MINISTRY OF FISHERIES
Te Tautiaki i nga tini a Tangaroa

ISSN 1175-1584

CPUE analysis and stock assessment of the west coast South Island orange roughy fishery (ORH 7B)

A. McKenzie

New Zealand Fisheries Assessment Report 2005/24
April 2005

CPUE analysis and stock assessment of the west coast South Island orange roughy fishery (ORH 7B)

A. McKenzie

NIWA
Private Bag 14901
Wellington

New Zealand Fisheries Assessment Report 2005/24
April 2005

Published by Ministry of Fisheries
Wellington
2005

ISSN 1175-1584

Citation:
McKenzie, A. (2005).
CPUE analysis and stock assessment of the west coast South Island
orange roughy fishery (ORH 7B).
New Zealand Fisheries Assessment Report 2005/24. 35 p.

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

EXECUTIVE SUMMARY

McKenzie, A. (2005). CPUE analysis and stock assessment of the west coast South Island orange roughy fishery (ORH 7B).

***New Zealand Fisheries Assessment Report 2005/24.* 35 p.**

This report updates the stock assessment for ORH 7B. The previous assessment was carried out in 2001 and is given in the 2003 Plenary Report. This has been updated with the addition of catch data up to the end of the 2002–03 fishing year, and new standardised CPUE indices based on mean catch per hour (instead of mean catch per tow as was used in the last assessment). These data were incorporated into a Bayesian stock assessment with deterministic recruitment to estimate biomass and conduct forward projections.

The ORH 7B fishery developed in the Cook Canyon in 1985. Reported annual landings have ranged from 90 t to 1760 t. The TACC was reduced from 1708 t to 430 t in the 1995–96 fishing year following several years from 1992 to 1995 when the TACC was not achieved. The TACC was reduced again to 110 t in the 2001–02 fishing year. Catch rates, both catch per tow and catch per hour, have remained low, with mean values being less than 10% of those at the start of the fishery. The mean distance towed in the last four years is more than three times the initial level.

Standardised CPUE indices were calculated from winter (June–July) mean daily catch rates using catch per tow and catch per hour. For both models, standardised year effects showed a similar pattern of steep decline from the initial years of the fishery. The relative year effects for 2002–03 were 4.6% (catch per tow) and 3.1% (catch per hour) compared to the 1985–86 year. Both standardisation models performed well, with the catch per tow model explaining 42% of the variation in the data and the catch per hour model explaining 48% of the variation. The standardised CPUE indices based on catch per hour were used in the stock assessement model.

Two assessments were examined. In the first (Beta1) it was assumed that the CPUE was proportional to biomass. In the second (EstBeta) it was assumed that the relationship between CPUE and the biomass could be non-linear with CPUE proportional to the biomass to the power of β. The estimated status of the stock depends strongly on which alternative assessment is used. If CPUE is assumed to be directly proportional to biomass (Beta1) then the current biomass is estimated to be 17% B_0 with a 95% confidence interval of 14–23% B_0. When this assumption is relaxed (EstBeta), the current biomass is much higher at 45% B_0, with a 95% confidence interval of 18–69% B_0. All yield estimates are higher than both the TACC and recent catches, and both assessments indicate that recent catches are allowing the stock to rebuild. One concern is that the model results indicate that the stock has been slowly rebuilding since the mid 1990s, whereas trends in catch rates and tow duration are not consistent with this conclusion.

1. INTRODUCTION

1.1 Overview

This report updates the stock assessment for the orange roughy fishery on the west coast South Island (ORH 7B). The previous assessment of this fishery by O'Driscoll (2001) is updated with the inclusion of data up to the end of the 2002–2003 fishing year. The work was carried out for Ministry of Fisheries project ORH2003/02 (orange roughy stock assessment). It covers for the west coast South Island stock (ORH 7B) Objective 1 (descriptive analysis of catch and effort data), Objective 2 (update the unstandardised and standardised catch per unit effort analyses), and Objective 4 (update the stock assessment).

1.2 Description of the fishery

Quota Management Area ORH 7B covers an area off the west coast of the South Island from near Westport to south of Jackson Head. Orange roughy occur throughout the QMA, which includes domestic fishing return areas 032 (northern part), 033, 034, 705, and 706 (Figure 1). The fishery is centred on an area near the Cook Canyon, which is a trench running out from the coast in roughly an east-west direction. Fishing also occurs to the south around the Moeraki Canyon.

The fishery developed from May 1985, with a rapid increase in the following year when aggregations of spawning orange roughy were targeted in winter. Most of the catch is taken in the winter, particularly in June and July. Reported landings have ranged from 90 to 1760 t per year (Table 1).

Catches in 1992–93 to 1994–95 were well below the TACC of 1708 t. The TACC was reduced to 430 t for the 1995–96 fishing year, but was reached only for the 1995–96 and 1996–97 fishing years. The TACC was further reduced in the 2000–01 fishing year to 110 t.

No non-commercial or Maori customary fisheries for orange roughy are known in this area.

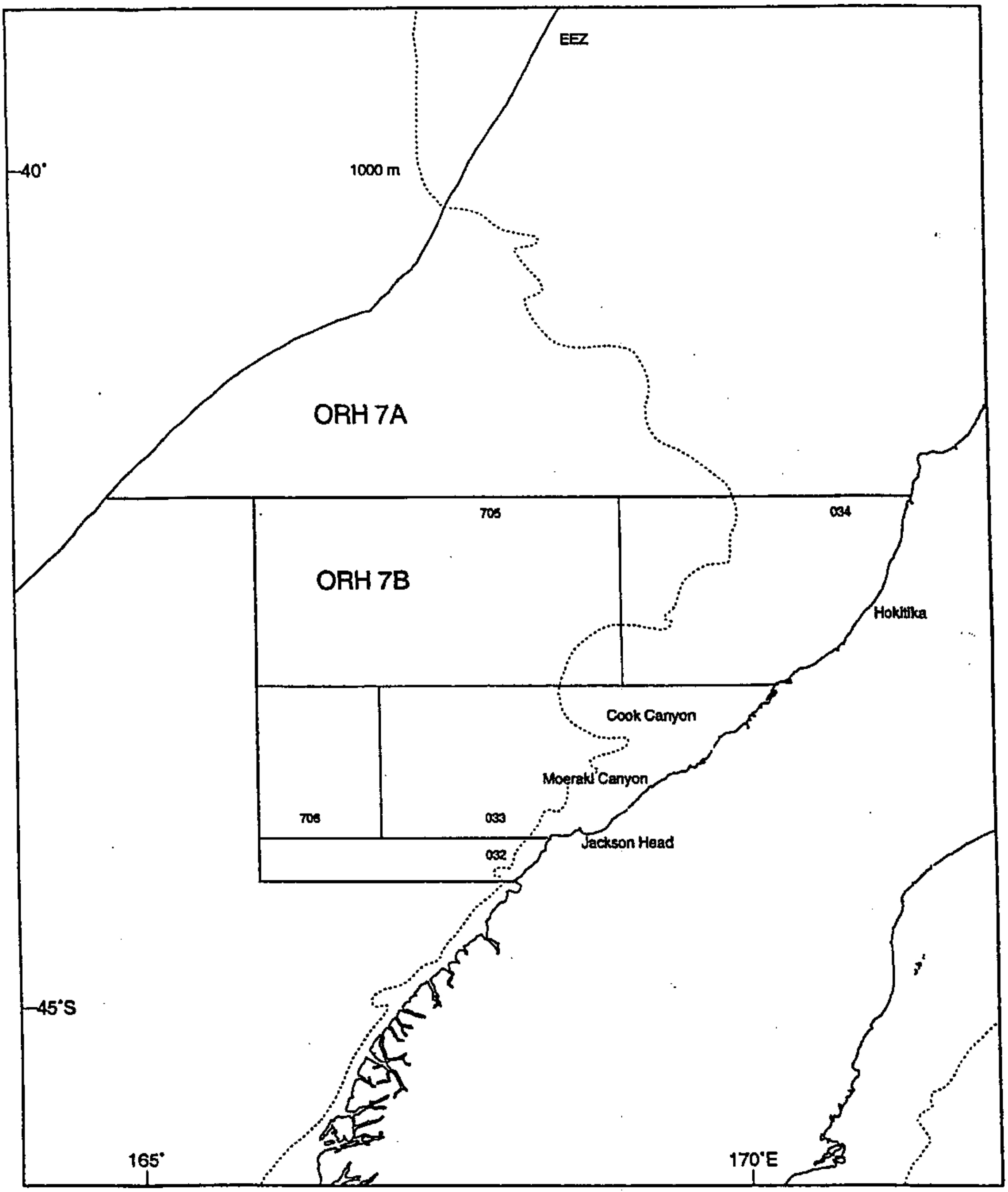


Figure 1: Location of the west coast South Island orange roughy fishery showing domestic fishing return areas.

Table 1: Reported landings (t) of orange roughy and TACs (t) for ORH 7B from 1983–84 to 2002–03. * denotes FSU data; † QMS data (Annala et al (2003, p. 357, table 1); 2002–2003 landing data from J. McKoy, NIWA, pers. comm.).

Fishing year	landings	TAC
1983–84*	2	-
1984–85*	282	-
1985–86*	1 763	1 558
1986–87*	1 446	1 558
1987–88†	1 413	1 558
1988–89†	1 750	1 708
1989–90†	1 711	1 708
1990–91†	1 683	1 708
1991–92†	1 604	1 708
1992–93†	1 139	1 708
1993–94†	701	1 708
1994–95†	290	1 708
1995–96†	446	430
1996–97†	425	430
1997–98†	330	430
1998–99†	405	430
1999–00†	284	430
2000–01†	161	430
2001–02†	95	110
2002–03†	90	110

1.3 Literature review

The initial development of the fishery and early research results were described by Armstrong & Tracey (1986). Several research surveys were carried out in the area in the 1980s (Tracey 1985, Armstrong & Tracey 1987, Tracey et al. 1990) and provided data on distribution and biology of orange roughy in the Cook Canyon area, but no time series of surveys has been developed to assess changes in relative abundance. The first stock assessment of this stock was in 1995 (Clark & Field 1995). This was followed by the most recent assessment in 2001 (O'Driscoll 2001) when it was estimated that the virgin biomass lies between 12 000 and 20 000 t.

2. REVIEW OF THE FISHERY

2.1 Data sources

Catch and effort data from the west coast South Island fishery are recorded on either trawl-catch-effort-processing-returns (TCEPR) or catch-effort-landing-return (CELR) forms. The TCEPR forms give tow-by-tow information, with location and estimated catch for each trawl. The CELR forms provide daily catch records with effort estimated as the number and total duration of tows in the day. CELR forms tend to be used by smaller inshore vessels. Larger deepwater vessels are required to complete TCEPR forms.

The west coast South Island fishery was defined as the area between latitudes 42° and 44.25° S, and longitudes 166° and 171.5° E. This area includes domestic fishing return areas 033, 034, 705, 706, and the northern part of 032 (Figure 1). Tows (TCEPR) or daily catch records (CELR) within this area that targeted or caught orange roughy were extracted for the fishing years 2000–01, 2001–02 and 2002–03.

To combine data from both TCEPR and CELR forms, tow-by-tow data from TCEPR were condensed into a daily format. All tows by a vessel on a day were combined and the catches from individual tows summed. This gave a total daily catch record comparable with CELR data.

The data from 2000–01, 2001–02, and 2002–03 were combined with groomed data from 1985–86 to 1999–2000 (summarised by Field (1999) and O'Driscoll (2001)).

2.2 Catch effort data

A total of 7990 tows from 2838 vessel days were present in the groomed data (Table 2). Almost all tows targeted orange roughy. The TACC was reduced to 110 t in 2001–02 and, associated with this, there has been a drop in the number of vessel days and tows. Catch rates, both catch per tow and catch per hour, have remained low, with their mean values being less than 10% of their values at the start of the fishery. The mean distance towed in the last four years is more than three times the initial level.

Table 2: Summary of groomed data from TCEPR and CELR forms. "*" denotes TCEPR data only.

Fishing year	Number of vessel days	Number of tows	Total recorded estimated catch (t)	Mean daily catch rate (t/tow)	Mean daily catch rate (t/h)	Mean tow speed* (kt)	Mean tow duration* (h)	Mean tow length* (n. mile)
1985–86	138	357	1544	4.5	2.9	2.3	1.8	4.4
1986–87	132	405	1250	4.0	2.7	2.3	1.9	4.3
1987–88	132	420	1250	3.4	2.3	2.8	1.6	4.6
1988–89	133	368	827	2.5	1.6	2.9	1.7	4.9
1989–90	123	356	1282	4.5	5.6	2.8	1.6	4.4
1990–91	208	632	1657	2.8	3.3	2.9	1.6	4.7
1991–92	238	810	1601	2.0	1.4	2.9	1.9	5.4
1992–93	258	784	1128	1.5	2.3	3.0	1.7	5.2
1993–94	298	708	660	1.1	0.9	2.8	2.3	6.6
1994–95	162	361	320	0.9	1.6	2.9	2.0	5.8
1995–96	66	150	275	2.2	1.7	2.9	2.1	6.1
1996–97	90	182	244	1.3	7.5	2.8	3.1	8.6
1997–98	96	228	170	0.7	0.3	2.8	2.5	7.0
1998–99	188	566	359	0.6	0.2	2.6	2.6	6.8
1999–2000	213	647	259	0.4	0.1	3.5	4.5	16.4
2000–2001	149	442	162	0.4	0.1	3.5	3.5	12.5
2001–2002	117	282	76	0.3	0.1	3.8	4.7	17.8
2002–2003	97	292	112	0.4	0.2	3.8	3.6	14.1

2.3 Seasonal and spatial distribution of catch and effort

Historically most effort (Table 3, Figure 2) and catch (Table 4, Figure 3) in the west coast South Island fishery has been concentrated in the winter spawning period (June and July) with a much smaller, secondary peak in catch and effort in September and October. Since 1996–97 effort has tended to be more spread throughout the year.

The geographical distribution of effort has changed over the course of the fishery (Figure 4). Initially effort was concentrated in a very small area near the intersection of statistical areas 033, 034, and 705. Effort became more dispersed in 1992–93 as fishers ranged widely in an attempt to catch the available quota, and has remained widespread.

Catch rate plots (Figure 5) show high catch rates in the Cook Canyon in the early years of the fishery. Catch rates have decreased as the fishery dispersed, but relatively high catches were taken in the

Moeraki Canyon to the south in 1992–93 and 1993–94. Catch rates have been low throughout ORH 7B in 1997–2003, with very few catches over 5 t.

Table 3: Monthly distribution of effort (number of tows) in the west coast South Island orange roughy fishery.

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1985–86	129	4	0	9	2	0	24	45	104	4	8	28
1986–87	111	14	0	0	1	0	2	1	238	2	33	3
1987–88	0	0	0	2	0	0	0	23	359	30	6	0
1988–89	0	0	0	0	0	0	0	43	229	11	51	34
1989–90	0	0	4	0	0	0	21	0	204	77	50	0
1990–91	88	26	3	22	2	0	12	77	228	115	4	55
1991–92	26	16	0	0	0	3	0	24	416	285	39	1
1992–93	72	0	0	0	0	0	0	43	185	436	15	33
1993–94	28	15	5	27	9	11	5	7	206	367	22	6
1994–95	2	21	15	13	2	13	1	35	76	149	24	10
1995–96	11	4	0	0	0	1	0	2	53	79	0	0
1996–97	6	1	0	2	0	0	0	7	127	39	0	0
1997–98	14	2	3	3	0	7	8	3	77	47	1	63
1998–99	33	28	12	48	11	42	25	25	128	76	0	138
1999–2000	22	23	12	15	4	10	79	65	208	96	16	97
2000–01	1	21	7	0	4	4	15	50	188	60	21	71
2001–02	1	6	0	16	0	21	14	17	44	64	20	79
2002–03	10	0	3	6	0	18	15	97	81	4	15	43

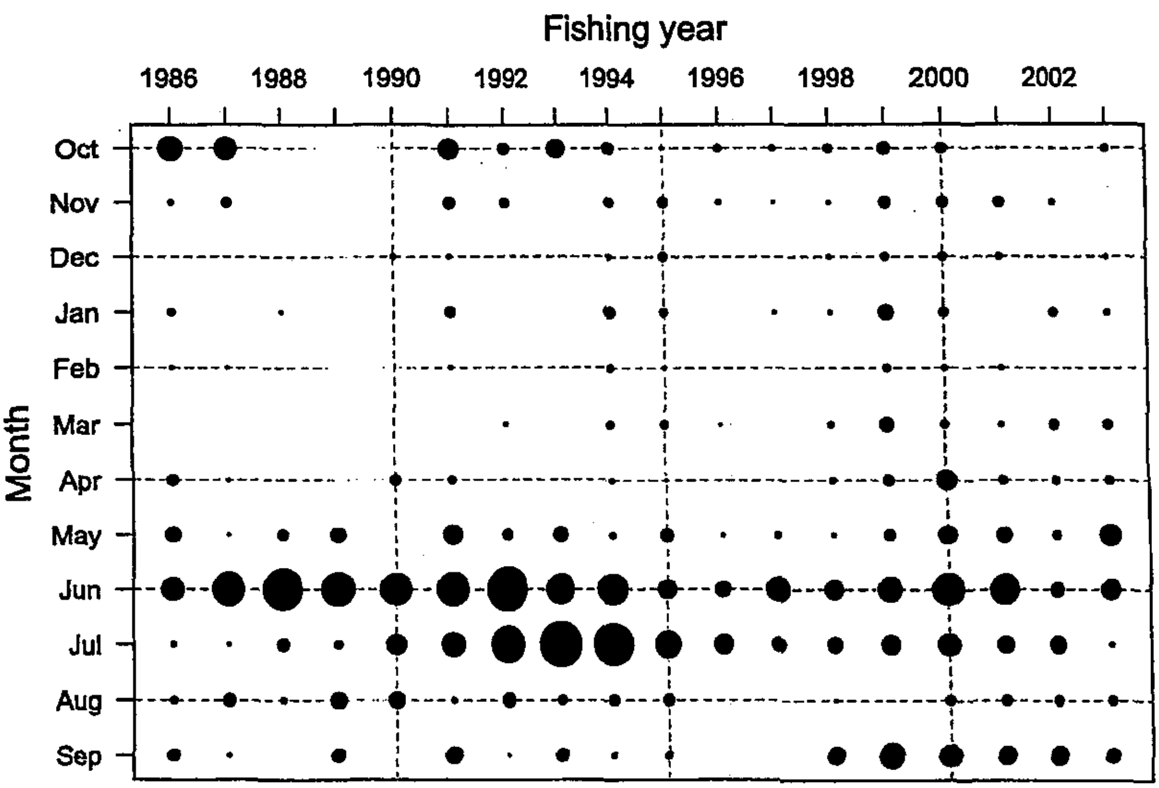


Figure 2: Monthly distribution of effort (number of tows) in the west coast South Island orange roughy fishery (see Table 3). The area of the circles is proportional to the number of tows; the largest circle represents 436 tows.

Table 4: Monthly distribution of reported catch (t) in the west coast South Island orange roughy fishery. Blanks indicate months when there was no effort (see Table 3).

Fishing year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1985–86	419	1		15	1		22	68	855	91	9	64
1986–87	144	0			1		0	0	994	19	44	48
1987–88				0				78	888	210	75	
1988–89								85	535	116	81	9
1989–90			6				14		248	827	188	
1990–91	184	34	12	30	1		3	62	474	734	12	111
1991–92	6	6				0		3	659	879	48	0
1992–93	30							17	494	531	19	36
1993–94	33	7	10	5	13	1	1	2	106	375	86	22
1994–95	0	43	10	3	2	5	0	8	76	164	3	3
1995–96	2	0				2		0	156	114		
1996–97	2	0		2				5	203	33		
1997–98	20	0	0	0		1	1	0	28	57	0	62
1998–99	45	31	7	22	2	10	10	3	94	68		69
1999–2000	7	12	7	4	0	1	27	13	91	57	3	38
2000–01	0	13	1		0	1	3	20	56	28	15	23
2001–02	0	1		5		11	3	4	16	18	4	15
2002–03	2		0	4		8	6	32	41	4	3	12

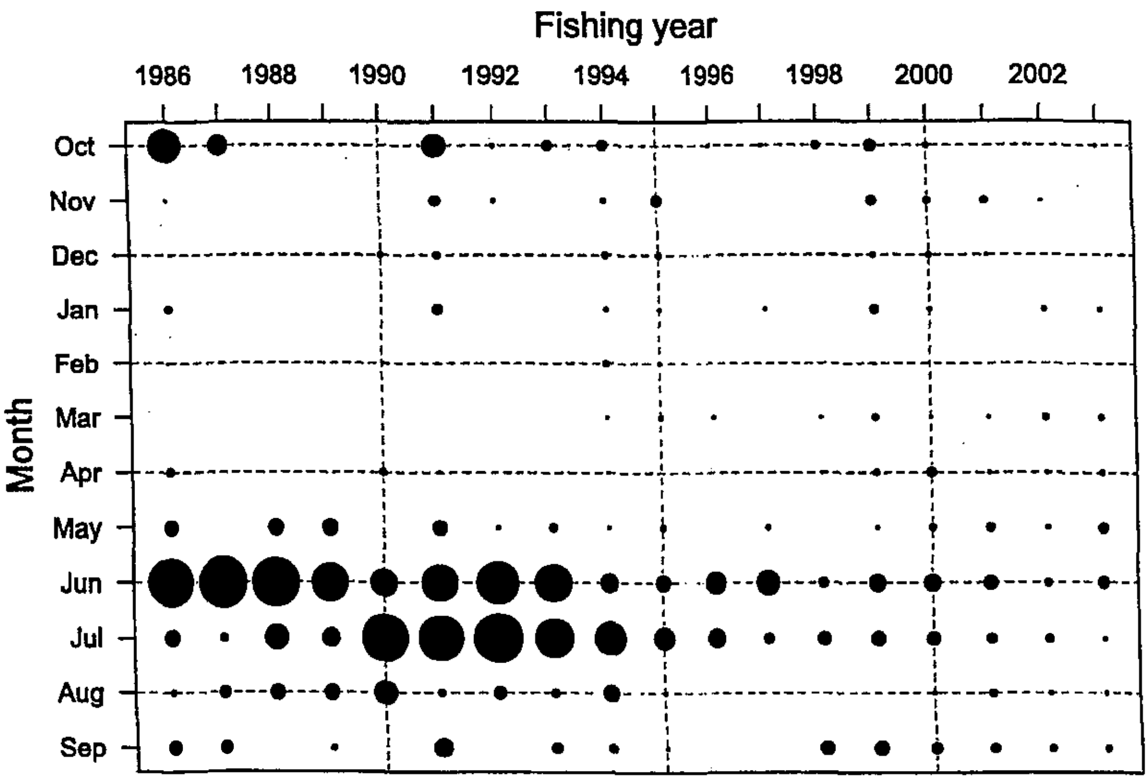


Figure 3: Monthly distribution of catch (t) in the west coast South Island orange roughy fishery (see Table 4). The area of the circles is proportional to the catch; the largest circle represents 994 tons. No circles indicate months where there was no effort.

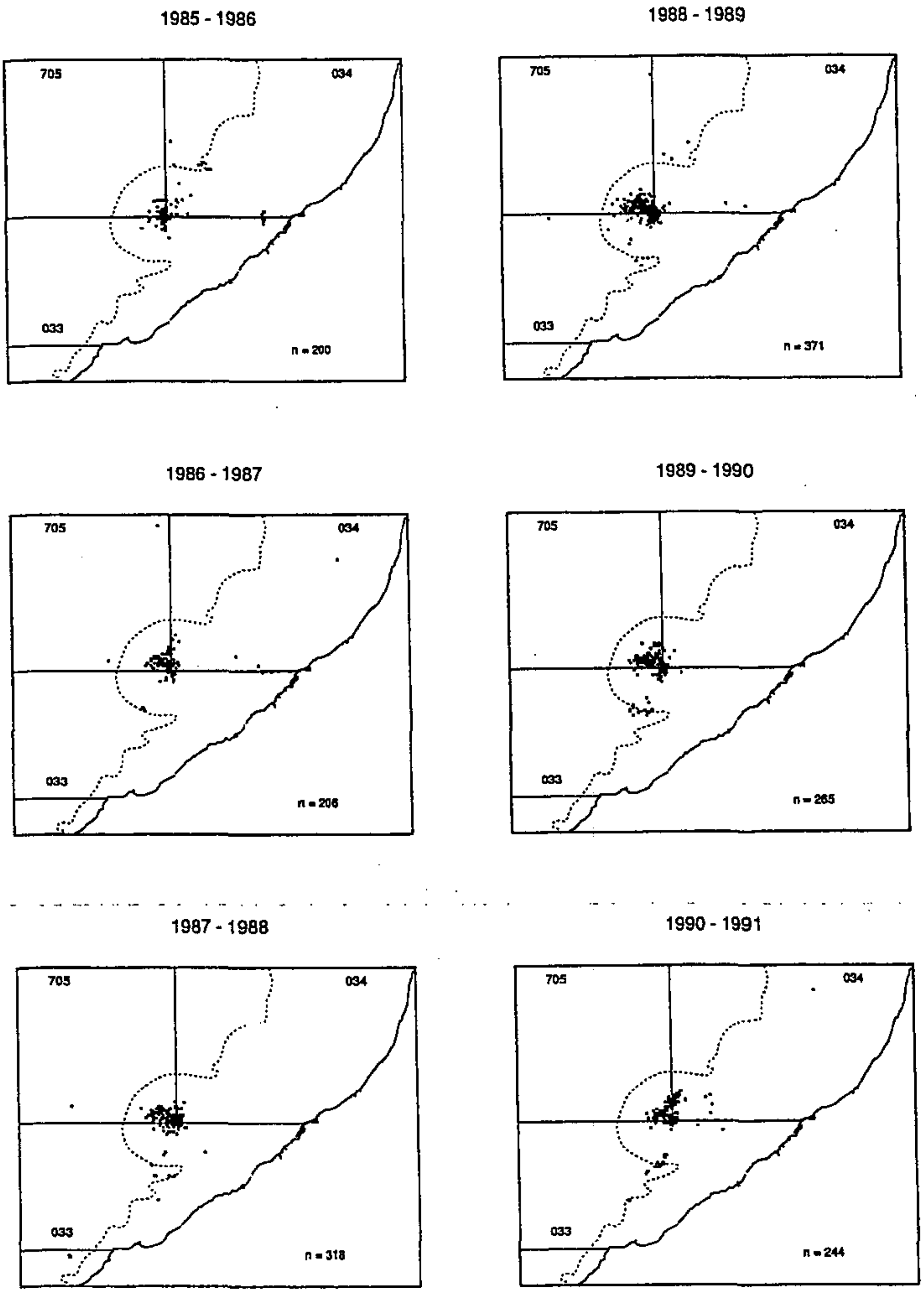


Figure 4: Positions of tows which targeted or caught orange roughy in the west coast South Island fishery 1985–86 to 1990–91. TCEPR data only. Dotted line is 1000 m isobath.

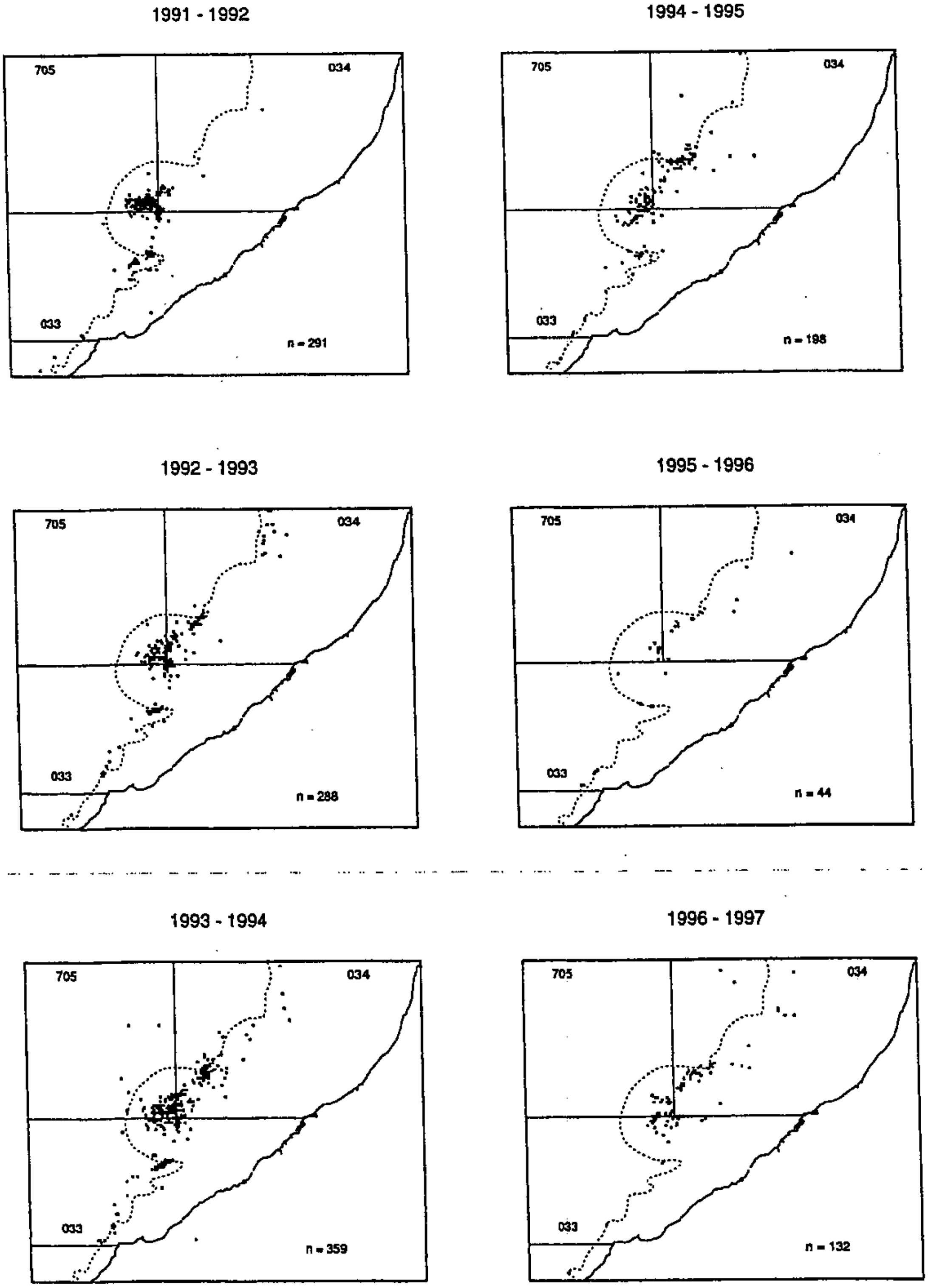


Figure 4 (cntd): Positions of tows which targeted or caught orange roughy in the west coast South Island fishery 1991–92 to 1996–97. TCEPR data only. Dotted line is 1000 m isobath.

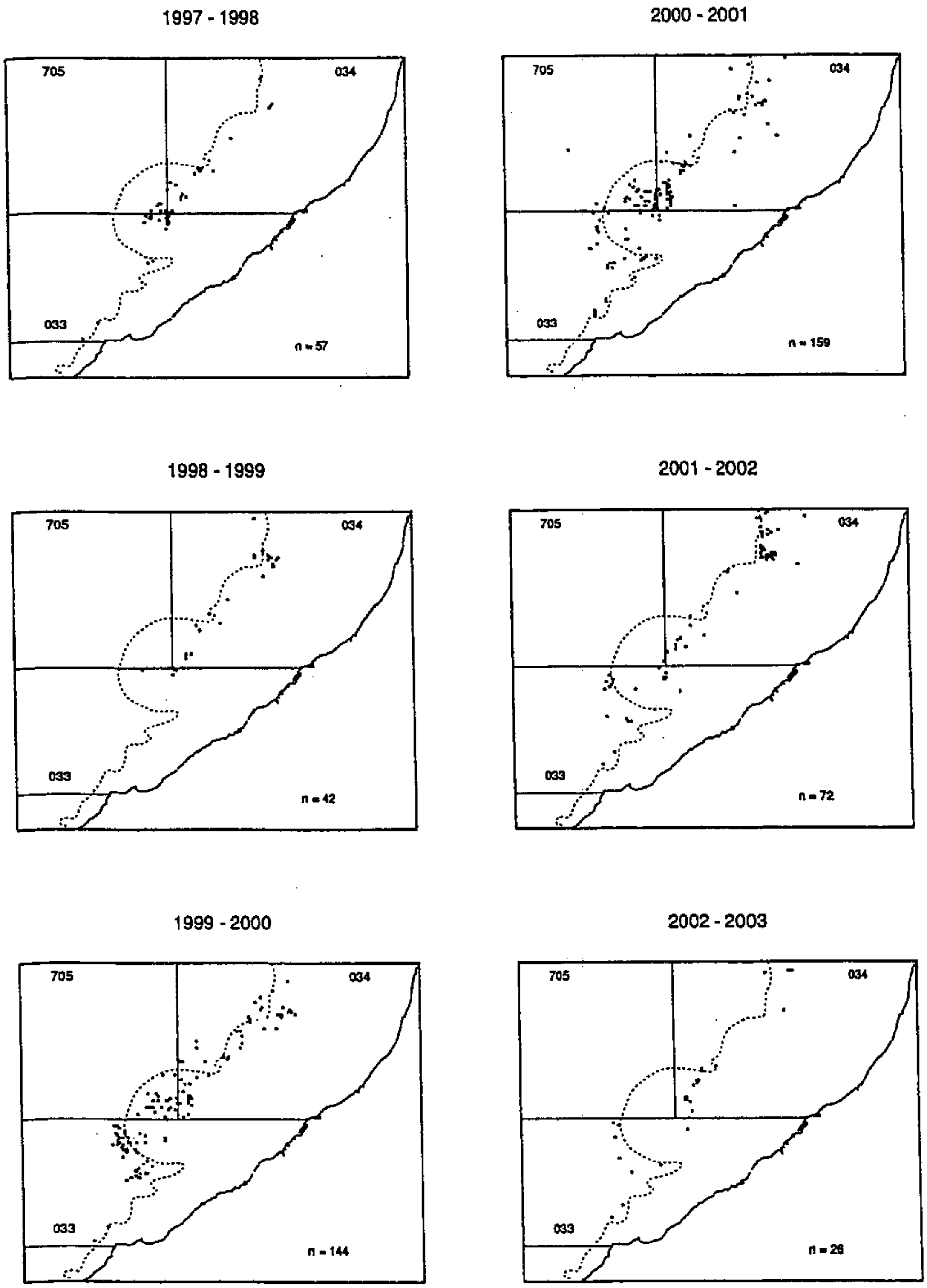


Figure 4 (cntd): Positions of tows which targeted or caught orange roughy in the west coast South Island fishery 1997–98 to 2002–2003. TCEPR data only. Dotted line is 1000 m isobath.

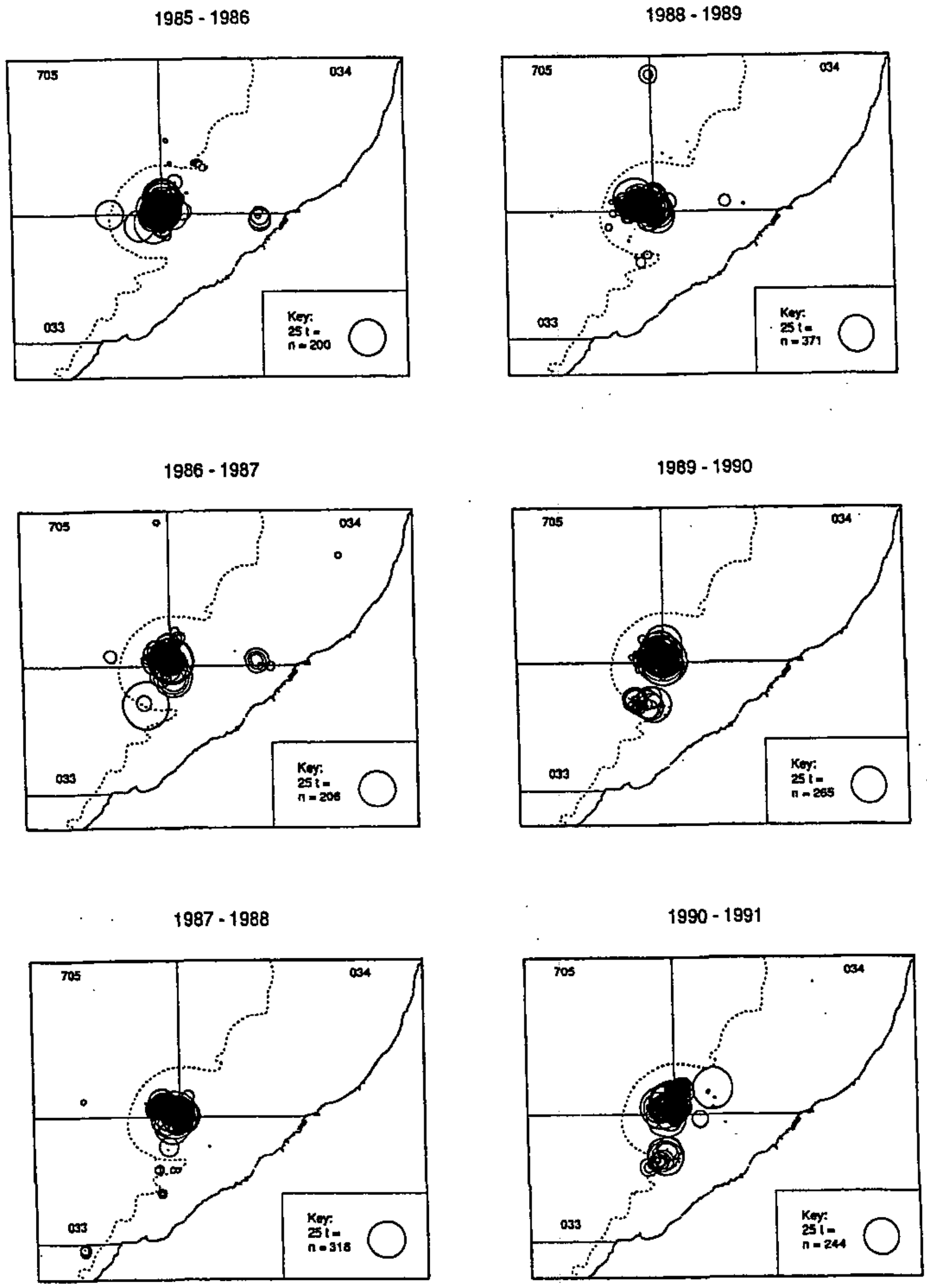


Figure 5: Unstandardised catch rates of tows which targeted or caught orange roughy in the west coast South Island fishery 1985–86 to 1990–91. Circle area is proportional to t/tow. TCEPR data only. Dotted line is 1000 m isobath.

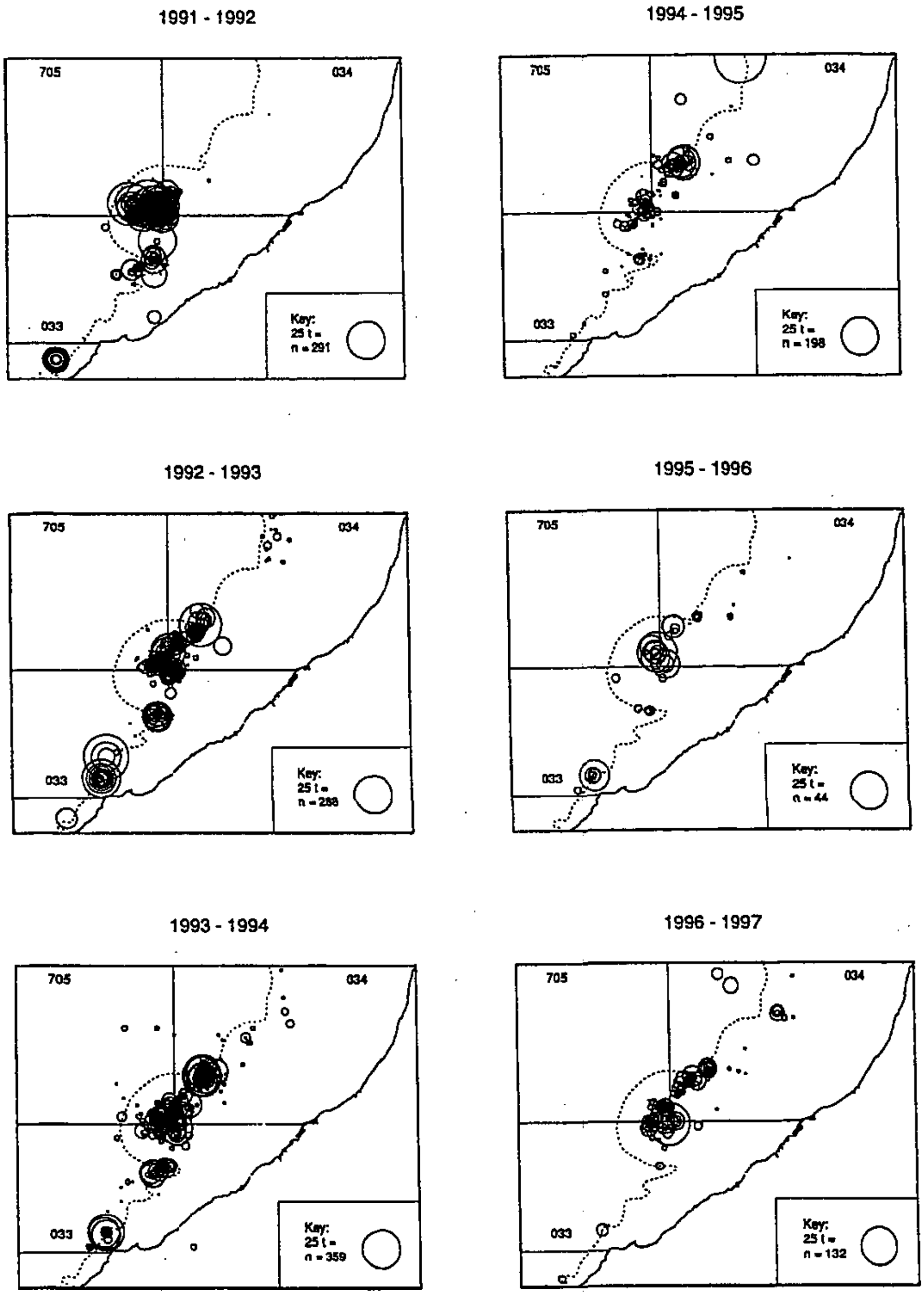


Figure 5 (cntd): Unstandardised catch rates of tows which targeted or caught orange roughy in the west coast South Island fishery 1991–92 to 1996–97. Circle area is proportional to t/tow. TCEPR data only. Dotted line is 1000 m isobath.

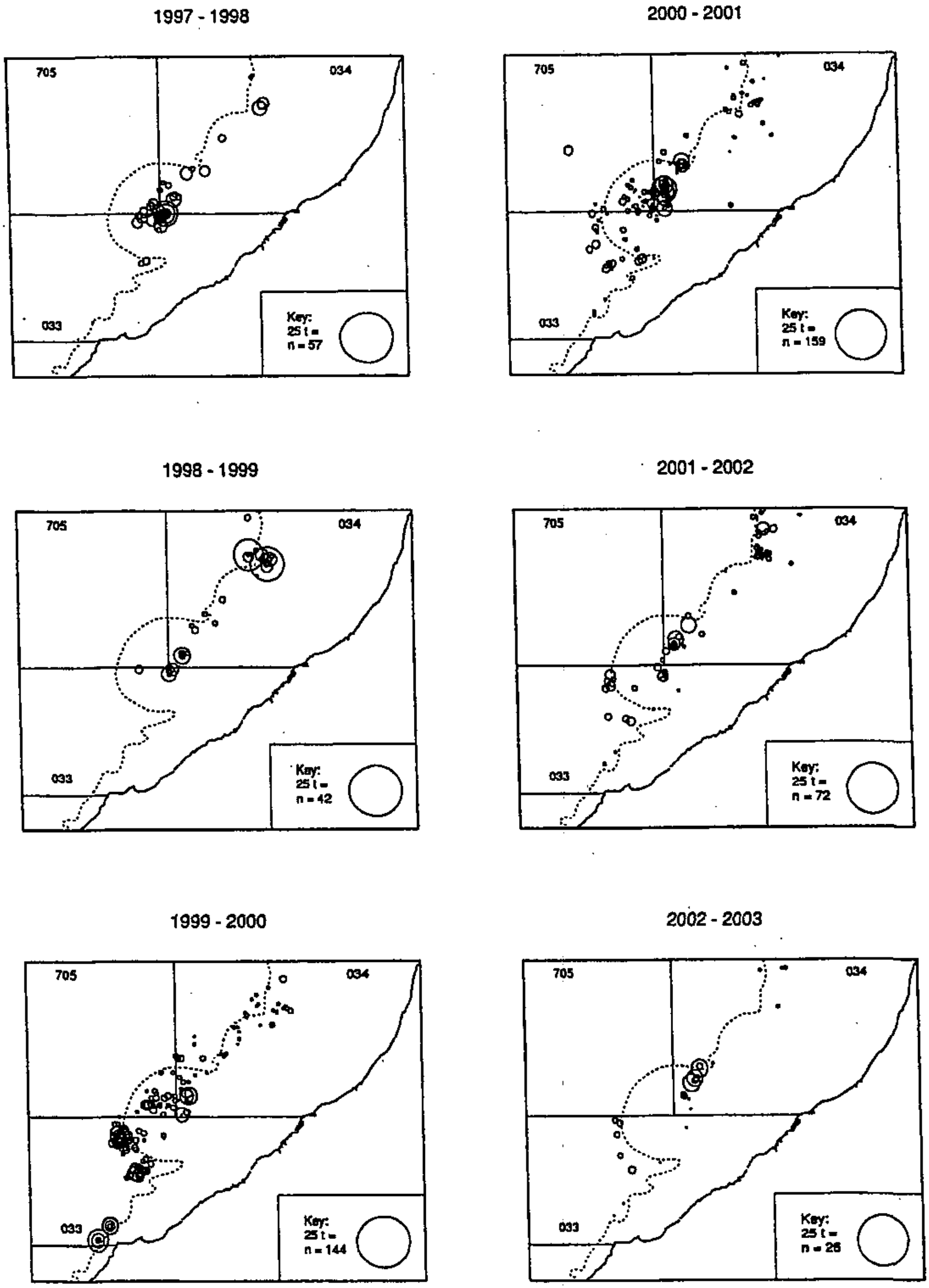


Figure 5 (cntd): Unstandardised catch rates of tows which targeted or caught orange roughy in the west coast South Island fishery 1997–98 to 2002–2003. Circle area is proportional to t/tow. TCEPR data only. Dotted line is 1000 m isobath.

3. RESEARCH

3.1 Stock structure

Orange roughy in this fishery are thought to be a single stock. Results from mitochondrial DNA studies indicate that fish from neighbouring fishing grounds of the Challenger Plateau and Puysegur Bank are distinct from those at Cook Canyon (Smith et al. 1996). Spawning in the Cook Canyon area also occurs at about the same time (late June, early July) as on the Challenger Plateau and the Puysegur Bank. The distance between the Cook Canyon and Challenger grounds is 330 km; the Challenger and Puysegur grounds are 520 km apart.

3.2 Resource surveys

Several research surveys were carried out in this area in the 1980s. Two cruises by GRV *James Cook* in February and December 1983 collected trawl and hydrological data (Tracey et al. 1990). Trawling was also carried out in October 1983 by FV *Arrow* under charter to MAF. In 1985 there was exploratory and research fishing by commercial vessels, as well as a biomass survey by *Arrow* on charter (Tracey 1985). Further bathymetric and trawling work was carried out on *James Cook* in February 1986, and there was another trawl survey by *Arrow* in July (Armstrong & Tracey 1987).

These surveys provided a range of data on distribution, relative abundance, and biology of orange roughy in ORH 7B. However, data that can be used in stock assessments are limited. Surveys on *Arrow* in 1985 and 1986 were both stratified random trawl surveys, but the 1985 survey took place before the spawning distribution was well known, and the 1986 survey was carried out after spawning had finished and some dispersal was likely to have occurred. No time series of surveys has been developed to measure changes in relative abundance.

4. STANDARDISED CATCH PER UNIT EFFORT (CPUE) ANALYSES

4.1 Input data

A subset of data which represented the most consistent effort over time was selected for standardised analysis. Data were selected from the winter spawning period (1 June to 31 July) only. There has been substantial effort during June and July in all years from 1985–86 to 2002–2003 (see Table 3) and this is the period when 78% of the catch in the fishery has been taken over these years (see Table 4). The input data were further restricted to vessels which had fished in winter for more than 20 days over at least two years between 1985–86 and 2002–2003, to reduce the effect of novice vessels on catch rate.

These restrictions resulted in an input data set consisting of 1605 daily records (4686 tows) from 18 vessels, and represented 75% of the recorded catch for all months from 1985–86 to 2002–2003. Selected vessels generally fished for more than 5 years and three vessels fished for more than 10 years (Table A1, Figure A1) providing good overlap and consistency in the data.

4.2 Methods

A standardised CPUE analysis for ORH 7B was carried out using a stepwise multiple regression technique (after Vignaux 1994). Catch rate (the dependent variable) was modelled as log(daily catch per tow) and log(daily catch per hour). There were a small number of daily records where the catch rate was zero (less than 3%) and these were ignored in the standardised analysis.

Variables used as possible predictors of CPUE were fishing year, season, vessel, and statistical area (Table 5). All were categorical variables. Season was categorised into 12 fixed periods of 5 days each beginning on 1 June. Other variables, such as depth, which are commonly included in other orange roughy CPUE analyses, were not recorded on CELR forms.

Table 5: Categorical variables entered into the standardised CPUE analysis.

Variable offered	Description
fishing year	Fishing year: 1995 = 1 Oct 94 – 30 Sep 95
vessel	Each vessel was an independent variable
area	Domestic fishing return area
season	12 periods of five days beginning on 1 June

A forward stepping procedure was used to select predictor variables, and they were entered into the model in the order which gave the maximum decrease in the Akaikee Information Criterion (AIC). Predictor variables were accepted into the model only if they explained at least 0.5% of the deviance.

4.3 Results

Variables selected by both the regression models were fishing year, season, and vessel (Table 6). The catch per tow model explained 42% of the variability in CPUE, and the catch per hour model 48%. Diagnostic plots suggest a good fit for both models, though for the catch per hour model the distribution of the observed variable (log of the catch per hour) had longer tails than that of the model (Figure 6). The seasonal effect had a peak on 11–15 July, which is consistent with the nature of the fishery.

For both models, standardised year effects showed a similar pattern of step decline from the initial years of the fishery (Figure 7). The relative year effects for 2002–03 were 4.6% (catch per tow) and 3.1% (catch per hour) compared to the 1985–86 year.

The Deep Water Fishery Asesssment Working Group decided to use for the stock assessment the standardised CPUE based on catch per hour rather than catch per tow (as was used in the previous assessment). This was because (1) the TCEPR data indicated that in recent years tows were increasing in both duration and speed, and (2) the predictor variables explained a greater percentage of the deviance in the catch per hour model. The standardised CPUE indices based on the catch per hour model are shown in Table 7, and plotted with 95% confidence intervals in Figure 8.

Table 6: Variables included in the final model (0.5% additional deviance explained).

	Dof	AIC	Percentage deviance explained	Additional % deviance explained
catch per tow				
fishing year	18	2 361.9	28.7	28.7
season	11	2 104.9	37.6	9.0
vessel	17	2 003.3	42.3	4.7
catch per hour				
fishing year	18	2 880.6	36.7	36.7
season	11	2 634.9	43.1	6.4
vessel	17	2 497.6	47.6	4.5

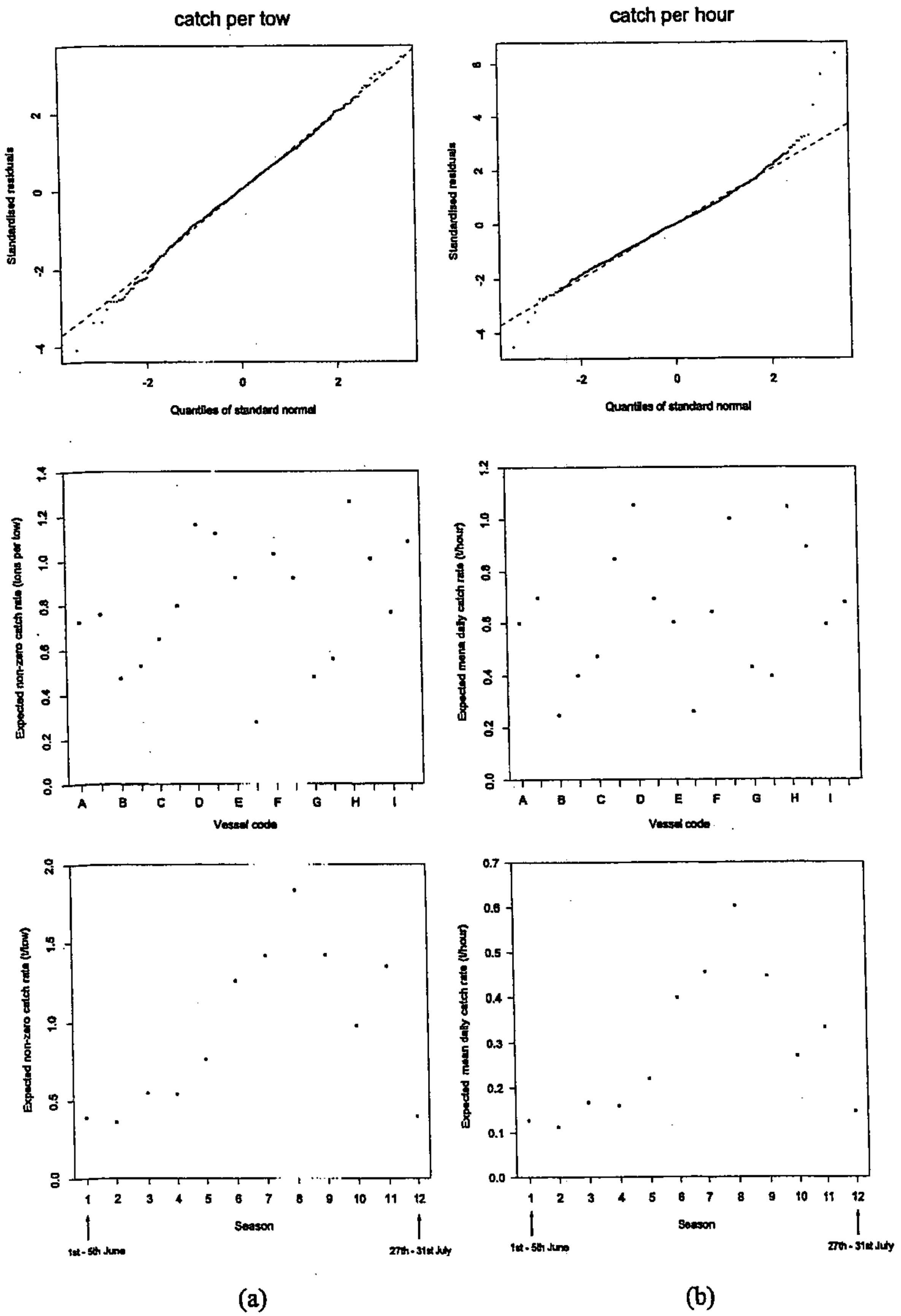


Figure 6: Diagnostic plots for model fits, vessel effects, and seasonal effects for the models fits in Table 6: (a) catch per tow (b) catch per hour.

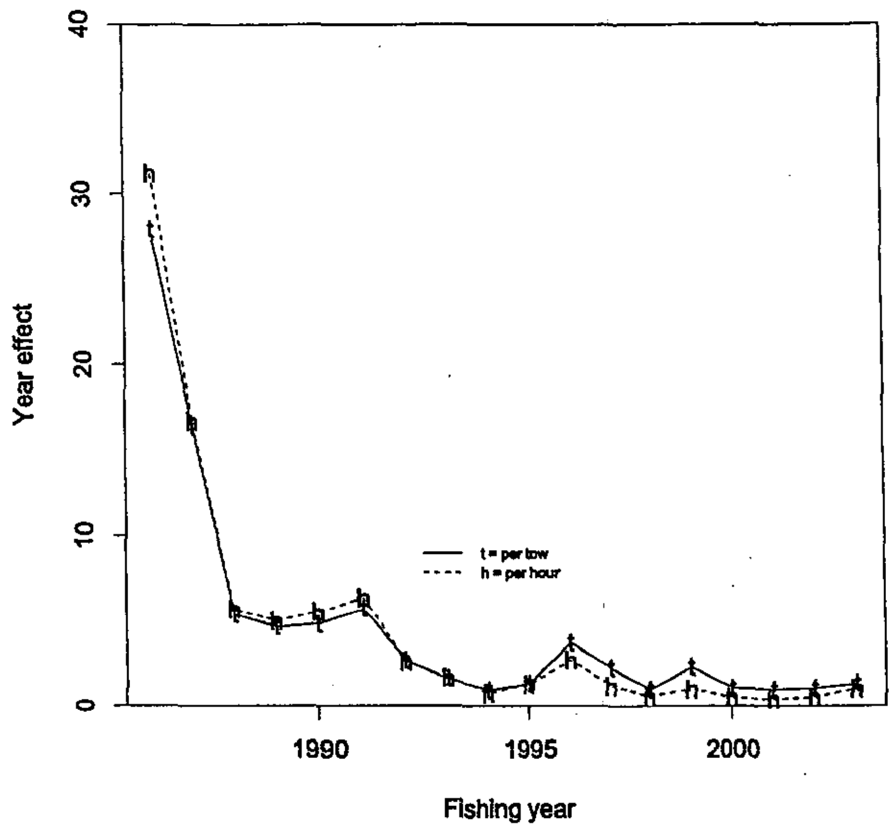


Figure 7: Standardised CPUEs based on t/tow vs t/h. The indices for t/h are scaled so as to have the same mean as the t/tow indices.

Table 7: Standardised CPUE indices (relative year effect) with number of vessel days fished during June-July from 1985–86 to 2002–03. These indices were used in the stock assessment. The c.v.s. were estimated by bootstrapping on the daily tow data set.

Year	CPUE index	c.v.	Number of days
1985–86	14.97	0.28	33
1986–87	8.01	0.29	62
1987–88	2.71	0.27	107
1988–89	2.38	0.26	75
1989–90	2.64	0.29	89
1990–91	3.02	0.22	119
1991–92	1.24	0.26	192
1992–93	0.78	0.25	205
1993–94	0.35	0.25	232
1994–95	0.60	0.30	78
1995–96	1.28	0.37	36
1996–97	0.54	0.33	72
1997–98	0.26	0.31	38
1998–99	0.46	0.29	54
1999–2000	0.22	0.32	70
2000–01	0.17	0.37	54
2001–02	0.23	0.40	29
2002–03	0.46	0.41	31

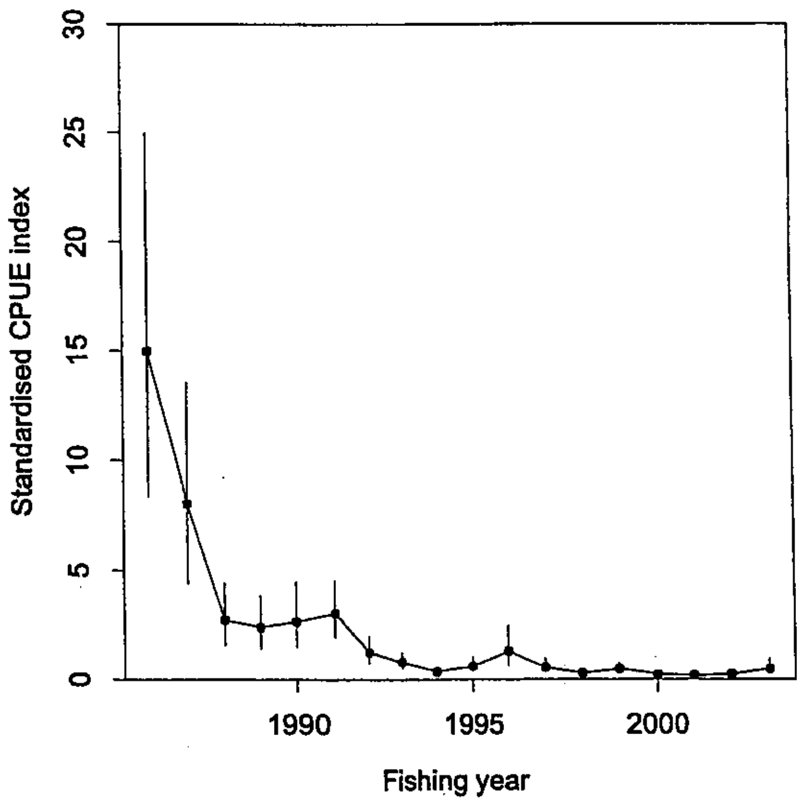


Figure 8: Standardised CPUEs based on t/h (see Table 7). Error bars represent the 95% confidence interval. This CPUE index was used in the stock assessment.

5. STOCK ASSESSMENT

5.1 Introduction

The previous assessment of this stock was by O'Driscoll (2001) who estimated that the virgin biomass (B_0) probably lay between 12 000 and 20 000 t, with current biomass as a percentage of virgin biomass in the range 12 to 45%. The previous stock assessment is updated with three more years of catch data and an updated standardised CPUE based on catch per hour (catch per tow was used in the previous assessment).

5.2 Two modelling issues

For this assessment, a new feature of the model structure was allowing for a non-linear relationship between CPUE and the vulnerable biomass: CPUE = q^*(rescaled biomass)$^{1/b}$. In this equation q^* is a relativity constant that transforms the right-hand side to have the same scale and units as the CPUE, the rescaled biomass is the vulnerable biomass scaled so as to have a maximum value of one, and β = 1/b the curvature. For $0<\beta<1$ the CPUE declines slower than the rescaled biomass ("hyperstability"); for $\beta>1$ CPUE declines faster than the rescaled biomass ("hyperdepletion").

Commonly, in orange roughy stock assesments (and for many other fisheries as well), β is taken as having value one; i.e., the relationship between CPUE and biomass is assumed to be linear. However, there is some evidence that for orange roughy fisheries, hyperdepletion takes places at least during the fishing down phase of the fishery. A meta-analysis was undertaken on orange roughy assessments where there were comparable estimates of stock abundance based on CPUE data and fishery independent surveys to determine the relationship between CPUE and abundance. Of the four stocks analysed, three showed significant hyperdepletion, where CPUE declines faster than abundance (Hicks 2004a). The fourth stock, ORH 3B NE, did not show a significant departure from a linear proportional relationship. Using these meta-analysis results, a prior for the parameter β was determined to allow this parameter (or equivalently $b = 1/\beta$) to be estimated within a Bayesian stock assessment model. The prior for β is log-normal with the mean of $\ln(\beta)$ equal to 0.7075 and the standard deviation of $\ln(\beta)$ equal to 1.0446 (Hicks 2004b). For further details see Annala et al. (2004, p. 324).

A second issue was that exploratory model fits for the Northwest Chatham Rise and Mid-East Coast orange roughy stocks demonstrated an apparent disparity between the age of sexual maturity, as found from the otolith data (using counts to the transition zone; Francis & Horn (1997)), and the age at which fish became vulnerable to the commercial fishery. For the west coast South Island stock, which does not have any data regarding vulnerability, the age of vulnerability was set equal to the age at maturity estimated from the otolith data. For further details see Annala et al. (2004, p. 325).

5.3 Model assumptions

The observational data were incorporated into an age-based Bayesian stock assessment with deterministic recruitment to estimate stock size. The stock was considered to reside in a single area, with partitions by sex (male and female) and maturity (mature and immature). Age groups were 1–70 years, with a plus group of 70+.

There is a single time step in the model, in which the order of processes is ageing, recruitment, maturation, growth, and mortality (natural and fishing). Each fish is aged by one year at the start of the time step, and fish are recruited into the model at age one year. It is assumed in the absence of information to the contrary that 50% of the recruits are males, and that year class strengths over the years 1983–2003 are equal. Recruitment numbers followed a Beverton-Holt relationship. Mortality was modelled as instantaneous with half the natural mortality applied first, then all of the fishing mortality, then the other half of the natural mortality. Only mature fish were taken in the model by the fishing fleet, and as with other orange roughy stock assessments a maximum fishing pressure of 0.67 was permitted (Francis et al. 1995).

Biological parameters are the same as for the previous assessment. These and the other model parameters are summarised in Table 8.

Table 8: Model parameters. Biological parameters (natural mortality, length-at-age, length-at-weight) are those estimated for the northeast Chatham Rise (ORH 3B) orange roughy fishery (Annala et al. 2000) where fish size is similar to orange roughy in ORH 7B. Updated values are now available for the length-at-age parameters (Annala et al. 2004, p. 323, table 1), but these were not used for this assessment.

Parameter	Symbol	Male	Female	Both sexes
Year class strengths	YCS	–	–	1
Proportion of recruited fish	p_m, p_f	–	–	0.5
Recruitment variability	σ_R	–	–	1.1
Recruitment steepness	h	–	–	0.75
Natural mortality	M	–	–	0.045 yr^{-1}
von Bertalanffy parameters	L_∞	36.4 cm	38.0 cm	–
	k	0.070 yr^{-1}	0.061 yr^{-1}	–
	t_0	–0.4 yr	–0.6 yr	–
Length-weight parameters	a	–	–	0.09
	b	–	–	2.71
Maximum fishing pressure	U_{max}	–	–	0.67

5.4 Model inputs

The only observational data available for the model were the standardised CPUE series based on the catch per hour model (see Table 7), for which a log-normal error distribution was assumed.

The catches taken in the model are those given in Table 1. For the current year (2003–04), the previous year's catch was assumed (90 t). Reported catch overruns are likely to occur because of fish loss from torn nets, and discarding of small or damaged fish. There is no estimate of the size of the overrun, but it means that actual catch is greater than reported catch. However, because overrun has not been added in the catch history, this will have no effect on the assessment as long as future overruns are similar to those in the past.

5.5 Methods

This assessment used the deterministic stock reduction method of Francis (1990). The free parameters in the model are: (1) the virgin biomass (B_0), (2) the relativity constant (q^*) which is involved in scaling the standardised CPUE index to a biomass, (3) the parameter $b=1/\beta$ describing the curvature of the relationship between CPUE and biomass, and (4) the process error which is "added" to the c.v. error for the standardised CPUE indices. The free parameters are summarised in Table 9.

Five initial model sensitivity runs were decided upon. There was some debate in the Deep Water Working Group concerning the utility of estimating β and it was decided to do model fits with β estimated (EstBeta), and with it fixed at one (Beta1). Furthermore, there was some concern that the first three years of the standardised CPUE indices were inaccurate and likely to have a significant effect on the stock assessment, so model fits were done with and without the first three years. The sensitivity tests for the CPUE series were done in combination with those for β giving four model sensitivity runs. Lastly, the base case of the previous assessment by O'Driscoll was emulated, based on catch per tow for the standardised CPUE, but with three more years of data. The five model runs are summarised in Table 10. Model fits were Bayesian Maximum Posterior Density (MPD) estimates, and the stock assessment program CASAL (Bull et al. 2002) was used to implement and fit the models (see Appendix A2 for the CASAL input files). Note that in CASAL the parameter b is estimated, then inverted to give β.

Table 9: Free parameters for the models.

Free parameter	Prior	Number of parameters
B_0	uniform-log	1
curvature ($b=1/\beta$)	lognormal	1
relativity constant (q^*)	uniform-log	1
process error	uniform	1

Table 10: Initial model sensitivity runs. The year 1986 denotes the fishing year 1985–86. If β is not estimated it is set to one.

Model	CPUE t/tow	CPUE t/h	estimate β	Drop 1986–89
Updating last assessment	√			
Beta1		√		
Beta1 drop 86–89		√		√
EstBeta		√	√	
EstBeta drop 86–89		√	√	√

5.6 Model fits

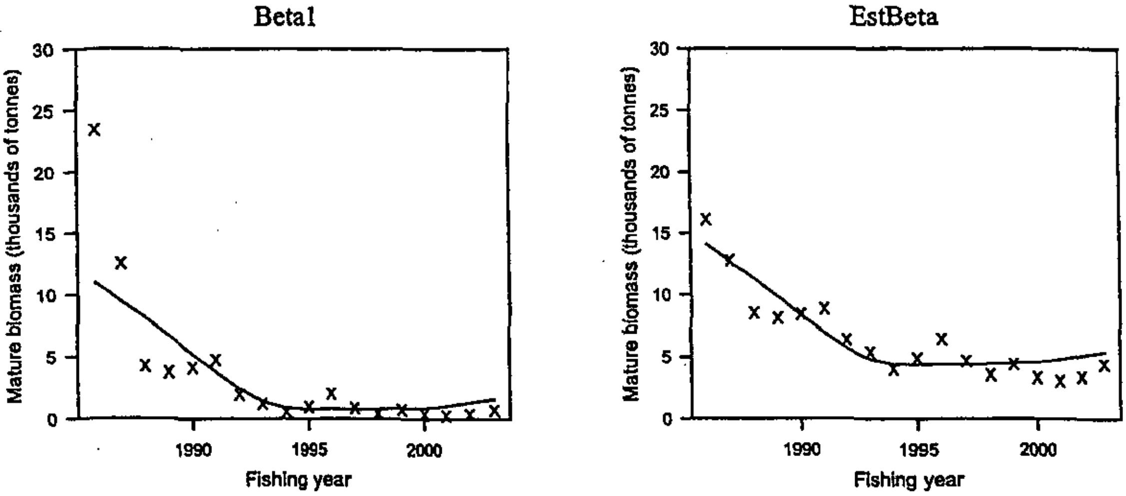
MPD estimates for the free parameters of the initial sensitivity runs are shown in Table 11. Dropping the CPUE indices for 1986–89 only has a small effect on B_0, and on $B_{current}$ as a percentage of B_0. Estimating β has a significant effect on the model biomass estimates. When β is estimated, B_0 increases by about 30% and $B_{current}$ by about 300%; consequently $B_{current}$ as a percentage of B_0 increases by about 20%. The estimated values for β are much larger than one (perhaps implausibly so), suggesting strong hyperdepletion.

Table 11: Summary of preliminary model runs. The run denoted "Last assess" is the base case from the previous assessment (O'Driscoll 2001, table 11). The less the likelihood, the better the fit.

	Last assess (t/tow)	Updating last assessment (t/tow)	Beta1	Beta1 drop 86–89	EstBeta	EstBeta drop 86–89
B_0	12 700	12 400	12 000	12 200	15 600	16 100
$B_{current}$	1 580	2 330	1 870	2 110	5 700	6 210
$B_{current}$ = %B_0	12	19	16	17	37	39
β	1	1	1	1	2.68	3.31
q*	-	12.3	6.7	2.4	10.4	3.2
process error	-	-	0.58	0.57	0.53	0.55
Total likelihood	-	20.4	12.0	10.9	10.3	9.8
CPUE	-	8.2	0.51	0.42	-0.68	0.07
prior on process error	-	-	0.0	0.0	0.0	0.0
prior on B_0	-	9.4	9.4	9.4	9.7	9.7
prior on b	-	0.23	0.23	0.23	-0.95	-1.08
prior on q*	-	2.51	1.9	0.89	2.3	1.2
catch penalty	-	0.0	0.0	0.0	0.0	0.0

As the biomass estimates were insensitive to the dropping of the 1986–89 CPUE indices, the Deep Water Working Group selected for analysis in more detail the two models Beta1 and EstBeta. The biomass trajectories and their fits to the CPUE are shown in Figure 9. The uncertainty in the biomass estimates for the two models was evaluated by Markov Chain Monte Carlo (MCMC) techniques using a total of 900 samples from a chain of length 1.8 million. Convergence was obtained for both chains (Appendix A3).

The best estimate of B_0 from the Beta1 model was 12 100 t. The 95% confidence interval was 11 800 t to 12 900 t (Table 12). The EstBeta model gave an estimated B_0 of 17 900 t. The 95% confidence interval was 12 300 t to 32 000 t.



(a) (b)

Figure 9: Biomass trajectories derived from MPD estimates of the model parameters. The biomass trajectories are shown by the solid lines and are, in order to align with the CPUE index, the biomass when three-quarters of the fishing years mortality has taken place. The crosses denote the CPUE index scaled to biomass (a) Beta1 (b) EstBeta.

***Table 12:* *Estimates of mid-year biomass (t) with 95% confidence intervals in parentheses.* $B_{current}$ *is the* mid-year biomass in 2004. Estimates are medians of the posterior distribution derived from MCMC analysis (with the process error fixed at the corresponding values in Table 11).**

Assessment	process error	β	B_0(t)	$B_{current}$(t)	$B_{current}$(t)(% B_0)
Beta1	0.58	1	12 100 (11 800 – 12 900)	2020	17 (14 – 23)
EstBeta	0.53	3.4	17 900 (12 300 – 32 000)	7950	45 (18 – 69)

5.7 Projections

Forward projections for the Beta1 and EstBeta models were carried out over a 5-year period using a range of constant-catch options. For each catch option, three measures of fishery performance were calculated: (1) the median biomass in 2009 (expressed as a percentage of B_0), (2) the probability that the biomass in 2009 is greater than 20% B_0 [P(B_{2009} > 20%B_0)], and (3) the probability that the biomass in 2009 is greater than 30% B_0 [P(B_{2009} > 30%B_0)] (30% B_0 has conventionally been taken as a proxy for B_{MSY} in orange roughy assessments).

For both assessments, the projections (Table 13) indicated that the biomass would increase for all but the highest catch level (500 t per year).

Table 13: Forward projections to 2009. The labels are: $P_{0.20}$ = [P(B_{2009} > 20%B_0)], P_{MSY} = [P(B_{2009} > 30% B_0)], B_{med} = median B_{2009} (as %B_0). $B_{current}$(% B_0) is given in parentheses next to the run name for Bmed. The values in the table are the probabilities associated with the corresponding performance measure.

		Annual catch (t, over five-year period)					
Performance measure	Run	50	75	100	125	150	500
$P_{0.20}$	Beta1	1.00	1.00	1.00	1.00	1.00	0.016
	EstBeta	1.00	1.00	1.00	1.00	1.00	0.92
P_{MSY}	Beta1	0.36	0.23	0.13	0.08	0.05	0.001
	EstBeta	0.98	0.97	0.96	0.95	0.94	0.75
B_{med}	Beta1 (17)	29.2	28.3	27.4	26.5	25.5	12.6
	EstBeta (45)	53.3	52.6	52.0	51.4	50.8	42.1

6. MANAGEMENT IMPLICATIONS

The estimated status of the stock depends strongly on which assessment is used. If CPUE is assumed to be strictly proportional to biomass (Beta1) then the current biomass is estimated to be 17% B_0 with a 95% confidence interval of 14–23% B_0. When this assumption is relaxed (EstBeta) the current biomass is much higher at 45% B_0, with a 95% confidence interval of 18–69% B_0. Forward projections indicate that recent catches are allowing the stock to rebuild. One concern is that the model results indicate that the stock has been slowly rebuilding since the mid 1990s, whereas trends in catch rates and tow duration are not consistent with this conclusion. This incongruity also occurs for model biomass trajectories in the ORH 7A (Challenger Plateau) and ORH 3B (South Chatham Rise) fisheries (Annala et al., 2004, p. 362 & p. 370). This is likely to be due to a combination of high recruitment (near virgin recruitment levels) and low recent catches.

7. ACKNOWLEDGMENTS

Thank you to Richard O'Driscoll for allowing me to reproduce parts of his previous FAR (in particular material in the introduction, review of the fishery, and research sections), and to Owen Anderson for the helpful comments he made when reviewing the manuscript.

8. REFERENCES

Annala, J.H.; Sullivan, K.J.; O'Brien, C.J. (Comps.) (2000). Report from the Fishery Assessment Plenary, May 2000: stock assessments and yield estimates. 495 p. (Unpublished report held in NIWA library, Wellington.)

Annala, J.H.; Sullivan, K.J.; O'Brien, C.J.; Smith, N.W.McL.; Grayling, S.M. (comps.) (2003). Report from the Fishery Assessment Plenary, May 2003: stock assessments and yield estimates. 616 p. (Unpublished report held in NIWA library, Wellington.)

Annala, J.H.; Sullivan, K.J.; Smith, N.W.Mcl.; Griffiths, M.H.; Todd, P.R.; Mace, P.M.; Connell, A.M. (comps.) (2004). Report from the Fishery Assessment Plenary, May 2004: stock assessments and yield estimates. 690 p. (Unpublished report held in NIWA library, Wellington).

Armstrong, J.H.; Tracey, D.M. (1986). History of the west coast South Island orange roughy fishery. Fisheries Research Division Internal Report 42. 34 p. (Unpublished report held in NIWA library, Wellington.)

Armstrong, J.H.; Tracey, D.M. (1987). *Arrow* orange roughy charter-for-quota cruise, west coast South Island, July–August 1986. Fisheries Research Division Internal Report 58. 31 p. (Unpublished report held in NIWA library, Wellington.)

Bull, B.; Francis, R.I.C.C.; Dunn, A.; Gilbert, D.J. (2002). CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v1.02.2002/10/21. 199 p. *NIWA Technical Report 117.*

Clark, M.R.; Field, K.D. (1995). Assessment of the ORH 7B orange roughy fishery for the 1995–96 fishing year. New Zealand Fisheries Assessment Research Document 95/19. 15 p. (Unpublished report held in NIWA library, Wellington.)

Field, K.D. (1999). ORH 7B, West Coast South Island descriptive analysis of commercial catch and effort data. Final Research Report to Ministry of Fisheries for ORH9802 Objective 1. 6 p. (Unpublished report held by Ministry of Fisheries, Wellington.)

Francis, R.I.C.C. (1990). A maximum likelihood stock reduction method. New Zealand Fisheries Assessment Research Document 90/4. 8 p. (Unpublished report held in NIWA library, Wellington.)

Francis, R.I.C.C.; Clark, M.R.; Coburn, R.P.; Field, K.D.; Grimes, P.J. (1995). Assessment of the ORH 3B orange roughy fishery for the 1994–95 fishing year. New Zealand Fisheries Assessment Research Document 95/4. 43 p. (Unpublished report held in NIWA library, Wellington.)

Francis, R.I.C.C.; Horn, P.L. (1997). Transition zone in otoliths of orange roughy (*Hoplostethus atlanticus*) and its relationship to the onset of maturity. *Marine Biology 129: 681–687.*

Hicks, A.C. (2004a). A meta-analysis of CPUE in orange roughy fisheries. WG-Deepwater-04/10. (Unpublished report held by Ministry of Fisheries, Wellington.)

Hicks, A.C. (2004b). A meta-analysis of CPUE in orange roughy fisheries: creating a prior. WG-Deepwater-04/20. (Unpublished report held by Ministry of Fisheries, Wellington.)

O'Driscoll, R. L. (2001). Assessment of the west coast South Island orange roughy fishery (ORH 7B) for the 2001-02 fishing year. *New Zealand Fisheries Assessment Report 2001/31.* 29 p.

Smith P.J.; McVeagh S.M.; Ede A. (1996). Genetically isolated stocks of orange roughy (*Hoplostethus atlanticus*) but not hoki (*Macruronus novaezelandiae*) in the Tasman Sea and Southwest Pacific Ocean around New Zealand. *Marine Biology 173*: 783–793.

Tracey, D.M. (1985). *Arrow* charter-for-quota cruise, 1985. Fisheries Research Division Internal Report 40. 14 p. (Unpublished report held in NIWA library, Wellington.)

Tracey, D.M.; McMillan, P.J.; Armstrong, J.M.; Banks, D.A. (1990). Orange roughy trawl survey: Challenger Plateau and West Coast South island, 1983. *New Zealand Fisheries Technical Report* 22. 34 p.

Vignaux, M. (1994). Catch per unit of effort (CPUE) analysis of west coast South Island and Cook Strait spawning hoki fisheries, 1987–93. New Zealand Fisheries Assessment Research Document 94/11. 29 p. (Unpublished report held in NIWA library, Wellington.)

APPENDIX A1: NON-ZERO TOWS FOR SELECTED VESSELS

Table A1: Annual effort (days of fishing) by the 18 core vessels used in the standardised CPUE analysis. Daily records were selected from 1 June to 31 July only. Core vessels were those that had fished more than 20 days in this period and in at least two years. Year 1986 is 1985–86 fishing season etc.

	Vessel Code																	
Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1986	8		5	8	2	1				9								
1987	13	15	3	3	6	9				10	5							
1988	11	12	12		9	21	20				22							
1989		17	24	14			22											
1990			14	4	5	6	39			14	12							
1991			4	15	9	5	34		2	26		10		10	5			
1992					8	26	38	21	6	19	24	17		19	18			
1993				15	5	15	50	9	9	27	22	17		20	20			
1994					8	19	14	1	4	27	11	58	65	15	13			
1995							5				13	20	20	22				
1996							10			12	14							
1997							11			45	18							
1998							13			5	17				4			
1999											3		4	28	22			
2000							3						1	26	21	19		
2001																20	14	20
2002																12	4	13
2003																	8	23

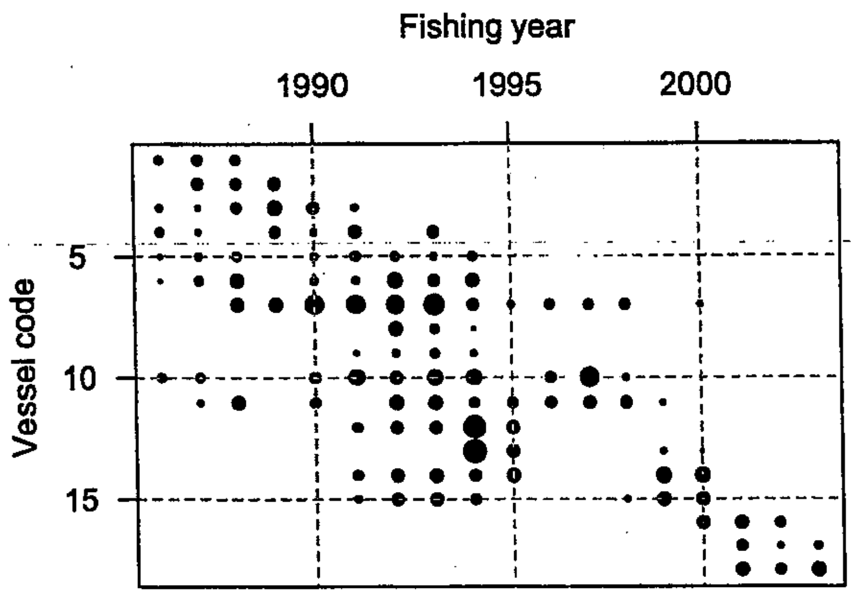


Figure A1: Tows by year and vessel code. The area of a circle is proportional to the number of tows; the largest circle represents 65 tows.

APPENDIX A2: CASAL INPUT FILES

A2.1 The Population File

```
#
# The model has a single area, within which the stock is
# partioned by sex and maturity. There is a single time step
# within which the default order of processes is:
#
# (1) Ageing
# (2) Recruitment
# (3) Maturation
# (4) Growth
# (5) Mortality (natural and fishing)
#
# There are two free parameters in the model: B0 and the CPUE process err
#

@initialization
B0 12000

@size_based False

@min_age 1
@max_age 70
@plus_group True

@sex_partition True
@mature_partition True
@n_areas 1

@initial 1984
@current 2004
@final 2009

@annual_cycle

time_steps 1
aging_time 1
recruitment_time 1
maturation_times 1

fishery_times 1
fishery_names WestCoast

spawning_time 1
spawning_p 1
spawning_part_mort 0.75

M_props 1  # proportion of natural mortality that occurs in each time step

baranov False

@y_enter 1

@recruitment
YCS_years 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995
1996 1997 1998 1999 2000 2001 2002 2003
YCS 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1
SR BH
```

```
steepness 0.75
p_male 0.5
# For stochastic recruitment
sigma_r 1.1
simulation_SR BH
simulation_steepness 0.75

# Also for stochastic recruitment
@randomisation_method lognormal

@natural_mortality
male 0.045
female 0.045

@fishery WestCoast
#recorded catch
#years 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999
2000 2001 2002 2003
#catches 1544 1250 1250 827 1282 1657 1601 1128 660 320 275 244 170 359
227
# From reported landings (Table 1 , pg 357 of Plenary May 2003 + 2003 given by John McCoy e-mail
years 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
1998 1999 2000 2001 2002 2003 2004
catches 2 282 1763 1446 1413 1750 1711 1683 1604 1139 701 290 446 425 330
405 284 161 95 90 90
future_years 2005 2006 2007 2008 2009
future_catches 500 500 500 500 500
selectivity WCmature
U_max 0.67

@selectivity_names WCmature
@selectivity WCmature
mature constant 1
immature constant 0

@size_at_age_type von_Bert
@size_at_age
k_male 0.070
t0_male -0.4
Linf_male 36.4
k_female 0.061
t0_female -0.6
Linf_female 38.0

@maturation
rates_all logistic_producing 25 33 29 3

@size_weight
a 9.21e-08
b 2.71
```

A2.2 The Estimation File

```
@estimator Bayes
@max_iters 300
@max_evals 1000

@MCMC
start 0     # 0 implies start chain at point estimate
length 1000000
keep 1000   # keep every 1000th sample
burn_in 100  # burn in for 1000*100=100 000 steps of the chain
systematic True  # if False then randomly sample from the chain

#---------------------------------------------------
#
# Standardised CPUE
#
#---------------------------------------------------

# The tonnes per hour standardised CPUE
@relative_abundance WCcpue
biomass True
ogive WCmature
proportion_mortality 0.75
dist lognormal
```

cv_process_error 0.53
q qWCcpue # divide CPUE index by this to scale to biomass
years 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
step 1
curvature True

1986 14.97
1987 8.01
1988 2.71
1989 2.38
1990 2.64
1991 3.02
1992 1.24
1993 0.78
1994 0.35
1995 0.60
1996 1.28
1997 0.54
1998 0.26
1999 0.46
2000 0.22
2001 0.17
2002 0.23
2003 0.46

cvs_1986 0.28
cvs_1987 0.29
cvs_1988 0.27
cvs_1989 0.26
cvs_1990 0.29
cvs_1991 0.22
cvs_1992 0.26
cvs_1993 0.25
cvs_1994 0.25

```
cvs_1995   0.30
cvs_1996   0.37
cvs_1997   0.33
cvs_1998   0.31
cvs_1999   0.29
cvs_2000   0.32
cvs_2001   0.37
cvs_2002   0.40
cvs_2003   0.41

@q_method free

# starting value for estimation of curvature (hyperstability/hyperdepletion) for CPUE
@q qWCcpue
q 1
b 1

@estimate
parameter q[qWCcpue].b
lower_bound 0.01
upper_bound 5
prior lognormal
mu 0.85
cv 1.41

@estimate
parameter q[qWCcpue].q
lower_bound 1e-6
upper_bound 20
prior uniform-log

{
@estimate
parameter relative_abundance[WCcpue].cv_process_error
lower_bound 0
upper_bound 2
prior uniform
}

#--------------------------------------------------
#
# Other estimations
#
#--------------------------------------------------

@estimate
parameter initialization.B0
lower_bound 1000
upper_bound 3e5
prior uniform-log
```

This allows the optimisation routine to account for taking less than
the presribed catch. This is more important when the biomass is getting
low.
@catch_limit_penalty
label catchPenalty
fishery WestCoast
multiplier 1000
log_scale False # Don't calculate the sum of squares on a log scale

A2.3 The Output File

@print
fits True
normalised_resids True
pearson_resids True
population_section False

@quantities
all_free_parameters True
nuisance_qs True
B0 True
SSBs True
actual_catches True
fishing_pressures True

To compare with standardised CPUE index
@abundance stand_cpue_biomass
biomass True
ogive WCmature
proportion_mortality 0.75
step 1
years 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003

APPENDIX A3: MCMC DIAGNOSTICS

For the MCMC chains a total of 900 samples from a chain of length 1.8 million was used.

A3.1 Beta1 model

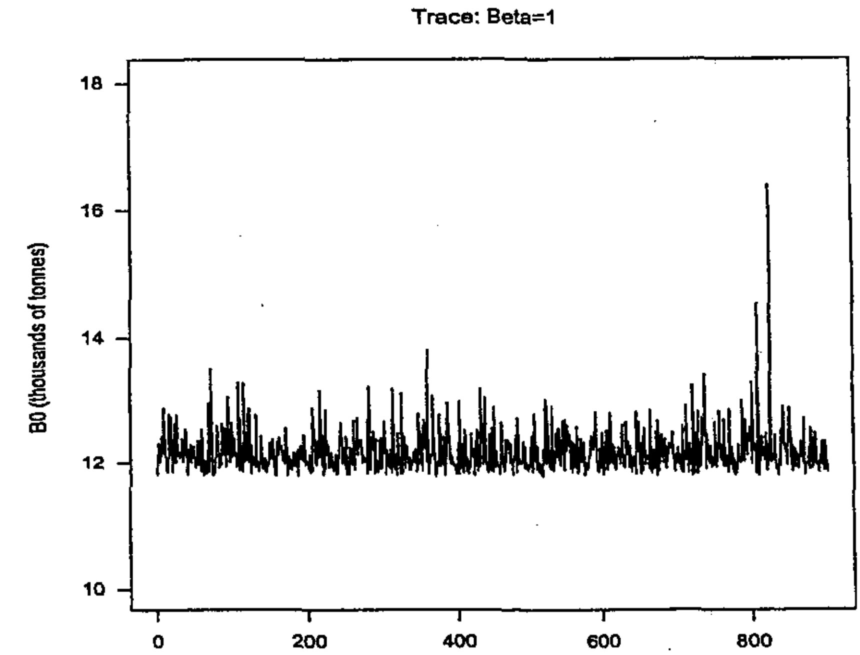


Figure A2: Trace for B_0.

A3.2 EstBeta model

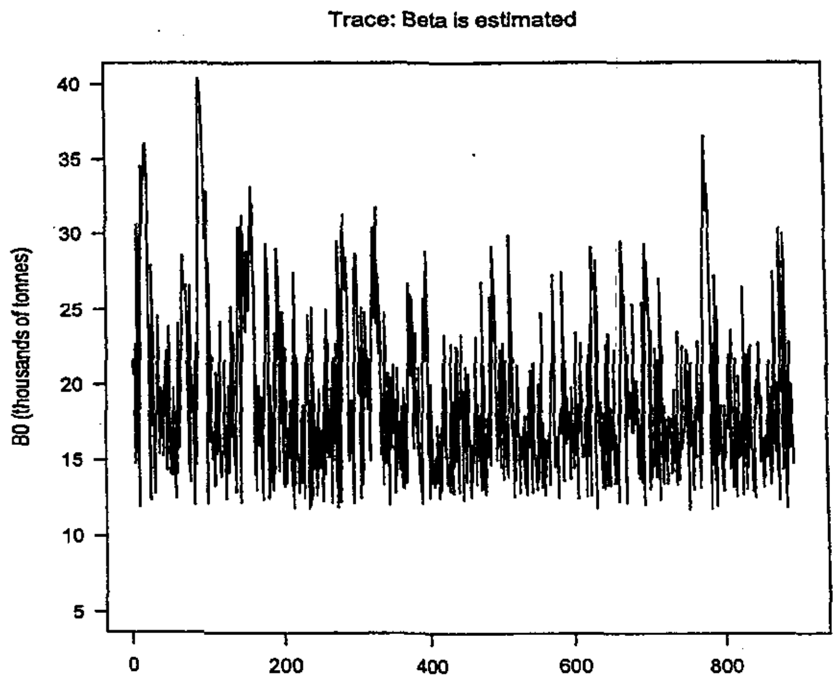


Figure A3: The trace for B_0.

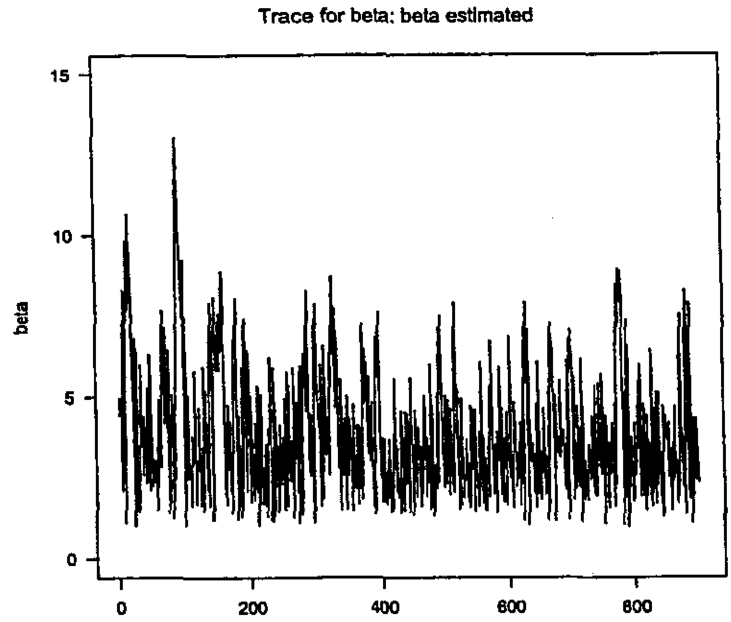


Figure A4: The trace for β.