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Southern blue whiting (*Micromesistius australis*) stock assessment for the Campbell Island Rise for 2003

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EXECUTIVE SUMMARY

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This report summarises landings, catch-at-age, and biological data from New Zealand southern blue whiting (SBW) fisheries in 2002, and presents a stock assessment for the Campbell Island Rise. There was no new acoustic survey of the Bounty Platform or Pukaki Rise and so the assessments for those stocks were not updated. There has been little fishing on the Auckland Island Shelf stock, and no abundance indices are available for this area.

Estimates of biomass and yield were provided for the Campbell Island Rise stock based on analyses using catch-at-age from the commercial fishery, pre-recruit and recruited acoustic survey indices, and estimates of biological parameters. Because of uncertainty over target strength, the acoustic indices were fitted in the model as relative estimates of mid-season abundance. This new Campbell Island Rise stock assessment used Bayesian estimation with the NIWA modelling program CASAL v1.02. New information since the 2001 assessment included the results of an acoustic survey carried out in 2002 and two more years of proportions-at-age data from the commercial fishery.

Because this was a new assessment a number of initial runs were made to explore the sensitivity of the results to changes in the various model assumptions and priors. Four main runs captured most of the variability. These runs differed in the priors used for the adult 4+ acoustic q and in whether or not natural mortality was estimated in the model. For the final assessment the Working Group agreed to use two of those runs as base cases. In base case 1 the adult 4+ acoustic q had a log-uniform (uninformative) prior, and in base case 2 it had a lognormal (informative) prior. In both base cases natural mortality was estimated in the model with a lognormal prior.

The population trajectories are very similar for both base cases. Both runs suggest that the stock biomass showed a steady decline from the early 1980s until 1993 followed by a large increase to 1996, and a slight decline thereafter. The 1991 year class still makes a large contribution to the commercial catch (especially by weight), and has been joined by the 1995, 1996, and 1998 year classes, all of which also appear to be moderately strong. The median estimates of mid-season biomass in 2002 (B_{2002}) for base cases 1 and 2 are 109 000 t and 85 000 t respectively. The 90% confidence intervals of B_{2002} from the MCMC runs were 60 000–216 000 t and 54 000–137 000 t respectively. The main difference between the runs lies in the median estimates of current biomass, and the bounds on the biomass estimates since the mid 1990s. Most of the sensitivity runs lie within the range of the two base cases indicating the model was robust to most of the assumptions made.

Estimates of B_0, B_{2000}, and B_{2000}/B_{1991} were compared between the current assessment and the last assessment carried out in 2001. Despite different models and different estimation methods, current estimates of these parameters are very similar to those of the previous assessment. The assessment results show the model to be data rich, which is shown by the lack of influence of the uniform-log prior on q, the similarity with last year's assessment despite some informed priors this year, and the tight uncertainty intervals on the biomass posteriors.

Two-year stochastic projections were made assuming fixed catch levels from 10 000 to 30 000 t per year with parameter uncertainty defined by the MCMC samples of the posterior distribution. The probability that the mid-season biomass for the specified year will drop below the threshold biomass reaches the 10% level by 2005 at catches of about 15 000 t (basecase 1) or 10 000–15 000 t (basecase 2). The year 1991 was chosen as a reference threshold biomass because biomass in 1991 was the lowest observed but gave rise to high recruitment and subsequent stock recovery.

1. INTRODUCTION

1.1 Overview

Southern blue whiting (SBW) are almost entirely restricted to subantarctic waters (QMA 6), and comprise four distinct stocks: Campbell Island Rise (SBW6I), Bounty Platform (SBW6B), Pukaki Rise (SBW6R), and Auckland Islands Shelf (SBW6A). Acoustic surveys and assessments of the Campbell Island Rise and Bounty Platform stocks are carried out in alternate years. An acoustic survey of the Campbell Island Rise was carried out in August–September 2002 and the assessment for this stock was revised based on the results of that survey, a new modelling approach, and on ancillary fisheries data. This report documents a Campbell Island Rise stock assessment and updates length-frequency, reproductive data, and catch-at-age data for the Bounty Platform and Campbell Island Rise stocks. The Campbell Island Rise stock assessment used Bayesian estimation with the NIWA modelling program CASAL v1.02 (Bull et al. 2002). Estimates of biomass and yield were provided based on age structured model analyses using catch-at-age from the commercial fishery, pre-recruit and recruited acoustic survey biomass indices, and estimates of biological parameters. Stochastic projections were provided under various constant catch scenarios for 2003 to 2005.

1.2 Description of the fishery

Since 1986, commercial fishing for SBW has been focused on the period August to October when fish are aggregated for spawning. This means that the main fishing period usually straddled two of the 1 October–30 September fishing years. So when SBW was introduced into the QMS in November 1999 the fishing year was changed to 1 April–31 March. Therefore, to avoid confusion in this paper the words "fishing season" refer to the period from August to October, the months of intense fishing when spawning occurs (i.e., the 2002 season is part of the 1 April 2002 – 31 March 2003 fishing year).

The SBW fishery was developed by Soviet vessels during the early 1970s, with total landings in 1973 and 1974 exceeding 40 000 t. It was recorded that SBW spawned in most years on the Bounty Platform (Shpak 1978) and in some years on the Campbell Plateau (Shpak & Kuchina 1983), and that feeding aggregations could be caught on the Pukaki Rise, southeast of the Campbell Island Rise, and on the Auckland Islands Shelf (Shpak 1978). Some fishing probably took place on each of the grounds, but the proportion of catch from each ground cannot accurately be determined before 1978. From 1978 to 1984, the entire Campbell Plateau was fished throughout the year, but highest catches were usually made while fish were spawning in September on the Pukaki Rise and the northern Campbell Island Rise. In some seasons (notably 1979, 1982, and 1983) vessels also targeted spawning fish on the Bounty Platform in August and September (Table 1).

As a result of the increase in hoki quota in 1985 and 1986, the Japanese surimi fleet increased its presence in New Zealand waters and some vessels stayed on after the hoki fishery to fish for SBW. Since then many of the Soviet and Japanese vessels which fish for hoki on the west coast of the South Island during July and August each year move in mid to late August to the SBW spawning grounds. Between 1986 and 1989, fishing was confined to the spawning grounds on the northern Campbell Island Rise. From 1990 onwards, vessels also started fishing spawning aggregations on the Bounty Platform, the Pukaki Rise, and the southern Campbell Island Rise. Fishing effort increased markedly between 1990 and 1992, culminating in a catch of over 75 000 t in 1992. The increased catch came mainly from the Bounty Platform. In 1993, a fishery developed for the first time on the Auckland Islands spawning grounds and fishing has continued there at a low level sporadically since then.

A catch limit of 32 000 t for all the areas was introduced for the first time in 1993. This was increased to 58 000 t in 1996–97, lowered to 35 140 t in 2000–2001, and increased to 45 140 t for the last two fishing years (Table 1). Annual landings since 1992–93 have averaged about 25 000 t, most of which has been taken from the Campbell Island Rise grounds. The fleet has comprised mainly Japanese surimi vessels, and Russian, Ukrainian, and Polish vessels that produce dressed product.

Fishing in most years has started in mid August and extended into October. However, over the past two fishing years there has been an increasing amount of SBW taken outside this main spawning season. Some has been taken as a bycatch of the hoki fishery, and the remainder has been targeted. In the 2000–01 fishing year about 350 t were taken between November and March, mainly from the Pukaki stock. In the 2002–03 fishing year about 2200 t were taken between November and March, from the Campbell Island Rise, Pukaki, and Auckland stocks.

1.3 Recent papers

Stock structure was reviewed by Hanchet (1998a, 1999), who concluded that SBW should be assessed as four stocks. Various designs for acoustic surveys of SBW were investigated using simulation studies by Dunn & Hanchet (1998) and Dunn et al. (2001). Eight acoustic surveys of southern blue whiting spawning grounds have now been completed, and results of recent surveys were reported by Hanchet & Grimes (2000, 2001) and Hanchet et al. (2002a, 2003). A re-analysis and decomposition of earlier acoustic survey results was carried out by Hanchet et al. (2000b), and Hanchet et al. (2000a) examined diel variation in southern blue whiting density estimates. Results of recent acoustic target strength work were summarised by McClatchie et al. (1998) and Dunford (2001a, 2001b), and of target identification by McClatchie et al. (2000) and Hanchet et al. (2002b).

A detailed account of the 1996 assessment of the Campbell Island Rise stock and documentation of the separable Sequential Population Analysis (sSPA) model was provided by Hanchet et al. (1998). Further developments to the sSPA model, and a comparison with other models, were given by Hanchet (1998b). In recent stock assessments, catch-at-age and acoustic data were modelled using the sSPA model (Hanchet 2002a, 2002b).

Objectives

This report addresses objectives 1 and 2 from MFish project SBW2002/01.

1. To determine catch-at-age from the commercial fisheries at Campbell Island Rise, Auckland Island, Bounty Platform, and Pukaki Rise for 2002/03 from samples collected at sea by Scientific Observers and other sources, with a target coefficient of variation (c.v.) of 20% (mean weighted c.v. across all age classes).

2. To update the stock assessments of the Campbell Island Rise stock, including estimating biomass and sustainable yields.

2. REVIEW OF THE FISHERY

2.1 TACs, catch, landings, and effort data

2.1.1 Total Allowable Catch

Catch quotas, allocated to individual operators, were introduced for the first time in the 1992–93 fishing year. The catch limit of 32 000 t, with stock-specific sub-limits, was retained for the next 3 years (Table 1). The stock-specific sub-limits were revised for the 1995–96 fishing year, and the total catch limit increased to 58 000 t in 1996–97 for 3 years (Table 1). Before 1997–98 there was no separate catch limit for Auckland Islands, but in 1997–98 a 1640 t limit was set for the Auckland Islands fishery.

The southern stocks of southern blue whiting were introduced to the Quota Management System on 1 November 1999 with the following TACCs: Auckland Islands (SBW 6A) 1640 t, Bounty Platform (SBW 6B) 15 400 t, Campbell Island Rise (SBW 6I) 35 460 t, and Pukaki Rise (SBW 6R) 5500 t (Table 1). A nominal TACC of 8 t (SBW 1) was set for the rest of the EEZ. At the same time, the fishing year was also changed to 1 April to 31 March to reflect the timing of the main fishing season. TACC changes since 2000–01 are shown in Table 1. The total catch limit was increased to 45 140 t for the 2001–02 fishing year, and retained for the 2002–03 fishing year. About 5 t was reported from SBW 1 in 2000–01, and less than 1 t in 2001–02 and 2002–03. The TACCS for 2003–04 have been reduced to 25 000 t for the Campbell Island Rise stock and to 4000 t for the Bounty Platform stock. SBW has been managed using a Current Annual Yield (CAY) strategy (Annala et al. 2002), which has resulted in the fluctuating catch limits and TACCs (Table 1).

2.1.2 Landings

Estimates of the annual landings of SBW by fishing year were given in Table 1. The reported landings for the 2002 season (2002–03 fishing year) from the Quota Monitoring Reports was 40 172 t. The TACC was undercaught on Auckland Islands Shelf and the Pukaki Rise, almost reached on Bounty Platform, and slightly exceeded on Campbell Island Rise.

2.1.3 The 2002 season

The location of trawls made during the 2002 season (mid August to mid October) is shown in Figure 1. Seventeen vessels, mainly from Japan and Ukraine, fished for southern blue whiting during the 2002 season (Table 2). The first vessels arrived on the Bounty Platform on 21 August, and vessels soon located SBW to the east of the Bounty Platform. Five vessels fished there during the 14 day season and took 7464 t. Spawning occurred slightly later than usual on the Bounty Platform, lasting from 30 August to 2 September (Section 2.2.3).

Two vessels fished the Pukaki Rise between 31 August and 8 October, making only 10 trawls. They fished there on three separate occasions. A catch of almost 140 t was made on 31 August, and another high catch of 80 t was made on 28 September. However, few data are available from observers and the timing of the spawning is unknown. The total catch on the Pukaki Rise was only 316 t. Two vessels reported five trawls from the Auckland Islands Shelf this season. Only one of the vessels was observed and this made a very small catch. The remaining vessel reportedly made four very large catches ranging from 90 to 180 t. The total catch was 491 t.

One vessel started fishing the Campbell Island Rise on 11 July and made reasonable catches through until early September. Most of the other vessels moved to the Campbell Island Rise grounds in early September. There were three different spawning aggregations on the Campbell Island Rise ground this season. One aggregation was being fished by most of the commercial fleet on the northern ground from 4 to 11 September. A second aggregation was surveyed in the southern area by *Tangaroa* from 8 to 10 September. A commercial vessel was also fishing a third aggregation to the east from 4 to 11 September. Fish were spawning in each aggregation over the period 8–10 September. Fish from the northern and eastern aggregations had a similar size distribution, but both were different from fish to the south. After the first spawning was finished on the northern ground, most vessels moved to the eastern aggregation for 2–3 days before moving to the southern aggregation on 15 September. They picked up fish spawning their second batch of eggs on the southern ground from 18 to 22 September. They then moved steadily north and east and had finished fishing by 13 October. By mid October, spawning was over and most vessels had left the area. A total of 31 600 t was taken during the 2002 season by 17 vessels (Table 2).

2.1.4 CPUE analysis

Standardised CPUE analyses of the Campbell Island Rise fishery have been carried out by Ingerson & Hanchet (1995), Chatterton (1996), Hanchet & Ingerson (1996), and Hanchet (2000a). The most recent analysis was not updated because there are concerns that the CPUE series may not be monitoring abundance accurately. This is because of the highly aggregated nature of the fishery, and the associated difficulty in finding and maintaining contact with the highly mobile schools in some years. The use of CPUE to monitor the SBW fisheries is currently being evaluated to meet the requirements of Objective 3 in a separate Ministry of Fisheries project SBW2001/01.

2.2 Other information

2.2.1 Size and age composition of the commercial catch

Methods

Scientific observers collected length-frequency data from 23% of all tows in the commercial fishery during 2002 (Table 2). A total of 497 and 149 otoliths, collected from the Campbell Island Rise and Bounty Platform fishing grounds respectively during the 2002 season, were read and used to derive age-length keys.

Historical time series of catch-at-age data are available for each of the stocks, and these form an important input into the SBW stock assessments. As part of the change to the new CASAL model (see Section 4), it was desirable to have estimates of the c.v.s for the numbers at age for each age and year in the commercial catch (Bull et al. 2002). Therefore, length and age data from all previous seasons were reanalysed using the NIWA catch-at-age software (Bull & Dunn 2002). This software produces c.v.s that incorporate the variance from both the length-frequency data and the age-length key using bootstrapping, and is an improvement over earlier algebraic calculations.

At the same time we took the opportunity to make several refinements to the approach used for the analysis. The length frequency files were virtually identical to those used for the original analysis. They differed slightly for the Campbell Island Rise stock in 1982 and 1983, where length frequency data collected from outside the spawning season were excluded.

Some of the age-length keys used for the analysis were also slightly modified. Where necessary, 'proxy' ages were assumed for those length intervals with no corresponding age. This applied mainly to smaller fish lengths (less than about 30 cm), which could be assigned age 1 or 2 depending on their size. We therefore ensured that an age was available for every length interval below 50 cm for males and 52 cm for females, for which length frequency observations were available. Any fish larger than this length would be put into an 'unassigned' category. For the modelling work these 'unassigned' fish were placed in the plus group.

Results

The weighted length-frequency data for the Campbell Island Rise stock are shown by sex for 2001 and 2002 in Figure 2. The proportion-at-age in the catch by sex is shown in Figure 3. The catch was numerically dominated by 4 year old fish (the 1998 year class). They formed the mode of smaller fish in the size distribution of both males and females. The broader mode to the right comprised mainly the 1991, 1995, and 1996 year classes.

The size composition of the catch on the Bounty Platform ranged from about 35 to 50 cm, with the main mode in both sexes at about 40–43 cm (Figure 4). Although only one vessel and a total of only 8 tows (10%) were observed this year (Table 2), the size composition appears to be consistent with that of previous years. The catch in 2001 comprised mainly the 1994 and 1997 year classes (Figure 5). However, neither year class dominated the catch in 2002, nor appeared to be particularly strong.

Only one tow was observed from the Auckland Island Shelf in 2002. The trawl catch from the Auckland Islands Shelf stock was small, and the observer data are not considered to be representative of the fishery. Consequently, catch-at-age estimates for the Pukaki Rise and Auckland Island Shelf have not been produced.

The entire time series of catch-at-age data for the Campbell Island Rise are given by sex together with their c.v.s in Appendices 1a and 1b. The revised catch-at-age matrices typically have slightly more young fish and slightly more plus group fish in each year than the previous matrices. However, in most cases the numbers differ by less than 5%.

2.2.2 Timing of spawning

Spawning was again late on the Bounty Platform in 2002. Only one commercial vessel was observed this year, from 28 August to 2 September. Their results suggest that fish were spawning from 30 August to 2 September (Table 3). Spawning took place mainly on the east of the Bounty Platform.

Spawning started early this year on the Campbell Island Rise. The first fish were sampled on the northern ground on 4 September, and they had started spawning by 5 September. The first spawning was finished by 11 September. Data collected by *Tangaroa* from 7 to 9 September showed that fish in the southern aggregation were spawning at a similar time. A commercial vessel was also fishing out to the east on a third aggregation in early September. Although no gonad staging data were collected, the echo traces recorded by the vessel from this aggregation over the same period had typical SBW spawning marks. The commercial vessels then moved south and recorded fish spawning their second batch of eggs from 18 to 22 September. By mid October most fish were spent.

3. RESEARCH

3.1 Stock structure

Stock structure of SBW was reviewed by Hanchet (1998a, 1999) who examined data on distribution and abundance, reproduction, growth, and morphometrics. There appear to be four main spawning grounds: Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise. There are also consistent differences in the size and age distributions of fish, in the recruitment strength, and in the timing of spawning between these four areas. Multiple discriminant analysis of data collected in October 1989 and 1990 showed that fish from Bounty Platform, Pukaki Rise, and Campbell Island Rise could be distinguished on the basis of their morphometric measurements. This constitutes strong evidence that fish in these areas return to spawn on the grounds to which they first recruit. There have been no genetic studies, but given the close proximity of the areas, it is unlikely that there would be detectable genetic differences in the fish between these four areas.

For stock assessment, it is assumed that there are four stocks of southern blue whiting with fidelity within stocks: the Bounty Platform stock, the Pukaki Rise stock, the Auckland Islands stock, and the Campbell Island Rise stock. They are also managed as four separate stocks.

3.2 Acoustic surveys

3.2.1 Campbell Island Rise

An acoustic survey of the Campbell Island Rise stock was carried out in September 2002 (Hanchet et al. 2003). Two acoustic snapshots of the area were completed during the survey. Two large areas of adult marks were located during each snapshot. In snapshot 1, the first was in the north of the survey area (strata 3S and 4, Table 4), and was being fished by commercial vessels. The second aggregation was in the south of the survey area (in the south of stratum 7). In snapshot 2, stratum 7 was subdivided and a box drawn around the aggregation seen in snapshot 1. This new sub-stratum (stratum 8) appeared to capture nearly all the biomass seen in the southern area as very little was found in strata 7N, 7S, or 6S (Table 4). The other main area of marks was found in strata 5 and 6N, which appeared to be northern fish that had dispersed south as in previous years. A smaller aggregation to the east of the standardised survey area, which was also being commercially fished, was surveyed in snapshot 2 (strata 8F1, 8F2).

The first snapshot had the highest biomass estimate, principally due to one transect which hit a high-density mark in stratum 7, but it also had a very high c.v. of 93%. The biomass estimate for the second snapshot was about 40% of the first snapshot. Again much of the biomass came from a single transect in the dense aggregation to the south (in stratum 8), and the biomass estimate again had a high c.v. of 65%.

The Ministry of Fisheries Middle Depths Working Group agreed that the fish outside the standardised survey area (in strata 8F1, 8F2), should not be included as part of the time series. They also agreed that the two snapshots should be averaged (by taking a simple arithmetic mean) to provide a single best estimate of about 165 000 t (c.v. = 70%). The biomass estimates were then decomposed into biomass at age. The complete time series of acoustic indices used in the modelling is shown in Table 5.

3.2.2 Target strength–fish length relationship

The estimates of backscatter were turned into biomass estimates by using the target strength–fish length relationship derived for blue whiting in the northern hemisphere (Monstad et al. 1992). Recent studies on gadoids in the northern hemisphere have suggested a higher target strength (similar slope but 2 dB higher intercept) (Rose 1998). Using this relationship would reduce all survey biomass estimates by about 30%. This would affect their use if modelled as absolute indices of abundance, but not if modelled as relative indices of abundance. Theoretical modelling studies suggest a steeper slope than the northern hemisphere studies (Dunford 2001a, 2001b). This would affect the use of the surveys in both an absolute and a relative sense, because the biomass of smaller fish would have been underestimated whilst the biomass of larger fish would have been overestimated. The target strength–fish length relationship used in previous SBW assessments was retained in the current analysis because it is not yet known which alternative relationship is most likely. However, these more recent target strength estimates were used when considering priors on the acoustic q (see Section 3.2.3).

3.2.3 Bounds on the acoustic q for the Campbell Island Rise

The acoustic q is the estimated model parameter that relates the estimated model biomass to the expected value of the acoustic index (Cordue 1996). In some stock assessments the maximum likelihood estimate of q can be very high or low, leading to unreasonably low or high estimates of biomass respectively for a particular stock. For this assessment, the bounds on the adult (4+) acoustic q were obtained outside the model to determine the 'credible' range for q.

Bounds for the adult (4+) acoustic q were obtained using the approach of Cordue (1996) and Hanchet (2002b). Cordue (1996) took into account uncertainty over various transient population model parameters (to deal with turnover), mean target strength, acoustic system calibration, target identification correction, shadow or dead zone correction, and areal availability. There is no evidence for turnover in the SBW population during the spawning season, so following Hanchet (2002b) the transient population parameters are not considered here. The other parameters are considered below. In addition to obtaining the bounds, an attempt at deriving a 'best estimate' for each factor has also been made.

Mean target strength

In situ target strength (TS) data collected during recent SBW acoustic surveys, and preliminary results from swimbladder modelling work, agree with recent northern hemisphere studies suggesting a higher target strength, and possibly also steeper slope, than the values currently used (Dunford 2001a, 2001b). If we assume that these recent estimates are correct, then the current mean TS would need to be adjusted by a value of 1.5. Using an "uncertainty" factor of 1.25 we obtained bounds of [1.2, 1.85]. Note that this addresses only the possibility of a higher TS, it does not address the possibility of a steeper slope.

Target identification

Target identification is reasonably good on Campbell Island Rise. Trawls carried out for mark identification using *Tangaroa* were used to obtain coarse estimates of species composition. A total of 77 bottom and midwater trawls have been made on the Campbell Island Rise during the six *Tangaroa* surveys from 1993 to 2002. The percentage composition of SBW in the trawls (calculated as the total weight of SBW divided by the total weight of all species) for the first five surveys averaged 78% (Hanchet et al. 2002b). The main bycatch species were ling, javelinfish, silverside, small scaled notothenid, and oblique banded rattail. The estimate does not include small species such as mesopelagic fish that go through the trawl meshes. Observer data from the SBW fishery were also examined for species composition. However, as in the other areas, SBW usually constitutes about 99% of the catch in most years.

Although some of the bycatch species have low target strength and/or may be in the dead zone, it is likely that the backscatter categorised as adult SBW does include other species, and that the biomass will be overestimated. We therefore consider that the 'best estimate' is 1.15 (100/86). Using a factor of 1.25 to introduce uncertainty we obtained bounds of [0.9, 1.45].

Dead zone correction

During the day some SBW acoustic marks are reasonably close to the seabed and a proportion of these may be in the dead zone, leading to an underestimate of biomass. An analysis of data from the Campbell Island Rise suggested biomass could be underestimated by 1–25% (Hanchet et al. 2000a). A similar range of underestimates (7–24%) was obtained for demersal cod and haddock in the northeast Atlantic (Ona & Mitson 1996). Based on these values we have assumed bounds of [0.75, 0.95], and a best estimate of 0.85.

Areal availability

It is believed that most of the adult fish are within the survey area at the time of spawning. However, in the 2002 survey a separate aggregation was discovered spawning outside the usual survey area. The size of this aggregation is unknown, but is unlikely to be as large as the two main aggregations found during the survey. Based on a survey estimate of about 5000 t, and a catch taken from this aggregation of about 5000 t, then the total size may have been around 10 000 t, which is just over 5% of the total biomass. For areal availability we have therefore used a best estimate of 0.95, and bounds of [0.90, 1.00].

Acoustic system calibration

Following Cordue (1996) we have assumed the calibrations are reasonably reliable and have used bounds within 10% [0.9, 1.1], and a best estimate of 1.0.

Overall acoustic q

Multiplying all the factors together gives a best estimate of 1.4 for the acoustic *q* and bounds of [0.65, 2.8].

4. STOCK ASSESSMENT

4.1 The stock assessment model

The stock assessment model partitions the Campbell Island Rise stock into two sexes and age groups 2–11, with a plus group at age 11. There are two time steps in the model (Table 6). In time step 1, 90% of natural mortality takes place. In time step 2, fish age, recruit, mature and are then subjected to fishing mortality and the remaining 10% of natural mortality.

The model assumes that the fishing selectivity after age 4 is 1.0, and estimates age-specific selectivity indices for each sex for ages 2 to 4. Selectivities were assumed constant over all years in the fishery, and hence there was no allowance for annual changes in selectivity. In line with previous assessments no stock-recruitment relationship is assumed in the model. The proportion of males at recruitment was assumed to be 0.5 of all recruits. As it is a spawning fishery the maturity ogive was assumed to be the same as the selectivity ogive estimated in the model. Note that the maturity ogive is only used to report spawning stock biomass. The maximum exploitation rate (U_{max}) was set at a value of 0.7. The choice of the maximum exploitation rate has the effect of determining the minimum possible virgin biomass allowed by the model. Because of the large inter-annual differences in growth, caused by the occurrence of the strong and weak year classes, length-at-age vectors were calculated for each year and stock, and used in the modelling (Appendix 2). Lengths-at-age were converted to weights-at-age in the model using the length-weight relationship given in Hanchet (1991). Mean length at age for 2003 was estimated by adding the mean growth for each age class to the length of that age class in 2002.

Equilibrium virgin biomass is equal to the population that there would have been if all the YCS were equal to 1 and there was no fishing. However, there was a period of unknown (and possibly large) catches from the Campbell Island Rise stock before 1979, and there is high recruitment variability in the stock, so the initial 1979 biomass was allowed to differ from the equilibrium virgin biomass.

4.2 Estimation

The model was fitted to the acoustic biomass estimates of ages 2, 3, and 4+ fish given in Table 5 and the proportions-at-age data from the commercial fishery. The acoustic survey estimates were used as relative estimates of mid-season biomass (i.e., after half the catch has been removed), with associated c.v.s estimated from the survey analysis. Catch-at-age observations were available from the commercial fishery for 1979 to 2002. A plus group for all the catch-at-age data was set at 11 with the lowest age set at age 2. Catch-at-age data were fitted to the model as proportions-at-age, where estimates of the proportions-at-age and associated c.v.s by age were estimated using the NIWA catch-at-age software by bootstrap (Bull & Dunn 2002) (see Section 2.2.1). Zero values were replaced with the value 0.0002 with an associated c.v. of 1.5. Ageing error was assumed to be zero.

Lognormal errors, with known c.v.s were assumed for the relative biomass and proportions-at-age data. The c.v.s available for these data allow for sampling error only. However, additional variance assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance. The additional variance, termed process error, was estimated in an initial run of the model using all the available data. A process error of 0.4 was estimated for the proportions-at-age data and was added to each observation for all subsequent model runs. The process error estimated for the acoustic indices was zero. The final relative weightings between the acoustic and age data were therefore a combination of observation error and process error. This was considered to be a big improvement over the more arbitrary weightings used in previous SBW stock assessments (e.g., Hanchet 2002a, 2002b).

Model parameters were estimated using Bayesian methods with the CASAL software (Bull et al. 2002). For initial runs, only the mode of the joint posterior distribution (MPD) was sampled. For the final runs, the full posterior distribution was estimated using the Markov Chain Monte Carlo (MCMC) method based on the Metropolis-Hastings algorithm.

MCMC chains were generated using a burn-in length of 5×10^5 iterations, with every 5000th sample taken from the next 5×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior). Tests for autocorrelations and single chain convergence (Heidelberger & Welch 1983, Geweke 1992) were applied to resulting chains to look for evidence of non-convergence.

The initial population in 1979 (ages 3 to 11+) was estimated for each sex and was therefore allowed to differ from equilibrium or virgin conditions. Year class strengths were estimated for all years from 1977 to 2000, under the assumption that the average of the estimates from the model should equal one.

4.3 Base case runs, sensitivity tests, and prior distributions

As this was a new assessment, a number of initial runs were made to explore the sensitivity of the results to changes in the various model assumptions and priors, and to identify potential base case runs. Four main runs captured most of the variability. These runs differed in the priors used for the adult 4+ acoustic *q* and in whether or not natural mortality was estimated in the model. For the final assessment the Working Group agreed to use two of those runs as base cases. In base case 1 the adult 4+ acoustic *q* was estimated with an uninformed (uniform-log) prior. In base case 2 the 4+ acoustic *q* was estimated with an informed (lognormal) prior. In both base cases natural mortality was estimated in the model with a lognormal prior. The decision to estimate natural mortality in the model was made by the Middle Depths Working Group. They considered that the use of a log-normal prior on M allowed uncertainty in this parameter to be included in the assessment.

The assumed prior distributions used in the assessment are given in Table 7. Apart from M and the acoustic *q*, priors were intended to be uninformed, and had wide bounds. The informed prior for the adult (4+) acoustic *q* was obtained using the approach of Cordue (1996) – see also Section 3.2.3. This independent evaluation of the bounds on the acoustic q suggested a range of 0.65–2.8, with a mean of 1.4 and a c.v. of 0.2. As the 90% confidence bounds of q from preliminary MCMC runs extended lower than 0.65 the Working Group agreed to extend the lower bound to 0.1.

The prior on natural mortality was determined by assuming that the true value could differ from the current estimate by about 0.05, and not more than 0.1. Natural mortality was parameterised by the average of male and female, with the difference estimated with an associated normal prior with mean 0.0 and standard deviation 0.05. Penalty functions were used to constrain the model so that any combinations of parameters that did not allow the historical catch to be taken were strongly penalised. A small penalty was applied to encourage the estimates of year class strengths to average to 1.
Several sensitivity runs were chosen to investigate model sensitivity to potentially strong assumptions, including constant M, catch-at-age error structure, maturity partitioning, and selectivity at age for older fish. Previous SBW stock assessments have been carried out assuming a constant M and a multinomial error structure for the age data, so the first two sensitivities were carried out for comparison with earlier years. The other two sensitivities examined the effect of treating immature and mature fish separately in the model, and of freeing up selectivity on the older female fish. This is the first time that these two sensitivities have been examined. The various runs are summarised in Table 8.

For each model run, MPD fits were obtained and qualitatively evaluated on the basis of the diagnostics of the standardised residuals. MCMC estimates of the median posterior and 90% credible intervals are reported for virgin biomass, B_{2002}, and B_{2002} / B_{1991}. B_{1991} was chosen as a reference threshold biomass for assessing the status of the stock because this biomass gave rise to the 1991 year class, which is the largest year class estimated in the model.

4.4 Results

4.4.1 MPD fits

The MPD fits to all observations were similar for both base cases, and so for brevity only those for base case 1 are shown. The fits to the acoustic indices appear to be reasonably good and the predicted biomass shows good correspondence with the acoustic indices (Figure 6). However, the model was unable to fit the high age 4+ indices in 1998 and 2002, and the age 3 index in 1994. This can also be seen in the residual and QQ plots, which show that the model has difficulty in fitting the very low and very high points in the acoustic time series (Figure 7).

Because of the large number of years of age data, the fits to the individual ages and years have not been presented. As in previous years (e.g., Hanchet 2002a) the fits for most years were reasonably good. The residual plots for the age data for all years and ages show no great departure from normality, and no obvious trends in the residuals (Figure 8). The main outliers were the first observations of the strong 1991 year class (as 2 year olds in 1993 in both sexes). These fish were particularly slow growing, and it is possible that a large proportion of these fish would not have been selected by the trawl. A change from an age-based selectivity ogive to a size-based selectivity ogive could improve this fit.

4.4.2 MCMC results

The MCMC estimates of marginal posterior distributions for spawning stock biomass by year are shown for the two base cases in Figure 9, and are summarised in Table 9. The population trajectories are very similar for both base cases. The main difference between them lies in the median estimates of current biomass, and the estimated uncertainty on the biomass estimates, particularly since the mid 1990s. Both runs suggest that the stock biomass showed a steady decline from the early 1980s until 1993 followed by a large increase to 1996, and a slight decline thereafter. The 1991 year class still makes a large contribution to the commercial catch (especially by weight), and has been joined by the 1995, 1996, and 1998 year classes, all of which also appear to be above average (Figure 10). The median estimates of mid-season biomass in 2002 (B_{2002}) for base cases 1 and 2 are 109 000 t and 85 000 t respectively. The 90% confidence intervals of B_{2002} from the MCMC runs were 60 000–216 000 t and 54 000–137 000 t respectively.

The only difference between the two base cases was the prior used for the adult acoustic q (Figure 11). In base case 1 an "uninformed" (log-uniform) prior was used, whereas in base case 2 an "informed" (lognormal) prior was used. The two resulting posterior distributions were quite different and since this parameter is a direct scalar, it gives rise to the difference between the two assessments. In base case 1, the median estimate of q was 0.94, whereas in base case 2, it was estimated as 1.13.

The estimated posterior distributions for average natural mortality were also different between the two base cases (Figure 12). The posterior distribution was very similar to the prior distribution in base case 1, but had a narrower range and a lower median value (0.17) for base case 2. In both runs there was minimal difference between the sexes. The effects of the narrower posterior distributions in both the acoustic q and in the average M gave rise to the reduced uncertainty in estimated biomass in base case 2 (see Figure 9).

The fishing selectivity estimated by the two models was similar, and so only those from base case 1 is shown here (Figure 13). The fishery selected significantly more males than females at ages 2 and 3, but by age 4 fish of both sexes were selected equally. Fish of both sexes were almost fully selected by age 4.

4.4.3 Sensitivity estimates

The results of sensitivity runs are presented in Table 9. Freeing up the age 5+ selectivity for females made little difference to the results, and the resulting selectivity pattern was very similar to that in base case 1 (Figure 14). Having maturity included in the partition also made little difference to the results, and the resulting maturity at age was very similar to the selectivity estimated in base case 1 (Figure 15). (Note that in the maturity ogive the proportions are expressed as the percentage of the remaining immature fish that become mature, so that the two graphs would not be expected to be identical.)

When a multinomial error structure was used for the age data and when M was fixed in the model, estimates of current biomass were slightly higher for both base cases (Table 9). The results of all the base cases and sensitivity tests are illustrated in Figure 16. Most of the sensitivity runs lie within the range of the two base cases.

4.5 Projections

Two-year stochastic projections were made assuming fixed catch levels from 10 000 to 30 000 t per year with parameter uncertainty defined by the MCMC samples of the posterior distribution, and assuming the TACC of 25 000 t will be taken in 2003–04. Recruitments were resampled from the distribution of historical year class strengths estimated by the model. The probability that the mid-season biomass for the specified year will be less than the mid-season biomass in 1991 is given for the two base case runs in Table 10. The probability of dropping below the threshold biomass reaches the 10% level by 2005 at catches of about 15 000 t (basecase 1) or 10 000–15 000 t (basecase 2). The year 1991 was chosen as a reference threshold biomass because biomass in 1991 was the lowest observed but gave rise to high recruitment and subsequent stock recovery.

5. DISCUSSION

5.1 Model fits and acoustic *q*

The model fits and residual analysis identified an inability of the model to fit the extreme (both high and low) acoustic data points. The worst fit was to the adult acoustic index for 2002. This data point had a very high c.v. (0.7) and therefore carried little weight relative to the other data. The age data show the persistence of the strong 1991 year class, and this, combined with the absence of any subsequent dominant year classes, suggests that the biomass is unlikely to be as high as that indicated by the survey. This is consistent with the conclusions of Hanchet et al. (2003) that the 2002 survey may have overestimated the adult biomass. During the 2002 survey most of the SBW biomass came from a single small dense aggregation in the south of the survey area. This aggregation was surveyed on two occasions (snapshots). In the first snapshot it was surveyed as part of an entire stratum (4217 km^2), whereas in the second snapshot it was surveyed as part of a smaller substratum (550 km^2). On each snapshot most of the density occurred in a single transect, and although the absolute backscatter of fish recorded in the two transects was similar, the corresponding biomasses differed four-fold because of the different stratum areas. Hanchet et al. (2003) concluded that the aggregation had been better defined in the second snapshot and so the lower value was a better estimate of the size of the aggregation. Thus the inability of the model to hit the high 2002 acoustic data point should not be cause for concern, as it reflects the high uncertainty in that observation.

Previous SBW assessments have demonstrated the importance of the adult (4+) acoustic q, which essentially acts as a scalar for the population size. In recent assessments of SBW on the Bounty Platform and the Pukaki Rise q was estimated by the models to be 2.3 and 2.7 respectively. Both estimates were considered to be unlikely, and consequently alternate base cases were run with the q fixed at 1.4 (Hanchet 2002a, 2002b, Annala et al. 2002). Because of these problems in the current assessment it was decided to have two base cases, with an uninformed (log-uniform) prior for base case 1 and an informed (log-normal) prior for base case 2. The prior for base case 2 was based on an independent consideration of the uncertainties and biases associated with the acoustic estimates (see Section 3.2.3). As long as the prior has accounted for inherent uncertainties and biases, then it should contribute to a better assessment than one where the parameter is uninformed.

The median estimates of q from the two base cases were 0.94 and 1.13 respectively, which are both considerably lower than the prior mean of 1.4. There are several possible reasons for this. The main source of bias and uncertainty is currently in the target strength–fish length relationship. The prior was constructed assuming bias and variation in the intercept of the relationship. However, if the slope is different, then this could have quite a different impact on the abundance indices. Research is being carried out to better estimate this relationship, and new estimates will be available for next year. The priors for some of the other variables, such as areal availability, dead zone correction, and target identification, could all be slightly different to the values used, again leading to a reduction in the value of the mean used for the prior. It is recommended that the acoustic prior be re-evaluated before the next assessment.

Despite different models and different estimation methods, the current assessment was reasonably consistent with the last assessment of the Campbell Island Rise stock carried out in 2001 (Table 11). Estimates of B_0 have increased slightly – probably as a result of the inclusion of recent above average strength year classes in the model. Estimates of B_{2000} and B_{2000} / B_{1991}, particularly for base case 1, are also reasonably similar to those from the 2001 assessment. As would be expected, the uncertainty over these parameters has decreased with the inclusion of more years data in the model. Lastly, the estimated value of the acoustic q was 1.02, which is about midway between the estimates from the two base cases in the current assessment.

In summary, the assessment results show the model to be data rich. This is shown by the lack of influence of the uniform-log prior on q, the similarity with last year's assessment despite some informed priors this year, and the tight uncertainty intervals on the biomass posteriors.

5.2 Future work

There are a number of further refinements that could be made to the next stock assessment of SBW. Some are points raised by the Working Group and Plenary at the 2003 meetings, whilst others have been developed in discussion with colleagues. They include the following:

- Explore the use of earlier Japanese LF data and Soviet age data for 1970–78 to extend the time series back and better understand longer-term dynamics in the population
- Try fitting the subantarctic trawl survey biomass estimates (and CPUE estimates when they become available) in the model
- Revisit the acoustic prior once the TS:FL relationship has been re-estimated
- Examine the sensitivity of the model to different ages for the plus group
- Use a size based trawl selectivity (to improve fits for slower growing year classes)
- Explore multi-stock model approach by estimating parameters (such as M, fishing selectivity, and the adult acoustic q) in all stocks simultaneously

6. MANAGEMENT IMPLICATIONS

Both runs suggest that the stock biomass showed a steady decline from the early 1980s until 1993 followed by a large increase to 1996, and a slight decline thereafter. The 1991 year class still makes a large contribution to the commercial catch (especially by weight), and has been joined by the 1995, 1996, and 1998 year classes, all of which also appear to be above average. The median estimates of mid-season biomass in 2002 (B_{2002}) from the two base cases are 85 000 t and 109 000 t respectively. This is more than double the biomass in the reference year (1991). This year was chosen as a reference threshold biomass because biomass in 1991 was the lowest observed, but gave rise to good recruitment and subsequent stock recovery.

Although the current stock status is well above the threshold level, forward projections suggest that a reduction in the TACC will be necessary to reduce the risk of dropping below the threshold level by 2005. The TACC has already been reduced to 25 000 t for the 2003 season (2003–04 fishing year). If the 25 000 t catch is taken in the 2003 season then the TACC would need to be further reduced for the 2004 and 2005 seasons to reduce the risk of dropping below the threshold biomass (B_{1991} level). For example, for all catch levels over 15 000 t, the probability of the stock falling below the 1991 biomass by 2005 is above 10%.

7. ACKNOWLEDGMENTS

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Table 1: Estimated catches (t) of southern blue whiting by area for 1978 to 2002–03 from vessel logbooks and QMRs.– no catch limit in place. Estimates for 2002–03 are preliminary. *, before 1997-98 there was no separate catch limit for Auckland Islands.

Fishing yr	Bounty Platform (SBW6B)		Campbell Island Rise (SBW6I)		Pukaki Rise (SBW6R)		Auckland Island (SBW6A)		Total (All areas)	
	Catch	Limit	Catch	Limit	Catch	Limit	Catch	Limit*	Catch	Limit
1978*f*	0	–	6 403	–	79	–	15	–	6 497	–
1978–79+	1 211	–	25 305	–	601	–	1 019	–	28 136	–
1979–80+	16	–	12 828	–	5 602	–	187	–	18 633	–
1980–81+	8	–	5 989	–	2 380	–	89	–	8 466	–
1981–82+	8 325	–	7 915	–	1 250	–	105	–	17 595	–
1982–83+	3 864	–	12 803	–	7 388	–	184	–	24 239	–
1983–84+	348	–	10 777	–	2 150	–	99	–	13 374	–
1984–85+	0	–	7 490	–	1 724	–	121	–	9 335	–
1985–86+	0	–	15 252	–	552	–	15	–	15 819	–
1986–87+	0	–	12 804	–	845	–	61	–	13 710	–
1987–88+	18	–	17 422	–	157	–	4	–	17 601	–
1988–89+	8	–	26 611	–	1 219	–	1	–	27 839	–
1989–90+	4 430	–	16 542	–	1 393	–	2	–	22 367	–
1990–91+	10 897	–	21 314	–	4 652	–	7	–	36 870	–
1991–92+	58 928	–	14 208	–	3 046	–	73	–	76 255	–
1992–93+	11 908	15 000	9 316	11 000	5 341	6 000	1 143	–	27 708	32 000
1993–94+	3 877	15 000	11 668	11 000	2 306	6 000	709	–	18 560	32 000
1994–95+	6 386	15 000	9 492	11 000	1 158	6 000	441	–	17 477	32 000
1995–96+	6 508	8 000	14 959	21 000	772	3 000	40	–	22 279	32 000
1996–97+	1 761	20 200	15 685	30 100	1 806	7 700	895	–	20 147	58 000
1997–98+	5 647	15 400	24 273	35 460	1 245	5 500	0	1 640	31 165	58 000
1998–00†	8 741	15 400	30 386	35 460	1 049	5 500	750	1 640	40 926	58 000
2000–01#	3 997	8 000	18 055	20 000	2 864	5 500	37	1 640	24 963	35 140‡
2001–02#	2 261	8 000	29 999	30 000	230	5 500	10	1 640	32 500	45 140‡
2002–03#	7 464	8 000	31 847	30 000	321	5 500	539	1 640	40 172	45 140‡

f 1 April-30 September
\+ 1 October-30 September
† 1 October 1998-31 March 2000
# 1 April -31 March
‡ SBW 1 (all EEZ areas outside QMA6) had a TACC of 8 t, and reported catches of 9 t in 2000–01, 1 t in 2001–02 and <1 t in 2002–03.

Table 2: Number of vessels, tows, and catch (t) for observed and all vessels targeting SBW by area for August to October in the 2002–03 fishing year. #, tows for which LF data were collected.

Area	Number of vessels		Number of tows		Total catch	Dates
	observed	total	#observed	total	(t)	
Bounty	1	5	8	80	7 466	21 Aug – 3 Sep
Pukaki	1	2	0	4	316	31 Aug – 27 Sep
Auckland	0	2	1	5	491	24 Sep – 26 Sep
Campbell	7	17	185	764	31 601	1 Aug – 13 Oct

Table 3: Dates of sampling and changes in SBW gonad condition in 2002 on Bounty, and north and south Campbell, and percentage of spent and reverted (fish which have spawned once and reverted back to the maturing stage) in the last sample. (–, could not be determined). No observer data from Pukaki Rise and Auckland Islands Shelf. Note fish caught on south Campbell by *Tangaroa* were spawning from 7 to 9 Sep.

Gonad stage	Bounty	Campbell	
		North (< 52° 30')	South (> 52° 30')
1st sample	28/8	4/9	14/9
>10% ripe	28/8	4/9	<14/9
>10% running ripe	30/8	5/9	<14/9
Main spawning	30/8–2/9	5–10/9	<14/9
>10% spent	31/8	11/9	<14/9
>10% reverted	30/8	10/9	–
>50% spent	–	24/9	22/9
2nd spawning	–	?	18/9–22/9
Last sample	2/9	10/10	14/10
% spent	25	86	99
% reverted	14	12	1

Table 4: Acoustic survey biomass estimates (t) and c.v. by stratum and snapshot of juvenile, immature, and adult SBW, for the Campbell Island Rise in 2002 (from Hanchet et al. 2003). The italicised entries were obtained from the previous snapshot. Best estimate is the mean of snapshots 1 and 2.

Stratum	Area	Juvenile		Immature		Adult	
		Biomass	c.v.	Biomass	c.v.	Biomass	c.v.
	(km^2)	(t)	(%)	(t)	(%)	(t)	(%)
Snapshot 1							
2	3 154	1 080	71	0	—	435	100
3N	2 342	0	—	0	—	0	—
3S	1 013	0	—	0	—	6 356	99
4	2 690	3 347	48	271	48	12 196	53
5	3 029	2 682	110	0	—	0	—
6	4 711	0	—	0	—	0	—
7	4 217	124	97	876	99	220 640	101
Total	**21 156**	**7233**	**48**	**1 147**	**76**	**239 627**	**93**
Snapshot 2							
2	3 154	*1 080*	*71*	—	—	—	—
3N	2 342	—	—	—	—	—	—
3S	1 013	0	—	0	—	0	—
4	2 690	337	63	0	—	0	—
5	3 029	604	70	0	—	10 506	36
6N	2 550	0	—	0	—	13 410	82
6S	2 161	0	—	0	—	1 491	101
7N	1 899	346	102	0	—	0	—
7S	1 916	0	—	0	—	188	93
8	550	0	—	0	—	63 457	88
Total	**21 304**	**2 367**	**41**	**0**	**—**	**89 052**	**65**
8F1	1 705	0	—	0	—	6 929	78
8F2	400	0	—	0	—	1 947	44
Mean 8F		0	—	0	—	4 438	62
Best estimate		**4 800**	**37**	**574**	**76**	**164 340**	**70**

Table 5: Decomposed acoustic survey biomass estimates (t) and c.v.s by survey and age group used for the Campbell Island Rise assessment (from Hanchet et al. 2003).

	Age 2		Age 3		Age 4+	
	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.
1993	71 902	23	14 781	22	24 033	21
1994	12 259	38	139 552	37	28 841	36
1995	11 176	25	23 228	28	130 535	30
1998	13 142	20	28 022	19	167 668	18
2000	10 460	23	8 421	20	135 612	17
2002	3 732	76	11 549	72	148 189	68

Table 6: Annual cycle of the stock model, showing the processes taking place at each step, and the available observations. Fishing mortality (F) and natural mortality (M) that occur within a time step occur after all other processes. M, proportion of M occurring in that time step.

Period	Process	M	Length at age	Observations
1. Nov–Aug	Natural mortality	0.9	–	–
2. Sep–Oct	Age, recruitment, F, M	0.1	Matrix applies here	Proportion at age, acoustic indices

Table 7: The distributions, priors, and bounds assumed for the various parameters being estimated. The parameters are mean and c.v. for lognormal; and mean and s.d. for normal. Note acoustic *q*s were treated as nuisance parameters in base case 1. (For further details of runs see Table 8.)

Parameter	N	Distribution	Values		Bounds	
All runs			**Mean**	**c.v. / s.d.**	**Lower**	**Upper**
B_0	1	Uniform-log	–	–	30 000	1 000 000
YCS	24	Lognormal	1.00	1.30	0.01	10
Initial population	18	Uniform-log	–	–	1	1 000 000
Selectivity ages 2-4	6	Uniform	–	–	0.0001	1
M (average)	1	Lognormal	0.20	0.20	0.07	0.35
M (difference)	1	Normal	0.00	0.05	-0.2	0.2
Base case 1						
Acoustic *q*s	3	Uniform-log	–	–	0.1	2.8
Base case 2						
Acoustic 4+q	1	Lognormal	1.40	0.20	0.1	2.8
Sensitivity analysis						
Select 5+	1	Uniform	–	–	0.0001	2

Table 8: Model run labels and descriptions for the base case and sensitivity runs.

Model label	Description
Base case 1	Base case model with uniform-log *q*, *M* estimated in the model, lognormal error structure, and selectivity estimated for ages 2–4.
Base case 2	Base case model with lognormal *q*, *M* estimated in the model, lognormal error structure, and selectivity estimated for ages 2–4.
Fixed *M*	As for base case 1, but with *M* fixed.
Fixed *M* and inf *q*	As for base case 2, but with *M* fixed.
Multinomial	As for base case 1, but with a multinomial error structure for age data with median sample size 80.
Maturity partition	As for base case 1, but with maturity in partition. Selectivity set to 1 and maturity estimated for ages 2–4.
Select 5+	As for base case 1, but with an additional selectivity estimated for age 5+ females, and *M* estimated in the model.
Select 5+ est *M*	As for base case 1, but with an additional selectivity estimated for age 5+ females.

Table 9: Bayesian median and credible intervals of B_0, B_{2002} (in '000 t), and B_{2002} as a percentage of B_{1991} for the reference case and sensitivity tests. Median estimates of M and the adult 4+ acoustic q are also provided for runs when these parameters were estimated. –, not estimated.

Model run	B_0	B_{2002}	B_{2002} / B_{1991}	*M*	*q*
Base case 1	242 (205–308)	109 (60–216)	234 (145–373)	0.20	0.99
Base case 2	238 (199–285)	85 (54–137)	205 (134–309)	0.17	1.24
Fixed *M*	239 (206–296)	120 (72–201)	251 (159–384)	–	0.94
Fixed *M* and inf *q*	220 (198–253)	93 (61–137)	205 (142–285)	–	1.13
Multinomial	241 (207–300)	126 (75–213)	297 (186–441)	–	0.96
Maturity partition	239 (204–297)	118 (69–203)	251 (157–373)	–	0.97
Select 5+	243 (205–305)	124 (74–210)	256 (162–391)	–	0.91
Select 5+ and est *M*	245 (207–309)	107 (60–217)	242 (152–377)	0.19	0.98

Table 10: Probability that the projected mid-season vulnerable biomass for 2004 and 2005 will be less than the mid-season vulnerable biomass in 1991, and the median projected biomass as % B_{1991}, for different constant catch levels for the two base case runs for the Campbell stock, assuming a 25 000 t catch in 2003.

	Probability (B_{proj}<B_{1991})		Median biomass as % B_{1991}	
Constant catch (t)	2004	2005	2004	2005
Base case 1				
10 000	0.08	0.07	200	217
15 000	0.09	0.10	196	202
20 000	0.09	0.13	191	187
25 000	0.11	0.18	185	173
30 000	0.12	0.24	180	157
Base case 2				
10 000	0.13	0.09	166	181
15 000	0.15	0.16	160	164
20 000	0.17	0.26	155	146
25 000	0.21	0.34	149	130
30 000	0.23	0.43	144	113

Table 11: Comparison of B_0, B_{mid00}, and B_{mid00} (as % B_{mid91}) for the 2001 and 2003 assessments of the Campbell Island stock. For the 2001 assessment the values are the MPD estimates and 90% bootstrapped confidence intervals and for the 2003 assessment they are the median and 90% credible intervals. 2001 data from Hanchet (2002a) and unpublished data).

Year of assessment	B_0		B_{mid00}		B_{mid00} (as % of B_{mid91})	
	Estimate	90% intervals	Estimate	90% intervals	Estimate	90% intervals
2001	215	175–294	139	64–282	3.2	1.9–5.9
2003 (BC 1)	242	205–308	137	92–239	2.9	2.2–4.1
2003 (BC 2)	238	199–285	112	85–156	2.7	2.2–3.5

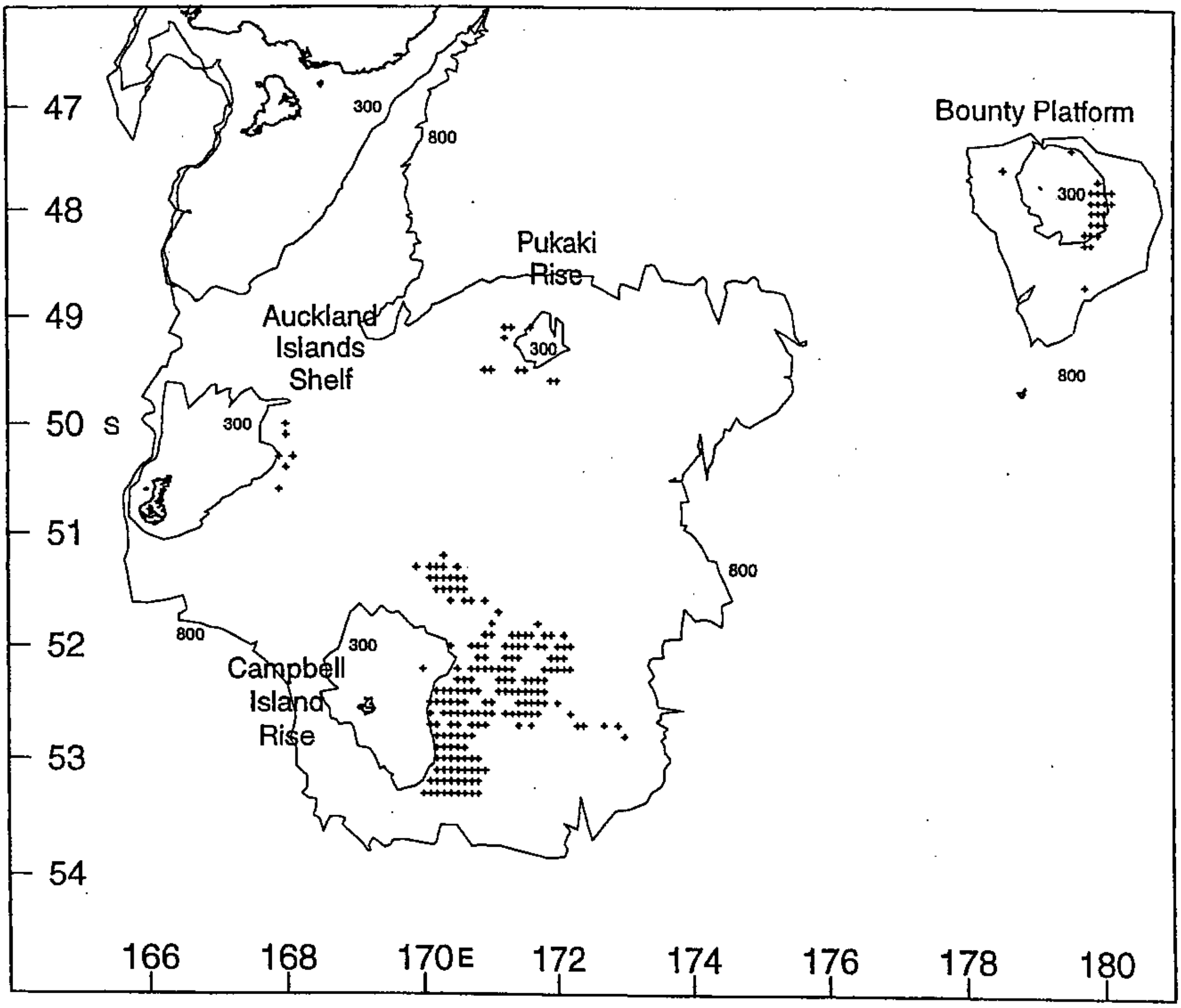


Figure 1: Commercial trawls made during the 2002 season targeting southern blue whiting.

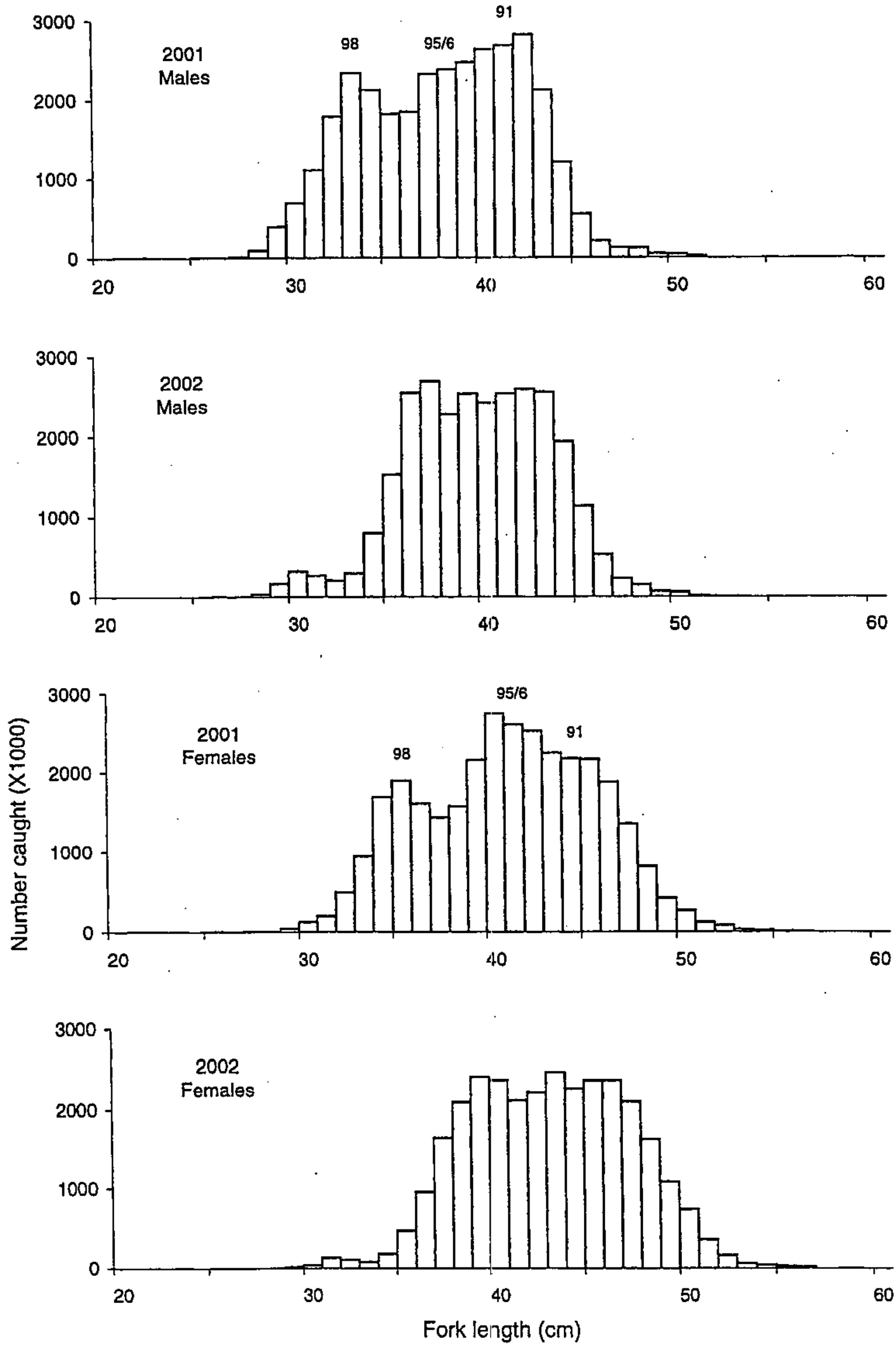
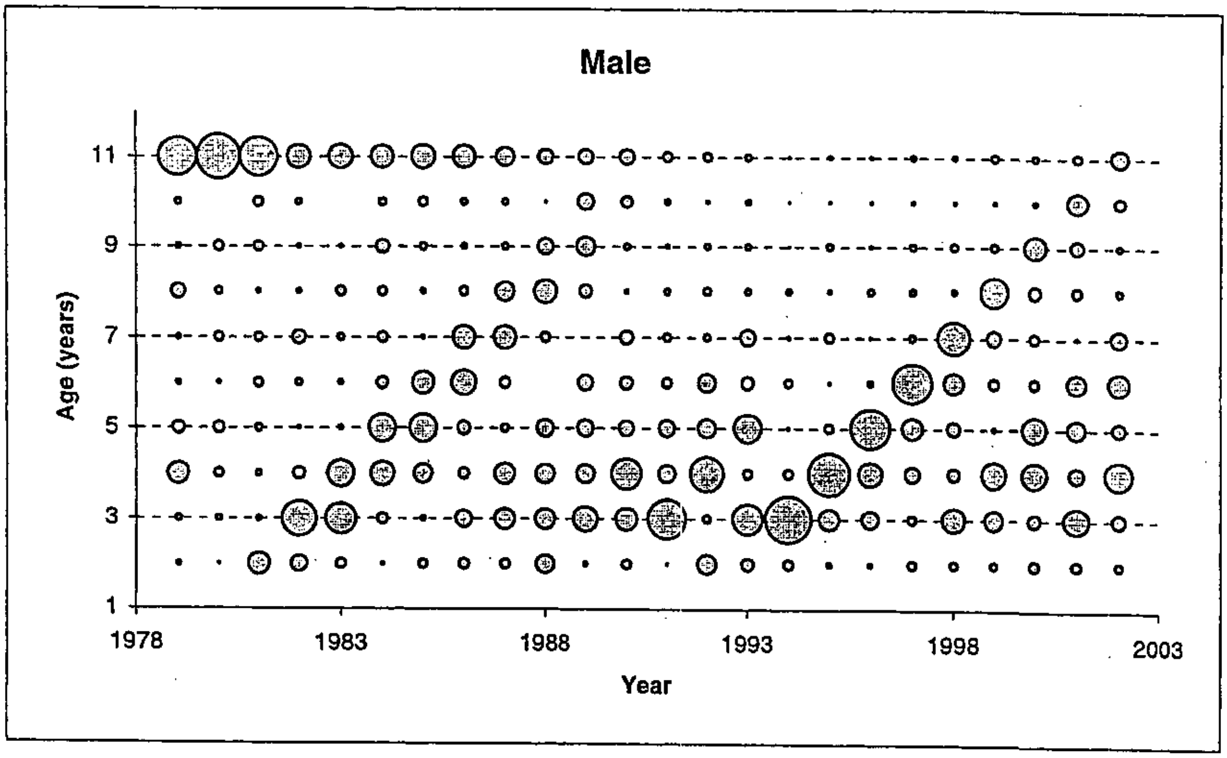


Figure 2: Weighted length frequency distribution of SBW for the Campbell Island Rise for the 2001 and 2002 seasons. The numbers above the modes are the most likely year classes corresponding to those length intervals.



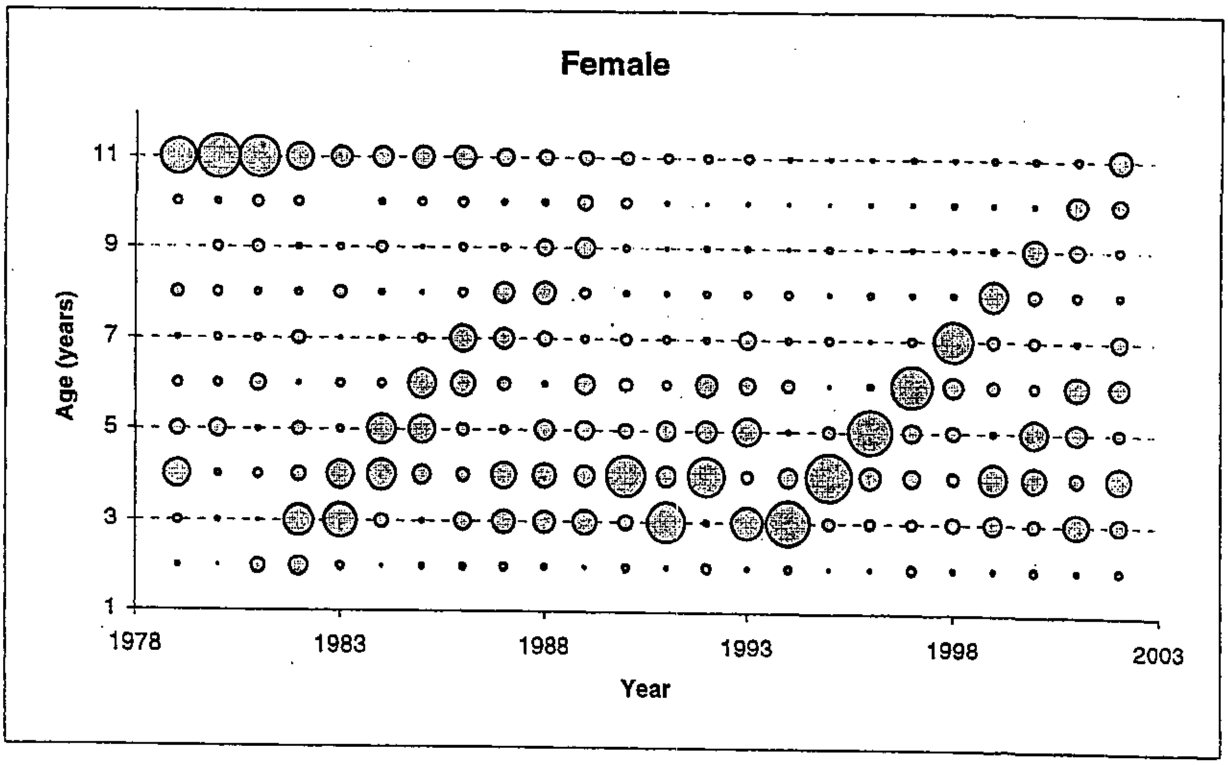


Figure 3: Male and female proportion at age in the Campbell Island catch from 1979 to 2002. Symbol area proportional to the proportions-at-age within the sampling event

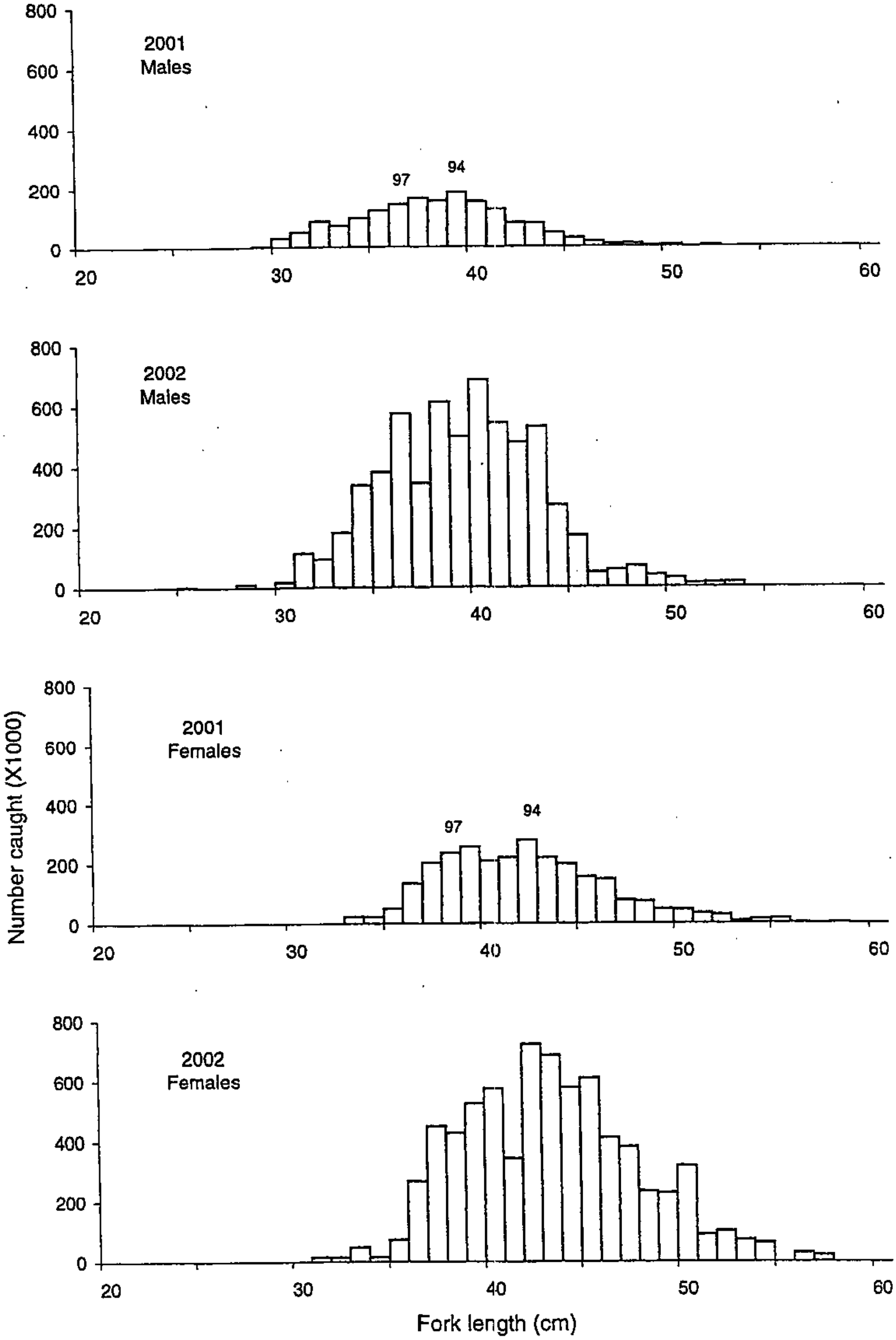


Figure 4: Weighted length frequency distribution of SBW for the Bounty Platform for the 2001 and 2002 seasons. The numbers above the modes are the most likely year classes corresponding to those length intervals.

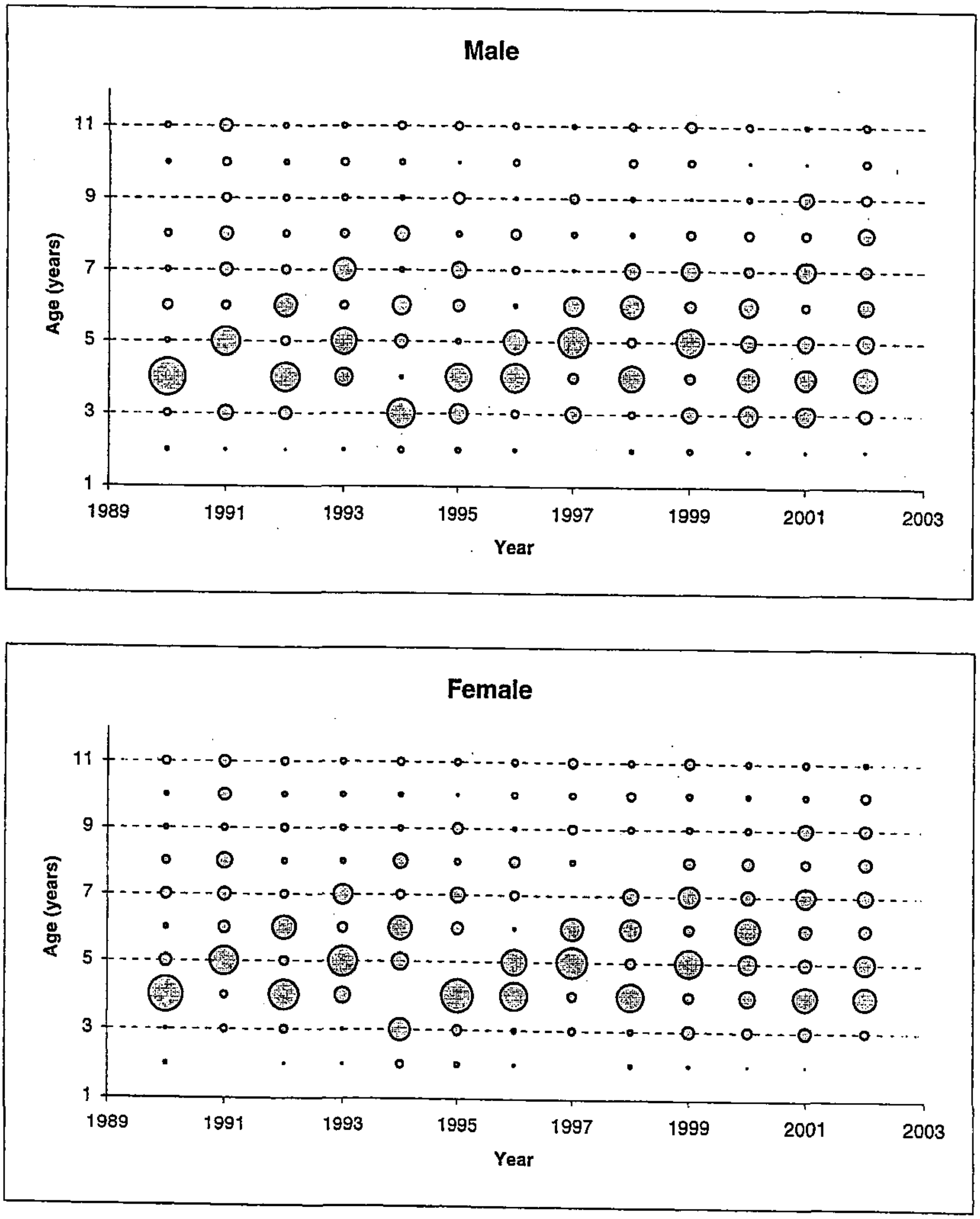


Figure 5: Male and female proportion at age in the Bounty Platform catch from 1990 to 2002. Symbol area proportional to the proportions-at-age within the sampling event

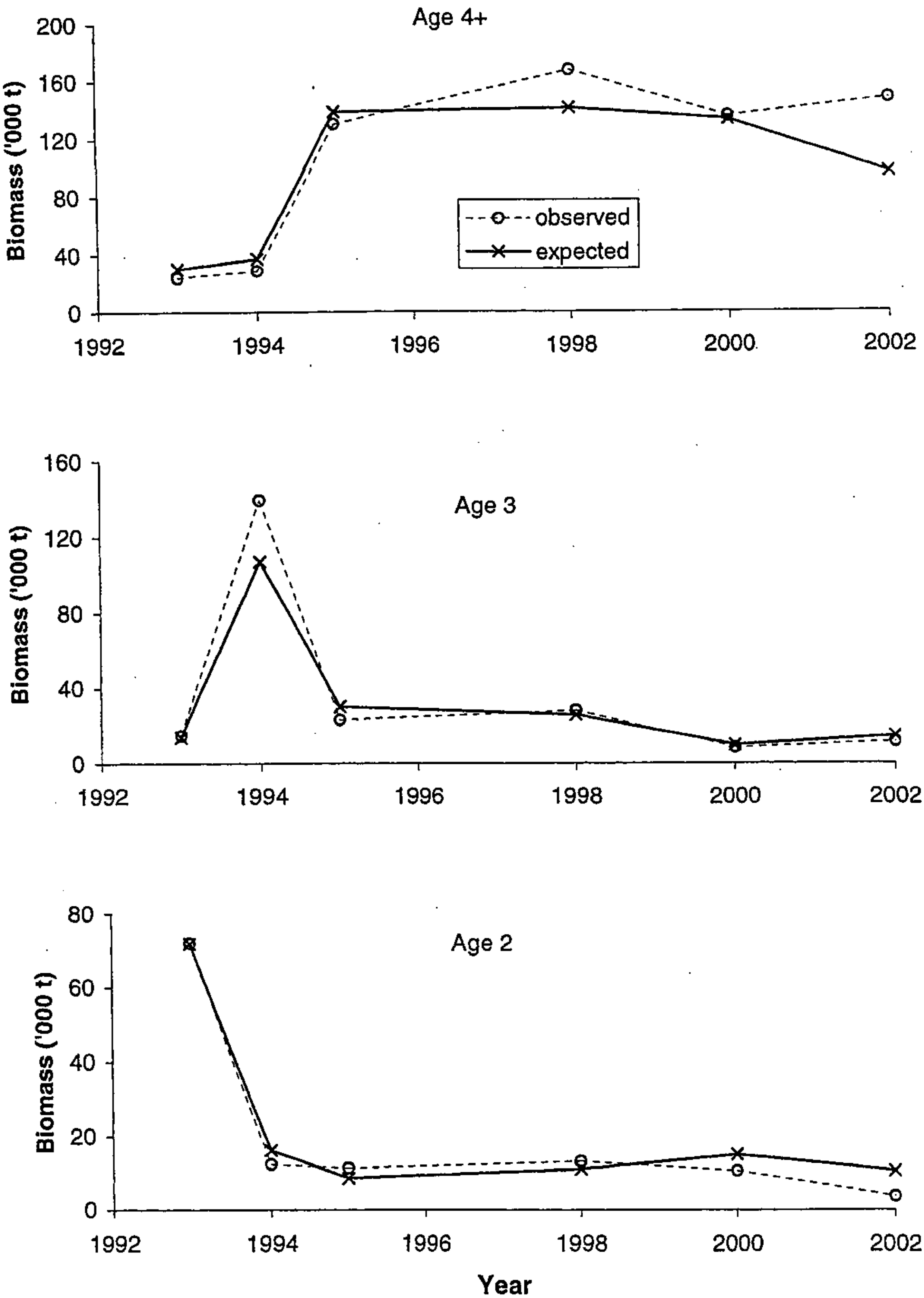


Figure 6: Estimated biomass from the model (expected) and the acoustics (observed scaled by the q s) for the MPD for base case 1 for age 2, 3, and 4+.

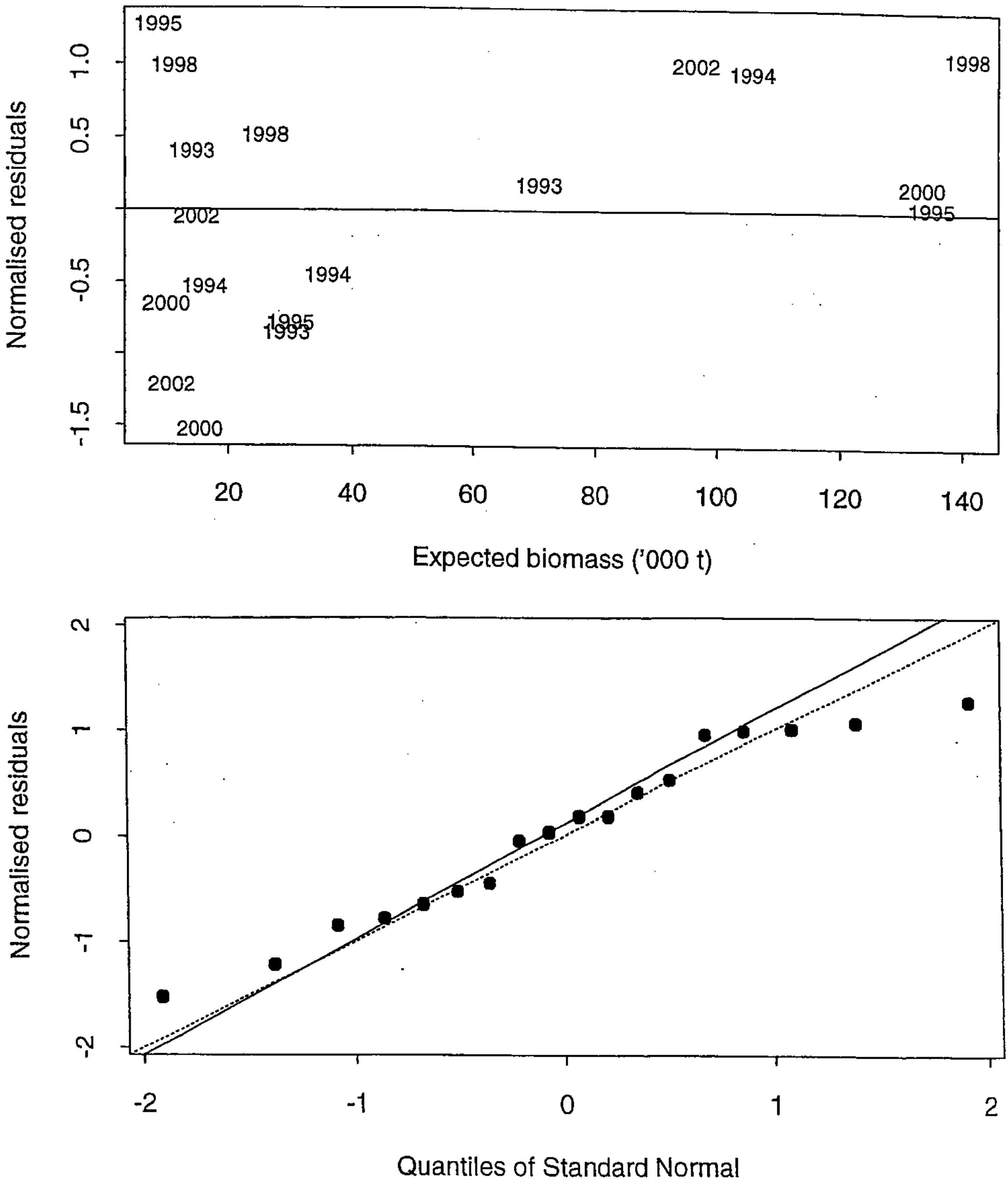


Figure 7: MPD (base case 1) normalised residuals (top) and QQ plot (bottom) for fit to all the acoustic indices combined.

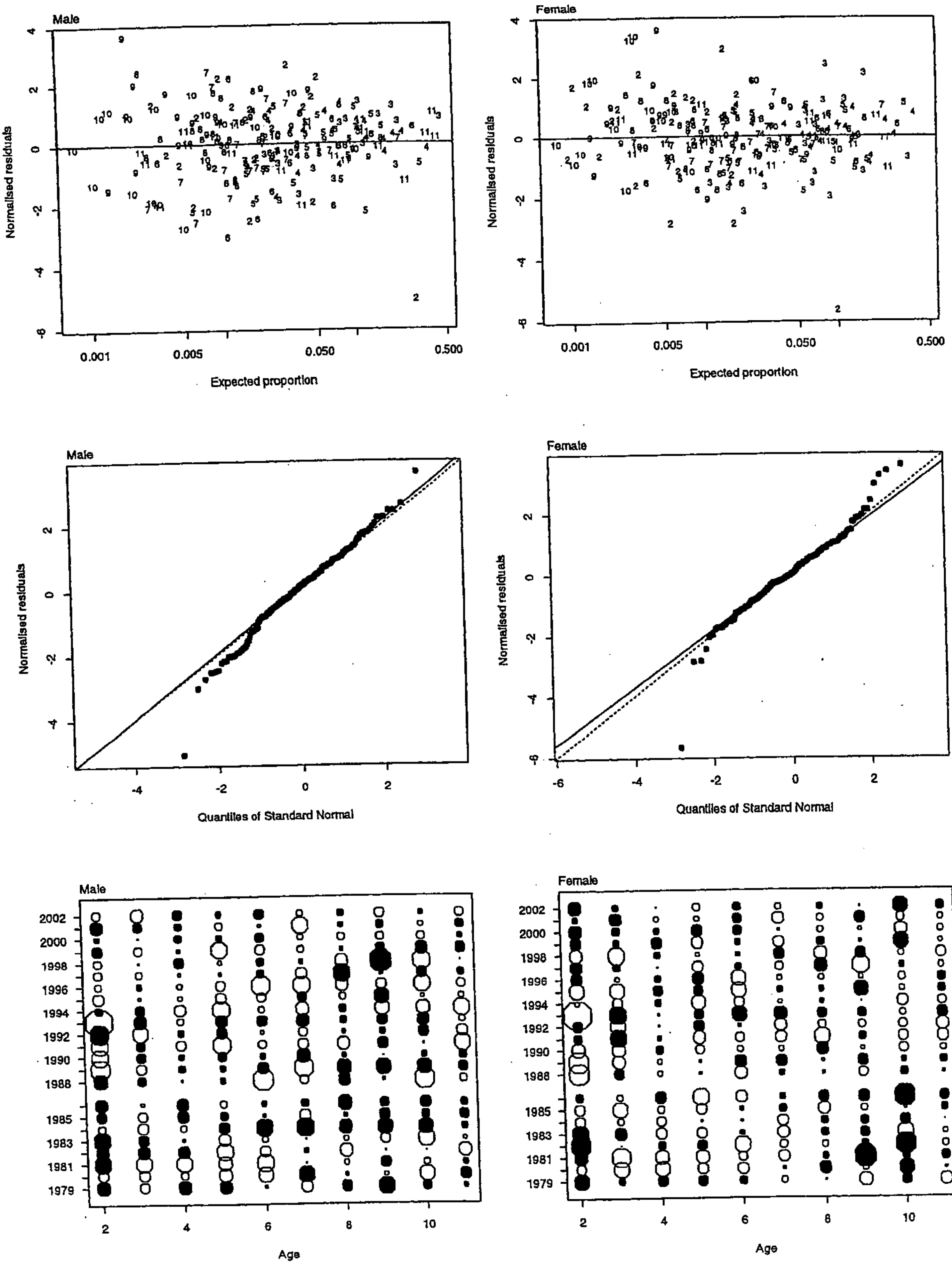


Figure 8: MPD (base case 1) normalised residuals (top), QQ plot (middle) and residual plot (bottom) for fit to the proportion-at-age data. Symbol area is proportional to the absolute value of the residual, with white circles indicating positive residuals and black circles indicating negative residuals.

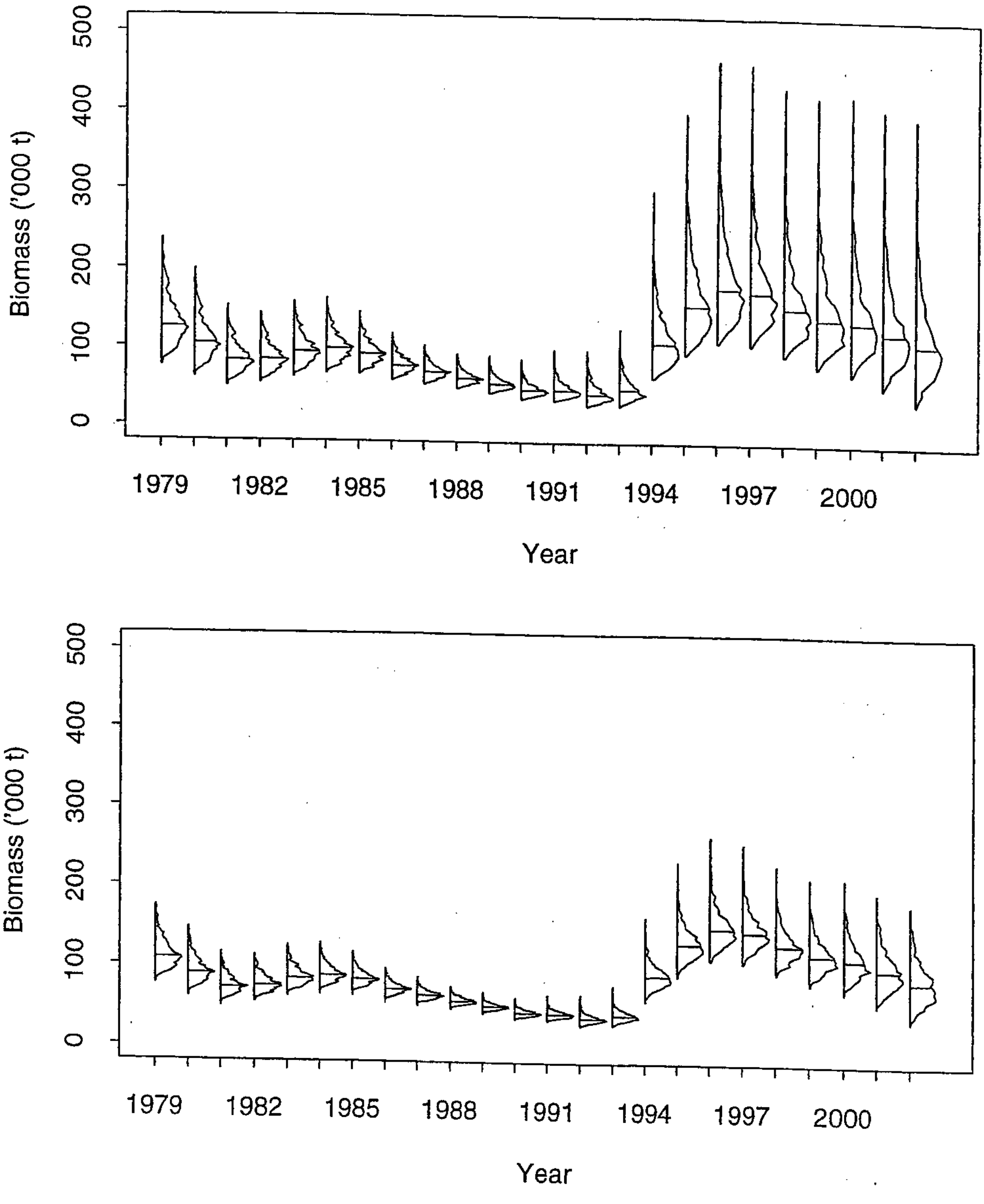


Figure 9: Estimated posterior distributions of mid season spawning stock biomass trajectories for base case 1 (top) and base case 2 (bottom). Horizontal lines indicate the medians.

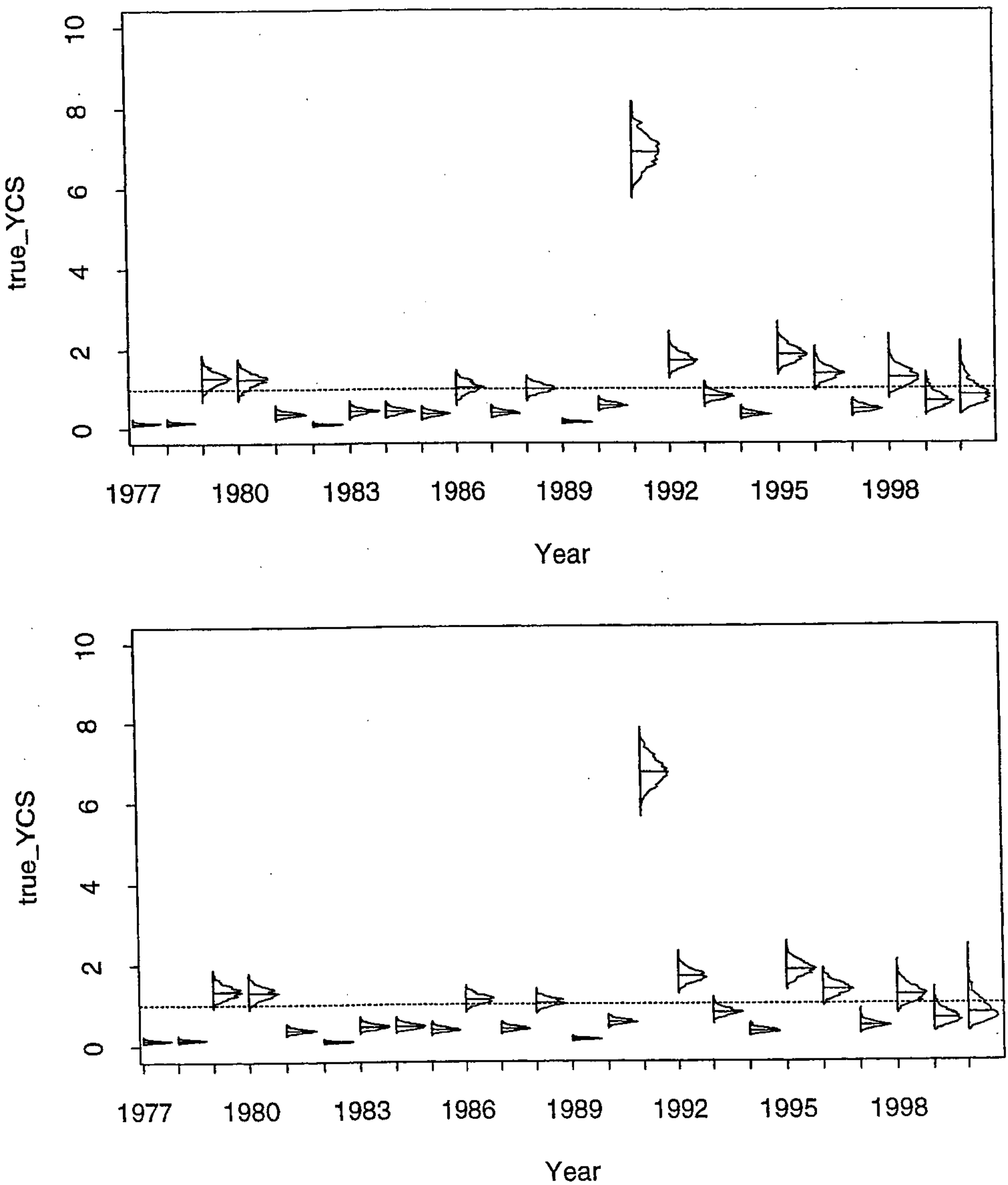


Figure 10: Estimated posterior distributions of year class strengths for base case 1 (top) and base case 2 (bottom). Horizontal lines indicate the medians.

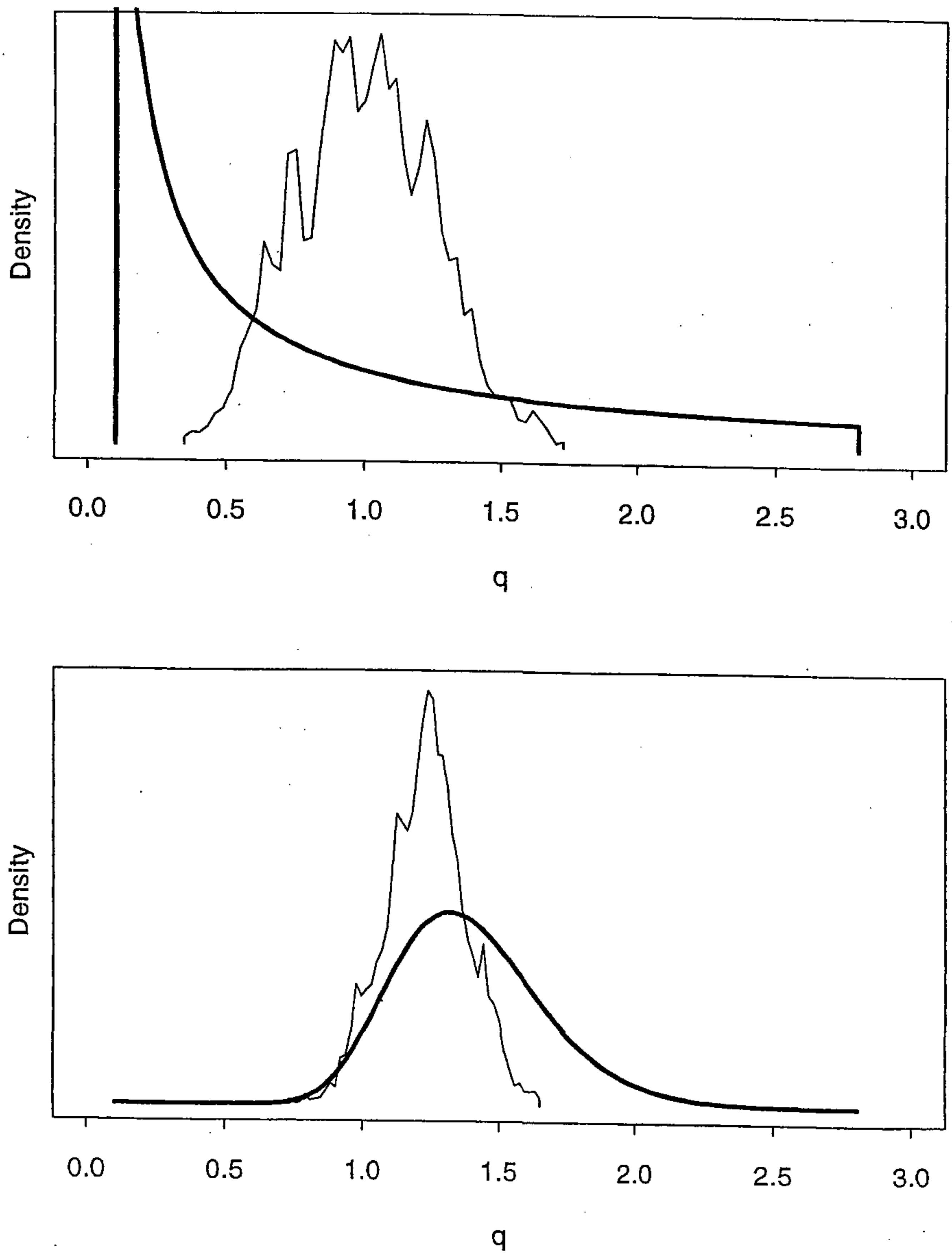


Figure 11: Prior (bold) and estimated posterior distributions of the adult survey relativity constant (age 4+ acoustic q) for base case 1 (top) and base case 2 (bottom).

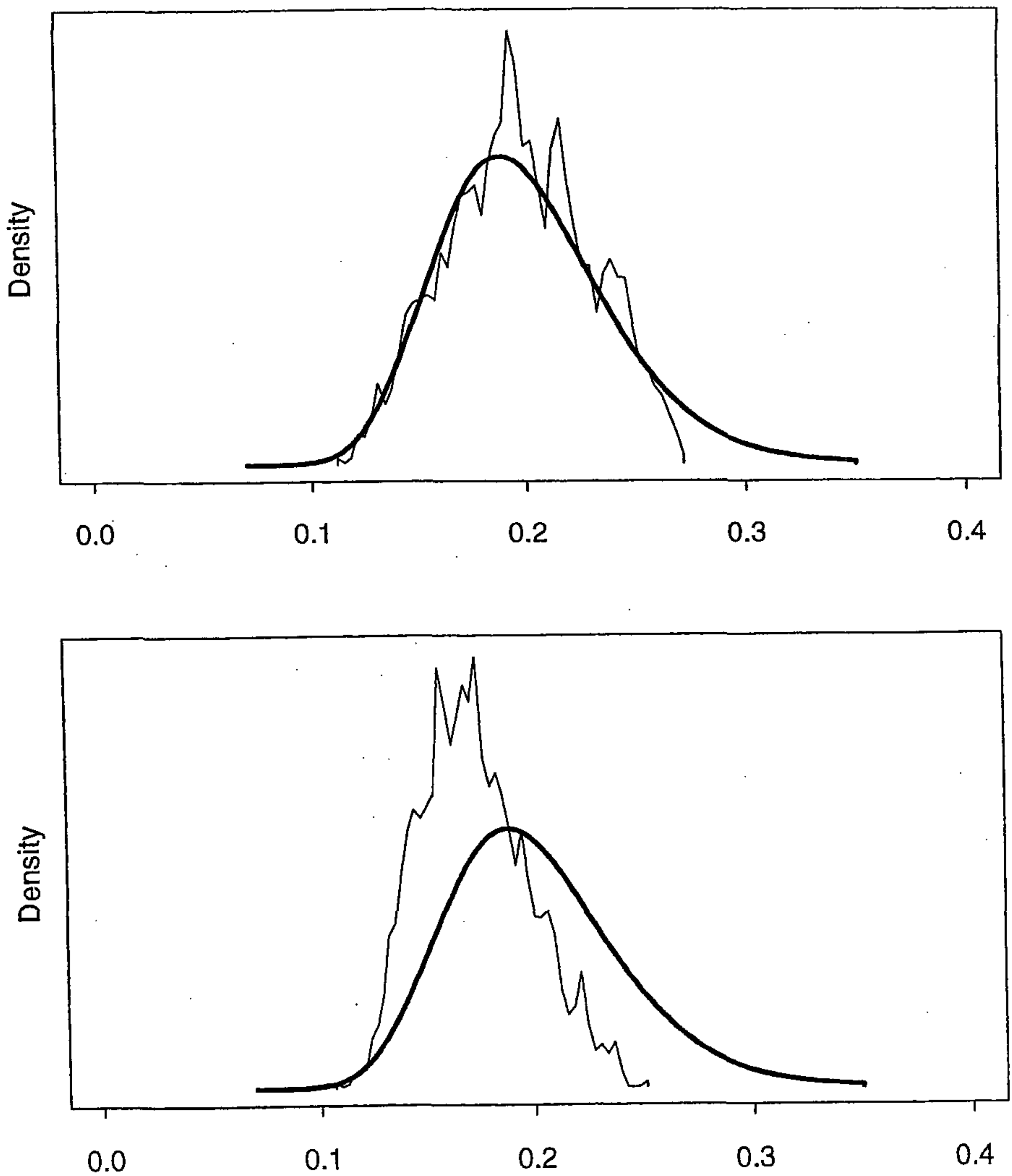


Figure 12: Prior (bold) and estimated posterior distributions of the average male and female natural mortality for base case 1 (top) and base case 2 (bottom).

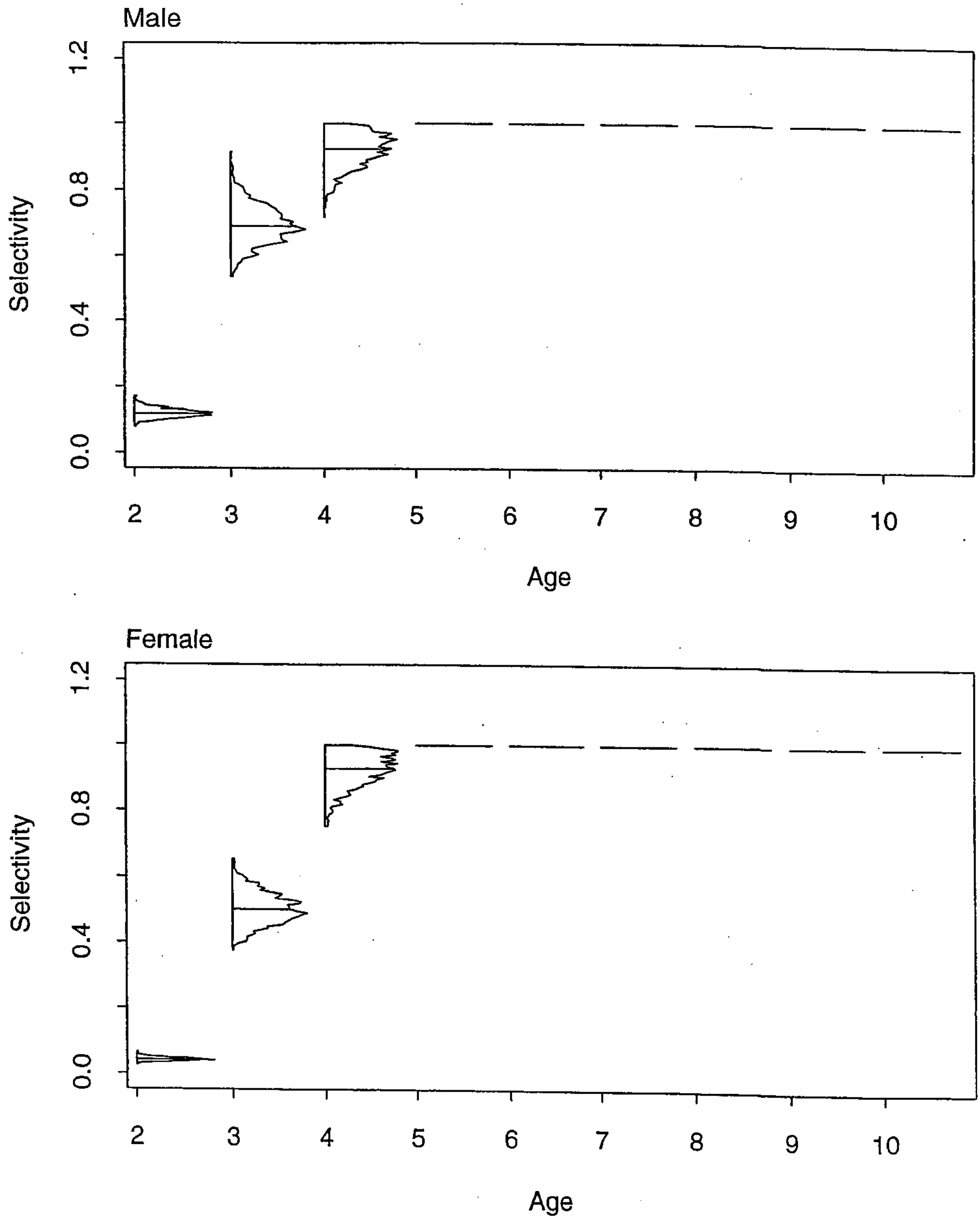


Figure 13: Estimated posterior distributions of fishing selectivity for ages 2, 3, and 4 for both sexes for base case 1 (base case 2 was very similar). Horizontal lines indicate the medians.

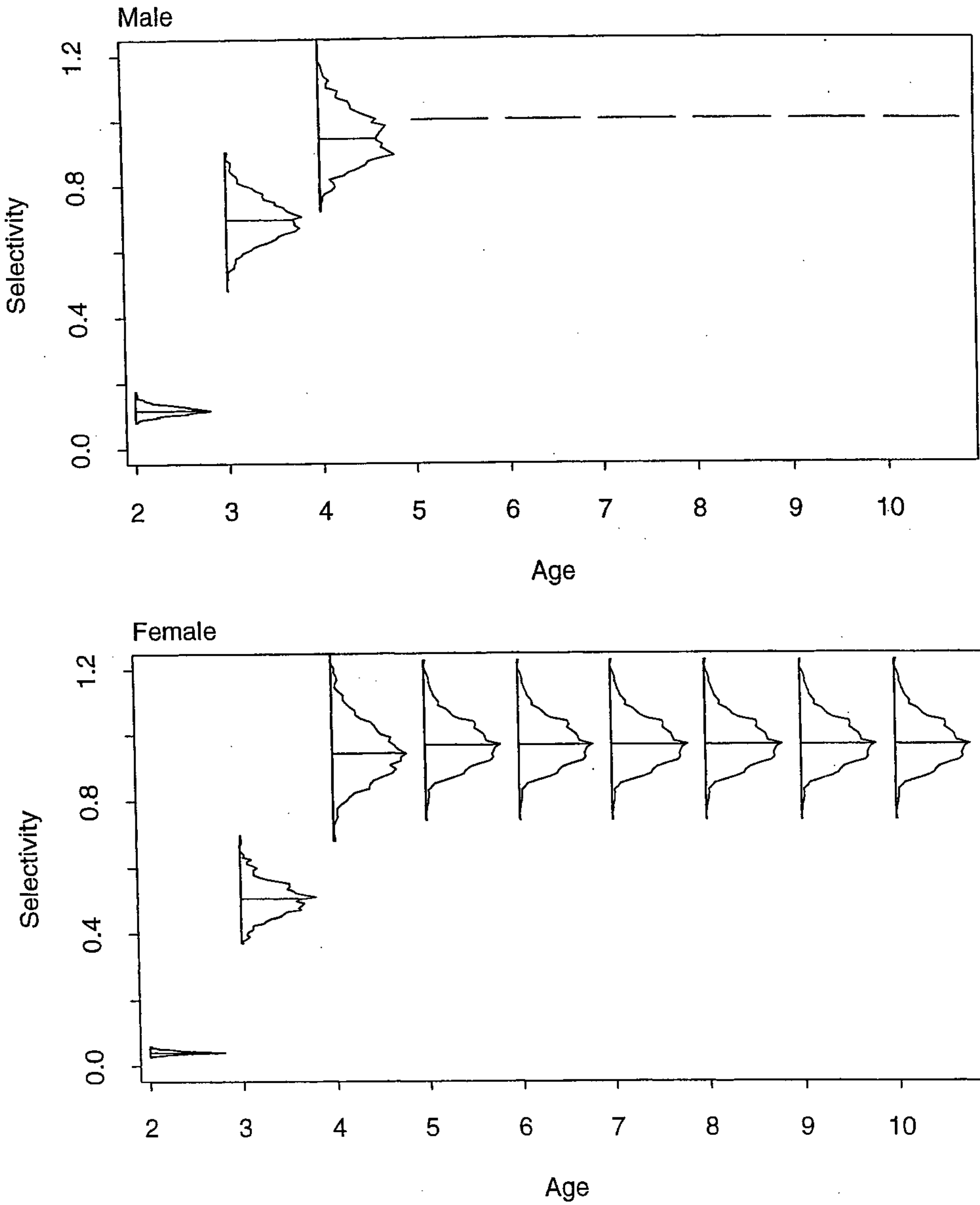


Figure 14: Estimated posterior distributions of fishing selectivity for ages 2, 3, 4 for both sexes, and for 5+ for fema for sensitivity run Select 5+ and est *M*). Horizontal lines indicate the medians.

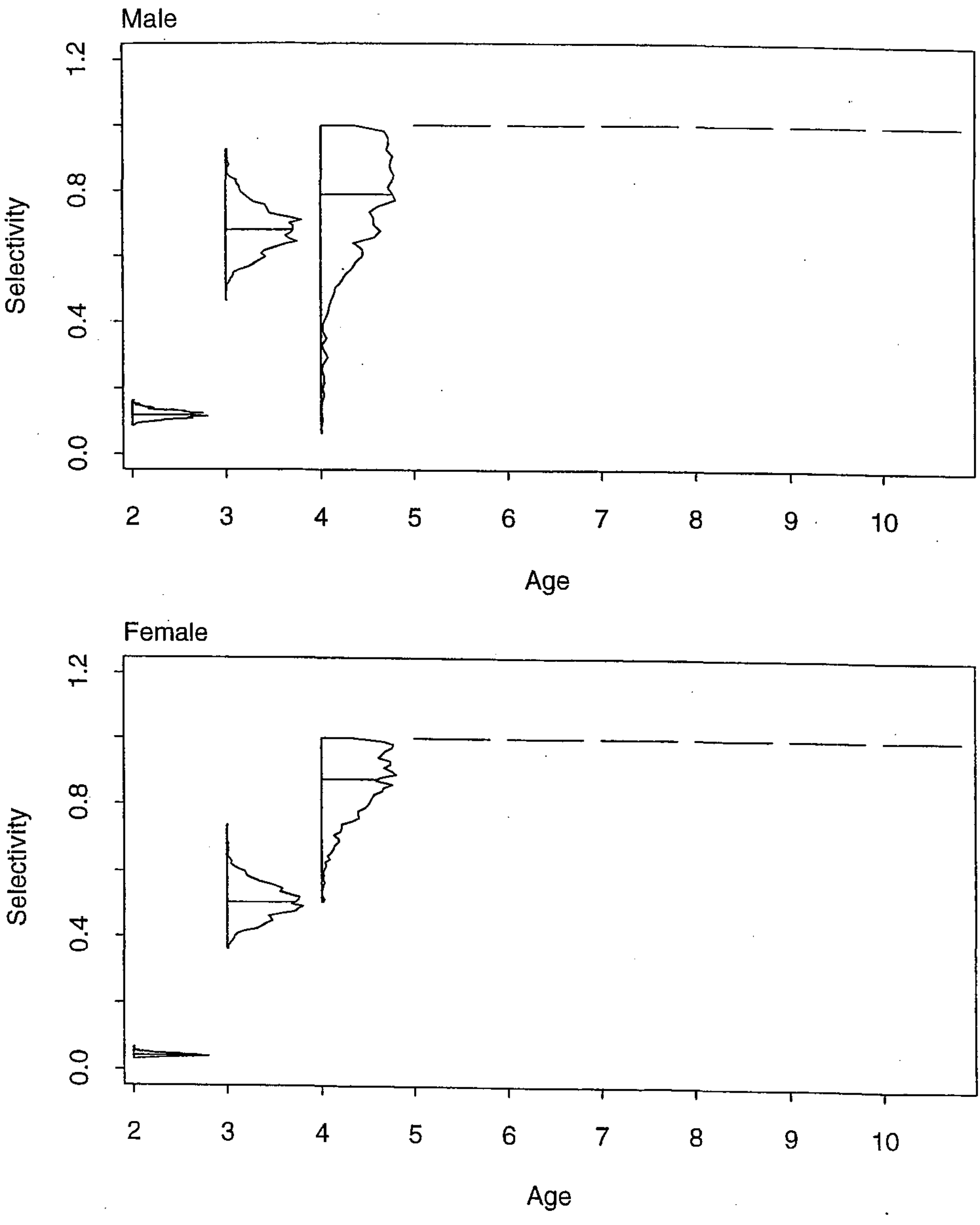


Figure 15: Estimated posterior distributions of maturity at age for ages 2, 3, 4 for both sexes for sensitivity run "Maturity partition". Horizontal lines indicate the medians.

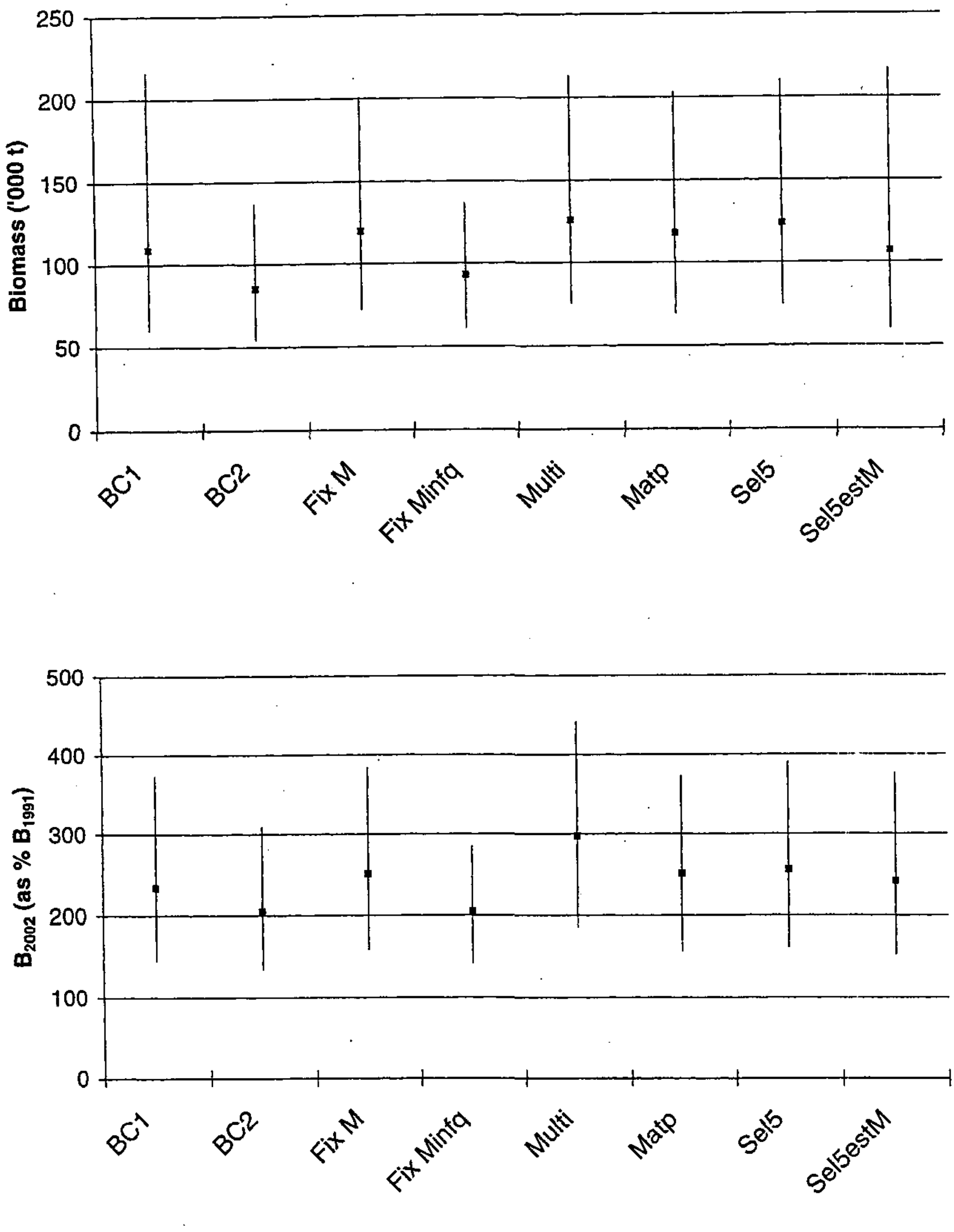


Figure 16: Median and 90% credible intervals for B_{2002} (top) and B_{2002} as a % B_{1991} (bottom) for the two base cases and sensitivity runs.

Appendix 1a: Number of male and female SBW in the Campbell fishery by age and year.

Males

Year	2	3	4	5	6	7	8	9	10	11+
1979	265	624	5 914	1 963	296	290	2 553	391	581	18 872
1980	37	198	503	753	62	516	288	526		11 198
1981	1 194	77	92	141	219	175	48	227	239	3 618
1982	1 225	5 655	653	46	222	817	73	69	165	2 530
1983	663	5 891	4 556	118	152	299	559	80		3 766
1984	34	563	2 781	3 684	583	479	376	815	252	2 569
1985	251	102	1 069	2 355	1 482	41	79	161	264	1 808
1986	658	1 753	681	1 068	3 664	3 081	465	202	288	3 232
1987	456	2 152	2 056	303	556	2 538	1 791	211	168	1 776
1988	2 514	2 917	2 680	2 179		624	3 711	1 764	18	1 673
1989	163	6 303	3 322	2 703	2 423		1 558	3 777	2 788	2 410
1990	600	3 477	6 546	1 639	1 084	1 206	99	271	837	1 607
1991	28	13 221	2 629	2 183	820	537	314	141	256	782
1992	2 190	349	6 505	1 855	1 752	252	285	213	49	424
1993	535	3 116	314	2 670	510	862	118	117	93	165
1994	1 122	24 027	908	64	761	96	322	9	10	37
1995	122	2 279	9 426	375	33	477	60	226	18	58
1996	84	1 615	3 009	8 184	167	27	187	42	35	55
1997	728	692	2 113	4 092	14 595	433	321	430	132	263
1998	949	7 764	2 152	2 542	5 760	15 399	353	743	99	347
1999	573	4 164	7 674	226	1 329	2 622	9 669	742	145	745
2000	699	1 028	3 952	3 801	606	586	1 010	3 140	149	288
2001	1 241	8 370	2 861	4 368	4 732	110	1 268	2 507	5 447	989
2002	754	2 222	8 812	2 031	5 103	3 045	513	416	1 498	3 606

Females

Year	2	3	4	5	6	7	8	9	10	11+
1979	125	355	3 583	1 073	415	128	688		368	6 392
1980	5	50	81	662	146	127	188	226	91	4 139
1981	314	14	112	36	346	73	68	208	164	2 388
1982	953	2 546	527	432	38	431	119	90	219	2 092
1983	261	4 907	3 171	212	282	40	604	187		1 979
1984	9	542	2 512	2 522	197	75	96	329	111	1 199
1985	38	45	612	1 408	1 553	144	24	23	128	868
1986	168	1 199	680	562	2 362	2 809	311	237	353	2 018
1987	233	2 190	2 507	285	662	1 754	1 662	178	131	1 186
1988	103	2 320	2 545	1 938	118	973	2 347	1 248	170	1 082
1989	29	4 037	2 772	2 375	2 604	391	666	2 668	1 528	1 303
1990	238	1 172	8 324	990	850	573	179	256	546	832
1991	122	17 327	4 354	4 170	888	595	242	103	176	1 000
1992	367	157	6 757	2 142	2 184	187	200	131	10	296
1993	43	3 500	446	2 655	830	997	145	103	39	250
1994	241	9 827	1 763	111	734	182	310	48	20	78
1995	12	819	14 365	891	33	450	88	245	15	74
1996	75	918	4 004	17 042	331	88	362	71	95	105
1997	648	799	2 267	2 688	14 191	528	215	162	96	186
1998	240	2 567	1 844	2 712	5 214	22 011	426	216	442	257
1999	202	4 517	11 076	458	2 075	1 983	11 666	529	241	499
2000	390	1 041	3 919	5 115	598	766	1 093	3 756	110	237
2001	261	7 544	2 200	5 036	6 897	366	951	2 894	4 898	668
2002	615	3 232	7 128	1 442	4 877	3 140	522	780	2 881	6 028

Appendix 1b: C.v. of number of male and female SBW caught in the Campbell Island fishery by age and year. MWCV, mean weighted c.v. for all ages.

Males

Year	2	3	4	5	6	7	8	9	10	11+	MWCV
1979	0.62	0.62	0.29	0.49	1.11	0.98	0.37	0.95	0.71	0.15	0.40
1980	0.93	0.57	0.42	0.34	1.22	0.68	1.06	0.64	0.00	0.13	0.40
1981	0.19	0.47	0.34	0.43	0.32	0.35	0.71	0.35	0.33	0.08	0.27
1982	0.27	0.10	0.26	0.91	0.45	0.24	0.69	0.76	0.49	0.15	0.23
1983	0.28	0.10	0.10	1.02	1.07	0.58	0.41	0.99	0.00	0.16	0.23
1984	0.62	0.32	0.13	0.11	0.31	0.38	0.33	0.23	0.41	0.13	0.23
1985	0.33	0.59	0.16	0.11	0.14	1.04	0.74	0.44	0.43	0.17	0.28
1986	0.27	0.16	0.28	0.24	0.11	0.12	0.32	0.47	0.38	0.12	0.22
1987	0.40	0.25	0.25	0.54	0.23	0.13	0.14	0.31	0.36	0.10	0.24
1988	0.08	0.11	0.14	0.16	0.00	0.37	0.11	0.20	0.66	0.20	0.18
1989	0.39	0.09	0.16	0.16	0.17	0.00	0.26	0.13	0.16	0.18	0.18
1990	0.17	0.09	0.07	0.18	0.19	0.20	0.67	0.39	0.18	0.16	0.15
1991	1.08	0.06	0.14	0.17	0.34	0.36	0.29	0.33	0.26	0.14	0.12
1992	0.13	0.41	0.06	0.13	0.13	0.41	0.39	0.46	0.99	0.32	0.14
1993	0.18	0.09	0.35	0.08	0.22	0.16	0.41	0.39	0.42	0.25	0.14
1994	0.28	0.04	0.18	0.40	0.13	0.32	0.19	1.20	1.11	0.48	0.06
1995	0.65	0.19	0.06	0.38	1.27	0.20	0.33	0.24	0.48	0.40	0.12
1996	0.76	0.27	0.19	0.09	0.36	0.48	0.33	0.44	0.48	0.58	0.15
1997	0.45	0.39	0.23	0.16	0.06	0.30	0.34	0.28	0.53	0.26	0.13
1998	0.28	0.08	0.39	0.40	0.23	0.10	0.58	0.37	0.62	0.43	0.17
1999	0.47	0.14	0.09	0.74	0.27	0.20	0.08	0.44	0.71	0.28	0.15
2000	0.20	0.38	0.15	0.17	0.54	0.56	0.34	0.18	0.54	0.36	0.24
2001	0.29	0.11	0.32	0.21	0.22	0.97	0.52	0.29	0.14	0.33	0.22
2002	0.18	0.20	0.10	0.33	0.18	0.24	0.68	0.72	0.29	0.19	0.21

Females

Year	2	3	4	5	6	7	8	9	10	11+	MWCV
1979	0.76	0.80	0.31	0.59	0.81	1.08	0.52	0.00	1.08	0.20	0.50
1980	2.18	0.97	0.69	0.33	0.60	0.74	0.62	0.59	1.00	0.13	0.41
1981	0.36	1.06	0.43	0.90	0.23	0.44	0.47	0.27	0.30	0.07	0.27
1982	0.28	0.15	0.25	0.28	0.69	0.23	0.40	0.47	0.29	0.09	0.24
1983	0.48	0.11	0.10	0.60	0.55	1.05	0.27	0.46	0.00	0.15	0.21
1984	0.55	0.29	0.12	0.11	0.36	0.63	0.45	0.22	0.49	0.13	0.21
1985	0.43	0.55	0.15	0.11	0.11	0.45	1.01	1.04	0.45	0.19	0.23
1986	0.37	0.20	0.30	0.26	0.11	0.10	0.39	0.43	0.31	0.13	0.23
1987	0.38	0.18	0.16	0.64	0.26	0.14	0.13	0.34	0.34	0.11	0.21
1988	0.38	0.11	0.14	0.14	0.70	0.24	0.14	0.20	0.60	0.21	0.21
1989	0.60	0.10	0.16	0.16	0.14	0.47	0.29	0.14	0.18	0.21	0.18
1990	0.34	0.17	0.06	0.26	0.25	0.30	0.45	0.33	0.23	0.19	0.15
1991	0.72	0.08	0.11	0.10	0.22	0.18	0.31	0.38	0.31	0.12	0.11
1992	0.21	0.79	0.06	0.14	0.13	0.49	0.46	0.52	1.28	0.37	0.13
1993	0.54	0.08	0.34	0.08	0.20	0.13	0.30	0.33	0.50	0.21	0.14
1994	0.69	0.06	0.13	0.41	0.14	0.23	0.16	0.40	0.54	0.39	0.10
1995	1.19	0.31	0.04	0.18	0.61	0.21	0.33	0.20	0.74	0.35	0.07
1996	0.57	0.39	0.14	0.05	0.19	0.37	0.18	0.39	0.31	0.33	0.09
1997	0.46	0.27	0.23	0.21	0.05	0.39	0.35	0.31	0.51	0.34	0.13
1998	0.30	0.15	0.32	0.23	0.15	0.05	0.40	0.41	0.38	0.27	0.12
1999	0.45	0.14	0.08	0.70	0.30	0.30	0.08	0.51	0.51	0.31	0.14
2000	0.26	0.32	0.13	0.11	0.46	0.32	0.29	0.11	0.47	0.26	0.17
2001	0.60	0.09	0.34	0.18	0.11	0.44	0.32	0.17	0.13	0.27	0.16
2002	0.26	0.20	0.11	0.31	0.15	0.17	0.42	0.37	0.18	0.11	0.18

Appendix 2: Mean length at age of male and female SBW in the Campbell fishery by year.

Males

Year	2	3	4	5	6	7	8	9	10	11+
1979	29.8	33.5	38.8	41.6	44.0	43.0	44.0	44.5	43.0	43.1
1980	29.5	34.4	38.4	39.8	40.0	41.0	44.0	41.3	44.3	44.8
1981	29.4	35.3	37.5	40.2	42.7	43.1	44.5	44.4	44.3	44.3
1982	28.0	33.9	38.1	38.5	43.8	43.0	44.0	45.5	44.0	44.3
1983	29.2	34.8	37.1	41.0	42.0	43.7	44.2	44.0	45.7	44.6
1984	29.5	34.6	38.5	40.4	42.2	43.4	44.1	44.6	45.7	45.4
1985	29.7	34.0	39.0	41.3	42.5	43.0	43.5	46.4	46.3	46.1
1986	28.9	34.5	38.4	41.7	42.6	43.6	44.7	45.8	45.5	46.2
1987	29.5	35.4	39.4	40.8	43.0	43.8	44.6	46.4	45.4	47.3
1988	30.3	35.7	39.5	41.2	43.0	43.9	45.2	45.8	50.3	48.3
1989	28.4	35.6	39.3	41.6	43.3	43.9	45.8	45.8	46.2	47.0
1990	27.3	35.7	39.3	42.1	43.4	44.9	46.0	45.9	46.9	47.5
1991	27.0	34.4	39.6	42.5	44.5	46.1	46.3	47.6	47.7	48.6
1992	32.3	35.5	39.4	42.8	44.7	46.5	45.9	48.0	48.0	48.6
1993	27.5	36.4	41.7	41.8	45.3	45.8	46.7	48.1	47.8	49.1
1994	27.4	31.0	40.8	42.7	43.7	45.5	46.0	49.0	47.0	51.0
1995	28.3	31.7	33.8	40.8	43.0	45.2	47.5	47.1	48.7	49.5
1996	27.8	33.8	35.1	36.5	44.8	46.6	46.2	47.4	47.8	48.6
1997	24.0	35.4	36.9	37.1	38.6	45.0	46.4	47.4	47.3	48.6
1998	24.7	30.1	37.4	38.3	39.0	39.6	45.0	46.3	49.3	49.2
1999	28.0	31.5	33.9	38.5	39.7	39.4	40.5	45.0	45.7	47.8
2000	27.8	34.5	35.8	37.7	40.3	41.5	41.9	42.6	46.5	47.8
2001	27.9	33.2	36.2	37.8	39.4	44.0	40.7	42.2	42.8	47.2
2002	28.4	34.8	37.1	38.9	40.6	41.6	43.0	42.5	43.4	45.1

Females

Year	2	3	4	5	6	7	8	9	10	11+
1979	29.8	34.1	40.0	42.0	44.0	44.0	45.8	46.3	46.0	46.2
1980	29.5	34.7	38.8	41.5	42.8	47.0	46.0	46.3	48.0	49.2
1981	29.0	36.4	38.7	40.0	44.4	45.3	46.8	46.3	46.2	48.1
1982	29.0	35.0	38.5	42.6	45.5	45.7	46.6	47.0	47.9	49.1
1983	27.9	36.0	38.9	42.7	43.5	48.0	46.0	47.6	47.9	49.2
1984	29.5	34.5	40.7	43.2	45.9	47.0	47.2	47.4	47.8	48.3
1985	29.5	34.8	40.5	43.2	45.0	45.8	48.0	46.0	47.6	49.5
1986	29.1	35.2	38.5	41.6	44.5	45.7	47.6	48.5	49.0	49.6
1987	30.8	38.2	40.3	41.8	44.6	45.8	46.7	48.9	49.7	50.8
1988	30.2	37.4	41.6	42.8	41.5	46.8	47.3	48.0	50.5	52.2
1989	28.5	36.9	41.4	43.7	46.6	47.2	48.7	48.9	50.0	50.8
1990	29.3	35.9	41.0	44.4	46.0	47.6	48.0	49.3	49.9	51.0
1991	27.9	35.4	41.9	44.9	47.2	48.3	48.2	51.4	51.0	52.0
1992	31.1	39.0	41.1	45.4	47.5	49.2	50.5	49.0	53.0	52.5
1993	28.1	38.5	40.8	44.0	47.3	48.6	50.1	50.8	50.8	52.5
1994	26.3	33.1	41.9	44.8	46.3	48.6	49.9	50.2	51.0	54.1
1995	27.0	34.3	36.1	43.6	46.3	47.3	50.3	49.8	52.7	51.8
1996	28.9	33.6	37.5	39.1	47.2	47.8	48.9	50.8	50.5	52.1
1997	28.9	36.8	39.0	39.7	42.0	46.3	49.2	49.9	51.4	52.5
1998	25.4	30.8	37.7	41.5	41.6	42.8	48.9	50.4	50.1	50.9
1999	29.0	34.0	35.7	39.5	41.7	43.8	44.2	47.6	48.3	51.2
2000	29.1	35.0	37.0	39.3	42.2	44.5	45.1	46.3	49.9	51.6
2001	27.4	35.0	38.3	39.9	41.9	46.2	46.1	47.0	47.1	51.3
2002	30.3	36.6	39.4	40.5	42.9	43.9	47.5	47.3	47.3	48.3