Length and age of red gurnard (*Chelidonichthys kumu*) from trawl surveys off west coast South Island in 2003, 2005, and 2007, with comparisons to earlier surveys in the time series

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EXECUTIVE SUMMARY

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Red gurnard (*Chelidonichthys kumu*) otoliths were collected from autumnal bottom trawl surveys off the west coast of South Island and in Tasman and Golden Bays (GUR 7) during 2003 (kah0304), 2005 (kah0503), and 2007 (kah0704). The survey area consisted of 16 separate strata representing different depths and geographical locations. Otoliths from 688 gurnard were prepared following a 'bake-and-embed' methodology, and a subset read by two readers.

A scaled length-frequency distribution of the research catch was produced for each survey. The target coefficient of variation (c.v.) for the catch-at-age was 30% (mean weighted across all age classes). This target was met for all survey years, including recalculated distributions for comparable surveys in 1994 and 1995.

Mean ages and lengths for fish sampled from off the west coast remained stable between 2003 and 2007, but varied for Tasman and Golden Bay fish due to the strong influence of young fish entering these areas. Red gurnard off the west coast were larger and older than those in Tasman and Golden Bays, and appeared to move into deeper water as they grow. The survey in 1995 was strongly influenced by a large cohort of age 1+ fish that lowered mean ages in Tasman and Golden Bays, and off the west coast.

The percentage of red gurnard below the size of sexual maturity (24 cm; 2 years old) in the survey catch increased from 1% to 15% between 2003 and 2007, and the percentage caught above the fishery recruitment size of 30 cm (3 years) dropped from 85% to 53%. Off the west coast the percentage of red gurnard below the size at sexual maturity in the survey catch was less than 1.5% in all five surveys, and the percentage above the fishery recruitment size remained stable above 87% for all surveys. In Tasman and Golden Bays the percentage of the red gurnard below the size of sexual maturity in the survey catch increased every survey year from 2003 to 2007, but the percentage caught above the fishery recruitment size almost halved between 2003 and 2007.

There was no clear progression of strong or weak length or age cohorts between surveys.

Estimates of total instantaneous mortality (Z) with 95% confidence intervals were derived for each survey using the Chapman-Robson and regression methods. There was significant overlap in Z estimates between all surveys, and consequently no significant change in Z over time.

1. INTRODUCTION

Red gurnard (*Chelidonichthys kumu*) are a major bycatch of inshore trawl fisheries in most regions around New Zealand. This includes a flatfish target fishery off the west coast of South Island (WCSI) and in Tasman and Golden Bays. There is also a minor target fishery for red gurnard within these areas (GUR 7). Commercial landings of red gurnard in GUR 7 declined steadily from 1992–93 to 1997–98, then increased from that time onward (Ministry of Fisheries Science Group 2010).

The biomass estimates from the WCSI and Tasman and Golden Bays inshore trawl surveys were consistent from 1992 to 2000 but showed a sharp decline in 2003, followed by a steady recovery to pre-2003 biomass levels in 2009 (Stevenson and Hanchet 2010).

The most recent ageing of red gurnard sampled from research trawls in GUR 7 was by Sutton (1997) using otoliths from the 1994 and 1995 surveys. The analysis of otoliths from surveys in 2003, 2005, and 2007 is reported here and compared with these previous findings. The overall objective of this research (Project INT2008-02) was "to determine the length-at-age of red gurnard (*Chelidonichthys kumu*) in GUR 7". The two specific objectives were:

1. To determine the length and age composition of the research trawl survey catch of red gurnard (*Chelidonichthys kumu*) in GUR 7 from historical and recent surveys. The target coefficient of variation (c.v.) for the catch at age was 30% (mean weighted c.v. across all age classes).

2. To explore the time series of research trawl survey catch-at-age for GUR 7 for any significant changes in the length and age composition of catches.

The following tasks were specified.

a. To produce estimates of total fishing mortality that incorporate uncertainty in key parameters (e.g., age at full recruitment) and the different properties of regression and Chapman-Robson estimators.
b. To compare the age/length composition of the catch to the age/length at maturity.
c. To compare mean length at age over time
d. To discuss the consistency of signals over time, e.g., is the progression of cohorts apparent and are estimates of Z stable between adjacent years?

2. METHODS

Red gurnard otoliths were collected during trawl surveys by the R.V. *Kaharoa* off WCSI and in Tasman and Golden Bays during March and April 1992, 1994, 1995, 1997, 2000, 2003, 2005, and 2007 (Table 1). During these surveys the trawl gear, trawling procedures, and collection protocols remained constant. This research used all the red gurnard otoliths collected from fish caught within the 16 strata during 2003, 2005 and 2007 (Table 2, Figure 1). Up to 20 red gurnard otoliths were collected using a stratified sampling procedure from each station until up to five otolith pairs per sex per centimetre size class were collected. The trawl survey started in Tasman and Golden Bays and moved south down the west coast; otoliths were collected in that order from north to south. Biological information for each fish (fork length, sex, weight, gonad maturity) with length to the nearest millimetre was recorded. Otoliths were removed, cleaned with tissue, and placed (dry) into paper envelopes. In addition, random samples were taken of the red gurnard catch which were sexed and measured to the nearest whole centimetre below the fork length.

All available otoliths were prepared, read, and analysed. The preparation followed the method used by Sutton (1997) where otoliths (sagittae) were baked at 275 ^{o}C for approximately four minutes, until

they become amber coloured, then embedded in clear epoxy resin (Araldite K142) and cut transversely through the nuclear region with a Struers Accutom-2 diamond-edged saw. The cut surface of the block was then polished with P1200 carborundum and coated with paraffin oil. Otoliths were then examined under a binocular microscope (x30) (Figure 2) illuminated by reflected light at an incident angle of about 30 ^{o}. Determination of the age of red gurnard was relatively straight-forward, as the zonation pattern of dark hyaline and light opaque zones were easily discernable. Age-length keys by sex were developed for each of the three surveys separately. The first reader developed a reference collection of 20 photographs of prepared red gurnard otoliths from GUR 7. The otolith reference set is stored with the prepared otoliths in the Otolith store at NIWA Greta Point Wellington. Fish represented the entire length range. The "annual" bands were marked on each photograph, so that both readers could learn to interpret these bands in a comparable way. Only when both readers were interpreting the reference otoliths comparably did reader two start reading the remaining red gurnard otoliths without knowledge of the sex or length of the fish. Two readers read 100 otoliths (14%) from the 2003–2007 surveys without prior knowledge of the sex or length of the fish, to determine inter-reader variability via an IAPE (index of average percentage error) comparison (Beamish and Fournier 1981). To determine inter-reader variability between the 1994–1995 and 2003–2007 otolith readings, both readers aged 110 otoliths from 1994 and 1995 (also without knowledge of the sex or length of the fish). Once all otoliths had been read, their length and zonal counts were compared and any outside a 95 percentile were re-examined for possible errors before being processed into age-length keys.

Purpose-written software (SurvCalc) developed at NIWA (Francis and Fu 2009) was used to produce a scaled length frequency of the research catch by year. The software then calculates catch-at-age by constructing age-length keys separately for each sex and applying them to the scaled length frequency data. The precision of each age frequency, as measured by the mean weighted coefficients of variation (c.v.s), was 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. Bootstrapping was used to calculate c.v.s, i.e., catches were resampled within each stratum, and otoliths were simply randomly resampled.

The 1994 and 1995 age and-length keys were re-calculated using SurvCalc to ensure that the catch-at-age distributions, produced by Sutton (1997), were identical to those undertaken here. Between-survey comparisons were then undertaken for the whole survey, for individual survey strata, and finally with all WCSI strata combined, and all Tasman and Golden Bays strata combined.

Red gurnard have a long spawning period which extends through spring and summer with a peak in early summer (Ministry of Fisheries Science Group 2010; Elder 1976), so a birthday of 1 January was chosen. All otoliths used were three months past their birthdays, because the trawl surveys were in March–April, so any year class referred to as 1-year-old (or 1+) could more accurately be referred to as being 1.25 years old.

Estimates of instantaneous total mortality (Z) were derived for each survey using the Chapman-Robson estimator (Chapman & Robson 1960) and regression of the right-hand limb of the catch curve (Ricker 1975, Dunn et al. 1999). The Chapman-Robson estimator is:

$$Z = \log_e\left(\frac{1 + a - 1/n}{a}\right)$$

where a is the mean age above recruitment age and n is the sample size. For this estimator, age at recruitment (R) should be the age at which 100% of fish are vulnerable to the sampling method (rather than the often used age at 50% recruitment); an R of 4 was used here. A 95% confidence interval around this estimator is $\pm 2*\sqrt{\text{var}}$, where $\text{var} = (1-e^{-Z})^2/(ne^{-Z})$.

Z was also estimated from the slope of the right hand limb (i.e., points where age is R or older) of the relationship between age and the natural logarithm of the frequency of fish in that age class (Ricker

1975). The regression model used here set R at 4 years. A 95% confidence interval around this estimator was taken as ± 2*SE of the slope.

The structure of the age-frequency distributions and the estimates of Z were compared between surveys.

3. RESULTS

In an early comparison of "annual" band counts versus length there were some male fish outside the 95 percentile. Further investigation showed no obvious error in either age estimation or data collection. These readings were left in the analysis as there was no valid reason to remove them.

The results of inter-reader variability of 100 (14%) otoliths from 2003, 2005, 2007 had an IAPE of 4.1%; the mean difference between the two readers was 0.07 years (Figure 3a). An inter-reader IAPE of 8.5% was calculated between the historic (reader one) and recent (reader two) readings of the 1994–95 otoliths. This indicates a moderate discrepancy between these two results. An age bias plot (Figure 3b) also shows a small bias in the age estimation of 1 and 2 year old fish, with reader one generally ageing them younger than reader two.

The mean weighted c.v.s across all age classes for the 2003, 2005, and 2007 surveys were 27.5%, 27.2%, and 25.7%, respectively. The target c.v. was also met for the recalculated 1994 and 1995 historic data, with mean-weighted c.v.'s of 23.1% and 23.9% (Table 3).

3.1 The survey overview

Catch-at-length

In 2003 the survey scaled length distribution (both sexes combined) was normally distributed with a strong central modal peak at 34 cm and a mean of 34.7 cm (Figure 4). In 2005 the scaled length distribution was more broadly distributed with a modal peak of 33 cm and a mean of 32.3 cm. In 2007 the scaled length distribution no longer had an identifiable modal peak. There were similar percentages of red gurnard between the lengths of 22–36 cm and the mean length was 30.4 cm (Figure 4). The scaled length distributions from the 1994 and 1995 surveys have modes of 27 and 32 cm and 22–24 cm and 33 cm, respectively. In 1995 the distribution is more skewed to the smaller fish (Figure 4). The percentage of large females (over 40 cm) in the research catch declined from 16% in 2003 to fewer than 7% in 2007. There are more small males than small females, and more large females than large males in the catch from all three recent surveys.

The mean length of males has declined in each survey year, from 32.7 cm in 2003 to 29.6 cm in 2007. In 1994 and 1995 the mean male lengths were stable at 30.6 cm and 30.5 cm, respectively (Table 4). The survey catch of females follows the same decreasing mean length trend, from 36.9 cm in 2003 to 31.7 cm in 2007. In 1994 and 1995 the mean female lengths were stable at 34.6 cm and 34.3 cm. The sex ratio of males to females in GUR 7 has varied during the survey series, from the combined 1994 and 1995 ratio of 1.4:1 in favour of males, to the more recent surveys (2003, 2005, 2007) combined ratio of 1.2:1.

The length at age of red gurnard in GUR 7 (Table 5) indicates that no 0+ fish, and very few 1+ or above 9+ year fish were sampled. The 10+ and 11+ males were possibly incorrectly labelled as these lengths and ages are more in keeping with ranges observed for females.

The growth rates of young red gurnard (2–5 years) were similar over the 2003–2007 surveys, but quite different to the rates estimated from the 1994 and 1995 survey data. The historic surveys had faster growth rates at ages 2–3, but by ages 4–5 all surveys had similar growth rates (Figure 5).

Length at maturity and commercial recruitment

Red gurnard sexual maturity for males and females is reached at a length of 24 cm (Ministry of Fisheries Science Group 2010; Elder 1976). The percentage of the GUR 7 research catch that is not yet sexually mature (i.e., are less than 24 cm, 1–2 years) increased with each survey from 2003 to 2007 (Table 6).

The percentage of the survey catches above the length of commercial recruitment of 30 cm (Michael Stevenson, NIWA, pers. comm.), or about 3–5 years, has been decreasing for the last three surveys, and in 2007 was lower than the 1994 and 1995 survey levels (Table 7).

Length-frequency progression

When GUR 7 scaled length frequency data is represented as 1 cm size groupings (Figure 4), it does not show any noticeable progression of strong or weak length cohorts.

Catch-at-age

Scaled age frequency distributions (by sex and for both sexes combined) for each of the five surveys are shown in Figure 6. The age distributions show a decreasing mean ages and modes from 2003–2007. The mean male age decreased from 2003 to 2007, and also from 1994 to 1995. The survey catch of females followed the same decreasing mean age over time. However, the variation in mean age was non-significant between all surveys (Figure 7).

In the three recent surveys in FMA 3 there were few male red gurnard above 8 years, or females above 9 years. There was only one fish over 11 years from 2003–2007. The two surveys in 1994 and 1995 had eight fish over 11 years of age, with the oldest 15 years old (Sutton 1997). The catch composition of more recent surveys consisted of more 2- to 5-year old fish than the historic surveys which produced more 1- and 2-year old fish (50% in 1995) (Figure 6). There are considerably fewer 1-year red gurnard in the three more recent surveys than historically.

Age at maturity and commercial recruitment

Red gurnard sexual maturity for both males and females is reached at a length of 24 cm (Ministry of Fisheries Science Group 2010; Elder 1976) or 2-years of age as estimated in this analysis. The percentage of the GUR 7 survey catch less than 2 years old has increased with each survey year, from 2003 to 2007, and in 2007 was higher than the 1994 and 1995 percentages (Table 6).

The age at sexual maturity and the age at commercial recruitment can be seen in Figure 6 as dashed vertical lines at 2-years and 3-years. The proportion of the GUR 7 research catch within these two age limits has been increasing as a percentage of the catch in each recent survey year.

Age-frequency progression

There is no obvious modal progression of cohorts between surveys.

3.2 Between-strata comparison

GUR 7 survey catch data were examined by stratum. Similarities were found that showed that strata could be grouped by depth, geographical area, and red gurnard catch. The individual survey strata can be sorted into similar depth groupings where similar sized red gurnard have been found (Figure 8 and 9). The four strata (2, 6, 8 and 12) with the biggest fish (mean 40–42 cm and 5.7–6.6 years) are on the west coast at depths of 100–200 m. The three strata with the smallest fish (mean 26–31 cm and 2.5–3.3 years) are 17, 18 and 19 in Tasman and Golden Bays with depths of 20–70 m. The five strata with mean lengths between 34 and 37 cm (mean age 4.3–4.7 years) are from the west coast inshore strata (1, 5, 7, 11 and 14) with depths between 20 and 100 m (Table 8).

Catch-at-length and catch-at-age

Red gurnard sampled from west coast inshore strata (20–100 m depth) (strata 1, 5, 7, 11 and 14) had longer mean lengths and older fish than those captured in the three strata in Tasman and Golden Bays (17, 18 and 19). Fish from the deeper (100–200 m) west coast strata (2, 6, 8 and 12) had even longer mean lengths and were even older (Table 8). During three years of research trawl surveys of GUR 7, only 41 red gurnard were caught from strata where the water was deeper than 100 m, 1405 red gurnard were caught from the shallow water strata (20–100 m), and no red gurnard were caught in the 200–400 m depth strata.

West coast inshore strata (1, 5, 7, 11 and 14)

The west coast inshore strata have surface areas ranging from 851–1438 km^2 and depths ranging from 20–100 m. Males tended to dominate females in the catch. Stratum 1 near Cape Farewell had a mean red gurnard length of 36.7 cm (mean age 4.6-years). Only 82 fish were caught in this stratum over three years of surveys; four fish were above 44 cm (greater than 9-years) and one fish less than 25 cm (under 2-years) (Figures 10 and 11). Stratum 5 just south of stratum 1 had a mean length of 34.9 cm (4.3-years), but three times more red gurnard were caught there (264 fish) than in stratum 1. Eight fish caught were above 44 cm and four fish were shorter than 25 cm (Figures 10 and 11). Stratum 7 extends south from Cape Foulwind where 306 red gurnard were caught over three years of surveys. The mean fish length was 35.1 cm (4.3-years) with 11 large fish above 44 cm and only one small fish less than 25 cm (Figures 12 and 13). Stratum 11 is just south of stratum 7 and both have the same mean length and age. In Stratum 11, 584 red gurnard were caught over the survey period with 13 fish above 44 cm and no small fish less than 25 cm (Figure 12). Stratum 14 was the most southern inshore stratum where the mean fish length was 36.5 cm (4.7-years) and 169 red gurnard were caught over three years of surveys including 12 large fish caught above 44 cm and only one fish less than 25 cm (Figures 12 and 13).

West coast offshore strata (2, 6, 8, 12 and 15)

The west coast offshore strata have surface areas ranging from 881–4302 km^2 and depths from 100 to 200 m. Numbers of red gurnard caught were very low, only 41 over three years of surveys. Strata 2 and 6 north of Cape Foulwind had a mean of 40.5 cm (5.8-years) and 41.5 cm (5.9-years) respectively but caught only 14 red gurnard between them with no large fish greater than 44 cm (over 9-years) and no fish under 25 cm (under 2-years) (Figures 10 and 11). The remaining strata are all south of Cape Foulwind. In strata 8 and 12 only 27 red gurnard were caught from three years of surveys with mean lengths of 40.7 cm (5.7-years) and 40.0 cm (6.6-years). Only two fish were longer than 44 cm and none were under 25 cm. No red gurnard were caught in the southernmost offshore stratum 15.

West coast offshore strata (9, 13 and 16)

No red gurnard were caught in any of the deepest strata (9, 13 and 16) where depths are between 200 and 400 m.

Tasman and Golden Bays strata (17, 18 and 19)

There are three inshore strata in Tasman and Golden Bays, with one stratum extending into deeper water than the other two. Stratum 17 covers an area of only 307 km^2 (Table 2) at depths between 20 and 33 m. From a three survey total of 248 fish caught in this stratum the mean red gurnard length was 26.1 cm (2.5-years). There was an even sex ratio, no large fish above 44 cm (over 9-years) and 116 fish less than 25 cm (2-years) were caught (Figures 14 and 15). Stratum 18 covers an area three times the size of stratum 17 (947 km^2) and has a similar depth range 20–42 m. From a three survey total, 696 fish were caught in this stratum and the mean red gurnard length was 27.8 cm (2.7-years). The sex ratio was 0.8:1 in favour of females and eight large fish above 44 cm and 222 small fish less than 25 cm were caught (Figures 14 and 15). Stratum 19 has the largest area in which red gurnard are regularly caught 2436 km^2 with depths from 20–70 m. In the three surveys a total of 612 fish were caught in this stratum with a slightly larger mean length of 30.7 cm (3.3-years). The sex ratio was 0.9:1 in favour of females and six large fish were at or above 44 cm and 61 small fish less than 25 cm were caught (Figures 14 and 15).

West coast inshore strata (1, 5, 7, 11 and 14) catch composition over time

The catch composition of the west coast inshore (20–100 m) strata showed great consistency in red gurnard catches for most survey years (Figure 16) with most of the catch between 3–6 years. The survey in 1995 shows a different picture, with a large percentage of 1–2 year old fish moving the catch composition curve towards the younger fish. All survey years caught a small percentage of red gurnard greater than 8 years old.

West coast offshore strata (2, 6, 8, 12 and 15) catch composition over time

The catch composition of the west coast offshore (100–200 m) strata showed little consistency between survey years (Figure 17) with very low numbers of red gurnard caught (65 fish from five years of surveys). In 1995, 2003 and 2005 the research catch had a modal peak at 5-years, whereas in 1994 and 2007 there were modal peaks at 6-years of age. Most of the catch in all surveys was 4–9 years old, and all surveys caught a few red gurnard over 8-years old.

Tasman and Golden Bays catch composition over time

The catch composition for each survey year in Tasman and Golden Bays (strata 17, 18 and 19) showed a high percentage of the catch being young red gurnard (Figure 18). From surveys in 1994 and 1995 the majority of the catch was 1–2 year old fish, and from 2003 to 2007 there has been a higher proportion of young fish in recent years. Only surveys in 1994 and 1995 caught red gurnard over 9 years old.

3.3 West coast and Tasman and Golden Bays

Catch-at-length and catch-at-age

Catches of red gurnard during the 1994, 1995, 2003, 2005 and 2007 WCSI trawl surveys have been represented as scaled length and age distributions for a west coast strata grouping (strata 1–14) (Figures 19, 20 and 21), and a Tasman and Golden Bays strata grouping (strata 17, 18 and 19) (Figures 22, 23 and 24). The west coast mean lengths for each survey year have been constant over time (Figure 19). The west coast mean age has been consistent around 4.5-years from 2003 to 2007 and in

1994, while the 1995 mean age was a full year younger at 3.5-years (Figure 14). The three recent west coast surveys show a strong modal grouping around the 3–5 year old fish with more than 68% of the red gurnard caught during each survey being from these year classes. The west coast mean male lengths have also remained stable with mean lengths from 33.1–34.6 cm (4.2–4.5 years) (Figure 19). The mean female length has also remained stable with lengths from 37.9–38.5 cm and ages 4.4–4.8 years, for all survey years except 1995 when the mean ages were much lower (Figures 19 and 20).

The scaled lengths for Tasman and Golden Bays (strata 17, 18 and 19) have shown periodic increases of small fish from 2003–2007 (Figure 22).

The scaled mean age for red gurnard caught in Tasman and Golden Bays dropped from 3.9-years in 2003 to 2.7-years in 2007 (Figure 23). Scaled mean age of male red gurnard decreased from 2003 to 2007; in 2007 it was higher than the 1994 and 1995 mean ages. The same trend is shown by Tasman and Golden Bays female mean age which declined between 2003 and 2007 (Figure 23). The scaled mean male length dropped from 29.6 cm in 2003 to 26.4 cm in 2007. The female scaled mean length also declined, from 34.2 cm in 2003 to 29.8 cm in 2007 (Figure 22).

Length and age at maturity and commercial recruitment

On the west coast the percentage of red gurnard caught below the size at sexual maturity of 24 cm (2-years) is small, i.e., less than 1.5% throughout the survey period (Table 6). The percentage of fish caught above the fishery recruitment size of 30 cm (3-years) has changed little during the last three trawl surveys (Table 7).

In Tasman and Golden Bays the percentage of red gurnard caught below the size at sexual maturity of 24 cm (2-years) increased in every survey year from 2003 to 2007. The historic 1994 and 1995 levels varied substantially, with the 1995 figure higher than the 2007 level (Table 6). The percentage of fish caught above the fishery recruitment size of 30 cm (3-years) in Tasman and Golden Bays halved between 2003 and 2007, and in 2007 was very similar to the 1995 value (Table 7).

Cohort progression

There was no progression of strong or weak west coast year classes through the biennial surveys. The strong 4-year old mode on the west coast in 2003 was not noticeable as a strong 6-year old mode in 2005, and the strong 3-year old mode in 2005 was not represented in 2007 as a strong 5-year mode (Figures 19 and 20). There was no tracking of strong red gurnard age or length classes through the biennial surveys in Tasman and Golden Bays, and the strong 3-year old mode in 2003 was not noticeable as a strong 5-year class in 2005 (Figures 22 and 23).

Mortality Z-estimates

Estimates of Z (and their confidence intervals) derived for each survey using the Chapman-Robson and regression methods are listed in Table 9. There is significant overlap in Z estimates from all surveys, and consequently no significant changes in Z (or F) over time.

Sex ratio

The male:female ratio for the west coast ranged from 1.1:1.0 in 2003 to 2.8:1.0 in 2007 and had a 3-survey mean considerably in favour of males 1.8:1.0. The 1994 and 1995 survey catches were overwhelmingly male dominant at 2.4:1.0 and 2.6:1.0, respectively. In Tasman and Golden Bays the 3-survey (2003, 2005 and 2007) mean ratio was relatively even 0.9:1.0, despite the 2005 survey ratio having twice as many females as males (0.5:1.0). The historic (1994, 1995) survey ratios were 0.8:1.0 and 1.3:1.0, respectively.

4. DISCUSSION

Before interpreting the age data it is essential to validate the periodicity of the zone formation in red gurnard otoliths. This involves two steps: firstly, the determination of the age at which the first increment forms and secondly, the assurance that the periodicity of the zonal banding exists across the age range of the species (Horn 2007). Step one was undertaken by Staples (1971) and step two by Elder (1976). A further step was to ensure that any variability in band counts was minimal between the two otolith readers. The counts between reader one and reader two had no inter-reader bias with increasing age (Figure 3a). The second IAPE (Figure 3b) showed that there was a moderate difference in the way young fish (1–2 years) were aged.

4.1 GUR 7

The observed trends from 2003 to 2007 are decreased lengths and ages over time, producing a shift in catch composition. The same trends were shown from 1994 to 1995 (Sutton 1997) with a shift in catch composition to more small (immature) fish.

For this research, 24 cm has been used as a proxy for the length at which red gurnard are sexually mature, and at this size fish are 1–2 years old. At the length of 30 cm (3–5 years) red gurnard are assumed to be recruited into the commercial GUR 7 fishery (Michael Stevenson, NIWA, pers. comm.). The MFish Plenary document states that "red gurnard reach sexual maturity at an age of 2 – 3 years and a fork length (FL) of about 23 cm" (Ministry of Fisheries Science Group 2010). This does not match the length at age data from this investigation, where red gurnard from GUR 7 at a length of 23 cm would be expected to be 1–2 years old not 2–3 years. This may be partially a reflection of the variability in early red gurnard growth rates, or a reflection of a reading discrepancy of the 1994 and 1995 1–2 year old fish. Red gurnard between 2–3 years had much faster growth rates during the historic surveys of 1994 and 1995 (Sutton 1997) than during the more recent 2003–2007 surveys. Variability between the historic and recent age at length data occurs primarily in the early faster growing years; by 4–5 years there is little to no variability between the two survey periods.

The red gurnard length at sexual maturity for the Hauraki Gulf was determined by Elder (1976) who noted that male and female fish were sexually mature at 23–25 cm in length. The catch of juveniles (1–2 years) in the GUR 7 survey catch has increased from 2003 to 2007 representing a changing age and length composition of survey catches. The matching decrease in fish greater than 30 cm (3-years) (as a percentage of the catch) is likely to be an artefact of the increased juvenile recruitment defined as a percentage, and not a real decrease in the numbers of these fish.

It was not possible to track age or length modal progressions through the 2003–2007 scaled frequency plots. A similar situation occurred with the 1994 and 1995 survey data in Sutton (1997) where the age and length frequencies showed no clear modal progression.

There was significant overlap in Z estimates from all surveys (1994–2007). The Z estimates from Elder (1976) for the Hauraki Gulf fitted within the 95% confidence intervals for all GUR 7 surveys.

4.2 Individual strata

Red gurnard caught in the deeper offshore strata are on average longer and older than in the inshore strata. This may show evidence of red gurnard moving into deeper water as they grow.

Within the west coast strata the research catch composition of red gurnard followed a similar theme, with most of the fish above the commercial recruitment size (30 cm, 3-years) and very few below the

length at maturity (24 cm, 2 years). The Tasman and Golden Bays strata had the highest catches of small red gurnard below the length at maturity. The red gurnard caught off WCSI are not all longer or older than the red gurnard in Tasman and Golden Bays, because both areas have a wide range of lengths and ages however the trend was for WCSI strata to have longer and older fish than the Tasman and Golden Bays strata.

4.3 WCSI and Tasman and Golden Bays

Sutton (1997) recognised consistent differences between east and west coast South Island red gurnard population age distributions. Similar differences were present within GUR 7 for all recent survey years when comparing the west coast with Tasman and Golden Bays.

The west coast had consistently larger and older fish than Tasman and Golden Bays. The Tasman and Golden Bays catch composition changed from 2003 to 2007 with decreasing modal peaks, but not to the 1994 and 1995 survey level where large 1 and 2-year old recruitment strongly influenced the catch composition. The 1995 pulse of mostly 1 year fish shows that the Tasman and Golden Bays stock can be quite variable, and strongly influenced by large juvenile recruitment years. The trends from Tasman and Golden Bays appear to match the catches of GUR 7 as a whole with an increase in juveniles (below 24 cm, 2-years) from research catches over the survey years 1994, 1995, 2003, 2005 and 2007. The recent trends from the west coast catches are different to that of GUR 7 as a whole, generally being more stable.

If we look at the differences between the Tasman and Golden Bays strata and the west coast strata to try to explain the differences seen in catch composition, the west coast has more survey area shallower than 100 m (5783 km^2) than the Tasman and Golden Bays (3690 km^2). This may explain why more large old fish are caught on the west coast. A nursery ground in Tasman and Golden Bays would explain the large numbers of small and young fish within this area. This raises the question, where do the west coast fish come from? If they migrate from the Tasman and Golden Bays nursery area south along the west coast, we might expect to see greater numbers of smaller fish in the northern west coast strata as compared to the southern strata. This trend does occur in the three southern most strata, but not in those north of Cape Foulwind. The red gurnard caught north of Cape Foulwind may be passing through that area during the March–April survey period and as a temporary and mobile population may not be sampled well by this survey.

5. ACKNOWLEDGMENTS

Thanks to Colin Sutton (NIWA) for preparing all the otoliths, reading many of them, and for providing a useful review of the manuscript. Thanks to Sira Ballara for help with the mortality estimates and Greg Lydon for tracking down the otolith reading results from 1997. This work was funded by the Ministry of Fisheries under Project INT2008-02.

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Table 1: Number of red gurnard otoliths available from WCSI trawl surveys in GUR7.

Year	Scientific voyage	Survey dates	Number of otoliths available	Number of otoliths read
1994	KAH9404	18 March 1994 – 20 April 1994	390	382
1995	KAH9504	21 March 1995 – 24 April 1995	324	321
1997	KAH9701	19 March 1997 – 13 April 1997	410	0
2000	KAH0004	17 March 2000 – 10 April 2000	237	0
2003	KAH0304	23 March 2003 – 14 April 2003	220	211
2005	KAH0503	23 March 2005 – 13 April 2005	260	247
2007	KAH0704	22 March 2007 – 15 April 2007	240	230

Note: 1994 and 1995 otoliths were prepared and read by Sutton (1997)

Table 2: Stratum depths and areas used in the west coast South Island, Tasman and Golden Bays WCSI trawl surveys.

Stratum	Depth range (m)	Area (km2)	Location
1	20–100	1 343	WCSI
2	100–200	4 302	WCSI
5	25–100	1 224	WCSI
6	100–200	3 233	WCSI
7	25–100	927	WCSI
8	100–200	2 354	WCSI
9	200–400	1 877	WCSI
11	25–100	1 438	WCSI
12	100–200	2 054	WCSI
13	200–400	1 101	WCSI
14	25–100	851	WCSI
15	100–200	881	WCSI
16	200–400	319	WCSI
17	20–33	307	TBGB
18	20–42	947	TBGB
19	20–70	2 436	TBGB

Table 3: Numbers of red gurnard measured, number of otoliths read and coefficients of variation (c.v.) for the catch at age (mean weighted across all age classes) for the five WCSI surveys.

Year	Scientific voyage	Number of red gurnard measured	Number of otoliths read	Mean weighted c.v.s %		
				Male	Female	Total
1994	KAH9404	1 423	382	30.1	26.6	23.1
1995	KAH9504	1 495	321	30.9	25.3	23.9
2003	KAH0304	575	211	36.7	34.3	27.5
2005	KAH0503	1 136	247	33.4	33.5	27.2
2007	KAH0704	1 292	230	30.3	29.4	25.7

Table 4: Scaled mean lengths and ages from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007.

Year	Scaled mean lengths (cm) GUR 7			Scaled mean ages (years) GUR 7		
	Male	Female	Total	Male	Female	Total
1994	30.6	34.6	32.4	3.5	3.7	3.6
1995	30.5	34.3	31.9	2.7	3.1	2.8
2003	32.7	36.9	34.7	4.2	4.7	4.4
2005	31.1	33.5	32.3	3.7	3.5	3.6
2007	29.6	31.7	30.4	3.5	3.3	3.4

Table 5: GUR 7 mean length-at-age (cm) for WCSI trawl surveys in 2003, 2005 and 2007 combined, S.D. = standard deviation, N = sample size.

Age	Male			Female			All		
class	Mean length	S.D.	N	Mean length	S.D.	N	Mean length	S.D.	N
0+	–	–	–	–	–	–	–	–	–
1+	18.0	4.2	2	20.0	4.1	4	19.3	3.8	6
2+	24.5	2.4	67	25.8	2.9	79	25.2	2.8	146
3+	29.6	3.3	72	32.1	3.8	104	31.1	3.8	176
4+	34.2	3.6	54	37.0	4.1	64	35.7	4.1	118
5+	36.6	4.1	50	41.8	3.5	48	39.2	4.6	98
6+	38.1	3.4	34	42.3	3.7	31	40.1	4.1	65
7+	39.3	2.5	18	44.9	3.9	25	42.5	4.3	43
8+	40.9	2.0	7	45.8	2.8	13	44.1	3.5	20
9+	–	–	–	44.4	1.9	8	44.4	1.9	8
10+	45.0	5.7	2	47.0	–	1	45.7	4.2	3
11+	45.5	2.1	2	45.0	0.0	2	45.3	1.3	4
12+	–	–	–	–	–	–	–	–	–
13+	–	–	–	48	–	1	48	–	1

Table 6: Percentage of GUR7 scaled lengths below and above the length at sexual maturity 24 cm (male and female combined) for survey years 1994, 1995, 2003, 2005 and 2007.

Survey year	Tasman & Golden Bays			West Coast			Total		
	% < 24 cm	% ≥ 24 cm	*n*	% < 24 cm	% ≥ 24 cm	*n*	% < 24 cm	% ≥ 24 cm	*n*
kah9404	6.0	94.0	812	1.5	98.5	611	4.1	95.9	1 423
kah9504	27.6	72.4	707	0.1	99.9	788	13.1	86.9	1 495
kah0304	3.8	96.2	130	0.4	99.6	445	1.2	98.8	575
kah0503	16.5	83.5	553	0.3	99.7	583	8.2	91.8	1 136
kah0704	22.8	77.2	874	0.2	99.8	418	15.5	84.5	1 292
Mean / totals	17.5	82.5	3 076	0.5	99.5	2 845	9.4	90.6	5 921

Table 7: Percentage of GUR7 scaled lengths below and above the length at fishery recruitment 30 cm (male and female combined) for survey years 1994, 1995, 2003, 2005 and 2007.

Survey year	Tasman & Golden Bays			West Coast			Total		
	% < 30 cm	% ≥ 30 cm	*n*	% < 30 cm	% ≥ 30 cm	*n*	% < 30 cm	% ≥ 30 cm	*n*
kah9404	48.4	51.6	812	9.2	90.8	611	31.6	68.4	1 423
kah9504	68.2	31.8	707	4.7	95.3	788	34.7	65.3	1 495
kah0304	36.2	63.8	130	8.1	91.9	445	14.5	85.5	575
kah0503	58.2	41.8	553	12.3	87.7	583	34.6	65.4	1 136
kah0704	66.7	33.3	874	6.2	93.8	418	47.1	52.9	1 292
Mean / totals	59.4	40.6	3 076	8.0	92.0	2 845	34.7	65.3	5 921

Table 8: Scaled mean lengths and ages from individual strata within GUR 7 for three survey years combined 2003, 2005 and 2007.

Strata	Depths (m)	Male		Female		Total	
		Mean length	Mean age	Mean length	Mean age	Mean length	Mean age
1	20 – 100	34.8	4.6	39.1	4.7	36.7	4.6
5	25 – 100	33.8	4.3	37.0	4.3	34.9	4.3
7	25 – 100	33.3	4.2	38.2	4.6	35.1	4.3
11	25 – 100	33.7	4.3	37.8	4.6	35.1	4.4
14	25 – 100	34.1	4.4	40.3	5.1	36.5	4.7
2	100 – 200	40.5	5.8	–	–	40.5	5.8
6	100 – 200	40.8	5.9	42.5	5.5	41.5	5.9
8	100 – 200	39.5	5.9	42.7	5.8	40.7	5.7
12	100 – 200	40.3	6.8	41.0	4.0	40.0	6.6
17	20 – 33	24.7	2.4	27.4	2.5	26.1	2.5
18	20 – 42	25.5	2.6	29.7	2.9	27.8	2.7
19	20 – 70	28.4	3.2	32.7	3.4	30.7	3.3

Table 9: GUR 7, Z estimates using Chapman-Robson and regression methods (sexes combined).

Survey year	Age at full recruitment	Chapman-Robson Z	95 % confidence intervals Lower	Upper	Regression Z	95 % confidence intervals Lower	Upper
1994	4	0.510	0.305	0.876	0.533	0.421	0.645
1995	4	0.456	0.283	0.780	0.422	0.278	0.566
2003	4	0.603	0.353	1.103	0.488	0.363	0.614
2005	4	0.706	0.422	1.239	0.856	0.771	0.941
2007	4	0.550	0.327	1.010	0.867	0.770	0.964

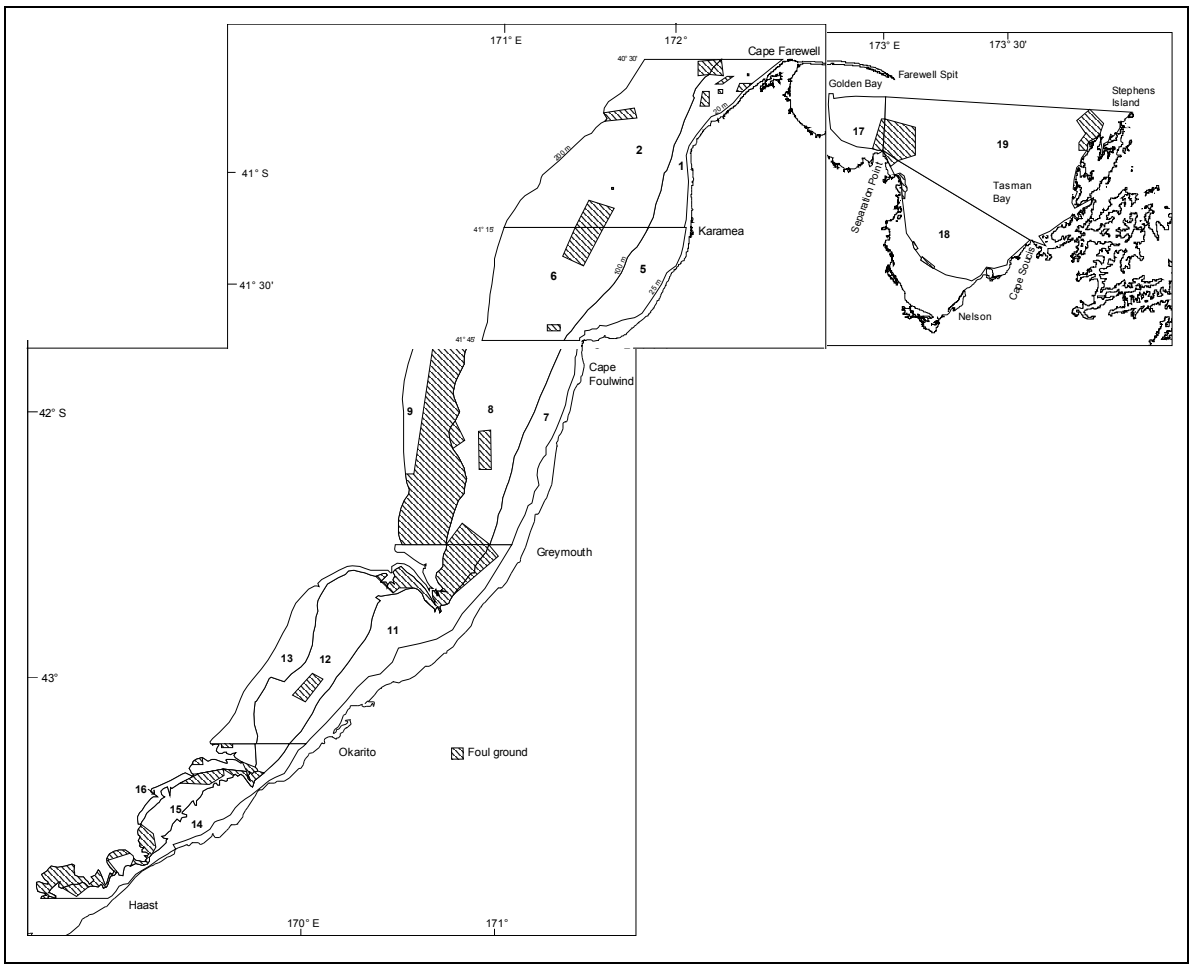

Figure 1: Map of west coast South Island, Tasman and Golden Bays (WCSI) trawl survey area showing strata boundaries and areas of foul ground.

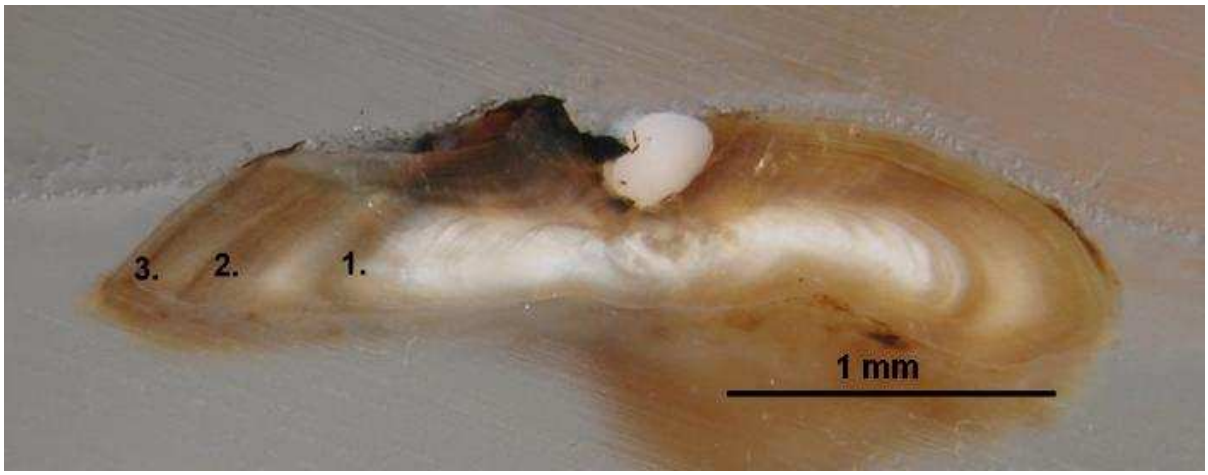

Figure 2: Prepared red gurnard otolith, that has been baked, embedded in epoxy resin, cut transversely and illuminated by reflected light at an incident angle of about 30° and photographed under 30x magnification. Zonal bands have been labelled and a scale bar added.

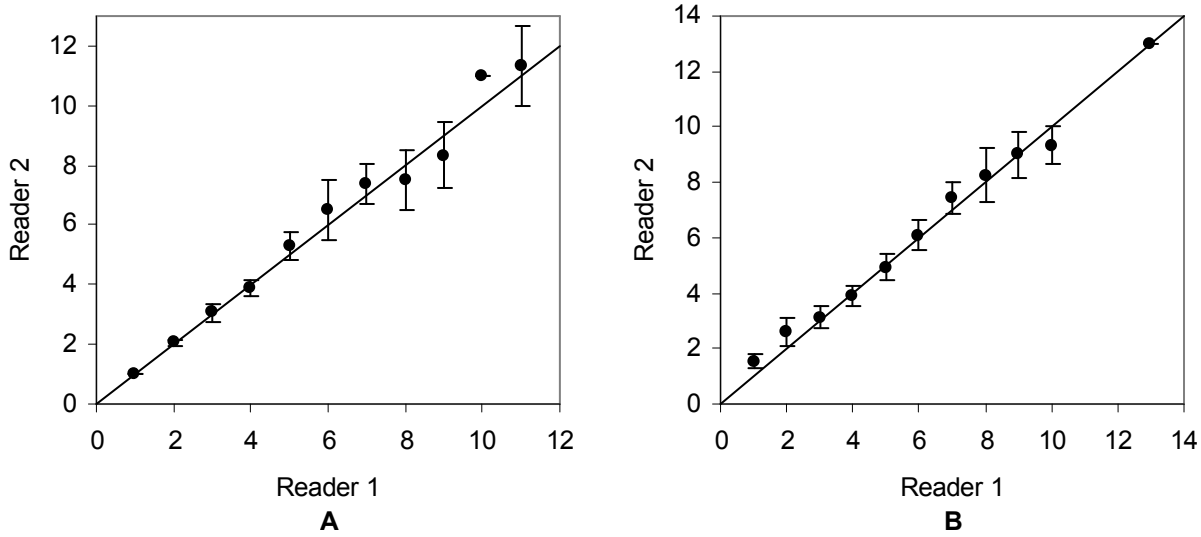

Figure 3: Between reader comparison of otolith zonal band counts of red gurnard from (a) 2003, 2005 and 2007 WCSI trawl surveys of GUR 7, and (b) the 1994 and 1995 research surveys. The diagonal line shows a 1:1 ratio between both readers.

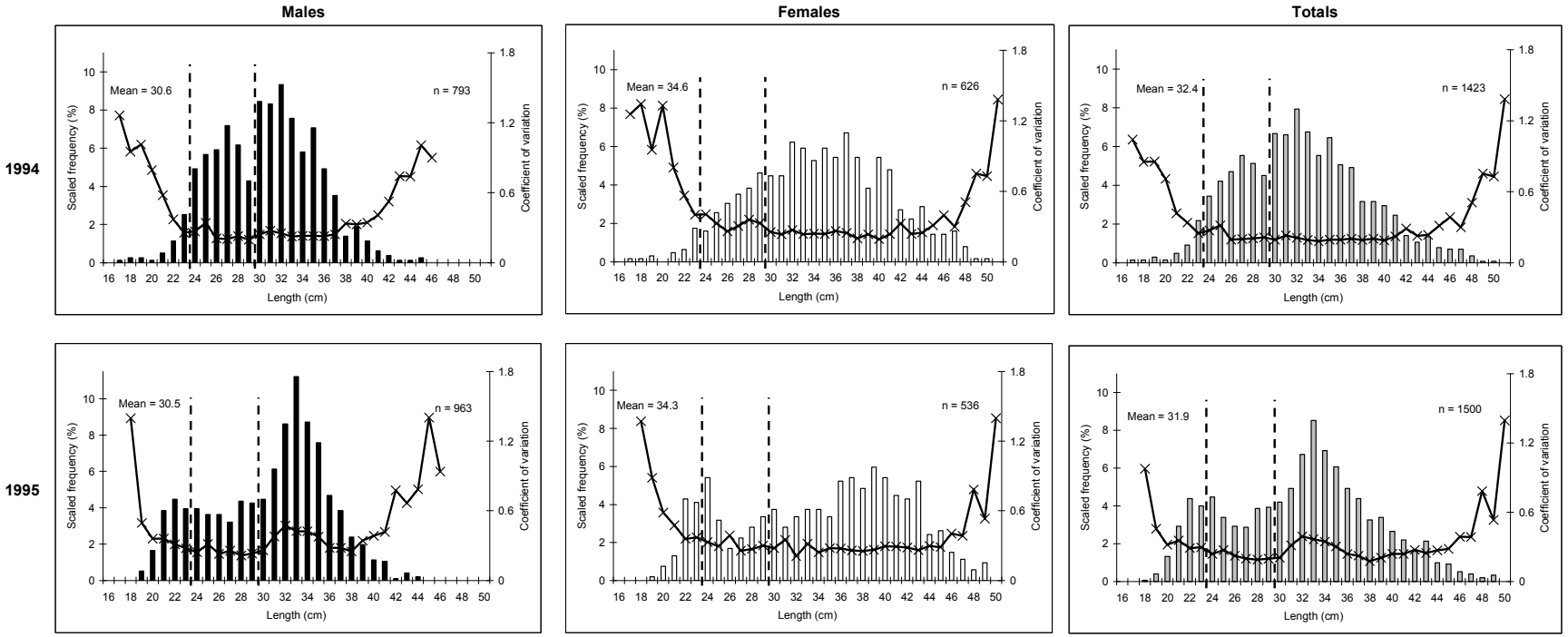

Figure 4: Red gurnard scaled length distributions from five inshore WCSI trawl surveys of GUR 7 in 1994, 1995, 2003, 2005 and 2007, males (black), females (white), total (grey) with c.v.s (coefficient of variation), n = number of scaled samples, the two dashed lines represent the length at sexual maturity (24 cm) and the length of commercial recruitment (30 cm).

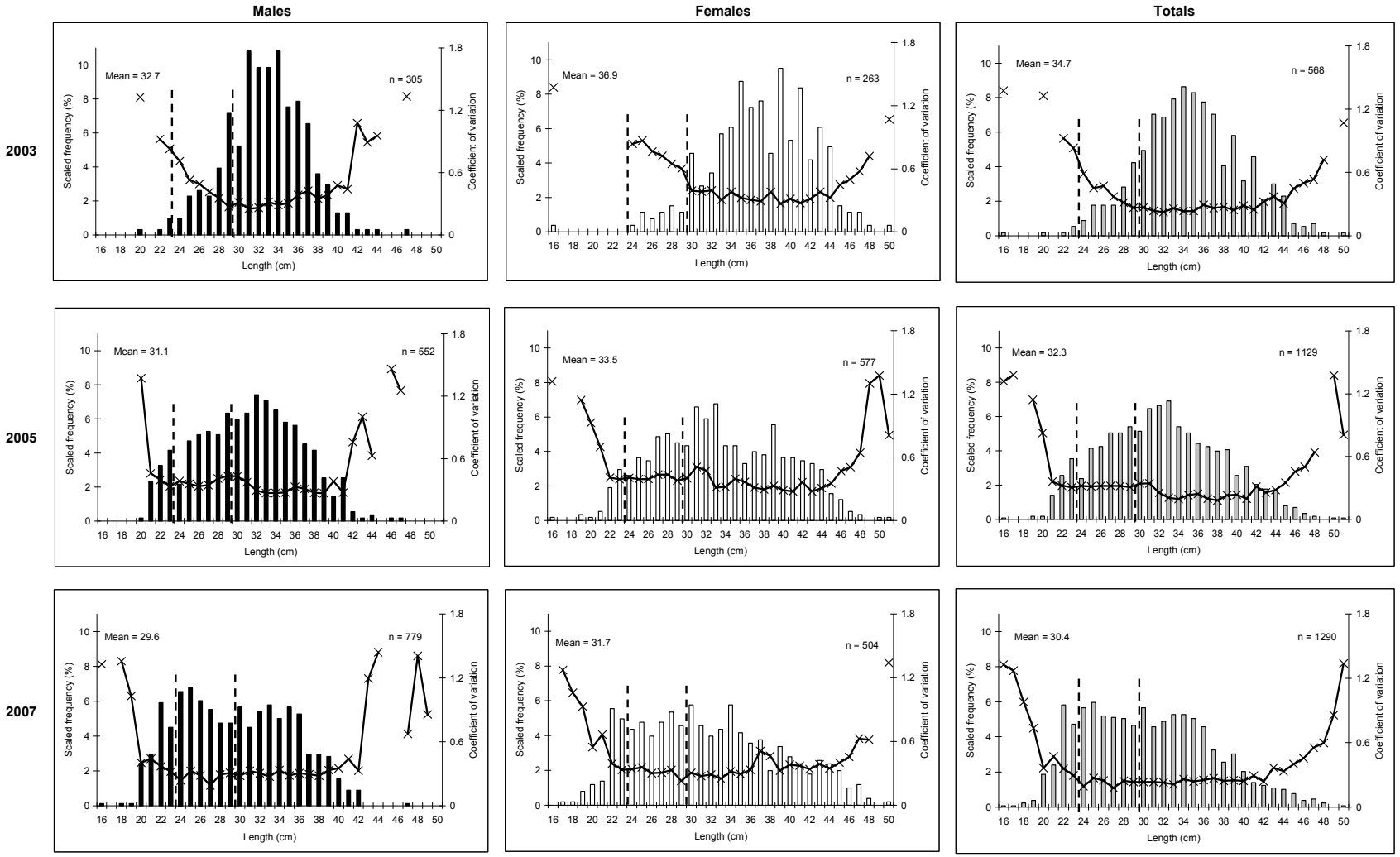

Figure 4: continued: Red gurnard scaled length distributions from five inshore WCSI trawl surveys of GUR 7 in 1994, 1995, 2003, 2005 and 2007, males (black), females (white), total (grey) with c.v.s (coefficient of variation), n = number of scaled samples, the two dashed lines represent the length at sexual maturity (24 cm) and the length of commercial recruitment (30 cm).

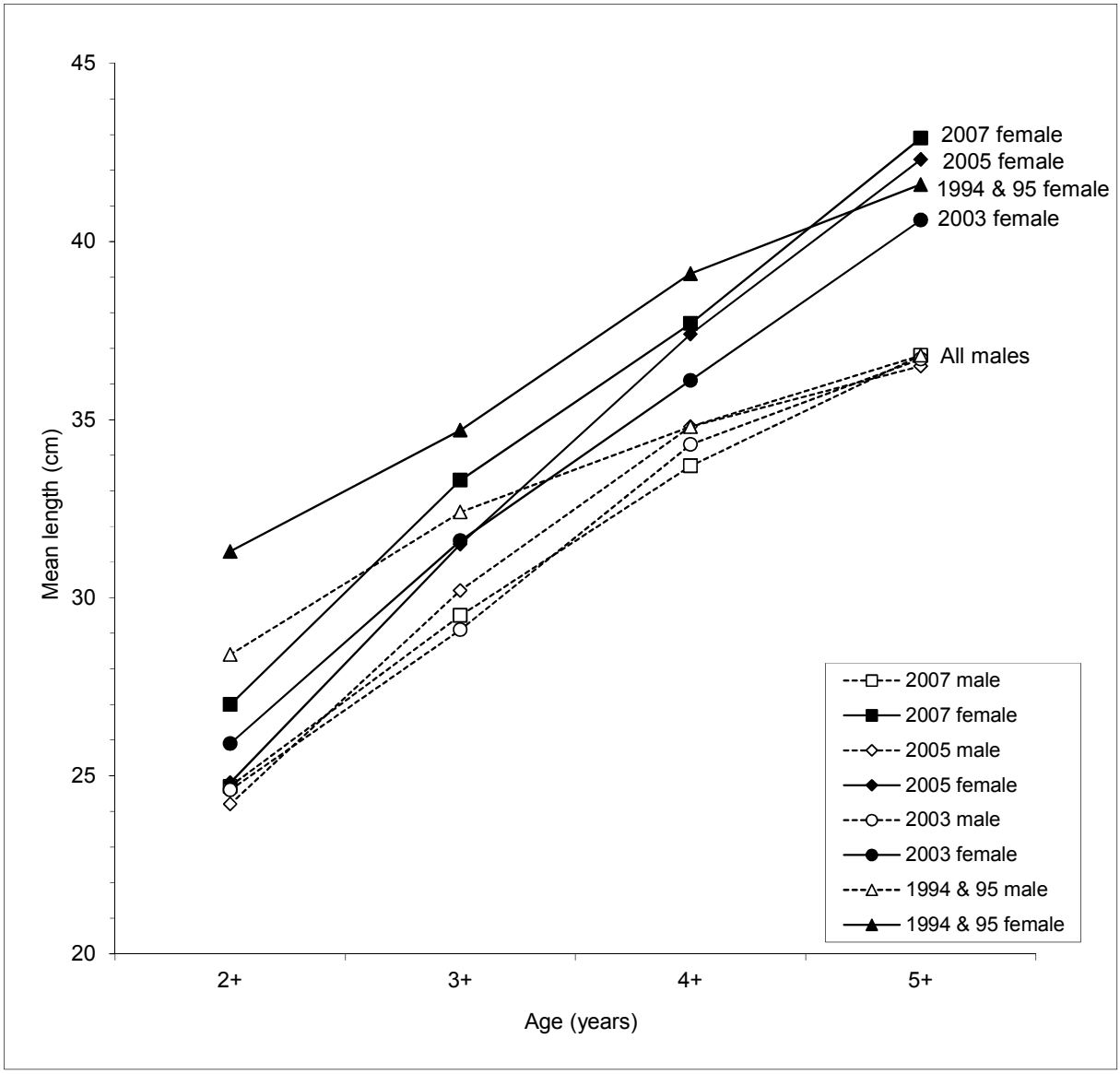

Figure 5: GUR 7 male and female early growth (2 – 5-years) for WCSI trawl survey years 1994, 1995, 2003, 2005 and 2007.

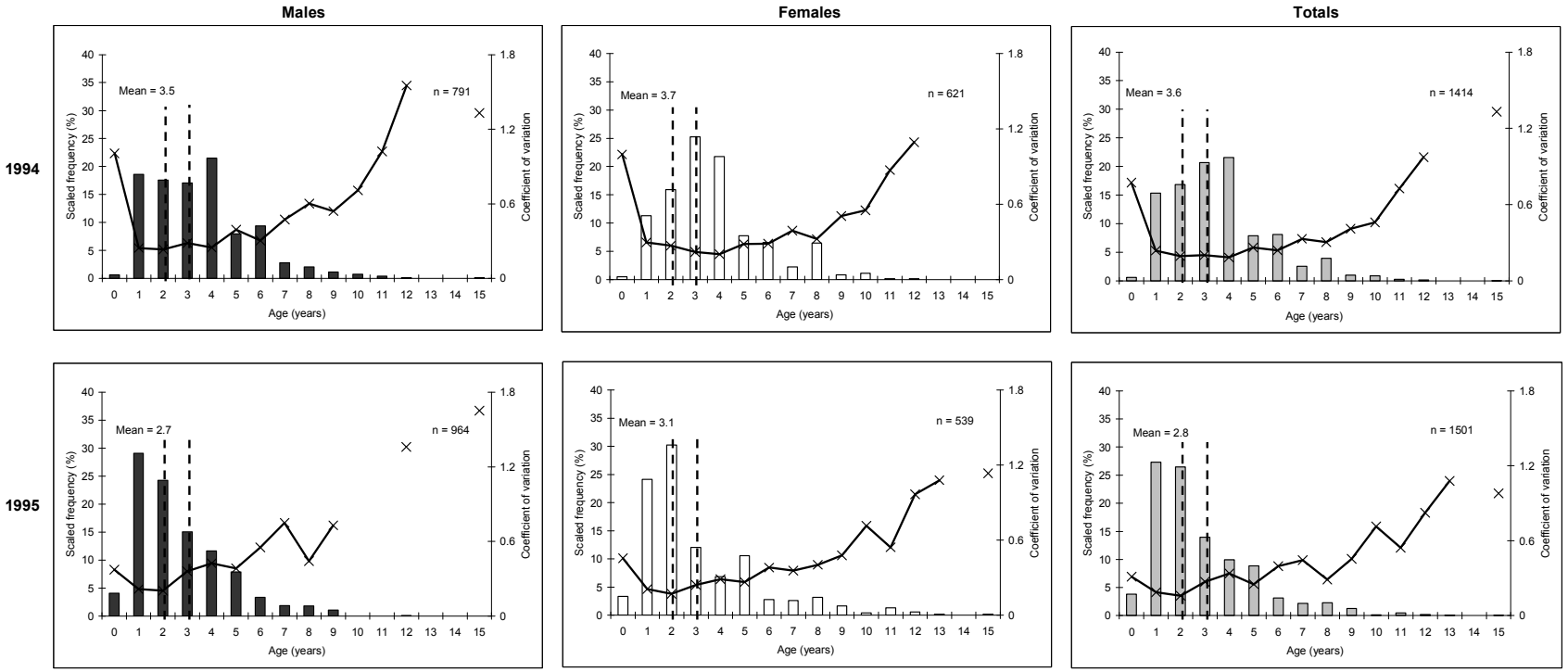

Figure 6: Red gurnard scaled age distributions from five inshore WCSI trawl surveys of GUR 7 in 1994, 1995, 2003, 2005 and 2007, males (black), females (white), total (grey) with c.v.s (coefficient of variation), n = number of scaled samples, the two dashed lines represent the age at sexual maturity (2–years) and the age of commercial recruitment (3–years).

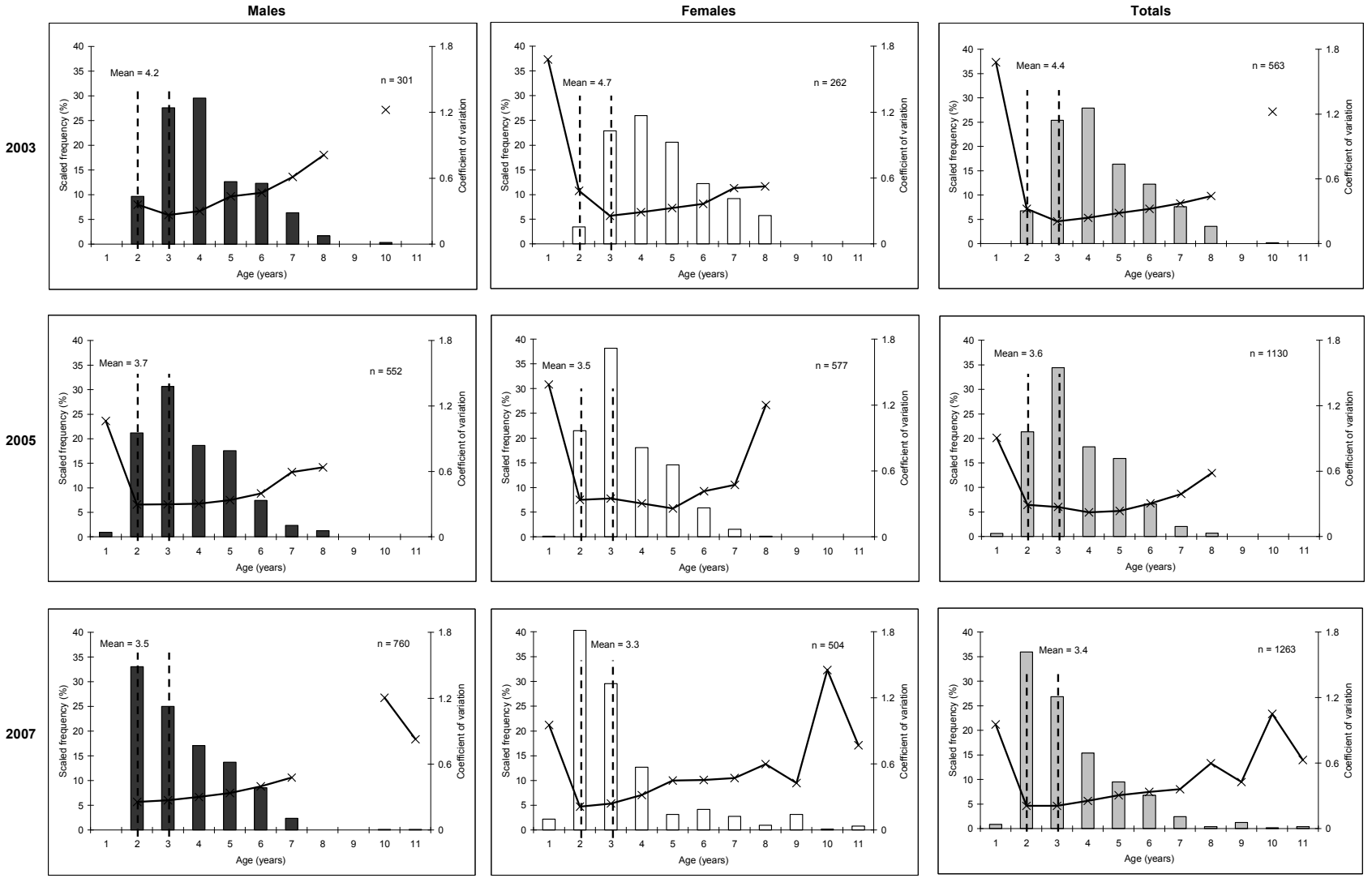

Figure 6: continued: Red gurnard scaled age distributions from five inshore WCSI trawl surveys of GUR 7 in 1994, 1995, 2003, 2005 and 2007, males (black), females (white), total (grey) with c.v.s (coefficient of variation), n = number of scaled samples, the two dashed lines represent the age at sexual maturity (2–years) and the age of commercial recruitment (3–years).

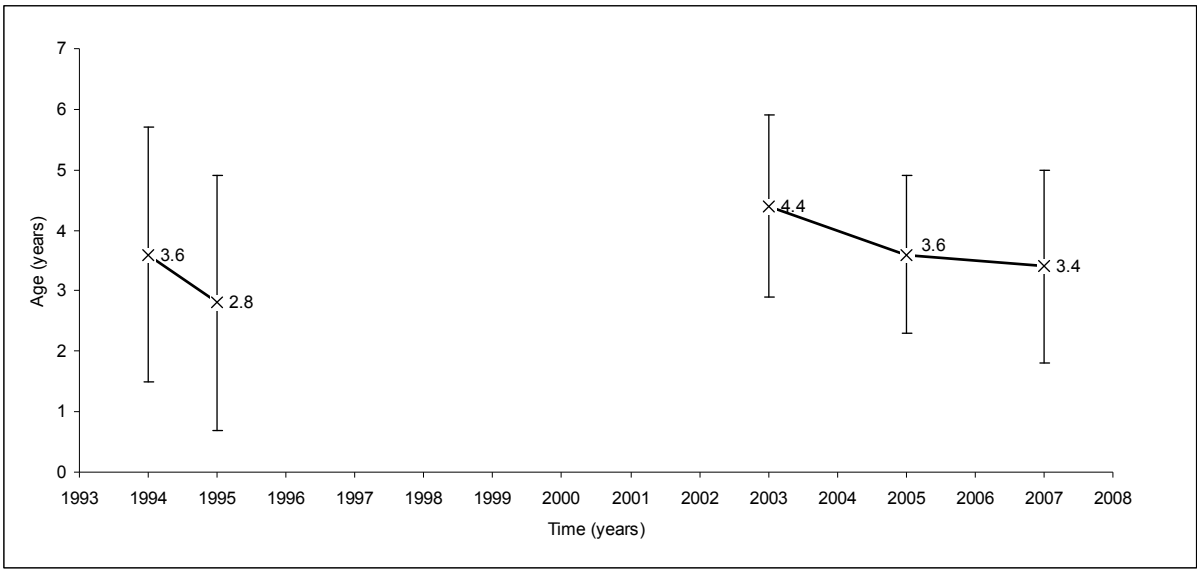

Figure 7: GUR 7 scaled mean age for red gurnard, with ± 1 standard deviation, from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007.

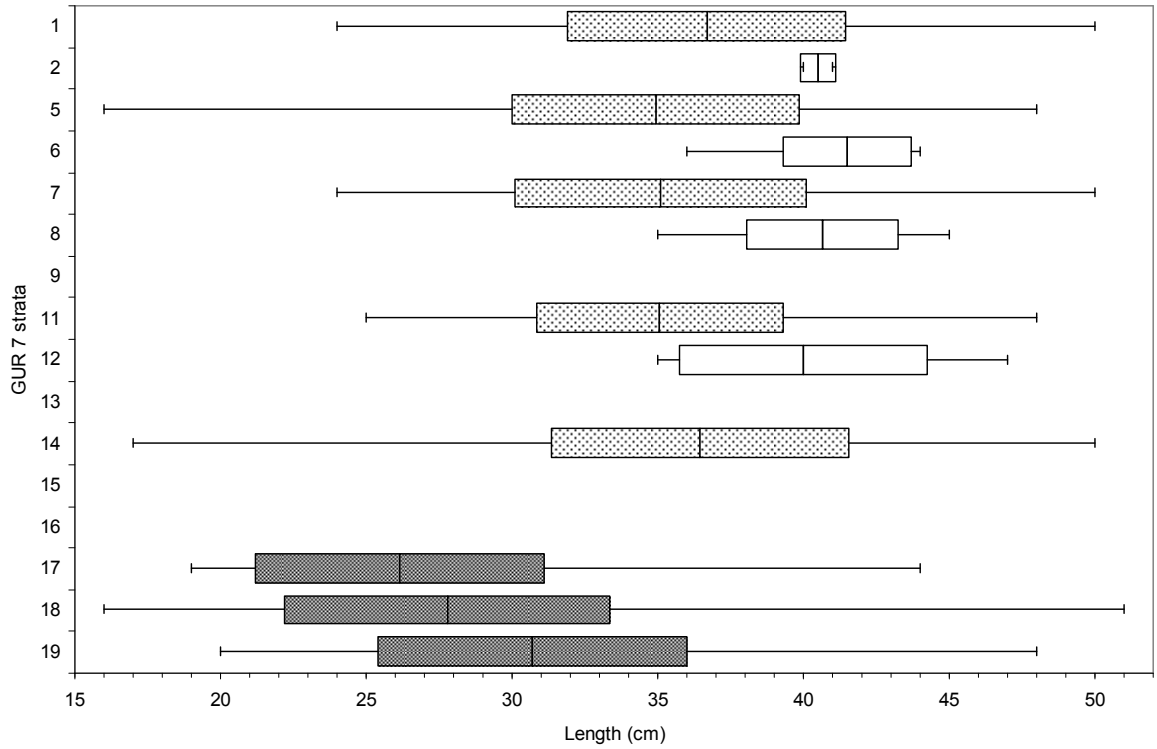

Figure 8: GUR 7 scaled lengths by stratum, from WCSI trawl surveys in 2003, 2005 and 2007 combined, mean ± STD, min, max, (STD = standard deviation). Dark-shading are Tasman and Golden Bays strata, mid-shading are west coast 20–100 m inshore strata, and no-shading are the west coast 100–200 m deep strata.

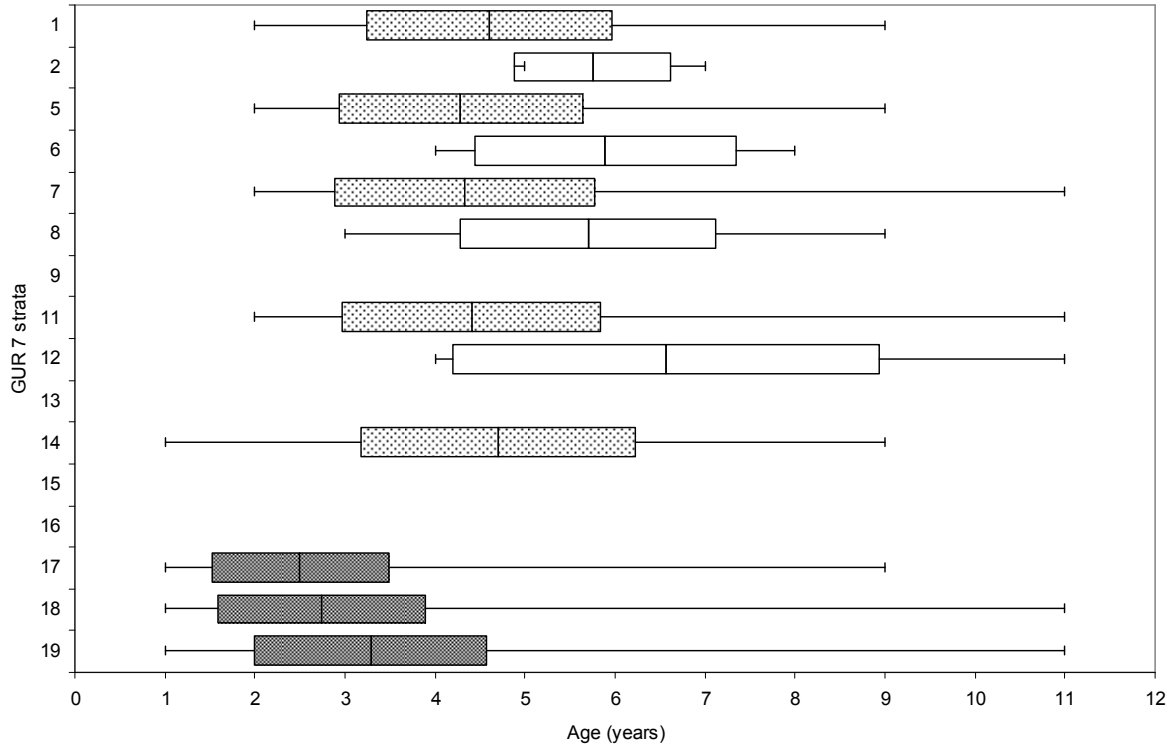

Figure 9: GUR 7 scaled age by stratum, from WCSI trawl surveys in 2003, 2005 and 2007 combined, mean ± STD, min, max, (STD = standard deviation). Dark-shading are Tasman and Golden Bays strata, mid-shading are west coast 20–100 m inshore strata, and no-shading are the west coast 100–200 m deep strata.

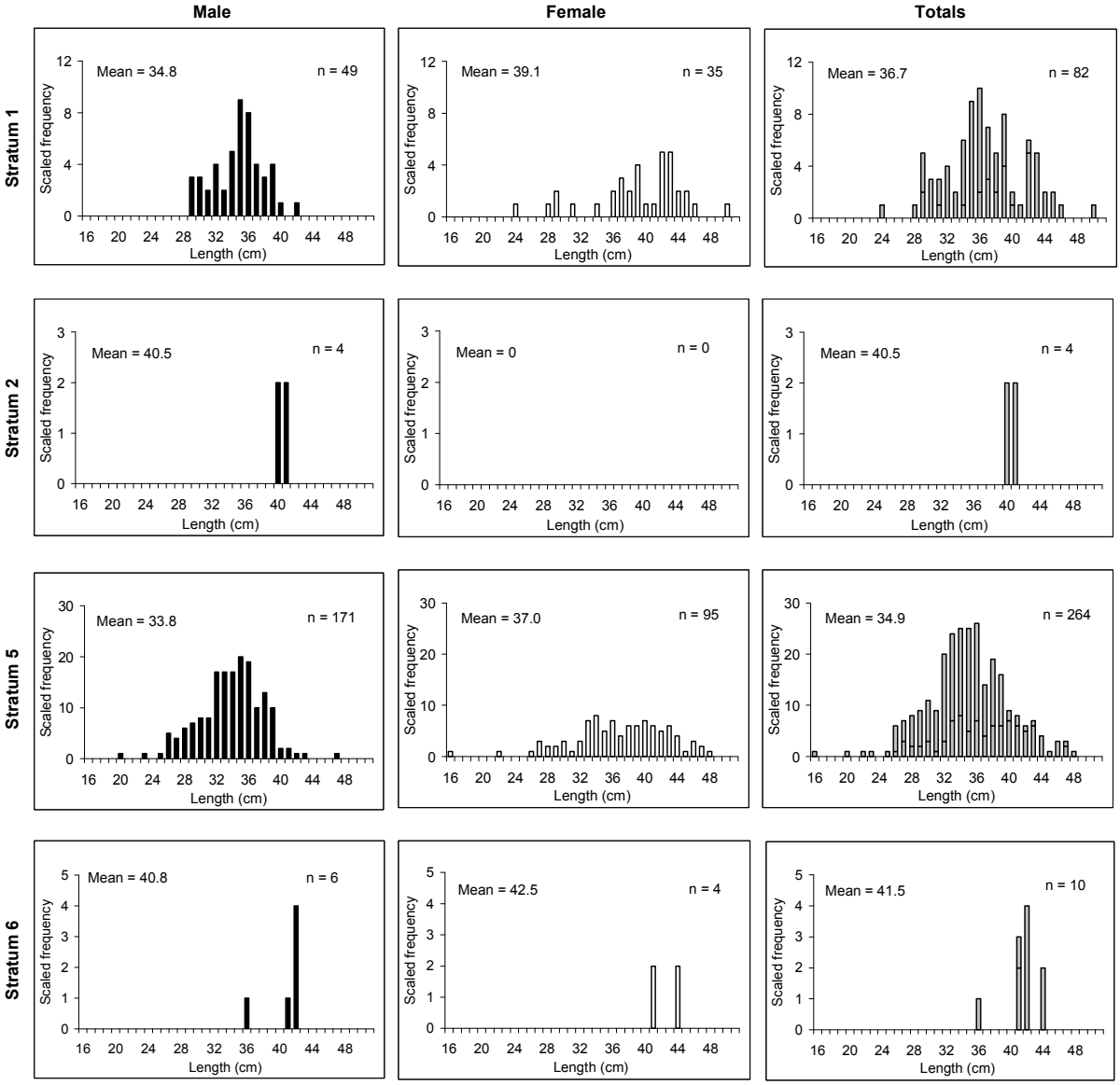

Figure 10: GUR 7 scaled length distributions from northern west coast strata 1, 2, 5 and 6, male (black), female (white), total (grey), from surveys in 2003, 2005 and 2007 combined.

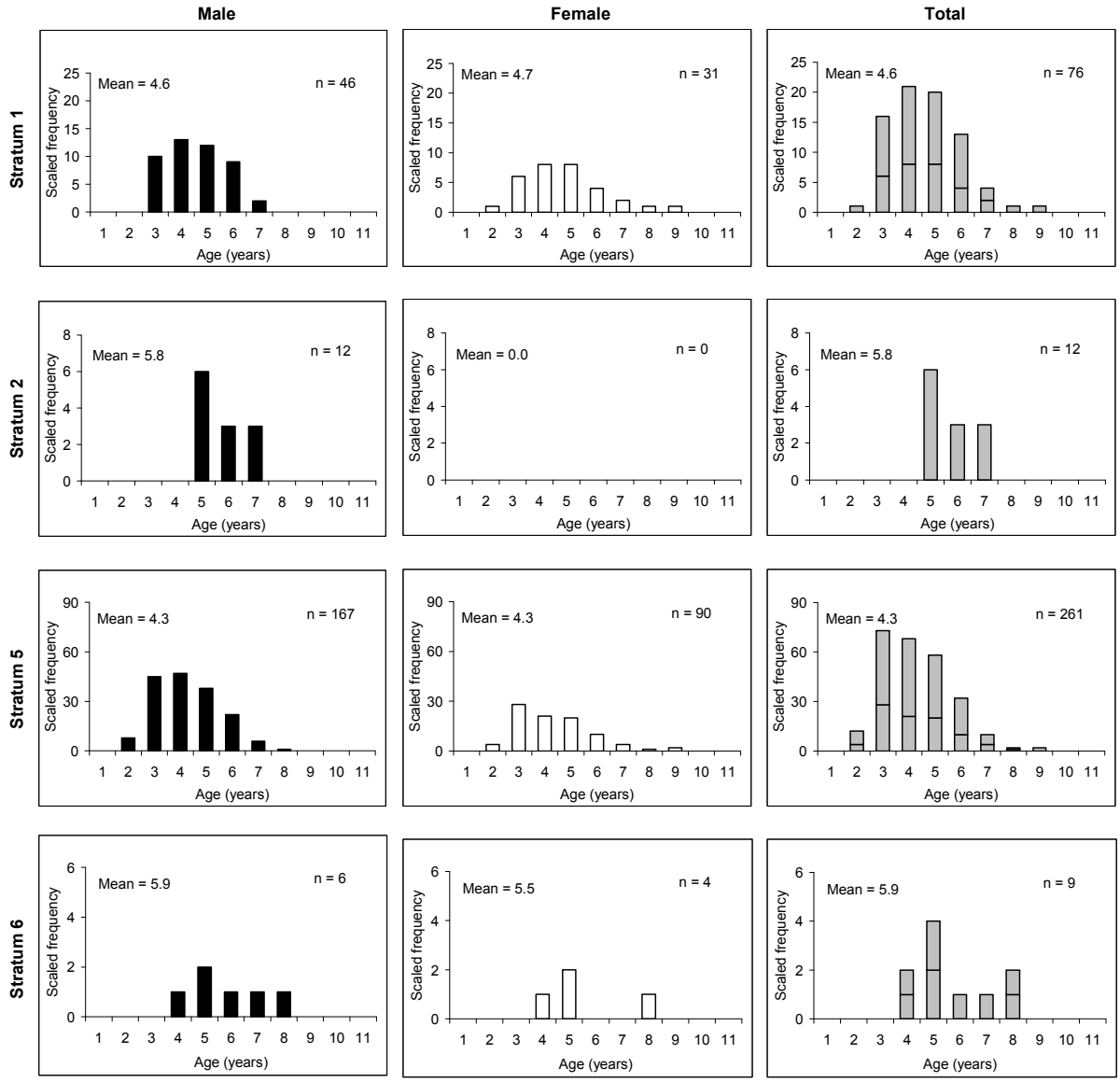

Figure 11: GUR 7 scaled age distributions from northern west coast strata 1, 2, 5 and 6, male (black), female (white), total (grey), from surveys in 2003, 2005 and 2007 combined.

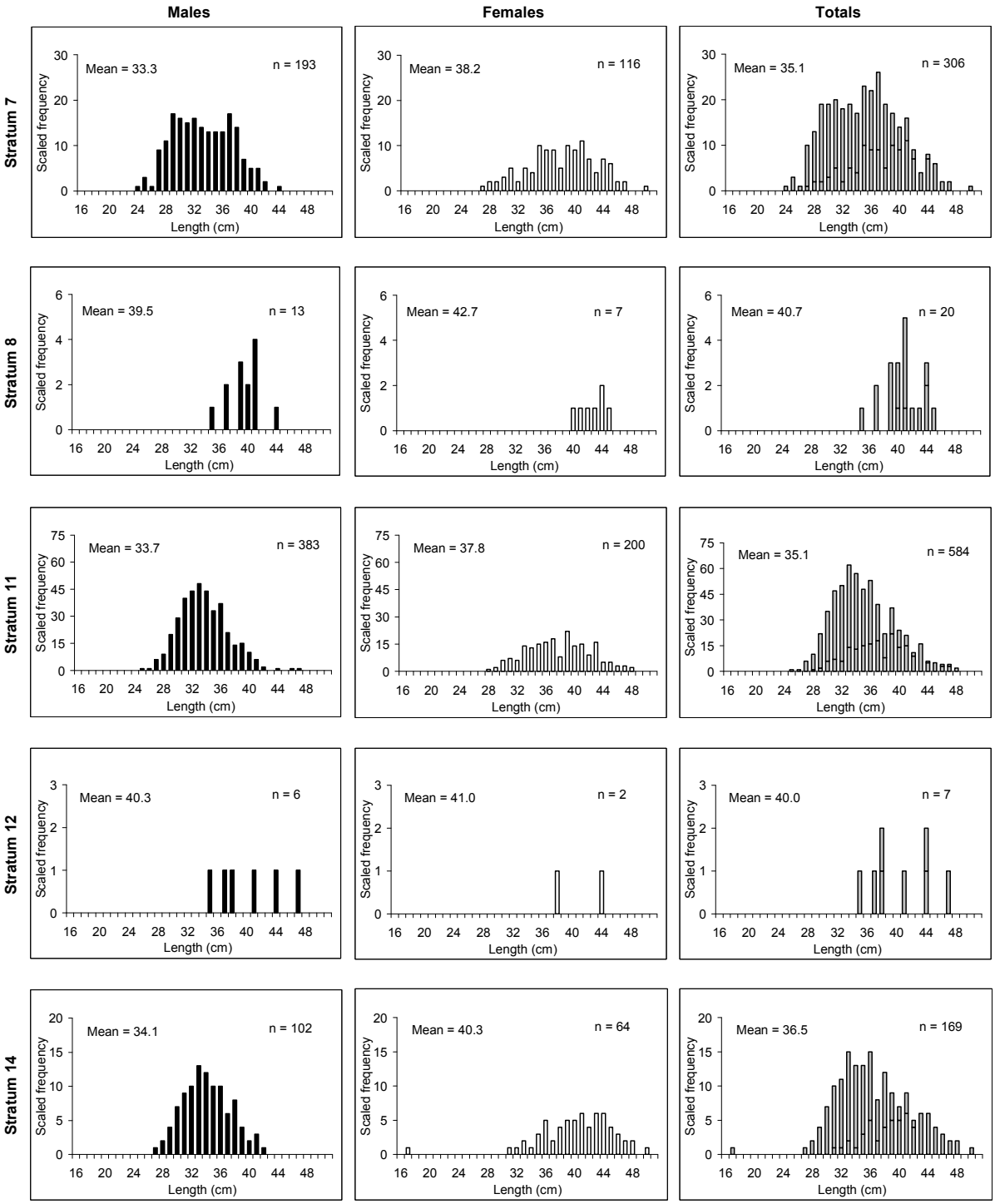

Figure 12: GUR 7 scaled length distributions from Southern west coast strata 7, 8, 11, 12 and 14, male (black), female (white), total (grey), from surveys in 2003, 2005 and 2007 combined.

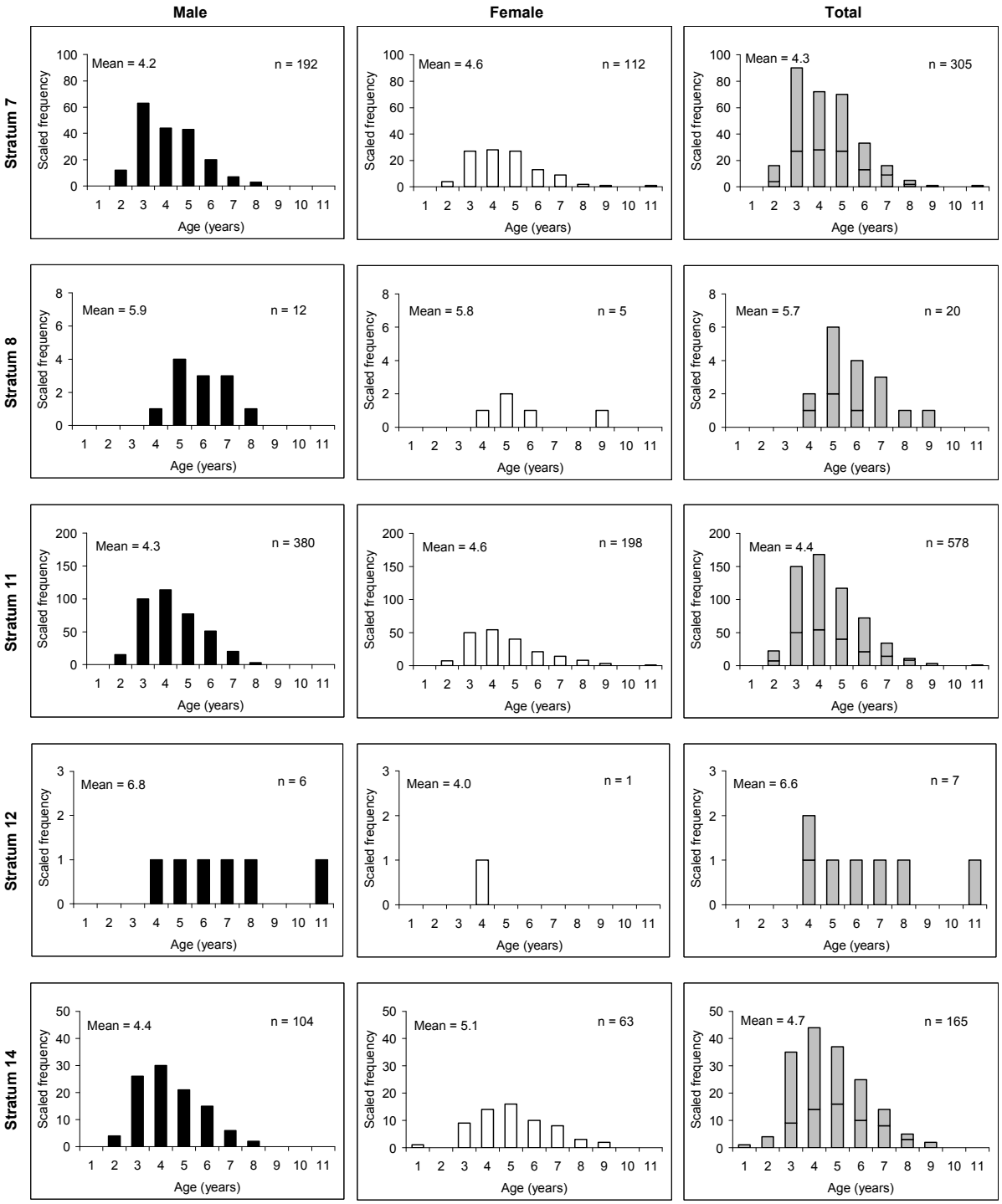

Figure 13: GUR 7 scaled age distributions from southern west coast strata 7, 8, 11, 12 and 14, male (black), female (white), total (grey), from surveys in 2003, 2005 and 2007 combined.

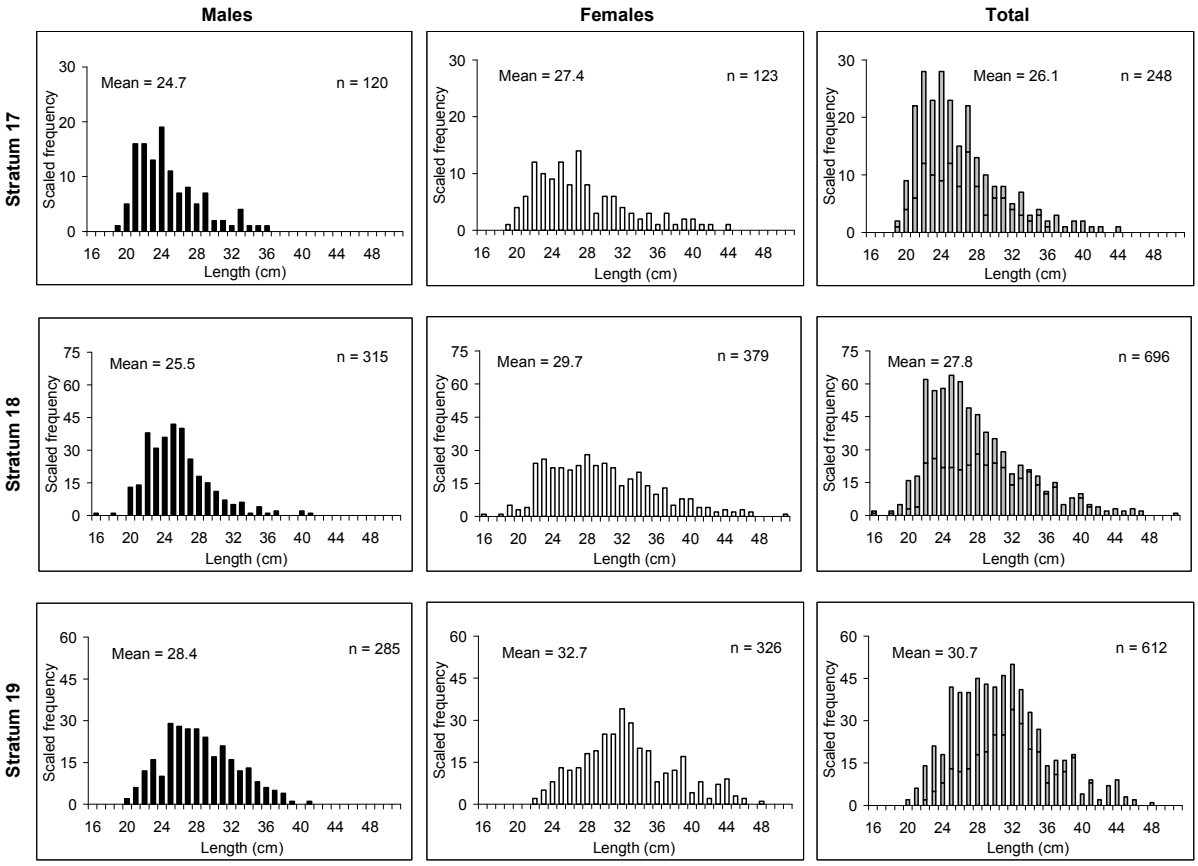

Figure 14: GUR 7 scaled length distributions from Tasman and Golden Bays strata 17, 18 and 19, male (black), female (white), total (grey), from surveys in 2003, 2005 and 2007 combined.

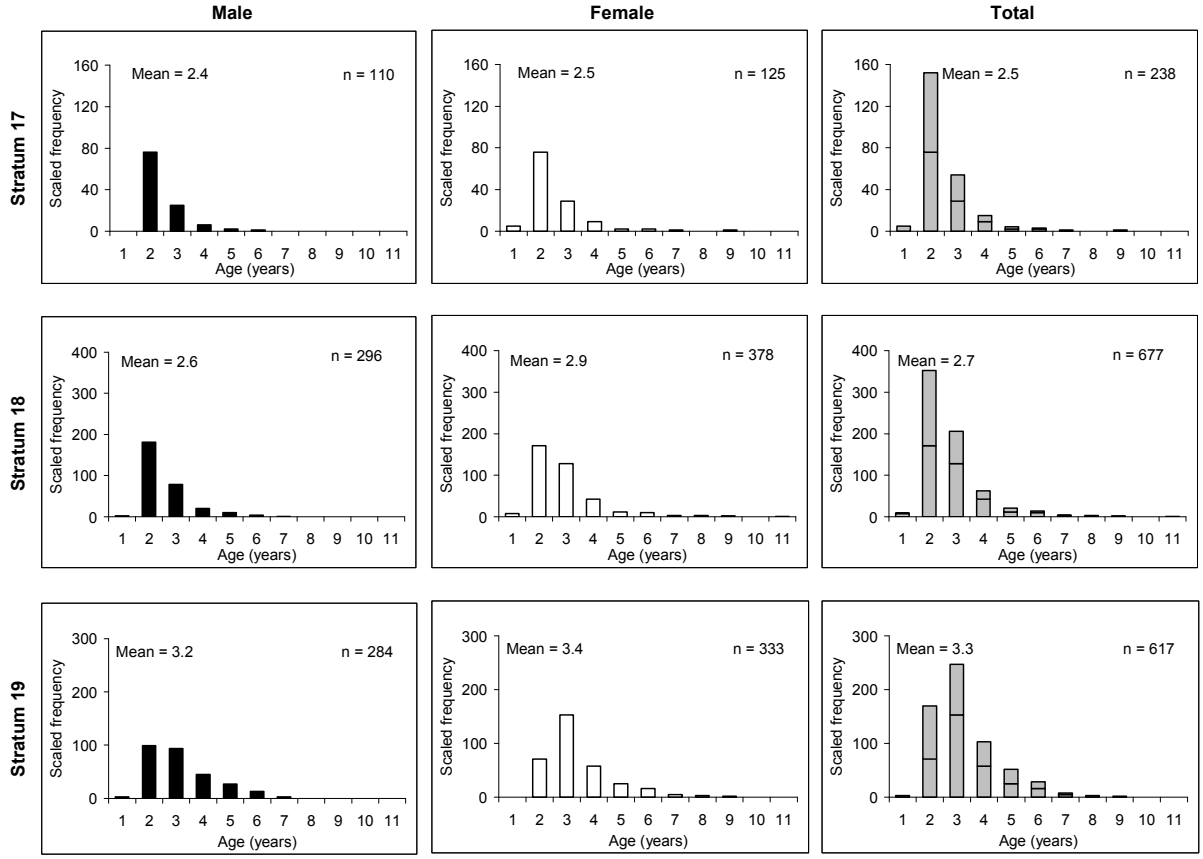

Figure 15: GUR 7 scaled age distributions from Tasman and Golden Bays strata 17, 18 and 19, male (black), female (white), total (grey), from surveys in 2003, 2005 and 2007 combined.

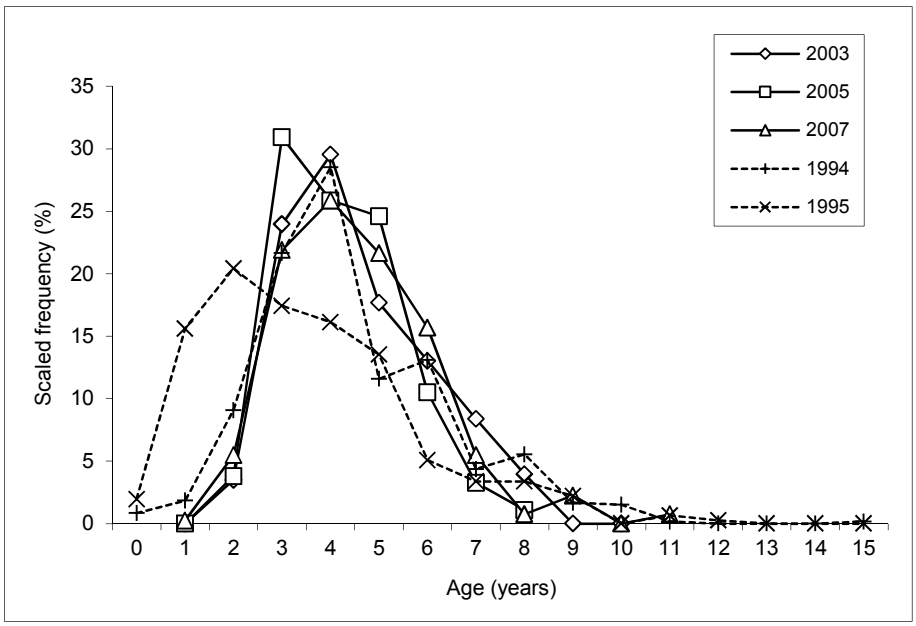

Figure 16: Catch composition for west coast inshore strata with depths 20–100 m (strata 1, 5, 7, 11 and 14) from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007.

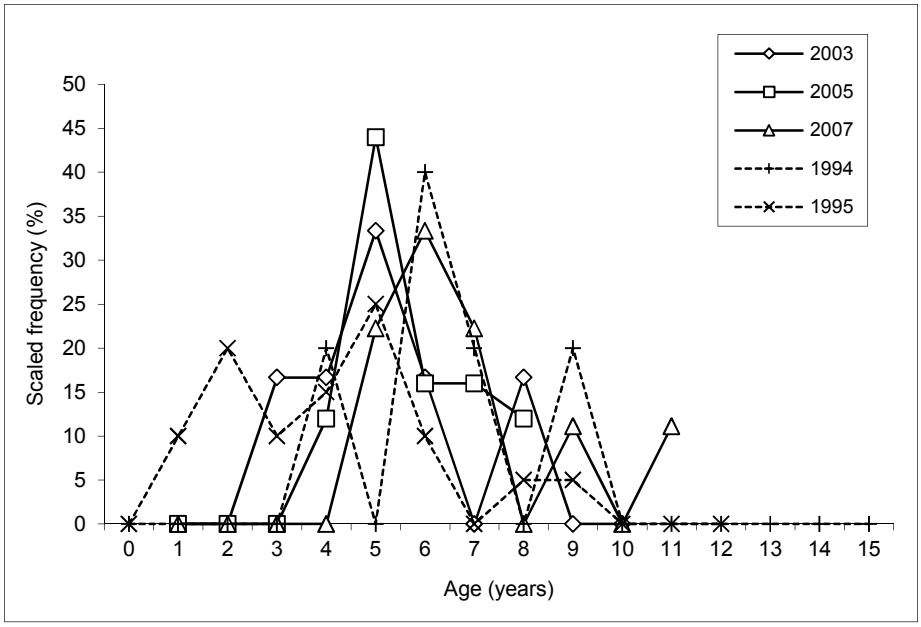

Figure 17: Catch composition for west coast offshore strata with depths 100–200 m (strata 2, 6, 8, 12 and 15) from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007.

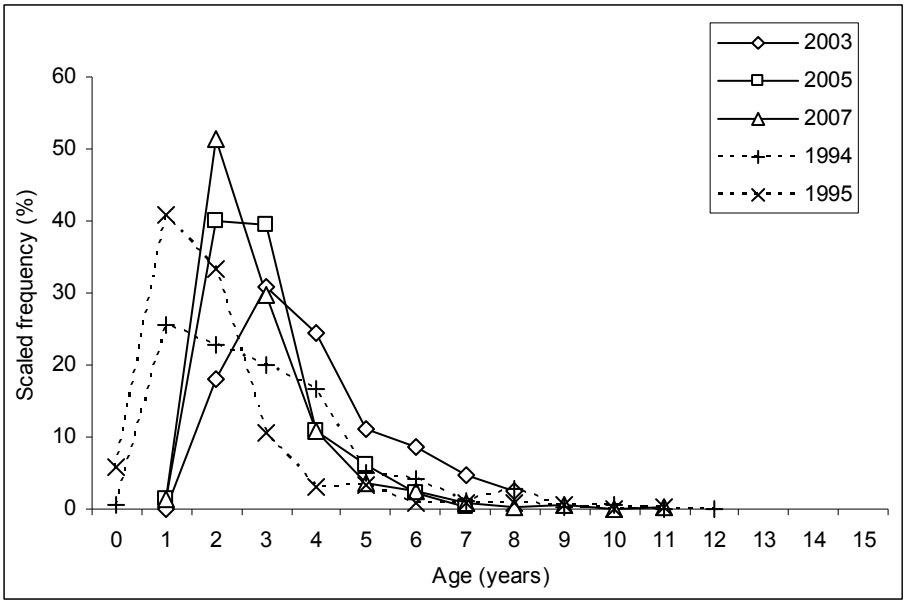

Figure 18: Catch composition from Tasman and Golden Bays (strata 17, 18, 19) from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007.

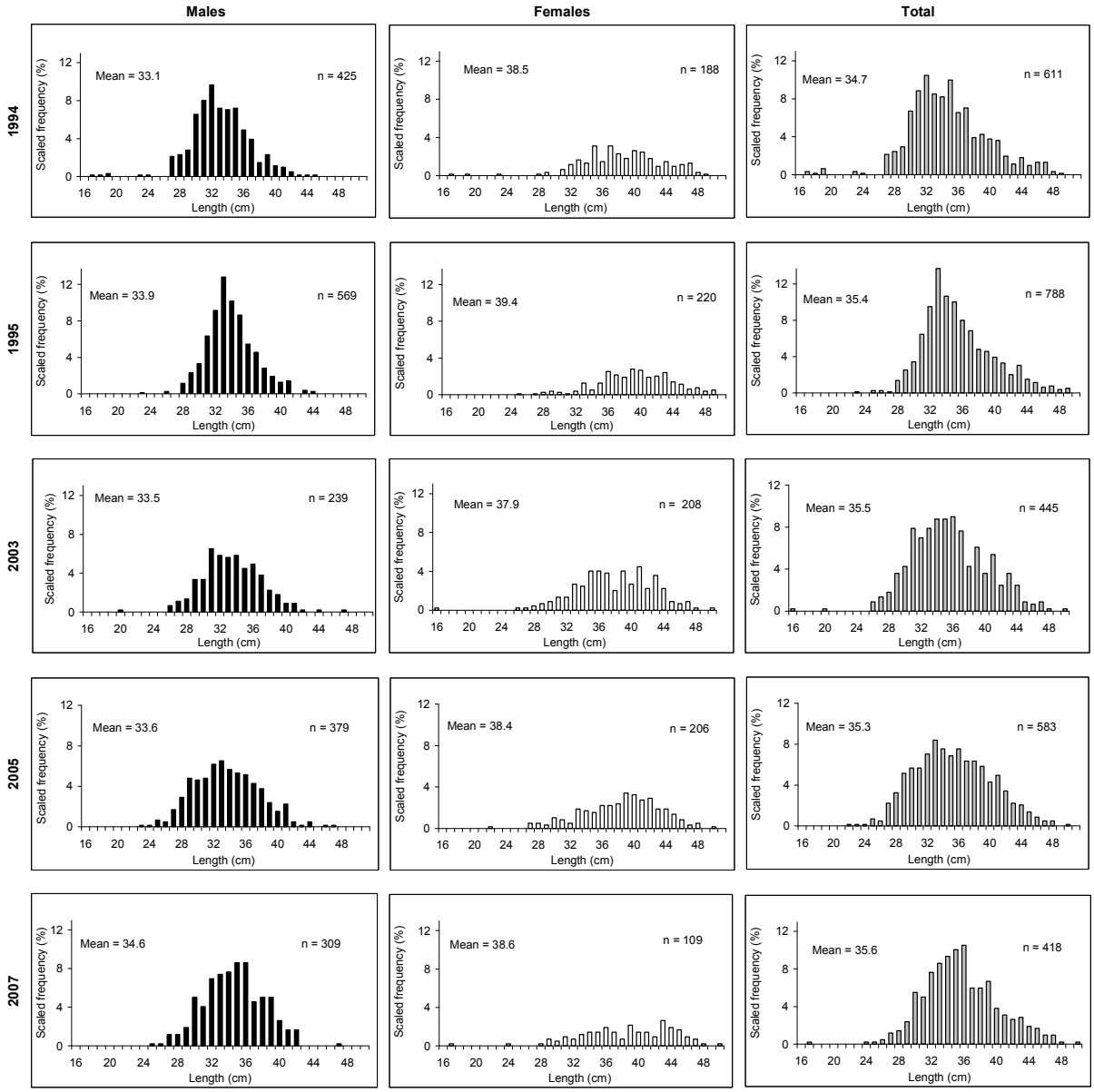

Figure 19: West coast (strata 1–14) red gurnard scaled length distributions from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007, male (black), female (white), total (grey).

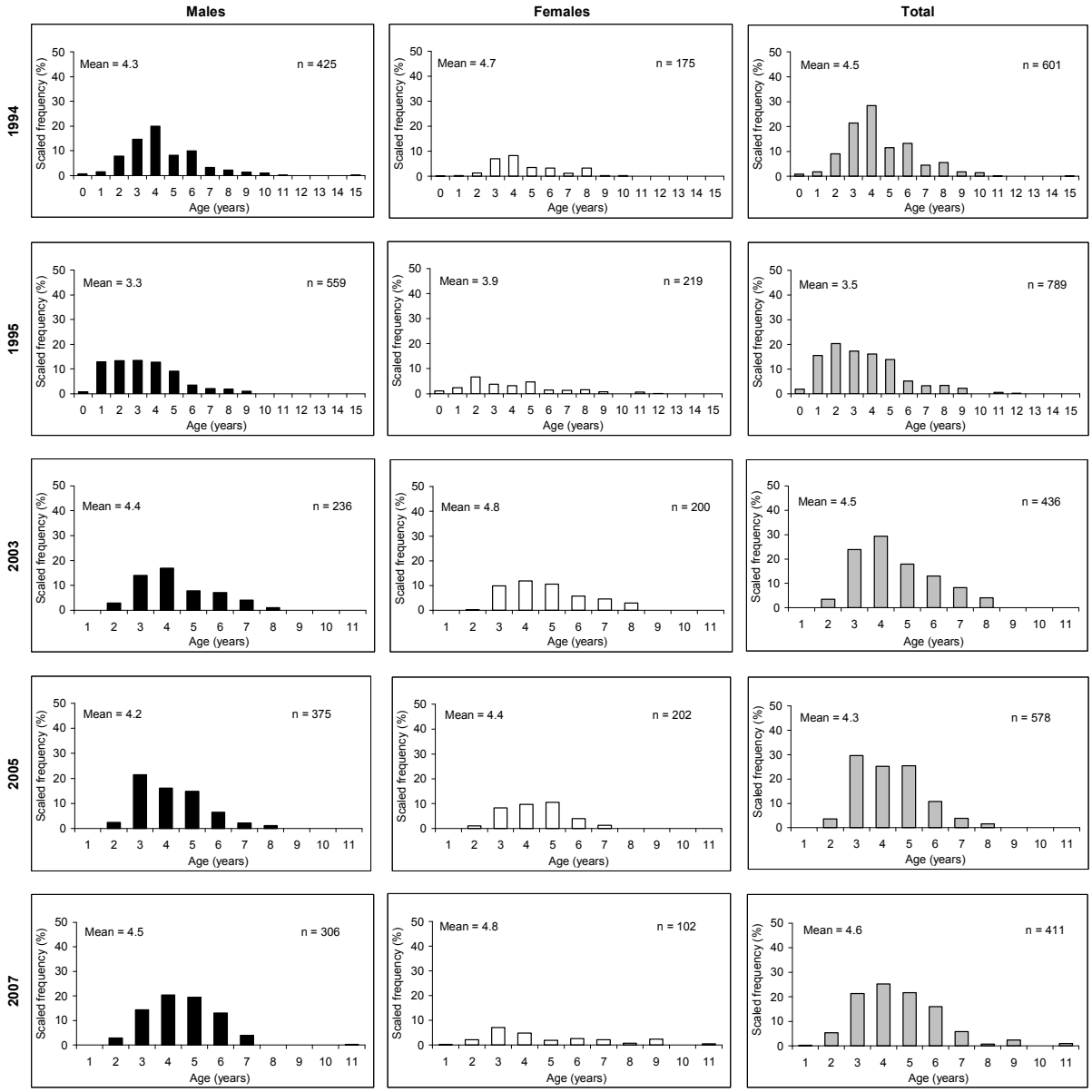

Figure 20: West coast (strata 1–14) red gurnard scaled age distributions from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007, male (black), female (white), total (grey).

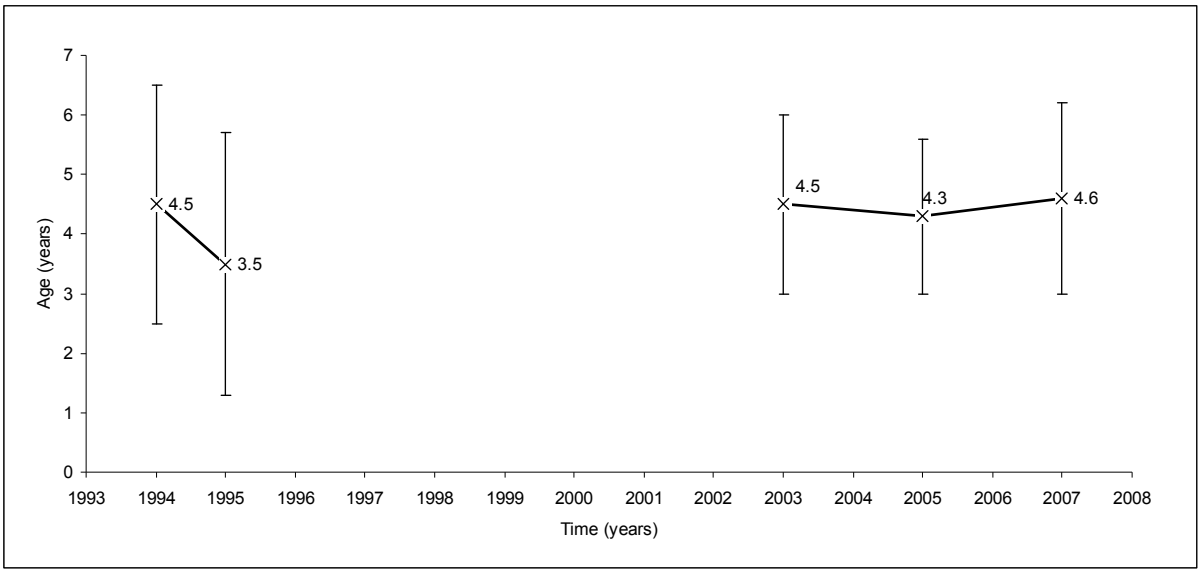

Figure 21: West coast (strata 1–14) red gurnard scaled mean ages, ± 1 standard deviation, from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007.

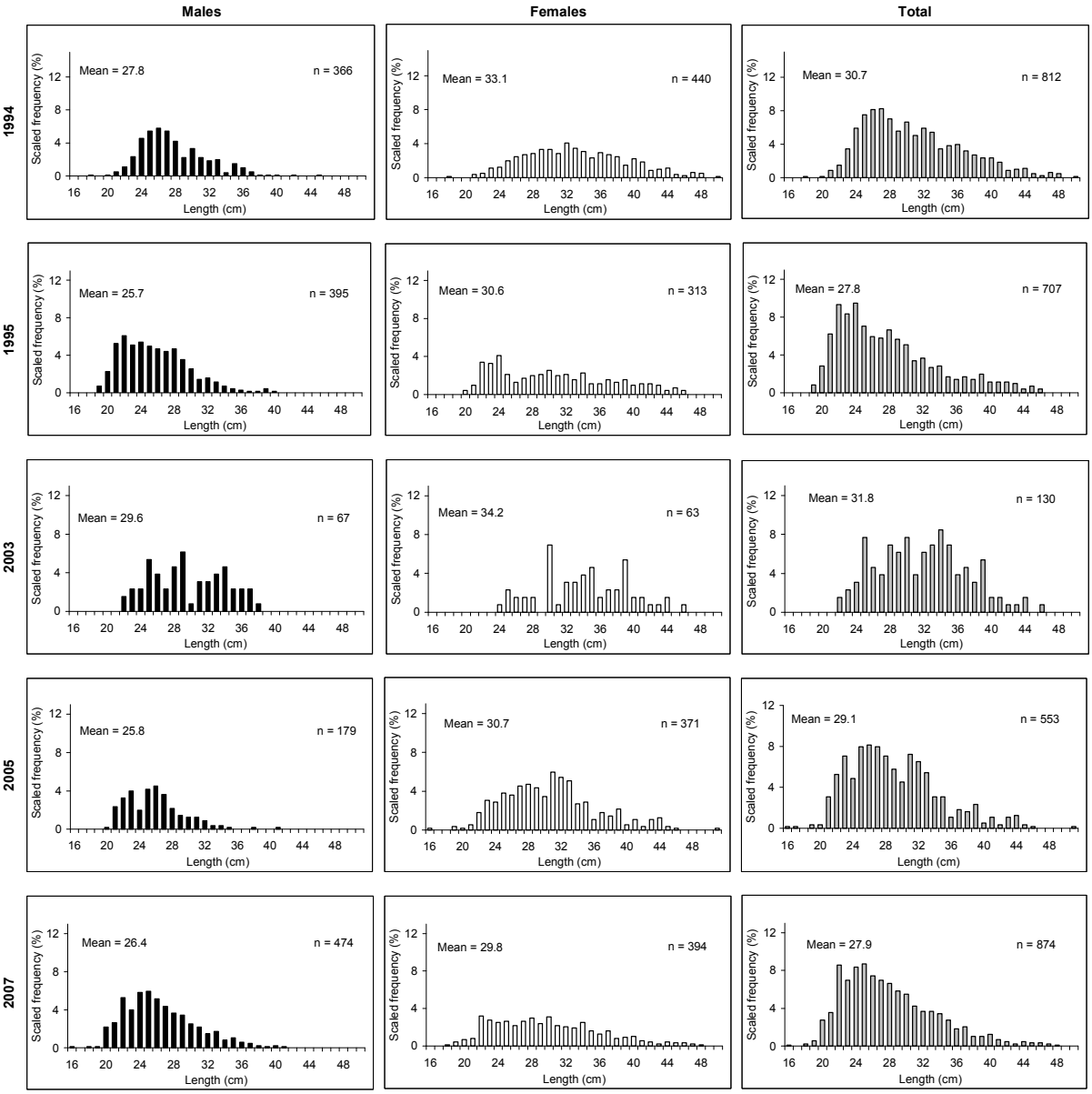

Figure 22: Tasman and Golden Bays (strata 17–19) red gurnard scaled length distributions from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007, male (black), female (white), total (grey).

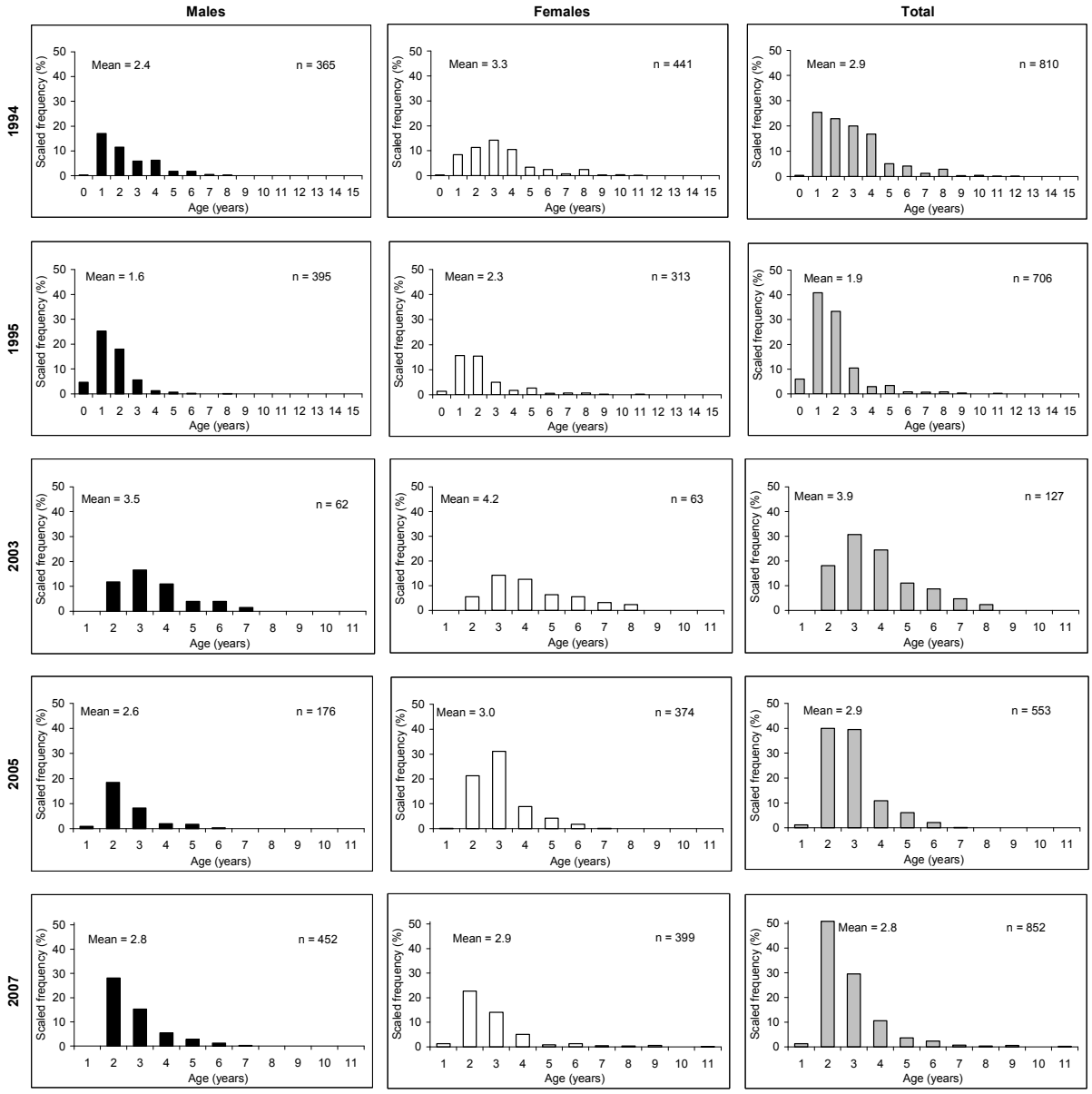

Figure 23: Tasman and Golden Bays (strata 17–19) red gurnard scaled age distributions from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007, male (black), female (white), total (grey).

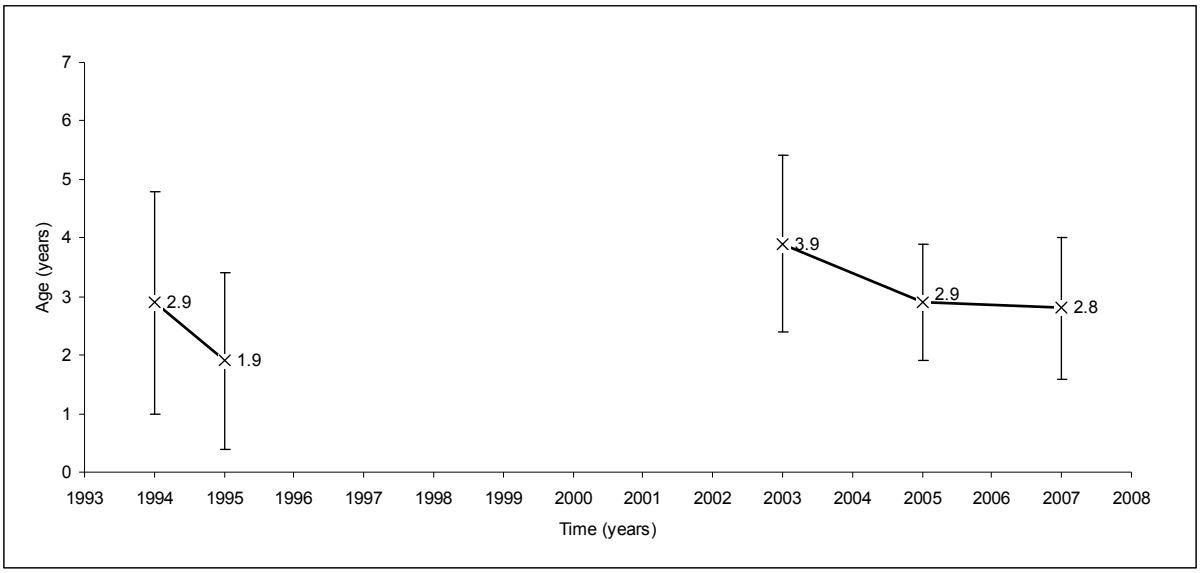

Figure 24: Tasman and Golden Bays (strata 17–19) red gurnard scaled mean ages, ± 1 standard deviation, from WCSI trawl surveys in 1994, 1995, 2003, 2005 and 2007.