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An ageing methodology, growth parameters, and estimates of mortality for hake (*Merluccius australis*) from around the South Island, New Zealand

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This series documents the scientific basis for stock assessments and fisheries management advice in New Zealand. It addresses the issues of the day in the current legislative context and in the time frames required. The documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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1. EXECUTIVE SUMMARY

A method is described to determine the age of hake by counting zones in sectioned otoliths. The technique was validated by examining the state of otolith margins from fish sampled regularly over a 1 year period. Von Bertalanffy growth parameters are estimated for hake on the Campbell Plateau and Stewart-Snares shelf, the Chatham Rise, and off the west coast of the South Island. Hake grow rapidly for about 5 years, but growth is slight after about 12 years. Female fish have a significantly faster rate of growth than males. A value for M of 0.20–0.25 is proposed. Differences in growth rates and population age distributions imply that there are at least two stocks of hake in New Zealand waters, with fish off the west coast of the South Island being distinct from those on the Campbell Plateau and Chatham Rise.

2. INTRODUCTION

Hake (*Merluccius australis*) are common throughout New Zealand waters south of latitude 40° S, in depths of 200–800 m. The same species also occurs off the south coasts of Australia and South America, and around the Falkland Islands, and similar species from the same genus occur in most other temperate regions of the Atlantic and eastern Pacific Oceans.

Most of the New Zealand commercial catch is taken from off the west coast of the South Island (WCSI), the Chatham Rise, and to the north and east of Auckland Island on the Campbell Plateau. Some target fishing for hake has occurred off WCSI and on the Chatham Rise (Patchell 1981, Colman & Vignaux 1992), but most of the landings have been a bycatch of other fisheries, particularly those targeting hoki (*Macruronus novaezelandiae*). Total annual landings in the last 8 years have varied between 4100 and 13 200 t (Annala 1995). Most hake taken commercially range between 65 and 140 cm total length.

Ageing of hake from New Zealand was first reported by Wyszyński (1986), who examined various hard parts of the fish and concluded that whole and cross-sectioned otoliths, and vertebrae could be used successfully for age determination, although cross-sectioned otoliths were preferred. The ageing methodology was not validated. He examined a narrow size range of fish (51–81 cm total length), did not separate the data by sex, and concluded that hake were about 55 cm long at age 3 and that the oldest fish in the sample were aged 8.

Colman *et al.* (1991) calculated von Bertalanffy parameters based on cross-sectioned and baked otoliths collected in 1976 from the Chatham Rise and WCSI. However, no fish in the sample were aged younger than 5 years, and the authors acknowledged that this resulted in unrealistic t_0 parameters of about –5 and L_∞ values greater than maximum recorded fish lengths. They also presented juvenile length mode data collected over a 1 year period indicating hake are about 15–20 cm long after 1 year. Colman & Vignaux (1992) used a new data set based on otoliths collected off WCSI in 1989 and 1990. Fish as young as 2 years were present in this sample, and the resulting von Bertalanffy parameters were more realistic than those from the previous study. Neither of these studies validated the ageing method.

An ageing study of *Merluccius australis* from off the coast of southern Chile examined zones in baked and cross-sectioned otoliths from fish with a length range of 45–155 cm (Ojeda & Aguayo 1986). The resulting von Bertalanffy parameters showed females to grow faster than males. The maximum recorded age for both sexes was 30 years, though few fish were older than 24. An examination of otolith margins over time indicated that the zonation pattern was probably an annual phenomenon.

Although the interpretation of merluccid otoliths has often been controversial, validated ageing techniques have been developed for numerous *Merluccius* species (*see* Alheit & Pitcher 1995). A variety of preparation methods have been used, i.e., whole unmodified otoliths, whole otoliths immersed in some clearing liquid, burned otolith cross-sections, and thin sections. Whole otoliths are not always useful to determine ages of old, slow-growing hakes owing to the narrowness of growth zones formed late in life. Most of successful studies have used cross-sections or thin sections through the dorso-ventral axis of the otolith. The present study aimed to develop and document a standardised and validated methodology to age hake using otoliths by interpreting patterns of early otolith growth and determining how many growth zones are laid down annually in otoliths of juvenile and mature fish. Growth parameters for hake from the three main New Zealand fishing areas could then be calculated, and estimates of instantaneous mortality derived.

3. METHODS

Definitions of terms used in this paper are as follows.

"Age" – the age of a fish in years and fractions of years, e.g., age 6.3 implies an age of about 6 years and 4 months.

"Age class" – fish of any age within a particular whole year, e.g., age class 3+ implies fish at least 3.0, but less than 4.0 years of age.

"Year class" – fish spawned in a particular year, e.g., the 1991 year class implies fish spawned in 1991.

Otoliths (sagittae) of hake from around the South Island have been collected by scientific observers since 1989. Otoliths were also obtained during trawl surveys of the Chatham Rise, Campbell Plateau, and Stewart-Snares shelf, conducted since 1989. Total length (TL, rounded to the nearest centimetre below actual length) and sex were recorded for all fish from which otoliths were taken. Otoliths were stored dry in paper envelopes.

All otoliths were examined in cross-section prepared in one of two ways. Initially, whole otoliths were broken across the dorso-ventral axis, one broken surface was ground smooth on a rotary grinder, and the half otoliths were baked in an oven until amber coloured (270 °C for about 4 minutes). Later preparations were made by baking whole otoliths in an oven until amber coloured, embedding them in clear epoxy resin (Araldite K142), and cutting the otolith along the dorso-ventral axis through the nucleus using a rotary diamond edged saw. The latter method was preferred as it produced uniformly flat cross-sections with unchipped edges. The prepared otolith cross-section was coated in paraffin oil, illuminated by reflected light with an incident angle of about 30°, and examined under a binocular microscope (x30). A pattern of dark brown (opaque) and light brown (translucent) zones was apparent. The number of complete opaque zones (i.e., dark zones with lighter material outside them) was counted. The zonation pattern was generally clearest on the ventral side of the otolith cross-section, so most counts were made in this area (Figure 1). Fish length and sex were unknown to the otolith reader.

To convert zone counts to estimates of age, it was necessary to validate the ageing method by determining when and how frequently the zones were laid down. Seven otolith samples each comprising 145–235 otoliths were selected to examine changes in otolith margin characteristics (Table 1). The samples were collected between April–May 1992 and May–June 1993 from the Campbell Plateau and Stewart-Snares shelf. Otolith margins were classified as either dark or light, and the number of complete opaque zones was counted. About 15% of the otoliths had a marginal state too indistinct to classify confidently, although a zone count could still be made. The month of collection was unknown to the otolith reader.

Validation of the ageing technique for adult fish was also attempted by examining the age structures from samples collected during trawl surveys of the Campbell Plateau in October–November 1989 and November–December 1991–93 to see whether strong and weak year classes moved logically through (*see* Table 1). The year of collection was known to the otolith reader. For each year, the age distribution of hake in the survey area was constructed from the length frequency distribution (scaled to represent the whole population in the survey area) and the otoliths read, in the following manner:

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

where A_t = the estimated proportion of fish of age class 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 length strata, x, were in 5 cm groupings (i.e., 50–54 cm, 55–59 cm, etc.) up to 89 cm for males and 114 cm for females. All remaining fish were grouped into a single length stratum (i.e., 90+ cm for males, 115+ cm for females).

The growth rate of the 0+ age class (i.e., fish less than about 25 cm TL) was examined by plotting length modes of hake caught during a series of trawl surveys by GRV *W. J. Scott* off the northwest of the South Island in 1982–83. The information was derived by Colman *et al.* (1991) from samples of small hake caught on the trawl meshes, presumably as the net was retrieved through midwater (N. Bagley, NIWA, Greta Point, pers. comm.). Because the fish were generally bent around mesh netting in the trawl wings, rather than being caught in the codend, they were seldom recorded in the formal length frequency samples.

Length frequency histograms from research trawl surveys by RV *Kaharoa* of the inshore WCSI often exhibit one or two distinct modes less than 55 cm, which were initially assumed to represent separate year classes of juvenile hake. Examining otoliths of fish from these length modes enabled the pattern of early growth of the otolith to be determined, and helped to define the growth rate of juveniles.

To assess the within-reader reproducibility of the results, 114 otoliths representing a range of ages, both sexes, and both clear and unclear otoliths, were read twice. Between-reader reproducibility was assessed by having a second reader familiar with hake otoliths read a set of 396 otoliths.

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 from each of the three main fishing areas.

4. RESULTS

4.1 Otolith interpretation

About 5% of all otoliths were considered unreadable. Interpretation difficulties were most common in the first five to seven zones which were often quite diffuse and complex in structure (*see* Figure 1). In general, the ventral side of the otolith appears to grow in width and thickness significantly for the first 2 years. Over the next 3–4 years the otolith continues to increase in width, while increases in thickness are often slight. Subsequent growth tends to increase otolith thickness, with little increase in width. Hence, the width of individual opaque and translucent zone pairs formed in years 3–7 are sometimes narrower than those formed in later years. The dorsal side of the otolith tends to grow more uniformly in width and thickness, but the zonation pattern on this side is often less clear than on the ventral side.

4.2 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 a linear regression to the right hand group of points indicates that hake have a length near zero about August, close to the known spawning season in August–September. There is also a clear indication that they are about 10–15 cm long by early April, and reach a length of 20–25 cm 1 year after spawning.

Length frequency histograms from three of the inshore trawl surveys conducted in March–April off the northwest of the South Island exhibit peaks in the 10–15 cm range (Figure 3). Otoliths from this mode in 1994 had no visible otolith zones, as would be expected for fish of age class 0+. In the 1995 sample, otoliths from 24–45 cm fish all had one clear band, those from 10–14 cm fish had no zones, and otoliths from 19–23 cm hake had either one or no zones. Hence, in this year, the 0+ age class is probably bimodal. The 1+ age class is apparent in three of the histograms, with mean values of 34–37 cm. A 2+ age class is abundant in only the 1992 sample, and has a mean length of about 44 cm.

Most of the individual age classes apparent in Figure 3 have broad size ranges. 0+ fish in 1994 and 1995 range from 9 to 23 cm. 1+ and 2+ fish have a 15–25 cm size range. The 1992 distribution is complicated. No otoliths are available from this survey, so it is not known whether the hake of size 20–30 cm are large 0+ or small 1+ fish.

In about half of the otoliths another distinct dark band was visible quite close to the nucleus, but clearly inside the first true zone. The radius to this band was generally about a third to a half as long as the radius to the first annulus, indicating that it forms when hake are about 7–12 cm long. Similar bands have been noted in other ageing studies of merluccids (e.g., Penttila & Dery 1988), and are often referred to as the "pelagic zone" (*see* Figure 1).

4.3 Validation

It was generally possible to determine whether an otolith margin was dark or light. Some interpretations for older fish were complicated because of the narrowness of the zone, and the diffuse early growth zones in some young otoliths were sometimes difficult to classify. Percentages of otoliths with dark margins, for each sample separated into three groups of age classes (2+ – 6+, 7+ – 12+, > 12+), are shown in Figure 4. It is apparent that dark material is initially laid down about May, that most otoliths have a dark margin in mid winter, and that most fish are again laying down light material by October. (Because some otoliths were not readable, or the marginal state of the otolith could not be determined confidently, the sample sizes in Figure 4 are less than those given in Table 1.)

These data support the hypothesis that one dark opaque and one light translucent zone are laid down annually in the otoliths of hake.

Hake spawn off WCSI about August–September, and during late spring and early summer on the western Chatham Rise and the northwestern Campbell Plateau (Colman 1995). Hence, a "birthday" of 1 October was chosen. As the dark zone in the otoliths appears to be complete by late winter (August–September), fish are about 1 year old on completion of the first dark zone. Hence, the number of complete dark zones, plus a correction for the time elapsed between 1 October and the date of sampling, was taken as the age of the fish.

Errors would result if no account was taken of the variable timing of zone completion. Consequently, margins of otoliths collected during September to December were subjectively graded as either wide or narrow, though this was difficult at times because of the narrow zones on otoliths of older fish. Since the new light zone appears to start forming about 1 September, fish caught after this time and showing n dark zones and a wide margin were assigned to the same age class as those with $n + 1$ zones and a narrow margin.

Further support for the ageing method was derived by examining the progression of a strong year class through estimated age distributions from the Campbell Plateau (Figure 5). The 1979 year class was abundant as 10-year-old fish in 1989, and progressed through the set of samples to be age 14 in 1993. However, some moderately strong year classes do not appear to progress between years, e.g., 13+ males in 1989, 9+ males in 1992.

4.4 Growth parameters

Von Bertalanffy growth curve parameters (with asymptotic 95% confidence intervals for the estimates) for fish from the Campbell Plateau, Chatham Rise, and WCSI are given in Table 2. Time of sampling, and, hence, part-year growth, is incorporated in this analysis. All of the samples (with the exception of the 1993 Chatham Rise and WCSI collections) comprise few fish younger than 4 years, so t_0 is poorly defined. Also, young fish that are caught 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 all fish, it is necessary to add information on the growth of juvenile hake. Mean lengths for hake at ages 0.6, 1.6, and 2.6 years as determined from modes in length frequency distributions collected off WCSI are 13, 35, and 44 cm TL, respectively (from Figure 3). A length-based data set of 300 points was created comprising three sets of 100 points, each normally distributed with means (and *c.v.*s) at 13 (16%), 35 (10%), or 44 (10%). The chosen *c.v.*s were similar to those calculated for the distributions in Figure 3. The length-based data were combined with observed age-length data for ages 3 and older from the three sample areas. This assumes that rates of juvenile growth are comparable in all areas. Von Bertalanffy parameters fitted to these combined data (*see* Table 2) are considered to be the best descriptors of growth for the three hake populations.

Mean lengths at age for fish sampled in November and December from the Campbell Plateau, December and January from the Chatham Rise, and July to September from WCSI, are presented in Tables 3 and 4. The calculated curves, raw data, and mean lengths at age (all corrected for part-year growth) are plotted in Figure 6. The calculated curves fit the observed data well. In all three areas, length at age is virtually identical for the two sexes up to age 4, although female hake grow significantly faster and reach a larger size than males. There are no significant differences in growth rates for female hake from the Campbell Plateau and Chatham Rise, but females off WCSI grow significantly slower than those in the other two areas. For male hake, the three L_∞ values calculated from the combined data sets are all significantly different, with growth being fastest on the Campbell Plateau and slowest off WCSI (*see* Table 2).

Male hake had a maximum age of 30 years, and females were aged to 27 years. Of all fish aged 20 years or more, 69% were male. The minimum age of the oldest 5% of fish from each area was similar between sexes, being 17 years on the Campbell Plateau, 16 years on the Chatham Rise, and 15 years off WCSI. For all areas combined, about 1% of females were older than 18 years, while 1% of males were older than 20 years.

4.5 Age replication

The results of the within-reader comparison are shown in Table 5. Of the 114 otoliths examined twice, 60% were aged identically and 92% differed by 1 year or less. There was no apparent bias in the ageing error over the entire age range.

Of the 396 between-reader comparisons available, 52% were aged identically and 86% differed by 1 year or less (Table 6). These data suggest that there may be a slight bias between readers. One reader appeared to age fish slightly older over the 2–6 year age range, and slightly younger over the 9–13 year age range, than the other reader. However, the von Bertalanffy parameters calculated separately for each reader's data set were not significantly different.

4.6 Population age distributions

The estimated age distributions for four samples from the Campbell Plateau (Samples 4, 8, 9, and 10 in Table 1) are presented in Figure 5. The distributions were quite similar for males and females in all years except 1992. In that year there was an unusually low number of males in the sample and the male age distribution was based on only 40 otolith readings. The 1979 year class is dominant in all distributions. Age distributions for two samples from each of the Chatham Rise and WCSI (Samples 11–14 in Table 1) are given in Figure 7. The strong 1979 year class apparent in the Campbell Plateau distributions also appears relatively abundant on the Chatham Rise. The 1979 year class is not dominant in the WCSI population, but a series of relatively strong year classes spawned in the early 1980s was apparent.

The age distributions from all three areas imply that hake recruitment is variable. Juvenile length frequency data from the WCSI (*see* Figure 3) support this hypothesis. The 1994 and 1995 samples were taken from the same area using identical fishing gear, and the estimated number of age class 1+ fish in the survey area in 1995 was over 70 times greater than the estimated number of 1+ fish in 1994. Hence, the 1993 year class spawned off WCSI is very large relative to other recently spawned year classes.

5. DISCUSSION

Studies of age and growth of *Merluccius* species are numerous because of the importance of these species as commercial fisheries in many of the world's oceans (Pitcher & Alheit 1995). However, the interpretation of merluccid otoliths has often been controversial because of 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., Penttila & Dery 1988). Similar problems were encountered in this study, but it was still possible to interpret the pattern of early growth and develop a generally validated methodology to age *M. australis* using otoliths. Growth was validated to age 1 by following the progression of length modes, and from age 2 onwards by examining the state of the otolith margins. The progression of a strong 1979 year class through age-frequency distributions over a 5 year period provided further evidence that the ageing method was valid.

Comparisons of the present work with previous ageing studies of *M. australis* from New Zealand (Wyszyński 1986, Colman & Vignaux 1992) suggest that all authors have been interpreting otoliths quite similarly at least for young fish (Figure 8). However, the growth curves for Chilean *M. australis* (Ojeda & Aguayo 1986) are very different from those for New Zealand fish, and imply either a different pattern of growth or different interpretation of the otoliths. Wyszyński (1986) commented on the dark band often apparent inside the first true annuli, and postulated that it represented a lifestyle change as the fish shifted from a pelagic to a demersal habitat. A similar "pelagic zone" has been noted in the otoliths of other *Merluccius* species (Penttila & Dery 1988).

Female hake are larger than males at corresponding ages, a trend noted for *M. australis* by Ojeda & Aguayo (1986) and Colman & Vignaux (1992), and general to *Merluccius* species (Pitcher & Alheit 1995). The differences in growth curves for males and females from the same area are statistically significant. The growth of both sexes is relatively rapid (and quite similar) up to about age 4–5, but then slows markedly. Hake begin to mature sexually at age 6 at lengths of about 65 cm for males and 70 cm for females (Colman 1995). Growth by both sexes, but particularly males, is slight after about 12 years.

Merluccius australis is amongst the largest and most long-lived of the *Merluccius* species, but this may be due in part to a low level of exploitation relative to hake from other areas. Longevity may differ slightly between sexes; 69% of hake aged 20 years or older were male. Also, while 1% of all aged males were older than 20 years, the comparable figure for females was 18 years. Studies of merluccids generally show females to grow larger and have a similar or slightly greater longevity than males (Alheit & Pitcher 1995). Colman *et al.* (1991) estimated that 1% of the fish in a 1976 sample from the Chatham Rise and WCSI survived to at least 23 and 21 years for females and males, respectively. This study examined fish sampled before major fishery exploitation, whereas all samples examined in the present study were collected since late 1989 and following several years of fishing (although no estimates of instantaneous fishing mortality are available). The implied reduction in longevities since 1976 may be due to exploitation concentrating on the larger female fish, though this conclusion is based on relatively small changes in maximum age.

The length range of fish in juvenile year classes is very broad, being at least 10 cm for hake aged 0.6 years and 15–25 cm for 1.6 year fish (from Figure 3). This suggests either an extended spawning season, or a wide variation in growth rates of individual fish in a year class. An examination of otoliths showed the 0+ age class in 1995 to be bimodal. The 1992 distribution showed a similar pattern, but ages could not be verified. Time of spawning is known to vary between years on the Chatham Rise (Colman 1995), and protracted or batch spawning has been reported for several *Merluccius* species (Pitcher & Alheit 1995). It appears most likely that the broad length ranges are due to extended spawning periods that sometimes result in bimodal distributions within individual year classes, and to rapid overall juvenile growth.

Year class strengths of *M. australis* can vary considerably, as has been noted for other species of *Merluccius* (e.g., Woodbury *et al.* 1995). The 1993 year class spawned off WCSI was almost two orders of magnitude more abundant than any year class spawned in the previous 5 years. Population age distributions from the Campbell Plateau, Chatham Rise, and WCSI indicate that recruitment is sufficiently variable to preclude the estimation of instantaneous total mortality (Z) using the slopes of the right hand limbs of the catch curve. However, it has been postulated in overseas studies that cannibalism may reduce the dominance of any exceptional year class and produce a more even pattern of recruitment to the fishery (Pitcher & Alheit 1995).

Estimates of instantaneous natural mortality (M) were derived from the equation

$$M = \log_e(100) \;/\; A_{max}$$

where A_{max} is the age reached by 1% of a virgin population (Sparre *et al.* 1989). The samples aged here suggest an A_{max} of about 20 years for male and 18 years for female hake, giving estimates for M of 0.23 and 0.26, respectively. However, these samples were not from virgin populations, so M may be slightly overestimated. Colman *et al.* (1991) used a similar method to produce estimates of M of 0.22 and 0.20 for males and females, respectively, from populations that had been only lightly exploited. It seems likely that M for hake is in the range 0.20–0.25.

The results from this age and growth study provide some insights into the possible stock structure of New Zealand hake. Hake from the WCSI have significantly slower growth rates than fish from the Campbell Plateau or Chatham Rise, and growth rates for males differ between the Chatham Rise and the Campbell Plateau. Populations from the last two areas both exhibit a strong 1979 year class, which is not apparent in the WCSI samples. A comparison of the estimated age distributions from the Campbell Plateau and Chatham Rise show younger age classes to be better represented on the Chatham Rise, particularly age classes 2+ and 3+ in summer 1992–93 and age classes 3+ to 8+ in 1989. Hence, it is likely that there are at least two separate stocks of hake in New Zealand waters, with WCSI fish being clearly distinct from the rest. The Chatham Rise and Campbell Plateau populations could also be separate stocks, despite their comparable female growth rates, as there are differences apparent in their population age structures and clearly defined spawning grounds are present in both areas.

Conclusions

A method to age hake using otoliths has been developed. The technique was validated to age 2 using the progression of modes in length frequency distributions, and for ages 2 onwards by examining the state of otolith margins from fish sampled regularly over a 1 year period. Growth parameters have been calculated for hake from the three main New Zealand fishing grounds; some between-area differences are apparent. Estimates of instantaneous total mortality could not be derived because of the large variation in year class strengths.

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7. REFERENCES

Alheit, J. & Pitcher, T. J. (Eds) 1995: Hake: Biology, fisheries and markets. *Fish and Fisheries Series 15.* Chapman & Hall, London. 478 p.

Annala, J. H. (Comp.) 1995: Report from the Fishery Assessment Plenary, May 1995: stock assessments and yield estimates. 227 p. (Unpublished report held in NIWA library, Wellington.)

Colman, J. A. 1995: Biology and fisheries of New Zealand hake (*M. australis*). *In* Alheit, J. & Pitcher, T. J. (Eds), Hake: Biology, fisheries and markets, p. 365–388. *Fish and Fisheries Series 15.* Chapman & Hall, London.

Colman, J. A., Stocker, M., & Pikitch, E. 1991: Assessment of hake (*Merluccius australis*) stocks for the 1991–92 fishing year. N.Z. Fisheries Assessment Research Document 91/14. 29 p. (Unpublished report held in NIWA library, Wellington.)

Colman, J. A. & Vignaux, M. 1992: Assessment of hake (*Merluccius australis*) for the 1992–93 fishing year. N.Z. Fisheries Assessment Research Document 92/17. 23 p. (Unpublished report held in NIWA library, Wellington.)

Ojeda, V. & Aguayo, M. 1986: Edad y crecimiento de merluza del sur (*Merluccius australis*) (Gadiformes-Merlucciidae). *Investigación Pesquera, Chile 33*: 47–59.

Patchell, G. J. 1981: The Westland hake fishery. *Fisheries Research Division Occasional Publication No. 31.* 18 p.

Penttila, J. & Dery, L. M. (Eds) 1988: Age determination methods for northwest Atlantic species. *NOAA Technical Report NMFS 72.* 135 p.

Pitcher, T. J. & Alheit, J. 1995: What makes a hake? A review of the critical biological features that sustain global hake fisheries. *In* Alheit, J. & Pitcher, T. J. (Eds), Hake: Biology, fisheries and markets, p. 1–14. *Fish and Fisheries Series 15.* Chapman & Hall, London.

Ralston, M. L. & Jennrich, R. I. 1978: DUD, a derivative-free algorithm for nonlinear least squares. *Technometrics 20*: 7–14.

Sparre, P., Ursin, E., & Venema, S. C. 1989: Introduction to tropical fish stock assessment. Part 1. Manual. *FAO Fisheries Technical Paper 306.* 337 p.

Woodbury, D., Hollowed, A. B., & Pearce, J. A. 1995: Interannual variation in growth rates and back-calculated spawn dates of juvenile Pacific hake (*Merluccius productus*). *In* Secor, D. H., Dean, J. M., & Campana, S. E. (Eds), Recent developments in fish otolith research, p. 481–496. *The Belle W. Baruch Library in Marine Science 19.* University of South Carolina Press.

Wyszyński, M. 1986: Attempt to determine the applicability of various bony elements for estimation of age and growth of hake *Merluccius australis* (Merluccidae) from New Zealand waters. *Reports of the Sea Fisheries Institute, Gdynia 21*: 62–88.

Table 1: Details of otolith samples examined to determine marginal state (samples 1–7), and to provide additional data to calculate growth parameters (samples 8–14). Area: CPSS, Campbell Plateau and Stewart-Snares shelf; CHAT, Chatham Rise; WCSI, west coast South Island. Type: TS, trawl survey sample; OB, scientific observer sample. *n*, number of otoliths available.

Sample no.	Area	Type	*n*	Sample period	Mean date
1	CPSS	TS	164	20 Apr–18 May 1992	4 May
2	CPSS	OB	198	11 Jun–28 Jul 1992	6 Jul
3	CPSS	TS	192	16 Sep–12 Oct 1992	29 Sep
4	CPSS	TS	235	22 Nov–20 Dec 1992	6 Dec
5	CPSS	TS	92	14–25 Feb 1993	
	CPSS	OB	94	10–27 Feb 1993	20 Feb
6	CPSS	OB	145	20 Mar–30 Apr 1993	8 Apr
7	CPSS	TS	160	3 May–2 Jun 1993	18 May
8	CPSS	TS	114	20 Oct–12 Nov 1989	
9	CPSS	TS	374	26 Nov–21 Dec 1991	
10	CPSS	TS	278	20 Nov–19 Dec 1993	
11	CHAT	TS	339	26 Nov–17 Dec 1989	
12	CHAT	TS	437	30 Dec 1992–5 Feb 1993	
13	WCSI	OB	450	1 Jul–30 Sep 1992	
14	WCSI	OB	299	12 Jul–22 Sep 1993	

Table 2: Von Bertalanffy parameters (with 95% confidence intervals) for hake from the Campbell Plateau (CP), Chatham Rise (CR), and off the west coast of the South Island (WC). Parameters are shown for the data sets comprising otolith readings only, and for a data set combining all otolith readings ≥ 3 years and length-based estimates of juvenile growth.

Area	n	L_∞		k		t_0	
Otolith data only							
Female							
CP	1086	122.3	(119.0–125.6)	0.134	(0.119–0.150)	–1.56	(–2.06 to –1.07)
CR	393	123.9	(119.1–128.7)	0.135	(0.117–0.153)	–1.13	(–1.56 to –0.68)
WC	365	110.6	(105.9–115.5)	0.146	(0.119–0.174)	–1.94	(–2.73 to –1.15)
Male							
CP	550	97.6	(95.0–100.2)	0.161	(0.135–0.188)	–2.34	(–3.21 to –1.47)
CR	345	93.1	(91.1–95.1)	0.207	(0.183–0.230)	–1.02	(–1.40 to –0.64)
WC	331	84.5	(83.0–85.9)	0.265	(0.228–0.302)	–0.67	(–1.25 to –0.09)
Otolith and length–based data							
Female							
CP	1383	115.5	(114.3–116.8)	0.185	(0.177–0.192)	–0.18	(–0.25 to –0.10)
CR	656	116.1	(113.9–118.3)	0.181	(0.170–0.192)	–0.21	(–0.29 to –0.12)
WC	637	111.1	(109.0–113.2)	0.194	(0.182–0.207)	–0.16	(–0.25 to –0.07)
Male							
CP	849	92.5	(91.6–93.4)	0.259	(0.249–0.269)	–0.06	(–0.11 to 0.00)
CR	601	88.8	(87.8–89.8)	0.294	(0.281–0.307)	0.00	(–0.05 to 0.05)
WC	625	83.5	(82.7–84.3)	0.308	(0.294–0.322)	0.00	(–0.05 to 0.06)

Table 3: Mean lengths at age (cm, with standard deviation and sample size) for female hake sampled during November and December on the Campbell Plateau (samples 4, 8, 9, and 10 from Table 1), December and January on the Chatham Rise (samples 11 and 12), and July to September off WCSI (samples 13 and 14).

	Campbell Plateau			Chatham Rise			WCSI		
Age class	Mean	S.D.	*n*	Mean	S.D.	*n*	Mean	S.D.	*n*
1+	–			–			45.6	3.5	9
2+	51.5	4.7	3	45.8	3.9	37	56.1	4.4	19
3+	59.8	4.1	30	56.4	4.5	35	61.0	3.2	4
4+	66.7	4.1	115	64.5	5.1	21	70.3	7.5	3
5+	71.3	4.8	95	71.6	5.3	26	77.4	7.3	5
6+	77.9	6.8	30	76.9	4.8	27	80.3	6.4	17
7+	82.8	6.7	29	82.2	7.1	32	82.9	5.2	30
8+	88.8	8.2	28	87.9	9.9	33	88.6	7.3	52
9+	92.3	8.3	36	96.1	8.9	16	90.7	7.7	55
10+	97.0	8.7	41	98.2	9.2	40	93.2	6.8	43
11+	101.0	11.5	30	103.7	8.4	18	93.2	9.2	31
12+	106.8	8.3	47	101.6	7.4	24	101.5	9.9	25
13+	103.8	8.5	42	108.9	6.7	23	98.9	8.6	21
14+	106.4	8.7	34	113.1	8.9	11	101.8	10.5	20
15+	110.0	9.0	24	108.0	10.4	19	98.1	4.3	12
16+	112.3	9.3	13	109.0	6.5	14	104.2	8.8	12
17+	105.8	11.5	12	113.3	10.1	7	102.0	–	1
18+	115.4	6.7	6	119.5	5.3	2	119.5	10.6	2
19+	115.2	3.7	5	117.0	13.3	4	107.3	9.9	3
20+	101.0	–	1	111.0	–	1	–		
21+	118.0	–	1	–			–		
22+	–			121.0	–	1	–		
23+	–			108.0	–	1	102.0	–	1
24+	–			–			–		
25+	–			–			–		
26+	–			–			–		
27+	–			124.0	–	1	–		

Table 4: Mean lengths at age (cm, with standard deviation and sample size) for male hake sampled during November and December on the Campbell Plateau (samples 4, 8, 9, and 10 from Table 1), December and January on the Chatham Rise (samples 11 and 12), and July to September off WCSI (samples 13 and 14).

	Campbell Plateau			Chatham Rise			WCSI		
Age class	Mean	S.D.	*n*	Mean	S.D.	*n*	Mean	S.D.	*n*
1+	–			–			37.4	1.5	5
2+	–			45.0	3.7	44	53.0	–	1
3+	59.0	3.4	19	55.9	4.1	37	59.0	4.2	6
4+	64.2	3.8	57	62.9	3.5	27	69.0	6.0	5
5+	68.4	4.2	50	68.5	5.3	35	71.4	3.9	8
6+	71.0	5.1	26	72.6	3.5	18	73.6	3.7	23
7+	73.0	4.2	15	75.2	4.3	26	76.2	4.3	28
8+	78.0	4.6	15	78.9	4.1	20	78.2	4.3	49
9+	83.1	6.3	11	79.7	4.5	20	78.4	4.5	42
10+	83.9	5.6	19	82.7	4.9	25	78.8	5.3	49
11+	85.2	3.3	9	85.4	7.1	18	80.0	6.5	31
12+	85.1	5.9	20	89.1	6.3	15	81.0	4.7	21
13+	87.4	6.3	9	88.9	5.9	18	80.6	4.7	14
14+	87.3	4.4	13	89.6	5.3	15	85.5	2.8	11
15+	88.7	1.8	4	87.6	3.6	8	82.0	4.7	7
16+	95.6	14.4	5	94.6	7.4	8	85.8	4.0	13
17+	90.6	–	1	90.5	3.5	5	84.3	1.2	3
18+	89.5	0.3	3	88.5	5.9	2	86.4	4.1	5
19+	90.0	–	1	91.0	–	1	112.0	–	1
20+	89.0	–	1	94.5	7.3	2	85.5	4.9	2
21+	–			93.0	–	1	84.0	1.4	2
22+	–			–			–		
23+	–			–			91.0	4.2	2
24+	–			–			–		
25+	–			–			–		
26+	100.5	10.3	2	–			91.0	–	1
27+	–			–			–		
28+	–			–			89.5	4.9	2
29+	–			–			–		
30+	89.0	–	1	–			–		

Table 5: Within-reader comparisons of 114 otoliths. Age class, age class at first reading; Diff, the extent by which the second reading differed from the first; Sim, the percentage of fish by age class for which both readings were the same.

	Age class																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15–16	17–19	20+	Total
Diff																	
+2							1							2			3
+1		1	2			1	2	2	2	2		3	1	2	1		19
0		5	8	3	2	1	2	4	3	5	8	8	8	6	4	1	68
−1			1	1			2		3	3	1	4	1	1	1		18
−2									1				1	2			4
−3														1	1		2
Sim		83	73	75	100	50	29	67	33	50	89	53	73	43	57	100	60

Table 6: Between-reader comparisons of 396 otoliths. Age class, age class allocated by first reader (PLH); Diff, the extent by which the age class allocated by the second reader (JAC) differed from that of the first reader; Sim, the percentage of fish by age class for which both readings were the same.

	Age class																
	2	3	4	5	6	7	8	9	10	11	12	13	14	15–16	17–19	20+	Total
Diff																	
+5			1														1
+4					1												1
+3					2	1	1		1								5
+2		1		1	2	1	2	2	2	3		1	1	1			17
+1	3		1		3	7	11	7	5	6	4	3	3	3			56
0	6	4	2	5	15	23	35	33	27	19	3	7	10	10	4	2	205
−1				1	4	7	10	15	10	9	6	9	2	4	1		78
−2						2	7	4	4	2	4	1	1	2	1	2	30
−3																	0
−4													2				2
−5												1					1
Sim	67	80	50	71	56	56	53	54	55	49	18	32	53	50	67	50	52

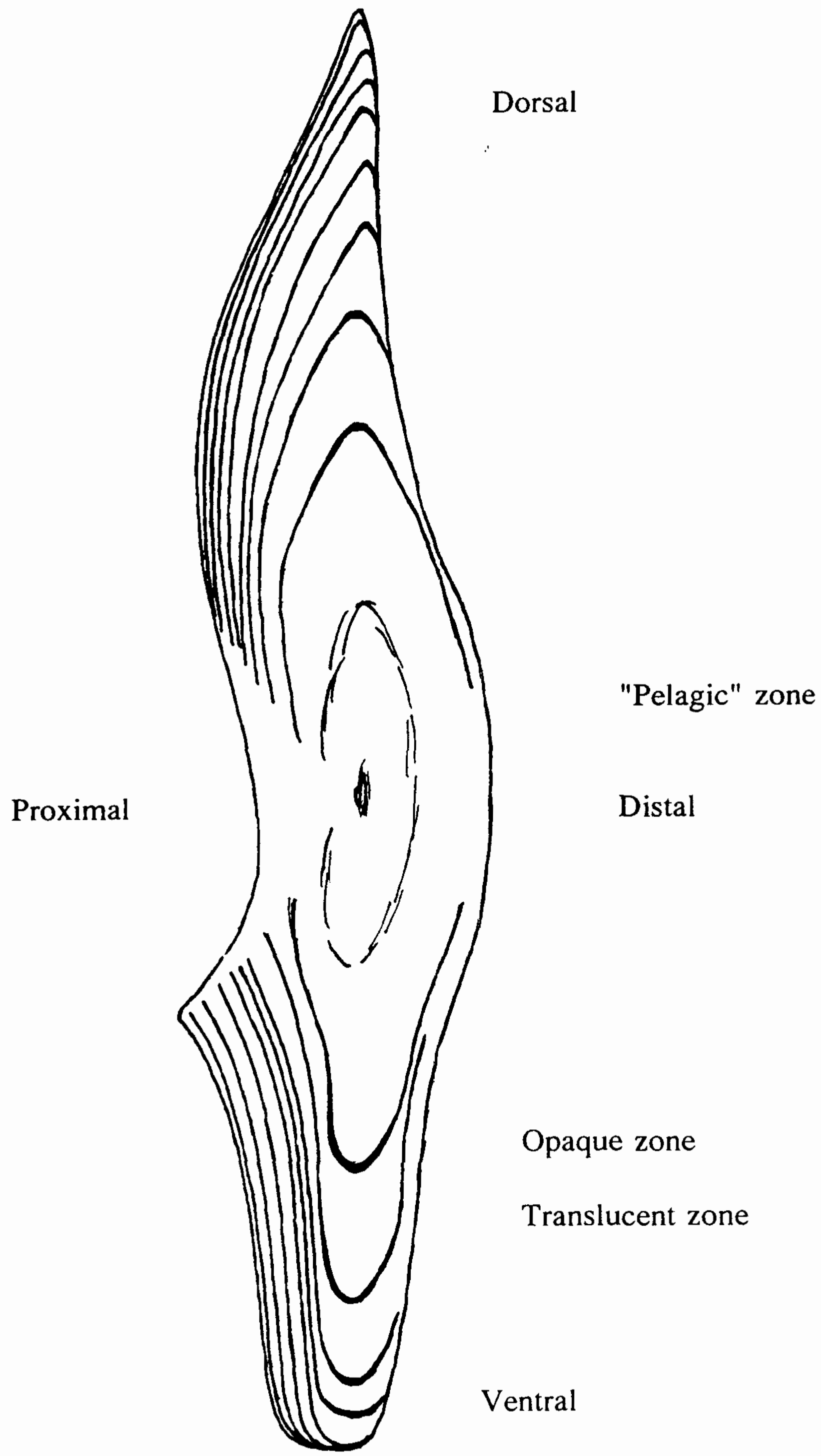

Figure 1: Sketch of a dorso-ventral cross-section of an otolith from an age class 8+ fish. showing the generalised pattern of growth.

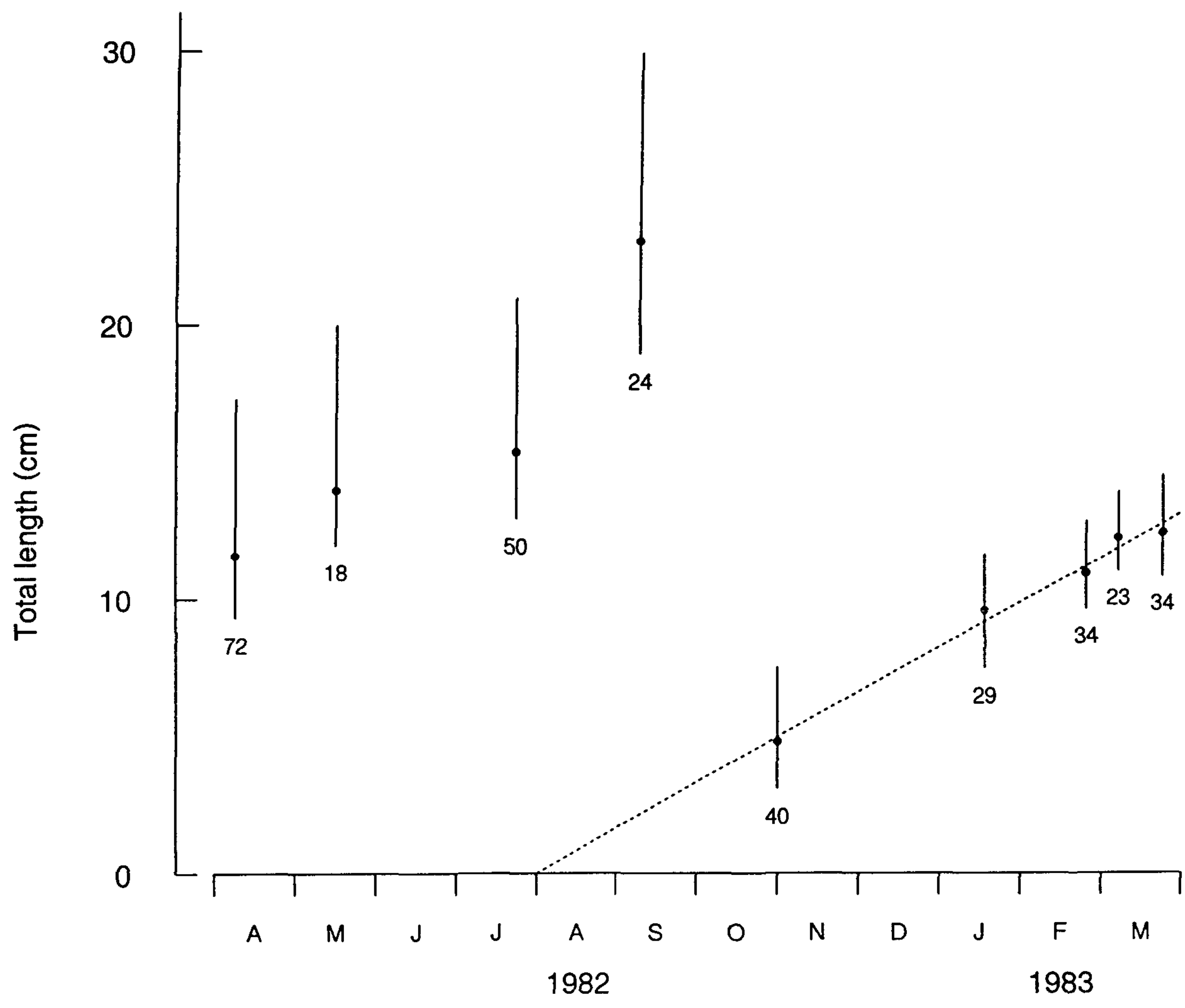

Figure 2: Length modes of juvenile hake caught during bottom trawl surveys by GRV *W.J. Scott* off the northwest of the South Island between April 1982 and March 1983. Points indicate the mean length and lines indicate the range. Sample sizes are plotted adjacent to each range. Broken line is the linear regression fitted to the right hand group of mean points.

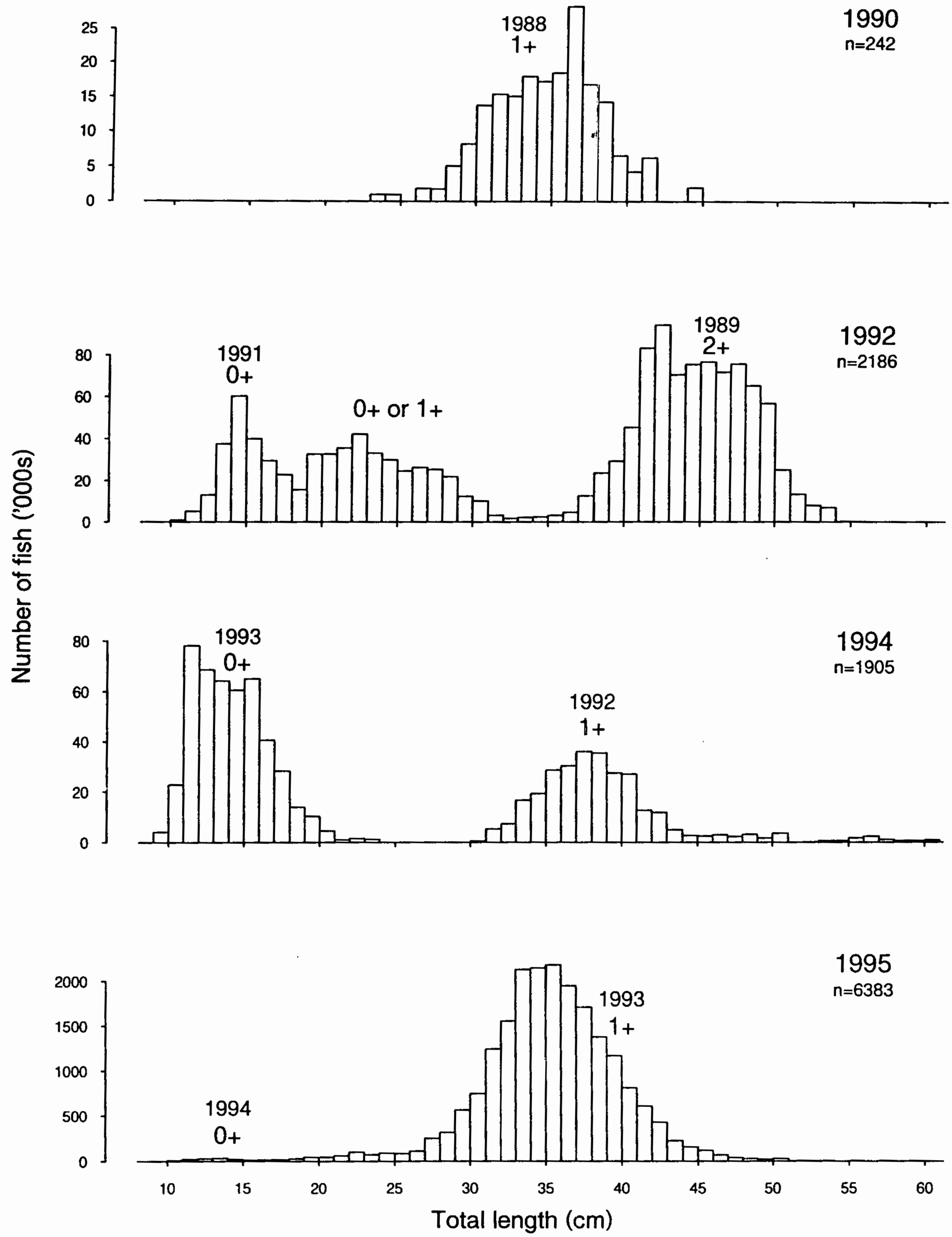

Figure 3: Length frequency histograms of hake (male, female, and unsexed combined) caught in research trawl surveys by RV *Kaharoa* off the northwest coast of the South Island during April–May 1990, 1992, 1994, and 1995. The data have been scaled to represent the estimated number of hake in the survey area. The last three distributions are directly comparable as they were sampled using the same vessel and fishing gear. The 1990 sample was taken by a different, and probably less efficient, trawl. n, number of fish measured. Length frequency peaks are labelled with year of spawning and age class.

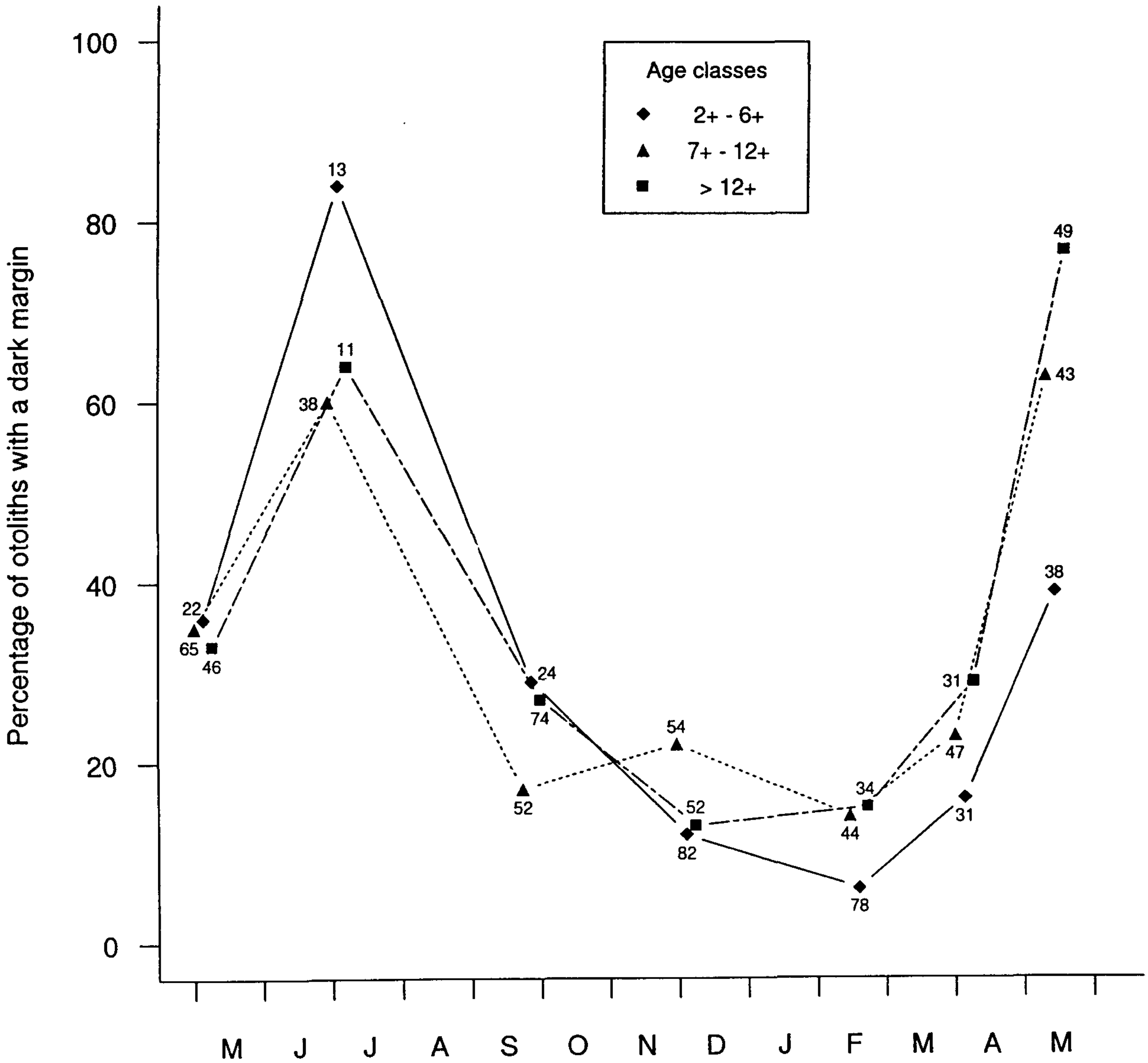

Figure 4: Seasonal change in the percentage of otoliths with a dark margin, over the period May 1992 to May 1993. Numbers adjacent to symbols denote sample size for the three age class groupings (i.e., 2+ – 6+, 7+ – 12+, > 12+).

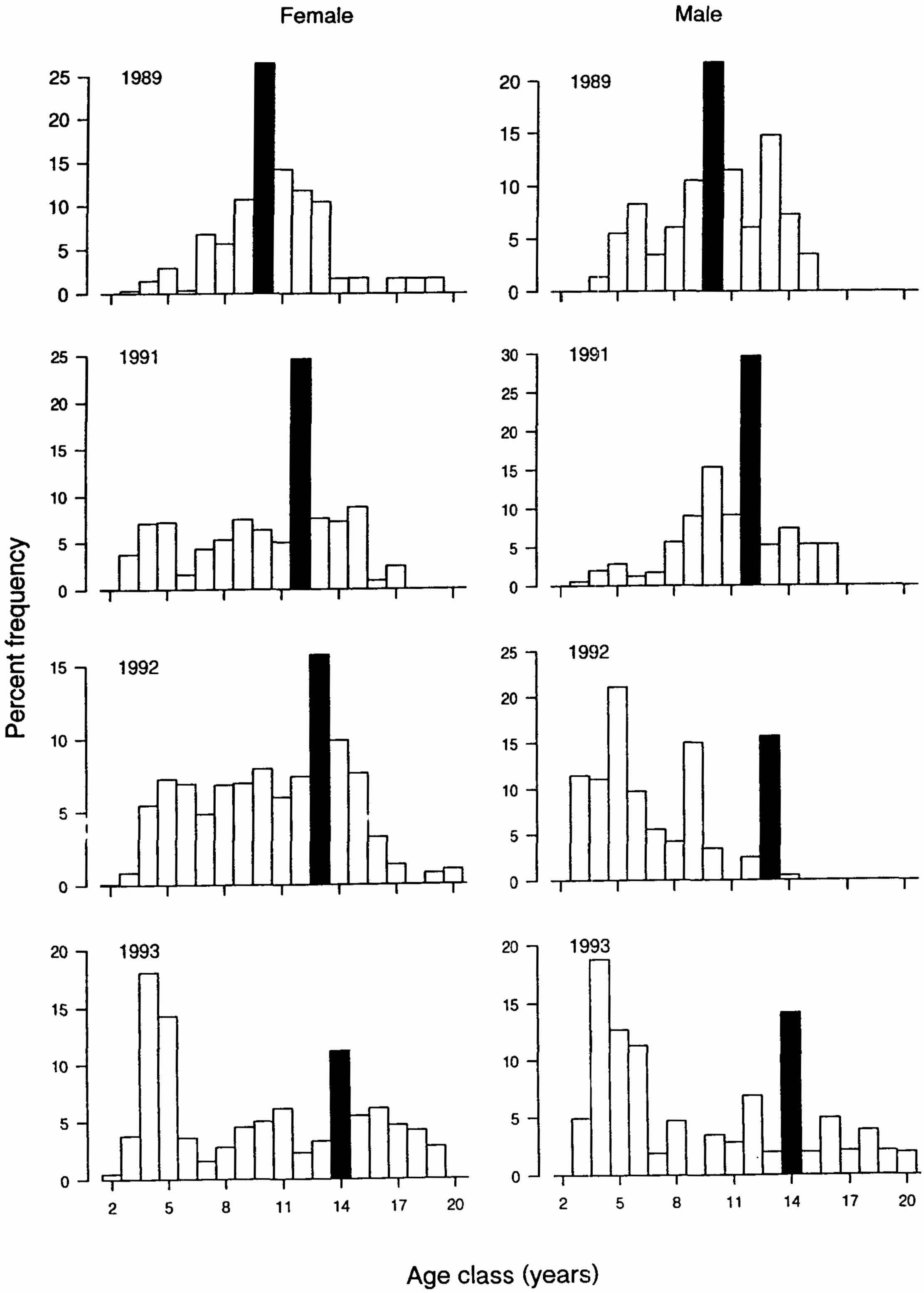

Figure 5: Calculated age distributions, by sex, for the total catch from trawl surveys of the Campbell Plateau in 1989 (by FV *Amaltal Explorer*), and 1991–93 (by RV *Tangaroa*). Dark bars indicate the strong 1979 year class.

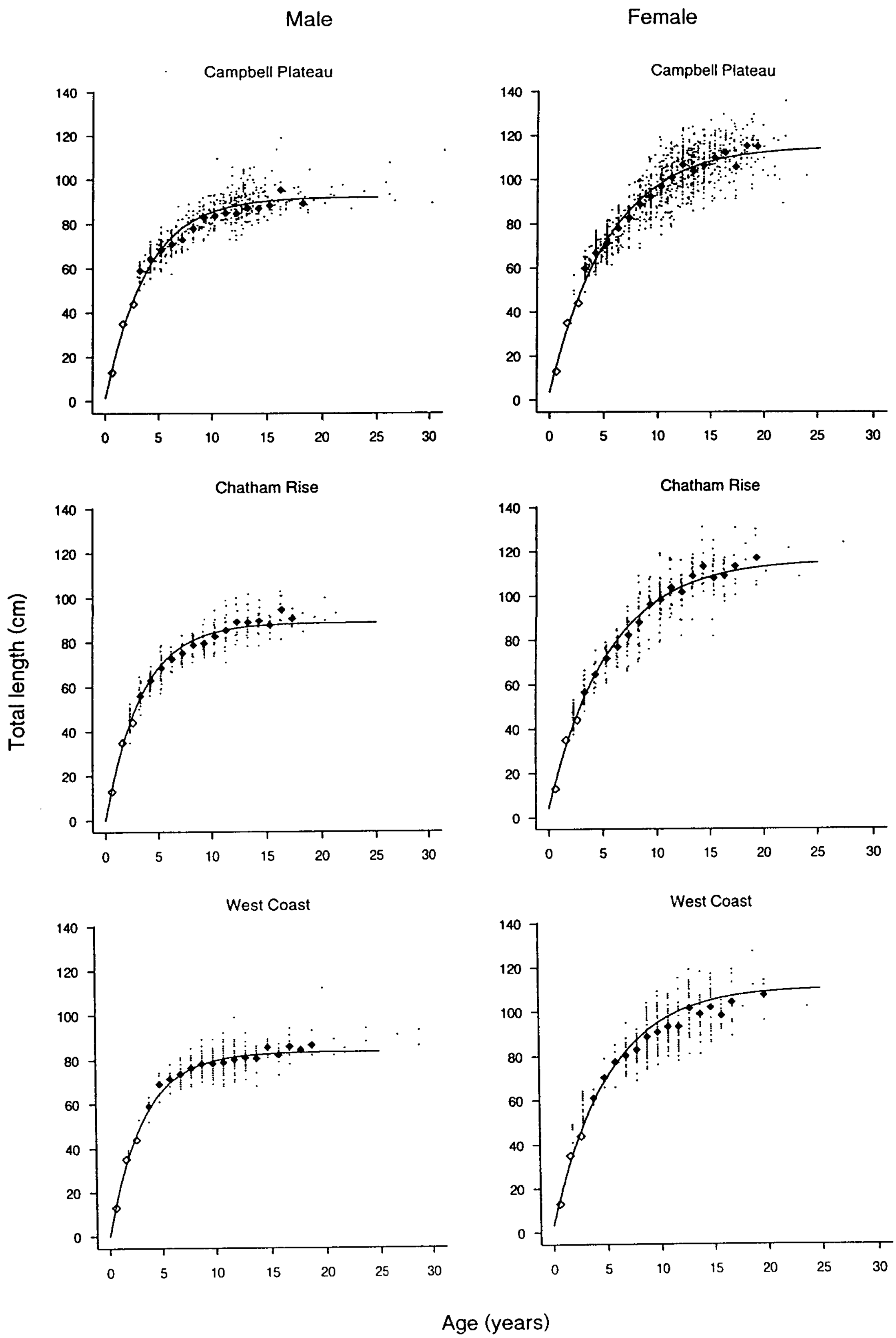

Figure 6: Raw age-length data, and the calculated von Bertalanffy growth curves for hake from the Campbell Plateau, Chatham Rise, and west coast of the South Island, by sex. Mean lengths at age (from Table 3 and 4, where $n \geq 3$) are plotted as closed diamonds. Open diamonds represent the estimated mean lengths at ages 0.6, 1.6, and 2.6 years, from Figure 3.

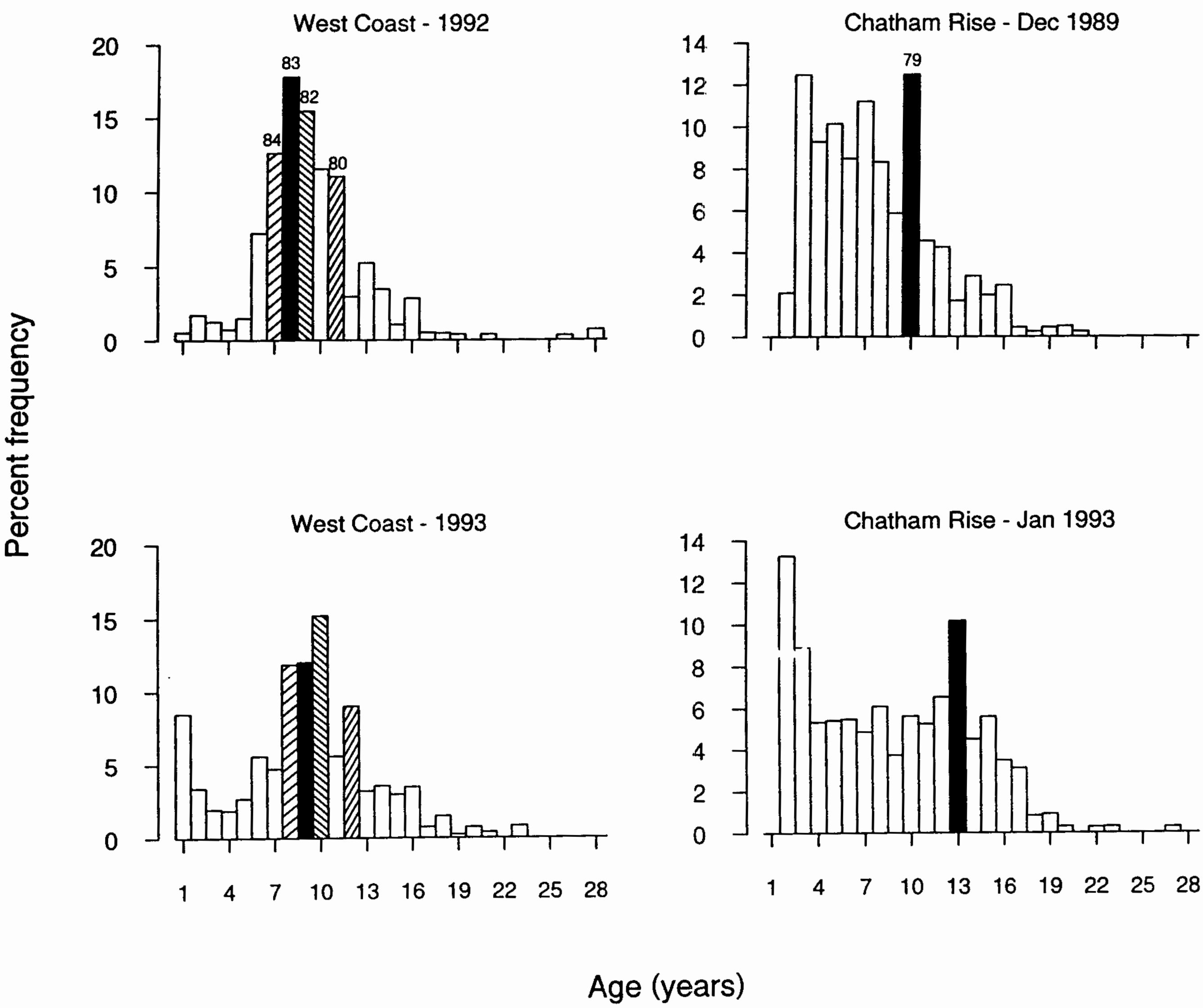

Figure 7: Calculated age distributions for the total catch from trawl surveys of the Chatham Rise in December 1989 and January 1993, and for the commercial catch from the west coast of the South Island in winter 1992 and 1993. Year classes mentioned in the text are noted on the figure.

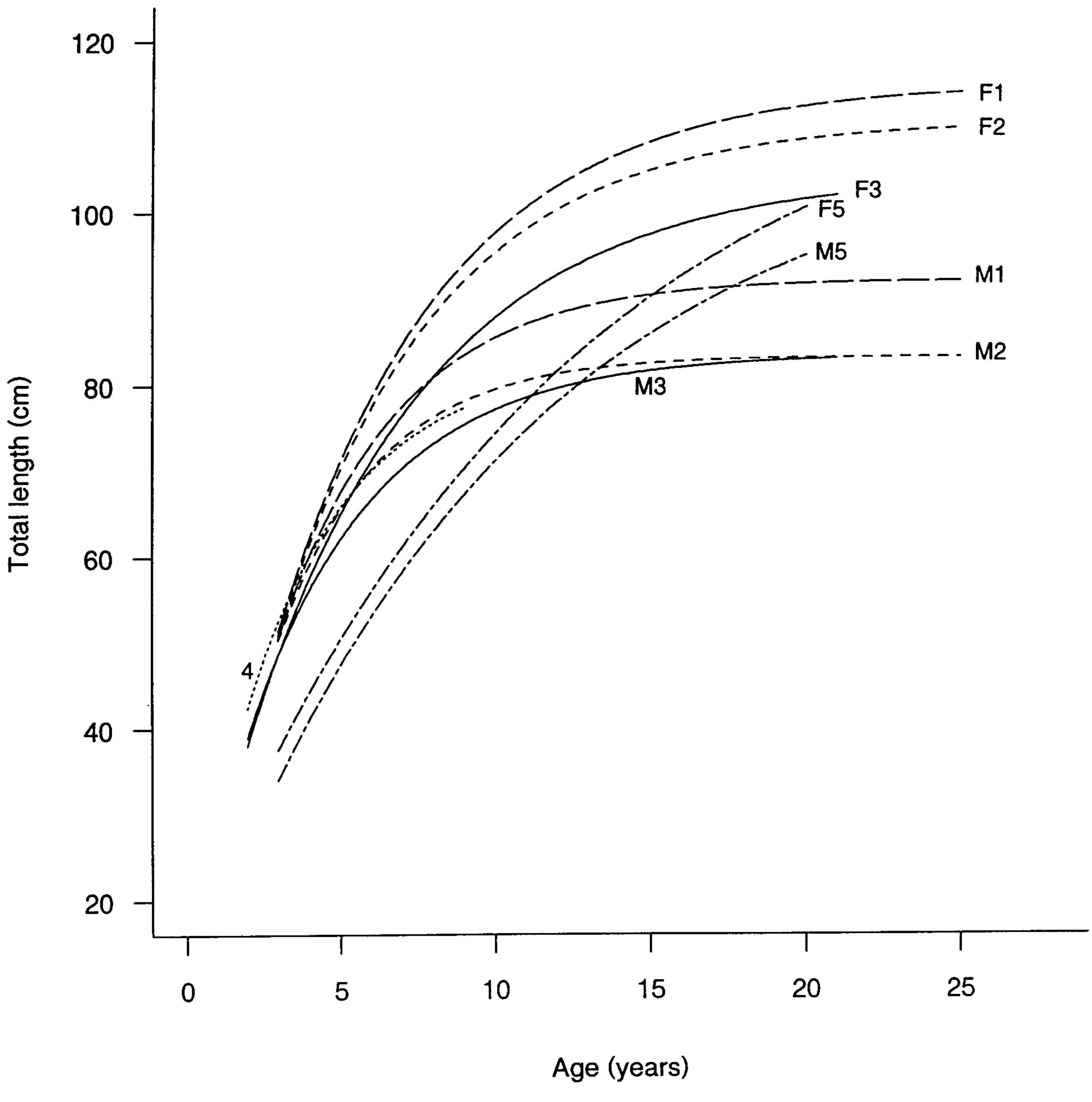

Figure 8: Calculated von Bertalanffy growth curves for *Merluccius australis*. Curves are plotted over the range of age data used to calculate the parameters. F, female; M, male. 1, Campbell Plateau (present study); 2, WCSI (present study); 3, WCSI (Colman & Vignaux 1992); 4, WCSI (Wyszyński 1986); 5, Chile (Ojeda & Aguayo 1986).