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A review of southern blue whiting (*M. australis*) stock structure

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1. EXECUTIVE SUMMARY

Southern blue whiting are currently assessed and managed as three stocks; the Bounty Platform, the Pukaki Rise (including the Pukaki and Auckland Islands fishing grounds), and the Campbell Island Rise (including the northern and southern fishing grounds). Data on southern blue whiting distribution, reproduction, growth, and morphometrics were examined to determine whether there are differences between the areas and fishing grounds.

Morphometric and biological studies demonstrated consistent differences between fish from the Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise. These differences provide strong evidence that fish return to spawn on the grounds to which they first recruit, and suggest that the fish are essentially acting as four separate stocks. The differences between northern and southern Campbell Island Rise fishing grounds were slight and inconsistent between years, and are thought to arise from ontogenetic differences in the behaviour of the fish.

It is recommended that southern blue whiting are assessed as four separate stocks: Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise.

2. INTRODUCTION

Inferences about stock structure of marine fishes have been based on a variety of methods including genetics, tagging, morphometrics, meristics, parasites, growth and spawning (Smith *et al.* 1990). Genetics can provide a clear indication of biological separation between stocks. Stocks which are genetically different clearly have little mixing, and should be treated separately for fisheries management. However, the time scale which gives rise to genetic heterogeneity may be far longer than is important to short term fisheries management.

Other methods, such as comparisons of morphometrics, meristics, parasites, growth, or spawning, have been used to identify stocks in NZ waters (e.g., Livingston *et al.* 1992, Horn 1993, Colman 1995, Livingston & Schofield 1996). Although such methods do not by themselves provide evidence of genetic differences between the groups, they are often used to identify stocks for management purposes.

Research in 1989 using morphometrics identified three stocks of southern blue whiting (SBW) in waters south of New Zealand – on Bounty Platform, Pukaki Rise, and Campbell Island Rise (Hanchet 1991). Since then considerably more data have been gathered on morphometrics, distribution, spawning, and growth, and a new spawning fishery has developed on the Auckland Islands Shelf.

With the introduction of a total catch limit in 1993 the fishery was managed as three stocks on the Bounty Platform, Pukaki Rise, and Campbell Island Rise. A line drawn at 50° 30' S separated the Pukaki Rise and Campbell Island spawning areas but bisected the Auckland Islands Shelf. A spawning fishery started to develop on the Auckland Islands Shelf in 1993, and the stock boundaries were redefined in 1996. A new line was drawn at 168° 30' E which divided off the Campbell Island Rise and combined the Auckland Islands Shelf with the Pukaki Rise. For the 1997 season, the industry agreed to separate catch limit for the Auckland Islands Shelf, in an effort to reduce the potential for bycatch of Hooker's sea lions on the Auckland Islands Shelf (T. Chatterton, MFish, pers. comm.).

The aim of the present research was to review the data to determine the number of stocks of southern blue whiting.

3. DISTRIBUTION AND ABUNDANCE

Methods

Data on the distribution and abundance of dispersed SBW were provided by trawl surveys of the Southland/Sub-Antarctic areas using *Tangaroa* during the spring, summer, and autumn, between 1991 and 1996. Most surveys used the standardised methodology proposed by Hurst *et al.* (1992), and tows were usually 3 n.miles long at an average speed of 3.5 knots. The surveys covered depths from 300 to 900 m in the Sub-Antarctic, and extended from 30 to 1000 m on the Stewart/Snares shelf and Puysegur Bank (Figure 1).

Results

Catch rates of southern blue whiting during those surveys are shown in Figure 2. Areas of moderate to high catch rate fall into four clusters around the Campbell Island Rise, Pukaki Rise, Bounty Platform, and Auckland Islands Shelf. Catch rates were low or zero between these locations and also low on the Stewart/Snares shelf.

4. REPRODUCTION

Methods

Since 1989, scientific observers on board commercial fishing vessels have recorded length, sex, and female gonad stage from up to 200 SBW per day. Observers have been instructed to collect samples at random times each day.

Svirskii & Shpak (1977) examined the timing, location, and characteristics of spawning in SBW in New Zealand waters. They concluded that the main spawning area was on the Bounty Platform but that isolated spawning also occurred on the Campbell Island Rise. On the Bounty Platform spawning occurred mainly during August and September, with a peak in mid August. By examining ovaries histologically and measuring oocyte diameters they concluded that two oocyte generations were formed by the beginning of the spawning season, and that that this led to two batches of eggs being spawned by females each season.

Gonad stages for females were recorded using the gonad staging system given in Table 1. The gonad staging system was accompanied by colour photographs and detailed descriptions in an attempt to minimise between-observer variation. Examples of the sequence and timing of the progression of gonad stages from maturing through to spent are shown in Figures 3a and 3b, and gonad staging data are summarised for all years in each area in Tables 2–6. Two spawning peaks (comprising ripe and running ripe fish) are visible in each figure, separated by a period of 10–15 days. The percentage of spent fish increased once the second spawning peak had passed. Observers reported that in both years most maturing fish caught after the first spawning period had residual ovulated eggs in the ovaries. This is consistent with the occurrence of two batches being spawned per female as reported by Svirskii & Shpak (1977). Although there was still likely to be some error in the identification of gonad stages, preliminary analysis of the data suggests that this was not a major problem.

Results

Location of spawning females

The location of all observed tows catching running ripe females suggests four distinct spawning areas on the Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise (Figure 4). When the data are plotted separately by year these spawning areas can be further subdivided into individual spawning grounds (Figure 5). In some years separate spawning grounds can be identified to the north and southeast of the Campbell Island Rise (1990 and 1994), and to the northeast and southwest of the Bounty Platform (1993).

The occurrence of separate spawning grounds within an area could reflect a further sub-division of stocks or merely reflect behavioural differences of the fish, and/or the fleet, between years. In the remainder of the paper, data from spawning areas and individual spawning grounds will be examined where possible.

Timing of spawning

The occurrence of the various gonad stages recorded by observers for the northern and southern Campbell Island Rise spawning grounds is summarised in Tables 2 and 3. (For the purposes of the analysis the Campbell Island Rise was arbitrarily divided into north and south at 52° 30' S.) In most years there was little overlap in the timing of fishing between the two grounds and so comparative data are not available. In 1991 and 1996, fishing occurred simultaneously on both grounds over a 2 day period and the percentage of running ripe females on each ground was almost identical. However, in 1994 and 1995, fish on the southern ground appeared to spawn 3–4 days later than on the northern ground.

The percentages of running ripe females on both Campbell grounds were combined and plotted together with data from the other spawning areas in Figure 6, and Tables 4 to 6. Unfortunately, coverage of the entire season is incomplete for most areas and for most years. Interpretation of the data is further complicated by the variability in the timing of spawning between years and because a particular spawning peak may be due to either the first or the second batch of eggs being spawned (*see* above). However, the data allow some tentative conclusions to be reached.

The year with the best coverage of all four areas was 1993. There was a clear difference in timing of spawning between all four areas with spawning occurring first on the Bounty Platform, then on the Pukaki Rise, next on the Auckland Islands Shelf, and last on the Campbell Island Rise. Data from the other years follows a similar pattern, with spawning on the Bounty Platform always starting 3–4 weeks before spawning on the Campbell Island Rise. There are too few data to be certain of the timing of spawning on the Pukaki Rise and Auckland Islands Shelf in other years.

5. AGE AND GROWTH

Methods

Otoliths have been collected from the commercial fishery by the Scientific Observer Programme. The number of otoliths read for the period 1990 to 1996 is shown in Table 7. Otoliths were read using the validated procedure of Hanchet & Uozumi (1996). Ageing data are available for the Pukaki Rise only for 1990 and 1991, so comparisons of growth between the three areas were restricted to these 2 years. Hanchet & Uozumi (1996) showed significant differences in growth between sexes, so von Bertalanffy growth parameters were fitted to the age length data from each sex and area separately using the NLIN procedure of SAS (SAS Institute 1988).

Results

Size and age distribution of the commercial catch

The complete length-frequency distribution of fish in the commercial fishery from all years and areas was given by Hanchet & Ingerson (1996b) and Hanchet (1997). A subset of the data encompassing years when data were collected from the four areas is shown for males and females in Figure 7. Modal peaks corresponding to different year classes have been identified by following modes from when the fish first recruited to the fishery. These tentative ages have been substantiated for the Bounty and Campbell areas by validated otolith readings (*see* below).

The length frequencies are different between areas but are consistent within an area between years. There are two important differences: (i) the relative strength of the year classes between areas, and (ii) the modal length of the year classes between areas.

The size distribution in 1994 and 1995 is dominated by the 1991 year class on the Campbell Island Rise, by the 1988 and 1991 year classes on the Bounty Platform, by the 1986, 1990, and 1991 year classes on the Pukaki Rise, and by the 1986, 1988, and 1991 year classes on the Auckland Islands Shelf. These differences may have come about through either differences in recruitment and/or differential fishing mortality, but that they are consistent between years suggests little mixing between these areas.

Secondly, the modal length of the 1988 and 1991 year classes differs between the four areas. The modal length of the 1991 year class appears to be smallest on the Pukaki Rise and largest on the Bounty Platform. In contrast, the modal length of the 1988 year class was larger on the Campbell Island Rise than on the Bounty Platform. The differences in length at age between the Campbell and Bounty fish are examined in more detail below.

Data on the size distribution of fish between the northern and southern grounds on the Campbell Island Rise are shown in Figure 8. In some years (e.g. 1991 and 1994 when strong year classes were recruiting to the fishery for the first time) the size distribution of the fish was different between these two grounds. The size distribution from the southern ground was dominated by 3 year old fish which were spawning for the first time, whereas the northern ground had a greater proportion of adults. In subsequent years (e.g., 1992, 1995, 1996), the size distribution between the two grounds was more similar. The modal size of the strong year classes has always been identical between the grounds.

Growth

The fitted growth curves are shown in Figure 9, and the von Bertalanffy parameters are given in Table 8 and plotted in Figure 10. The growth curves show considerable overlap between the three areas, and the von Bertalanffy growth parameters were not significantly different between them. Although overall growth was not significantly different between areas, there appeared to be differences in growth of particular year classes between areas.

Growth of individual year classes

Mean lengths at age of the strong 1988 and 1991 year classes are given in Tables 9 and 10 and shown in Figure 11. The mean length at age of the 1988 year class has been significantly greater on the Campbell Island Rise than on the Bounty Platform for most ages in both sexes (t test, $P < 0.001$). In the last 2 years the growth rate of the Campbell Island fish has declined slightly and the mean lengths have become closer. In contrast the mean length at age of the 1991 year class has been significantly greater on the Bounty Platform than on the Campbell Island Rise for most ages in both sexes (t test, $P < 0.001$).

6. MORPHOMETRICS

Methods

Morphometric measurements and meristic counts were made from southern blue whiting collected from the Bounty Platform, Pukaki Rise, and Campbell Island Rise during two trawl surveys in summer 1989 (AEX8902) and winter 1990 (AEX9001).

The numbers of fish sampled from each area during each survey are listed in Table 11. To reduce bias caused by allometric growth, sampling was restricted to fish of length 45–50 cm. Between 5 and 10 fish were randomly sampled from each tow. During 1989, 13 morphometric measurements (Figure 12) and 6 meristic counts (number of finrays in each of the dorsal and ventral fins, and the number of gill rakers in the first branchial arch) were taken from each fish. Preliminary analysis of the 1989 data suggested that only 6 measurements (X6, X12, X13, X15, X16, X17) were useful in discriminating fish between areas and so during the 1990 survey only these 6 variables were measured. All measurements were made using dial callipers to the nearest 0.05 mm. In 1989 all fish were measured by one reader. In the 1990 survey, fish were measured by two readers.

The data were analysed using multiple discriminant analysis (MDA) with the STEPDISC, DISCRIM, and CANDISC procedures of SAS (SAS Institute 1988). Because of possible bias caused by using fish of different mean sizes from the three areas, both raw data and ratios (raw data/fish length) were used in the analysis. Because of differences in growth between the sexes (Hanchet & Uozumi 1996) the data were first analysed by sex separately and then the sexes were combined.

In each analysis an initial stepwise discriminant analysis (STEPDISC) was carried out to determine which variables significantly improved the discrimination between the areas. Then a discriminant function analysis (DISCRIM) was carried out using those variables to determine class rules. Cross validation was used to determine the classification success of the original data (after Livingston & Schofield 1996). This involves removing each fish from the data set in turn and seeing how well it classified into the class rules determined by the remaining fish. The priors indicate the expected classification success by chance if the data are homogeneous.

Results

The classification success for the AEX8902 survey is shown in Table 12. The results were similar between raw data and ratios, and usually the variables entering the model were the same. The most significant variables were the head measurements X6, X15, X16, and X17. The other body measurements and meristic counts usually did not improve the discrimination significantly. Overall classification success was between 54 and 70%, which is considerably higher than the 33% expected by chance. Bounty Platform and Campbell Island Rise fish tended to be misclassified as Pukaki Rise fish, whilst Pukaki Rise fish were misclassified equally into the other two areas.

Results of the canonical discriminant analysis showed that fish from the Campbell Island Rise and Bounty Platform were separated along canonical variate 1 (CAN 1), whilst fish from the Pukaki Rise were separated from the other two areas along canonical variate 2 (CAN 2) (Figure 13). Proportionally, CAN 1 explained 65% of the total variation and CAN 2 35%.

The classification success for the AEX9001 survey is shown in Table 13. Males again tended to have a higher classification success than females, and the results were similar whether raw data or ratios were used in the analysis. Overall classification success was between 73 and 87%, which is considerably higher than the 50% expected by chance.

7. DISCUSSION

The data on distribution and abundance suggest that there are four main areas of abundance of southern blue whiting in New Zealand waters: the Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise. There is strong evidence that fish on the Bounty Platform form a separate stock from fish in the other three areas. They have a consistently different size distribution, they spawn at least 3 weeks earlier than fish from the other areas, they appear to have different morphometric measurements from the Pukaki and Campbell fish, and the strong year classes grow at a different rate from the Campbell fish.

The Bounty Platform is separated bathymetrically, and possibly hydrologically, from the rest of the Campbell Plateau. Depths between the two topographic features exceed 1000 m, which may restrict the mixing of adult fish between the two regions. Although there is a prevailing eastward flow of sub-Antarctic water across the Campbell Plateau towards the Bounty Platform, ocean circulation models predict the presence of "squirts" which force water northwards between the eastern edge of the Campbell Plateau and the Bounty Platform (M.Moore, NIWA, pers. comm.). These squirts may deflect any eggs and larvae spawned on the Campbell Plateau north towards the Chatham Rise, and hence restrict movement of larvae between the two regions.

Although no such bathymetric or hydrological barriers are known to exist between the three areas on the Campbell Plateau, there also appear to be consistent differences between fish there. For example, there are consistent differences in the size distribution of the fish between all three areas, and also morphometric differences between fish on the Pukaki Rise and the Campbell Island Rise. These differences suggest that there is little mixing of adult fish once they have recruited to a particular area within the Campbell Plateau.

On a finer scale again there is some evidence for two separate spawning grounds on the Campbell Island Rise, at least in some years. This may indicate a further subdivision of stocks or merely reflect behavioural changes in the fish or the fleet between years. Fleet fishing activity depends to a large extent on where the fish are first found and subsequent catch rates. Generally speaking, vessels will remain in the same location as long as catch rates remain high, and will move only if catch rates fall and/or higher catch rates are reported elsewhere. Therefore there is the possibility that the two spawning grounds on the Campbell Island Rise are consistent features implying that they may be occupied by two independent sub-populations of fish.

However, there is evidence from data on size distribution and biomass that the occurrence of two spawning grounds in some years results from ontogenetic differences in the behaviour of the fish. The length frequency data suggested that in years of good recruitment there was a higher proportion of small fish on the southern ground. It is possible that fish spawning for the first time tend to recruit to the southern ground, but in future years most of these fish return to spawn on the northern ground. Abundance data from acoustic surveys support this hypothesis (Table 14). The proportion of the acoustic biomass found on the southern ground increased from 15% in 1993 to 85% in 1994 and decreased back to 40% in 1995. This is consistent with the recruitment of the strong 1991 year class to the fishery in 1994. Although these estimates have high *c.v.*s, the catch rates and location of the fleet in those years further support differences of this magnitude between the two grounds (Hanchet *et al.* 1994, Hanchet & Ingerson 1996a, Ingerson & Hanchet 1996).

In conclusion, morphometric and biological studies have identified differences between fish from the main fishing grounds on the Bounty Platform, Pukaki Rise, Auckland Islands Shelf, and Campbell Island Rise. These differences provide strong evidence that these fish return to spawn on the grounds to which they first recruit, and suggest that the fish are essentially acting as four separate stocks. Without genetic studies it is not possible to determine whether these differences are genetically or environmentally determined. Mixing may occur during the early life history stages, but is unlikely to occur once fish have recruited to the fishery.

SBW has been assessed as three stocks since 1991, with catches from the Auckland Islands and Pukaki Rise being combined as a single "Pukaki stock". It is recommended that in future SBW are assessed as four separate stocks with the Auckland and Pukaki stocks being assessed separately.

Future work

Liver, muscle and gill tissue samples were collected from 100 SBW from each of the Bounty Platform and Pukaki Rise during the 1997 SBW acoustic survey. These samples were requested by a group of laboratories in the Northern Hemisphere which is looking at new genetic techniques for stock discrimination. This will be the first genetic study carried out on SBW and may provide further evidence of stock structure.

Otoliths from the Pukaki Rise and Auckland Islands Shelf are currently being read. Growth data from this study will augment the results of the growth studies considered in this paper and could be used to further discriminate between the stocks on the Campbell Plateau.

8. ACKNOWLEDGMENTS

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Table 1: Description of female southern blue whiting gonad stages given to scientific observers.

1. Immature/resting

Ovary very small and white, no eggs visible.

2. Maturing

Ovary creamy white. White eggs barely visible. No clear (hyaline) eggs present in egg mass. Fish which have already spawned this season may have a few clear (ovulated) eggs present in centre of ovary.

3. Ripe

At least one clear (hyaline) egg present in egg mass. Ovary considerably enlarged, swollen and speckled. In fish which have already spawned this season the ovary may become purplish and have a few (<10%) clear (ovulated) eggs in its centre.

4. Running ripe

Clear (ovulated) eggs freely extrudible either from vent or cut ovary. Eggs should flow freely and smoothly off the surface of a knife. At least 10% of eggs in the ovary should be in this state.

5. Spent

Ovary bloody, flaccid and dark red/purple. Ovary wall often thickened. Up to 100 residual opaque (white) or ovulated (clear) eggs may be present, depending on size of fish.

Table 2: Dates associated with SBW gonad stages in 1988–96 on northern Campbell Island Rise, and percentage spent and reverted in the last sample. (–, could not be determined). RR, running ripe

Gonad stage	1988	1989	1990	1991	1992	1993	1994	1995	1996
1st sample	31/8	31/8	9/9	19/9	12/9	9/9	12/9	8/9	8/9
>10% ripe	12/9	11/9	–	–	–	9/9	15/9	11/9	<8/9
>10% RR	15/9	16/9	9/9	–	–	21/9	17/9	13/9	8/9
Main spawning	16–19/9	17–21/9	9–13/9	?–20/9	–	20–25/9	17–21/9	13–17/9	8–14/9
>10% spent	19/9	19/9	13/9	19/9	–	26/9	–	16/9	23/9
>10% reverted	17/9	21/9	13/9	20/9	–	26/9	–	16/9	11/9
>50% spent	22/9	22/9	–	–	26/9	–	–	–	–
2nd spawning	29–30/9	–	–	–	21–25/9	–	–	–	–
Last sample	2/10	22/9	13/9	20/9	22/9	26/9	21/9	28/9	4/10
% spent	50	35	16	20	80	40	8	20	50
% reverted	50	10	10	10	5	10	4	45	15

Table 3: Dates associated with SBW gonad stages in 1988–96 on southern Campbell Island Rise, *and percentage spent and reverted in the last sample. (–, could not be determined)*

Gonad stage	1988	1989	1990	1991	1992	1993	1994	1995	1996
1st sample	–	–	20/9	13/9	9/9	28/8	13/9	5/9	21/9
>10% ripe	–	–	–	13/9	–	–	13/9	–	–
>10% running ripe	–	–	–	16/9	–	–	21/9	–	–
Main spawning	–	–		16–21/9	9–11/9	–	21–29/9	?–20/9	–
>10% spent	–	–		19/9	11/9	–	25/9	–	–
>10% reverted	–	–	–	21/9	–	–	26/9	–	–
>50% spent	–	–	20/9	23/9	–	–	–	–	27/9
2nd spawning	–	–	23–27/9	–	–	–	–	–	24–28/9
Last sample	–	–	27/9	25/9	11/9	1/9	29/9	21/9	29/9
% spent	–	–	36	70	26	0	10	30	60
% reverted	–	–	10	20	10	0	20	40	20

Table 4: Dates associated with SBW gonad stages in 1990–96 on Bounty Platform, and percentage spent and reverted in the last sample. (–, could not be determined)

Gonad stage	1990	1991	1992	1993	1994	1995	1996
1st sample	2/9	2/9	4/8	10/8	12/8	19/8	26/8
>10% ripe	–	–	15/8	15/8	19/8	22/8	–
>10% running ripe	–	–	17/8	21/8	22/8	24/8	–
Main spawning	–	–	17–22/8	21–28/8	22–27/8	24–28/8	–
>10% spent	4/9	–	2/9	–	25/8	–	–
>10% reverted	<2/9	<2/9	22/8	28/8	26/8	28/8	–
>50% spent	–	–	5/9	–	–	–	–
2nd spawning	3–6/9	2–7/9	30/8–6/9	–	–	–	31/8–6/9
Last sample	6/9	7/9	7/9	29/8	31/8	31/8	6/9
% spent	10	2	50	8	0	1	11
% reverted	50	75	30	73	78	70	16

Table 5: Dates associated with SBW gonad stages in 1989–96 on Pukaki Rise, and percentage spent and reverted in the last sample. (–, could not be determined)

Gonad stage	1989	1990	1991	1992	1993	1994	1995	1996
1st sample	22/9	14/9	8/9	8/9	25/8	2/9	3/9	18/9
>10% ripe	–	<14/9	<8/9	<13/9	4/9	–	16/9	<18/9
>10% running ripe	–	<14/9	<8/9	<13/9	7/9	–	–	–
Main spawning	–	?–14/9	8–11/9	–	7–?/9	–	–	–
>10% spent	4/9	14/9	11/9	–	–	–	–	–
>10% reverted	<23/9	15/9	11/9	–	9/9	–	–	–
>50% spent	–	–	–	–	–	–	–	–
2nd spawning	22–24/9	22–?/9	–	27–28/9	–	–	–	–
Last sample	26/9	22/9	11/9	30/9	9/9	8/9	17/9	18/9
% spent	30%	5%	20%	60%	0	0	0	3
% reverted	60%	70%	30%	40%	40	0	0	0

Table 6: Dates associated with SBW gonad stages in 1989–96 on Auckland Island Shelf, and percentage spent and reverted in the last sample. (–, could not be determined)

Gonad stage	1993	1994	1995
1st sample	15/9	11/9	19/9
>10% ripe	<16/9	12/9	<19/9
>10% running ripe	16/9	13/9	<19/9
Main spawning	16/9	13–16/9?	<19/9
>10% spent	16–18/9	–	19/9
>10% reverted	17/9	–	19/9
>50% spent	–	–	23/9
2nd spawning	–	27–28/9	–
Last sample	18/9	2/10	24/9
% spent	5	5	25
% reverted	28	–	67

Table 7: Number of otoliths read by year, sex, and area

	Bounty Platform		Campbell Island Rise		Pukaki Rise	
	Males	Females	Males	Females	Males	Females
1990	67	57	346	282	88	52
1991	85	56	281	413	67	95
1992	208	197	323	267	–	–
1993	213	319	247	321	–	–
1994	255	252	428	351	–	–
1995	211	186	219	364	–	–
1996	201	280	182	347	–	–

Table 8: Von Bertalanffy parameters (with 95% confidence intervals) calculated for each area and sex for otoliths collected during August and September in 1990 and 1991

Area	L_∞		K		t_0	
Male						
Bounty Platform	50.39	(49.02 – 51.75)	0.29	(0.21 – 0.37)	–0.62	(–1.62 – 0.36)
Pukaki Rise	48.66	(47.83 – 49.49)	0.34	(0.27 – 0.41)	–0.54	(–1.21 – 0.13)
Campbell Island Rise	48.42	(48.03 – 48.82)	0.40	(0.35 – 0.44)	–0.16	(–0.50 – 0.18)
Female						
Bounty Platform	53.92	(53.34 – 54.50)	0.38	(0.33 – 0.43)	0.79	(0.38 – 1.20)
Pukaki Rise	52.96	(52.18 – 53.73)	0.28	(0.22 – 0.33)	–1.33	(–2.32 – –0.34)
Campbell Island Rise	51.96	(51.39 – 52.53)	0.39	(0.34 – 0.44)	0.08	(–0.28 – 0.45)

Table 9: Mean length at age for the 1988 year class by area and sex. Mean, mean length (cm); s.d., standard deviation; n, sample size

	Bounty Platform males			Campbell Island males			Bounty Platform females			Campbell Island females		
Age	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n
3	32.58	1.93	12	34.45	1.52	64	–	–	–	35.48	1.41	102
4	35.63	1.67	56	39.39	1.34	131	37.02	1.66	58	41.12	1.58	115
5	37.59	1.91	70	41.81	1.46	53	40.48	2.18	149	44.01	1.55	68
6	40.55	2.13	60	43.75	1.56	67	43.48	2.26	61	46.31	2.07	59
7	42.33	2.04	40	45.21	2.08	29	45.96	3.10	25	47.36	2.04	47
8	44.06	2.30	17	46.22	1.44	23	47.42	2.42	26	48.92	1.92	37

Table 10: Mean length at age for the 1991 year class by area and sex. Mean, mean length (cm); s.d., standard deviation; n, sample size.

	Bounty Platform males			Campbell Island males			Bounty Platform females			Campbell Island females		
Age	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n	Mean	s.d.	n
3	32.00	1.65	107	30.97	1.85	250	33.70	1.45	58	33.06	2.26	106
4	36.09	2.04	56	33.86	2.11	90	37.65	1.87	74	36.17	2.31	197
5	38.56	2.22	70	36.46	1.95	91	40.15	2.04	97	39.13	2.59	202

Table 11: Number of fish used in the analysis by voyage, sex, and area

	Bounty Platform		Campbell Island Rise		Pukaki Rise	
Voyage	Males	Females	Males	Females	Males	Females
AEX8902	19	19	19	19	19	19
AEX9001	–	–	57	39	57	39

Table 12: The percentage of fish correctly classified using the cross validation procedure of linear discriminant analysis into each area from voyage AEX8902. CI, Campbell Island Rise; PR, Pukaki Rise; BP, Bounty Platform; *n* sample size; Var, number of variables. (priors = 33%)

	CI	PR	BP	Total	*n*	Var
Raw data						
Males	68	68	53	63	57	7
Females	58	37	84	60	57	3
Total	47	61	74	61	114	10
Ratios						
Males	68	68	74	70	57	9
Females	58	37	68	54	57	4
Total	55	66	74	65	114	11

Table 13: The percentage of fish correctly classified using the cross validation procedure of linear discriminant analysis into each area from AEX9001. CI, Campbell Island Rise; PR, Pukaki Rise; *n* sample size; Var, number of variables. (priors = 50%).

	CI	PR	Total	*n*	Var
Raw data					
Males	84	89	87	114	3
Females	82	77	80	78	2
Total	76	70	73	192	3
Ratios					
Males	83	89	86	114	2
Females	87	85	86	78	2
Total	76	75	76	192	4

Table 14: Biomass estimate and percentage of recruited southern blue whiting on northern and southern Campbell Island Rise spawning grounds from acoustic surveys (Source: Hanchet *et al.* (1994), Hanchet & Ingerson (1996a), Ingerson & Hanchet (1996))

		1993	1994	1995
North	Biomass (t)	16 000	24 000	72 500
	%	85%	18%	58%
South	Biomass	2 500	135 000	53 000
	%	15%	82%	42%

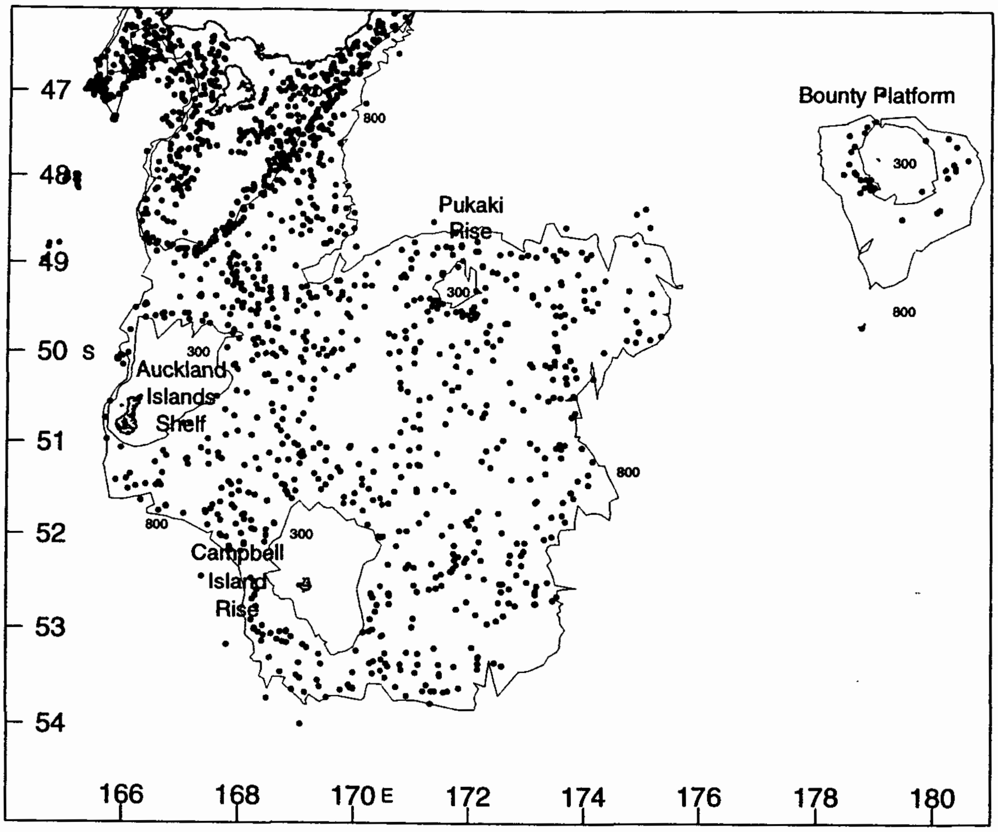

Figure 1: Location of all *Tangaroa* research tows from 1991 to 1997.

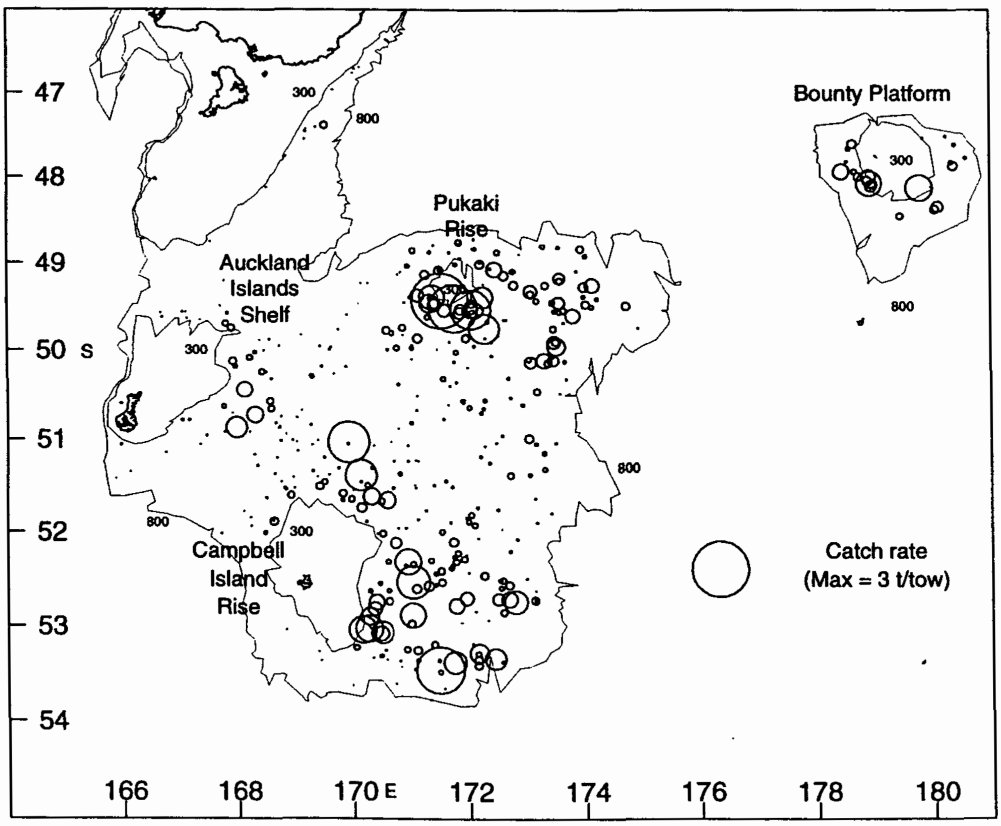

Figure 2: Catch rates (t. per tow) of southern blue whiting from all *Tangaroa* research trawls from 1991 to 1997.

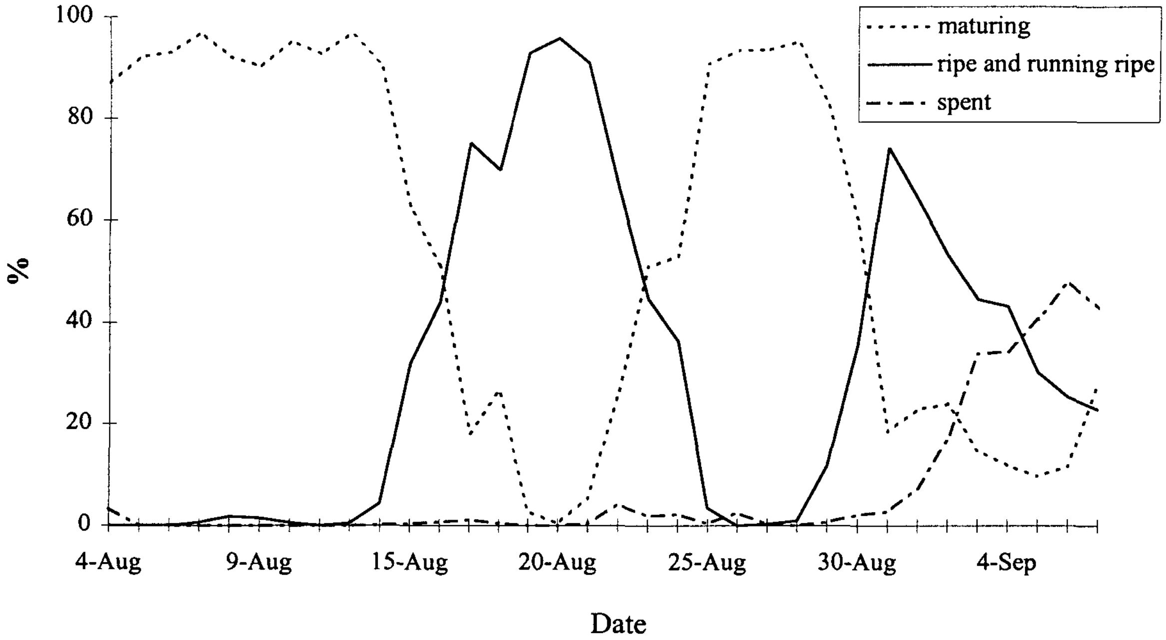

Figure 3a: Percentage of females at each gonad stage on the Bounty Platform in 1992.

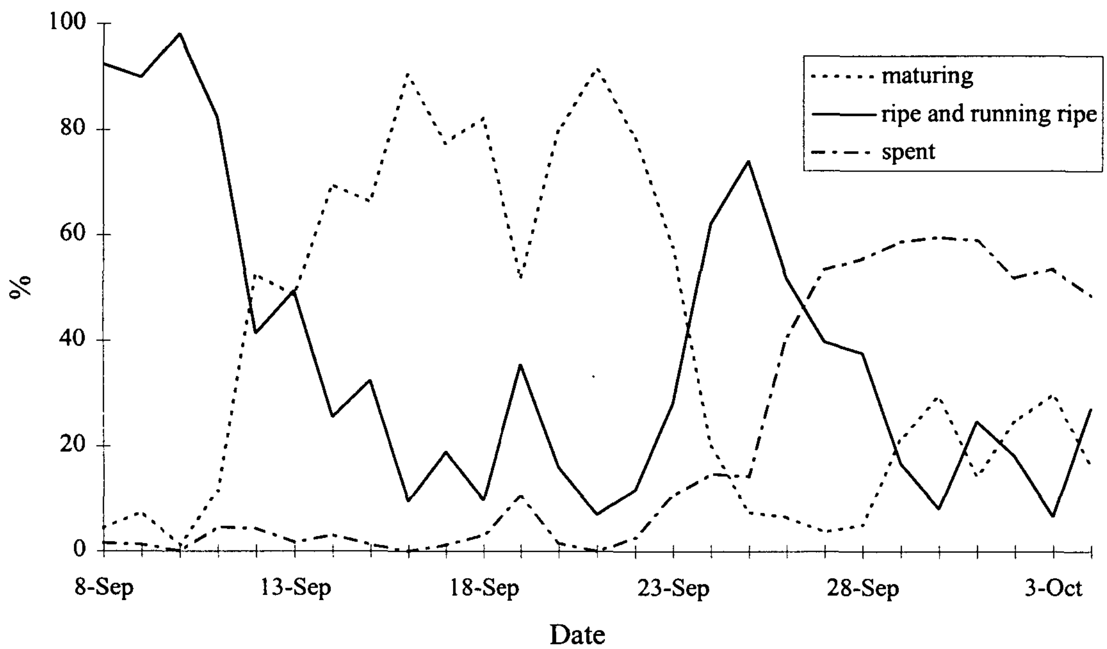

Figure 3b: Percentage of females at each gonad stage on the Campbell Island Rise in 1996.

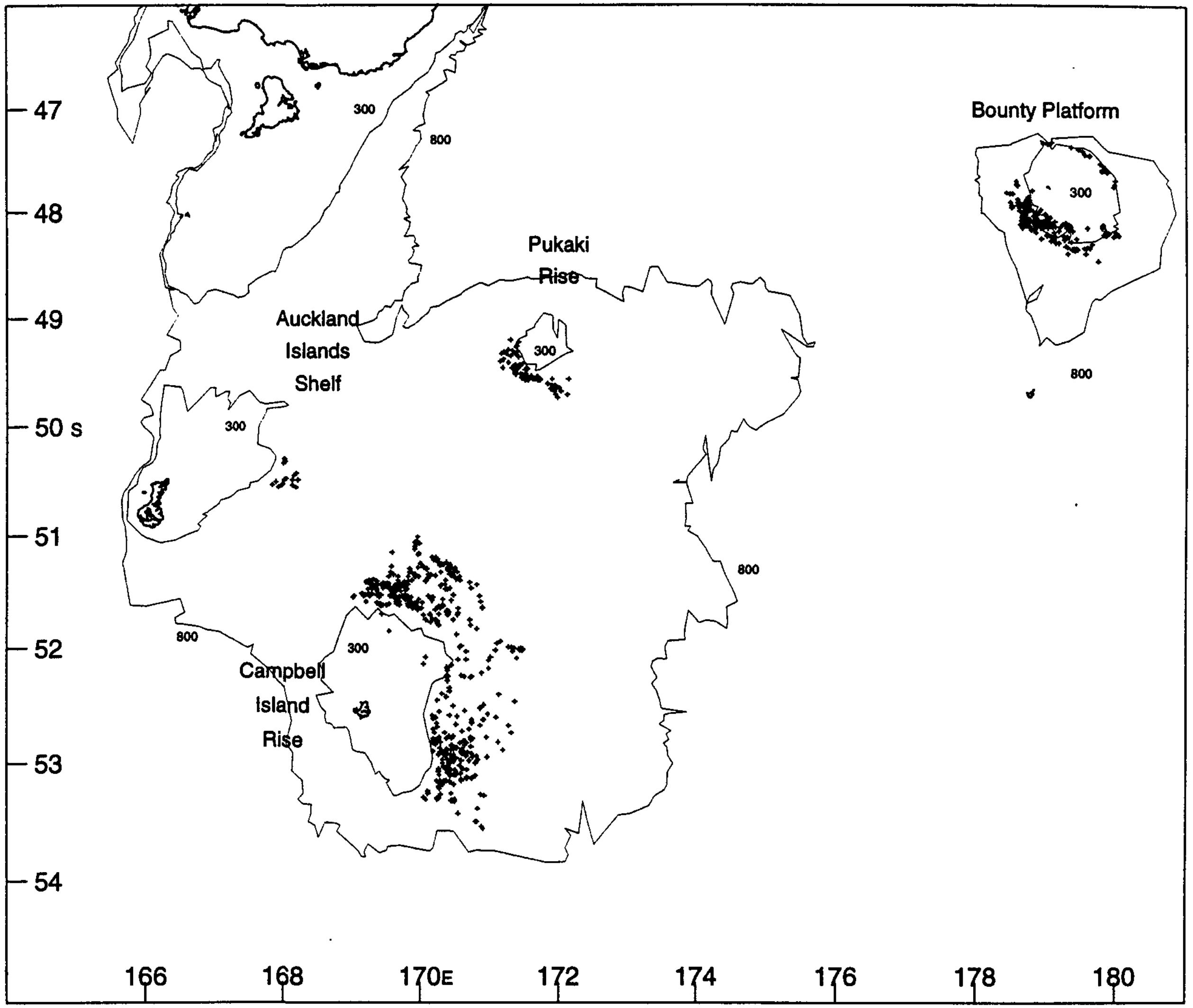

Figure 4: Positions of all observed tows catching running ripe female southern blue whiting.

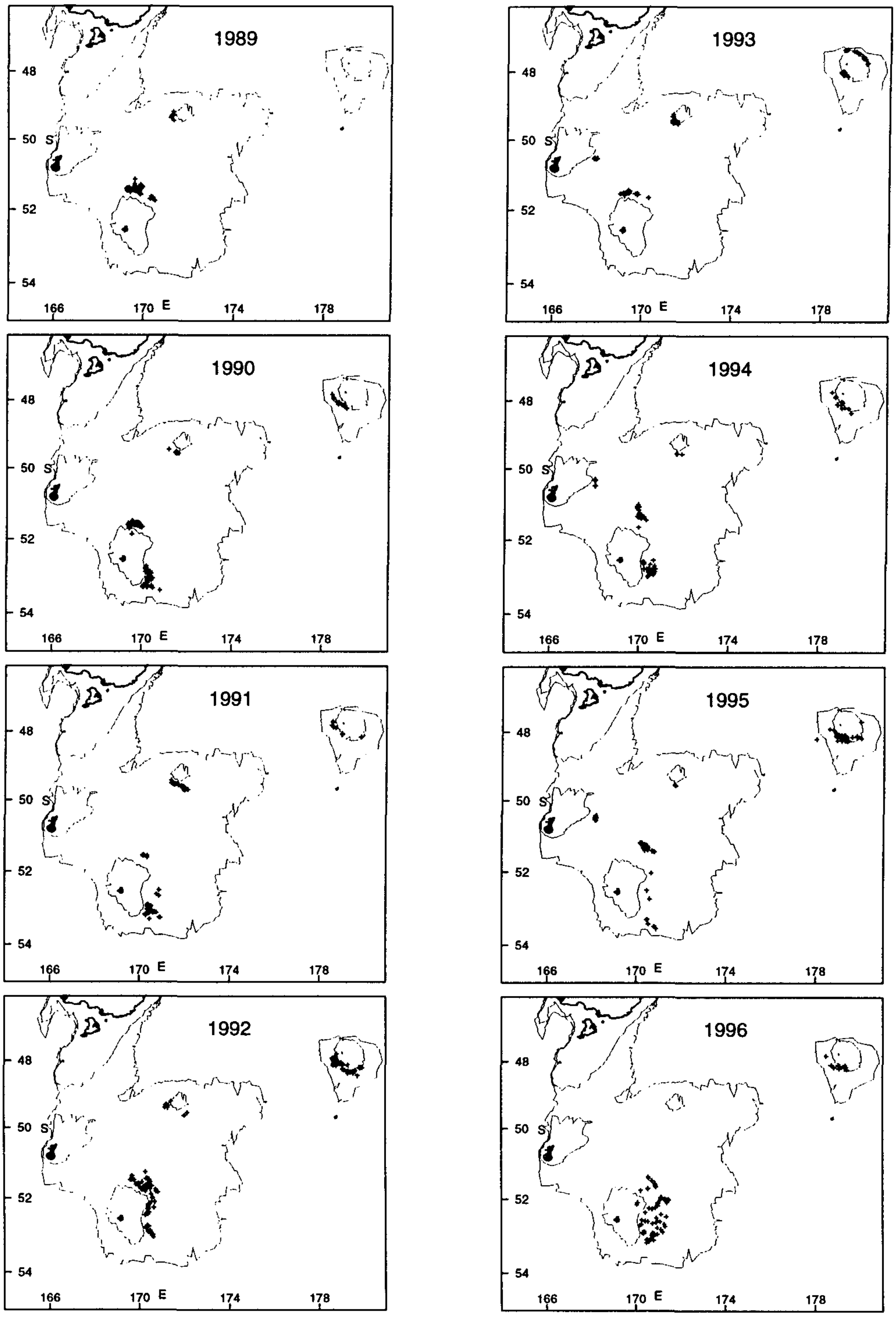

Figure 5: Locations of all observed tows catching running ripe female southern blue whiting from 1989 to 1996.

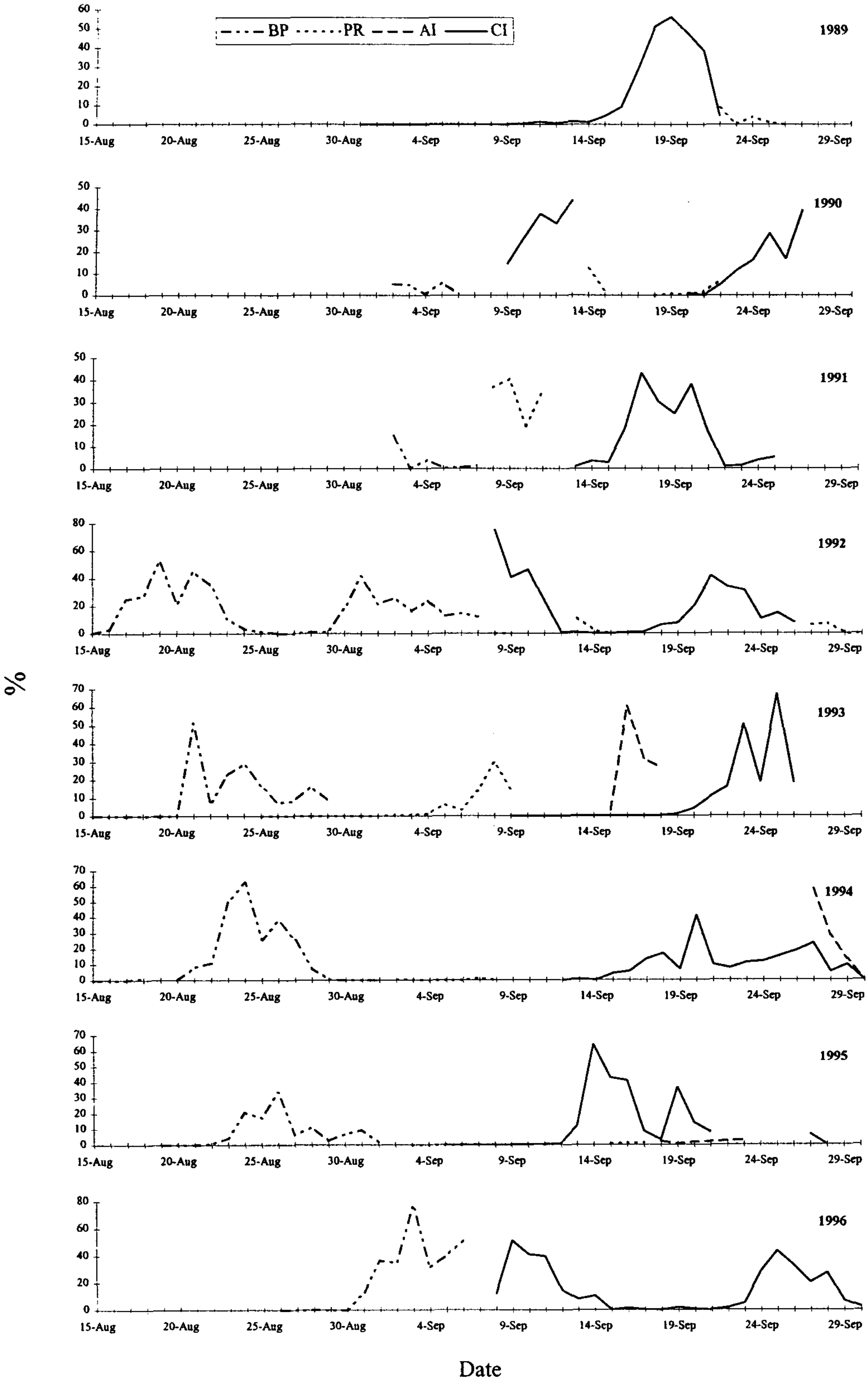

Figure 6: Percentage of running ripe females by area and year. BP, Bounty Platform; PR, Pukaki Rise; AI, Auckland Islands Shelf; CI, Campbell Island Rise.

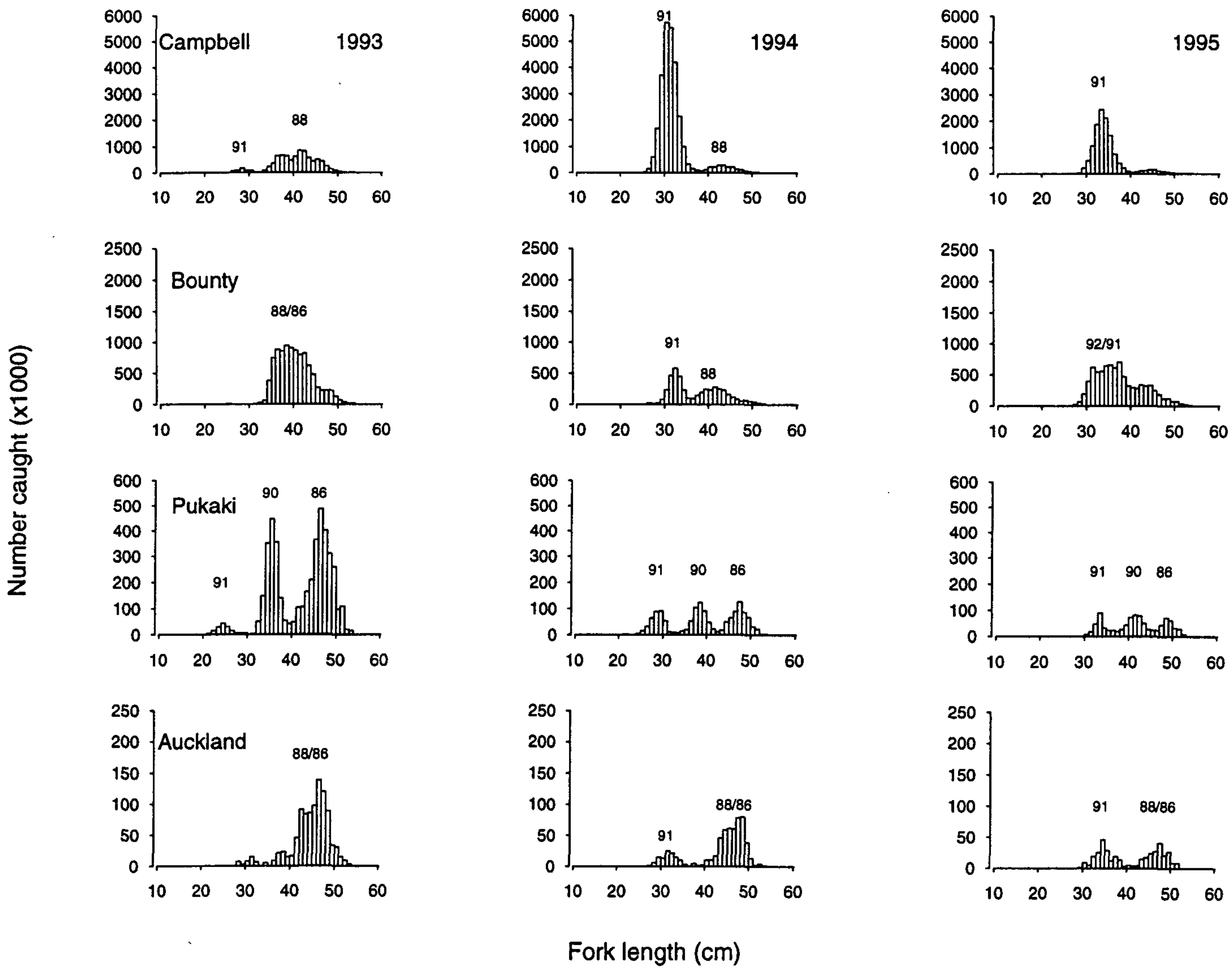

Figure 7: Weighted length frequency distribution of males in the catch by area. Numbers mark the modal lengths of strong year classes.

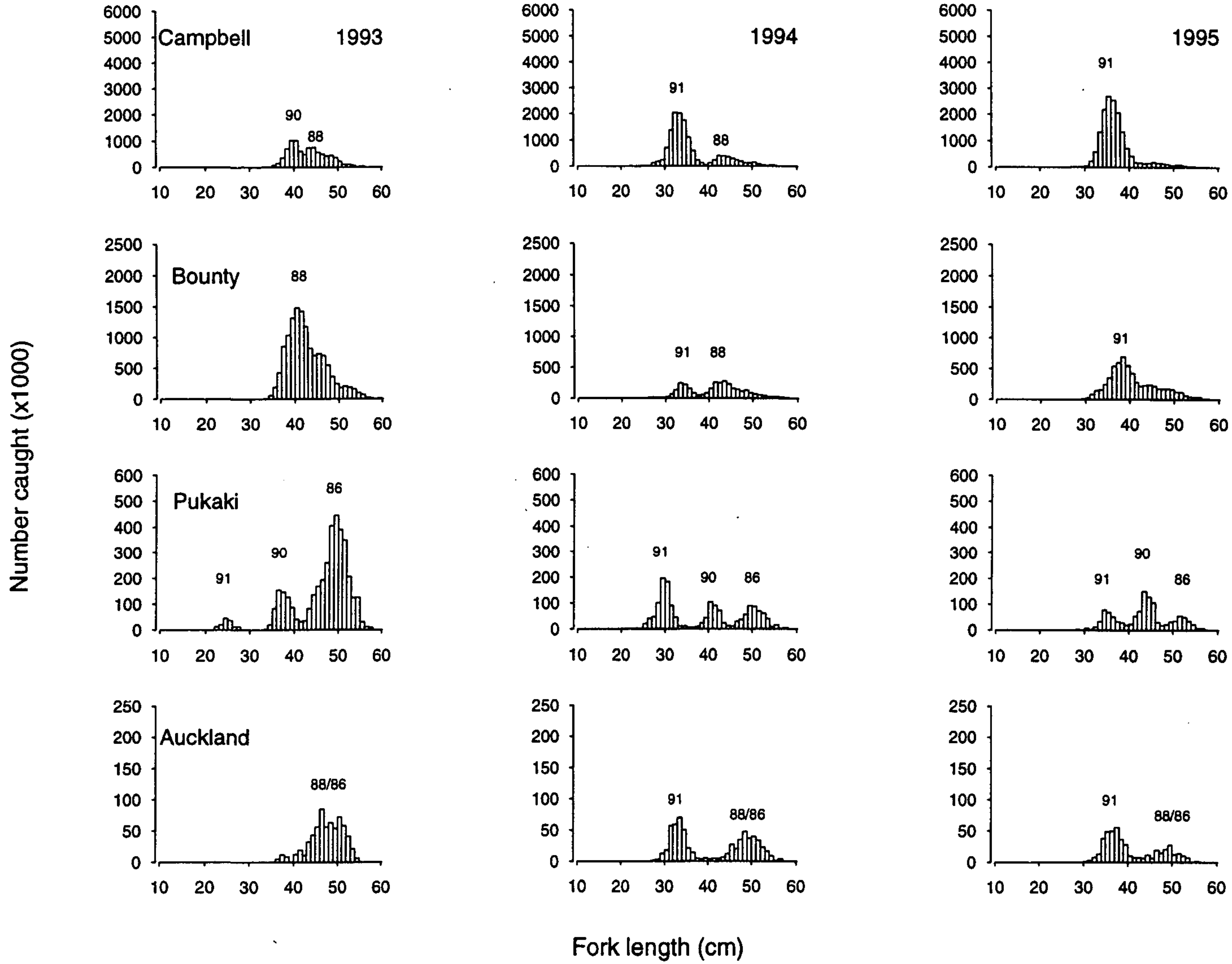

Figure 7: Weighted length frequency distribution of females in the catch by area. Numbers mark the modal lengths of strong year classes.

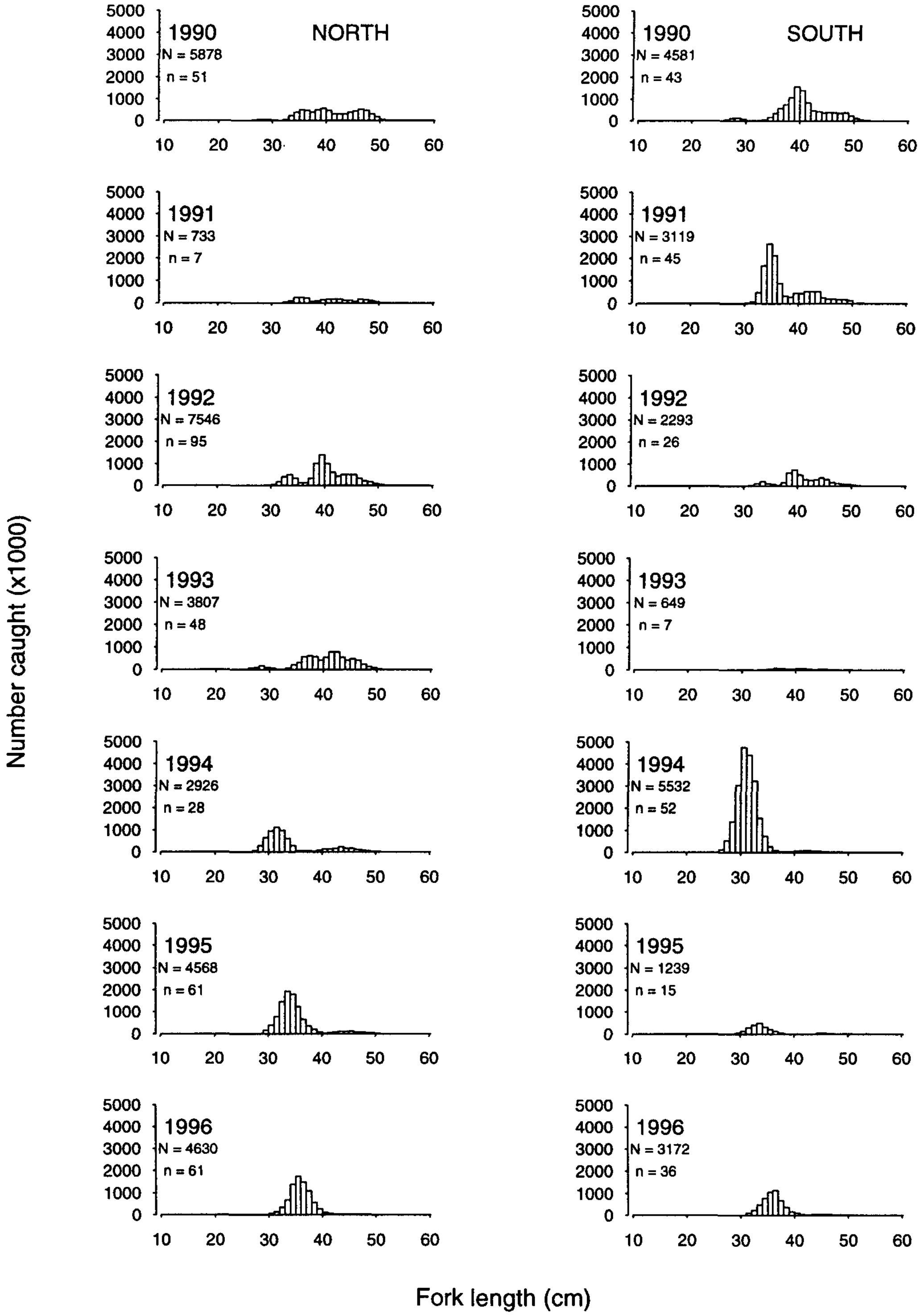

Figure 8: Weighted length frequency distribution of males in the catch from the northern and southern Campbell Island Rise. (N, number of fish measured; n, number of samples).

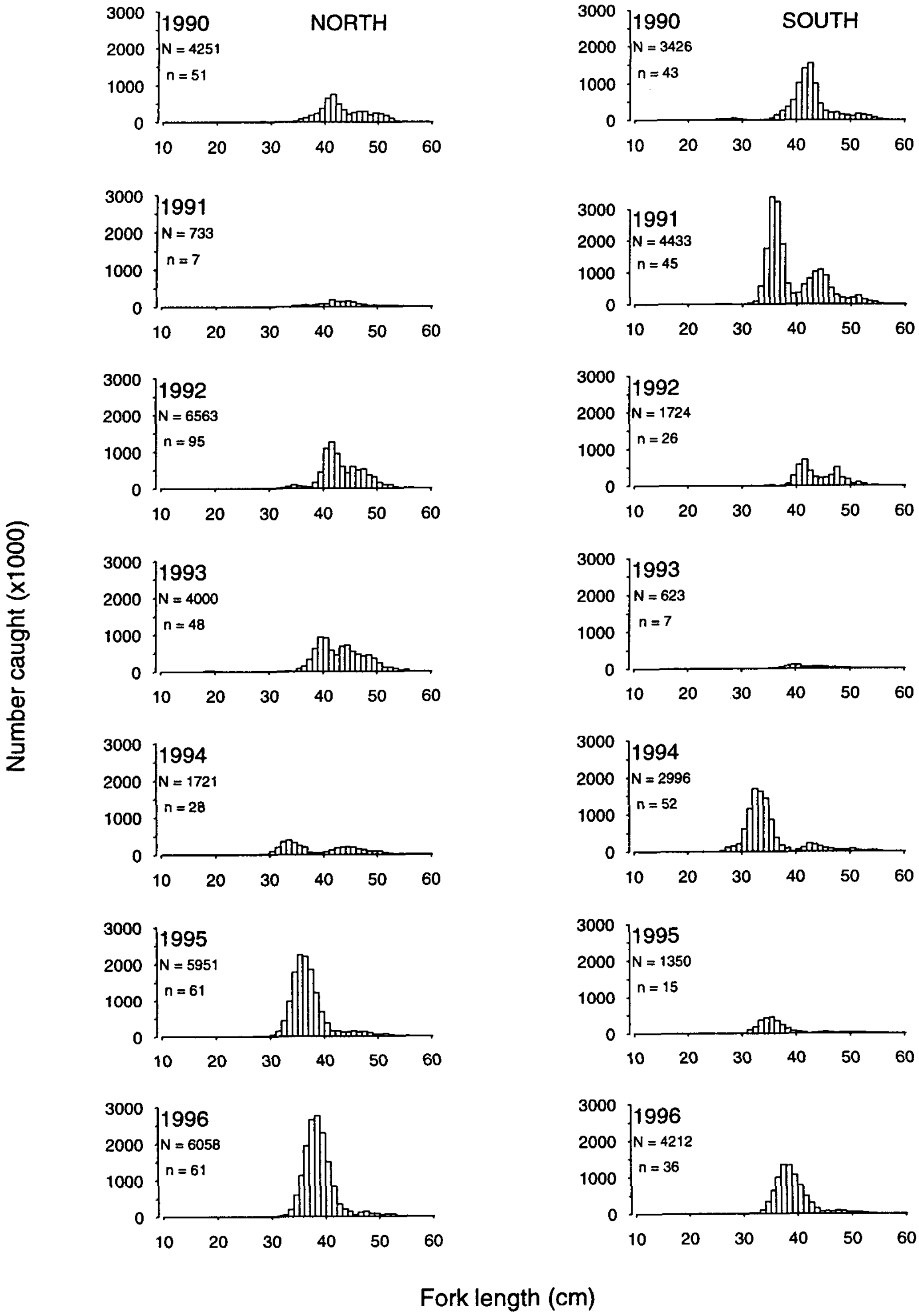

Figure 8: Weighted length frequency distribution of females in the catch from the northern and southern Campbell Island Rise. (N, number of fish measured; n, number of samples).

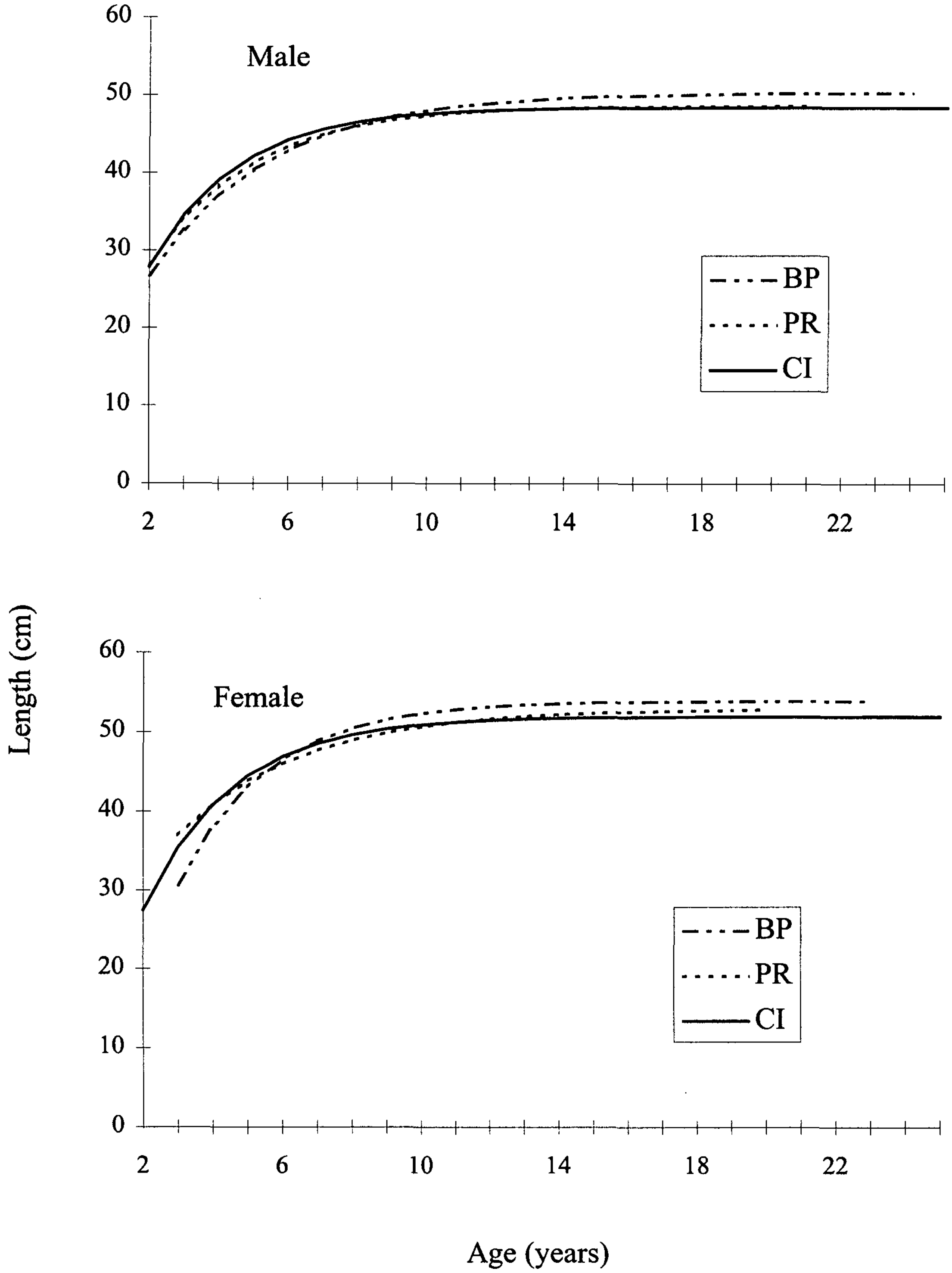

Figure 9: Comparison of male and female growth between areas.
BP, Bounty Platform; PR, Pukaki Rise; CI, Campbell Island Rise.

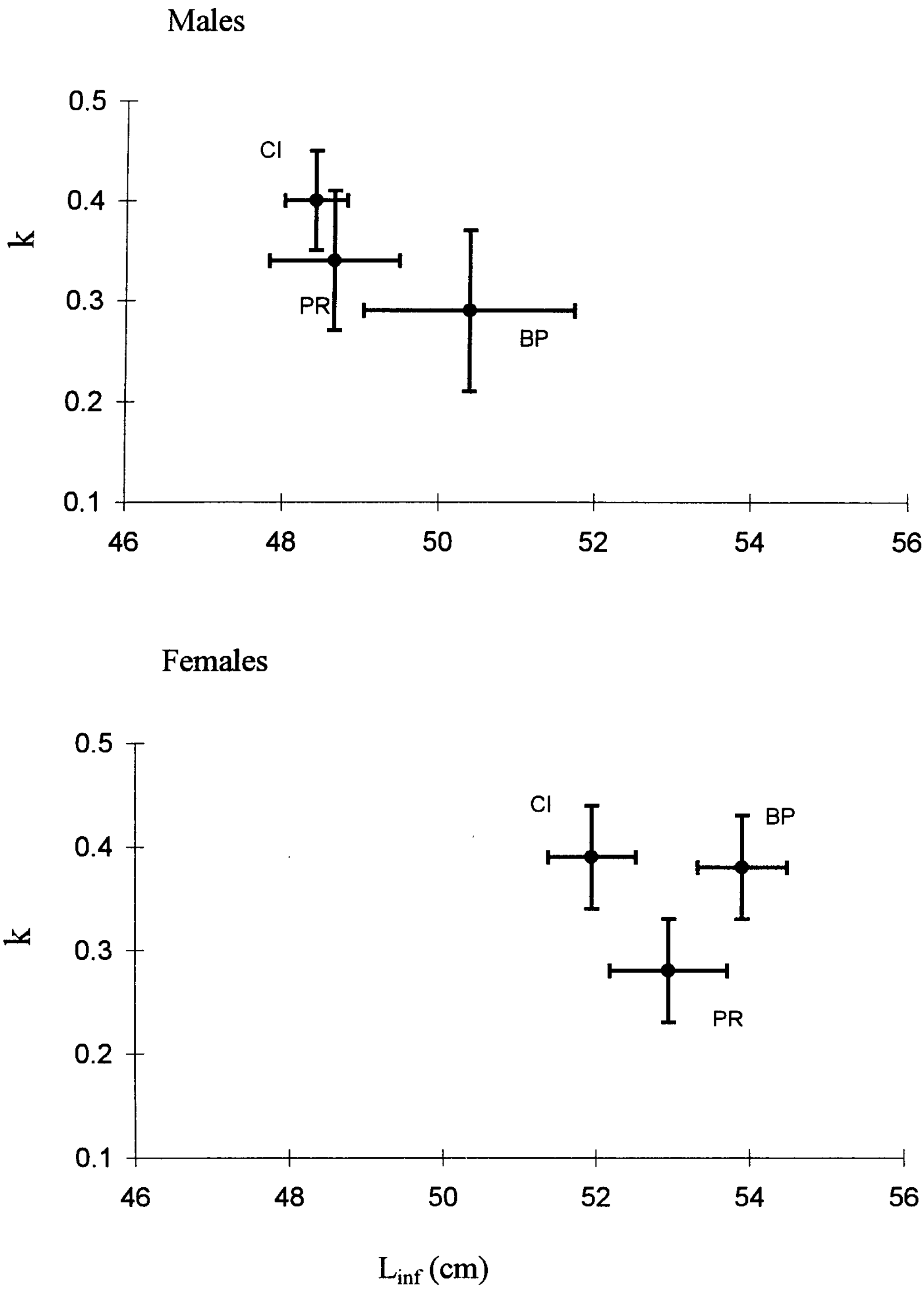

Figure 10: Estimated values of L_{inf} and k (with 95% confidence intervals). BP, Bounty Platform; CI, Campbell Island Rise; PR, Pukaki Rise.

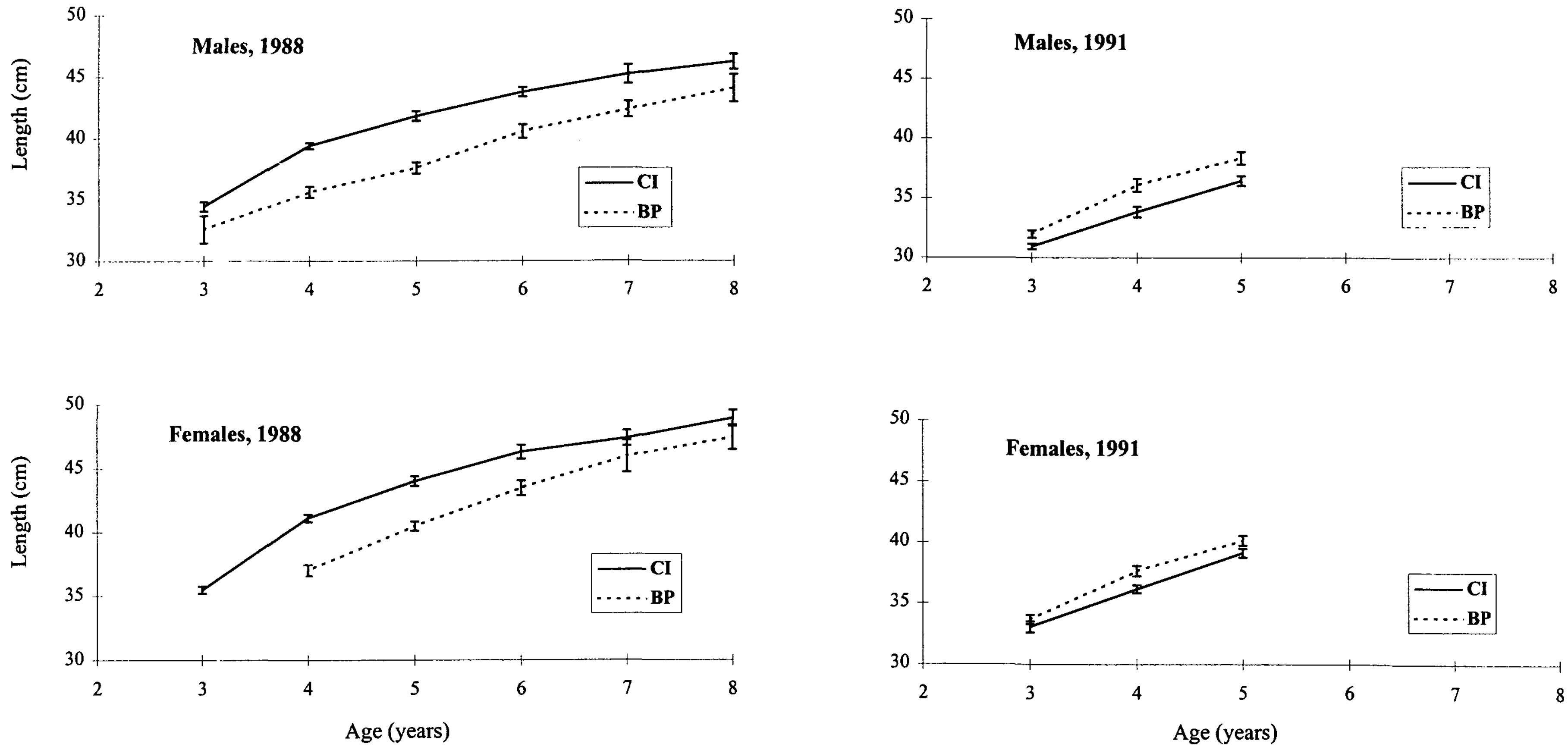

Figure 11: Mean lengths at age of the 1988 and 1991 year classes by sex and area, with 95% confidence intervals.
CI, Campbell Island Rise; BP, Bounty Platform

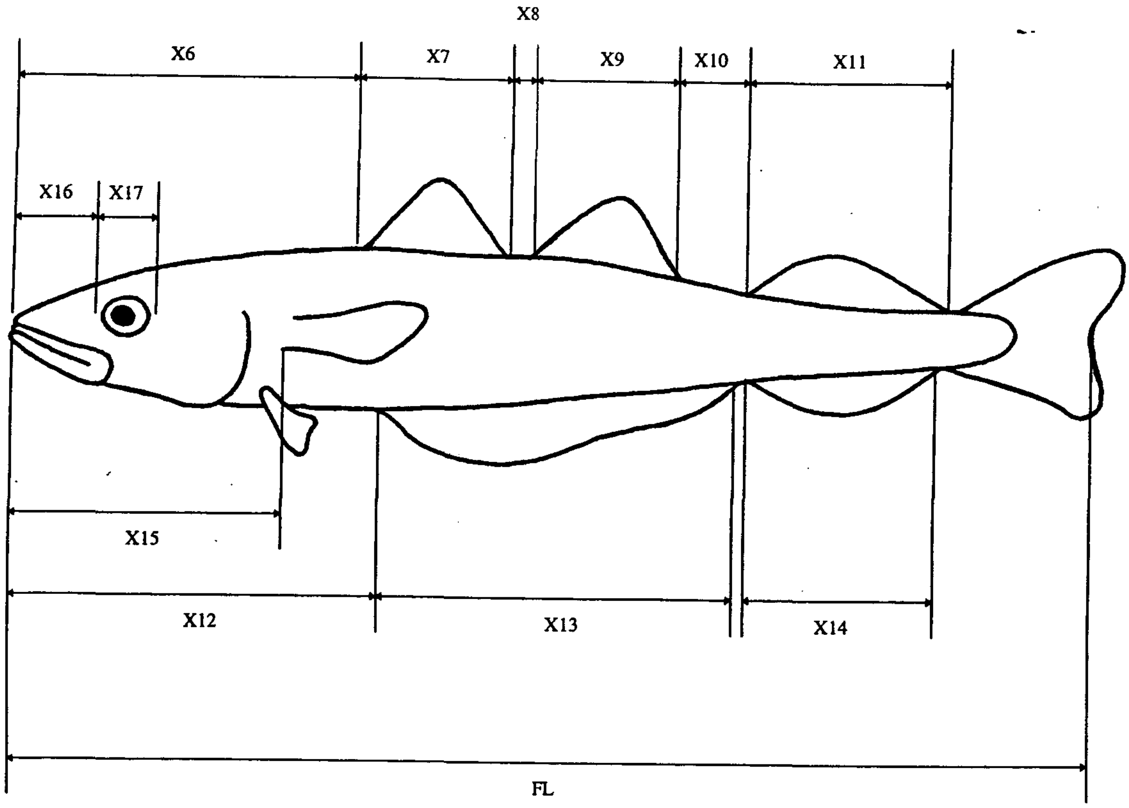

Figure 12: SBW morphometrics - reference points

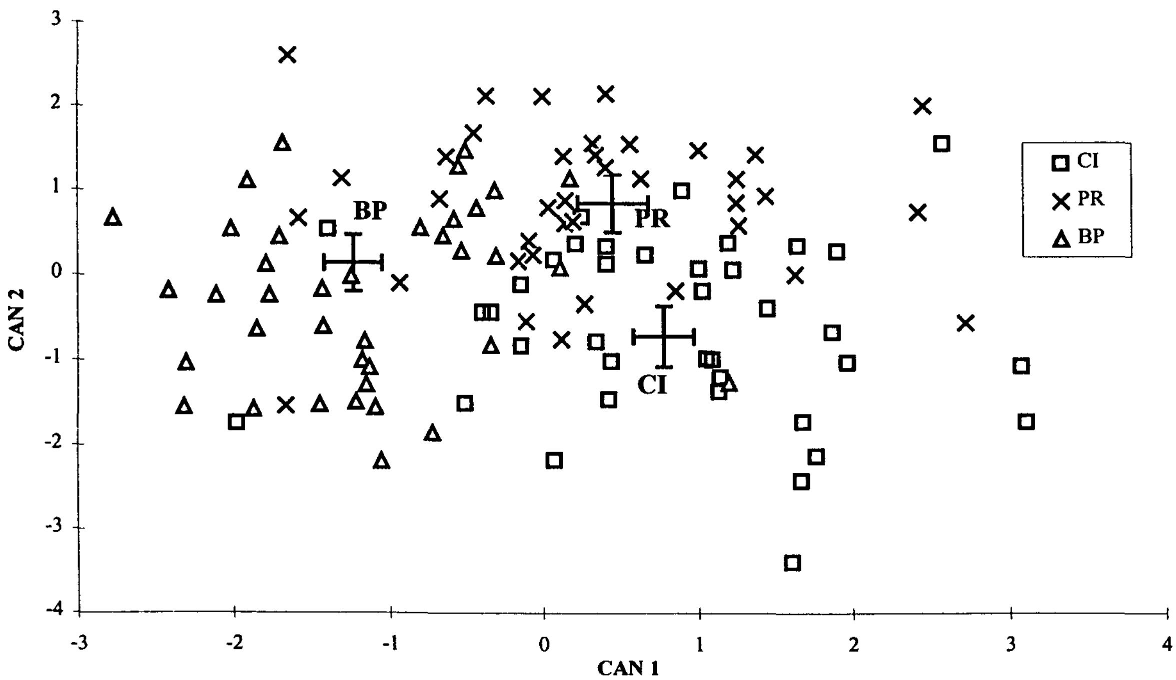

Figure 13: Class means and canonical variable scores for fish from the Campbell Island (CI), Pukaki Rise (PR), and Bounty Platform (BP) from voyage AEX8902.