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Growth and age structure of tarakihi (*Nemadactylus macropterus*) off the west coast of the South Island

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EXECUTIVE SUMMARY

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Growth data for tarakihi off the west coast of the South Island were derived by counting translucent zones in otoliths collected during four comparable trawl surveys conducted in March–April 1995, 1997, 2000, and 2003. Otoliths from fish up to 25 cm fork length were read whole and untreated; those from larger fish were baked and sectioned before examination. Tarakihi otoliths were found to be relatively straightforward to interpret, with good levels of within-reader and between-reader agreement (indices of average percentage error were less than 2%). Von Bertalanffy parameters estimated using all data from the four surveys combined were: L_∞ = 43.2 cm, k = 0.252, t_0 = –0.55, for males; L_∞ = 46.0 cm, k = 0.221, t_0 = –0.69, for females. There was a significant between-sex difference in growth parameters, with females reaching a larger size than males on average. Based on a visual comparison of published von Bertalanffy parameters, the growth rates of tarakihi off the west and east coasts of the South Island, and at the Chatham Islands, appear to be very similar.

A validation of the ageing method was not attempted, but data from juvenile length modes and from the progression of weak year classes throughout the survey series indicated that one opaque and one translucent zone are laid down annually in tarakihi otoliths. The exception to this is that a post-larval translucent metamorphosis check is formed inside the first true annual translucent zone, probably at about age 7–9 months.

Numbers-at-age distributions from the surveys were dominated by fish aged 0+ to 3+, with relatively few fish older than 15 years. Recruitment strength appears to be quite variable between years. However, year class strengths were often not well defined; the data available from each of the surveys were insufficient to enable precise determination of proportions-at-age in the population for year classes older than about 8 years.

1. INTRODUCTION

Tarakihi (*Nemadactylus macropterus*) is an important species in most of the time series of inshore trawl surveys around New Zealand carried out on RV *Kaharoa* (e.g., Stevenson & Hanchet 2000a, 2000b). Otoliths have been collected from at least one survey in each of the time series from five different areas (i.e., west coast North Island, Bay of Plenty, east coast North Island, east coast South Island, west coast South Island (WCSI)), but only a sample of 171 otoliths from the 1996 west coast North Island survey has been read (Morrison 1998). Hanchet & Field (2001) reviewed current and historical data for tarakihi and concluded that recruitment variability in tarakihi was moderately high. They recommended that otoliths from these trawl surveys should be read, and the data used to determine proportions-at-age. This would aid in the interpretation of any trends from these survey time series and would allow the estimation of year class strength and other biological parameters in future stock assessments. The work reported here describes the ageing of tarakihi from four trawl surveys off west coast South Island conducted between 1995 and 2003 from RV *Kaharoa*. This survey series was chosen for ageing analysis because it was the only one exhibiting a clearly declining trend in biomass. This series also comprises two earlier surveys (in 1992 and 1994), but no tarakihi otoliths were available from these.

An ageing methodology, including the validation of early growth and trials determining the level of repeatability of otolith readings, was described in detail by Tong & Vooren (1972). They found that tarakihi otoliths had a consistent pattern of alternating opaque and translucent zones. A wide opaque zone was laid down in spring–summer and a narrow translucent zone in autumn–winter, but irregular within-year checks occasionally occurred. They found a good agreement between the number of opaque zones and estimated ages from following juvenile length-frequency modes. Variability between otolith readers was low, with 83% agreement between two independent age readings of 409 otoliths. They concluded that the age of individual tarakihi could be reliably determined from the zonation patterns of the otoliths. Ageing studies were reported for tarakihi from the Bay of Plenty (Tong & Vooren 1972), East Cape (Vooren & Tong 1973), and WCSI and the Chatham Islands (Vooren 1977). Annala (1987) summarised the available information on the biology and fishery for tarakihi, and Annala et al. (1990) studied age, growth, mortality, and yield-per recruit for tarakihi from the northeast coast of the South Island. A similar investigation was completed for tarakihi from the Chatham Islands (Annala et al. 1989). Age-length data were derived from the 1996 west coast North Island survey (Morrison 1998), and were analysed to produce catch-at-age distributions (by direct age sampling) but not a growth curve. Jordan (2001) reported on the age, growth, and spatial and interannual trends in age composition of *N. macropterus* in Tasmanian waters. Available von Bertalanffy parameters for this species are listed in Table 1.

The current work aimed to confirm that tarakihi otoliths could be read consistently, to describe any evidence supporting the validity of the ageing method, to calculate von Bertalanffy parameters for WCSI fish, and to estimate the age composition of tarakihi taken in the 1995, 1997, 2000, and 2003 WCSI trawl surveys. We determine whether juvenile ages correspond to juvenile length-frequency modes in the trawl survey data, compare age parameters from the present study with those given in the literature, and determine whether it was possible to follow strong or weak year classes through the time series.

2. METHODS

Otoliths from between 260 and 313 tarakihi were available from each of four WCSI trawl surveys conducted in March–April of 1995, 1997, 2000, and 2003 by RV *Kaharoa* (trip codes KAH9504, KAH9701, KAH0004, and KAH0304). Otoliths had been removed, cleaned, and stored dry in paper envelopes. Additional length-frequency data were available for each survey (see Tables 2 and 3 for sample details).

Growth zones in otoliths from tarakihi with a fork length (FL) of 25 cm or less were read by examining the otoliths whole and untreated, distal surface up, in water against a dark background, with illumination from reflected light, at a magnification of ×25. Measurements to determine the radial width to the outer edge of the first translucent zone were taken from the nucleus to the ventral margin using a micrometer eyepiece. Otoliths from fish over 25 cm FL examined in this work were baked whole in an oven at 280 °C for about 5 minutes, until amber coloured. They were then embedded in epoxy resin and sectioned transversely through the nucleus. The sectioned surfaces were examined using reflected light under a binocular microscope, usually at ×25, although a higher power of ×40 was sometimes used for reading the outer edge of otoliths from older fish. The number of complete translucent (dark) zones was counted. Zone counts were made usually on the ventral part of the section, often adjacent to the sulcus, but sometimes also on the dorsal surface or along the dorso-ventral axis. Sometimes the count was started near the sulcus, but finished in some other area of the section; counts in the two areas were linked by tracing a clear zone across the section. The readers had no knowledge of the length or sex of the fish at the time of reading.

Otoliths from fish less than 20 cm FL from all surveys were read whole because of their small size and fragile nature. One otolith of each pair from 41 fish with lengths 21 to 25 cm from the 1997 survey was baked, embedded, and sectioned, as described above. The corresponding untreated otolith from each pair was read whole to ascertain if it was more efficient to read them whole or sectioned. The results of this trial are presented below, but as a consequence of it, for all other surveys, otoliths from fish of 25 cm or less were read whole.

A "birthday" of 1 May was chosen for tarakihi off WCSI based on biological data collected during the survey series. Running-ripe and maturing fish were captured, so it appeared that spawning occurred during and just after the surveys. Hence, the birthday represents the estimated end of the spawning season.

To assess within-reader variability, 124 otoliths representing a range of sizes and both sexes were read twice, 2 weeks apart, by the primary reader. Between-reader variability was assessed by having a second reader familiar with otolith interpretation read the same 124 otoliths used in the within-reader test. Indices of average percentage error (IAPE) (Beamish & Fournier 1981) were produced for the two comparisons. This index is independent of fish age, and is used to compare precision within or between readers; greater precision is achieved as the IAPE is minimised. The mean c.v.s of the two comparisons are also presented (Chang 1982).

Von Bertalanffy growth curves (the 3-parameter model, $L_t = L_\infty(1-e^{-k(t-t0)})$) were fitted to the age-length data from the four trawl surveys combined using the maximum likelihood procedure of Kimura (1980). The full model assumed separate von Bertalanffy parameters by sex, and the reduced model assumed a single set of parameters for both sexes combined. The parameters were compared using likelihood ratio tests (Kimura 1980). The model assumes independent, normally distributed errors, and a single, constant variance parameter. Part-year growth (i.e., the time elapsed between the 'birthday' and mean date of sample) was accounted for by adding 0.9 years to all integer estimates of age. The 4-parameter model, $L_t = L_\infty(1-e^{-k(t-t0)})^p$, was also fitted to the data in an attempt to better fit the data from older fish.

Catch-at-age and catch-at-length estimates scaled to the survey catch by stratum were produced using the 'catch.at.age' software developed by NIWA (Bull & Dunn 2002). The software scales the length frequency of fish from each landing up to the landing weight, sums over landings in each stratum and scales up to the total stratum catch, to yield length frequencies by stratum and overall. An age-length key is constructed from otolith data and applied to the length frequencies to yield age frequencies. The precision of each length or age frequency is measured by the mean weighted c.v., which is calculated as the average of the c.v.s for the individual length or age classes weighted by the proportion of fish in each class. Coefficients of variation are calculated by bootstrapping: fish are resampled within each landing, landings are resampled within each stratum, and otoliths are simply randomly resampled. Some juvenile fish, primarily taken in the 1995 and 1997 surveys, had not been able to be sexed. In creating the scaled length-frequency distributions by sex, it was assumed that 50% of the unsexed fish were female and 50% male.

3. RESULTS

3.1 Otolith interpretation

Whole otoliths exhibited a pattern of broad opaque and narrow translucent zones. The first translucent zone was generally less clear than any outside it. The distance from the nucleus to the outer edge of the first translucent zone was measured on 28 whole otoliths from tarakihi 11–19 cm long from the 1997 survey. The mean distance was about 0.5 mm (range 0.47–0.63 mm). Ten of the otoliths exhibited a second translucent zone; its distance from the nucleus averaged 0.83 mm (range 0.77–0.93 mm). All otoliths from fish less than 15 cm FL had only one translucent zone.

The estimated ages of 41 fish of lengths 21–25 cm aged from both whole untreated otoliths and baked otolith sections are presented in Figure 1. All but two were aged identically by both methods. We conclude that reading whole, untreated otoliths from tarakihi up to a length of 25 cm FL does not undercount the number of translucent zones present.

Otolith sections exhibited a structure of relatively clear alternating translucent and opaque zones, narrowing with increasing age. The innermost translucent zone was generally less well defined than those outside it, as observed on the whole otoliths. Therefore, the first translucent zone was assumed to be a check formed about the time of post-larval metamorphosis, and the second to be the first annual increment. Consequently, age was estimated as the number of complete translucent zones, excluding the first zone about 0.5 mm from the nucleus.

The otoliths, whether whole or sectioned, were moderately easy to read, although the post-larval check was sometimes difficult to determine in whole otoliths from fish older than 1 year (because of increasing thickness of the otolith) and also in some sectioned otoliths. Some otolith sections had blurred areas where the distance between clear zones indicated that one additional zone should be present. Magnification greater than ×25 sometimes resolved this problem, but in a few cases the zone count was incremented based on the distance between distinct translucent zones as this was believed to provide a more accurate estimate of age.

3.2 Within- and between-reader comparisons

Age bias plots from the within- and between-reader trials on 124 otoliths are shown in Figure 2. The primary reader read 81% of the otoliths identically in the two trials, and the secondary reader read 72% the same as the primary reader. For fish aged less than 15 years, within-reader agreement was 95% and between-reader agreement was 78%. There were no obvious biases in either of the comparisons, although the second readings by the primary reader were, on average, higher by about 0.1 years than the first. The indices of average percentage error were 1.3% for the within-reader trial and 1.9% for the between-reader trial. Chang's (1982) coefficients of variation for these two trials were 1.9% and 2.7%, respectively.

3.3 Comparison of juvenile length modes and age data

Length-frequency distributions from most of the six surveys in the west coast South Island trawl series show generally consistent modes at 10–15 cm, and about 16–21 and 22–27 cm (Figure 3). Age data are available from only the last four surveys in the series. The length distributions of fish aged 0+, 1+, or 2+ years from the four surveys are presented in Figure 4. There is very little overlap in length between 0+ and 1+ fish, with 0+ fish generally ranging between 10 and 15 cm FL. 1+ fish range from 15 to 24 cm, and 2+ fish from 20 to 31 cm FL. The length distributions of the aged fish correlate well with the modes from the survey distributions. The modes occur at similar positions in several surveys conducted at the same time of the year, and hence are likely to represent consecutive age classes. As the number of translucent zones in the otoliths of fish from these consecutive modes increments by 1 each year, it appears that one translucent zone is formed annually in otoliths of juvenile tarakihi.

3.4 Fitted growth curves

Von Bertalanffy growth parameters, by sex, were estimated using all the age data from the four trawl surveys (Table 1, Figure 5). The 3-parameter von Bertalanffy model, which has been used in all other published studies of tarakihi growth, appears to fit the data reasonably well, although the older fish (i.e., over 25 years) tend to be above the fitted curve. There is a significant between-sex difference in the equations ($\chi^2 = 91.7$, df = 3, $p < 0.0001$). The estimated L_∞ for female fish is 2.8 cm more than for males; females reach a significantly larger size on average than males. Maximum recorded ages were 39 years for males and 44 years for females. The data were also fitted, separately by sex, to the 4-parameter von Bertalanffy model (Table 1, Figure 5). The residual sums of squares are lower for the 4-parameter model (2568 compared to 2775 for males, 2934 compared to 3092 for females), implying better fits, although the shapes of the curves have changed little. The 4-parameter curves fit the older data points better than the 3-parameter curves.

3.5 Trawl survey age-frequency distributions

Age-frequency distributions by sex, with individual age class c.v.s, for the four trawl surveys are given in Tables 2 and 3. Plots of the distributions exhibit generally similar shapes for the two sexes from individual surveys (Figure 6). The main between-sex differences occur in 1995 (females of 10–15 years are abundant but males are scarce) and 2000 (females of 6–9 years are much more abundant than males). In the scaled age-frequency distributions, about 2% of males were 20 years or older, compared to about 3% of females.

The year class distributions (Figure 6) indicate some quite strong fluctuations in year class strengths. Some weak year classes can be followed (at least partially) through parts of the series. The 1995 distributions have a clearly weak 5+ cohort; it is also apparent as a weak 7+ year class in both the 1997 distributions, and as weak 10+ and 13+ male cohorts in the 2000 and 2003 distributions, respectively. A weak 0+ year class in 2000 manifests as a weak 3+ year class in 2003. The weak 4+ year class in 2000 is weak as 7+ males in 2003, but the 7+ females in 2003 are strong.

4. DISCUSSION

4.1 Otolith interpretation

The interpretation of the zonation pattern in otoliths of tarakihi is relatively straightforward. The indices of average percentage error for within- and between-reader trials were both less than 2%, and are indicative of a relatively consistent and precise level of interpretation. It appears that fish up to 25 cm FL (or about 2 years of age) could be reliably aged from whole otoliths. It may be possible to use whole otoliths to age fish over 25 cm, but this is not recommended for two reasons. First, the translucent zones in baked sections tend to be clearer than the same zones in whole otoliths. Second, as fish age, the otolith zones tend to narrow and the otolith tends to thicken rather than increase in width, so whole otolith counts can underestimate true age (e.g., Beamish 1979, Horn & Sutton 1996). The method described here of ageing fish 25 cm or shorter using whole otoliths, and fish longer than 25 cm using sections, is believed to be suitable for this species. However, the 0+ age class apparent in the trawl survey distributions (see Figure 1) generally does not overlap the 1+ age class, so 0+ fish could be reliably aged from their position in the length frequency.

Other reported ageing studies of tarakihi have variously read whole otoliths and sections. Tong & Vooren (1972) and Vooren & Tong (1973) examined whole, untreated otoliths immersed in oil. However, Vooren (1977) noted that this method was not satisfactory for most larger fish, and for some small ones, because of the poor visibility of narrow zones near the edge of the whole otolith. Consequently, otoliths of fish over 40 cm FL, and any unusually thick otoliths from smaller fish, were aged by examining burnt cross-sections. Annala et al. (1989, 1990) read most otoliths whole and untreated, immersed in oil, but those that could not be read whole were re-examined after breaking and burning. Jordan (2001) examined thin sections through untreated otoliths. Tong & Vooren (1972) and Vooren & Tong (1973) reported very few fish older than 15 years, but all subsequent studies reported fish in excess of 30 years old. It is possible that the examination of only whole otoliths in the two early studies resulted in the under-estimation of some ages. It is also likely that a similar under-estimation of age occurred in initial studies of the same species in Australia. Smith (1982) reported a maximum age of 16 years based on zone counts in whole otoliths. This method was used to age Australian tarakihi until 1994, when an examination of thin sections indicated a maximum age of about 30 years (Kalish et al. 2002).

The assumption that the first, generally weak, translucent zone is a post-larval check was based primarily on information from the trawl survey length-frequency distributions. All the surveys have modes at about 12–13 cm and 19–20 cm. The consistency between surveys indicates that these are consecutive year classes with an annual growth increment between them of 7 cm. Otoliths from the first mode had the one faint translucent zone, those from the second mode had one faint and one strong translucent zone. The timing of the survey series is just before the estimated birthday, hence we conclude that the first length mode comprises fish just before either their first or second birthday. If it is just before their first birthday, then the growth increment in their first year is about 13 cm. If it is just before their second birthday, then their annual growth increment is about 6 cm. The observed growth increment of 7 cm between the first and second modes is compatible with a previous annual increment of 13 cm, but not compatible with increments of about 6 cm in each of two previous years. Beentjes & Stevenson (2001) noted that tarakihi about 7–10 cm long in December appeared to have recently metamorphosed from the plankton. Assuming that metamorphosis occurs during the first year of life, then the 12–13 cm mode probably comprises fish approaching their first, rather than second, birthday. Consequently, we conclude that the first length-frequency mode comprises 0+ fish (i.e., true age of about 0.9 years) with otoliths exhibiting a weak post-larval translucent zone. The first true annual zone is apparent in otoliths of fish from the 19–20 cm mode, so fish of 19–20 cm are in their second year.

The interpretation of a post-larval zone is consistent with the study by Jordan (2001). He measured otolith radii and compared the progression of mean lengths of the 0+ and 1+ cohorts for *Nemadactylus macropterus* from Tasmania, and found the first opaque zone to have been formed immediately before, or during, settlement. The second opaque zone was formed when the fish were just over a year old. The radial measurement of this first opaque zone (i.e., the distance to the inside of the first translucent zone) was 0.50 mm, the same as the radial measurement to the outer edge of the first translucent zone in the current work. Jordan's mean measurements to the second and third opaque zones (0.68 and 0.92 mm, respectively) bound the measurement to the second translucent zone from the current study (0.83 mm). The various reports by Vooren and Tong note the common occurrence of sub-annual translucent check zones, but no specific mention is made of a consistent check inside the first translucent zone. However, based on the mean age-at-length data given by these authors, they were interpreting the juvenile otolith zones similarly to the current work. Annala (1987) noted that post-larval metamorphosis occurs in spring or early summer, when the fish are 7–12 months old and 7–9 cm long. The length frequency distribution for tarakihi caught in December and January in the Canterbury Bight during the east coast South Island trawl series showed a mode at 7–10 cm (Beentjes & Stevenson 2001). The smallest of these had only recently metamorphosed from the plankton (and are described as 'paper' tarakihi).

Tong & Vooren (1972), Vooren & Tong (1973), Vooren (1975), and Annala et al. (1990) assumed a birthdate of 1 March for tarakihi from various sites around New Zealand. Running ripe fish had been observed from January through to April, and 1 March was considered to be a reasonable estimate of mid spawning season. The choice in the current work of a 1 May birthday was derived as an estimate of the end of spawning off WCSI.

4.2 Age validation

Validating the ageing method used in this work was not a specific aim of the project. However, zone counts in otoliths from distinct and consecutive juvenile length modes were found to increment by 1 with increasing mode size. The modes almost certainly represent consecutive year classes, so it appears that one translucent zone is laid down annually in otoliths of juvenile tarakihi, after the weak post-larval zone formed probably at about 7–9 months.

The numbers-at-age estimated from the surveys (Figure 6) show the progression of some apparently weak year classes. Because these year class strengths are based on otolith zone counts, the progressions support the assumption that post-juvenile tarakihi also form one translucent zone annually in their otoliths. However, because the abundance of older age classes is based generally on very small otolith sample sizes, individual year class estimates have high c.v.s, and the actual estimate can change markedly with the addition or subtraction of even one aged fish. Consequently, the progressions can be easily blurred as the fish age. The progression of the weak 1989 year class (5+ years in 1995) can be followed through most of the distributions. A weak 1999 year class (0+ in 2000) is also clear in the 2000 and 2003 distributions. The 2002 year class (0+ in 2003) also appears very weak. Interestingly, the 1989 and 1999 year classes for hoki (*Macruronus novdezelandiae*) spawned off WCSI are also believed to be very weak (Francis et al. 2003).

Kalish et al. (2002) reported an analysis of the bomb radiocarbon from cores of eight tarakihi otoliths. Five of the cores were not analysed successfully (including several of the samples from older fish), but the authors were still able to conclude that the age estimates based on otolith sections were not dramatically under-estimated (e.g., by more than 5 years). A maximum age of at least 20 years was deduced from the successfully analysed samples.

4.3 Growth parameters

Like many teleosts, female tarakihi are, on average, larger than males at corresponding ages after about age 7, and they have a larger estimated L_∞. A similar trend is also apparent in most of the sets of von Bertalanffy parameters calculated for tarakihi from other areas (see Table 1). Vooren (1977) showed the mean length-at-age data for female tarakihi from WCSI and the

Chatham Islands to be consistently higher than males at similar ages, but no von Bertalanffy parameters were calculated.

The three von Bertalanffy curves for New Zealand tarakihi stocks calculated by sex using both whole and sectioned otoliths are shown in Figure 7. They are very similar, and hence, indicative of a relatively consistent growth pattern for tarakihi around the South Island. The fitted curves for tarakihi from off the northeast coast of the North Island (Tong & Vooren 1972, Vooren & Tong 1973) are not included in Figure 7 as it is considered likely that the ages of some of the fish in these studies were underestimated because only whole otoliths were examined. The growth curves for tarakihi off Tasmania have markedly lower L_∞ values than the New Zealand populations, although the actual rate of growth up to about age 6 looks similar for all the plotted curves. Because of the relative ease with which tarakihi otoliths can be interpreted, it is most likely that there is a real difference in patterns of growth between the Tasmanian and southern New Zealand stocks.

There was some indication from Figure 5 that there was a step in the male data between ages 16 and 17, suggesting that males older than 17 had grown more rapidly at earlier equivalent years than did younger fish. However, a similar characteristic was not apparent for females. It was considered possible that the older males might have been collected from a different stock or geographical area during the surveys, or that growth had changed over time. Data split into three areas of origin (i.e., Tasman Bay, WCSI north of Greymouth, WCSI south of Greymouth) are presented in Figure 8. Tarakihi were generally younger than 5 years in Tasman Bay. Von Bertalanffy curves calculated separately for the two WCSI areas were not significantly different (males: $\chi^2 = 34.8$, df = 3, $p < 0.0001$, females: $\chi^2 = 34.6$, df = 3, $p < 0.0001$), indicating no geographical variation in growth. Raw age data plotted by survey (Figure 9) provide no evidence of a step in growth rates from a particular year class. (Because the four surveys are spread over 8 years, the 'step' age would be expected to increase over time.) In conclusion, the perceived step in the male growth curve at age 17 (see Figure 5) is probably a random event, exacerbated by the inadequate fit of the von Bertalanffy models to the older age data.

4.4 Population age composition

The trawl survey samples tend to be dominated by 0+ to 3+ age fish, although those aged 4+ to about 14+ can also be relatively abundant. Although it is likely that tarakihi can live for more than 40 years, fish older than 15 years are relatively rare in the survey samples. The catch taken by the commercial trawl fishery will be very different from the trawl survey population for two reasons. First, commercial vessels use a 100 mm mesh codend (compared to the 74 mm mesh research codend), so they will select fewer juvenile fish. Annala et al. (1989, 1990) estimated that a 100 mm mesh codend would retain only about 25% of 2-year-old fish, and that full selection occurred at age 5. Second, commercial vessels targeting tarakihi or taking it as a bycatch in other target fisheries concentrate their effort in areas were larger tarakihi predominate, or in deeper waters where juveniles are rare (Hurst et al. 2000). Hence, the commercial catch is likely to comprise fish mainly 4 years and older.

Morrison (1998) aged 171 tarakihi from a research trawl survey off the northwest coast of the North Island. The survey samples were dominated by fish 4–8 years old. The youngest fish were aged 2+ (few fish under 25 cm FL were taken), and 17% of the sampled fish were aged over 10 years. This age distribution is quite different from those from the WCSI trawl surveys, and indicates younger year classes (i.e., 0+ to 3+) were not available to the trawl in the survey area in 1996.

The variation in year class strengths of tarakihi has been used above to provide a partial validation of the ageing method. A relatively marked variation in year class strengths has been noted as a characteristic of tarakihi populations in most of the ageing studies (e.g., Tong & Vooren 1972, Vooren 1977, Annala et al. 1989, 1990, Jordan 2001).

The mean weighted c.v.s over all age classes were close to 30% for the 1995 and 1997 surveys, but over 40% for the 2000 and 2003 surveys. The number of aged fish varied slightly between surveys (276 to 313), but the number of measured fish varied markedly (1843 to 4534). The numbers of 0+ to 3+ fish were high in the 1995 and 1997 surveys, but much lower in the 2000 and 2003 surveys. Having a large proportion of the sampled fish in a relatively small number of age classes, each with quite well defined length modes, will decrease the mean weighted c.v. The number of aged and measured fish necessary to achieve a mean weighted c.v. over all age classes of 30% appears to be over 350 ages and 2500 lengths. However, if the sampled population is dominated by older fish (as in the 2003 survey), samples of these sizes may still be totally inadequate. Based on the data from the four surveys, individual year class c.v.s for male fish aged older than about 8 years and females older than about 12 years are always likely to be high.

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Table 1: Von Bertalanffy parameters for tarakihi from the literature, and estimated in the current study using all available age-length data from the four trawl surveys. Age ranges (R_{age}) and length ranges (R_{length}) of the data used to calculate the parameters are also listed.

Location	L_∞	k	t_0	p	n	R_{age}	R_{length}	Reference
Unsexed								
Bay of Plenty	39.9	0.26	–0.49	–	741	1–20	12–45	Tong & Vooren 1972
Male								
East Cape	50.0	0.086	–4.30	–	–	5–15	–	Vooren & Tong 1973
Northeast South Island	42.1	0.209	–1.40	–	275	2–42	19–48	Annala et al. 1990
Chatham Islands	44.7	0.167	–2.48	–	234	2–41	18–50	Annala et al. 1989
Tasmania	36.2	0.42	0.15	–	127	1–26	13–42	Jordan 2001
WCSI (3-parameter)	43.2	0.252	–0.55	–	529	0–39	10–47	Current work
WCSI (4-parameter)	44.3	0.167	0.40	0.514	528	0–39	10–47	Current work
Female								
East Cape	52.9	0.110	–4.30	–	–	5–15	–	Vooren & Tong 1973
Northeast South Island	44.6	0.201	–1.10	–	324	1–42	12–51	Annala et al. 1990
Chatham Islands	44.6	0.221	–1.03	–	197	2–41	18–50	Annala et al. 1989
Tasmania	38.4	0.33	–0.07	–	184	1–30	13–45	Jordan 2001
WCSI (3-parameter)	46.1	0.221	–0.69	–	608	0–44	10–51	Current work
WCSI (4-parameter)	47.2	0.156	0.24	0.561	608	0–44	10–51	Current work

Table 2: Calculated numbers-at-age in the survey area, separately by sex, with c.v.s, for tarakihi caught during trawl surveys off the west coast of the South Island in 1995 and 1997. Summary statistics for the samples are also presented. True age is estimated to be about 0.9 years older than the integer age listed.

	KAH9504			
Age	Male	c.v.	Female	c.v.
0	160 331	0.211	171 688	0.175
1	279 184	0.385	257 737	0.375
2	103 560	0.315	79 954	0.301
3	152 757	0.240	203 980	0.227
4	51 282	0.359	72 899	0.355
5	14 418	0.713	24 749	0.555
6	33 844	0.529	44 181	0.440
7	39 475	0.456	23 593	0.593
8	40 794	0.514	32 145	0.551
9	10 324	0.853	42 238	0.430
10	37 523	0.547	60 988	0.407
11	4 607	1.126	70 995	0.417
12	0	–	35 468	0.565
13	3 924	1.023	42 528	0.491
14	10 839	0.626	39 976	0.480
15	8 815	1.187	5 532	1.140
16	0	–	0	–
17	2 120	1.200	15 785	0.597
18	3 329	0.843	12 340	0.840
19	5 205	0.696	11 304	0.740
20	3 924	1.098	0	–
21	2 120	1.319	4 205	0.878
22	0	–	12 276	0.641
23	1 067	1.322	3 315	1.113
24	1 067	1.357	7 618	1.058
25	0	–	0	–
26	0	–	0	–
27	0	–	3 724	0.856
28	0	–	0	–
29	0	–	3 315	1.091
30	1 209	1.156	890	1.357
31	0	–	0	–
32	0	–	0	–
33	0	–	0	–
34	0	–	0	–
35	0	–	0	–
36	1 209	1.196	5 532	1.059
37	389	1.749	0	–

	KAH9701			
Age	Male	c.v.	Female	c.v.
0	283 340	0.252	255 779	0.257
1	215 875	0.381	254 263	0.362
2	295 238	0.392	310 754	0.320
3	114 780	0.494	42 694	0.463
4	54 400	0.355	146 712	0.200
5	68 439	0.428	51 383	0.366
6	8 921	0.814	38 754	0.466
7	11 644	0.842	16 120	0.712
8	9 792	1.001	16 962	0.784
9	7 577	0.976	62 363	0.383
10	9 432	0.793	14 087	0.632
11	15 490	0.698	40 311	0.423
12	8 979	1.040	5 027	1.131
13	7 053	1.298	21 088	0.591
14	4 222	1.247	31 623	0.570
15	4 316	1.321	13 930	0.596
16	894	1.481	7 006	0.825
17	4 874	0.790	2 723	1.034
18	0	–	10 328	0.797
19	4 316	1.331	508	1.592
20	0	–	0	–
21	0	–	0	–
22	1 926	1.403	7 793	0.754
23	0	–	10 037	0.663
24	2 134	1.404	4 562	0.976
25	1 926	1.322	0	–
26	4 222	1.345	0	–
27	0	–	508	1.409
28	0	–	367	1.768
29	0	–	0	–
30	2 384	1.192	0	–
31	0	–	0	–
32	0	–	0	–
33	0	–	0	–
34	0	–	2 737	1.167
35	894	1.458	0	–

	KAH9504	KAH9701
Measured males	1 371	711
Measured females	2 185	1 370
Measured unsexed	978	413
Aged males	134	115
Aged females	156	145
No. of shots with tarakihi	88	73
Meanweighted c.v. (sexes poled)	32.9	33.1

Table 3: Calculated numbers-at-age in the survey area, separately by sex, with c.v.s, for tarakihi caught during trawl surveys off the west coast of the South Island in 2000 and 2003. Summary statistics for the samples are also presented. True age is estimated to be about 0.9 years older than the integer age listed.

			KAH0004					KAH0304	
Age	Male	c.v.	Female	c.v.	Age	Male	c.v.	Female	c.v.
0	55 306	0.271	45 555	0.234	0	6 589	0.662	5 800	0.487
1	196 381	0.448	197 201	0.482	1	93 961	0.310	75 524	0.319
2	162 504	0.610	241 033	0.644	2	66 676	0.316	80 539	0.320
3	102 668	0.468	114 251	0.440	3	27 948	0.347	28 537	0.327
4	23 088	0.580	19 481	0.882	4	74 932	0.300	56 096	0.281
5	17 044	0.788	143 373	0.277	5	55 733	0.444	12 968	0.545
6	14 211	0.699	97 122	0.340	6	29 615	0.620	45 523	0.396
7	32 461	0.429	54 763	0.495	7	10 994	1.036	54 374	0.421
8	23 385	0.553	62 941	0.378	8	21 852	0.722	12 176	0.788
9	13 469	0.578	0	–	9	30 798	0.562	32 108	0.621
10	4 352	0.837	25 286	0.626	10	28 175	0.634	16 178	0.687
11	5 911	0.834	32 485	0.525	11	27 689	0.586	10 000	0.959
12	3 136	1.057	12 443	0.671	12	13 677	0.884	7 989	0.724
13	4 087	1.157	15 686	0.573	13	4 808	1.172	12 330	0.837
14	9 013	0.655	8 934	0.928	14	9 477	0.807	10 152	0.951
15	0	–	12 487	0.641	15	12 423	0.649	25 684	0.622
16	6 428	0.744	5 252	1.090	16	16 697	0.680	10 152	0.884
17	3 292	0.905	15 421	0.613	17	7 810	0.790	12 496	0.718
18	0	–	0	–	18	6 407	0.776	2 482	1.180
19	2 106	0.913	3 233	0.881	19	0	–	0	–
20	2 579	0.831	1 251	1.449	20	6 259	0.776	10 567	0.810
21	0	–	7 557	0.732	21	6 085	0.927	8 568	0.872
22	2 302	1.157	0	–	22	1 298	1.337	2 707	1.087
23	2 223	1.231	3 983	0.830	23	4 381	1.111	7 533	0.674
24	0	–	5 755	0.861	24	3 404	1.084	3 190	1.020
25	3 866	0.787	0	–	25	1 476	0.827	3 190	1.045
26	0	–	2 000	1.086	26	0	–	2 344	1.202
27	1 542	1.165	2 880	0.906	27	738	1.207	2 482	1.079
28	0	–	0	–	28	1 298	1.405	0	–
29	789	1.285	879	1.634	29	7 082	1.141	2 707	1.332
30	0	–	0	–	30	0	–	734	1.231
31	332	1.857	1 426	1.324	31	0	–	734	1.434
32	0	–	0	–	32	0	–	734	1.322
33	457	1.497	1 251	1.270	33	3 083	1.508	734	1.554
34	457	1.744	0	–	34	0	–	0	–
35	0	–	0	–	35	0	–	0	–
36	1 542	1.078	0	–	36	0	–	0	–
37	0	–	995	1.899	37	0	–	0	–
38	0	–	0	–	38	1 298	1.356	0	–
39	0	–	0	–	39	0	–	0	–
40	0	–	0	–	40	0	–	846	1.462
41	0	–	0	–					
42	0	–	0	–					
43	0	–	1 426	1.524					

	KAH0004	KAH0304
Measured males	820	953
Measured females	1 257	890
Measured unsexed	0	6
Aged males	132	147
Aged females	144	164
No. of shots with tarakihi	65	55
Meanweighted c.v. (sexes poled)	46.2	40.3

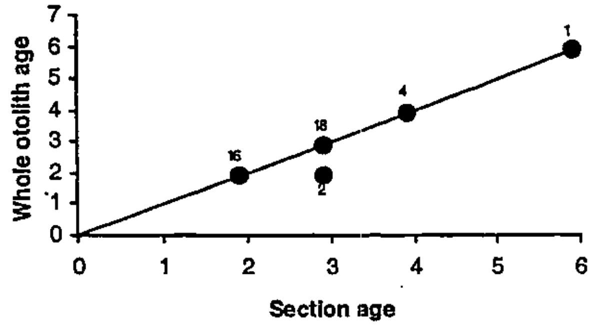


Figure 1: Comparison of ages derived from whole and sectioned otoliths from 41 fish. Numbers by symbols indicate sample size. The 1:1 relationship line is also plotted.

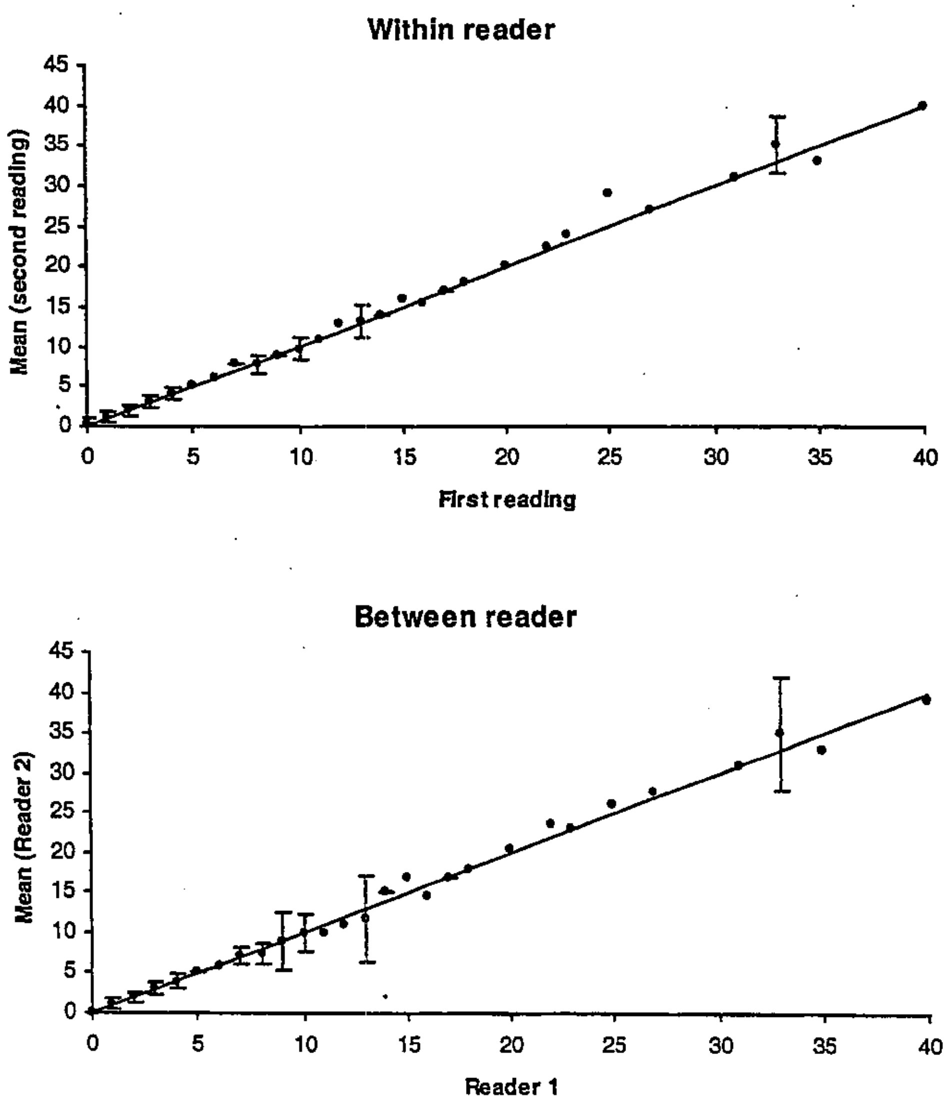


Figure 2: Within-reader and between-reader comparisons, showing the mean of the second reading, against the first reading. The 1:1 relationship line is plotted, and 95% confidence intervals are shown where sample size is 3 or more.

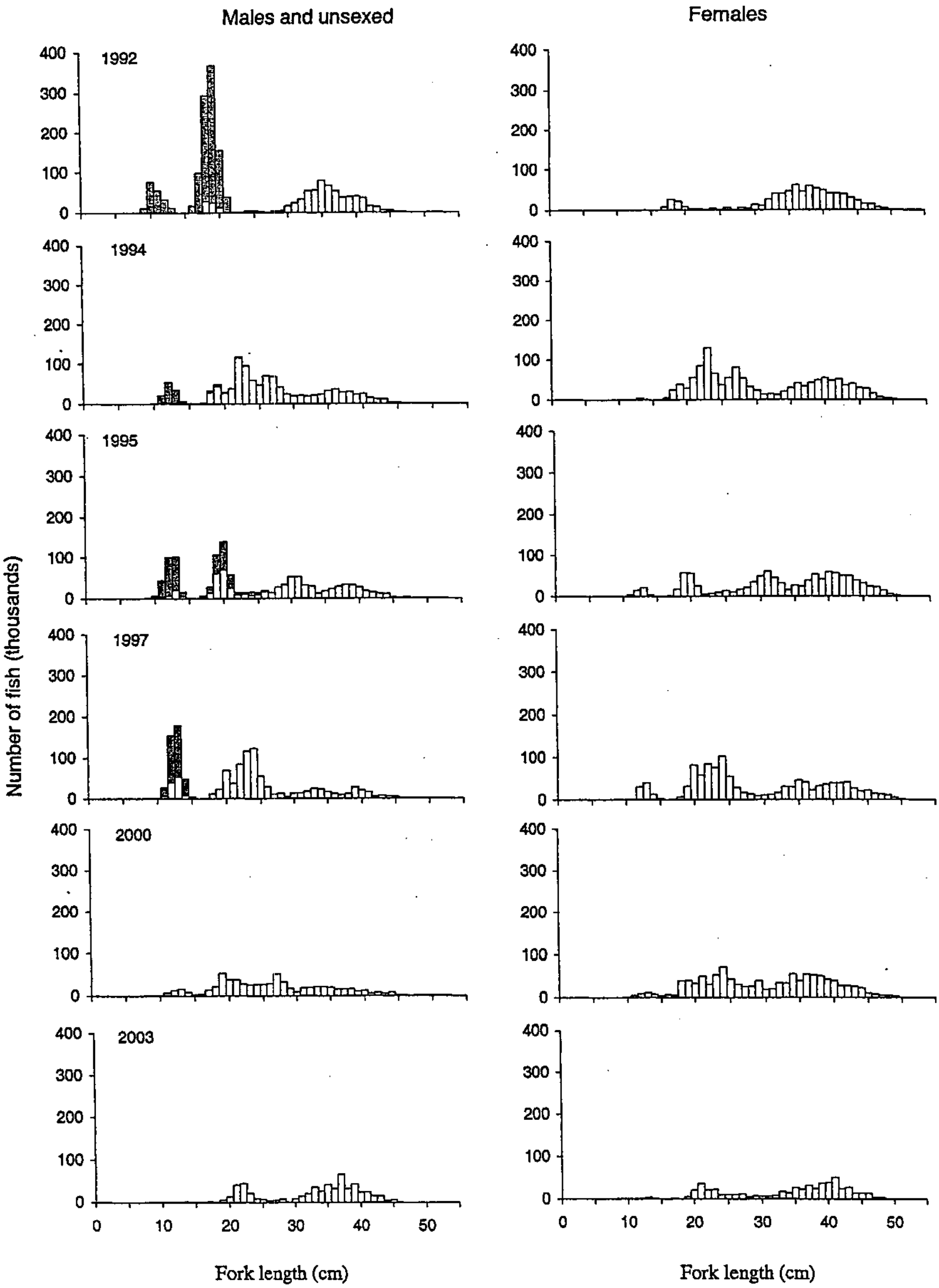


Figure 3: Scaled length-frequency distributions, by sex, for tarakihi caught during six comparable research trawl surveys off the west coast of the South Island. Shaded bars denote unsexed fish. Age data were available from only the last four surveys in the 1992–2003 series.

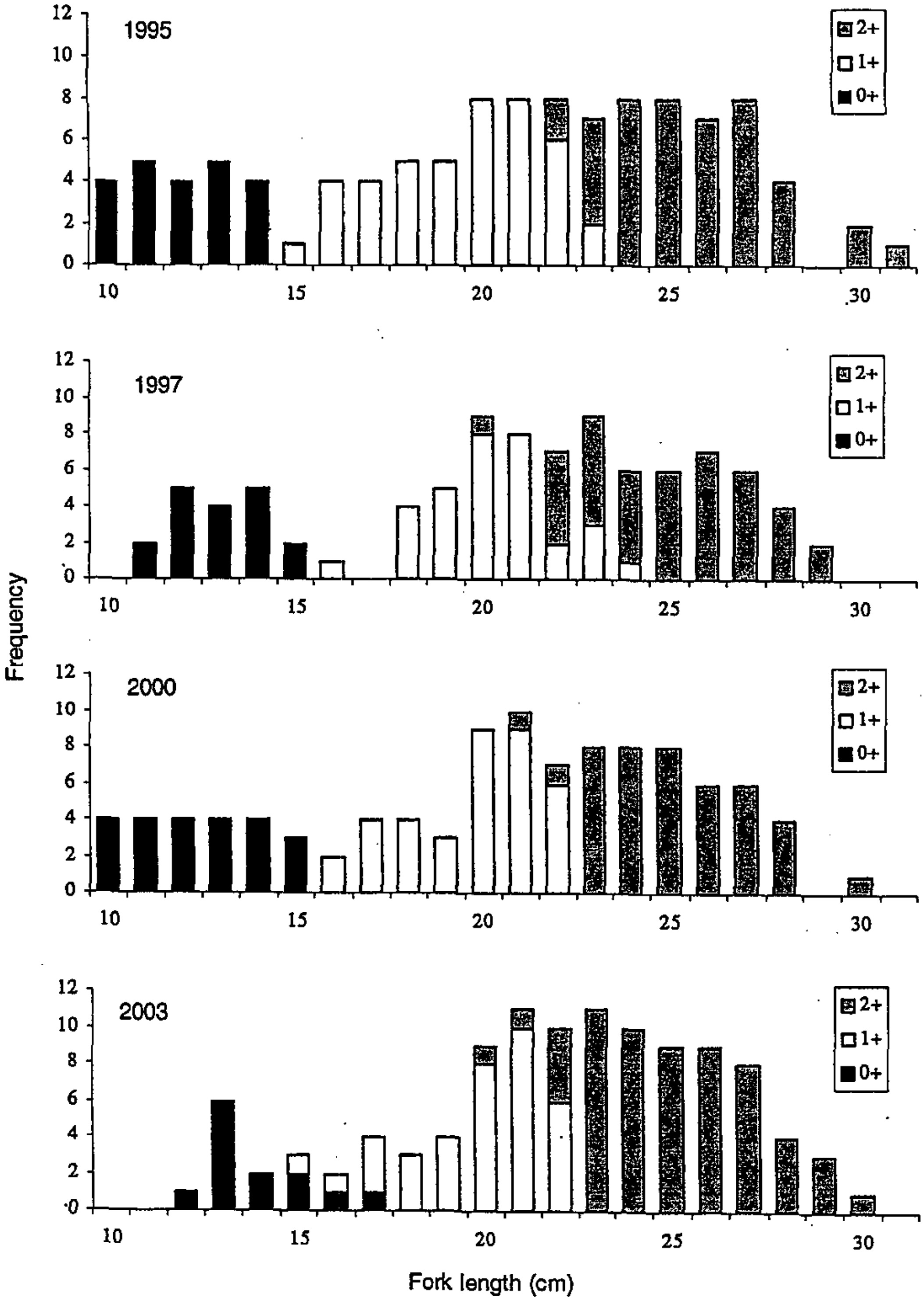


Figure 4: Frequency histograms showing the absolute number of fish aged 0+, 1+, and 2+, by 1 cm length class, from each of the four aged trawl surveys.

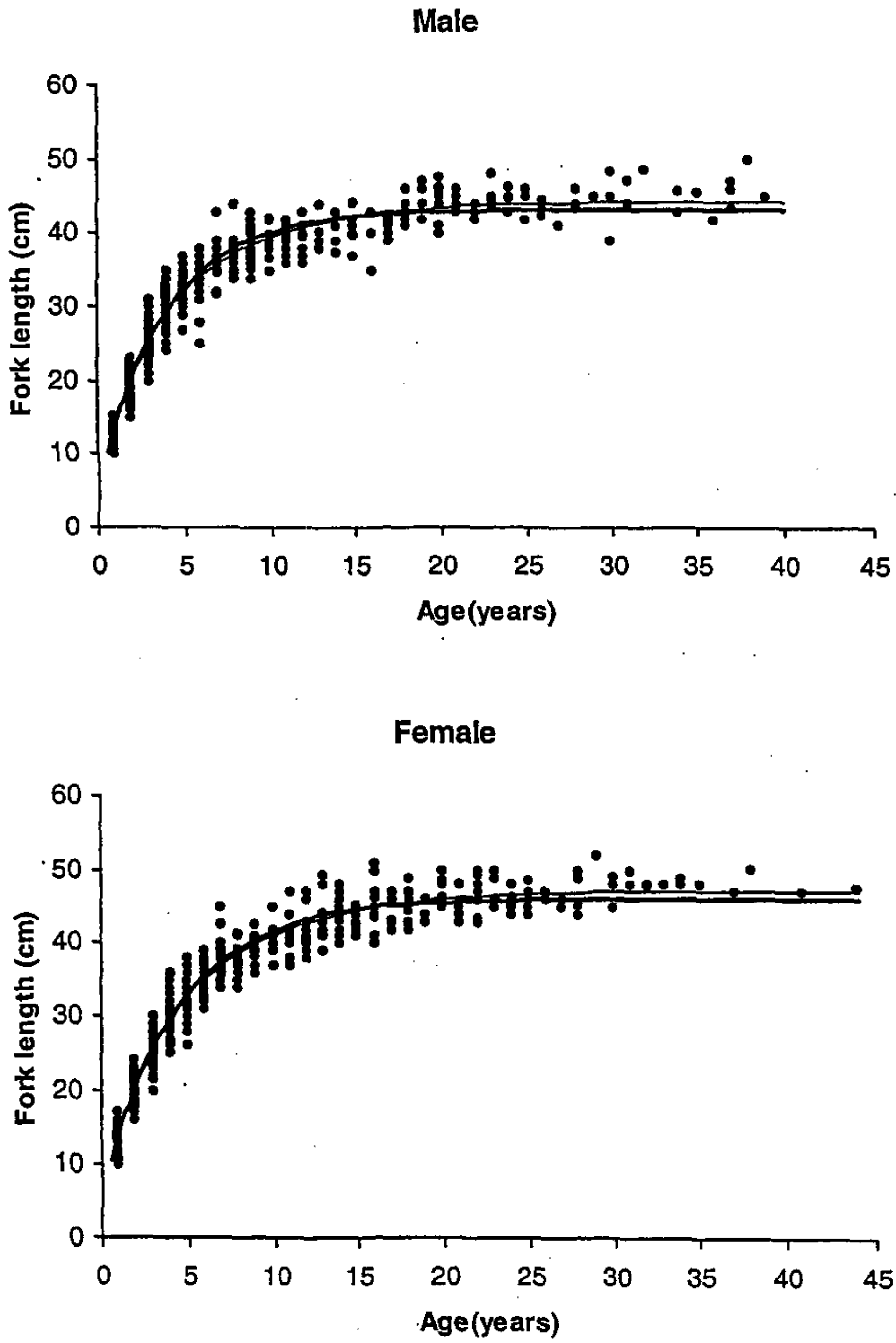


Figure 5: Raw age data for tarakihi from the four trawl surveys, by sex, with fitted 3-parameter (thick lines) and 4-parameter (thin lines) von Bertalanffy growth curves.

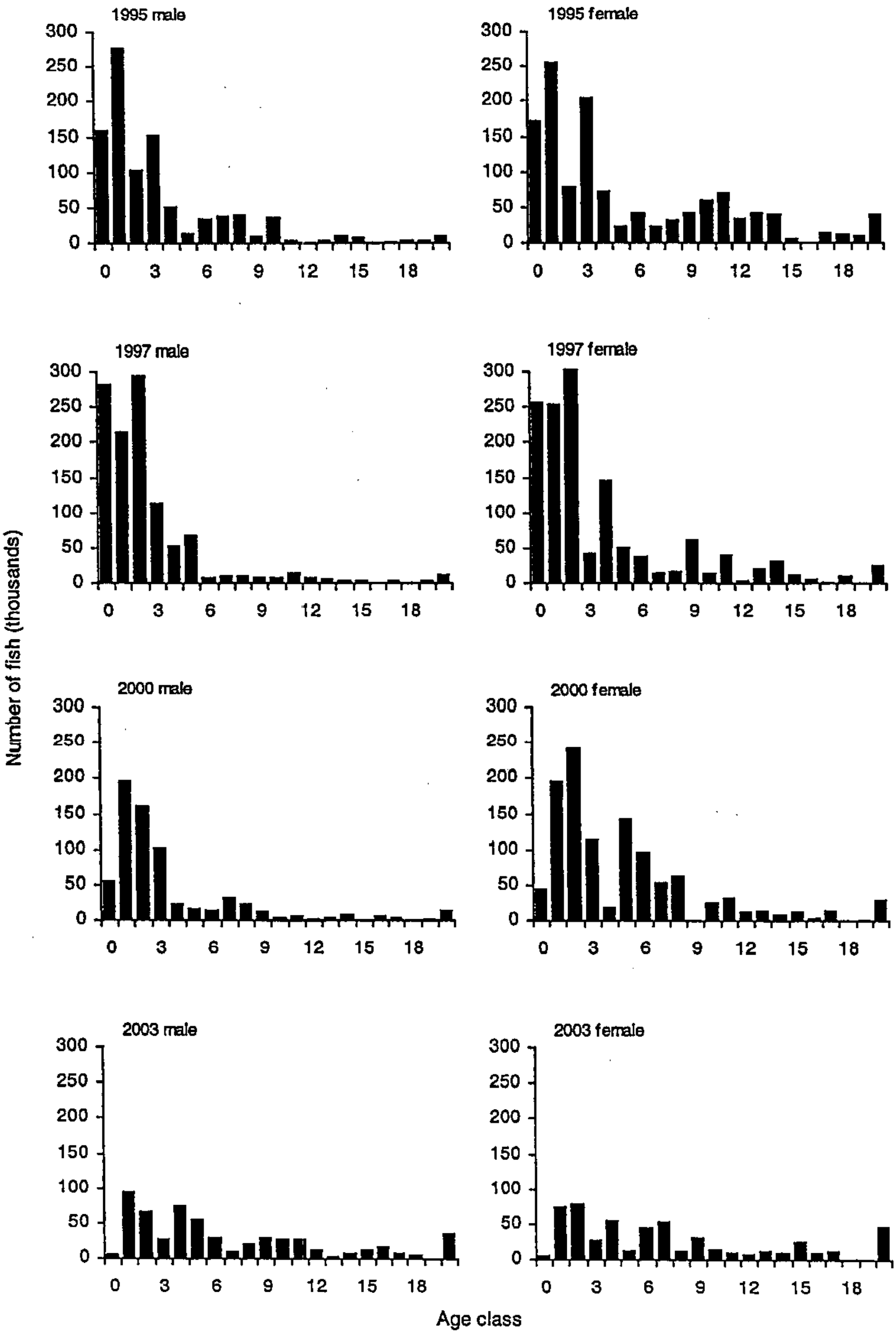
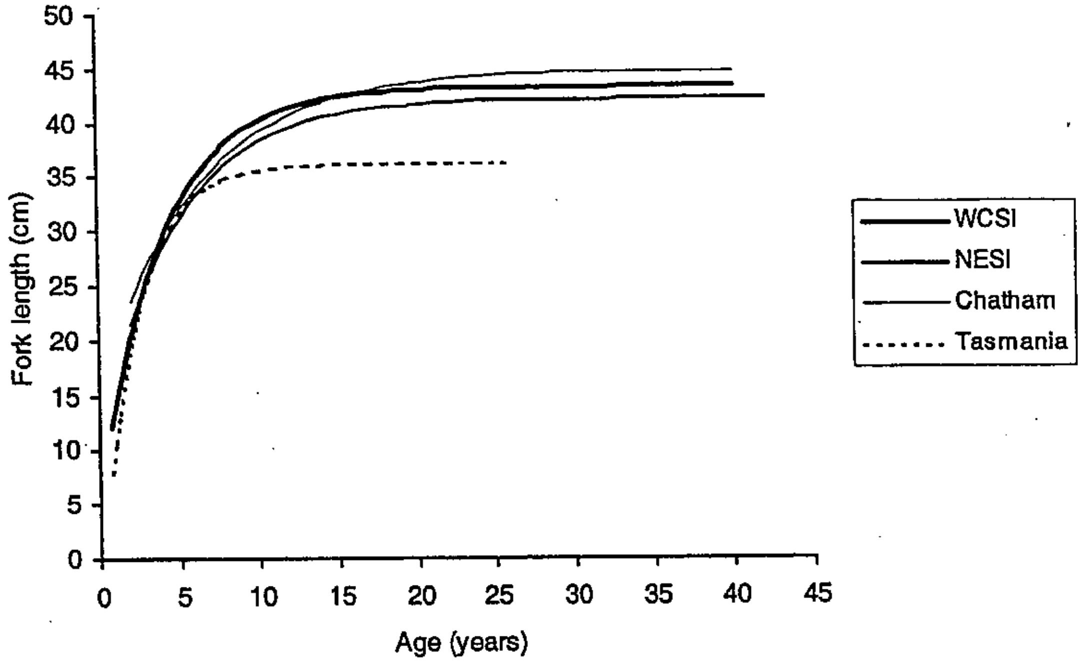


Figure 6: Estimated numbers-at-age, by sex, from four trawl surveys off WCSI. The last column in each plot combines all fish aged 20 years or more.

Male



Female

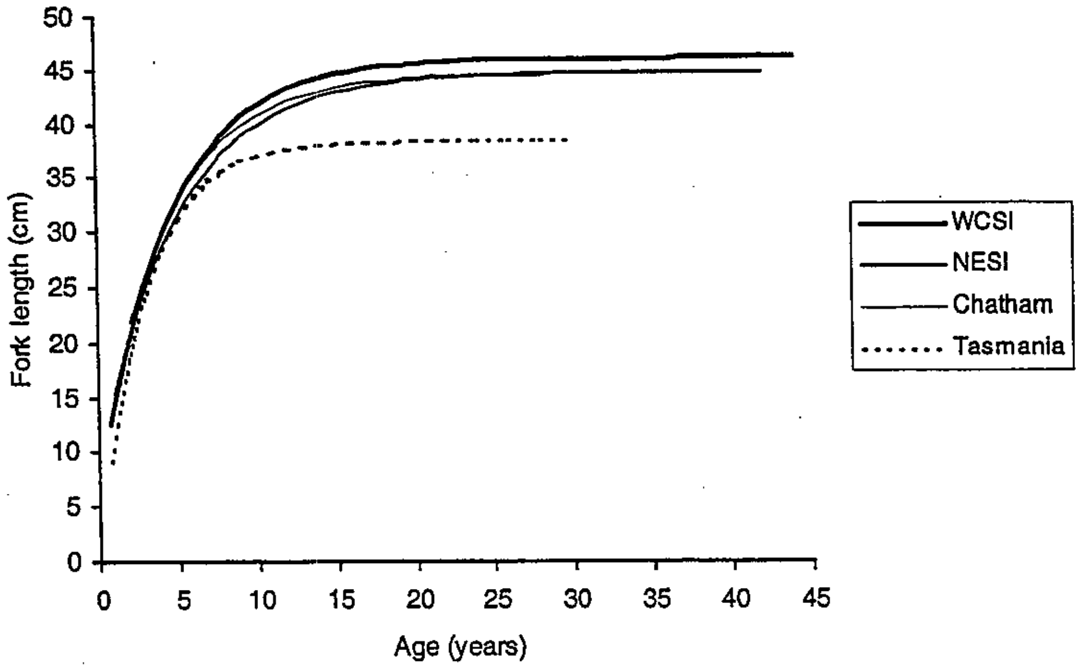


Figure 7: Calculated von Bertalanffy growth curves, by sex, for tarakihi off west coast South Island (WCSI, current study), off northeast South Island (NESI, Annala et al. 1990), at the Chatham Islands (Annala et al. 1989), and off southern Tasmania, Australia (Jordan 2001).

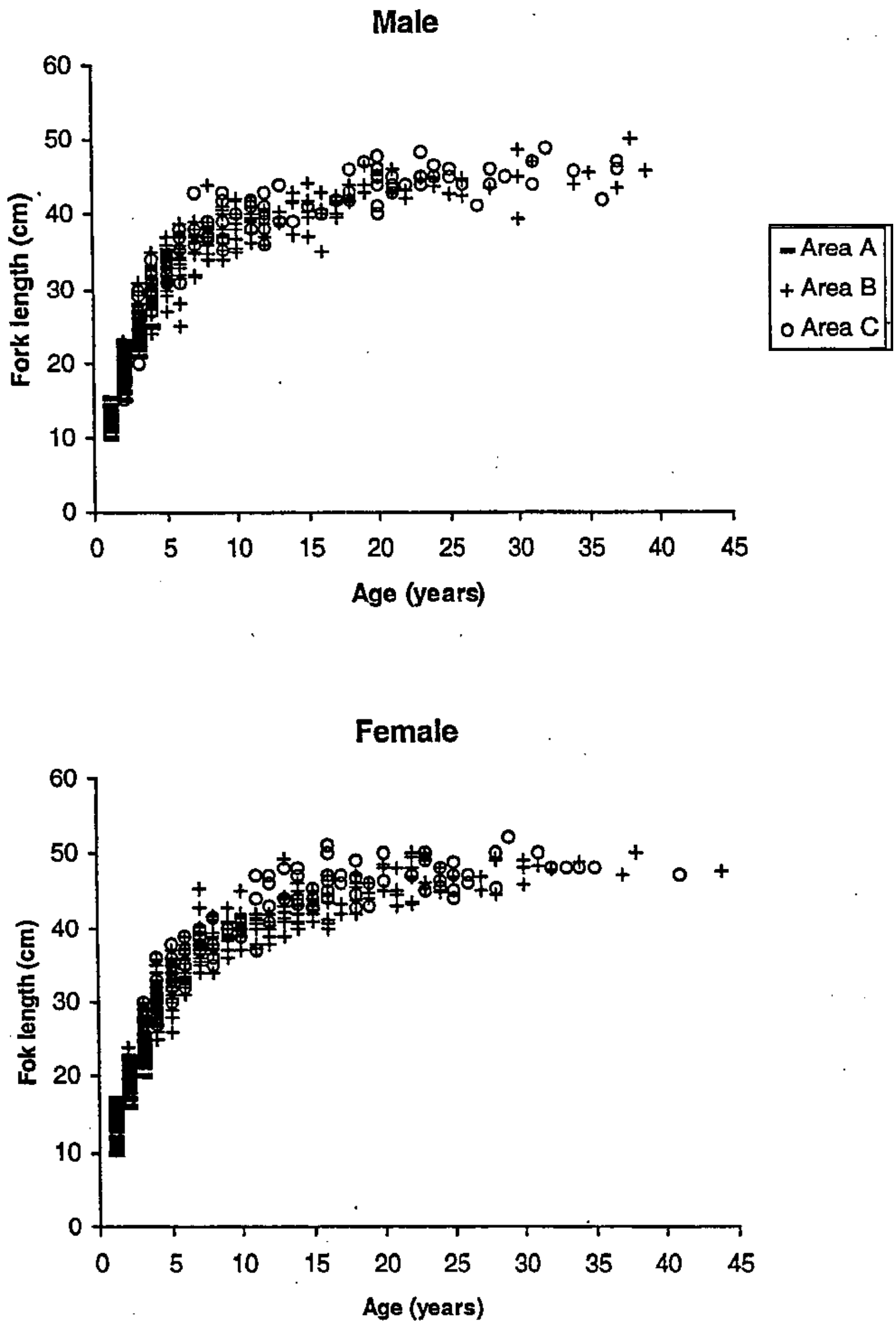


Figure 8: Raw age data, by sex and area. Areas: A, Tasman Bay; B, WCSI north of Greymouth; C, WCSI south of Greymouth.

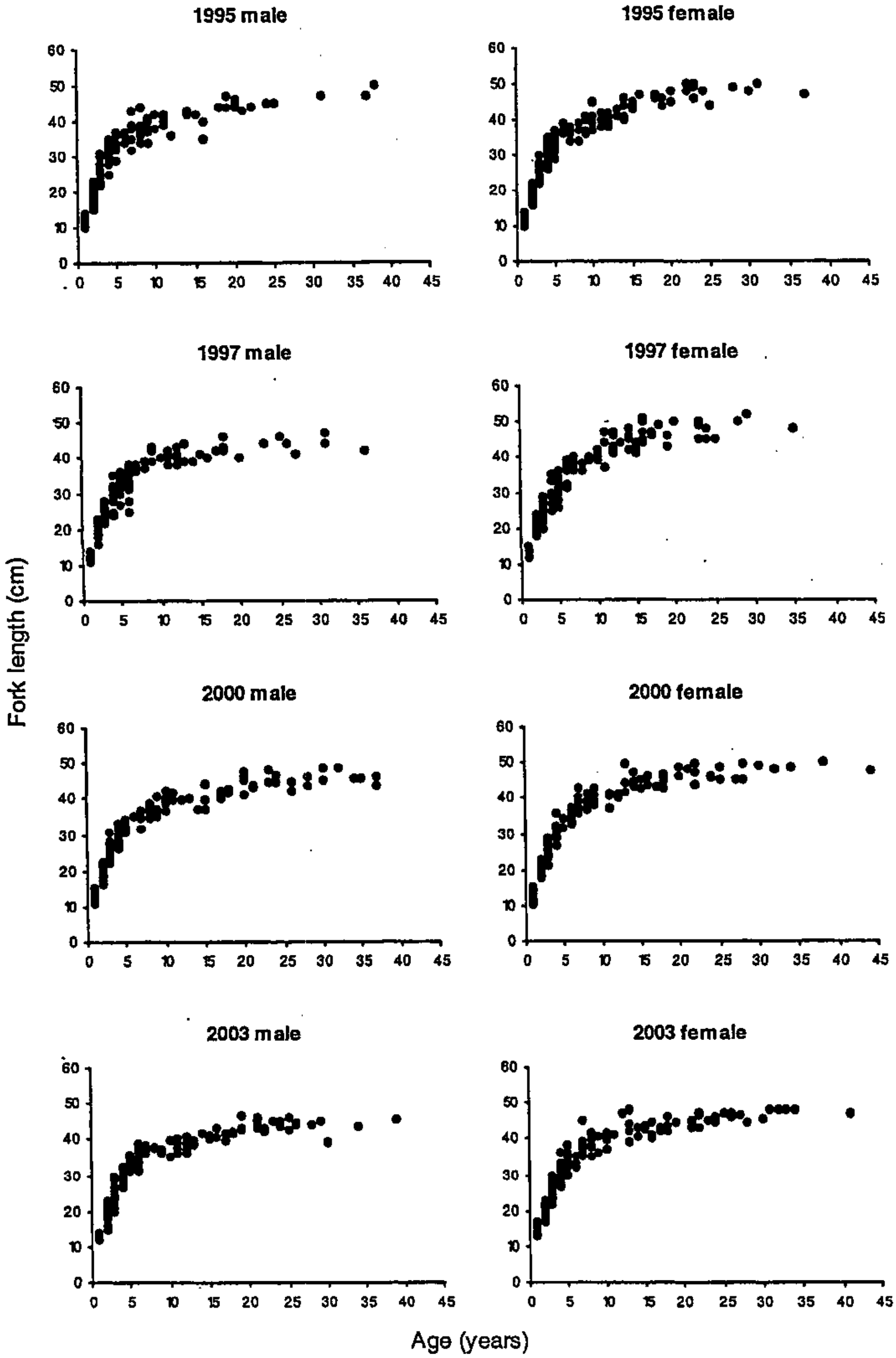


Figure 9: Raw age data, by sex and trawl survey.