International Council for the Exploration of the Sea

CM 1998/0:14
Deepwater Fish and Fisheries

ARE DEEPWATER FISHERIES SUSTAINABLE? - THE EXAMPLE OF ORANGE ROUGHY IN NEW ZEALAND.

Malcolm Clark

National Institute of Water & Atmospheric Research (NIWA)
P O Box 14-901
Wellington 6003
New Zealand

ABSTRACT

The deepsea environment is generally regarded being one of low energy and productivity. Species exploited at depths of over 800 m like orange roughy (*Hoplostethus atlanticus*), oreos (e.g. *Allocyttus niger, Pseudocyttus maculatus*), and macrourid rattails (e.g. *Coryphaenoides rupestrus, Macrourus berglax*) have slow growth rates and high longevity compared to traditional commercial species from the continental shelf. They have low levels of sustainable yields, are vulnerable to overfishing, and have slow recovery rates. Yet, they are often high-value species, and this has maintained interest in developing new fisheries for deepwater species.

In New Zealand waters orange roughy has been fished for almost 20 years. Familiar patterns of rapid fishery development with large catches, followed by contractions in stock distribution, and reductions in catch levels as the stocks become overexploited, have occurred. Quotas in a number of New Zealand fisheries were reduced in the early 1990s, and this enables an insight into how stocks respond with reduced levels of exploitation, and how resilient and sustainable these fisheries may be in the long-term. Examples are given for several New Zealand orange roughy fisheries. Computer model predictions are compared with observed changes in available data on abundance, fishery performance, and biological characteristics. In some cases fish stocks appear to be holding their own, and are supporting relatively stable catch rates, but in others stocks are still declining. There are few signs of biological compensation, and recruitment levels appear to be low. Lack of good data on levels and patterns of recruitment is a major source of uncertainty in current stock assessments, and a principal concern for long-term sustainability of such fisheries

INTRODUCTION

The deep sea environment, being dark and cold, has generally been regarded as a system of low energy and low productivity. Production of phytoplankton is restricted to the euphotic zone in the upper part of the water column, and historically, the world's major marine fisheries have taken place on the relatively narrow and shallow continental shelf. Until the last few decades, there had been little activity or interest in deeper water, apart from the occasional foray by scientists. The continental slope was regarded as having little or no commercial potential (e.g. Merrett & Haedrich 1997).

However, deepwater fisheries on the upper continental slope below about 800 m have developed, and are today an important component of commercial fisheries in a number of countries, and continue to be of potential interest to nations whose coastal and shelf fisheries are fully or over-exploited.

These fisheries include species like orange roughy (*Hoplostethus atlanticus*), oreos (*Allocyttus niger, Pseudocyttus maculatus*), roundnose grenadier (*Coryphaenoides rupestris*), roughhead grenadier (*Macrourus berglax*), blue ling (*Molva dypterygia*), black scabbardfish (*Aphanopus carbo*), redfish (e.g. *Sebastes mentella, S. marinus.*), Greenland halibut (*Reinhardtius hippoglossoides*) and a number of deepwater dogfish (e.g. Portuguese shark *Centroscymnus coelolepis*) (Hopper 1995).

The ecological characteristics of these fish can make them vulnerable to overexploitation, and slow to recover from it. The species often have a slow growth rate, high longevity, low fecundity, and hence low productivity. Catches can be high initially in the fishery development and fishing-down phase, but very low on a long-term sustainable basis, as with orange roughy where maximum average yield is estimated at around 2% of virgin biomass (Francis *et al* 1995). Often, given these characteristics, there is talk of mining rather than managing. The history of orange roughy fisheries in New Zealand and Australia tends to illustrate this, with rapid development to a relatively high level, and then an equally dramatic decline (Figure 1).

But is this viewpoint justified? Is it worthwhile trying to conserve and manage these types of resources? In this paper I look briefly at some fishery and biological aspects of the New Zealand fishery for orange roughy, which has been going now for almost 20 years. Associated with the fishery has been a major research programme, and this can give some insight into how deepwater species might respond to exploitation, and how resilient and sustainable these fisheries may be in the long term.

THE NEW ZEALAND ORANGE ROUGHY FISHERY

Orange roughy occurs throughout the New Zealand region at depths of 700 m to 1500 m. The species has a widespread distribution, but forms localised aggregations for spawning or feeding in a number of separate areas (Figure 2). The fishery first developed on the Chatham Rise in 1979, followed by new grounds being located on the Challenger Plateau, off the East Coast (Wairarapa, Kaikoura, Ritchie Banks), and Cook Canyon in the mid-1980s, and Puysegur Bank, East Cape, and Bay of Plenty in the early 1990s (Clark 1995).

The size of the total fishery was relatively steady at around 40–50 000 t during the 1980s, but started to decrease in the 1990s with reductions in TACs as some of the main stocks became fully or over-exploited (Figure 3). Recent years have seen a mixture of reduced catch levels in the major established fisheries, supplemented with short-term high levels of catch from newly developed fisheries.

The Chatham Rise fishery is New Zealand's largest and most-established fishery (Table 1). Catch levels have been reduced from 1990, to levels which should be sustainable in the long-term.

Table 1: Annual reported catches (rounded to nearest 100 t) and Total Allowable Catch (TAC) of orange roughy from the Chatham Rise. Catches are for an October-September fishing year., but prior to 1983–84 TACs were set for April-March year. Figures in early years are underestimates due to unreported mortality (Data are derived from figures given in Annala et al. 1998).

Year	Catch(t)	TAC (t)
1978-79	11 800	–
1979-80	31 100	–
1980-81	28 200	23 000
1981-82	24 900	23 000
1982-83	15 400	23 000
1983-84	24 900	30 000
1984-85	29 300	30 000
1985-86	30 100	29 865
1986-87	30 100	38 065
1987-88	24 200	38 065
1988-89	32 800	38 300
1989-90	31 500	32 787
1990-91	20 600	23 787
1991-92	15 500	18 787
1992-93	13 700	14 000
1993-94	14 000	14 000
1994-95	8 000	8 000
1995-96	7 900	7 200
1996-97	7 300	7 200

The stocks (it is currently assumed there are three stocks on the Chatham Rise, but boundaries are poorly defined) had been heavily fished in the 1980s. There were strong declines in the geographical distribution of the aggregations, and biomass indices from trawl surveys (Clark 1995). The virgin biomass of the main stock in the northeastern part of the Rise is estimated at about 300 000 t. This has been fished down to about 50 000 t in 1998 (15-20% of virgin levels). The stock has been overexploited, but should be rebuilding (Figure 4). Estimates of MAY are 6 000–7 000 t, which would continue to have orange roughy as a viable and valuable commercial fishery.

FISHERY INDICATORS

Major changes in distribution, abundance, and biological parameters are expected as a stock is fished down from a virgin state. With orange roughy on the Chatham Rise this has occurred over 20 years, which typically would be plenty of time in which to see changes and responses in the fished population. However, with an unproductive deepwater species, it is a relatively short time, measured against the life history and longevity of the species. Below I summarise a number of aspects of orange roughy ecology, and examine the extent of changes, with a particular focus on those since 1990 for signs of a population response with decreased catch levels. There has been an active research programme, based primarily on annual trawl surveys, since 1984. This provides much of the data summarised below, with additional information from commercial catch records, and data from scientific observers in the fishery.

Distribution
The distribution of orange roughy in the trawl survey area (termed the 'Spawning Box') changed substantially between years (Figure 5). In 1984 and 1985 catch rates in excess of 1 $t.km^{-1}$ were observed across a wide area between 177°30' and 176°30'W. There were also several more isolated aggregations out to the east. These areas of moderate density began to contract from 1986–1987. The broad region of high catch rates (over 5 $t.km^{-1}$) centred around 177°W became more broken up, and by 1990 had become very localised. There were no high catch rates taken out to the east. In 1992 there was a single aggregation only, covering a small area. In 1994 and 1995 surveys, the situation seemed to improve, with both higher catch rates, and a larger area of distribution. This was still limited compared with the early years of the fishery, but suggests the contraction has stabilised, if not even improved slightly.

The distribution of orange roughy catch on the Chatham Rise has changed substantially over the period of the fishery. Fishing was heavily concentrated in the Spawning Box in the early years of the fishery, with areas of the northwest and southwest slope being targeted in the mid-1980s, and seamounts on the eastern end of the Rise in the early 1990s (Figure 6). Effort over the whole Chatham Rise almost doubled between 1980 and 1990 with much of this increased effort taking place on seamount complexes in southern and eastern regions of the Rise. Catches on the South Rise were maintained by vessels discovering new seamounts, and serial depletion of seamount populations occurred. The distribution of the fishery now appears to have stabilised.

Abundance
Biomass indices from trawl surveys between 1984 and 1994 in the Spawning Box are given in Table 2. These show a clear declining trend in relative abundance. The variance of the biomass index was consistent until 1992, when it started to increase, and was very high for the 1994 result which limits interpretation of the trend in recent years. The 1994 survey result was strongly influenced by a single catch, and is not considered reliable.

Abundance indices (standardised CPUE) for the Chatham Rise orange roughy fishery are also summarised in Table 2. The regressions calculated for the full and spawning data-sets of commercial CPUE accounted for about 50% and 20% of the variance in the data respectively. The full year indices declined rapidly up to 1982 followed by a much more gradual decline. In contrast, the spawning data-set indicated biomass did not change substantially over the period from 1980 through to 1986, but then declined quite rapidly.

Unstandardised catch rates for the Chatham Rise as a whole (summarised as total catch divided by number of trawls) were generally about 7–9 t/tow for most of the 1980s, but started to decline to 5–7 t/tow in the late 1980s (Table 2). Overall catch rates are at present 2–4 t/tow. This has varied with area. Catch rates on hill features throughout the Chatham Rise have generally shown a decreasing trend.

Table 2: Summary of abundance information for the Chatham Rise orange roughy fisheries. Year 1979 refers to the fishing year 1978-79.

Area	1980	1982	1984	1986	1988	1990	1991	1992	1993	1994	1995	1996	1997
<u>Trawl survey</u>													
Spawning Box			130	77	73	34	–	22	–	61	–	–	–
<u>Standardised CPUE</u>													
Entire Rise	0.58	0.27	0.26	0.17	0.13	0.11	0.08	–	–	–	–	–	–
Spawning Box	1.0	1.57	0.83	0.96	0.52	0.47	0.26	–	–	–	–	–	–
<u>Unstandardised CPUE</u>													
Entire Rise	8.9	7.5	8.7	7.9	6.2	6.1	7.1	7.2	6.2	3.8	2.4	3.2	3.5
Spawning Box	9.8	8.6	12.5	10.7	10.3	11.7	12.6	6.7	–	–	–	9.5	6.9
NE seamounts							7.8	5.8	7.5	5.1	3.4	2.7	4.5
E seamounts								9.8	8.6	5.6	2.9	2.6	2.9
SE seamounts						5.3	6.9	6.0	4.7	3.3	2.1	3.8	3.2
S seamounts			3.9	3.0	2.7	1.3	1.2	0.7	2.2	1.5	0.5	0.8	1.2
NW seamounts									11.0	6.1	4.2	5.0	3.6

<u>Size structure</u>

Size distributions of orange roughy in the Spawning Box remained consistently unimodal over the ten year period covered. There has been no apparent shift in the position of the mode (Figure 7). Every second year is plotted here, which makes individual years impossible to separate, but the point to note is that most are very similar, with only small fluctuations around the overall shape. Some differences are apparent in 1994-1995 data sets, and these distributions are identified separately.

Mean lengths calculated from each survey varied between years, but there has not been a strong or consistent trend. The length of females has fluctuated around 35.5 cm. The mean length of male fish decreased between 1992 and 1994, but the reliability of the 1994 result is uncertain.

More detailed analysis was carried out of both limbs of the size distributions to examine if more subtle changes were occurring in size composition with fishing (Table 3).

Table 3: Changes in proportion of the population size structure consisting of 'large' (>39 cm SL for males, 41cm for females) and 'small' (<30 cm SL) over time.

Year	1984	1985	1986	1987	1988	1989	1990	1992	1994	1995
Male										
%large	2.6	3.3	2.9	4.5	2.3	2.9	1.4	3.4	1.3	1.6
%small	6.7	6.8	11.4	6.8	6.7	5.3	10.7	17.3	17.4	14.4
Female										
%large	5.8	7.0	5.3	6.6	5.8	5.3	3.6	8.6	4.9	2.2
%small	6.4	5.0	11.8	4.2	6.6	3.8	9.5	7.6	2.8	3.8

The proportion of large fish in the length distribution varies between years, with no strong or consistent trend. The proportion of small males increased markedly in 1990, and has stayed at relatively high levels through to 1995. The percentage of large females also increased in

1990, but has since decreased. So the signals here about the strength and consistency of recruitment are mixed.

The lack of major change in the size structure was unexpected, given the extent of the decline in abundance of the stock. With heavy exploitation a truncation of the distribution at the upper end, and a reduction in mean size of 1-2 cm, would have been expected in this population (Francis and Smith 1995). One explanation for this is that recruitment levels have been low for some time, and smaller fish have not been entering the population in the numbers expected. Mean recruitment is likely to have been above average in the 1970s, but below through the 1980s by on average 25% (Francis et al. 1992).

Similar stability of size structure despite substantial decreases in stock size have been reported for other orange roughy populations in New Zealand (Clark and Tracey 1994, Field et al. 1994) as well as Australia (Bax 1997).

Age structure

A strong linear relationship has been shown between orange roughy age (from otolith ring counts), and the weight of the otolith. The latter has been examined from random samples collected during trawl surveys of the Chatham Rise, and used as a proxy for age. The mean weight of otoliths showed no significant change over the period from 1984 to 1992 (range 0.216–0.232 g). The proportion of small-sized otoliths (<0.15 g) in the samples declined over the period.

However, although no major change in age structure appears to have occurred on the Chatham Rise, off Tasmania a substantial shift in age structure has been reported (Bax 1997), with a modal age in 1995 about 20 years younger than in 1992. Size structure has remained similar.

Reproduction

There appear to have been no reproductive responses over time. Timing and location of spawning has been very consistent each year. There are few data on fecundity, although samples in 1994 had lower fecundity than fish in 1990. Fecundity hasn't changed on the Challenger Plateau over time (Clark et al 1994), but in the Australian fishery, an increase in fecundity was recorded as stock size declined (Koslow et al 1995).

Size at maturity varied considerably between years (Figure 8). Mean length in recent years was generally about 1 cm greater than in early surveys. However, there was no significant trend over time. Age at maturity, assessed from the otolith transition zone, showed no difference between 1984 and 1990.

OTHER FISHERIES

This description has focused on the Chatham Rise, but other orange roughy fisheries in New Zealand have shown similar responses. The Challenger Plateau and Ritchie Bank fisheries saw substantial quota reductions in the early 1990s as they became fully exploited. In both areas, the fisheries have struggled, as CPUE indices have not recovered, and the TACs have not always been fully taken. This is shown for the Challenger Plateau stock in Figure 9. CPUE might not track orange roughy biomass well, but given its aggregation behaviour, if abundance was increasing one would expect the fishing success (in either locating or targeting the aggregation) to improve. That it hasn't, and has in fact remained at very low levels, is of concern.

In the Australian fishery on St Helens seamount off the east coast of Tasmania, modelling also indicates that stock size should be increasing slowly, after being fished down to about 30% of virgin biomass in the early 1980s. Acoustic survey and CPUE results suggest the stock decline has slowed, but stock size has not increased (Bax 1997, Koslow et al. 1997).

DISCUSSION

The jury is still out on the question of whether orange roughy fisheries are sustainable in the long-term. Substantial and rapid depletion has occurred in most New Zealand fisheries, which lead to quota cuts in the early 1990s as the most established fisheries became fully exploited. New Zealand deepwater fisheries are now well-regulated by regional 'stock' quotas, and management regimes are more or less in line with research recommendations on sustainable catch levels. Stock assessment modelling for the main stocks indicates that population sizes in areas such as the Chatham Rise, Challenger Plateau, and East Coast should be increasing slowly. There is still considerable uncertainty in stock assessments, as reliable biomass measurement is problematic for orange roughy (Clark 1996), and productivity parameters are not well known. As stock size and catch levels have come down, so too has the research effort (especially expensive fishery-independent surveys) so monitoring the status of the stocks relies heavily on CPUE. This might not track abundance well at low stock levels. The rate of any rebuild, given the biological parameter values currently accepted in New Zealand stock assessment (Annala et al. 1998) is slow at about 2.5% of virgin biomass per year (Francis et al. 1995). This level of increase would be difficult to recognise amongst the 'noise' of an abundance index (especially CPUE), but there are few (although some) positive signals in the fishery to indicate a rebuilding, or substantial resilience in the stocks with lessening of fishing pressure.

The New Zealand experience overall with orange roughy fisheries is mixed. The relatively large stocks (e.g. Chatham Rise, Challenger Plateau, East Coast) have had major research programmes, but smaller stocks have not fared so well. The 'fishdown' phase has been controlled with varying degrees of success (Table 4). The Chatham Rise stock was reduced to about 20% of virgin biomass, which although less than the target 30% (B_{msy}), has maintained a fairly stable fishery. East Coast and Challenger Plateau fisheries were less depleted (25–30% B_0), but the fisheries in these areas are now variable, and the TAC has not been regularly taken each year. Smaller stocks on the Puysegur Bank and Cook Canyon were considerably overexploited (<20% B_0), and although still important for small vessels despite small quotas, it is uncertain whether they are sustainable or can rebuild. The total New Zealand TAC and catch of orange roughy inside the EEZ is about 16 000 t, which is close to the sum of estimated long-term yields (MAY) at 14 000 t. At this size, it is a viable and valuable fishery. It is certainly worth the effort of management, and mining for short-term gain is neither legal (under New Zealand fisheries regulations) nor desirable with the longer-term benefits that the fishery can have.

Table 5: Summary of the status of New Zealand orange roughy stocks.

Fishery	Year	Historical max TAC	1997 TAC	LTYield	Stock status 1997
Bay of Plenty	1994	190	1 190	?500	>Bmsy ⇓
East Cape	1994	3 000	2 500	?700	≥Bmsy ⇓
Ritchie	1986	6 300	1 260		
Wairarapa	1982	3 500	260	2 400	≅Bmsy ?⇑
Kaikoura	1984	2 900	580		
Chatham Rise	1979	38 000	7 200	8 000	<Bmsy ⇑
Puysegur	1991	5 000	0	?400	<Bmsy
Challenger	1983	12 000	1 900	1 500	≅Bmsy ?⇑
Cook Canyon	1985	1 700	430	?300	<Bmsy
Total			**15 800**	**14 000**	

However, to qualify this, the question of recruitment remains central to any consideration of long-term sustainability. With a high age at maturity (and recruitment to the adult fished population) increased levels of recruitment induced by fishing down the stock will not enter the fishery for another 5-10 years. Coupled with indications that recruitment may be infrequent, or at low levels for extended periods, this poses major concerns for management (Clark 1995). Lack of adequate knowledge of recruitment, or sporadic and unpredictable recruitment, can clearly lead to increased risk of overexploitation, or stock collapse. The duration of the fishery, even on the Chatham Rise, is still too short to be confident that such deepwater stocks will have sufficient resilience to commercial fishing pressure to last the distance. Even though catch levels are thought to be at safe levels, monitoring both abundance and biological characteristics of the stocks remains a high priority for prudent management of the resource.

ACKNOWLEDGEMENTS

Much of this paper draws on results of analyses on the Chatham Rise fishery for a manuscript nearing completion (Clark et al, in prep). Thanks to my co-authors of this: Owen Anderson, Chris Francis, and Di Tracey (all NIWA). Some of this work was funded by the New Zealand Ministry of Fisheries (project DEOR02) during 1997.

REFERENCES

Annala, J.A., Sullivan, K.J., O'Brien, C.J., and Iball, S.D. 1998: Report from the Fishery Assessment Plenary, May 1998: stock assessments and yield estimates. 409 p. Avail. Ministry of Fisheries, P.O. Box 1020, Wellington.

Bax, N. 1997: Stock assessment report 1997: Orange roughy (*Hoplostethus atlanticus*). (Unpub. report prepared for the South East Fishery Stock Assessment Group, 64 p).

Clark, M.R. 1995: Experience with management of orange roughy (*Hoplostethus atlanticus*) in New Zealand waters, and the effects of commercial fishing on stocks over the period 1980–1993. P. 251-266. *In* A.G. Hopper [ed.] Deep-water fisheries of the North Atlantic oceanic slope. Kluwer Academic Publishers, Netherlands.

Clark, M.R. 1996: Biomass estimation of orange roughy: a summary and evaluation of techniques for measuring stock size of a deep-water fish species in New Zealand. J. Fish Biol. 49 (Suppl. A): 114-131.

Clark, M.R., and D.M. Tracey 1994: Changes in a population of orange roughy, *Hoplostethus atlanticus*, with commercial exploitation on the Challenger Plateau, New Zealand. Fish. Bull. (U.S.) 92: 236-253.

Clark, M.R., Fincham, D.J., and Tracey, D.M. 1994: Fecundity of orange roughy (*Hoplostethus atlanticus*) in New Zealand waters. N.Z. J. Mar. Freshwater Res. 28: 193-200.

Clark, M.R., Anderson, O.F., Francis, R.I.C.C., and Tracey, D.M. In prep: The effects of commercial exploitation on orange roughy (*Hoplostethus atlanticus*) of the continental slope of the Chatham Rise, New Zealand, from 1979 to 1996.

Field, K.D., R.I.C.C. Francis, J.R. Zeldis, and J.H. Annala 1994: Assessment of the Cape Runaway to Banks Peninsula (ORH 2A, 2B and 3A) orange roughy fishery for the 1994–95 fishing year. N.Z. Fish. Assess. Res. Doc. 94/20. Avail. NIWA, P.O. Box 14-901, Wellington.

Francis, R.I.C.C., and D.C. Smith 1995: Mean length, age, and otolith weight as potential indicators of biomass depletion for orange roughy, *Hoplostethus atlanticus*. N.Z. J. Mar. Freshwater Res. 29: 581-587.

Francis, R.I.C.C., D.A Robertson, M.R. Clark, and R.P Coburn 1992: Assessment of the ORH 3B orange roughy fishery for the 1992/93 fishing year. N.Z. Fish. Assess. Res. Doc. 92/4. 45 p. Avail. NIWA, P.O. Box 14-901, Wellington

Francis, R.I.C.C., M.R. Clark, R.P. Coburn, K.D. Field, and P.J. Grimes 1995: Assessment of the ORH 3B orange roughy fishery for the 1994–95 fishing year. N.Z. Fish. Assess. Res. Doc. 95/4. 43 p. Avail. NIWA, P.O. Box 14-901, Wellington.

Hopper, A.G. (ed) 1995: Deep-water fisheries of the North Atlantic oceanic slope. Proceedings of the NATO Advanced Research Workshop on Deep-water fisheries of the North Atlantic oceanic slope, Hull, U.K. 1994. Kluwer Academic Publishers, Netherlands. 421 p.

Koslow, J.A., J. Bell, P. Virtue, and D.C. Smith 1995: Fecundity and its variability in orange roughy: effects of population density, condition, egg size, and senescence. J. Fish. Biol. 47: 1063-1080.

Koslow, J.A., N.J. Bax, C.M. Bulman, R.J. Kloser, A.D.M. Smith, and A. Williams 1997: Managing the fishdown of the Australian orange roughy resource. p. 558-562. *In* Hancock, D.A., D.C. Smith, A. Grant, and J.P. Beumer [ed.] Developing and sustaining world fisheries resources: the state of science and management. CSIRO Australia.

Merrett, N.R., and R.L. Haedrich 1997: Deep-sea demersal fish and fisheries. Chapman and Hall, London. 282 p.

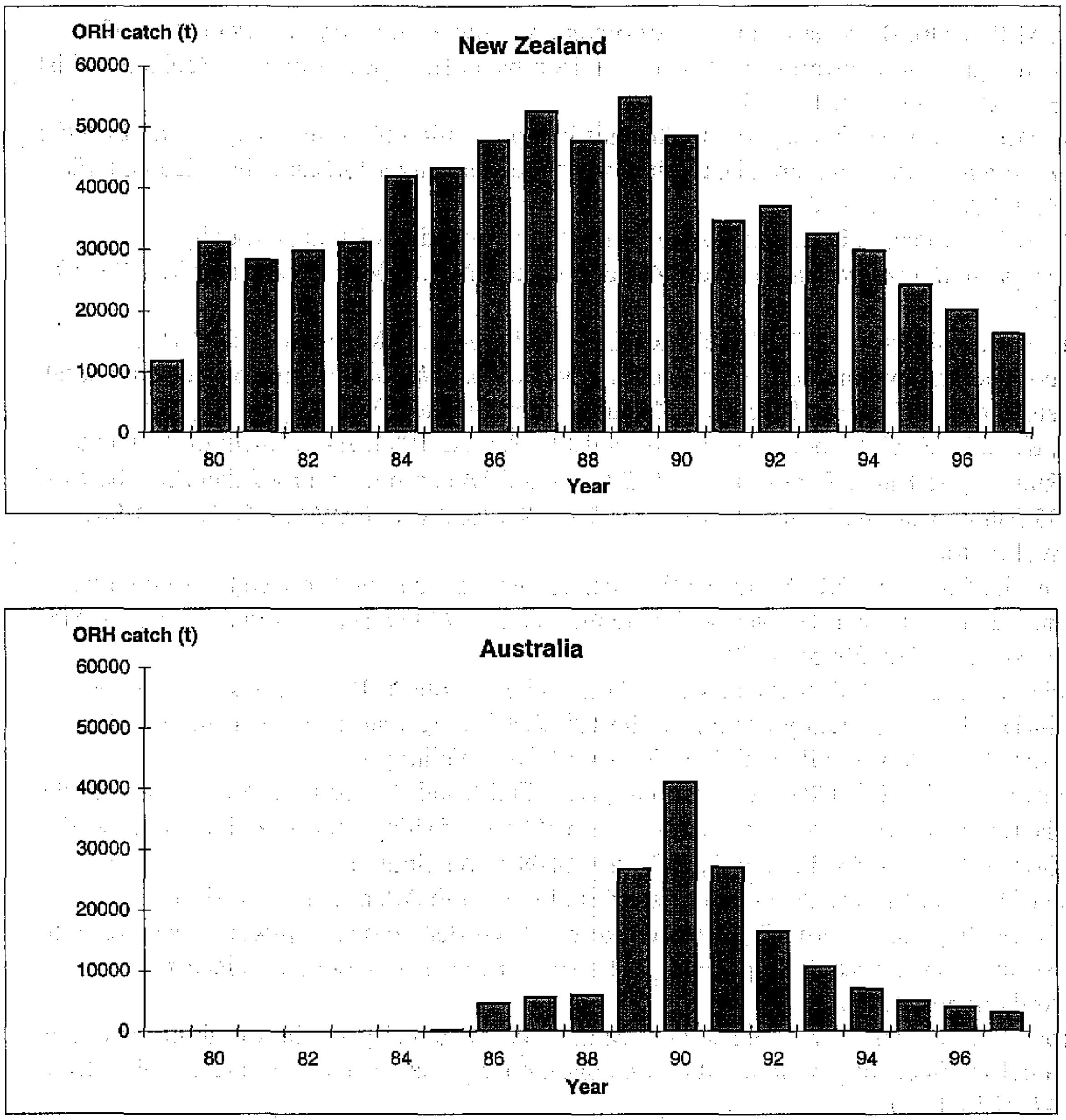

Figure 1:
Catch of orange roughy in the main world fisheries off New Zealand and Australia.

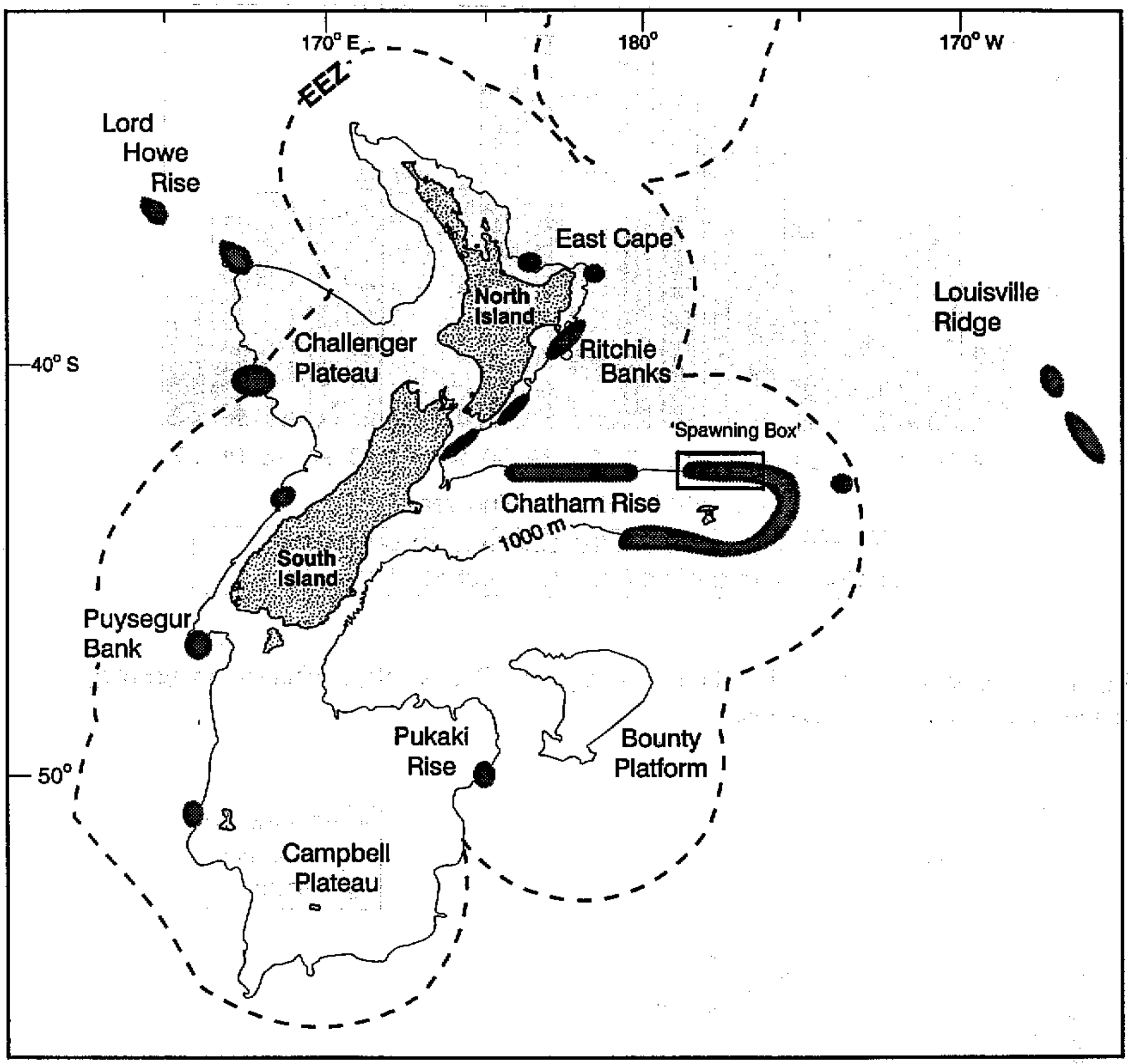

Figure 2: The New Zealand region, showing location of main fishing grounds for orange roughy (shaded), the Chatham Rise, the 'Spawning Box', and other locations referred to in this paper.

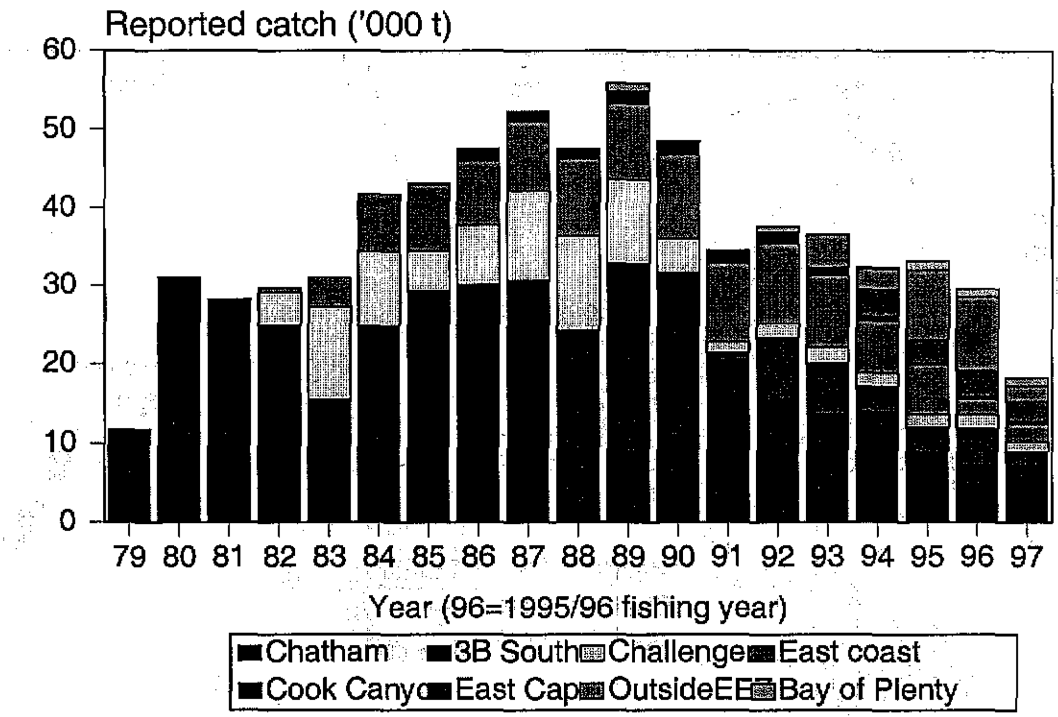

Figure 3: Reported annual catch ('000 t, fishing year = October-September) of orange roughy in the main New Zealand fisheries.

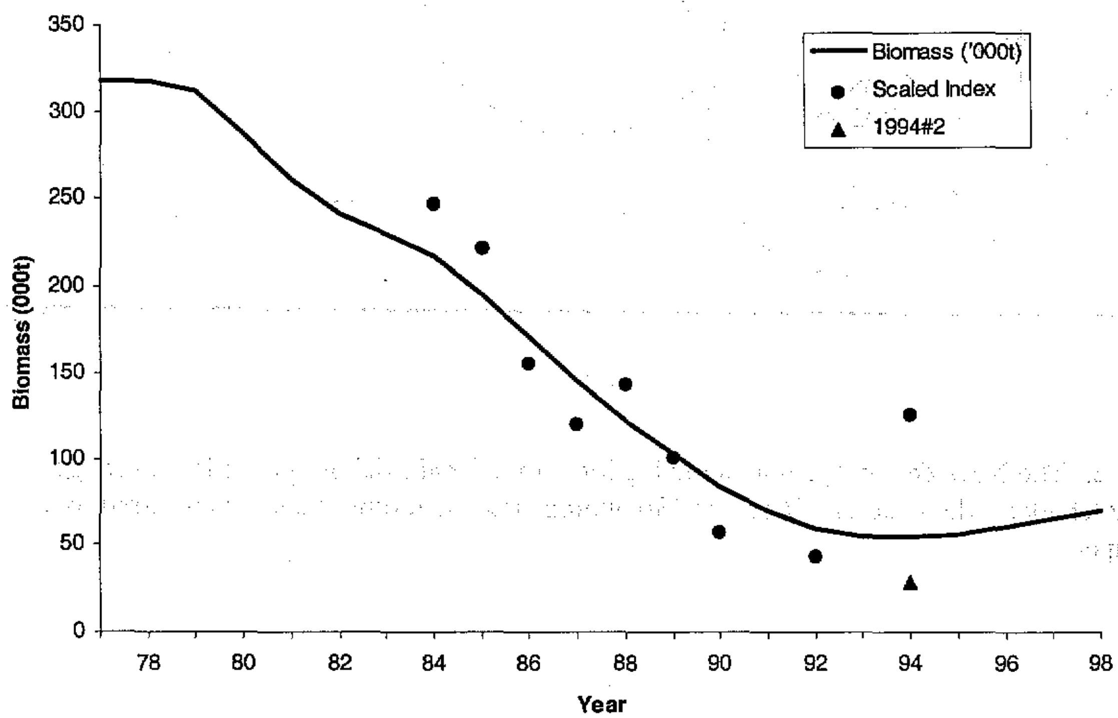

Figure 4:Estimated population biomass trajectory, and scaled trawl survey abundance indices for the northeast Chatham Rise stock.

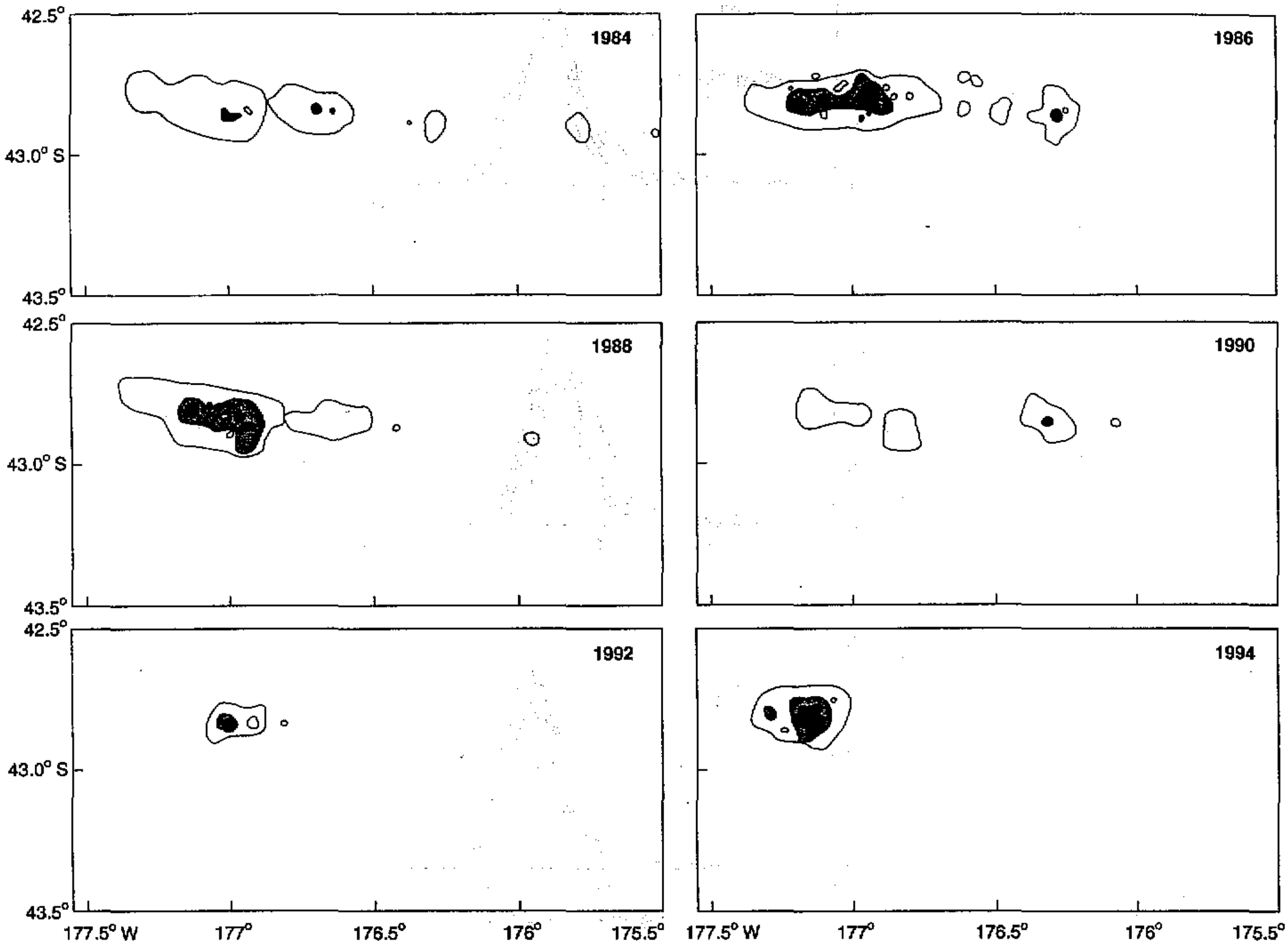

Figure 5: Contours of trawl survey catch rates (kg.km^{-1}) of orange roughy in the Spawning Box from 1984 to 1994. Only surveys every second year are shown. Light grey = 1000–4999 kg.km^{-1}, dark grey = 5000–9999 kg.km^{-1}, black = > 10,000 kg.km^{-1}.

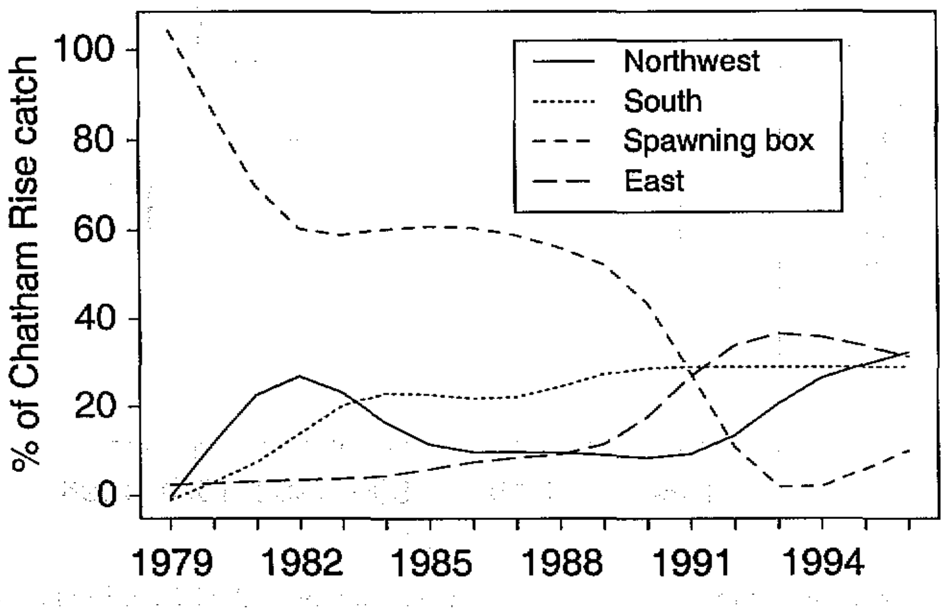

Figure 6: Distribution of reported orange roughy catch from 4 sub-areas of the Chatham Rise.

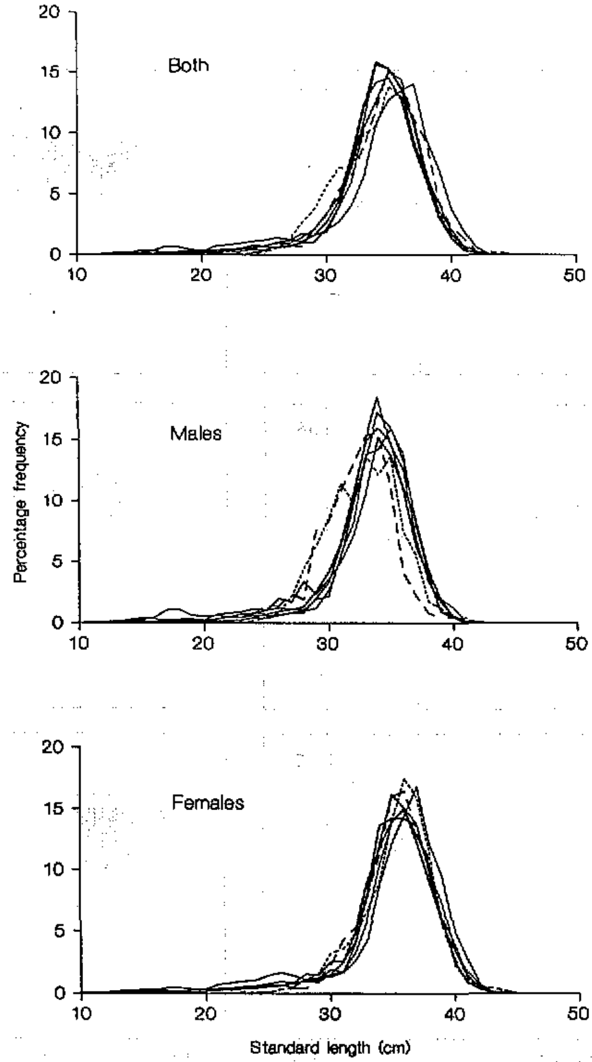

Figure 7: Length frequency distributions of orange roughy, 1984 to 1995 (every second year is plotted, dashed line = 1994 survey, dotted line = 1995 survey). Distributions are scaled to represent the total population.

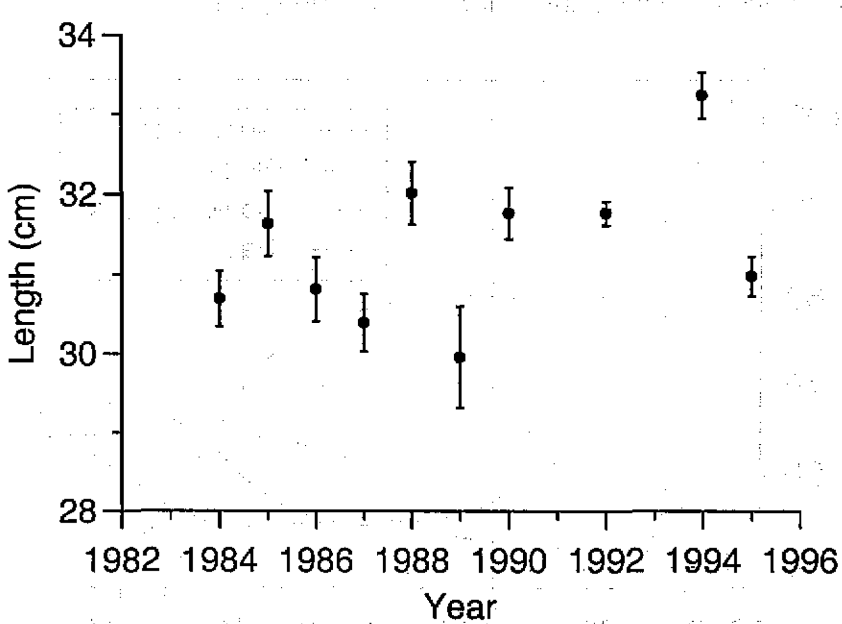

Figure 8: Mean length at maturity for female orange roughy, and 95% confidence intervals, from probit analyses.

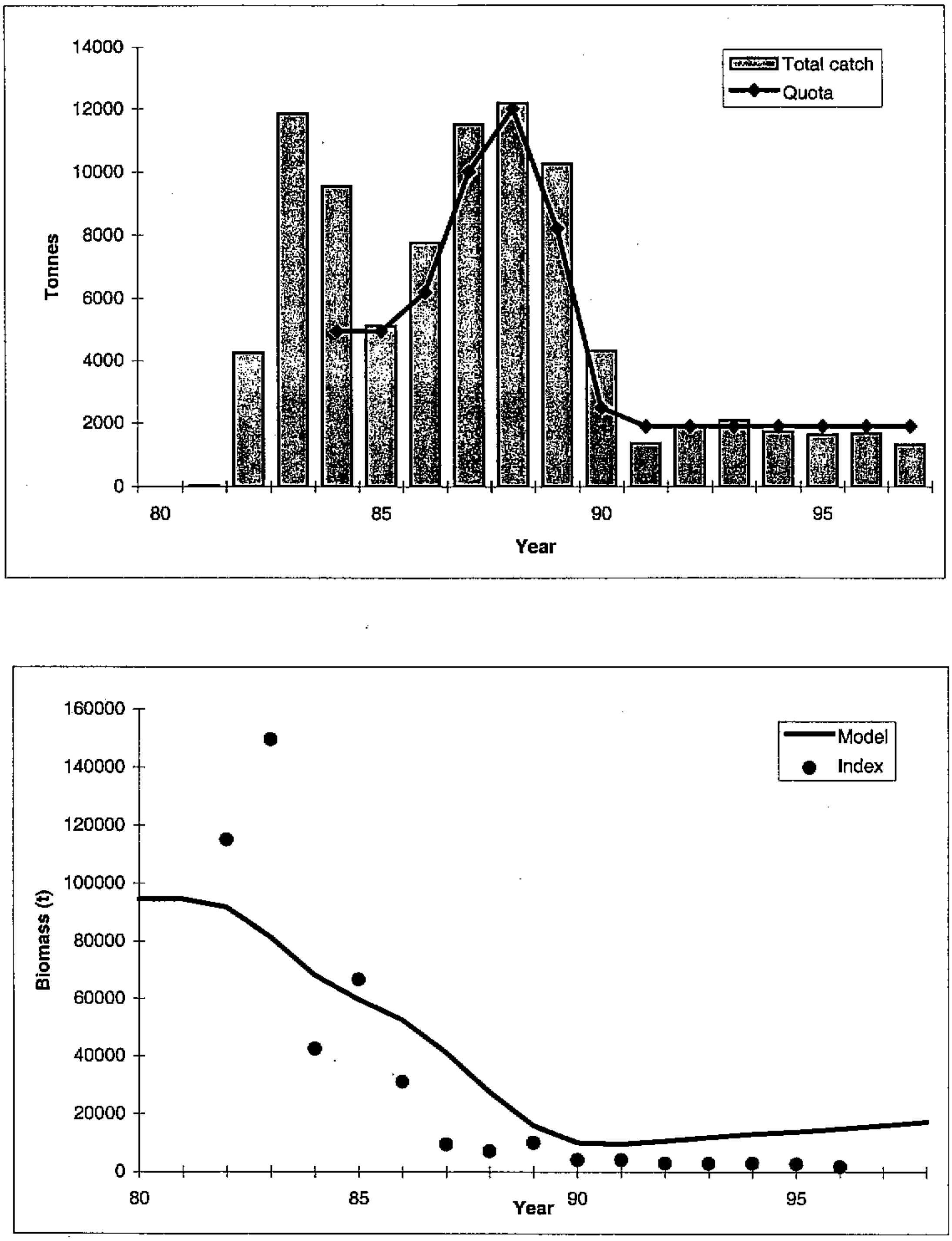

Figure 9: Reported catch of orange roughy and TAC on the Challenger Plateau (top), and biomass trajectory estimated from stock reduction analysis using standardised CPUE indices (bottom).