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Growth parameters and estimates of mortality for red gurnard (*Chelidonichthys kumu*) from the east and west coasts of the South Island

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1. EXECUTIVE SUMMARY

Red gurnard are aged by counting zones in sectioned otoliths, a technique that has been validated. Von Bertalanffy growth parameters are estimated for red gurnard sampled from the east and west coasts of the South Island. Fish growth is rapid for about the first 5 years, and is negligible after about 8 years. Females have a significantly faster growth rate and reach a greater maximum length than males. Differences in population age distributions between the east and west coasts of the South Island suggest that there may be separate stocks in these two areas. A substantial variation in year class strength is indicated, particularly for fish from the east coast. A value for M of 0.30 is proposed.

2. INTRODUCTION

The genus *Chelidonichthys* (Teleostei: Triglidae) is represented in New Zealand waters by five species, and red gurnard, *Chelidonichthys kumu* (Lesson & Garnot 1826) is the most common. The species also occurs around southern Australia, South Africa, and Japan.

Red gurnard are widely distributed in coastal waters around New Zealand, except for southern Fiordland, and occur over muddy or sandy substrates to a depth of about 180 m (Baird 1994). Most of the commercial catch is taken in less than 55 m.

Reported annual landings of red gurnard have fluctuated between 2403 t and 3966 t since 1983–84 (Annala & Sullivan 1996). Much of the catch is a bycatch of trawl fisheries targeting snapper and tarakihi around the North Island, and red cod and flatfish around the South Island. Minor target fisheries exist for red gurnard off Mahia Peninsula, in Pegasus Bay, and off the west coast of the South Island. Longlining and set-netting account for a small amount of the total red gurnard catch.

Yunokawa (1961) studied the age and growth of *Chelidonichthys kumu* occurring in Japanese waters. However, there is some uncertainty as to the taxonomic status of the species examined in this work, and Ochiai & Okada (1966) believe it is more likely to be *Chelidonichthys spinosus.*

Staples (1967, 1971, 1972) studied age determination and growth based on samples from Pegasus Bay. He presented a validated ageing methodology and von Bertalanffy growth parameters for both sexes combined, and found no difference between male and female growth rates. This conclusion was based on a comparison of mean lengths at each age for a sample of

106 females and 32 males from five age classes; two of the male age classes were represented by only one fish each (Staples 1967).

Elder (1976) examined the growth rate and age structure of fish sampled from four sites in the Hauraki Gulf, and provided a validated methodology for ageing the species, along with von Bertalanffy growth parameters for each location. In contrast to Staple's work, Elder found significant differences in the growth rates of male and female fish, with females reaching a greater length than males. He also concluded that red gurnard from the Hauraki Gulf have a slower growth rate and a smaller L_∞ than those from Pegasus Bay.

Accurate ageing of individual members of a fish stock is fundamental to yield estimation. The present study aimed to develop growth parameters for east coast South Island (ECSI) red gurnard that were more reliable than previous estimates. Growth parameters for fish from the west coast of the South Island (WCSI) are presented for the first time. Age-frequency distributions were calculated and instantaneous natural mortality rates were estimated.

3. METHODS

3.1 Otolith collection, preparation, and reading

Red gurnard otoliths (sagittae) and length-frequency data were collected during trawl surveys conducted by R.V. *Kaharoa* off ECSI during May–June 1992, 1993, and 1994, and off WCSI during March–April 1994 and 1995. Total length (TL, measured to the nearest whole centimetre below actual length) and sex were recorded for all fish from which otoliths were extracted. Otoliths were cleaned and stored dry in paper envelopes.

In preparation for reading, otoliths were baked in an oven until amber-coloured (275 °C for about 4 min), embedded in clear epoxy resin (Araldite K142), and cut transversely through the nuclear region with a revolving diamond-edged saw. The cut surface of the resin block was sanded with P1200 carborundum and coated in paraffin oil. Otoliths were then examined under a binocular microscope (x30) illuminated by reflected light at an incident angle of about 30°. A pattern of hyaline (dark) and opaque (light) brown zones was evident. The number of complete hyaline zones (i.e., hyaline zones with opaque material outside them) was counted. Fish length and sex were unknown to the otolith reader. All otoliths collected from the three ECSI (n = 316) and two WCSI (n = 703) surveys were aged.

Determining the age of red gurnard was straightforward because the zonation pattern in the otoliths was easily discerned. The pattern of hyaline and opaque zones was best observed adjacent to the longitudinal sulcus, i.e., along the lateral radius of the otolith. Split zones were sometimes evident, but they were usually easily identified because of the regularly decreasing distances between true annuli with increasing age. Zones on both sides of the prepared section were examined, and a count from the clearest side was recorded.

Despite the relative ease of obtaining age estimates for red gurnard, counting growth rings in otoliths is subjective; a worker reading the same otoliths twice will not always obtain the same results for all fish aged. To assess the "within-reader" variability of the results, 133 otoliths representing a range of ages and both sexes were read twice. First and second readings were made 3 months apart.

3.2 Validation

To convert otolith zone counts to age estimates, it is necessary to determine how frequently hyaline and opaque bands are deposited. Staples (1971) calculated marginal growth increments of red gurnard sampled from Pegasus Bay by measuring the distance between the outer margin and the ultimate ring and the distance between the ultimate and penultimate rings. The proportion of the outer zone width to the inner was then calculated as a decimal fraction. This method illustrated a gradual increase in the width of the outer opaque zone as the year progressed. Staples considered this to be sufficient evidence that red gurnard lay down one hyaline zone annually. Elder (1976) has also shown that red gurnard sampled from two sites in the Hauraki Gulf deposit a single hyaline zone each year. His work involved examining the marginal state of fish sampled monthly (except February 1970) over a 16 month period. This study suggested that usually the hyaline zone was laid down during late winter or spring and became visible close to the edge of the otolith during December, when opaque material was deposited outside it. These findings were quantified using the method described by Staples (1971).

It was considered that the validation work by Staples (1971) and Elder (1976) was sufficient to validate the annual deposition of rings in red gurnard otoliths.

3.3 Growth parameters

To convert zone counts in otoliths to estimates of age it is necessary to know:

(i) when spawning occurs;

(ii) when the formation of the hyaline zone in the otolith is completed;

(iii) when sampling was conducted.

Red gurnard have a long spawning period which extends through spring and summer with a peak in early summer (Annala & Sullivan 1996), so it was appropriate to select a "birthday" of 1 January for all the fish examined in this study. Elder (1976) concluded that the hyaline zone in the otoliths appears to be complete by December, and hence fish are about 11 months old on the completion of the first hyaline zone.

All sampling was conducted between May and June on ECSI and between March and April on WCSI. Sampling dates of 1 June and 1 April were used for these two areas, respectively.

The information on time of spawning, time of zone formation, and sampling time can then be used to obtain an appropriate age from otolith zone counts. For example, an otolith sampled on 1 April, with opaque material outside one complete hyaline zone would be allocated an age of 1 year and 3 months (1.25 years). This is because the time elapsed between completion of the hyaline zone (1 December) and time of sampling (4 months) is added to the time elapsed between spawning (1 January) and formation of the dark zone (11 months).

Von Bertalanffy growth curves were fitted to the age-length data using a non-linear least-squares regression procedure (Ralston & Jennrich 1978). Separate equations were derived for each area and sex. Mean lengths at age were calculated for fish from both areas.

Length-frequency histograms from research trawl surveys often show clear modes in young fish, suggesting distinct year classes. Plotting the histograms chronologically and examining the progression of modes over time provides an independent check on the growth curve calculated for young fish from counts of zones in otoliths.

The age distribution of red gurnard in each of the five *Kaharoa* surveys was constructed from the length-frequency distribution (scaled to represent the whole population in the survey area) and the otoliths read, from:

$$A_t = \sum_{x=1}^{n} L_x \, p_{tx}$$

where

$A_t =$ estimated proportion of fish of age class t in the survey area
$L_x =$ proportion of fish of length x in the length frequency distribution
$p_{tx} =$ proportion of aged fish of length x which were age t
$n =$ number of length classes in the length-frequency

The length strata, x, were grouped in 3 cm intervals (i.e., 18–20 cm, 21–23 cm,) up to 50 cm for both males and females. All remaining fish were grouped into a single length stratum (i.e., 51+ cm). Intervals of 3 cm were selected because it is likely that the limited age data available, particularly for some of the smaller and larger length classes, may have caused atypical age-at-length data to be overemphasised in the analysis.

Estimates of instantaneous natural mortality (M) were calculated for male and female fish from both sample areas. M was derived from the equation:

$$M = \frac{\ln(100)}{A_{max}}$$

where

$A_{max} =$ maximum age reached by 1% of an unfished population (Sparre *et al.* 1989).

4. RESULTS

4.1 Age replication

The results of the within-reader comparison show that of the 133 otoliths examined 123 were aged identically, and all but 2 of the remaining 10 differed by only 1 year (Table 1). Ageing error appeared to be negligible over the entire age range.

Table 1: Within-reader comparison of 133 otoliths. Age: represents age at first reading; Difference (Diff): represents the extent by which the second reading differed from the first; Agree: shows the percentage of fish by age for which both readings were the same

	Age									
Diff	1	2	3	4	5	6	7	11	12	Total
2+				1				1		2
1+	1	2	3		1				1	8
0	10	64	17	5	13	11	2	1		123
Agree (%)	91	97	85	83	93	100	100	50	0	133

4.2 Growth parameters

Data from all examined otoliths were used to calculate von Bertalanffy growth curve parameters (with asymptotic 95% confidence intervals for the estimates) for fish from the east and west coasts of the South Island (Table 2). The raw data, mean lengths–at–age, and calculated von Bertalanffy curves are plotted in Figure 1.

Table 2: Von Bertalanffy growth parameters (with 95% confidence intervals) for red gurnard sampled from the east and west coasts of the South Island

	East coast		West coast	
	male	female	male	female
L_∞	42.2	48.2	40.3	45.7
	(41.2–43.2)	(46.3–50.1)	(39.0–41.7)	(44.5–46.8)
k	0.49	0.44	0.37	0.40
	(0.39–0.58)	(0.35–0.53)	(0.30–0.44)	(0.35–0.46)
t_0	–0.44	–0.17	–1.12	–0.51
	(–0.86 to –0.01)	(–0.50 to 0.17)	(–1.52 to –0.71)	(–0.76 to –0.25)
Age range	1–16	1–13	1–15	1–15
n	157	159	302	401

Von Bertalanffy growth parameters and the age ranges obtained by Staples (1972) and Elder (1976) are given in Table 3.

Table 3. Growth parameters from Staples (1972) and Elder (1976).

	Elder (1976)		Staples (1972)
	male	female	both sexes
L_∞	28.8	36.4	52.0
k	0.57	0.64	0.41
t_0	0.55	–0.64	0.29
Age range	1 –10+	1 –10+	1 – 10
n	2 513	5 607	138

Male red gurnard sampled from ECSI and WCSI reached a maximum age of 16 years and 15 years, respectively, but only about 3% of fish were older than 10 years. Females were aged to a maximum of 13 years on the east coast and 15 years on the west coast. However, less than 2% were older than 10 years.

Female red gurnard had significantly greater L_∞ values than males in both areas. Both male and female fish from the east coast grew consistently larger and faster than west coast fish, but the difference in L_∞ and k between the two areas was not significant at the 95% level of confidence.

Mean lengths at age (with standard deviation and sample size) for all fish aged are presented in Table 4. These data fit the calculated von Bertalanffy curves in Figure 1 well. For the west and east coasts the lengths at age are virtually identical for both sexes up to age 2. Female red gurnard grow consistently faster and reach a greater size than males after this initial growth period.

4.3 Length-frequency modal progression

Length-frequency histograms for red gurnard caught during *Kaharoa* trawl surveys off the east and west coasts of the South Island are presented in Figures 2 and 3, respectively. The data have been scaled by size of catch and area trawled to represent the total population of red gurnard in the survey area. In the ECSI samples it is possible to follow the progression of the 1991 year class clearly from the 1992 to the 1993 histogram, but less confidently to the 1994 histogram. These data indicate that red gurnard grow to about 24 cm after 1.42 years, to 32 cm a year later, and to 39 cm at age 3.42 years. For the WCSI samples, only the progression of the 1993 male year class is apparent.

4.4 Age-frequency distribution

Scaled age-frequency histograms are presented for red gurnard off the east (Figure 4) and west (Figure 5) coasts of the South Island. There was a strong 1+ year class on the east coast in 1992 for both female and male fish which progressed as strong 2+ and 3+ cohorts in 1993 and 1994, respectively (Figure 4). The 2+ year class was also well represented for both female and male fish sampled in 1994, but this was not preceded by a high proportion of 1+ fish in 1993. These small fish may not be adequately sampled by the trawl in some years. A weak 4+ year class in 1992 appears to be stronger as 5+ and 6+ cohorts in 1993 and 1994, respectively. This may be due to the small sample sizes available for this study.

WCSI male red gurnard display consistent 1+ to 4+ cohorts in 1994 and a similar distribution is evident for 1+ to 5+ fish in 1995 (Figure 5), but it is not clear whether this pattern represents average or strong year class strengths. No clear patterns are apparent in the female data.

Table 4. Mean lengths at age (cm, with standard deviation, S.D., and sample size, *n*) for fish sampled during May–June and March–April from the east and west coasts of the South Island, respectively. Fish at these times are about x + 0.42 years old on the east coast and x + 0.25 years old on the west coast, where x is the age class.

	East coast						West coast					
	Male			Female			Male			Female		
Age class	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N	Mean	S.D.	N
0+	–	–	0	–	–	0	–	–	0	–	–	0
1+	24.31	2.10	13	24.35	3.23	20	23.39	2.46	64	23.02	2.74	60
2+	32.30	2.02	44	32.78	3.22	49	28.35	1.49	49	31.31	2.90	64
3+	35.18	3.11	22	37.90	3.23	30	32.41	2.91	39	34.71	3.29	59
4+	39.00	3.21	8	42.31	2.66	13	34.76	3.38	49	39.10	3.96	59
5+	39.33	1.88	21	44.77	2.58	22	36.77	4.51	31	41.60	4.44	50
6+	40.32	2.40	22	45.20	3.47	15	37.45	2.97	29	42.45	3.79	29
7+	39.71	3.35	7	42.00	-	1	36.22	1.56	9	44.96	2.82	23
8+	42.67	0.58	3	48.00	1.41	2	39.29	2.89	14	42.62	3.54	29
9+	43.50	2.12	2	47.40	4.34	5	40.00	3.13	10	45.77	2.62	13
10+	42.40	3.05	5	–	–	0	38.33	1.53	3	47.00	4.75	8
11+	39.67	1.53	3	52.00	–	1	37.00	–	1	43.33	6.43	3
12+	44.50	–	1	43.00	–	1	44.00	1.41	2	44.50	3.54	2
13+	44.67	0.58	4	–	–	0	42.00	–	1	45.00	–	1
14+	–	–	0	–	–	0	–	–	0	–	–	0
15+	–	–	0	–	–	0	40.00	–	1	46.00	–	1
16+	45.00	1.41	2	–	–	0	–	–	0	–	–	0

4.5 Instantaneous natural mortality rates

The ECSI samples aged suggest an A_{max} of about 16 years for male and 13 years for female red gurnard, giving estimates for M of 0.29 and 0.35, respectively. WCSI samples indicate an A_{max} of about 15 years for both sexes, giving an estimate for M of 0.31. These samples were not from virgin populations, so M may be slightly overestimated. It is likely that M is in the range 0.25–0.35, and 0.30 is probably a satisfactory estimate at this stage.

5. DISCUSSION

Red gurnard is a relatively easy species to age, although few studies have been conducted on its age and growth in New Zealand waters. Staples (1967, 1971, 1972) and Elder (1976) aged fish from Pegasus Bay and Hauraki Gulf, respectively. Both studies indicated that growth rate is initially rapid but slows dramatically after the first 5 years, and is negligible after about 8 years. It was also shown that maximum age was about 15 years. These findings are consistent with those outlined in this paper.

Staples (1972) growth rate of red gurnard sampled from Pegasus Bay yielded an L_{∞} value of 52.0, which is considerably higher than the values obtained in the present study. Staples's growth equations were pooled for both male and female fish and were based on a relatively small sample which may have biased the result. Staples's sample also contained a disproportionate number of large female fish and this may have artificially increased L_{∞}.

The current work and that of Elder (1976) show that female red gurnard are larger than males at corresponding ages and have a significantly greater L_{∞}, and that east coast fish grew faster and reached a greater size than west coast fish. Consistent differences in growth rates and population age distributions between red gurnard from the ECSI and WCSI suggest that these two areas may contain discrete stocks, but it was not possible to confirm this solely from the age and growth data.

Growth parameters and age structure distributions of WCSI fish are given for the first time. Red gurnard from ECSI and WCSI have similar growth rates, but both grow significantly faster and larger than the fish sampled from the Hauraki Gulf by Elder (1976). It is possible that an increase in water temperature inversely affects red gurnard growth rate. This hypothesis is presented by Beverton & Holt (1959) who noted: "Differences in environmental temperature... affect both k and L_{∞}; thus with an increase in water temperature k increases roughly proportionally with the logarithm of temperature and L_{∞} decreases, but to a lesser extent ..."

Differences in k and L_{∞} between South Island and Hauraki Gulf red gurnard are large, and it is possible that other factors, such as genetic variability, may be involved (M. P. Francis, NIWA, pers. comm.).

The scaled length-frequency distribution and scaled age-frequency histograms for ECSI fish showed a consistent annual progression of length modes and year classes, respectively. Male red gurnard from off the WCSI also showed a progression of length modes but this trend was not reflected in the scaled age-frequency distribution. The absence of a clear trend for female fish may be due to the fact that only 2 years of data were available. It was evident from the von Bertalanffy growth curves that there is a wide variation in length at a particular age, especially for young fish. This could be attributed to the extended spawning season (Annala & Sullivan 1996) and individual variation in growth rates.

6. ACKNOWLEDGMENTS

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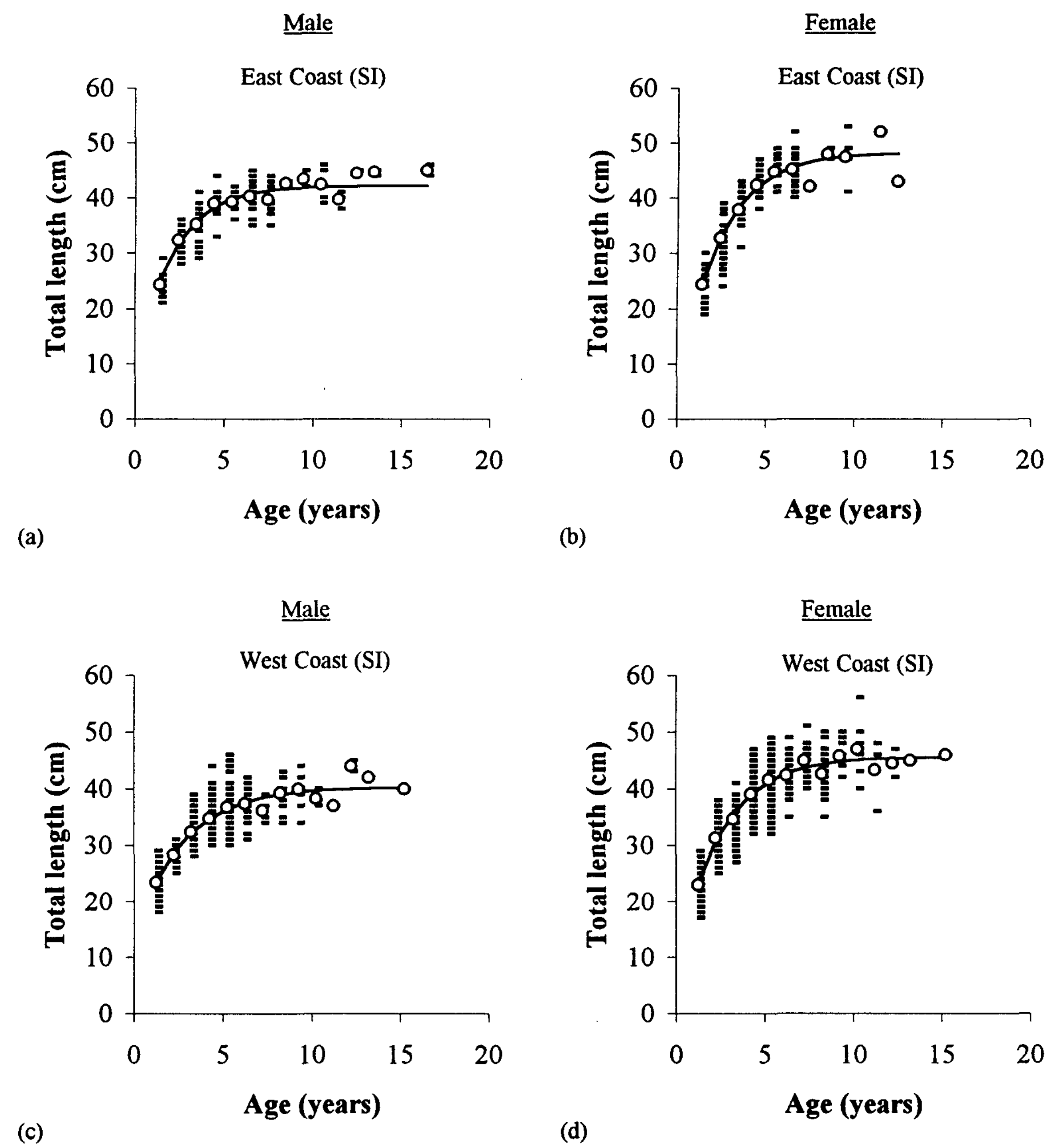

Figure 1(a-d). Age-length data, calculated mean lengths-at-age (o), and von Bertalanffy growth curves for male and female red gurnard sampled from the east and west coasts of the South Island.

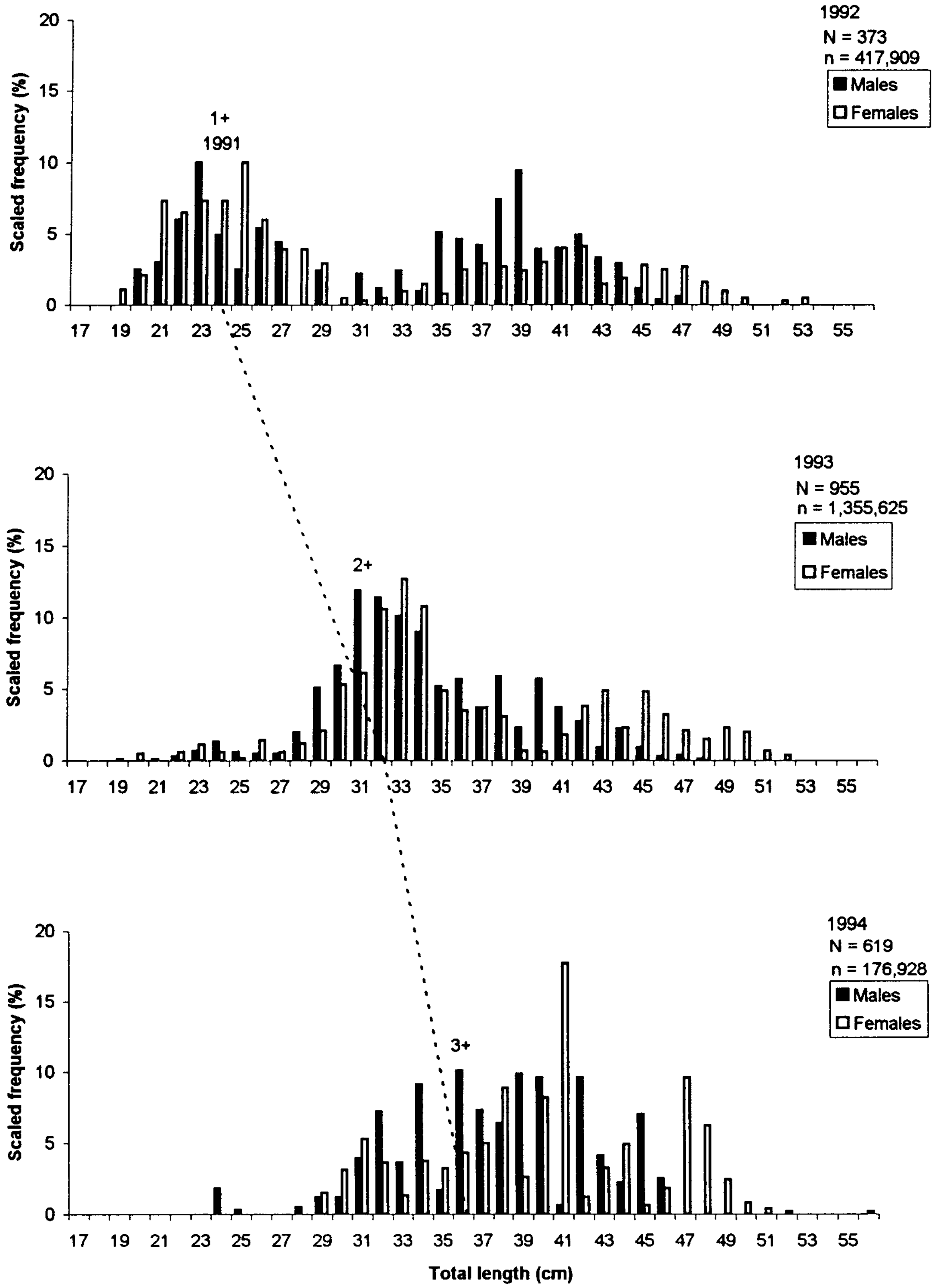

Figure 2. Scaled length-frequency histograms for red gurnard surveyed from the east coast of the South Island in May-June 1992-94. N, sample size of measured fish; n, estimated number of red gurnard in the survey area are provided above the legend. Length-frequency peaks are labelled with year of spawning and age class.

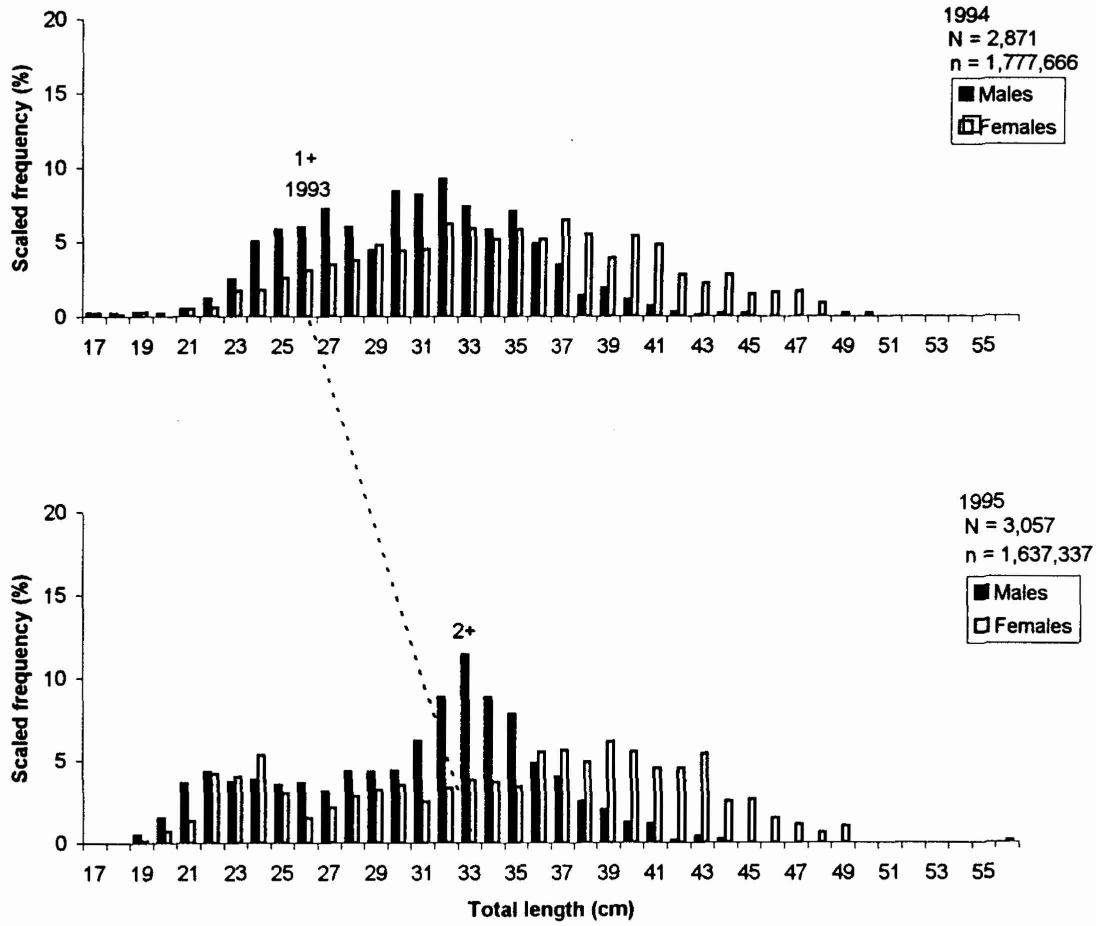

Figure 3. Scaled length-frequency histograms for red gurnard surveyed from the west coast of the South Island in March-April 1994-95. N, sample size of measured fish; n, estimated number of red gurnard in the survey area are provided above the legend. Length-frequency peaks are labelled with year of spawning and age class.

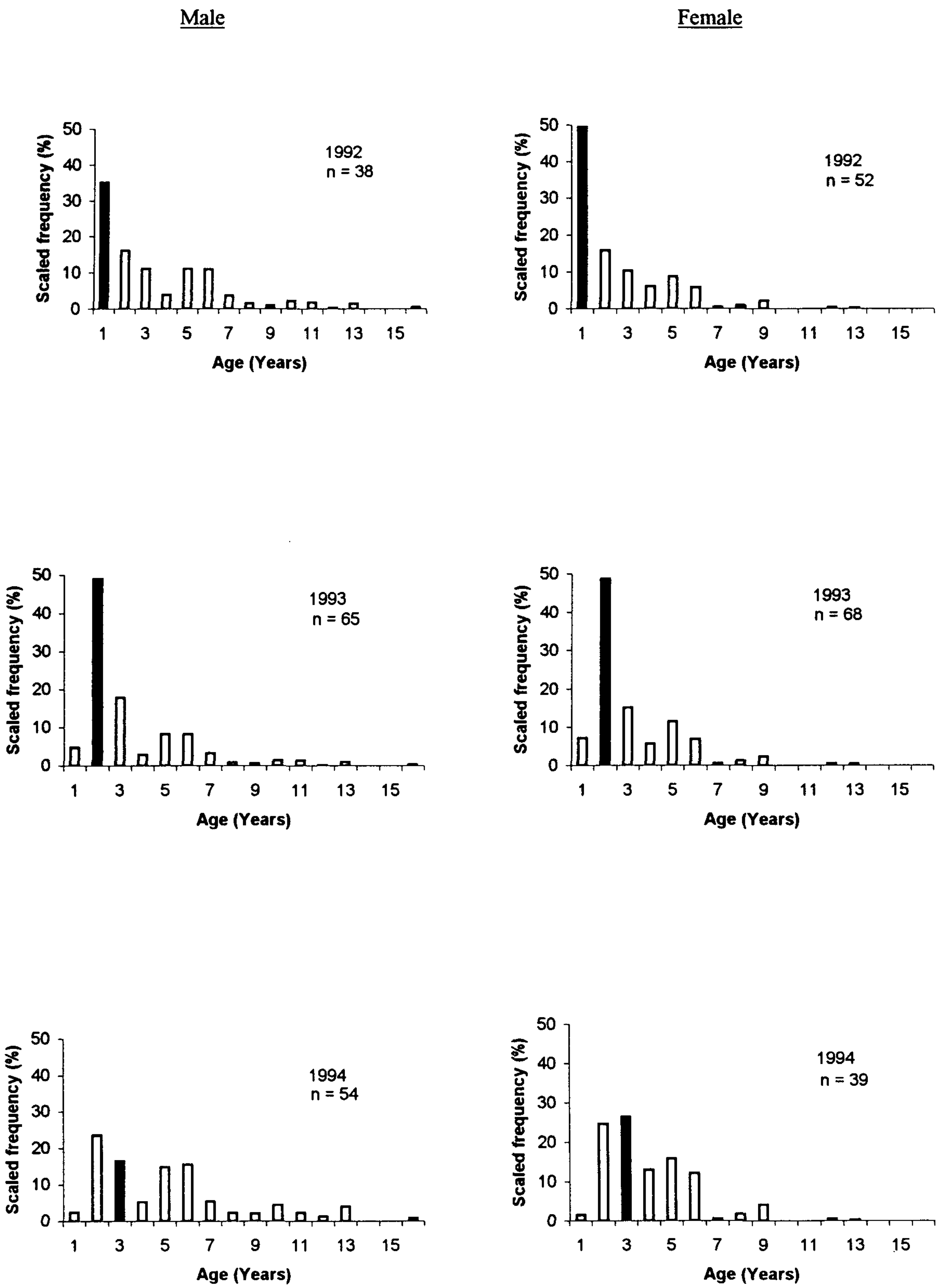

Figure 4. Scaled age-frequency histograms of male and female red gurnard sampled from the east coast of the South Island in May-June 1992-94. Year and number of otoliths read (n) are shown on the histograms. The black bars illustrate the progression of a strong year class.

Male | Female

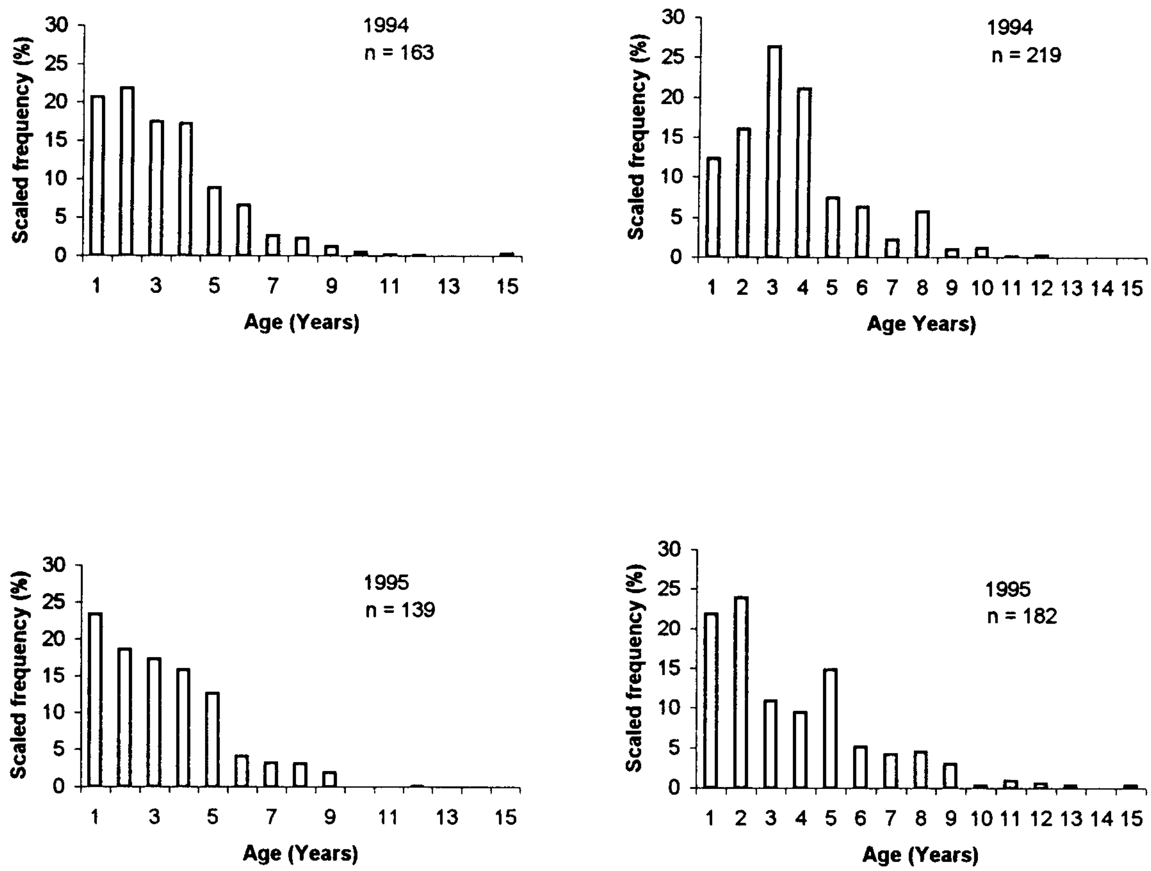

Figure 5. Scaled age-frequency histograms of male and female red gurnard sampled from the west coast of the South Island in March-April 1994-95. Year and number of otoliths read (n) are shown on the histograms.