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Southern blue whiting (*Micromesistius australis*) stock assessment for the 1996–97 and 1997–98 fishing years

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SOUTHERN BLUE WHITING (*Micromesistius australis*) STOCK ASSESSMENT FOR THE 1996–97 and 1997–98 FISHING YEARS

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1. EXECUTIVE SUMMARY

This paper reviews the stock assessment of southern blue whiting (SBW) resources in New Zealand waters.

The results of a standardised catch per unit effort analysis for the Campbell Island fishery for the period 1986 to 1996 are presented. The 1996 index was the highest in the series. The 1996 catch was dominated by the strong 1991 year class which formed over 80% by number. Catch-at-age data and acoustic estimates of adult biomass for the Campbell Island stock were fitted using the separable Sequential Population Analysis used in previous assessments. Estimates of mid-season spawning stock biomass declined steadily from 1979 to 1993, but then increased sharply to 1996 because of the recruitment of the very strong 1991 year class to the fishery. The estimate of current biomass of 175 000 t is well above B_{MAY}. The estimate of Current Annual Yield (CAY) for 1996–97 is 30 000 t and for 1997–98 is 25 000 t. The CAY estimates are very sensitive to the size of the 1991 year class, which is still uncertain.

For the Bounty Platform stock catch-at-age data and acoustic estimates of adult biomass were fitted using the separable Sequential Population Analysis for the first time. Current biomass is not well known, but is thought to be above B_{MAY}. Estimates of CAY for 1996–97 and 1997–98 are about 15 000 t and are well above the current catch limit and recent levels of catch. A strong year class is predicted to recruit to the fishery in 1997–98, which would substantially increase the short-term yields for this stock.

Virgin and current biomass for the Pukaki Rise stock was estimated by fitting the absolute acoustic estimates using stock reduction analyses. Current biomass is not well known, but is thought to be above B_{MAY}. Estimates of CAY for 1996–97 and 1997–98 on the Pukaki Rise are about 7 000 t and are above current catch limits and recent levels of catch.

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2. INTRODUCTION

2.1 Overview

This paper reviews the stock assessment of southern blue whiting (SBW) resources in New Zealand waters. Length-frequency and reproductive data for the commercial fishery are presented. The results of a standardised catch per unit effort (CPUE) analysis for the Campbell Island fishery for the period 1986 to 1996 are presented. The catch-at-age data and estimates of biomass from acoustic surveys from 1993 to 1995 (Ingerson & Hanchet 1996) were used in a separable Sequential Population Analysis (sSPA) to estimate historic and current biomass for the Campbell Island and

Bounty Platform stocks. Estimates of virgin and current biomass for the Pukaki Rise stock was derived from stock reduction analyses fitted to the acoustic estimates. Estimates of Current Annual Yields for 1996–97 and 1997–98 are provided for all three stocks.

2.2 Description of fishery

In this paper the word "season" refers to August and September, the months of intense fishing at the end of the fishing year (i.e., the 1996 season is part of the 1995–96 fishing year).

The SBW fishery was developed by Soviet vessels during the early 1970s, with landings exceeding 40 000 t in 1973 and 1974 (Table 1). It was known 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 be determined.

From 1978 to 1984, the entire Campbell Plateau was fished throughout the year, but highest catches were usually made whilst fish were spawning in September on the Pukaki Rise and the northern Campbell Island Rise (Figure 1). In some seasons (notably 1979, 1982, and 1983) vessels also targeted spawning fish on the Bounty Platform in August and September.

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 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 started fishing spawning aggregations on Bounty Platform, Pukaki Rise, and Campbell Island Rise. Fishing effort increased quite markedly between 1990 and 1992, culminating in the record catch of over 75 000 t in 1992. The increased catch came predominantly from the Bounty Platform where catches increased from zero to almost 60 000 t in only 3 years. There was concern that the large 1992 catch was not sustainable, so a catch limit of 32 000 t was introduced for the first time in the 1992–93 fishing year, and has been retained since then. This catch limit has not been reached in the 4 years since it was introduced.

2.3 Recent papers

Results of the first three acoustic surveys of spawning SBW stocks on Bounty Platform, Pukaki Rise, and Campbell Island Rise in August and September 1993 and 1994 were presented by Hanchet *et al.* (1994), Hanchet & Ingerson (1996a), and Ingerson & Hanchet (1996). Standardised analyses of CPUE data were reported by Ingerson & Hanchet (1995a), Chatterton (1996), and Hanchet & Ingerson (1996b). Stock assessments were made by Hanchet (1991, 1992, 1993), Hanchet & Haist (1994), Punt (1994), and Hanchet & Ingerson (1995, 1996b). In the most recent stock assessment of the Campbell Island Rise stock, CPUE data from 1986 to 1995, together with catch-at-age data for the period 1979 to 1995, and acoustic data from 1993 to 1995 were modelled using an sSPA (Hanchet & Ingerson 1996b). Catch projection models were run to examine the effect of future catches on stock size and fishing mortality.

3. REVIEW OF THE FISHERY

3.1 TACs, catch, landings, and effort data

3.1.1 Total Allowable Catch

Catch quotas, allocated to individual operators, were introduced for the first time in the 1992–93 fishing year. The total catch limit of 32 000 t was divided as follows: 15 000 t from the Bounty Platform, 11 000 t from south of a line drawn at 50° 30' S, and the remaining 6000 t to be caught north of 50° 30' S (but west of Bounty Platform) (*see* Figure 1). This line separates the Campbell Island fishery from the Pukaki Rise fishery, but divides into two a smaller spawning ground on the Auckland Islands Shelf where some vessels have fished in the past 3 years. The area proportions changed for the 1995–96 fishing year, with 8000 t for the Bounty Platform, 3000 t for the Pukaki Rise and 21 000 t for the Campbell Island Rise.

3.1.2 Landings

Estimates of the annual landings of SBW are given in Tables 1 and 2. There are some discrepancies between figures on the Licensed Fish Receiver Returns (LFRRs) and the catches from vessel logbooks. This is partly because the main fishing season for SBW is September, but catches are often not reported on the LFRRs until October, which is after the start of the new fishing year. A more accurate estimate of the season's landings was therefore obtained by combining landings for all months from each calendar year (*see* Table 2). Before 1990–91, when the conversion factors were changed, landings from LFRRs were further corrected by multiplying the surimi catch by 1.16 to account for the lower conversion factors used by the Quota Monitoring System. There is reasonably good agreement between the totals from the vessel logbooks (*see* Table 1) and the estimated calendar year total from the LFRRs (*see* Table 2) for most years. Catches during the fishing season (August to October) are used for modelling purposes.

The estimated total catch for 1995–96 was about 22 000 t with the catch limit being undercaught on each fishing ground. The catch limits have been undercaught on most grounds in most years since their introduction. This appears to reflect the low economic value of the fish and difficulties experienced by operators in this fishery, rather than low stock sizes. In particular, the effort on the Bounty Platform depends largely on the success of the hoki fishery. If there is a poor hoki season, then the vessels remain longer on the hoki grounds and miss the peak fishing season on the Bounty Platform. On the Pukaki Rise, operators have a smaller allocation and have also found it difficult to locate large aggregations of fish. On the Campbell Island Rise the catch limit has usually been reached.

3.1.3 The 1996 season

The change in quota distribution between the areas resulted in more fishing this year on the Campbell Island Rise. Because of the late hoki season vessels did not arrive on the Bounty Platform until late August and caught spawning fish during early September. However, the five vessels caught about 6500 t out of the 8000 t allocation.

Five vessels fished the Pukaki Rise and Auckland Islands Shelf at various times during September and October. The vessels were unable to find large aggregations of fish and only poor catches were made. The total catch was 800 t on the Pukaki Rise and 50 t on the Auckland Islands Shelf out of the 3000 t allocation.

Vessels started fishing on the Campbell Island Rise on 8 September and located spawning fish to the east of the Campbell Islands. A total of 10 vessels caught about 16 500 t from this area, with about 2500 t being caught in October. The catch was dominated by 5 year olds of the 1991 year class (*see* Section 3.2.3).

3.1.4 CPUE analysis

Campbell Island Rise

A multivariate standardised approach to the CPUE analysis has been carried out in each of the last three assessments (Ingerson & Hanchet 1995a, Chatterton 1996, Hanchet & Ingerson 1996b). The same approach has been used for the current assessment and the data were analysed using a gamma distribution model with a log-link function (GLL).

Only 342 tows were made in the Campbell Island Rise fishery during the 1996 season. About 20 of these tows (5.9%) were recorded as having caught no SBW (Table 3).

The significant variables for the GLL model were similar to last year. In order of importance the variables were: year, vessel length, time/depth, tow position, season, end time, headline height, and nation. The CPUE indices show a very similar trend to the analysis carried out last year, with a general decline from 1986 to 1992, followed by an increase from 1993 to 1995. The 1996 index is the highest on record (Table 3, Figure 2). The large error bars around the 1995 and 1996 indices are due both to the relatively small number of tows carried out during the last two seasons, and to the high CPUE.

The CPUE indices were converted to annual indices of relative fishing effort by dividing the total catch for each year by the CPUE index for that year (*see* Table 3). The effort data were used in the sSPA model.

There are concerns that because of the highly aggregated nature of the fishery, and the associated difficulty in finding and maintaining contact with the highly mobile schools in some years, the CPUE series may not be monitoring abundance accurately. There is also concern that there is not a direct relationship between CPUE and abundance. A decline in biomass may not necessarily lead to a decline in CPUE because the fleet may still be able to target dense aggregations and maintain high catch rates. Similarly an increase in biomass may not lead to a proportional increase in CPUE. For this reason the CPUE indices were not used in the base case assessment this year.

3.2 Other information

3.2.1 Size composition of the commercial catch

Length frequency data were collected by scientific observers from the commercial catch from each fishing ground during 1996. The length frequency data were scaled up to the total catch for each strata and each fishing ground.

The size distribution of the catch on the Campbell Island Rise since 1979 is shown in Figure 3. A number of strong year classes have dominated the fishery throughout this period. In the 1996 season the strong 1991 year class again dominated the catch, with males being slightly outnumbered by females. The modal length at age of the 1991 year class continued to be much smaller than that of previous year classes.

The size distribution of the catch on the Bounty Platform since 1990 is shown in Figure 4. The catches during this period have largely comprised the 1986 and 1988 year classes. In the past 2 years the slow growing 1991 year class has recruited to the fishery, but it has not dominated the catch on this ground to the same extent that it has dominated the catch on the Campbell Island grounds. The 1992 year class dominated the catch for each sex in 1996.

Only one length frequency sample was collected from the Pukaki Rise. This was dominated by the 1991 year class. No length frequency samples were collected from the Auckland Islands Shelf.

3.2.2 Age composition of the commercial catch

A total of 529 otoliths from the Campbell Island Rise collected in 1996 were read for use as an age-length key. 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. Catch-at-age data are illustrated in Figure 5. They show the strong dominance of the 1991 year class in the past 3 years that was seen in the length frequency data.

A total of 481 otoliths from the Bounty Platform collected in 1996 were read for use as an age-length key. 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. Catch-at-age data are illustrated in Figure 6.

3.2.3 Timing of spawning

The spawning cycle of SBW was described by Hanchet (1993). Table 4 summarises the 1996 reproductive data collected by observers.

The second spawning on the Bounty Platform occurred from 31 August to 6 September. The timing of spawning on the Pukaki Rise or the Auckland Islands Shelf could not be determined.

The timing of spawning on the Campbell Island Rise was the earliest recorded. The main spawning was from 8 to 14 September. The second spawning occurred from 24 to 28 September, slightly south of the first spawning.

3.3 Recreational, Maori customary fisheries, illegal catches, and other sources of mortality

(i) Recreational fisheries

There is no recreational fishery for southern blue whiting.

(ii) Maori customary fisheries

There is no customary fishery for southern blue whiting.

(iii) Illegal catches

There is no known illegal catch of southern blue whiting.

(iv) Other sources of mortality

Scientific observers have reported discards of undersized fish and accidental loss from torn or burst codends. There is no quantitative estimate of this mortality.

4. RESEARCH

4.1 Stock structure

No genetic studies have been carried out and, given their close proximity, it is unlikely that there would be genetic differences between the fish in the different areas of the sub-Antarctic. However, there do appear to be consistent differences between fish from the main fishing grounds on Bounty Platform, Pukaki Rise, and Campbell Island Rise based on morphometric and biological data (*see* Hanchet & Ingerson 1995).

For the purposes of stock assessment the stock has been split into three substocks assuming fidelity within substocks. The stocks are: the Bounty Platform, the Pukaki Rise (including Pukaki Rise and Auckland Islands Shelf), and the Campbell Island Rise (including both spawning grounds on the Campbell Island Rise).

4.2 Resource surveys

4.2.1 Acoustic survey

Acoustic surveys of the Bounty Platform, Pukaki Rise, and Campbell Island Rise were carried out in August and September 1993, 1994, and 1995 and the Auckland Islands Shelf was surveyed in 1995 (Table 5). The surveys are reported in detail in Hanchet *et al.* (1994), Hanchet & Ingerson (1996a), and Ingerson & Hanchet (1996). The abundance indices were turned into absolute estimates by using the target strength – fish length relationship derived for blue whiting in the northern hemisphere (Monstad *et al.* 1992. *In situ* target strength work carried out during the 1994 survey and theoretical modelling studies have produced results which are consistent with that relationship.

4.2.2 Trawl surveys

A trawl survey of sub-Antarctic waters was carried out in 1996 (Colman 1996). The results of all relevant trawl surveys of the area are summarised in Table 6. Doorspread biomass estimates for the Campbell and Pukaki grounds are the highest since the *Shinkai Maru* surveys carried out in the early 1980s. The size distribution of southern blue whiting on the Pukaki Rise and Campbell Plateau was dominated by the 1991 year class.

4.4 Biomass estimates

(i) Campbell Island stock

The data were again analysed using the sSPA used in recent assessments of this stock (Hanchet & Haist 1994, Hanchet & Ingerson 1995, 1996b). The sSPA model uses a maximum likelihood method to find the set of parameter values which minimises the following objective function:

$$- \sum_{y} W_{Sy} \sum_{a} p_{ya} \ln \hat{p}_{ya} + \sum_{y} W_{Cy} (\ln C_y - \ln \hat{C}_y)^2 + \sum_{y} W_{Ey} (\ln E_y - \ln \hat{E}_y)^2$$

$$+ \sum_{y} W_{By} (\ln B_y - \ln \hat{B}_y)^2$$

where:

W_{Sy} = sample size for catch-at-age data for year y
p_{ya} = observed proportions-at-age a in year y
$\hat{p}_{ya}$ = predicted proportions-at-age a in year y
W_{Cy} = penalty weight in year y on estimated annual catch
C_y = observed catch in year y
$\hat{C}_y$ = predicted catch

W_{Ey} = penalty weight in year y on annual effort data
E_y = observed effort in year y
$\hat{E}_y$ = predicted effort in year y
W_{By} = penalty weight in year y on annual acoustic biomass data
B_y = observed mid-season spawning stock biomass in year y, from acoustic surveys
$\hat{B}_y$ = predicted mid-season spawning stock biomass in year y, from acoustic surveys

Note that for the current assessment the weights for catch, effort, and biomass are equal for each year.

The model was fitted using catch-at-age data from 1979 to 1996, and acoustic estimates from 1993 to 1995. The catch-at-age data covered ages 2 to 10 with a plus group at age 11. The model assumes that the selectivity after age 4 is 1.0, estimates a single selectivity for age 4, and allows the option of estimating annual selectivities for both ages 2 and 3 or just for age 2. Because of the sensitivity of the model to selectivity of 3 year olds in last year's assessment, the selectivity of 2 and 3 year olds in the last four and three years respectively was fixed at the mean. The acoustic data were fitted as absolute indices of abundance. Natural mortality was assumed to be 0.2, and mean weight at age was calculated from the weight-length regression and von Bertalanffy growth parameters given in Hanchet (1993). The main input parameters used for the base case and for the sensitivity tests for the assessment are listed in Table 7.

Penalty weights were assigned to the catch at age data based on the sample size in a multinomial distribution. Sample sizes were assigned a median of 100, and adjusted between years by the number of tows sampled. The acoustics data were fitted as absolute indices of abundance. They were assigned a weighting corresponding to a *c.v.* of about 30%. A penalty weight equivalent to a *c.v.* of about 5% was given to each year's estimated annual catch.

The data were bootstrapped to estimate 90% confidence limits for the results. Three sources of uncertainty were included in the procedure. The length at age data within individual years were bootstrapped (with replacement) and then scaled up to catch at age using the weighted length frequency of the catch for that year. Uncertainty in the acoustics data and annual catch was captured by assuming the data were log-normally distributed with *c.v.*s of 25% and 5%, respectively. For each of the 500 bootstrap runs data were randomly selected from each distribution. Runs which estimated a catch : biomass ratio greater than 0.5 in 1995–96 were considered unlikely and were excluded from further analysis.

Results

The biomass trajectory and 90% confidence intervals are plotted in Figure 7, and summarised in Table 8. The assessment suggests that the stock biomass showed a steady decline from the early 1980s until 1993 followed by a large increase from 1994 to 1996. The reason for the large increase is the recruitment of the strong 1991 year class which should now be fully recruited to the fishery. Although not used in the assessment, the CPUE indices have shown a similar large increase since the early 1990s.

For the modelling, it has been assumed that the fish have a constant growth rate. The 1991 year class is growing at a much slower rate than that used in the model. The implications of this for the assessment are uncertain at this stage.

The size of the 1991 year class is not yet well known, but is estimated to be 3–5 times larger than the previous highest recruitment. Further support for a large 1991 year class comes from the 1993 acoustic estimate of pre-recruits. The 90 000 t biomass estimate equated to about 600 million fish, which is similar to the value of 623 million fish estimated by the model.

The distribution of the mid-season 1995–96 biomass from bootstrapping results is shown in Figure 8. About 40% of the runs resulted in unrealistic estimates of 1995–96 biomass and were discarded. The reason for these crashes is unclear but may be because of a loss of stability in the model caused by the exclusion of the CPUE data this year, and also because of the relative weightings of the two data series.

The results of the sensitivity analyses are shown in Table 9. Historical biomass was sensitive to the value of M used in the analysis, but insensitive to the other changes examined. Current biomass was insensitive to whether the acoustic estimates were treated as relative or absolute. (When fitted as relative indices of abundance, q was estimated by the model to be 0.99.) Current biomass was most sensitive to the inclusion or exclusion of the CPUE indices, particularly when the acoustic estimates were fitted as relative abundance indices. The model was unable to fit a natural mortality rate of 0.25 without reaching very high exploitation rates in the final year.

Retrospective analysis showed that the population trajectory and biomass estimates were relatively insensitive to the removal of the more recent years' data (Figure 9).

A plot of the observed and predicted proportions at age are shown in Figure 10. The predicted data fit the data very well for most year classes, although the fit to the 1980 year class is not so good over ages 4 to 8.

Estimation of virgin biomass

An estimate of virgin biomass (B_0) was obtained from the product of the spawning stock biomass per recruit (age 2) in an unfished stock (2.17 kg per recruit) and the arithmetic mean of the recruitment of 2 year olds from the period 1978–79 to 1992–93 calculated from the sSPA. Using a mean recruitment of 94.3 million fish gave a virgin biomass estimate of 206 000 t.

(ii) Bounty Platform stock

The data were analysed using the sSPA used in recent assessments of the Campbell Island stock (*see* above). The model was fitted to catch at age data from 1990 to 1996, and acoustic data from 1993 to 1995 (*see* Table 5). The other input parameters, penalty weights, bootstrapping approach and sensitivity analysis were identical to those used for the Campbell Island assessment above (*see also* Table 7).

The population trajectory and 90% confidence intervals are shown in Figure 11, and summarised in Table 10. The biomass declined from 1990 to 1994, primarily as a result of the large catch taken in 1992, but has since increased back to 1990 levels. The catch to pre-season biomass ratio for 1992 was 0.50, which is similar to the highest exploitation rate estimated for the Campbell Island fishery. Such a high exploitation rate is consistent with the level of fishing effort in that year and the aggregated nature of the fishery.

The modelled biomass provides a poor fit to the three acoustic indices. It is suspected that the 1993 biomass was overestimated whilst the 1995 biomass was underestimated (Ingerson & Hanchet 1996). The 1994 estimate is probably the most reliable because it has the lowest *c.v.*, and a further snapshot in that year provided a very similar estimate of the biomass (Hanchet & Ingerson 1995).

The distribution of the mid-season 1995–96 biomass from bootstrapping results is shown in Figure 12. Although no runs resulted in unrealistically low estimates of 1995–96 biomass, the distribution of this biomass was strongly bimodal with peaks at 40 000 t and 80 000 t. The reason for this is unclear, but again may be related to the relative weightings of the two data series used in the model.

The results of sensitivity and retrospective analyses are shown in Table 11. The model was unable to fit the acoustic estimates as relative indices of abundance without reaching very high exploitation rates in the final year. When only the more reliable 1994 data point was fitted in the model the current biomass was considerably higher.

Estimates of virgin biomass have not been calculated for this stock because estimates of recruitment are available for only 4 years.

(iii) Pukaki Rise stock

For the purposes of stock assessment the catch history was applied back to 1978–79 and included fish caught on both the Pukaki Rise and Aucklands Island Shelf. It has also been assumed that the absolute biomass indices calculated from acoustic surveys carried out in September 1993, 1994, and 1995 (Table 5) represent the entire stock. Because of the small biomass on the Auckland Islands Shelf this is unlikely to have a large effect on the stock assessment results.

The acoustic estimates were modelled, both as relative and as absolute indices of abundance, using stock reduction analysis with deterministic recruitment. The stock was assumed to be in a virgin state in 1979, although catches had been taken before this. Growth rates, the maturity ogive, the weight-length relationship, and other input parameters were assumed to be the same as for the Campbell Island stock (Table 12).

The best fits to the relative indices were at B_{min} and the q was estimated to be about 10, which was considered unrealistic when compared to the q of 1.0 estimated for the Campbell stock. When the acoustic estimates were fitted as absolute, B_0 was estimated to be 51 000 t, and $B_{1995-96}$ was estimated to be 33 300 t (Table 13).

The population trajectory does not fit the acoustic indices very well (Figure 13). The 1995 acoustic biomass is almost certainly underestimated as the survey was carried out well before the spawning season started. The 1993 and 1994 surveys were carried out just before spawning started, but the acoustic biomass estimates appear to be too high because they are not consistent with the catches that have been taken from the fishery and the difficulty fishers experience in catching fish in this area. The acoustic estimates may be high because of uncertainty in target identification of fish on this ground. Furthermore, the large numbers of pre-recruits (2 year olds) found in 1993 do not appear to have recruited to the Pukaki Rise fishery in the numbers expected.

(b) Estimation of Maximum Constant Yield (MCY)

The simulation method of Francis (1992) was used to determine the MCY reference harvest rate. This harvest rate is the highest constant catch policy (as a percentage of B_0) which allows the stock to go below $0.2B_0$ only 10% of the time. Using the input parameters shown in Table 10, MCY was calculated as 5.1% of B_0.

(i) Campbell Island stock

MCY was estimated by multiplying the harvest level by the estimate of B_0.

$$MCY = 0.051 * 206\,000 \text{ t} = 10\,500 \text{ t}$$

(ii) Bounty Platform stock

No reliable estimates of B_0 are available so MCY has not been calculated.

(iii) Pukaki Rise stock

No reliable estimates of B_0 are available so MCY has not been calculated.

(c) Estimation of Current Annual Yield (CAY)

CAY for 1996–97 and 1997–98 were calculated for each stock and their 90% confidence intervals calculated for the Campbell Island and Bounty Platform stocks.

The simulation method of Francis (1992) was also used to determine u_{CAY}, the ratio of catch to pre-season biomass. Using the input parameters shown in Table 12, u_{CAY} equalled 0.21. This harvest rate is the highest constant F policy (as a percentage of B_0) which 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 $8.6\%B_0$.

(i) Campbell Island stock

CAY was estimated by multiplying the u_{CAY} by pre–season biomass in 1996–97 and 1997–98. Pre–season biomass in 1996–97 was calculated by projecting forward the 1996–97 beginning-of-year numbers for ages 4 through to 11+ for each of the base runs, assuming all of M had occurred before the fishing season started. The number of 3 year olds in 1995–96 was estimated by the model by fixing the selectivity of that age class at the geometric mean over the period 1978–79 to

1992–93. The geometric mean rather than the arithmetic mean was used because recruitment data are lognormally distributed and so a geometric mean will be closer to the average value of recruitment in most years. Recruitment of 2 year olds in 1995–96 and 1996–97 was assumed to be the geometric mean of recruitment over the period 1978–79 to 1992–93. The projection was carried forward to 1997–98 by making the same assumptions about recruitment, and assuming the 1996–97 catch equalled (i) $CAY_{1996-97}$ and (ii) the current catch limit (21 000 t). The resulting CAY estimates and 90% confidence intervals are shown in Table 10.

(ii) Bounty Platform stock

CAY was estimated by multiplying u_{CAY} by pre-season biomass in 1996–97 and 1997–98. Pre-season biomass in 1996–97 was calculated by projecting forward the 1996–97 beginning-of-year numbers for ages 4 through to 11+, assuming all of M had occurred before the fishing season started. The number of 3 year olds in 1995–96 was estimated by the model by fixing the selectivity of that age class at the geometric mean over the period 1989–90 to 1992–93. Recruitment of 2 year olds in 1995–96 were obtained from two sources: (a) from the geometric mean of recruitment over the period 1989–90 to 1992–93 obtained from the model (36.3 million fish), and (b, c) from the estimate of 1 year old fish from the 1995 acoustic survey (*see* Table 5), after accounting for M. Because the 1 year old fish were surveyed during only one snapshot, and the biomass estimate had a high *c.v* (37%), this estimate was regarded as being highly uncertain. Therefore projections were carried out using both (b) the lower 95% confidence bound of 400 million fish and (c) the point estimate of 1500 million fish.

Recruitment of 2 year olds in 1996–97 was assumed to be equal to the geometric mean of recruitment over the period 1989–90 to 1992–93.The projection was carried forward to 1997–98 by making the same assumptions about recruitment and assuming the 1996–97 catch equalled (i) $CAY_{1996-97}$ or (ii) the 1996–97 catch limit (8000 t). The resulting CAY estimates and 90% confidence intervals are shown in Table 10.

(iii) Pukaki Rise stock

Biomass estimates from 1995–96 were projected forwards assuming deterministic recruitment. The projections were carried forward to 1997–98 making the same assumptions about M, recruitment and growth, and assuming the 1996–97 catch equalled (i) $CAY_{1996-97}$, or (ii) the 1996–97 catch limit (3000 t). CAY was calculated by multiplying the pre-season biomass by the u_{CAY}, 0.21. CAY estimates are shown in Table 13.

(d) Long-term sustainable yield

The long-term yield available from the southern blue whiting 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 17 700 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 10 500 t.

5. MANAGEMENT IMPLICATIONS

For all stocks, CAY estimates for 1996–97 and 1997–98 are greater than recent catch levels and current catch limits. In general, estimates for 1996–97 are much better known than estimates for 1997–98, and there is more confidence in the estimates for the Campbell Island stock than for the Bounty Platform and Pukaki Rise stocks. The yields are summarised in Table 14.

(i) Campbell Island stock

Estimates of current and reference biomass are available. The stock appears to be well above B_{MAY}.

There is some uncertainty over the estimates of current biomass and yields for this stock. Current biomass depends to a large extent on the size of the recently recruited 1991 year class. All the available evidence from catch at age data, acoustic data, and CPUE data suggests that this year class is extremely large in number.

Yields are largely dependent on the size of the 1991 year class. CAY estimates for both 1996–97 and 1997–98 are considerably greater than recent catch levels and current catch limits. The 1993 year class which recruited into the Campbell Island Rise fishery for the first time in 1995–96 was also estimated to be well above average by the model and by the 1995 acoustic survey.

(ii) Bounty Platform stock

Estimates of current biomass are available. Because B_{MAY} cannot be estimated it is not known where current biomass is in relation to B_{MAY}.

There is uncertainty over the estimate of current biomass because of the highly variable acoustic survey indices. Exclusion of the more uncertain 1993 and 1995 estimates resulted in a 35% increase in current biomass.

Yield estimates are uncertain largely because of uncertainty over future recruitment. The CAY estimates for 1996–97 and 1997–98 are above the current catch limit and recent catch levels. The CAY estimate for both years could be very high because the strong 1994 year class is expected to start recruiting to the fishery in 1996–97, and be almost fully recruited by 1997–98. An acoustic survey of this stock is planned for August-September 1997 and this should improve estimates of the size of this year class and of current biomass.

(iii) Pukaki Rise stock

Estimates of current and reference biomass are available. The model estimates the stock size is above B_{MAY}.

There is considerable uncertainty over the estimate of current biomass because the decline in the acoustic indices cannot be fitted given the catch history, biological parameters, and deterministic recruitment. An acoustic survey of this stock is planned for August-September 1997 which should improve estimates of current biomass.

Yield estimates are uncertain because of uncertainty over current biomass and future recruitment. CAY estimates for both 1996–97 and 1997–98 are above recent catch levels and above the current catch limit. These yield estimates are at the same level as the highest historical landings from this fishery.

6. ACKNOWLEDGMENTS

I thank Ralph Coburn for the CPUE analysis, Graeme Mackay for drafting Figure 5, and Roger Coombs for comments on an earlier draft of the manuscript. This work was funded by the Ministry of Fisheries, Project Number MDBW02.

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Table 1: Estimated catches (t) of southern blue whiting by area for the 1 October to 30 September fishing years for the period 1971 to 1995–96. Source – vessel logbooks. For the purposes of this table Bounty Platform is > 176°E; Campbell Island Rise is > 50°30'S and > 168°30'E; and Pukaki Rise is the remaining area (*see* Figure 1). –, no data. 1995–96 estimates are preliminary

Fishing year	Bounty Platform	Campbell Island Rise	Pukaki Rise	Total
1971~	–	–	–	10 400
1972~	–	–	–	25 800
1973~	–	–	–	48 500
1974~	–	–	–	42 200
1975~	–	–	–	2 378
1976~	–	–	–	17 080
1977~	–	–	–	26 435
1978*	0	6 403	94	6 497
1978–79+	1 211	25 305	1 620	28 136
1979–80+	16	12 828	5 789	18 633
1980–81+	8	5 989	2 469	8 466
1981–82+	8 325	7 915	1 355	17 595
1982–83+	3 864	12 803	7 572	24 239
1983–84+	348	10 777	2 249	13 374
1984–85+	0	7 490	1 845	9 335
1985–86+	0	15 252	567	15 819
1986–87+	0	12 804	906	13 710
1987–88+	18	17 422	161	17 601
1988–89+	8	26 611	1 220	27 839
1989–90+	4 430	16 542	1 393	22 365
1990–91+	10 897	21 314	4 659	36 870
1991–92+	58 928	14 208	3 119	76 255
1992–93+	11 908	9 316	6 484	27 708
1993–94+	3 877	11 668	3 015	18 560
1994–95+	6 386	9 492	1 599	17 478
1995–96+	6 508	14 959	812	22 279

~ Calendar year

* 1 January – 30 September

\+ 1 October – 30 September

Table 2: Reported landings (t) of southern blue whiting by fishing year from 1986–87 to 1995–96 and by calendar year for 1987 to 1996. Source — Licensed Fish Receiver Returns. 1995–96 estimates are preliminary

Fishing year	Catch	Calendar year	Catch
1986–87	3 468	1987	10 696
1987–88	13 720	1988	16 374
1988–89	30 692	1989	28 556
1989–90	24 514	1990	22 127
1990–91	35 593	1991	42 025
1991–92	83 427	1992	78 592
1992–93	29 184	1993	27 382
1993–94	13 300	1994	14 670
1994–95	19 280	1995	19 520
1995–96	15 630	1996	19 870

Table 3: Results of standardised CPUE analysis for the Campbell Island Rise, showing the number of tows, percentage of zero tows, relative year effect, catch, and relative effort for each year. Note the catch in Table 3 is the catch for the season used in the modelling

Year	Number of tows	Percentage zero tows	Relative year effect	Catch (t)	Relative effort
1986	893	4.6	1.00	15 252	15 252
1987	637	5.3	0.68	12 804	18 829
1988	843	7.1	0.52	17 422	33 504
1989	1008	4.7	0.53	26 611	50 209
1990	994	7.8	0.48	16 652	34 692
1991	1057	3.7	0.36	21 314	59 206
1992	1091	18.7	0.24	14 208	59 200
1993	411	10.7	0.65	9 316	14 332
1994	384	6.8	0.54	11 668	21 607
1995	170	2.4	1.05	10 436	9 939
1996	342	5.9	1.46	16 504	11 304

Table 4: Dates associated with presence of certain gonad stages in 1996 in each of the three areas, and percentage spent and reverted in the last sample (–, could not be determined)

Gonad stage	Bounty	Pukaki	Campbell
1st sample	26/8	18/9	8/9
>10% ripe	–	<18/9	<8/9
>10% running ripe	–	–	8/9
Main spawning	–	–	8–14/9
>10% spent	–	–	23/9
>10% reverted	–	–	11/9
>50% spent	–	–	27/9
2nd spawning	31/8– 6/9	–	24–28/9
Last sample	6/9	18/9	4/10
% spent	11	3	50
% reverted	16	–	15

Table 5: Acoustic (mid-season) biomass estimates (t) on Bounty Platform, Pukaki Rise, Campbell Island Rise, and Auckland Islands Shelf. All values are t x 10^3. –, not surveyed

	1993			1994			1995		
	Adults	Age 2	Age 1	Adults	Age 2	Age 1	Adults	Age 2	Age 1
Campbell Island Rise	18.5	89.6	–	161.4	22.4*	–	121.1	20.0	–
c.v. %	(21)	(23)		(36)	(38)		(30)	(25)	
Bounty Platform	94.6	5.9	7.2	55.0	15.8	0.2	35.2	0.0	93.3
c.v. %	(46)	(43)	(46)	(22)	(87)	(80)	(24)		(37)
Pukaki Rise	49.8	26.3	–	39.0*	0.0	–	12.8	0.0	–
c.v. %	(24)	(20)		(45)			(18)		
Auckland Islands Shelf	–	–	–	–	–	–	7.8	–	–
c.v. %							(20)		

* Includes some immature 3 year old fish.

Table 6: Doorspread biomass estimates (t) of southern blue whiting by area from the results of trawl surveys assuming vulnerability, areal availability and vertical availability equal 1 (*after* Hanchet & Haist 1994). AI, Auckland Islands, BP, Bounty Platform, CIR, Campbell Island Rise, PR, Pukaki Rise. –, not surveyed

Month	Year	Vessel	Voyage code	Biomass (t) AI	BP	CIR	PR	Total	*c.v.* %	Source
Mar-May	1982	*Shinkai Maru*	SHI8201	187	34 588	38 046	20 566	93 480	30	van den Broek *et al.* (1984)
Oct-Nov	1983	*Shinkai Maru*	SHI8302	341	5 975	46 264	4 382	56 905	20	Hatanaka *et al.* (1989)
Oct-Nov	1989	*Amaltal Explorer*	AEX8902	67	13 306	13 539	6 436	33 348	30	Livingston & Schofield (1993)
Jul-Aug	1990	*Amaltal Explorer*	AEX9001	6	1 910	7 950	2 637	11 941	30	Hurst & Schofield (1995)
Nov-Dec	1990	*Amaltal Explorer*	AEX9002	5	13 982	2 714	1 803	17 392	55	Hurst & Schofield (1995)
Nov-Dec	1991	*Tangaroa*	TAN9105	618	–	2 476	3 037	6 131	27	Chatterton & Hanchet (1994)
Apr-May	1992	*Tangaroa*	TAN9204	1	–	5 964	2 897	8 863	44	Schofield & Livingston (1994a)
Sep-Oct	1992	*Tangaroa*	TAN9209	79	–	2 449	1 277	3 805	42	Schofield & Livingston (1994b)
Nov-Dec	1992	*Tangaroa*	TAN9211	123	1 380	5 079	2 368	8 950	21	Ingerson *et al.* (1995)
May	1993	*Tangaroa*	TAN9304	216	–	1 882	4 123	6 222	31	Schofield & Livingston (1994c)
Nov-Dec	1993	*Tangaroa*	TAN9310	3 169	825	2 862	3 564	10 420	22	Ingerson & Hanchet (1995b)
Mar-Apr	1996	*Tangaroa*	TAN9605	770	–	31 149	13 689	45 608	31	Colman (1996)

Table 7: Values for the input parameters to the separable Sequential Population Analysis for the base-case runs and sensitivity analyses for the Campbell Island and Bounty Platform stocks

Parameter	Campbell	Bounty	Sensitivity
M	0.2	0.2	0.15, 0.25
Acoustic time series	absolute	absolute	relative
Acoustic *c.v.*	0.3	0.3	–
Catch–at–age sample sizes	100	100	–
Catch-at-age data	1979–1996	1990–1996	removed final year(s)
Ages for which selectivity allowed to vary annually	2, 3	2, 3	2

Table 8: Estimates of mid-season spawning stock biomass (t), for the Campbell Island stock in 1979, 1993, and 1996, fully selected F in 1996, $GMR_{1979-93}$, geometric mean of the recruitment (number of 2 year olds in thousands) over the period 1979 to 1993, $CAY_{1996-97}$, and $CAY_{1997-98}$ assuming 1996–97 catch equals (i) $CAY_{1996-97}$, or (ii) 21 000 t. Also shown are the bootstrap medians and percentile 90% confidence intervals. –, not estimated

Parameter	Estimate	Bootstrap median	Bootstrap 90% confidence interval	
B_{1979}	146 000	144 000	135 000	155 000
B_{1993}	26 000	25 000	19 000	33 000
B_{1996}	175 000	178 000	119 000	261 000
F_{1996}	0.110	–	–	–
$GMR_{1979-93}$	43 900	43 000	40 000	47 000
$CAY_{1996-97}$	30 100	30 700	20 400	45 300
$CAY_{1997-98}$ (i)	25 000	25 400	17 400	36 500
$CAY_{1997-98}$ (ii)	26 700	–	–	–

Table 9: Relative changes (expressed as percentages) of selected parameter estimates as a result of alternative model assumptions for the Campbell Island stock. B, mid-season spawning stock biomass; $N_{2,1993}$ size of the 1991 year class; GMR, geometric mean of the recruitment of 2 year olds omitting the last three years. selages, number of ages for which selectivity allowed to vary annually; aco, acoustic biomass estimate. Figures with an absolute value larger than 20% are shown in bold

Model	B_{1979}	B_{1993}	B_{1996}	$N_{2,1993}$	GMR
selages = 2	2.1	-3.8	-1.1	-0.6	-0.5
M = 0.15	**-24.0**	-3.8	9.1	-10.9	**-21.1**
M = 0.25	**37.0**	**-42.3**	**-97.1**	**-71.1**	2.8
CPUE	-0.7	0.0	10.9	8.5	7.6
aco = relative	0.0	-3.8	-1.7	11.4	-0.3
aco = relative + CPUE	0.0	**23.1**	**38.3**	**30.0**	7.6

Table 10: Estimates of mid-season spawning stock biomass (t), for the Bounty Platform stock in 1990, 1993, and 1996, fully selected F in 1996, $GMR_{1990\text{-}93}$, geometric mean of the recruitment (number of 2 year olds in thousands) over the period 1990 to 1993, $CAY_{1996\text{–}97}$, and $CAY_{1997\text{–}98}$ assuming 1996–97 catch equals (i) $CAY_{1996\text{–}97}$, or (ii) 21 000 t and assuming either (a) $N_{2,\ 1996} = GMR_{1990\text{-}93}$, (b) $N_{2,\ 1996}$ = 400 million fish, or (c) $N_{2,\ 1996}$ = 1500 million fish. Also shown are the bootstrap medians and percentile 90% confidence intervals. –, not estimated

Parameter	Estimate	Bootstrap median	Bootstrap 90% confidence interval	
B_{1990}	81 000	76 300	64 600	89 000
B_{1993}	47 000	42 300	21 000	61 800
B_{1996}	85 000	70 000	21 000	118 700
F_{1996}	0.09	–	–	–
$GMR_{1990\text{-}93}$	36 300	32 200	18 300	45 900
$CAY_{1996\text{–}97}$ (a)	15 700	12 700	3 200	22 200
$CAY_{1996\text{–}97}$ (b)	20 000	16 700	7 400	26 300
$CAY_{1996\text{–}97}$ (c)	32 100	29 100	19 800	38 600
$CAY_{1997\text{–}98}$ (i) (a)	13 200	10 700	3 700	18 300
$CAY_{1997\text{–}98}$ (i) (b)	28 000	25 900	19 000	33 000
$CAY_{1997\text{–}98}$ (i) (c)	73 500	50 600	64 400	78 300
$CAY_{1997\text{–}98}$ (ii) (a)	14 500	–	–	–
$CAY_{1997\text{–}98}$ (ii) (b)	30 300	–	–	–
$CAY_{1997\text{–}98}$ (ii) (c)	77 900	–	–	–

Table 11: Relative changes (expressed as percentages) of selected parameter estimates as a result of alternative model assumptions for the Bounty Platform stock. B, mid-season spawning stock biomass; F, fishing mortality rate; $N_{2,1990}$, size of the 1988 year class; GMR, geometric mean of the recruitment of 2 year olds omitting the last three years. selages, number of ages for which selectivity allowed to vary annually; aco, acoustic biomass estimate. *, B_{1995}. Figures with an absolute value larger than 20% are shown in bold

Model	B_{1990}	B_{1993}	B_{1996}	$N_{2,1990}$	GMR	F_{1992}
selages = 2	2.5	0.0	16.5	-4.6	9.0	8.7
M = 0.15	-11.1	-4.3	11.8	-16.8	-13.8	7.5
M = 0.25	13.6	6.4	-8.2	**21.4**	16.5	-6.3
aco = relative	**-22.2**	**-68.1**	**-99.9**	**-26.0**	**-56.0**	**73.8**
aco = 1994 only	4.9	17.0	**35.3**	8.2	17.1	-6.3
yrs = 79-95	3.7	2.1	-2.8*	0.0	**-37.5**	-2.5

Table 12: Input parameters for stock reduction analysis of the Pukaki Rise stock

Parameter		Males	Females
Natural mortality (M)		0.21	0.21
Age of recruitment (years)		3	3
Gradual recruitment (years)		1	1
Age at maturity (years)		3	3
Gradual maturity (years)		1	1
L_∞	cm	47.6	51.5
k	$year^{-1}$	0.35	0.32
t_0	year	– 0.93	– 1.03
a	) From weight-length relationship	0.0052	0.0041
b	)	3.09	3.15
Recruitment variability		1.0	1.0
Recruitment "steepness"		0.95	0.95

Table 13: Estimates of B_0, $B_{1995–96}$ (mid–season spawning stock biomass), $B_{1996–97}$ (pre–season spawning stock biomass), $CAY_{1996-97}$, $CAY_{1997–98}$ assuming a catch in 1996–97 equal to (i) $CAY_{1996–97}$ or (ii) the 1996-97 catch limit (3000 t) for the Pukaki Rise. All values in t x 10^3

	B_0	$B_{1995–96}$	$B_{1996-97}$	CAY 1996–97	CAY 1997–98 (i)	CAY 1997–98 (ii)
Pukaki Rise	51	33.3	37	7.7	6.7	7.5

Table 14: Summary of yields, catch levels, and reported landings. $CAY_{1997–98}$ was estimated assuming the 1996–97 catch equals (i) $CAY_{1996-97}$, or (ii) the 1996–97 catch limit. All values are t x 10^3. – not estimated

Area	MCY	$CAY_{1996–97}$	$CAY_{1997–98}$ (i)	$CAY_{1997–98}$ (ii)	1996–97 Catch limit	1995–96 Landings
Campbell Island	10.5	30.1	25.0	26.7	21.0	14.9
Bounty Platform†	–	15.7–32.1	13.2–73.5	14.5-77.9	8.0	6.5
Pukaki Rise	–	7.7	6.7	7.5	3.0	0.8
Total	–	53.5-69.9	44.9-105.2	48.7-112.1	32.0	22.3

† Range of estimates is based on projections under different recruitment assumptions

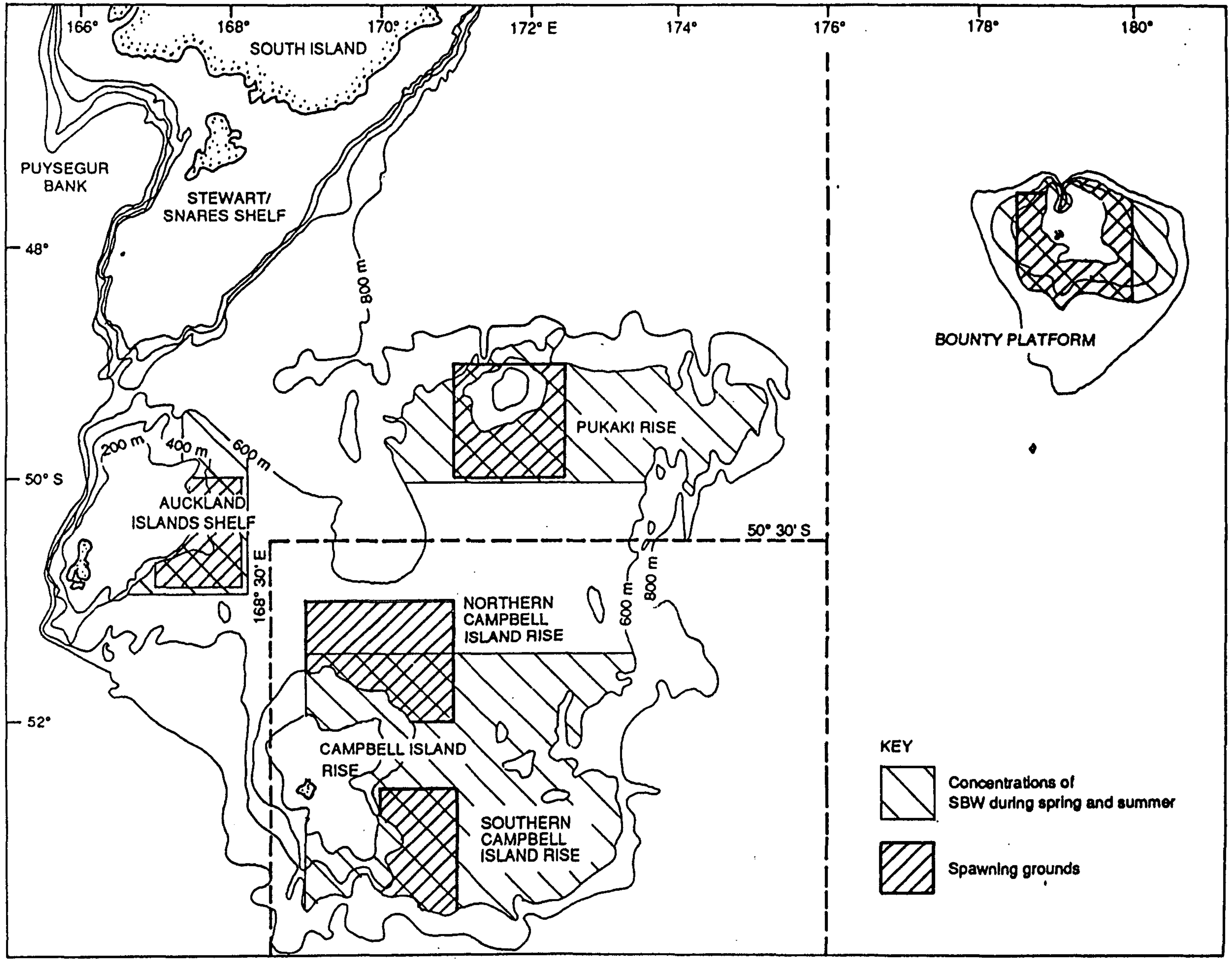

Figure 1. Main feeding grounds and spawning grounds of southern blue whiting, showing proposed stock boundaries.

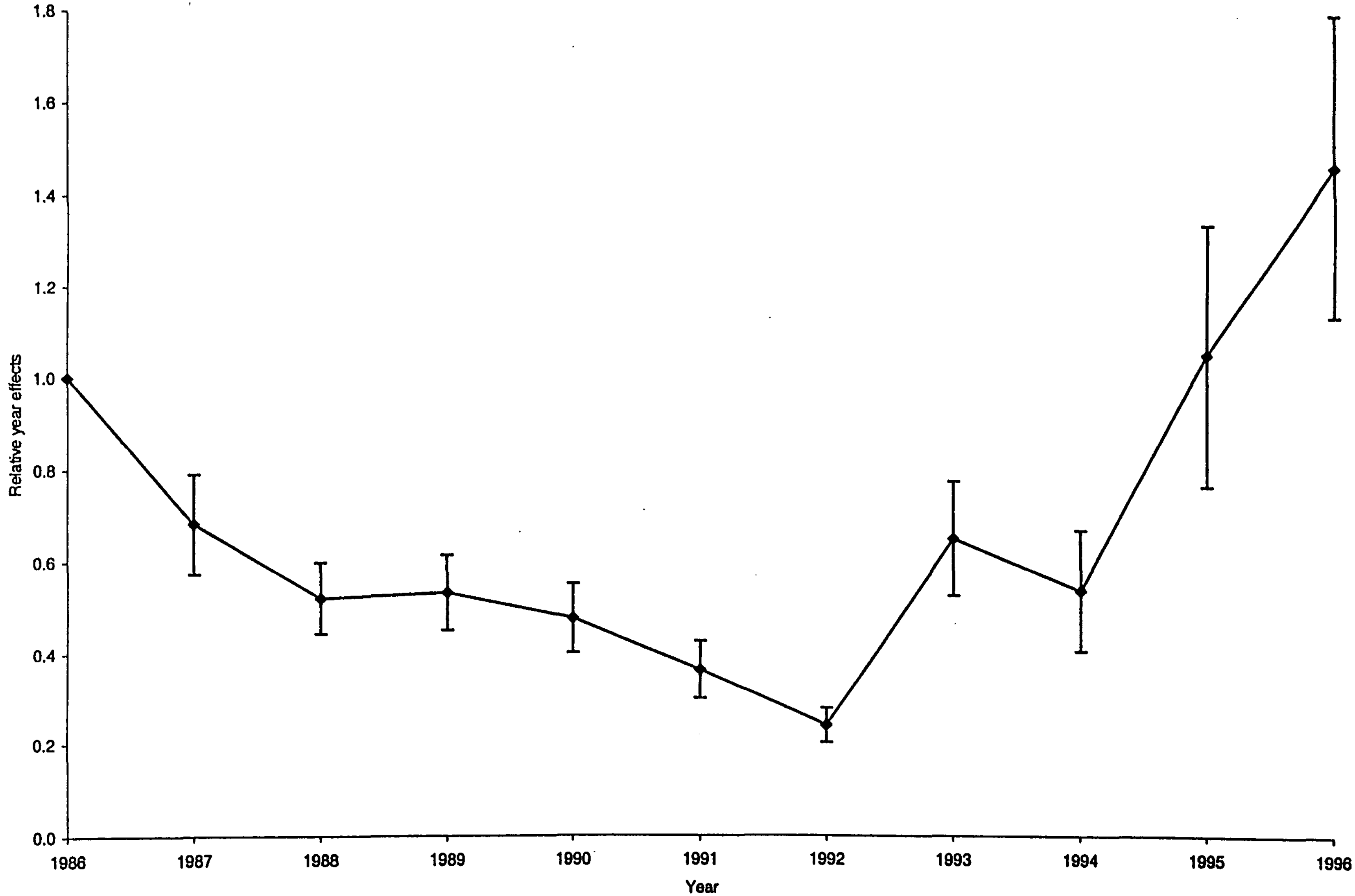

Figure 2. Relative year effects from the CPUE analysis for the Campbell Island Rise using the gamma log link (GLL) model ± 2 standard errors.

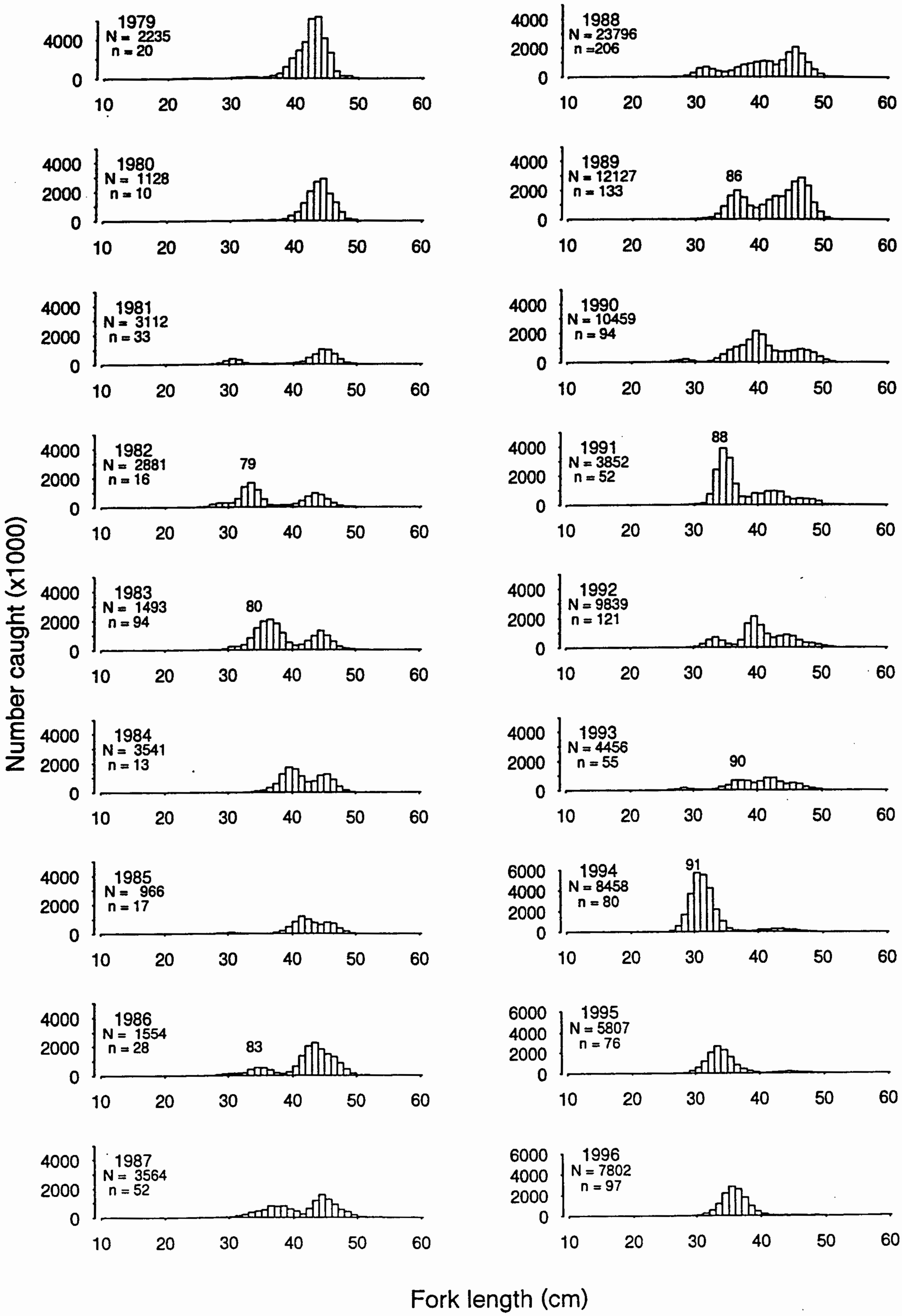

Figure 3a. Weighted length frequency distribution of males in the catch from the Campbell Island Rise. (N, number of fish measured; n, number of samples). Modal lengths of 3 year old fish from strong year classes are shown.

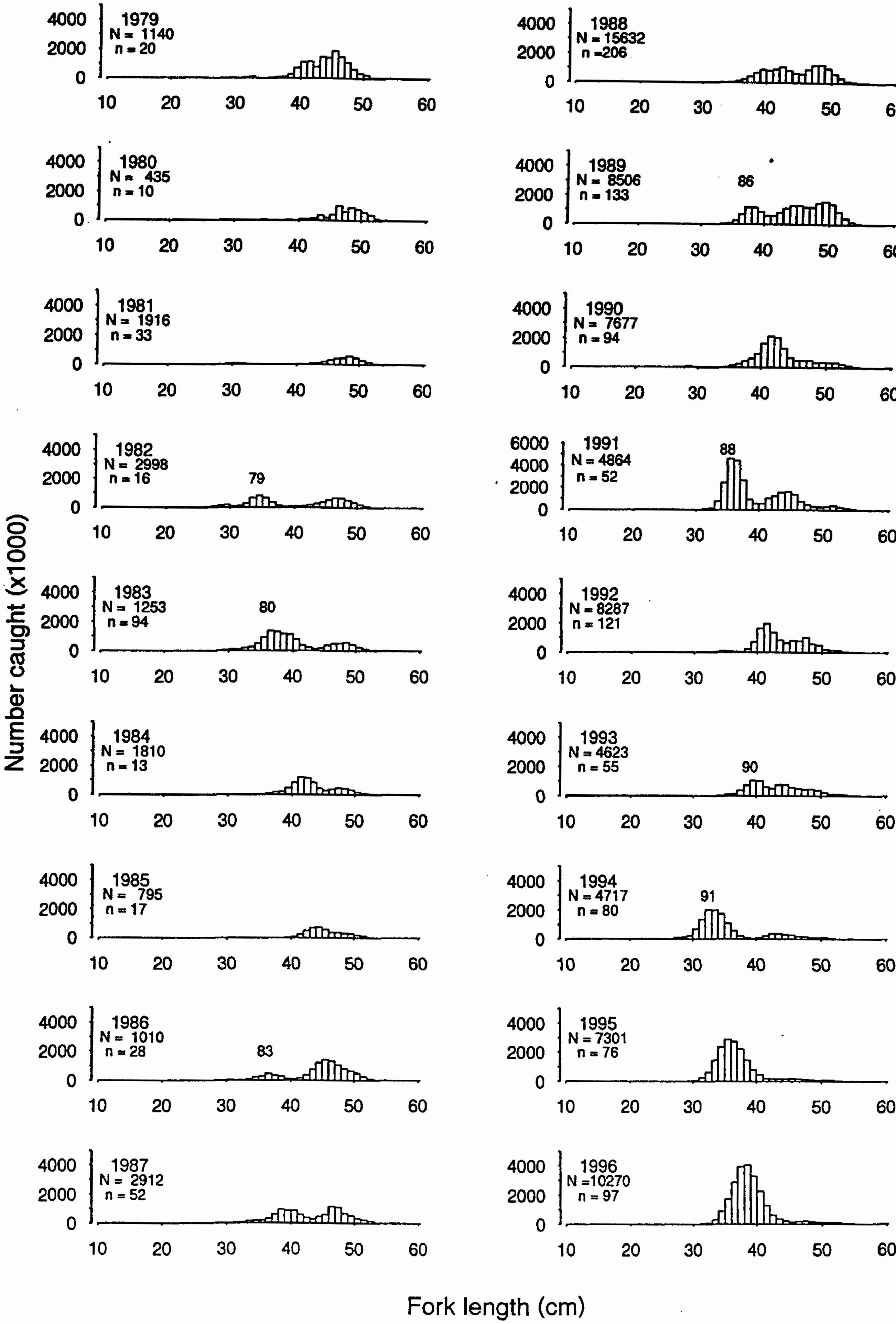

Figure 3b. Weighted length frequency distribution of females in the catch from the Campbell Island Rise. (N, number of fish measured; n, number of samples). Modal lengths of 3 year old fish from strong year classes are shown.

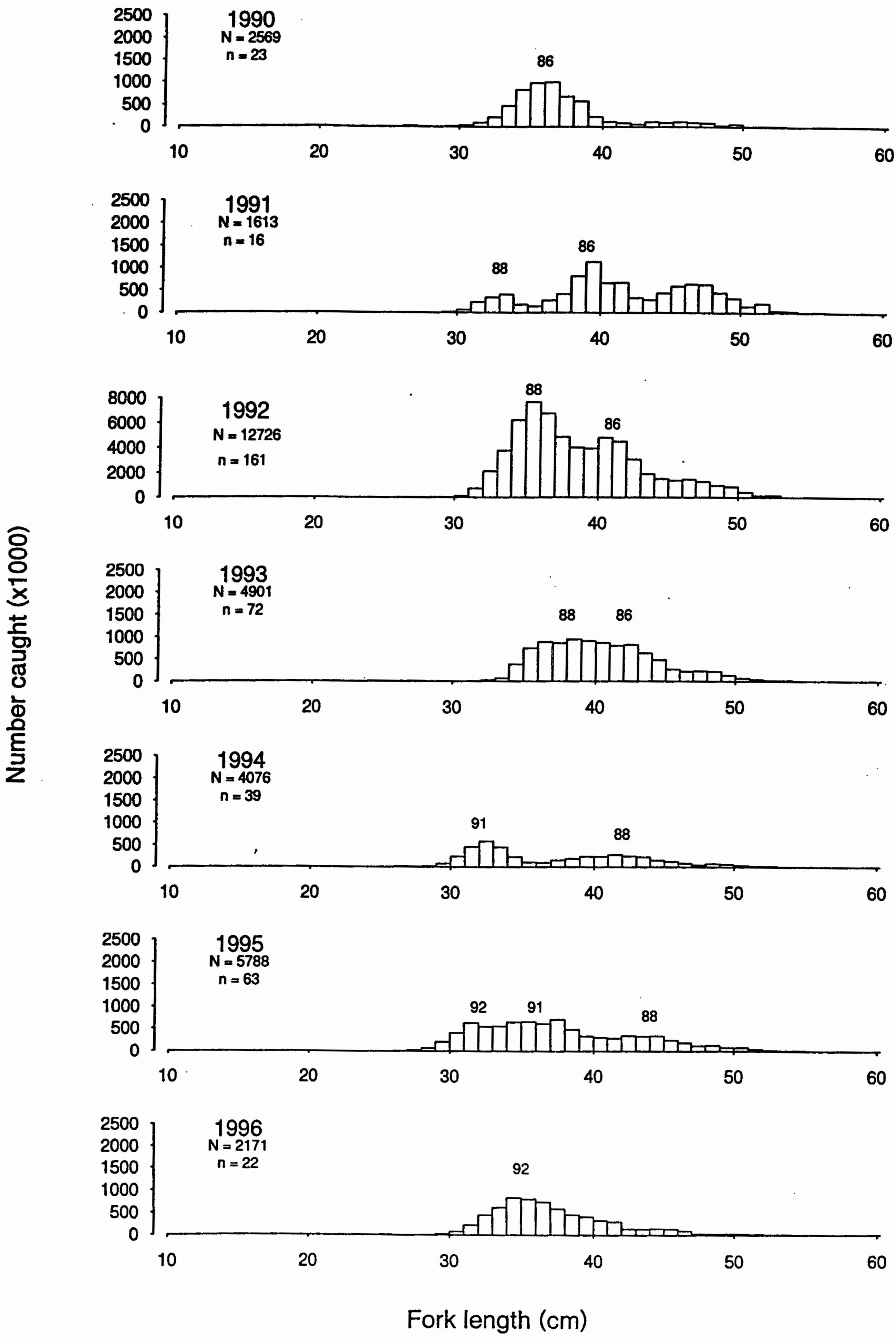

Figure 4a. Weighted length frequency distribution of males in the catch from the Bounty Platform. (N, number of fish measured; n, number of samples). Modal lengths of strong year classes are shown.

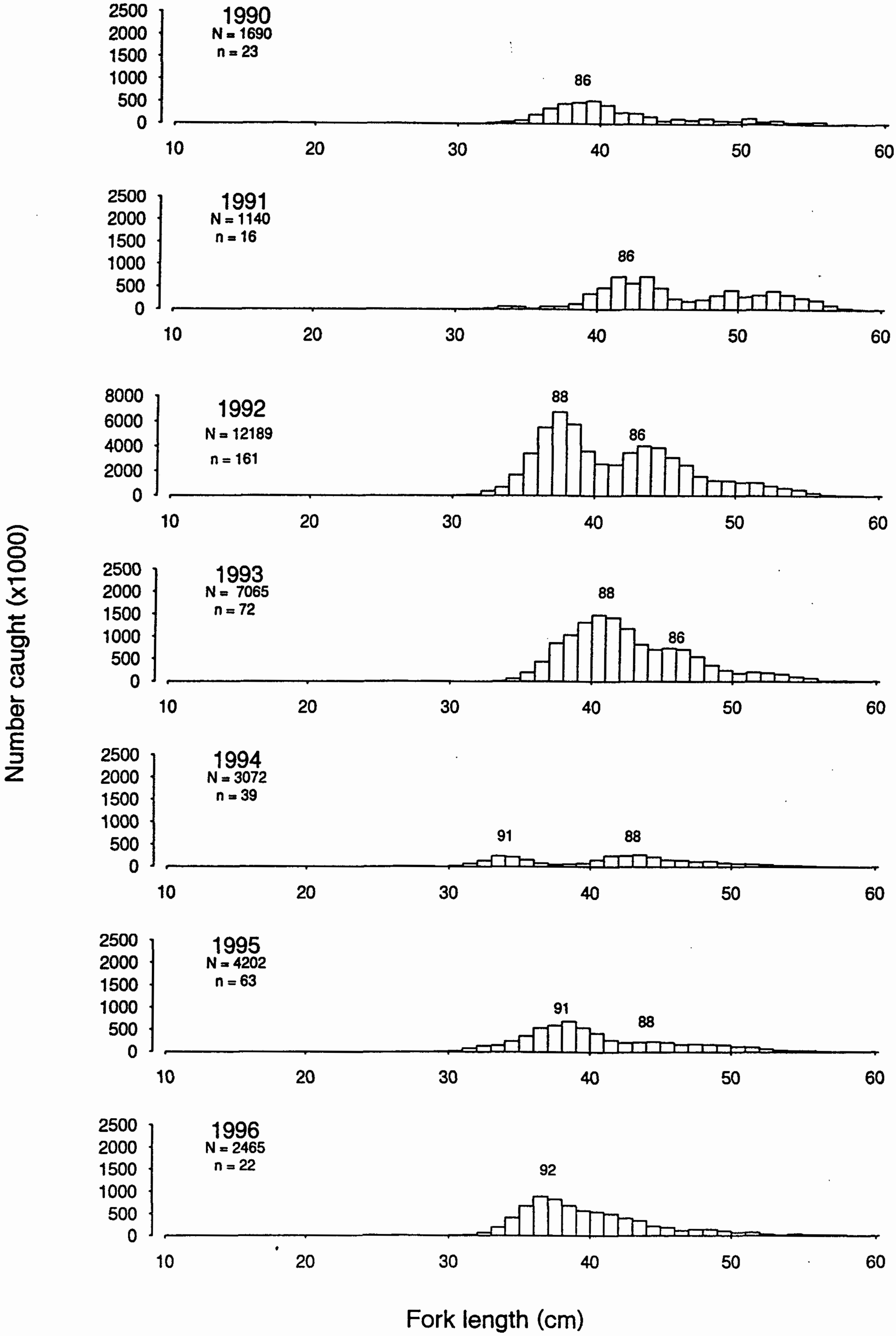

Figure 4b. Weighted length frequency distribution of females in the catch from the Bounty Platform. (N, number of fish measured; n, number of samples). Modal lengths of strong year classes are shown

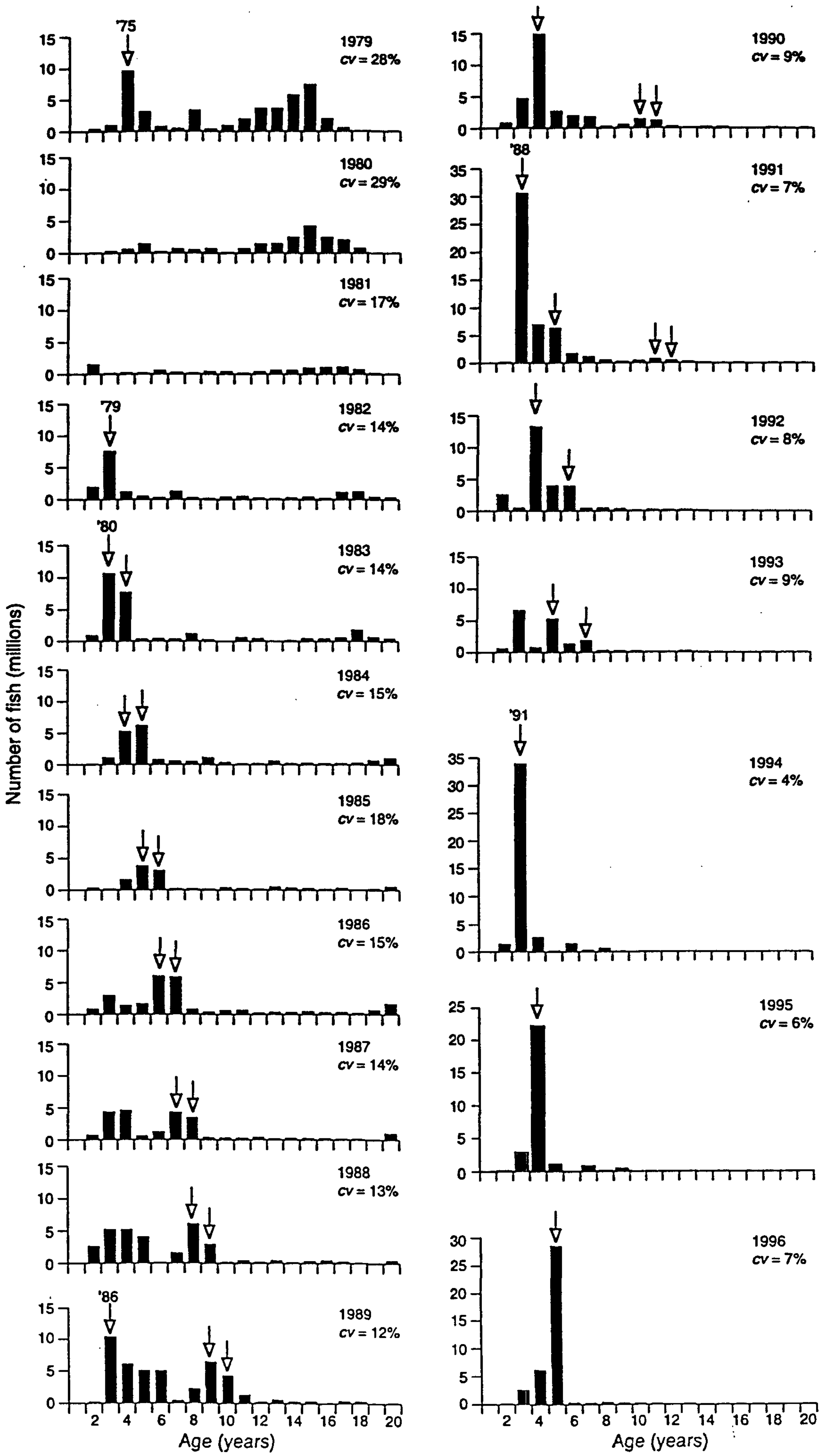

Figure 5. Age composition of the catch on the Campbell Island Rise from 1979 to 1996. Arrows denote strong year classes and the year they were spawned. Mean weighted *c.v.* given for each year.

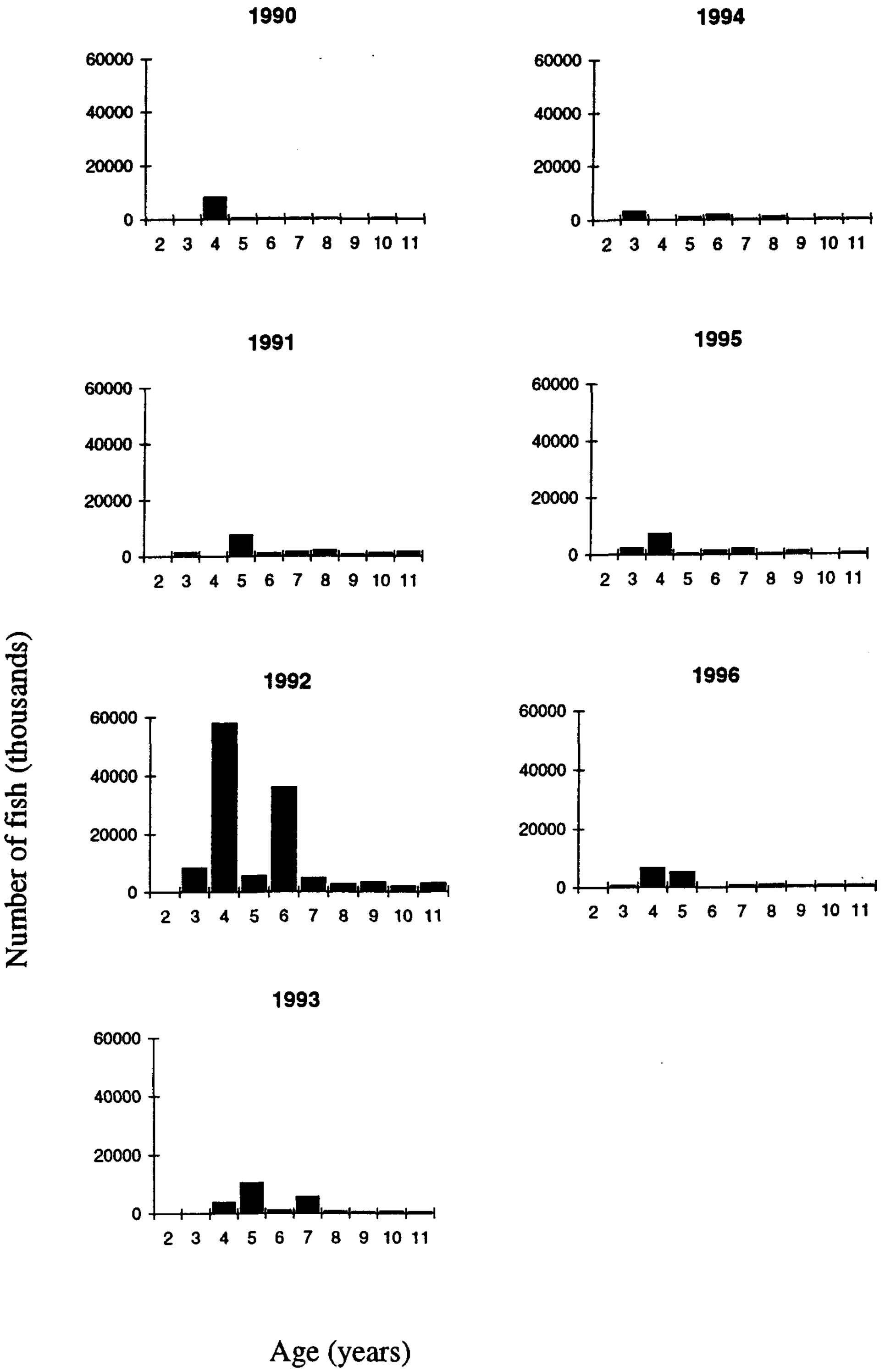

Figure 6. Age composition of the catch on the Bounty Platform from 1990 to 1996

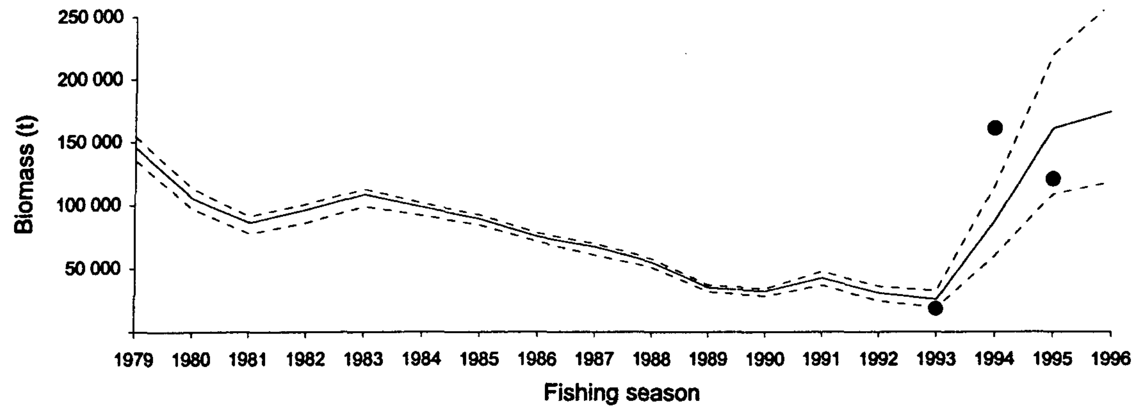

Figure 7. Mid-season spawning stock biomass (t) for the Campbell Island Rise with 90% confidence intervals, showing the fit to the acoustic survey absolute biomass estimates.

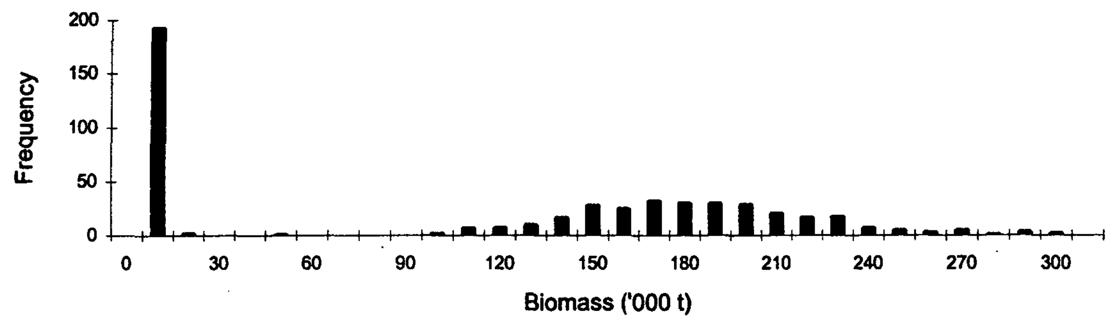

Figure 8. Distribution of mid-season 1995-96 biomass on the Campbell Island Rise from bootstrapping the acoustic and catch at age data.

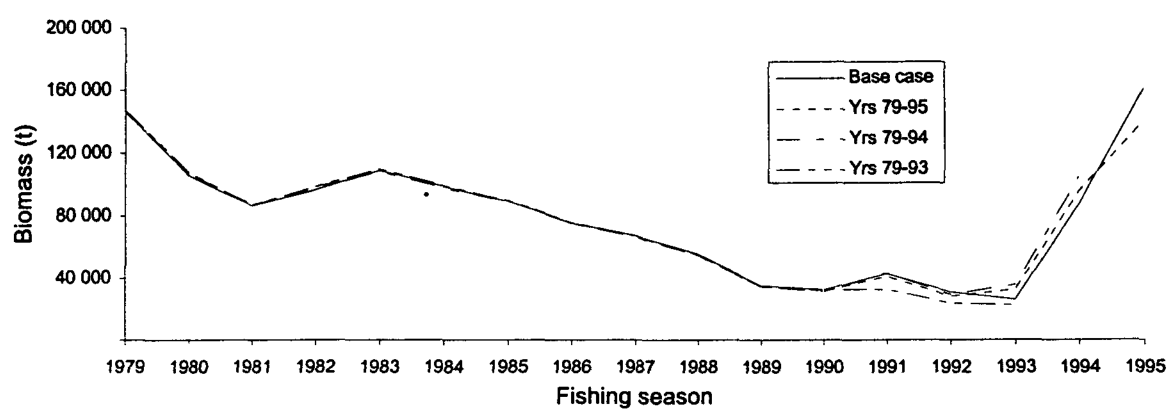

Figure 9. Retrospective analysis of the base case assessment for the Campbell Island Rise.

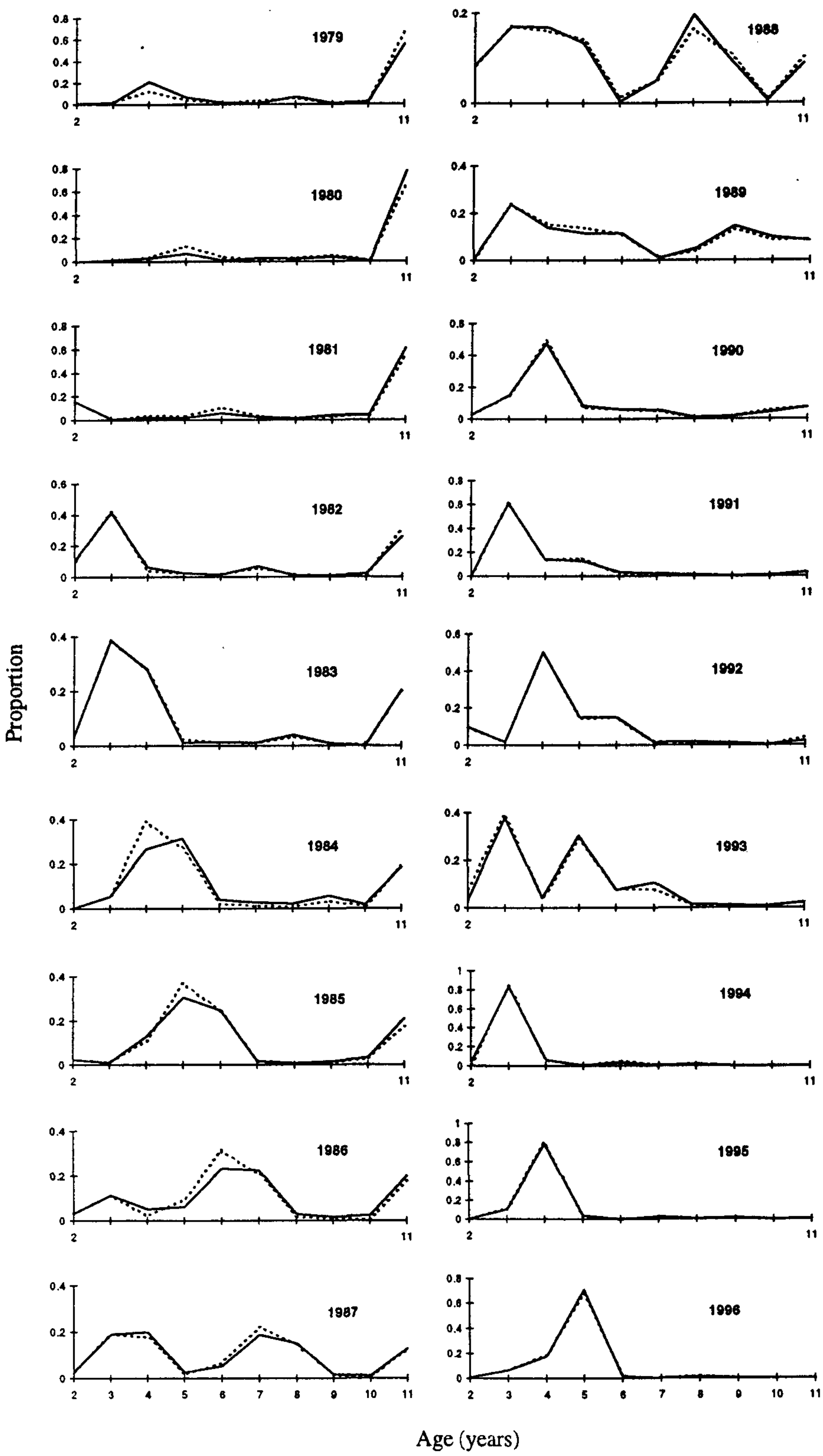

Figure 10. Observed (solid) and expected (dashed) proportions at age for the Campbell Island stock.

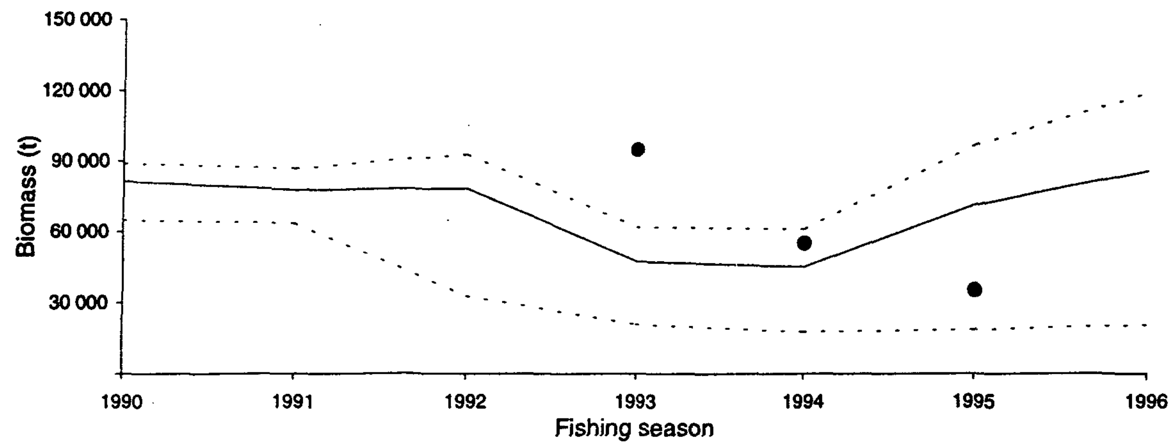

Figure 11. Mid-season spawning stock biomass (t) for the Bounty Platform with 90% confidence intervals, showing the fit to the acoustic survey absolute biomass estimates.

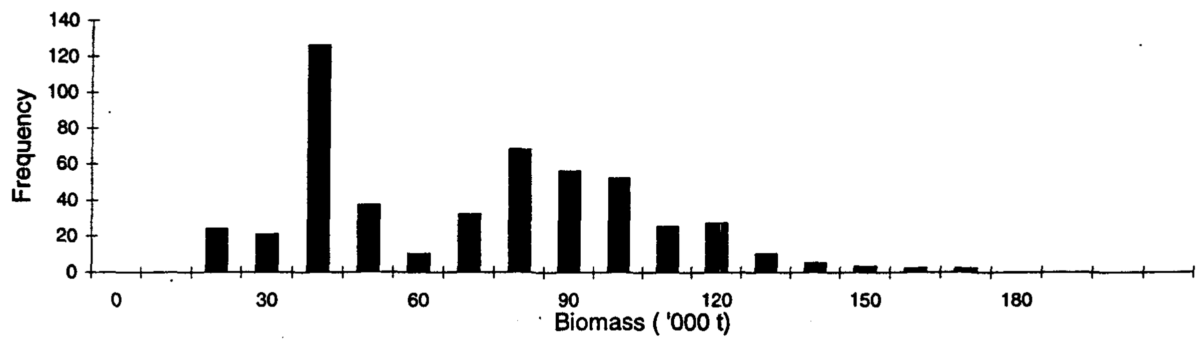

Figure 12. Distribution of mid-season 1995-96 biomass on the Bounty Platform from bootstrapping the acoustic and catch at age data.

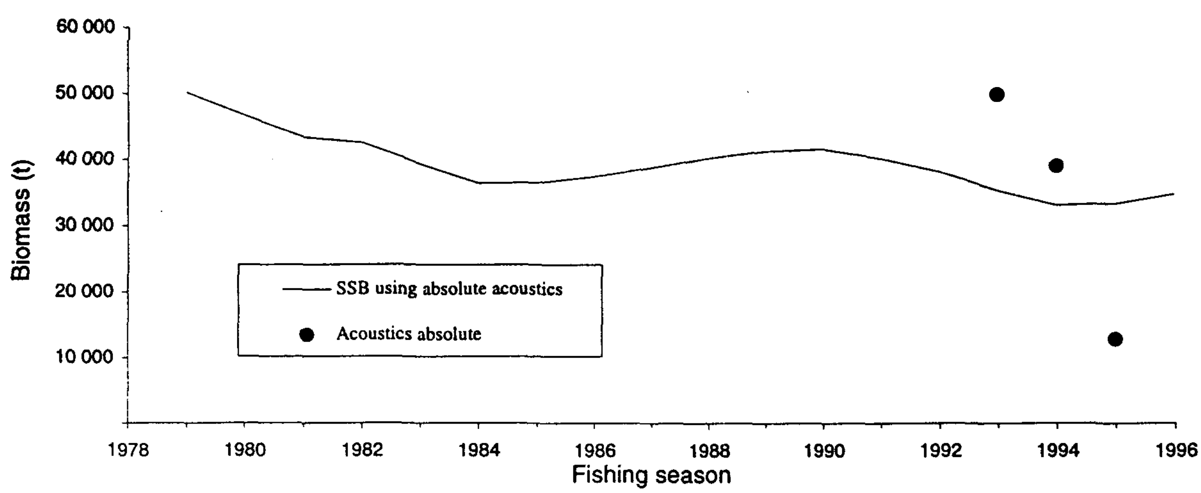

Figure 13. Mid-season spawning stock biomass for the Pukaki Rise stock showing the fit to the acoustic survey absolute biomass estimates.