New Zealand Fisheries Assessment Research Document 94/10

A validated ageing methodology using otoliths, and growth parameters for hoki (*Macruronus novaezelandiae*) off the west coast of the South Island, New Zealand

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June 1994

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N.Z. Fisheries Assessment Research Document 94/10. 23 p.

1. EXECUTIVE SUMMARY

A method is described to determine the age of hoki, using the bands in sectioned otoliths. The technique was validated using the progression of length modes in length frequency distributions (for age classes 0+ to 4+) and the progression of strong and weak year classes in age frequency distributions from commercial catches sampled off the west coast of the South Island from 1988 to 1993. Von Bertalanffy growth parameters for the west coast spawning population are estimated.

2. INTRODUCTION

The main fishery for hoki (*Macruronus novaezelandiae*) targets spawning aggregations off the west coast of the South Island (WCSI) during winter. Comprehensive length frequency data (since 1986) and otolith collections (since 1988) are available from the WCSI fishery. These data could be used in a sequential age structured model of the population if a validated ageing methodology was available.

Attempts to age hoki have been made using scales (Blagoderov 1978) and otoliths (Kuo & Tanaka 1984a, b, Kenchington & Augustine 1987, Sullivan & Coombs 1989), but none of these studies was validated past the first 3 years of growth. Preliminary studies of otoliths by MAF Fisheries researchers highlighted problems with the interpretation of the early growth zones; Kenchington & Augustine (1987) had identified similar problems. The first three growth zones are often split or consist of a series of finer bands, and many otoliths exhibit a clear ring inside the first true hyaline band. An inflated estimate of age is derived if all these bands are counted. Consequently, when readers aged a sample containing a strong year class of known age, the strong year class could not be identified correctly (Sullivan & Cordue 1994). Because of this problem Sullivan & Cordue (1994) rejected the otolith readings and used length based analysis to estimate the parameters of the von Bertalanffy growth equation using MULTIFAN.

We undertook the present study to develop a repeatable and validated methodology to age hoki using otoliths by interpreting early otolith growth and determining how many growth bands are laid down annually in the otoliths.

3. METHODS

Hoki otoliths (sagittae) were collected from 1988 to 1993 by scientific observers on commercial vessels fishing the WCSI spawning aggregations. Total length (TL, rounded to the nearest centimetre below actual length) and sex were recorded for all fish from which otoliths were taken. Samples were taken regularly throughout each season enabling length frequency data to be scaled to represent the entire catch from the fishery.

Otoliths were cleaned and stored dry in paper envelopes. For the purpose of age-length keys, stratified random samples of otoliths of each sex were selected from the total assemblage collected each year. Numbers in each sample for which ages were determined ranged from 247 to 393 for males and 246 to 439 for females. In preparation for reading, the otoliths were broken transversely through the nucleus, the broken surface was ground flat using sandpaper on a rotating disc, and the prepared section baked in an oven until amber-coloured (275 °C for 10–30 minutes, dependent on otolith size). [Note: The 1988 sample was heated in a spirit flame until amber-coloured, rather than being baked.] The sections were mounted in plasticine and the smoothed surface coated in paraffin oil. Examination under a binocular microscope (x 30), with illumination by reflected light just above the plane of the prepared surface, revealed a pattern of alternating light and dark zones (Figure 1). Measurements of ring radii were made using a micrometer eyepiece. The otolith reader had no knowledge of the size of the fish.

The growth rate of the 0+ year class (i.e., fish less than about 30 cm TL) was examined by plotting length modes of hoki caught opportunistically during a series of trawl surveys by GRV *W. J. Scott* off the northwest South Island in 1981–1983. The information was derived from entries in the survey diary noting the approximate size range of hoki caught on the trawl meshes, presumably as the net was retrieved through midwater (N. Bagley MAF Fisheries Greta Point, pers. comm.). Because the fish were generally meshed, rather than being caught in the codend, they were seldom recorded in the formal length frequency samples. Hoki less than 25 cm are seldom captured in bottom trawling operations.

Length frequency histograms from commercial landings and research trawl surveys often exhibit several modes less than 75 cm which represent separate year classes of juvenile hoki. Length frequencies of commercial landings from the west coast spawning fishery (scaled to represent total catch) are presented for the years 1989–1993. Also, the histograms from 13 trawl surveys carried out in various areas around the South Island over a period of about 2 years were examined (Table 1). By examining the rate of progression of these juvenile length modes between surveys, the age of fish in the length modes may be validated and the rate of juvenile growth determined. Examining otoliths of fish from these length modes of known age also enables the pattern of early growth of the otolith to be determined. When the banding pattern was clear and unambiguous on otoliths from the 3+ year class, measurements were made along the longest ventral axis of the section from the centre of the nucleus to the outer edges of the first three dark bands (Figure 1), and mean distances were calculated. Additional measurements of the first three radii were also made on clear otoliths from older fish. As hoki generally spawn from late June to mid September a "birthday" of 1 August was chosen.

The mean distances to the first three otolith radii were used to help interpret the age of adult fish when their otoliths had indistinct early growth patterns. By measuring out from the nucleus to points equating to the three mean radial distances and searching the otolith near those points, the likely position of the first three true dark bands could generally be determined. Because of the variance around the radial measurements, the interpretive process was intuitive rather than strictly quantitative. Individual fish grow at different rates, so a long, narrow otolith cross-section was judged to be from a faster growing fish than a short, wide one (assuming otolith width is related to fish length). Hence, the former otolith would be interpreted as having radial distances at the high end of the three ranges, while the latter would be assumed to have smaller than average radial distances. Growth zones after the first three were generally more regular and distinct, although split bands and growth checks were sometimes apparent. Dark zones in otoliths of hoki have been shown to form during the winter months (Kuo & Tanaka 1984b, Kenchington & Augustine 1987). Otoliths collected during the fishery on spawning aggregations (July to September) generally had wide dark or narrow light margins. Age was taken as the number of complete, or nearly complete, dark zones (after the interpretation of the "true" positions of the early growth bands), i.e., an otolith with five dark bands and a dark margin (the sixth band) was considered the same age as one with six dark bands and a light margin.

Validation of the ageing technique for adult fish was attempted by examining the progression of strong and weak year classes in the WCSI spawning aggregation over several years. Estimated age distributions of the commercial catch from the WCSI spawning ground each year from 1988 to 1993 were compared to demonstrate the progression of year classes through the adult population. For each year, the age distribution of the catch was constructed from the estimated length frequency of the total catch from that year and the age-length key from the otolith sample, as follows:

$$A_t = \Sigma_x(L_x \, p_{tx})$$

where A_t = the estimated proportion of fish of age t in the catch, L_x = the proportion of fish of length x in the length frequency, and p_{tx} = the proportion of aged fish of length x which were age t.

The proportions of 4 and 5 year old fish in the commercial catch based on otolith readings were also compared with those derived from length based methods using MIX software (Sullivan & Cordue 1994).

To assess the within-reader reproducibility of the results, 200 otoliths representing a range of ages, both sexes, and both clear and unclear otoliths, were read twice by one author. First and second readings were made at least 1 month apart. Between-reader comparisons will be made after another reader is taught the established reading technique.

Von Bertalanffy growth curves were fitted to the data using a non-linear least-squares regression procedure (Ralston & Jennrich 1978). Separate equations were derived for each sex, and curves were fitted for each year separately and for all years combined.

4. RESULTS

4.1 Interpretation of early growth

Plotted length modes from surveys by GRV *W. J. Scott* off the WCSI exhibit two clear diagonal groups of points (Figure 2). Fitting straight lines to the points by eye indicates that hoki have a length near zero at about July-August, which is their known spawning season.

There is also a clear indication that 1 year after spawning, hoki are about 24-30 cm long.

Length frequency histograms of small hoki (≤ 75 cm TL) caught in various research trawl surveys from 1991 to 1994 are plotted in Figure 3. Each data set (except sample 11) was scaled by percentage of catch sampled and stratum area, so the histograms represent the population of hoki in the survey area. Sample 11 is an unscaled length frequency of hoki caught by trawl during an acoustic survey. Although hoki growth may vary between areas and from year to year, these recent samples are representative of early hoki growth (Sullivan & Cordue 1994). Table 1 details the dates of the samples and the areas fished. While not all year classes are represented in all samples, it is possible to follow the progression of the 1988 and 1990–92 year classes through parts of the time series. The 1991 year class is particularly dominant and can be identified in most samples. The 1992 year class is also quite clear. The 1988 year class is clear in samples 2 and 3, and appears again a year later in sample 8. The modal size of the 1988 year class in January 1993 (sample 8) is similar to the modal size of the strong 1987 year class about a year earlier (sample 2). Analyses of length frequencies from research surveys have indicated that the 1989 year class is virtually non-existent (Sullivan & Cordue 1994); this conclusion is adopted here. The 1990 year class can be traced through most distributions. It appears to grow very fast from late 1992. Other examples of variation in growth rates between years are apparent, e.g., on the Southern Plateau in May 1992 (sample 5, Figure 3) the modal size of the 1+ year class was 47 cm, while a year later (sample 9) the next 1+ year class had a mode of 42–43 cm.

Length frequency histograms of the commercial catch from the west coast spawning fishery show the progression of the strong 1987 year class from age 2 to age 6 (Figure 4). The strong 1991 year class is also apparent in the 1993 length distribution. The data also indicate that female hoki grow faster than males, and that males appear to recruit to the spawning fishery about a year earlier than females. The patterns seen in the length distributions of the male hoki are mimicked in the following year in the female length frequencies.

From the length frequency modes in Figures 2, 3, and 4 it is apparent that hoki generally grow to about 27–30 cm TL in their first year of life, 42–47 cm in the second, 55–58 cm in the third, and 63–68 cm by age 4.

While some otoliths from 1+ fish exhibited a single dark band, many others had either two dark bands or a series of narrow bands. Although the ages of these fish could be determined with confidence from the progression of the length frequency peaks, determining their age by counting dark bands would often give incorrect estimates. The banding pattern laid down during the second and third years of growth can also be complex and difficult to interpret without the added information provided by the length frequency distributions.

To aid the interpretation of early growth in otoliths, measurements were made from the nucleus to the outer edges of the dark zones on otoliths from fish at least 3 years old where the first three bands were clear. Distributions of the measurements (with means and 95% confidence intervals for the raw data) are shown in Figure 5. There is no overlap of the 95% confidence intervals for the first and second radial measurements, but some overlap of the confidence intervals for the second and third measurements. These ring sizes correspond closely to radial measurements of whole otoliths from fish known from length frequency distributions to be of ages 1, 2, or 3 years and sampled in winter months (Table 2).

4.2 Growth parameters

The von Bertalanffy growth curve parameters (with asymptotic 95% confidence intervals for the estimates) for fish from the WCSI spawning aggregation are given in Table 3 for each sample and for all samples combined. The apparent wide variation in parameter values between samples is expected as the von Bertalanffy parameters are strongly dependent on the extremes of the age range and size range of available data. Many of the samples comprise few fish younger than 4 years (Tables 4 and 5), so t_0 is poorly defined. The 1988 female sample had a relatively large number of large fish (Table 4), resulting in a high value of L_∞. The parameters most likely to represent mean growth rate in the population are those derived from the combined samples. However, even in the combined data set, young fish (particularly ages 1 and 2) are still poorly represented, and those caught in the WCSI spawning fishery may not be truly representative of the mean size of their year class.

To estimate population growth parameters that will be applicable over the entire life of the fish, it is necessary to add information on the growth of juvenile hoki. Mean lengths for all New Zealand hoki at ages 1, 2, and 3 as determined from modes in length frequency distributions (described above) are 28, 44, and 56 cm TL, respectively. A length-based data set of 300 points was created comprising three sets of 100 points, each normally distributed with means at 28, 44, or 56, and CVs of 5%. This is the mean CV of hoki juvenile modes measured by one of the authors (Sullivan & Cordue 1994). The length-based data were combined with all observed age-length data for ages 4 and older. Von Bertalanffy parameters fitted to these combined data (Table 3) are considered to be the best descriptors of growth for the hoki population that spawns off the WCSI. The calculated curves fit the observed data well (Figure 6). Growth rates for male and female hoki are significantly different. Female fish have a greater L_∞ (102.0 cm TL compared with 90.8 cm for males), but males have a higher k (0.286 compared with 0.230).

The effect of using length-based data sets of different sizes was examined. Sets of 30, 150, 300, and 600 points were created, with the same means and CVs as described above. Adding more points reduced L_∞, increased k, and moved t_0 closer to zero. The parameters calculated using the two largest data sets were similar to at least two significant figures, so it was concluded that adding any more than 300 points would not improve the quality of the calculated parameters. All the data sets produced growth curves that were virtually identical over the age range 5–13 years, which makes up most of the commercial catch.

Mean lengths at age for each sample, by sex, are presented in Tables 4 and 5. Maximum age from all samples was 20 years for females and 15 years for males. For the bulk of the commercial catch (i.e., fish of age 5–11), mean length at a particular age can vary by up to 7 cm across the six samples, for both sexes.

4.3 Sample age structures

The frequency distributions of each age group in the commercial catch are shown in Figure 7. The bulk of the commercial catch of female hoki is age 6–11 years, and 5–10 years for males. Based on observations of the 1987 year class, males do not appear to recruit fully into the spawning fishery until age 5 (Figure 4). Females appear to recruit to the fishery a year older than male hoki.

The estimated proportions at age (with coefficients of variation) are given in Table 6. The CVs of the strong year classes are quite small (0.05 in some instances) and show that the proportions at age are well estimated.

The marked change in the age-frequency distribution of fish in the commercial catch over time (Figure 7) is probably due to a combination of fishing pressure and recent strong year class strengths. Before 1986, landings from the western hoki stock were generally less than 40 000 t annually (Sullivan & Cordue 1994). Landings peaked at 240 000 t in 1988, and have declined since then. The intensive fishing in the late 1980s would have removed many of the older fish from the stock. Hence, when a strong year class first recruits into the fishery it can dominate the age distribution until a younger strong year class appears. This pattern is apparent for the 1983, 1984, and particularly the 1987 year classes.

4.4 Age replication

The results of the within-reader comparison are shown in Table 7. Of the 200 otoliths examined twice, 66.5% were aged identically, 29% differed by 1 year, and the remaining 4.5% differed by 2 years. There was no apparent bias in the ageing error. Precision declines with age, so the estimates of catch at age will also be less reliable for older year classes. For fish aged 2–10 years at the first reading, 71% of paired readings were identical, but only 50% were identical for fish older than 10.

4.5 Age validation

Growth by hoki up to 4 years old was validated using the progression of modes in length frequency distributions (described above). The progression of weak and strong year classes through the estimated catch age distributions (Figure 7) was used to validate older ages. Strong 1987 and weak 1986 year classes are apparent for both sexes in samples since 1991. Strong year classes spawned in 1983 and 1984 progress throughout the entire set of samples, though their dominance is diluted from 1992 by the 1987 year class. In general, the distributions from the same year for male and female fish are similar, and strong or weak year classes do progress through the samples in a way which supports the hypothesis that one dark band is laid down annually in the otoliths of adult fish. While some anomalies are apparent (e.g., weak 10 year old male year classes in both the 1989 and 1990 samples), ageing error probably results in poor estimation of older age class strengths. The 1988 distributions have a relatively high proportion of older fish, particularly for females. This is expected as the fishery in 1988 had not been operating for many years at a large scale (Sullivan & Cordue 1994).

Further support for the ageing method is derived by examining the progression of mean length at age of particular year classes. Growth rates can vary between years for juvenile fish, and hence, probably for adults also, but by tracing down the diagonals in Tables 4 and 5, it is apparent that the mean length of a particular year class almost always increases (at least where $n \geq 5$ for any year class in any year).

The estimated proportions of 4 and 5 year old fish in the catch from the WCSI spawning season, calculated here from the otolith data, may be compared with the proportions derived by Sullivan & Cordue (1994) using MIX software (length based analysis) in Table 8. Similar patterns of strong and weak year classes were apparent from the two methods.

5. DISCUSSION

The interpretation of otoliths of merluccid species has generally been controversial due to the complex nature of the early growth zones, the common occurrence of growth checks, and the frequent lack of clarity of true annuli (e.g., Wysokiński 1983, Penttila & Dery 1988). Although the otoliths of many *Merluccius* species have been examined, studies of *Macruronus* species are few. Kenchington & Augustine (1987) presented a detailed interpretation of the otoliths of *Macruronus novaezelandiae* from off southeastern Australia and validated the ageing methodology to 3 years using the progression of length frequency modes. Sullivan & Coombs (1989) presented growth parameters for New Zealand hoki based on interpretation of otolith readings, but Sullivan & Cordue (1994) found that this method gave unreliable results. Aguayo & Gili (1984) used both a quantitative marginal increment analysis and a qualitative study of otolith edge composition to attempt to validate the ageing of *Macruronus magellanicus* from off Chile.

The results of the present study agree closely with those of Kenchington & Augustine (1987) and have validated the growth of *Macruronus novaezelandiae* to age 4 using progression of length frequency modes, and from age 4 onwards using the progression of strong and weak year classes over a 6 year period. Inconsistencies in the year class progression data occur mainly at older ages where sample numbers are small and the precision of age reading declines.

Comparisons of the present work with previous ageing studies of *Macruronus* species (other than that by Kenchington & Augustine 1987) are probably not valid. Kenchington & Augustine (1987) compared their work with that of Kuo & Tanaka (1984a, b), and concluded that different ageing techniques and the lack of access to small fish in the latter study were responsible for the differences in conclusions. Some studies have counted the relatively common band inside the first true dark zone as the first true annulus (Kuo & Tanaka 1984b, Aguayo & Gili 1984, Tomo & Torno 1987). Deducting 1 year from the ages in these publications makes the three data sets quite similar to the first few years of the growth curve presented here.

No complete age validation of *Macruronus* species has been presented in any previous study. Aguayo & Gili (1984) provided an analysis of otolith margins, but they had only 6 months of data. Previous investigations have used whole otoliths either untreated (Aguayo & Gili 1984) or ground thin (Kuo & Tanaka 1984a), but these methods are likely to underestimate the ages since the annuli in otoliths of older fish are either very close together or tend to thicken the otolith rather than increase its width. The reported maximum age from these studies, and that of Blagoderov (1978) using scales, was 13 years.

All otoliths in the present study were ultimately examined as baked sections to ensure a consistent technique and aid the interpretation of the early growth bands, but it is possible to determine the ages of fish up to about 6 years by examining whole otoliths using the method of Kenchington & Augustine (1987). Fish in the 0+ to 2+ year classes could be accurately aged from their position in the length frequency histogram, as there is usually little or no overlap in length modes of these year classes. However, it is essential that otoliths older than about 7 years be examined in section as older rings can either be too narrow to clearly distinguish on whole otoliths or can be added in a manner that thickens the otolith rather than increases its width. The interpretation of the early growth bands in otolith sections is a problem that can only be solved by experience. Measurement of radii, combined with a subjective analysis of the otolith shape, can help with this interpretation. The developed methodology appears to provide relatively precise results, with 67% of otoliths covering a wide age range being aged the same at both readings. However, precision does decrease with increasing age.

Female hoki are larger than males at corresponding ages, and also appear to have a greater life expectancy. Similar trends were indicated for *Macruronus magellanicus* off Chile (Tomo & Torno 1987), but Blagoderov (1978) and Kuo & Tanaka (1984b) found no significant differences between sexes for New Zealand hoki.

Hoki grow rapidly during the years before first spawning, but the growth rate slows markedly near sexual maturity (at about 4 and 5 years for males and females, respectively). The calculated growth curves for each sex for all sample data combined were virtually identical to those given by Kenchington & Augustine (1987). However, the maximum recorded age for Australian hoki is about 5 years greater than for New Zealand fish examined in this study. The fishery off the WCSI has been operating since about 1976 (Sullivan & Cordue 1994), so the first sample examined here (1988) was not from a virgin fishery. The von Bertalanffy parameters calculated from the sample data combined with the set of length-based juvenile growth data differ slightly from those given by Kenchington & Augustine (1987) in that the t_0 values are nearer to 0 and the k values are greater (Table 3). This difference is caused by the inclusion of juvenile data which forces the curve to better describe juvenile growth. It is recommended that this set of parameters be used in any future modelling of the western hoki stock.

6. ACKNOWLEDGMENTS

We thank Neil Bagley for providing the information on length modes of juvenile hoki caught during surveys by GRV *W. J. Scott*, Sira Ballara for preparing Figure 4, and Mary Livingston and Malcolm Francis for their useful reviews of the manuscript.

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Table 1: Details of length frequency samples of young hoki collected during research surveys. Trip code prefixes: TAN, GRV *Tangaroa*; KAH, GRV *Kaharoa*. *n* = number of fish ≤ 75 cm measured during the survey

Sample no.	Trip code	Date	*n*	Area
1	KAH9111	Nov 91	12	South Taranaki Bight
2	TAN9105	Nov-Dec 91	9 619	Southern Plateau
3	TAN9106	Jan 92	26 943	Chatham Rise
4	KAH9204	Apr 92	5 305	West coast South Island
5	TAN9204	May 92	4 599	Southern Plateau
6	TAN9209	Sep-Oct 92	1 566	Southern Plateau
7	TAN9211	Nov-Dec 92	5 416	Southern Plateau
8	TAN9212	Jan 93	24 998	Chatham Rise
9	KAH9301	Jan 93	1 376	Lower east coast North Island
10	TAN9304	May 93	2 434	Southern Plateau
11	TAN9307	Aug 93	756	West coast South Island
12	TAN9310	Nov-Dec 93	3 824	Southern Plateau
13	TAN9401	Jan 94	26 658	Chatham Rise

Table 2: Measurements from the nucleus to the outer margins of the first three dark bands on the ventral sides of otolith sections, and measurements of the ventral radii of whole otoliths collected from various areas around the South Island in winter from fish known to be of age 1, 2, or 3 years. CI = 95% confidence intervals for the raw data

Nucleus to band measurements

	1st band	2nd band	3rd band
Mean (mm)	2.28	2.89	3.31
n	109	109	109
CI	±0.24	±0.26	±0.23

Whole otolith radii

	Age 1	Age 2	Age 3
Mean (mm)	2.20	2.84	3.40
n	15	30	37
CI	±0.44	±0.33	±0.32

Table 3: Von Bertalanffy parameters (with 95% confidence intervals) for hoki from the WCSI spawning population calculated, by sex, for each otolith sample separately, all otolith samples combined (All), and for a data set combining all otolith readings ≥ 4 years and length-based estimates of juvenile growth (Age + Lgth). K&A 1987 = parameters calculated for hoki from southeastern Australia by Kenchington & Augustine (1987), with confidence limits expressed as asymptotic standard errors

Year	*n*	L_∞		*k*		t_0	
Female							
1988	385	118.9	(108.2-129.5)	0.107	(0.071-0.142)	-3.32	(-5.07 to -1.47)
1989	246	100.0	(97.1-103.0)	0.233	(0.192-0.274)	-0.74	(-1.46 to -0.02)
1990	268	103.1	(100.1-106.1)	0.222	(0.188-0.256)	-0.59	(-1.15 to -0.02)
1991	389	103.6	(100.1-107.0)	0.214	(0.179-0.249)	-0.90	(-1.52 to -0.29)
1992	400	101.0	(95.8-103.5)	0.236	(0.203-0.269)	-0.79	(-1.31 to -0.26)
1993	439	107.5	(104.4-110.6)	0.184	(0.161-0.207)	-1.07	(-1.56 to -0.58)
All	2127	104.0	(102.8-105.2)	0.200	(0.186-0.213)	-1.09	(-1.35 to -0.82)
Age + Lgth		102.0	(101.1-102.9)	0.230	(0.222-0.238)	-0.46	(-0.54 to -0.37)
K&A 1987		99.3	(± 0.7)	0.203	(± 0.007)	-1.48	(± 0.11)
Male							
1988	307	97.9	(93.3-102.5)	0.168	(0.129-0.207)	-1.97	(-3.01 to -0.93)
1989	247	89.8	(87.5-92.1)	0.313	(0.259-0.366)	-0.05	(-0.65 to 0.55)
1990	248	90.4	(87.7-93.1)	0.283	(0.231-0.334)	-0.38	(-0.94 to 0.18)
1991	393	93.6	(91.1-96.1)	0.250	(0.219-0.282)	-0.77	(-1.14 to -0.41)
1992	292	97.6	(91.1-104.2)	0.177	(0.117-0.236)	-2.39	(-3.89 to -0.90)
1993	284	94.3	(91.4-97.2)	0.264	(0.231-0.296)	-0.39	(-0.69 to -0.09)
All	1771	91.9	(90.8-92.9)	0.262	(0.246-0.278)	-0.63	(-0.83 to -0.44)
Age + Lgth		90.8	(90.0-91.5)	0.286	(0.276-0.296)	-0.32	(-0.39 to -0.25)
K&A 1987		90.7	(± 0.6)	0.256	(± 0.009)	-1.21	(± 0.11)

Table 4: Mean length at age for female hoki, by sample. Mean = mean length (cm TL); s.d. = standard deviation; *n* = sample size

	1988			1989			1990			1991			1992			1993		
Age	Mean	s.d.	*n*	Mean	s.d.	*n*	Mean	s.d.	*n*	Mean	s.d.	*n*	Mean	s.d.	*n*	Mean	s.d.	*n*
1	-			-			-			34.5	2.1	2	30.0	0.0	2	31.0	1.4	2
2	-			45.5	3.0	4	42.5	3.5	2	-			45.3	1.2	3	44.9	2.5	10
3	46.0	-	1	-			56.1	3.6	18	59.3	3.7	11	59.3	7.0	4	51.0	5.7	2
4	64.0	2.8	11	68.8	3.6	6	67.0	2.3	7	65.6	3.7	22	68.2	3.9	19	62.0	5.1	4
5	68.9	2.8	16	75.2	4.0	14	75.1	4.2	7	72.1	4.1	12	76.2	5.4	99	75.6	3.9	34
6	74.3	3.6	31	79.2	3.6	47	80.0	5.2	39	81.4	5.2	52	82.1	4.0	9	78.6	4.6	146
7	80.0	4.3	32	82.4	4.0	35	83.9	5.2	55	85.2	4.7	83	83.9	5.5	38	81.1	4.6	15
8	85.9	4.6	51	86.9	5.0	29	87.1	5.8	26	88.0	6.6	75	88.3	5.5	38	85.5	5.5	57
9	85.8	4.4	32	88.7	5.1	27	89.0	6.2	32	89.8	5.8	42	89.1	3.9	56	90.0	5.8	50
10	87.9	5.0	52	93.8	7.1	26	92.6	5.1	20	92.5	6.2	31	91.9	6.1	26	92.9	5.5	35
11	91.4	6.4	43	94.4	6.3	19	97.4	6.0	15	93.5	8.8	20	95.1	5.5	24	97.3	7.0	21
12	96.2	6.8	53	93.3	5.8	16	96.8	5.3	13	95.9	9.2	17	97.8	9.3	14	97.3	8.6	23
13	96.4	7.2	25	95.1	6.8	15	97.1	9.0	9	98.5	6.0	10	94.9	4.6	9	99.5	6.9	10
14	103.1	6.5	15	97.7	9.5	3	100.1	6.9	14	106.2	6.1	5	99.3	7.6	10	101.7	9.3	14
15	103.0	10.2	13	100.0	7.3	4	107.7	4.5	3	99.8	9.7	5	101.5	12.6	4	100.3	13.1	4
16	104.0	6.3	5	-			102.0	12.5	4	113.5	10.6	2	103.8	8.7	4	104.0	10.0	8
17	107.0	10.5	3	98.0	-	1	95.3	2.1	3	-			108.5	10.6	2	112.0	-	1
18	104.5	2.1	2	-			98.0	-	1	-			-			98.0	-	1
19	-			-			-			-			-			116.0	-	1
20	-			-			-			-			-			112.0	-	1

Table 5: Mean length at age for male hoki, by sample. Mean = mean length (cm TL); s.d. = standard deviation; *n* = sample size

	1988			1989			1990			1991			1992			1993		
Age	Mean	s.d.	*n*	Mean	s.d.	*n*	Mean	s.d.	*n*	Mean	s.d.	*n*	Mean	s.d.	*n*	Mean	s.d.	*n*
1	-			-			-			34.5	1.5	6	-			32.0	-	1
2	43.0	1.4	2	43.3	2.1	3	45.0	1.7	3	-			46.5	0.7	2	43.1	2.2	23
3	54.3	3.1	3	47.0	-	1	55.6	2.8	20	57.0	5.2	30	54.0	-	1	55.6	2.3	5
4	63.1	2.8	27	60.3	4.0	4	67.0	1.5	7	65.2	4.1	112	67.4	3.5	41	67.4	3.5	12
5	68.2	3.5	33	73.1	4.2	40	69.0	4.3	14	70.1	3.5	21	71.0	4.2	131	72.3	4.2	68
6	71.7	3.8	51	75.9	4.7	73	75.2	3.4	40	78.8	4.3	34	75.1	6.3	10	76.2	4.2	109
7	75.5	4.4	46	78.4	5.2	34	79.4	5.2	67	79.9	5.5	66	78.0	4.7	22	84.6	4.0	5
8	79.3	5.3	32	82.5	5.2	20	81.8	5.6	27	82.5	4.5	66	81.8	4.7	38	81.4	6.0	18
9	83.4	5.1	21	86.5	5.2	20	85.5	6.3	26	86.7	4.9	24	84.5	4.5	24	86.8	6.3	14
10	85.8	5.3	24	86.6	6.6	8	88.1	7.7	10	88.5	5.6	13	90.2	5.3	6	89.1	5.5	14
11	86.8	4.3	24	86.3	6.4	12	84.6	4.5	14	89.4	4.8	9	89.9	3.5	11	87.0	6.4	6
12	87.9	4.6	31	87.8	4.5	10	88.4	6.7	11	89.3	4.2	3	77.0	-	1	92.8	6.8	4
13	91.4	4.4	7	88.6	6.2	9	88.5	9.1	4	87.0	6.2	5	86.0	7.1	2	95.4	9.8	5
14	90.8	9.0	4	87.0	4.2	2	86.0	3.7	5	91.3	2.5	4	90.0	-	1	-		
15	92.5	9.2	2	88.0	-	1	-			-			98.0	5.7	2	-		

Table 6: Estimated proportion (%) by age class of fish caught in the spawning fishery off the west coast of the South Island, with coefficient of variation (CV), by year

	1988		1989		1990		1991		1992		1993	
Age	%	CV	%	CV	%	CV	%	CV	%	CV	%	CV
Male												
1	0.07	0.41	0.05	0.89	0.02	0.68	0.13	0.31	0.14	0.70	0.32	0.20
2	0.34	0.16	0.90	0.18	0.28	0.24	0.07	0.43	0.60	0.15	4.32	0.08
3	1.15	0.11	0.60	0.19	4.54	0.10	11.07	0.08	0.98	0.12	0.68	0.20
4	7.62	0.12	0.71	0.55	2.88	0.32	26.20	0.05	12.54	0.14	4.31	0.28
5	11.06	0.14	15.49	0.13	6.10	0.22	5.23	0.20	43.17	0.06	27.75	0.09
6	17.18	0.11	30.41	0.09	17.30	0.13	8.44	0.15	5.08	0.25	44.51	0.06
7	16.60	0.12	14.31	0.15	29.56	0.10	16.74	0.10	12.57	0.15	1.42	0.45
8	11.44	0.16	12.25	0.16	11.85	0.18	16.69	0.10	10.33	0.16	6.42	0.22
9	6.95	0.21	8.24	0.20	10.14	0.18	6.35	0.19	5.60	0.23	3.81	0.26
10	7.70	0.19	3.12	0.34	3.54	0.33	3.55	0.26	4.28	0.26	3.24	0.27
11	7.30	0.19	4.86	0.27	6.20	0.25	2.63	0.31	3.11	0.29	1.47	0.44
12	8.90	0.16	3.99	0.30	4.05	0.29	0.84	0.58	0.37	0.99	0.74	0.63
13	1.78	0.36	3.81	0.29	1.38	0.51	1.11	0.44	0.64	0.70	0.95	0.53
14	1.22	0.49	0.83	0.70	2.08	0.42	0.88	0.50	0.00	0.00	0.00	0.00
15	0.60	0.67	0.36	0.98	0.00	0.00	0.00	0.00	0.52	0.64	0.00	0.00
Female												
1	0.02	0.69	0.01	10.01	0.01	1.49	0.05	1.16	0.11	0.61	0.16	0.43
2	0.10	0.69	0.47	0.26	0.22	0.27	0.02	0.78	0.15	0.56	1.53	0.22
3	0.28	0.21	0.13	0.53	1.47	0.13	3.87	0.12	0.75	0.52	0.11	0.54
4	3.26	0.24	2.49	0.37	1.19	0.28	6.26	0.15	6.00	0.19	0.71	0.42
5	5.70	0.20	6.84	0.22	3.22	0.37	3.86	0.25	30.01	0.06	9.96	0.15
6	10.87	0.14	20.65	0.11	18.97	0.13	13.80	0.12	4.68	0.24	41.58	0.05
7	10.01	0.15	15.49	0.15	26.18	0.11	21.08	0.09	14.15	0.12	4.15	0.25
8	12.95	0.12	12.56	0.16	11.27	0.18	19.32	0.10	15.62	0.10	14.12	0.12
9	8.69	0.16	10.81	0.18	13.01	0.16	10.53	0.14	11.07	0.13	10.39	0.13
10	13.20	0.12	9.46	0.18	7.13	0.21	7.87	0.16	7.27	0.16	6.44	0.15
11	10.42	0.14	7.17	0.21	4.17	0.25	5.00	0.21	3.24	0.23	3.08	0.22
12	12.16	0.12	5.84	0.24	3.87	0.27	3.87	0.23	2.33	0.28	3.41	0.22
13	5.79	0.19	5.25	0.25	2.78	0.33	2.33	0.30	1.98	0.30	1.27	0.33
14	2.56	0.25	1.18	0.57	3.62	0.25	0.80	0.41	1.10	0.38	1.47	0.32
15	2.41	0.28	1.28	0.48	0.57	0.54	1.02	0.44	0.51	0.61	0.54	0.59
16	0.77	0.46	0.00	0.00	1.10	0.52	0.27	0.64	0.72	0.46	0.75	0.42
17	0.47	0.61	0.29	0.98	0.86	0.57	0.00	0.00	0.23	0.71	0.03	1.00
18	0.25	0.70	0.00	0.00	0.25	0.98	0.00	0.00	0.00	0.00	0.15	0.98
19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	1.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	1.00

Table 7: Within-reader comparisons of 200 otoliths. Age = age at first reading; Diff = the extent by which the second reading differed from the first; Sim = the percentage of fish by age for which both readings were similar

	Age																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
Diff																	
+2	-	-	-	-	-	-	-	2	-	1	1	1	1	-	-	1	7
+1	-	-	1	4	1	1	4	4	5	4	1	3	-	-	1	-	29
0	5	10	15	16	8	15	19	13	12	6	5	3	4	1	-	1	133
-1	-	2	-	3	3	5	4	3	4	2	-	1	1	1	-	-	29
-2	-	-	-	-	-	-	-	1	-	-	1	-	-	-	-	-	2
Sim	100	83	94	70	67	71	70	57	57	46	63	38	67	40 (ages 15–17)			67

Table 8: Estimated proportions of 4 and 5 year old fish in the commercial catch from the WCSI spawning fishery. MIX = proportions derived by Sullivan & Cordue (1994) using MIX software; ALK = proportions derived from the current study using an age-length key

	Male				Female			
	4 yr old		5 yr old		4 yr old		5 yr old	
Year	MIX	ALK	MIX	ALK	MIX	ALK	MIX	ALK
1988	11.0	7.6	24.5	11.1	2.6	3.3	8.7	5.7
1989	0.0	0.7	10.8	15.5	0.0	2.5	8.0	6.8
1990	1.9	2.9	0.0	6.1	1.0	1.2	0.0	3.2
1991	27.4	26.2	7.1	5.2	7.3	6.3	2.7	3.9
1992	5.8	12.5	45.3	43.2	5.6	6.0	32.4	30.0
1993	0.0	4.3	24.1	27.8	0.0	0.7	17.9	10.0

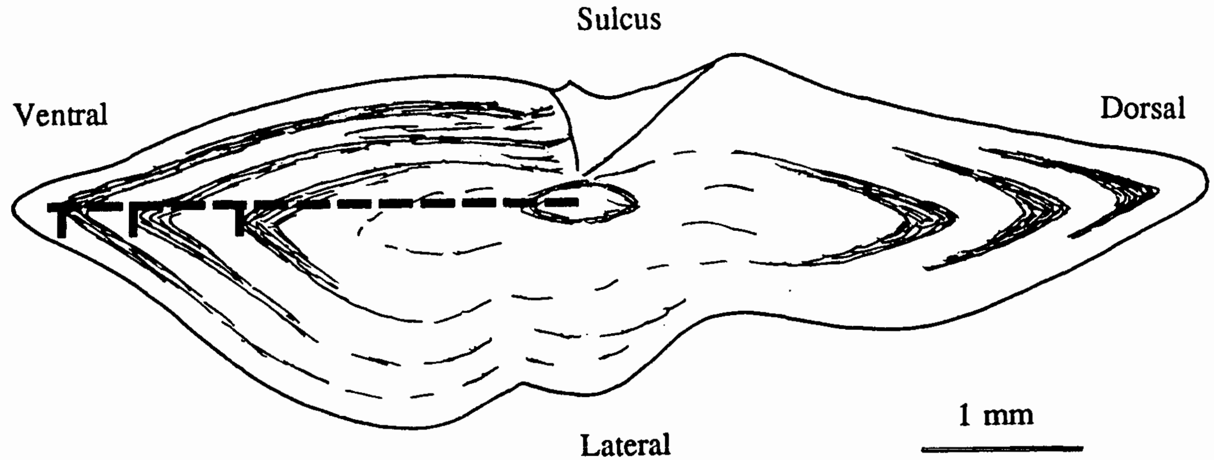

Figure 1: Sketch of an otolith section from a 3+ year class fish. The broken line shows the axis along which measurements to the first three dark bands are made.

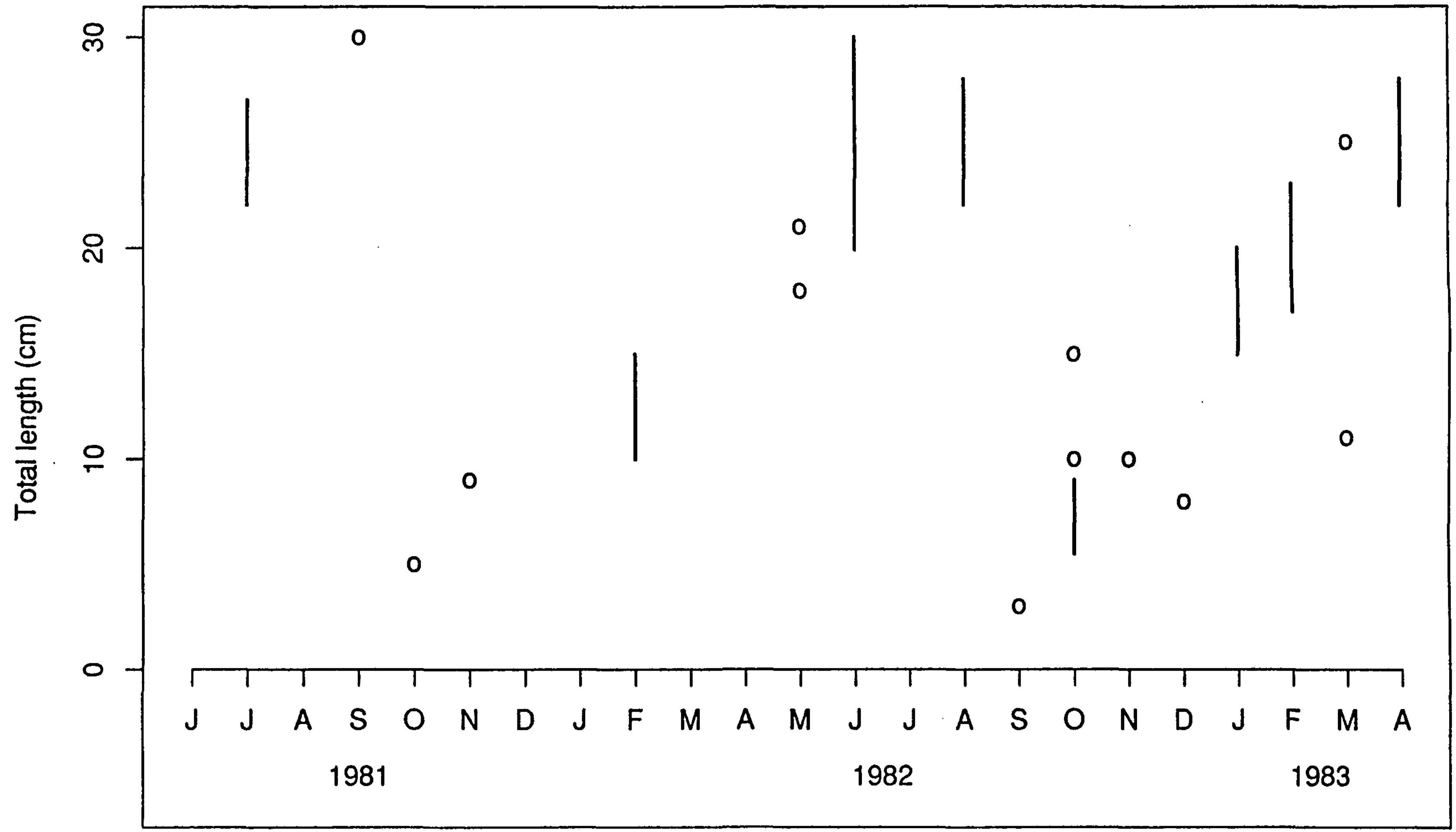

Figure 2: Length modes of juvenile hoki caught opportunistically during bottom trawl surveys off the northwest South Island between July 1981 to April 1983. Points indicate where a single modal length was estimated for the observed fish; lines indicate where a range of length was noted.

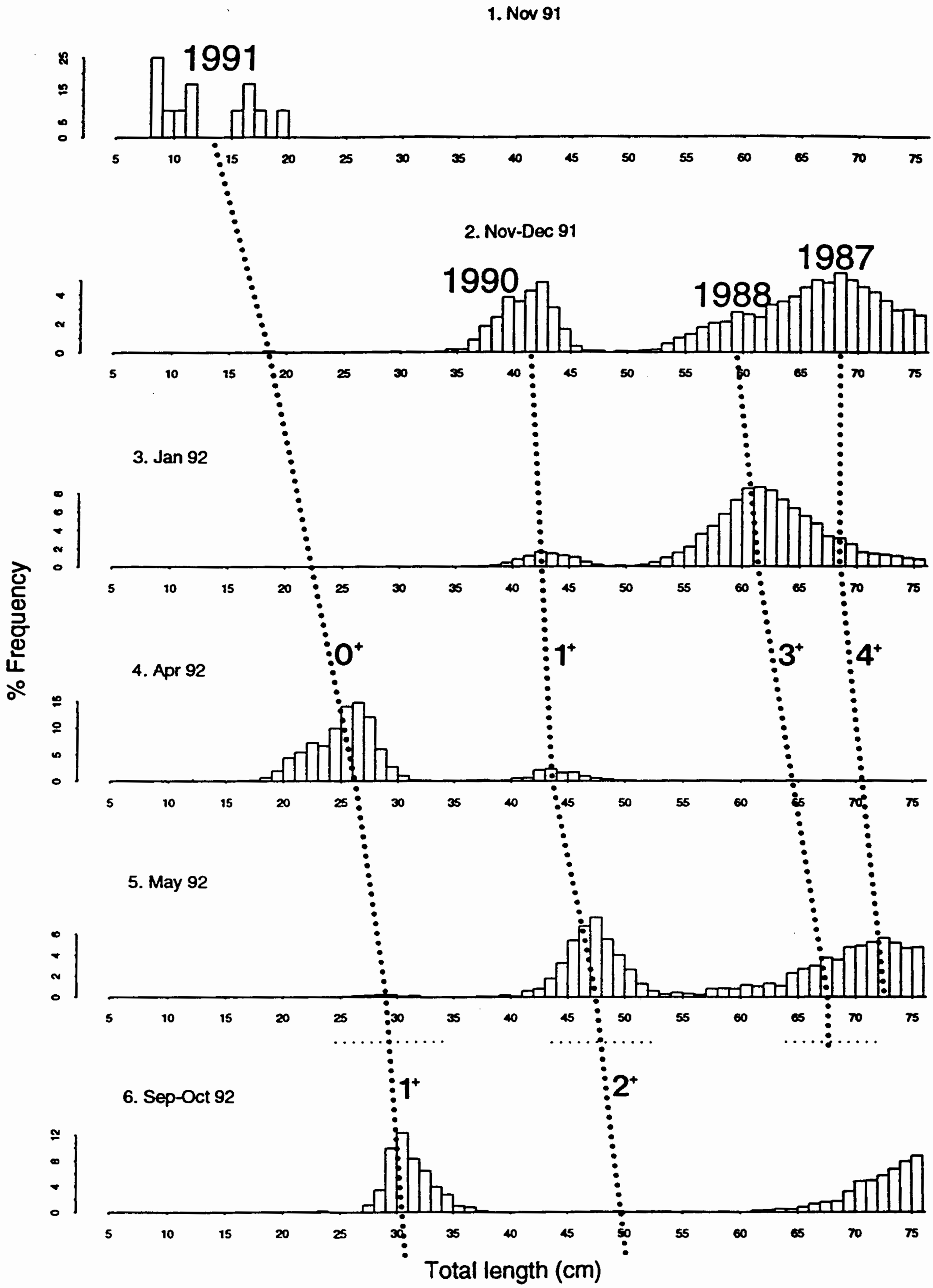

Figure 3: Length frequency histograms of small hoki (≤ 75 cm TL), both sexes combined, caught in research trawl surveys. Details of the research trip, area, and time are listed in Table 1. Means (estimated by eye) of individual year classes are joined with dotted lines. Year class ages (1+ to 4+) and year of spawning are indicated on the figure.

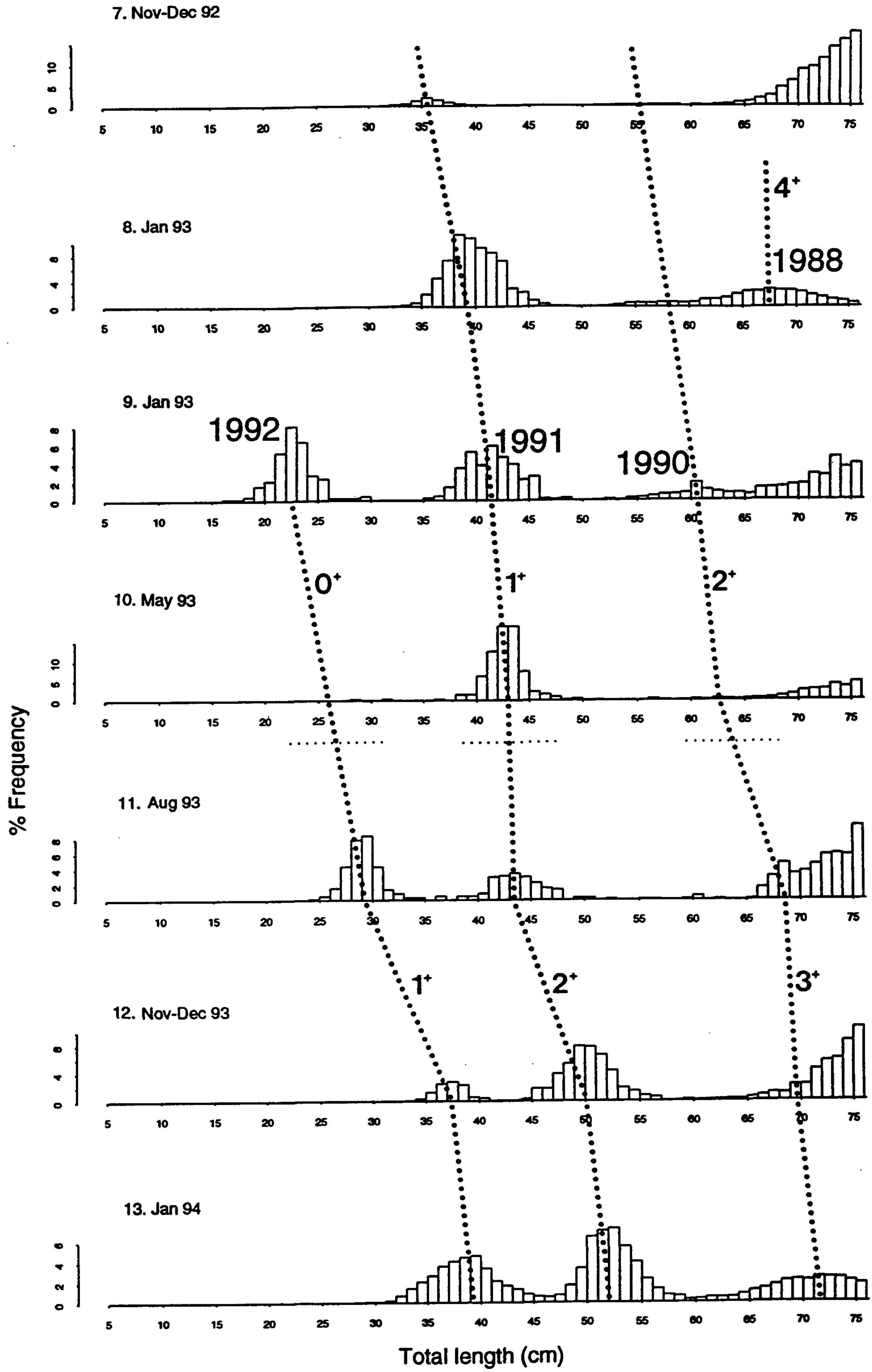

Figure 3 (cont.)

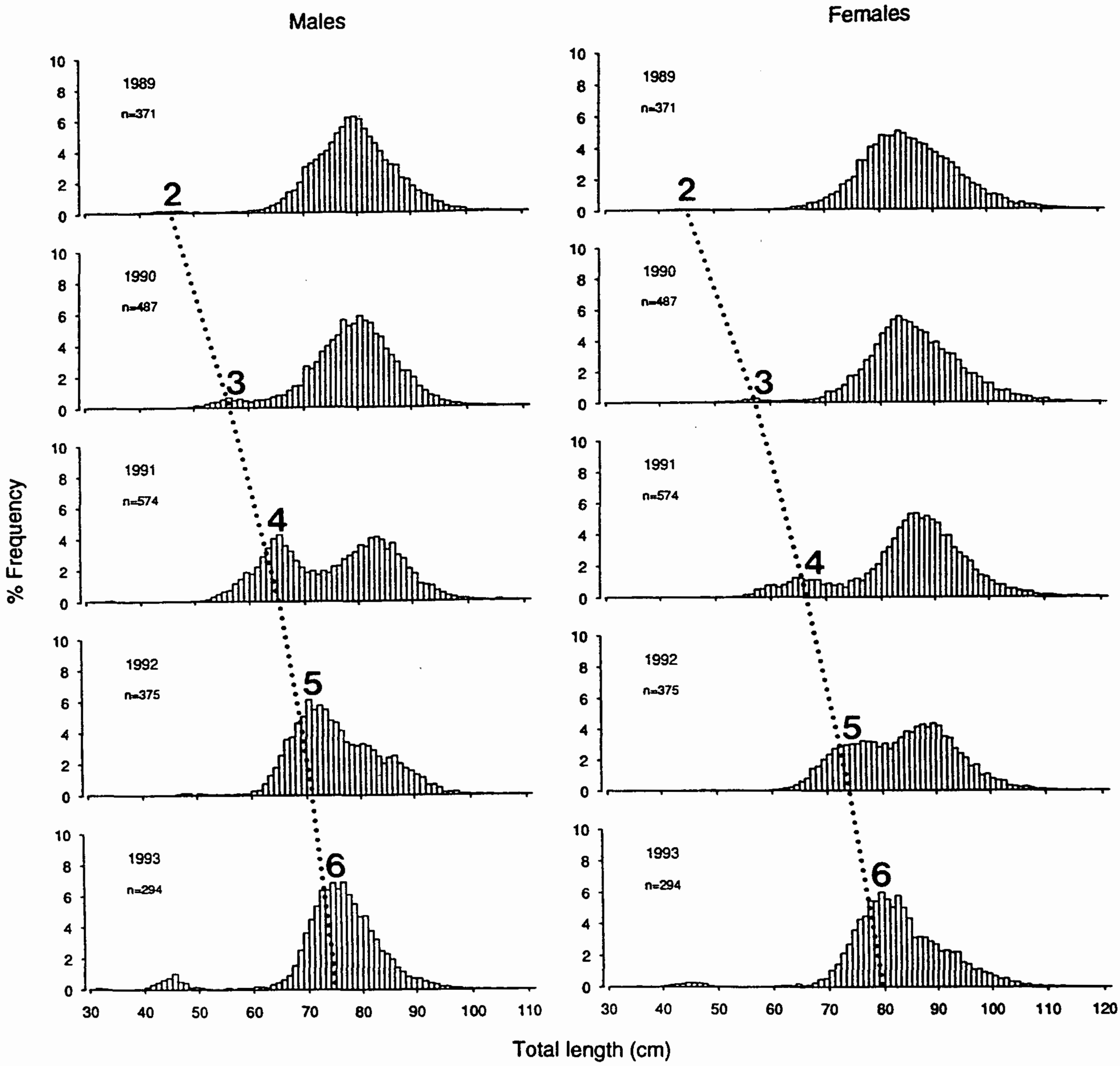

Figure 4. Length frequency distributions of the commercial catch of hoki taken from the spawning fishery off the west coast, South Island, 1989 to 1993. The broken lines show the progression of the modal length of fish from the 1987 year class. Large numbers denote age in years. n = number of trawl shots sampled.

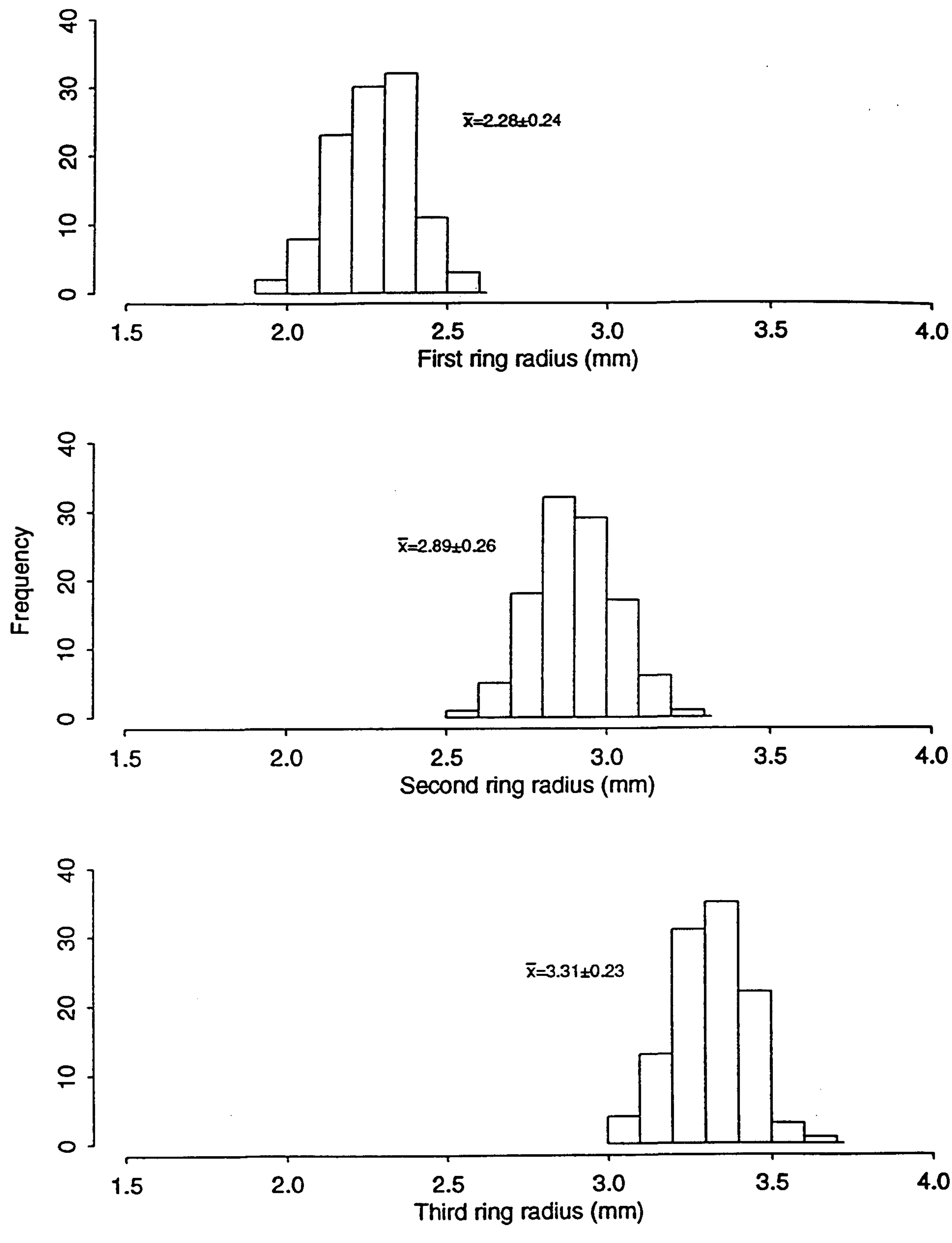

Figure 5: Distributions of measurements of the distance from the nucleus to the outer edges of the first three hyaline zones in 109 otolith sections. Measurements were made on the ventral side of the otolith. The mean width ($\bar{x}$), with 95% confidence interval, is presented for each zone.

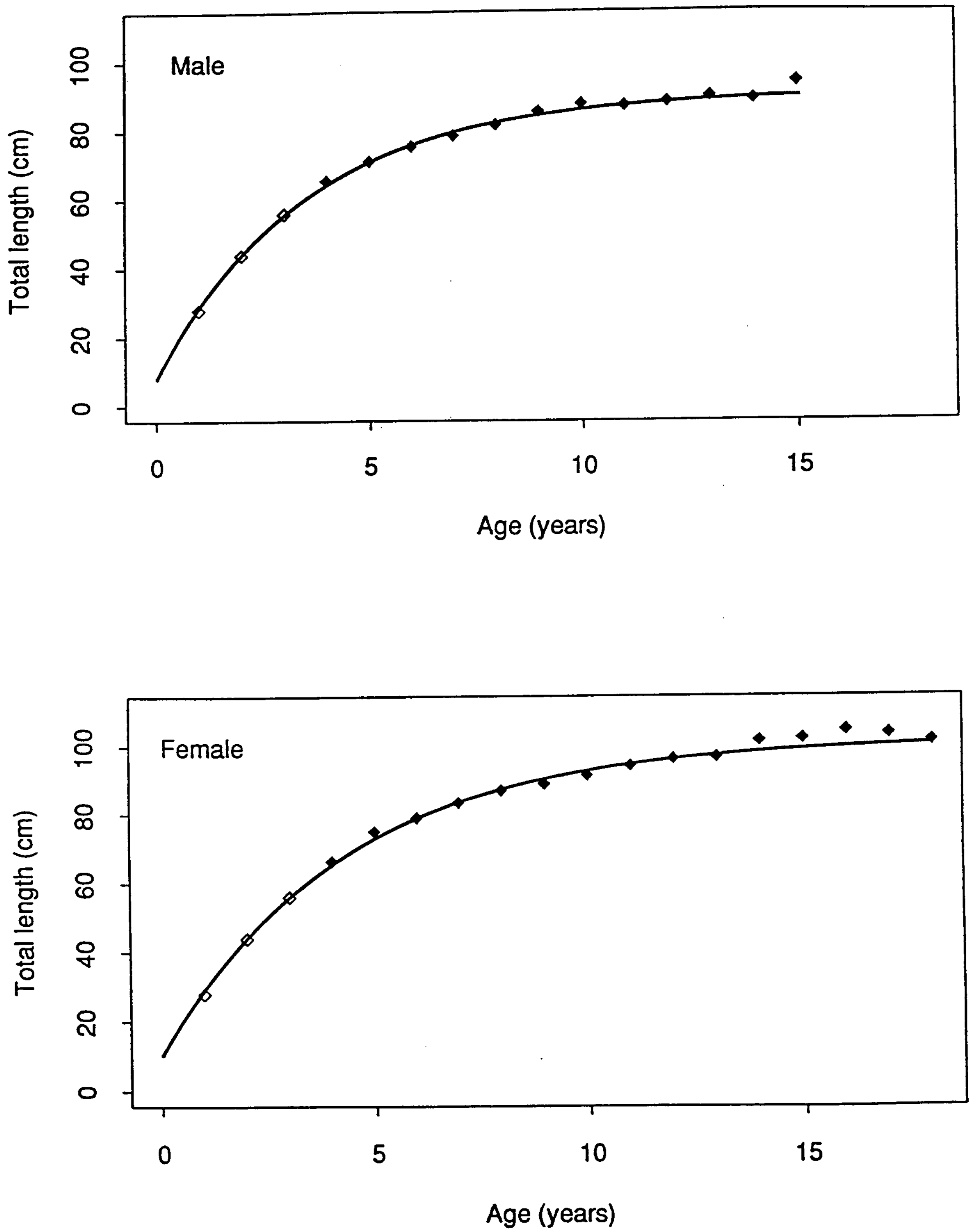

Figure 6: Von Bertalanffy curves for male and female hoki fitted to all age-length data from fish 4 years and older combined with the set of length-based juvenile growth data (ages 1-3). Observed mean lengths at age from length frequency modes (open diamonds) and from aged fish sampled during 1988-1993 from the WCSI spawning aggregation (closed diamonds) are plotted.

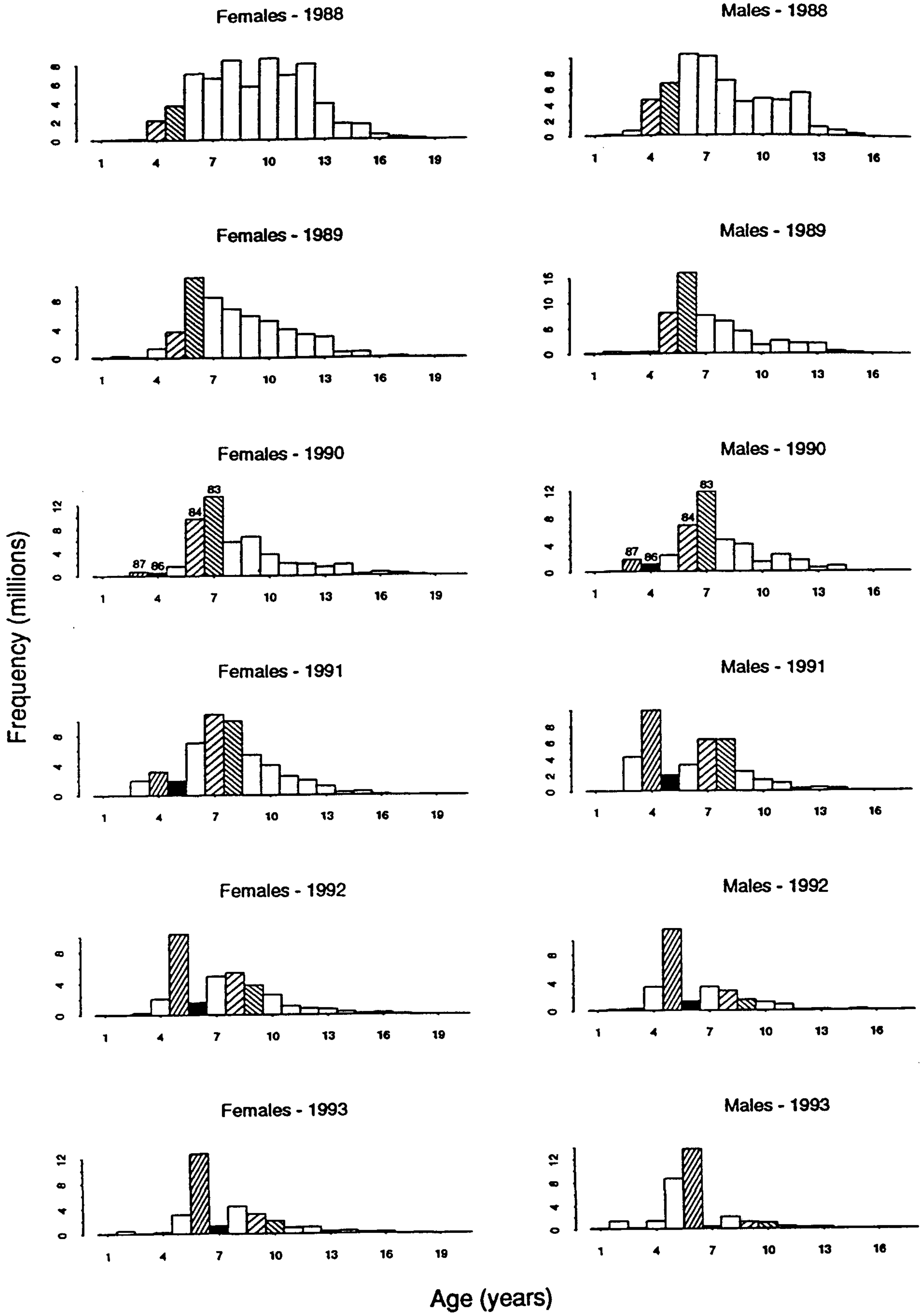

Figure 7: Calculated age distributions, by sex, for the total commercial catch from the west coast South Island spawning fishery from 1988 to 1993. Years of spawning of individual year classes mentioned in the text are noted on the 1990 figures. Shading indicates year classes.