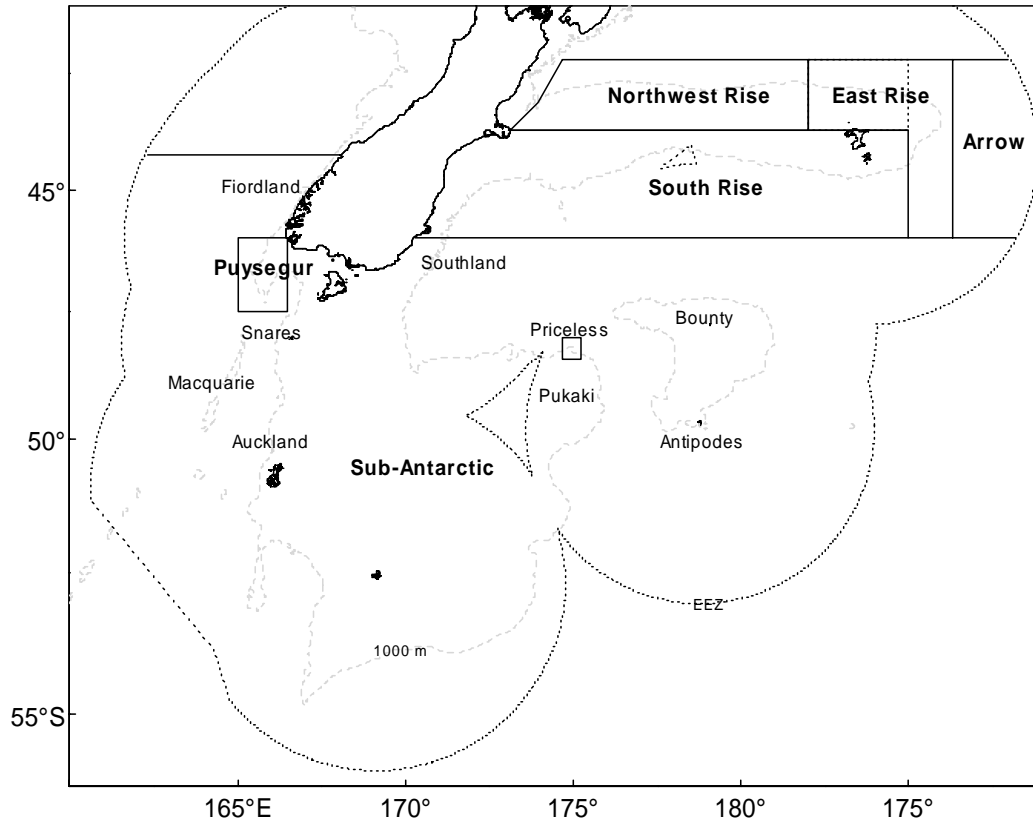


Figure 1: The ORH 3B designated sub-area boundaries (drawn and labelled in bold), and the approximate position of other named fisheries outside of the Chatham Rise. The Spawning Box is the western part of the area East Rise (to the west of the vertical broken line at 175° W). The Sub-Antarctic is all areas below 46° S on the east coast, and 44°16' S on the west coast, except Puysegur.

In previous stock assessments, the fishery on the Chatham Rise has been split into five assumed stocks; the Northwest Rise, then the Spawning Box and Eastern Flat, Northeast Hills, and Andes (these three together formed the East Rise), and then the South Rise (Anderson 2005, Dunn 2007a, Ministry of Fisheries, Science Group 2008; Figure 2). The 2008 assessment was different for two reasons. First, following an holistic analysis of the available information relating to stock structure, the East Rise and South Rise were assumed to contain a single continuous stock (Dunn 2008). Second, an assessment of the status of the combined East and South Rise stock for 2008 was completed without using a population model. To distinguish this approach from the population model approach used elsewhere, it has been referred to in this document as an “evaluation of stock status”.

The stock assessment model was not used in 2008 because in the previous assessment of the Spawning Box and Eastern Flats stock all the model runs predicted that stock biomass had been rebuilding since catches were substantially reduced in the early 1990s. However, this rebuild was insensitive to the recent observational data: when all of the data after 1994 were excluded the model gave an almost identical result to when they were included (Dunn 2007a, 2007b). From this, it became clear that the rebuild was being driven largely by model assumptions concerning productivity, rather than actual data. Specifically, an assumption was made that annual recruitment had been constant, largely because

of a lack of useable observations to the contrary. Results from model runs estimating year class strength were rejected by the Deepwater Fisheries Assessment Working Group, because the data on which they were based was indirect (i.e., length rather than age frequencies). The previous stock assessment of the south Chatham Rise provided a poor fit to the observational data, also assumed constant annual recruitment, and also predicted a biomass rebuild which was not seen in the biomass indices (Anderson 2005).

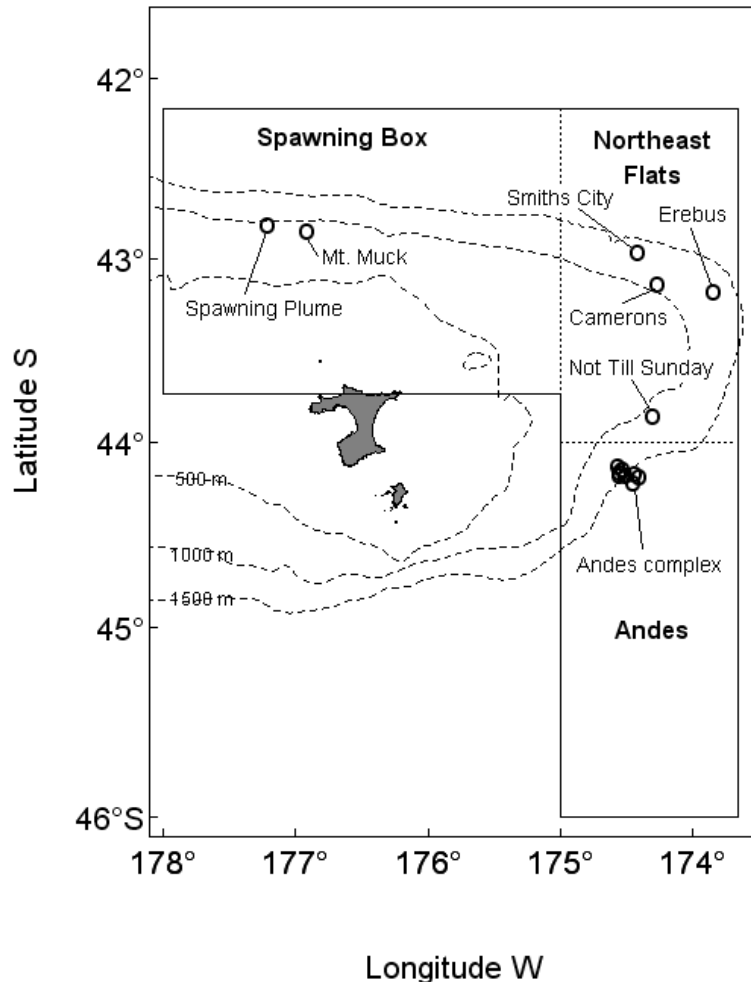


Figure 2: The east Chatham Rise area (solid box), showing the boundaries between the Spawning Box and Northeast Flats, and Northeast Flats and Andes (dotted lines), the position of the main features (circles), including the approximate position of the seasonal Spawning Plume. Mt Muck is also known as the "Crack".

As the Ministry of Fisheries Deepwater Fisheries Assessment Working Group did not believe the extent of the biomass rebuild predicted from stock assessment models, the models were set aside temporarily and stock status was instead evaluated from independent analyses of the main observational data (Ministry of Fisheries Science Group 2008). The data that were considered are presented in this report, and include catch and effort patterns, research trawl surveys, acoustic surveys of the Spawning Plume and background areas, standardised CPUE, and recruitment observations. Not all of the data sets or analyses described in this report were eventually accepted into the final Ministry of Fisheries Plenary Report on stock status (Ministry of Fisheries Science Group 2008).

The work described in this report was carried out under Ministry of Fisheries project ORH2007/02: Objective 4, “1. To evaluate the status of the stock by examining all relevant sources of data for the following areas: South and East Chatham Rise (ORH 3B).”

2. CATCH AND EFFORT PATTERNS

The total reported catch in ORH 3B for 2006–07 was 11 271 t, of which about 9100 t (81%) came from the east and south Chatham Rise. The historical patterns of catch and effort on the east and south Chatham Rise were described in detail by Anderson & Dunn (2008). The spatial extent of the fishery in each year was mapped by allocating individual catches to the nearest point on an axis, which ran clockwise around the Chatham Rise from the northwest to southwest corners (Figure 3). The fishery started in the Spawning Box during the spawning season (July), and on central areas of the south Rise outside of spawning. Around the time of the Spawning Box closure (1992–93 to 1994–95) large catches were taken during the spawning season on the Northeast Hills, Andes, and Big Chief and neighbouring hills. Spawning season catches continued on Smith’s City in subsequent years, but were negligible from 2001–02. In recent years the Spawning Box has been the only substantial spawning season fishery (Figure 4).

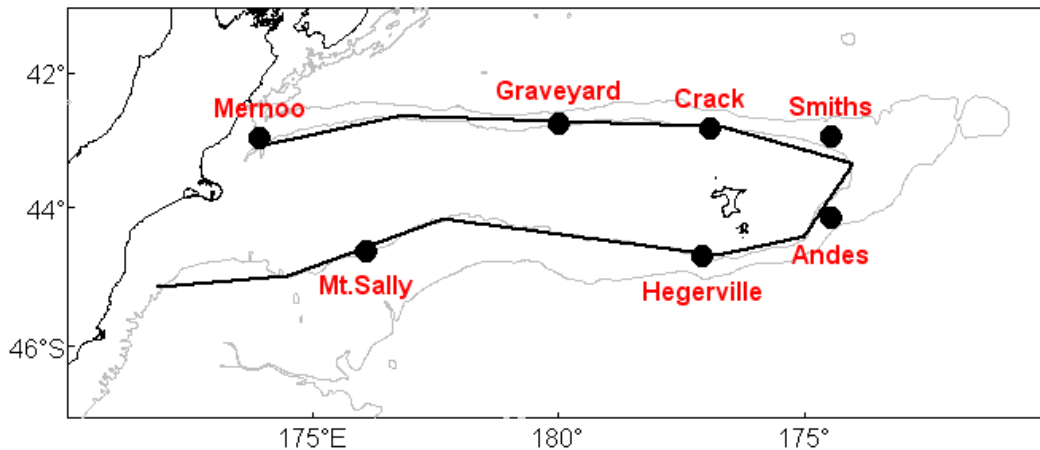


Figure 3. The position of the axis on the Chatham Rise. The labelled positions are those shown on Figures 4 and 5 for reference.

During the spawning season, the fishery initially focused on the spawning plumes near the Crack until the Spawning Box was closed in the early 1990s (Figure 4). At this point the fishery moved to the hills, first Smith’s City, then the Andes, and then Graveyard. The Spawning Box fishery restarted once the closure was lifted in 1994–95. Since 1994–95, the only persistent and substantial spawning season fisheries have been in the Spawning Box and on the Graveyard.

During the non-spawning season, on the south Rise the catches progressed eastwards during the mid to late 1980s (Figure 5), an effect which has been described as a serial depletion of orange roughy from the hills (Clark 1999). Since the early 1990s, the focus of the non-spawning fishery was on the Northeast Hills, the Andes, and Big Chief and neighbouring hills. Little catch came from the south Rise west of Big Chief and neighbours, and the only notable catches on the north Rise west of the Northeast Hills were at the western end of the Spawning Box in 2003–04 and 2004–05, and at the eastern end of the Spawning Box pre-spawning (peaking in May) during 2005–06 and 2006–07. The non-spawning fishery therefore contracted largely to the hill complexes on the southeast corner of the Rise, where in recent years some new fishing locations were developed. These have been between the Andes and Big Chief since 2000–01 (“Middleground”), and between the Andes and Not Till Sunday (“Kenwood”) since 2005–06 (Anderson & Dunn 2008).

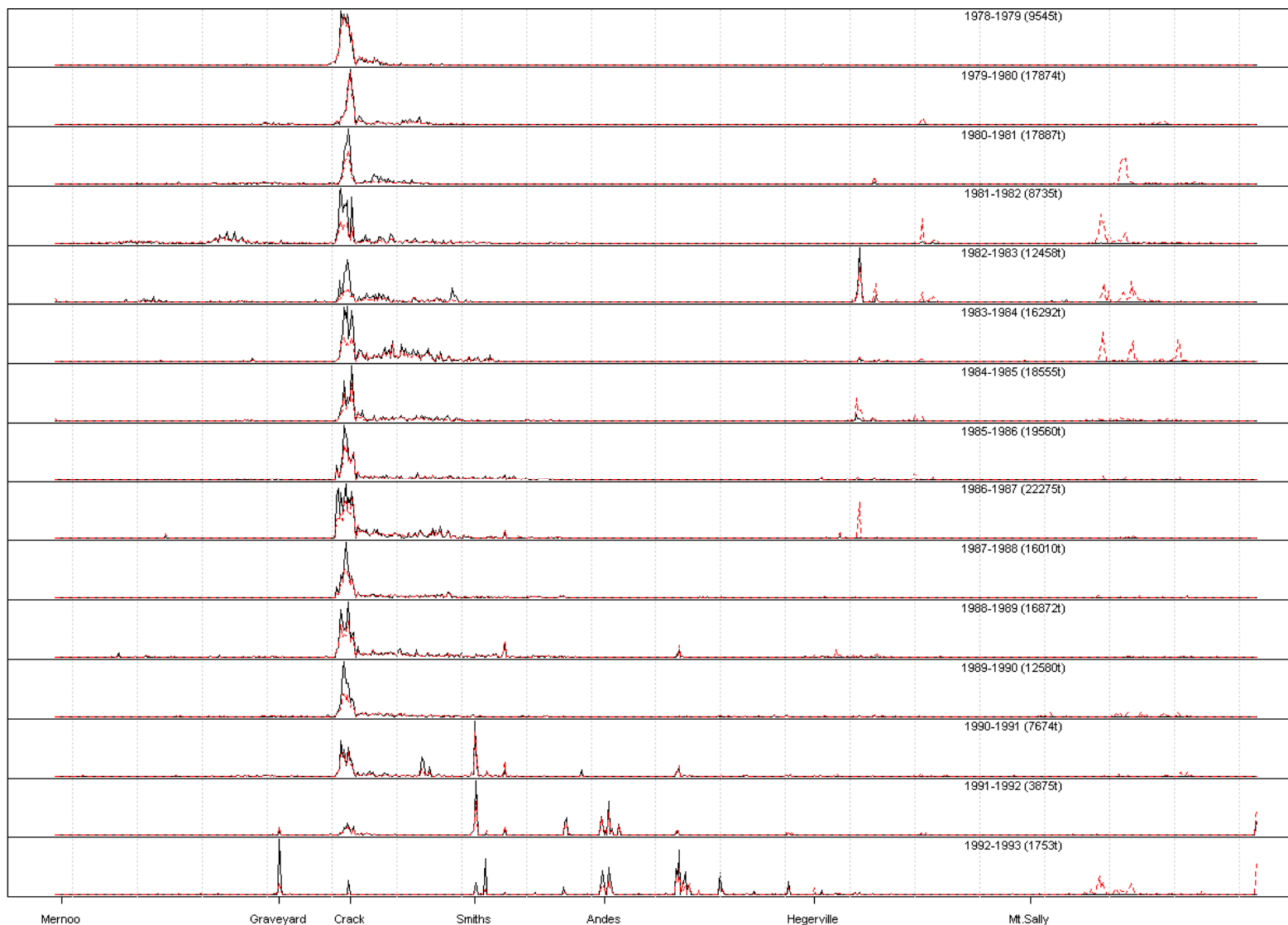


Figure 4: The proportion of annual catch (solid line) and effort (broken line) taken around the Chatham Rise (see Figure 3) during the spawning season (June, July, and August). The annual catch for each year is shown in parentheses. The Crack is towards the western end of the Spawning Box.

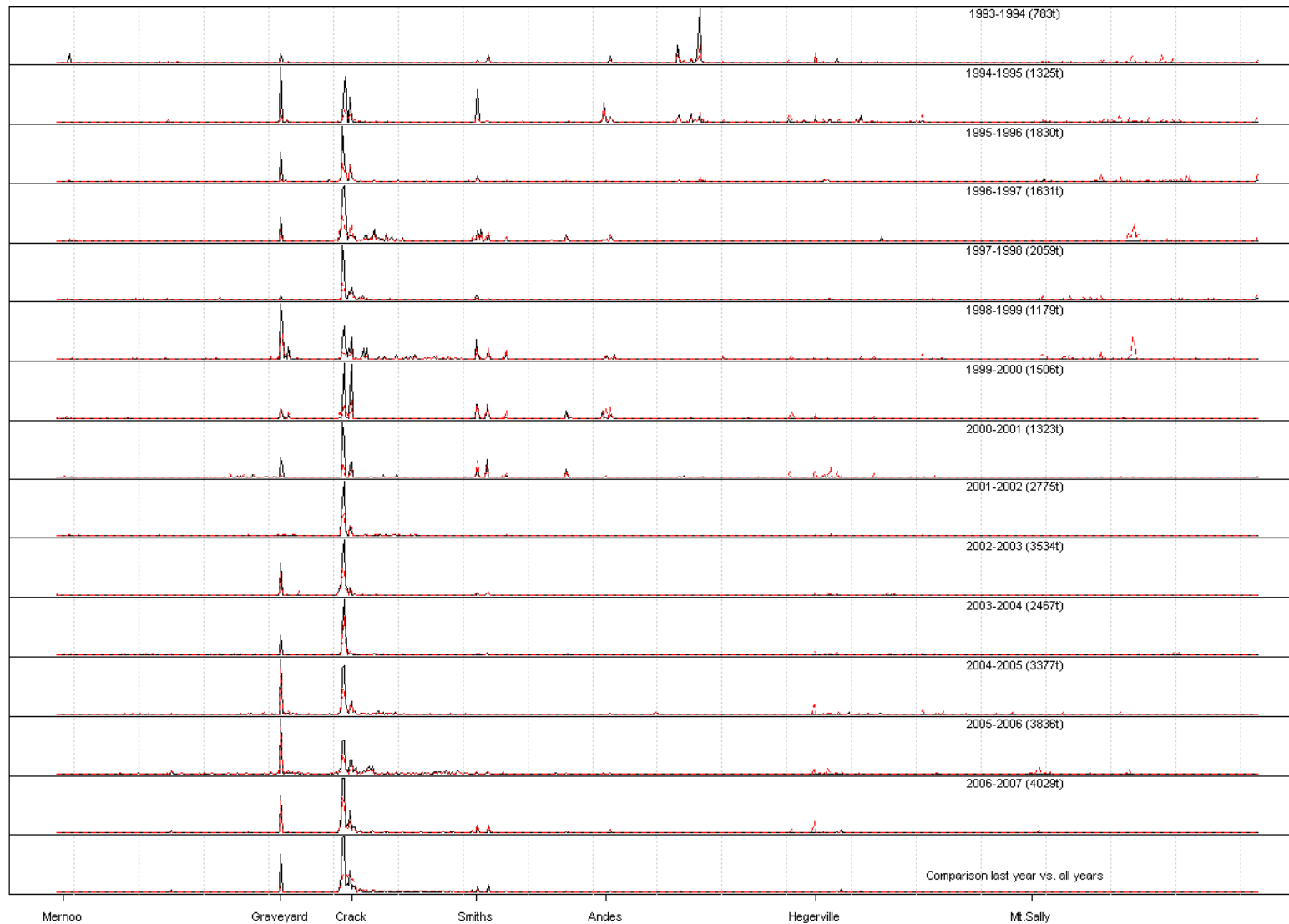


Figure 4 (cont.): The proportion of annual catch (solid line) and effort (broken line) taken around the Chatham Rise (see Figure 3) during the spawning season (June, July, and August). The annual catch for each year is shown in parentheses. The Crack is towards the western end of the Spawning Box.

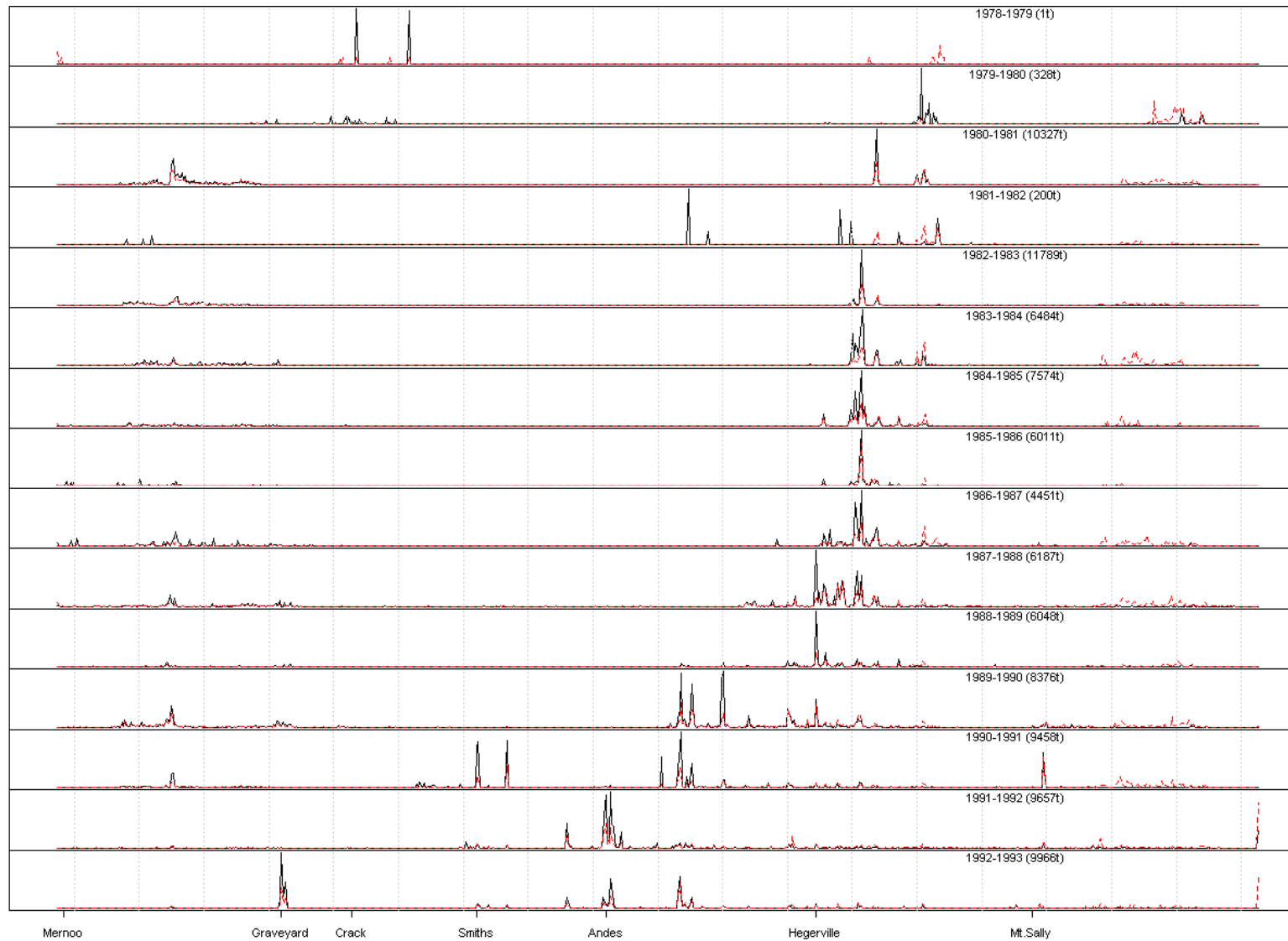


Figure 5: The proportion of annual catch (solid line) and effort (broken line) taken around the Chatham Rise (see Figure 3) outside of the spawning season (September to May). The annual catch for each year is shown in parentheses. The Crack is towards the western end of the Spawning Box.

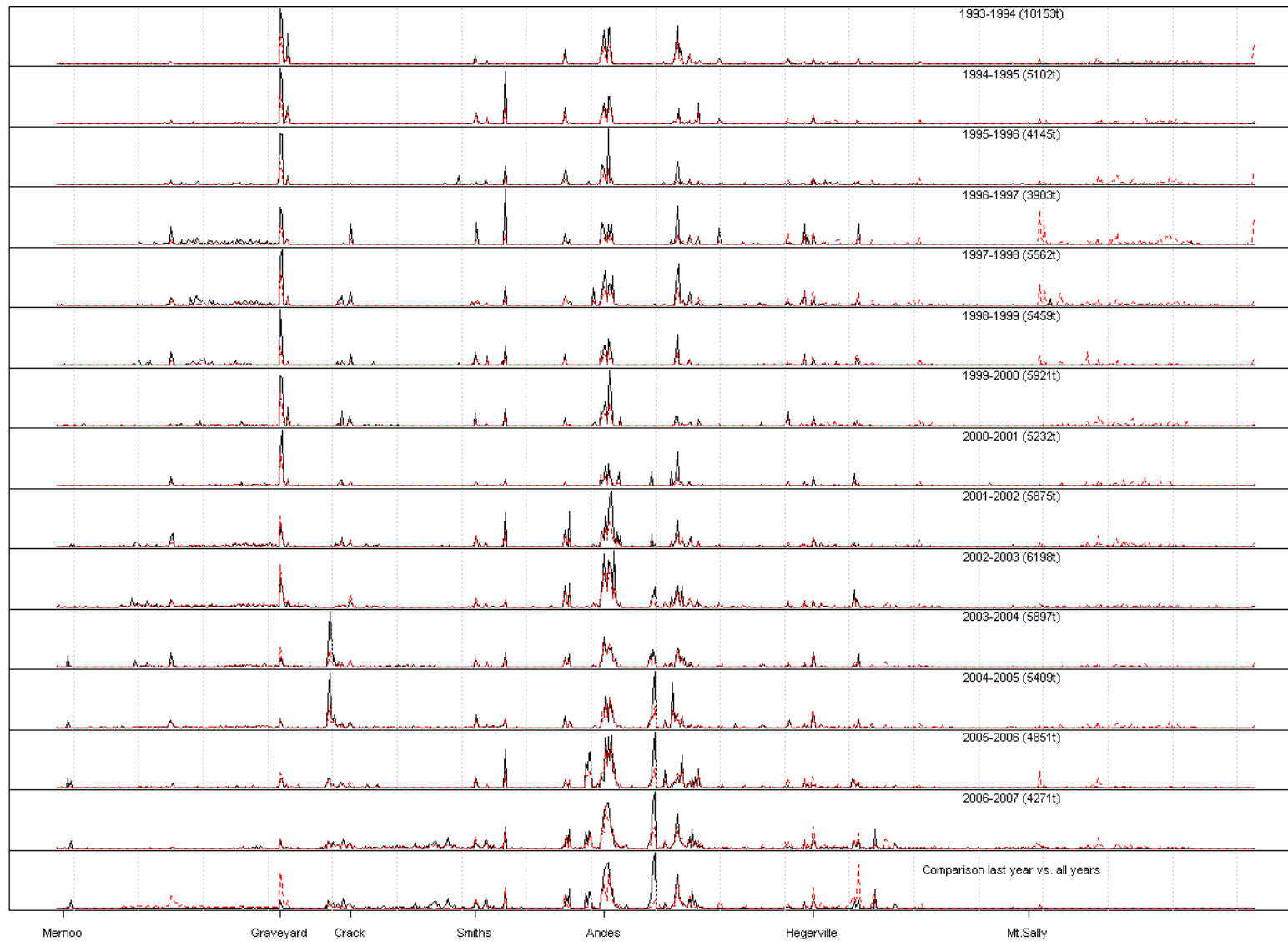


Figure 5 (cont.): The proportion of annual catch (solid line) and effort (broken line) taken around the Chatham Rise (see Figure 3) outside of the spawning season (September to May). The annual catch for each year is shown in parentheses. The Crack is towards the western end of the Spawning Box.

The catch and effort data support the following conclusions for the east and south Chatham Rise stock.

- There has been a spatial contraction of the spawning fishery to the Spawning Box, and a spatial contraction of the non-spawning fishery towards the southeast corner of the Rise (Clark 1999, 2001).
- Within the east Chatham Rise, the Spawning Box has increased in importance, with 54% of the catch in 2006–07, compared to an average of 53% in the 5 years before, and 39% in the 5 years before that (Anderson & Dunn 2008).
- Within the east Chatham Rise, the area over which vessels are searching for and fishing orange roughy has expanded (Anderson & Dunn 2008). The area fished has roughly doubled between 2002–03 and 2006–07.
- New fishing areas have been developed throughout the life of the fishery, and substantial catches of orange roughy have been taken from areas which were developed only within the last 10 years.
- The proportion of the quota caught when targeting pre-spawning or spawning aggregations in June and July has continued to slowly increase (Anderson & Dunn 2008).
- The number of tows completed by the fishery in recent years has been at the highest sustained level since the fishery began (Anderson & Dunn 2008).

We might also make the following inferences.

- If we assume that the fishery focuses effort on the areas where abundance and catch rates are consistently highest, we can infer the southeast corner of the Chatham Rise is the centre of the distribution for this stock outside of the spawning season. The contraction of the fishery would therefore be consistent with the spatial extent of the stock contracting as a result of exploitation.
- The location of new fishing grounds within the last 10 fishing years, for example the “Kenwood” fishery only in the last 2 fishing years, suggests there might still be some areas where orange roughy remain unfished. However, because of the increasing spatial coverage, the historical wide extent of the fishery, and because the new grounds were primarily in the southeast corner of the Rise, it now seems unlikely that any of these areas would be extensive.

In conclusion, the relatively high effort levels, increase in spatial extent of the fishery but spatial contraction of high catch areas, increasing focus on the Spawning Box, and the only substantial new grounds developed being towards the centre of the stock distribution, do not suggest a relatively large and rebuilding stock (Dunn 2007a), but they do support a depleted stock which has contracted towards the centre of its distribution.

3. RESEARCH TRAWL SURVEYS

3.1 Spawning Box surveys 1984 to 1994

Research trawl surveys of the Spawning Box during July were completed from 1984 to 1994, using three different vessels: FV *Otago Buccaneer*, FV *Cordella*, and RV *Tangaroa* (Figure 6). A consistent area was surveyed using fixed station positions, with some random second phase stations each year (Anderson & Fenaughty 1996).



Figure 6: The Spawning Box trawl survey biomass index (assuming a catchability of 1), with 95% confidence intervals shown as vertical bars. Vessels indicated as B, FV *Otago Buccaneer*; C, FV *Cordella*; T, RV *Tangaroa*. There were two alternative estimates for the trawl survey biomass in 1994, one including all tows (T), and one made after excluding a single large tow (indicated as “o”).

The trawl surveys indicated a decline in biomass between 1984 and 1992 (Table 1). The sequence in which the stations were fished was reviewed and changed for 1992 and 1994 to try to improve the estimate of fish density during the second phase of the trawl survey (Francis 1996). The 1992 and 1994 surveys estimated a relatively low proportion of males in the catch (having been close to 50:50 in previous surveys), and the precision of the indices was considered poor (Tracey et al. 1997). The 1994 estimate was especially uncertain because a single tow in the second phase caught a spawning plume, catching 71.7 t in 0.48 n. mile. The tow length was usually 3 n.mile, but this tow was hauled early due to the large volume of fish being caught. The single tow accounted for 66% of the biomass caught during the entire survey (Tracey & Fenaughty 1997). The high coefficients of variation (c.v.s) obtained were a result of the contraction of the high catch area (Tracey & Fenaughty 1997; Figure 7). Hypotheses for the observed low fraction of males and high c.v. of the biomass estimate were investigated in a survey in 1995, but were not resolved, and the Spawning Box survey was subsequently abandoned (Tracey et al. 1997). The large catch in 1994 suggested a substantial spawning plume was fished during that survey, but smaller maximum catches in previous surveys suggest such a substantial plume may not always have been fished (Table 1).

Table 1: Summary of trawl surveys of the Spawning Box. “Cumulative catch” is the cumulative commercial catch with over-runs (to allow for lost catches/burst nets, etc) added as specified by Ministry of Fisheries Science Group (2008).

Year	Survey code	Dates	Biomass estimate (t)	No. tows with >10 t catch	Maximum catch (t)	Cumulative catch + over-runs (t)
1984	BUC8401	9–24 July	130 000	13	44.8	143 000
1985	BUC8501	6–20 July	111 000	21	43.3	179 000
1986	BUC8601	6–26 July	77 000	11	45.9	212 000
1987	BUC8701	5–25 July	60 000	10	34.7	247 000
1988	COR8801	13 July – 11 August	73 000	7	49.0	275 000
1989	COR8901	10 July – 5 August	54 000	10	36.0	310 000
1990	COR9002	6 July – 10 July & 16 July – 31 July	34 000	5	67.7	344 000
1992	TAN9206	7–25 July	22 000	3	41.1	383 000
1994	TAN9406	7–30 July	61 000 ₁	3	71.7	405 000

1. Alternative estimate was 21 000 t, which excluded a single phase 2 tow of 72 t, where the tow distance was reduced to 9 minutes duration (0.48 n.mile) because a large mark was observed entering the net.

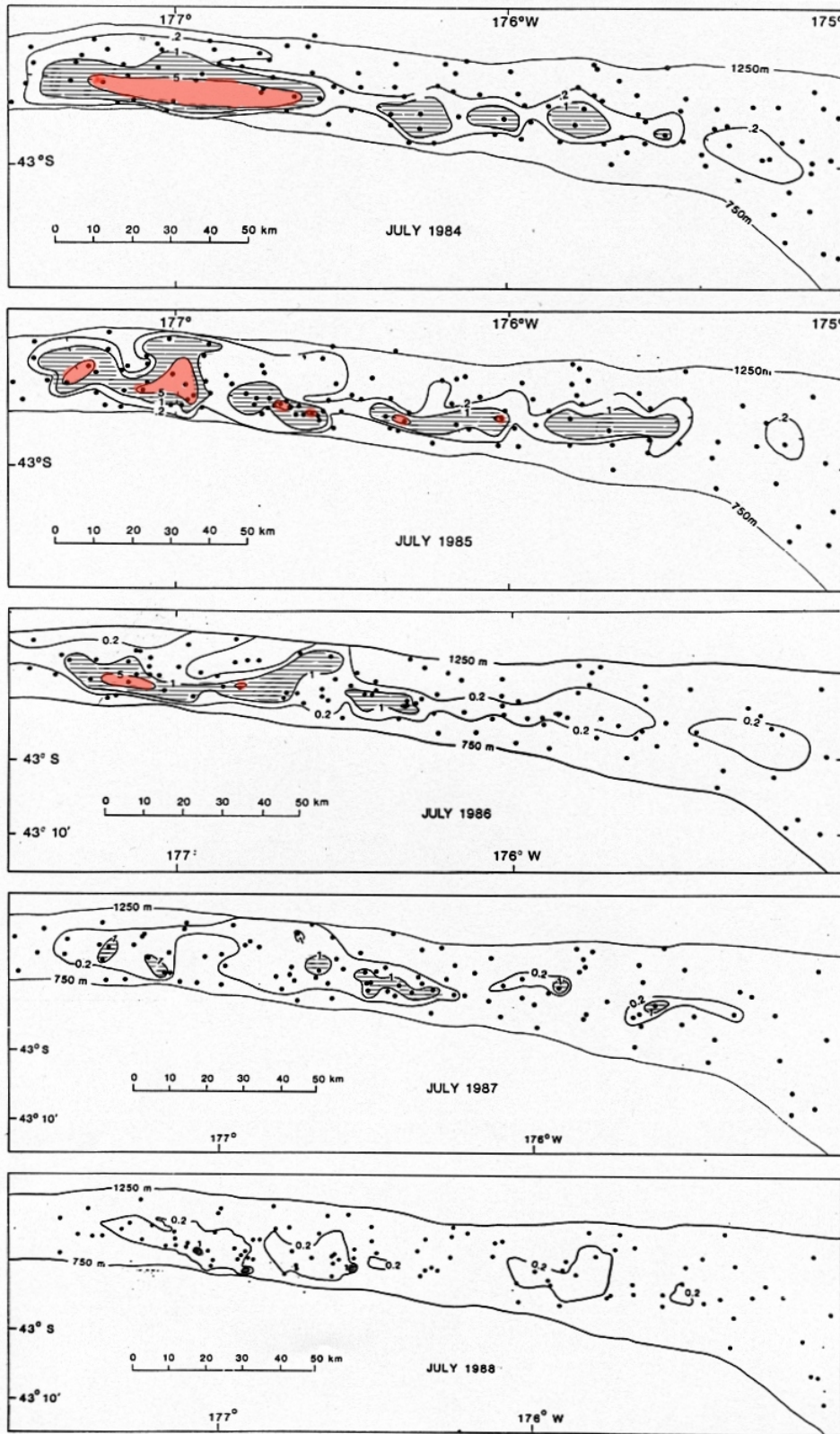


Figure 7: Catch rate contours ($t.km^{-1}$) for the trawl survey series from 1984 to 1988. Shaded areas are within the $5 t.km^{-1}$ contour, and the stippled area covers the 1 to $5 t.km^{-1}$ catch rates. Dots locate the trawl positions. Mt Muck is located at approximately $176^{\circ} 55' W$.

Whether the survey estimates of biomass are comparable within each series depends on whether the trawl surveys were consistently indexing the full spawning biomass. It appears that only a few tows in each survey encountered the large spawning plumes (Table 1). Whilst this would result in an underestimate of the biomass, it would not affect the trend provided that the spawning plume(s) in each year contained a constant proportion of the spawning biomass. However, if there was an increasing proportion of biomass within the plume(s), then the trawl indices would tend to overestimate the decline in spawning biomass, or vice-versa.

Depending on treatment, the Spawning Box trawl surveys indicated a reduction in biomass by 1990 to 21% or 26% of the 1984 level. When considered as independent unbiased indices, the trawl surveys indicate the biomass in 1987 was 46.1% of the 1984 level (*FV Otago Buccaneer*), and the biomass in 1990 was 46.6% of the 1988 level (*FV Cordella*). If the catchability during all surveys was the same, then the biomass in 1990 would be 26% of the 1984 level. If the series are treated as separate (i.e., the biomass in 1987 is assumed to be the same as 1988), then the biomass in 1990 would be 21% of the 1984 level. The biomass estimates from *RV Tangaroa* increased from 22 000 t to 61 000 t, a roughly 2.8-fold increase. However, the 1994 survey had very wide confidence bounds. If the catchability during the *RV Tangaroa* surveys is assumed to be the same as the previous surveys, then the biomass estimates in 1992 and 1994 were 17% and 47% respectively of the 1984 level.

The relative catchabilities are poorly informed. Whilst catchability ratio priors were developed for use in the 2006 stock assessment (P.Cordue unpublished results, Dunn 2007a), these were not appropriate for use in the present analysis.

3.2 Wide-area surveys 2004 and 2007

The Spawning Box and Northeast flat area, which extends from the eastern edge of the Spawning Box around to the northern edge of the Andes, were surveyed in 2004 (Doonan et al. 2006) and 2007 by *RV Tangaroa*. The area surveyed did not include the Spawning Plume or the Northeast Hills. The survey used a random stratified design, and was a combined acoustic and trawl survey in 2004, and a trawl survey in 2007. The trawl net used was the full-wing and relatively fine mesh ‘ratcatcher’ net.

The abundance of orange roughy estimated from the trawl surveys did not change significantly between 2004 and 2007 (Table 2). The size distribution of the fish changed, however, with an increase of about 2 cm in the left hand limb of the length frequency distribution (Figure 8, also see Section 6).

Table 2: Estimates of orange roughy mature abundance in biomass and number of fish (c.v. in parentheses) from the 2004 and 2007 trawl surveys, assuming a catchability of 1 between the wingtips (wingtip width of 25.4 m).

Year	Biomass (t)		Numbers ('000,000)
	Total	Mature (≥ 33 cm SL)	Total
2004	17 000 (10%)	7 000 (12%)	19.1 (13%)
2007	17 000 (13%)	7 100 (17%)	18.8 (12%)

3.3 Other surveys

There have been several other trawl surveys on the Chatham Rise, for other objectives, and for other species (notably oreos, *Allocyttus niger* and *Pseudocyttus maculatus*). These were not fully investigated for potential information about the status of the east and south Rise orange roughy stock.

A brief review of the trawl catch data from surveys of the southwest Chatham Rise seems to support the contraction in the spatial extent of the orange roughy stock suggested by the commercial catch data, as the frequency of occurrence of orange roughy in the research trawls declined from about 9% in the late 1980s to zero in 2002 and 2006 (Table 3).

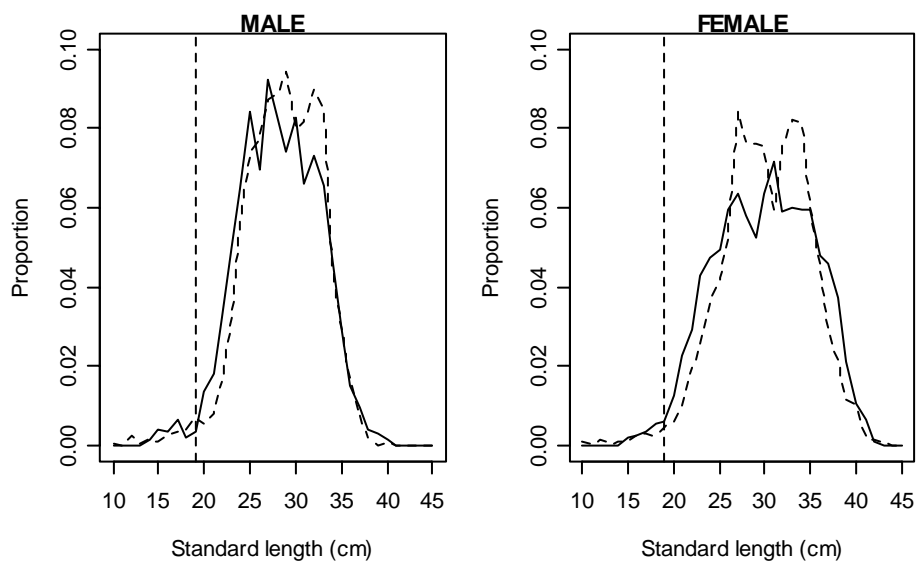


Figure 8: Orange roughy proportion at length estimated from the RV *Tangaroa* wide-area trawl survey of the Spawning Box and Eastern Flats in July 2004 (solid line) and July 2007 (dashed line). The vertical broken lines indicate a length of 19 cm, equivalent to the length of 50% vulnerability to the trawl net (see Section 6).

Table 3: Occurrence of orange roughy in trawl surveys covering the South Chatham Rise west of 176°E.

Year	Trip code	N tows	% occurrence orange roughy
1986	arr8603	84	10
1987	aex8702	87	8
1990	cor9004	62	10
1991	tan9104	44	5
1992	tan9210	24	4
1993	tan9309	44	0
1997	tan9713	48	2
2002	tan0213	21	0
2006	tan0615	22	0

3.4 Summary of trawl surveys

The various trawl surveys support the following conclusions for the east and south Chatham Rise stock.

- Although the relative catchabilities of the surveys of the Spawning Box trawl surveys are not known, it is highly likely that the component of the south and east Chatham Rise stock which spawned in the Spawning Box suffered a biomass decline of more than 50% between 1984 and 1994.
- By 1987, the FV *Otago Buccaneer* series alone showed a decline of over 50%. The continued decline of the subsequent FV *Cordella* series by more than 50% again would be consistent with the continued high commercial catch levels in this period. Together, these indices suggest an overall depletion by 1990 to about one quarter of the 1984 level.
- A substantial depletion of the biomass in the Spawning Box would be consistent with the large commercial catch having been removed (about 405 000 t between 1984 and 1994), and with the spatial contraction of the high catch rate areas.

- The cumulative commercial catch from the stock was about 150 000 t between 1979 and when the FV *Otago Buccaneer* survey started in July 1984, therefore the stock would have been well below virgin biomass levels (B_0) before the trawl survey indices started. About 550 000 t would have been removed from the stock between the start of the fishery and the end of 1994.
- The 2004 and 2007 trawl surveys of the background (non-plume) flat areas of the northeast and east Chatham Rise suggested no recent change in mature biomass.
- Other surveys supported a spatial contraction of the stock away from the southwest Rise.

In conclusion, the trawl surveys indicated a substantial depletion of the Spawning Box spawning aggregations during the 1980s (Clark 2001), most likely to levels below B_{msy} (30% B_0 , Ministry of Fisheries Science Group 2008). At the same time, the spatial area over which higher densities of mature orange roughy were found in the Spawning Box dramatically declined. The occurrence of orange roughy at the limits of the stock distribution on the south Rise has also declined. Recent trawl surveys found no change in biomass, suggesting biomass between 2004 and 2007 did not decline (nor rebuild).

4. ACOUSTIC BIOMASS SURVEYS

Acoustic biomass estimates are available for the spawning plumes in the Spawning Box, on various hills, and of dispersed fish on the background flat areas (Table 4). The hill areas surveyed at various times have included the Crack, Smith's City, Camerons, Erebus, Not Till Sunday, and the Andes. However, the techniques used to measure acoustic backscatter (e.g., hull mounted or towed transducers), and the analysis methods used to derived biomass estimates, have varied over time. As a result, a review and standardisation of the acoustic biomass estimates of the spawning plumes in the Spawning Box is planned for the 2008–09 fishing year.

In the following section, all of the acoustic biomass estimates have been converted to the arithmetic mean of the alternative biomass estimates obtained using the NIWA (Smith et al. 2008) and the Kloser & Horne (2003) target strength relationships. This method was used because of uncertainty in the true target strength for orange roughy.

Table 4: Orange roughy acoustic biomass estimates for the Spawning Box post-closure period, as the arithmetic mean of the biomass estimates using the NIWA (Smith et al. 2008) and Kloser & Horne (2003) target strengths. Plume survey estimates were derived from Soule et al. (2007). For the flat survey, the acoustic biomass estimates refer to spawning orange roughy, and were derived from tables 3 and 5 of Doonan (DW-WG 2005/76 revised). Estimates for the Northeast (NE) Hills refer to total orange roughy (this was almost entirely spawning); estimates for the Andes and the Crack refer to spawning orange roughy; all were derived from Doonan et al. (2001, 2006). All biomass estimates have been rounded to the nearest 100 t, with c.v.s given in parentheses.

Year	Plume survey	Acoustics	NE Hills	Andes	The Crack
1998	27 500 _{1,2} (30)	28 400 ₃ (48)	–	–	–
1999	–	–	–	–	–
2000	41 000 ₂ (29)	–	29 400 (16)	2 400 (40)	–
2001	–	–	–	–	–
2002	67 400 (25)	–	–	–	–
2003	57 100 (27)	–	–	–	–
2004	48 600 (25)	5 700 (30)	600 (53)	–	1 500 (64)
2005	43 400 (25)	–	–	–	–
2006	46 800 (26)	–	–	–	–
2007	55 200 (25)	–	800 ₄ (86)	–	–

1. Including the Crack.

2. NIWA snapshots only

3. Expanded from the survey area to the 2004 equivalent area using a factor of 4.3 by Doonan (DW-WG 2005/76 revised).

4. Estimated using catch composition from 2004.

4.1 Spawning Box plume surveys

The Deepwater Group (formerly the Orange Roughy Management Company) contracted Fisheries Resource Surveys (South Africa) to conduct a series of acoustic surveys of the spawning plumes in the Spawning Box using FV *San Waitaki*. Eight acoustic surveys during July were available (Figure 9). Surveys in 1998 and 2000 were completed by NIWA, and were not directly comparable to the later series. Note that when treated as a biomass index, the c.v.s shown in Figure 9 will be smaller, because the estimates shown in Figure 9 include the uncertainty associated with target strength.

If treated as absolute biomass index, the last six plume surveys indicate little change in spawning biomass (Figure 9), with a mean level of about 53 000 t.

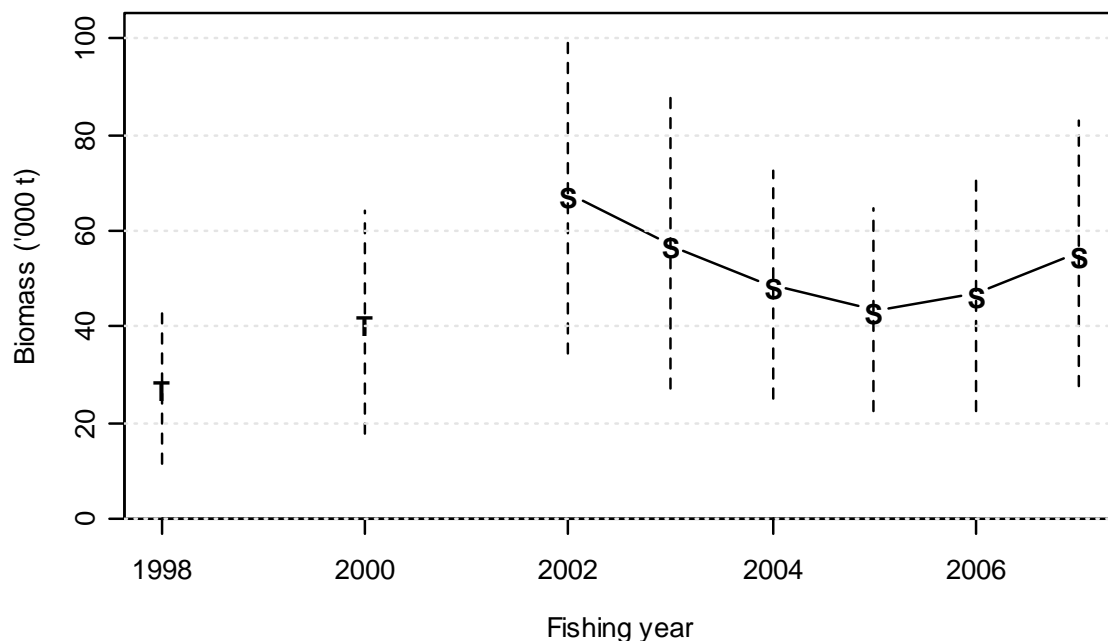


Figure 9: Acoustic biomass estimates for the spawning aggregations in the Spawning Box during July, completed by MFish/NIWA using RV *Tangaroa* (T), or by the Deepwater Group/FRS using FV *San Waitaki* (S), with 95% confidence intervals of the absolute biomass estimates shown as vertical bars. The biomass estimates plotted are the arithmetic mean of the biomass estimates obtained from the NIWA (Smith et al. 2008) and Kloser & Horne (2003) target strength relationships.

4.2 Hill surveys

Acoustic surveys of the Northeast Hills (Smith's City & Camerons) have been completed by industry vessels, and in 2000, 2004 and 2007 by RV *Tangaroa* (Table 4). The species mix in acoustic marks on hills has been determined by trawling, but the veracity of this method is believed to be poor because of unknown species' reactions to the trawl gear, and mismatches between the acoustic mark measured and the time and area trawled. As a result, the use of acoustic methods to determine biomass of orange roughy on hills has been regularly disputed within the Ministry of Fisheries Deepwater Fisheries Assessment Working Group. For the Northeast Hills, the species mix observed in 2004 was assumed for 2007, the results effectively indicate that the total acoustic backscatter showed little or no change between 2004 and 2007, although the survey in 2000 suggested that larger quantities of roughy may have been present (Table 4). Surveys of the Andes and the Crack found relatively small amounts of orange roughy compared to the spawning plume in the Spawning Box (Table 4).

4.3 Wide-area flat surveys

In addition to the acoustic biomass series for the Spawning Plume, a wide-area survey of the Spawning Box background areas and Northeast Flats combined was completed by *Tangaroa* in 2004. This survey, and the one in 1998, demonstrated that there may be substantial amounts of mature orange roughy outside the Spawning Plume, and an allowance needs to be made for this biomass in determining stock size (Table 4).

It is difficult to regard the wide-area estimates as unbiased estimates of absolute biomass because they include fish from mixed-species and usually diffuse marks. The low target strength of orange roughy relative to other species in these mixed-species marks means that there is a high potential for bias. Although there is obviously some mature biomass outside the plume, the proportion is difficult to determine.

4.4 Summary of acoustic surveys

The various trawl surveys support the following conclusions for the east and south Chatham Rise stock.

- The plume surveys from FV *Waitaki* 2002 to 2007 suggest no substantial change, or perhaps a decline, in spawning biomass over recent years, with a mean plume biomass of 53 000 t. This estimate of absolute biomass has substantial uncertainty, primarily associated with uncertainty in orange roughy target strength.
- A review of methods, and a subsequent standardisation, is required before the 1998 and 2000 surveys of the plume may be considered as part of the same index. However, if unchanged, they could indicate an increase in plume biomass between 1998 and 2007.
- The variability in the biomass estimates for the plume may be real, and indicate variability in the proportion of mature fish coming to spawn in any given year (see Section 5).
- Mature and some spawning orange roughy, occur on the Northeast Hills, the Crack, and the Andes. However, most of the spawning orange roughy appear to be in the spawning plumes in the Spawning Box.

In conclusion, the acoustic surveys indicate the main spawning biomass has been in the Spawning Box, with an uncertain but probably relatively small amount of spawning roughy on other flat areas and the hills. The biomass in the Spawning Box plumes does not appear to have changed substantially over recent years, but the estimates need to be reviewed and standardised before further conclusions about trend can be made.

5. THE PROPORTION OF NON-SPAWNING ADULTS

This section reviews the published information on the proportion of non-spawning but mature female orange roughy (Dunn & Dunn 2008) (Table 5). This is required to scale the acoustic absolute estimates of spawning orange roughy biomass (primarily) in the plumes to the total mature biomass. The total spawning stock biomass is the spawning biomass multiplied by the scalar. We might then add an amount to this to allow for fish outside the areas measured.

An alternative method would be to avoid the scalar, and directly estimate total mature biomass. This has been the objective of the wide-area surveys. The only case where this might give a complete estimate is for the northwest Chatham Rise in 2006 (Smith et al. 2008). Previous surveys of the

remainder of the Rise have been restricted to the east Rise area, consistent with the previously assumed stock structure (Doonan et al. 2006). Following the revised stock structure, where the east and south Rise are combined, these surveys are now considered incomplete.

Only a single study was found considering the frequency of non-spawning males (Table 5). There were also additional data from trawl surveys and commercial fishing which might have enabled further estimates to be made, but this would have required further analyses and was beyond the scope of this project.

Table 5: Published estimates of the ratio used to raise spawning to total mature orange roughy. All but two of these estimates are based on comparing the proportion of stage 3 and above fish (fish assumed to spawn that year) with those above the maturity L50 (fish assumed to be mature). The other two estimates are made directly from wide-area surveys. There are undoubtedly problems identifying skipped spawning both macroscopically, and also histologically (see review by Rideout et al. (2005)). In particular, the stages maturing, resting, and spent are especially difficult to distinguish (see review by Murua et al. (2003)). For example, Doonan et al. (2004) found 72% of individuals classified as stage 2 (maturing) were in fact stage 6 (spent). All estimates are for females, unless specifically stated.

Scalar	Source	Area	Method	Comment
1.82	Bell et al. (1992)	Australia	Trawl survey measurement of No. spawning / No. assumed mature (from length)	23% resting, 27% atretic. Had a 'best estimate' which was the highest value found for 1990. Could be biased (a little high) because of timing.
1.56-1.91 (mean 1.7)	Anon. (MFish WG Document)	New Zealand (Ritchie Bank)	Trawl survey measurement of No. spawning / No. assumed mature (from length)	From document "Estimation of the biomass ratio mature to spawning mature, Smat". The 1992-94 surveys were, in order, 1.63 (c.v. 0.2), 1.56 (0.09) and 1.91 (0.07).
1.20-1.46	Kirchener & McAllister (2002)	Namibia	Literature review/surveys/other?	The authors cite Branch (unpublished MSc thesis, 1998) developed a prior for use in stock assessment, with minimum 1.1 maximum 2.0 most likely range 1.20-1.46
1.35	Anon (MFish WG Document).	New Zealand (NW Chatham Rise)	Trawl survey measurement of No. spawning / No. assumed mature (from length)	From document "Estimation of the biomass ratio mature to spawning mature, Smat". From the 1994 survey. c.v. 0.04.
1.17-1.38	Doonan et al. (1999)	New Zealand (NE Chatham Rise)	Trawl survey measurement of No. spawning / No. assumed mature (from length)	For the hill survey was 1.17 (c.v. 0.04). For the Spawning Box, the estimate was 1.38 (0.1). This estimate is likely to be biased, as it was done during July on the spawning grounds, whereas it should have been done in March/April on dispersed (mixed) fish.
1.11-1.41	Koslow et al. (1995)	Australia	Trawl survey measurement of No. spawning / No. assumed mature (from length)	The same as Bell et al. (1992) but for subsequent years. For 1991 and 1992 the ratio was 1.11 for males (c.v. 0.2) and 1.41 for females (c.v. 0.06). Mean of these is 1.26.
1.25	Smith et al. (2008)	New Zealand (NW Chatham Rise)	Acoustic biomass survey.	Total spawning abundance of 7200 t, and total mature abundance of 9035t. Gives a ratio of $9035/7200 = 1.25$.
1.09-1.26	Shephard & Rogan (2006)	NE Atlantic	Trawl survey measurement of No. spawning / No. assumed mature (from length)	An overestimate, as it includes too many immature fish (used 30 cm cut-off when the L50 was 34.1-37.0 cm). Also potential bias because of potential staging errors. An underestimate if the full geographic range wasn't sampled.

Table 5 (cont.)

Scalar	Source	Area	Method	Comment
1.10	Anon. (MFish WG Document).	New Zealand (East Cape)	Trawl survey measurement of No. spawning / No. assumed mature (from length)	From document "Estimation of the biomass ratio mature to spawning mature, Smat". From the 1995 survey. c.v. 0.02.
1.01-1.02	Berrehar et al. 1998	NE Atlantic	Proportion classified as resting in commercial catch	Likely to be biased (low) if the fishing focused on spawning aggregations (this is unclear).
1.01	Doonan et al. (2006)	New Zealand (East Chatham Rise)	Acoustic biomass survey (wide-area + hills + plume survey)	Probably biased low because the survey didn't cover the Andes or south Chatham Rise. Estimate of spawning biomass is Spawning Box plume + Smiths + Camerons + Mt.Muck + 89% of wide-area (where 11% of adult fish were classified as resting). The estimate of resting is 11% of wide-area survey.

The two cases where non-spawning proportion was estimated in consecutive years suggested significant variability from year to year, between 1.56 and 1.91 for the Ritchie Bank on the east coast of New Zealand, and 1.41–1.82 for northeast Tasmania (Table 5).

Overall, the estimates of the non-spawning scalar are not widely divergent, and fall within the range 1.01 to 1.91. After excluding Kirchener & McAllister (2002), and excluding males (Koslow et al. 1995) because macroscopic assessments were believed to be less reliable, of the remaining 14 estimates three-quarters fall within the range 1.1–1.63, and the median is 1.26. This median is within, but at the lower end of, the 'most likely range' given by Kirchener & McAllister (2002).

An alternative approach would be to focus on the most reliable estimates, and because of the apparent variability between areas, include only a single (mean) estimate for each area. The range of these estimates is 1.1 to 1.91, and the area estimates used would be 1.54 for northeast Tasmania (weighting the estimates by the number of years), 1.7 for the Ritchie Bank, 1.28 for the northeast Chatham Rise, and 1.3 for the northwest Chatham Rise, giving an overall median of 1.42 and mean of 1.46.

Limited information on the proportion of mature orange roughy which might occur on the south Rise was available from the trawl survey that covered the whole Chatham Rise between May and July 1994 (Tracey & Fenaughty 1997). Although confounded by survey timing, the proportion of resting fish was low on the north Rise, and increased clockwise onto and along the south Rise. Compared to the northeast Hills in July, the catch rates were relatively low on the hills around Big Chief and the Andes in July, and very low on the rest of the south Rise in May.

Other sources of data which were not investigated here include the industry acoustic surveys biomass on the Northeast Hills, which were difficult to interpret because they assumed 100% orange roughy in the acoustic marks (Deepwater Fisheries Assessment Working Group Document DW-WG 05/09). There have also been some commercial and research tows, particularly in the 1980s, on the south Rise during July.

The non-spawning proportion review supports the following conclusions for the east and south Chatham Rise stock.

- About one-third of the mature biomass might not turn up to spawn each year.
- The proportion spawning each year might be variable. Variability in spawning plume biomass estimates over a short time series might therefore be indicative of variations in spawning proportion rather than SSB trend. The proportion spawning might change in response to, for

example, natural collective cycles in intermittent maturation, changes in environmental conditions, or perhaps the amount of disturbance encountered on preferred feeding grounds.

- It is possible the non-spawning proportion of males might be different, and the single published estimate suggested a lower ratio (Koslow et al. 1995). This could be consistent with males spawning more often, because of a lower energetic investment associated with spawning.

In conclusion, there are no estimates of the non-spawning proportion for the east and south Chatham Rise. As a result, it is not clear whether any observed trends in spawning biomass (Section 4) can be used to describe trends in mature biomass, because they could be a result of trends in the non-spawning proportion.

6. SPATIAL EXTENT OF COMMERCIAL CATCHES IN THE SPAWNING BOX

The spatial extent of the spawning plume was estimated using commercial catch data, assuming the areas where large catches were most frequent indicated the location of the plume, and the area over which large catches were taken was an index of the spatial extent of the plume. Catches were plotted using the tow start positions, for a period either 1 week either side of peak spawning (and where tow length was less than 1 hour), or 2 weeks either side of peak spawning (tow length less than 2 hours). Peak spawning was estimated from the available maturity stage data. The area in which high catch rates were taken was more extensive in the past (Figures 10 & 11), and extended from the position of the current spawning plume, through to the east of the Crack, a distance of about 12 n.miles. The high catch rate area appears to have contracted to the west of this area by the early 2000s. The catch distribution in the 1980s was similar to the biomass distribution from the research trawl survey (see Figure 7).

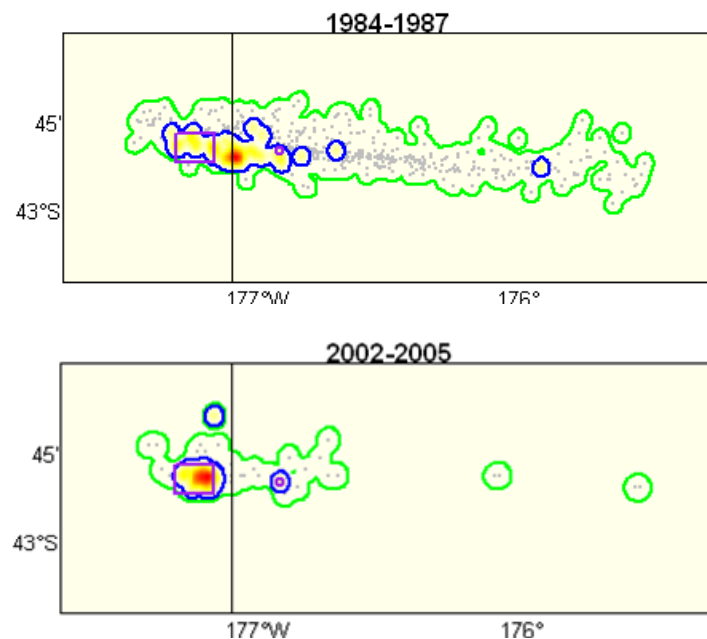


Figure 10: Contour of start positions for commercial trawls that were within 1 week of the peak of spawning and less than 1 hour duration. Outer contour is the extent of all tows in the data set, the darker inner contour is for tows that caught 30 t or more. Within the 30 t contour, the density of tows is shown using a “heat” plot where darker represents the highest density. The gray dots are the positions of tows outside the ≥ 30 t area. The box marks the approximate position of the recent plume, and the circle to the east of 177° W marks the Crack.

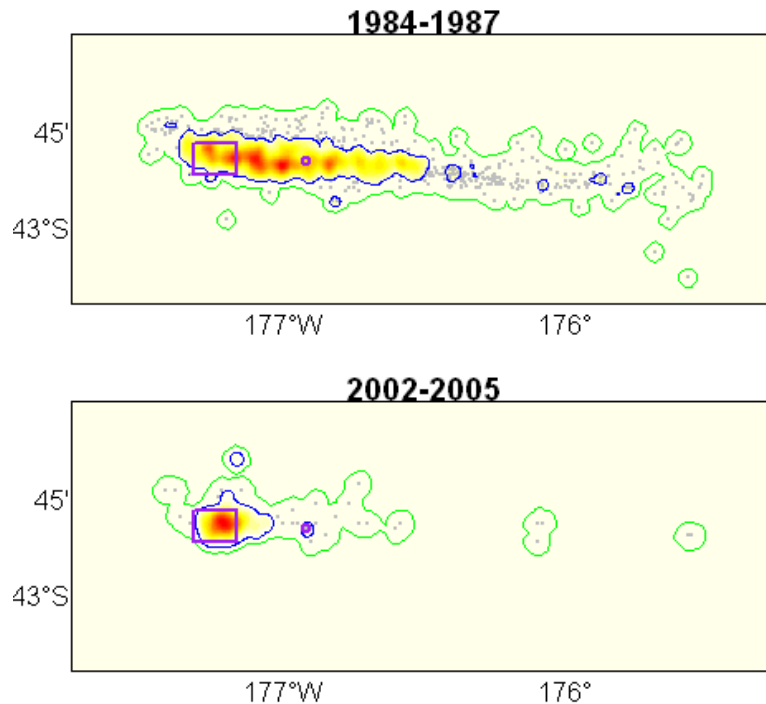


Figure 11: Contour of start positions for commercial trawls that were within two weeks of the peak of spawning and less than 2 hours duration. Outer contour is the extent of all tows in the data set, the darker inner contour is for tows that caught 30 t or more. Within the 30 t contour, the density of tows is shown using a “heat” plot where darker represents the highest density. The gray dots are the positions of tows outside the ≥ 30 t area. The box marks the approximate position of the recent plume, and the circle to the east of 177° W marks the Crack.

The results indicate the high catch rate area in 2002–05 was 31–72% (median 39%) of the area before 1988 (Tables 6 & 7). The research trawl surveys suggested a greater decline in abundance and spatial distribution than the commercial fisheries data (Section 3).

Table 6: Area within the contours (km^2) and the ratio of the area to that in 2002–05 (%) for the ≥ 10 t and the ≥ 30 t catches. Data were restricted to 1 week either side of peak spawning and tows of <1 hours duration. Contours used are those that touched either the Crack or the spawning survey stratum (Figure 10).

Year group	Area	Catch 10+ t		Catch 30+ t	
		Area	$A_{2002-05}/\text{Area} (\%)$	Area	$A_{2002-05}/\text{Area} (\%)$
1980-1983	515		38	219	72
1984-1987	510		39	395	40
1988-1991	413		48	373	42
1992-2001	252		78	245	64
2002-2005	197		-	157	-

Table 7: Area within the contours (km^2) and the ratio of the area to that in 2002–05 (%) for the ≥ 10 t and the ≥ 30 t catches. Data restricted to 2 weeks either side of peak spawning and tow of <2 hours duration. Contours used are those that touched either the Crack or the spawning survey stratum (Figure 11).

Year group	Area	Catch 10+ t		Catch 30+ t	
		Area	$A_{2002-05}/\text{Area} (\%)$	Area	$A_{2002-05}/\text{Area} (\%)$
1980-1983	734		32	331	63
1984-1987	746		31	537	39
1988-1991	598		39	538	39
1992-2001	387		60	286	73
2002-2005	232		-	208	-

An analysis of acoustic surveys of the spawning plumes from July 2002 to 2007 to determine the spatial extent of the plume found that within each year the spatial extent appeared to be negatively correlated with fish density (Hampton & Nelson 2008). As a result, the spatial extent of the aggregations derived from the analysis of commercial catch and effort data cannot be considered a reliable index of abundance.

The spatial extent of the commercial fishery in the Spawning Box supports the following conclusions for the east and south Chatham Rise stock.

- Orange roughy were caught in high densities over an extensive area of the Spawning Box in the past, consistent with the result of research trawl surveys.
- The area over which high densities of orange roughy have been caught was smaller in 2002–05 than during the 1980s.

In conclusion, the results of this analysis indicate changes in the spatial extent of the fishery, but should not be used as an index of abundance because the spatial extent of the spawning plumes has been demonstrated to be inversely correlated with density.

7. STANDARDISED CPUE

Eight standardised CPUE indices were accepted by the Deepwater Fisheries Assessment Working Group for the east and south Rise, five of which were updated to the end of the 2006–07 fishing year (S. Mormede NIWA, unpublished results, Figure 12).

Standardised CPUE indices have been used in all orange roughy stock assessments, even though concerns have been raised about their validity (e.g., Dunn 2007b). The CPUE indices from hill complexes characteristically show a steep initial decline followed by prolonged period of no trend or slow decline. Stock assessments assuming a linear relationship between CPUE and fish abundance have found that the initial steep decline in CPUE is faster than can be explained by catch removals (Dunn 2007b). The cause of the initial steep decline in CPUE is unknown, but hypotheses to explain it include the fishing of a local and resident sub-stock in the initial period followed by fishing of a larger and more transient stock or new recruits (to the hill sub-area), or that there is a non-linear relationship between abundance and CPUE. The indices from the Spawning Box fishery, which focuses on the spawning aggregations, are presented here for completeness but are not likely to be reliable indices of abundance as they target predictable spawning aggregations (Coburn & Doonan 1994, Dunn 2007b). The estimation of indices took no account of potential technology creep.

Standardised CPUE indices for the Spawning Box pre-closure fishery show a reduction by the early 1990s to about 35% of the 1980 level fishery, but post-closure there is little trend (Figure 12). The fishery on the eastern flats, which targeted orange roughy believed to be migrating out of the Spawning Box, showed a greater decline, to about 35% of the initial level over the period 1983 to 1988.

The remaining CPUE indices showed initial steep declines, followed by little trend for Hegerville and Neighbours and south Rise flats, or a continuing decline for the Northeast Hills, Andes complex, and Big Chief and Neighbours (Figure 12). Since 1995, all of the hill indices, except Hegerville and Neighbours, have shown an overall decline of more than 50% (Figure 13). Overall, the Northeast Hills, Andes complex, and Big Chief and Neighbours indices suggest biomass in these areas in 2006–07 was about 5% of that in the early 1990s. On Hegerville and Neighbours, this level is about 20%. The South Rise Flats index indicates a similar decline to very low levels. A standardised CPUE index of the fishery on the northeast Flats was estimated (S. Mormede NIWA, unpublished results), but rejected by the Deepwater Fisheries Assessment Working Group because relatively little data were available; however this index also indicated a substantial decline in catch rates. There were no other

substantial areas of the fishery not considered in these analyses (S. Mormede NIWA, unpublished results).

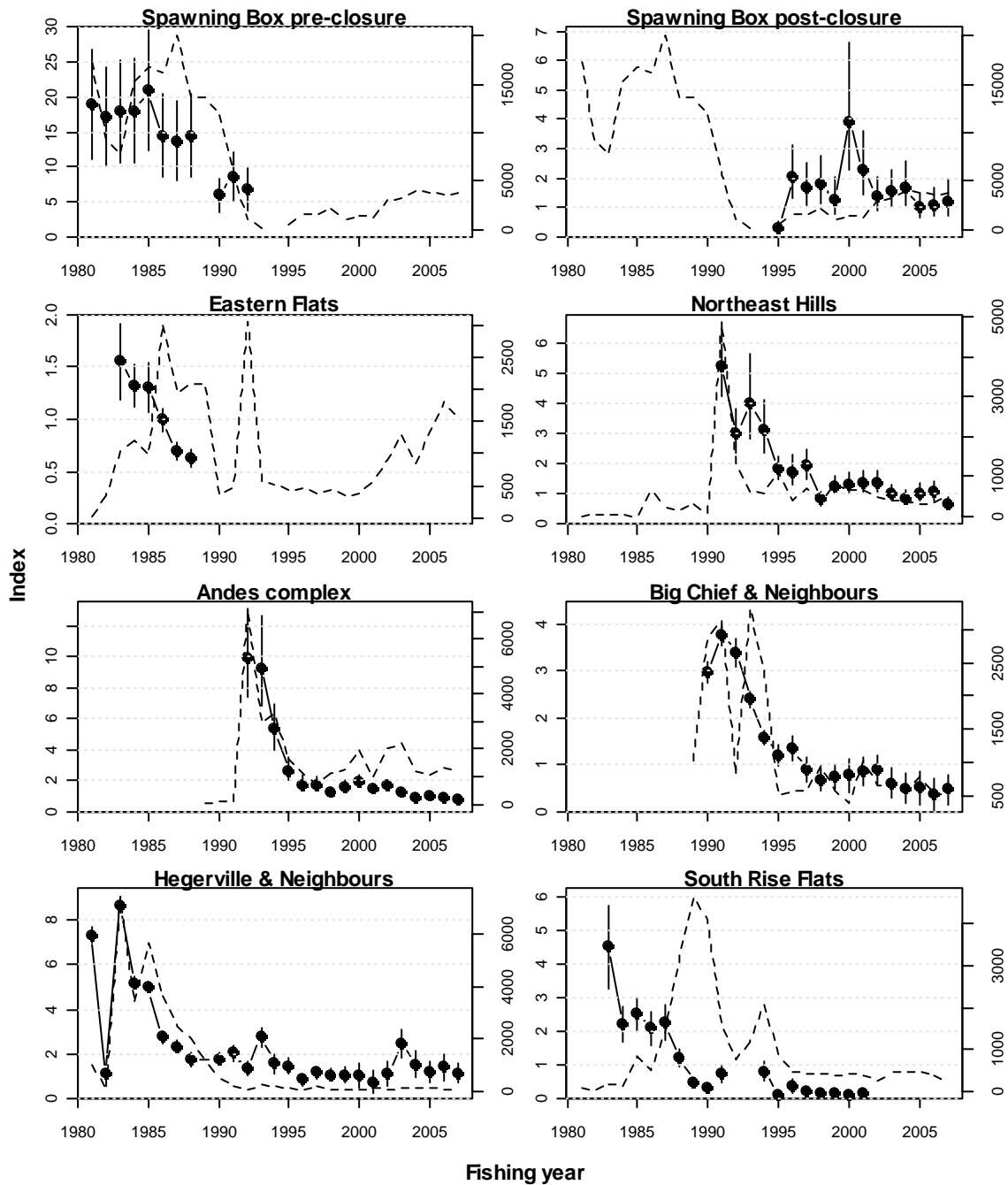


Figure 12: Orange roughy standardised CPUE indices (black circles with bars showing 95% confidence intervals) and annual estimated catches (broken lines) from the commercial fisheries on the east and south Chatham Rise.

The steep declines in CPUE observed here have been observed in many other orange roughy stocks, particularly for hill CPUE indices, and are too rapid to be indexing total stock abundance. For example, if the biomass in the early 1990s was 30% B_0 , then current biomass would have to be perhaps 3% B_0 , which if B_0 was about 300 000 t would be close to current annual catches. Therefore it seems likely that each index measures only local abundance. The relationship between local abundance and stock abundance is unknown. Nevertheless, almost all of the current indices show a continuing decline, and all of the hill indices except Hegerville and Neighbours show a similar rate of

decline over recent years (Figure 13), suggesting vulnerable biomass is continuing to decline at current catch levels.

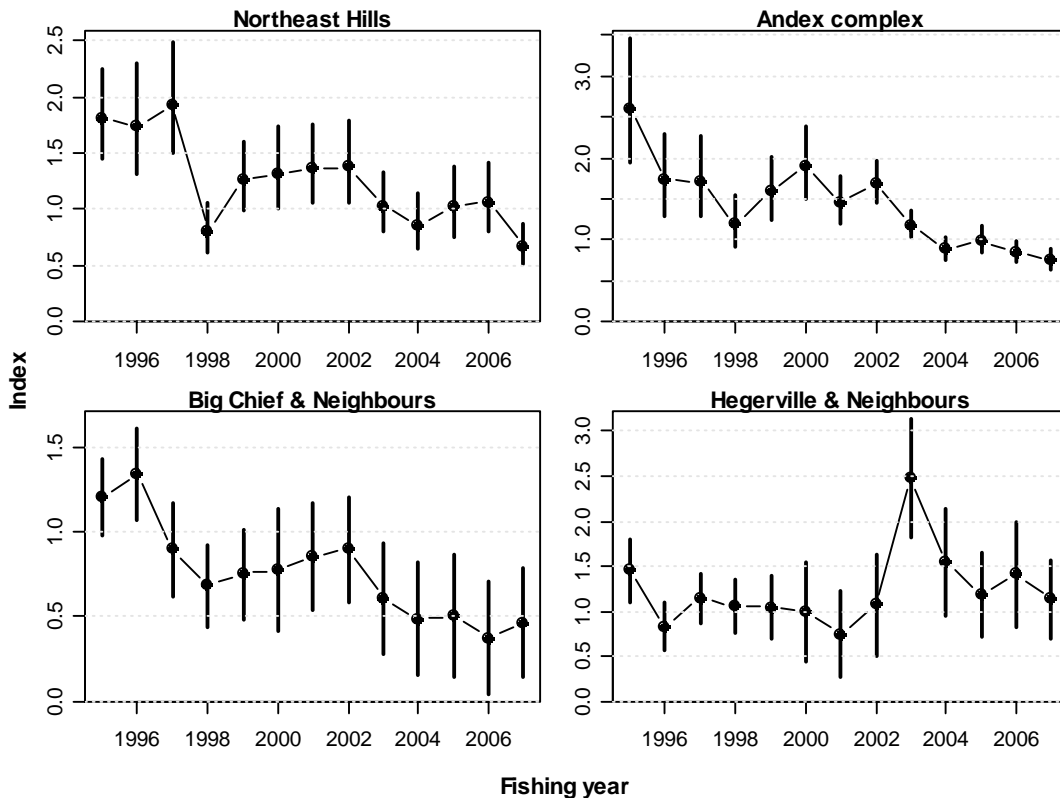


Figure 13: Orange roughy standardised CPUE indices (with 95% confidence intervals) for the main hill complexes in the commercial fishery on the East and South Chatham Rise between 1994–95 and 2006–07.

The standardised CPUE indices support the following conclusions for the east and south Chatham Rise stock.

- The vulnerable biomass was reduced to less than 40% of the virgin level by the early 1990s, and possibly substantially lower. This is supported by all the available indices: the Spawning Box, Hegerville and neighbours, eastern Flats and south Rise Flats, and is consistent with fishing down the accumulated biomass.
- The vulnerable biomass on all hill complexes declined rapidly at the onset of exploitation. The reason for this is unclear, but could be associated with fishing different components of the stock. For example, in the first years a resident sub-stock may be fished and depleted, but in subsequent years the hill is replenished, and the fishery sustained, by fish moving onto the hill from other areas. The years after the initial steep decline might therefore be a measure of stock abundance, or a measure of the rate at which an immigration occurs (which could be size specific (Dunn 2008) and/or density dependent), or both.
- The vulnerable biomass on the hill complexes forming the focus of the current non-spawning fishery (northeast Hills, Andes and Big Chief and neighbours, see Section 3), have declined at a similar rate and by 50–60% between 1994–95 and 2006–07.
- Because most of the fishery targets orange roughy on hills and other features, the CPUE indices may not be linearly proportional to overall stock abundance, and must be interpreted with care. For example, CPUE from hill complexes could also be biased because of serial depletion (Clark 1999).

In conclusion, the use of CPUE is routine in stock assessments, but its utility for orange roughy is unclear. The CPUE indices suggest the east and south Chatham Rise vulnerable biomass was rapidly and substantially depleted during the 1980s, and that the vulnerable biomass has subsequently continued to decline. Whilst it is reasonable to argue that CPUE indices for orange roughy are likely to be biased (to an unknown degree) and should therefore be discounted, the possible risk to sustainability associated with ignoring the CPUE trends seems high, as they indicate a substantially depleted stock which is continuing to decline at current catch levels. It would not be consistent with a precautionary approach to ignore these trends at present.

8. RECRUITMENT ESTIMATES

The likely location of the nursery grounds for orange roughy on the East and South Chatham Rise have been described by Dunn et al. (in press). The use of research trawl surveys for estimating an upper bound to recruitment was subsequently described by Doonan & Dunn (unpublished results). These studies concluded that the 2004 and 2007 trawl surveys indicated a recruitment hole (see Figure 8). The difference between the 2004 and 2007 length frequency distributions was about 2 years on the left hand side to 3 years for the common peaks, which was consistent with the 3 year difference in the timing of the surveys. This would imply that there was little or no recruitment taking place. The recruitment hole would have originated from the late 1980s, when the fishery in the Spawning Box was at its peak and, if real, the poor recruitment would affect the fishery in about 11 years. Doonan & Dunn (unpublished results) also concluded that recruitment to the east and south Chatham Rise fishery over the next 10 years (up until the hole arrives) was likely to be substantially lower than estimated by the previous stock assessment models assuming constant recruitment (Dunn 2007a), and also lower than the recent catch levels.

9. OTHER INFORMATION

9.1 Length frequency data

There was little change in the length frequency distributions and mean standard lengths obtained from samples taken during the research trawl surveys of the Spawning Box between 1984 and 1994 (Section 4), with the median length remaining at 35 cm throughout, and mean length declining only slightly from 34.7 cm in 1984 to 33.9 cm in 1994 (Dunn 2006). Relative stability in life history measurements, such as mean length, would be consistent with the long-lived nature of orange roughy (Clark 2001).

Length frequency distributions for the commercial fishery in the Spawning Box have shown a greater decline in mean standard length, from about 36 cm in 1989–91 to 34 cm in 2002–04 (Dunn 2006). The mean standard length from samples of catches on hills was unchanged on the Northeast Hills, but declined from about 34.5 cm in 1993–87 to 33.7 cm in 2001–2003 on the Andes (Dunn 2006). The relatively large decline in mean length observed for the Spawning Box could not be fitted by the stock assessment model which estimated a biomass rebuild since the early 1990s (Dunn 2007a).

These observations suggest mean length of spawning orange roughy declined only slightly over the first 10–15 years of the fishery, but the mean length of the commercial catches declined by a greater amount over the next 10–15 years, and more so for catches of spawning fish in the Spawning Box than non-spawning fish on the hills. This could be consistent with an increase in the proportion of small fish, caused either by a relative increase in recruitment, or a depletion of larger and older fish.

9.2 Fish condition

The Fulton's K and relative condition factor was estimated for orange roughy from around the Chatham Rise and presented by Dunn (2008). For the Spawning Box, the indices indicated a small (about 5%) but steady decline in fish condition between the early 1990s and 2007; for the Eastern Flats a steady or perhaps increasing condition factor between 1982 and 1989, followed by a decline of about 15% between 1989 and 2007; the samples from hills showed no clear trend in condition factor; and the far western areas of the south Chatham Rise (west of Hegerville) showed a decline in condition factor of about 20% between 1982 and 2007.

All samples of orange roughy from flat areas showed a decline in condition since the late 1980s or early 1990s. A decline in condition would cause a bias in previous stock assessment models, where the conversion from weight to number of fish has been assumed to be constant (Dunn 2007a). If not the result of a sampling bias, then this declining trend in condition is perhaps most likely to be the result of a natural environmental cycle, but it could be caused by fishing disturbance or damage, for example the disturbance of feeding orange roughy by fishing vessels.

9.3 Mean length at maturity

The mean standard length of first maturity (L_{50}) was estimated for orange roughy from around the Chatham Rise and presented by Dunn (2008). For the Spawning Box, the L_{50} from research survey samples was relatively constant between 1982 and 1995 at about 30 cm for females, and slightly less for males, but then declined by about 5 cm in both sexes by 2000. The samples from the Northeast Hills showed a similar pattern, with the L_{50} declining steadily between 1992 and 2000 and by 2–3 cm. Samples from the Eastern Flat area showed no clear trend, and data were insufficient for the south Rise.

A decline in maturity L_{50} would be consistent with an increase in the relative abundance of mature fish (or a decrease in the relative abundance of immature fish), a bias in selectivity (catching proportionally more mature fish), or a real decline in the mean age and length at maturity (possibly unlikely given the previous stability of life-history parameters for orange roughy).

10. DISCUSSION

This document provides additional detail of the data sets and analyses available to the discussion of stock status described by Ministry of Fisheries Science Group (2008).

The substantial cumulative commercial catch, combined with the decline in trawl survey biomass indices and in standardised CPUE indices, all indicated the east and south Chatham Rise stock was substantially fished down during the 1980s. By the early 1990s, the cumulative catch had reached the same level as the estimated virgin biomass (Ministry of Fisheries Science Group 2008), and the biomass spawning in the Spawning Box was probably reduced to 30% or less of initial levels. Earlier stock assessments of the east Chatham Rise based on the Spawning Box trawl surveys suggested biomass in the mid 1990s was only 10–17% B_0 (Francis et al. 1995). Since the early 1990s there is no evidence of a biomass rebuild; in fact, there is evidence that the vulnerable biomass has probably continued to decline.

The acoustic surveys in 2002–07 estimated about 53 000 t of orange roughy in the spawning plumes in the Spawning Box. The mature biomass will be higher, allowing for non-spawning adults and spawning fish outside of the Spawning Box plumes. Ministry of Fisheries Science Group (2008) estimated the total mature biomass in 2006–07 to be about 100 000 t, and with estimates of virgin biomass derived from stock reduction analyses, and in consideration of the other data sets available,

concluded stock status in 2007 was most likely to be 15–30% B_0 . A substantial reduction of the stock would be consistent with the observed reduction in spatial extent of the fishery.

If the stock is indeed substantially depleted, then medium-term yields will be largely dependent upon productivity (recruitment). The relatively low recruitment estimated by Doonan & Dunn (unpublished results) would be consistent with a drop in productivity, which would be consistent with the decline in fish condition and in maturity L_{50} . If recruitment has been relatively low, then the observed decline in mean length since the mid 1990s indicates a continued depletion of the stock. This would be consistent with the standardised CPUE indices. Overall, these observations suggest a continued depletion of the stock has taken place since the early 1990s.

11. ACKNOWLEDGMENTS

This work was funded by the Ministry of Fisheries (Project ORH2007/02).

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