New Zealand Fisheries Assessment Research Document 90/1

Revised assessment of the Challenger Plateau (QMA 7A) orange roughy fishery for the 1989–90 fishing year

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Amendment to

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Page 1, Section 1.2 Description of the fishery

In the second paragraph, delete the fourth sentence (lines 6 and 7) beginning 'A further increase in quota to 12 000 t ....' and replace with:

> 'A further increase in TAC to 12 000 t occurred in 1987–88. Some of this was used for a short-term quota trade between Chatham Rise and Challenger Plateau fisheries'.

REVISED ASSESSMENT OF THE CHALLENGER PLATEAU (QMA 7A) ORANGE ROUGHY FISHERY FOR THE 1989–90 FISHING YEAR

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1. INTRODUCTION

1.1 Overview

This document updates the Challenger Plateau (QMA 7A) orange roughy stock assessment for 1989-90 prepared in early 1989 (Clark 1989). Results of a research survey in July 1989 are incorporated, together with recent commercial catch data. Yields are estimated for the 1989–90 fishing year, and the management implications of the estimates are discussed.

1.2 Description of the fishery

The fishery developed from late 1981 and is currently the second largest for orange roughy in New Zealand waters. Orange roughy are caught throughout the year, but most fishing occurs in a relatively small area during winter and spring. Initially, foreign chartered vessels dominated the fishery, but these have in recent years been progressively replaced by domestic vessels.

Before 1983–84 there was no specific quota for the area; however catches were limited by a TAC for the rest of the EEZ apart from the Chatham Rise (old EEZ areas C and D) and Wairarapa coast. From 1983–84 a TAC of 4950 t was set for the Challenger Plateau and west coast of the South Island (Table 1). In 1985–86 a quota of 6190 t was set specifically for the Plateau. This was raised in 1986–87 to 10 000 t to assess the effects of heavier fishing on the population. A further increase in quota to 12 000 t occurred in 1987–88 as the result of a quota trade between Chatham Rise and Challenger Plateau fisheries. Part of this quota trade continued into 1988–89, together with some quota transferred from Wairarapa and Kaikoura fisheries. For the 1988–89 year, there was a total allocated quota of 8219 t, comprising 5626 t ITQ, and 2593 t ATQ. MAFFish held 3781 t.

A fishery has recently developed for orange roughy in the western region of the Challenger Plateau outside the 200 mile EEZ. Reported catches increased rapidly in 1987 and 1988 from low levels prior to 1986. Most fish are caught on the 'Westpac Bank', approximately 25 nautical miles outside the EEZ boundary.

1.3 Literature review

Relevant papers to this assessment are outlined in previous stock assessment reports (Clark 1988, 1989).

2. REVIEW OF THE FISHERY

2.1 Catch, landings, and effort data

Reported catches of orange roughy from the Challenger Plateau inside the EEZ (old EEZ area H, corresponding to QMA 7A) and outside are given in Table 1. These reported catches are estimated to be 30% low due to an incorrect product conversion factor, and other fishing, processing, and reporting practices (Robertson 1986). Consequently, these values have been increased by 30%, and combined with total catches from research surveys (which are not included in FSU statistics) for analyses in this assessment. It is noteworthy that in the last two fishing years, reported catch inside the EEZ has been less than the TAC and amount of allocated quota.

Fishing effort data have been collected since 1983. Catch and effort information for orange roughy, however, is difficult to interpret. Fish can be aggregated at various times of the year; saturation fishing occurs; the catch can be taken in a very short time, or in a small proportion of the total time a trawl is on the bottom; gear damage with loss of catch can frequently occur; vessels have different gear and fishing power; target quantity of fish per tow may vary; fishing performance can improve with experience and advances in technology; and fishing logbooks often do not have accurate information on length of tow on the bottom. Fishing occurs on flat bottom, in troughs, and on pinnacles, and in each case effective bottom fishing time differs greatly. Consequently, data have been analysed on the basis of catch per tow, although it is acknowledged that this gives only a general indication of catch rate trends.

Catch per tow values by month for domestic ice vessels (generally 25–40 m, up to 55 m) and domestic factory trawlers (65–95 m) are presented separately in Table 2 (see also Table 7 where for stock reduction analyses catch per unit effort data have been combined from all vessels for two seasonal periods: months of the "winter fishery", and other months). The trend of declining catch rates noted for non–winter months from 1983–86 by Clark (1988) continued with both classes of vessel in 1987 through to 1989. Catch rates in the winter months, when the fishery centres on aggregations associated with spawning, are high and declined consistently from 1983 to 1987. There was a marked decrease in catch rates in winter 1988, and this continued in 1989. Because the fishery at this time targets on schooling fish, catch rates would be expected to remain high even when biomass was declining. In addition, there have been recent improvements in technology for fishing rough ground in the area, and the level of experience of most fishermen involved in the fishery is high. Because of these factors, this decline in catch rates indicates there have been major changes in abundance or availability of orange roughy.

2.2 Other information

Extensive data on length, sex, gonad stage, and otoliths from orange roughy on the Challenger Plateau have been collected from commercial vessels in 1988 and 1989 for a stock monitoring programme. Length frequency data from June to September 1988 have been analysed, and showed little change in fish size. This suggests the size structure of the population remains relatively constant over the main winter fishing period.

2.3 Recreational, traditional, and Maori fisheries

There are no known non-commercial fisheries for orange roughy.

3. RESEARCH

3.1 Stock structure

Orange roughy on the Challenger Plateau are regarded as a single, separate stock. Size structure of the population differs from other major fisheries, with orange roughy being smaller than elsewhere. Spawning occurs at a similar time to fish on the Cook Canyon, Ritchie Banks, and Chatham Rise. A study of parasite loads in fish from the Challenger Plateau, Cook Canyon, and Chatham Rise in 1986 reported differences between the areas (Lester *et al.* 1988). Flesh mercury levels differ between Challenger Plateau and Chatham Rise fish (Van den Broek and Tracey 1983). Research at FRC on stock separation of orange roughy is currently being conducted involving mitochondrial DNA, electrophoretic analysis, and parasite composition and infestation rate comparisons.

There are two main fishing grounds for orange roughy on the Challenger Plateau: inside the EEZ, and outside on the Westpac Bank. Information on fish from these areas has been collected during research surveys in 1987, 1988 and 1989, and by the Scientific Observer Programme in 1988 and 1989. Available data at present do not provide conclusive evidence on stock structure, but indicate the fish are likely to be from the same stock. Data supporting the hypothesis that these fish form one stock are as follows:

(i) Size: length frequency distributions are similar inside and outside the EEZ. The modal peak is at 32–33 cm, compared with 34–36 cm in all other New Zealand orange roughy fisheries, and on the Lord Howe Rise.

(ii) Reproductive condition: data collected in 1989 shows spawning occurs at about the same time on the Westpac Bank as on flat and pinnacle areas inside the EEZ, with the peak in the second–third weeks of July. This differs from several other orange roughy fisheries.

(iii) Biochemical data: preliminary results of electrophoretic and mitochondrial DNA analyses show no differences between the areas, yet do indicate that they differ from orange roughy in the region of the Cook Canyon.

(iv) Migration: fishing areas inside and outside are only 40 nautical miles apart. Analysis of commercial catch data from July to September 1987 indicated some dispersal after spawning inside to parts of the Plateau outside the EEZ (Clark 1989).

3.2 Resource surveys

Trawl surveys to measure the distribution and abundance of orange roughy on the Challenger Plateau have occurred annually since 1983 (Table 3). In addition there have been several cruises of GRV *James Cook* directed at collection of biological, plankton, and hydrographic data.

3.3 Other studies

Mace *et al.* (in press) have studied age and growth of orange roughy from the Chatham Rise. They compared annual ring counts on otoliths with length frequency modes of juvenile fish, and concluded that orange roughy grow very slowly and recruit to the fishery at ages of 18–20 years. Preliminary analysis of otoliths collected from juvenile orange roughy on the Challenger Plateau in 1983, 1984, and 1989 suggest that juvenile growth is similar to that of Chatham Rise fish.

3.4 Biomass estimates

Biomass estimates from stratified random trawl surveys carried out from 1983 to 1989 are presented in Table 3 (the estimates from 1987–89 have been recalculated from earlier assessment documents using an improved computer programme). The values are derived from doorspread area swept, assuming vulnerability = 0.28 (= wingtip/doorspread distance), vertical availability = 1.0, and areal availability = 1.0. The area surveyed, timing of the survey, and the vessel used have varied, and consequently all results are not directly comparable. The survey in 1983 occurred at a different time of year from the others, and those in 1985 and 1986 covered a very small area with a low number of trawls.

In stock reduction analyses presented in the next section, data from 1984, 1987, 1988 and 1989 surveys are used. The 1984 survey did not extend beyond depths of 1100 m, and in the analysis with 1987–89 surveys (which sampled to 1200 m) the largest area in common was used. The most comparable surveys are those of 1987, 1988 and 1989, which covered the same area with the same vessel.

The distribution of orange roughy during the 1988 survey differed from that observed previously, with the absence of one of two concentrations regularly recorded. A further contraction of high density areas was observed in 1989. There were no aggregations on the flat (see Figure 1). In both the 1988 and 1989 surveys no heavy marks or plumes of fish were recorded on the echo-sounder (this was also noted by vessels commercially fishing at the time), and no trawls were shortened because of indications on the net monitor of possible large catches.

These changes are reflected in the distribution of biomass among strata (Table 4). In both 1987 and 1988 about 90% of the biomass occurred in central areas on the flat and around pinnacles. In the 1989 survey, this percentage had dropped to 70%, with over 20% in surrounding areas. The proportion on the Westpac Bank remained constant.

Catch rates in depth strata outside the main spawning areas have been examined to determine if 'background' densities of fish that are not schooling differ between years. Identical strata outside the spawning area were surveyed in 1987,1988 and 1989, and catch rates in general decreased between 1987 and 1988. Changes were not marked in 1989, except for an increase in catch rates at depths of 1000m to 1100m (Table 5). Nevertheless, 1989 catch rates are all considerably less than in 1987.

3.5 Yield estimates

All yield estimates in this section apply to the entire assumed stock area (including the fishery outside the EEZ) and not just to the fishery inside the EEZ.

3.5.1 Stock reduction analyses

The method used here is described in the Appendix.

Growth, mortality and recruitment parameters used were the same as in the previous assessment (Clark 1989), except for estimates of A_r and A_m. These are derived from the length at recruitment, which in the past has been taken subjectively where the length frequencies are increasing markedly. The length at recruitment used here is defined as the 50% level on the ascending limb of the length frequency distribution (taken from the commercial catch, winter 1988). The estimates are:

$L_{infinity}$	= 39.5 cm
K	= 0.059 /year
t_0	= -0.346
a	= 0.0963
b	= 2.68
A_r	= 24 years
A_m	= 24 years
M	= 0.05
Recruitment "steepness"	= 0.95

It should be noted that a rate of natural mortality (M) of 0.05 $year^{-1}$ is considered the value most consistent with the other parameters (Orange Roughy Working Group 1989). This value is used throughout this document. Based on analyses carried out for the Chatham Rise stock assessment in 1989 if the value of M was lower than 0.05 (e.g. 0.025), virgin biomass would be higher, current biomass higher, productivity less, and yield would be reduced. A higher value of M (e.g. 0.10) would imply a lower virgin biomass, lower current biomass, higher productivity, and greater yield (Orange Roughy Working Group 1989).

The catch history from Table 1 was used. Four separate stock reduction analyses were done, using two sequences of trawl survey indices and two of commercial catch per unit effort indices. These resulted in estimates of virgin biomass (B_0) of 102000, 94000, 89000, and 89000 t (Table 6).

These values of B_0 imply relatively high levels of fishing mortality in the 1988–89 season (Table 7). Harvesting rates associated with B_0 values of 102000, 94000, and 89000 t are 48%, 67%, and 87% respectively. The latter two values from non-winter catch per unit effort and trawl survey biomass data appear to be unrealistically high. The trawl survey results also have very high values of catchability (q) (2.18, 2.09). These compare with 0.57 derived from a longer time series (6 years) of orange roughy biomass indices on the Chatham Rise, where similar vessels and nets were used in surveys (R.I.C.C. Francis, unpublished result). (However, if q = 0.57 is used in the present analyses, B_0 is estimated at 90000 t. The highest value of B_0 obtainable from the trawl survey series is 91000 t when q is 1.0. These results still suggest very high fishing mortality rates in 1988–89). In addition, the results here using the trawl survey data do not follow the expected behaviour of stock reduction analyses, which is when an assumed value of q is used, the lower the value of q, the higher the estimated B_0. This expected pattern does occur with the catch per unit effort data. Therefore, it appears that the 3–4 year time series of trawl survey results used here are too short for reliable estimation of B_0.

Our best estimate of B_0 is taken as 102000 t from the winter catch per unit effort data.

For the estimate B_0 = 102000 t, the 95% confidence interval based on a coefficient of variation of the catch per unit effort data (c) = 8% is 99000 to 108000 t. This interval is likely to be too narrow for two reasons. Firstly, it incorporates only the uncertainty associated with the catch rate data, and so ignores errors in the structure and parameter values of the computer model (e.g., uncertainty in growth parameters, assumption of deterministic recruitment). Secondly, the value of c = 8% seems very low as a coefficient of variation for catch per unit effort as an index of abundance. Simulations show that this parameter is not well estimated with only seven abundance indices. For example, if the true value of c for these indices was 15%, there would be a 5% chance that the estimated value of c was as low as 8%.

3.5.2 Yield per recruit analysis

Yield per recruit analysis was carried out to estimate the reference fishing mortality $F_{0.1}$. The model of Mace *et al.* (in press) was used (with a "plus group" to include all year classes with age over 70 years), with the growth values specified above. The value of $F_{0.1}$ was calculated as 0.075.

3.5.3 Estimation of Maximum Constant Yield (MCY)

The fishery for orange roughy on the Challenger Plateau is relatively new, but sufficiently developed with adequate data to conduct a stock reduction analysis. Consequently MCY has been calculated using Method 3 of "Guide to biological reference points for the 1990 Fisheries Assessment Meetings" (MAF Fisheries, unpublished report).

$$MCY = {}^2/_3\ MSY$$

MSY was calculated using the yield per recruit analysis and the Beverton and Holt stock–recruitment relationship as follows. Given a level of fishing mortality, F, the associated stable age distribution was calculated. The stock–recruit relationship was then used to calculate the biomass (as a percentage of B_0) and recruitment that would sustain this age distribution; and from the yield per recruit analysis the catch (as a percentage of B_0) at this level of recruitment was calculated. This procedure was repeated for a range of trial values of F. The MSY was then found by searching for the value of F that maximised the catch. For the above growth, mortality and recruitment parameters it was found that

$$MSY = 2.8\%\ B_0$$

$$\begin{aligned} \text{therefore } MCY &= {}^2/_3\ MSY \\ &= 0.67 * 0.028 * 102\ 000 \\ &= 1\ 900\ t \end{aligned}$$

This MCY value as a level of catch should be reduced if overrun of reported catch is expected to continue in the future.

3.5.4 Estimation of Current Annual Yield (CAY)

CAY was calculated by running the computer model from the estimated virgin biomass, B_0, using the historical catches up to 1988–89 (Table 1) and then applying the optimal fishing mortality, $F_{0.1}$ = 0.075. Biomass values given below for 1989–90 and 1990–91 are beginning of season values.

i) B_0 = 102 000 t

$B_{1989\text{-}90}$ = 18 000 t
$CAY_{1989\text{-}90}$ = 1 300 t

$B_{1990\text{-}91}$ = 20 000 t
$CAY_{1990\text{-}91}$ = 1 400 t

These CAY values as a level of catch should be reduced if overrun of reported catch is expected to continue in the future..

3.5.5 The effects of a constant catch policy

The effects of a constant catch policy were investigated using three options:

i) Constant catch of 12 000 t (the current TAC)
ii) Constant catch of 8 200 t (the quota held by the industry at present — including annual quota).
iii) Constant catch of 5600 t (the amount of permanent quota).

Computer model simulations were run using two levels of catch over–runs (0% and 30%) to project forward assuming the above catch levels from 1989–90 onwards. Quota levels cannot be maintained under any of the constant catch policies. With the lowest catch option (5600 t, 0% overrun), quota cannot be taken in the 1994/95 season, but fishing mortality levels are extremely high from 1993.

3.5.6 Long term yield

The current level of biomass is below long-term equilibrium predicted by the computer model simulations under an $F_{0.1}$ fishing strategy. Long–term CAY is estimated at 2500 t under fishing levels of $F_{0.1} = 0.075$, with an equilibrium (midseason) biomass of 34000 t.

4. MANAGEMENT IMPLICATIONS

The orange roughy stock in the south–western region of the Challenger Plateau is overexploited. Both research survey results and commercial catch per unit effort data indicate the population has declined markedly in recent years. The biomass at the start of the 1989–90 season is below 20% of virgin biomass, which is considered to be the minimum "safe" level. There is no accumulated biomass left to buffer the population.

Yield estimates for the 1989–90 fishing year are appreciably below the existing TAC, as well as the level of permanent quota held by the industry. Simulation model results show the population is below its equilibrium level under an $F_{0.1}$ fishing strategy, and consequently, the CAY estimate of 1300 t is less than the MCY of 1900 t. Both CAY and MCY strategies should allow the population to rebuild : CAY more rapidly than MCY (Figure 2). However, it takes four to five years for the population to increase to above 20% of B_0. Closure of the fishery results in this level being reached in two years. Catch levels up to 2900 t (assuming no catch overrun) may prevent further population decline, but this takes no account of variability in recruitment, and keeps the population at very low levels (Figure 2).

The orange roughy fishery in the area has expanded in recent years, with quota increases since 1986. The TAC was initially increased to investigate the effects of heavier fishing, and then to accomodate a quota trade with the Chatham Rise. This has increased total catches from the fishery inside the EEZ, as well as promoted a change in fishing effort. Large factory trawlers entered the winter fishery, which had previously been dominated by ice vessels. Consequently, there has been sustained pressure from factory vessels able to stay on the grounds for long periods from early in the season when fish first begin to form spawning schools.

Catches of orange roughy outside the EEZ on the Westpac Bank have increased since 1987. In 1989 there have been foreign vessels fishing there constantly. The fish in the south-western region of the Plateau (both inside and outside the EEZ) are likely to be the same stock, and the fishery outside could have adversely affected that inside. New Zealand at present has no control over this fishery. Continued fishing outside the EEZ is a severe constraint to effective management of the fishery inside the EEZ.

5. ACKNOWLEDGMENTS

We thank Ian Doonan for assistance with yield analyses, and Dave Gilbert, John Annala, as well as members of the orange roughy working group for comments on the manuscript.

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Table 1: Reported catches (t) of orange roughy from the Challenger Plateau (QMA 7A). Data from Fisheries Statistics Unit and Quota Management System (*). TAC (t) for 1983–84 and 1984–85 is combined Challenger Plateau and west coast South Island. Catches reported outside in 1982–83 to 1983–84 probably caught inside. Catches outside the EEZ are estimated for 1988/89).

Fishing year (Oct-Sep)	Catch Inside EEZ	Catch Outside EEZ	Total reported catch	+ 30% overrun	Research catches	Total catch	TAC
1980/81	1	32	33	43	-	43	
1981/82	3 539	709	4 248	5 522	-	5 522	
1982/83	4 535	7 304	11 839	15 391	18	15 409	
1983/84	6 332	3 195	9 527	12 385	129	12 514	4 950
1984/85	5 043	74	5 117	6 652	55	6 707	4 950
1985/86	7 711	42	7 753	10 079	172	10 251	6 190
1986/87	10 555	937*	11 492	14 940	810	15 750	10 000
1987/88	10 086	2 095*	12 181	15 835	397	16 232	12 000
1988/89	6 791	4 000	10 791	14 028	117	14 145	12 000 (8 219 allocated)

Table 2: Comparison of monthly catch rate (t/trawl) in Area H by domestic trawlers: (a) ice boats (specified trawlers); (b) factory trawlers (CR = catch rate; Nt = number of trawls; N/A = data not yet available; 1983–88 data from FSU, 1989 data from QMS).

(a)

	1983		1984		1985		1986		1987		1988		1989	
Month	CR	Nt	CR	Nt	CR	Nt	CR	Nt	CR	Nt	CR	Nt	CR	Nt
Jan	-		8.9	41	5.9	123	5.9	92	3.9	68	1.6	14	1.8	47
Feb	-		9.0	65	5.6	55	3.1	15	-		0.9	51	-	
Mar	-		10.3	28	-		-		7.7	2	-		-	
Apr	-		-		2.3	18	9.3	6	-		-		6.5	15
May	0.3	2	<0.1	11	8.0	21	1.2	15	1.1	19	-		2.6	3
Jun	-		-		18.7	7	13.4	110	11.9	146	4.6	208	N/A	
Jul	14.0	30	13.5	21	18.4	26	12.9	100	13.9	92	8.3	97	N/A	
Aug	-		17.8	9	16.2	13	16.8	42	14.6	28	5.0	138		
Sep	-		15.9	24	8.2	41	10.5	68	5.4	68	2.1	64		
Oct	4.1	20	5.6	43	6.3	100	1.0	23	1.3	15	N/A			
Nov	8.7	112	3.4	123	2.4	34	3.1	42	0.7	26	N/A			
Dec	5.6	55	4.2	29	4.4	14	1.5	44	<0.1	10	N/A			

(b)

	1983		1984		1985		1986		1987		1988		1989	
Month	CR	Nt	CR	Nt	CR	Nt	CR	Nt	CR	Nt	CR	Nt	CR	Nt
Jan	-		-		3.4	12	-		-		<0.1	2	0.8	9
Feb	-		-		-		-		1.6	22	-		-	
Mar	-		-		-		-		-		-		-	
Apr	-		-		-		-		-		-		-	
May	-		-		-		-		-		6.9	29	2.6	14
Jun	-		-		-		-		14.8	83	5.9	388	3.6	130
Jul	21.4	37	-		-		-		14.1	35	9.1	208	6.7	99
Aug	13.4	107	-		-		8.0	6	5.9	72	5.5	113		
Sep	19.9	48	-		-		6.2	186	6.5	157	1.9	53		
Oct	13.9	70	4.4	121	3.1	89	4.5	95	1.3	52	N/A			
Nov	10.5	48	-		3.0	34	2.1	154	2.4	41	N/A			
Dec	-		2.4	54	0.4	30	-		-		N/A			

Table 3: Orange roughy trawl surveys on the Challenger Plateau from 1983 to 1989. (Biomass estimates are for fish of all sizes; c.v. = coefficient of variation.)

Date (month/year)	Area (km^2)	Vessel	Number of trawls	Biomass estimate (t)	c.v. (%)
8-10/1983	101 000	Arrow	180	103 657	38
7/1984	11 956	Arrow	118	185 366	60
7/1985	209	Arrow	16	103 903	85
7/1986	94	Arrow	10	184 893	83
6-7/1987	8 270	Amaltal Explorer	129	96 651	26
7/1988	8 270	Amaltal Explorer	85	30 946	27
7/1989	8 270	Amaltal Explorer	160	11 747	11

Table 4: Comparison of biomass estimates (t) by region, 1987–89

	1987		1988		1989	
Region	Biomass estimate	%	Biomass estimate	%	Biomass estimate	%
Central flat, Pinnacles	86 534	89.6	27 116	87.6	8 467	72.1
Surrounding "background" area	6 603	6.8	2 029	6.6	2 717	23.1
Westpac Bank	3 514	3.6	1 802	5.8	563	4.8
Total biomass	96 651		30 946		11 747	

Table 5: Comparison of mean catch rate (kg/km) of orange roughy in comparable survey strata outside the main spawning areas

Depth Stratum (m)	1987	1988	1989
800 - 899	48.1	13.4	15.0
900 - 999	20.9	15.7	13.1
1000 - 1099	28.7	2.8	11.2
1100 - 1199	1.3	2.3	1.5

Table 6: Summary of four stock reduction analyses: biomass indices used; parameter estimates; and best estimates. The catch per unit effort data combine indices for ice boats and factory trawlers (from Table 2). The first set of trawl survey data is directly from Table 3; the second set is for the area of 6200 km^2 which is common to both the 1984 and 1987–1989 surveys.

A. Biomass Indices Used	Catch per unit effort (t/trawl)		Trawl survey data (biomass estimate in t (cv))	
Year	Winter (Jun-Sep)	Other months	Full area	Reduced area
1983	16.2	9.2		
1984	15.3	5.2		134824 (78)
1985	13.3	4.6		
1986	10.5	3.3		
1987	10.2	2.4	96651 (26)	92828 (28)
1988	5.9	2.8	30946 (27)	28954 (29)
1989	4.0	1.0	11746 (11)	11062 (11)
B. Parameter estimates				
Virgin biomass, B_0(t)	102000	94000	89000	89000
Catchability, q	0.00019	0.00008	2.18	2.09
Coef. of var., c (%)	8	27	40	30
C. Best estimate				
Virgin biomass, B_0 (t)	102000			

Table 7: Relationship between virgin biomass (B_0) and fishing mortality in 1988/89 (assuming the growth, mortality and stock–recruit parameters listed in the text). The mortality is expressed both as an instantaneous rate and as a harvest rate (mortality is assumed the same across all recruited age classes, and harvest rate is equal in terms of both numbers and weight).

Bo (t)	Annual Instantaneous fishing mortality rate (F)	Harvest rate (%/year)
87000	>10	>99
88000	2.92	93
89000	2.19	87
90000	1.82	82
92000	1.39	74
94000	1.14	67
96000	0.97	61
98000	0.85	56
100000	0.75	52
102000	0.68	48
110000	0.49	38
120000	0.36	30
150000	0.21	18

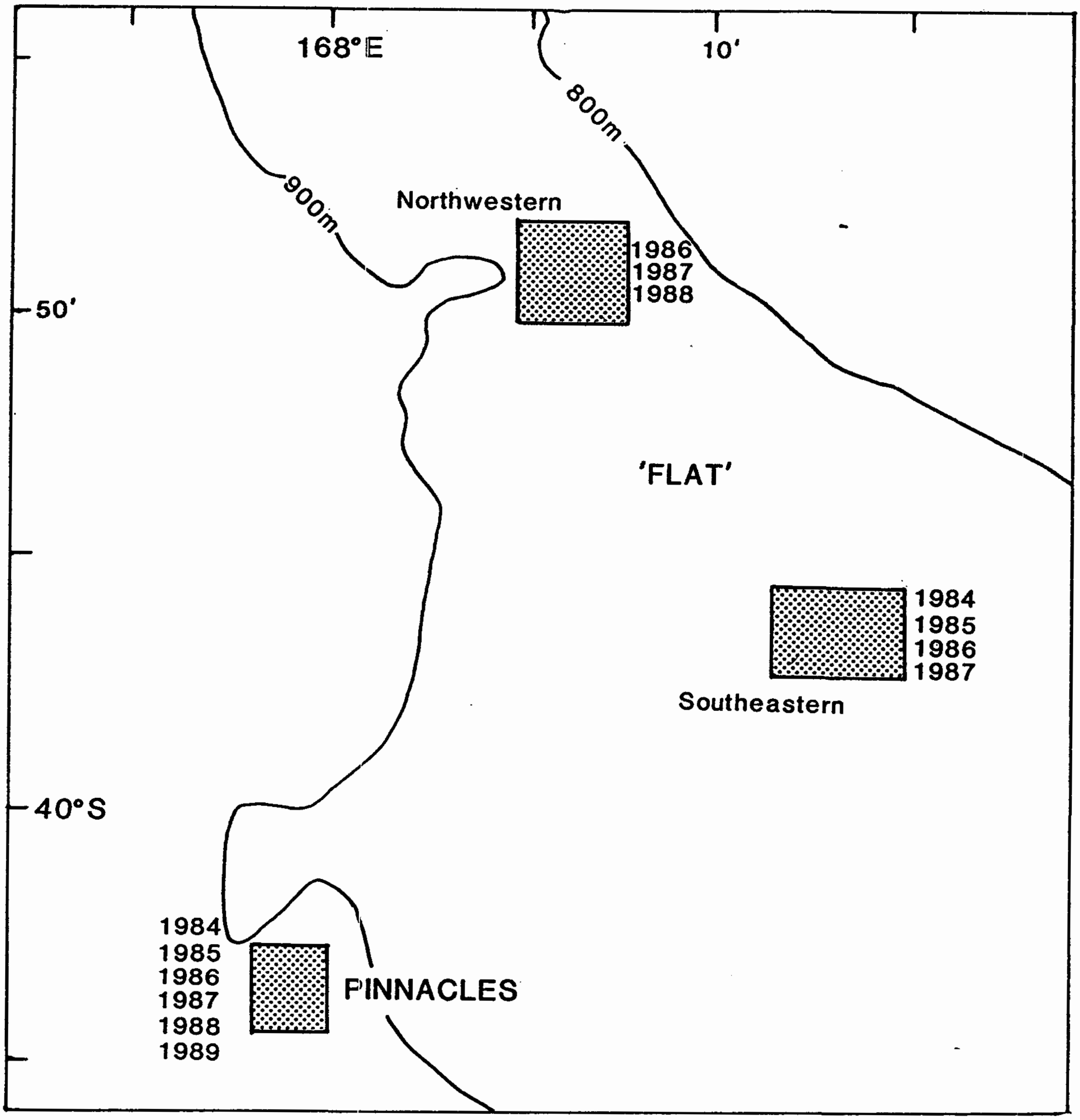

Figure 1

Position of aggregations of orange roughy inside the EEZ during research surveys in July, 1984-1989.

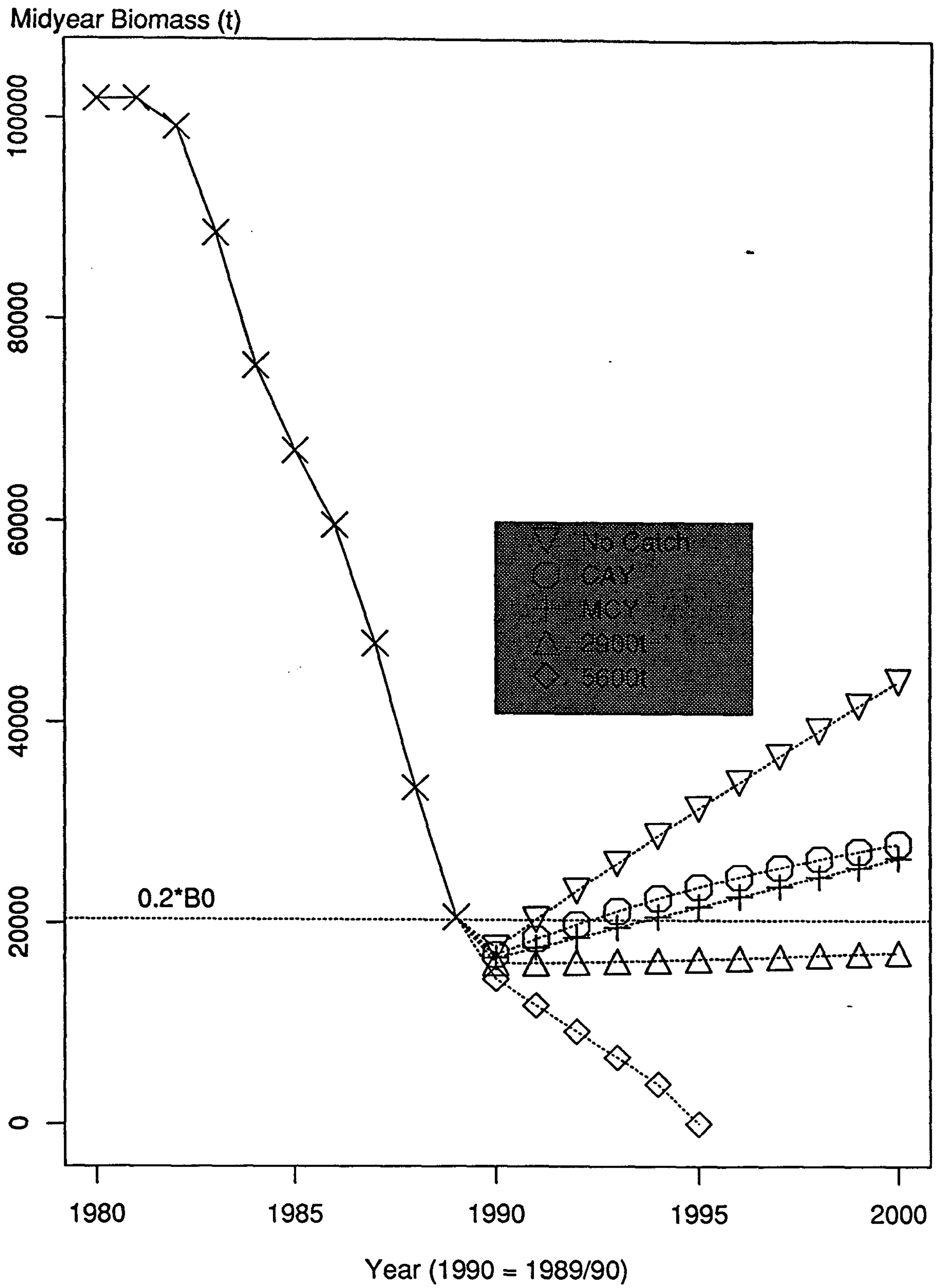

Figure 2

Changes in midyear biomass derived from computer model simulations. Levels are predicted from 1989-90 onwards under five different catch scenarios (0 overrun of quota is assumed in the future).

APPENDIX

A MAXIMUM LIKELIHOOD STOCK REDUCTION METHOD

Stock reduction methods are designed to estimate the virgin biomass for a fish population using

- a complete catch history,
- a series of (relative) biomass indices, and
- information on the productivity of the species.

The general principles of stock reduction methods may be illustrated by a simple example. Suppose that, over a period of time, biomass indices for a certain stock decrease by 50%. Then the sum of the catches during that period, minus a certain amount to allow for the productivity of the stock, must be approximately equal to 50% of the biomass at the beginning of the period.

In the method used here a complete age-structured model (a slightly modified version of Mace and Doonan 1988) was used so the productivity information was derived from

- a length-weight relationship,
- natural mortality and von Bertalanffy growth parameters,
- a Beverton and Holt stock-recruitment relationship (with "steepness" parameter as described by Mace & Doonan, 1988), and
- ages at maturity and recruitment.

Let O_i represent the ith biomass index. Given the virgin biomass, B_0, the above age-structured model, together with the catch history, may be used to calculate the true biomass, E_i, corresponding to each O_i. We assume that O_i is normally distributed with mean qE_i and standard deviation cqE_i for all i (the meanings of q and c are discussed further below). With this assumption the maximum likelihood technique allows us to calculate how likely it is that the biomass indices, O_i, would be observed given a supposed value of B_0. A search procedure may then be used to find the value of B_0 for which this likelihood is maximum. Best estimates of q and c are also obtained.

The parameters q and c merit further discussion. q, which may be called the catchability, is simply the number that converts the relative biomass estimates to absolute estimates. The assumption is that this is the same for all the O_i. This assumption would be invalid if, for example, the biomass indices were average catch per boat-day and the boats used had significantly increased in fishing power over the period of the indices. The assumption that the standard deviation of O_i is cqE_i implies that all the O_i have the same coefficient of variation, c. This was felt to be the most plausible of three alternative assumptions. Because the biomass indices used here varied greatly in size the simplest assumption — that they all had the same variance — was considered untenable. The third alternative — using estimated variances — was not used because it was not available for the catch per unit effort indices and the variance estimates for the trawl survey indices were not considered sufficiently reliable.

For the trawl survey indices a slight refinement to the above assumptions was tried: the variance of O_i was assumed to be $(100/m_i)(cqE_i)^2$, where m_i is the number of stations in the ith survey. With this assumption c becomes the coefficient of variation of a "standard" trawl survey using 100 stations, and the variance of survey indices is assumed to be inversely proportional to the number of stations. However, this modification made no substantial difference to the estimate of B_0 and so, for simplicity, was omitted.

The equations used in estimating B_0 are:

$$\log(\text{likelihood}) = -n*\log(q) - n*\log(c) - \Sigma_i \log(E_i) \quad (1)$$

where n = the number of biomass indices,

$$q = (1/n)\ \Sigma_i(O_i/E_i) \quad (2)$$

and, $$c = (1/n)\ \Sigma_i(O_i/(qE_i)-1)^2 \quad (3)$$

If q is known from other sources the equation (2) is ignored and the assumed value of q is used in (1) and (3).

A confidence interval for the estimated B_0 was estimated by simulation. From a trial value of B_0 the "true" biomasses E_i were calculated, biomass indices O_i were simulated (using a normal distribution with mean E_i and s.d. cE_i), and the stock reduction analysis was used to estimate B_0. This was repeated 100 times for each of a sequence of trial B_0s. For each trial B_0 let p be the proportion of the estimated B_0s that were greater than the B_0 estimated from the actual biomass indices. Then the 95% confidence interval for the estimate of B_0 is (B_1, B_2) where for B_1, $p = 0.975$; and for B_2, $p = 0.025$.