ISSN 1175-1584

MINISTRY OF FISHERIES
Te Tautiaki i nga tini a Tangaroa

Southern blue whiting (*Micromesistius australis*) stock assessment for the Bounty Platform for 2004–05

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New Zealand Fisheries Assessment Report 2005/45
September 2005

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New Zealand Fisheries Assessment Report 2005/45
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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
for the Bounty Platform for 2004–05.
New Zealand Fisheries Assessment Report 2005/45. 36 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 2003–04, and presents a stock assessment for the Bounty Platform.

Estimates of biomass and yield were provided for the Bounty Platform 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 Bounty Platform stock assessment used Bayesian estimation with the NIWA modelling program CASAL v2.06. New information since the 2002 assessment included one more year of proportions-at-age data from the commercial fishery. Some early Soviet trawl survey data, including proportion-at-age, were also available for the first time.

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. In particular, their sensitivity to the prior used for the adult (4+) acoustic catchability coefficient q and the starting date and initial starting conditions were evaluated. In the 2002 assessment of the Bounty stock, the estimated values for the adult acoustic q were considered to be unrealistic and runs with q fixed (or with informed priors) were used instead. Therefore, for most runs in this assessment the adult acoustic q was estimated with an informed (lognormal) prior. In the base case run the model was started in 1990 and the initial numbers-at-age were estimated. In two other sensitivity runs the model was started in 1971 and two alternative starting conditions were assumed. In one run the starting biomass was allowed to be different from B_0; in the other run the starting biomass was assumed to be at B_0.

Estimates of year class strength were similar for all runs. Results of the base case run suggest that the stock biomass increased in 1991, followed by a large decline from 1991 to 1993, as a result of the 60 000 t catch taken in 1992. Biomass increased gradually to 1998 as the 1991 to 1994 year classes recruited to the fishery, and has since remained relatively stable at 25 000–30 000 t. The biomass trajectories from the two runs starting in 1971 were generally similar, but differed in the estimates of biomass at the start and end of the period. Under the $B_{initial}$ starting conditions, B_{1971} was 34 000 t and the current biomass was 22 000 t. Under the B_0 starting conditions, B_{1971} was much higher at 69 000 t, and the current biomass was much lower at 13 000 t. In contrast, estimates of B_{1990} were almost identical between all three runs.

Two-year stochastic projections were made assuming fixed catch levels of 3500 t per year with parameter uncertainty defined by the MCMC samples of the posterior distribution. The probability that the mid-season biomass will drop below the threshold biomass (20%B_0) at current catch levels is less than 10% for the base case run. For the other two runs there is a 10% probability that the biomass is already at or below the threshold level, and that it will remain below that level under catches of 3500 t. However, under average recruitment conditions the biomass is expected to increase after 2005 in all runs.

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 (SBW 6I), Bounty Platform (SBW 6B), Pukaki Rise (SBW 6R), and Auckland Islands Shelf (SBW 6A). Acoustic surveys and assessments of the Campbell Island Rise and Bounty Platform stocks are usually carried out in alternate years. No acoustic survey of the Bounty Platform was carried out in 2003, but the assessment for this stock was revised based on a new modelling approach, and using new ancillary fisheries data. This report documents the Bounty Platform stock assessment and updates length-frequency, reproductive data, and catch-at-age data for the Bounty Platform and Campbell Island Rise stocks. The Bounty Platform 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 and 2006.

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 meant that the main fishing period usually straddled two of the 1 October–30 September fishing years. When SBW was introduced into the QMS in November 1999, the fishing year was changed to 1 April–31 March. 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. Changes in the catch limits by area since then are summarised in 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 three fishing years SBW have also been 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 & Grimes (2000, 2001) and Hanchet et al. (2002a, 2003). 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 southern blue whiting 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 the most recent stock assessment of the Bounty Platform stock, catch-at-age and acoustic data were modelled using the sSPA model (Hanchet 2002). However, in 2003, a Bayesian assessment of the Campbell Island Rise stock was made using the CASAL software for the first time (Hanchet et al. 2003). Standardised CPUE analyses of the Bounty and Campbell stocks were summarised by Hanchet & Blackwell (2003).

Objectives

This report addresses objectives 1 and 2 from MFish project SBW2003/01.

1. To determine catch-at-age from the commercial fisheries at Campbell Island Rise, Auckland Islands, Bounty Platform, and Pukaki Rise for 2003/04 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 Bounty Platform 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 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 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. SBW has been managed using a Current Annual Yield (CAY) strategy (Annala et al. 2004), which has contributed to the fluctuating catch limits and TACCs (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 2003 season (2003–04 fishing year) from the Quota Monitoring Reports was 27 812 t. The TACC was undercaught on Auckland Islands Shelf and the Pukaki Rise, almost reached on Campbell Island Rise, and slightly exceeded on Bounty Platform.

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 2003 season

The location of trawls made during the 2003 season (mid August to mid October) is shown in Figure 1. Fourteen vessels, mainly from Japan and Ukraine, fished for southern blue whiting during the 2003 season (Table 2). The first vessels arrived on the Bounty Platform on 24 August, and vessels soon located SBW to the east of the Bounty Platform. Three vessels fished there during the 9 day season and took 3812 t. Unfortunately no vessels carried observers.

No vessels fished the Pukaki Rise or the Auckland Islands Shelf this season.

Vessels started fishing the Campbell Island Rise on 4 September and continued fishing until 3 October. There were two main spawning aggregations on the Campbell Island Rise ground this season. One aggregation was being fished by most of the commercial fleet on the northeastern ground from 4 to 20 September. A second aggregation was being fished in the southern area from 4 to 13 September. Fish were spawning in the northeastern aggregation over the period 15–20 September. After the first spawning was finished, most vessels initially moved south and west into shallower water before moving back to the east. A total of 23 715 t was taken during the 2003 season by 14 vessels (Table 2). Fish from both aggregations had a similar size distribution.

2.1.4 CPUE analysis

Standardised CPUE analyses were carried out for the southern blue whiting (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. (2003), who 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 Bounty Platform analysis was based on a data set of 3288 non-zero records from 1990 to 2002 (Hanchet & Blackwell 2003). The CPUE indices fluctuated considerably peaking in 1992, 1996–1998, and again in 2002. The indices were similar between most of the CPUE models until 1997, but after 1997 they became more erratic between years and inconsistent amongst vessel subsets. The authors noted that there were other problems with the model assumptions, and that the model structure may be inadequate to reliably determine the indices and their standard errors. Trends in CPUE for the Bounty Platform fishery were consistent with trends in biomass from the 2002 NIWA assessment model of Hanchet (2002), apart from the first two years and last two years. The lower indices in the first two years may be due to lack of experience, whilst the higher indices in the last two years is suggestive of hyper-stability. The authors noted that the CPUE indices needed to be more fully examined in a modelling context, and possible reasons for hyper-stability examined further, before the indices could be endorsed. As such the indices were rejected by the MDWG and not used for the 2004 stock assessment.

2.2 Other information

2.2.1 Size and age composition of the commercial catch

Methods

Scientific observers collected length-frequency data from about 20% of all tows in the commercial fishery during 2003 (Table 2). About 620 otoliths collected from the Campbell Island Rise fishing ground during the 2003 season were read and used to derive an age-length key. No observers were on board vessels in the other fished area (Bounty).

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 last year 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. (2003).

The weighted length-frequency data for the Campbell Island Rise stock are shown by sex for 2001 to 2003 in Figure 2. As seen in previous years, the length structure is sexually dimorphic with females growing larger than males. The proportion-at-age in the catch by sex is shown in Figure 3. The catch for the 2003 season was numerically dominated by 5 year old fish (the 1998 year class), and by the plus group (mainly the 1991 year class).

The proportion-at-age in the catch for the Bounty Platform stock by sex is shown in Figure 4. The catch for the 2002 season was numerically dominated by 4 year old fish (the 1999 year class).

The entire time series of catch-at-age data for the Bounty Platform are given by sex together with their c.v.s in Appendices 1a and 1b.

2.2.2 Soviet research data from 1970 to 1977

Data from Soviet research trawl surveys from 1970 to 1979 were recently obtained by the Ministry of Fisheries (K. Sullivan, MFish, pers. comm.). A summary of the number of trawls, SBW catch, and mean length of fish is given for 1970 to 1976 and by area in Table 3. It is evident that the research trawl survey data represent only a small percentage (1–7%) of the total catch each year. The data are therefore not useful for partitioning the early catch between areas/stocks.

A set of unsexed proportion-at-age data was also available for 1972 to 1977 from a Soviet scientist (Shpak 1978), and the set is reproduced in Table 4. These ageing data were based on scale readings, and there was some concern regarding the reliability of the ages. Shpak (1978) also provided estimates of mean length-at-age. The mean length-at-age data given in Table 3 provided an opportunity to independently verify these proportion-at-age data.

Mean length-at-age of SBW from the Bounty Platform is given in Table 5. The mean length at age from the Soviet paper (Shpak 1978) is given in (i). The mean length at age from observer data collected from 1990 to 2002 (see also Appendix 2) is given in (ii). After age 2, the mean lengths at age from the observer data are almost identical to Shpak's estimates for ages 1 year older. We have never found fish of 14 cm in August/September, although fish occasionally have a within-year check equivalent to about that length. Therefore, to be consistent with the rest of the New Zealand data, 1 year has been subtracted from the Russian ages.

One further check of the Soviet data was carried out to determine whether the proportion-at-age from Shpak's paper was consistent with the mean length from the Soviet trawl database. The proportion-at-age was multiplied by the mean length-at-age (from Shpak's paper) and summed across all ages to predict the mean length in the fishery for each year from 1972 to 1976. This predicted mean length agreed almost exactly with the observed mean length from the Soviet trawl database (Table 6). It can therefore be concluded that the proportion-at-age data in Shpak's paper are consistent with the mean length from the Soviet database. The full time series of age data for both sexes combined, offset to accentuate year class strengths, is given in Figure 5.

2.2.3 Timing of spawning

Spawning was later than usual in 2003 on the Campbell Island Rise (Table 7). The first fish were sampled on the northern ground on 4 September, but they did not start spawning until 15 September. The first spawning was finished by 20 September. The timing of the second spawning could not be determined. No data were available for the other three 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.

4. STOCK ASSESSMENT

4.1 The stock assessment model

The stock assessment model partitions the Bounty stock into two sexes and age groups 2–11, with a plus group at age 11. A two-sex model is used primarily because of differences in growth and in fishing selectivity between the sexes. There are two time steps in the model (Table 8). 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. 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 used only to report spawning stock biomass. The maximum exploitation rate (U_{max}) was set at 0.8. 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 by sex for each year, 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 by Hanchet (1991). Mean length at age for 2003 and 2004 was estimated by adding the mean growth for each age class to the length of that age class in 2002 and 2003 respectively.

Three different starting conditions were explored. In the base case, the initial numbers at age in the population in 1990 were estimated for each sex. Year class strengths were estimated for all years from 1988 to 2000. In the other two runs, the model was started at the beginning of the fishery in 1971. In one of these the population in 1971 was assumed to be at the virgin level (i.e., at B_0), in the other the population in 1971 was allowed to be different to virgin biomass and was estimated (B_{init}). (Note that 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.) In these two runs year class strengths were estimated for all years from 1970 to 2000. In all three runs it was assumed that the estimates of YCS should average.

The catch history assumed in the model runs were the revised estimates of catch by year since 1978 given in previous stock assessment documents (e.g., Hanchet 2002). Annual catches from 1971 to 1977 for the Bounty Platform stock are unknown, but were assumed to be equal to the average proportion of the catch from the Bounty Platform over the period 1978 to 2003 (23% of the total). To test the model results to this assumption, the catch history from 1971 to 1977 was doubled in one of the model runs as a sensitivity test (see Section 4.5).

4.2 Observations

The model was fitted to the acoustic biomass estimates of ages 2, 3, and 4+ fish given in Table 9 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 by sex were available from the commercial fishery for 1990 to 2002. These catch-at-age data were fitted to the model as proportions-at-age by sex, 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). For the 1990–2003 model the plus group was at age 11, but for the runs back to 1971 the plus group was at age 17, which allowed the estimation of more year class strengths. A set of unsexed proportion-at-age data was also available for the period 1972 to 1977 from Soviet scientists (see Section 2.2.2). These ageing data were based on scale readings, and were assumed to be less precise than ages from otoliths. Each proportion-at-age was therefore arbitrarily assigned a c.v. equal to 1.5 times the median c.v. from the corresponding age class in the 1990–2002 data set. For both data sets, zero values were replaced with 0.001 with an associated c.v. of 2.0, and ageing error was assumed to be zero. The 1972 to 1977 period was treated as a separate fishery within the model, thus allowing fishing selectivity to be estimated for ages 2 to 4 separately for this time period. Note that the 1972–1977 Soviet age data were fitted only in the sensitivity analyses starting in 1971 and were not fitted in the base case.

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.

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 each of the initial runs (MPDs) using all the available data. Process errors ranging from 0.37 to 0.44 were estimated for the 1990–2002 proportions-at-age data, and from 0.75 to 0.90 for the 1972 to 1977 Soviet proportion-at-age data. The process error estimated for the acoustic indices were zero for the age 4+ index, and ranged from 0.51 to 0.6 for the age 3 index and from 0.66 to 0.92 for the age 2 index. The MPD process errors were added to each observation for all subsequent MCMC runs

MCMC chains were estimated 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. Because of poor convergence, the number of iterations was doubled for the run where $B_{initial}$ was estimated (Binit.7103).

4.4 Prior distributions

The assumed prior distributions used in the assessment are given in Table 10. Most priors were intended to be uninformed, and had wide bounds. However, a log-normal prior was used for the acoustic survey 4+ catchability coefficient *q*. This prior was obtained using the approach of Cordue (1996), and was detailed further by Hanchet (2002). 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 0.75–2.5, with a mean of 1.4 and a c.v. of 0.2. These bounds were extended to 0.1–2.8 as a result of discussions within the MDWG so as to encapsulate a wider range of uncertainty in this model parameter.

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 run and sensitivity tests

As this assessment used new information and a revised modelling approach, a number of different runs were considered (Table 11). In recent stock assessments of SBW the estimates of current biomass have been driven to a large extent by the estimate of the 4+ (adult) acoustic q (Hanchet 2002). In the 2002 assessment of the Bounty stocks, the estimated values for this q were considered to be unrealistic by the Working Group and runs with q fixed (or with informed priors) were used instead. Therefore, for most runs in the current assessment the adult acoustic q was estimated with an informed (lognormal) prior. As discussed in Section 4.1, several runs were also carried out to determine the sensitivity of the results to alternative starting conditions and years used in the analysis. As an additional sensitivity test, the catch history from 1971 to 1977 was doubled for one of these runs (see also Section 4.1).

Two further sensitivity tests to the base case were carried out. One run was made to explore the sensitivity of the results to the adult acoustic q, by giving it an uninformed (uniform-log) prior. A retrospective analysis was also carried out (by omitting the 2002 and 2003 catch and proportion-at-age data) to enable a direct comparison with the results of the 2002 assessment. The model runs are summarised in Table 11.

For each model run, MPD fits were obtained and qualitatively evaluated. MCMC estimates of the median posterior and 90% credible intervals are reported for virgin biomass, initial biomass, B_{2003}, and B_{2003} (as $\%B_0$).

4.6 Results

4.6.1 MPD fits

The MPD fits for the base case to the acoustic indices are moderately good for most ages and years (Figure 6). However, the model was unable to fit the high age 4+ index in 1993 and the low age 4+ index in 2001, and also had problems fitting the two highest indices in the age 3 acoustic series. In general, the residual and QQ plots for all acoustic indices combined were reasonable (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, 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).

4.6.2 MCMC results

The base case MCMC estimates of marginal posterior distributions for spawning stock biomass by year are shown in Figure 9 and are summarised in Table 12. The results suggest that the stock biomass increased to 1991 followed by a large decline from 1991 to 1993, as a result of the large catch taken in 1992. Biomass increased gradually to 1998 as the 1991 to 1994 year classes recruited into the fishery, and has since remained relatively stable at about 25 000–30 000 t. Year class strengths since 1994 have been below average, with the 2000 year class being amongst the lowest on record (Figure 10). The exploitation rate (catch: biomass ratio) was estimated to be almost 0.7 in 1992, the year with the highest catch, but has averaged about 0.2 more recently (Figure 11). The initial age structure was completely dominated by 3 year old fish of the strong 1986 year class (Figure 12). The fishing selectivity estimated by the base case is shown in Figure 13. The fishery selected significantly more males than females at age 3, but by age 4 fish of both sexes were selected equally. Fish of both sexes were almost fully selected by age 4. The posterior distribution for the adult acoustic q is very similar to the prior distribution (Figure 14).

No evidence of lack of convergence was found in estimates of biomass, although some estimates of selectivity parameters, YCS, and initial ages showed evidence of lack of convergence (Table 13).

4.6.3 Sensitivity estimates

The results of the sensitivity runs are presented in Table 12 and Figures 15 to 17. The model was relatively insensitive to the assumptions over the informed prior on the adult acoustic q and to the retrospective analysis. When the prior on q was uninformed (run *Cinit.9003.estq*) the estimate of q was similar to that in the base case. The model was slightly more sensitive to the runs dealing with different initial starting conditions, with respect to B_{init} and B_{2003}.

The biomass trajectories from the three runs covering the period 1971 onwards were generally similar, but differed in the estimates of biomass at the start and end of the period (Table 12, Figure 15). Under the $B_{initial}$ starting conditions, B_{1971} was 34 000 t and the current biomass was 22 000 t. Under the B_0 starting conditions, B_{1971} was much higher at 69 000 t, and the current biomass was much lower at 13 000 t. In contrast, estimates of B_{1990} were almost identical between all runs (Figure 15). The run using a higher pre-1979 catch had higher initial recruitments (Figure 16), but otherwise differed little from the other two runs.

The median and 90% confidence intervals of current stock size estimates from the base case and sensitivity runs are illustrated in Figure 17. The base case lies within the range provided by the sensitivity tests.

4.6.4 Comparison with the 2002 assessment

The results of the assessment are slightly more optimistic than those of the 2002 stock assessments for the Bounty Platform stock. The results of the more credible 2002 NIWA and SeaFIC assessments provided best estimates of B_{2001} between 15 000 and 23 000 t. In contrast, the median estimate of B_{2001} in the current assessment was 28 000 t from the base case assessment, and 29 000 t from the retrospective analysis. The reason for this slightly more optimistic assessment is unclear, but could be related to the different weightings used in the assessments, the use of different priors, and several other model and error structure assumptions (e.g., 1 sex vs 2 sex model, multinomial vs lognormal error structures).

4.7 Projections

Projections were made assuming a fixed catch level of 3500 t per year using the MCMC samples, and assuming the TACC of 3500 t will be taken in 2003–04. Recruitments were drawn randomly from the distribution of year class strengths estimated by the model. The probability that the mid-season biomass for the specified year will be less than the threshold level (20% B_0) is given for the base case and two of the sensitivity runs in Table 14. The probability of dropping below the threshold biomass at current catch levels is less than 10% for the base case run. For the other two runs there is a 10% probability that the biomass is already at or below the threshold level, and that it will remain below that level under catches of 3500 t. However, under average recruitment conditions the biomass is expected to increase after 2005 in all runs.

4.8 Yields

Estimates of sustainable yields were made for the Bounty Platform stock 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 method used to estimate MCY was $MCY = \rho B_0$, where ρ is determined for each stock using the simulation method described by Francis (1992), and is such that 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 MCY was 4832 t.

The simulation method of Francis (1992) was also used to estimate u_{CAY} with the same definition of risk. The estimate of u_{CAY} was 0.2. The corresponding estimate of MAY was 6461 t and of $CAY_{2004\text{-}05}$ was 4034 t.

5. DISCUSSION

5.1 Model fits and acoustic *q*

Previous SBW assessments have demonstrated the importance of the adult (4+) acoustic *q*, which essentially acts as a scalar for the population size. In the 2002 assessment of SBW on the Bounty Platform, *q* was estimated by the model to be 2.3. This estimate was considered to be unlikely, and consequently an alternative base case was run with the *q* fixed at 1.4 (Hanchet 2002). Because of these problems, in the current assessment it was decided to use an informed (log-normal) prior for the base case and most other runs. The sensitivity to this assumption was explored by carrying out a sensitivity test using an uninformed (log-uniform) prior. The results from this test provided similar results to the base case, and so it can be concluded that this assessment was less sensitive to the acoustic *q* than previous assessments. 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 estimate of *q* from the base case was 1.35, which is very similar to the prior of 1.4.

Although the model trajectories are similar since 1990, there is considerable uncertainty in biomass at the start of the fishery in 1970. In the Binit.7103 run the initial biomass was estimated to be only 30 000 t or about 50% B_0. How likely is it that in the absence of fishing the initial biomass could be only 50% of the virgin level? A simple simulation function was written in Splus by A. Dunn (NIWA, pers. comm.) to answer that question. The usual SBW population parameters given elsewhere in this document were used in the simulation. In addition, two other parameters were required: recruitment variability (rsd) and YCS autocorrelation (phi). An estimate of rsd came from the series of recruitments estimated by the SBW population model for the Bounty Platform stock and equalled 1.05. Phi was assumed to be 0.4, as this was the median value from a meta-analysis carried out by Myers et al. (1995). Using 5000 simulations the probability of the initial biomass being below 50% of B_0 was only 0.1. So although it is certainly possible, it is not that likely.

This raises doubts over the usefulness and validity of the early Soviet data. There are no additional data from the Bounty fishery, but there are some historical data from the Campbell fishery, which may shed light on this. In his paper, Shpak (1978) also presented age composition data for the Campbell fishery for 1972–76. These data are also dominated by young fish, mainly the 1966–68 year classes. A trawl survey of the Campbell Plateau carried out by the Japanese research vessel *Kaiyo Maru* in 1970–71 caught predominantly 2–4 year old fish also comprising the 1966–68 year classes (Anon. 1972). Lastly, the catch-at-age data for the Campbell Island Rise from the late 1970s and early 1980s comprised a large proportion of 12–20 year old fish suggestive of several strong year classes born in the mid 1960s. An exploratory stock assessment using these data (i.e., with a plus group at age 20) estimated two strong year classes for 1964 and 1965, which were of a similar magnitude to the very strong 1991 year class seen in that fishery more recently (Hanchet 1998b). Thus, although there are likely to be subtle differences in the interpretation of age reading structures (otoliths and/or scales) between different nations, the Soviet data for Campbell are quite consistent with other data available for that fishery. Although there are no additional data for the Bounty fishery, and so these data cannot be confirmed, it is likely that these are also reasonably reliable.

Despite different models and different estimation methods, the current assessment was reasonably consistent with the last assessment of the Bounty Platform stock carried out in 2002. Estimates of B_0 have decreased slightly – probably as a result of the inclusion of recent below average strength year classes in the model. Estimates of stock status (e.g., B_{2001} and B_{2001} / B_0) are slightly higher than those from the 2002 assessment.

In summary, the assessment results show the model to be moderately robust. 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 moderately 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 2004 meetings, whilst others have been developed in discussion with colleagues. They include the following.

- Revisit the acoustic prior once the target strength–fish length relationship has been re-estimated.
- Examine the sensitivity of the model to different ages for the plus group.
- 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

The base case gave a median estimate of B_{2003} of 30% of B_0. At catches at the level of the current TACC (3500 t), the biomass is projected to remain stable or increase slightly. Higher yields will only be available when there is good recruitment – which occurs only sporadically in this stock.

7. ACKNOWLEDGMENTS

I am grateful to the scientific observers for the collection of the length frequency data and otoliths. I also thank Michael Stevenson and Colin Sutton for reading 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 Nick Davies for making useful comments on an earlier draft of the manuscript, and to Mike Beardsell for editorial comments. The Ministry of Fisheries project SBW2003/01 funded this work.

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Table 1: Estimated catches (t) of southern blue whiting by area for the period 1978 to 2003–04 from vessel logbooks, QMRs, and MHRs..– no catch limit in place. *, 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	33 433	30 000	712	5 500	254	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‡

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, and 2.6 t in 2003–04.

Table 2: Number of vessels, tows, and catch (t) for observed and all vessels targeting SBW by area from August to October in the 2003–04 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	0	3	0	24	3 812	24 Aug – 2 Sep
Pukaki	0	0	0	0	0	–
Auckland	0	0	0	0	0	–
Campbell	5	14	115	598	23 715	4 Sep – 3 Oct

Table 3: Summary of number of trawls (N), SBW catch (t), and mean length (cm) by area made by Soviet research vessels from 1970 to 1976 (data provided by MFish). Note: Bounty Platform data include only the period from July to September; catches from Pukaki Rise and Campbell Island Rise were almost all outside this period. –, no data. Total catch, total catch reported from all Soviet vessels (Annala et al. 2004).

Year	Bounty			Campbell			Pukaki			All areas	Total
	N	Catch	Length	N	Catch	Length	N	Catch	Length	catch	catch
1970	–	–	–	72	112	36.9	14	5	38.9	117	–
1971	–	–	–	220	657	37.7	31	15	38.5	672	10 400
1972	64	319	32.4	182	754	37.0	27	19	30.6	1 092	25 800
1973	151	1 055	33.3	124	370	37.2	7	4	51.3	1 429	48 500
1974	10	37	37.3	45	186	38.1	3	2	41.7	225	42 200
1975	26	75	37.4	–	–	–	–	–	–	75	2 378
1976	72	768	40.3	127	472	40.0	–	–	–	1 240	17 089

Table 4: Proportion-at-age data (both sexes combined) for the Bounty Platform fishery from 1972 to 1977 from Shpak (1978).

Year	Age											
	2	3	4	5	6	7	8	9	10	11	12	13
1972	0.001	31.3	46	10.7	4	4	2.7	0.9	0.4	0	0	0
1973	0.01	23.6	46	21.4	5.1	2.3	1.2	0.3	0.1	0	0	0
1974	0.2	3	24.5	31.3	16	9.7	5	3.3	4	2	0.7	0
1975	0.4	5.6	14	46.1	17	7.1	4.5	2	2	0.9	0.4	0
1976	0.9	0.4	8.3	18	29	16	8.6	7.5	4.9	4.3	1.8	0.15
1977	0.1	2.4	17	20.6	20.3	17.3	10	6	4.3	1.4	0.4	0.14

Table 5: Mean length at age for SBW on the Bounty Platform. (i) Summary of Soviet data from 1968 to 1977 (Shpak 1978, Table 6); and (ii) Summary of observer data from 1990 to 2002 (Appendix 2).

Age (years)	Mean length (cm)	
	(i) Shpak	(ii) Hanchet
1	14.8	20.3
2	22.3	27.0
3	28.0	32.1
4	32.6	36.0
5	36.4	39.0
6	39.0	41.6
7	41.8	44.2
8	44.6	47.0
9	47.4	48.5

Table 6: Predicted and observed mean length length-at-age in the Bounty Platform fishery from 1972 to 1976 (see text for details).

	Predicted mean length	Observed mean length
1972	32.73	32.35
1973	33.08	33.27
1974	37.79	37.27
1975	37.24	37.36
1976	40.70	40.34

Table 7: Dates of sampling and changes in SBW gonad condition in 2003 on north and south Campbell Island Rise, 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 were collected from Bounty Platform, Pukaki Rise, and Auckland Islands Shelf in 2003.

Gonad stage	Campbell	
	North (< 52° 30')	South (> 52° 30')
1st sample	4/9	11/9
>10% ripe	10/9	–
>10% running ripe	16/9	–
Main spawning	15–20/9	–
>10% spent	20/9	–
>10% reverted	19/9	–
2nd spawning	–	–
Last sample	27/9	25/9
% spent	55	3
% reverted	63	1

Table 8: 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 9: Estimates of biomass (*t*) for age 1, 2, 3 and 4+ fish (and associated c.v.s) from acoustic surveys of Bounty Platform used in modelling the fisheries.

Year	Age 1		Age 2		Age 3		Age 4+	
	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.	Biomass	c.v.
1993	8 814	0.46	6 870	0.43	1 410	0.46	62 857	0.46
1994	94	0.80	5 871	0.87	32 066	0.22	27 672	0.22
1995	59 284	0.37	4 856	0.24	6 658	0.24	30 770	0.24
1997	1 679	0.12	4 144	0.12	24 598	0.35	37 518	0.35
1999	429	0.96	745	0.39	4 969	0.77	42 722	0.77
2001	135	0.28	2 551	0.28	6 010	0.35	21 677	0.35

Table 10: The distributions, priors, and bounds assumed for the various parameters being estimated.

Parameter	Run	N	Distribution	Values		Bounds	
				Mean	c.v.	Lower	Upper
B_0	1–6	1	Uniform-log	–	–	20 000	250 000
NZ select. ages 2-4 (by sex)	1–6	6	Uniform	–	–	0.0001	1
Soviet select. ages 2–4	4–6	3	Uniform	–	–	0.0001	1
Process errors	1–6	4	Uniform-log			0.0001	1
Process errors (Soviet age)	4–6	1	Uniform-log			0.0001	1
Acoustic 4+*q*	1,3–6	1	Lognormal	1.40	0.20	0.1	2.8
Acoustic 4+*q*	2	1	Uniform-log	–	–	0.1	2.8
Acoustic *q* age 2, 3	1–6	2	Uniform-log	–	–	0.1	2.8
YCS (1988–2000)	1–6	13	Lognormal	1.00	1.30	0.01	100
YCS (1970–1987)	4–6	18	Lognormal	1.00	1.30	0.01	100
Initial population (by sex)	1–4	18	Uniform	–	–	5e4	2e8
B initial	5	1	Uniform-log			1 000	200 000

Table 11: Model run labels and descriptions for the base case and sensitivity runs tested. Note apart from run 2 all runs used an informed prior on the adult (4+) acoustic q.

	Model label	Description
1.	Base case	Model starting in 1990 and estimating initial numbers-at-age.
2.	Cinit.9003.estq	Model starting in 1990 and estimating initial numbers-at-age with uniform-log (uninformed) prior on the adult acoustic q.
3.	Cinit.9001	Retrospective analysis starting in 1990, finishing in 2001, and estimating initial numbers-at-age.
4.	Binit.7103	Model starting in 1971 and estimating initial biomass with equilibrium age structure.
5.	B0.7103	Model starting in 1971 at virgin biomass with equilibrium age structure.
6.	B0.7103.hi	Model starting in 1971 at B_0 with equilibrium age structure, but double the pre-1979 catch.

Table 12: Bayesian median and 90% confidence intervals of B_0, B_{2003} (in '000 t), and B_{2003} as a percentage of B_0 for the various runs. * refers to B_{2001}.

Model run	B_0	B_{init}	B_{2003}	B_{2003} (% B_0)	Adult acoustic q
Base case	86 (70–111)	64 (60–68)	25 (10–52)	30 (15–46)	1.35 (1.12–1.56)
Cinit.9003.estq	91(71–167)	64 (61–70)	31 (11–104)	34 (16–63)	1.27 (0.70–1.64)
Cinit.9001	91 (76–117)	64 (60–67)	*29 (17–50)	*32 (23–43)	1.35 (1.11–1.56)
Binit.7103	76 (70–87)	34 (27–44)	22 (10–45)	29 (14–52)	1.37 (1.16–1.54)
B0.7103	69 (65–75)	69 (65–75)	13 (6–25)	19 (8–33)	1.48 (1.32–1.63)
B0.7103.hi	75 (70–82)	75 (70–82)	17 (7–30)	22 (10–37)	1.44 (1.27–1.58)

Table 13: Percentage of parameters that passed the Geweke and Heidelberger & Welch convergence diagnostics for selected parameters from the base case MCMC runs.

Parameter	n	Geweke	Heidelberger & Welch	
			Stationarity	Half width test
B_0, B_{init} etc.	4	Passed	Passed	Passed
Selectivity	6	83%	Passed	Passed
YCS	14	71%	Passed	97%
SSB	14	Passed	Passed	Passed
Initial ages	18	94%	Passed	Passed

Table 14: Probability that the projected mid-season vulnerable biomass for 2005 and 2006 will be less than 20% B_0, and the median projected biomass as a % B_0, for the Bounty Platform stock, at projected catches of 3500 t.

	Probability (B_{proj}<20% B_0)			Median biomass as a % of B_0		
	2003	2005	2006	2003	2005	2006
Base case	0.04	0.07	0.06	36.2	36.5	38.5
Binit.7103	0.10	0.16	0.15	34.1	33.6	35.5
B0.7103	0.44	0.52	0.45	21.2	19.6	21.5

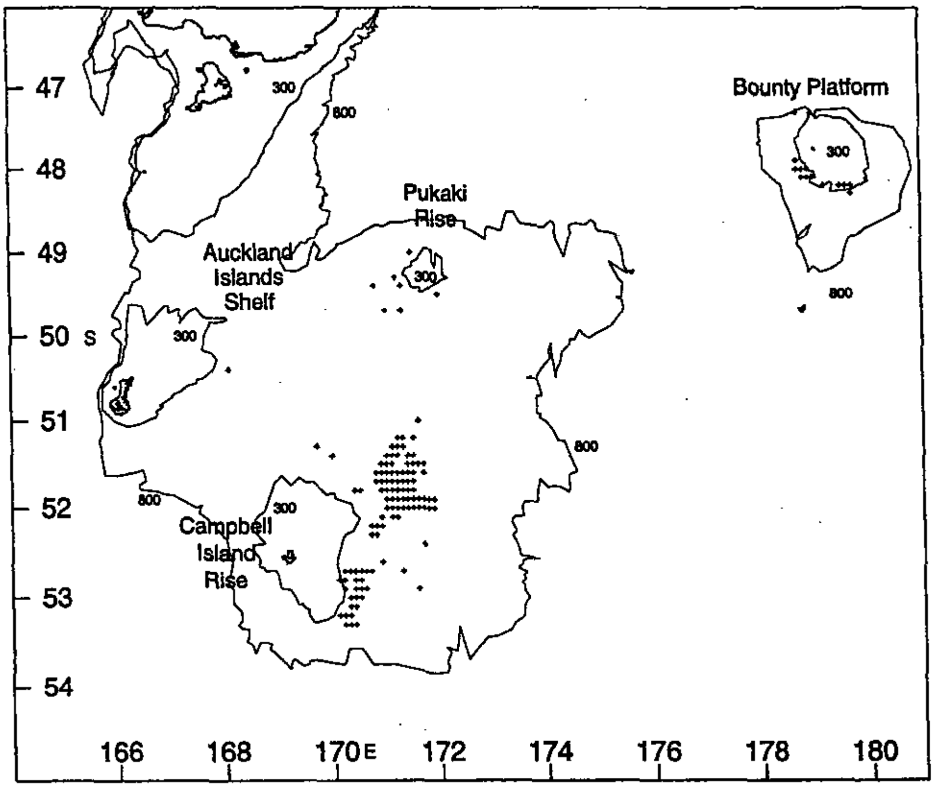

Figure 1: Commercial trawls made during the 2004 season (late August to early-October) targeting southern blue whiting.

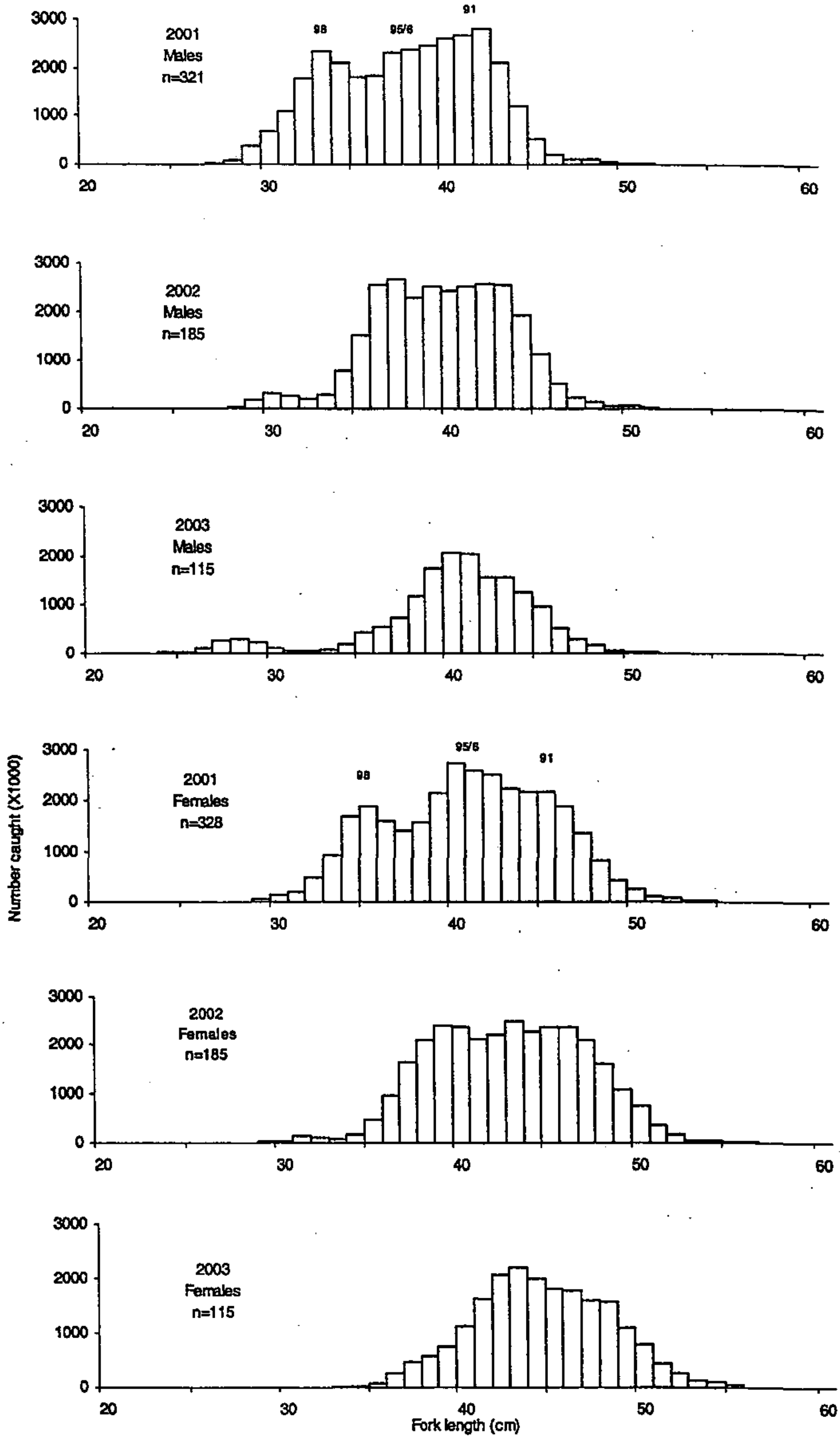

Figure 2: Weighted length frequency distribution of SBW for the Campbell Island Rise for the 2001 to 2003 seasons. The numbers above the modes are the most likely year classes corresponding to those length intervals.

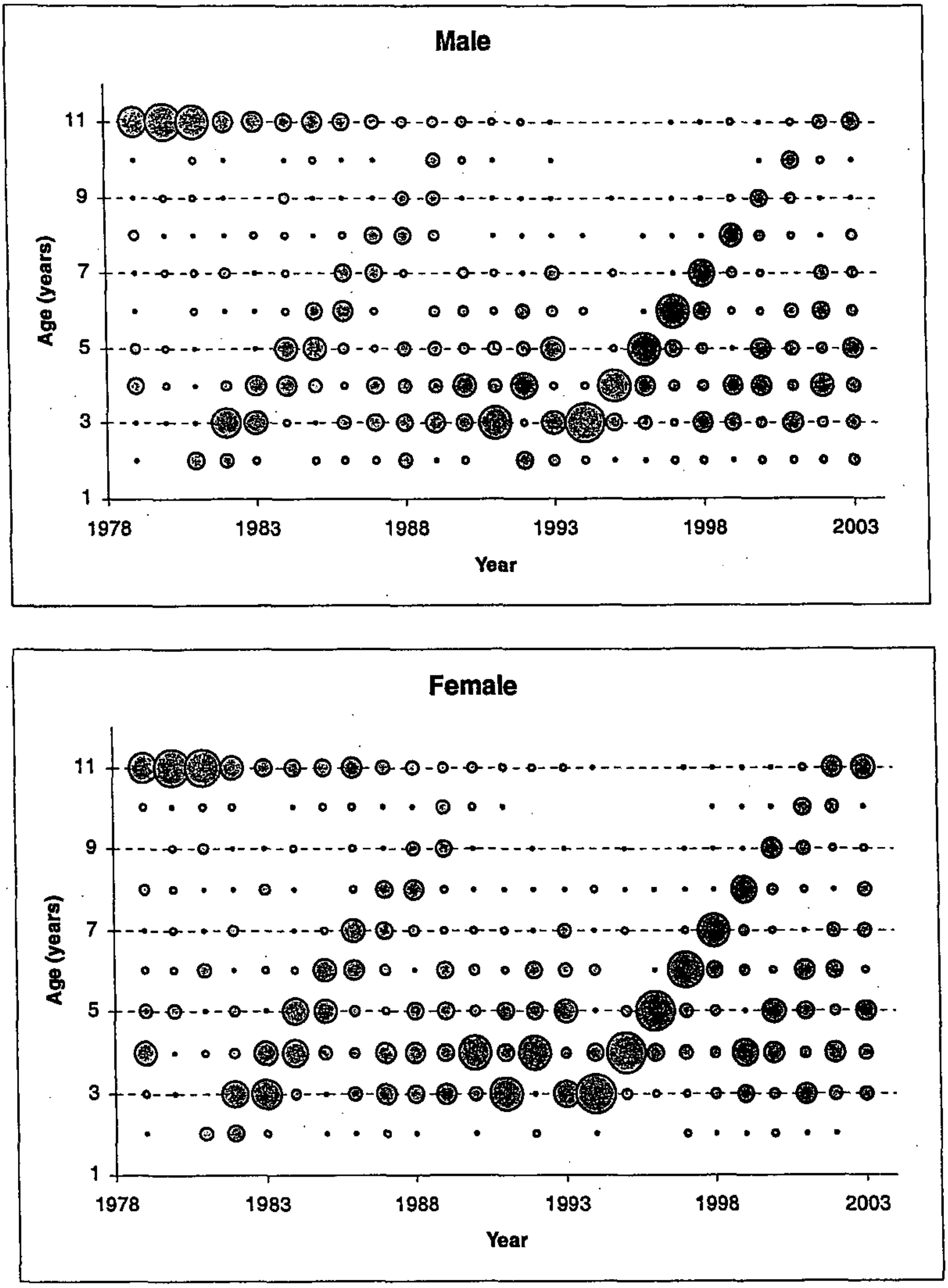

Figure 3: Male and female proportion at age in the Campbell catch from 1979 to 2003. Symbol area proportional to the proportions-at-age within the sampling event.

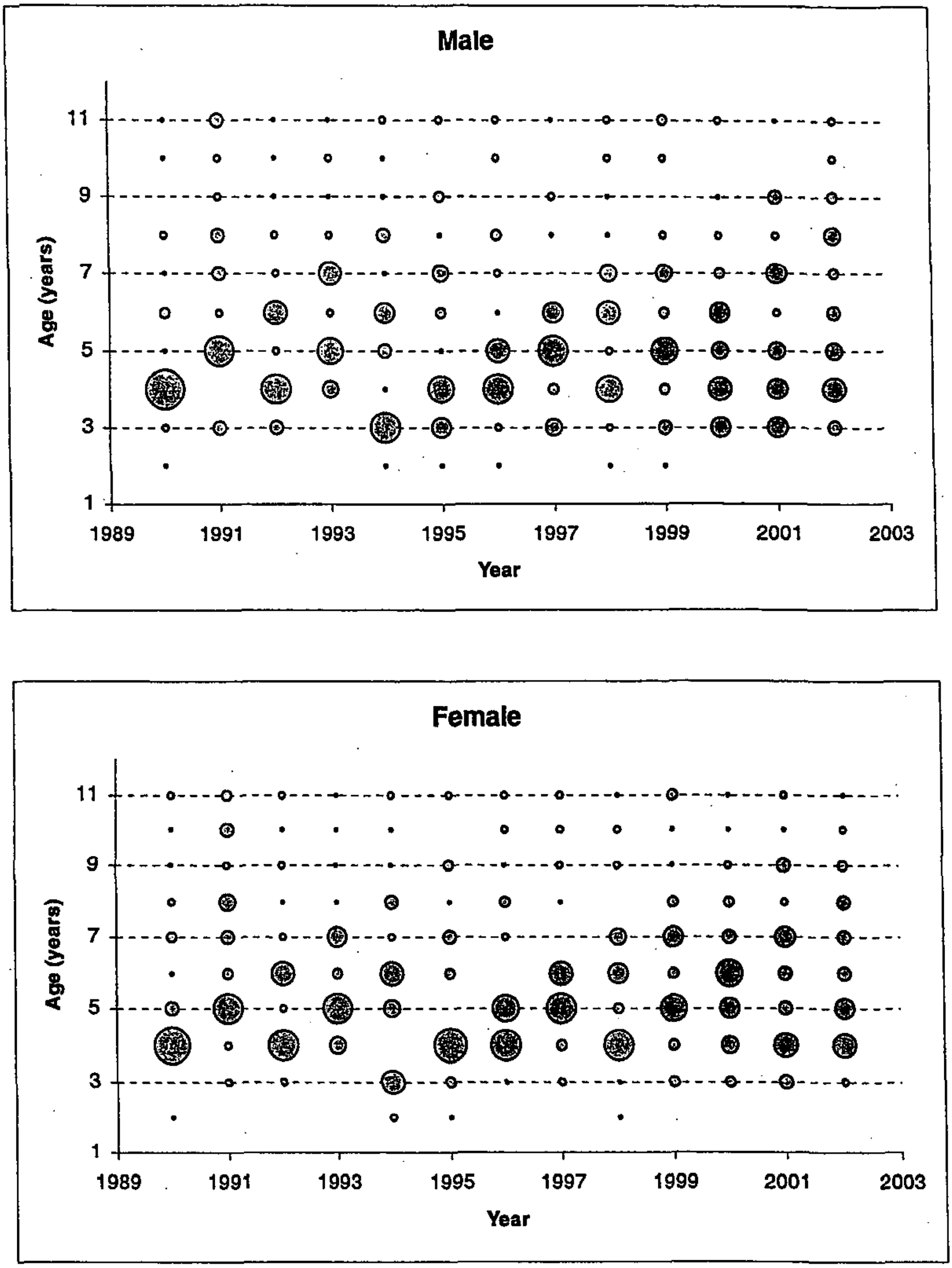

Figure 4: Male and female proportion at age in the Bounty Platform catch from 1990 to 2002. Symbol area proportional to the proportions-at-age within the sampling event. (No observer data for 2003).

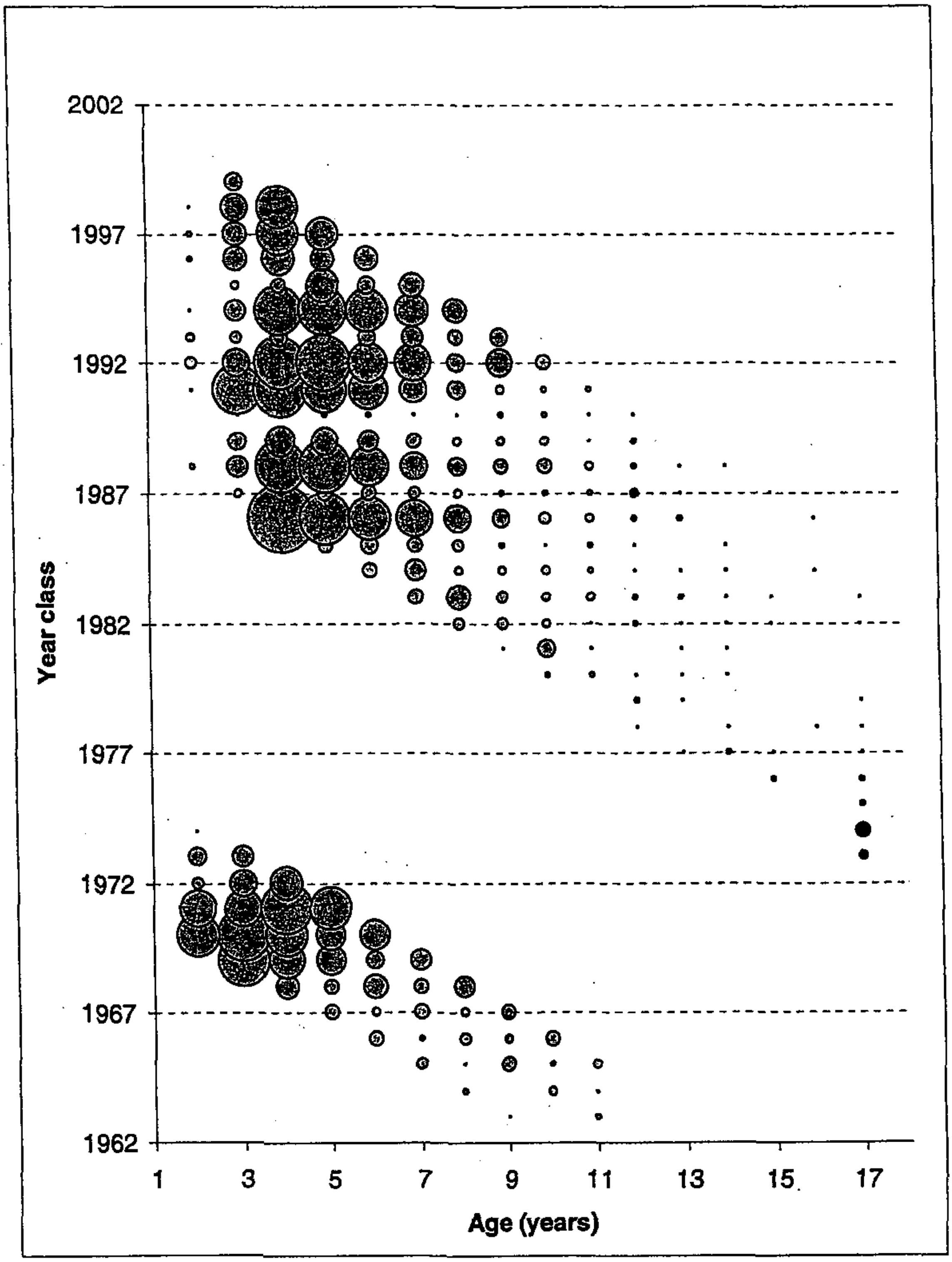

Figure 5: Proportion at age in the Bounty Platform catch from 1990 to 2002. The Russian data were unsexed. Sexes were combined in the more recent observer data for illustrative purposes only. Symbol area is proportional to the proportions-at-age within the sampling event. (No observer data for 2003).

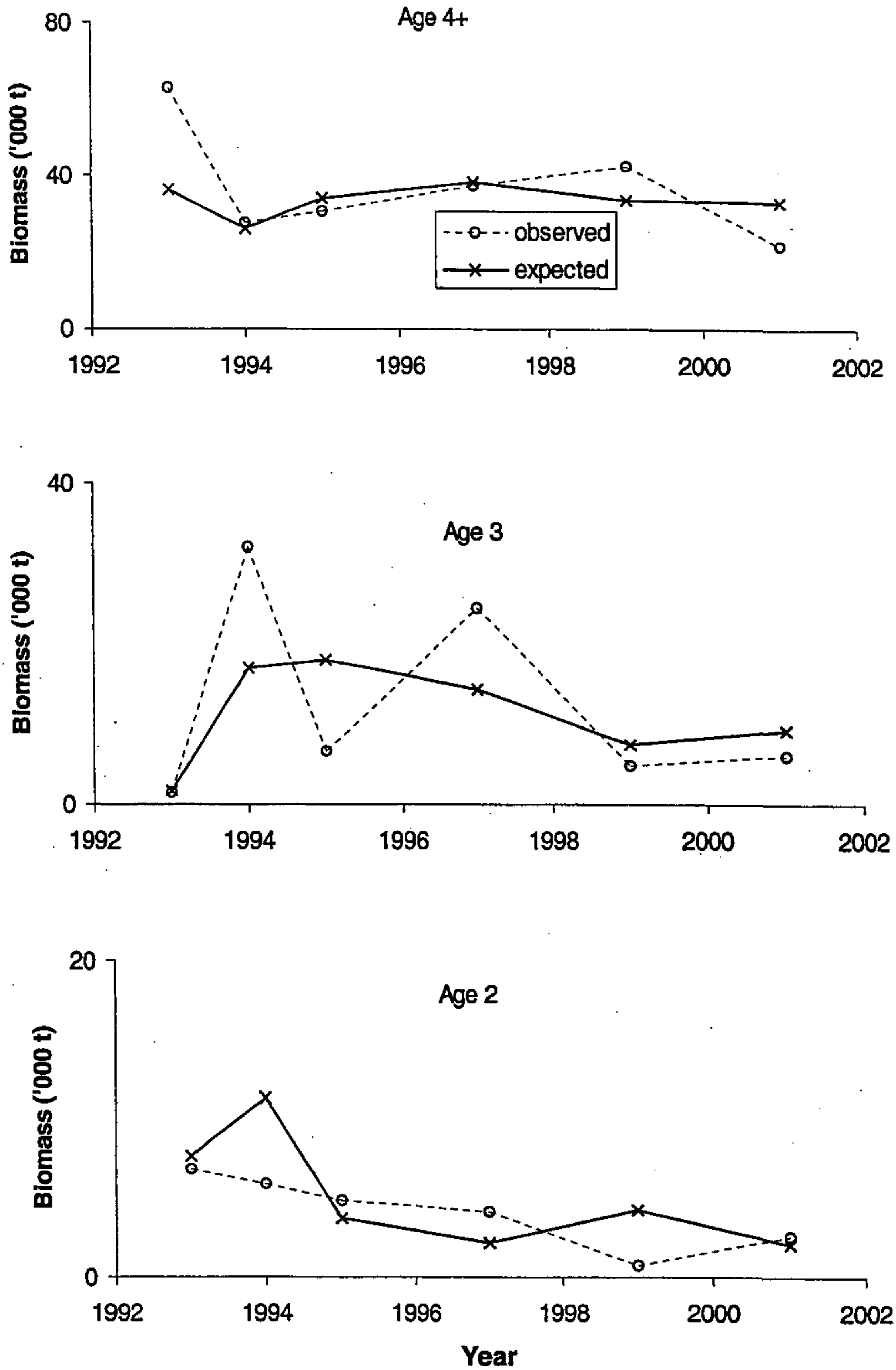

Figure 6: Estimated biomass from the model (expected) and the acoustic surveys (observed scaled by the *qs*) for the MPD for the base case model for ages 2, 3, and 4+.

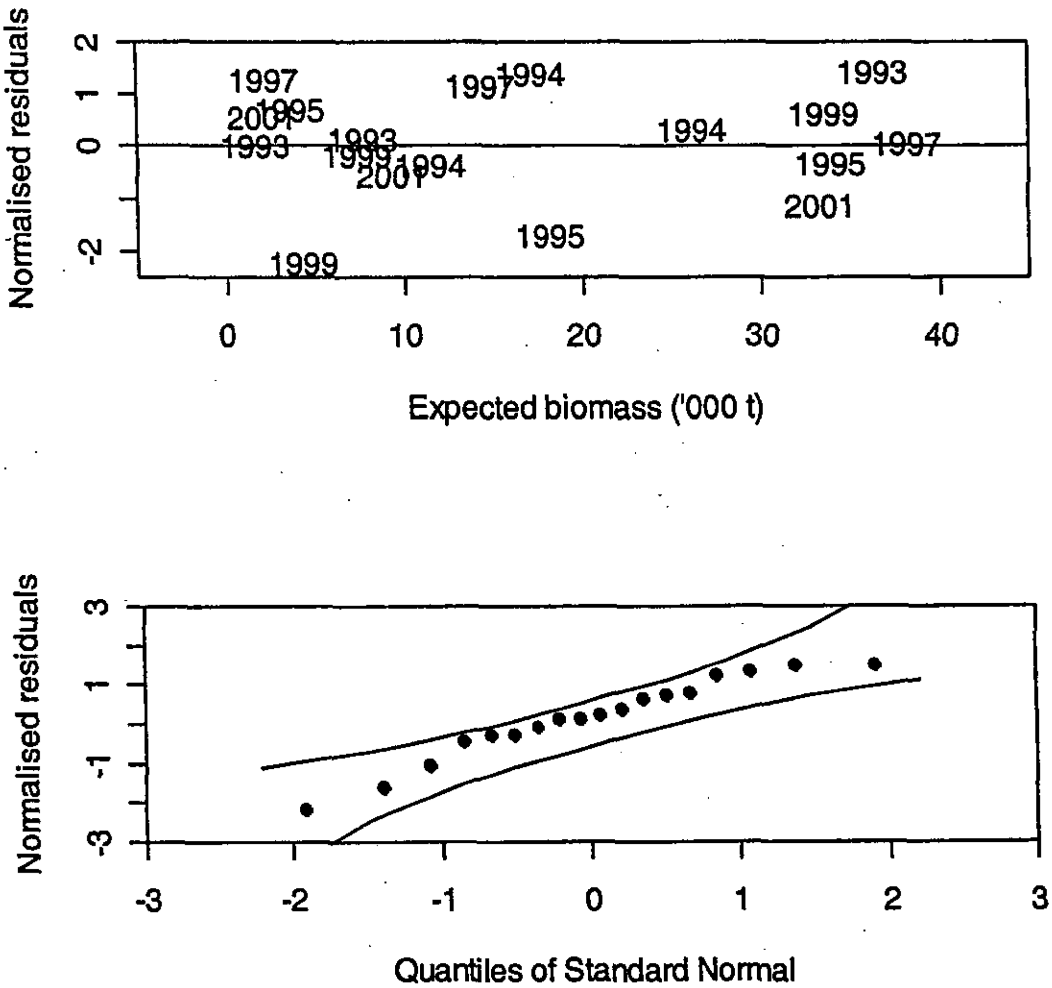

Figure 7: Base case MPD normalised residuals (top) and QQ plot (bottom) for fit to all the acoustic indices combined.

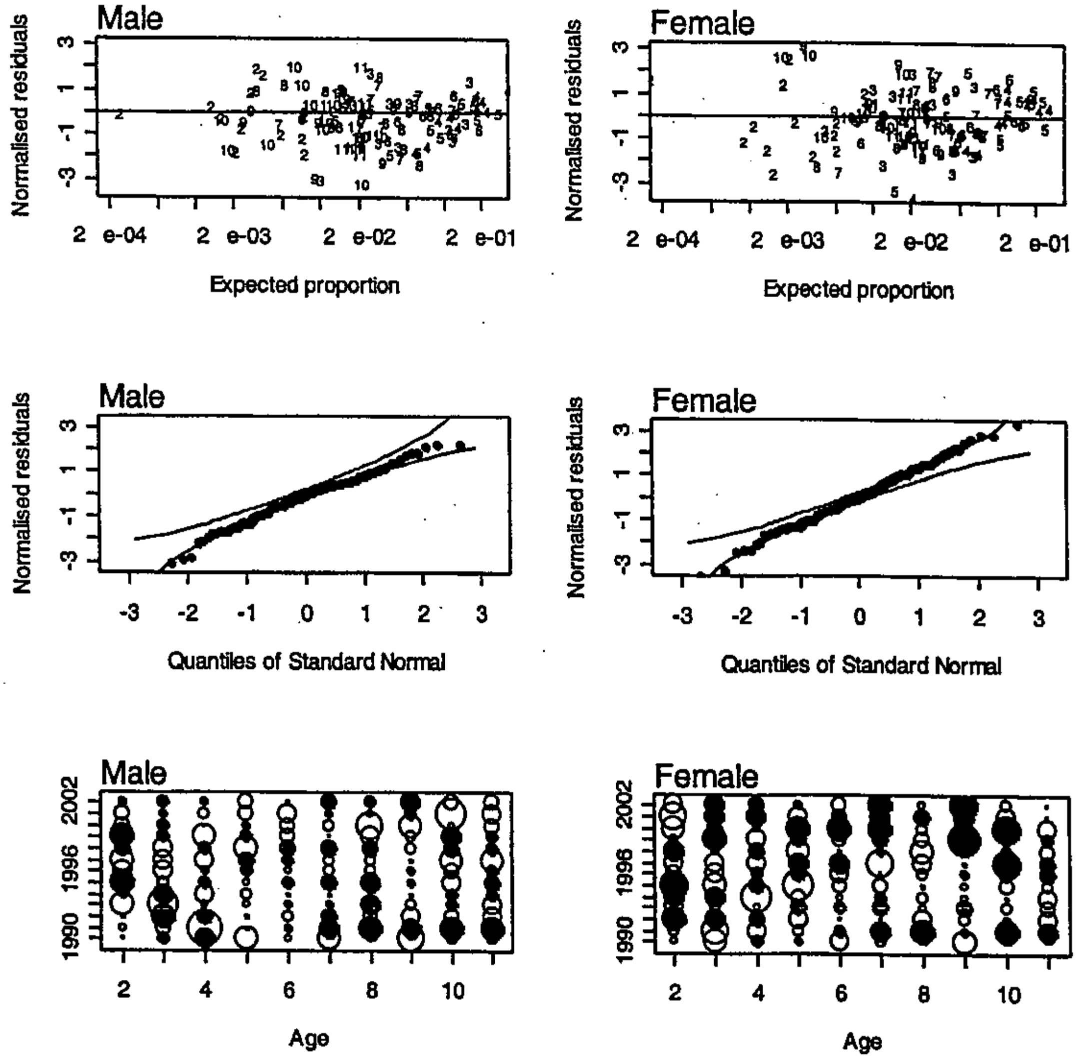

Figure 8: Base case MPD normalised residuals (top), QQ plot (middle) and residual plot (bottom) for fit to the proportion-at-age data. Symbol area is proportional to the absolute value of the residual, with white circles indicating positive residuals and black circles indicating negative residuals.

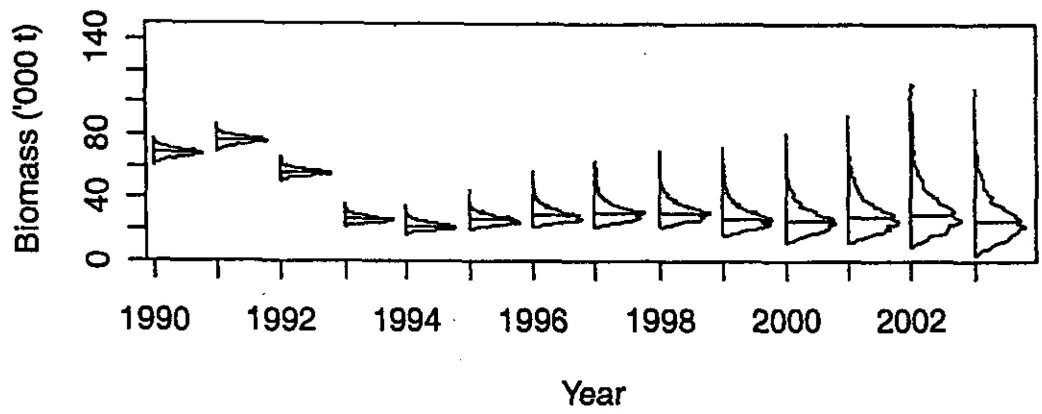

Figure 9: Estimated posterior distributions of mid season spawning stock biomass trajectories for base case. Horizontal lines indicate the medians.

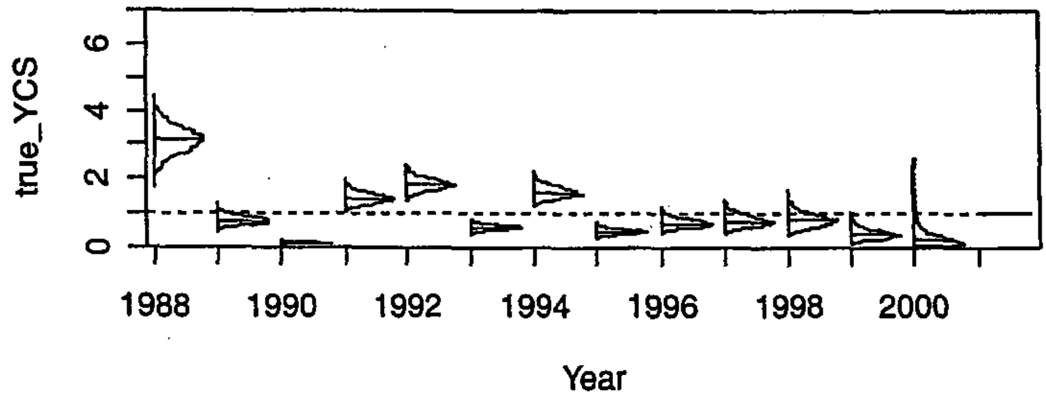

Figure 10: Estimated posterior distributions of year class strengths for base case. Horizontal lines indicate the medians.

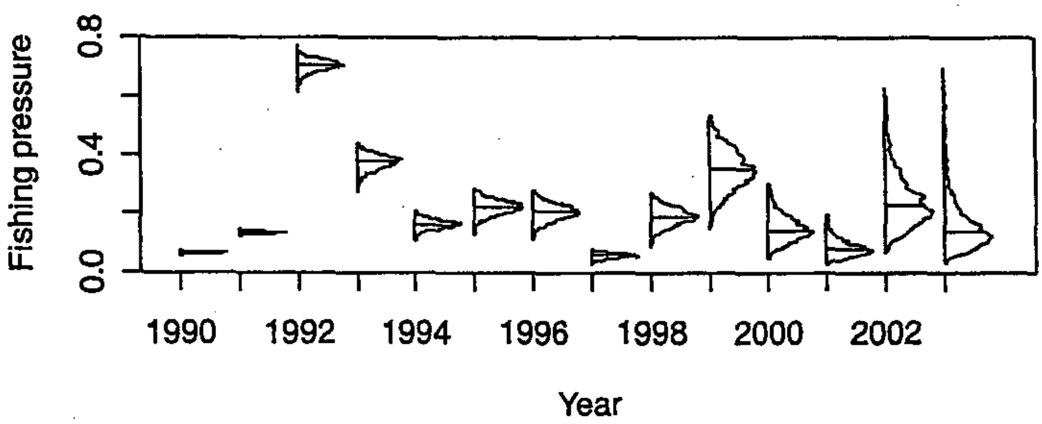

Figure 11: Estimated posterior distributions of fishing pressure for base case. Horizontal lines indicate the medians.

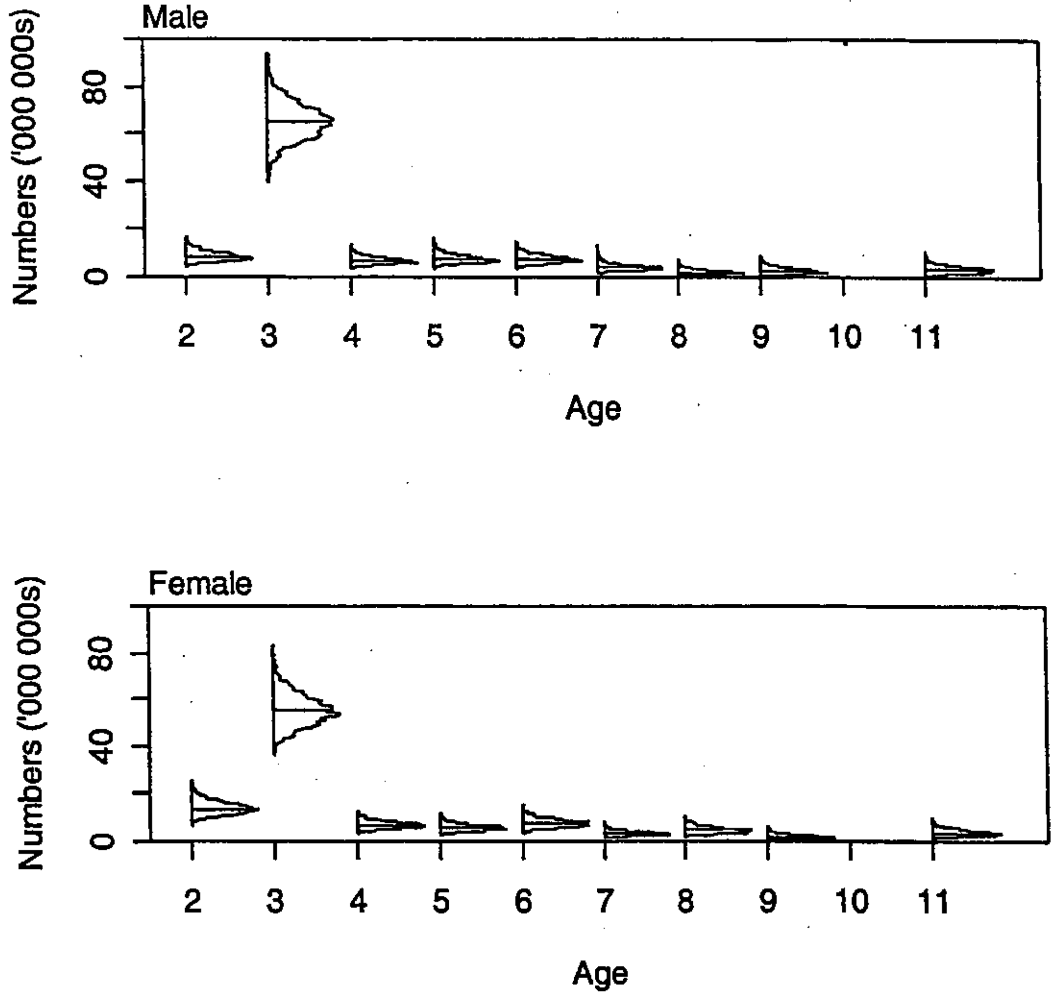

Figure 12: Estimated posterior distributions of initial numbers at age for base case (in 1989). Horizontal lines indicate the medians.

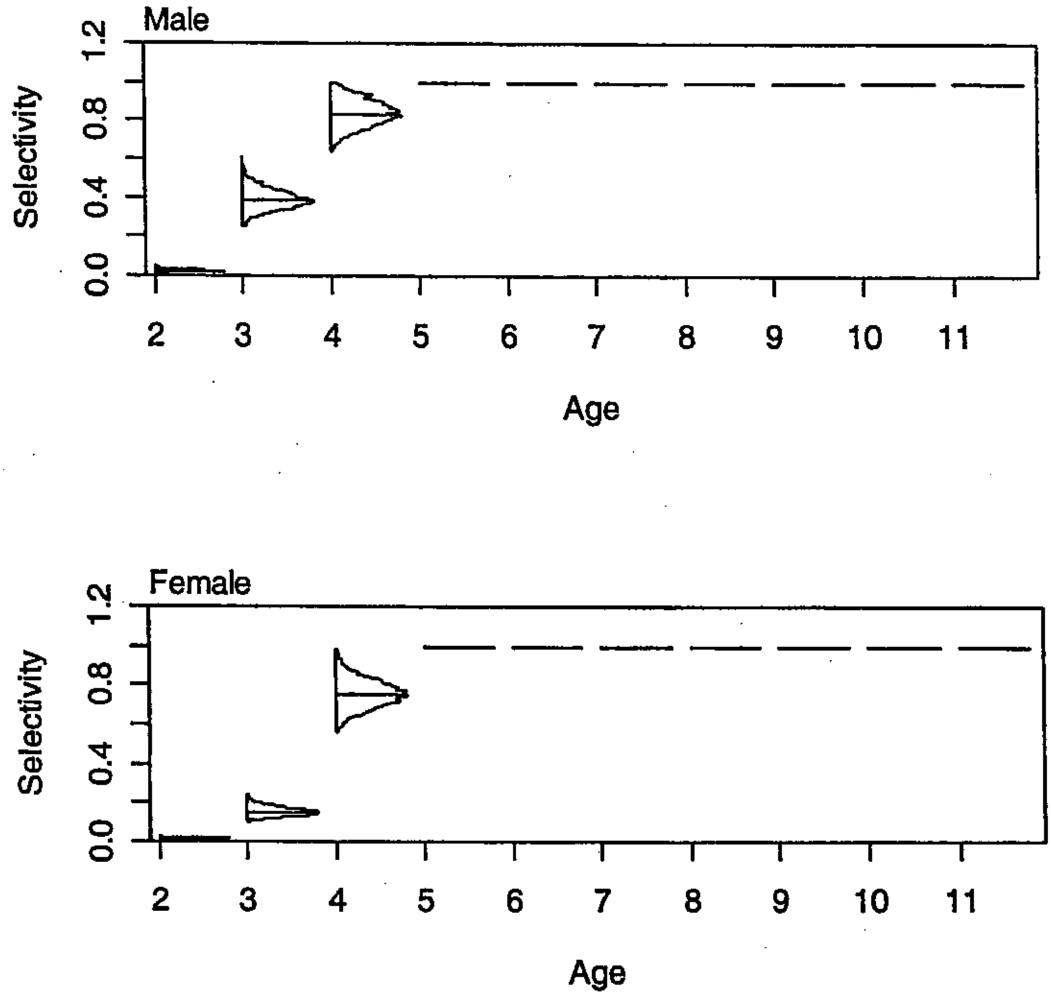

Figure 13: Estimated posterior distributions of fishing selectivity for ages 2, 3, and 4 for both sexes for base case. Horizontal lines indicate the medians.

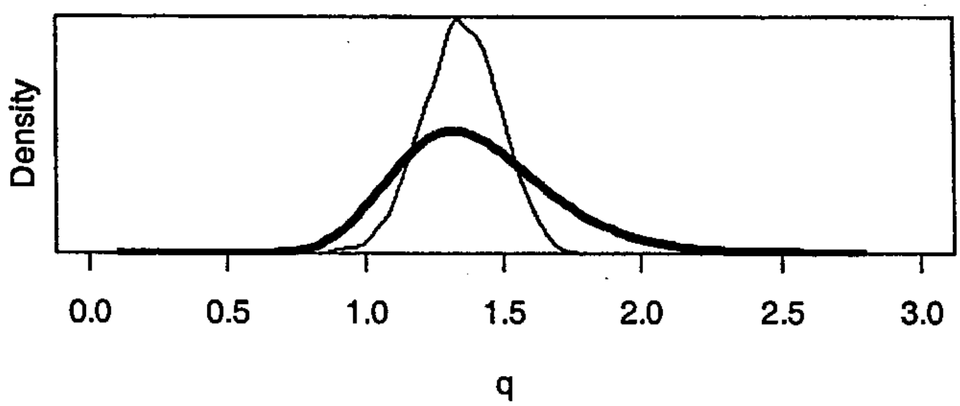

Figure 14: Prior (bold) and estimated posterior distributions of the adult survey relativity constant (age 4+ acoustic *q*) for base case.

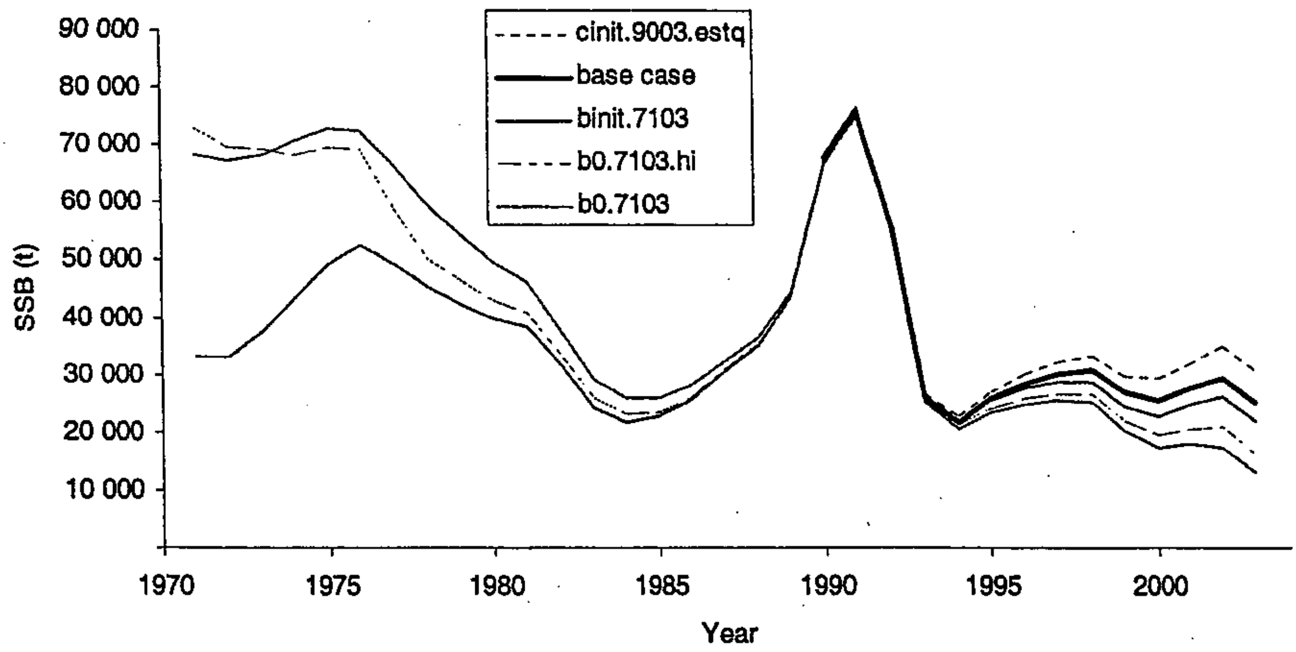

Figure 15: Median MCMC mid season spawning stock biomass trajectories for all runs.

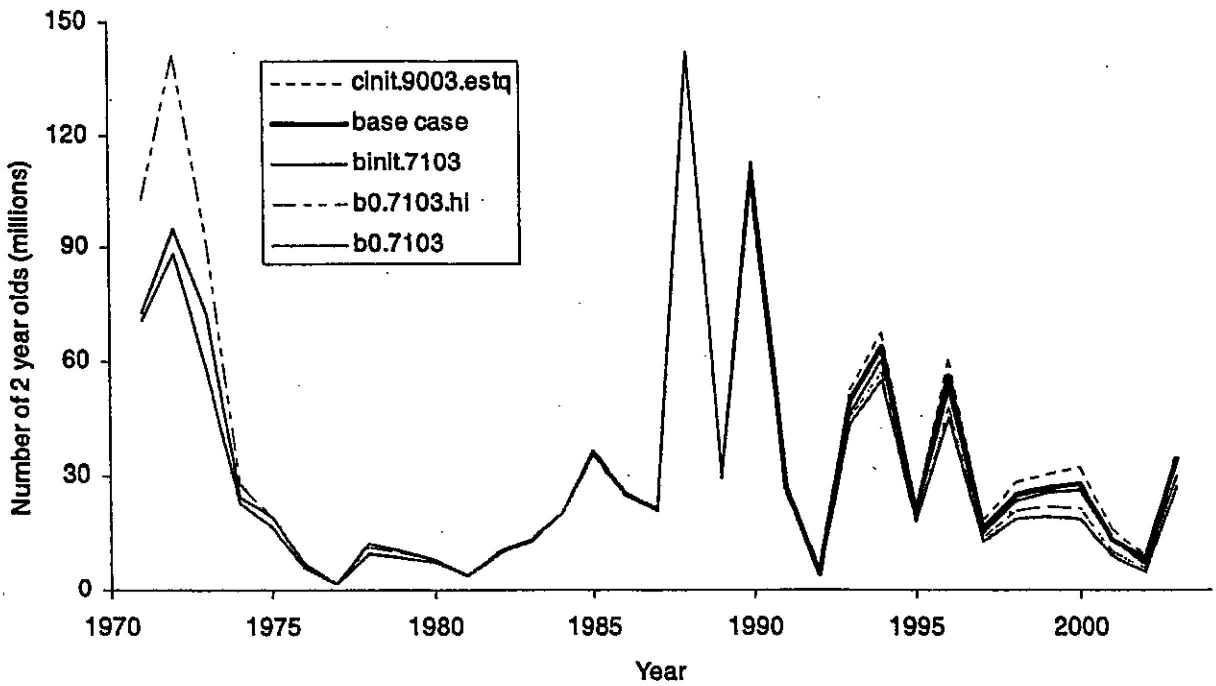

Figure 16: Median MCMC estimates of recruitment (number of 2 year old fish) for all runs.

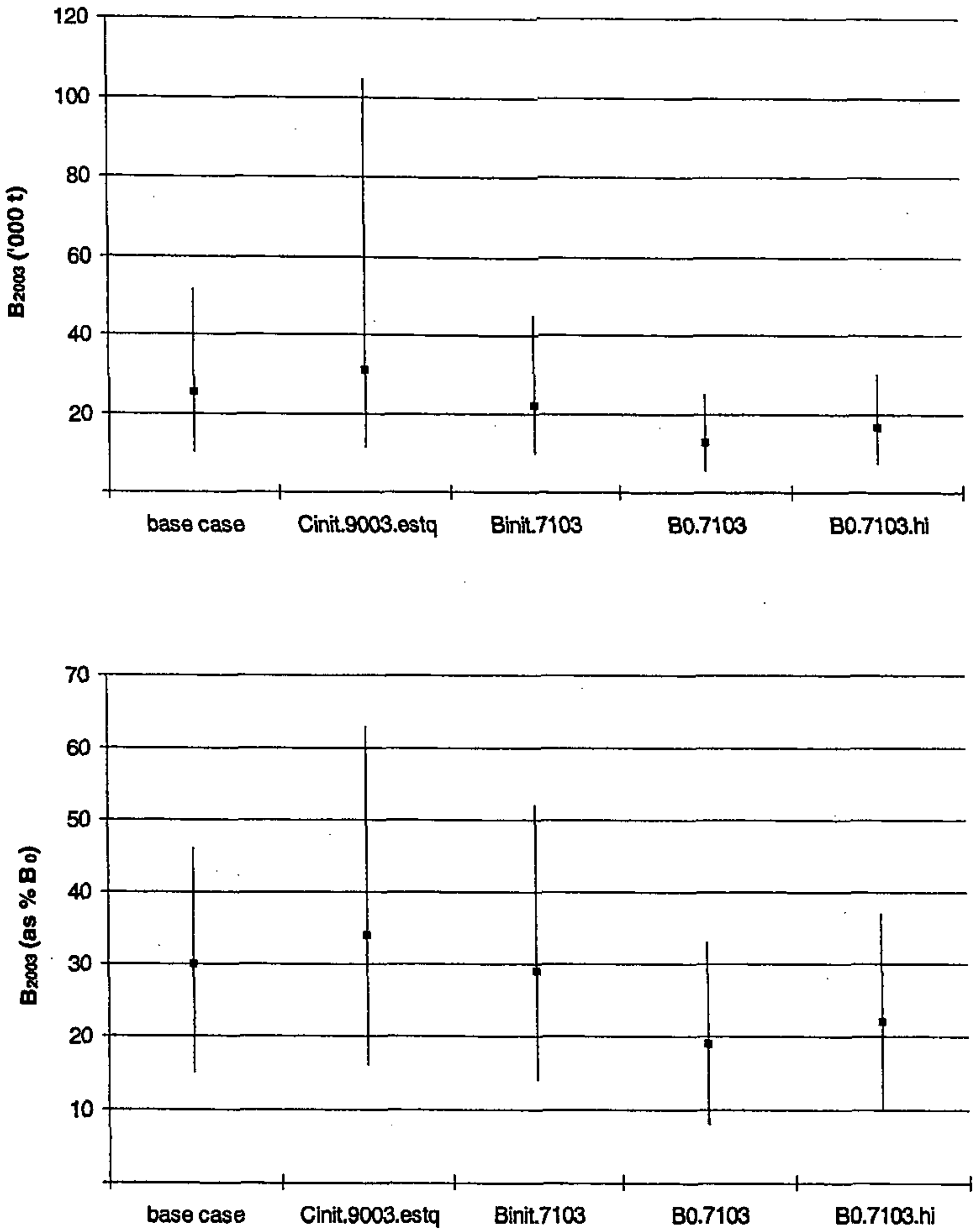

Figure 17: Median and 90% credible intervals for B_{2003} (top) and B_{2003} as a % B_0 (bottom) for the various runs.

Appendix 1a: Number of male and female SBW (in thousands) in the Bounty fishery by age and year.

Males

Year	2	3	4	5	6	7	8	9	10	11+
1990	58	203	4 995	103	345	99	170		63	118
1991	13	1 223		4 365	415	829	959	410	356	874
1992	10	5 996	29 215	2 864	17 803	2 625	1 462	1 261	802	1 061
1993	48		1 733	3 708	353	2 713	364	191	324	155
1994	92	2 121	32	444	936	65	566	49	70	169
1995	128	1 739	3 442	119	611	1 183	133	575	15	284
1996	40	255	3 179	2 264	57	226	380	36	172	152
1997		105	46	391	168	3	12	35		9
1998	55	186	2 675	312	2 155	1 012	69	80	257	231
1999	188	1 511	618	4 831	762	2 108	467	28	310	650
2000	14	636	779	394	574	152	124	46	7	81
2001	3	338	411	234	59	348	69	217	2	19
2002	12	560	1 854	933	793	447	868	327	185	165

Females

Year	2	3	4	5	6	7	8	9	10	11+
1990	36	18	2 998	385	60	295	153	61	58	180
1991		177	211	3 177	535	663	957	162	674	506
1992	60	2 035	28 411	2 540	18 156	1 973	1 001	1 846	1 007	1 798
1993	29	35	1 936	6 671	676	2 859	187	272	200	261
1994	110	865		531	1 016	145	390	50	46	95
1995	101	348	3 730		493	773	115	423	20	146
1996	33	102	3 302	2 794	29	342	467	68	171	171
1997		28	48	522	274		16	45	22	46
1998	55	115	2 779	371	1 674	910		157	260	132
1999	47	1 086	691	5 828	681	3 378	875	273	270	669
2000	1	286	753	987	1 800	510	384	116	52	89
2001		239	867	247	243	558	121	317	40	62
2002		307	2 179	1 638	623	938	653	605	323	78

Appendix 1b: C.v. of number of male and female SBW caught in the Bounty 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
1990	0.61	0.45	0.10	0.59	0.29	0.64	0.42	0.00	0.83	0.56	0.18
1991	1.35	0.28	0.00	0.11	0.57	0.42	0.27	0.55	0.68	0.36	0.31
1992	2.19	0.17	0.07	0.28	0.07	0.22	0.27	0.27	0.35	0.27	0.12
1993	0.55	0.00	0.15	0.10	0.41	0.12	0.35	0.32	0.32	0.48	0.16
1994	0.52	0.16	1.05	0.19	0.15	0.62	0.18	0.63	0.57	0.31	0.21
1995	0.57	0.18	0.10	0.75	0.29	0.14	0.49	0.20	0.78	0.27	0.18
1996	0.63	0.42	0.11	0.11	1.11	0.39	0.22	0.63	0.33	0.31	0.17
1997	0.00	0.36	0.52	0.19	0.23	1.36	0.82	0.57	0.00	0.66	0.28
1998	0.60	0.41	0.09	0.36	0.11	0.15	0.82	0.64	0.32	0.37	0.17
1999	0.39	0.21	0.30	0.10	0.31	0.17	0.40	1.08	0.36	0.32	0.21
2000	0.80	0.22	0.20	0.31	0.22	0.50	0.46	0.67	1.15	0.44	0.28
2001	1.15	0.25	0.23	0.29	0.61	0.24	0.51	0.32	1.46	0.63	0.29
2002	1.89	0.42	0.19	0.34	0.40	0.52	0.43	0.57	0.59	0.56	0.28

Females

Year	2	3	4	5	6	7	8	9	10	11+	MWCV
1990	0.72	0.88	0.09	0.41	1.13	0.38	0.44	0.72	0.68	0.38	0.23
1991	5.52	0.40	0.75	0.14	0.48	0.43	0.28	0.85	0.30	0.36	0.31
1992	1.21	0.32	0.06	0.31	0.07	0.28	0.24	0.24	0.30	0.24	0.13
1993	0.79	1.06	0.14	0.06	0.23	0.08	0.49	0.41	0.53	0.41	0.13
1994	0.54	0.23	0.00	0.18	0.13	0.39	0.17	0.32	0.36	0.25	0.21
1995	0.39	0.37	0.10	0.00	0.32	0.21	0.40	0.20	0.87	0.28	0.18
1996	0.67	0.57	0.08	0.08	1.04	0.28	0.23	0.50	0.25	0.26	0.13
1997	0.00	0.58	0.43	0.10	0.13	0.00	0.41	0.29	0.47	0.32	0.18
1998	0.66	0.54	0.12	0.31	0.11	0.15	0.00	0.33	0.21	0.23	0.16
1999	0.38	0.18	0.29	0.08	0.31	0.10	0.20	0.31	0.29	0.16	0.14
2000	1.73	0.29	0.18	0.17	0.10	0.18	0.24	0.32	0.41	0.27	0.17
2001	1.10	0.32	0.18	0.31	0.29	0.19	0.40	0.22	0.55	0.45	0.25
2002	0.00	0.52	0.23	0.28	0.40	0.32	0.32	0.31	0.40	4.15	0.24

Appendix 2: Mean length (cm) at age of male and female SBW in the Bounty fishery by year.

Males

Year	2	3	4	5	6	7	8	9	10	11+
1990	26.8	31.6	35.9	38.0	43.0	47.0	45.6	45.9	46.5	48.5
1991	29.0	31.9	35.2	39.0	44.8	46.6	47.0	46.6	44.5	49.7
1992	26.0	32.5	35.7	39.6	41.2	45.4	47.4	47.1	47.6	49.4
1993	26.8	31.6	35.6	37.6	40.0	42.9	45.5	48.4	47.2	49.3
1994	27.0	32.0	36.0	38.4	40.4	44.0	44.7	45.3	48.0	49.9
1995	27.0	30.5	36.1	37.5	41.2	42.3	44.4	46.1	47.0	49.1
1996	25.0	31.3	34.5	38.4	38.0	42.3	44.1	45.0	46.1	49.1
1997	25.4	29.2	35.0	36.4	39.3	39.0	44.7	45.5	46.9	50.6
1998	26.5	30.8	32.3	36.1	37.9	40.7	41.0	45.3	46.7	50.2
1999	26.9	31.5	35.0	35.4	39.1	39.8	42.8	43.0	46.1	48.6
2000	25.5	32.9	34.9	39.5	40.5	41.0	44.0	45.0	45.0	48.1
2001	27.0	32.3	35.7	38.5	41.3	41.0	42.0	44.3	47.0	49.6
2002	25.0	32.1	36.1	39.4	41.1	41.5	41.9	44.0	46.8	50.9

Females

Year	2	3	4	5	6	7	8	9	10	11+
1990	27.0	30.7	37.7	43.5	45.0	48.5	50.7	50.0	52.8	53.7
1991	27.5	32.5	37.0	41.9	46.4	46.7	50.7	49.5	52.0	53.9
1992	27.0	33.8	37.3	42.2	44.3	47.9	50.6	50.4	51.7	52.7
1993	26.4	37.0	37.1	40.5	43.4	45.8	50.0	51.8	52.5	54.6
1994	28.8	33.6	36.7	41.0	43.4	47.0	49.1	52.9	52.0	54.2
1995	28.8	31.5	37.7	40.8	45.1	46.4	49.0	50.4	53.0	55.1
1996	25.1	30.5	36.2	40.2	43.0	46.5	47.4	49.8	50.8	53.2
1997	26.0	30.5	35.8	38.6	43.0	46.1	48.3	49.2	50.8	54.0
1998	26.7	30.3	33.8	39.4	39.8	45.0	48.6	49.7	50.2	54.6
1999	27.9	32.6	35.3	37.7	41.8	43.5	46.3	49.0	50.5	52.7
2000	25.5	32.5	36.3	40.4	41.6	45.1	46.7	49.0	50.0	54.6
2001	27.5	34.1	37.8	42.1	42.2	44.3	46.1	48.6	50.2	54.3
2002	25.5	33.0	38.8	42.5	43.9	45.0	48.5	49.4	51.4	57.5