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An ageing methodology, and growth parameters for red cod (*Pseudophycis bachus*) off the southeast coast of the South Island, New Zealand

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1. EXECUTIVE SUMMARY

A method is described to determine the age of red cod using the bands in sectioned otoliths. The technique was validated by examining the state of otolith margins over a 1 year period, and by following the progression of length modes in length frequency distributions (for age classes 0+ to 3+). Von Bertalanffy growth parameters are estimated for red cod off the southeast coast of the South Island. Few fish appear to live longer than 4 years. Because of the few age classes in the population at any time, most fish can probably be aged from their position in a length frequency distribution.

2. INTRODUCTION

The main fishery for red cod (*Pseudophycis bachus*) targets schooling aggregations adjacent to Banks Peninsula and Timaru between November and June (Beentjes 1992). This species is one of the major contributors to total wetfish landings in Lyttelton and Timaru. Annual landings fluctuate widely and are thought to be linked to actual variation in yearly biomass due to fast growth, high mortality, and variable recruitment (Annala 1994). Beentjes (1992) provided von Bertalanffy parameters, and validated the growth curve up to an age of about 1.7 years by following length frequency modes from research trawl surveys. However, no studies validating the growth of red cod over the entire life span of the fish have been conducted, so the assumptions of fast growth and high mortality have not been proven.

Large samples of otoliths were collected during commercial catch sampling of red cod from the Canterbury Bight over the seasons 1989–90 to 1992–93. Otoliths were also collected during inshore trawl surveys covering the distribution of red cod off the southeast coast of the South Island, conducted annually each May from 1990 to 1994. These otolith collections were prepared and read (Beentjes 1992, Beentjes unpublished data). However, the calculated catch at age distributions for each of the 4 years of commercial catch were quite uniform and did not show the progression of a strong cohort spawned in 1990 and apparent in commercial landings and the trawl survey in the 1992–93 fishing year.

The investigation reported here comprises a re–examination of part of the otolith collection described above and an attempt to validate an ageing technique over the full age range using information from otolith margins and time series of length frequency distributions.

3. METHODS

Otoliths (sagittae) of red cod in the Canterbury Bight were collected from 1990 to 1994 from commercial landings and trawl surveys. Most samples were taken between January and May, but a few collections from November, December, and June were available. Limited samples collected by scientific observers were available from the period July to October. Total length (TL, rounded to the nearest centimetre below actual length) and sex were recorded for all fish from which otoliths were taken.

Eleven otolith samples each comprising 36–66 otoliths (totalling 481 otoliths) were selected to allow an examination of changes in otolith margin characteristics over a period of approximately 12 months (Table 1). It was not possible to compile a single chronological series, but a combination of two series (January–October 1993, and November 1990 – January 1991) did allow a complete seasonal coverage. Where landings from different days were combined to form a sample, the sample date listed in Table 1 is a mean of the actual sample dates. All samples were from the southeast coast area except the August 1993 sample which was from the west coast of the South Island, and parts of the November and December 1990 samples which were from Kaikoura. It was assumed that any regular banding pattern in the otoliths forms in a consistent manner between years and areas.

Otoliths were broken transversely at mid length to expose the nucleus, then placed, 20 at a time, broken surface down, in moulds containing PS404 epoxy resin. After setting, the mould surface with the broken otolith ends was polished on a grinding wheel using coarse and then fine grades of sandpaper to produce a smooth and flat otolith surface. The block was baked in an oven at 250 °C for 10–15 min until the otoliths became light amber in colour. The smoothed otolith surfaces were then coated with paraffin oil and examined under a binocular microscope (x25) using reflected light. Patterns of dark and light bands were generally apparent on the polished surface of the otolith.

The bands which appeared dark in reflected light were assumed initially to represent a period of dense, slow growth in the otolith. To convert band counts to age estimates, it is necessary to determine when and how frequently the bands were laid down. The number of complete dark zones (i.e., dark bands with lighter coloured material outside them) on the otolith were counted, and the otolith margin was classified as either dark or light. Using a binocular microscope with a micrometer eyepiece, the distance between the outer edge of the outermost completed dark zone and the otolith edge (measured whenever possible on the lateral part of the otolith section) was expressed as a proportion of the distance between the outermost edges of the two most recently formed complete dark zones.

Few small red cod were available in the commercial catch samples as many escape through the 100 mm codend mesh and processors discourage fishers from landing fish shorter than 40 cm. The research trawl surveys did catch smaller fish, so two additional samples (samples 12 and 13 in Table 1) were aged to provide more data points for the younger end of the growth curve.

Von Bertalanffy growth curves were fitted to the age-length data using a non-linear least-squares regression procedure (Ralston & Jennrich 1978). Separate equations were derived for each sex.

To assess the within-reader reproducibility of the results, 100 otoliths representing a range of ages and both sexes were read twice. First and second readings were made 3 weeks apart.

Length frequency histograms from commercial landings and research trawl surveys often exhibit up to three modes, and it was assumed that these modes represent consecutive year classes. Plotting the histograms chronologically and examining the progression of modes over time provides an independent check on the growth curve calculated from counts of bands in otoliths. Two sub-annual time series of length frequency data were available from the Canterbury Bight region; monthly samples of commercial and research catches collected from October 1971 to October 1972 (Habib 1975), and samples taken as bycatch during research trawl surveys of barracouta from March 1980 to December 1982 by GRV *James Cook* (R.J. Hurst, MAF Fisheries Greta Point, unpublished data). Length frequency modes from the series of inshore trawl surveys along the east coast of the South Island conducted annually since May 1990 by GRV *Kaharoa* were also plotted.

4. RESULTS

4.1 Otolith interpretation

Otoliths were often difficult to interpret for the following reasons.

a. Split bands: Some dark bands consisted of two diffusely linked, but distinct, rings. This was most common on the second band, but also occurred on the first and occasionally on the third.

b. Band coloration: Colour intensity of dark bands on the same otolith varied greatly. The first band was often relatively faint, while the second band was generally the darkest. The transition from a dark band to a light band was often represented by a gradual change in shade rather than a distinct band margin.

c. Band clarity: The banding pattern was not consistently clear in any particular area of the otolith section. The first and second bands could often be traced around the entire section, but later bands were seldom complete.

d. Uneven deposition of material: Although the otoliths are basically oval in section, the rate of deposition of new material at any particular part of the otolith varied between years. Hence, individual bands often varied considerably in thickness, and an older band could be thicker in parts than a younger one.

4.2 Marginal increments

Mean proportional marginal increments for the 11 samples covering a 12 month period ranged from 0.38 to 0.56, had relatively large standard deviations, and exhibited no seasonal cycle (Table 2). There was also no evidence of a bimodal distribution in any sample representing a combination of small and large marginal increments, which would be expected when otoliths are changing from having a wide dark margin to a narrow light one. This inconclusive result is not surprising given the problems of indistinct band margins, uneven deposition of new material, and the inability to take measurements at the same position on each otolith.

4.3 Marginal state

It was generally possible to determine whether an otolith margin was dark or light, although some interpretations were complicated because of the gradual transition from a dark to a light band. Percentages of otolith sections with dark margins, for each sample, are shown in Figure 1. It is apparent that dark material is initially laid down about April and that most fish are again laying down light material by October. Deposition of the dark band may start slightly earlier in fish from the 3+ and 4+ year classes than it does in 2+ fish. The marginal state of the 1+ year class could not be examined because they are seldom landed by commercial fishers and were not sampled. The one available data point for 1+ fish (from otoliths collected in a research trawl survey) indicates that they also have a predominantly dark margin by early winter.

These data support the hypothesis that one dark and one light band are laid down annually in the otoliths of red cod.

4.4 Growth parameters

The spawning season for red cod in the Canterbury Bight is probably from August to October (Habib 1975), although there is some evidence of spawning later than this period (Beentjes 1992). A "birthday" of 1 October was chosen for red cod. As the dark band in the otoliths appears to be complete by late winter (August–September), fish are almost 1 year old on completion of the first dark band.

Errors would result if no account was taken of the variable timing of zone completion. Consequently, margins of otoliths collected during June to October were subjectively graded as either wide or narrow, although this was difficult at times because of the otolith interpretation problems described above. Since the new light zone was considered to start forming about 1 September, fish caught before September and showing n complete rings and a narrow margin were assigned to the same age class as fish with $n-1$ rings and a wide margin. Conversely, fish caught after 1 September and showing n rings and a wide margin were assigned to the same age class as those with $n+1$ rings and a narrow margin.

Data from all otoliths listed in Table 1 were used to calculate von Bertalanffy growth curve parameters (with asymptotic 95% confidence intervals for the estimates) for fish from off the southeast coast of the South Island (Table 3). Time of sampling, and hence part-year growth, is incorporated in this analysis (e.g., a fish with two complete rings sampled in early February would be allocated an age of 2.30 years). Mean lengths at age for fish sampled from early April to early June are presented in Table 4. The curves and raw data are plotted in Figures 2 and 3. The confidence intervals are quite large due to the relatively wide variation in size at age (and probably to ageing uncertainty especially in 3–4 year old fish). Female red cod appear to grow faster than males, but this difference is not statistically significant.

No red cod older than 5 years were identified. Aged samples collected from the Stock Monitoring Programme (see Table 1) indicated that the bulk of the commercial catch was aged 2+ and 3+, with a small 4+ component.

4.5 Age replication

The results of the within-reader comparison are shown in Table 5. Of the 100 otoliths examined twice, 80% were aged identically and the remaining 20% differed by 1 year. There was no apparent bias in the ageing error for fish aged 0 to 3. Ageing error increases with increasing age.

4.6 Length frequency modal progression

Length frequency histograms of red cod caught during research trawl surveys of barracouta in the Canterbury Bight from March 1980 to December 1982 are presented in Figure 4. Raw data are presented; they have not been scaled by size of catch or area trawled. Not all year classes are represented in all samples, but it is possible to follow the progression of the 1978 and 1979 year classes through most of the time series, and also to identify the 1977, 1980, and 1981 year classes in some samples.

Length frequency modes from Habib (1975, figure 26) and from the two research trawl survey series in 1980–82 and 1990–94 (Beentjes & Wass 1994, Beentjes 1995a, 1995b, R. Hurst unpublished data) are plotted in Figure 5. The points fit the superimposed von Bertalanffy growth curves approximately, but are generally below the curves at ages between 1 and 2 years and above the curves at ages greater than 3 years.

5. DISCUSSION

Gadiform species have been extensively investigated in the Northern Hemisphere, and numerous growth studies, particularly of *Gadus morhua* and *G. macrocephalus* (family Gadidae), are available (e.g. Jørgensen 1992, Lai *et al.* 1987). The *Gadus* species are relatively fast growing and short lived, with most of the commercial catch being about 2–7 years old and few fish living longer than 10 years. Their growth rates can vary significantly between area and season.

There is little in the literature on the growth of *Pseudophycis* species (family Moridae). Walker (1972) presented an unvalidated ageing study of *P. barbata* (previously known as *Physiculus barbatus*) from off Tasmania. He concluded that most of the fish were aged 3+ or 4+, and only 2 of the 381 specimens examined were older than 6 years. Beentjes (1992) examined otoliths from 371 male and 542 female *Pseudophycis bachus* collected during the 1990 and 1991 trawl surveys, and calculated von Bertalanffy parameters which implied slower rates of growth than those deduced from the current study (Table 3). The interpretation of otoliths by Beentjes and the current author was generally similar for fish aged to about 3 years, but diverged after that with Beentjes ageing fish about 1–2 years older. Beentjes (1992) concluded that the bulk of the commercial catch comprises fish 3–4 years old, with a maximum age of about 7 years.

The present study indicates that *Pseudophycis bachus* has an even shorter life span; no fish older than 5 years were found. The pattern of annual commercial landings provides support for *P. bachus* having a short life span. Landings fluctuate widely between years, presumably due to actual variation in yearly biomass. If a strong year class recruits to the fishery when it is about 2 years old and 40 cm long, and if few survive beyond age 4+, then above-average landings in the fishery should last 2–3 years while the strong year class is fished. Annual landings since 1970 have exhibited three major peaks, 2 of 3 years duration (1977–78 to 1979–80, and 1983–84 to 1985–86) and another that began in 1992–93 and continued in 1993–94 (Annala 1994).

It is apparent that one light and one dark band are laid down annually in red cod otoliths. The progression of length frequency peaks provided support for the growth curves calculated from counts of bands in otoliths, but only up to age 3+. Fish with four otolith bands would be hard to distinguish in the length frequency histograms as their length range almost completely overlaps the length range of 3+ fish (Figures 2 and 3). This length overlap of 3+ and 4+ fish could explain why many of the length frequency modes assumed to represent 3+ fish and plotted in Figure 5 are above the calculated von Bertalanffy curve.

The relatively poor fit of some length frequency modes to the calculated von Bertalanffy curves (see Figure 5) could also be explained by interannual or seasonal variations in growth rate. Both types of variability have been demonstrated for *Gadus morhua* by Jørgensen (1992). There is some evidence from the present study that *Pseudophycis bachus* have periods of fast growth in summer/autumn and slow growth in winter/spring.

The range of fish lengths at a particular age is wide. Some fish have almost certainly been aged incorrectly. However, there is evidence that the growth of individual fish within a year class can vary greatly; a distinct peak of 1+ females in May 1982 (see Figure 4) ranged in length from 29 to 47 cm. Size-at-age between years can also vary substantially. In the 1991 and 1992 trawl surveys the 0+ year classes (theoretically at about 7 months of age) had mean lengths of about 22 cm, while in 1993 the mean length of the 0+ year class was 16 cm. An extended spawning season, or seasonal variation in the time of peak spawning, could explain the apparent variation in growth. Fluctuations in water temperature and prey availability have been shown to strongly influence the growth rate of *Gadus morhua* (Jørgensen 1992).

This work has indicated that in recent years at least, red cod off the southeast coast of the South Island probably died before their fifth birthday. However, it is possible that older fish do occur in the population but were not identified in the samples examined due to lack of otolith clarity. In the sample examined by Beentjes (1992), about 6% of fish were aged older than 5 years. It should theoretically be possible to determine the normal longevity of this species by following a strong year class through aged samples from consecutive years. However, the relatively poor reading repeatability for older fish may confound this process. Only 62% of fish aged 4 at the first reading were allocated the same age at the second reading, although within-reader repeatability was good for fish aged 0–3 years.

Counting bands in otoliths is a satisfactory method of ageing red cod, at least up to age class 3+. The growth curve derived from otolith readings closely coincided with that from the position and movement of length modes. Interannual differences in the positions of similar aged modes can complicate the interpretation of growth, particularly when only one-off samples are available. However, given the few age classes in a red cod population at any one time, and the fast growth leading to relatively distinct length frequency peaks for most age classes, it should be possible to age most fish from their lengths.

6. ACKNOWLEDGMENTS

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Table 1: Details of otolith samples examined to determine marginal state and provide data for the calculation of growth parameters. Area: SEC, southeast coast South Island; NWC, northwest coast South Island; KAI, Kaikoura. Source: SMP, Stock Monitoring Programme sample numbers; SOP, Scientific Observer Programme trip numbers; KAH, research voyage and station numbers.

Sample no.	Date	Area	Source		*n*
1	10 Jan 1993	SEC	SMP 800, 801, 803		55
2	9 Feb 1993	SEC	SMP 819, 820		37
3	8 Mar 1993	SEC	SMP 841, 842		38
4	6 Apr 1993	SEC	SMP 861, 862		40
5	8 May 1993	SEC	SMP 875, 876	38	
		SEC	KAH9306/2	19	57
6	4 Jun 1993	SEC	SMP 877	17	
		SEC	KAH9306/66, 67, 71	49	66
7	10 Aug 1993	NWC	SOP 638, 667		36
8	12 Oct 1993	SEC	SOP 687, 688		44
9	25 Nov 1990	SEC	SMP 925	20	
		KAI	SMP 926	20	40
10	16 Dec 1990	SEC	SMP 935, 938	39	
		KAI	SMP 937	18	57
11	26 Jan 1991	SEC	SMP 807, 808		40
12	24 May 1991	SEC	KAH9105/11, 12, 43, 47		69
13	13 May 1993	SEC	KAH9306/11, 14, 19		31

Table 2: Mean proportional marginal increments (with standard deviation and sample size) for otoliths from samples 1–11 in Table 1.

Sample no.	Mean	S.D.	*n*	Sample no.	Mean	S.D.	*n*
1	0.53	0.11	50	7	0.48	0.20	30
2	0.38	0.19	33	8	0.51	0.18	38
3	0.44	0.17	35	9	0.56	0.15	33
4	0.51	0.21	34	10	0.52	0.19	38
5	0.56	0.24	35	11	0.42	0.14	30
6	0.45	0.16	15				

Table 3: Von Bertalanffy parameters from this study (with 95% confidence intervals) for red cod from off the southeast coast of the South Island, and comparable parameters from Beentjes (1992) (B92).

Parameter	Female		Male	
	This study	B92	This study	B92
L_∞	76.5 (69.5 – 83.4)	65.9	68.5 (62.8 – 74.1)	61.5
k	0.41 (0.32 – 0.50)	0.42	0.47 (0.37 – 0.57)	0.43
t_0	–0.03 (-0.18 – +0.12)	–0.27	+0.06 (-0.09 – +0.21)	–0.46
n	320	542	229	371

Table 4: Mean lengths at age (cm, with standard deviation and sample size) for fish sampled between early April and early June off the southeast coast of the South Island.

Age class	Female			Male		
	Mean	S.D.	n	Mean	S.D.	n
0+	19.1	5.3	30	17.4	4.6	16
1+	35.3	5.6	29	33.3	4.5	31
2+	50.2	6.5	42	48.9	3.9	48
3+	57.7	4.6	33	53.8	4.8	26
4+	65.4	5.4	9	-		0

Table 5: Within-reader comparisons of 100 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 the same.

	Age					
	0	1	2	3	4	Total
Diff						
+1	1	2	2	4	0	9
0	10	16	16	30	8	80
–1	–	1	1	4	5	11
Sim	91	84	84	79	62	80

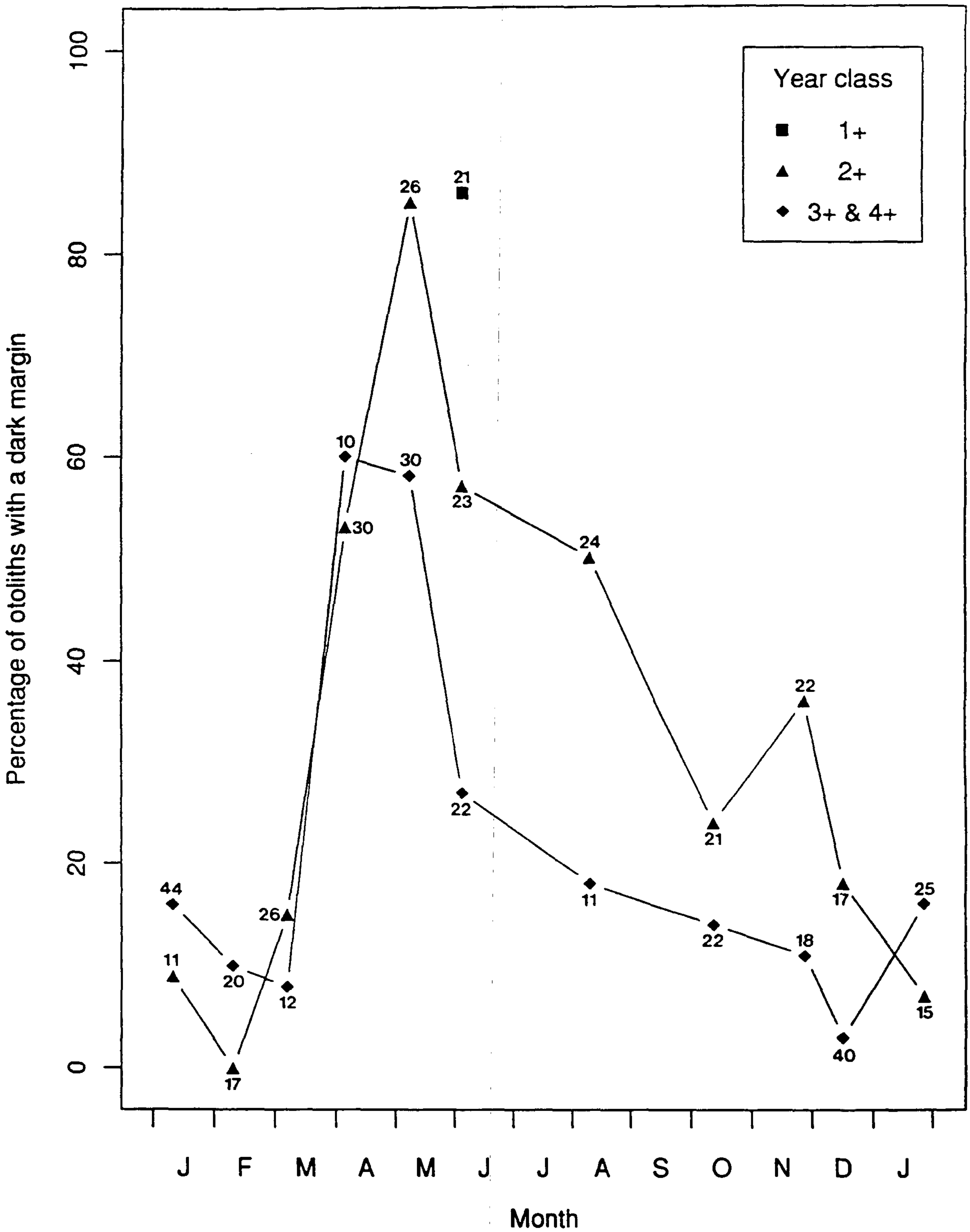

Figure 1: Seasonal change in the percentage of otoliths with a dark margin. Numbers adjacent to symbols denote sample size. Data from year classes 3+ and 4+ are combined.

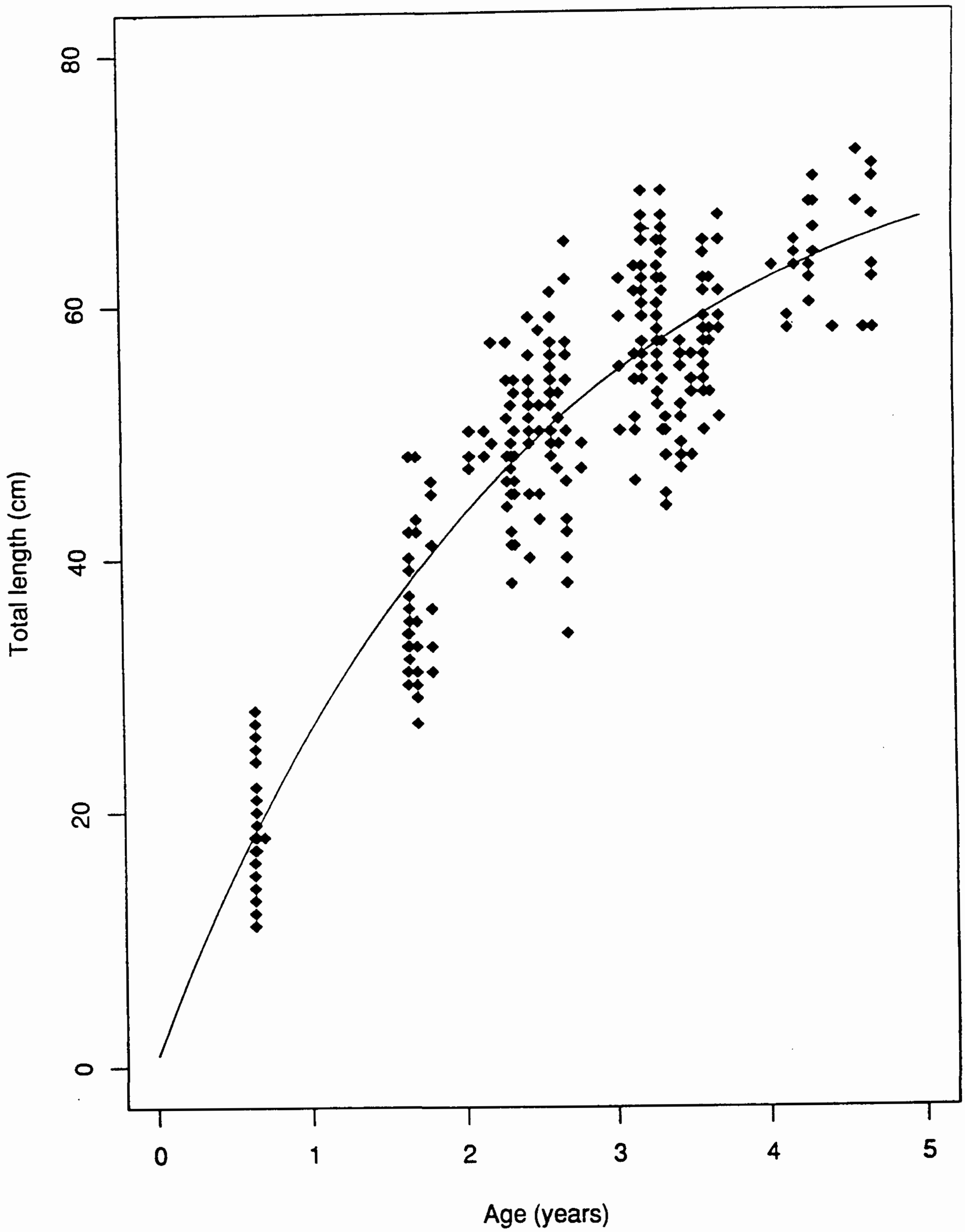

Figure 2: Raw age-length data and the calculated von Bertalanffy growth curve for female red cod from off the southeast coast of the South Island.

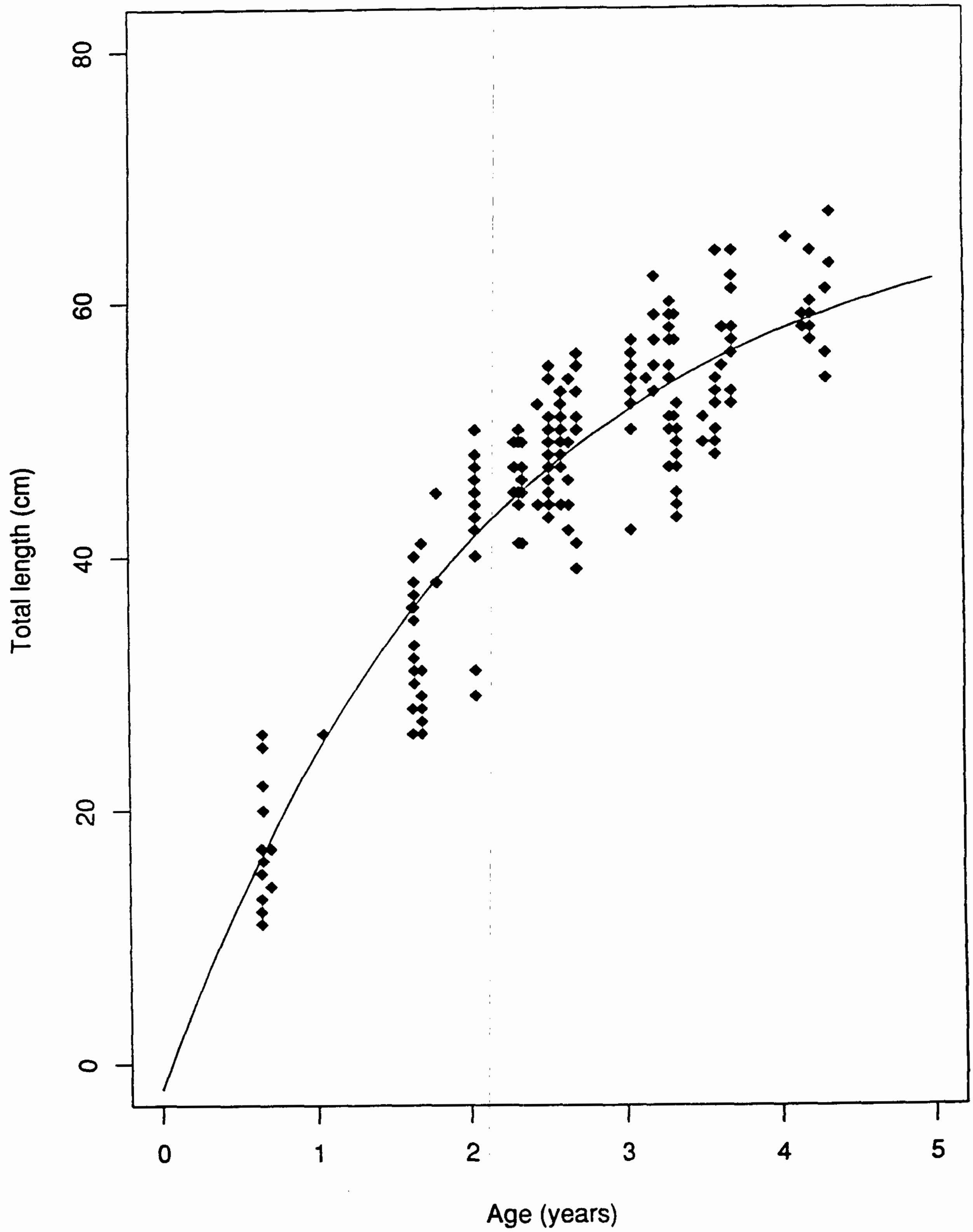

Figure 3: Raw age-length data and the calculated von Bertalanffy growth curve for male red cod from off the southeast coast of the South Island.

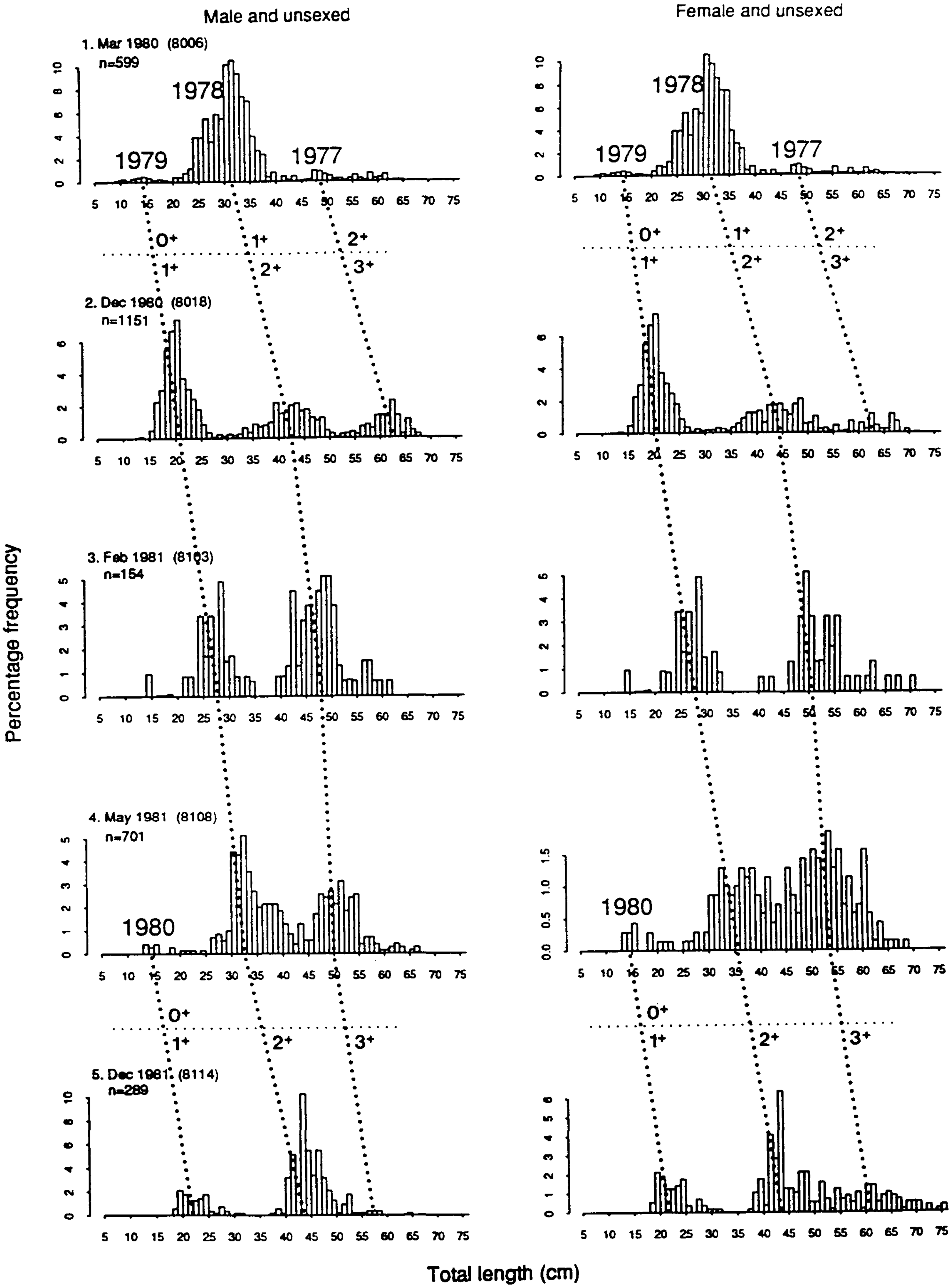

Figure 4: Length frequency histograms of red cod caught in research trawls by GRV *James Cook* off the southeast coast of the South Island between March 1980 and December 1982. Survey date, trip number, and sample size (n) are shown on the histograms. Means (estimated by eye) of individual year classes are joined with dotted lines. Year class ages (0+ to 3+) and year of spawning are indicated on the figure. Note that the 3+ mode may contain some 4+ fish.

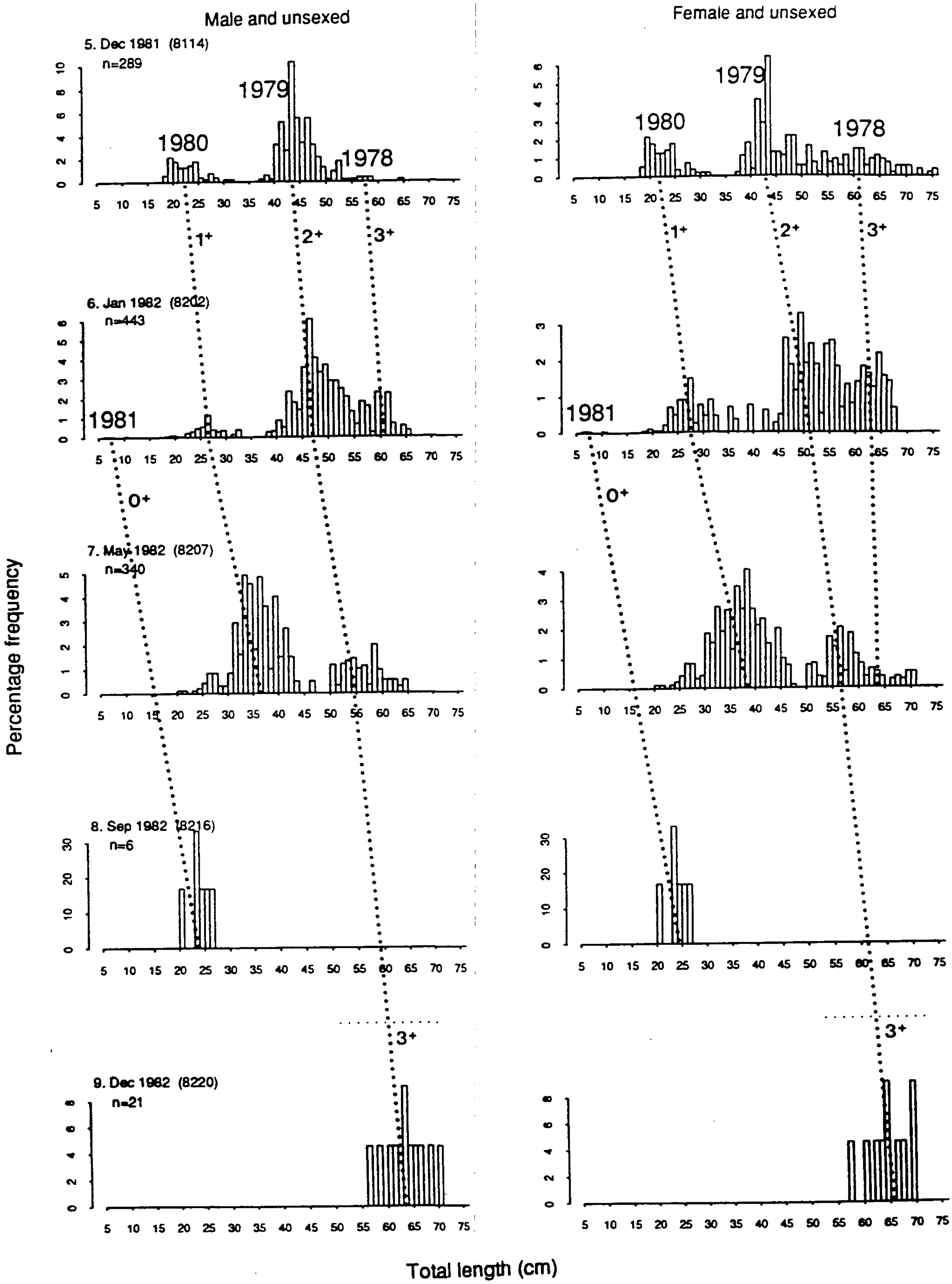

Figure 4 (cont.)

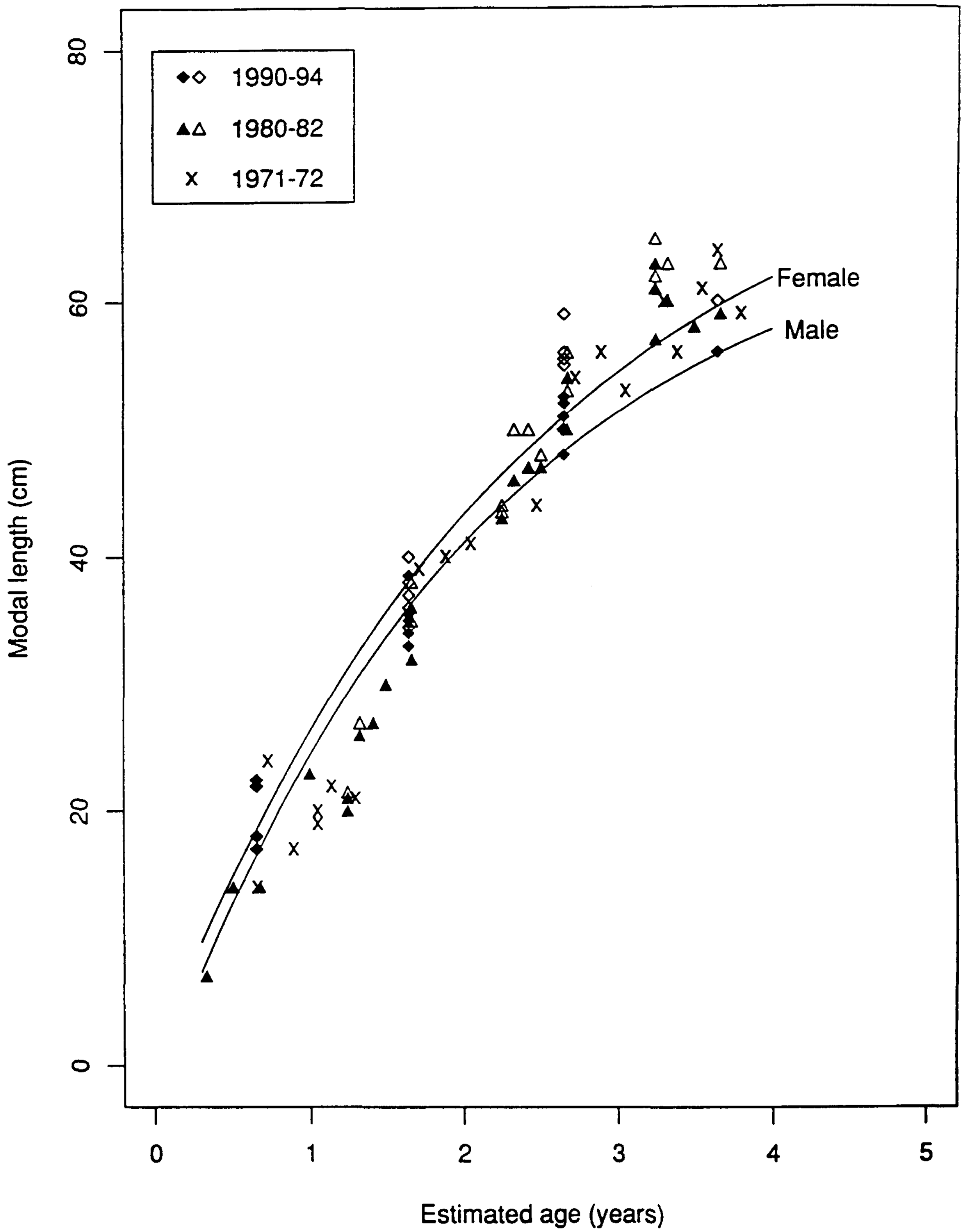

Figure 5: Length frequency modes plotted against estimated age. All fish were caught off the southeast coast of the South Island, in 1971–72 (from Habib 1975), 1980–82 (from Figure 4), and 1990–94 (GRV *Kaharoa* trawl surveys). Closed symbols represent modes of male and juvenile fish, and open symbols represent female modes. All data from Habib (1975) were unsexed. Von Bertalanffy growth curves (calculated from the data in Figures 2 and 3) are superimposed on the length modes.