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**Southern blue whiting (*Micromesistius australis*) stock assessment for
the Campbell Island Rise and Pukaki Rise for the 2001–02
and 2002–03 fishing years**

S. M. Hanchet

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EXECUTIVE SUMMARY

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This report summarises landings, catch-at-age, and biological data from New Zealand southern blue whiting fisheries in 2000. Stock assessments were carried out for Campbell Island Rise and Pukaki Rise stocks using updated catch-at-age data and the results of acoustic surveys carried out in 2000. Biomass and yield estimates are given for these two fisheries. There was no new acoustic survey of the Bounty Platform and so the assessment was not updated. There has been little fishing on the Auckland Island Shelf stock, and no abundance indices are available, so no assessment has been carried out for this area.

For both stocks the data were analysed using the separable Sequential Population Analysis (sSPA) used in recent assessments of the SBW stocks. The model was fitted to landings, proportion-at-age data, and the pre-recruit and recruited acoustic survey indices. Weightings and other model details differed between the two assessments. Because of uncertainty over target strength, the acoustic indices were fitted in the model as relative estimates of mid-season abundance (i.e., after half the catch has been removed).

The spawning stock biomass on the Campbell Island Rise showed a steady decline from the early 1980s until 1993, followed by a large increase to 1996 and a decline to 2000. The extent of the increase and subsequent decline is uncertain. The estimate of CAY for the Campbell stock is sensitive to the strength of recent recruitment. The base case CAY estimate for 2001 is 31 600 t with bias corrected 90% confidence intervals of 15 400–67 400 t. The base case CAY estimate for 2002 (assuming the CAY catch is taken in 2001) is 27 800 t with bias corrected 90% confidence intervals of 14 200–55 200 t.

Estimates of biomass and yield for the Pukaki Rise stock are very uncertain. Model based estimates using the reference case input parameters appear to be overly pessimistic because the adult (4+) acoustic q is 2.7. An independent evaluation of the bounds on the acoustic q suggested a range of 0.65–2.8, with a best estimate of 1.4. Clearly the q from the reference case is almost at the upper bound and probably outside the credible range. As an alternative assessment, bounds on virgin and current biomass were calculated by fixing the adult (4+) acoustic q in the model at 0.65 and 2.8, and by fixing the minimum and maximum exploitation rates at 0.2 and 0.7. Combining the bounds from the exploitation rates and the acoustic q gave estimates of B_{2000} from 8000 to 31 000 t and values of CAY_{2001} from 1700 to 6900 t. A 'best estimate' was obtained by fixing the adult (4+) acoustic q in the model at 1.4, which gave a value of 13 000 t for B_{2000} and of 2700 t for CAY_{2001} .

1. INTRODUCTION

1.1 Overview

This paper reviews the stock assessment of southern blue whiting (SBW) resources in New Zealand waters. Length-frequency, reproductive data, and catch-at-age data for the Bounty Platform, Campbell Island Rise, and Pukaki Rise stocks are updated. The catch-at-age data and estimates of recruited and pre-recruit biomass from acoustic surveys are used in a separable Sequential Population Analysis (sSPA) to estimate historic and current biomass for the Campbell Island Rise and Pukaki Rise stocks. Estimates of Current Annual Yield (CAY) are provided for the Campbell stock for 2001 and 2002. Estimates of biomass for the Pukaki stock from the population were not considered credible. Instead, bounds on estimates of biomass and yield were provided by making assumptions about the likely range of acoustic q_s (the scalar relating the estimated model biomass to the expected value of the acoustic index) and exploitation rates.

1.2 Description of the fishery

In this report the word fishing "season" refers to the period from August to October, when the southern blue whiting are aggregating to spawn, and are subject to their main fishing pressure. Up until 1997–98 the fishing year was 1 October – 30 September, so the season overlapped two fishing years. The fishing year has now been changed to 1 April – 31 March to reflect the timing of the main fishing season (Table 1).

The SBW fishery was developed by Soviet vessels during the early 1970s, with landings exceeding 40 000 t in 1973 and 1974. 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. 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 areas was introduced for the first time in 1993. This was increased to 58 000 t in 1996–97, but was lowered to 35 140 t for the 1999–2000 fishing year (Table 1). Annual landings since 1992–93 have averaged about 25 000 t, most of which has been taken from the Campbell grounds. The fleet has comprised mainly Japanese surimi vessels, and Russian, Ukrainian, and Polish head and gut vessels. Fishing in most years has started in mid August and extended into October.

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). Seven acoustic surveys of southern blue whiting spawning grounds have now been completed, and results of recent surveys were reported by Hanchet et al. (2000b), Hanchet & Grimes (2000), and Hanchet & Grimes (2001). A re-analysis and decomposition of earlier acoustic survey results was carried out by Hanchet et al. (2000c). The diel variation in SBW density estimates was examined by Hanchet et al. (2000a). Results of recent acoustic target strength work were summarised by McClatchie et al. (1998) and Dunford (2001a, 2001b), and target identification by McClatchie et al. (2000).

A detailed account of the 1996 assessment of the Campbell Island stock and documentation of the sSPA model was provided by Hanchet et al. (1998). Other recent developments to the sSPA model, and a comparison with other models, were given by Hanchet (1998c). In the most recent stock assessments, catch-at-age and acoustic data were modelled using the sSPA model (Hanchet 1997, 1998b, 2000a, 2000b).

Cherel et al. (1999) found that juvenile (0+) SBW formed a large part of black-browed albatross diet during the summer chick-rearing period. They concluded that 0+ SBW are pelagic and occur in dense schools in the top 5 m of the water column close to the Campbell Islands during the summer months. Hanchet & Renwick (1999) found a strong negative correlation ($r = -0.73$) between year class strength and anticyclonic, stable atmospheric conditions centred over the Campbell Plateau.

1.4 Objectives

This report addresses objectives 1, 2, and 3 from MFish project SBW2000/01.

1. To complete a descriptive analysis of the commercial catch and effort data with the inclusion of data up to the end of the 1999/2000 fishing year for the following southern blue whiting fishery areas: Campbell Islands, Pukaki Rise, Bounty Platform, and Auckland Islands.
2. To determine catch at age from the commercial fisheries at Campbell Island, Bounty Platform, and Pukaki Rise for 1999/2000 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).
3. To update the stock assessments of Campbell Island, Auckland Island, Pukaki Rise, and Bounty Platform stocks, 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 area sub-limits, was retained for the next 3 years (Table 1). The area sub-limits were revised for the 1995–96 fishing year, and the total catch limit increased to 58 800 t for the next three fishing years. A single combined catch limit was set for the Pukaki Rise

and Auckland Islands fisheries of 7700 t, but in 1997–98 the industry agreed to a 1640 t limit for the Auckland Islands fishery. The total catch limit was lowered to 35 140 t for 1999–2000 (Table 1).

2.1.2 Landings

Estimates of the annual landings of SBW by fishing year are given in Table 1.

Landings for the 2000–01 fishing year from the Quota Monitoring Reports were almost 25 000 t. Because the main fishing season in recent years has been from August to October, catches for November to October were used in the stock assessment modelling when considering removals from the various stocks (Table 2). Therefore, in some years, for some stocks, the numbers will differ between the two tables.

2.1.3 The 2000 season

The location of trawls made during the 2000 season is shown in Figure 1. Fifteen vessels mainly from Japan, Russia, Ukraine, Poland, and New Zealand, fished for SBW during the 2000 season (Table 3). The first vessels arrived on the Bounty Platform on 22 August. Vessels found an aggregation to the southeast of the Bounty Islands and gradually moved north over the next 10 days. Six vessels fished there during the short 10 day season and took almost 4000 t. Spawning occurred at about the usual time on the Bounty Platform, lasting from 24 August to 1 September (Section 2.2.3).

Six vessels fished the Pukaki Rise from 2 to 6 September. Large catches (over 100 t per tow) were made throughout this period on pre-spawning aggregations. It is unknown when spawning took place. The total catch on the Pukaki Rise was about 2600 t. There was no targeted fishing on the Auckland Islands Shelf this season, although one vessel took about 5 t as bycatch in midOctober.

Two vessels searched the northern Campbell Island Rise briefly on 2–3 September, but found no aggregations and returned to the Pukaki Rise. Vessels started fishing on the Campbell Island Rise on 7 September and made good catches on the northern ground until about 13 September. Spawning was underway for the first two days, but by 10 September most fish had reverted back to the maturing stage. Spawning typically takes 5–7 days and so must have started on 2 or 3 September, which is the earliest start to the spawning season recorded for this area. Catches were low from 14 to 17 September as the northern aggregation dispersed and the vessels searched the area to the south. They found fish aggregating to spawn for the second time on 17 September and again made good catch rates until spawning had finished on 25 September. During this period the vessels fished a wide area extending from 52° S to 53° S. By the end of September more than 50% of the fish were spent and fishing was poor and all vessels had left the area by 4 October. About 18 000 t was taken during the 2000 season by 15 vessels.

2.1.4 CPUE analysis

A standardised CPUE analysis of the Campbell Island Rise fishery was carried out by Ingerson & Hanchet (1995), Chatterton (1996), Hanchet & Ingerson (1996), and Hanchet (2000a). The analysis has not been updated because of concerns that the CPUE series may not be monitoring abundance accurately. This is because of the highly aggregated nature of the fishery, and the associated difficulty in finding and maintaining contact with the highly mobile schools in some years. For this reason the Middle Depths Working Group rejected the CPUE indices for use in the 1997 and subsequent stock assessments.

However, the trend in CPUE indices for the Campbell stock shows a very similar pattern to the spawning stock biomass trajectory for the stock in recent stock assessments (Hanchet 2000a, 2000b). Therefore an MFish project (SBW2001/01) is currently underway to review the CPUE indices for the Campbell and Bounty stocks, and to determine whether they are monitoring abundance.

2.2 Other information

2.2.1 Size composition of the commercial catch

Scientific observers collected length frequency data from 41% of all tows in the commercial fishery during 2000 (Table 3). The length frequency data were scaled up to the total catch for each stratum and each fishing ground following Hanchet & Ingerson (1995). Year classes have been assigned to modes on the basis of ageing work (Section 2.2.2).

The size distribution of the Campbell Island stock in 2000 was bimodal, being dominated by the strong 1991 and 1995 year classes on both northern and southern grounds (Figure 2). A small proportion of 2 year old males (1998 year class) were also present at 25–30 cm on each ground. The combined size distributions were consistent with earlier years (Figure 3). The catch has continued to be dominated by the 1991 year class, but the 1995 year class also appears strong relative to the intervening years. Fish in both year classes continue to show slow growth rates.

The 2000 catch on the Bounty Platform was dominated by the 1994 year class (Figure 4). The 1994 year class was predicted to be very strong by the 1995 and 1997 acoustic surveys. Although relatively large numbers of this year class were caught it has not recruited into the fishery in the numbers predicted.

The 2000 catch on the Pukaki Rise was bimodal (Figure 5). Because of the missing years, and small sample sizes, it is more difficult to track strong year classes in this area. From ageing otoliths the population appears to be dominated by the 1990–93 and 1995–97 year classes.

No observer data were collected in 2000 from the Auckland Islands Shelf.

2.2.2 Age composition of the commercial catch

Otoliths collected from the Campbell Island Rise, Bounty Platform, and Pukaki Rise fishing grounds during the 2000 season were read and used to derive age-length keys. Catch-at-age was estimated by combining the scaled length frequency data with the age-length key (see Hanchet & Ingerson 1995). The c.v.s incorporate the variance from both the length-frequency data and the age-length key. The resulting catch-at-age data are illustrated in Figures 6, 7, and 8. The target c.v. of 20% was achieved for each area in 2000. Results with hoki suggest that c.v.s estimated using bootstrapping are somewhat higher than those using analytical methods (O'Driscoll, NIWA, pers. comm.). I recommend that the c.v.s are recalculated before next year's assessment using bootstrapping.

2.2.3 Timing of spawning

Spawning on the Bounty Platform lasted from 24 August to 1 September (Table 4). This is about 1 week earlier than in 1999, and is about average for this area. Spawning took place mainly on the southeast and east of the Bounty Platform.

Spawning started very early this year on the Campbell Island Rise. The first fish were caught on the northern ground on 7 September, and were in a range of gonad stages indicating that spawning was already underway (Table 4). The first spawning finished by 9 September, because by then most fish had reverted back to the ripe or ripening stage and some fish were spent. The second spawning started on 17 September and coincided with a marked increase in catch rates by the vessels, which were now fishing due east of Campbell Island. Spawning continued in this area until 25 September. At the end of the second spawning about 50–60% of the fish were spent/resting, and the remainder had again reverted to the maturing stage. This is the first indication that some SBW may spawn more than two batches of eggs.

Fish were sampled on the Pukaki Rise from 3 to 7 September: most fish were in the ripening stage, with less than 10% spawning. This suggests that the first main spawning event had not yet begun. The fish were sampled again on 27 September by *Tangaroa* (Hanchet & Grimes 2001). At this stage most fish had reverted to the ripening stage suggesting that the first spawning was over but that the second spawning had not yet begun.

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. No genetic studies have been carried out, 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 stock.

3.2 Acoustic surveys

3.2.1 Campbell Island Rise

A survey of the Campbell Island Rise was carried out in September 2000 (Hanchet & Grimes 2001). Two acoustic snapshots of the Campbell Island Rise were completed. Two areas of adult spawning fish were located in snapshot 1. The first was in the north of the survey area in depths of 450–500 m, and was being fished by commercial vessels. The second aggregation was found in the south of the survey area in a similar depth. In snapshot 2, dispersed adult fish were found covering a large area in

the southern ground. The estimate from both snapshots was very similar equalling about 150 000 t (c.v. =17%). Most previous surveys of the grounds have been on pre-spawning and spawning aggregations, whereas the 2000 survey was on spawning and post-spawning aggregations. Hanchet & Grimes (2001) noted that biomass estimates of spawning fish from previous surveys were on average about 20% higher than those of pre-spawning fish. However, in the current assessment, no adjustment has been made and the mean of the snapshots was taken to be the best estimate. The biomass estimates were then decomposed into biomass at age for use in the modelling (Table 5).

3.2.2 Pukaki Rise

The fifth acoustic survey of the Pukaki Rise grounds was carried out in 2000 (Hanchet & Grimes 2001). They considered that the timing of the survey was similar to that of previous surveys of the Pukaki Rise, and that the biomass estimates should therefore be comparable to those from previous surveys. The decomposed biomass estimates for all five surveys are given in Table 6. As with the series of surveys from the Campbell Island Rise (see above), the biomass estimates were turned into absolute estimates using the target strength–fish length relationship derived for blue whiting in the Northern Hemisphere (Monstad et al. 1992).

3.2.3 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. Recent studies on gadoids in the Northern Hemisphere have suggested a higher target strength (similar slope but 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. *In situ* target strength work carried out during recent SBW acoustic surveys and theoretical modelling studies suggest a steeper slope than the Northern Hemisphere studies (Dunford 2001a, 2001b). This would affect the use of the surveys in both an absolute and a relative sense, because the biomass of smaller fish would have been underestimated whilst the biomass of larger fish would have been overestimated. The target strength–fish length relationship used in previous years was retained in the current analysis because it is not yet known which relationship is most likely.

3.2.4 Bounds on the acoustic q for Pukaki Rise

The acoustic q is the estimated model parameter that relates the estimated model biomass to the expected value of the acoustic index (Cordue 1996). In some stock assessments the maximum likelihood estimate of q can be very high or low, leading to unreasonably low or high estimates of biomass respectively for a particular stock. In this year's assessment of the Pukaki Rise some members of the Middle Depths Working Group considered that the estimate of the adult acoustic q was too high, so bounds on acoustic q were obtained outside the model to determine the 'credible' range for q in the Pukaki Rise assessment.

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

Mean target strength

As noted above (Section 3.2.3), the acoustic survey estimates were turned into absolute estimates using the target strength-fish length relationship used for blue whiting in the Northern Hemisphere by Monstad et al. (1992). Recent studies on gadoids in the Northern Hemisphere (Rose 1998) have suggested a higher target strength (similar slope but intercept is 2 dB higher). *In situ* target strength data collected during the 1998 and 2000 SBW acoustic surveys agree with the recent Northern Hemisphere relationship (Dunford 2001a, b). Preliminary results from recent swimbladder modelling studies suggest a higher target strength, and possibly also steeper slope, than the Northern Hemisphere studies.

If we assume that the recent Northern Hemisphere estimates of target strength are correct then the value we currently use for target strength would be underestimated by about 1.5. Our 'best estimate' is therefore 1.5, and using a factor of 1.25 to introduce uncertainty we obtained bounds of [1.2, 1.85].

Target identification

Target identification is typically more problematic on Pukaki than on the Campbell and Bounty grounds, and most trawls catch a range of other species. Trawls carried out for mark identification using *Tangaroa* were used to obtain coarse estimates of species composition. A total of 32 trawls have been made on the Pukaki grounds during the five surveys. The composition of SBW (calculated as the total weight of SBW divided by the total weight of all species) has varied from 49% to 99% between surveys and has averaged 86%. The main bycatch species were silverside, ling, ghost shark, smooth rattail, spiny dogfish, hake, and hoki. The estimate does not include small species such as mesopelagic fish which go through the trawl meshes.

Observer data from the SBW fishery were also examined for species composition. However, as in the other areas, SBW usually constitutes about 99% of the catch in most years.

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

Vertical availability

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

Areal availability

It is believed that most of the adult fish are within the survey area at the time of spawning. However, a small proportion may be deeper, may arrive late or early, or may not be spawning in any particular year, leading to a slight underestimate of biomass. We have assumed arbitrary bounds of [0.90, 1.00], and a best estimate of 0.95.

Acoustic system calibration

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

Overall acoustic q

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

3.3 Biomass estimates

3.3.1 Input data and weights

The data were analysed using the separable Sequential Population Analysis (sSPA) used in recent assessments of the SBW stocks (Hanchet 1997, 1998b, 2000a, 2000b). The model was fitted to proportion-at-age data, and the acoustic indices are given in Tables 5 and 6. Weightings and other model details differed between the two assessments. Because of uncertainty over target strength, the acoustic indices were fitted in the model as relative estimates of mid-season abundance (i.e., after half the catch has been removed).

Adult (4+) and age 3 acoustic c.v.s for Campbell were weighted by the number of snapshots, resulting in c.v.s of 0.35 for the 1993–95 and 2000 surveys and 0.25 for the 1998 survey (see Hanchet 2000b). A c.v. of 0.5 was used for the Campbell age 1 and 2 acoustic survey indices. The adult (4+) and age 3 acoustic indices for the Pukaki Rise for all years were given a c.v. of 0.3. A c.v. of 0.7 was used for the Pukaki age 1 and 2 acoustic survey indices.

Weights were assigned to the proportion-at-age data based on the sample size in a multinomial distribution. The amount and precision of the data collected from these fisheries suggest sample sizes of over 100 may be warranted, but these are probably too high given factors such as ageing error and sampling bias. Also, because of the large number of data points, a value of more than 100 gave too much weight to the age data relative to the acoustic data. For the Campbell base case a weight (sample size) of 100 (equivalent to a c.v. of about 0.2) was given to the age data. For the Pukaki base case a weight of 50 (equivalent to a c.v. of about 0.3) was given to the age data.

For the Campbell assessment the model assumes that the selectivity after age 4 is 1.0, estimates a single selectivity for age 4, and annual selectivity for ages 2 and 3. For the Pukaki assessment single selectivities were estimated for ages 2 to 4. The sSPA model was used to estimate the numbers at age in the initial population in 1979 (for Campbell) and 1989 (for Pukaki) and subsequent recruitment. As a sensitivity analysis for the Pukaki stock an equilibrium age structure in 1979 was assumed and subsequent recruitment was estimated. A number of other sensitivity tests were run to evaluate the sensitivity of the assessment to M , and to the estimation of annual selectivity deviations. Details of the input parameters, and sensitivity runs are given in Tables 7 and 8 for the two assessments.

Preliminary results for the Pukaki Rise using the reference case input parameters and also the sensitivity analyses all appeared to be over-pessimistic because the adult (4+) acoustic q was very high. For example, for the base case the age 4+ acoustic q was estimated to be 2.7. As an alternative approach it was decided to try and bound virgin and current biomass following the method of Cordue (1996). Bounds were obtained using two approaches: firstly using the bounds from the adult (4+) acoustic q , and secondly using maximum and minimum exploitation rates.

The model was run using the same input parameters as were used for the base case, but fixing the adult (4+) acoustic q at a range of different values from 0.65 to 2.8 (see also Section 3.2.4).

Estimates of B_{\min} and B_{\max} were calculated for the Pukaki Rise by constraining the maximum or minimum exploitation rate in the year with the highest exploitation rate to the appropriate value following Cordue (1996). Typical values in other assessments for the exploitation rates are $r_{\max} = 0.7$

and $r_{\max} = 0.05$. These give very wide bounds for B_0 of 18 000 and 196 000 t respectively. The year with the highest exploitation rate was 1993 for each run.

Tighter bounds could be obtained by drawing an analogy with the Campbell Island fishery and stock assessment results. In 1993, the year with the greatest effort on the Pukaki Rise, 22 vessels made 326 trawls. Most (85%) trawls were made during the pre-spawning and spawning season between 31 August and 8 September. The catch for that year was 6500 t. In the same year on the Campbell Island Rise, 365 trawls were made by 19 vessels yielding a catch of 8960 t. Now the Campbell exploitation rate in 1993 was 0.2. Given that there was a similar amount of effort in both grounds, and that the Campbell fished area is about three times larger than the Pukaki fished area, we would expect that the exploitation rate on Pukaki must have been at least 0.2, if not higher. So the model was also run using $r_{\max} = 0.20$.

3.3.2 Estimation of confidence intervals

The 90% confidence limits for the results were estimated using parametric bootstrapping. The length at age data within individual years were resampled (with replacement) and then scaled up to proportion-at-age using the weighted length frequency of the catch for that year. Uncertainty in the acoustics data was included by resampling from the MLE estimate with an acoustic c.v. calculated empirically from the model fits. For each of the 500 bootstrap runs, data were randomly selected from each distribution. Bias corrected confidence intervals were obtained by "inverting" the bootstrap distribution following Gilbert et al. (2000).

3.3.3 Estimation of virgin biomass

Virgin biomass (B_0) was estimated from the product of the spawning stock biomass per recruit (age 2) in an unfished stock (1.87 kg per recruit for Campbell and Pukaki) and the arithmetic mean of the recruitment of 2 year olds from 1978–79 to 1996–97 calculated from the sSPA.

3.4 Results and discussion

3.4.1 Campbell Island stock

The assessment 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 to 2000 (Figure 9, Table 9). The extent of this recent increase and subsequent decline is uncertain as shown by the wide confidence intervals in current biomass. Selectivity at age was consistent with the results of previous assessments, with about 50% of fish being selected at age 3 and over 90% selected at age 4 (Table 10). The initial large increase in biomass was due to the 1991 year class, which is estimated to be almost eight times the average year class strength from 1979 to 2000 (Table 11). The biomass has remained high due to the recruitment of the moderately strong 1995 and 1996 year classes to the fishery. In fact, the assessment suggests most recent year classes have been moderately high with seven of the last eight year classes above the median value for the 1979 to 2000 period.

There are generally good fits to the catch-at-age data, and the adult (4+), age 3, and age 2 acoustic indices (Figure 10). Fits to the age 1 acoustic index was poor, and had a very low acoustic q suggesting it is not monitoring abundance particularly well. Selectivity of age 3 fish appears to be highly variable between years, ranging from about 0.2 to 1.2 (Figure 10). Age 2 and age 3 fish appeared to have above average selectivity in the early 1980s, but have been closer to the average in

recent years. The acoustic q for the adults (4+) and age 3 fish were very similar and were close to 1.0. Because the current target strength is believed to be too low (see Sections 3.2.3 and 3.2.4), the model is probably overestimating the abundance of the stock. The acoustic q for 2 year olds was slightly lower than for adults, suggesting that not all 2 year old fish are present in the survey area. This is consistent with trawl survey results, which have shown some 2 year old fish in the east of the Campbell Plateau away from the acoustic survey area.

The assessment was sensitive to several parameters tested (Table 12). A higher M and less weight (lower sample size) for the catch-at-age data both increased the estimates of current biomass. Trends in year class strength were similar between runs.

3.4.2 Pukaki Rise stock

Biomass estimates using the reference case input parameters are shown in Table 13, and in Figure 11. It appears that the results of the reference case are overly pessimistic because the adult (4+) acoustic q was 2.7, which is very high. Bounds for the adult (4+) acoustic q were obtained using the approach of Cordue (1996). This independent evaluation of the bounds on the 4+ acoustic q suggested a range of 0.65–2.8, with a best estimate of 1.4. Clearly the q from the reference case is almost at the upper bound and probably outside the credible range. Results of the sensitivity runs and the confidence intervals estimated from bootstrapping also estimated high acoustic qs and correspondingly pessimistic biomass estimates (Table 13).

The effect of fixing qs at different values on the estimates of biomass and yield are given in Table 14. When the model was run fixing the acoustic q at 0.65 and 2.8 estimates of B_0 were 54 000 t and 18 000 t, and B_{2000} were 48 000 t and 8000 t respectively. Assuming the 'best estimate' of q of 1.4 gave B_0 equal to 22 000 t and B_{2000} equal to 13 000 t.

Using a minimum exploitation rate of 0.2 gave a maximum estimate for B_0 of 39 000 t, with a corresponding B_{2000} of 31 000 t. Using a maximum exploitation rate of 0.7 in 1993 gave a minimum estimate for B_0 of 16 000 t, with a corresponding B_{2000} of 4000 t.

Combining the bounds obtained assuming a minimum exploitation rate of 0.2 in 1993 and a maximum adult acoustic q of 2.8 gave estimates of B_0 ranging from 18 000 to 39 000 t and of B_{2000} from 8000 to 31 000 t. Within these bounds current biomass is greater than B_{may} . Biomass trajectories from these bounds are shown in Figure 12. A 'best estimate' was obtained by fixing the adult (4+) acoustic q in the model at 1.4, which gave a value of 13 000 t for B_{2000} .

During the discussions of this stock assessment at the 2002 Plenary, the bounds based on the exploitation rates were rejected because they were believed to be too subjective. However, I believe that the upper bound from the exploitation rate is considerably more plausible than that obtained from the adult acoustic q . The reason for this is detailed in Section 3.3.1.

3.5 Yield estimates

3.5.1 Estimation of Maximum Constant Yield (MCY)

The simulation method of Francis (1992) was used to determine the appropriate reference harvest rate for MCY. Using the growth parameters and selectivity given by Hanchet (1997), together with a recruitment variability of 1.0 and a steepness parameter of 0.95, MCY was calculated as 5.1% of B_0 for both stocks.

3.5.1.1 Campbell Island stock

MCY was estimated for the Campbell Island stock by multiplying the harvest rate by the estimate of B_0 .

$$\text{MCY} = 0.051 * 215\,000 \text{ t} = 10\,900 \text{ t}$$

3.5.1.2 Pukaki Rise stock

MCY was estimated for the Pukaki Rise stock by multiplying the harvest rate by the two estimates of B_0 .

$$\text{MCY} = 0.051 * 18\,000 \text{ t} = 900 \text{ t}$$

$$\text{MCY} = 0.051 * 39\,000 \text{ t} = 2000 \text{ t}$$

3.5.2 Estimation of Current Annual Yield (CAY)

Estimates of CAY and their 90% confidence intervals were calculated for the Campbell Island stock for 2001 and 2002 and the Pukaki Rise stock for 2001. No estimates of CAY are available for the Bounty Platform or Auckland Islands Shelf stocks.

The simulation method of Francis (1992) was used to determine u_{CAY} , the ratio of catch to preseason biomass, which equalled 0.21. This harvest rate is the highest constant F policy that allows the stock to go below $0.2B_0$ only 10% of the time. Under a CAY harvest strategy the mean biomass (B_{MAY}) was estimated to be $0.38B_0$, and the mean yield to be $8.6\%B_0$ for both stocks.

The model of Francis (1992) does not use the selectivities or maturities estimated from within the model. Because of this, the estimates for the reference biomasses will not correspond exactly to the equivalent estimates in the assessment. For instance, B_0 will be defined differently by each model.

3.5.2.1 Campbell Island stock

CAY was estimated by multiplying u_{CAY} by pre-season biomass in 2001. Pre-season biomass in 2001 was calculated by projecting forward the 2001 beginning of year numbers at age. The number of 2 year olds in 2001 and 2002 was assumed to be equal to the arithmetic mean of the recruitment of 2 year olds from 1978–79 to 1996–97. The numbers at age were projected forward to 2002 assuming the 2001 catch equalled CAY_{2001} . The estimate of CAY was 31 600 t for 2001, and 27 800 t for 2002.

3.5.2.2 Pukaki Rise stock

CAY was estimated by multiplying μ_{CAY} by pre-season biomass in 2001. Pre-season biomass in 2001 was calculated by projecting forward the 2001 beginning of year numbers at age. The number of 2 year olds in 2001 was assumed to be equal to the arithmetic mean of the recruitment of 2 year olds from 1988–89 to 1996–97.

Using the upper and lower bounds from the assessment, the estimate of CAY_{2001} ranged from 1700 to 6900 t, and equalled 2700 t for the best estimate.

3.5.3 Other yield estimates

The long-term yield available from the SBW stocks depends on the strategy used to manage the fishery. The stock size will fluctuate because of recruitment variability and maximising the long-term yield would require a CAY-based management strategy. Based on simulation models incorporating stochastic recruitment and a CAY-based fishing strategy resulted in a mean yield (MAY) of 8.6% B_0 .

Applying this value to the Campbell stock would suggest a long-term yield of about 20 600 t based on the most recent estimate of B_0 from the sSPA model. In comparison, a constant catch (MCY) strategy would suggest a long-term yield of 10 900 t.

4. MANAGEMENT IMPLICATIONS

4.1 Campbell stock

Estimates of current and reference biomass and yields are available from the model. The model indicates that current biomass is well above B_{MSY} at about 50–60% of virgin biomass. The very strong 1991 year class has persisted in the fishery in 2000 but good recent recruitment has also entered the fishery from the 1995 and 1996 year classes. The assessment is more optimistic than last year because the 2000 acoustic survey adult biomass estimate was high suggesting that recent recruit strength is higher than previously estimated. However, because the current target strength is believed to be too low (see Sections 3.2.3 and 3.2.4), the model is probably overestimating the abundance of the stock. The estimate of CAY was 31 600 t for 2001, and 27 800 t for 2002.

4.2 Pukaki Rise stock

Estimates of biomass and yield for the Pukaki Rise stock are very uncertain. Model-based estimates using the reference case input parameters appear to be overly pessimistic because the adult (4+) acoustic q is 2.7. An independent evaluation of the bounds on the acoustic q suggested a range of 0.65–2.8, with a best estimate of 1.4 (see Section 3.2.4). Clearly the q from the reference case is almost at the upper bound and probably outside the credible range.

As an alternative assessment, bounds on virgin and current biomass were calculated by fixing the adult (4+) acoustic q in the model at 0.65 and 2.8, and by fixing the minimum and maximum exploitation rates at 0.2 and 0.7. Combining the bounds obtained assuming a minimum exploitation rate of 0.2 in 1993 and a maximum adult acoustic q of 2.8 gave estimates of B_{2000} from 8000 to 31 000 t. Corresponding values of CAY_{2001} ranged from 1700 to 6900 t. A 'best estimate' was obtained by fixing the adult (4+) acoustic q in the model at 1.4, which gave a value of 13 000 t for B_{2000} and of 2700 t for CAY_{2001} .

Despite the uncertainty of the assessment, it appears that current biomass is greater than B_{may} , and that recent catches are probably sustainable. However, it is unknown if the current TACC is sustainable or will allow the stock to move towards a size that will support the MAY.

During the discussions of this stock assessment at the 2002 Plenary, the bounds based on the exploitation rates were rejected because they were believed to be too subjective. However, I believe that the upper bound from the exploitation rate is considerably more plausible than that obtained from the adult acoustic q . The reason for this is detailed in Section 3.3.1. Further support for this value is that the corresponding CAY is more consistent with the highest catches reported from the Pukaki Rise. The highest catches of about 6000–7500 t were made when there were no restrictions on effort in the fishery. The CAY accepted by the Plenary is 10 900 t, which in my opinion is not credible.

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6. REFERENCES

- Chatterton, T.D. (1996). Catch per unit effort (CPUE) analysis of the Campbell Island Rise southern blue whiting (*Micromesistius australis*) trawl fishery from 1986 to 1993. N.Z. Fisheries Assessment Research Document 96/1. 26 p. (Draft report held in NIWA library, Wellington.)
- Cherel, Y.; Waugh, S.; Hanchet, S.M. (1999). Albatross predation of juvenile southern blue whiting *Micromesistius australis* on the Campbell Plateau. *New Zealand Journal of Marine and Freshwater Research* 33(3): 437–442.
- Cordue, P.L. (1996). A model-based method for bounding virgin biomass using a catch history, relative biomass indices, and ancillary information. New Zealand Fisheries Assessment Research Document 96/8. 48 p. (Draft report held in NIWA library, Wellington.)
- Dunford, A. (2001a). Estimates of target strength of southern blue whiting (*Micromesistius australis*). Final Research Report for Ministry of Fisheries Research Project SBW9801 Objective 4. 12 p. (Unpublished report held by the Ministry of Fisheries, Wellington.)
- Dunford, A. (2001b). Estimates of target strength of southern blue whiting (*Micromesistius australis*) from the Campbell Rise and Pukaki Rise, September 2000. Final Research Report for Ministry of Fisheries Research Project SBW1999/01 Objective 3. 18 p. (Unpublished report held by the Ministry of Fisheries, Wellington.)
- Dunn, A.; Hanchet, S.M. (1998). Two-phase acoustic survey designs for southern blue whiting on the Bounty Platform and the Pukaki Rise. *NIWA Technical Report* 28. 29 p.
- Dunn, A.; Grimes, P.J.; Hanchet, S.M. (2001). Comparative evaluation of two-phase and adaptive cluster sampling designs for acoustic surveys of southern blue whiting (*M. australis*) on the Campbell Rise. Final Research Report for MFish Research Project SBW1999/01. Objective 1. 15 p. (Unpublished report held by the Ministry of Fisheries, Wellington.)
- Francis, R.I.C.C. (1992). Recommendations concerning the calculation of maximum constant yield (MCY) and current annual yield (CAY). New Zealand Fisheries Assessment Research Document 92/8. 27 p. (Draft report held in NIWA library, Wellington.)
- Gilbert, D.G.; McKenzie, J.R.; Davies, N.M.; Field, K.D. (2000). Assessment of the SNA 1 stocks for the 1999–2000 fishing year. *New Zealand Fisheries Assessment Report* 2000/38. 52 p.

- Hanchet, S.M. (1997). Southern blue whiting (*Micromesistius australis*) fishery assessment for the 1996-97 and (1997-98 fishing years. New Zealand Fisheries Assessment Research Document 97/14. 32 p. (Draft report held in NIWA library, Wellington.)
- Hanchet, S.M. (1998a). A review of southern blue whiting (*M. australis*) stock structure. New Zealand Fisheries Assessment Research Document 98/8. 28 p. (Draft report held in NIWA library, Wellington.)
- Hanchet, S.M. (1998b). Southern blue whiting (*Micromesistius australis*) stock assessment for the Bounty Platform and Pukaki Rise for 1998 and 1999. New Zealand Fisheries Assessment Research Document 98/32. 33 p. (Draft report held in NIWA library, Wellington.)
- Hanchet, S.M. (1998c). Documentation of the separable Sequential Population Analysis used in the assessments of southern blue whiting, and a comparison with other models. New Zealand Fisheries Assessment Research Document 98/33. 22 p. (Draft report held in NIWA library, Wellington.)
- Hanchet, S.M. (1999). Stock structure of southern blue whiting (*Micromesistius australis*) in New Zealand waters. *New Zealand Journal of Marine and Freshwater Research* 33(4): 599-610.
- Hanchet, S.M. (2000a). Southern blue whiting (*Micromesistius australis*) stock assessment for the Campbell Island Rise for 1999 and 2000. *New Zealand Fisheries Assessment Report 2000/15*. 36 p.
- Hanchet, S.M. (2000b). Southern blue whiting (*Micromesistius australis*) stock assessment for the Bounty Platform and Campbell Island Rise for 2000. *New Zealand Fisheries Assessment Report 2000/44*. 35 p.
- Hanchet, S.M.; Bull, B.; Bryan, C. (2000a). Diel variation in fish density estimates during acoustic surveys of southern blue whiting. *New Zealand Fisheries Assessment Report 2000/16*. 22 p.
- Hanchet, S.M.; Grimes, P.J. (2000). Acoustic biomass estimates of southern blue whiting (*Micromesistius australis*) from the Bounty Platform, August 1999. *New Zealand Fisheries Assessment Report 2000/30*. 25 p.
- Hanchet, S.M.; Grimes, P.J.; Bull, B. (2000b). Acoustic biomass estimates of southern blue whiting (*Micromesistius australis*) from the Campbell Island Rise, September 1998. *New Zealand Fisheries Assessment Report 2000/9*. 28 p.
- Hanchet, S.M.; Grimes, P.J. (2001). Acoustic biomass estimates of southern blue whiting (*Micromesistius australis*) from the Campbell Island Rise and Pukaki Rise, September 2000. *New Zealand Fisheries Assessment Report 2001/58*. 37 p.
- Hanchet, S.M.; Haist, V.; Fournier, D. (1998). An integrated assessment of southern blue whiting (*Micromesistius australis*) from New Zealand waters using separable Sequential Population Analysis. In Funk, F., et al. (eds). *Alaska Sea Grant College Program Report No. AK-SG-98-01*. University of Alaska Fairbanks, 1998.
- Hanchet, S.M.; Ingerson, J.K.V. (1995). Southern blue whiting (*Micromesistius australis*) fishery assessment for the 1995-96 fishing year. New Zealand Fisheries Assessment Research Document 95/20. 37 p. (Draft report held in NIWA library, Wellington.)
- Hanchet, S.M.; Ingerson, J.K.V. (1996). Southern blue whiting (*Micromesistius australis*) fishery assessment for the 1995-96[sic] fishing year. New Zealand Fisheries Assessment Research Document 96/12. 34 p. (Draft report held in NIWA library, Wellington.)
- Hanchet, S.M.; Renwick, J.A. (1999). Prediction of southern blue whiting (*Micromesistius australis*) year class strength in New Zealand waters. New Zealand Fisheries Assessment Research Document 99/51. 24 p. (Draft report held in NIWA library, Wellington.)
- Hanchet, S.M.; Richards, L.; Bradford, E. (2000c). Decomposition of acoustic biomass estimates of southern blue whiting (*Micromesistius australis*) using length and age frequency data. *New Zealand Fisheries Assessment Report 2000/43*. 37 p.
- Ingerson, J.K.V.; Hanchet, S.M. (1995). Catch per unit effort (CPUE) analysis of the Campbell Island Rise southern blue whiting (*Micromesistius australis*) fishery from 1986 to 1994. New Zealand Fisheries Assessment Research Document 95/21. 15 p. (Draft report held in NIWA library, Wellington.)

- McClatchie, S.; Macaulay, G.; Hanchet, S.; Coombs, R.F. (1998). Target strength of southern blue whiting (*Micromesistius australis*) using swimbladder modelling, split beam and deconvolution. *ICES Journal of Marine Science* 55: 482-493.
- McClatchie, S.; Thorne, R.; Grimes, P.J.; Hanchet, S. (2000). Ground truth and target identification for fisheries acoustics. *Fisheries Research* 47: 173-191.
- Monstad, T.; Borkin, I.; Ermolchev, V. (1992). Report of the joint Norwegian-Russian acoustic survey on blue whiting, spring 1992. *ICES C.M. 1992/H:6, Pelagic Fish Committee*. 26 p.
- Ona, E. & Mitson, R.B. (1996). Acoustic sampling and signal processing near the seabed: the deadzone revisited. *ICES Journal of Marine Science* 53: 677-690.
- Rose, G.A. (1998). Review of southern blue whiting acoustic projects for the Ministry of Fisheries, Wellington, NZ. (Unpublished report, Ministry of Fisheries, Wellington.)
- Shpak, V.M. (1978). The results of biological investigations of the southern putassu *Micromesistius australis* (Norman, 1937) on the New Zealand plateau and perspectives of its fishery. Unpublished TINRO manuscript. (Translation held in NIWA library, Wellington.)
- Shpak, V.M.; Kuchina, V.V. (1983). Dynamics of abundance of southern putassu. *Biologiya Morya* 2: 35-39. (Translation held in NIWA library, Wellington.)

Table 1: Estimated catches (t) of SBW by area for the period 1978 to 1998-00 from vessel logbooks. Estimates for 2000-01 are based on QMRs and are preliminary. *, before 1997-98 there was no separate catch limit for Auckland Is.

Fishing yr	Bounty Platform		Campbell Island Rise		Pukaki Rise		Auckland Island		Total	
	Catch	Limit	Catch	Limit	Catch	Limit	Catch	Limit*	Catch	Limit
1978f	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	34 900	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‡

f 1 April - 30 September

+ 1 October - 30 September

† 1 October 1998 - 31 March 2000

1 April 2000 - 31 March 2001

‡ In 2000-01 SBW1 (all EEZ areas outside QMA6) had a TACC of 8 t and a total catch of 10 t.

Table 2: Catch history (t) of the Campbell, Bounty, and Pukaki stocks used in the modelling.

Season	Campbell	Bounty	Pukaki
1979	25 305	1 211	1 620
1980	12 828	16	5 789
1981	5 989	8	2 469
1982	7 915	8 325	1 355
1983	12 803	3 864	7 572
1984	10 777	348	2 249
1985	7 490	0	1 845
1986	15 252	0	567
1987	12 804	0	906
1988	17 422	18	161
1989	26 611	8	1 220
1990	16 542	4 430	1 393
1991	21 314	10 897	4 659
1992	14 208	58 928	3 119
1993	9 316	11 908	6 484
1994	11 668	3 877	3 015
1995	10 436	6 386	1 750
1996	16 504	6 508	812
1997	18 923	1 761	2 122
1998	27 164	6 508	1 385
1999	27 205	11 367	1 009
2000	18 049	3 997	2 864

Table 3: Number of vessels, tows, and dates for observed and all vessels for each area for the August–October 2000 season. #, tows for which LF data were collected.

Area	Number of vessels		Number of tows		Dates	
	observed	total	#observed	total	observed	total
Bounty	3	6	27	75	23 Aug – 1 Sep	22 Aug – 2 Sep
Pukaki	3	6	15	50	3 Sep – 6 Sep	2 Sep – 7 Sep
Auckland	0	1	0	5	–	14 Oct – 15 Oct
Campbell	10	15	168	407	7 Sep – 1 Oct	7 Sep – 4 Oct

Table 4: Dates of sampling and changes in SBW gonad condition in 2000 on Bounty, Campbell, and Pukaki, 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 Auckland.

Gonad stage	Bounty	Campbell	Pukaki
1st sample	23/8	7/9	3/9
>10% ripe	23/8	<7/9	3/9
>10% running ripe	24/8	<7/9	–
Main spawning	24/8–1/9	?–8/9	–
>10% spent	30/8	10/9	–
>10% reverted	–	9/9	–
>50% spent	–	30/9	–
2nd spawning	–	17–25/9	–
Last sample	1/9	1/10	6/9
% spent	17	53	0
% reverted	27	22	0

Table 5: Estimates of biomass (t) for age 1, 2, 3 and 4+ fish from acoustic surveys of Campbell Island Rise used in modelling the fisheries. –, no data.

Year	Age 1	Age 2	Age 3	Age 4+
1993	1 817	71 902	14 781	24 033
1994	329	12 259	139 552	28 841
1995	0	11 176	23 228	130 535
1996	–	–	–	–
1997	–	–	–	–
1998	2 283	13 142	28 022	167 668
1999	–	–	–	–
2000	961	10 460	8 421	135 612

Table 6: Estimates of biomass (t) for age 1, 2, 3 and 4+ fish from acoustic surveys of Pukaki Rise used in modelling the fisheries. –, no data.

Year	Age 1	Age 2	Age 3	Age 4+
1993	578	26 848	9 315	31 152
1994	8	1 193	6 364	35 969
1995	0	102	775	11 743
1996	–	–	–	–
1997	22	2 838	864	34 086
1998	–	–	–	–
1999	–	–	–	–
2000	64	3 035	2 065	29 446

Table 7: Values for the input parameters to the separable Sequential Population Analysis for the base case and sensitivity runs for the Campbell Island Rise. Adult acoustic c.v.s given for individual surveys for base case. -, not tested

Parameter	Base case	Sensitivity
M	0.2	0.15, 0.25
Acoustic time series	Relative	-
Acoustic adult c.v. (1993,1994, 1995, 1998, 2000)	0.35, 0.35, 0.35, 0.25, 0.35	-
Acoustic pre-recruit c.v. (all surveys)	0.5	-
Median weighting on proportion-at-age data	100	10, 400
Annual selectivity (2 & 3 year olds)	Free	Constant

Table 8: Values for the input parameters to the separable Sequential Population Analysis for the reference case and sensitivity runs for the Pukaki assessment. NF, not fitted. -, not tested

Parameter	Reference case	Sensitivity
M	0.2	0.15, 0.25
Acoustic age 3 and 4+ c.v.	0.3	0.1, 0.5
Acoustic age 1 and 2 c.v.	0.7	0.5, 1.0
Median weighting on proportion-at-age data	50	5, 100
Annual selectivity for 2 and 3 yo	Constant	Free
Years used in analysis	1989-2000	1979-2000
Acoustic q	Estimated	0.68, 1.4, 2.8
Maximum exploitation rate (r_{max})	Estimated	0.7
Minimum exploitation rate (r_{min}) in year with highest catch	Estimated	0.2

Table 9: Campbell Island estimates (MLE) of B_0 , B_{mid00} (mid-season spawning stock biomass), $B_{pre2001}$ (pre-season spawning stock biomass), MCY, CAY_{2001} , CAY_{2002} , and their 90% confidence intervals and bias corrected 90% confidence intervals. All values in $t \times 10^3$.

	B_0	B_{mid00}	$B_{pre2001}$	B_{mid00} (% B_0)	MCY	CAY_{2001}	CAY_{2002}
Base case	215	139	150	65%	10.9	31.6	27.8
CI	175-294	64-282	71-310	37-96%	8.9-15.0	14.8-65.1	14.0-54.6
CI (corrected)	157-262	68-299	73-321	44-114	7.9-13.4	15.4-67.4	14.2-55.2

Table 10: Mean selectivity of 2, 3 and 4 year old fish estimated by the model for the base case run for the Campbell Island stock.

Age	Selectivity
2	0.05
3	0.47
4	0.94

Table 11: Estimated number of 2 year old fish for the base case run in the Campbell Island stock (i.e., the 1979 year corresponds to the 1977 year class).

Year	Number of 2 year olds (millions)
1979	10
1980	14
1981	138
1982	159
1983	35
1984	6
1985	47
1986	42
1987	34
1988	95
1989	45
1990	120
1991	14
1992	50
1993	770
1994	163
1995	68
1996	26
1997	228
1998	159
1999	71
2000	102

Table 12: Changes in parameter estimates as a result of alternative model assumptions (see Table 7) for the Campbell Island stock. B_{mid} , mid-season spawning stock biomass ($t \times 10^3$); $N_{2,1993}$ size of the 1991 year class (millions). All values in $t \times 10^3$.

Parameter	B_0	$B_{mid\ 79}$	$B_{mid\ 00}$	$N_{2,1993}$	$B_{mid\ 00}$ (% B_0)	$B_{mid\ 00}$ (% B_{may})	MCY	CAY 2001	CAY 2002
Base case	215	118	139	770	65	180	10.9	31.6	27.8
$M = 0.15$	236	89	100	500	42	124	10.2	20.0	18.4
$M = 0.25$	236	166	222	1368	94	254	15.3	56.5	47.2
Lower weight on age data	240	118	184	931	77	213	12.3	42.4	36.4
Higher weight on age data	211	119	133	753	63	175	10.8	30.1	26.8
No annual selectivity deviations (2 & 3 y)	209	112	125	745	60	166	10.7	30.0	27.6

Table 13: Changes in parameter estimates as a result of alternative model assumptions for the Pukaki stock. B_{mid} , mid-season spawning stock biomass; $N_{2,1992}$ size of the 1990 year class (millions). ¹ Bias adjusted values were 19 and 5. All values in $t \times 10^3$.

Parameter	B_0	$B_{mid\ 89}$	$B_{mid\ 00}$	$N_{2,1992}$	$B_{mid\ 00}$ (% B_0)	$B_{mid\ 00}$ (% B_{may})	MCY	CAY ₀₁
Reference case	19	19	9	24	46	129	1.0	1.7
$M = 0.15$	22	16	7	18	31	92	1.0	1.3
$M = 0.25$	18	25	11	34	60	162	1.2	2.4
High acoustic c.v.	19	20	10	24	52	143	1.0	1.9
Low acoustic c.v.	21	20	11	22	53	146	1.1	2.2
High wt on proportion-at-age	19	20	9	24	46	129	1.0	1.8
Low wt on proportion-at-age	24	22	12	29	50	139	1.2	2.5
Annual selectivity deviations 1979-2000 data	16	20	9	27	58	161	0.8	1.8
Upper 95% CI	18	19	6	22	34	93	0.9	1.3
Lower 95% CI	26	21	¹ 16	29	62	173	1.3	3.5
	15	18	¹ 4	19	25	69	0.8	0.7

Table 14: Parameter estimates for the Pukaki stock as a result of (a) fixing the adult 4+ acoustic q at various values and (b) fixing the fully selected exploitation rate in 1993 at various values. B_{mid} , mid-season spawning stock biomass; $N_{2,1992}$ size of the 1990 year class (millions). All values in $t \times 10^3$.

Parameter	B_0	$B_{mid\ 89}$	$B_{mid\ 00}$	$N_{2,1992}$	$B_{mid\ 00}$ (% B_0)	$B_{mid\ 00}$ (% B_{may})	MCY	CAY ₀₁
(a) fixing the acoustic q								
$q = 0.65$ ($F_{1993} = 0.15$)	54	36	48	63	88	246	2.8	10.9
$q = 1.4$ ($F_{1993} = 0.32$)	22	22	13	28	58	161	1.1	2.7
$q = 2.8$ ($F_{1993} = 0.39$)	18	19	8	23	44	123	0.9	1.7
(b) fixing the 1993 exploitation rate								
$F_{1993} = 0.2$ ($q = 0.97$)	39	29	31	46	80	222	2.0	6.9
$F_{1993} = 0.7$ ($q = 6.0$)	16	14	4	23	26	72	0.8	0.7

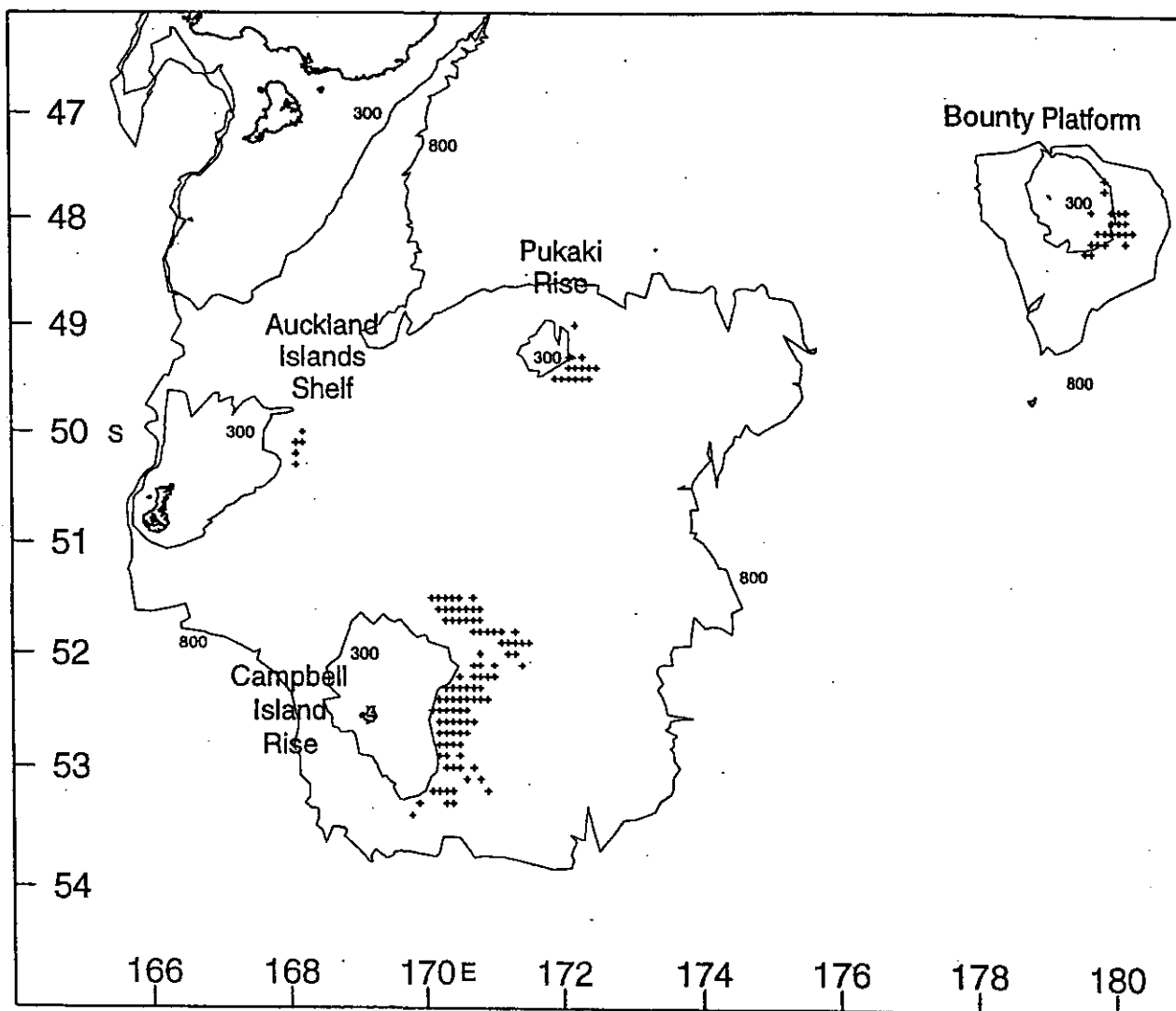


Figure 1: Commercial trawls made during the 2000 season targeting southern blue whiting.

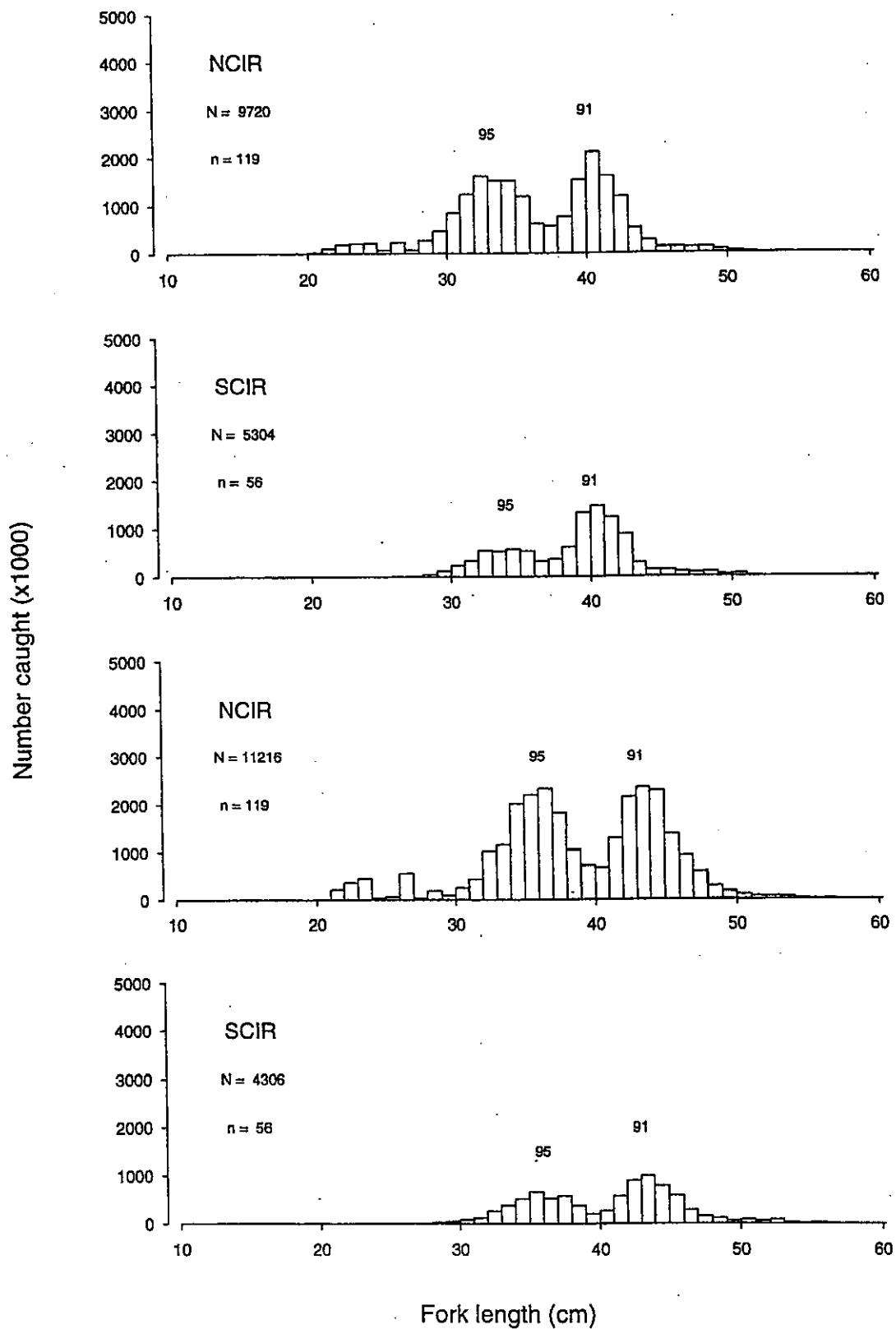


Figure 2: Weighted length frequency distribution of males (top) and females (bottom) in the 1999 catch from the northern Campbell Island Rise (NCIR), and southern Campbell Island Rise (SCIR). (N, number of fish measured; n, number of samples). Modal lengths of strong year classes determined from otolith readings are shown.

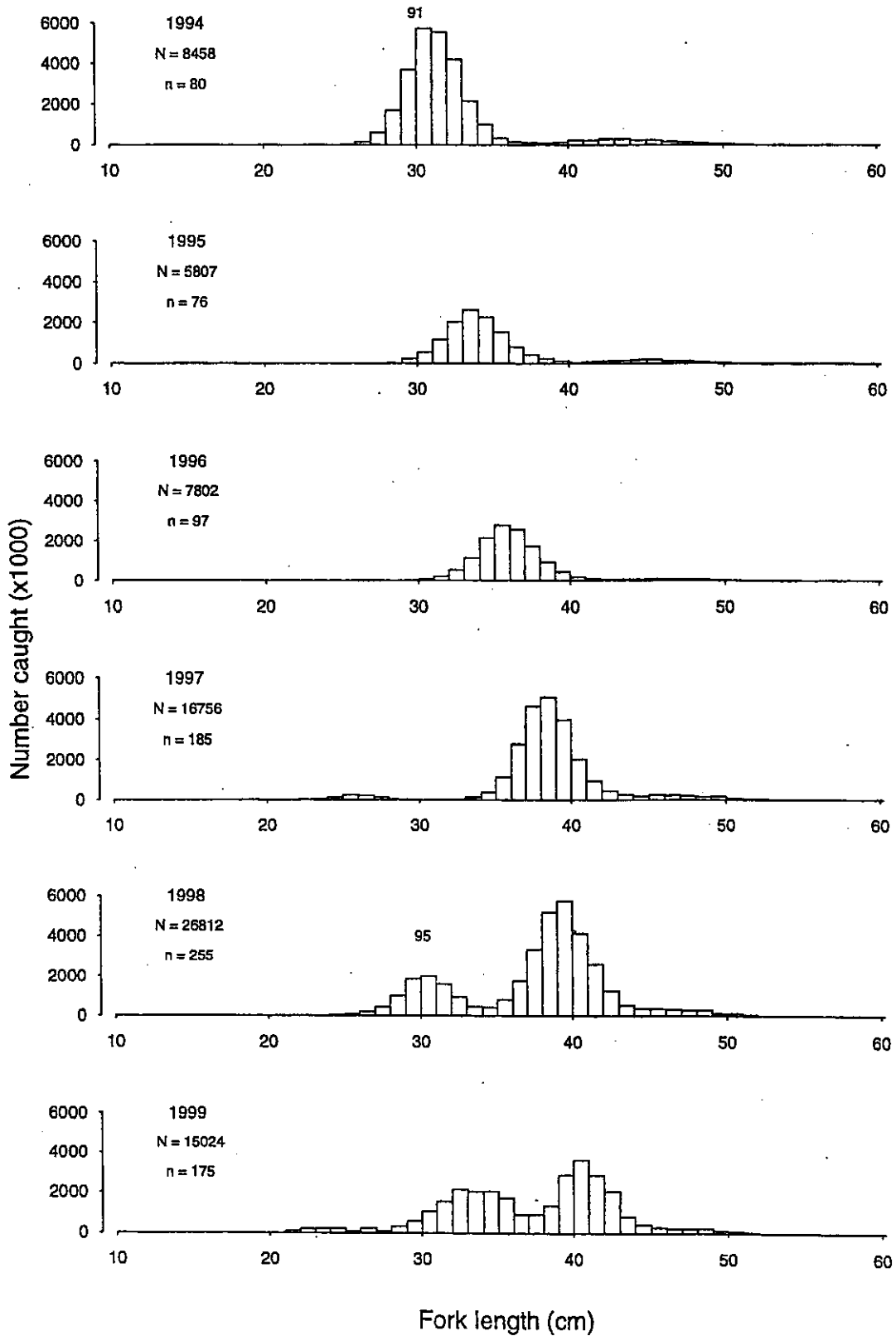


Figure 3a: Weighted length frequency distribution of males in the catch from the Campbell Island Rise. (N, number of fish measured; n, number of samples). Modal lengths of 3 year old fish from strong year classes determined from otolith readings are shown.

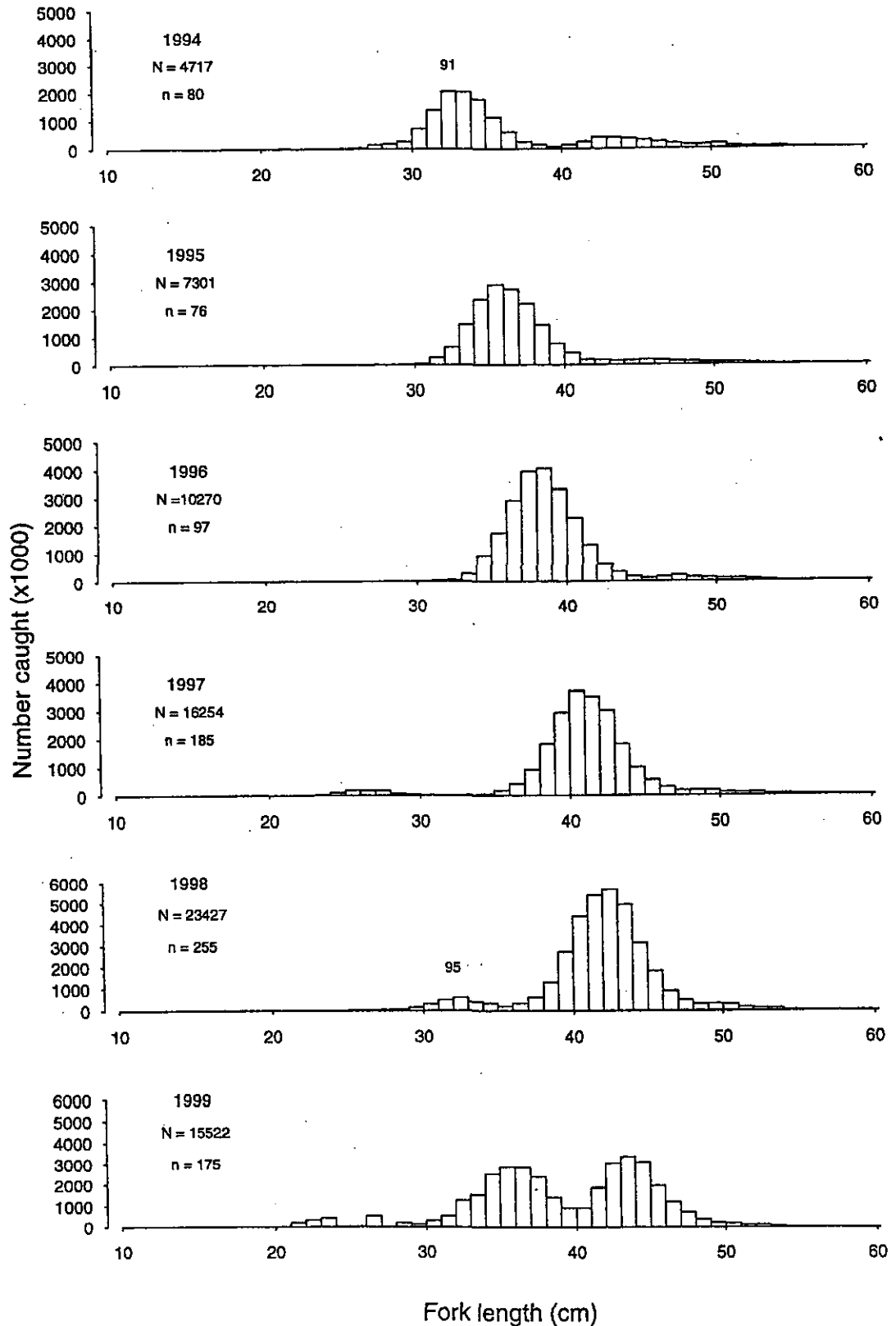


Figure 3b: Weighted length frequency distribution of females in the catch from the Campbell Island Rise. (N, number of fish measured; n, number of samples). Modal lengths of 3 year old fish from strong year classes determined from otolith readings are shown.

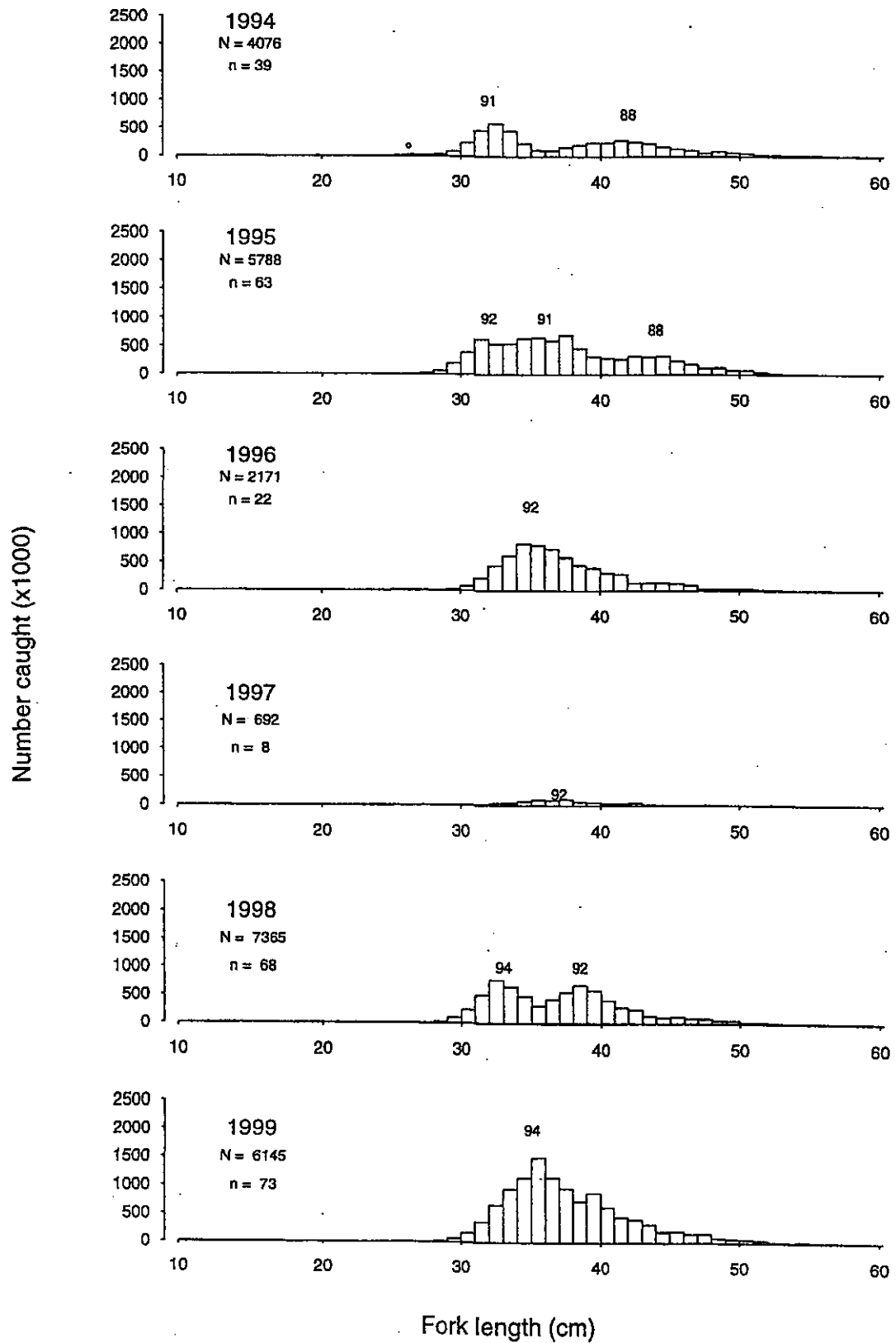


Figure 4a: Weighted length frequency distribution of males in the catch from the Bounty Platform. (N, number of fish measured; n, number of samples). Modal lengths of strong year classes determined from otolith readings are shown.

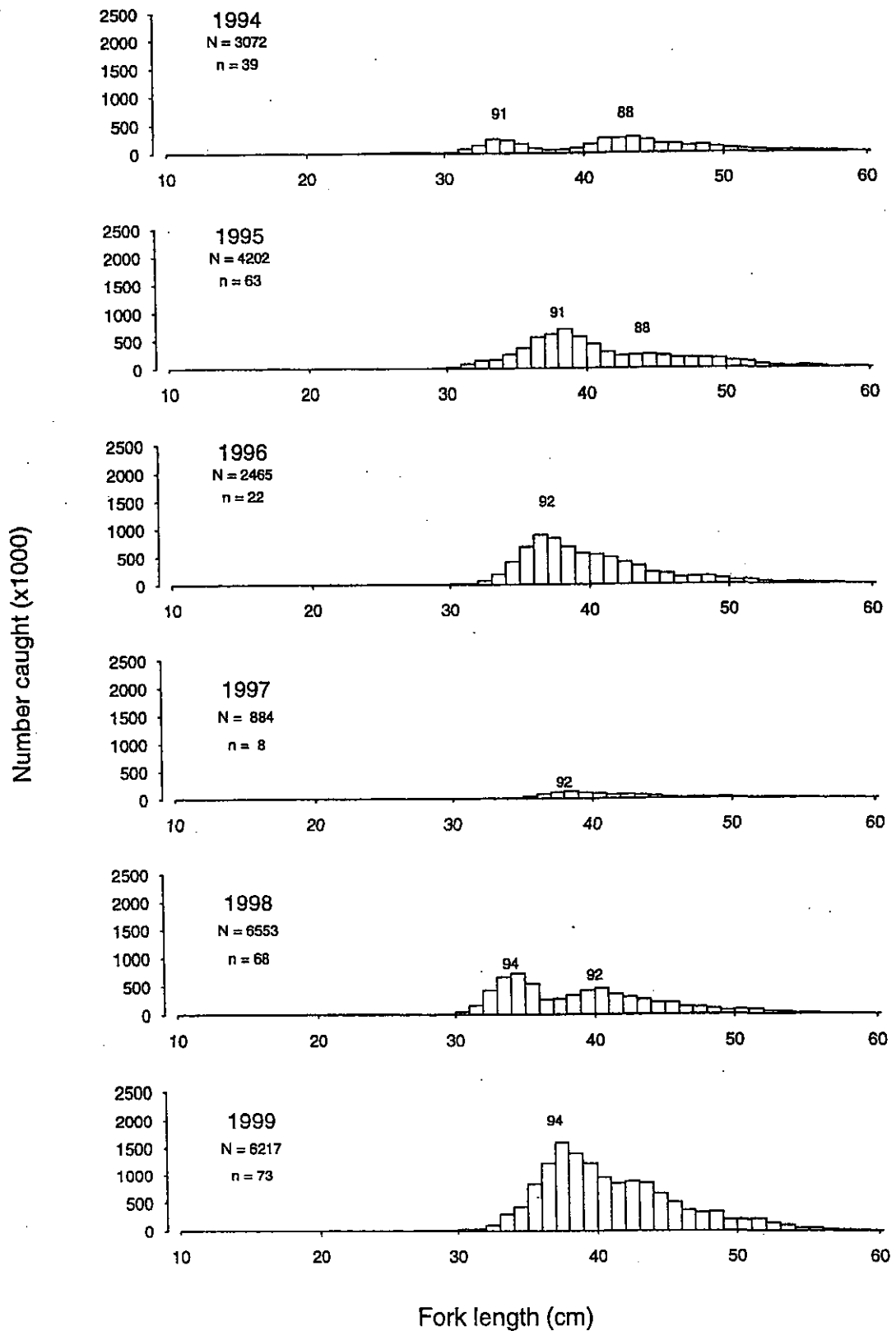


Figure 4b: Weighted length frequency distribution of females in the catch from the Bounty Platform. (N, number of fish measured; n, number of samples). Modal lengths of strong year classes determined from otolith readings are shown.

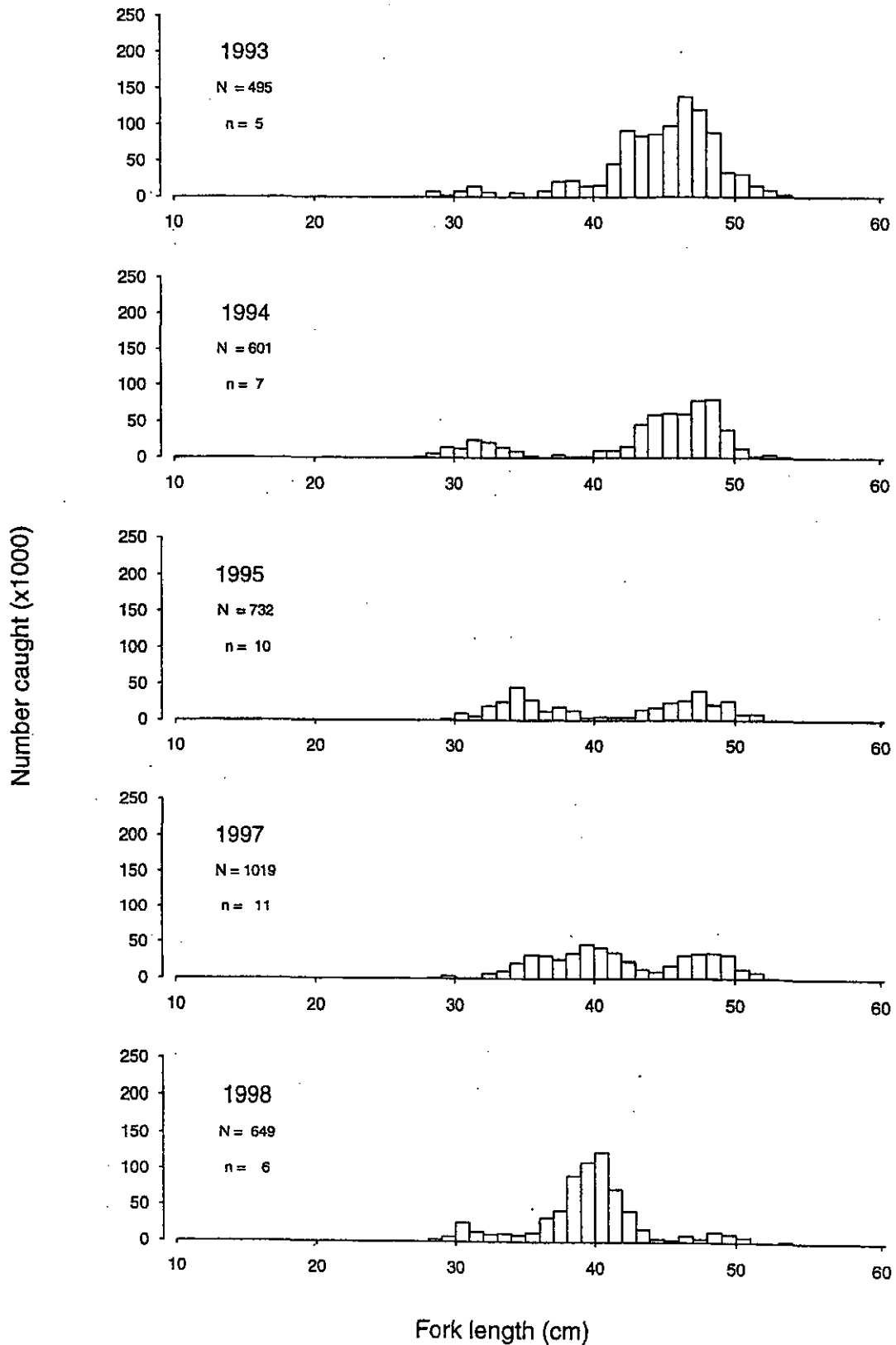


Figure 5a: Weighted length frequency distribution of males in the catch from the Auckland Islands Shelf. (N, number of fish measured; n, number of samples). Modal lengths of strong year classes determined from otolith readings are shown.

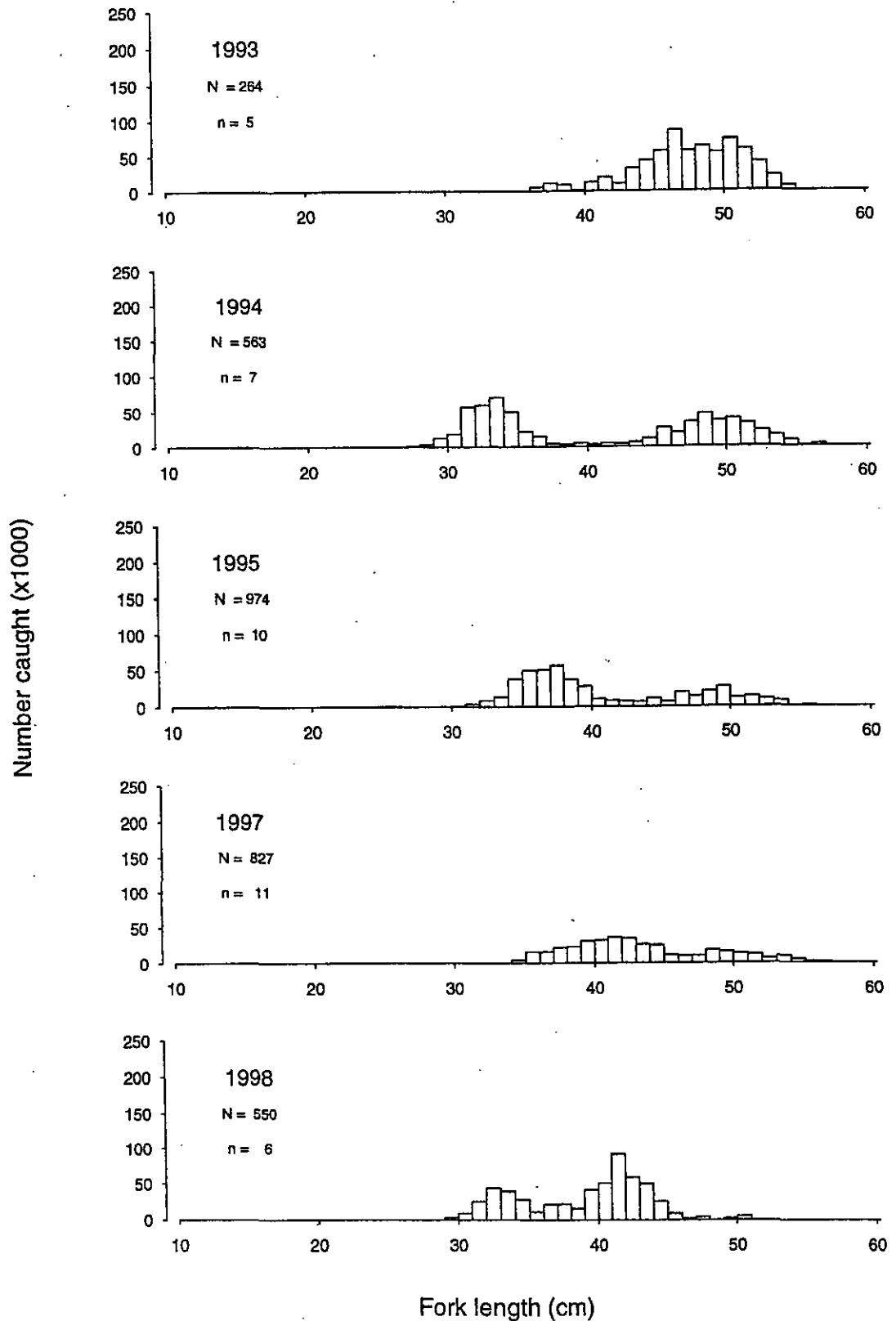


Figure 5b: Weighted length frequency distribution of females in the catch from the Auckland Islands Shelf. (N, number of fish measured; n, number of samples). Modal lengths of strong year classes determined from otolith readings are shown.

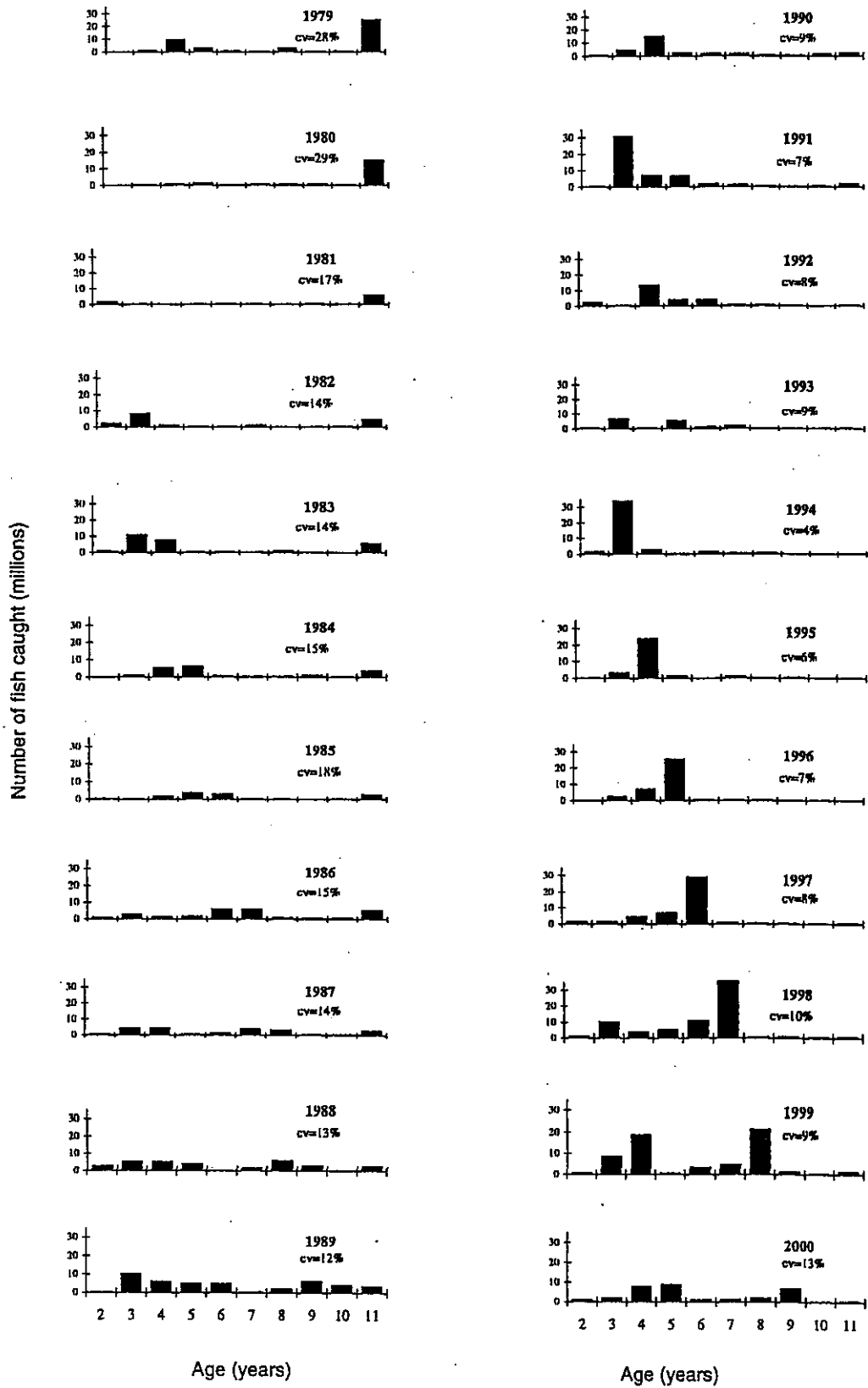


Figure 6: Age composition of the catch on the Campbell Island Rise from 1979 to 2000, with the mean weighted c.v. (%).

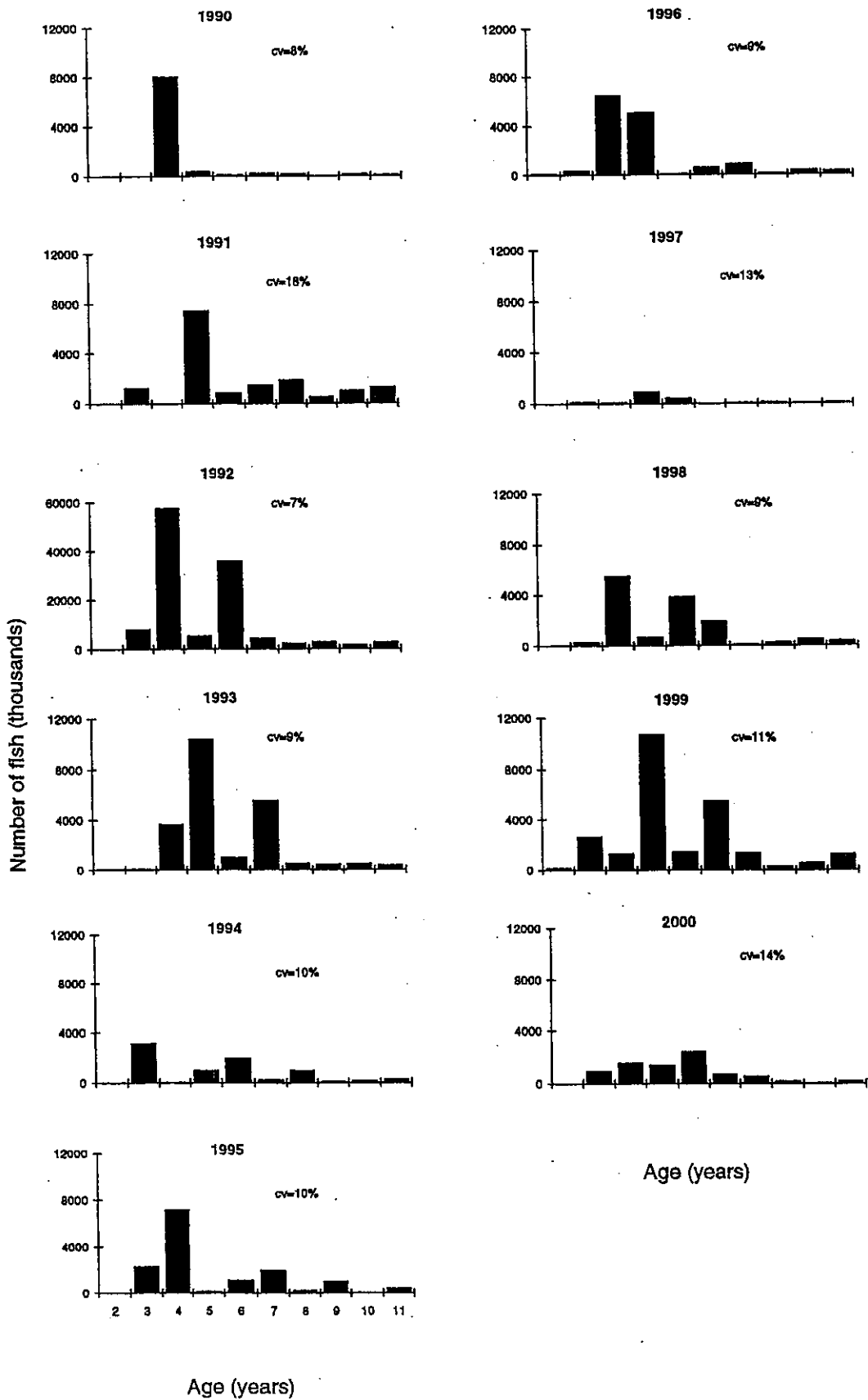


Figure 7: Age composition of the catch on the Bounty Platform from 1990 to 2000, with the mean weighted c.v. (%).

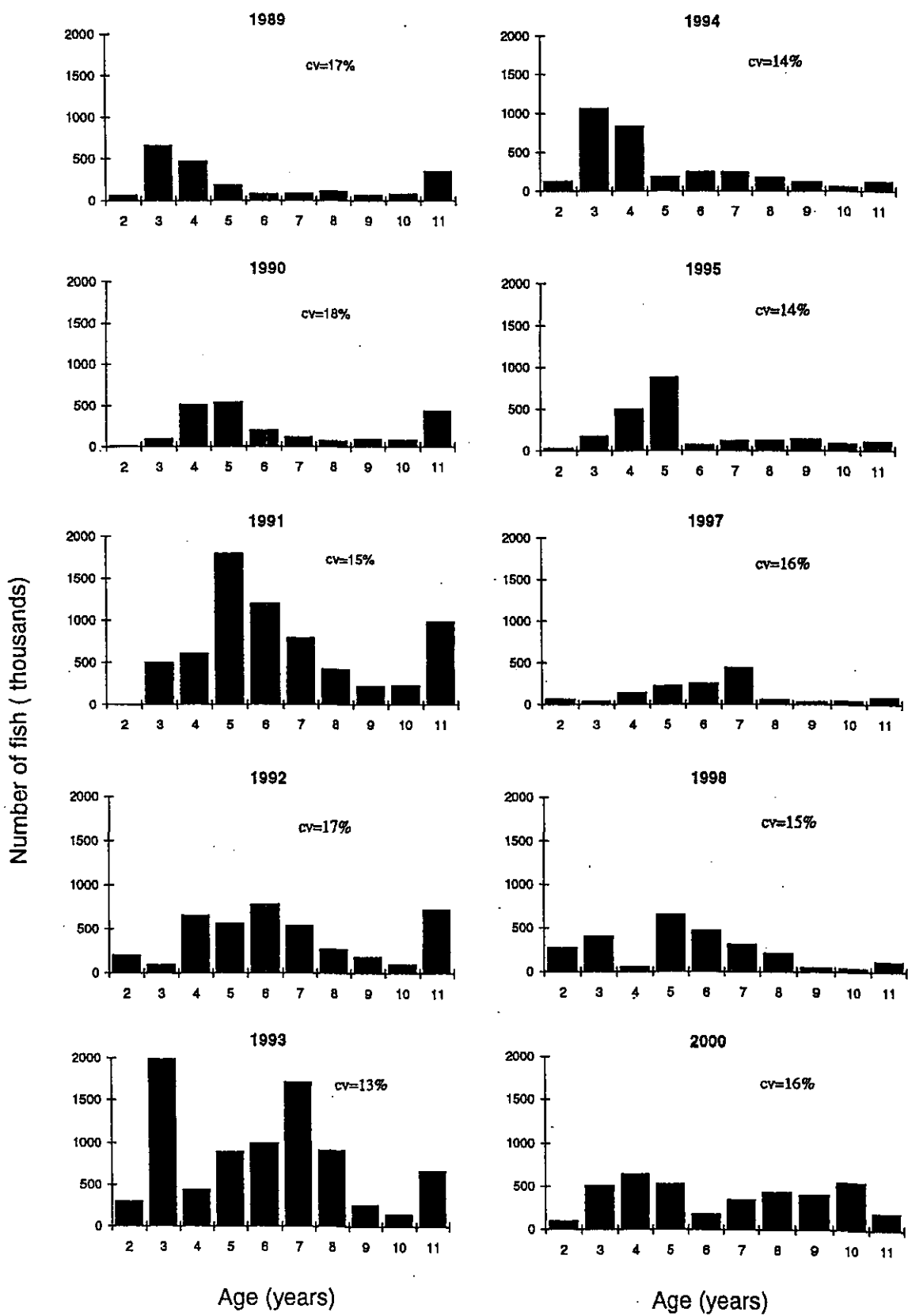


Figure 8: Age composition of the catch on the Pukaki Rise from 1989 to 2000, with the mean weighted c.v. (%).

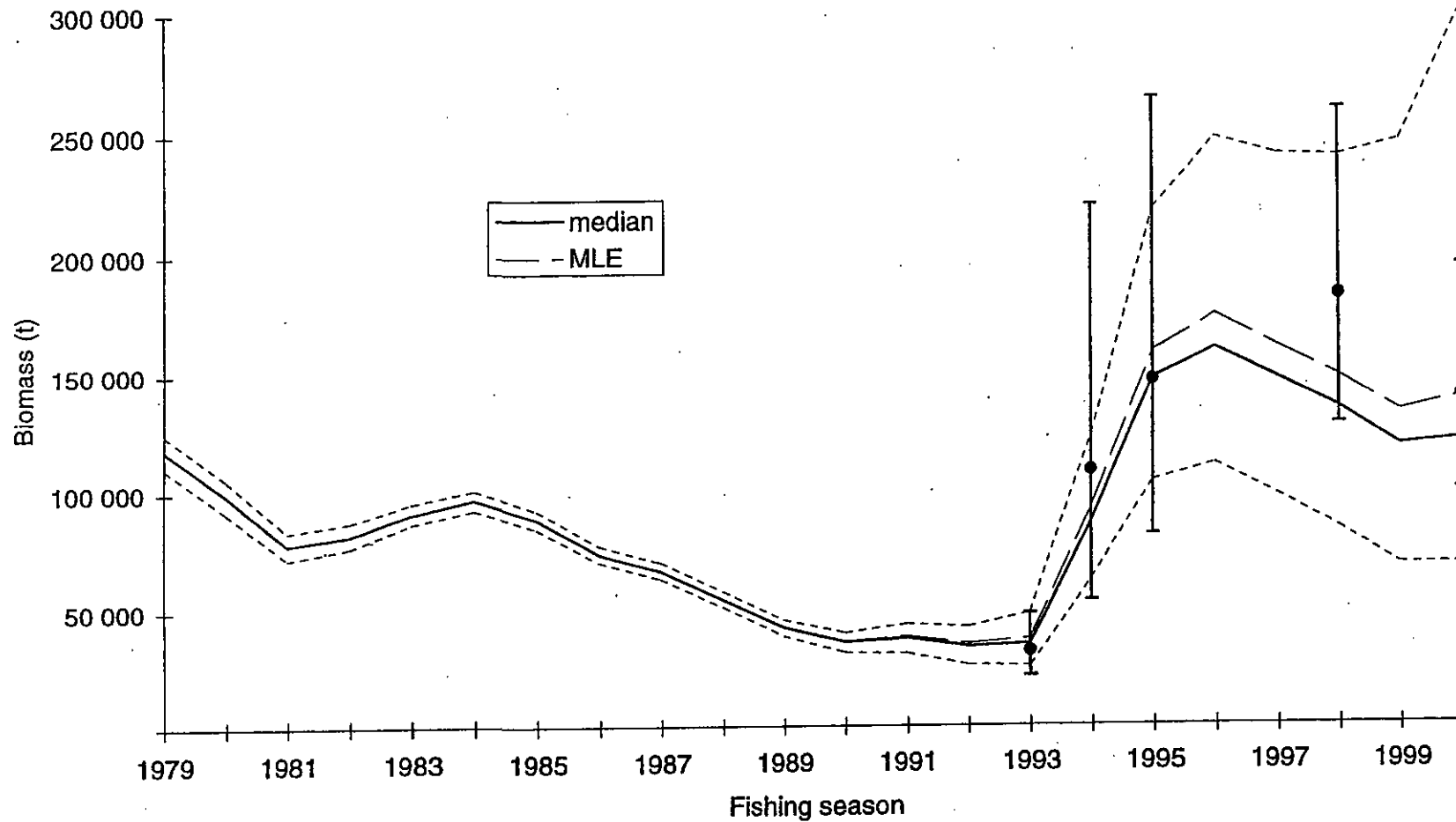
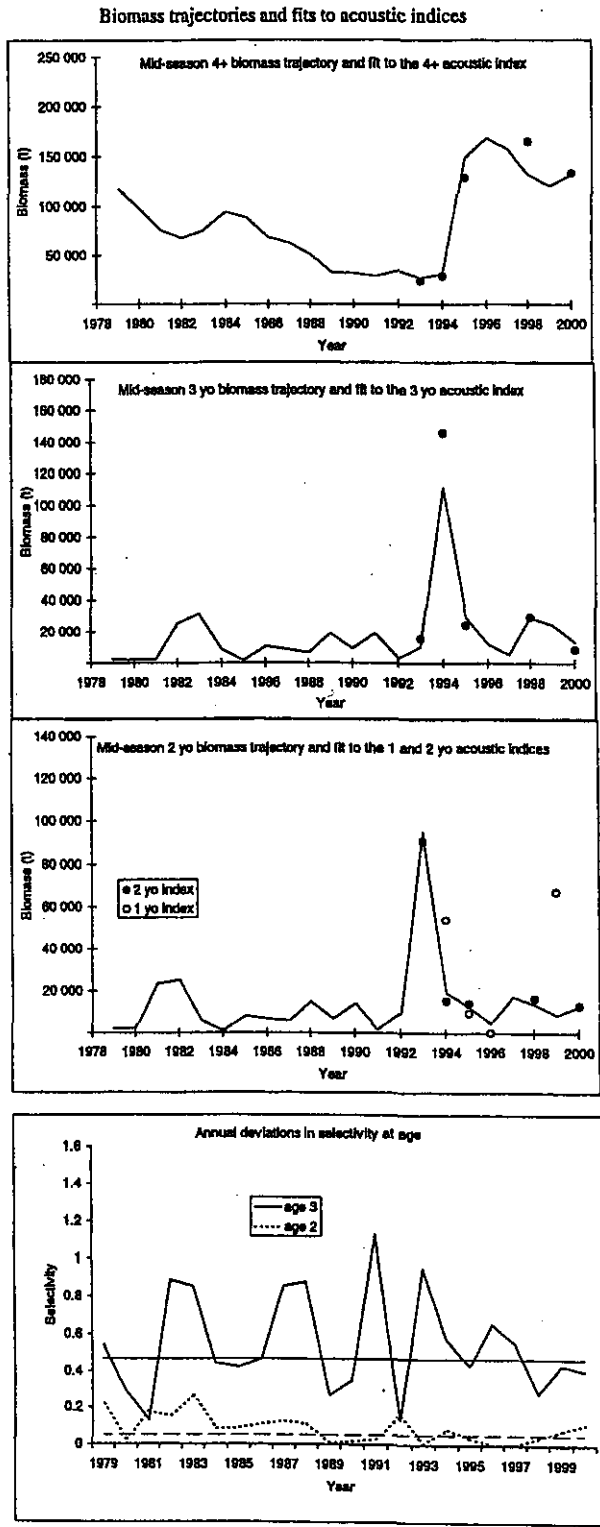
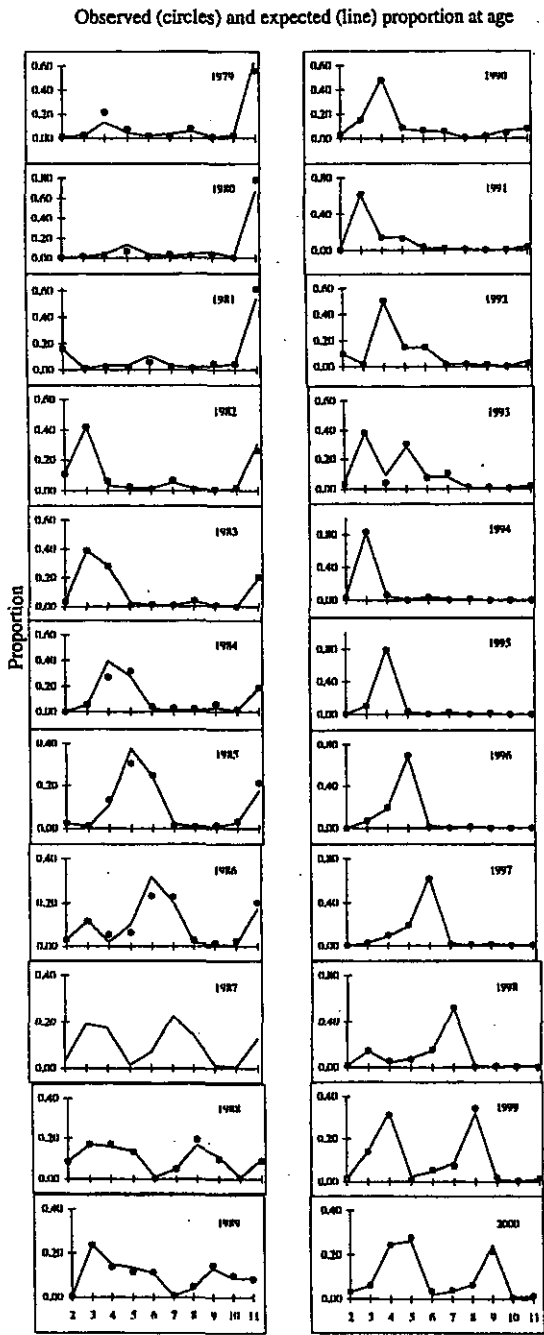


Figure 9: Median and MLE mid-season spawning stock biomass trajectories and bias corrected 90% confidence intervals for the Campbell Island stock, showing the fit to the acoustic indices. The acoustic indices are the sum of the age 3 and 4+ biomass estimates scaled by the acoustic q s and selectivities. The acoustic 90% confidence intervals were calculated using their observed c.v.s.



Selectivity at age				Acoustic qs		Likelihoods	
2	3	4	5	Adults	1.02	Adults	0.533
				1 year olds	0.03	1 year olds	12.86
0.05	0.47	0.94	1.00	2 year olds	0.79	2 year olds	0.19
				3 year olds	0.96	3 year olds	1.966
				Age data		Age data	27.85
				Penalties		Penalties	0
				Total		Total	43.4

Figure 10: Diagnostics for the Campbell Island assessment showing the fit to the proportion-at-age, and acoustic indices, selectivity at age, acoustic qs and likelihoods.

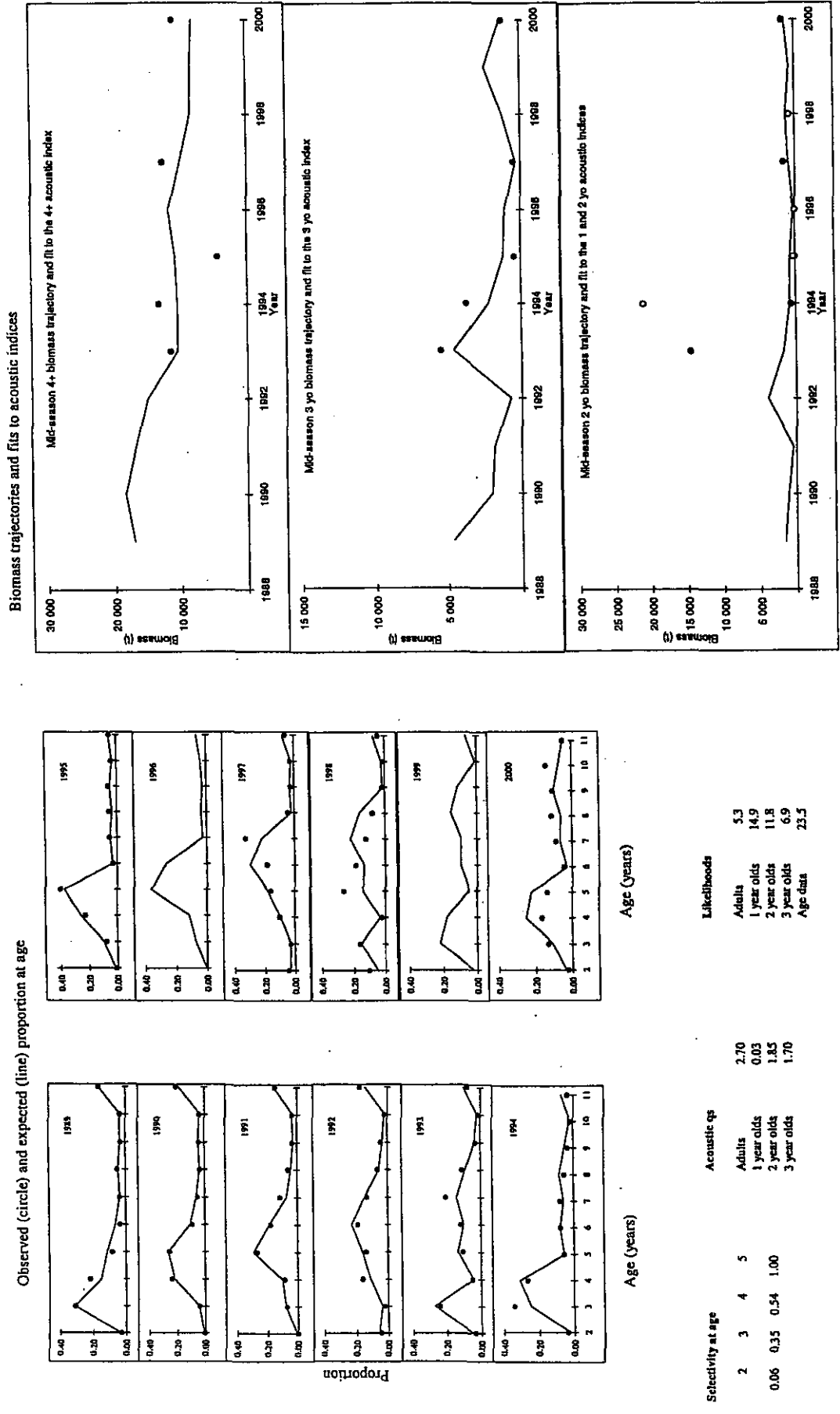


Figure 11: Diagnostics for the Pukaki Rise assessment showing the fit to the proportion-at-age, and acoustic indices.

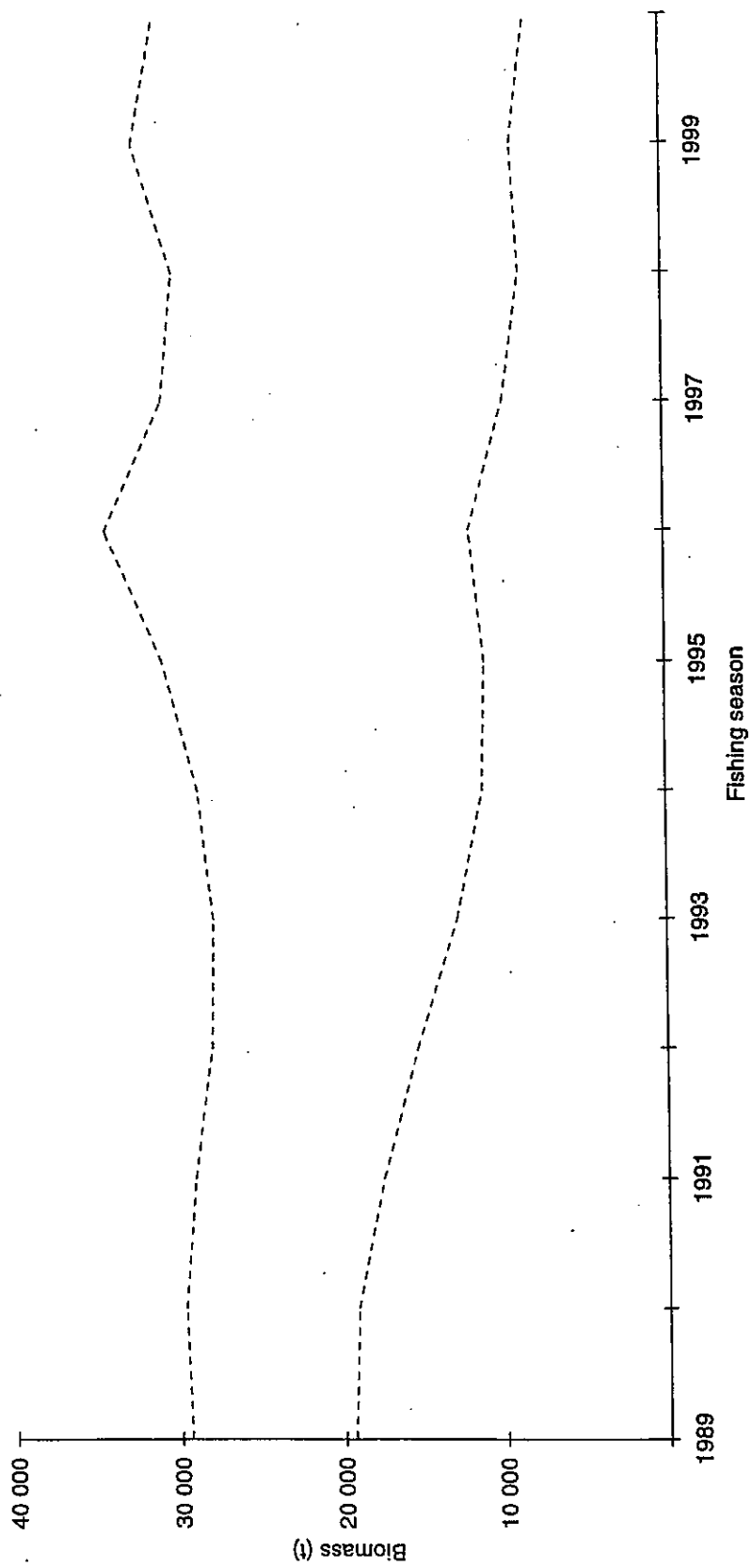


Figure 12: Mid-season spawning stock biomass trajectory bounds for the Pukaki Rise. Upper bound based on a minimum exploitation rate of 0.2, and lower bound based on an adult acoustic q of 2.8.