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I. J. Doonan
P. J. McMillan
R. P. Coburn
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P. J. McMillan
R. P. Coburn
A. C. Hart

NIWA
Private Bag 14901
Wellington

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EXECUTIVE SUMMARY

Doonan, I.J.; McMillan, P.J.; Coburn, R.P.; Hart, A.C. (2003). Assessment of OEO 4 smooth oreo for 2002–03.

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The biomass of smooth oreo in OEO 4 was estimated with Bayesian methods using a CASAL age-structured population model. Input data included research and observer-collected length data, two absolute abundance estimates from research acoustic surveys carried out in 1998 (TAN9812) and 2001 (TAN0117), and relative abundance indices from standardised catch per unit effort analyses. Biomass estimates were made for the whole of OEO 4 and also separately for the west and east parts of OEO 4 divided at 178° 20' W. This separation was based on an analysis of commercial catch, standardised CPUE, and research trawl and acoustic results which suggested distinct fisheries and fish distribution patterns for the west and east parts of OEO 4. The base case used the east/west split, the 1998 and 2001 acoustic abundance estimates, three standardised CPUE indices, the observer length data, the 2001 acoustic survey length data, no migration from east to west, but a fixed recruitment split into east and west, a fixed M (0.063) and with growth (L_∞ and c.v. of the length distribution) estimated within the model.

For the base case the median estimate for the mature fish B_0 for OEO 4 was 172 000 t (90% confidence interval of 147 000–209 000 t). The estimate of $MCY_{long\text{-}term}$ was 4200 t and the mid-year vulnerable biomass B_{MCY} was 37 000 t. The CAY estimate was 7700 t and CSP was 3500 t. The smooth oreo catch in OEO 4 from 2001–02 was 4284 t, about the same as the long-term MCY.

These results suggest that there are no immediate sustainability issues, but there are problems with the inputs to the assessment that were not resolved in this study. The main concern is the use of the two acoustic survey abundance estimates as absolute values. In particular, the large proportion of the smooth oreo acoustic abundance from both surveys (about 70%) that came from the layer mark-type. Determining the exact mixture of species in the layers had unmeasured uncertainty that may have resulted in an overestimate of the smooth oreo abundance. Layers are not normally fished by the commercial fleet, but within the model the vulnerable selectivity allocated part of the layer abundance to the fished population because the selectivity was based on length distributions. There is more confidence assigned to the acoustic abundance estimated for the school mark-type because these marks were composed mostly of smooth oreo and they are fished. Poor model fits also suggest that the estimates of natural mortality and growth of smooth oreo need to be re-examined. Other uncertainties in the biomass and yield estimates are due to the sensitivity to the target strength of smooth oreo and the use of deterministic recruitment.

Contents

1. INTRODUCTION

1.1 Overview

This work addresses the following objectives in MFish project "Oreo stock assessment" (OEO2001/02).

Overall objective

1. To carry out a stock assessment of black oreo and smooth oreo, including estimating biomass and sustainable yields.

Specific objective

4. To carry out a stock assessment of smooth oreo in OEO 4.

A new stock assessment for smooth oreo in OEO 4 (Figure 1) is presented based on a new absolute abundance estimate for smooth oreo derived from a research acoustic survey carried out in 2001 (TAN0117), plus a previous absolute abundance estimate from 1998 (TAN9812), and relative abundance indices from revised and updated standardised CPUE analyses.

Previous major assessments in 1997 and 2001 aimed to estimate virgin and current biomass (Doonan et al. 1997a, 2001). The 1997 assessment used a stock reduction analysis (PMOD) with relative abundance estimates from standardised CPUE, and relative abundance estimates from past trawl surveys (1991–93, 1995) with q values constrained. The 1997 assessment was considered uncertain because of the problems with the trawl survey catchabilities (Doonan et al. 1997a). The 2001 assessment used a stock reduction analysis (PMOD) with the single 1998 absolute abundance estimate as well as the relative abundance estimates from standardised CPUE (base case) and estimated a 95% confidence interval of 100 000 to 148 000 t for B_0, and long-term MCY of 1600–2400 t compared to catch levels of about 6200 t (1989–90 to 1998–99).

The new stock assessment analyses were conducted using the CASAL age-structured population model (Bull et al. 2002). This took account of the sex and maturity status of the fish and allowed inclusion of length frequency data. The assessment modelled separate west and east fisheries as well as a combined area fishery (OEO 4). Initial model runs gave poor fits to the data and indicated that there were major conflicts between the absolute abundance estimates, the observer collected length data, and previous estimates (Doonan et al. 1997b) of growth and natural mortality (M).

Smooth oreo are caught throughout the year by bottom trawling at depths of 800–1300 m in southern New Zealand waters. The OEO 4 south Chatham Rise fishery is the largest oreo fishery in the EEZ and operates between 176° E and about 172° W, mostly on undulating terrain (short plateaus, terraces, and "drop-offs") at the west end, and mostly on seamounts in the east. Most smooth oreo is caught as a bycatch to orange roughy fishing and in recent years the oreo TACC may have constrained orange roughy fishing as the orange roughy TACC was reduced. Black oreo is the other main species caught and has been a small bycatch from 1994–95 to 2001–02. There is no known recreational or Maori customary catch of oreos.

Smooth oreo are thought to be slow-growing and long-lived with the larger females reaching maximum sizes of around 50 cm TL at about 80 years and males reaching 45 cm and 70 years (Doonan et al. 1997b). Age estimates for New Zealand fish are unvalidated but similar results were reported by Australian workers (D.C. Smith and B.D. Stewart, Victorian Fisheries Research Institute, unpublished). They are a schooling species and form localised aggregations to feed (all year) or to spawn (October-December).

Stock structure of Australian and New Zealand samples of smooth oreo were examined using genetic (allozyme and mitochondrial DNA) and morphological counts (fin rays, etc.). No differences between

New Zealand and Australian smooth oreo samples were found using these techniques (Ward et al. 1996). A broad scale stock is suggested by these results but this seems unlikely given the large distance between New Zealand and Australia. A New Zealand pilot study examined smooth oreo stock relationships using samples from four management areas (OEO 1, OEO 3A, OEO 4, and OEO 6) of the New Zealand EEZ. Techniques used included genetic (nuclear and mitochondrial DNA), lateral line scale counts, settlement zone counts, parasites, otolith microchemistry, and otolith shape. Otolith shape from OEO 1 and OEO 6 was different to that from OEO 3A and OEO 4 samples. Weak evidence from parasite data, one gene locus, and otolith microchemistry suggested that OEO 3A samples were different from those from other areas. Lateral line scale and otolith settlement zone counts showed no differences between areas (Smith et al. 1999).

Observations available include biological data from research trawl surveys (1991–93, 1995, *Tangaroa*) but relative abundance estimates from these surveys are considered unreliable because of catchability issues (Doonan et al. 1997a). Absolute abundance estimates were made using acoustic methods in 1998 and 2001. Annual observer length/catch data are available from 1990–91 on, although sampling was erratic and was influenced by the progression of fishing from west to east with time and possibly by a trend from flat to seamount fishing in the east.

Catch history data are available from the late 1970's although the early data and some subsequent data required reconstruction of species catch from known species proportions because of the use of the aggregated species code (OEO) (see 1.2 below). Dumping of unwanted or small fish and accidental loss of fish (lost or ripped codends) were features of oreo fisheries in the early years. These sources of mortality were probably substantial but are now thought to be relatively small. No estimate of mortality from these sources has been made because of lack of data and because they now appear to be small. Estimates of discards of oreos were made for 1994–95 and 1995–96 from MFish observer data. This involved calculating the ratio of discarded oreo catch to retained oreo catch and then multiplying the annual total oreo catch from the New Zealand EEZ by this ratio. Estimates were 207 and 270 t for 1994–95 and 1995–96 respectively (Clark et al. 2000).

1.2 TACCs, catch, and landings data

Oreos are managed as a group that includes black oreo (*Allocyttus niger*, BOE), smooth oreo (*Pseudocyttus maculatus*, SSO), and spiky oreo (*Neocyttus rhomboidalis*, SOR). The last species is not sought by the commercial fleet and is a minor bycatch in some areas, e.g., the Ritchie Bank orange roughy fishery. The management areas used since October 1986 are shown in Figure 1.

Separate catch statistics for each oreo species were not requested in the version of the catch statistics logbook used when the New Zealand EEZ was formalised in April 1978, so the catch for 1978–79 was not reported by species (the generic code OEO was used instead). From 1979–80 onwards the species were listed and recorded separately. When the ITQ scheme was introduced in 1986, the statutory requirement was only for the combined code (OEO) for the Quota Management Reports, and consequently some loss of separate species catch information has occurred even though most vessels catching oreos are requested to record the species separately in the catch-effort logbooks.

Reported landings of oreos (combined species) and TACs from 1978–79 until 2001–02 are given in Table 1. The OEO 4 TAC was about 7000 t from 1982–83 to 2000–01 but reduced to 5200 t in 2001–02. Reported estimated catches by species from data recorded in catch and effort logbooks (Deepwater, TCEPR, and CELR) are given in Table 1. Soviet catches from the New Zealand area from 1972 to 1977 were assumed to be black oreo and smooth oreo combined and to be from area OEO 3A (Doonan et al. 1995).

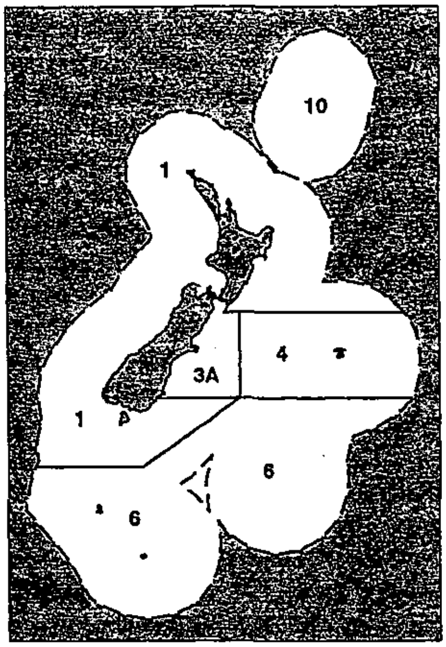

Figure 1: **Oreo management areas.**

Table 1: Total reported landings and TACs (t) for all oreo species combined and total estimated catch (t) for smooth oreo (SSO) and black oreo (BOE) for OEO 4 from 1978–79 to 2001–02. – na.

Fishing	Landings		Estimated catch	
year	t	TAC	SSO	BOE
1978–79*	8 041	–	0	0
1979–80*	680	–	114	566
1980–81*	10 269	–	849	5 224
1981–82*	9 296	–	3 352	5 641
1982–83*	3 927	6 750	2 796	1 088
1983–83#	3 209	#	1 861	1 340
1983–84†	6 104	6 750	4 871	1 214
1984–85†	6 390	6 750	4 729	1 651
1985–86†	5 883	6 750	4 921	961
1986–87†	6 830	6 750	5 670	1 160
1987–88†	8 674	7 000	7 771	903
1988–89†	8 447	7 000	6 427	1 087
1989–90†	7 348	7 000	5 320	439
1990–91†	6 936	7 000	5 262	793
1991–92†	7 457	7 000	4 797	1 702
1992–93†	7 976	7 000	3 814	1 326
1993–94†	8 319	7 000	4 805	1 553
1994–95†	7 680	7 000	5 272	545
1995–96†	6 806	7 000	5 236	364
1996–97†	6 962	7 000	5 390	530
1997–98†	7 010	7 000	5 868	811
1998–99†	6 931	7 000	5 613	844
1999–00†	7 034	7 000	5 985	628
2000–01†	7 358	7 000	5 924	799
2001–02†	4 864	5 200	3 806	515

Source: FSU from 1978–79 to 1987–88; QMS/MFish from 1988–89 to 2001–02. *, 1 April to 31 March; #, 1 April to 30 September. Interim TACs applied; †, 1 October to 30 September.

2. ASSESSMENT MODEL

2.1 Population dynamics

2.1.1 Partition of the population

The stock assessment model partitioned the OEO 4 smooth oreo population into two sex groups, and age groups 1–70 years, with a plus group. There were two optional area partitions (west and east), and two optional fishing partitions, layers (unfished) and schools (fished).

2.1.2 Annual cycle

The nominal unit time in the model is one year during which processes (e.g., recruitment) were applied. Since these processes cannot be modelled simultaneously they were carried out in a specified sequence (Table 2). For convenience in the specifications, these were grouped into three time steps. Events were given a specified time within the year (month) through the specification of the percentage of natural mortality that was applied, assuming that it was applied uniformly throughout the year. Observations were fitted to model predictions specified by the time step and the time within the year (Table 2).

Table 2: Stock model: timing within a year for processes and when data were fitted. –, not applicable.

Model time step	Time	Process (in the order applied)	Observations fitted Time	Observations fitted Description
1	Oct	Recruitment	–	
	Oct	Spawning	–	
	Oct	Increment age	–	
2	Oct	Migration (if applicable)	–	
3	Oct-Sep	Fishing mortality	Oct	Acoustic abundance
			Oct	Acoustic length data
			Mar	CPUE indices
			Mar	Observer length data

2.2 Selectivities, ogives, and other assumptions

Selectivities

Separate age-based selectivity ogives were estimated for males and females and for the separate east and west analyses. Selectivities were estimated for the commercial fishery (catch) and for the acoustic survey (abundance data). The ogives were logistic curves with parameters for the age of 50% selection and for the ages from 50 to 95% selection. Young fish (less than about 7 years old) are probably in mid-water and so were not counted by the acoustic survey. At 6–7 years these fish settle on the bottom and are then available to the acoustic survey technique. The young fish are almost fully selected by the trawl gear when they do settle on the bottom, and therefore the estimated selectivity should represent the biological and not the fishing process.

The last observation is particularly relevant to the selectivities for the acoustic abundance data that were estimated from the associated length data collected during the 2001 survey. The length data were collected by trawling, which has a selectivity that could bias the acoustic selectivity. However, the acoustic selectivity is due to the fish settling on the bottom and once settled are fully selected by the trawl gear so the trawl selectivity is irrelevant.

Migration

An aged-based double-normal capped ogive was used. The ogive used four parameters and was intended to give a pulse of fish over a restricted age range to populate the west area, i.e., once migration occurred fish did not migrate back to the east and after a certain age no fish migrated from east to west. When migration was used there was no acoustic selectivity for the west acoustic data.

Maturity

The maturity ogive developed during the 2002 stock assessment was used (see Appendix A).

2.3 Modelling methods, parameters, assumptions about parameters

The stock assessment analyses were conducted using CASAL (Bull et al. 2002). This was implemented as an age-structured population model that took account of the sex and maturity status of the fish and allowed inclusion of length frequency data. The Bayesian estimator was employed. The model incorporated deterministic recruitment, life history parameters, and catch history (see Table 3). Data fitted in the analysis were the 1998 and 2001 acoustic abundance estimates (see Table 6), standardised combined CPUE indices (see Tables 4a, 4c, & 4d), observer length data (Tables 7 & 8), and the 2001 acoustic survey length data (see Figures 9 & 10). The model was used to estimate biomass and generate yield estimates including $MCY_{long\text{-}term}$ and CAY. These procedures were conducted with the following steps.

1. Model parameters were estimated using maximum likelihood and the prior probabilities.
2. Samples from the joint posterior distribution of parameters were generated with the Markov Chain Monte Carlo procedure (MCMC) using the Metropolis algorithm.
3. A marginal posterior distribution was found for each quantity of interest by integrating the product of the likelihood and the priors over all model parameters; the posterior distribution was described by its median, 5, and 95 percentiles for parameters of interest.

The following assumptions were made in the analyses carried out to estimate biomasses and yields.
(a) The acoustic abundance estimates were unbiased absolute values.
(b) The CPUE analyses provided a relative index of abundance for smooth oreo in the whole of OEO 4.
(c) The ranges used for the biological values covered their true values. (Smooth oreo growth was estimated by the model.)
(d) One assumed value (0.9) of the maximum fishing mortality (F_{max}) was used in all the analyses of smooth oreo below.
(e) Recruitment was deterministic and followed a Beverton & Holt relationship with steepness of 0.75.
(f) Catch overruns were 0% during the period of reported catch.
(g) The population of smooth oreo in OEO 4 was a discrete stock or production unit.
(h) The catch history was accurate.

3. OBSERVATIONS AND MODEL INPUTS

3.1 East and west fisheries

Initial analysis of OEO 4 oreo catch data showed marked changes in fishing patterns over time. This involved a progression of high catches over time starting in the west and moving east and appeared to represent successive exploitation of new areas (Figure 2). Areas in the west previously exploited did not later return to sustained high catches. The target species and the type of fishing changed over time with smooth oreo the target species in the west on flat, dropoff, and seamounts from the late 1970s, with a gradual change to target fishing for orange roughy on seamounts in the east in the late 1980s (Figure 3). For some runs CPUE, catch, length and abundance data were split at 178° 20' W.

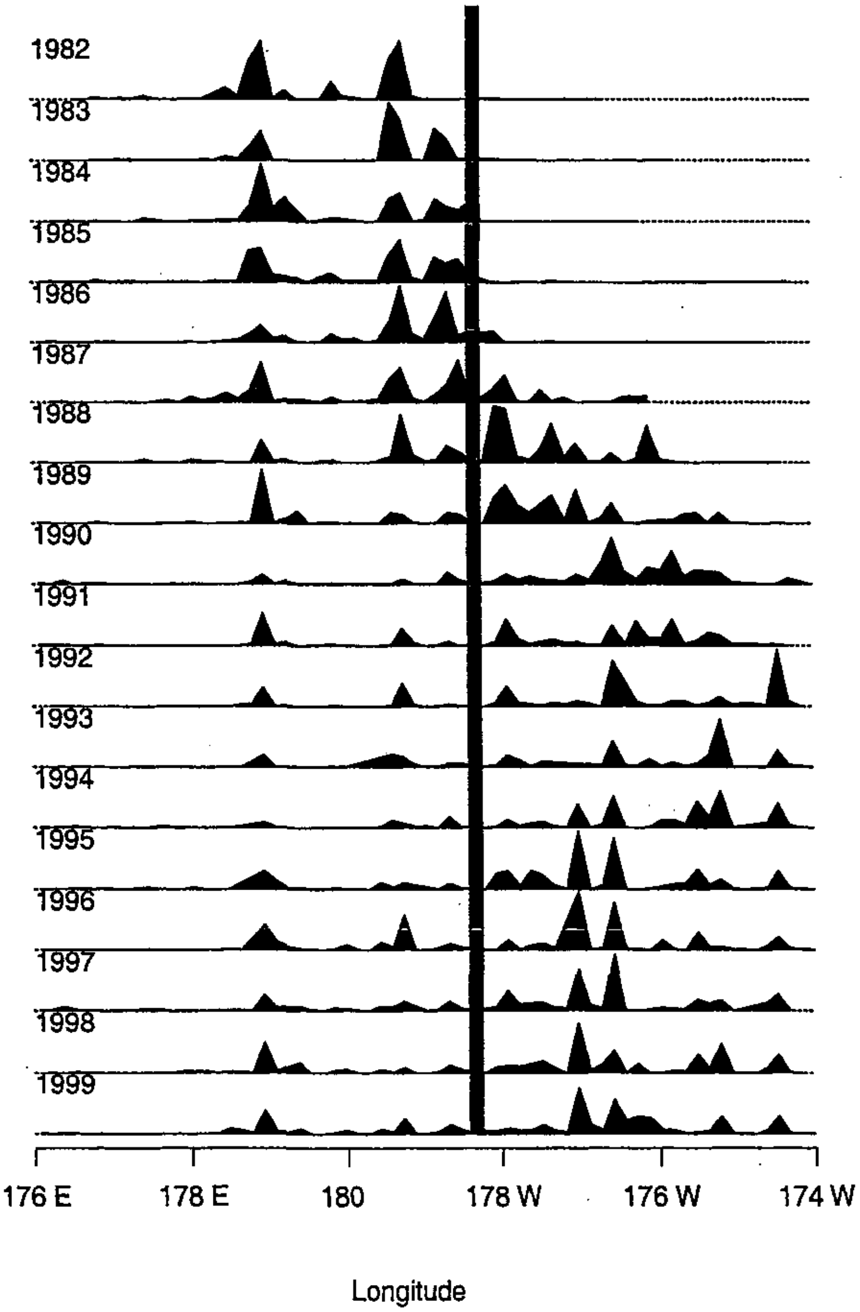

Figure 2: All estimated reported catches of smooth oreo (black shading, t) by longitude over time from OEO 4 on the south Chatham Rise between 176° E and 174° W, south of 44° S. Years are fishing years, e.g., 1982 is 1981–82. There were low reported catches of smooth oreo before 1981–82 so 1982 included that year plus prior catches. Vertical scale is 1000 t between years (horizontal lines). The vertical line at 178° 20' W marks the split between west and east parts of OEO 4.

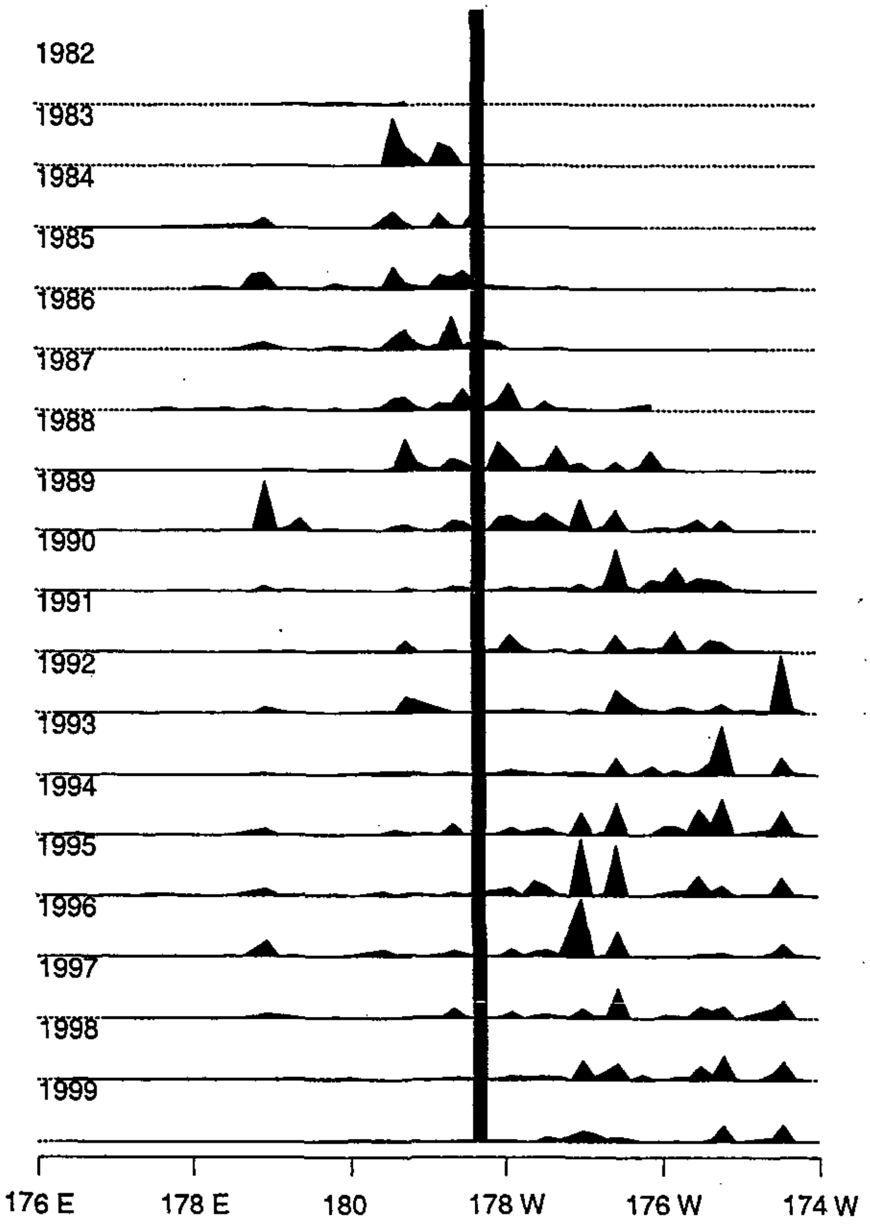

Figure 3: Estimated reported catches of smooth oreo (black shading, t) where target species was orange roughy, by longitude over time from OEO 4 on the south Chatham Rise between 176° E and 174° W, south of 44° S. Years are fishing years, e.g., 1982 is 1981–82. There were low reported catches of smooth oreo before 1981–82 so 1982 included that year plus prior catches. Vertical scale is 1000 t between years (horizontal lines). The vertical line at 178° 20' W marks the split between west and east parts of OEO 4.

3.2 Catch history

Catch history is presented in Table 3 and includes the yearly total catch for OEO 4 and catches from west and east (split at 178° 20' W). Catches from 1978–79 to 1982–83 (1 April to 31 March) were assumed to be for fishing years (1 October to 30 September).

1. The 1978–79 landings of unspecified oreo (8041 t, see Table 1) were assumed to be the same proportion of smooth oreo to black oreo estimated catch reported in 1979–80 (114/(114+566) = 0.168). The estimate of the 1978–79 smooth oreo catch was 8041 t x 0.168 = 1351 t.
2. The 6 month landings of smooth oreo reported as 1983–83 (1861 t, Table 1) were split and half each (930.5 t) added to the preceding and subsequent years (1982–83 and 1983–84). There was only an 8 t difference between estimated and reported landings in 1983–83 (Table 1), so no adjustment to the reported smooth oreo catch was made.
3. From 1979–80 to 2001–02 the landings were calculated by multiplying the value by the proportion of smooth oreo to black oreo estimated catch in Table 1.
4. The last two years of the catch history are assumed projected catch.

Table 3: **Reconstructed catch history (t) of smooth oreo from OEO 4. "OEO 4" is the catch from the whole area. "West" is the proportion of the total taken west and "East" is the catch taken to the east of 178° 20' W. ‡ indicates assumed catch.**

Year	OEO 4	West	East
1978–79	1 351	1 351	0
1979–80	114	114	0
1980–81	1 436	1 436	0
1981–82	3 465	3 430	35
1982–83	3 757	3 757	0
1983–84	5 817	5 759	58
1984–85	4 736	4 547	189
1985–86	4 922	4 380	541
1986–87	5 670	4 196	1 474
1987–88	7 771	2 642	5 129
1988–89	7 225	2 457	4 769
1989–90	6 788	1 154	5 634
1990–91	6 028	1 808	4 220
1991–92	5 504	1 211	4 293
1992–93	5 918	1 420	4 498
1993–94	6 287	1 069	5 218
1994–95	6 961	1 392	5 568
1995–96	6 364	2 227	4 137
1996–97	6 339	1 712	4 627
1997–98	6 159	1 848	4 311
1998–99	6 025	1 749	4 283
1999–00	6 366	1 800‡	4 200‡
2000–01	6 484	1 800‡	4 200‡

3.3 Relative abundance estimates from CPUE analyses

The analyses were revised and updated from those described by Coburn et al. (2001) by including two more years data (1999–2000 and 2000–01).

Data

The catch and effort data were restricted to that area within OEO 4 (the "study area") where the main smooth oreo fishery occurred from 1978–79 to 1998–99 (Figure 4). Data from OEO 4 were divided into target smooth oreo and bycatch smooth oreo and into pre- and post-global positioning system (GPS) with a further subdivision into a west series from 1979–80 to 1988–89 and an east series from 1992–93

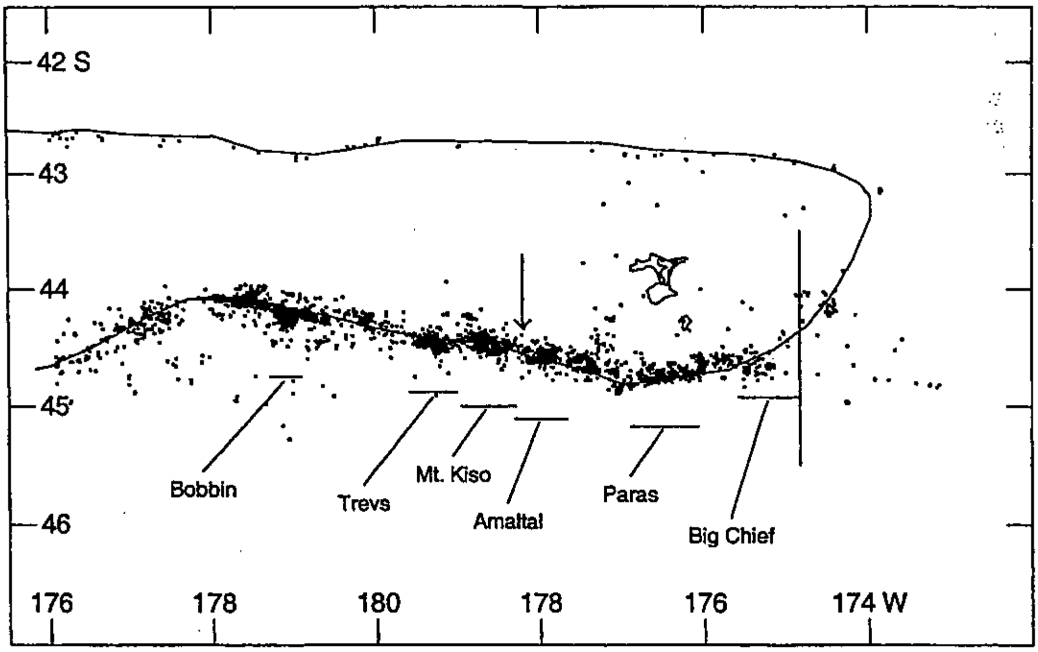

Figure 4: **Start position (dots) of all trawls targeting smooth oreo in OEO 4 from 1978–79 to 1998–99. The western end of the study area is the boundary of OEO 4 at 176° E. The eastern boundary of 174° 50' W is shown with a vertical line. An arrow shows the position of the west/east split at 178° 12.6' W. Some main fishing patches are also indicated with horizontal bars. The axis-line (curved line) onto which positions were projected is also shown.**

to 2000–01). The intermediate years (1989–90 to 1991–92) represented a period of rapid improvement of fishing ability due largely to the introduction of GPS and therefore those data were omitted from the analysis.

Method of CPUE analysis

The CPUE analysis method was described by Doonan et al. (1995, 1996, 1997a) and involved regression-based methods where the zero catch tow and the positive catch tow data were analysed separately to produce positive catch and zero catch indices. For target fishing, a combined index was calculated (see Coburn et al. 2001). The predictor variables considered in the analysis included axis-position (position along a line drawn west to east through the fished band along the continental slope of the south Chatham Rise), depth, season, time, seamount (indicated if a tow started within 5 km of a known seamount), and vessel. The reference year was arbitrarily assigned to a year near the middle of the time series. A revised method was used to convert the index values to a canonical form by dividing each value by the geometric mean of the index series following the suggestion of Francis (1999) and resulted in the index value for the reference year being a value other than 1. Annual c.v.s for the combined indices were estimated using a jackknife technique (Doonan et al. 1995), but the method was revised by using the canonical index values to calculate the jacknife c.v. values and resulted in the reference year c.v. having a value other than 0.

For the smooth oreo (SSO) and unspecified oreo (OEO) target fisheries, combined indices were used in the assessment model, but for bycatch fisheries (orange roughy target fishing) only the positive catch indices were used.

Results of CPUE analysis

Six analyses were carried out: target smooth oreo or unspecified oreo pre-GPS, target smooth oreo or unspecified oreo post-GPS, bycatch smooth oreo (target orange roughy) pre-GPS, bycatch smooth oreo (target orange roughy) post-GPS, target smooth oreo or unspecified oreo post-GPS west, target smooth oreo or unspecified oreo post-GPS east (Coburn et al. 2001), but only four (a–d below) were chosen for use in the assessment model analyses. Three satisfied the criteria of preferring the target smooth oreo or unspecified oreo analyses to bycatch analyses, but the bycatch post-GPS series (7 years) was used instead of the target smooth oreo or unspecified oreo post-GPS east series because the latter had only 4 years in the series including one where the jacknife c.v. was 236%. The base case stock assessment analysis used only the indices for a, c, and d below (Figure 5).

a Target SSO, pre-GPS series. Data used were from 1981–82 to 1988–89 and were mainly from the west. The final model for positive catch used vessel, season, and axis-position and that for zero catch used vessel, axis-position, and season. The combined index from the final year was approximately half that of the first year (Table 4a).

b Target SSO or OEO, post-GPS series. Data used were from 1992–93 and 1994–95 to 2000–01 and were from east and west. The final model for positive catch used season, depth, vessel, and axis-position and that for zero catch used vessel, axis-position, year, depth, and season. The combined index changed little over time (Table 4b).

c Target SSO or OEO, post-GPS west series. Data used were from 1992–93 and 1995–96 to 2000–01. The final model for positive catch used depth, season, axis-position, vessel, and year and that for zero catch used axis-position, vessel, year, time, depth, and season. The final combined index was approximately twice that of the first year index (Table 4c).

d Bycatch post-GPS series. Data used were from 1992–93 to 2000–01 and were mainly from the east. The final model for positive catch used axis-position, vessel, season, and depth. The positive catch index in the last year was about half that of the first year (Table 4d).

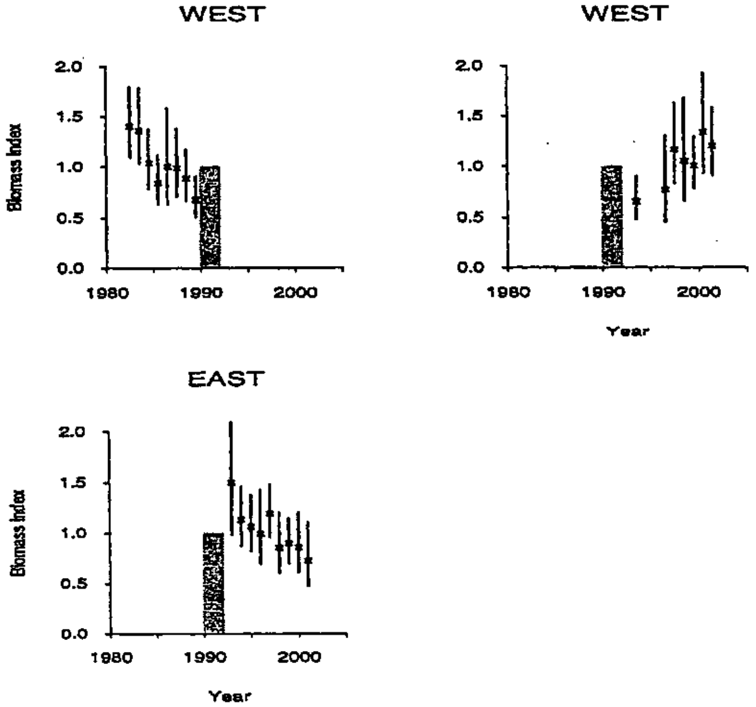

Figure 5: Standardised CPUE indices (crosses) for target SSO, pre-GPS series (upper left), target SSO or OEO, post-GPS west series (upper right), bycatch post-GPS series (lower). The vertical lines are ±1 s.d. The grey rectangle represents the years when data were excluded because of the introduction of GPS.

Table 4: Smooth oreo time series of combined and positive catch abundance indices from standardised CPUE analyses.

Year	Combined index	Jackknife c.v.
(a) Target SSO pre-GPS		
1981–82	1.40	14.7
1982–83	1.36	19.2
1983–84	1.04	20.7
1984–85	0.84	20.2
1985–86	1.00	43.7
1986–87	0.99	28.1
1987–88	0.89	20.3
1988–89	0.68	21.7
(b) Target OEO/SSO post-GPS		
1992–93	1.00	31.1
1994–95	1.23	28.5
1995–96	0.73	63.5
1996–97	1.06	21.7
1997–98	0.87	109.3
1998–99	0.92	27.8
1999–2000	1.17	34.0
2000–01	1.10	42.8
(c) Target OEO/SSO post-GPS, west		
1992–93	0.66	25.6
1995–96	0.77	53.1
1996–97	1.16	27.9
1997–98	1.05	44.6
1998–99	1.01	15.9
1999–2000	1.34	31.9
2000–01	1.20	19.6
(d) Bycatch post-GPS		
Year	Positive catch index	Jacknife c.v.
1992–93	1.50	39.1
1993–94	1.13	16.1
1994–95	1.06	16.6
1995–96	0.99	31.3
1996–97	1.19	92.4
1997–98	0.85	28.7
1998–99	0.90	14.7
1999–2000	0.85	28.4
2000–01	0.72	39.2

3.4 Relative abundance estimates from trawl surveys

Trawl surveys of oreos on the south Chatham Rise were carried out in seven years between 1986 and 1995 (Table 5). The abundance estimates from the surveys before 1991 were not considered to be comparable with the *Tangaroa* series because different vessels were used. Other data from those early surveys were used, e.g., gonad staging to determine length at maturity. The 1991–93 and 1995 "standard" (flat, undulating, and drop-off ground) surveys are comparable but were considered to be problematic because catchability estimates were inconsistent (Doonan et al. 1997a). The estimates were not included in the base case for the 2001 stock assessment (Doonan et al. 2001) and are not included in this assessment.

Table 5: Random stratified trawl surveys (standard, i.e., flat tows only) for oreos on the south Chatham Rise (OEO 3A & OEO 4).

Year	Area (km^2)	Vessel	Survey area	No. of stations	Reference
1986	47 137	*Arrow*	South	186	Fincham et al. (1987)
1987	47 496	*Amaltal Explorer*	South	191	Fenaughty et al. (1988)
1990	56 841	*Cordella*	South, southeast	189	McMillan & Hart (1994a)
1991	56 841	*Tangaroa*	South, southeast	154	McMillan & Hart (1994b)
1992	60 503	*Tangaroa*	South, southeast	146	McMillan & Hart (1994c)
1993	60 503	*Tangaroa*	South, southeast	148	McMillan & Hart (1995)
1995	60 503	*Tangaroa*	South, southeast	172	Hart & McMillan (1998)

3.5 Absolute abundance estimates from acoustic surveys

Absolute abundance estimates were made using revised target strength estimates for black oreo and smooth oreo.

1998 survey

Absolute estimates of abundance were available from the acoustic survey on oreos that was carried out from 26 September to 30 October 1998 on *Tangaroa* (voyage TAN9812) (Doonan et al. 2000). The survey covered 59 transects over 6 strata on the flat and 29 transects on 8 seamounts (Figure 6). A total of 95 tows was carried out for target identification and to estimate target strength and species composition. The 1998 survey abundance was re-estimated for total smooth oreo, instead of just recruited fish as reported in Doonan et al. (2000, 2001). The scale-up factor to take the flat survey abundance to the trawl survey area was also re-estimated for total (versus recruited) smooth oreo. The latter value became 1.75 (2.0 for recruited fish) for the abundance as a single area and also for the east area, and 2.21 for the west area. The scale-up factor to take the trawl area abundance to the whole of OEO 4 was also revised upwards from 1.07 to 1.11. The same values were used when the abundance was split into layer (unfished) and school (fished) mark-types. Abundance estimates are in Table 6.

2001 survey

Absolute estimates of abundance were available from the acoustic survey on oreos carried out between 16 October and 14 November 2001 using *Tangaroa* for acoustic work and *Amaltal Explorer* for trawling (Doonan et al. 2003). The flat survey included 138 transects and 84 trawls over 10 flat area strata whilst the seamount survey included 46 transects and 36 trawls over 14 seamounts (Figure 7). Abundance estimates are given in Table 6.

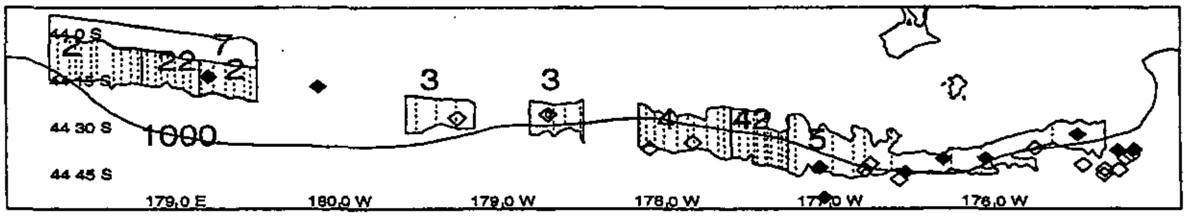

Figure 6: 1998 OEO 4 acoustic survey area showing smooth oreo (2–5, 22 & 42) and black oreo (7) flat strata (dark lines) and transects (dashed lines). Seamounts selected for sampling (♦) plus seamounts listed but not selected for sampling(◊).

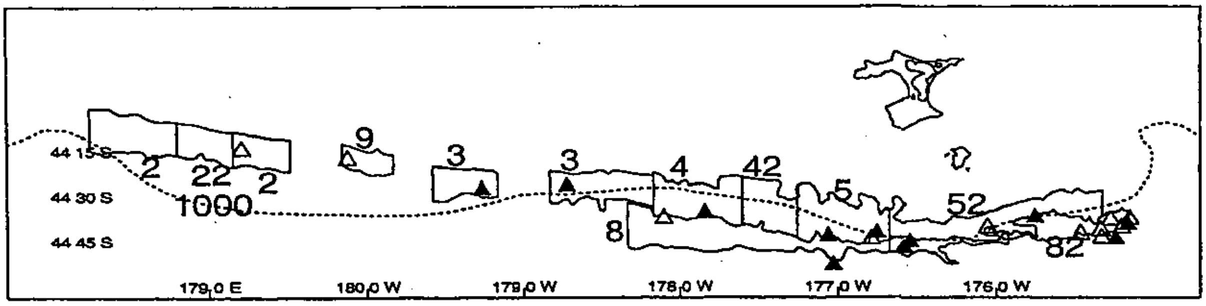

Figure 7: **Flat strata and seamounts surveyed (filled triangles) in the 2001 acoustic survey. Seamounts not surveyed are the empty triangles. The dotted line is the 1000 m depth contour.**

Table 6: **Estimated absolute abundance (t) from acoustic surveys in 1998 and 2001 by mark type, east, west and for the combined area. c.v.s are in parentheses (%). –, not estimated.**

		Mark-types	
Area	All	Layer	School
1998			
West	34 900 (52)	20 300 (77)	14 600 (61)
East	192 000 (37)	136 000 (57)	56 300 (28)
All	222 000 (34)	156 000 (51)	71 000 (26)
2001			
West	51 700 (35)	37 800 (48)	12 300 (34)
East	236 000 (22)	163 000 (29)	70 000 (25)
All	279 000 (22)	201 000 (25)	81 000 (22)

3.6 Length data analyses

Observer length frequencies

Observer length data were extracted from the observer database. These data represent proportional catch at length and sex. Starr (Deepwater Working Group unpublished document #02/51, 6 June 2002) found that the observer data needed stratifying on the basis of a west-east split at 178° 12.6' W and also on a 6 month seasonal split. The working group settled on October-March and April-September periods resulting in a total of four strata for OEO 4 with two in each of the west and east parts. The length frequencies were combined over strata by the proportion of catch in each stratum. Using seasonal strata meant that many years did not have data for each stratum (Table 7). The rules used to form length frequencies were:

- there must be data in each stratum, except when the proportion of catch in a stratum was lower than 5% (all areas) or 10% (east or west area separately);
- a total of at least 5 tows for the year;
- tows were excluded where there was not more than 30 fish measured or if there were no data on either females or males.

This resulted in 10 years' data for the east, 5 years' data for the west (Table 7), and 3 years' of length data being selected for OEO 4 for all areas Table 8).

Table 7: **Observer length frequencies for the west, east, and combined areas: percentage catch and number of tows with length data by season strata, and whether a length frequency was used in the stock assessment assessment.**

	Catch percentage		Number of tows		
Year	October-March	April-September	October-March	April-September	Assess
West area					
1987	72.6	27.4	2	2	
1989	70.1	29.9	10	5	Yes
1990	80.5	19.5	4	0	
1991	70.6	29.4	16	0	
1992	55.9	44.1	6	0	
1993	34.0	66.0	0	0	
1994	56.5	43.5	1	0	
1995	41.9	58.1	1	0	
1996	75.7	24.3	9	10	Yes
1997	74.2	25.8	11	0	
1998	60.2	39.8	2	9	Yes
1999	78.8	21.2	0	7	
2000	72.6	27.4	3	15	Yes
2001	70.1	29.9	9	15	Yes
East area					
1987	61.9	38.1	0	0	
1989	60.3	39.7	1	0	
1990	71.0	29.0	0	0	
1991	65.9	34.1	25	4	Yes
1992	55.6	44.4	45	8	Yes
1993	61.4	38.6	13	15	Yes
1994	43.8	56.2	62	32	Yes
1995	46.8	53.2	42	28	Yes
1996	67.4	32.6	6	6	Yes
1997	85.9	14.1	28	3	Yes
1998	91.3	8.7	20	9	Yes
1999	83.5	16.5	30	21	Yes
2000	65.9	34.1	14	0	
2001	51.5	48.5	50	4	Yes

Table 8: **Observer length frequencies for the combined area: percentage catch and number of tows by stratum (season and area) for the length data, and whether a length frequency was used in the stock assessment.**

	Catch (%)				Number of tows				
	West		East		West		East		
Year	Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Oct-Mar	Apr-Sep	Assess
1987	53.7	20.3	16.1	9.9	2	2	0	0	
1989	23.9	10.2	39.8	26.2	10	5	1	0	
1990	13.5	3.3	59.1	24.1	4	0	0	0	
1991	21.0	8.7	46.3	24.0	16	0	25	4	
1992	12.3	9.7	43.3	34.6	6	0	45	8	
1993	8.1	15.7	46.8	29.4	0	0	13	15	
1994	9.8	7.5	36.2	46.5	1	0	62	32	
1995	8.5	11.8	37.3	42.4	1	0	42	28	
1996	26.4	8.4	44.0	21.2	9	10	6	6	Yes
1997	20.2	7.1	62.5	10.2	11	0	28	3	
1998	18.1	12.0	63.9	6.1	2	9	20	9	Yes
1999	22.9	6.2	59.2	11.7	0	7	30	21	
2000	19.0	7.2	48.6	25.1	3	15	14	0	
2001	18.6	7.9	37.8	35.6	9	15	50	4	Yes

The distribution employed for the length frequency was lognormal (Bull et al. 2002) and required the c.v.s to be estimated for the frequencies. This was done using an estimated relationship between $\log(cv_j\, n^{0.5})$ and $1/\log(\text{proportion}_j)$, where j indexes the length classes, n is the number of tows, and $cv_j\, n^{0.5}$ represents the c.v. of a length class for one tow. The data for this regression were obtained by bootstrapping the tows within each stratum for a particular year. Only datasets with five or more tows were used. Preliminary investigations showed that for the west area, there were no seasonal c.v. differences so the data sets were combined. There were three relationships estimated: west, east Oct-March, and east April to September. The linearity of the log(cv) and 1/log(proportion) is shown in Figure 8 for the east October to March data. Results are in Table 9.

Table 9: C.v. estimates for the length frequencies: estimated coefficients for the regression, log(cv) = A + B /log(proportion). S.E., standard error.

	West		East Oct-March		East April-Sept	
Coefficient	Value	S.E.	Value	S.E.	Value	S.E.
A	2.25	0.04	2.58	0.03	2.35	0.06
B	8.73	0.17	9.03	0.14	8.73	0.25

Length frequency data from the 2001 acoustic survey

Population length frequencies were generated for the whole area, the east and west parts, and for the school and layer mark-types in the east and west parts. These frequencies were in the CASAL form that included an implicit sex ratio, i.e., the normalisation was over both male and female frequencies so that the sum of the frequencies over both summed to 1, not 2 as in the more usual way. Each frequency was estimated using the length data from trawls in each mark-type sub-stratum weighted by the catch rates and the proportion of abundance in the sub-stratum. For the flat strata, the method was:

$$f_{l,s} = \sum_{i,j} \frac{N_{i,j}}{\sum_{i2,j2} N_{i2,j2}} \sum_{k} \frac{cr_{i,j,k,s}}{\sum_{k2}\left(cr_{i,j,k2,male} + cr_{i,j,k2,female}\right)} f_{i,j,k,s,l}$$

where f is the length frequency, l is the length class, s = sex, I = stratum, j = mark-type, k = tows within mark j and stratum i, cr = catch rate, and N = abundance by numbers. N was estimated as the abundance by weight divided by the mean weight, where the mean weight was a mean weighted bycatch rate. The denominator for the catch rate part was over both males and females to account for the sex ratio. For seamounts, the same form was used, but some changes were needed to account for subsampling of seamounts within each of the three groups of seamounts. The length frequency for the whole area is given in Figure 9A, for females in the east part in Figures 9B and 9C, and for females in the west are in Figures 10A and 10B.

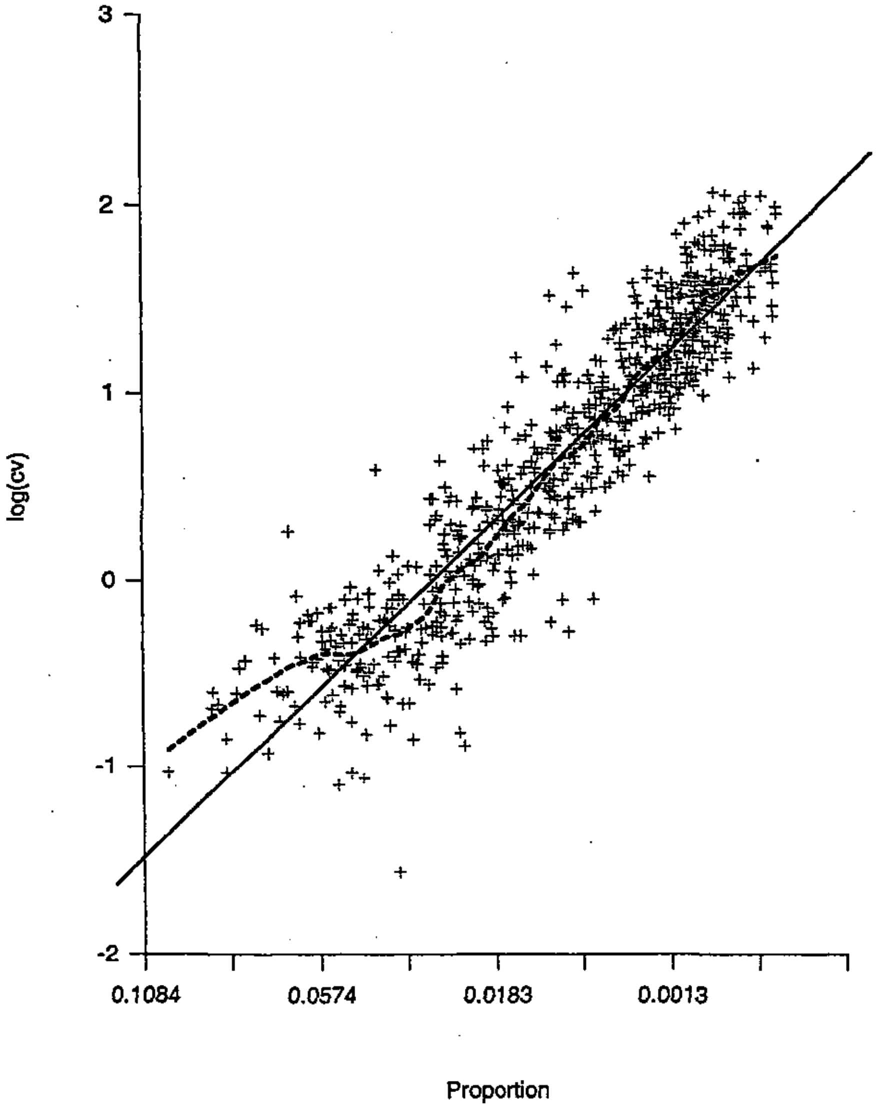

Figure 8: East, October to March stratum: log(cv) versus 1/log(proportion). Dashed line, a smooth curve (Lowess) through the data. Solid line, estimated regression line.

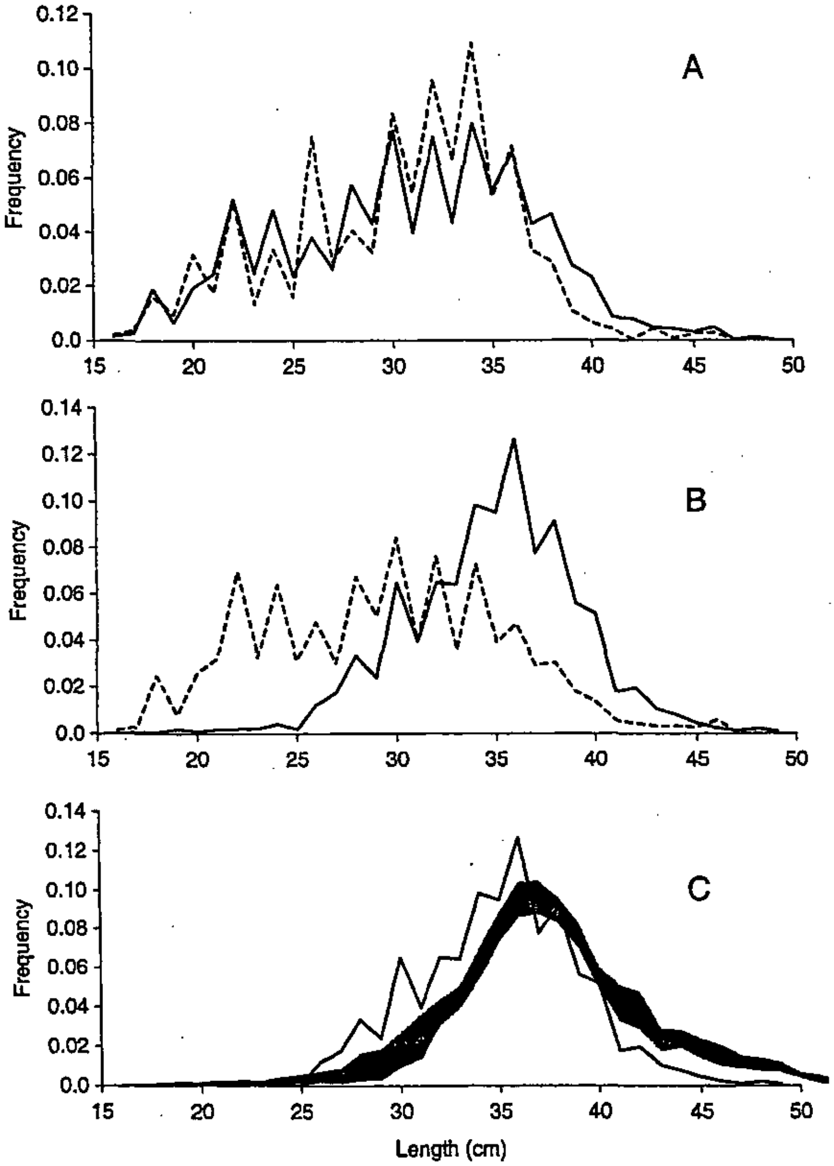

Figure 9: Acoustic survey 2001 length frequencies. A) female (solid line) and male (dashed line) frequencies for the trawl survey area. B) east female length frequency for the school mark-types (solid line) and layer mark-types (dashed line). C) east female frequency for the school mark-types (solid line) and an approximate inter-quartile region (shaded area) for the annual observer length frequencies in the east area for the years 1991 to 2001. Annual observer length frequencies were obtained by weighting the tow data by catch only, i.e., seasonal adjustments were not used.

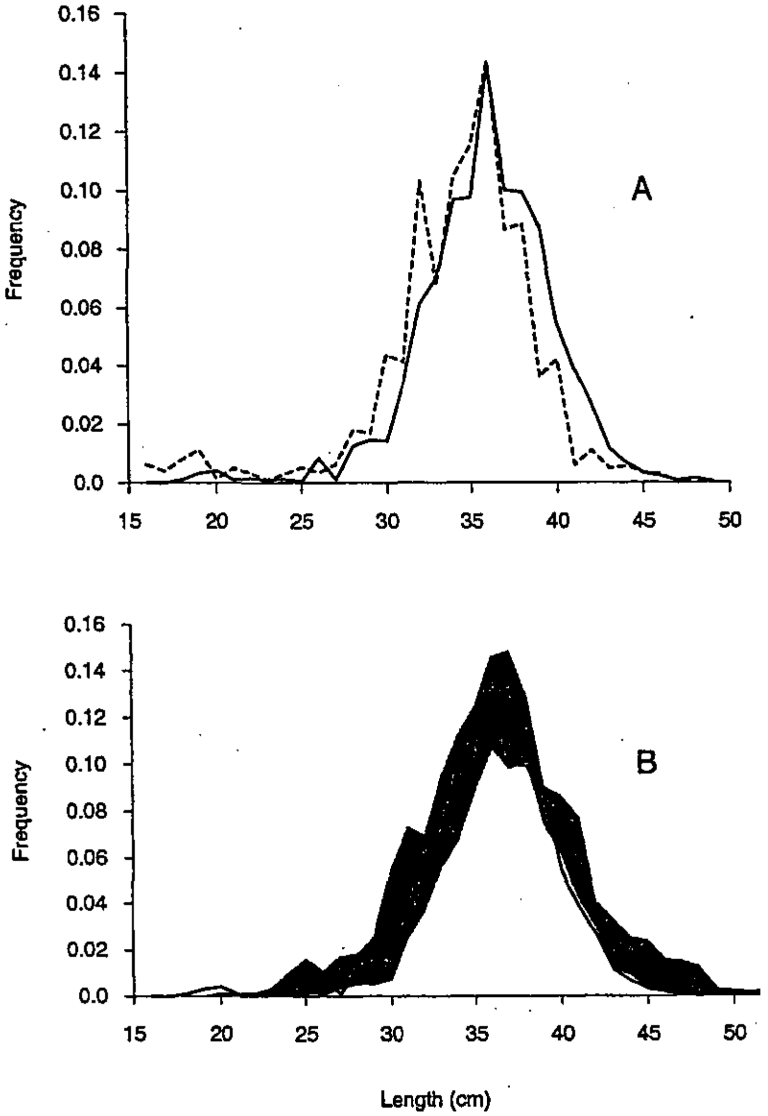

Figure 10: Acoustic survey 2001 length frequencies. A) west female length frequency for the school mark-types (solid line) and layer mark-types (dashed line). B) west female frequency for the school mark-types (solid line) and an approximate inter-quartile region (shaded area) for the annual observer length frequencies in the west area for the years 1991 to 2001. Annual observer length frequencies were obtained by weighting the tow data by catch only, i.e., seasonal adjustments were not used.

A lognormal distribution was used for the error structure of the length frequencies and the c.v.s estimated from a log(cv) versus 1/log(p) relationship, where p was the frequency. The relationship was estimated from bootstrapped c.v.s that had two parts. First, the tow data were re-sampled within each sub-stratum (mark-type in an area stratum) and, secondly, the $N_{i,j}$ were bootstrapped from the estimated abundance (i.e., they included bootstrapping from catches, acoustic backscatter and target strengths). The trawl catches induced a correlation between the bootstrapped $N_{i,j}$ and the re-sampled tow data for the length frequencies because these data were used in both parts of the analysis and to be consistent they should be re-sampled once and used in both parts. However, this correlation was ignored here since the development of software to continue this analysis was beyond the scope of the study and so the tow data in each part were treated independently. The estimated relationships based on 200 bootstrap values are given in Table 10.

Table 10: c.v. estimates for the 2001 survey acoustic length frequencies: estimated coefficients for the regression, log(cv) = A + B /log(proportion).

		A		B	
Area	Mark-types	Value	S.E.	Value	S.E.
Whole	All	0.33	0.09	7.49	0.41
West	All	0.74	0.1	7.74	0.49
West	School	0.63	0.13	8.07	0.6
West	Layer	0.83	0.12	7.86	0.55
East	All	0.39	0.1	7.73	0.47
East	School	1.08	0.14	10.43	0.63
East	Layer	0.52	0.16	7.62	0.68

Figure 9C shows the close correspondence between the observer length data and the school mark-types. The observer data relate well to the school mark-types length frequency, but not to the layer mark-type frequency, although there appears to be some selectivity within the school mark-types since the observer data is shifted to larger values by about 1.5 cm in the case shown (female, east area). Similar patterns occur for the length frequencies of males and those from the west area.

Observations of fishing during the survey and anecdotal evidence from fishers corroborate this correspondence. Further, catch rates in the layer mark-types were too low to be economic. Also, remarks from the skipper of the catcher vessel indicated that some marks in the school mark-types would not be fished as they were too small and shallow, so some selectivity is practised and this may be the cause of the shifts in length frequencies from the school mark-types and the observer data.

3.7 Biological data

The fixed values for the life history parameters used in the assessment are from Doonan et al. (1997b) (Table 11). Growth was von Bertalanffy and recruitment was Beverton & Holt. In some cases growth or natural mortality (M) were estimated.

Table 11: Fixed life history parameters for smooth oreo.

Parameter	Symbol (unit)	Female	Male
Natural mortality	M (yr^{-1})	0.063	0.063
von Bertalanffy parameters	L_∞ (cm, TL)	50.8	43.6
	k (yr^{-1})	0.047	0.067
	t_0 (yr)	-2.9	-1.6
Length-weight parameters	a	0.029	0.032
	b	2.90	2.87
Recruitment variability		0.65	0.65
Recruitment steepness		0.75	0.75

3.8 Development of base case

A base case was used to develop the Markov Chain Monte Carlo (MCMC) analysis and to estimate yields. Early model runs showed that the likelihood values were dominated by the fits to the observer length frequency data. In order to fit the length frequency data, either growth or M needed to be estimated in the model. When M was estimated the value doubled from 0.063 to about 0.12 depending on the exact data inputs used. At this value the chance of seeing fish over 50 years old was small, but this is at variance with the age data that contained fish of more than 50 years. It was therefore more logical to estimate growth and this strategy was approved by the Deepwater Working

Group. The poor model fits involved the right-hand limb of the length frequency distributions where fixed growth parameters values caused the model to estimate more large fish than were observed. Changing L_∞ and the spread of the lengths-at-age distributions had the merit of fitting the data directly rather than via a chain of indirect links as happened when M was estimated by the model. It is acknowledged that allowing the model to estimate growth shows that there is a conflict between the data used to estimate the fixed parameter values of growth, the M estimate, and the length frequency data, and therefore that this makes this assessment more uncertain.

The base case used an east/west split for all data inputs, a fixed M (0.063), and assumed that a fixed proportion of year 1 fish went to the west area with no migration from the east to the west area. Estimated model parameters included two growth parameters (L_∞ and the c.v. of the length distribution) with the third growth parameter (k) fixed at the values in Table 11 (it was not possible at the time to incorporate length and age data into the model). All sets of length data were fitted to the model using a log-normal likelihood with process errors.

Estimated model parameters and priors are presented in Table 12 and parameter names and codes are listed in Table 13.

Table 12: Estimated parameters and priors of the NIWA CASAL assessment model. U, uniform distribution estimated for both sexes combined. *, estimated for males and females separately.

Parameter	Number	Prior
Virgin biomass	1	ln B_0 ~U[0, ln (500 000)]
West catchability coefficient [pre-GPS CPUE]	1	U[0, 1]
East catchability coefficient [post-GPS CPUE]	1	U[0, 1]
West catchability coefficient [post-GPS CPUE]	1	U[0, 1]
Age-based selectivity - commercial fishery		
Age at 50% selected (east & west)	2	U[1, 50]
Extra years to 95% selected (east & west)	2	U[1, 35]
Age-based selectivity - acoustic survey		
Age at 50% selected (east & west)	2	U[1, 50]
Extra years to 95% selected (east & west)	2	U[1, 35]
Von Bertalanffy parameters*		
L_∞	2	U[30, 60 cm]
c.v. of length-at-age distribution*	2	U[0, 0.3]
c.v. of proportion of year 1 fish going to the west	1	U[0, 1]
Process errors		
Commercial length data	2	U[0,1.5]
Acoustic length data (east)	1	U[0,1.5]

Table 13: Parameters for which correlations and posterior distributions are given: parameter codes and descriptions.

Code	Description
B_0	Mature virgin biomass
R2W	Proportion of year 1 recruits moving to the west
L_f	Length-at-infinity, females
L_m	Length-at-infinity, males
cv_f	c.v. for female length-at-age distribution
cv_m	c.v. for male length-at-age distribution
WF.50	West fishery selectivity, age at 50% selection
WF.95	West fishery selectivity, ages from 50% to 95% selection
EF.50	East fishery selectivity, age at 50% selection
EF.95	East fishery selectivity, ages from 50% to 95% selection
EA.50	East acoustic 2002 selectivity, age at 50% selection
EA.95	East acoustic 2002 selectivity, ages from 50% to 95% selection
WA.50	West acoustic 2002 selectivity, age at 50% selection
WA.95	West acoustic 2002 selectivity, ages from 50% to 95% selection

3.9 Projections

No projections were performed because of the uncertainty associated with this assessment.

3.10 Biomass, yields, current surplus production

Biomass was estimated as the median of the posterior distributions. For all the yield calculations, a fixed catch split between east and west was used that was estimated from the catch data from 1996–97 to 2000–01. The split was 29% for the west and 71% from the east.

Estimation of Maximum Constant Yield (MCY)

The method of Francis (1992), extended by Bull et al. (2002), was used.

Estimation of Current Annual Yield (CAY)

CAY was estimated using the methods given by Francis (1992), extended by Bull et al. (2002).

Estimation of Current Surplus Production (CSP)

The CSP was estimated by finding a catch for the current year that kept vulnerable biomass the same at the start of the subsequent year.

4. RESULTS

4.1 MPD results

The MPD parameter estimates and run details are listed in Tables 14 and 15. Estimating growth or M reduced the total log-likelihood very significantly (Table 14), with a change of more than 170 units

Table 14: Run summary: MPD fits. Run 1 – fixed growth and mortality, no migration from east to west. Run 2 (base case, bold) – growth estimated by the model, mortality fixed, no migration from east to west. Run 3 – mortality estimated by the model, growth fixed, no migration from east to west. Run 4 - growth estimated by the model, mortality fixed, migration from east to west. – , not applicable.

	Run 1	**Run 2**	Run 3	Run 4
(a) Estimated parameters				
Virgin biomass (t)	115 000	**165 000**	137 000	154 000
L_∞_female (cm)	–	**47.26**	–	47.19
L_∞_male (cm)	–	**41.08**	–	41.04
c.v. L_∞ female	–	**0.1**	–	0.1
c.v. L_∞ male	–	**0.1**	–	0.1
Natural mortality	–	–	0.13	–
Selectivity (years):				
West fishery, age at 50% selection	22.08	**26.04**	21.13	26.71
West fishery, ages 50–95% selection	0.26	**0.1**	0.1	0.1
East fishery, age at 50% selection	18.31	**24.72**	22.5	25.18
East fishery, ages 50–95% selection	0.1	**5.67**	4.13	5.24
East acoustic, age at 50% selection	7.59	**8.45**	11.1	9.81
East acoustic, ages 50–95% selection	0.1	**0.17**	3.95	2.42
West acoustic, age at 50% selection	19.32	**22.68**	19.05	–
West acoustic, ages 50–95% selection	0.1	**0.1**	0.28	–
Migration, east to west (double normal capped ogive, see Bull et al. 2002, p. 41):				
a_1 – age at maximum selectivity (years)	–	–	–	22.75
S_L – S.D of left hand limb	–	–	–	0.1
S_R– S.D of right hand limb	–	–	–	0.36
a_{max} – maximum selectivity at a_1	–	–	–	0.39
Proportion recruited to West	0.31	**0.26**	0.25	–
C.v of process error for length frequencies:				
East acoustic survey	1.17	**0.9**	0.67	0.79
West acoustic survey	0.02	**0.02**	0.02	0.01
East fishery (observer)	0.85	**0.49**	0.47	0.49
West fishery (observer)	0.68	**0.58**	0.88	0.58
(b) Log-likelihoods for data sets				
East acoustic abundance	18	**2.2**	-1.8	2.2
West acoustic abundance	22.7	**11.8**	2.5	11.8
East (bycatch) post-GPS CPUE	-10.1	**-10**	-9.8	-10.1
West (target) post-GPS CPUE	1.2	**-3.1**	-6.2	-2.6
West (target) pre-GPS CPUE	-3	**-4.5**	-6.5	-4.4
East acoustic survey length frequency	37.2	**27.2**	18.6	23.3
West acoustic survey length frequency	110.6	**96.5**	137.8	98.3
East fishery (observer) length frequency	197.7	**66.8**	43.3	65.5
West fishery (observer) length frequency	111.5	**104.4**	136.1	104.4
West fishery catch penalty	11.7	**12**	11.8	11.9
East fishery catch penalty	0	**0**	0	0
Prior on B_0	0	**0**	0	0
Prior on natural mortality	–	–	0	–
Total	497.4	**303.2**	328.6	300.5

Table 15: Run summary: MPD fits. Run 1 – fixed growth and mortality, no migration from east to west. Run 2 (base case, bold) – growth estimated by the model, mortality fixed, no migration from east to west. Run 3 – mortality estimated by the model, growth fixed, no migration from east to west. Run 4 - growth estimated by the model, mortality fixed, migration from east to west. – , not applicable.

Biomass estimates				
Mid-year, mature				
B_0	111 000	**159 000**	128 000	148 000
B_{2002}	35 900	**83 400**	82 700	73 000
B_{2002}/B_0	32%	**53%**	64%	49%
Mid-year, mature_W				
B_0	33 700	**41 000**	32 000	36 900
B_{2002}	4 640	**12 200**	16 700	7 790
B_{2002}/B_0	14%	**30%**	52%	21%
Mid-year, mature_E				
B_0	77 600	**118 000**	96 400	111 000
B_{2002}	31 300	**71 200**	66 000	65 200
B_{2002}/B_0	40%	**60%**	68%	59%
Mid-year, vulnerable				
B_0	121 000	**138 000**	114 000	127 000
B_{2002}	39 900	**62 600**	65 500	51 800
B_{2002}/B_0	33%	**45%**	58%	41%
Mid-year, vulnerable_W				
B_0	33 100	**33 800**	29 900	33 600
B_{2002}	2 160	**4 470**	13 200	4 120
B_{2002}/B_0	7%	**13%**	44%	12%
Mid-year, vulnerable_E				
B_0	87 600	**104 000**	83 900	93 600
B_{2002}	37 700	**58 100**	52 300	47 700
B_{2002}/B_0	43%	**56%**	62%	51%

for only four extra parameters (growth) or one extra parameter (M). Most of this change was associated with the east observer length frequency data. Estimating growth or M also increased the estimate of B_0 and made the assessment more optimistic, in terms of the current biomass relative to the virgin state (Table 15). Estimating growth also influenced the age distribution and therefore changed the selectivities (length/age), e.g., for the east fishery the age at 50% selection increased from 18 to 25 years.

The east abundance data fitted the model except for the 2001 acoustic abundance which was above the biomass trajectory (Figure 11). The west acoustic abundance data did not fit the model well (Figure 11). The acoustic survey and observer length frequency data fits were mostly poor at the peak of the distributions, with the model acoustic length frequency systematically to the left of the observed distribution on the left hand limb (Figure 12). The Q-Q normal plots of the residuals (Figures 13–16) are approximately standard normal (as they are assumed to be in the model) with the exception of the west acoustic length frequency (Figure. 16). The latter is normal shaped over most of it's range but the model wanted to increase the process error (fixed at 0.015). Fits and Q-Q normal plots to annual observer length frequencies are given in Appendix B.

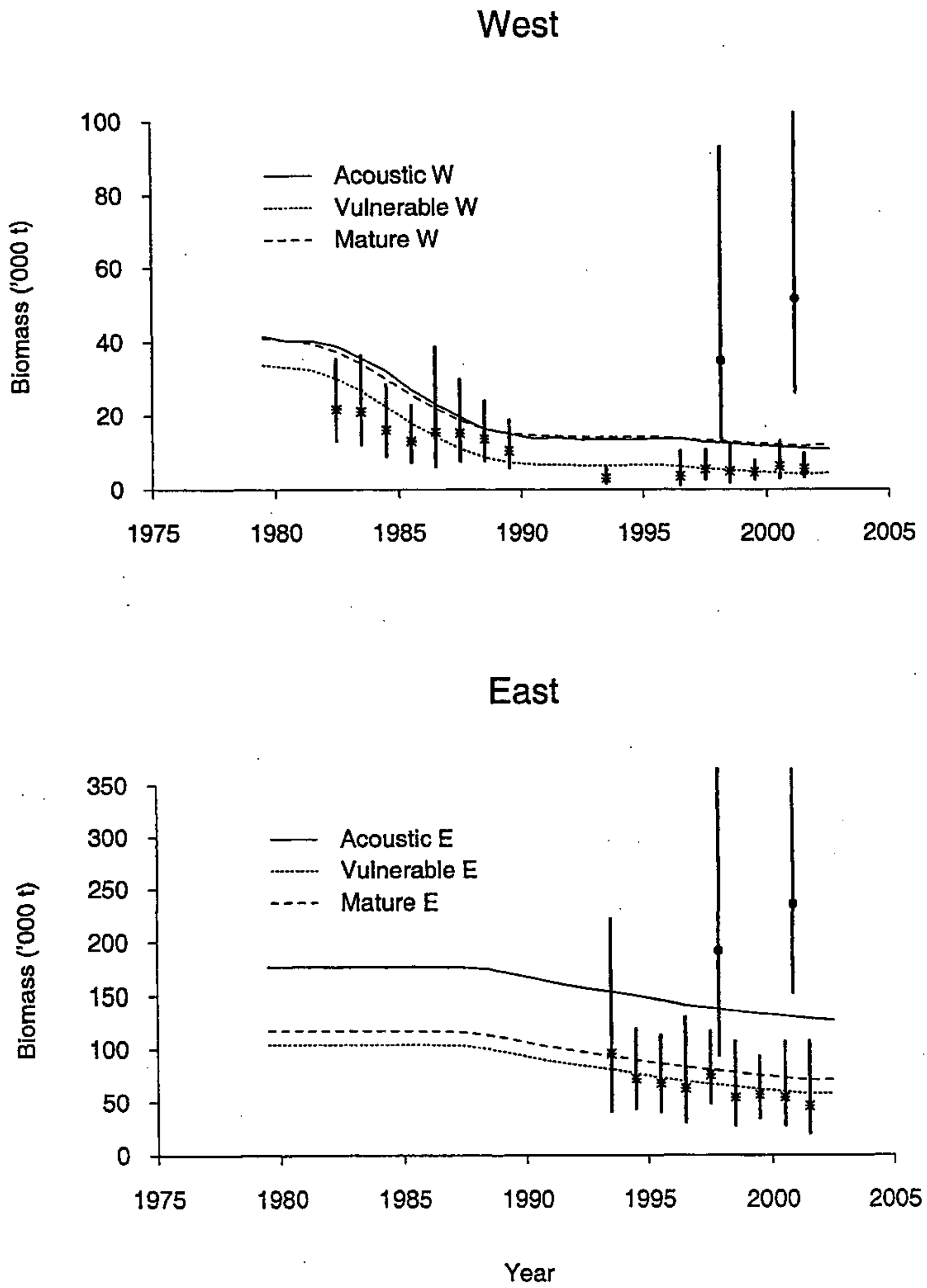

Figure 11: Fits of the abundance data in the base case. Black dots are the acoustic (absolute) estimates. Asterisks are the CPUE indices scaled by catchabilities to abundance. Curved lines are the model estimates of biomass (t). Vertical error bars for acoustic and CPUE estimates are ± 2 S.D.

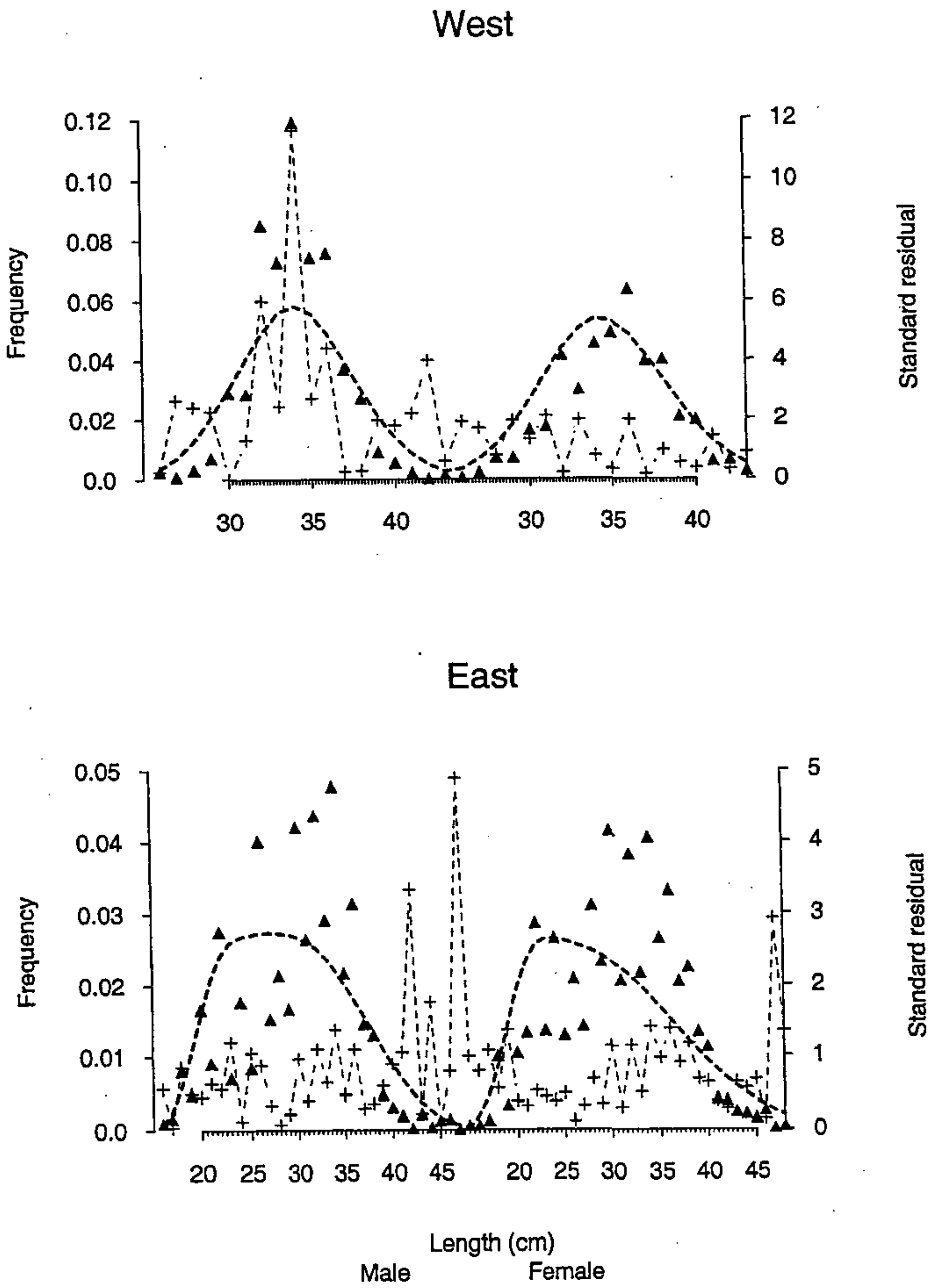

Figure 12: Model fits (dashed line) of the 2001 acoustic length frequency data (triangles) in the base case, males on the left and females on the right. The right-hand axis shows a plot of normalised residuals (crosses) averaged as absolute values across years.

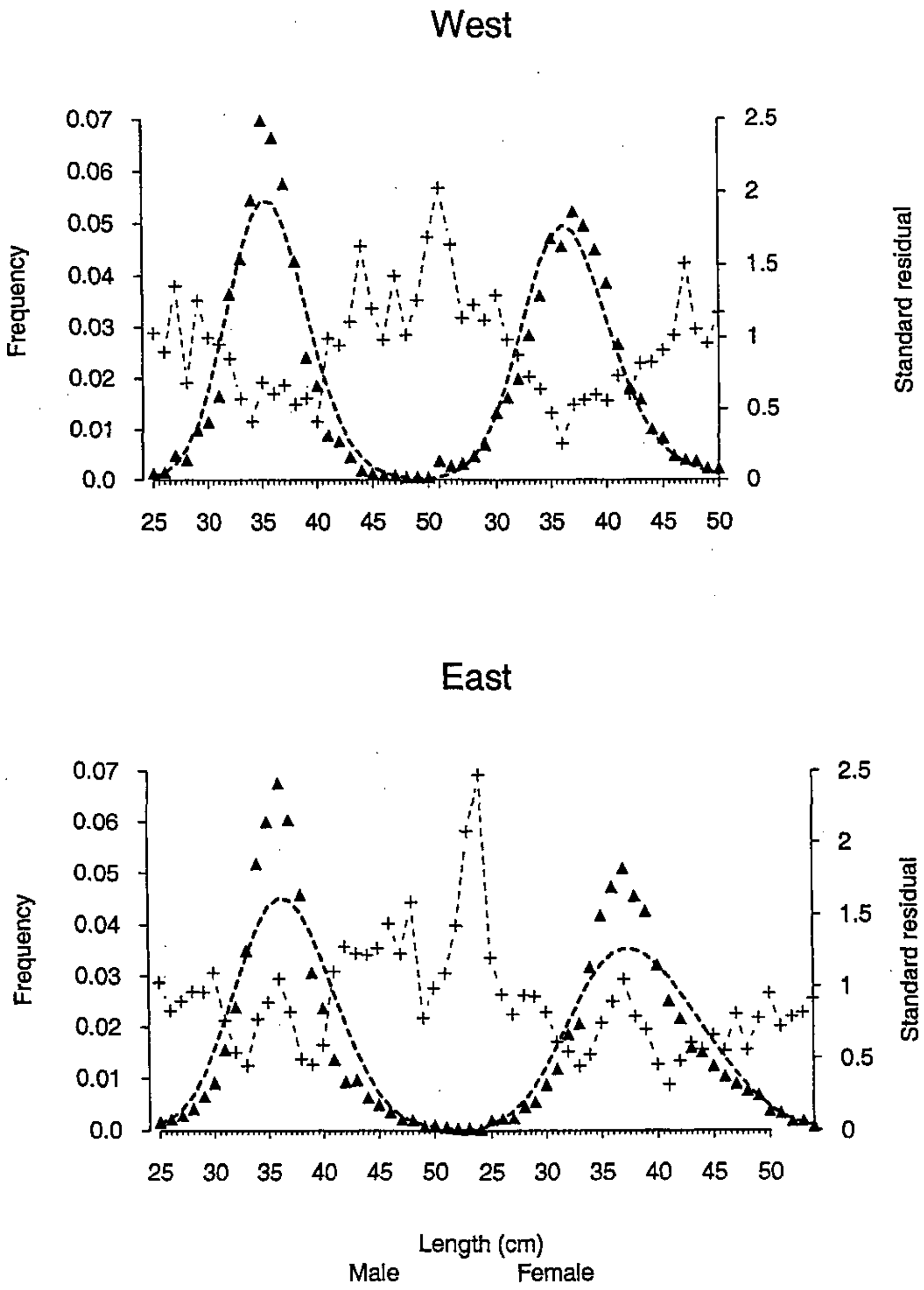

Figure 13: Fits of the composite observer length frequency data (triangles) in the base case, males on the left and females on the right. The composite length frequency distribution (dashed line) was generated by averaging the model length frequency data across years. The right hand axis shows a plot of normalised residuals (crosses) averaged as absolute values across years.

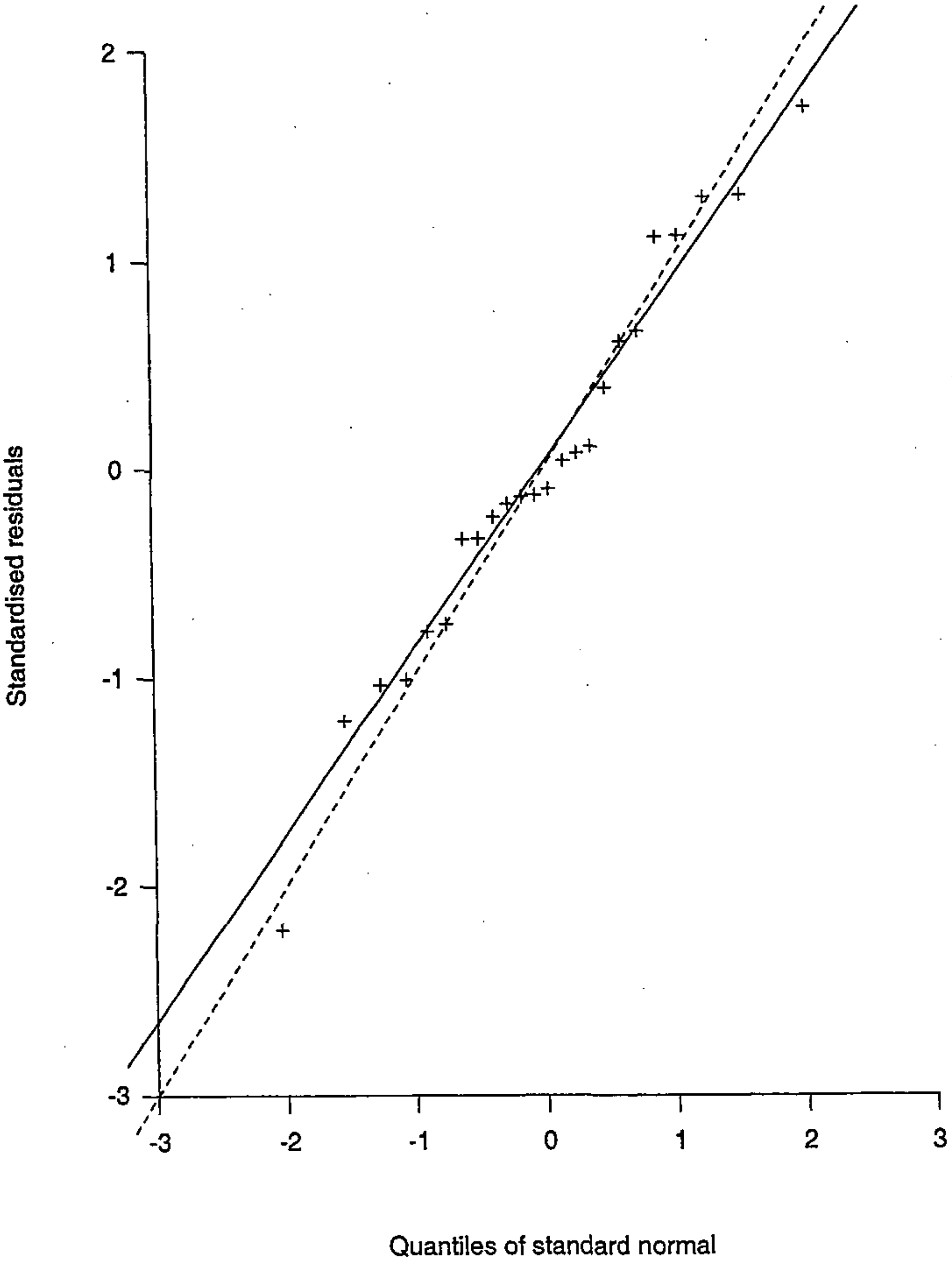

Figure 14: Q-Q normal plots for all the normalised residuals (crosses) from the three CPUE indices. The dashed line is the 1:1 line and the solid line is the regression line estimated from the residual points between –1 and 1 on the x-axis.

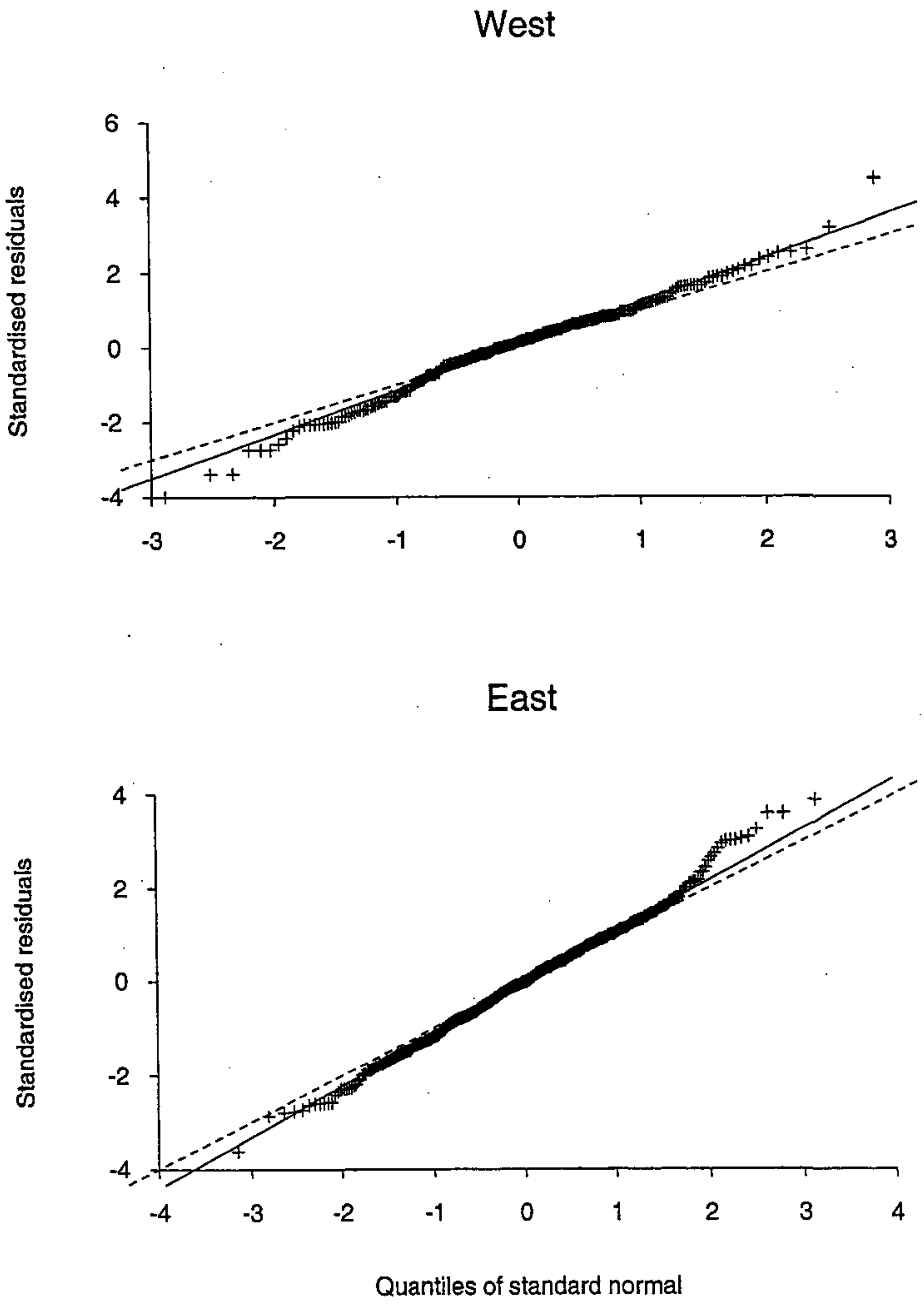

Figure 15: Q-Q normal plots for all the observer length frequency normalised residuals (crosses). The dashed line is the 1:1 line and the solid line is the regression line estimated from the residual points between –1 and 1 on the x-axis.

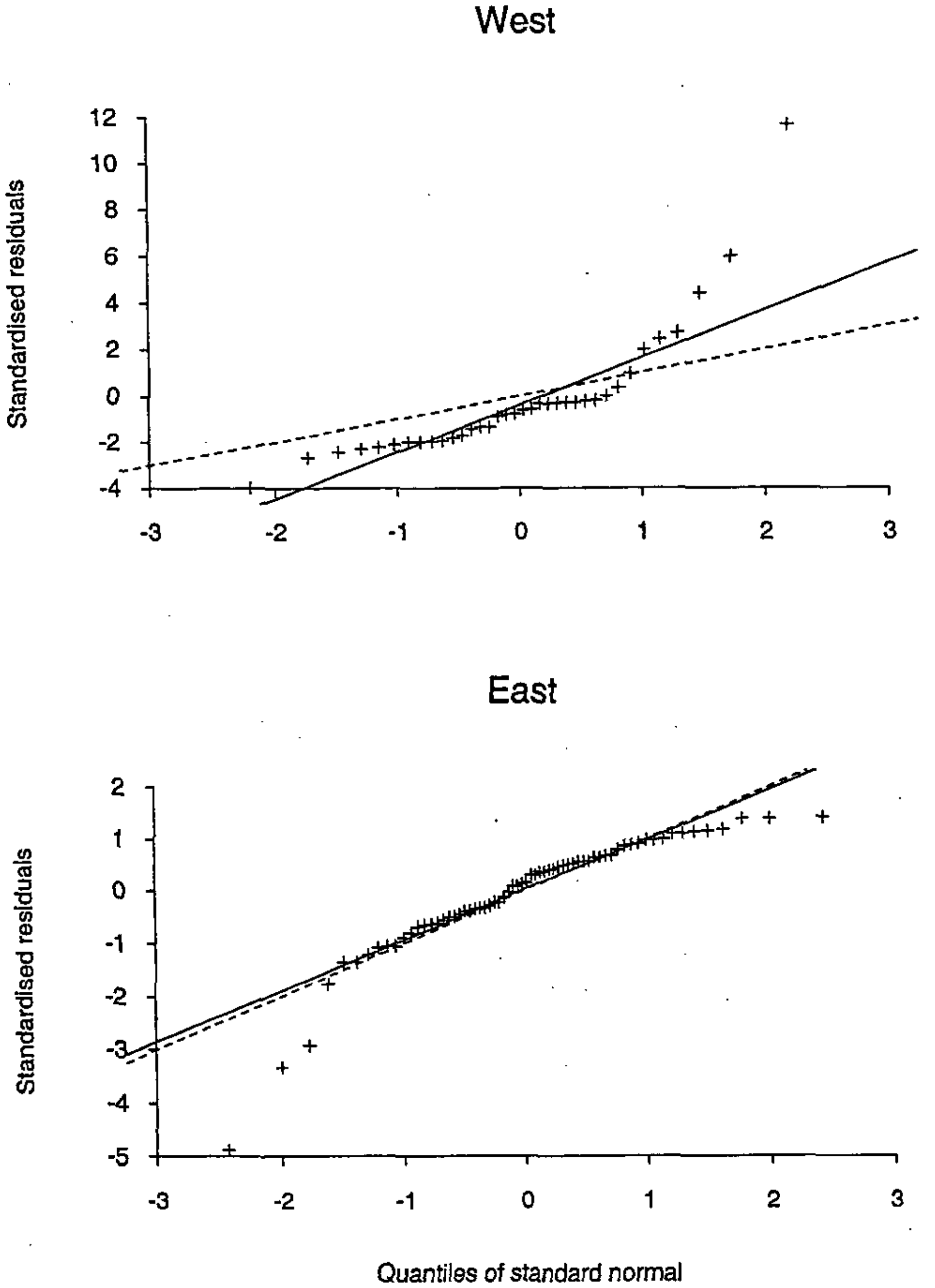

Figure 16: Q-Q normal plots for all the 2001 acoustic length frequency data normalised residuals (crosses). The dashed line is the 1:1 line and the solid line is the regression line estimated from the residual points between –1 and 1 on the x-axis.

4.2 Bayesian estimates

Convergence diagnostics were run on a chain of final length 3886 x 10^3, after a burn-in of 300 x 10^3 iterations, after systematically subsampling every 1000th sample. Autocorrelations and single chain convergence tests of Geweke (1992) and Heidelberger & Welch (1983) were applied to the resulting chain to determine non-convergence. The tests used a significance level of 0.05 and the diagnostics were calculated using the Bayesian Analysis Output software (Smith, B.J., 2001. Bayesian output analysis program. Version 1.00 user's manual. Unpublished manuscript. 45 p. University of Iowa College of Public Health. http://www.public-health.uiowa.edu/boa). Table 16 shows that the MCMC runs converged.

Table 16: Convergence tests carried out on the MCMC chain. See Table 13 for parameter codes and description.

	Heidleberger and Welch test		Geweke test
Parameter	Stationarity	Halfwidth	P value
B_0	Passed	Passed	0.05
R2W	Passed	Passed	0.04
L_f	Passed	Passed	0.63
L_m	Passed	Passed	0.74
cv_f	Passed	Passed	0.62
cv_m	Passed	Passed	0.20
WF.50	Passed	Passed	0.42
WF.95	Passed	Passed	0.36
EF.50	Passed	Passed	0.73
EF.95	Passed	Passed	0.40
EA.50	Passed	Passed	0.90
EA.95	Passed	Passed	0.67
WA.50	Passed	Passed	0.54
WA.95	Passed	Passed	0.48

Bayesian estimates were therefore based on the median of a 3886 long MCMC. The MCMC runs did not estimate the process error of the length data so these were fixed at the MPD estimates. Table 17 shows that the summarised posterior distributions and most parameters had low c.v.s, i.e., 11% or less. The parameters that did not have a low c.v. included all the selectivity parameters of the extra age from 50% to reach 95% selection. Three of these had large c.v.s (greater than 60%) but median value ranges were small, 0.5–2 years, and these low values suggest almost knife-edge selectivities.

Table 17: Bayesian estimates: summary statistics of the posterior distributions for the base case. See Table 13 for parameter codes and description.

	5% quartile	Median	Mean	95% quartile	c.v. (%)
B_0	147 000	172 000	173 000	209 000	11
R2W	0.21	0.25	0.26	0.30	10
L_f	46.41	46.96	46.97	47.49	1
L_m	40.54	40.88	40.88	41.20	0
cv_f	0.09	0.10	0.10	0.11	3
cv_m	0.09	0.10	0.10	0.10	2
WF.50	25.85	27.14	27.16	28.56	3
WF.95	0.20	1.34	1.61	4.05	77
EF.50	23.60	25.19	25.21	26.88	4
EF.95	3.33	5.65	5.50	7.03	22
EA.50	8.27	9.25	9.35	10.74	7
EA.95	0.34	1.99	2.20	4.60	63
WA.50	22.20	23.04	23.04	23.86	2
WA.95	0.14	0.53	0.62	1.37	64

There were some strong correlations between the proportion of year 1 recruits moving to the west (R2W) and mature virgin biomass (B_0), female and male L_∞ (L_f & L_m), the c.v. for female and male length-at-age distributions (cv_f & cv_m), the two east fishery selectivity parameters (EF.50 &

EF.95), and the two east acoustic selectivity parameters (EA.50 & EA.95), Appendix C, Figure C1. Plots of posterior distributions for the base case model results using 500 samples of the MCMC chain are shown in Appendix C, Figures C2–C5. The posterior distributions all had relatively low variation

The distributions for the current mature biomass and the current vulnerable biomass as a percentage of virgin biomass (Figure 17) are approximately symmetrical.

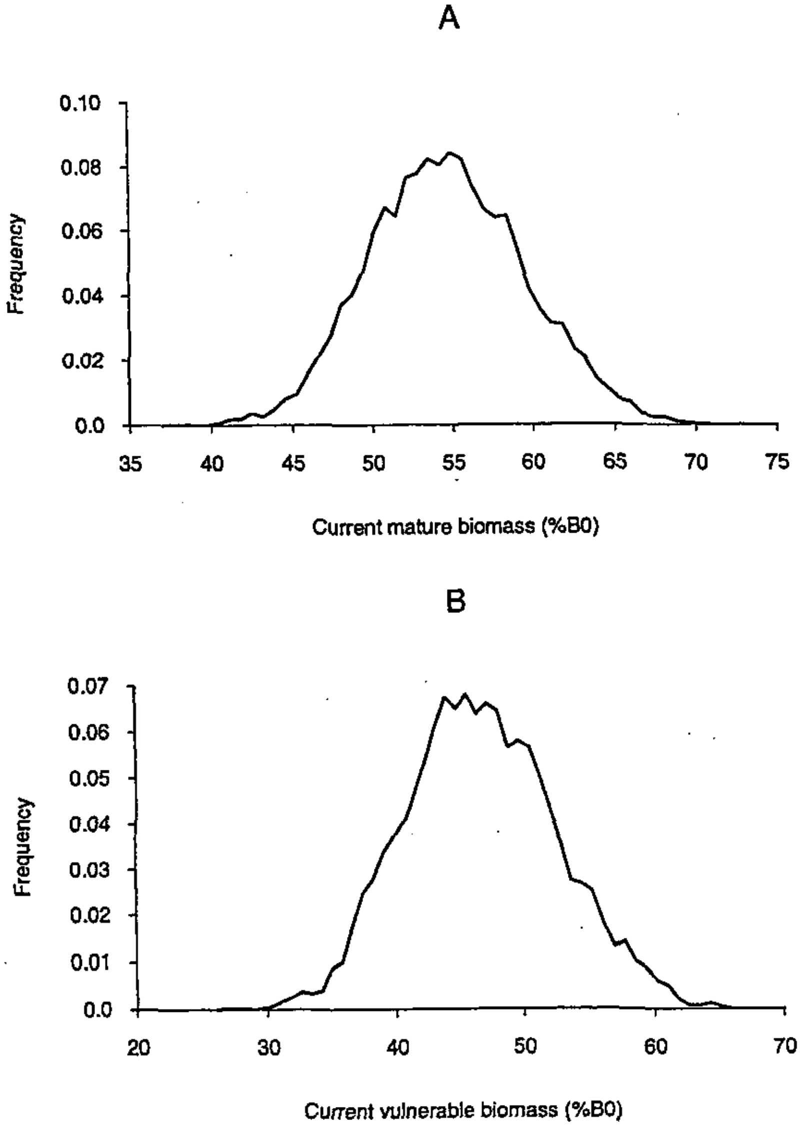

Figure 17: Posterior distribution of the derived parameters: current mature biomass as a percentage of the virgin biomass (A) and current vulnerable biomass as a percentage of the virgin biomass (B).

4.3 Parameter uncertainty

The very small spreads (range) in the posterior distributions suggest a very precise analysis, and this conclusion is in contrast to the fit achieved in the model. This implies that there is enough data used in the analysis, given the error structure, to give a precise solution. However, the solution is a compromise between the competing data sets that on their own would give different solutions. These data conflicts are expressed through the poor fits, especially for the west data. The ability of the model to find a compromise solution is expressed through the small spreads in the posterior distribution.

4.4 Interpretation of uncertainty

Sampling error and the quantity of data are not a problem in this analysis, but there are large potential biases in the data that could shift the assessment substantially. These include: using deterministic recruitment, the large proportion of the total acoustic abundance found in the layer marks, using a linear relationship between standardised CPUE and abundance, and treating the acoustic abundance as an absolute value. In addition, the growth data, and perhaps the M data, are in conflict with the observer length frequency data and this conflict was dealt with by estimating growth within the model. This is not a satisfactory solution and further work is required (outside the time frame for this study) to investigate the precise reason for the conflict. The error in the estimate of M was not incorporated into the model although it potentially could be since the M estimate had a c.v. of 25% (Doonan et al. 1997b).

4.5 Biomass, yields, current surplus production

The estimates of biomass and yield from the base case analysis were dominated by the acoustic absolute abundance estimates and observer length data. The biomass estimates are given in Table 18.

Table 18: Biomass, yield, and Current Surplus Production (CSP) estimates (t). –, not estimated or na.

(a) Biomass estimates			
OEO 4	Median	90% C.I.	% mid-year OEO 4 B_0
Mature virgin	172 000	147 000–209 000	–
Mature 2001–02 mid-year	90 400	67 000–127 000	55
Vulnerable virgin	140 000	119 000–174 000	–
Vulnerable 2001–02 mid-year	65 100	44 500–98 200	46
	Mean	% mid-year OEO 4 B_0	
B_{MCY}	†37 000	34	
B_{MAY}	†23 000	21	
† mid-year vulnerable biomass.			
East			% mid-year east B_0
Mature 2001–02 mid-year	77 000	54 300–113 000	62
Vulnerable 2001–02 mid-year	60 700	39 900–93 400	57
West			% mid-year west B_0
Mature 2001–02 mid-year	13 300	11 700–15 400	32
Vulnerable 2001–02 mid-year	4 390	3 390–5 500	13
(b) Yield estimates			
	Mean		
$MCY_{long\text{-}term}$	4 200		
CAY	7 700		
(c) CSP estimate			
CSP	3 500		

Estimation of Maximum Constant Yield (MCY)

The B_{MCY} estimate was 34% of vulnerable B_0. Base case estimates using vulnerable biomass are in

Table 18.

Estimation of Current Annual Yield (CAY)

Estimates are summarised in Table 18. B_{MAY} is 21% of vulnerable B_0. F_{CAY}, the maximum constant fishing exploitation rate (F) that can be applied to the vulnerable population (without reducing the mature population below 20% B_0 more than 10% of the time), for a population with the life history parameters as in Table 11 is 0.081. The mean catch when fishing at F = 0.081 was 4100 t.

Estimation of Current Surplus Production (CSP)

The CSP estimate was 3500 t (Table 18) and was the catch that ensured that the vulnerable biomass at the end of the 2002–03 fishing year was the same as the mature biomass at the end of 2001–02.

5. DISCUSSION AND CONCLUSIONS

The smooth oreo biomass estimates from the base case analysis for the whole of OEO 4 (median mature 2001–02 mid-year biomass of 90 400 t, 55% of B_0) and yield estimates from the base case ($MCY_{long-term}$ of 4200 t) suggest that an annual catch of 4284 t (mean catch in OEO 4 from 2001–02) is sustainable. But there are problems with some of the inputs to this assessment that require further work (beyond the scope of this project). The main concern is the use of the two acoustic survey abundance estimates as absolute values. The assumption that the acoustic estimates were unbiased absolute estimates is a difficult one to test. A large proportion of the smooth oreo acoustic abundance from both the 1998 and 2001 surveys (about 70%) came from the layer mark-type, but layers are not normally fished by the commercial fleet. The model does not "know" this and uses a selectivity to partition the population into unfished and fished parts. The selectivity is based on the observer length distribution and that distribution overlaps with part of the layer length distribution and so some layer abundance can be allocated to the fished part of the abundance. The acoustic estimate from layer mark-types may be biased high because small fish were not sampled in the trawl catches resulting in an overestimate of the proportion of smooth oreo in the mix of species found in layers. The relative catchabilities of other species is also unknown, but are assumed to be the same as that for smooth oreo. In contrast, school marks are fished by the commercial fleet, the composition of smooth oreo in these schools is high, and there is more confidence that the estimated acoustic abundance for the school mark-type is unbiased.

Growth or natural mortality (M) had to be estimated within the model in order to fit the available data, particularly to fit the commercial and acoustic length frequency data. This result implies that these data are inconsistent with the estimate of M derived from the ageing data or with the growth rate estimates obtained from the age-length data (Doonan et al. 1997b). It is possible that either the age-length data or the commercial length frequency data are biased, but it is not possible to determine which data set is incorrect within this project. Alternatively there could be a mis-specification in the structure or assumptions of the assessment model. An example of the latter might be migration of fish to an area outside the area considered by the model.

Model biomass estimates have extra uncertainty from a number of other factors that are outside the model and the analyses, including the sensitivity to the target strength of smooth oreo and the use of deterministic recruitment Another uncertainty is that the east and west areas may have behaved differently, i.e., the west area mid-year (2001–02) mature biomass was 32% B_0 while the east area was 62% B_0. Vulnerable biomass from the west was 13% west B_0, below the 21% ratio of B_{MAY} for OEO 4, while the east estimate was 57% east B_0 and much greater than the 34% ratio of B_{MCY} for OEO 4 and suggests that the effects of fishing weren't spatially uniform along the Chatham Rise.

Some conclusions can be drawn from this assessment.

- A smooth oreo catch of about 4200 t may be sustainable in OEO 4, but that conclusion depends on the key assumption that the acoustic abundance values from the 1998 and 2001 surveys are unbiased estimates of absolute abundance. That assumption was questioned because of the large amount of acoustic abundance attributed to the layer mark-type in both surveys.

- In future it may be better to consider the acoustic estimates as relative abundance, but this depends on having a series of acoustic estimates, so it is essential to continue to build a series of OEO 4 smooth oreo acoustic estimates over time.
- Poor model fits required M or growth to be estimated within the model. This suggests that these parameters should be re-estimated experimentally in the future to corroborate or otherwise the earlier estimates.

6. ACKNOWLEDGMENTS

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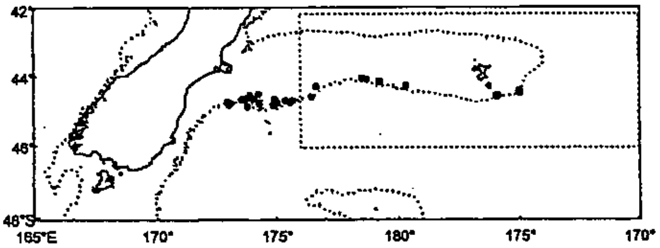
APPENDIX A

Analysis of the maturity of smooth oreo

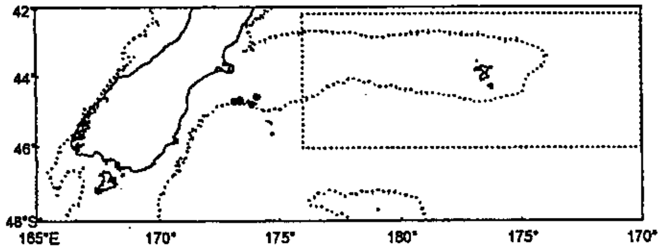
Allan Hicks, Ian Doonan, Peter McMillan

The data used are the aged smooth oreo data from six trawl surveys. The positions of the stations from which fish were sampled in each trawl survey are plotted below.

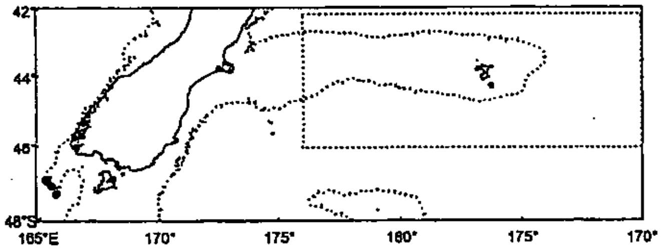
cor9004



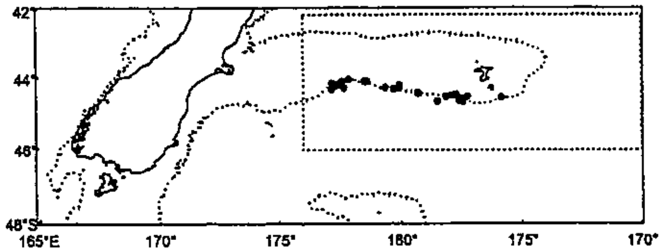
jco8417



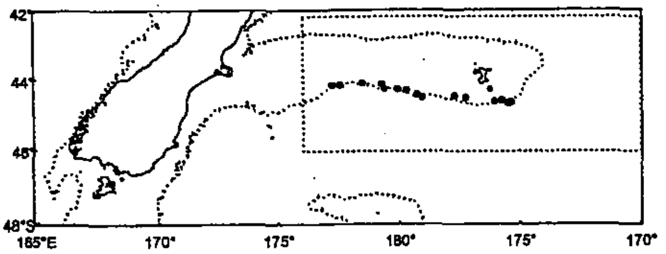
tan9208



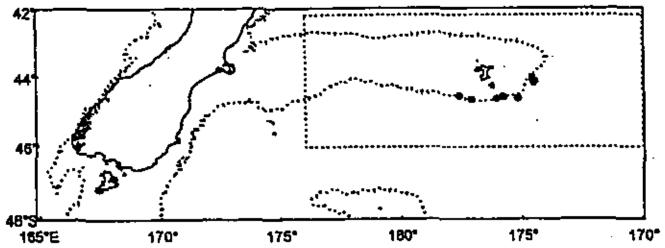
tan9210



tan9309



tan9406

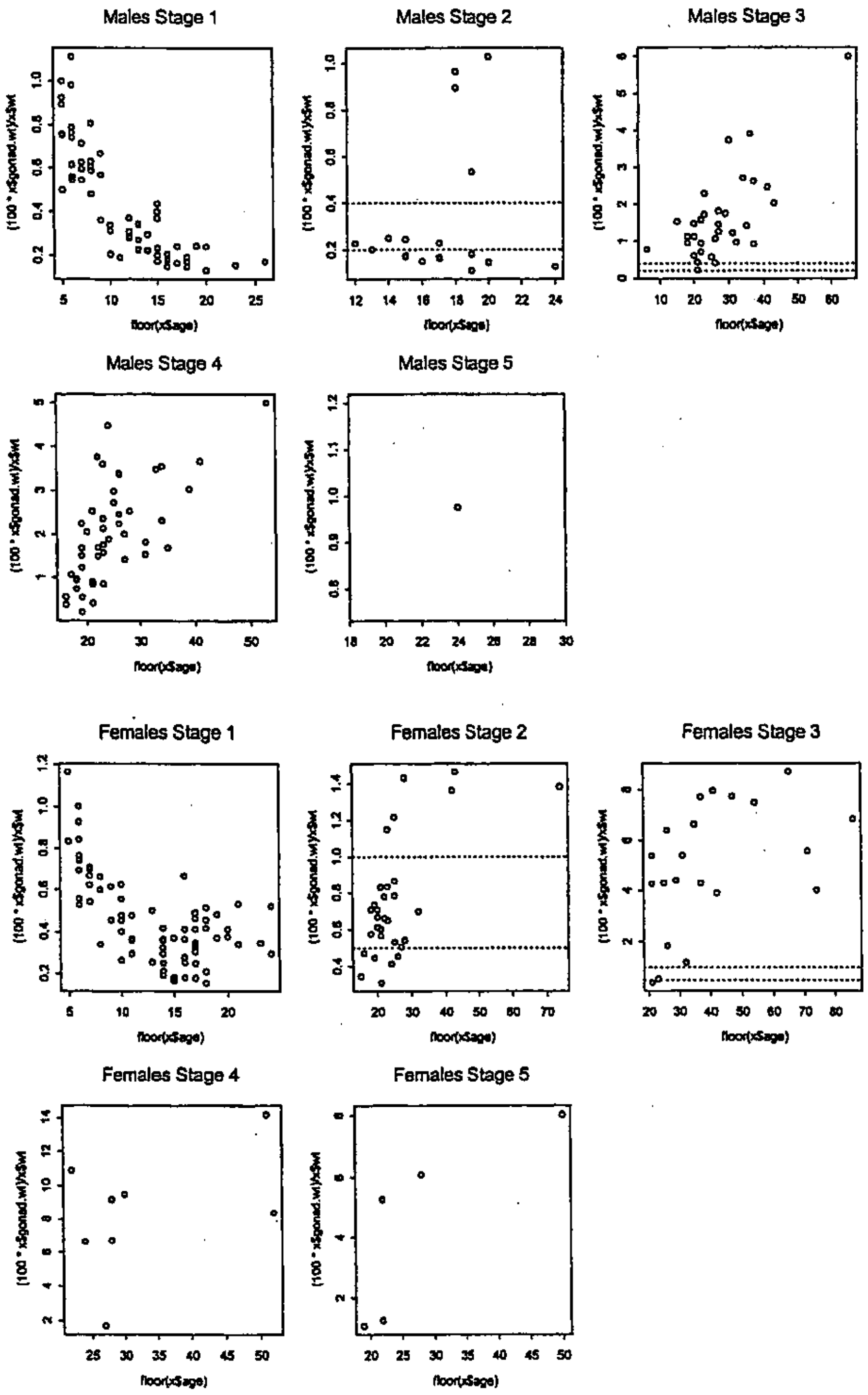


Survey TAN9208 was done at Puysegur and was excluded from this analysis because the stock assessment is for OEO 4 on the Chatham Rise, the survey was done in the early spawning season (August/September), and initial analyses of the Puysegur data indicate that there are differences when compared to the Chatham Rise data. Survey TAN9406 was also excluded because it occurred outside the spawning season (was in May, June, July). Therefore, four surveys were used: COR9004, JCO8417, TAN9210, and TAN9309.

CHATHAM RISE SSO MATURITY ANALYSIS

A glm with the logit link was used to fit the proportion mature at age. Ageing error was not assessed. Both sexes were analysed to determine if one maturity ogive could be used, or if significant differences occur.

Because stages 2 and 3 may not indicate mature or immature fish (some error of classification), the gonad somatic index (GSI) was used to classify fish as mature or immature when called stage 2 or 3. GSI is the ratio of the gonad weight to the total fish weight times 100. Plots of the GSI vs. age were studied and a threshold was defined where observations above this line would be classified as mature and observations below as immature. The decision of a threshold was somewhat subjective, although a minimum GSI for older fish that were almost certainly mature was easily seen. A sensitivity analysis was carried out with a threshold GSI of half that of mature fish. All stage 1 fish were classified as immature and all stage 4 and 5 fish were classified as mature.



A GSI threshold of 0.4 for males and 1 for females was chosen based on the plots above. There were clear clusters of points above and below these thresholds, especially with the stage 2 fish. The thresholds classify few stage 3 fish as immature.

Using these thresholds and a indicator variable, the glm indicates that the slopes between the two lines are not significantly different, but the intercepts are. Males appear to mature earlier than females (Figure A1).

GLM RESULTS

```
                    Value Std. Error    t value
(Intercept) -9.89042367  1.9202236 -5.1506624
       ages  0.38968373  0.0812896  4.7937709
        sex  2.13272760  2.3301200  0.9152866
   ages:sex  0.03738302  0.1079672  0.3462443

    Null Deviance: 270.8059 on 78 degrees of freedom
Residual Deviance: 31.42039 on 75 degrees of freedom

Analysis of Deviance Table
Terms added sequentially (first to last)
         Df Deviance Resid. Df Resid. Dev   Pr(Chi)
    NULL                   78   270.8059
    ages  1 186.5539       77    84.2519 0.0000000
     sex  1  52.7143       76    31.5376 0.0000000
ages:sex  1   0.1172       75    31.4204 0.7320445
```

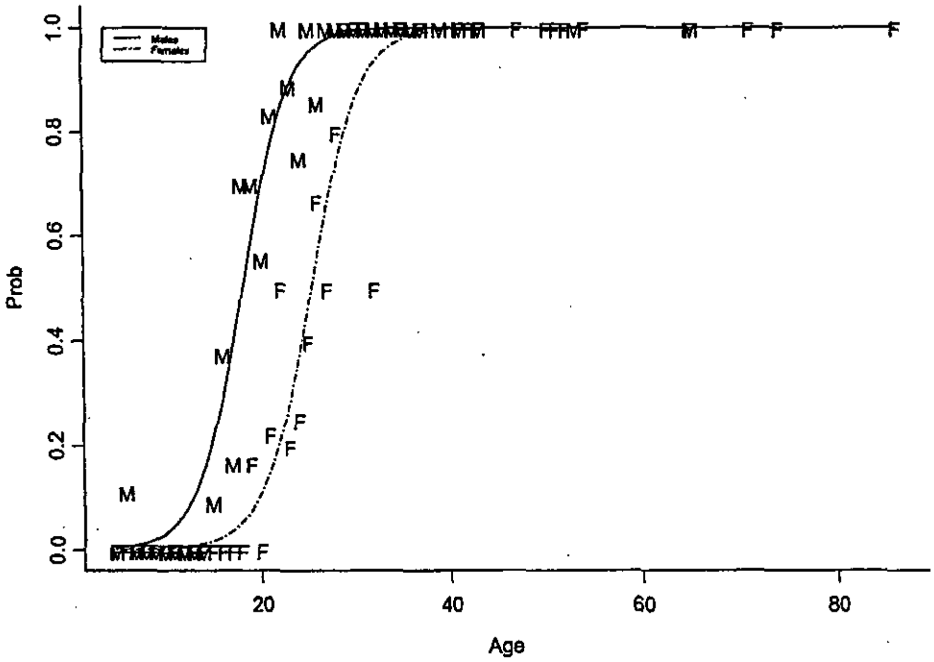


Figure A1: Plots of the observed and fitted points for male and female maturity data when using GSI thresholds of 0.4 and 1 for males and females, respectively.

The sensitivity to the threshold was assessed by halving the threshold for each sex to determine the difference in the estimated curve (Figure A2). The threshold was not increased since the values used above were the upper bounds of likely thresholds, judged by looking at the GSI plots. The lower threshold resulted in the curves shifting slightly to the left since more fish would be classified as mature. More difference was seen with the females since more stage 2 fish at young ages were classified as mature.

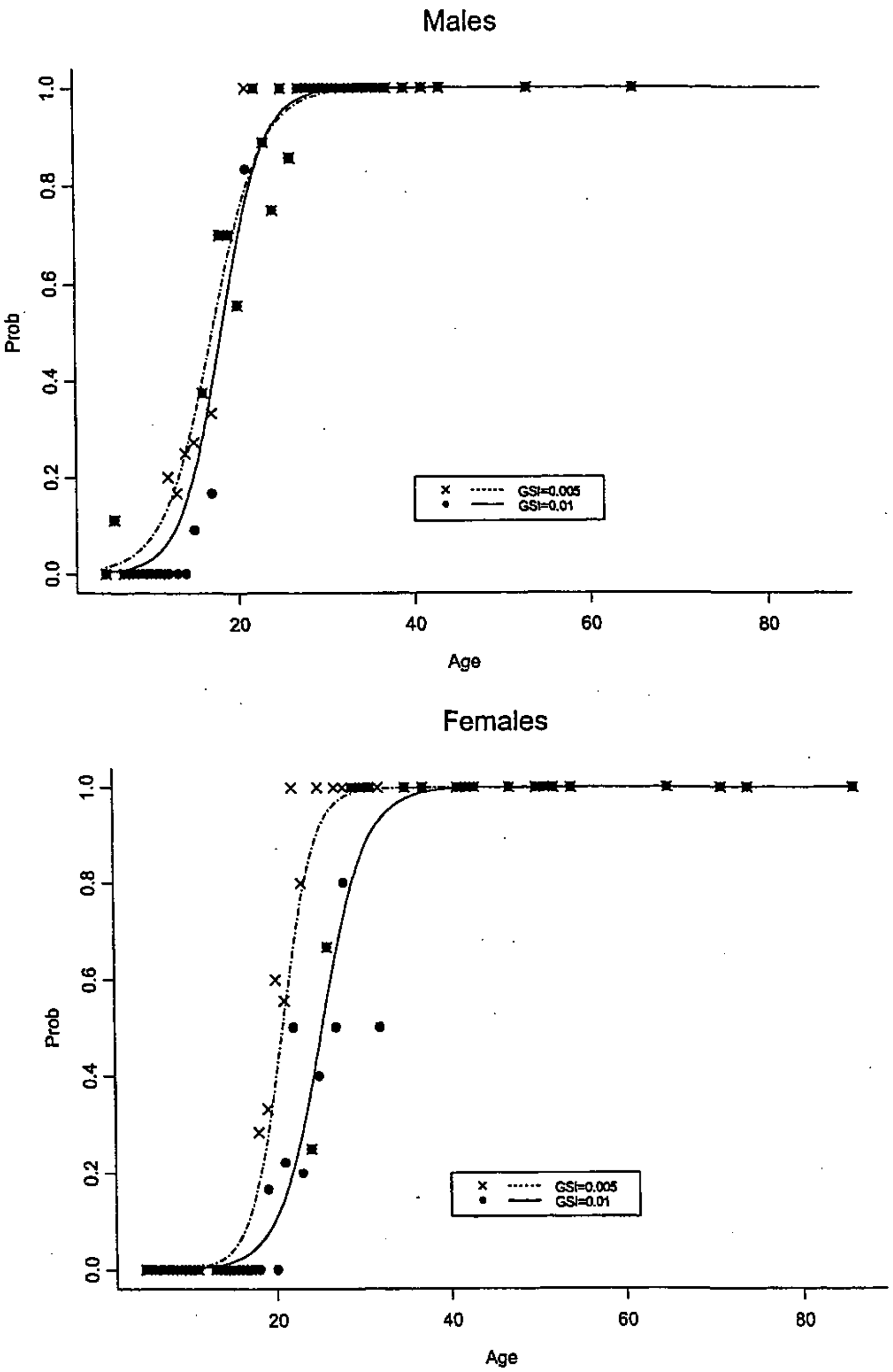


Figure A2: **Sensitivity plots for the threshold GSI values for males and females. maturity data when using GSI thresholds of 0.4 and 1 for males and females, respectively.**

The predicted probabilities of maturity for males and females at two different GSI thresholds for each sex are in Table A1.

Table A1: Predicted probabilities of maturity for males and females at two different GSI thresholds for each sex.

	Males		Females	
Age	GSI=0.4	GSI=0.2	GSI=1	GSI=0.5
5	0.00	0.01	0.00	0.00
6	0.01	0.02	0.00	0.00
7	0.01	0.03	0.00	0.00
8	0.01	0.04	0.00	0.00
9	0.02	0.05	0.00	0.00
10	0.03	0.07	0.00	0.00
11	0.04	0.10	0.00	0.00
12	0.07	0.14	0.01	0.01
13	0.10	0.19	0.01	0.01
14	0.14	0.25	0.01	0.02
15	0.21	0.32	0.02	0.04
16	0.28	0.40	0.03	0.07
17	0.38	0.49	0.04	0.11
18	0.48	0.58	0.05	0.18
19	0.59	0.66	0.08	0.28
20	0.69	0.73	0.11	0.40
21	0.77	0.80	0.15	0.53
22	0.84	0.85	0.21	0.66
23	0.89	0.89	0.28	0.77
24	0.92	0.92	0.37	0.85
25	0.95	0.94	0.46	0.91
26	0.97	0.96	0.56	0.94
27	0.98	0.97	0.65	0.97
28	0.99	0.98	0.74	0.98
29	0.99	0.98	0.80	0.99
30	0.99	0.99	0.86	0.99
31	1.00	0.99	0.90	1.00
32	1.00	0.99	0.93	1.00
33	1.00	1.00	0.95	1.00
34	1.00	1.00	0.97	1.00
35	1.00	1.00	0.98	1.00
36	1.00	1.00	0.98	1.00
37	1.00	1.00	0.99	1.00
38	1.00	1.00	0.99	1.00
39	1.00	1.00	1.00	1.00

Using the GSI thresholds of 0.4 and 1 for males and females, respectively are recommended. Therefore, the age at which 50% are mature would be between 18 and 19 for males and between 25 and 26 for females. This obviously means using sex specific maturity ogives.

APPENDIX B: Fits and Q-Q normal plots for each observer length frequency in the MPD base case.

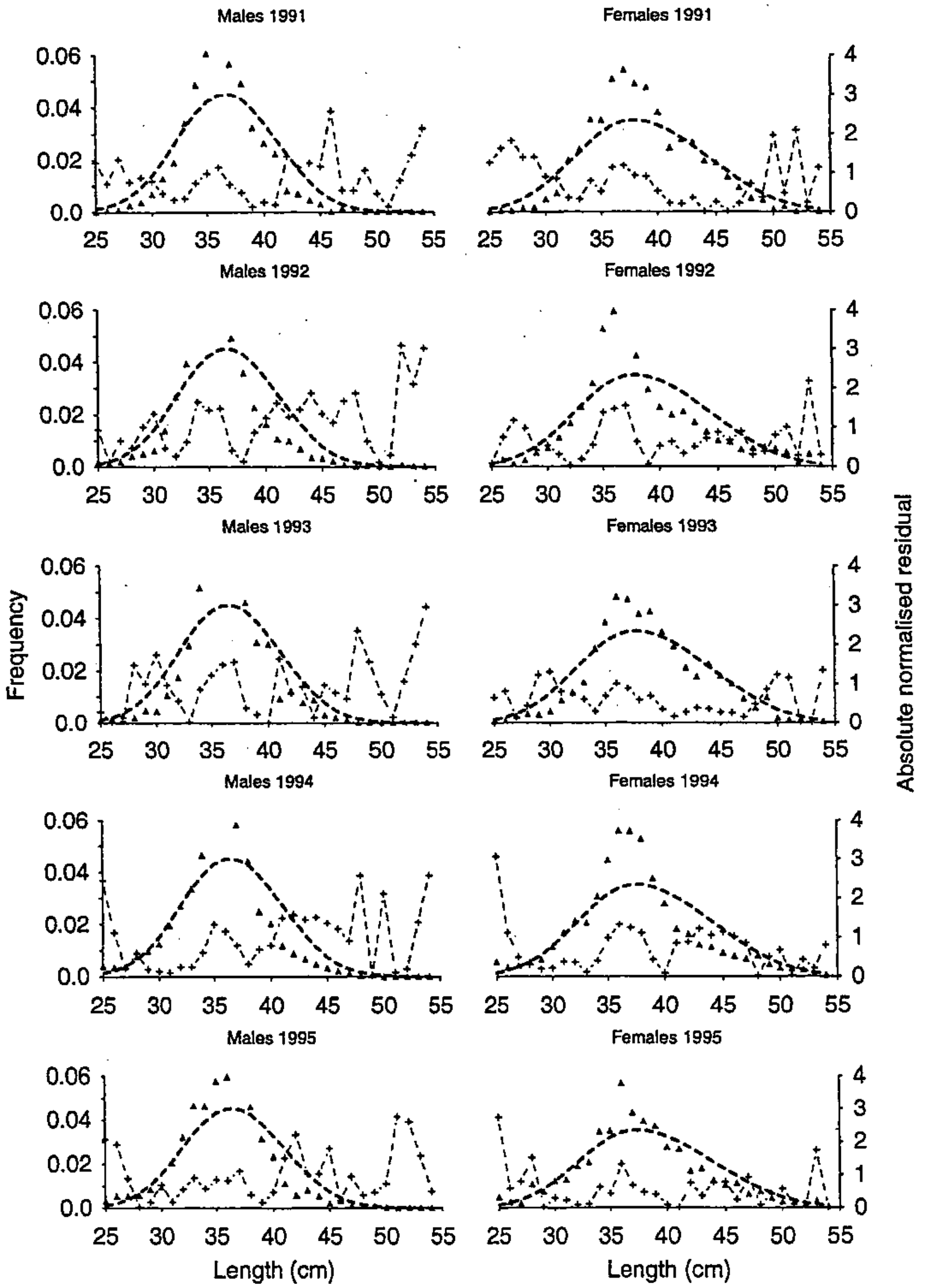


Figure B1: Annual east observer length frequency distributions (triangles) fitted to the model base case (dashed line). The right hand axis shows a plot of absolute normalised residuals (crosses).

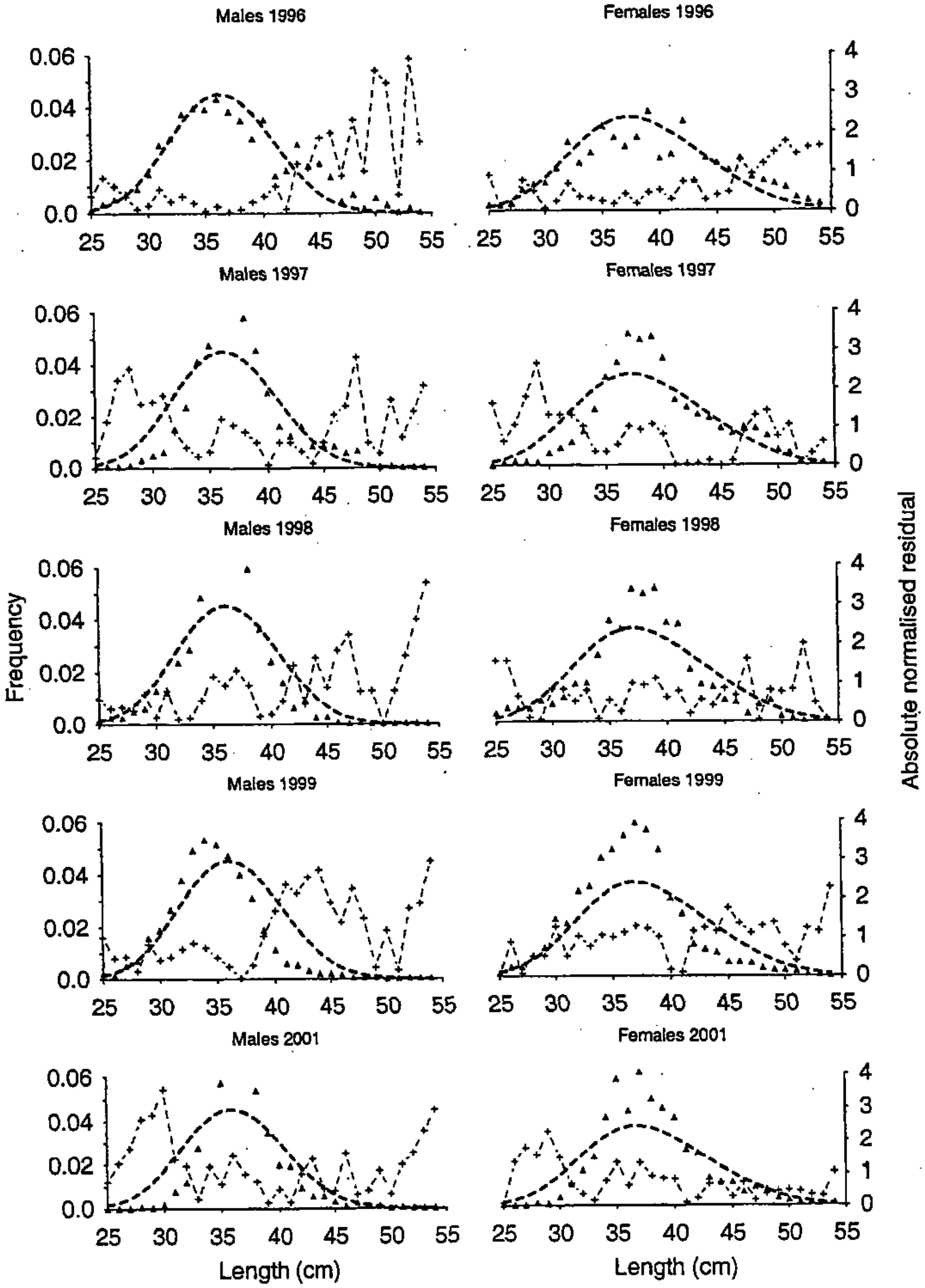


Figure B1 ctd: Annual east observer length frequency distributions fitted to the model base case.

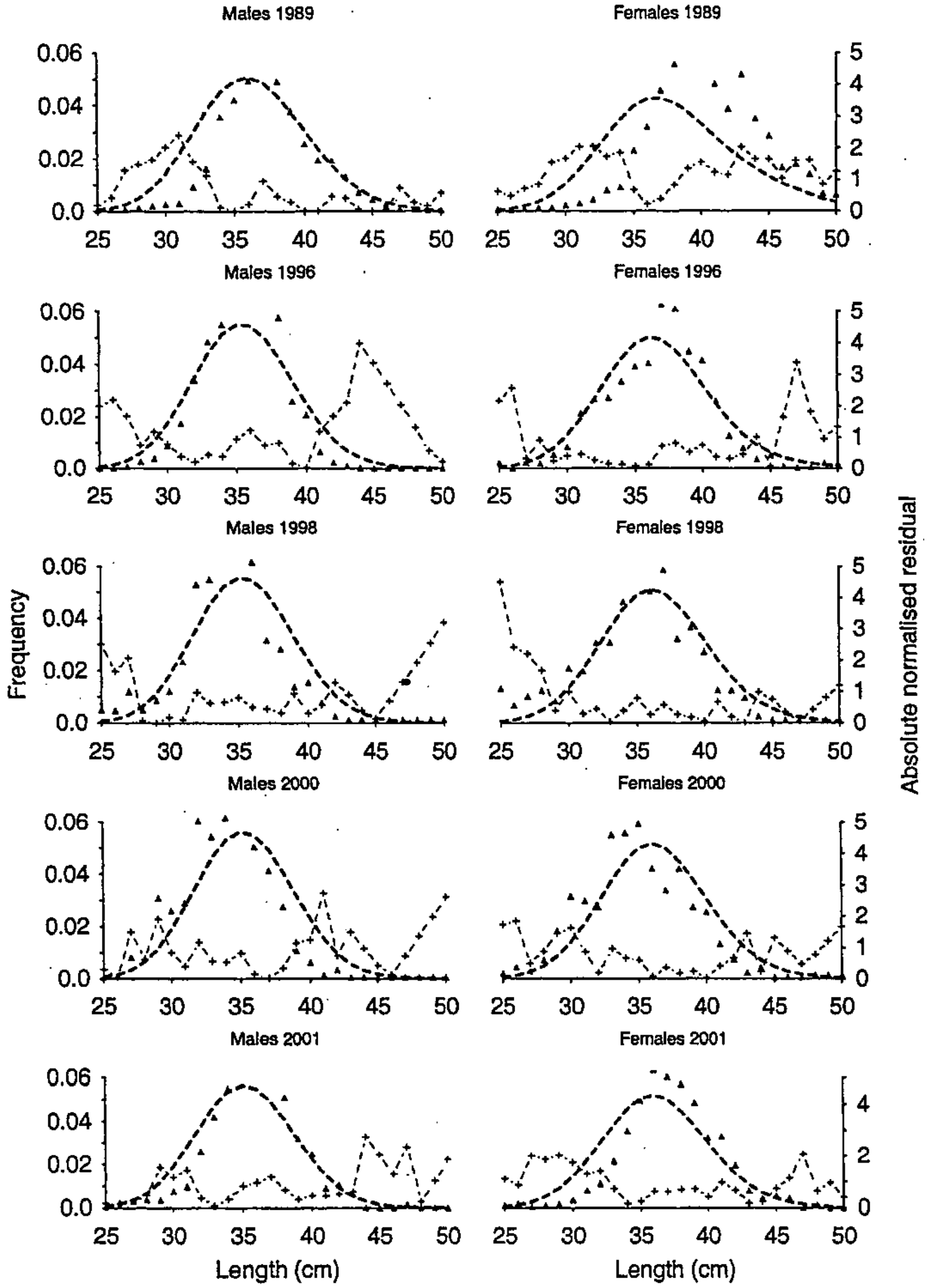


Figure B2: Annual west observer length frequency distributions (triangles) fitted to the model base case (dashed line). The right hand axis shows a plot of absolute normalised residuals (crosses).

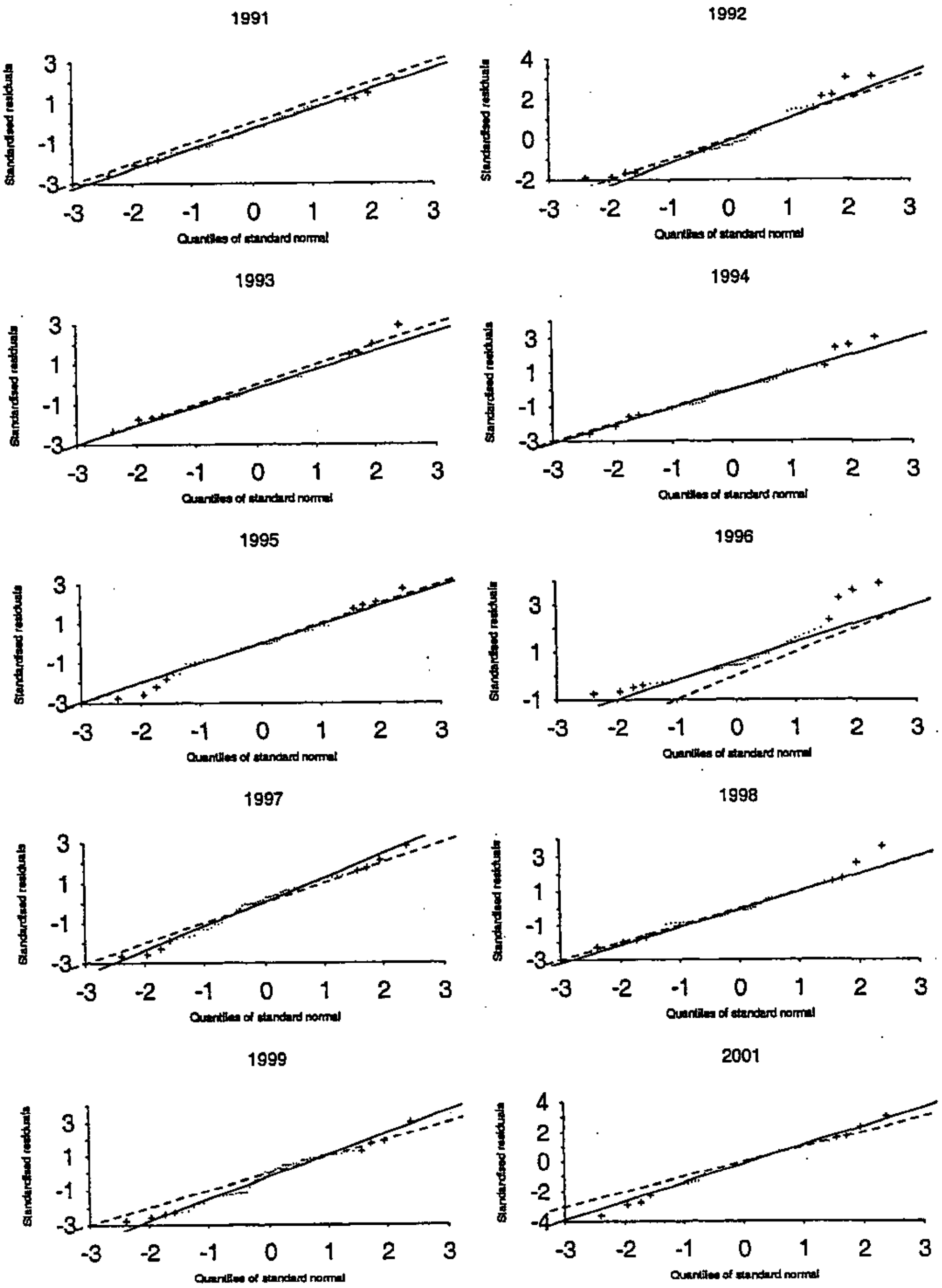


Figure B3: Q-Q normal plots of the normalized residuals (crosses and dots) for each east observer length frequency distribution. The dashed line is the 1:1 line and the solid line is the regression line estimated from the residual points between –1 and 1 on the x-axis.

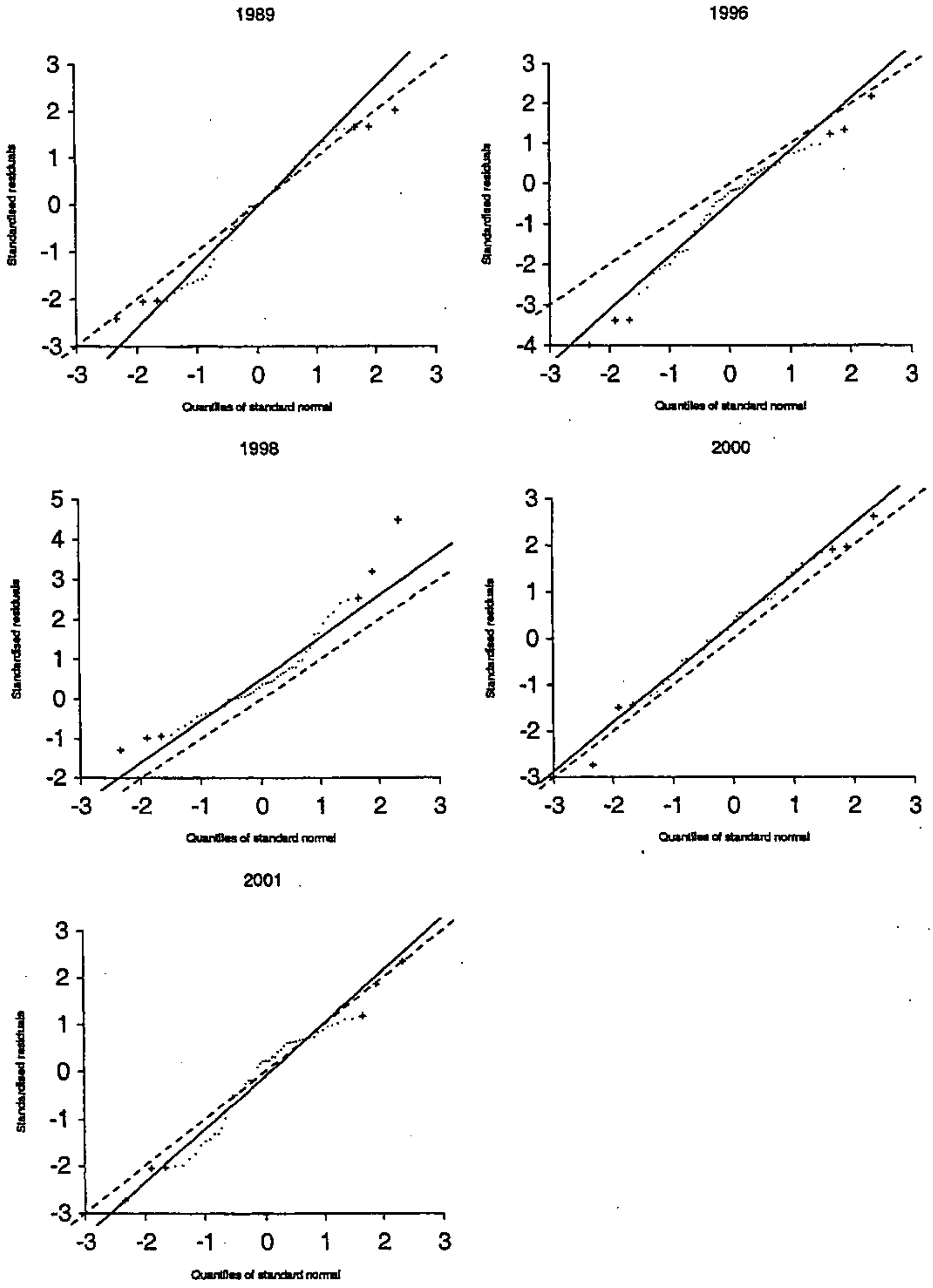
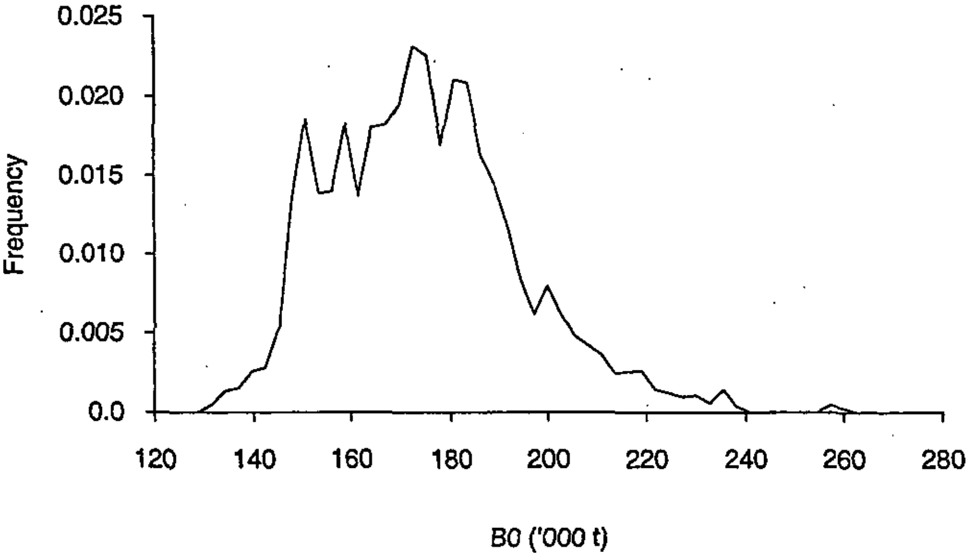


Figure B4: Q-Q normal plots of the normalized residuals (crosses and dots) for each west observer length frequency distribution. The dashed line is the 1:1 line and the solid line is the regression line estimated from the residual points between –1 and 1 on the x-axis.

APPENDIX C: Bayesian estimate plots

Figure C1: Pairwise plots of MCMC parameter estimates. (See parameter definition and abbreviations in Table 13.)



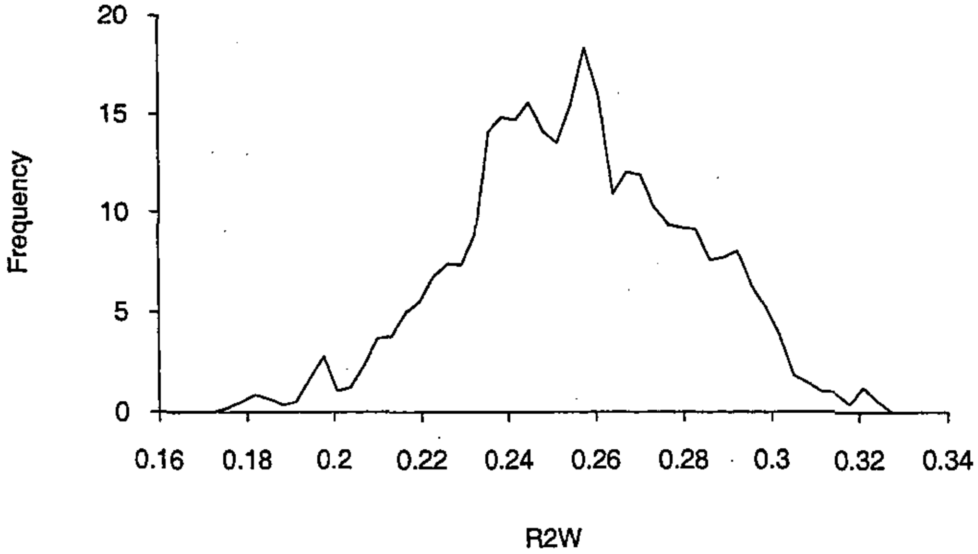


Figure C2: Posterior distribution plots for mature virgin biomass (upper) and the proportion of year one recruits moving to the west (lower). See parameter definition and abbreviations in Table 13.

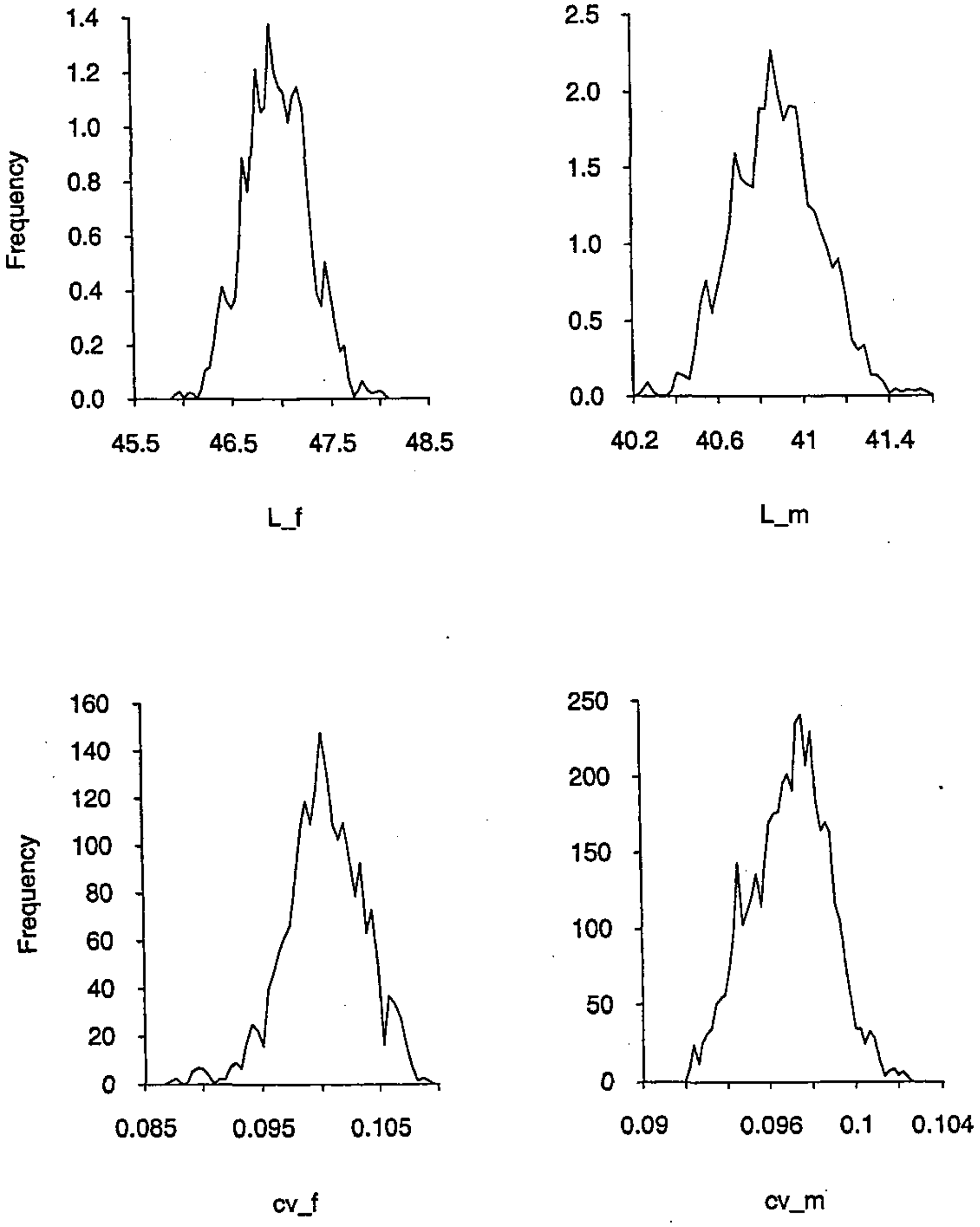


Figure C3: Posterior distribution plots for female (top left) and male (top right) L_∞, and female (bottom left) and male (bottom right) c.v. for the length-at-age distributions. See parameter definition and abbreviations in Table 13.

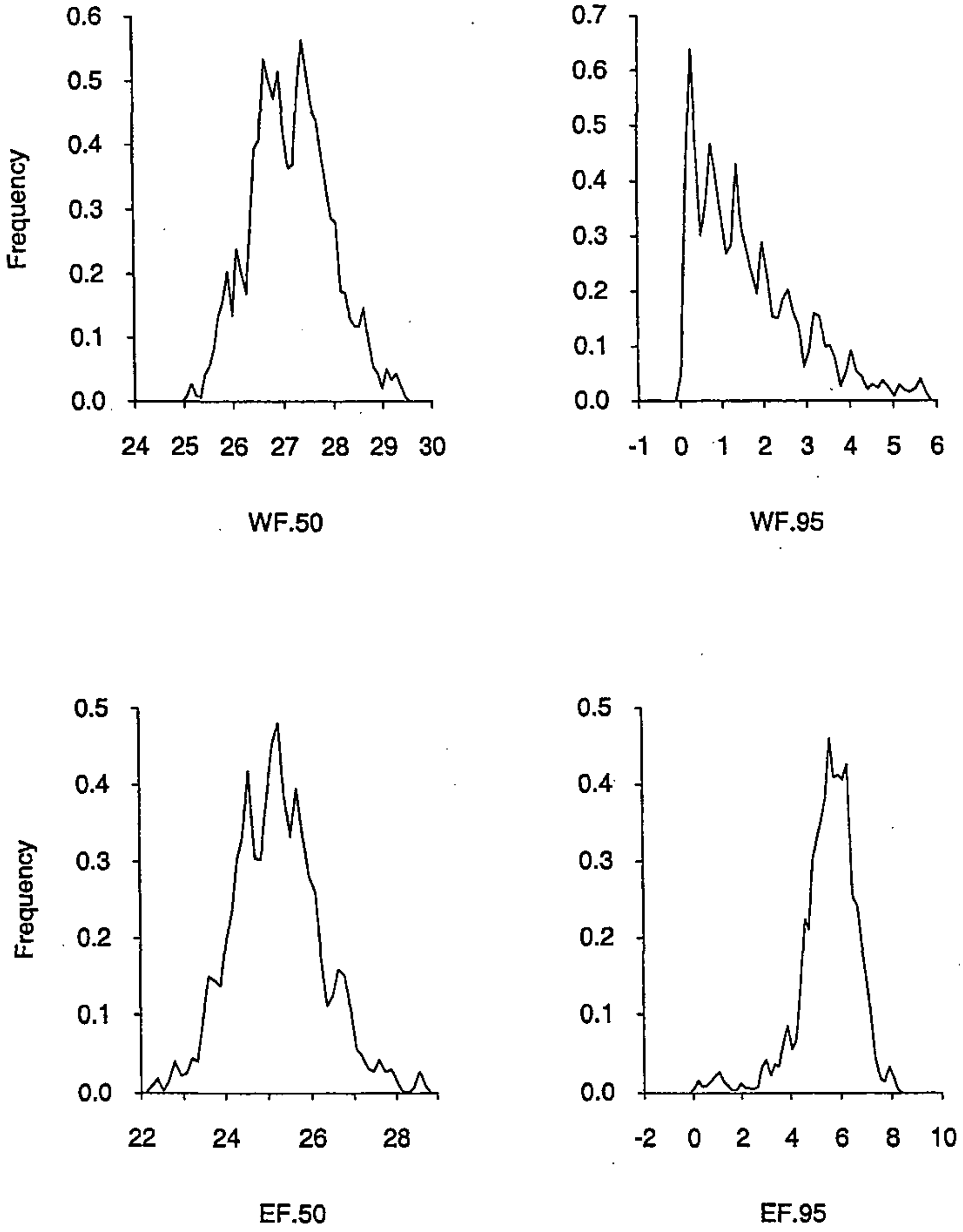


Figure C4: Posterior distribution plots for the west fishery selectivity, age at 50% selection (top left); west fishery selectivity, for ages from 50% to 95% selection (top right); east fishery selectivity, age at 50% selection (bottom left); east fishery selectivity, for ages from 50% to 95% selection (bottom right). See parameter definition and abbreviations in Table 13.

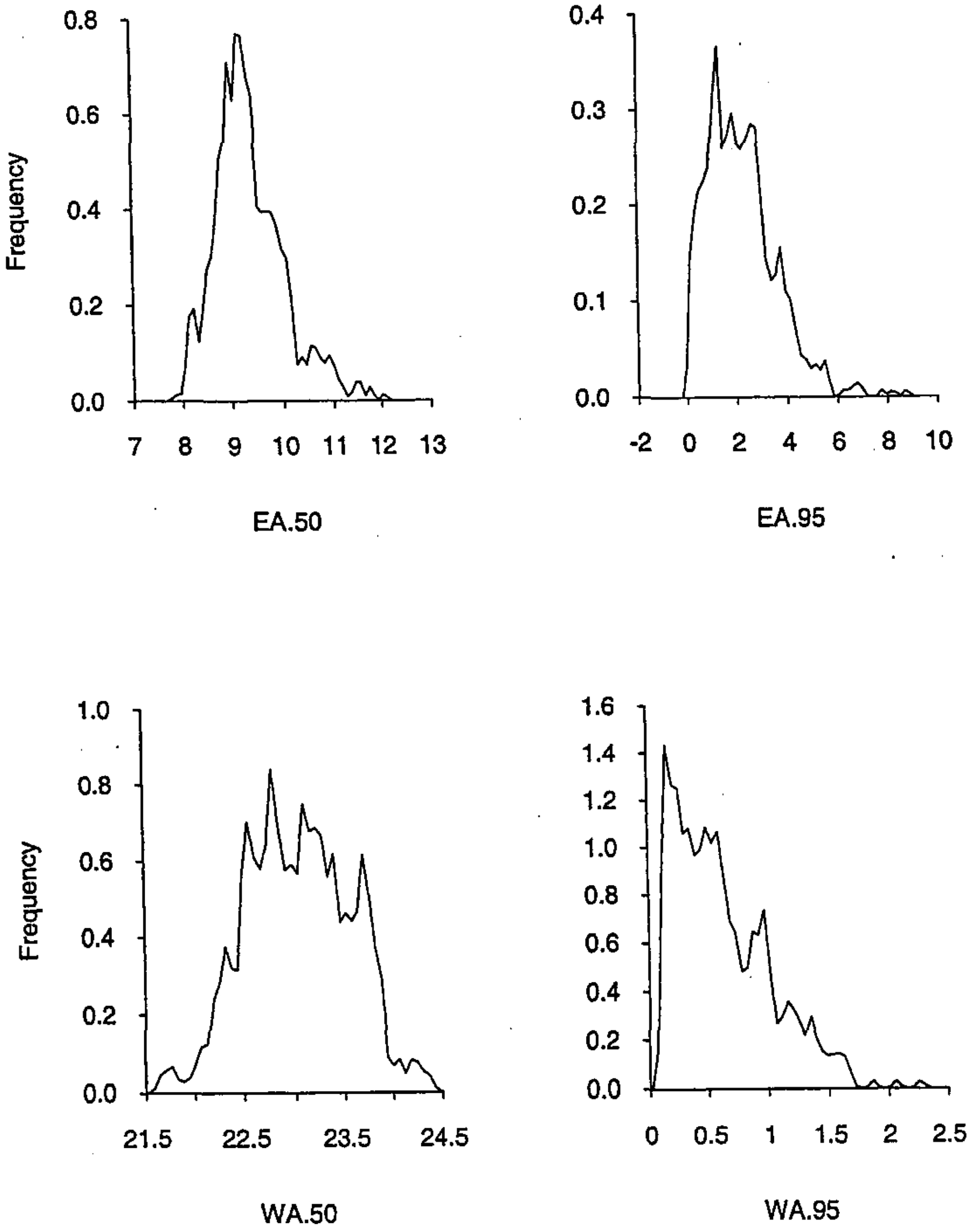


Figure C5: Posterior distribution plots for the east acoustic 2001 selectivity, age at 50% selection (top left); east acoustic 2001 selectivity, for ages from 50% to 95% selection (top right); west acoustic 2002 selectivity, age at 50% selection (bottom left); west acoustic 2002 selectivity, for ages from 50% to 95% selection (bottom right). See parameter definition and abbreviations in Table 13.