ISSN 1175-1584

MINISTRY OF FISHERIES
Te Tautiaki i nga tini a Tangaroa

Southern blue whiting (*Micromesistius australis*) stock assessment update for the Campbell Island Rise for 2005

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New Zealand Fisheries Assessment Report 2005/40
August 2005

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New Zealand Fisheries Assessment Report 2005/40
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Published by Ministry of Fisheries
Wellington
2005

ISSN 1175-1584

Citation:
Hanchet, S.M. (2005).
Southern blue whiting (*Micromesistius australis*) stock assessment
update for the Campbell Island Rise for 2005.
New Zealand Fisheries Assessment Report 2005/40. 40 p.

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

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 2004, and presents an updated 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 updated Campbell Island Rise stock assessment used Bayesian estimation with the NIWA modelling program CASAL v2.06. New information since the 2003 assessment included the results of an acoustic survey carried out in 2004 and two more years of proportions-at-age data from the commercial fishery.

Because this was an updated assessment, and carried out within a very limited timeframe, only four initial runs were made. Three of these runs captured most of the variability. These runs differed in the priors used for the adult 4+ acoustic q and in the indices used for the acoustic survey series. For the final assessment, the Working Group agreed to use one of those runs as a base case, and to present the other two runs (which bracket the base case) as sensitivities. In the base case run the series with the higher acoustic biomass estimates was used and the adult 4+ acoustic q had a lognormal (informative) prior. In all runs natural mortality was estimated in the model with a lognormal prior.

The base case run suggests 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, 1998, and 2001 year classes, all of which also appear to be above average. The median estimates of mid-season biomass in 2004 (B_{2004}) for the base case is 82 000 t. The 90% confidence intervals of B_{2004} from the MCMC runs were 51 000–122 000 t. The sensitivity runs show that the estimates of B_{2004} and stock status are very sensitive to the choice of acoustic biomass series and the prior used for the acoustic q.

Estimates of B_0, B_{2002}, and B_{2002}/B_{1991} were compared between the current assessment and the last assessment carried out in 2003. Current estimates of these parameters are very similar to those of the previous assessment. The assessment results show the model to be moderately robust, which is shown by the similarity with previous assessments and the tight uncertainty intervals on the biomass posteriors.

Current stock size is estimated to be at about B_{may}. Two-year stochastic projections were made assuming fixed catch levels from 10 000 to 25 000 t per year with parameter uncertainty defined by the MCMC samples of the posterior distribution. At catches of 20 000 t or more, the biomass is projected to decline below B_{may}. The probability that the mid-season biomass for the specified year will drop below the threshold biomass (B_{1991}) reaches 13% by 2007 at catches of 25 000 t. 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. Risks based on the alternative threshold biomass (20% B_0) exceeded 10% by 2006 at catches of 25 000 t and by 2007 at catches of 20 000 t. $CAY_{2004-05}$ is estimated to be 19 000 t, which is consistent with these results.

1. INTRODUCTION

1.1 Overview

Southern blue whiting (*Micromesistius australis*) (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). Assessments of the Campbell Island Rise and Bounty Platform stocks have recently been carried out in alternate years. An acoustic survey of the Campbell Island Rise was carried out in August–September 2004 and the assessment for this stock was updated based on the results of that survey 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 v2.06 (Bull et al. 2004). 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 2005 to 2007.

1.2 Description of the fishery

Since 1986, commercial fishing for SBW has been focused on 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 in September while fish were spawning 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 sporadically at a low level 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 2000–01, increased to 45 140 t for 2001–02 and 2002–03, and then decreased to 35 460 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. Off-season catches were about 350 t in 2000–01, 2200 t in 2002–03, and 200 t in 2003–04.

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 using *Tangaroa*, and results of recent surveys were reported by Hanchet et al. (2002a, 2003a) and O'Driscoll et al. (2005). The first industry survey of the Campbell stock was carried out in September 2003 (O'Driscoll & Hanchet 2004). 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 SBW density estimates. Results of recent acoustic target strength work were summarised by McClatchie et al. (1998) and Dunford (2003), 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 2003, a Bayesian assessment of the Campbell Island Rise stock was made using the CASAL software for the first time (Hanchet et al. 2003b). The first Bayesian assessment of the Bounty Platform stock using the CASAL software has also recently been completed (Hanchet, unpublished results). Standardised CPUE analyses of the Bounty and Campbell stocks were summarised by Hanchet & Blackwell (2003).

1.4 Objectives

This report addresses objectives 1 and 2 from MFish project SBW2004/01.

1. To determine catch-at-age from the commercial fisheries at Campbell Island Rise, Auckland Island, Bounty Platform, and Pukaki Rise for 2004–05 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 assessment 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 1998–2000 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. Stock assessments carried out in that year suggested these catch levels were not sustainable. The TACCS for 2003–04 were reduced to 25 000 t for the Campbell Island Rise stock and to 3500 t for the Bounty Platform stock, and these changes retained for 2004–05. SBW has been managed using a Current Annual Yield (CAY) strategy (Annala et al. 2004), which has resulted in the fluctuating catch limits and TACCs shown in Table 1.

2.1.2 Landings

Estimates of the annual landings of SBW by fishing year are given in Table 1. The reported landings for the 2004 season (2004–05 fishing year) from the Quota Monitoring Reports was 21 173 t. The TACC was undercaught in all four stocks.

The level of illegal and unreported catch is thought to be low; however, the operators of one vessel have recently been convicted for area misreporting. In 2002–03, the vessel caught about 204 t on the Campbell Island Rise (SBW 6I) that were reported against quota for the Pukaki Rise (SBW 6R), and another 480 t caught on the Campbell Island Rise were reported against quota for the Auckland Islands Shelf (SBW 6A). Table 1 shows corrected totals by area for 2002–03.

2.1.3 The 2004 season

The location of trawls made during the 2004 season (mid August to early October) is shown in Figure 1. Fourteen vessels, including 3 from Japan, 4 from Ukraine, and 4 from New Zealand fished for southern blue whiting during the 2004 season (Table 2). This is the most New Zealand vessels that have taken part in this fishery to date. The first vessel arrived on the Bounty Platform on 26 August. Fishing was poor until 29 August when vessels found an aggregation of SBW to the southwest of the Bounty Islands. Catches remained high until 31 August, but then dropped off, and the vessels had all left for the Campbell Island Rise by 2 September. Significant numbers of spawning females (over 10%) were recorded only on the first tow, suggesting that the spawning may have occurred earlier (see also Section 2.2.3). Three vessels fished there during the 6-day period, made 24 tows and took 1500 t.

Three vessels fished the Pukaki Rise during early October, making only nine trawls. The total catch during the season was only 34 t. No data are available from observers and the timing of the spawning is unknown. The total catch from this stock for the 2004–05 fishing year is 97 t. One vessel reported a single trawl from the Auckland Islands Shelf this season and caught only 5 t. The total catch from this stock for the 2004–05 fishing year is 48 t.

As in previous years, most fishing was carried out on the Campbell Island Rise stock. Vessels started fishing on the Campbell Island Rise on 28 August and fished in the north-east of the area. As in previous seasons there were two main aggregations one to the north and one to the south. However, the aggregation in the north comprised at least three smaller aggregations, which were fished at different times during the pre-spawning and spawning period. Most of the fishing in the north was carried out further east than is normal, continuing the pattern seen over the past few seasons (see Section 3.2.1). Fish were spawning in the north between 12 and 19 September. Two Japanese vessels made several trawls in early September in the south, but the catches had a high proportion of small fish, unsuitable for processing, and so they returned north (R. O'Driscoll, NIWA, pers. comm.). After the first spawning was finished on the northern ground, most vessels moved to the southern aggregation for several days. Vessels located fish spawning their second batch of eggs to the east of Campbell Island from 27 to 30 September. All vessels had finished fishing by 13 October. A total of 19 700 t was taken during the 2004 season by 14 vessels (Table 2).

2.1.4 CPUE analysis

Standardised CPUE analyses were carried out for the SBW spawning fisheries on the Campbell Island Rise from 1986 to 2002, and on the Bounty Platform from 1990 to 2002 by Hanchet & Blackwell (2003). Indices were calculated using lognormal linear models of catch per tow, catch per hour, and catch per day for all vessels, and catch per tow for subsets of vessels based on processing type (surimi or dressed), and by relative experience in each fishery. The authors summarised the data and the method of calculating the indices, and then compared the CPUE indices with the results of recent stock assessments.

The Campbell Island Rise analysis was based on 11 853 non-zero records, from 1986 to 2002. CPUE indices decreased slowly to a minimum in 1992, increased to a peak in 1996, followed by a slight decline to 2002. This trend was consistent among alternative measures of effort and among subsets of surimi and dressed vessels. The trends in CPUE for the Campbell Island Rise fishery were consistent with the trends in the 2003 NIWA assessment model of Hanchet et al. (2003b). Hanchet & Blackwell (2003) concluded that the CPUE indices for the Campbell Island Rise were monitoring the stock abundance and could be used in future stock assessments. However, they cautioned that there was considerable variability in the CPUE indices for individual years, and that several years' data may be necessary before any new trends become apparent. The analysis was not updated to include more recent data, and the indices were not included in the assessment update.

2.2 Other Information

2.2.1 Size and age composition of the commercial catch

Scientific observers collected length-frequency data from almost 20% of all tows in the commercial fishery during 2004 (Table 2). A total of 709 and 194 otoliths, collected from the Campbell Island Rise and Bounty Platform fishing grounds respectively during the 2004 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. Catch-at-age data for each stock were reanalysed in 2003 using the NIWA catch-at-age software (Bull & Dunn 2002). The revised catch-at-age series for the Campbell Island Rise were presented by Hanchet et al. (2003b).

The weighted length-frequency data for the Campbell Island Rise stock are shown by sex and ground for 2004 in Figure 2. The size distribution for 2004 was strongly bimodal. The proportion of fish in each of the two modes varied considerably between vessels and ground fished. In general, vessels caught a higher proportion of large fish in the northern area, and a higher proportion of small fish in the southern area. The exceptions were one Japanese vessel, which caught a much higher proportion of larger fish in both areas, and a Korean vessel, which caught a much higher proportion of small fish in all areas. The reason for these differences in size distribution between vessels is not known.

The weighted length-frequency data for the Campbell Island Rise stock are shown for the past four years in Figure 3. The overall size distribution for 2004 was bimodal with the heights of the two modes being approximately equal. The first mode was dominated by 3 year old fish (the 2001 year class), whilst the mode of larger fish comprises the 1995, 1996, and 1998 year classes together with the plus group (mainly the strong 1991 year class) (Figure 4).

The weighted length-frequency data for the Bounty Platform stock for recent years are shown in Figure 5. The population is currently dominated by larger fish ranging from 38 to 50 cm. The proportion-at-age in the catch for the Bounty Platform stock by sex is shown in Figure 6. The catch for the 2004 season was numerically dominated by 5, 6, and 7 year old fish (the 1997–1999 year classes). These year classes were all estimated to be of a similar size (slightly below average) in the last stock assessment in 2004 (Hanchet, unpublished results). There are therefore no indications of new strong year classes entering the fishery, and so there is no evidence of stock recovery.

2.2.2 Timing of spawning

The timing of spawning on the Bounty Platform could not be accurately determined this year (Table 3). The first trawl sampled on 26 August was the only one with significant numbers (over 10%) running ripe fish. For the following week, samples comprised a mixture of ripening and ripe fish suggesting that the first spawning had already finished.

Spawning was later than usual this year on the Campbell Island Rise (Table 3). The first fish were sampled on the northern ground on 4 September, and 10% of the fish were ripe by 9 September. However, fish did not start spawning (over 10% running ripe) until 14 September. This is surprising because it usually only takes 1–2 days for fish to progress from ripe to running ripe (Hanchet 1998a). Gonad data collected from the *Tangaroa* acoustic survey first recorded 10% running ripe fish on 12 September (O' Driscoll et al. 2005), suggesting there may be slight differences in timing of spawning between the different aggregations. The first spawning was finished by 19 September. The second spawning occurred on the southern ground from 26–30 September. No data were available for the other two areas.

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

Acoustic surveys of southern blue whiting have been carried out since 1993. A further acoustic survey of the Campbell Island stock was completed in August–September 2004 (O'Driscoll et al. 2005) Two snapshots were carried out on pre-spawning and spawning aggregations on the Campbell Island Rise. The distribution of fish on the 'northern' ground during the 2004 survey was quite different to that of previous years. Most of the fish caught by the commercial vessels, and about 50% of the biomass from the acoustic survey, came from several aggregations to the east of the core survey area (see also Section 2.1.3).

There are two possible hypotheses regarding the observed distribution of fish outside the core area: (1) the northern aggregation had moved further east and was spawning outside the survey area; (2) the fish which previously had spawned in the northern area had been depleted and the fish observed outside the core area represent a new unsurveyed part of the population. Under hypothesis 1, the biomass estimate used in the assessment model should include all fish surveyed because it implies that the proportion of the surveyed population within the core area has changed. Hypothesis 2 implies that the proportion of the total biomass within the core area has remained unchanged and that the biomass estimate used in the assessment model should include only those fish surveyed in the core area. The two hypotheses represent extreme ends of a continuum, so that the fish outside the core area could include both fish that have a changed distribution as well as previously unsurveyed fish.

Recent catch/effort and length frequency data were examined to assess which hypothesis was more likely. The positions of commercial trawls carried out in September during the 1997–2004 SBW seasons are shown in Figure 7. There was some fishing outside the main acoustic survey area before 2002, but this was relatively limited. In 1998, vessels started fishing deeper outside the stratum 3 boundary early in the season, but were all fishing within the survey area on the boundary between strata 3 and 4 by the time of the first snapshot. In 2000, the fleet spent one day fishing east of stratum 6 but caught very little (only 400 t in 22 tows). In 2001, vessels fished east of stratum 6 late in the season (after 23 September) as they followed spent fish leaving the area to the east. The first year when there were significant catches outside the survey area during the main spawning season was in 2002. One vessel fished at about 172° E from mid July and the fleet shifted to this eastern aggregation on 12 September, catching about 3000 t in three days. The eastern aggregation was surveyed as a fleet stratum during the 2002 *Tangaroa* acoustic survey, but no particularly dense marks were detected and the estimate of adult biomass was only 4400 t (Hanchet et al. 2003a). In 2003, the main northern aggregation was centred in the north of stratum 6, but also extended east (into stratum 8) (O'Driscoll & Hanchet 2004). The pattern of fishing was even more extreme in 2004, with most of the effort in the north, outside the usual survey boundaries (Figure 7).

The size distributions of male and female SBW from the northern, eastern, and southern aggregations for 2001–2004 are shown in Figure 8. (For this analysis, northern fish were defined to be north of 51°45'S, eastern fish to be east of 171°E, and southern fish to be south of 53°S.) In each of the four years the size distributions of fish in the northern and eastern aggregations were very similar, whilst the size distributions of fish in the southern aggregations were quite different. If the northern aggregation had experienced high exploitation while the eastern aggregation had experienced little or no exploitation, the size or age structures of the two aggregations should differ. Since this was not the case, this lends more support for hypothesis 1, but does not rule out hypothesis 2. The stock assessment was run using both sets of acoustic biomass estimates to examine the stock status under each hypothesis (see Section 4.5). The acoustic biomass estimates for all years and both hypotheses are given in Table 4.

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 2003). 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.

4. ASSESSMENT OF THE CAMPBELL ISLAND RISE STOCK

4.1 The stock assessment timetable

The last assessment of the Campbell Island Rise stock was carried out in 2003 (Hanchet et al. 2003b). The assessment suggested that the stock was slightly above B_{may} but well above the threshold level (B_{1991}). However, at annual catches of 25 000 t (the current TACC) and under assumptions of average recruitment, the stock was projected to decline giving rise to sustainability concerns in the 2004–05 fishing year. As a consequence of the reduction in the hoki quota, the Minister of Fisheries agreed to retain the southern blue whiting TACC at 25 000 t for the 2004–05 season, but to review the stock status by taking into account the results of the 2004 acoustic survey in time for the start of the 2005–06 fishing year. Because of the time required to work up the results of the 2004 survey and ancillary fisheries data, and the time needed by MFish for full consultation and the TACC setting process, there was insufficient time to carry out a completely new stock assessment. Therefore, the Middle Depths Working Group (WG) agreed to simply update the 2003 base case assessments with the new catch-at-age data and acoustic indices. A more thorough assessment is proposed for later in 2005.

4.2 The stock assessment model

The stock assessment model partitions the Campbell Island 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 5). In the first time step, 90% of natural mortality takes place. In the second time step, fish ages are incremented; the 2-year-olds are recruited to the population, which is 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 selectivity 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 (age 2) 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 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 used in the modelling. Lengths-at-age were converted to weights-at-age in the model using the length-weight relationship given by 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.

The model was fitted to the two series of acoustic biomass estimates of ages 2, 3, and 4+ fish given in Table 4 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 2004. 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). Zero values were replaced with 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.

4.3 Estimation

Model parameters were estimated using Bayesian methods implemented using the NIWA stock assessment program CASAL v2.06 (Bull et al. 2004). For initial runs, only the mode of the joint posterior distribution was sampled. For the final runs presented here, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm.

MCMC chains were estimated using a burn-in length of 0.5 million iterations, with every 2000th sample taken from the next 2 million iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior).

Equilibrium "virgin" biomass is equal to the population that there would have been if all the year class strengths (YCS) were equal to one and there was no fishing. However, there was a period of unknown (and possibly large) catches from the Campbell Island 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. The initial population in 1979 (ages 3 to 11+) was estimated for each sex. Year class strengths were estimated for all years from 1977 to 2002, under the assumption that the estimates from the model should average 1.

4.4 Prior distributions

The assumed prior distributions used in the assessment are given in Table 6. Most priors were intended to be uninformed, and had wide bounds. However, a log-normal prior was used for natural mortality and for the acoustic survey 4+ q.

The informed prior for the adult (4+) acoustic q was obtained using the approach of Cordue (1996), and is given in full by Hanchet et al. (2003a). Uncertainty over various factors including mean target strength, acoustic system calibration, target identification, shadow or dead zone correction, and areal availability were all taken into account. In addition to obtaining the bounds, a mean for each factor was also assumed. The factors were then multiplied together. 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 WG agreed to extend the lower bound to 0.1. The informed prior for the adult acoustic q will need to be revised in future to take account of the new estimates of the absorption coefficient, towbody motion (pitch and roll), and the target strength-fish length relationship.

The prior on natural mortality was determined by assuming that the true value could differ from the current value 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 zero 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.

4.5 Base case and sensitivity tests

Initially four runs were considered. These runs were essentially updates of the two base case assessments used in 2003, together with the two alternative time series of acoustic estimates (see Section 3.2.1). The two base case assessments in 2003 differed only in the priors used for the adult acoustic q (one was uniform-log and the other was an informed lognormal prior). In preliminary analyses, the run using an uninformed (uniform-log) q with the acoustic biomass series based on all strata sometimes led to unrealistically low estimates of q (e.g., see Table 9). The resulting high estimates of current biomass appeared to be inconsistent with reports from fishers that large fish were difficult to locate. The two runs that used the acoustic biomass series based only on the core survey strata gave very similar results. Both indicated that exploitation rates had been very high in 2004 (e.g., see Table 9), which was considered implausible, particularly because the southern aggregation had very little catch taken from it.

The Middle Depths Working Group and Stock Assessment Plenary agreed to use the model run using an informed prior on q, and which included the acoustic biomass indices incorporating all surveyed strata, as the base case. The justification for these choices is as follows: (i) the informed prior is based on prior knowledge about characteristics of the acoustic index and it was therefore important to include this knowledge in formulating the prior; (ii) there was sufficient evidence to suggest that the main northern aggregation had changed its distribution in the past few years. It was also agreed to report two sensitivity runs bracketing the base case assessment. One sensitivity test explored the effect of an uninformed prior on the acoustic q, whilst the second explored the effect of using the acoustics series based on only the core strata (i.e., Hypothesis 2 in Section 3.2.1). Details of the three model runs are summarised in Table 7.

4.6 Performance indicators

Since 2001, B_{1991} has been used as a threshold reference biomass level for the Campbell Island Rise stock. Recruitment in this stock is characterised by periods of moderate recruitment interspersed by relatively rare, extremely strong, recruitment events. Only one such event (1991 year class) has been observed within the timeframe of the model, although historical data suggest that this may have happened in the past (Anon. 1972). Given the high variability in recruitment levels, B_0 is probably not well determined. Therefore, the Stock Assessment Plenary considered that B_{1991} may be a better threshold reference point than the more commonly used 20% B_0. However, in documenting this assessment I believe it is useful to report current biomass in relation to 20% B_0, and so have also included that particular reference point in this report.

For each model run, MPD fits were obtained and qualitatively evaluated. MCMC estimates of the median of the posterior and 90% credible intervals are reported for virgin biomass, B_{2004}, B_{2004} (as $\%B_0$), and B_{2004} (as $\%B_{1991}$).

4.7 Results

4.7.1 MPD fits

The objective function values and preliminary results from the MPD runs are given in Table 8. Objective function values differed little between runs. Estimates of most parameters were also similar between runs, except for estimates of B_{2004}, which were considerably lower for the *core acoustics* run. The fits to the acoustic indices appear to be reasonably good (Figure 9). 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 10).

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 (Figures 11 and 12). 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. Because of the many years of proportion-at-age data, only the fits to the males for the last 10 years have been shown (Figure 13). As in previous Campbell Island assessments, the model fits the age data well.

4.7.2 MCMC results

The MCMC trace for current biomass (B_{2004}) for the base case looks reasonable (Figure 14).

The estimated MCMC marginal posterior distributions for spawning stock biomass by year are shown for the base case in Figure 15, and are summarised in Table 9. The results suggest that stock biomass showed a steady decline from the early 1980s until 1992 followed by a large increase to 1996, followed by a gradual decline. Exploitation rates peaked in the early 1990s at about 0.4, declined to about 0.1 in 1995, but have shown a steady increase since then and currently exceed 0.25 (Figure 16). The 1991 year class is still the most dominant year class in the population and the 1992, 1995, 1996, and 1998 year classes are all estimated to be above average (Figure 17). The 2001 and 2002 year classes are also estimated to be above average by the model, with moderate numbers caught in the fishery and seen by the acoustic survey.

The fishery selected significantly more males than females at ages 2 and 3, but by age 4 fish of both sexes were selected equally (Figure 18). Plots of the initial age structure show that most of the fish at the beginning of the fishery were in the plus group (Figure 19). The median estimate of the adult acoustic q was 1.13 (Table 9). This is very similar to the estimate from the 2003 assessment. The posterior distribution of the adult acoustic q was shifted slightly to the left of the prior (Figure 20). The posterior distribution for average natural mortality was very similar to the prior distribution (Figure 21), but had a narrower range and a lower median value (0.17). There was minimal difference between the sexes.

The MCMC predicted distributions and observed acoustic indices for the base case run are shown in Figures 22 and 23. The fits show a similar pattern to those for the MPD (see also Figure 9). The 'worst' fit is for the 2002 adult acoustic index, which had a very high c.v., and is thought to have been an overestimate of fish abundance (Hanchet et al. 2003a, 2003b).

4.7.3 Sensitivity estimates

The MCMC traces for current biomass (B_{2004}) for the *uninformed q* run shows evidence of poor convergence (see Figure 14). The trace for the *core acoustics* run is clearly truncated at the lower end by a bound – probably due to the maximum exploitation rate being reached. The MCMC predicted distributions and observed adult acoustic indices for the *uninformed q* run are similar to the base case, but fits appear to be slightly worse for the *core acoustics* run (Figure 23).

The results of the sensitivity runs show that the estimates of B_{2004} and stock status are very sensitive to the choice of acoustic biomass series and the prior used for the acoustic q (Table 9, Figures 24 and 25). When the adult acoustic q was uninformed it was estimated to be 0.88 and B_{2004} was 36% higher than in the base case. When the core acoustic biomass series was used, the adult q was estimated to be 1.23 and B_{2004} was almost 60% lower than in the base case.

4.7.4 Projections

Three-year stochastic projections were made assuming fixed catch levels from 10 000 to 25 000 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 2004–05. (Note that at the time of the assessment the estimate of the 2004–05 was uncertain and the fishing year had not yet finished.) 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, or less than 20% B_0, is given for the base case in Table 10.

At catches of 20 000 t or greater, the biomass is projected to decline. The probability that the mid-season biomass for the specified year will drop below the threshold biomass (B_{1991}) reaches 13% by 2007 at catches of 25 000 t. 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. However, the biomass in 1991 was estimated to be only about 16%B_0 (see Table 9), which is well below the more conventional threshold biomass of 20%B_0. Risks based on the alternative threshold biomass (20% B_0) exceeded 10% by 2006 at catches of 25 000 t, and exceeded 10% by 2007 at catches of 20 000 t.

4.7.5 Yield estimates

Estimates of sustainable yields were made for the Campbell Island Rise base case model. Yield estimates were based on the 1000 samples from the Bayesian posterior, with yield estimates based on stochastic simulations run over 100 years.

The simulation method of Francis (1992) was used to estimate u_{CAY}. The yields were maximised subject to the constraint that spawning stock biomass should not fall below 20% of B_0 more than 10% of the time. The estimate of u_{CAY} was 0.2. The corresponding estimate of MAY was 19 500 t and of $CAY_{2005\text{-}06}$ was 19 000 t.

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. 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. Perhaps of greater concern is the inability of the model to hit the 2004 acoustic data point. A substantial proportion of the posterior distribution lies above the observed data point. Although the 2004 acoustic estimate was not particularly precise, there are no obvious reasons why it should have underestimated the stock abundance (O'Driscoll et al. 2005). An acoustic survey carried out in 2003 using F.V. *Aoraki* estimated a mid-season SSB of 85 000 t (c.v. = 26%) (O'Driscoll & Hanchet 2004). That estimate (which comprised few 2 and 3 year old fish and is therefore equivalent to the age 4+ acoustic index) is consistent with a biomass intermediate between the 2004 acoustic survey data point and the median of the posterior distribution. The 2004 acoustic survey estimates and the age data both show the occurrence of moderately strong 2001 and 2002 year classes. These were estimated to be above average and of a similar size to other recent above average year classes (1995 and 1998), but are considerably less than the strong 1991 year class which sustained the large fishery during the 1990s. The 2001 and 2002 year classes should allow stock size to be maintained at its current level, given the current level of catches, but will not be large enough to allow the stock to rebuild.

The median estimate of q from the base case was 1.13, which is identical to the estimate from the base case 2 assessment in 2003. Both are 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 effect on the abundance indices. Research is being carried out to better estimate this relationship. The priors for some of the other uncertainties could also be different from the values used, again leading to a reduction in the value of the mean used for the prior. In particular, O'Driscoll et al. (2005) noted that changes in the absorption coefficient increased biomass by 9–33% and implementing towbody motion correction further increased biomass by 5–15%. 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 in 2003 (Table 12). 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_{2002} and B_{2002} / B_{1991} are also similar to those from the 2003 assessment. As would be expected, the uncertainty over these parameters has decreased with the inclusion of more years data in the model.

One point of uncertainty arising from the assessment is the difference in parameter estimates between the MPD and the MCMC. The reason for this is unclear, but it has been observed in previous SBW assessments (pers. obs.) and in other NIWA Bayesian assessments (C. Francis, NIWA, pers. comm.). The MPD estimates have not been used at all in the assessment, so this uncertainty does not feed through to the current assessment. However, caution needs to be taken if MPD runs are used to evaluate other model assumptions.

In summary, the assessment results show the model to be moderately robust. This is shown by the similarity with previous assessments 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 2005 meetings, whilst others have been developed in discussion with colleagues. They include the following:

- Explore the use of earlier Japanese LF data (Anon. 1972) and Soviet age data for 1970–78 (Shpak 1978) 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
- Examine alternative parameterisations for the selectivity ogive, so that the age-length data are used only once. At present they are used to decompose the acoustic indices into numbers at age and also as a direct estimate of proportion-at-age in the commercial fishery.
- Include 2003 industry acoustic survey results.

6. MANAGEMENT IMPLICATIONS

The base case run suggests 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, which sustained the large fishery during the 1990s, still makes a moderate contribution to the commercial catch (especially by weight), but there have been no new strong year classes to replace it. There are several year classes, including those from 2001 and 2002, which appear to be above average. The median estimate of mid-season biomass in 2004 (B_{2004}) is 82 000 t, which is 32% B_0. This is slightly below B_{may}, which is the target biomass under a CAY policy.

At catches of 20 000 t or more, the biomass is projected to remain below B_{may}. The probability that the mid-season biomass for the specified year will drop below the threshold biomass (B_{1991}) reaches 13% by 2007 at catches of 25 000 t. 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. Risks based on the alternative threshold biomass (20% B_0) exceeded 10% by 2006 at catches of 25 000 t and by 2007 at catches of 20 000 t. $CAY_{2004-05}$ is estimated to be 19 500 t, which is consistent with these results.

7. ACKNOWLEDGMENTS

I am grateful to the scientific observers for the collection of the length frequency data and otoliths, and to Aurora Fishing for making available data collected in the 2004 season by the *Tomi Maru 87*. I also thank Michael Stevenson and Colin Sutton for reading, inventorying, and processing the otoliths. Alistair Dunn provided significant assistance with the use of the CASAL model. This assessment benefited from discussions with members of the Middle Depths Working Group. Many thanks to Richard O'Driscoll for making useful comments on an earlier draft of the manuscript, and to Mike Beardsell for editorial comments. The Ministry of Fisheries, Project Number SBW2004/01, funded this work.

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Table 1: Estimated catches (t) of southern blue whiting by area for the period 1978 to 2004–05 from vessel logbooks, QMRs, and MHRs. – no catch limit in place. Estimates for 2004–05 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#	7 564	8 000	32 749	30 000	712	5 500	744	1 640	41 785	45 140‡
2003–04#	3 812	3 500	23 718	25 000	163	5 500	116	1 640	27 812	35 640‡
2004–05#	1 478	3 500	19 671	25 000	34	5 500	18	1 640	21 207	35 640‡

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, 16 t in 2002–03, 2.6 t in 2003–04, and 5.7 t in 2004–05.

Table 2: Number of vessels, tows, and catch (t) for observed and all vessels targeting SBW by area for August to October in the 2004–05 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	2	3	11	24	1 477	24 Aug – 2 Sep
Pukaki	0	3	0	9	34	5 – 14 Oct
Auckland	1	1	1	1	4	4 Oct
Campbell	6	14	119	645	19 670	28 Aug – 6 Oct

Table 3: Dates of sampling and changes in SBW gonad condition in 2004 on north and south Campbell Island Rise and the Bounty Platform 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.

Gonad stage	Campbell Island Rise		Bounty Platform
	North (< 52° 30')	South (> 52° 30')	
1st sample	3 Sep	6 Sep	26 Aug
>10% ripe	9 Sep	–	–
>10% running ripe	14 Sep	–	26 Aug
Main spawning	14–18 Sep	–	?–26 Aug
>10% spent	–	–	–
>10% reverted	19 Sep		26 Aug
2nd spawning	–	26–30 Sep	–
Last sample	5 Oct	30 Sep	1 Sep
% spent	75%	25%	1%
% reverted	14%	5%	73%

Table 4: Decomposed acoustic survey biomass estimates (t) and assumed c.v.s by survey and age group used for the Campbell Island Rise assessment. *, estimates include fish from outside the core strata.

	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
2002 *	3 829	76	11 842	72	152 184	68
2004	14 412	16	18 873	24	17 283	32
2004 *	17 327	16	34 527	27	56 197	38

Table 5: 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, abundance indices

Table 6: 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.

Parameter	N	Distribution	Values		Bounds	
All runs			Mean	c.v. / s.d.	Lower	Upper
B_0	1	Uniform-log	–	–	30 000	800 000
YCS (1977–2002)	26	Lognormal	1.00	1.30	0.001	100
Initial population (by sex)	18	Uniform-log	–	–	2e5	2e12
Selectivity ages 2-4	6	Uniform	–	–	0.0001	1
M (average)	1	Lognormal	0.20	0.20	0.075	0.325
M (difference)	1	Normal	0.00	0.05	-0.05	0.05
Acoustic *q* age 2, 3	2	Uniform-log	–	–	0.1	2.8
Base case and low acoustic run						
Acoustic *q* age 4+	1	Lognormal	1.40	0.20	0.1	2.8
Uninformed *q* run						
Acoustic *q* age4+	2	Uniform-log	–	–	0.1	2.8

Table 7: Model run labels and descriptions for the base case and sensitivity runs.

Model label	**Description**
Base case	**Lognormal prior on adult acoustic *q*, and acoustic biomass series based on all strata**
Uninformed *q*	Uniform-log prior on adult acoustic *q*, and acoustic biomass series based on all strata
Core acoustic	Lognormal prior on adult acoustic *q*, and acoustic biomass series based on core strata

Table 8: Objective function values and parameter estimates for the MPD fits.

Parameters	Base case	Uninformed *q*	Core acoustic
acoustics_2	-5.93	-5.90	-6.95
acoustics_3	-6.83	-6.84	-7.15
acoustics_4	-7.37	-7.34	-5.54
observer_proportions_at_age	-36.88	-36.84	-35.55
prior_on_initialisation.B0	12.64	12.64	12.53
prior_on_natural_mortality.avg	0.808	0.738	0.989
prior_on_natural_mortality.diff	0.004	0.004	0.006
prior_on_recruitment.YCS	-3.48	-3.46	-4.21
prior_on_initialisation.Cinitial_male	151.52	151.52	151.43
prior_on_initialisation.Cinitial_female	147.33	147.34	147.26
Total	**252.7**	**252.7**	**254.2**
Parameter estimates			
M.avg	0.122	0.122	0.120
M.diff	-0.0046	-0.0047	-0.0053
acoustics_2_q	1.25	1.23	1.48
acoustics_3_q	1.49	1.47	1.73
acoustics_4_q	1.31	1.28	1.47
B_0	308 254	308 489	275 351
B_{1991}	35 438	35 600	38 542
B_{2004}	69 583	71 851	29 270

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_{2004}	B_{2004} (% B_{1991})	B_{2004} (% B_0)	B_{1991} / B_0
Base case	**257 (227–304)**	**82 (51–122)**	**194 (128–288)**	**32 (20–44)**	**0.16 (0.12-0.21)**
Uninformed *q*	264 (232–321)	112 (66–215)	230 (153–340)	43 (25–69)	0.19 (0.13-0.25)
Core acoustic	225 (202–252)	36 (26–60)	90 (66–140)	16 (11–26)	0.18 (0.15-0.23)

Model run	*q*	U_{2004}	*M*
Base case	**1.13 (0.96–1.33)**	**0.27 (0.19–0.40)**	**0.17 (0.13–0.20)**
Uninformed *q*	0.88 (0.54–1.21)	0.20 (0.11–0.33)	0.19 (0.14–0.25)
Core acoustic	1.23 (1.03–1.38)	0.53 (0.35–0.67)	0.17 (0.14–0.213)
Uninf *q* + low aco			

Table 10: Probability that the projected mid-season vulnerable biomass for 2005, 2006, and 2007 will be less than the mid-season vulnerable biomass in 1991, or less than 20% B_0, and the median projected biomass as a percentage of B_0 (with 90% credible intervals) for different constant catch levels for the Campbell Island stock base case run.

	Probability (B_{proj}<B_{1991})			Probability (B_{proj}<B_0)			Median biomass as proportion B_0		
Constant catch (t)	2005	2006	2007	2005	2006	2007	2005	2006	2007
10 000	<0.01	<0.01	<0.01	0.03	0.02	0.01	0.34	0.38	0.41
15 000	<0.01	<0.01	0.01	0.04	0.03	0.04	0.33	0.35	0.35
20 000	<0.01	0.02	0.05	0.06	0.06	0.12	0.32	0.33	0.31
25 000	0.01	0.05	0.13	0.06	0.12	0.25	0.31	0.30	0.27

Table 11: Yield estimates (MAY and CAY) and associated parameters for the Campbell Island Rise.

Run	B_{MAY} (% B_0)	MAY (t)	U_{CAY}	$CAY_{2005-06}$ (t)
Base case	34	19 500	0.20	19 000

Table 12: Comparison of B_0, B_{mid02}, and B_{mid02} (as % B_{mid91}) for the 2003 and 2005 assessments of the Campbell Island stock. For both assessments the values are the median MCMC estimates and 90% credible intervals. 2003 results from Hanchet et al. (2003).

Year of assessment	B_0		B_{mid02}		B_{mid02} (as % of B_{mid91})	
	Estimate	90% intervals	Estimate	90% intervals	Estimate	90% intervals
2003 (BC 1)	242	205–308	109	60–216	234	145–373
2003 (BC 2)	238	199–285	85	54–137	205	134–309
This assessment	257	227–304	100	75–134	239	184–315

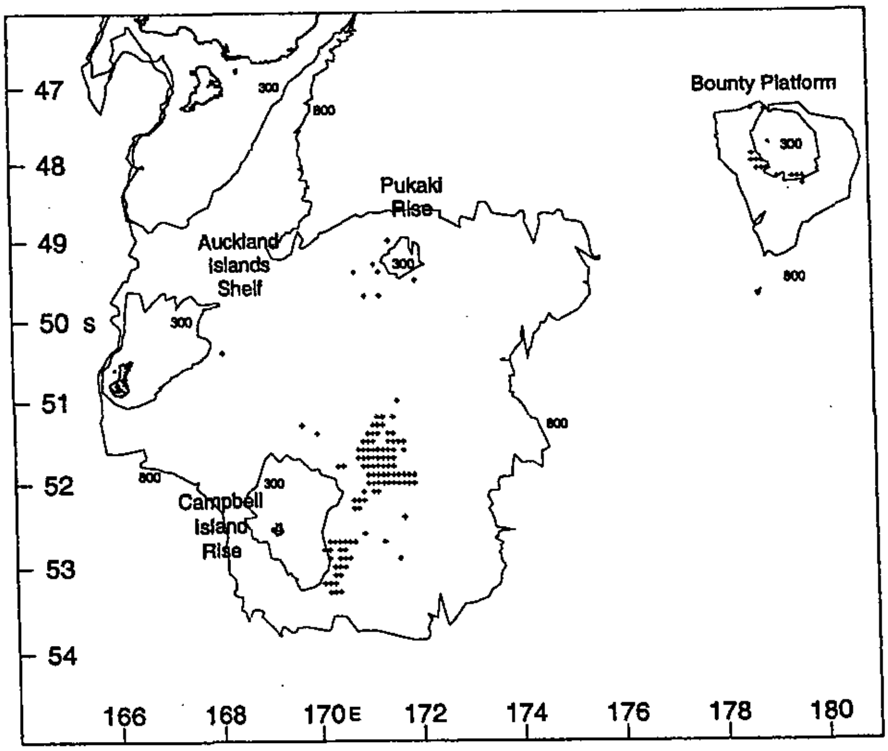


Figure 1: Commercial trawls made during the 2004 season (late August to early-October) targeting southern blue whiting.

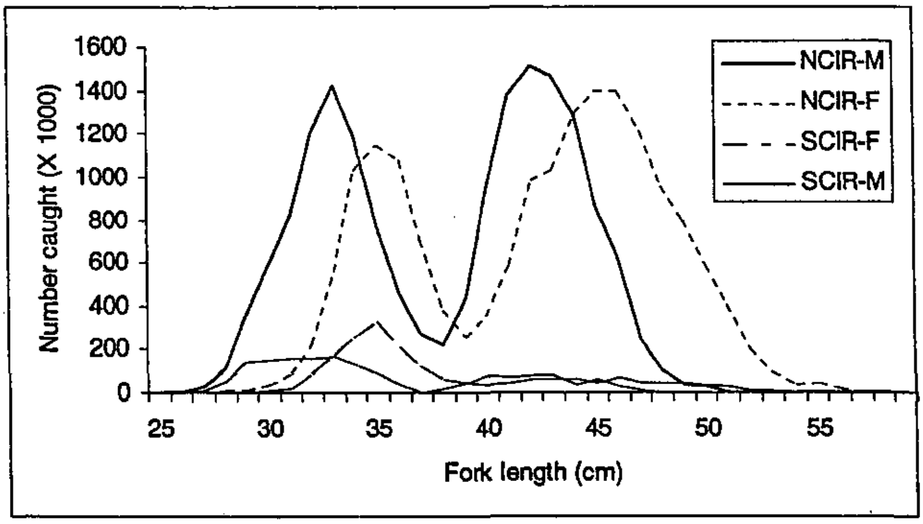


Figure 2: Weighted length frequency distribution of SBW for the Campbell stock by area (northern and southern Campbell Island Rise) and sex (M and F) in the 2004 season.

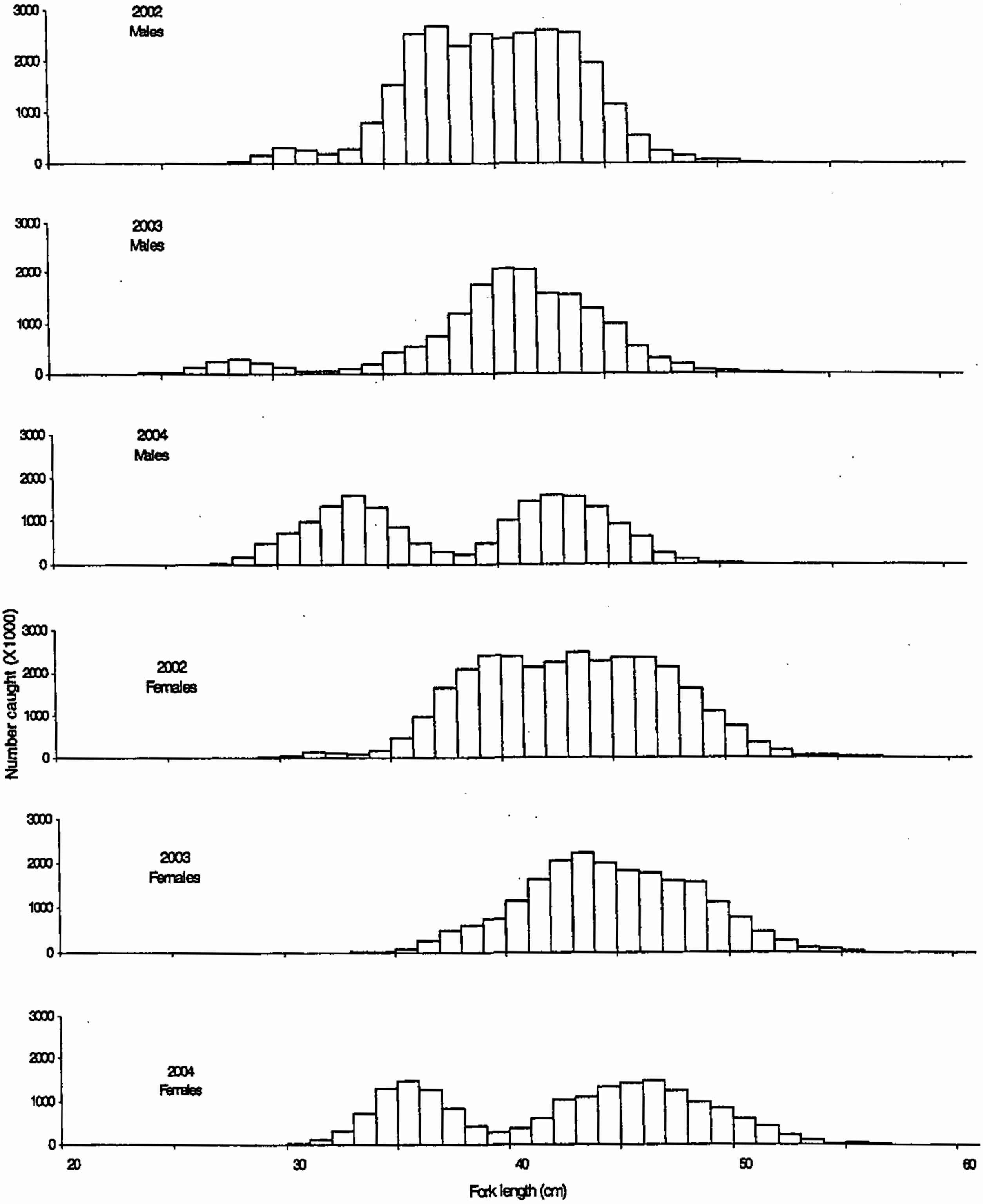


Figure 3: Weighted length frequency distribution of SBW for the Campbell stock by sex in the 2002–04 seasons.

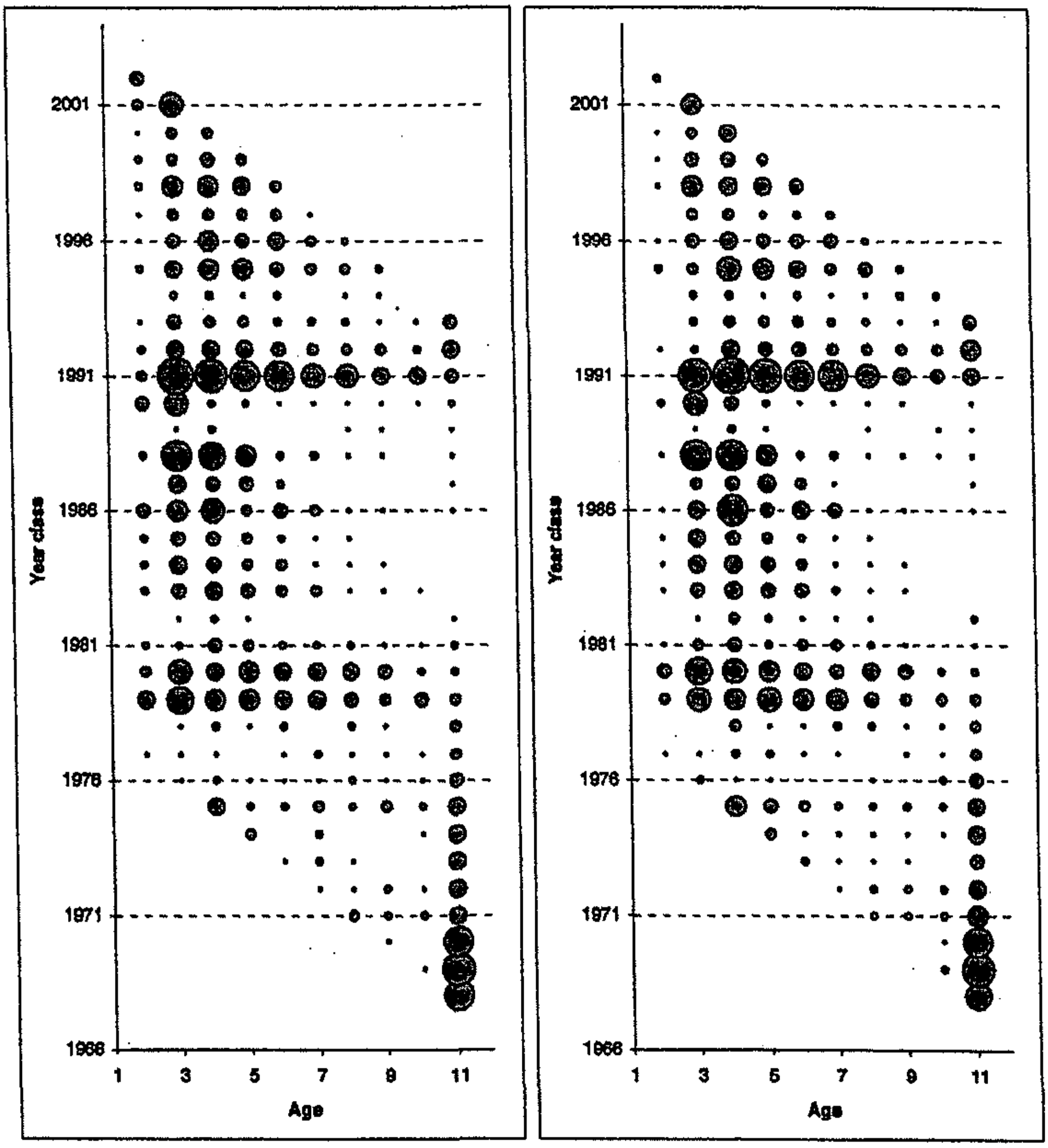


Figure 4: Age composition of the catch for the Campbell stock for males (left) and females (right) from 1979 to 2004.

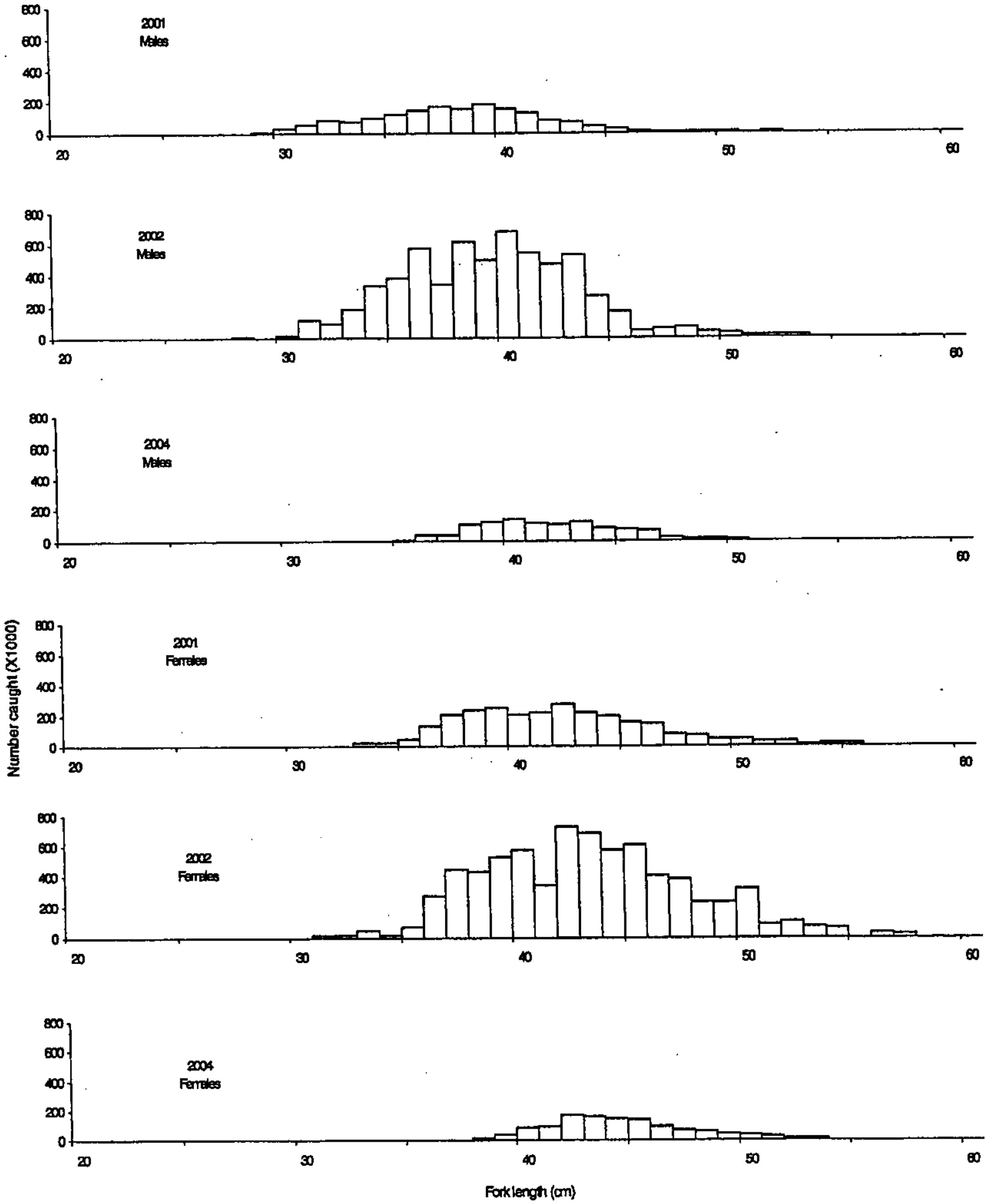
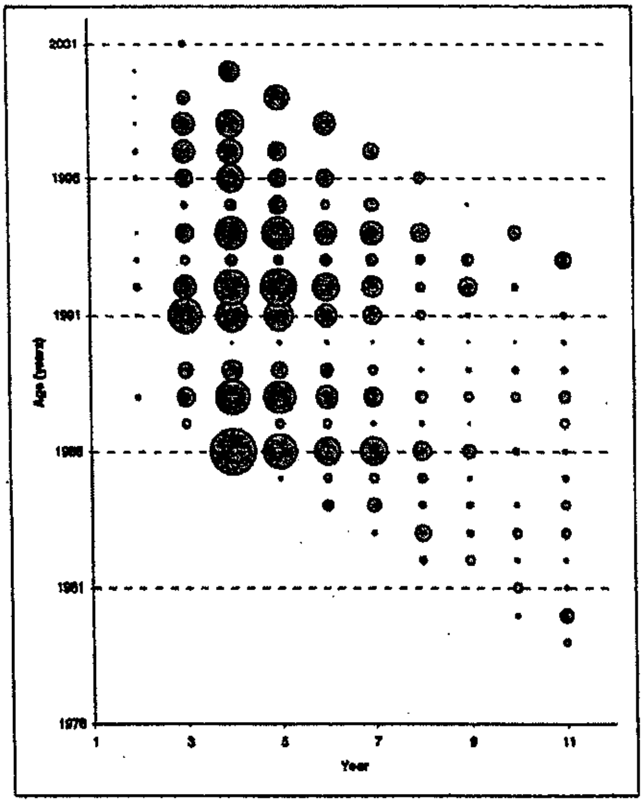


Figure 5: Weighted length frequency distribution of SBW for the Bounty stock by sex in the 2001, 2002 and 2004 seasons.

Males



Females

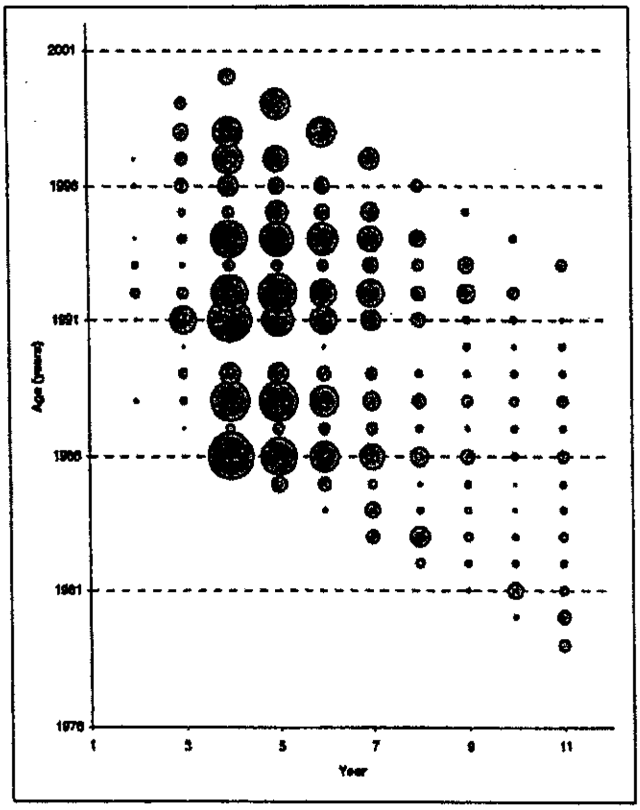


Figure 6: Age composition of the catch for the Bounty stock from 1990 to 2004.

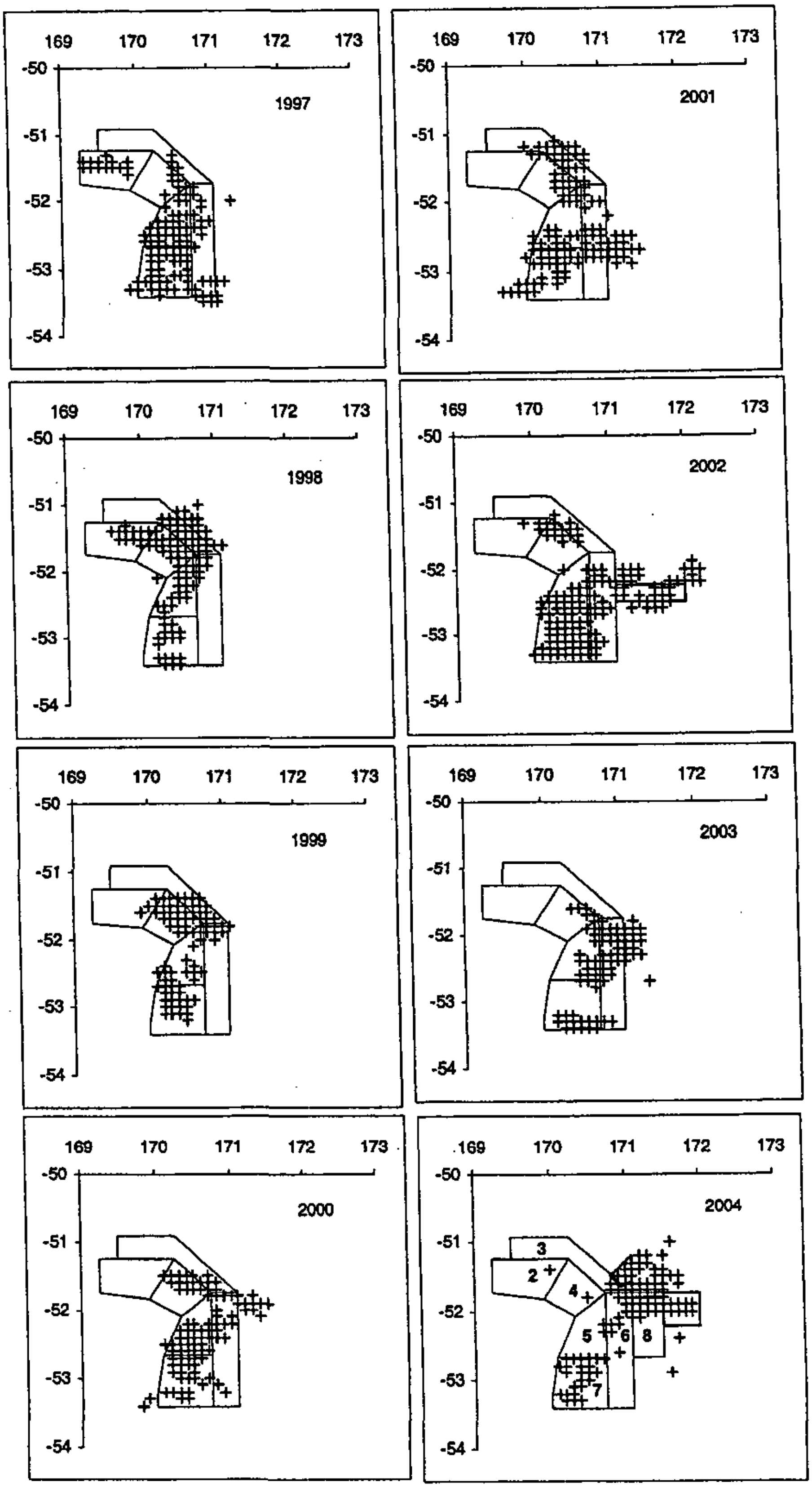
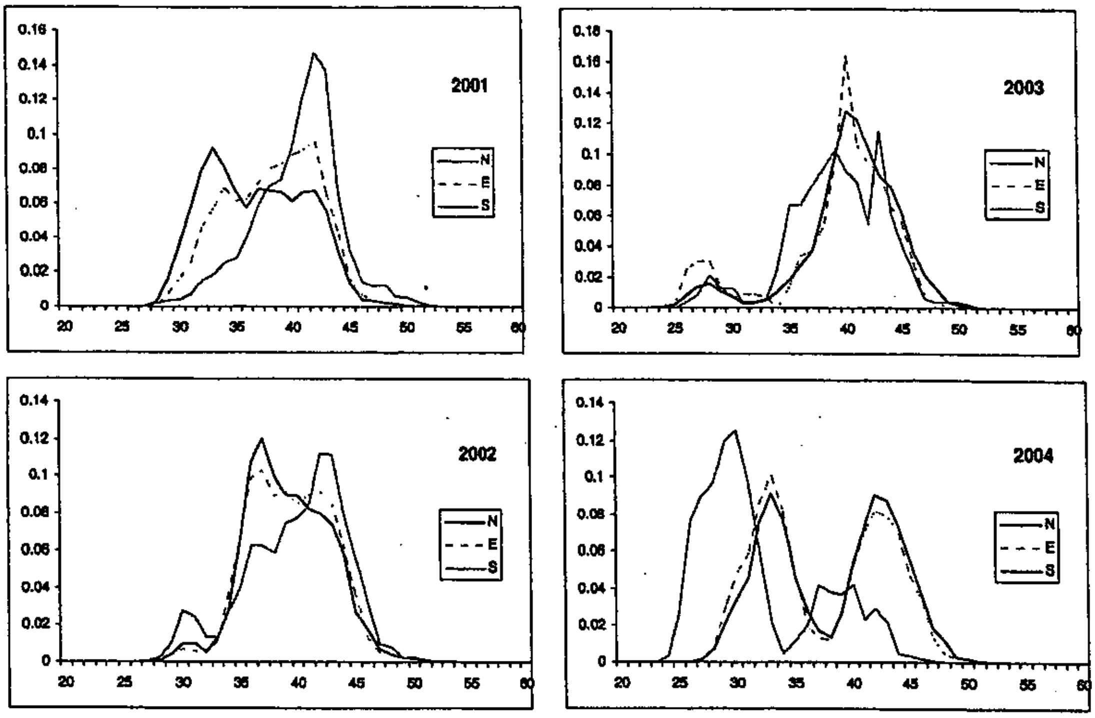


Figure 7: Start positions of all commercial trawls for SBW on the Campbell Island Rise carried out in September during 1997–2004 seasons. The main acoustic stratum boundaries (strata 2–8) are given for reference. Note that each cross may represent more than one tow.

Males



Females

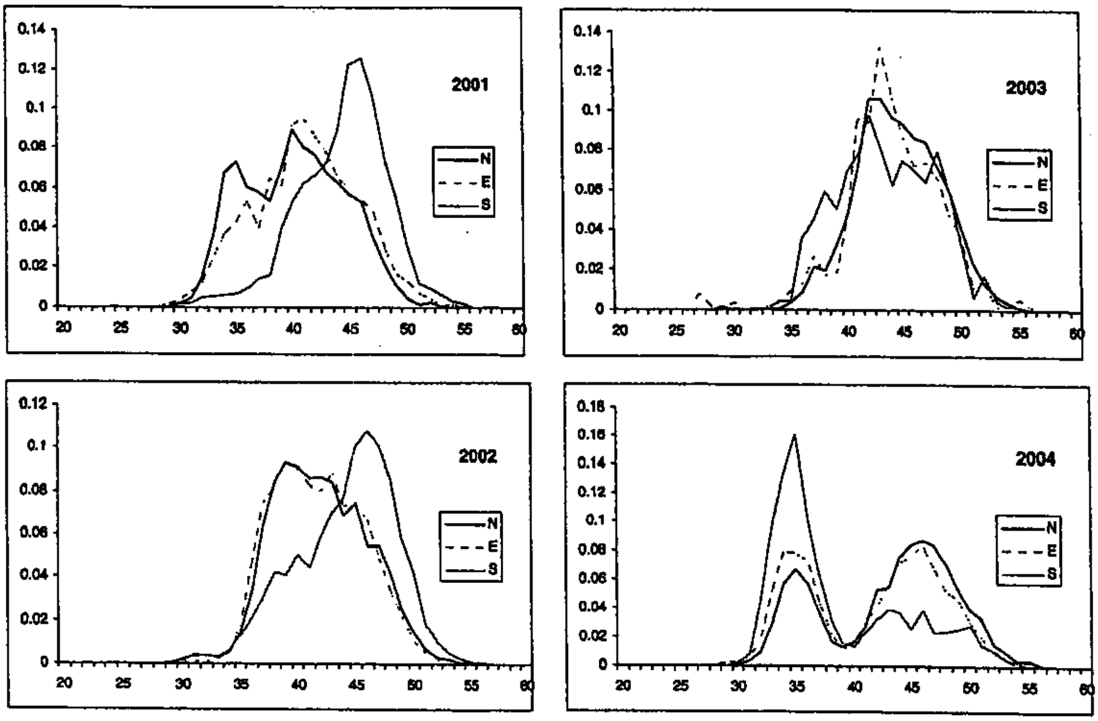


Figure 8: Size distribution of male and female SBW in each aggregation by year, for 2001 to 2004 seasons. The following definitions were used: N, north of 51°45'S; E, east of 171°E; and S, south of 53°S.

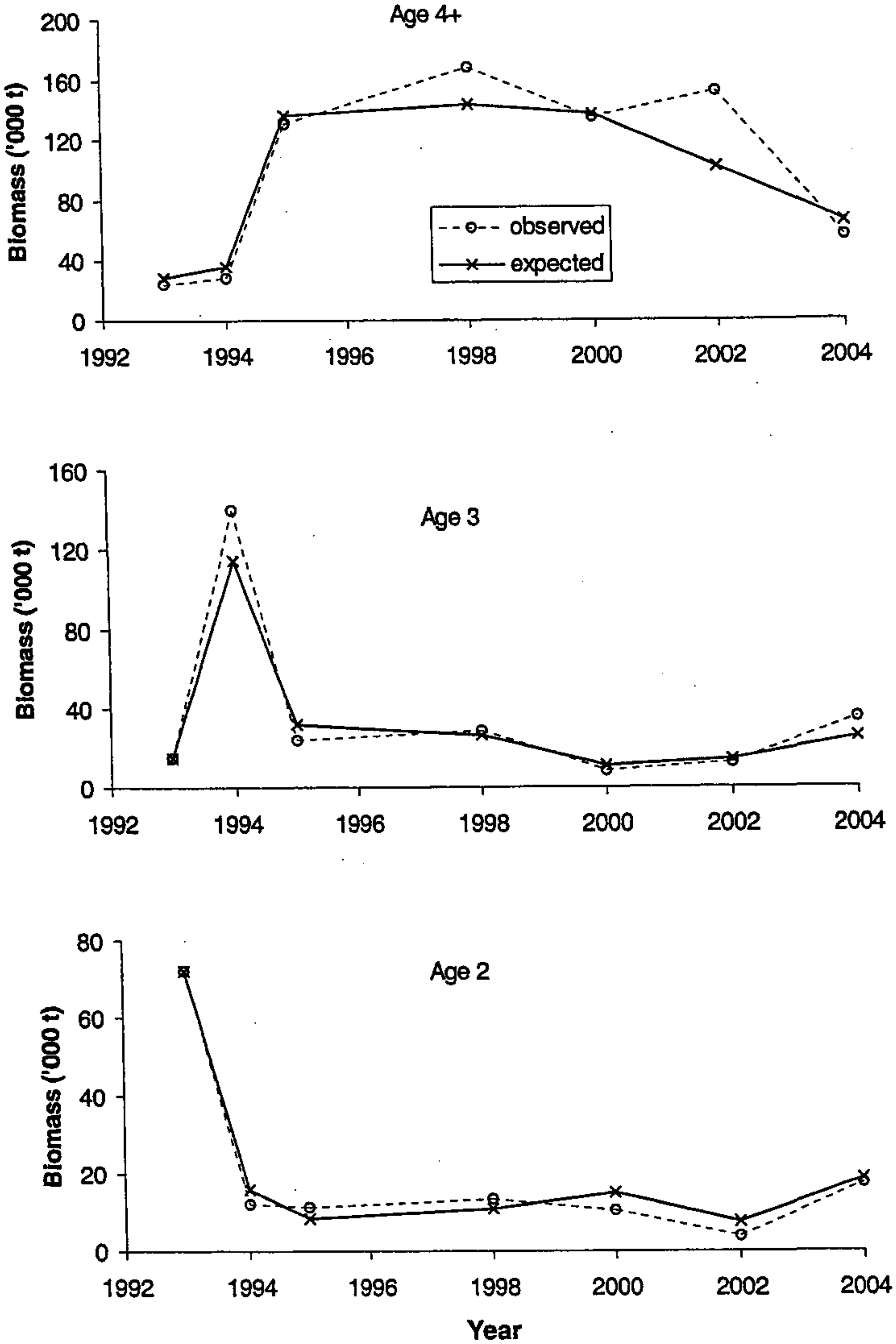


Figure 9: Base case MPD fits to the age 2, 3, and 4+ acoustic indices.

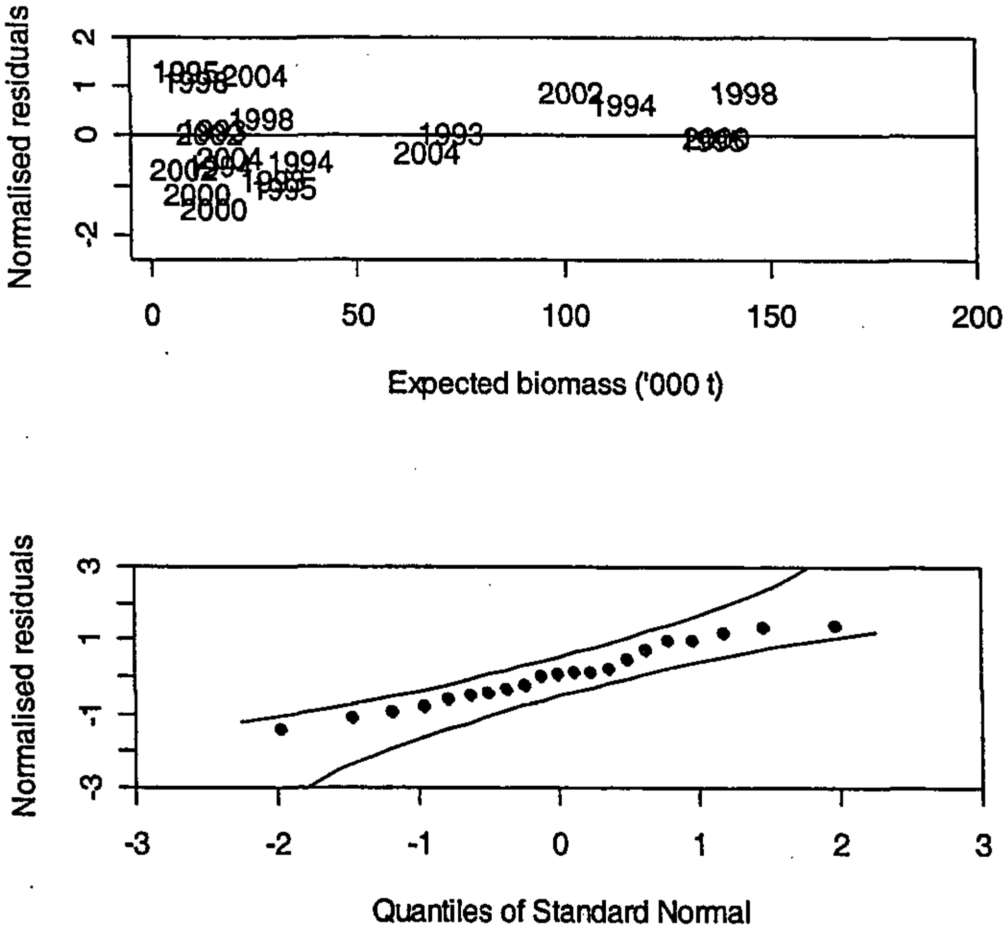


Figure 10: Base case MPD normalised residuals (top) and QQ plot (bottom) for fit to all the acoustic indices combined.

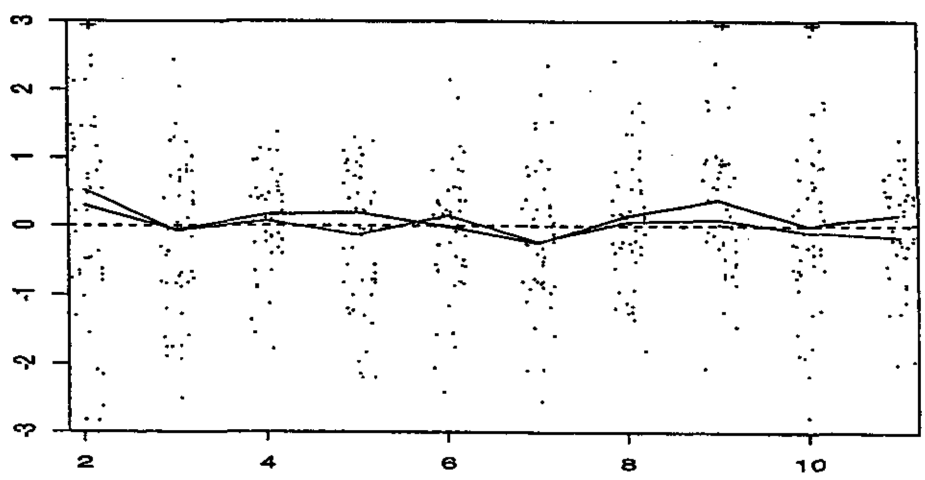


Figure 11: Base case MPD normalised residuals versus age with medians for male (black) and female (grey).

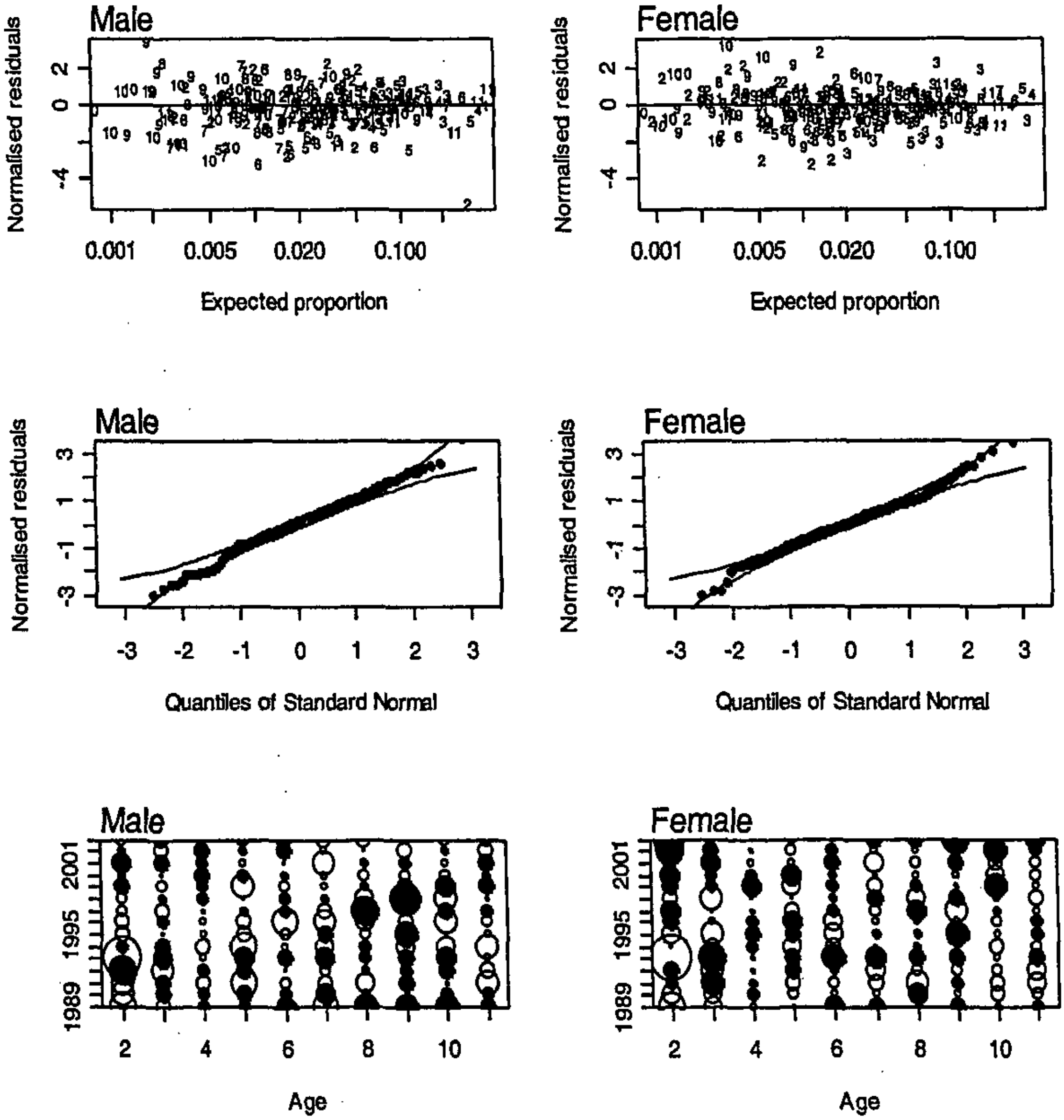


Figure 12: Base case MPD normalised residuals (top), QQ plot (middle) and residual plot (bottom) *for fit to the proportion-at-age data. Symbol area is proportional to the absolute value* of the residual, with white circles indicating positive residuals and black circles indicating negative residuals.

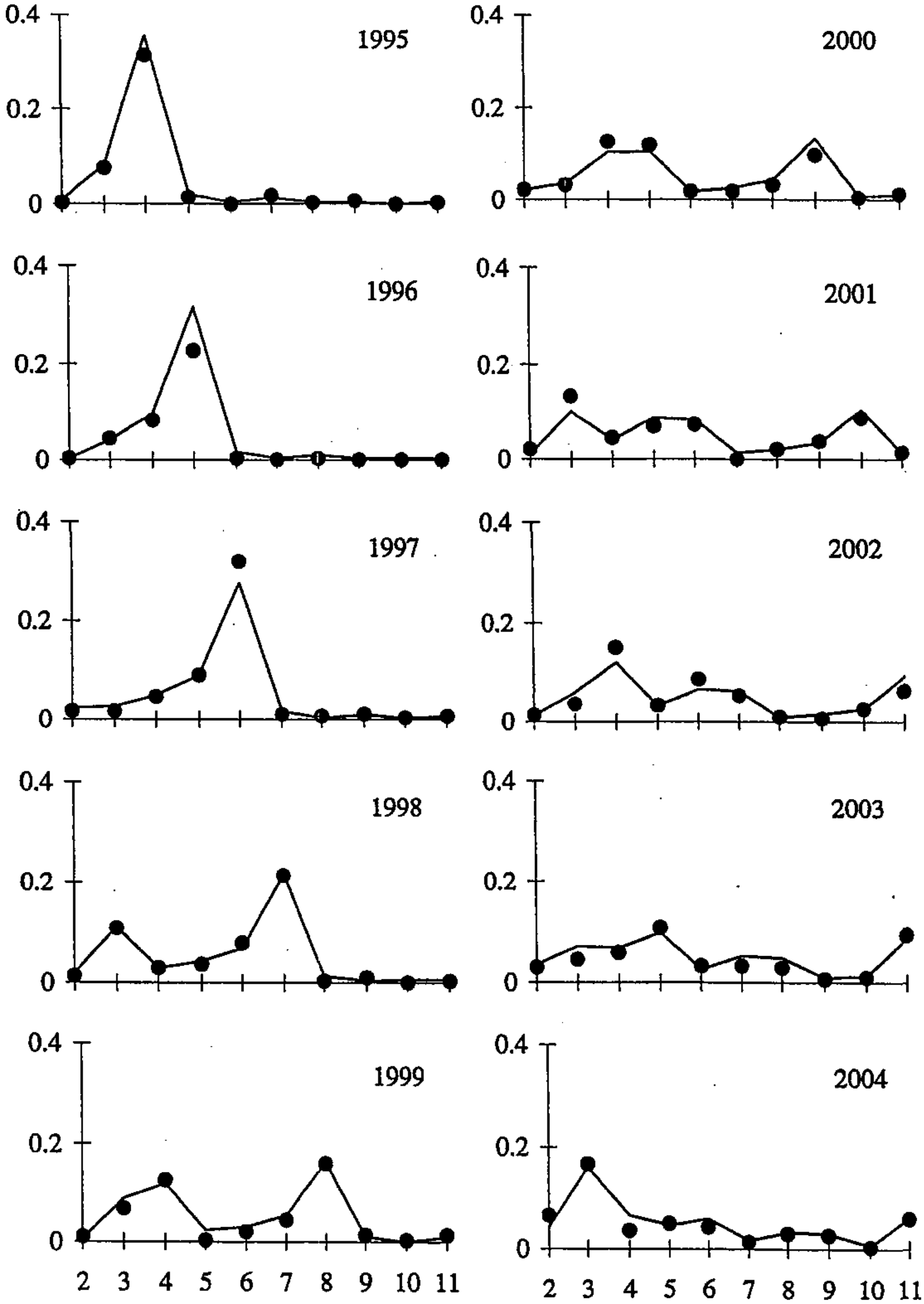


Figure 13: MPD fits to male proportion-at-age data from 1995 to 2004 (circles observed, lines predicted).

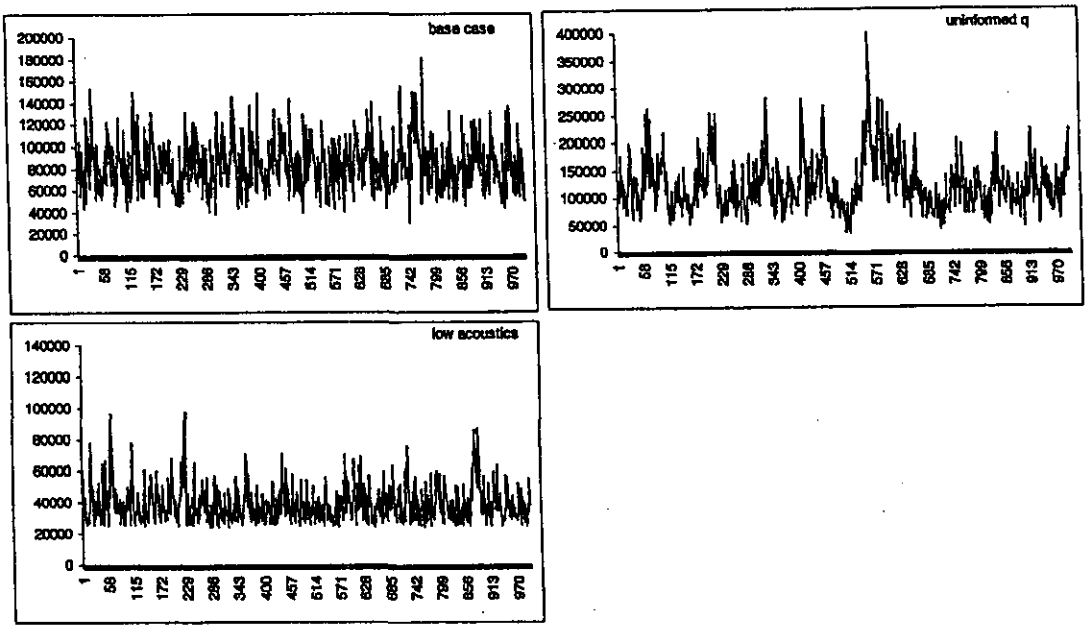


Figure 14: MCMC traces for the three runs.

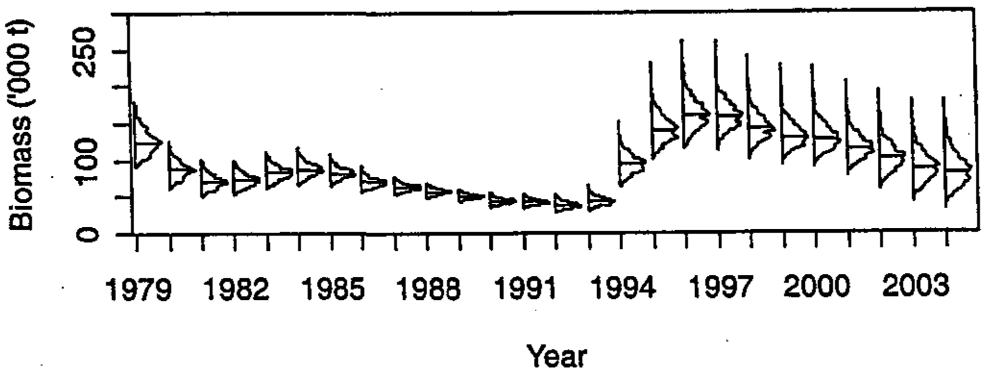


Figure 15: Estimated posterior distributions of mid season spawning stock biomass for the base case. Horizontal lines indicate the medians.

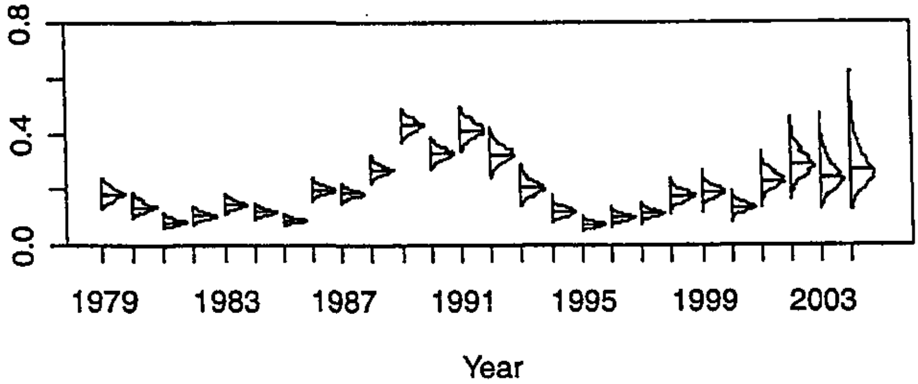


Figure 16: Estimated posterior distributions of exploitation rate for the base case. Horizontal lines indicate the medians.

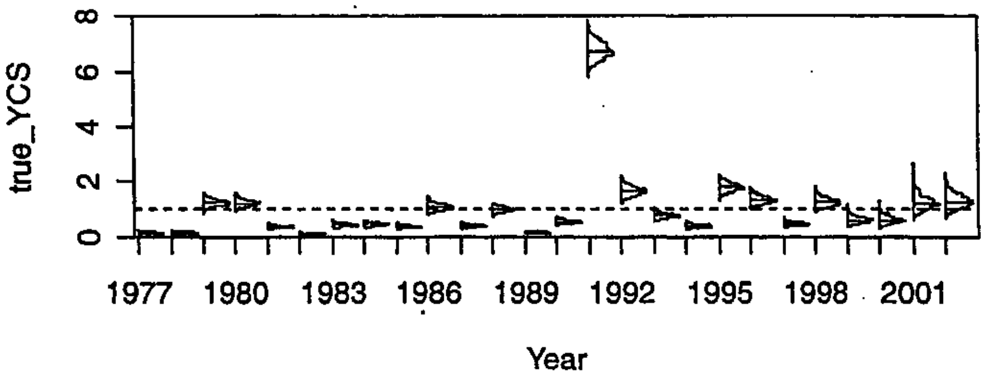


Figure 17: Estimated posterior distributions of year class strengths for the base case. Horizontal lines indicate the medians.

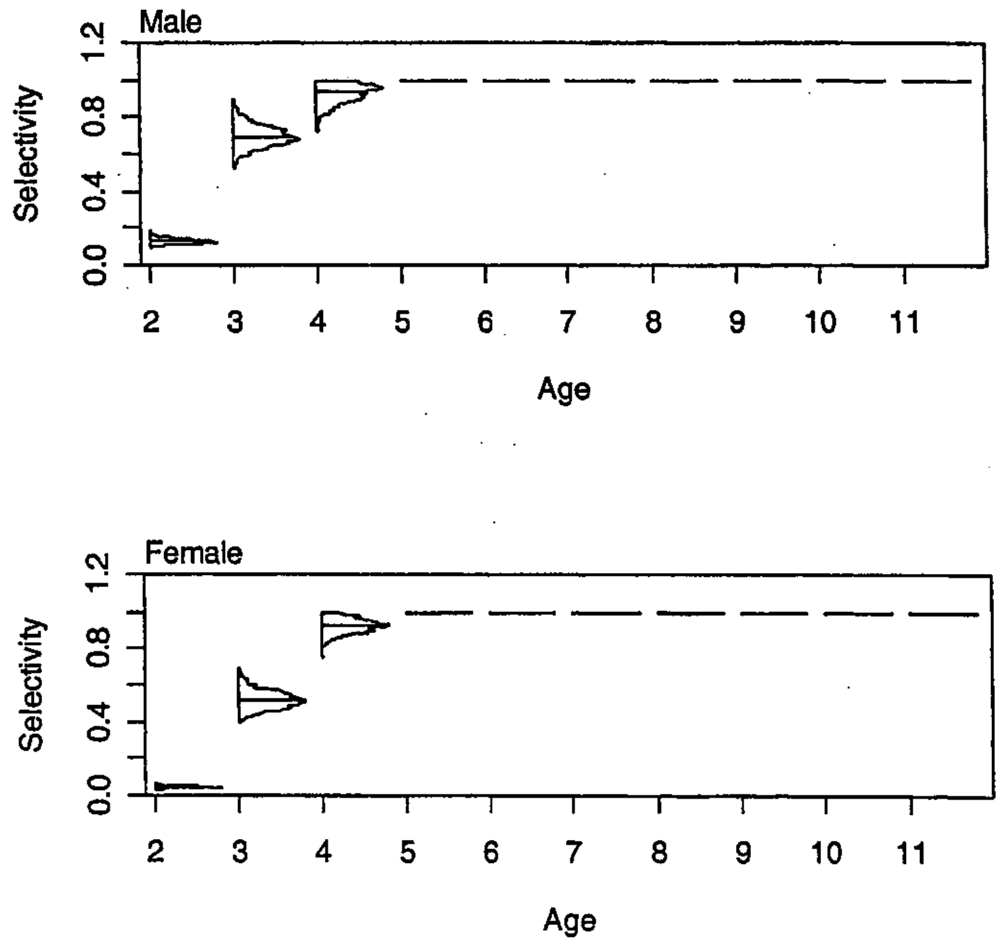


Figure 18: Estimated posterior distributions of fishing selectivity for ages 2, 3, and 4 for both sexes for the base case. Horizontal lines indicate the medians. Note selectivity assumed to be 1 at ages 5 and older.

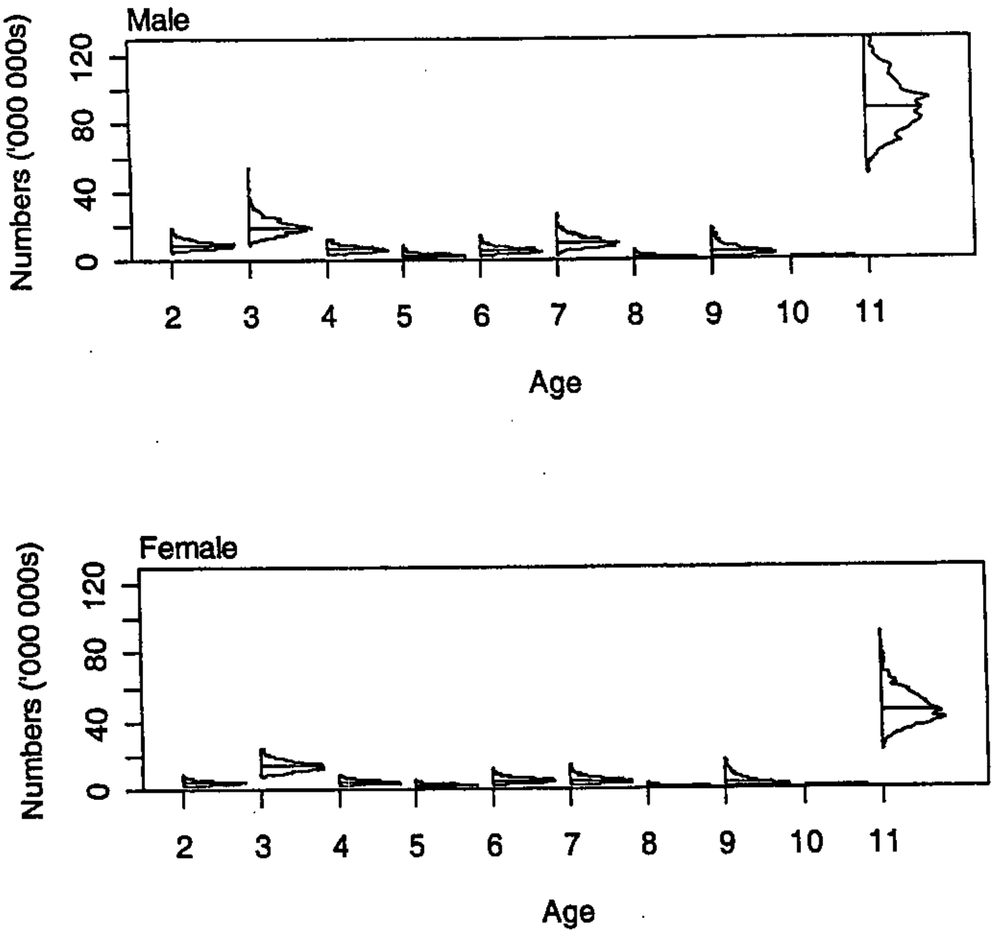


Figure 19: Estimated posterior distributions of initial numbers at age in the population (1978) for the base case. Horizontal lines indicate the medians.

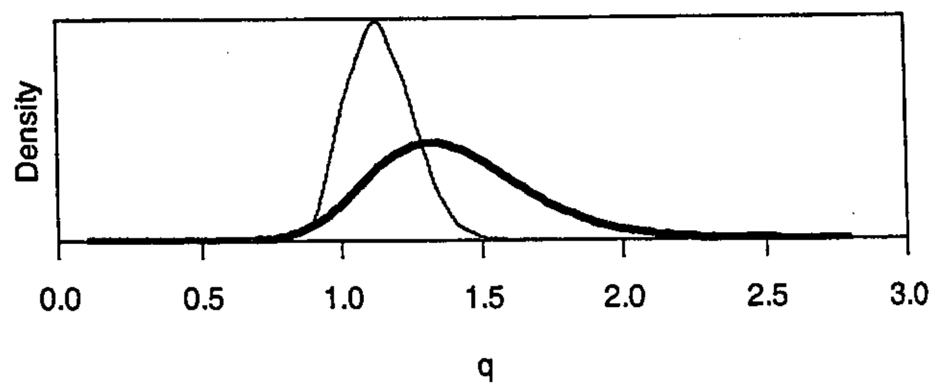


Figure 20: Prior (bold) and estimated posterior distributions of the adult survey relativity constant (age 4+ acoustic q) for the base case.

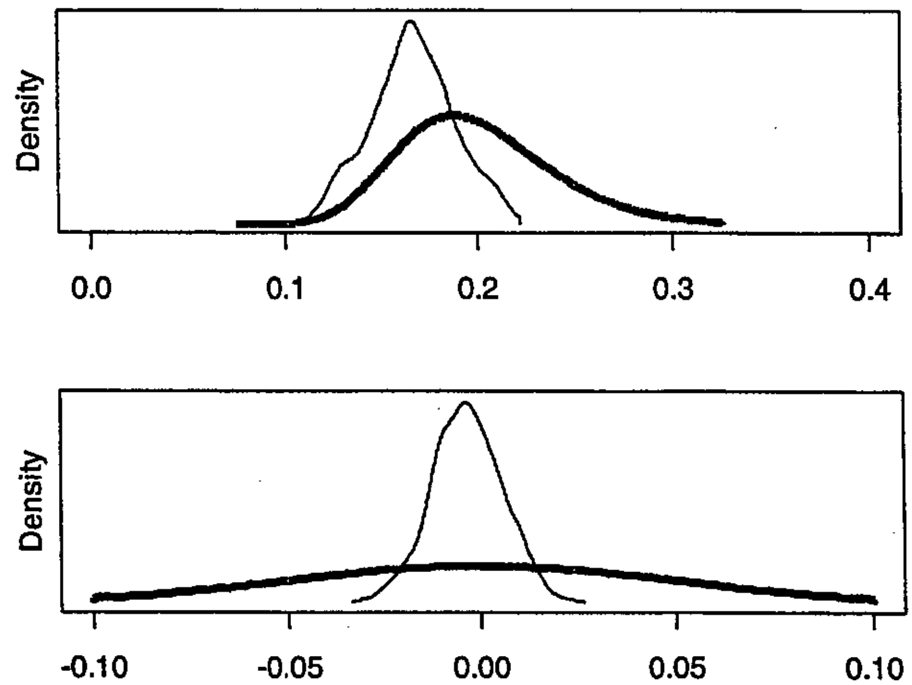


Figure 21: Prior (bold) and estimated posterior distributions of the average natural mortality (top), and the difference in natural mortality (bottom), for the base case.

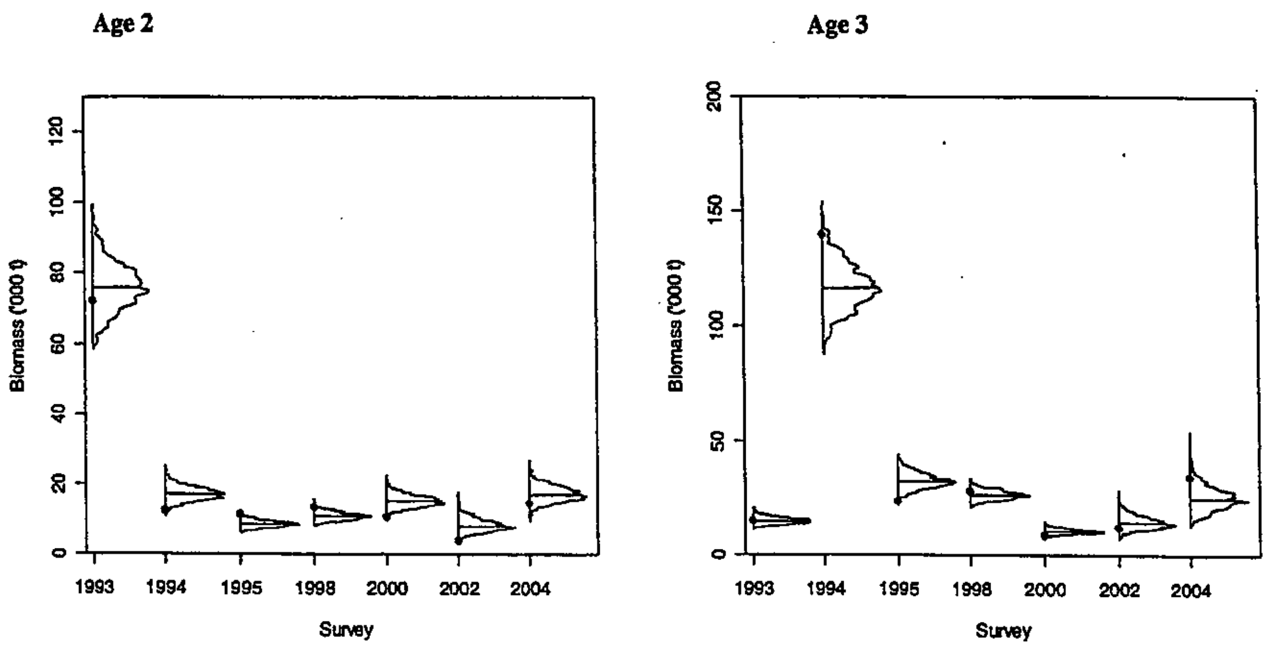
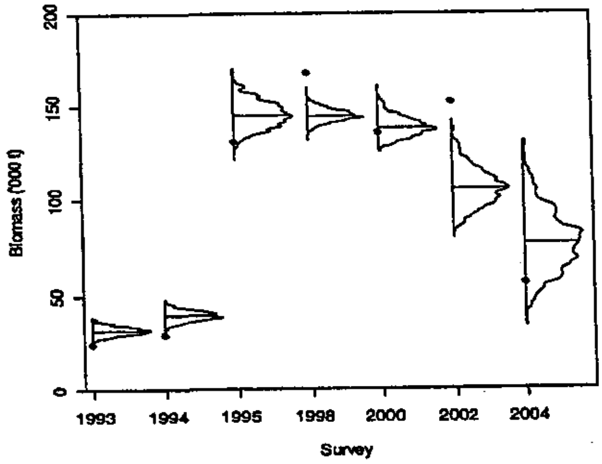
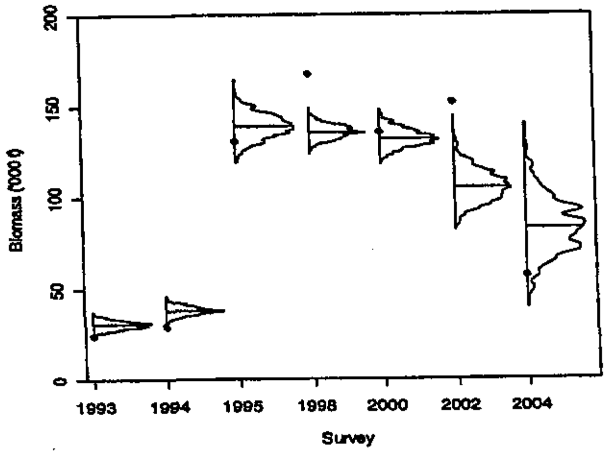


Figure 22: MCMC predicted distributions and observed acoustic indices (circles) for age 2 and 3 year old fish for the base case run.

Base case



Uninformed *q*



Core acoustics

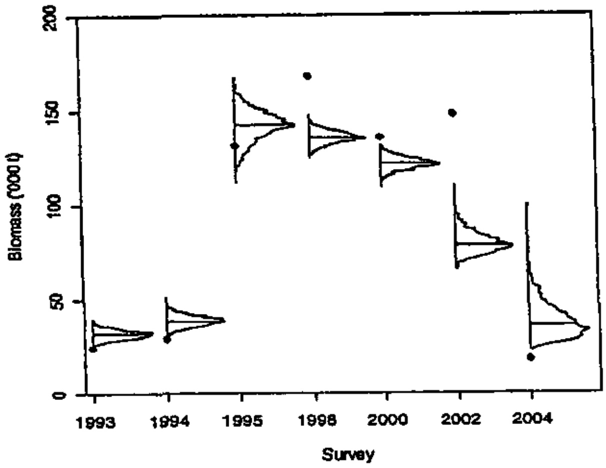


Figure 23: MCMC predicted distributions and observed acoustic indices (circles) for age 4+ fish for each of the runs.

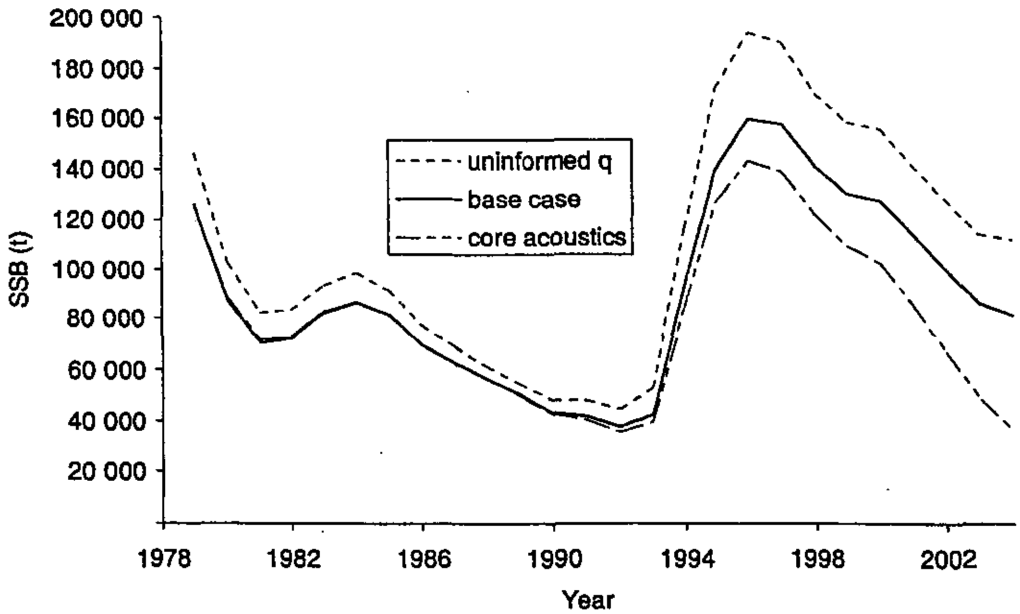


Figure 24: Median MCMC mid season spawning stock biomass trajectories for each run.

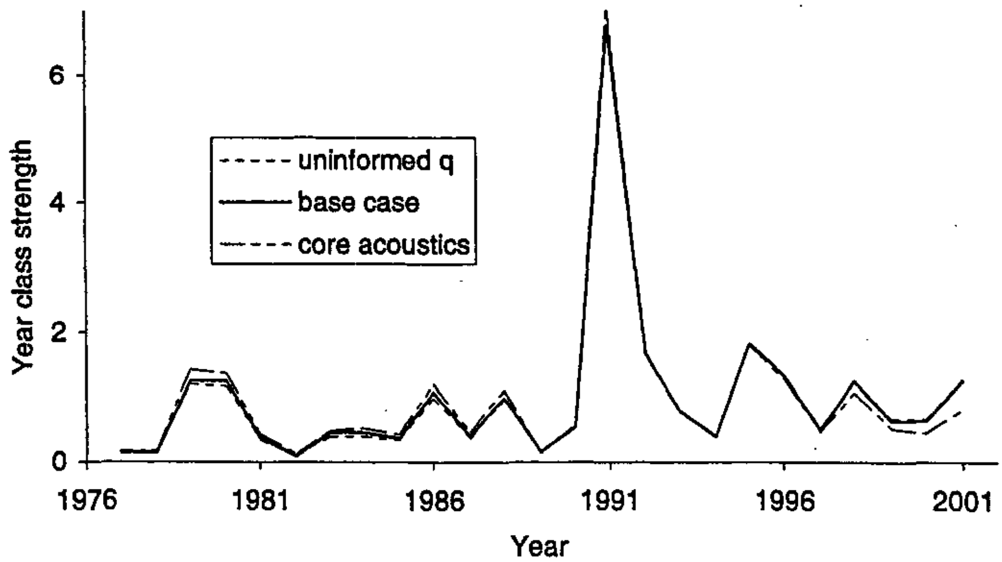


Figure 25: Median MCMC year class strengths for each run.