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EXECUTIVE SUMMARY

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This orange roughy stock assessment covers the area from the Ritchie Bank, east of Hawke's Bay, south as far as Banks Peninsula, and includes the QMAs ORH 2A South, ORH 2B, and ORH 3A. Catches from the fishery developed in the early 1980s and peaked in the early 1990s. Since then, catches have reduced following a series of catch quota reductions. The Mid-East Coast stock was last assessed in 2002.

The inputs to this assessment are adjusted catch data, relative biomass indices from three trawl surveys and standardised catch per unit effort (CPUE) over 19 years, absolute biomass estimates from two egg surveys and two acoustic surveys, age frequency samples from 1989, 1990, 1991, and 2002, and estimates of biological parameters. Of these, the most influential data in the stock assessment were the CPUE and the age frequency samples. Higher weight on the age samples made the fit to the CPUE data worse, and resulted in higher estimates of B_0 and mean age of selectivity.

There was a discrepancy between the age of maturity and age of vulnerability, with maturity estimated from otolith analysis taking place about 9 years earlier than vulnerability estimated from commercial catch at age data. Following this assumption, the assessment model indicated relatively high stock biomass, but that only about 33% of this was vulnerable to the fishery. Fixing either maturity to selectivity, or selectivity to maturity, made all mature fish vulnerable, with both runs indicating similar and relatively low current biomass levels.

The estimated current status of the stock was strongly dependent on how the CPUE data were treated. When the relationship between CPUE and biomass was assumed to be linear (β =1), the current stock was estimated to be below B_{MSY} (18% B_0). When β was estimated, current stock size was estimated to be near B_{MSY} (30% B_0). A similar result was obtained when the CPUE data were excluded (32%B_0).

Model projections indicated that recent catch levels (catch quota of 800 t) were sustainable and that stock size would increase at any catch level under 3000 t. These projections were considered uncertain because the magnitude and rates of future increases in stock size were driven by the assumption that future recruitment will be constant at the virgin level. However, this assumption was not supported by any direct observations or data.

This document is a final report on work carried out as part of the Ministry of Fisheries project ORH2003/02. It covers parts of objective 2 (unstandardised and standardised CPUE), and objective 4 (stock assessment) that concern the Mid-East Coast stock (ORH 2A South, ORH 2B, ORH 3A).

1. INTRODUCTION

Orange roughy are the focus of an important deepwater fishery in New Zealand, and have been fished for over 20 years (Annala et al. 2004). The Mid-East Coast (MEC) orange roughy stock covers an area off the east coast of the North Island from the Ritchie Bank, east of Hawke's Bay, south to Banks Peninsula (Figure 1). It consists of the orange roughy fishery management areas ORH 2A South (the part of ORH 2A south of 38° 23' S), ORH 2B (Wairarapa), and ORH 3A (Kaikoura). These areas have been treated together as a separate stock since 1995. Before that, the stock assessment area also included the northern part of ORH 2A. This area, known as the "East Cape stock", is now assessed separately (Annala et al. 2004).

This report addresses the parts of objectives 2 and 4 of the Ministry of Fisheries project ORH2003/02 that deal with the Mid-East Coast orange roughy fishery:

"To update the unstandardised and standardised catch per unit effort analyses with the inclusion of data up to the end of the 2002/03 fishing year ..." and *"To update the stock assessment, including estimating biomass and sustainable yields..."*

It updates the previous assessment of the MEC stock in 2002 (Anderson et al. 2002), and incorporates updated catches and catch per unit effort (CPUE), existing acoustic, trawl, and egg survey biomass indices, new age frequency data, and a new acoustic biomass estimate.

2. REVIEW OF THE FISHERY

This section provides a brief review of the MEC fishery. More detailed descriptions of the orange roughy fisheries in the MEC, and in other management areas, were presented by Dunn et al. (2005).

The first reported landings from the MEC were in the fishing year 1981–82 (fishing years run from 1 October to 30 September) with the development of the Wairarapa fishery (Table 1). The fishery then expanded south to Kaikoura and north to Ritchie Bank, with overall landings peaking between 1989–90 and 1991–92. Since 1993–1994 there has been a decline in landings, following a series of reductions in the Total Allowable Commercial catch (TACC), to a level of 800 t in 2002–03.

The main fishing areas in the 2002–03 fishing year tracked the 1000 m contour along almost the entire extent of the MEC (Figure 1). The largest fishery took place in an area in the centre of ORH 2A South known as the Rockgarden, and also extending from this area south along the 1000 m contour towards the boundary with ORH 2B.

Two spawning locations have been identified off the east coast, one at the Ritchie Bank in 2A South (visible as the most northerly concentration of catches in 2A South), and one at the East Cape Hills in 2A North (Figure 1). No large concentrations of spawning orange roughy have been found in ORH 2B or 3A, and fish are believed to migrate from these areas to the Ritchie Bank to spawn. The presence of a second, simultaneous, spawning site at East Cape (ORH 2A North) is considered as evidence of stock separation from the MEC. Allozyme studies have shown that orange roughy from areas within the MEC cannot be separated, but were distinct from fish on the eastern Chatham Rise (ORH 3B) (Smith & Benson 1997).

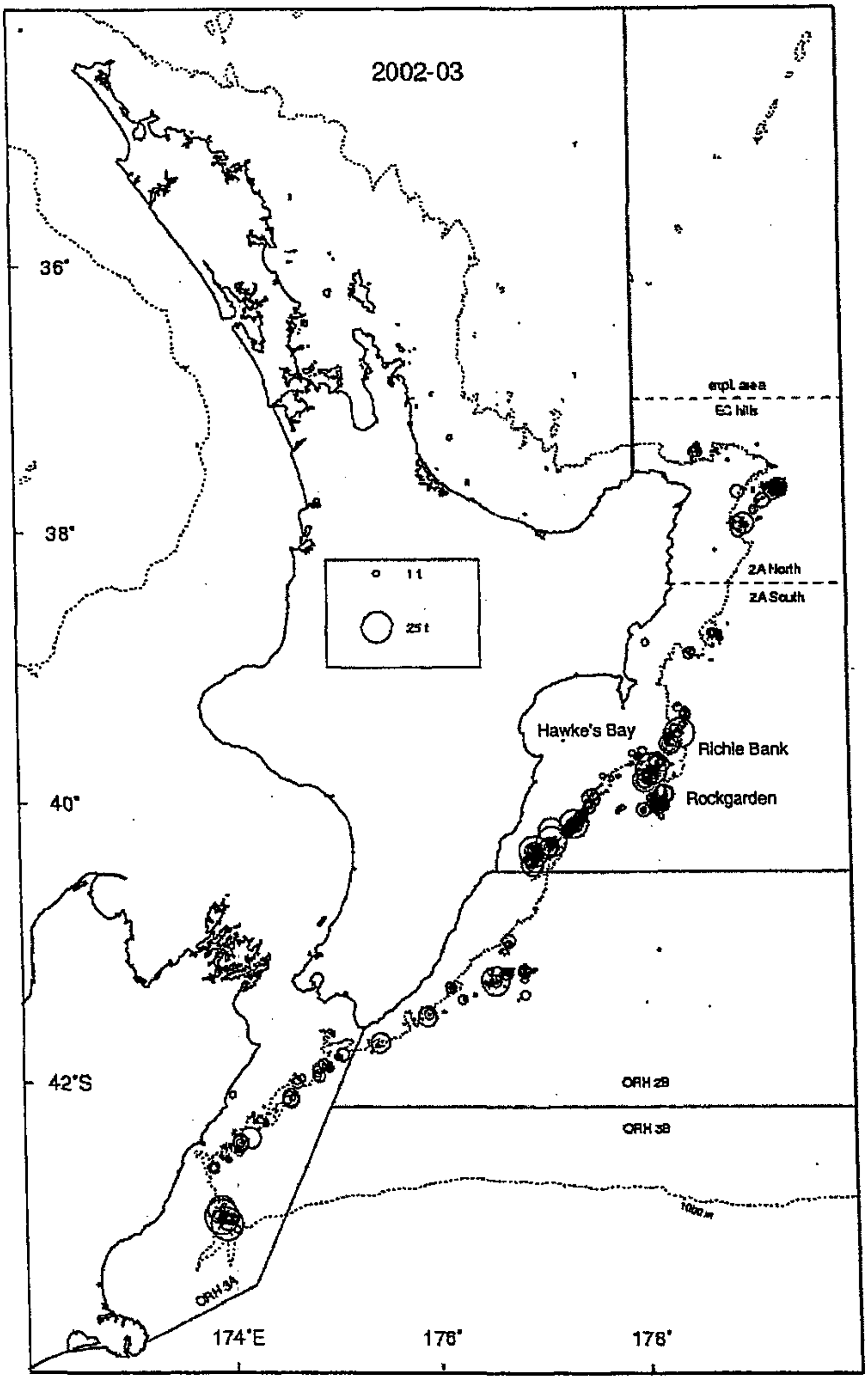

Figure 1: Catch (t) per tow of orange roughy in the MEC (ORH 2A South, 2B, 3A) and EC fish (ORH 2A North) stocks for the 2002–03 fishing year. Depth contour is at 1000m.

Table 1: Reported landings (t) and TACCs (t) by QMA for the MEC fishstock for the fishing years 1981–82 to 2002–2003.

Fishing year	ORH 2A (South) Landings	ORH 2A (South) TACC	ORH 2B Landings	ORH 2B TACC	ORH 3A Landings	ORH 3A TACC	MEC ALL Landings	MEC ALL TACC
1981–82*	–	–	554	–	–	–	554	–
1982–83*	–	–	3 510	–	253	–	3 763	–
1983–84†	162	–	6 685	–	554	–	7 401	–
1984–85†	1 858	–	3 310	3 500	3 266	§	8 434	–
1985–86†	2 778	4 576	867	1 053	4 326	2 689	7 971	8 318
1986–87‡	4 934	5 500	963	1 053	2 555	2 689	8 452	9 242
1987–88‡	6 203	5 500	982	1 053	2 510	2 689	9 695	9 242
1988–89‡	5 710	6 060	1 236	1 367	2 431	2 839	9 377	10 266
1989–90‡	6 239	6 106	1 400	1 367	2 878	2 879	10 517	10 352
1990–91‡	6 051	6 106	1 384	1 367	2 553	2 879	9 988	10 352
1991–92‡	6 329	6 286	1 327	1 367	2 443	2 879	10 099	10 532
1992–93‡	5 807	6 386	1 080	1 367	2 135	2 879	9 022	10 632
1993–94‡	3 173	6 666	1 259	1 367	2 131	2 300	6 563	10 333
1994–95‡	3 281	4 000	754	820	1 686	1 840	5 721	6 660
1995–96‡	1 033	1 261	245	259	612	580	1 890	2 100
1996–97‡	1 270	1 261	272	259	580	580	2 122	2 100
1997–98‡	#1 416	1 261	254	259	570	580	2 240	2 100
1998–99‡	#1 434	1 261	257	259	582	580	2 273	2 100
1999–00‡	#1 666	1 261	234	259	617	580	2 517	2 100
2000–01‡	#1 083	900	190	185	479	415	1 752	1 500
2001–02‡	#901	900	180	185	400	415	1 480	1 500
2002–03‡	#546	480	105	99	235	221	886	800

MAF data; † FSU data.; ‡ QMS data.; § Included in QMA 3B TAC; # Pro-rated from ORMC figures for ORH 2AN and ORH 2AS, to QMS data for ORH 2A.

3. INPUT DATA

3.1 Catch overruns

There has been a history of catch overruns in this area because of lost fish and discards. In this assessment (as in previous ones), total removals were assumed to exceed reported catches by the overrun percentages given in Table 2.

Table 2: Catch overruns (%) by QMA and fishing year. – no catches reported.

Fishing year	2A (north and south)	2B	3A
1981–82	–	30	–
1982–83	–	30	30
1983–84	50	30	30
1984–85	50	30	30
1985–86	50	30	30
1986–87	40	30	30
1987–88	30	30	30
1988–89	25	25	25
1989–90	20	20	20
1990–91	15	15	15
1991–92	10	10	10
1992–93	10	10	10
1993–94	10	10	10
1994–95 and subsequently	5	5	5

3.2 Catch per unit effort (CPUE)

3.2.1 CPUE and abundance

Commercial fishery CPUE has been used in orange roughy stock assessments as an index of stock abundance. Changes in CPUE caused by factors other than abundance, such as changes in the composition and activity of the fishing fleet, have been previously estimated using standardised analysis. This analysis is repeated here.

However, some previous orange roughy assessments have shown inconsistencies between CPUE and research survey indices, with models based on CPUE biomass indices estimating lower relative stock sizes than models based solely on survey biomass indices (Annala et al. 2004). This result could be caused if catch rates declined at a faster rate than abundance, a bias known as hyper-depletion (Hilborn & Walters 1992). A meta-analysis of previous orange roughy stock assessments investigated this effect by allowing a non-linear relationship between CPUE and vulnerable biomass (V), as in Equation 1 (Hilborn & Walters 1992).

$$CPUE = qV^{\beta} \qquad (1)$$

The meta-analysis study indicated significant hyper-depletion occurred in three of the four stocks analysed (A.Hicks, University of Washington, unpublished results). The results were used to estimate a prior for β (Eq. 1), for use within a Bayesian stock assessment model. The prior for β was log-normal with the mean of $\ln(\beta)$ equal to 0.7075 and the standard deviation of $\ln(\beta)$ equal to 1.0446 (A. Hicks, University of Washington, unpublished results).

During the 2004 assessments there was some debate about the utility of estimating β (Annala et al. 2004). For the current assessments, it was agreed that at least two alternative runs would be carried out for each stock: one in which β was estimated using the prior from the meta-analysis ('EstBeta'), and another in which it was not estimated but was set equal to 1 ('Beta1'). For stocks with fishery-independent data, such as the MEC, a third run was made in which the CPUE data were excluded (NoCPUE).

3.2.2 Catch and effort data

The collation and error-checking of catch and effort data were described in detail by Dunn et al. (2005). Catch and effort data from the trawl catch effort processing return (TCEPR) and catch, effort and landing return (CELR) forms were combined for 1983–84 to 2002–03, and summarised in a daily aggregated format. Although this results in some loss of detail from the tow-by-tow details on TCEPR forms, it is necessary as most of the early data were recorded on the daily summary CELR forms, and most recent data on TCEPR forms.

Following Anderson et al. (2002), the CPUE analysis included only records for vessels which had fished in the MEC for at least 8 years, and completed at least 100 tows. Data from ORH 3A were excluded due to the belief that mis-reporting of that catch had been widespread during some years, and data for 1988–89 excluded because much of the landings for that year were not accounted for in catch effort records. The resulting data set consisted of 19 vessels, and is summarised in Table 3.

Table 3: Number of tows by vessel and fishing year in the MEC CPUE data set, with the total number of tows, % of tows with zero catch, and the total catch from all vessels as a percentage of the total catch for that year.

Vessel	1983–84	1984–85	1985–86	1986–87	1987–88	1988–89	1989–90	1990–91	1991–92	1992–93
1		40	7		23		33		34	6
2	321	240	9	36	29		33	43	55	86
3	131	12	29	8	76		81	7	44	64
4	170	33	92	24	41		89	113	157	182
5					70		48	146	275	292
6									325	395
7		122	6	25				213	314	289
8			10				22	91	47	146
9							39	64	172	107
10								9	34	37
11	134	7			4			70	144	192
12	125	7	4	17			18			
13	5				24		246	176	5	30
14	208	41	75	106	88		66	108	124	210
15										
16										
17		3	130	104	69		125	137	144	113
18			24	41	24		13	64	53	83
19		37	1				110	127	226	114
Total tows	1 094	542	387	361	448	–	923	1 368	2 153	2 346
% zero catch	1.2	4.4	1.0	4.7	2.6	–	7.8	5.2	3.6	5.2
% of total catch	75	39	43	21	34	–	52	67	78	83

Vessel	1993–94	1994–95	1995–96	1996–97	1997–98	1998–99	1999–00	2000–01	2001–02	2002–03
1	6	29					1			
2	132									
3	13	185	55	26	56	110	88	68	33	29
4	292	293	55							
5	269	64	23	5	26	11	23	7		4
6		1	7	8	2	112	238	117	31	128
7	309	312	136	188	344	393	342	290	104	
8		54	67	1	1		10			
9	104	26						24	32	16
10	50	60		49	21	84	80	62		
11	182	68	25	49	47	100				
12	5	34			9	25	47			
13		86	11							
14	314	285								
15	32	115	23	30	9	15		4	28	
16		59	112	82	161	211	247	111	54	39
17	34	28	4							
18	189	20								
19	31	35				15	1			
Total tows	1 962	1 754	518	438	676	1 076	1 077	683	282	216
% zero tows	5.7	3.6	5.0	3.1	3.6	3.8	2.3	1.7	2.1	0.9
% of total catch	81	56	59	59	61	63	52	72	58	43

3.2.3 Standardised CPUE analysis

The standardised CPUE analysis was carried out using the stepwise multiple regression technique described by Field (1992) and Francis & Field (2000). The units of CPUE used were tonnes per hour (t/h) or tonnes per tow (t/tow), and data were log-transformed to approximate a normal distribution. Due to the aggregation of data in a daily format there were very few records with no catch of orange roughy (Table 3), and therefore a binomial model, examining CPUE in terms of fishing success or failure, was not considered.

The initial model run used the same criteria and input variables as the previous CPUE analysis for this fishery (Anderson et al. 2002). The predictor variable *Fishing year* was forced into the model and the following variables tested for inclusion: the categorical variables *Vessel*, *Month*, and *Statistical Area*. Variables describing vessel statistics were not derived and tested, as previous analyses did not select such variables into the model, and much of their effect would have been encompassed by *Vessel*.

Terms were added to the model if this resulted in an improvement in the R^2 of 0.5% or more. All possible interaction terms, from pairs of the selected variables, were also tested. The run using log(t/h) produced a model with the form CPUE = Fishing year + Vessel + Month + Statistical Area (Table 4).

Table 4: Selected variables and cumulative R^2 for the log(t/h) model.

Variable	Cumulative R^2
Fishing year	11.2
Vessel	21.1
Month	25.1
Statistical Area	25.7

These are the same order of variables as selected in the previous analysis (Anderson et al. 2002). CPUE varied roughly 12-fold between vessels, roughly 3-fold between months, and roughly 2-fold between statistical areas (Figure 2). The Deepwater Working Group considered that differences of this magnitude were acceptable.

The alternative model using log(t/tow) produced the same variable selection, and a similar trend in CPUE over time, but explained slightly less of the variation (20.6%). In addition, there have been concerns raised over the consistency of protocols for recording tow duration over time (Anderson et al. 2002). An alternative model replaced *Area* with the second order interaction term (*Month*Vessel*). This model explained marginally more of the variance than the *Area* variable, but was excluded in favour of a less complex model. Consequently the t/h model was selected for use in the stock assessment. The CPUE index values are shown in Figure 3 and Table 5.

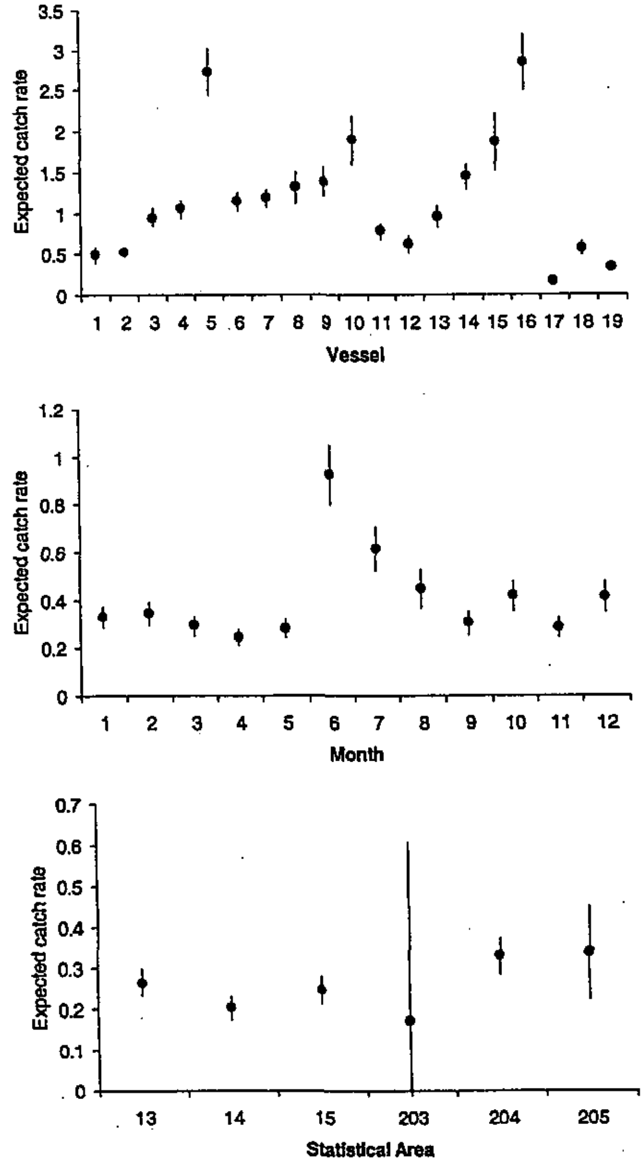

Figure 2: Standardised CPUE (t/h) model predictions by vessel, month, and statistical area, with standard error bars.

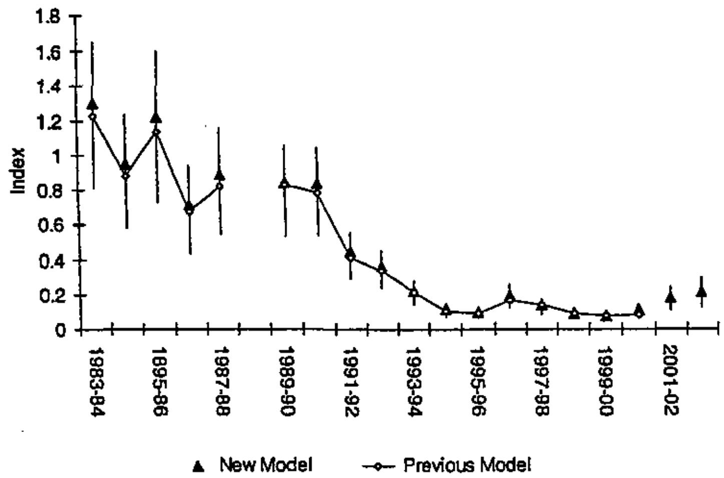

Figure 3: Annual CPUE indices (t/h) for the new standardised model, with 95% condifence intervals, and the previous model (Anderson et al. 2002) scaled to have the same means.

Table 5: Standardised CPUE (t/h) index for the Mid-East Coast, with standard errors.

Fishing year	Index value	Standard Error
1983-84	1.177	0.186
1984-85	0.863	0.149
1895-86	1.100	0.209
1986-87	0.646	0.123
1987-88	0.803	0.145
1988-89*		
1989-90	0.759	0.110
1990-91	0.755	0.103
1991-92	0.403	0.053
1992-93	0.329	0.045
1993-94	0.199	0.028
1994-95	0.103	0.015
1995-96	0.088	0.015
1996-97	0.174	0.031
1997-98	0.121	0.020
1998-99	0.078	0.012
1999-00	0.069	0.011
2000-01	0.097	0.016
2001-02	0.160	0.033
2002-03	0.194	0.044

* Excluded from the analysis

3.4 Resource surveys

Seven resource survey biomass estimates were available for this assessment (Table 6): three from trawl surveys (Grimes 1994, 1996a, 1996b), two from egg surveys (Zeldis et al. 1997), and two from acoustic surveys (Doonan 2003, Doonan & Hart unpublished; Hicks, unpublished). Following Anderson et al. (2002), the 1995 egg survey was excluded because it was deemed unreliable (due to the survey's brief duration and unexpected hydrological conditions encountered), and because it was found to have little influence in the assessment by Francis & Field (2000). A time series of length frequency distributions was also included from the trawl surveys (Figure 4).

Table 6: Survey biomass estimates (with c.v.s) for the MEC stock. For the egg surveys, estimates are corrected for turnover.

	Trawl surveys		Egg surveys		Acoustic surveys	
Year	Biomass (t)	c.v.	Biomass (t)	c.v.	Biomass (t)	c.v.
1992	7 073	28				
1993	4 823	15	22 000	49		
1994	5 129	18				
1995*			7 000	50		
2001					26 700	38
2003					18 486	76

* Egg survey not used in the stock assessment

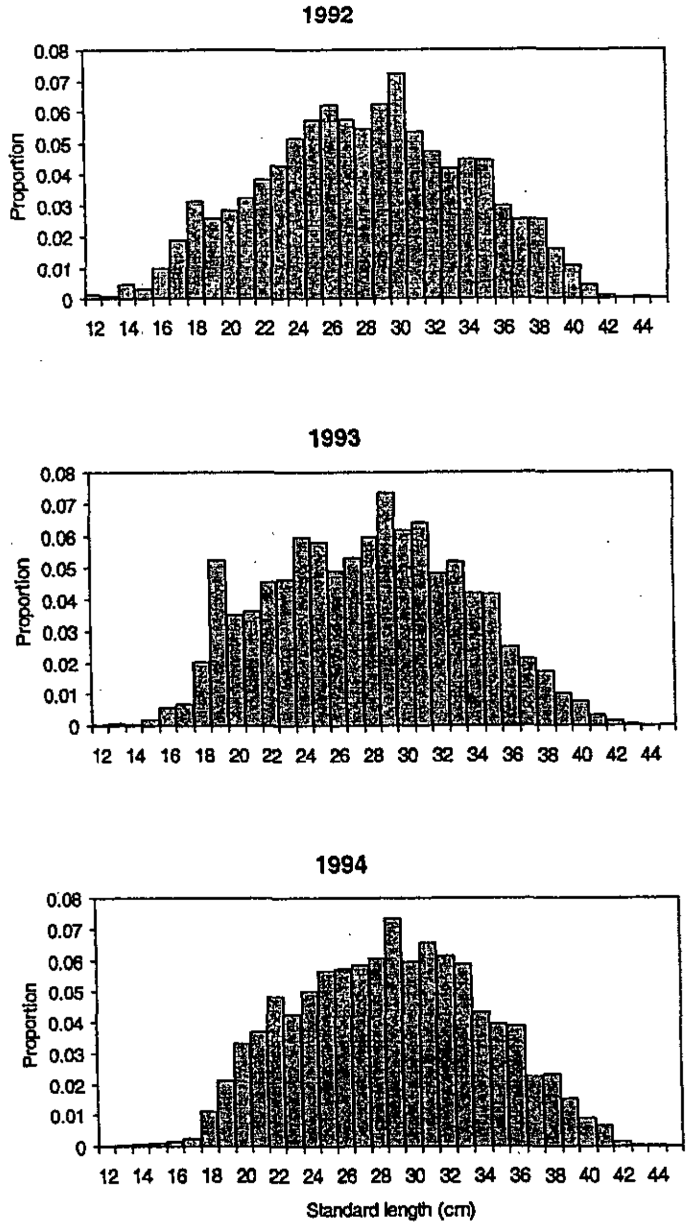

Figure 4: Length frequency distributions from the wide-area trawl surveys of the MEC in 1992, 1993, and 1994.

3.5 Age data

Orange roughy age frequency estimates from commercial catches were included for the first time in this assessment. These age data were used in preference to the time series of mean length data used by Anderson et al. (2002), which had little influence in that assessment.

Length and age samples were taken randomly, unless otherwise indicated (Table 7). All were taken from the MEC stock, although the actual sample region varied over time, from Ritchie Bank in the 1989–91 period, to an area west of Ritchie Bank or south at the Rockgarden in 2002. Sex ratios were variable, but the proportion of males was noticeably low from the area west of Ritchie Bank in 2002.

If otoliths are sampled randomly, age estimates can be raised directly to the total catch. If otoliths are not sampled randomly, then it is necessary to apply an age-length key. The assumption that the orange roughy otoliths from the MEC were sampled randomly was tested following Francis (2002).

Table 7: Summary of the location and number of orange roughy length and age samples taken from the MEC stock. The samples were measured from the landings in port, therefore allocation to specific tows was not possible. Non-random samples include those that were deliberately selected because they were large fish.

		Length samples		Age samples			
Year	Area fished	N	% male	N	% male	N non-random	N not aged or sexed
1989	Ritchie Bank	525	54	50	52		
1989	Ritchie Bank	509	90	50	88		
1989	Ritchie Bank	504	91	50	88		
1990	Ritchie Bank	511	85	50	86		
1990	Ritchie Bank	517	90	50	88		
1990	Ritchie Bank	504	64	50	68		
1990	Ritchie Bank	521	91	50	88		
1991	Ritchie Bank	492	77	49	71		
1991	Ritchie Bank	505	50	50	48		
1991	Ritchie Bank	500	73	50	68		
1991	Ritchie Bank	517	57	50	60		
1991	Ritchie Bank	515	60	50	66		
2002	Rock garden	196	88	96	84	3	5
2002	Anywhere in region	201	31	97	26	8	7
2002	Area W of Ritchie Bank	202	27	96	26	8	7
2002	Area W of Ritchie Bank	201	17	98	16	21	2
2002	Area W of Ritchie Bank	196	13	99	14	10	3
2002	Area W of Ritchie Bank	204	44	99	37	15	1
2002	Rockgarden	237	91	112	92		8

Using this method, the length distribution of the fish from the otolith sample was ranked according to the fish length distribution from the length sample. If the fish in the otolith sample were a random selection from the length sample, then a histogram of their ranking would have an approximately uniform distribution. The null hypothesis of a uniform distribution was tested using a Chi-squared test, and indicated that all samples were randomly selected. However, despite a non-significant result, the samples from 1991 and 2002 were considered doubtful, as there was an apparent pattern of sampling of the extremes of the length range (Figure 5). Therefore, as a cautious tactic, all samples were raised using an age-length key.

Differences between growth and maturity in different years were tested in pair-wise comparisons using randomisation tests. In each test, a measure of the difference between each sample, *D*, was evaluated for the true pair of samples, and evaluated a further 999 times following random permutations of the data. The p-value was calculated as the proportion of the 1000 *D* values that were greater or equal to the *D* value obtained with the true pair of samples. In the following tests, *D* was calculated as the sum of squares between the fitted growth or maturity curves.

The randomisation tests indicated fitted von Bertalanffy growth curves were not significantly different between any combination of years for either male or female orange roughy (Table 8). Samples from all years were therefore aggregated, and growth parameters estimated after fixing t_0 to account for the lack of data approaching the origin (Figure 6).

Maturity was estimated from the counts to the transition zone on the otoliths (Francis & Horn 1997). The randomisation tests within the period 1989–91 indicated the fitted logistic maturity curves were not significantly different for females, and not significant or close to the 5% level for males (Table 9). The combined samples for 1989–91 were not significantly different from 2002. Although the test approached the significance level for males when comparing between 1989–91 and 2002, the effect was not considered significant because the pattern of changes was inconsistent, with the mean length of first maturity (L_{50}) decreasing from 1989 to 1991, but then increasing to 2002 (Figure 7). In addition, changes in L_{50} over a short period (1989–91) would be relatively unlikely for a long-lived species such as orange roughy, and are likely to be an artifact of sampling error. Samples from all years were therefore aggregated, and parameters of the logistic curve estimated.

The proportions at age were estimated for 1989–91 and 2002. Samples from 1989–91 were aggregated because a change in age structure caused by size-selective mortality would not be expected over such a short period. Randomisation tests between the proportions at age in 1989–91 and 2002 were not conducted because both samples would be used separately in the assessment. In addition, there was a clear difference between the proportions at age in 1989–91 and 2002, with a relative decline in the abundance of older fish in 2002 (Figure 8). In 1989–91, about 23% of the fish were aged in the plus group, whereas in 2002 this had dropped to about 4%.

Table 8: Results of paired-comparison randomisation tests for von Bertalanffy growth curves fitted to length at age of male and female orange roughy. A p-value of <0.05 is considered significant.

	Year comparison	p-value
Male	1989 – 1990	0.92
	1990 – 1991	0.35
	1989 – 1991	0.52
	1989–91 – 2002	0.61
Female	1989 – 1990	0.81
	1990 – 1991	0.64
	1989 – 1991	0.55
	1989–91 – 2002	0.15

Table 9: Results of paired-comparison randomisation tests for logistic curves fitted to proportion mature at age of male and female orange roughy. A p-value of <0.05 is considered significant.

	Year Comparison	p-value
Male	1989 – 1990	0.21
	1990 – 1991	0.06
	1989 – 1991	0.05
	1989–91 – 2002	0.06
Female	1989 – 1990	0.33
	1990 – 1991	0.43
	1989 – 1991	0.43
	1989–91 – 2002	0.07

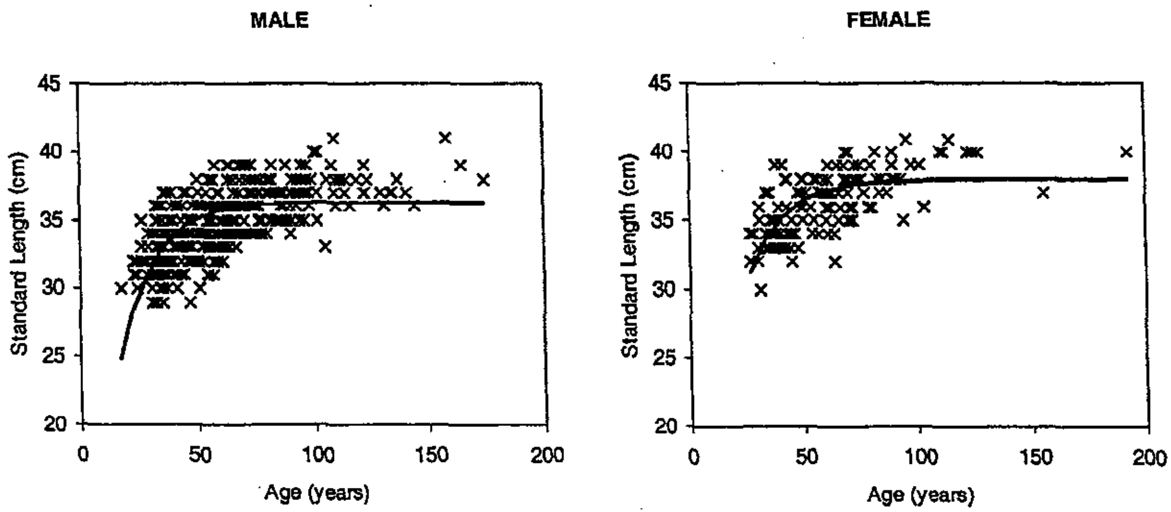

Figure 6: Von Bertalanffy growth curves fitted to male and female orange roughy from the MEC. All years combined. Parameter t_0 fixed using values from Annala et al. (2003). Growth parameters, Male: K=0.07, L_∞=36.3, t_0=-0.4; Female K=0.06, L_∞=37.9, t_0=-0.6. Note y-axis starts at 20 cm.

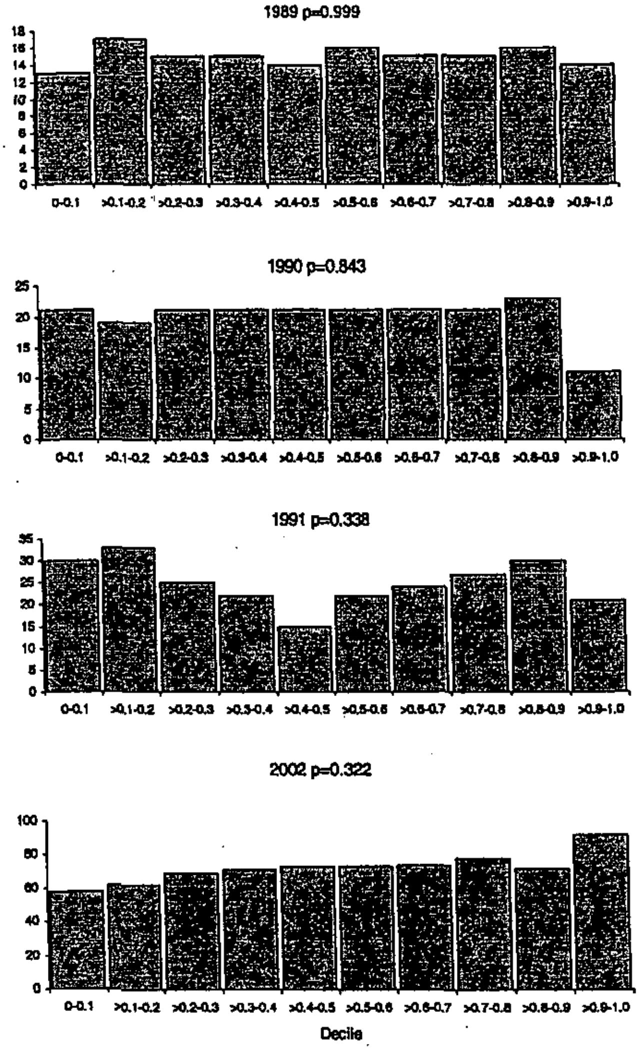

Figure 5: Results of the tests for random sample selection for orange roughy sampled from the MEC in 1989, 1990, 1991, and 2002. A flat histogram would indicate fish were selected randomly by length for otolith sampling, as compared to the overall length sample.

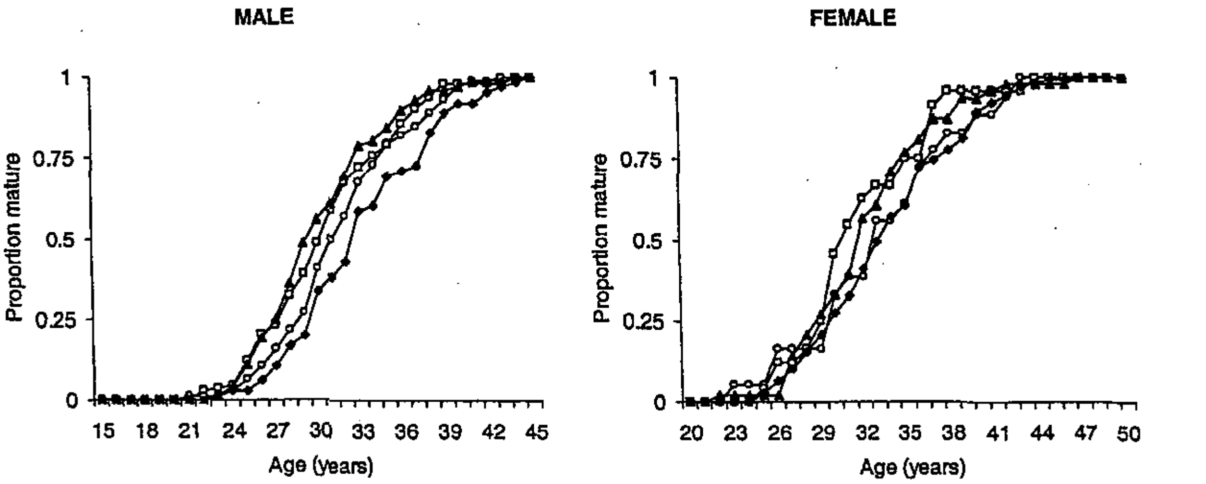

Figure 7: Proportion mature at age for male and female orange roughy, estimated from annuli counts to the transition zone on otolith samples from 1989, 1990, 1991, and 2002.

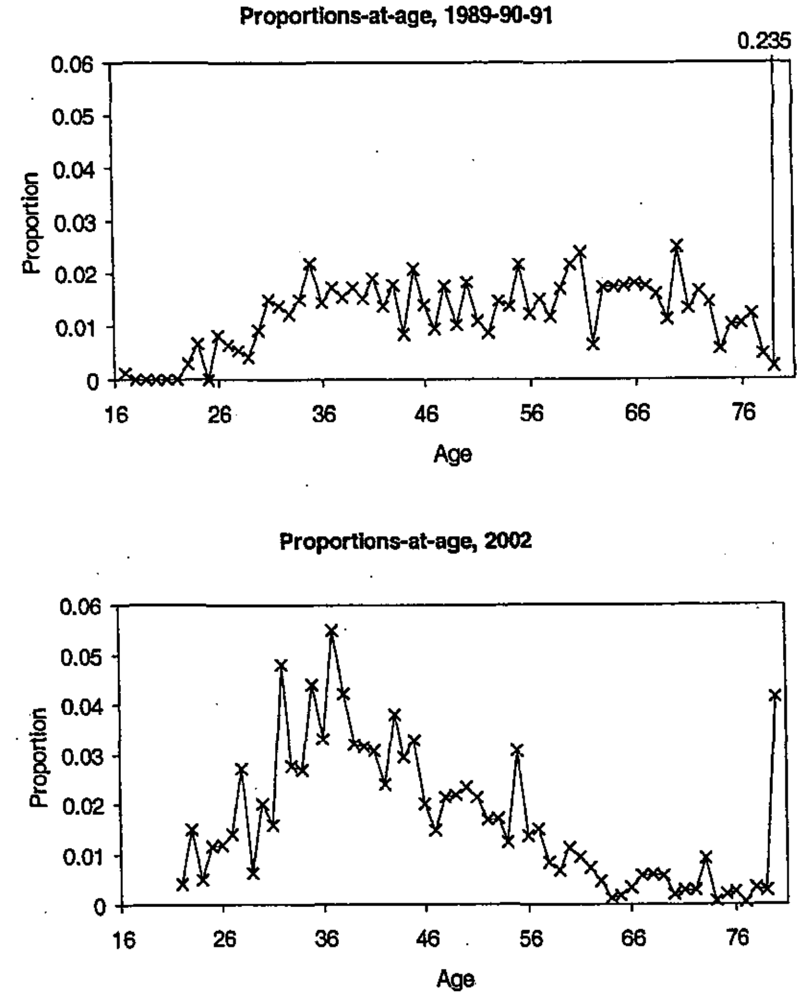

Figure 8: Proportion of orange roughy at age from otolith samples aggregated for 1989–91, and for 2002, with a plus group at age 80.

4. STOCK ASSESSMENT

The observational data were incorporated into a Bayesian stock assessment with deterministic recruitment to estimate stock size. The stock was considered to reside in a single area, with no partition by sex or maturity. A single maturation episode was modelled by a logistic ogive fixed equal to the fishery selectivity ogive, and the stock was partitioned by age, with age groups 1–80 years, with a plus group at 80+.

There was a single time step in the model, in which the order of processes was ageing, recruitment, growth, and mortality. In the absence of information to the contrary, recruits were assumed to be 50% male. Growth was modelled using the von Bertalanffy growth formula, with mixed sex parameters $K=0.065$, $L_\infty=37.2$, $t_0=-0.5$. The catch equation used was the instantaneous mortality equation from Bull et al. (2003), whereby half the natural mortality was applied, followed by the fishing mortality from a single fishery, then the remaining natural mortality. Natural mortality was constant at 0.045 yr^{-1}.

The acoustic and egg survey biomass estimates were assumed to be absolute, whereas CPUE and trawl estimates were relative indices. Lognormal errors, with known (sampling error) c.v.s were assumed for the CPUE, trawl survey, and egg and acoustic survey indices. Following Anderson et al. (2002), an additional process error variance of 0.2 was added to the c.v.s from the CPUE indices and the trawl survey estimates to give an overall c.v. of about 30%. An ageing error misclassification matrix was applied, derived from an analysis of all orange roughy re-ageing data available to the working group (J.Valero et al., Univeristy of Washington, unpublished data).

Stock assessments were performed using the stock assessment program CASAL (Bull et al. 2003). A penalty function was included to discourage the model from allowing the stock biomass to drop below a level at which the historical catch could not have been taken. Maximum posterior density (MPD) estimates were found for the free parameters in the model, which were the estimated virgin biomass, B_0, and one catchability and two selectivity parameters each for the fishery and the trawl survey (therefore a total of seven parameters). This increased to eight parameters when β was estimated for the CPUE. The uncertainty in the estimates was also evaluated by using Monte Carlo Markov Chain (MCMC) simulations. The CASAL input code, also showing the input data, is given in Appendix A.

4.1 Sensitivity runs

A number of alternative model runs were considered to determine the sensitivity of biomass estimates to the model assumptions. Previously mentioned are the three cases agreed by the Deepwater Working Group and reported in the Plenary document (Annala et al. 2004):

1. *Beta1*: Initial model with β set to 1.
2. *EstBeta*: Initial model with β estimated.
3. *NoCPUE*: Initial model with the CPUE index excluded.

A number of other sensitivities were investigated, of which three examples are reported here. The first is the effect of estimating recruitment deviates. Recruitment deviates were estimated for 1923 to 1964. The year 1923 was chosen because fish from this cohort would be 79 in 2002, the last year for which year class strength was estimated. The year 1964 was chosen because fish from this cohort would be 26 in 1990, the first year for year class strength estimates are available, and because age 26 was the first cohort after which year class strength estimates were continuous. Therefore all year class strengths were estimated using data from both 1990 and 2002. Because of the recruit deviates, the total number of parameters estimated was 49 in this model, compared to 7 in other models. The sensitivity run was:

4. *Recruit*: *Beta1* model with recruitment deviates estimated.

The second area of sensitivities was the effective sample size applied to the age data, which is effectively the weight these data received in the estimation procedure. It was difficult assigning effective sample sizes, and trials determined three alternative values. The value chosen for the base model was 30, which was about 5% of the total numbers of otoliths aged, or about half of the number of ages with observations in the model. The other alternatives presented were:

5. *HighN*: *Beta1* model with the effective sample size on age data set to 120. This gave a relatively high weight to the age data.
6. *LowN*: *Beta1* model with the effective sample sizes on age data set to 12 (1990) and 7 (2002). These were the number of landings sampled in each period for otoliths. This gave relatively low weight to the age data.

The third area of sensitivity concerned the assumptions of maturity and selectivity. Until recently, it was assumed in New Zealand orange roughy stock assessments that all mature fish were vulnerable to commercial fishing but that no immature fish were. Annala et al. (2004) stated that the original assumption was based on the fact that, in the early years, most orange roughy fishing took place on spawning aggregations. There was no evidence that immature fish were present in substantial numbers in these spawning aggregations, nor that fishers were avoiding smaller (or younger) mature fish. Because there were no data available on the age at which fish entered the fishery, it seemed reasonable to assume, as an approximation, that this was the same as the age at which they reached maturity. As fisheries developed, more fishing took place outside the spawning season when, on average, somewhat smaller fish were caught. Thus, there were grounds for assuming that the age of vulnerability was slightly less than the age at maturity. However, as vulnerability data were still lacking, the original assumption persisted.

Sensitivity runs suggested the assumption that all mature fish were vulnerable might be wrong, as the age of vulnerability was estimated to be greater than the age at maturity, and consequently current mature biomass to be substantially larger than the vulnerable biomass. The Deepwater Working Group rejected this idea, as they were not comfortable with current vulnerable biomass being much less than the mature biomass. Also, the maturity data were deemed to be indirect because they were based on the assumption that the transition zone in the otolith marked the onset of maturity (Francis & Horn 1997). In contrast, the age- and length-frequency data used for estimating vulnerability were direct observations from the commercial fishery. Therefore, the assumption agreed by the Deepwater Working Group was that the ages of maturity and vulnerability were the same, where the age of maturity was set to the age of vulnerability (Annala et al. 2004). Alternative assumptions and sensitivity runs presented here are:

7. *Mat&Sel*: *Beta1* model with the maturity and selectivity estimated separately, the maturity ogive from otolith transition zone data, and the selectivity ogive from the proportions at age data. The combined sex mean age of maturation used was 31.5, with 95% mature at age 38.4.
8. *SeltoMat*: *Beta1* model with the selectivity ogive set to equal the maturity ogive (logistic parameters as in run 7).

4.2 Biomass estimates

Biomass and other model parameter estimates for the eight model runs are shown in Tables 10–12, likelihoods in Table 13, and fits to selected data shown in Figures 9–11. Confidence intervals estimated from MCMC were calculated only for the three runs accepted by the Deepwater Working Group (*EstBeta*, *Beta1*, *NoCPUE*). Traces for the MCMCs are shown in Appendix B.

Rather than improve the fit to the age data, the addition of recruitment residuals improved the fit to the CPUE, but made little difference to the estimate of B_0 (*Recruit*). Although not apparent from the likelihoods, the visual fit to the age data looked better, particularly for the plus group.

The assessments were sensitive to the weight given to the proportions at age data (*HighN*, *LowN*). The higher value of N gave more weight to the age samples and improved the visual fit to these data, made the fit to the CPUE data worse, and resulted in higher estimates of B_0 and mean age of selectivity.

The separate estimation of maturity and selectivity indicated maturity took place about 9 years earlier than vulnerability (*Mat&Sel*). The run also indicated a higher biomass, but only about 33% of this was vulnerable to the fishery. This ratio changed over time depending on the state of depletion of the stock, and was higher at a higher biomass level (maximum of about 70% vulnerable at the start of the fishery). Fixing either maturity to selectivity (*Beta1*) or selectivity to maturity (*SeltoMat*) made little difference to the estimates of the current status of the stock (%B_0), but the fit to the age data was relatively poor under *SeltoMat*.

The estimated current status of the stock was strongly dependent on how the CPUE data were treated. When the relationship between CPUE and biomass was assumed to be linear (*Beta1*), the current stock was estimated to be below B_{MSY} (18% B_0; Table 11). When β was estimated (*EstBeta*), current stock size was estimated to be near B_{MSY} (30% B_0). A similar result was obtained when the CPUE data were excluded (*NoCPUE*; 32% B_0). Estimates of the mean age of selectivity (a_{50}) were higher when β was estimated, and when CPUE was dropped. The model was not sensitive to the trawl survey or catch at length data.

Table 10: MPD biomass estimates for the sensitivity runs. $B_{current}$ is the mid-year biomass in 2004. % vulnerable is the percentage of the mature biomass vulnerable to fishing.

Run	B_0 (t)	$B_{current}$ (t)	$\%B_0$	%vulnerable
Beta1	94 500	17 300	18	100
EstBeta	105 600	31 000	29	100
NoCPUE	100 000	31 000	31	100
Recruit	110 800	20 100	18	100
HighN	91 200	21 000	23	100
LowN	99 900	17 400	17	100
Mat&Sel	124 500	38 900	31	33
SeltoMat	113 700	24 600	22	100

Table 11: MCMC biomass estimates (medians, with 95% confidence intervals in parentheses) for the three Deepwater Working Group runs. $B_{current}$ is the mid-year biomass in 2004. % vulnerable is the percentage of the mature biomass vulnerable to fishing.

Run	B_0 (t)	$B_{current}$ (t)	$\%B_0$	%vulnerable
Beta1	93 600 (91 300–104 200)	17 300 (13 300–23 000)	18 (15–23)	100
EstBeta	105 200 (88 700–125 600)	31 400 (21 700–47 200)	30 (23–38)	100
NoCPUE	103 700 (83 200–128 300)	33 200 (21 800–51 500)	32 (25–41)	100

Table 12: Assessment estimates of all non-biomass parameters (as MCMC medians, with 95% confidence intervals in parentheses for the three Deepwater Working Group runs, and as MPD estimates for the other runs). β is a parameter describing the curvature of the relationship between CPUE and biomass (if $\beta = 1$ there is no curvature); a_{50} (or a_{95}) is the age at which 50% (or 95%) of fish are available to either the commercial fishery or the trawl surveys.

		Commercial		Trawl survey	
Run	β	a_{50}	a_{95}	a_{50}	a_{95}
Beta1	1.0	41 (37–47)	53 (45–64)	14 (10–42)	24 (12–74)
EstBeta	1.9 (1.4–2.5)	43 (37–52)	58 (48–73)	13 (10–26)	19 (11–54)
NoCPUE	–	47 (37–54)	64 (49–78)	13 (10–21)	18 (11–41)
Recruit	1.0	44	52	11	14
HighN	1.0	45	61	12	14
LowN	1.0	37	44	12	16
Mat&Sel	1.0	40	51	12	16
SeltoMat	1.0	31	38	13	18

Table 13: Assessment likelihood estimates for the three runs. The lower the likelihood value the better the model fit to the observations.

Run	CPUE	Catch at age	Egg and acoustic surveys	Trawl surveys	Trawl survey catch at length	Total
Beta1	-0.06	-258.85	0.24	-3.45	-199.63	-441.53
EstBeta	-1.05	-263.71	-1.94	-3.41	-200.21	-450.02
NoCPUE	–	-264.04	-1.93	-3.40	-200.33	-449.55
Recruit	-12.80	-263.49	0.16	-3.33	-197.94	-494.99
HighN	9.36	-236.23	-1.34	-3.42	-200.09	-411.77
LowN	-3.42	-266.28	0.69	-3.46	-199.27	-451.36
Mat&Sel	-3.19	-256.88	-1.54	-3.46	-199.33	-443.74
SeltoMat	0.26	-247.37	-1.33	-3.49	-198.93	-430.45

4.3 Forward projections

Forward projections were carried out over a 5-year period using a range of constant-catch options for the three Deepwater Working Group runs (Table 14). For each catch option, three measures of fishery performance were calculated. The first one, Bmed, is the median biomass in 2009, as a percentage of B_0. The second one, $P_{0.2}$, is the probability that the biomass at the end of the 5-year period is greater than 20% B_0 (biomass levels below 20% B_0 are considered risky to the stock (Annala et al. 2003). The third, P_{MSY}, is similar to the $P_{0.2}$, except that the reference biomass level is the Maximum Sustainable Yield (interpreted for orange roughy as 30% B_0) (Annala et al. 2003).

All projections indicate that the biomass will increase for all catch levels under about 3000 t (Table 14). As stated by Annala et al. (2004), the Deepwater Working Group noted that these projections are uncertain because the magnitude and rates of future increases in stock size are driven by the assumption that future recruitment will be constant at the virgin level. However, this assumption is not supported by any direct observations or data.

Table 14: Probability of the mid-year spawning biomass in 2008–09 exceeding 20% B_0 ($P_{0.2}$) and 30% B_0 (P_{MSY}), and the median biomass in 2008–09 as a percentage of B_0 (Bmed) for the Mid-East Coast stock for each of three assessments and eight constant catch options. The current biomass, $B_{2003-04}/B_0$ (%), is given in parentheses next to the assessment name for Bmed.

		Annual catch (t, over 5 year period)							
Performance measure	Run	0	400	800	1200	1500	2100	3000	4000
$P_{0.2}$	*Beta1*	1	0.99	0.98	0.95	0.94	0.84	0.54	0.19
	EstBeta	1	1	1	1	1	1	0.99	0.97
	NoCPUE	1	1	1	1	1	1	0.99	0.98
P_{MSY}	*Beta1*	0.40	0.28	0.15	0.09	0.06	0.02	0	0
	EstBeta	0.94	0.91	0.88	0.85	0.82	0.74	0.59	0
	NoCPUE	0.93	0.91	0.89	0.86	0.84	0.80	0.69	0
Bmed (%B_0)	*Beta1* (18)	29	28	27	25	25	23	20	18
	EstBeta (30)	39	38	37	36	35	34	31	29
	NoCPUE (32)	41	40	39	38	37	36	33	31

5. DISCUSSION

This stock assessment was carried out between February and April 2004, with the support of the Deepwater Working Group, and with a parallel assessment carried out by University of Washington (UW)/New Zealand Seafood Industry Countcil (SeaFIC.) The differences between the NIWA and UW/SeaFIC assessment models were discussed by Annala et al. (2004); however, there was essentially good agreement between the results from both assessments.

The previous NIWA assessment concluded that the stock was either declining or stable at a low level, that biomass was below 20% of B_0, and that at recent catch levels (1500 t) the stock was unlikely to rebuild (Anderson et al. 2002). The present stock assessment using similar assumptions (β = 1) indicated the current stock biomass was still close to 20% of B_0, but had been rebuilding since the mid 1990s, and would continue to rebuild at similar catch levels.

The Deepwater Working Group recommended additional research take place into the relationship between adundance and CPUE, the relationship between maturity and vulnerability, and the relationship between maturity and the transition zone in orange roughy.

6. ACKNOWLEDGMENTS

This project was funded under Ministry of Fisheries contract ORH200302. Thanks to Chris Francis, Andy McKenzie, and Owen Anderson for their help during the stock assessments.

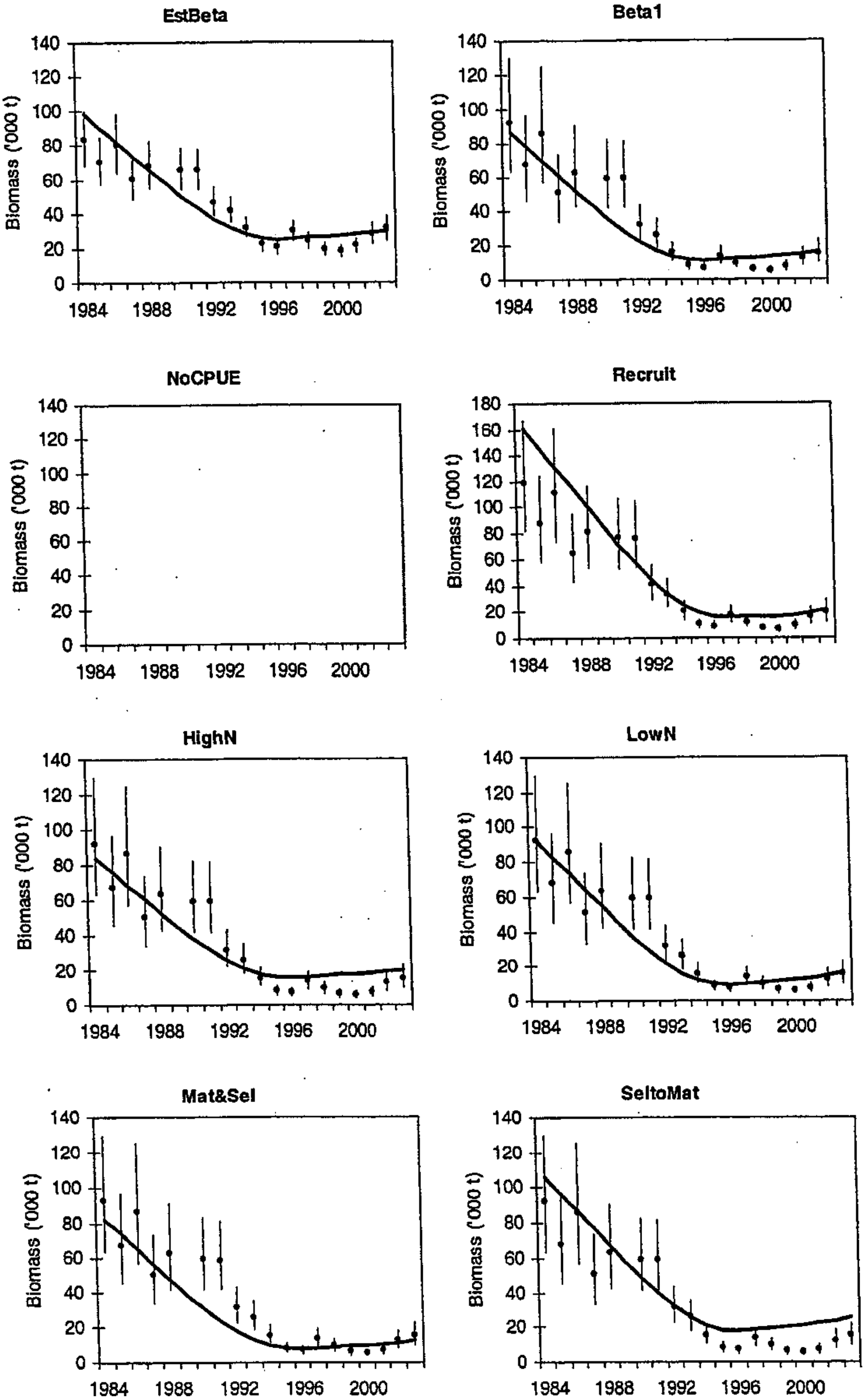

Figure 9: Model MPD fits to the CPUE indices. Solid lines are model estimates; vertical lines are 95% confidence intervals for the indices (divided by estimated catchabilities).

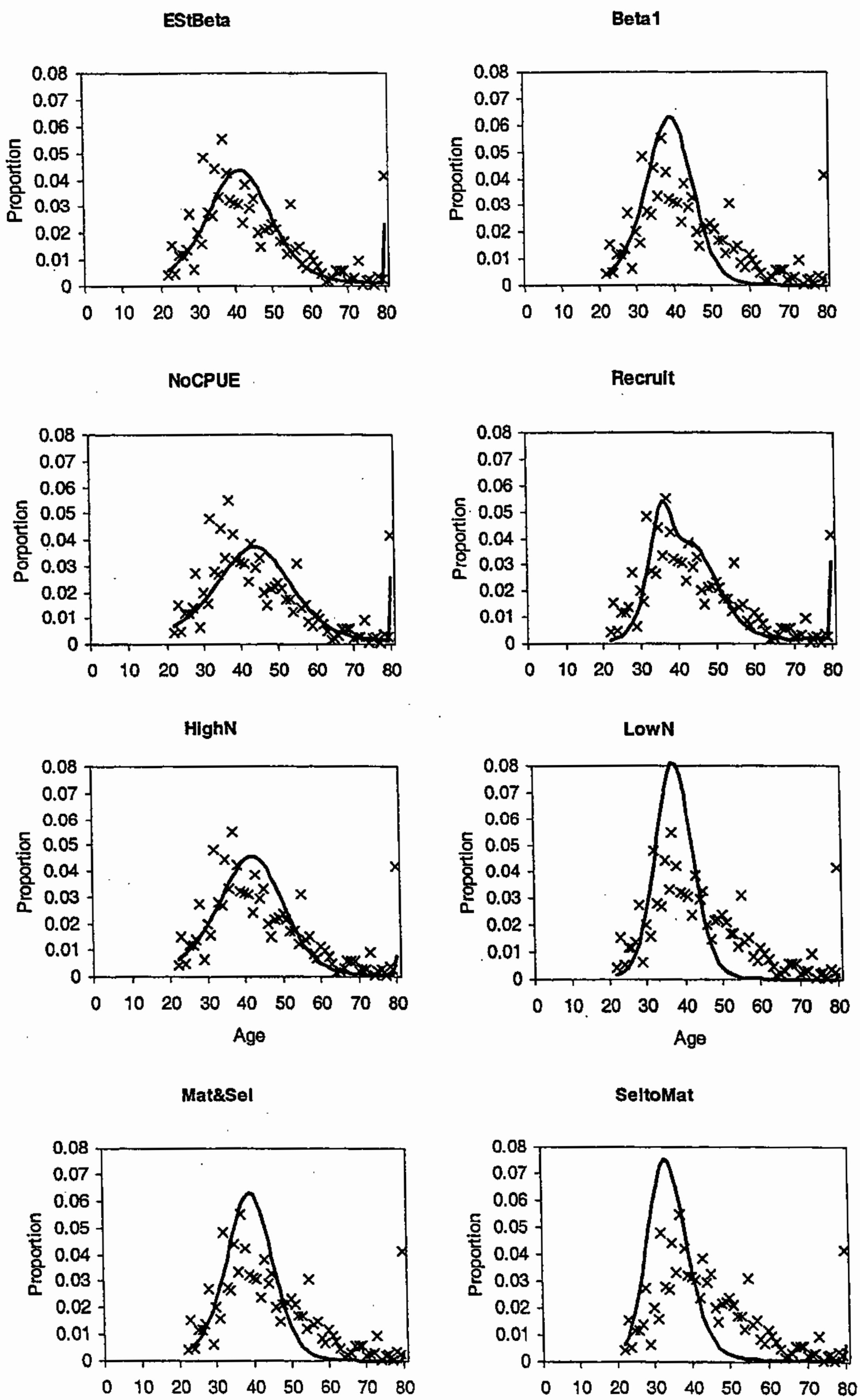

Figure 10: Model MPD fits to the proportion at age data for 2002. Solid lines are model estimates; plus group at age 80.

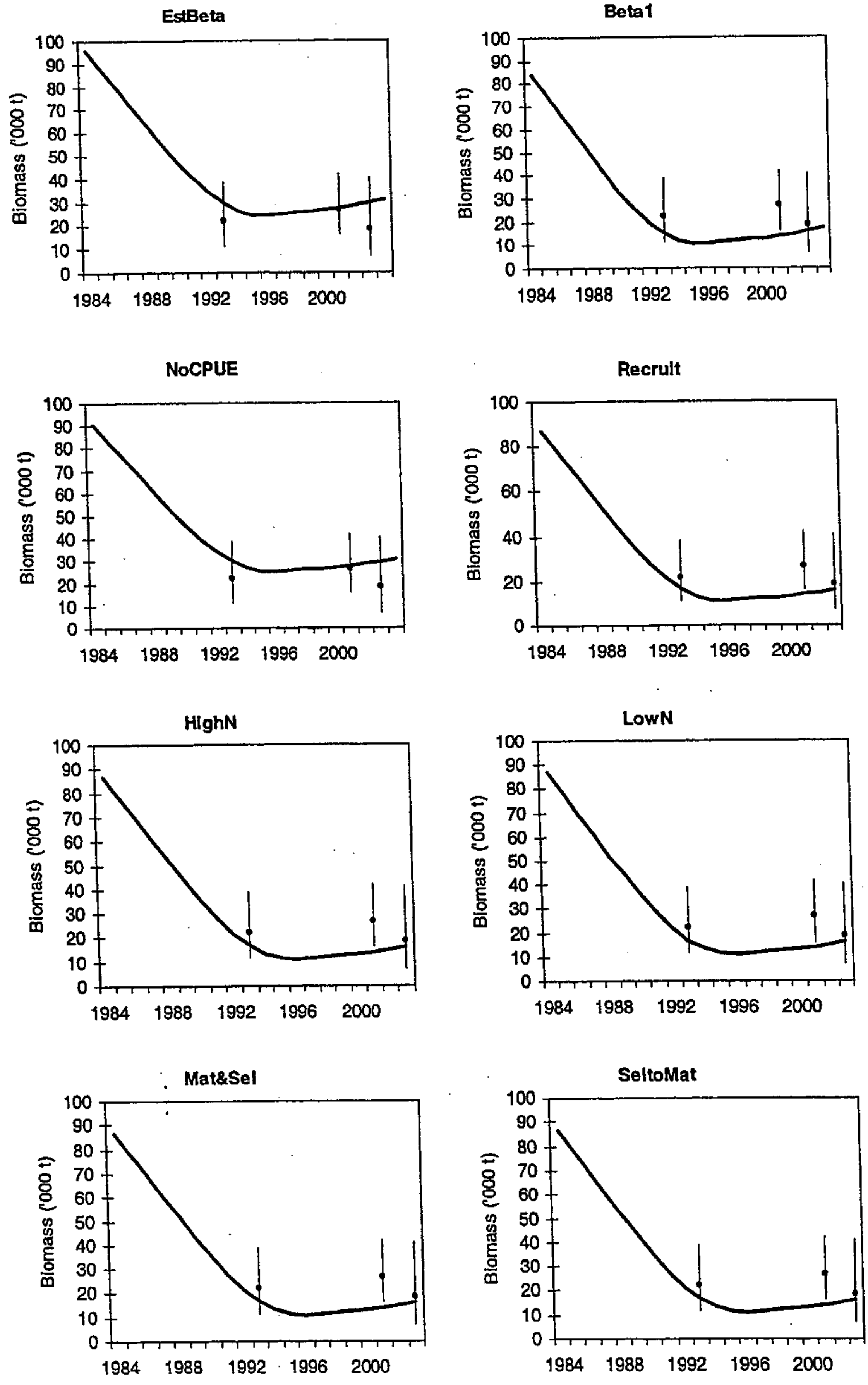

Figure 11: Model MPD fits to the absolute biomass indices (acoustic and egg production surveys). Solid lines are model estimates; vertical lines are 95% confidence intervals for the indices.

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APPENDIX A

THE POPULATION FILE

```
## THE POPULATION FILE
# Provides the basic setting for the stock assessment

@initialization
Bmean 110000
@use_mean_YCS True

@size_based False
@min_age 1
@max_age 80
@plus_group True

@sex_partition False
@mature_partition True
@n_areas 1

@initial 1924
@current 2004
@final 2009

@annual_cycle
time_steps 1
aging_time 1
recruitment_time 1
maturation_times 1

fishery_times 1
fishery_names MECfishery

spawning_time 1
spawning_p 1
spawning_part_mort 0.75

M_props 1   # Proportion of natural mortality that occurs at each time step

@y_enter 1
@recruitment
YCS_years
1923  1924  1925  1926  1927  1928  1929  1930  1931  1932  1933  1934
1935  1936  1937  1938  1939  1940  1941  1942  1943  1944  1945  1946
1947  1948  1949  1950  1951  1952  1953  1954  1955  1956  1957  1958
1959  1960  1961  1962  1963  1964  1965  1966  1967  1968  1969  1970
1971  1972  1973  1974  1975  1976  1977  1978  1979  1980  1981  1982
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     1     1     1     1     1
1     1     1     1     1     1     1     1     1     1     1     1     1
1     1     1     1     1     1     1     1     1     1     1     1     1
1     1     1     1     1     1     1     1     1     1     1     1     1
1     1     1     1     1     1     1     1     1     1     1     1     1
1     1     1
SR none
first_free 1923
last_free 1964

# For stochastic recruitment only (yield runs)
sigma_r  1.1
simulation_SR  BH
simulation_steepness 0.75
@randomisation_method lognormal

# This is made the same as fishery selectivity in the estimation block
@maturity_props
all logistic 40 5

@natural_mortality
all    0.045

@fishery MECfishery
years
1950  1951  1952  1953  1954  1955  1956  1957  1958  1959  1960  1961
```

```
1962    1963    1964    1965    1966    1967    1968    1969    1970    1971    1972    1973
1974    1975    1976    1977    1978    1979    1980    1981    1982    1983    1984    1985
1986    1987    1988    1989    1990    1991    1992    1993    1994    1995    1996    1997
1998    1999    2000    2001    2002    2003    2004
catches
0       0       0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       0       0       0       0       0       0       0
0       0       0       0       0       0       720     4892    9654    11336   10918   11481
12604   11721   12620   11486   11109   9924    7219    6007    1985    2228    2352    2387
2643    1840    1555    930     930
future_years 2005 2006 2007 2008 2009
future_catches 4200 4200 4200 4200 4200
selectivity MECfishery
U_max 0.9

@selectivity_names MECfishery MECtrawl MECmature
# for acoustic and egg survey data
@selectivity MECmature
mature   constant 1
immature constant 0
# for trawl survey
@selectivity MECtrawl
all logistic 31.3100684 7.07297065
# For cpue, catch
@selectivity MECfishery
all logistic 31.3100684 7.07297065

@size_at_age_type von_Bert
@size_at_age_dist normal
@size_at_age
k 0.065
t0 -0.5
Linf 37.19
cv 0.08

@size_weight
a 9.21e-8
b 2.71
```

ESTIMATION FILE

Includes observations and parameter estimation settings

```
@estimator Bayes
@max_iters 1000
@max_evals 3000
@grad_tol 1e-05

@MCMC
start 0
length 1000000
keep 1000
burn_in 100
systematic True
adaptive_stepsize True
adapt_at 50000 100000

# cpue data and estimation blocks
@relative_abundance MECcpue
biomass True
ogive MECfishery
proportion_mortality 0.5
dist lognormal
cv_process_error 0.2
q qMECcpue
years
1984 1985 1986 1987 1988 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
step 1
curvature True
1984  1.177
1985  0.863
1986  1.100
1987  0.646
1988  0.803
1990  0.759
1991  0.755
```

```
1992  0.403
1993  0.329
1994  0.199
1995  0.103
1996  0.088
1997  0.174
1998  0.121
1999  0.078
2000  0.069
2001  0.097
2002  0.160
2003  0.194

cvs_1984        0.192
cvs_1985        0.210
cvs_1986        0.230
cvs_1987        0.230
cvs_1988        0.219
cvs_1990        0.176
cvs_1991        0.165
cvs_1992        0.160
cvs_1993        0.166
cvs_1994        0.171
cvs_1995        0.177
cvs_1996        0.206
cvs_1997        0.216
cvs_1998        0.200
cvs_1999        0.187
cvs_2000        0.193
cvs_2001        0.200
cvs_2002        0.250
cvs_2003        0.275

@estimate
parameter q[qMECcpue].q
lower_bound 1e-10
upper_bound 20
prior uniform-log
phase 1

# Optimise q using analytical formulas (use free method otherwise)
# @q_method nuisance

@q_method free
@q qMECcpue
q  1
b  1

@estimate
parameter q[qMECcpue].b
lower_bound 0.1
upper_bound 4
prior lognormal
mu 0.85
cv 1.41
phase 4

# egg and acoustic survey data and estimation blocks
@abundance egg_and_acoustic
step 1
proportion_mortality 0.5
biomass True
ogive MECmature
years 1993 2001 2003
1993 22000
2001 26700
2003 18486
cv_1993 0.49
cv_2001 0.38
cv_2003 0.76
dist lognormal
```

```
# trawl surveys
@relative_abundance trawl_surveys
step 1
q qtrawl_surveys
curvature True
proportion_mortality 0.5
biomass True
ogive MECtrawl
years 1992 1993 1994
1992 7073
1993 4823
1994 5129
cv_1992 0.28
cv_1993 0.15
cv_1994 0.18
dist lognormal
cv_process_error 0.2

@q qtrawl_surveys
q  1
b  1

@estimate
parameter q[qtrawl_surveys].q
lower_bound 1e-10
upper_bound 10000
prior uniform-log
phase 1

@estimate
parameter q[qtrawl_surveys].b
lower_bound 1
upper_bound 1
prior lognormal
mu 0.85
cv 1.41
phase 4

@proportions_at Trawl_Survey_lengths_92
years 1992
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size True
plus_group False
ogive MECtrawl
class_mins
12      13      14      15      16      17      18      19      20      21      22      23      24
25      26      27      28      29      30      31      32      33      34      35      36      37
38      39      40      41      42      43      44      45      46
1992
0.0013  0.0006  0.0047  0.0034  0.01    0.0188  0.0311
0.0257  0.0285  0.0322  0.0381  0.0424  0.0514
0.0575  0.0621  0.0575  0.0547  0.0627  0.0723
0.0533  0.0472  0.0418  0.0448  0.0442  0.0297
0.0253  0.0255  0.016   0.0105  0.0045  0.0012  0.0002
0.0009  0.0001
dist Coleraine
N 14

@proportions_at Trawl_Survey_lengths_9394
years 1993 1994
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
at_size True
plus_group False
ogive MECtrawl
class_mins
12      13      14      15      16      17      18      19      20      21      22      23      24
25      26      27      28      29      30      31      32      33      34      35      36      37
38      39      40      41      42      43      44      45      46
1993
0.0004  0.0007  0.0005  0.0017  0.0059  0.0068
0.0201  0.0521  0.0354  0.0363  0.0453  0.0463
```

```
0.0596 0.058  0.0491 0.0528 0.0595 0.0735 0.0615
0.0641 0.0484 0.0518 0.0422 0.0418 0.025  0.0214
0.017         0.0101 0.0074 0.0031 0.0014 0.0004
0.0001 0
1994
0      0.0004 0.0006 0.001  0.0014 0.0024 0.0111
0.0213 0.0331 0.0366 0.0483 0.0427 0.05   0.0566
0.0572 0.0585 0.0605 0.0735 0.0594 0.0656
0.0611 0.0589 0.0431 0.0398 0.0388 0.0224
0.0231 0.0152 0.0089 0.0066 0.0013 0.0004
0.0003 0
dist Coleraine
N 18

@estimate
parameter selectivity[MECtrawl].all
lower_bound    5      0.1
upper_bound    55     1e3
prior uniform
phase 2


# proportions at age, from the commercial fishery
@proportions_at Proportions_at_age_1990
years 1990
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
min_class 17
max_class 80
plus_group True
ogive MECfishery
1990
0.0013      0         0         0         0         0
0.00299     0.00678 0          0.00822 0.00644 0.0056
0.00439     0.00932 0.01513 0.01392 0.01238 0.01518
0.02193     0.01459 0.01743 0.01547 0.0174  0.01522
0.01918     0.01376 0.01779 0.00855 0.02083 0.01403
0.00955     0.01761 0.01037 0.01839 0.01111 0.00874
0.01487     0.01384 0.02161 0.01241 0.01497 0.01175
0.01713     0.02147 0.0238  0.00662 0.01733 0.01742
0.01761     0.01808 0.01759 0.016           0.01138 0.02485
0.01324     0.01668 0.01464 0.00585 0.01018 0.01048
0.01225     0.00479 0.0024  0.23543
ageing_error True
dist Coleraine
N 30

@proportions_at Proportions_at_age_2002
years 2002
step 1
proportion_mortality 0.5
sexed F
sum_to_one True
min_class  22
max_class 80
plus_group True
ogive MECfishery
2002    0.00415 0.01512 0.00501 0.0115  0.01177 0.0139  0.02711 0.0062  0.01987 0.01571 0.04815
        0.02766 0.02674 0.04415 0.03317 0.05491 0.04226 0.03217 0.0315  0.03075 0.02384 0.03817
        0.0294  0.03286 0.01991 0.01485 0.02138 0.02195 0.02347 0.0213  0.01685 0.01704 0.01231
        0.03089 0.01374 0.01507 0.00838 0.00692 0.01142 0.00947 0.00729 0.00477 0.00141 0.00188
        0.00338 0.00578 0.00597 0.00583 0.00221 0.00287 0.00293 0.00933 0.00071 0.00203 0.00271
        0.00062 0.00353 0.00281 0.04152
ageing_error True
dist Coleraine
N 30

# In order to save space, details of the ageing error misclassification matrix have been
# omitted (it is very large, 80*80 matrix). Contact M.Dunn for further details if necessary.
@ageing_error
type misclassification_matrix

@estimate
parameter selectivity[MECfishery].all
same maturity_props.all
```

```
lower_bound    5      0.01
upper_bound    55     1e3
prior uniform
phase 3

@estimate      # biomass estimation
parameter initialization.Bmean
lower_bound 10000
upper_bound 500000
prior uniform-log
phase 1

# recruit residuals (for sensitivity run)
{
@estimate
parameter recruitment.YCS
lower_bound    0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02
       0.02    0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02
       0.02    0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02   0.02
       0.02    0.02   0.02   0.02   0.02   0.02   0.02   1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1
upper_bound    16     16     16     16     16     16     16     16     16     16     16
       16      16     16     16     16     16     16     16     16     16     16     16
       16      16     16     16     16     16     16     16     16     16     16     16
       16      16     16     16     16     16     16     1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1
prior lognormal
mu             1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1      1      1
       1       1      1      1      1      1      1      1      1      1
cv             1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1
       1.1     1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1
       1.1     1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1
       1.1     1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1
       1.1     1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1
       1.1     1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1
       1.1     1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1    1.1
phase 3
}

@catch_limit_penalty   # catch penalty
label catchPenalty
fishery MECfishery
multiplier 1000
log_scale False
```

THE OUTPUT FILE

```
@print
fits True
normalised_resids True
pearson_resids True
population_section False
covariance False

@quantities
all_free_parameters True
B0 True
Bmean True
R0 True
SSBs True
actual_catches True
YCS True
fishing_pressures True
ogive_arguments maturity_props.all
```

```
# To compare with standardised CPUE index
@abundance stand_cpue_biomass
biomass True
ogive MECfishery
proportion_mortality 0.5
step 1
years 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
2001 2002 2003

# To compare with egg and acoustic surveys
@abundance mature_biomass
biomass True
all_areas True
step 1
proportion_mortality 0.75
ogive MECfishery
years 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000
2001 2002 2003
```

APPENDIX B: MCMC traces

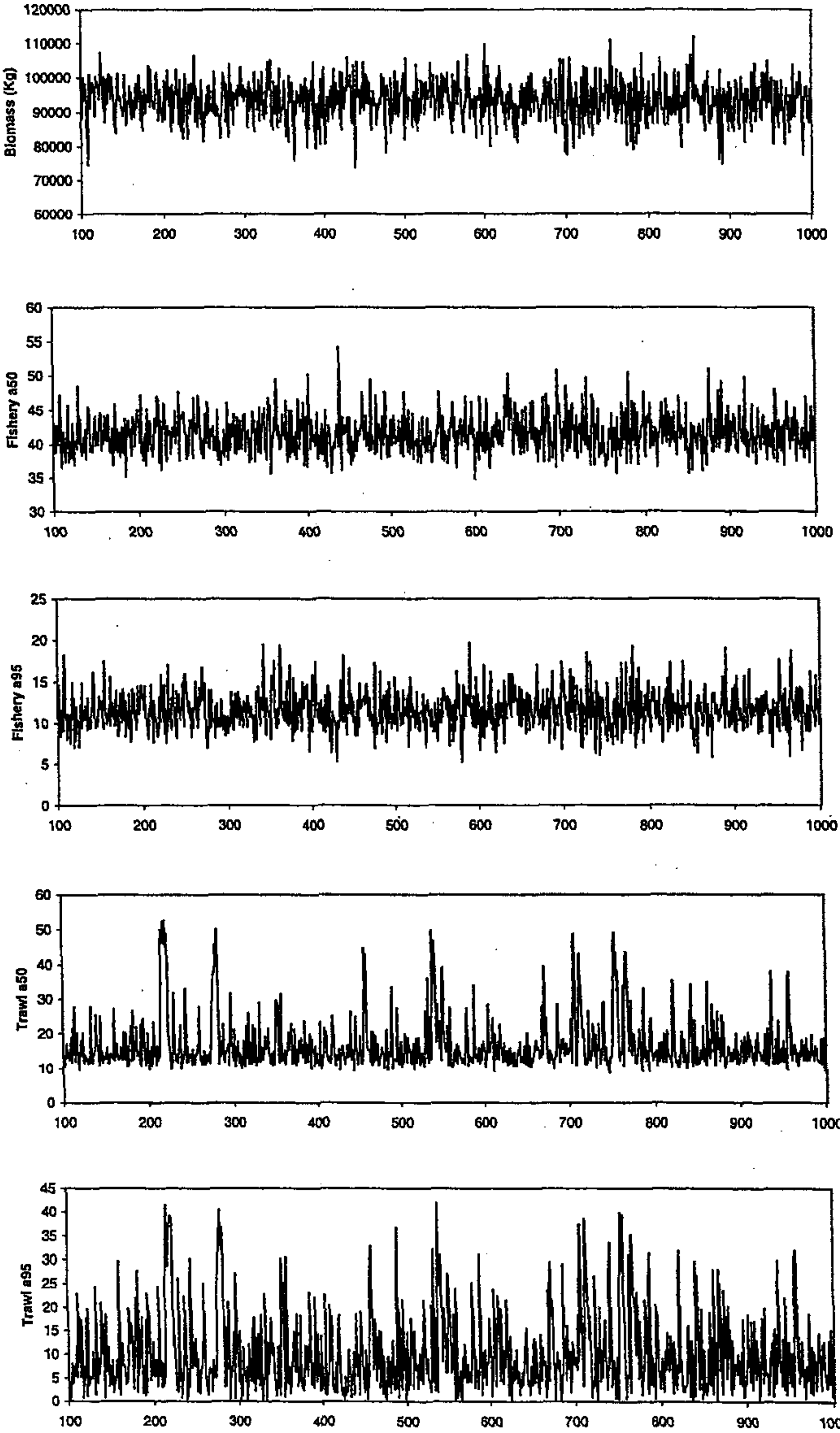

Figure B1: MCMC traces for the Beta1 run.

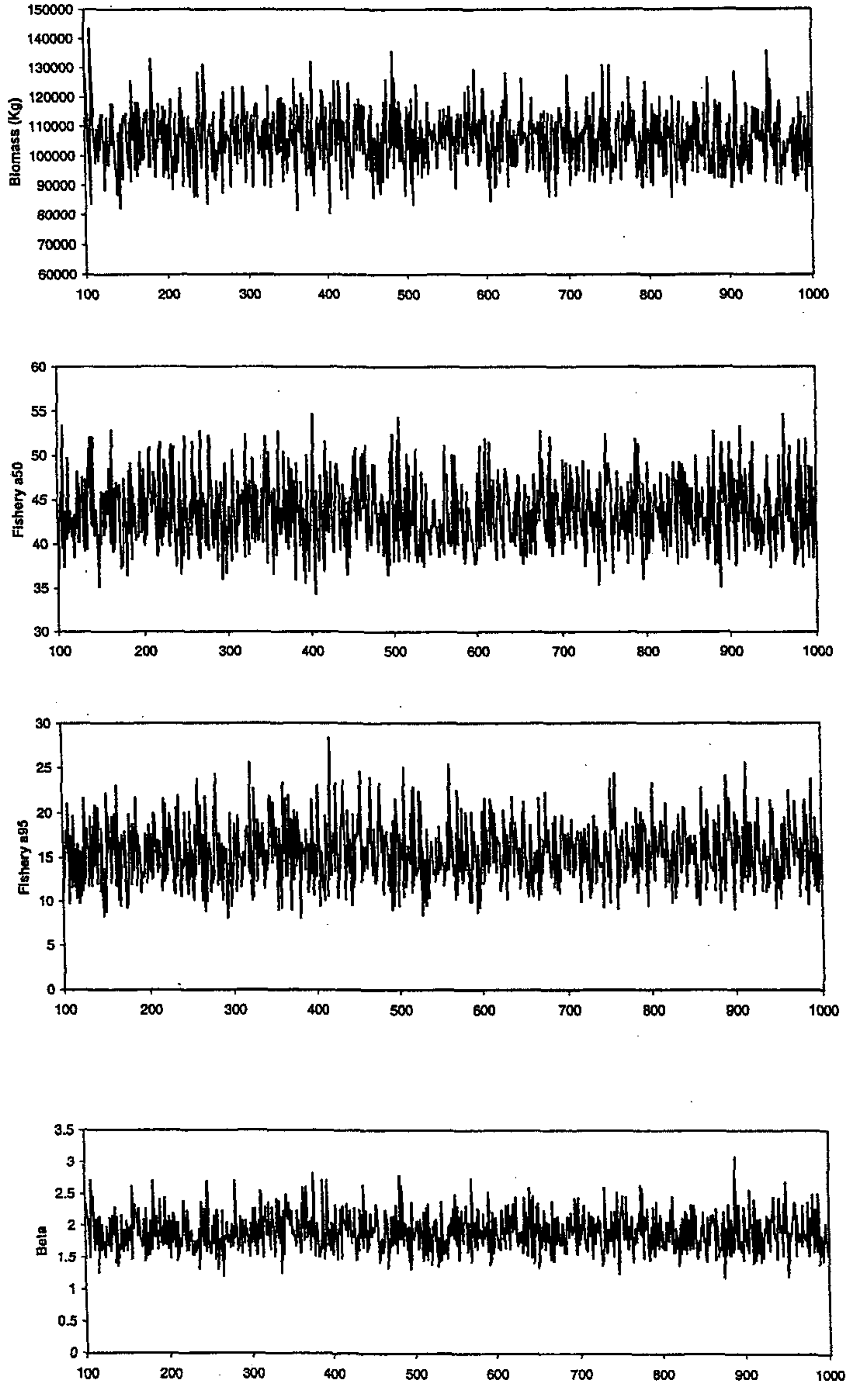

Figure B2: MCMC traces for the EstBeta run.

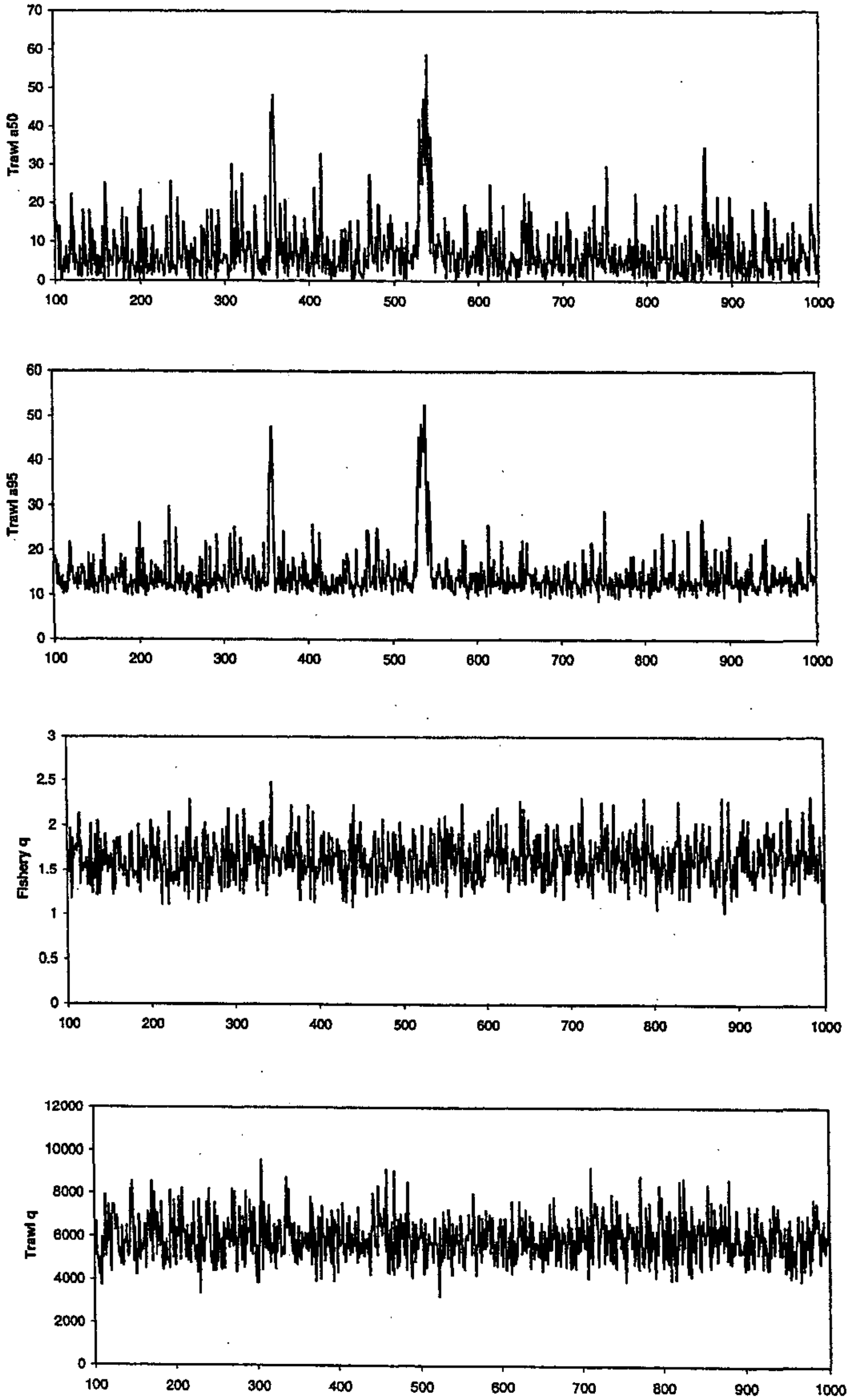

Figure B2 (cont.): MCMC traces for the EstBeta run.

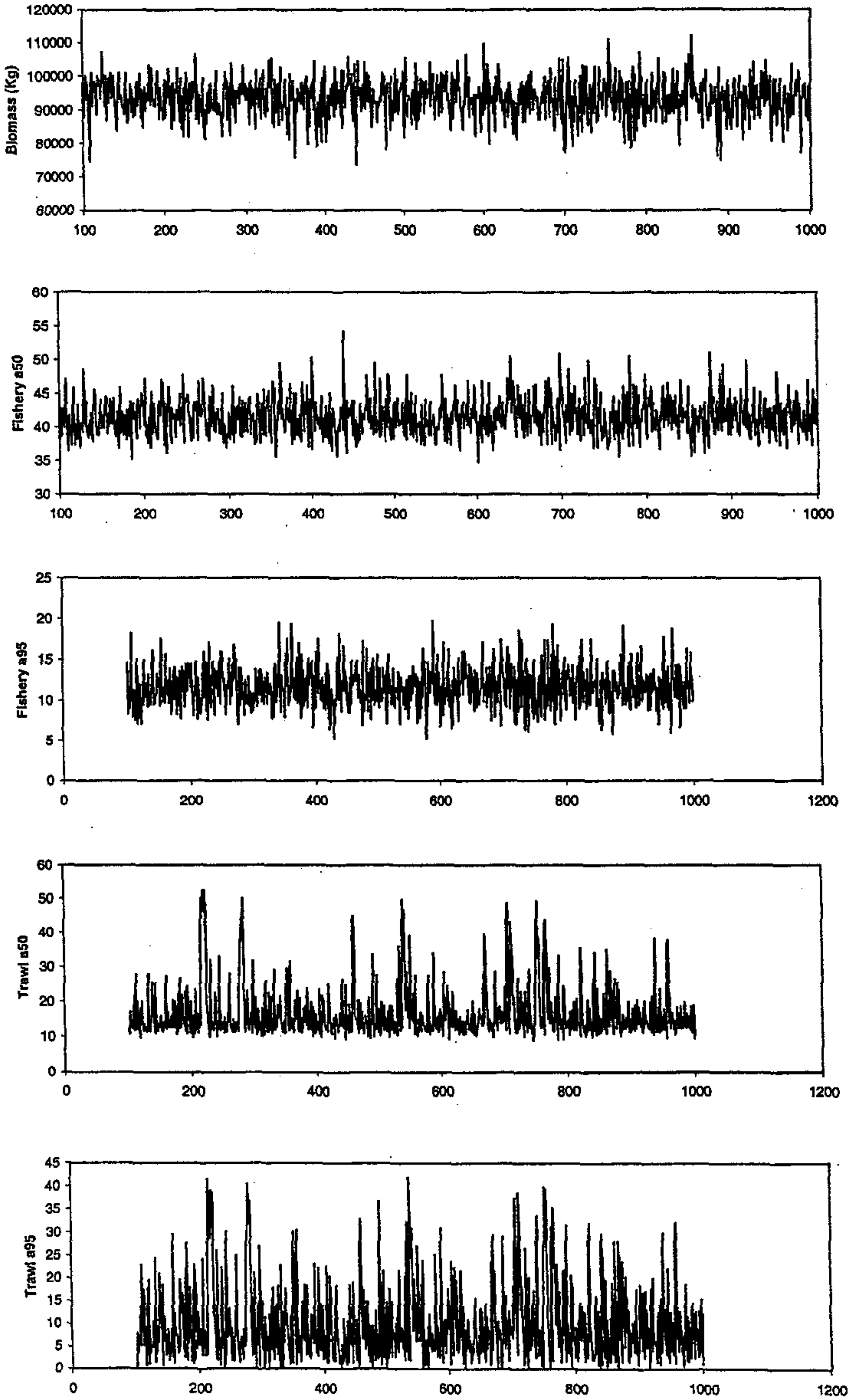

Figure B3: MCMC traces for the NoCPUE run.