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The length and age composition of the commercial catch of blue mackerel (*Scomber australasicus*) in EMA 1 during the 2006–07 fishing year

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Commercial purse seine catches of blue mackerel in EMA 1 were sampled during the 2005–06 fishing year by personnel from NIWA and associated fishing companies as part of the MFish funded research project EMA2007-01 “Stock monitoring of blue mackerel”.

The target purse-seine fishery in EMA 1 is estimated to have accounted for over 99.9% of the total catch in EMA 1 during the 2006–07 fishing year. Thirty-three landings were sampled in fish processing factories, 27 317 fish length observations collected, and 397 sagittal otolith pairs were prepared and read from the EMA 1 fishery during the 2006–07 fishing year. The data collected from the EMA 1 fishery are thought to be representative of the fishery.

Estimated numbers-at-length and numbers-at-age were calculated using all available groomed length and length-at-age data separately by sex, and scaled to estimates of the total catch from each of the fisheries. Bootstrapped coefficients of variation (CVs) and mean-weighted (MW) CVs were computed for each length and age class, and overall for each length- and age-frequency distribution. Although the maximum of the age range here appears similar to that in 2005–06, the minima have increased by two years and older fish have appeared in the fishery relative to 2005–06.

The EMA 1 fishery appears to be composed of fish 2–18 years, although most fish present in the catch are 4–15 years of age. The MWCVs for each sex and all fish in the EMA 1 length analysis were within the 30% target. The MWCVs for the age compositions were 30.6% for males, 31.7% for females, and 23.4% for sexes combined.

An investigation of proportions-at-length and proportions-at-age indicates a lack of coherence in some of the results that make interpretation difficult. The plots of proportions-at-age by year and year class show no reliable patterns, suggesting an unstable population, probably due to the highly mobile nature of the species. An abrupt change in the peak of the proportion-at-length plot between November and December of 2006 may be the result of a number of factors including a change in targeting or the appearance of an additional sub-population in the fishery. In summary, the results are highly variable, to such an extent that it is unlikely that length- and age-based methods can reliably monitor what is probably a small and varying portion of a single stock.

1. INTRODUCTION

Blue mackerel (*Scomber australasicus*) is a small- to medium-sized schooling teleost inhabiting epi- and mesopelagic waters throughout the Indo-Pacific, including the northern half of the New Zealand Exclusive Economic Zone (EEZ). It was introduced into the New Zealand Quota Management System (QMS) at the start of the 2002–03 fishing year and is managed as five separate Quota Management Areas (QMAs) or fishstocks: EMA 1–3, 7, and 10 (Figure 1).

The commercial catch is caught by a variety of methods in all QMAs, but most is caught north of latitude 43 °S (Morrison et al. 2001). The largest and most consistent catches across fishing years are by purse-seine vessels targeting blue mackerel schools in EMA 1–3 and 7. Catches by midwater trawl vessels targeting jack mackerels (*Trachurus* spp.) in EMA 7 are also important. Nevertheless, the target purse-seine catch in EMA 1 is the single largest component of the catch by any method in any QMA (Morrison et al. 2001). Total catches by QMA and fishing year are given in Table 1.

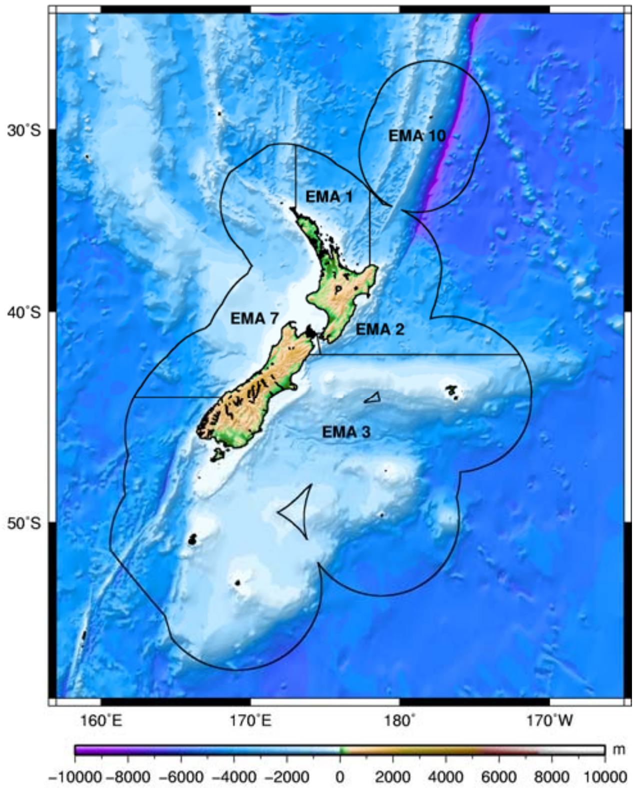

Figure 1: Map of the New Zealand EEZ showing the boundaries of blue mackerel QMAs and bathymetry of the New Zealand region.

Table 1: Blue mackerel total reported landed catch by fishing year and QMA (adapted from Ministry of Fisheries 2006). Landings reported from EMA 10 are probably attributable to misreporting of catches made in Statistical Area 010 in the Bay of Plenty (i.e., EMA 1). Unsp., QMA not specified. *, FSU data; †, CELR data; ‡, QMS data.

Fishing year	EMA 1	EMA 2	EMA 3	EMA 7	EMA 10	Unsp.	Total
1983–84*	480	259	43	245	–	1	1 028
1984–85*	565	222	18	865	–	73	1 743
1985–86*	618	30	189	408	–	51	1 296
1986–87†	1 431	7	423	489	–	49	2 399
1987–88†	2 641	168	863	1 895	–	58	5 625
1988–89†	1 580	< 1	1 141	1 021	–	469	4 211
1989–90†	2 158	76	518	1 492	–	< 1	4 245
1990–91†	5 783	94	477	3 004	–	–	9 358
1991–92†	10 926	530	65	3 607	–	–	15 128
1992–93†	10 684	309	133	1 880	–	–	13 006
1993–94†	4 178	218	222	1 402	5	–	6 025
1994–95†	6 734	94	153	1 804	10	149	8 944
1995–96†	4 170	119	172	1 218	–	1	5 680
1996–97†	6 754	78	339	2 537	–	< 1	9 708
1997–98†	4 595	122	77	2 310	–	< 1	7 104
1998–99†	4 505	186	62	8 762	–	4	13 519
1999–00†	3 602	73	3	3 169	–	–	6 847
2000–01†	9 738	113	5	3 278	–	< 1	13 134
2001–02†	6 368	177	48	5 101	–	–	11 694
2002–03‡	7 609	115	88	3 562	–	–	11 375
2003–04‡	6 523	149	1	2 701	–	–	9 373
2004–05‡	7 920	8	< 1	4 817	–	–	12 746
2005–06‡	6 713	13	133	3 784	–	–	10 643
2006–07‡	7 815	133	42	2 698	–	–	10 688

The level of commercial catch in the New Zealand EEZ has varied greatly over time, both within and between fishing years. Catches are highly seasonal, with the target purse-seine fishery in EMA 1 operating between July and December (Morrison et al. 2001). Catches also vary between fishing years. Total annual reported landings increased rapidly from the 1989–90 to the 1991–92 fishing years and have fluctuated between about 6000–15 000 t since then. Reported landings peaked at 15 128 t during 1991–92, of which about 70% was caught by purse-seine vessels (Morrison et al. 2001).

It has been suggested that inter-annual variation in catches reflects variable market demand rather than changes in stock abundance (Morrison et al. 2001), but more recent work using aerial sightings data (Taylor 2014) has shown that the available biomass varies dramatically between years. Given that blue mackerel has been one of the higher valued species in the purse-seine fishery after skipjack, availability is likely to be a primary cause of annual catch variability.

This report presents length and age data collected from commercial catches of blue mackerel in EMA 1 during the 2006–07 fishing year; and was funded by the Ministry of Fisheries (MFish) research project EMA 2004–01, and carried out under a joint contract between NIWA and Sanford Ltd. The aim was to representatively sample the target purse-seine catch in EMA 1. The target mean-weighted coefficient of variation (CV) for catch-at-age in both fishstocks was 30%. The 2006–07 sampling results are compared with earlier results by Morrison et al. (2001), Manning et al (2006, 2007a, 2007b), and Devine et al (2009). A brief review of the EMA 1 fishery during the 2005–06 fishing year is provided. The representativeness of the data collected to the catch sectors sampled is reviewed. The required level of sampling to achieve the mean-weighted CV target in future fishing years is also discussed. This report fulfils the reporting requirements of project EMA2007–01.

1. To conduct representative sampling and determine the length, sex, and age composition of commercial catches of blue mackerel in EMA 1 during the 2007/08 fishing year. The target coefficient of variation (CV) for the catch at age will be 30% (mean weighted CV across all age classes).
2. To explore the times series of catch sampling data, in particular, for any significant changes in the length and age composition of commercial catches and any indications of change in stock status in EMA 1.

2. METHODS

2.1 Catch-effort and landings data

All fishing trips and associated fishing and landing events records where a landing of blue mackerel in EMA 1 was recorded between 1 October 1989 and 30 September 2007 (the 1989–90 to 2006–07 fishing years) were extracted from the Ministry of Fisheries catch-effort and landings database, *warehou* (Duckworth 2002).

2.2 Overview of the sampling programme design

Landings by purse-seine vessels targeting blue mackerel in EMA 1 during the 2005–06 fishing year were sampled in fish processing factories in Tauranga using a stratified sampling scheme. Landings were sampled from vessel holds during the unloading process similar to the 2004–05 fishing year (Manning et al. 2007a). Samples were collected from the vessel-hold strata in each landing using the following method: about 100 fish were randomly sampled from each hold at a rate of three samples per hold, one each at the top, middle, and bottom. Fish sex and length to the nearest centimetre below actual fork length were recorded. As in the 2002–03, 2003–04, 2004–05, and 2005–06 fishing years, sampling was carried out at the Sanford Ltd factory by Sanford Ltd and NIWA staff; and sampling at

Pelco NZ Ltd was carried out by NIWA staff. There was no formal spatial or temporal allocation of sampling effort (e.g., monthly targets based on average trends in the catch over a number of fishing years).

A stratified, fixed-allocation sampling scheme (Davies et al. 2003) was used to collect sagittal otolith pairs from the catches in all sampled landings. Up to 20 otolith pairs per sex per centimetre length-class were collected non-randomly from the fish in the random length-frequency samples. Fish were measured to the nearest centimetre below fork length and fish sex, and a five-point macroscopic gonad maturity score was recorded for each sampled fish (the "Stock Monitoring" (SM) scale described in Mackay 2001) from which a sagittal otolith pair was collected. Each otolith pair was cleaned and stored dry in individual 1.5 ml plastic Eppendorf centrifuge tubes immediately following collection.

All landings and length-frequency data were entered into MFish database *market* (Fisher & Mackay 2000). All otoliths were inventoried, the otoliths lodged in the MFish otolith collection, and the data entered into MFish database *age* (Mackay & George 2000).

2.3 Otolith preparation and analysis

2.3.1 Terminology

The terminology we use follows that suggested by Kalish et al. (1995). The terms “opaque” and “translucent” refer to winter slow-growth and summer fast-growth zones, respectively. A single year’s growth, an “annulus”, is composed of a single completed opaque zone followed by a single completed translucent zone.

2.3.2 Preparation and reading

Up to 15 otoliths per sex per centimetre length-class were randomly sampled from the set of all otoliths collected during the 2006–07 fishing year and prepared and read using the methods of Manning & Marriott. (2011). Up to five otoliths were embedded in rows in blocks of clear epoxy resin (Araldite K142) and left to cure at 50 °C overnight. After the resin blocks had cured, a 1 mm transverse section was cut from each block along the nuclear plane in each otolith, using a Struers Accutom-2 revolving diamond-edged saw. The sections were ground and polished on one side and mounted polished surface down on glass microscope slides using a quick-setting epoxy resin (“5-minute” Araldite). The upper surface of each slide was ground down on a Struers Planopol-2 grinder with progressively finer carborundum papers (400 and 800 grades) to a thickness of about 350 μm. The upper, ground surface of the section was then sealed using a commercial artist’s clear lacquer spray (Nuart Crystal Clear).

The otolith sections were read using a Leica MZ12 stereo dissecting microscope and transmitted light. Magnification of 63 times was used to observe zone patterns near the nucleus and magnification of 100 times was used to observe zone patterns near the margin in each otolith. The number of complete annuli present in each otolith was counted and recorded. A five-point “readability” score and a three-point “margin-state” score were also recorded (Table 2). All otoliths were read “blind” – fish length and sex were unknown to the reader prior to reading. All prepared otoliths were read at least once by one reader.

Table 2: Five-point otolith readability and three-point otolith margin-state scores used in all readings.

Readability

Readability	Description
1	Otolith very easy to read; excellent contrast between successive opaque and translucent zones; ± 0 or so between subsequent opaque-zone counts in this otoliths
2	Otolith easy to read; good contrast between successive opaque and translucent zones, but not as marked as in 1; ± 1 or so between subsequent opaque-zone counts in this otoliths
3	Otolith readable; less contrast between successive opaque and translucent zones than in 2, but alternating zones still apparent; ± 2 or so between subsequent opaque-zone counts in this otolith
4	Otolith readable with difficulty; poor contrast between successive opaque and translucent zones; ± 3 or more or so between subsequent opaque-zone counts in this otoliths
5	Otolith unreadable

Margin-state

Margin	Description
Narrow	Last opaque zone present deemed to be fully formed; a very thin, hairline layer of translucent material is present outside the last opaque zone
Medium	Last opaque zone present deemed to be fully formed; a thicker layer of translucent material, not very thin or hairline in width, is present outside the last opaque zone; some new opaque material may be present outside the thicker layer of translucent material, but generally does not span the entire margin of the otolith.
Wide	Last opaque zone present deemed not to be fully formed; a thick layer of translucent material is laid down on top of the last fully formed translucent zone, with new opaque material present outside the translucent layer, spanning the entire margin of the otoliths

2.3.3 Quantifying reader precision

Otolith reading precision was quantified by carrying out within and between-reader comparison tests following Campana et al. (1995). A subsample of 400 otoliths was randomly selected from the set of all otoliths prepared in this study. These were stratified by the first reader's first recorded age with up to six otoliths randomly sampled from each available age class to ensure that each putative age class in the catch was adequately covered. The subsampled otoliths were read by a second reader and the results were compared with the first reader's set of results. The second reader re-read the protocol set prior to carrying out their readings. The Index of Average Percentage Error, IAPE (Beamish & Fournier 1981), and mean Coefficient of Variation, CV (Chang 1982), were calculated for each test. The IAPE is

$$\mathrm{IAPE} = 100 \times \frac{1}{N} \sum_{j=1}^{N} \left[\frac{1}{R} \sum_{i=1}^{R} \frac{\left| X_{ij} - X_j \right|}{X_j} \right], \tag{1}$$

and the mean CV is

$$\text{mean c.v.} = 100 \times \frac{1}{N}\sum_{j=1}^{N}\left[\frac{\sqrt{\sum_{i=1}^{R}\frac{\left(X_{ij}-X_j\right)^2}{R-1}}}{X_j}\right], \tag{2}$$

where X_{ij} is the ith count of the jth otolith, R is the number of times each otolith is read, and N is the number of otoliths read or re-read.

2.3.4 Converting opaque-zone counts to age estimates

Opaque-zone counts were converted to estimated ages by treating estimated fish age as the sum of three time components. The estimated age of the ith fish, $\hat{a}_i$, is

$$\hat{a}_i = t_{i,1} + t_{i,2} + t_{i,3}, \tag{3}$$

where $t_{i,1}$ is the elapsed time from spawning to the end of the first opaque zone present, $t_{i,2}$ is the elapsed time from the end of the first opaque zone present to the end of the outermost fully-formed opaque zone, and $t_{i,3}$ is the elapsed time from the end of the outermost fully-formed opaque zone to the date when the ith fish was captured. Hence,

$$\begin{aligned} t_{i,1} &= t_{i,\text{ end first opaque zone}} - t_{i,\text{ spawning date}} \\ t_{i,2} &= (n_i + w) - 1 \\ t_{i,3} &= t_{i,\text{ capture}} - t_{i,\text{ end last opaque zone}} \end{aligned} \quad . \tag{4}$$

where n_i is the total number of opaque zones present for fish i, and w is an edge interpretation correction after Francis et al. (1992) applied to n_i: w = 1 if the recorded margin state = "wide" *and* fish i was collected *after* the date when opaque zones are assumed to be fully formed, $w = -1$ if the recorded margin state = "narrow" *and* fish i was collected *before* the date when opaque zones are assumed to be fully formed, otherwise w = 0. A standardised "birth-date" of 1 January and a standardised opaque zone completion date of 1 November were used for all fish. Stewart et al. (1999) found that opaque zones in Australian fish were not always visible on the edge of the otolith until spring or summer despite being formed during winter. Landing date was substituted for the capture date of each fish. Thus a fish with four completed opaque zones and a "narrow" otolith margin that was landed on 19 November is estimated to be 3.88 years of age.

2.3.5 Data grooming

All estimated ages derived from otoliths where a readability score of "4" or better was recorded by the first reader were used in the following analyses. Two male and five female fish were dropped from the analysis because they had readability scores of 5 so the fish could not be aged. No other data grooming was carried out prior to the analyses.

2.4 Estimating the length- and age-composition of the catch

2.4.1 *Catch-at-age*

Catch-at-age (Bull & Dunn 2002) is a package of *R* functions (R Development Core Team 2005) developed by NIWA that computes scaled length-frequency distributions by sex and by stratum from commercial catch- and length-frequency data using the calculations in Bull & Gilbert (2001). When passed a set of length-at-age data, the program constructs an age-length key which is then applied to the estimated scaled length-frequency distributions to compute estimated scaled age-frequency distributions. It computes the CV for each length and age class and the overall mean-weighted CV (MWCV) for each length and age distribution using a bootstrapping routine: fish length records are resampled within each landing, landings are resampled within each stratum, and the length-at-age data are resampled, all with replacement. The bootstrap length- and age-frequency distributions are computed for each resample, and the CVs for each length and age class are computed from the bootstrap distributions.

2.4.2 Length-weight relationship

Three length-weight relationships were used to calculate the catch-at-length for males, females and unsexed fish:

$$\textit{males}\text{:}\ w = 3.3743 \times 10^{-6} (l^{3.4047}) \tag{5}$$

$$\textit{females}\text{:}\ w = 3.2305 \times 10^{-6} (l^{3.4145}) \tag{6}$$

$$\textit{unsexed}\text{:}\ w = 3.3489 \times 10^{-6} (l^{3.4058}) \tag{7}$$

where l is fish length in centimetres and w is fish weight in kilograms. The relationship is from a linear regression of log-transformed length and weight data for blue mackerel from the EMA 1 fishery (Manning et al. 2007b).

2.4.3 Analyses performed

The EMA 1 analysis assumed a single stratum that represented the target purse-seine fishery. Age-length keys were computed from the groomed length-at-age data subsets for each Fishstock and used to convert the calculated numbers-at-length distributions to numbers-at-age. Bootstrapped CVs and mean weighted CVs (MWCV) were calculated for each length and age class and frequency distribution by resampling the data 1000 times.

2.4.4 Temporal variation in age and length of the catch

Aerial sightings data indicate that the purse seine fishery only samples a portion of the wider population of blue mackerel. This suggests that commercial catch at age may not be useful for monitoring the stock. To investigate this, a fine-scale analysis of temporal variation in age and length was carried out. Plots of proportion-at-length and proportions-at-age were produced by landing and by month for 2006–07 and examined for any evidence of variation.

3. RESULTS

3.1 Summary of the EMA 1 fishery during 2006–07

The most common gear method was identified for each valid fishing trip in the catch-effort and landings datasets (Table 3). The reported greenweight catch in the landings data was cross-tabulated by gear and area to yield estimates of the total reported catch by these factors. Purse-seine vessels where blue mackerel was the most common recorded target species dominated the EMA 1 catch in 2006–07, accounting for all but 3 tonnes (99.96%) of the total catch.

Table 3: **Reported greenweight catch (t) of blue mackerel in EMA 1 by month and fishing method from the catch-effort and landings datasets for the 2006–07 fishing year (from QMS reports). BLL is bottom longline, BT is trawl using a bottom net, HL is handline, PS is purse seine, and SN is set net.**

	BLL	BT	HL	PS	SN	Total
October	–	<1	<1	4 192	<1	4 192
November	<1	<1	<1	2 060	1	2 061
December	<1	<1	<1	788	<1	789
January	–	<1	<1	18	<1	18
February	–	<1	–	261	<1	261
March	–	–	–	89	<1	89
April	–	–	–	47	<1	47
May	–	–	–	73	<1	73
June	–	–	–	1	<1	1
July	–	–	–	2	<1	3
August	–	–	–	86	<1	86
September	<1	–	–	195	<1	195
Total	<1	<1	<1	7 812	1	7 815

3.2 Summary of sampling results

A total of 33 landings were sampled but for 4 of these the fish were not sexed. Therefore, a total of 27 317 fish were measured from 29 landings. A total of 400 sagittal otolith pairs were sampled from otoliths collected; 397 of these were prepared and read because three otoliths pairs were damaged. The temporal distributions of catch and sampling effort (Figure 2) suggested that the sampling data is probably representative of the fishery, but only for October to December 2006.

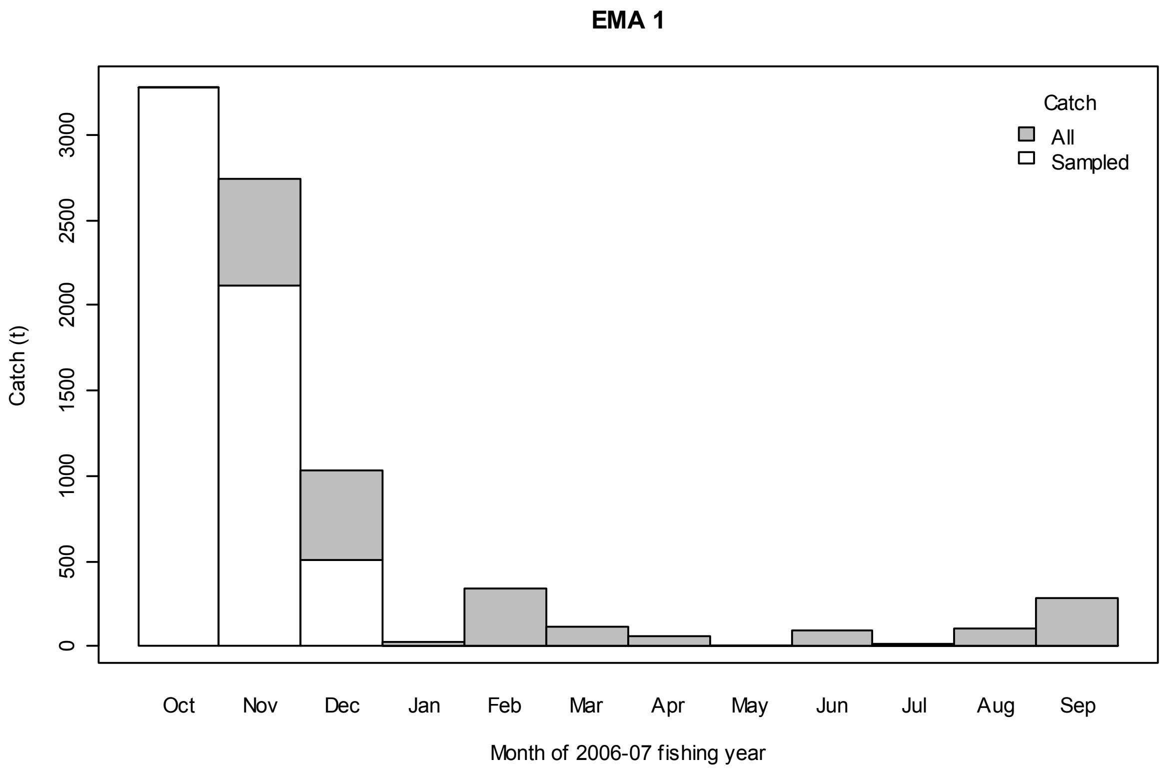

Figure 2: **Summaries of fishing and sampling activity for EMA 1 during the 2006–07 fishing year. Histograms of the total reported landed (grey bars) and sampled (white bars) catch are overlaid for each bar.**

3.3 Otolith reading results

Most readability scores were 3 or 4 (Table 4). Reader 1 (the more experienced reader of Blue Mackerel otoliths) read 390 otoliths and reader 2 (relatively inexperienced reader of Blue Mackerel otoliths) read 392 otoliths. A readability score of 5 was assigned to seven and five otoliths by readers 1 and 2 respectively. Annulus counts for otoliths with a readability of 5 were not recorded. The CV and IAPE calculated for the between readers comparison for the otoliths aged in common (386) in this study were 19.47% and 13.77%, respectively. The right shift in the histogram in Figure 3(a), the clustering of points above the zero-line in Figure 3(b) and below the one-to-one line in Figure 3(c), and the steeply declining curve of the CV and APE profiles in Figure 3(d) all suggest that there was a systematic differences between the readers in interpretation of blue mackerel otoliths in this study. The positive displacement in Figure 3(a) means that the second reader under-counted opaque zones present (by between 1 and 2 on average) relative to the first reader. This suggests that there was an inconsistency between readers in identifying the first true opaque zone present. Only data from Reader 1 were used in the analysis.

Table 4: Readability scores for otoliths read by readers 1 and 2; otoliths with a readability of 5 were not read and are not included here.

	Reader 1						Reader 2					
Band	Readability scores						Readability scores					
count	1	2	3	4	5	Total	1	2	3	4	5	Total
2	–	–	1	–	–	1	–	1	3	–	–	4
3	–	7	5	1	–	13	–	12	43	12	–	67
4	–	6	14	1	–	21	–	3	45	13	–	61
5	–	5	38	7	–	50	–	3	24	20	–	47
6	–	3	44	11	–	58	–	3	14	10	–	27
7	–	1	34	24	–	59	–	7	11	9	–	27
8	–	–	17	12	–	29	–	7	11	7	–	25
9	–	–	19	8	–	27	–	2	12	4	–	18
10	–	–	18	6	–	24	–	9	17	1	–	27
11	–	–	10	7	–	17	–	5	5	2	–	12
12	–	2	12	5	–	19	–	7	7	1	–	15
13	–	1	10	5	–	16	–	4	7	2	–	13
14	–	–	5	5	–	10	–	2	6	3	–	11
15	–	2	5	2	–	9	–	5	4	–	–	9
16	–	–	5	5	–	10	–	–	8	–	–	8
17	–	–	8	3	–	11	–	1	7	1	–	9
18	–	–	5	1	–	6	–	–	1	–	–	1
19	–	–	3	–	–	3	–	2	3	–	–	5
20	–	–	2	2	–	4	–	–	4	1	–	5
21	–	–	1	1	–	2	–	–	–	–	–	–
22	–	–	1	–	–	1	–	1	–	–	–	1
			–	–								
Total	–	27	257	106	–	390	–	74	232	86	–	392

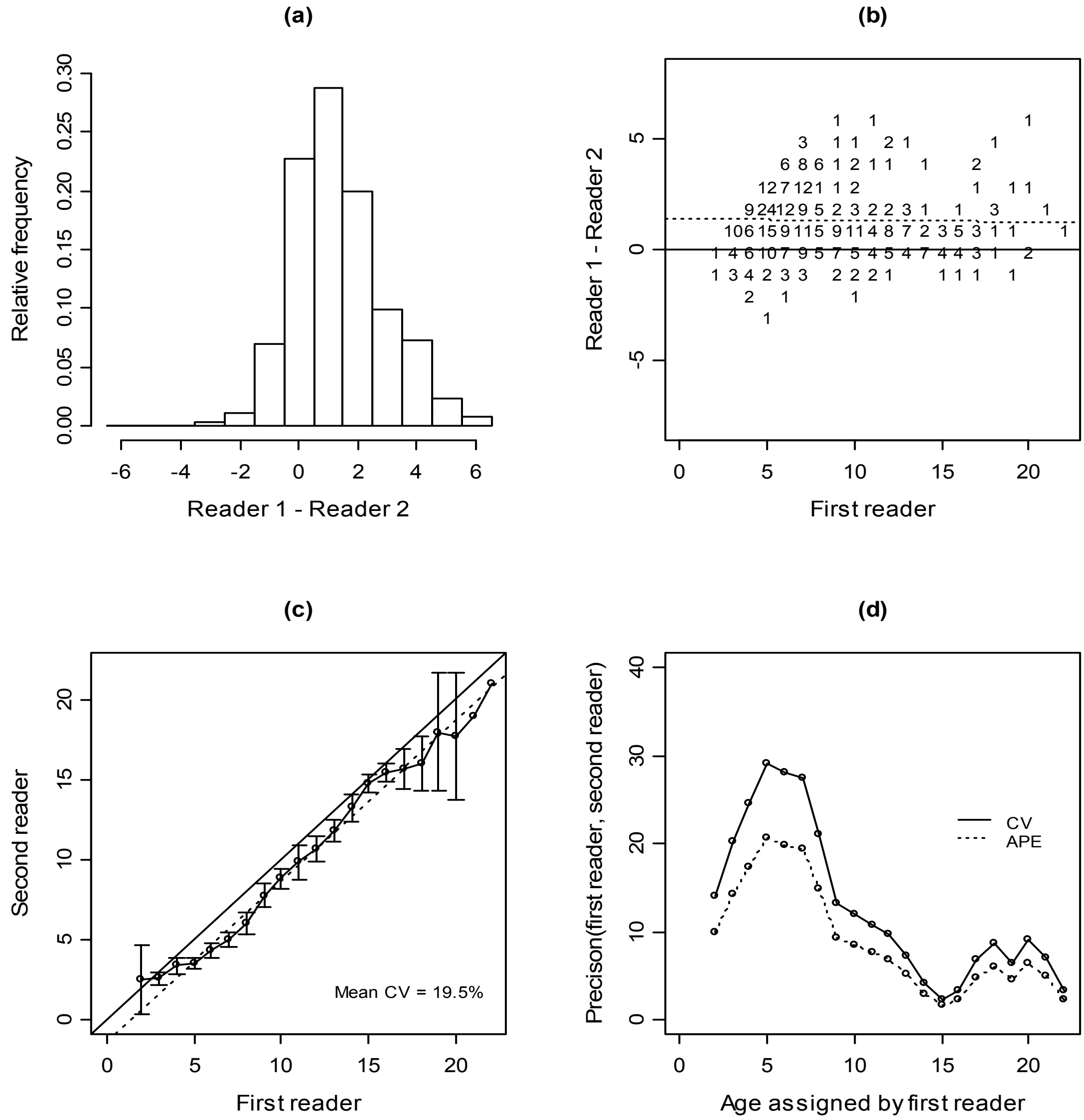

Figure 3: Results of the between-reader comparison test (reader 1 and 2): (a) histograms of differences between readings for the same otolith; (b) differences between the first and second reading for a given age assigned during the first reading; (c) bias plots; and (d) CV. and APE profiles relative to the ages assigned during the first set of readings. The expected one-to-one (solid line) and actual relationship (dashed line) between the first and second ages are overlaid on (b) and (c).

3.4 Length- and age-frequency distributions

The estimated scaled proportions-at-length distributions calculated for all three fisheries are shown in Figure 4. Cumulative proportions-at-length for the 2002–03, 2003–04, 2004–05, and 2005–06 fishing years are plotted and compared in Figure 5. The estimated scaled proportions-at-age distributions calculated by applying the age-length keys derived from the prepared and read otoliths are plotted in Figure . Cumulative proportions-at-age for the 2002–03, 2003–04, 2004–05, 2005–06, and 2006–07 fishing years are plotted and compared in Figure 6. To aid in interpreting the cumulative proportions-at-length and proportions-at-age, scaled proportions-at-length and proportions-at-age distributions for

2002–03, 2003–04, 2004–05, 2005–06 calculated for all three fisheries are included in Figures 4a and 6a respectively.

Length distributions in 2006–07 were roughly centred around 42 cm, with no fish smaller than 33 cm or larger than 50 cm in any of the fisheries sampled (Figure 4). The distributions of all fish, males and females, were strongly unimodal with some skew to the left. The cumulative proportions-at-length by sex suggest that the 2006–07 catch contained a slightly higher proportion of large males than in the previous year; females had a slightly lower proportion of large fish than in 2005–06.

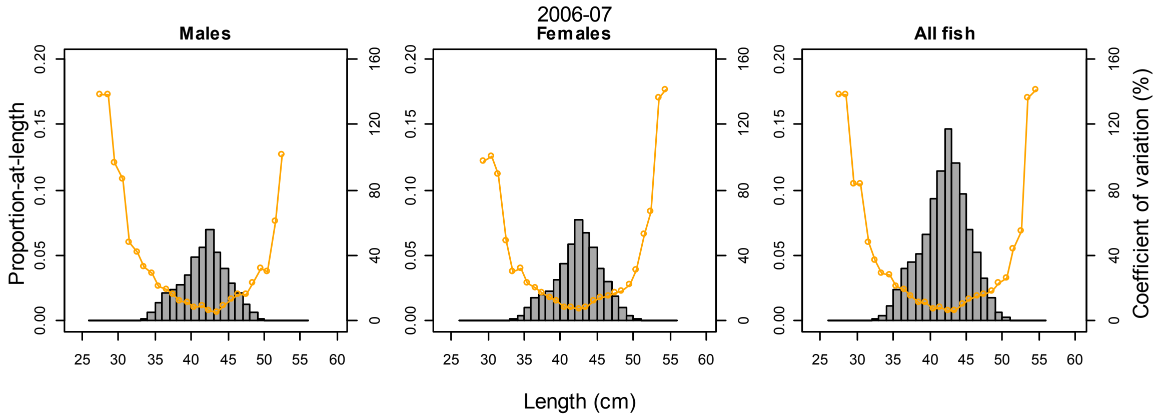

Figure 4: Estimated scaled proportions-at-length for male, female, and all fish combined for the EMA 1 fishery in the 2006–07 fishing year with bootstrapped coefficient of variation for each length class.

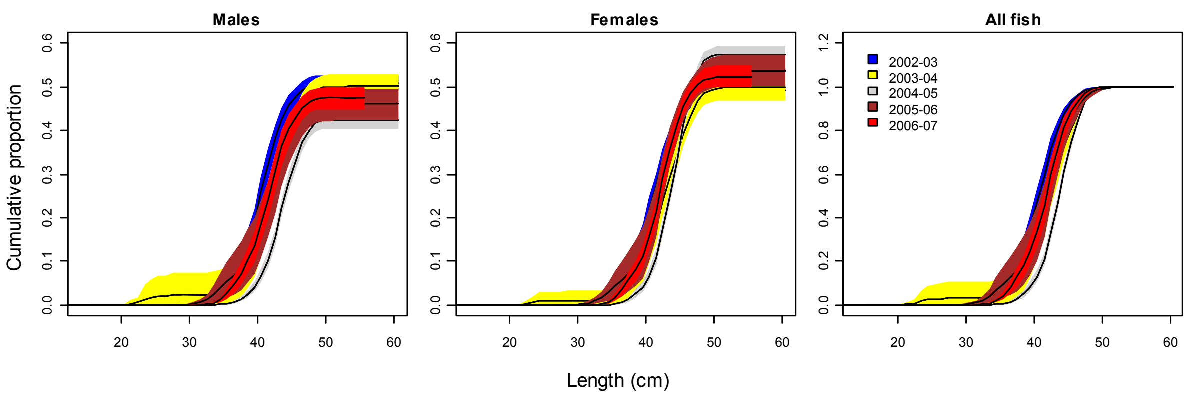

Figure 5: Overlaid cumulative proportions-at-length from data collected during the 2006–07 fishing year in EMA 1 and the previous years (2002–03, 2003–04, 2004–05, and 2005–06). The dashed line in each plot is the cumulative proportion-at-length or age and the surrounding region is a bootstrapped 95% confidence region about the cumulative proportion-at-length.

In the five years from 2002–03 to 2006–07, the peaks of the proportions-at-length distributions are 40–42, 42, 43–44, 42–43, and 42 (Figures 4 and 4a), which is relatively similar, with the range mostly being about 32–36 to 50–52. There are some clear differences. In 2003–04 a small mode of fish with lengths less than 28 cm are evident and in 2005–06 there is evidence of a small pulse of fish in what appears to be the 30–37 cm range that skews the overall distributions to the left.

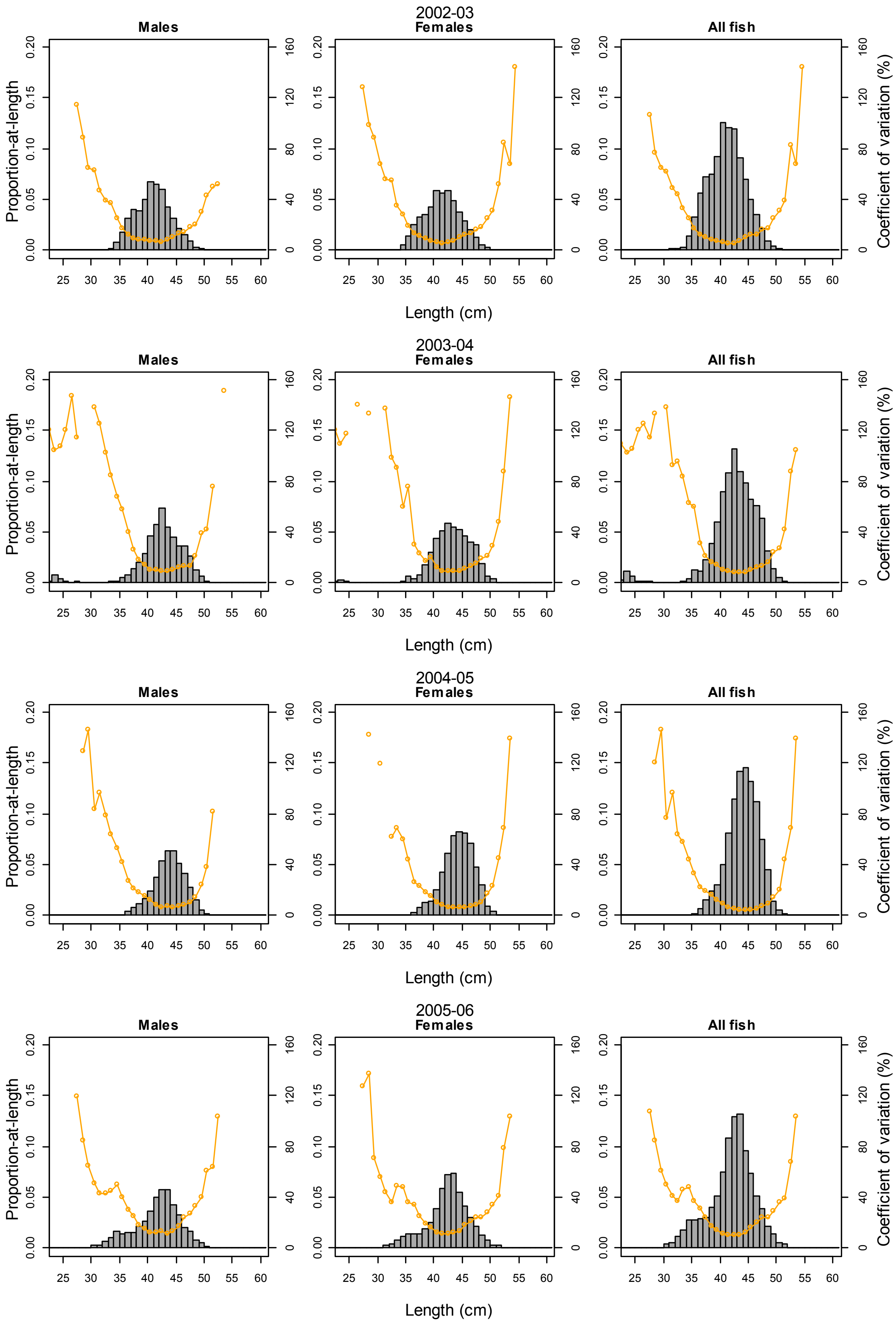

Figure 4a: **Estimated scaled proportions-at-length for male, female, and all fish combined for the EMA 1 fishery in the 2002–03, 2003–04, 2004–05, and 2005–06 fishing years, with a bootstrapped coefficient of variation for each length class.**

The estimated scaled proportions-at-age for 2006–07 show that catches were mostly of fish 4–15 years old, although fish as old as 18 appear to be present in the catch; the modal peak is at about 7 yr although this is less clear for males than females (Figure). There was a difference in the cumulative distribution for males and females (Figure 7), with the curve shifted to the right and the ascending arm steeper in females than males. Consequently males have a higher proportion of fish in the middle ages and a lower proportion of fish in the largest size classes.

Considering the data for all years, the range of ages in 2006–07 is similar for the earlier years (Figure 6a) except for 2004–05 when it appears that older fish, particularly males, were more strongly represented. Modal peaks in the earlier years are not as clear as in 2006–07 except for2003–04 when it is also around 7 yr. The lack of coherence of the age distributions in the earlier years makes them

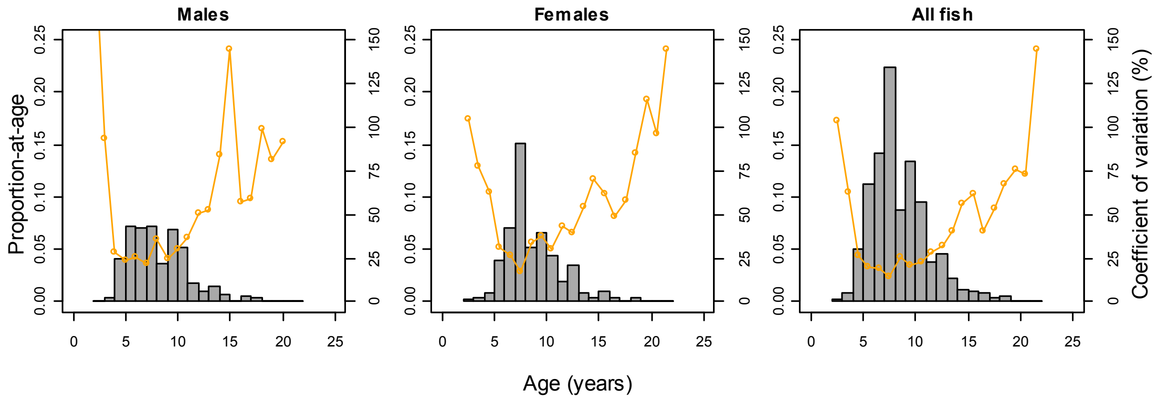

Figure 6: Estimated scaled proportions-at-age for male, female, and all fish combined for the EMA 1 fishery in the 2006–07 fishing year with bootstrapped coefficient of variation for each age class.

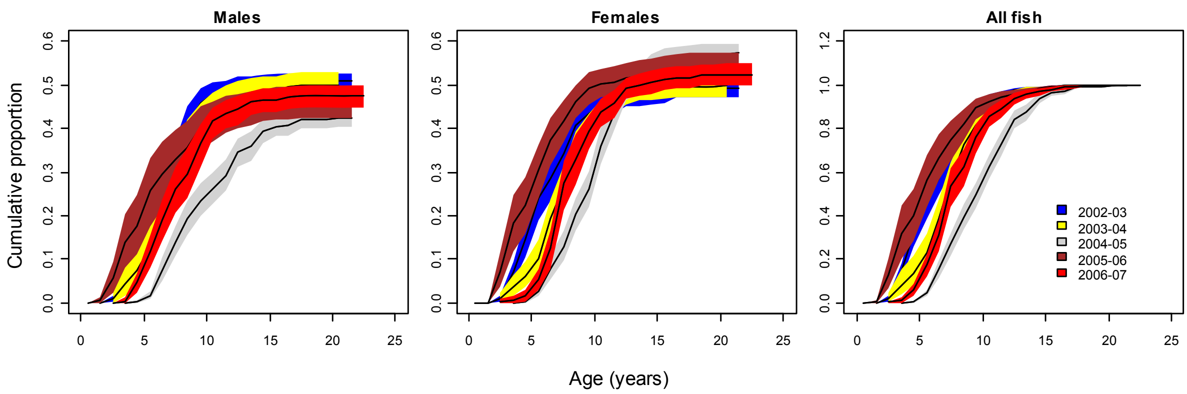

Figure 6: Overlaid cumulative proportions-at-age calculated from data collected during the 2006–07 fishing years in EMA 1 and previous years (2002–03, 2003–04, 2004–05, 2005–06). The dashed line in each plot is the cumulative proportion-at-length or age and the surrounding region is a bootstrapped 95% confidence region about the cumulative proportion-at-age.

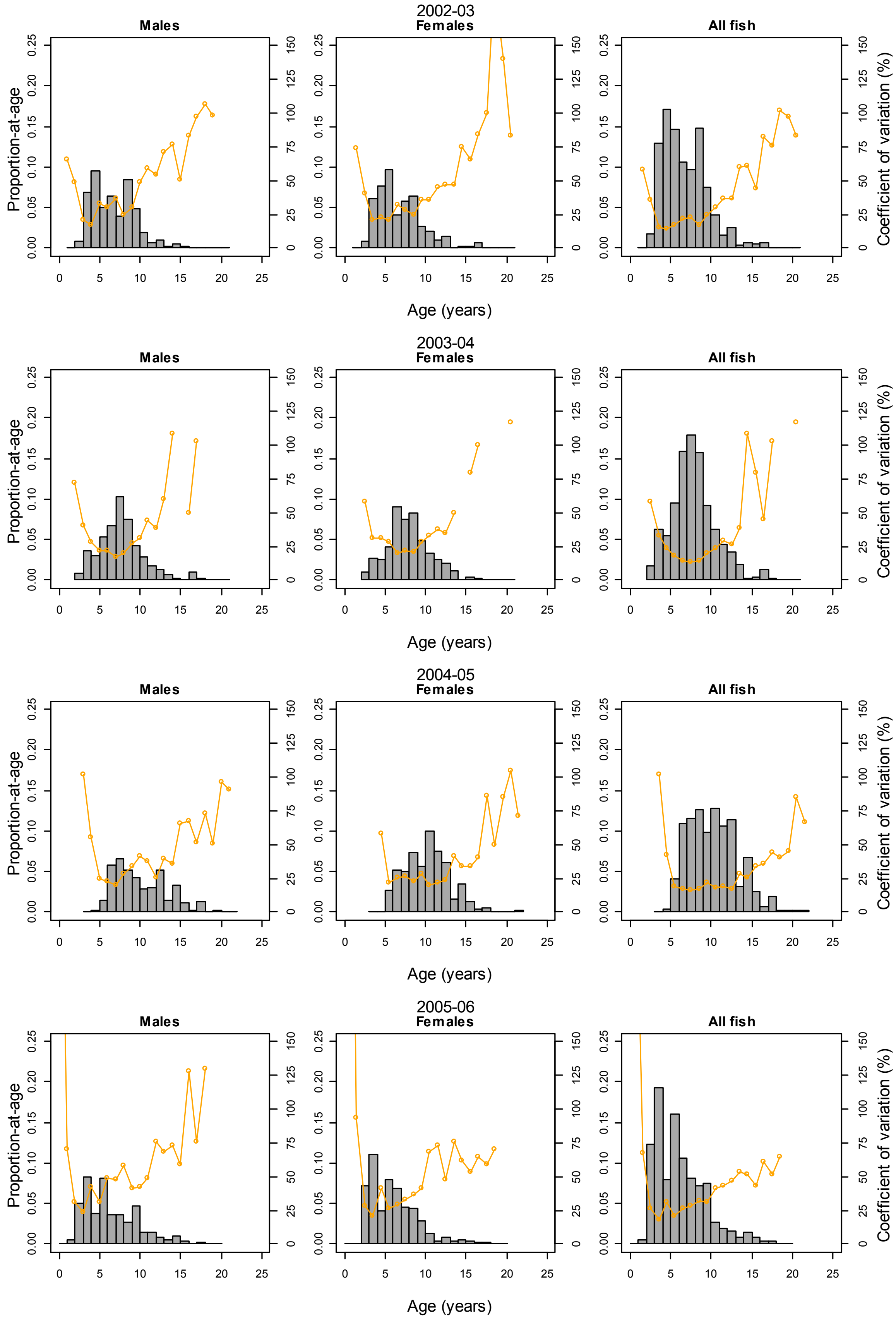

Figure 6a: Estimated scaled proportions-at-age for male, female, and all fish combined for the EMA 1 fishery in the 2002-03, 2003-04, 2004–05, and 2005–06 fishing years, with bootstrapped coefficient of variation for each age class.

difficult to interpret, but there is a definite lack of consistency between years. For example, the age distributions in 2004–05 seem to vary considerably between males and females, whereas the age distributions in 2005–06 are similar between males and females but show a skew to the right, which is opposite to the skew in the length distributions for the same year.

The estimated scaled proportions-at-age by year class and fishing year is shown in Figure 8. It is difficult to draw any reliable information from it however, because patterns of year-class strength show little consistency between years.

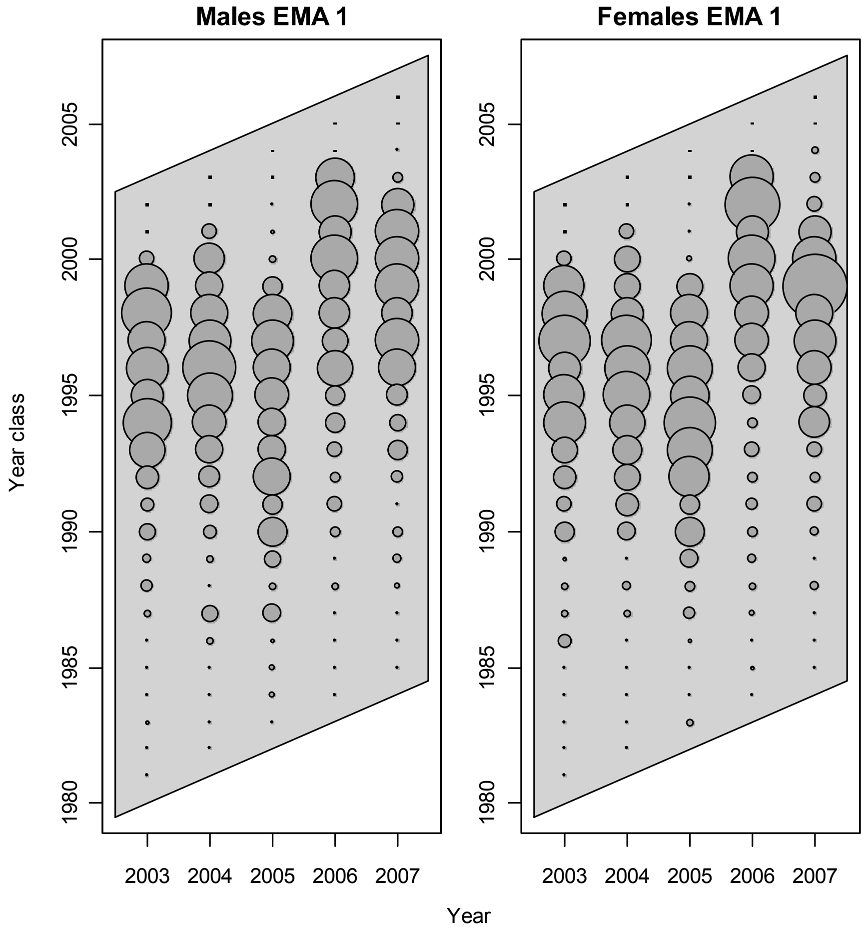

Figure 8: Estimated scaled proportions-at-age (ages 2–20) by year class and fishing year for males and females in the EMA 1 purse seine fishery over the 2002–03 to 2006–07 fishing years. Circle area is proportional to the corresponding proportion-at-age within each sampling event. Circle area represents proportion-at age. The area of the largest circle (Females, year class 1995, fishing year 2006–07) is equal to a proportion-at-age of 0.22. The dashes represent year classes where the proportion-at-age was zero or was not estimated. Age 2 is a minus group and age 20 is a plus group.

The MWCVs for the proportions-at-length and proportions-at-age distributions are shown in Table . The representativeness analysis (above) suggests that these results are probably representative of the fishery during October to December 2006. The MWCVs for both sexes and all fish in the length analyses were within the 30% target. However, the MWCV for each sex was slightly above the target 30% for the age analyses, but well within the target CVs. for age for all fish.

Table 5 Mean-weighted coefficients of variation (%) for the scaled length- and age-frequency distributions calculated by sex.

	Sex		
	Males	Females	All fish
Length	14.0	13.5	10.9
Age	30.6	31.7	23.4

Estimated scaled numbers-at-length and CVs. by sex are given in Appendix B. Estimated scaled numbers-at-age and CVs by sex are given in Appendix C. The age-length keys used to convert the scaled numbers-at-length distributions to numbers-at-age are given in Appendix D.

3.4 Temporal variation in age and length of the catch

Proportion-at-length distributions by month in 2006–07 suggest little difference between October and November, but there is evidence that larger fish were taken during December (Figure 9). Proportion-at-length distributions by landing also show a shift towards larger fish in the catch during December but they do not provide any additional information on size variation (Figure A1). Generally size is similar between landings within a particular period.

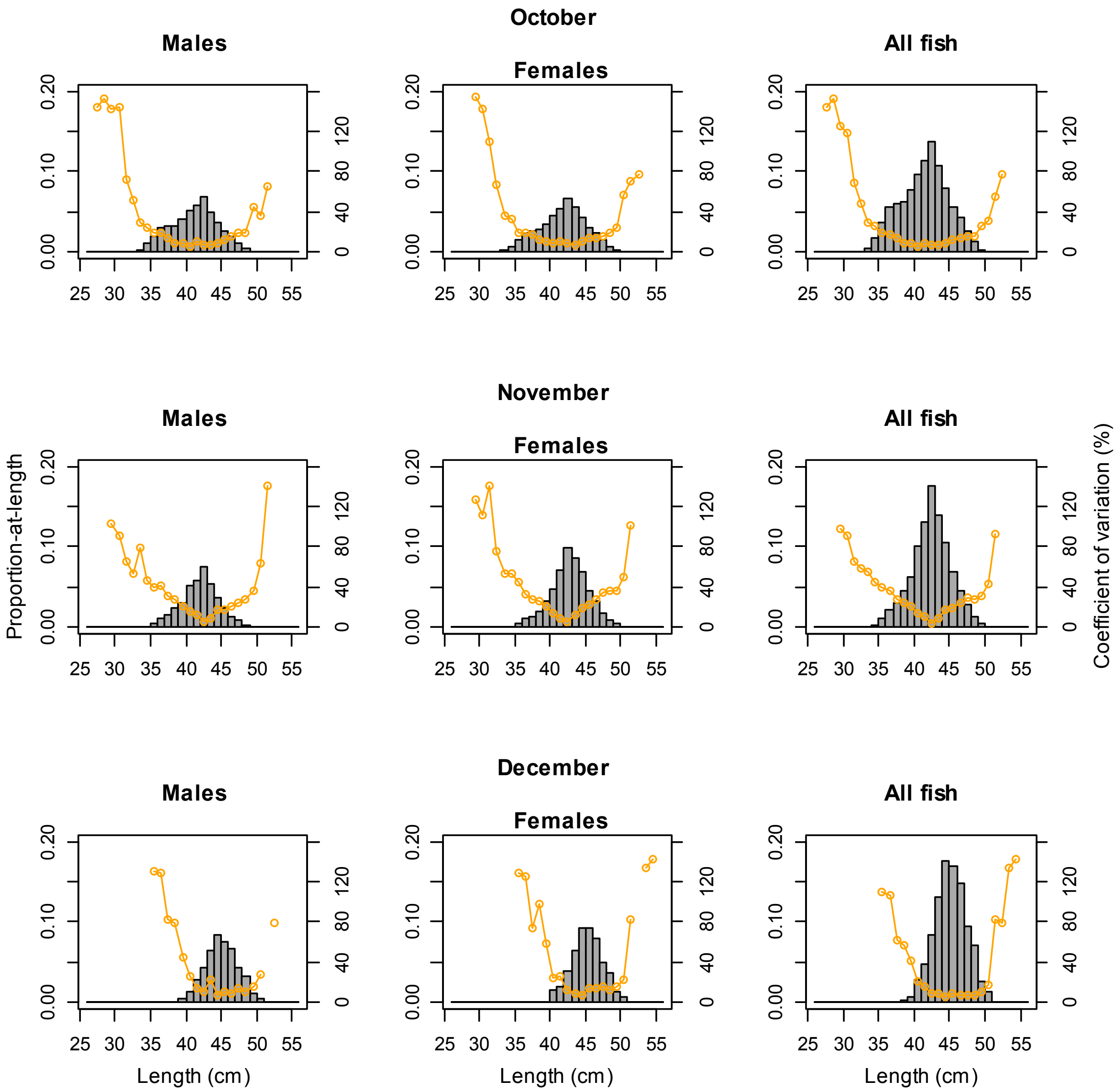

Figure 9: **Estimated scaled proportions-at-length by month for male, female, and all fish combined for the EMA 1 fishery in the 2006-07 fishing year, with a bootstrapped coefficient of variation for each age class**

Proportion-at-age distributions by month (Figure 10) indicate a shift towards older fish in December which is also reflected in the estimated distributions by landing (Figure A2). Like the length distributions, age distributions remain quite stable between landings within a particular period.

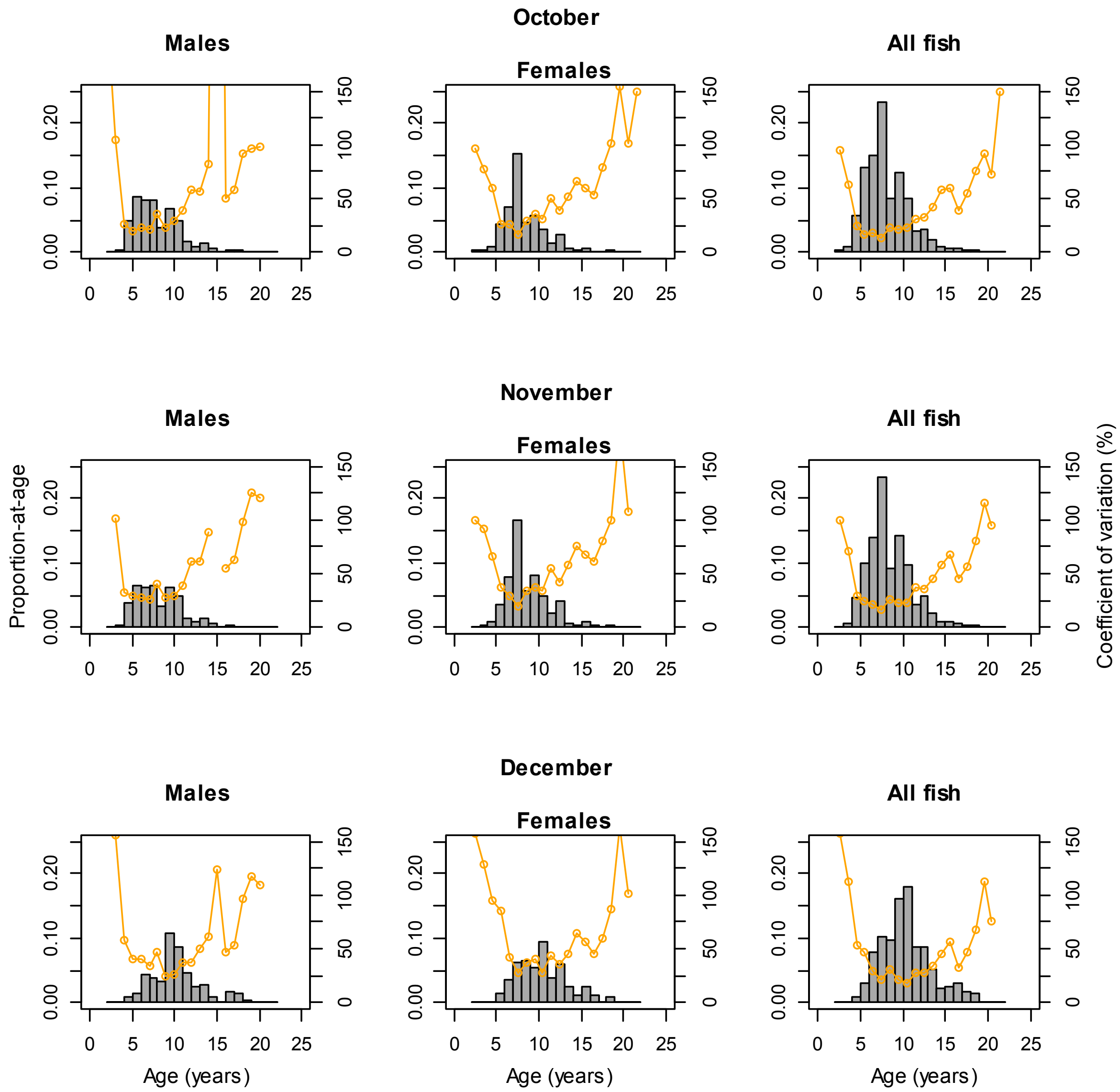

Figure 10: **Estimated scaled proportions-at-age by month for male, female, and all fish combined for the EMA 1 fishery in the 2006–07 fishing year, with a bootstrapped coefficient of variation for each age class.**

4. DISCUSSION

4.1 Catch-sampling success and recommendations for future sampling

The mean weighted CV targets for males and females were exceeded slightly in the catch-at-age analyses, which is a marked improvement over the previous year (Devine et al. 2009).

As was noted above, there was a systematic difference between reader 1 and reader 2. This may in part be due to the inexperience of reader 2 in reading blue mackerel otoliths. However, as has been documented many times, blue mackerel otoliths are very difficult to read. In the analyses this problem was dealt with by only using data from Reader 1. For the future, it is important that blue mackerel otolith readers are both experienced otolith readers and experienced at reading blue mackerel otoliths. This may require more extensive start-up time to be allowed for within projects where blue mackerel otoliths are to be read. Otolith reading in EMA2007-01 included the two experienced otoliths readers spending time together reading protocol sets as a preliminary to beginning the reading proper (as one was more experienced with blue mackerel than the other), but this may not be enough. It may be worth considering more regular between-reader comparisons as the year's readings are being conducted.

4.2 Apparent trends in the catch-at-length and catch-at-age

From the shape of the catch-at-length and catch-at-age curves, blue mackerel appear to be fully recruited to the purse-seine fishery in EMA 1 at about 45 cm fork length, which translates to ages ranging between about 8 and 12 years. This does not, however, include the information from 2004–05 which lies well outside the range, an outcome that is mainly the result of an uncharacteristic cumulative distribution for males. The proportion-at-age analysis also highlights a difference between males and females in 2004–05 that is difficult to explain: although far from clear there is the suggestion that the modal peak for males is considerably lower than females.

Generally, there are variations between the proportion-at-length distributions for the years 2002–03 to 2006–07 both in the position of the peak and the range. Mostly these variations are small, although the minima do vary a little more than the maxima or the peaks, particularly in 2003–04 and 2005–06. It is possible that the small fraction observed in 2003–04 is the same as that observed in 2005–06, but unfortunately it is absent from the proportion-at-age histograms, probably as a result of not being represented in the otolith sampling, and is therefore not identifiable in the year-class plot.

Perhaps the main feature of the annual proportion-at-age plots is the lack of consistency between years, which is reflected in the year-class plot. This is probably the most unsatisfactory result of the analysis and highlights the potential lack of reliability there would be in adopting only length-based methods to monitor this stock.

The fine-scale analysis of data from 2006–07 is perhaps a little more consistent than the interannual analysis. However, although proportion-at-length plots by month are similar for October-November they show a shift to larger fish in December. Not only is the peak shifted several size classes to the right, but there appears to be a higher proportion of fish larger than 15 cm. As is to be expected, this pattern is repeated in the inter-landing length distributions, which feature a high level of variation in the sampling, probably as a result of the schooling-by-size characteristic believed to occur in this species.

The monthly proportion-by-age analysis for 2006–07 shows a shift to older fish in December, which is repeated in the inter-landing age distributions thus reflecting the pattern of the monthly/landing length analysis. The structure of these distributions is clearly more coherent than the inter-annual age distributions and therefore easier to interpret. However, the sudden shift to older fish in December suggests another potential weakness in using these methods to monitor this species.

There are several possible explanations for the variations that occur in data. They may correspond to recruitment pulses or changes in behaviour of the fish and/or fishers, or they may reflect the presence of different sub-groups of the population in the fishery. Blue mackerel is believed to be a highly mobile species and may be represented by quite different sub-groups of the overall population from year to year in a given area. Indices of relative abundance for blue mackerel in the Bay of Plenty using the aerial sightings data showed such high inter-annual variability that that method of monitoring the stock had to be abandoned. By contrast, similar indices for the less highly-mobile species trevally and kahawai were far more stable, thus allowing the method to be adopted for them.

Two questions must be considered. First, are the variations in the data representative of changes in the population and, second, do they reliably represent variations across the entire population? If sampling was from an entire population a reasonable level of consistency would be expected in the results. The length and age analyses documented here are not characterised by consistent inter-annual patterns, such as a year class plot with clear inter-annual relations between cohorts. Instead they are characterised by features that might come from an unstable population. If variations in the data are caused by fishing practices, like changing targeting to larger fish, such is not representative of changes in the population. Under these conditions it is unlikely that a reliable measure of population age structure could be obtained. What seems most likely, given the highly mobile nature of this species, is that blue mackerel should be treated as a single stock, which would then provide a good basis for developing a reliable monitoring method.

5. ACKNOWLEDGEMENTS

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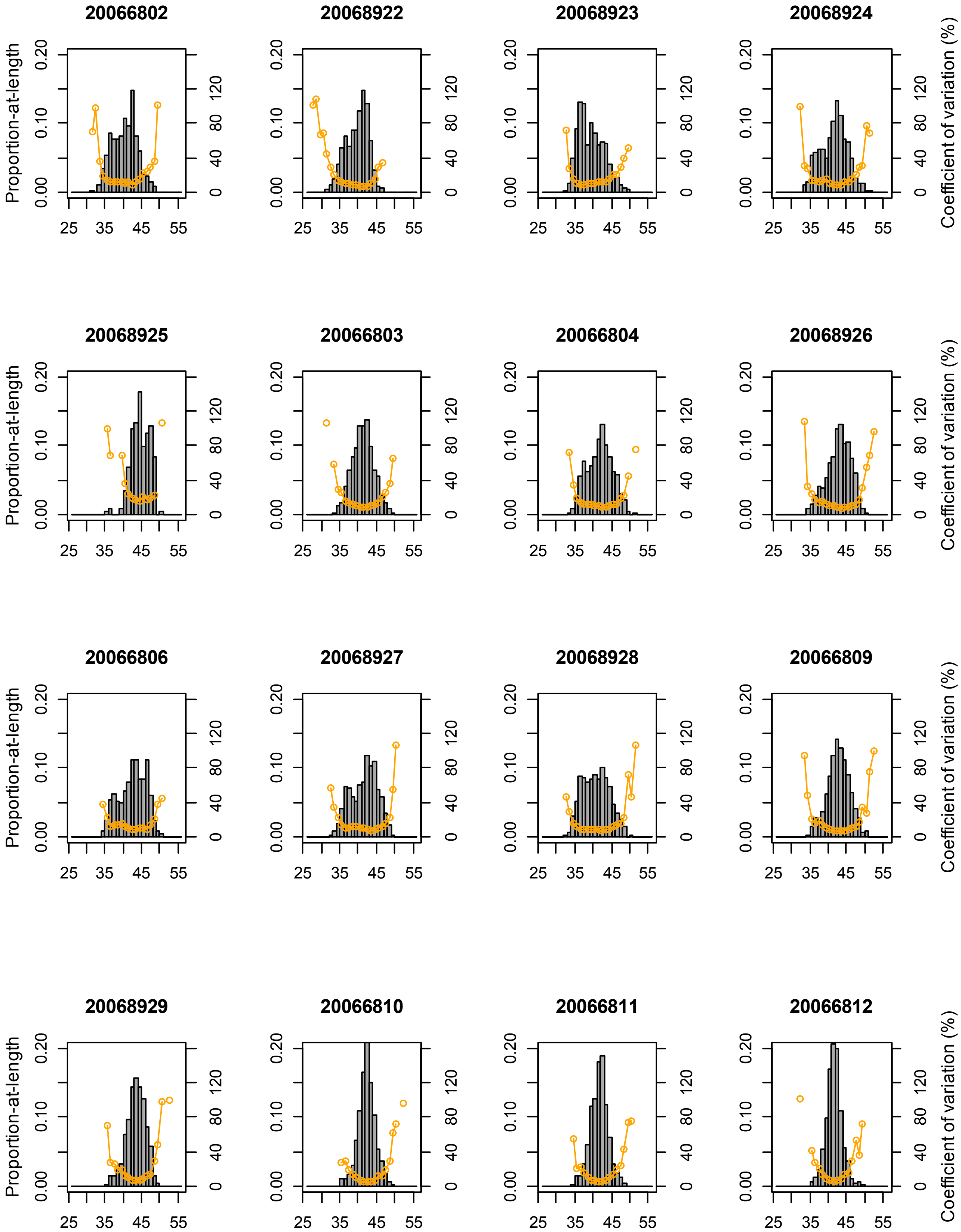
7. APPENDICES

Appendix A: Estimated scaled proportions at length and age by landing – all fish combined



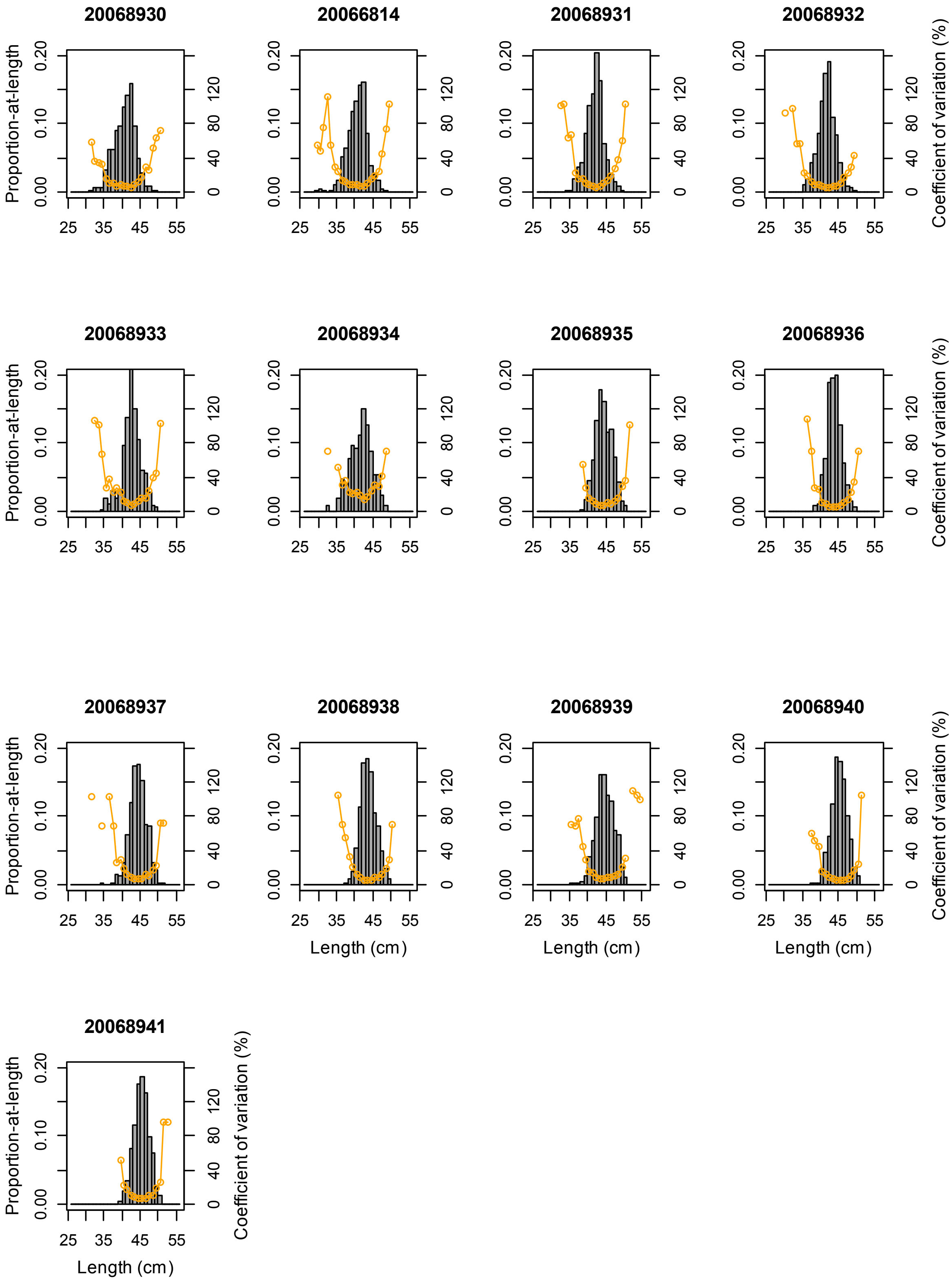
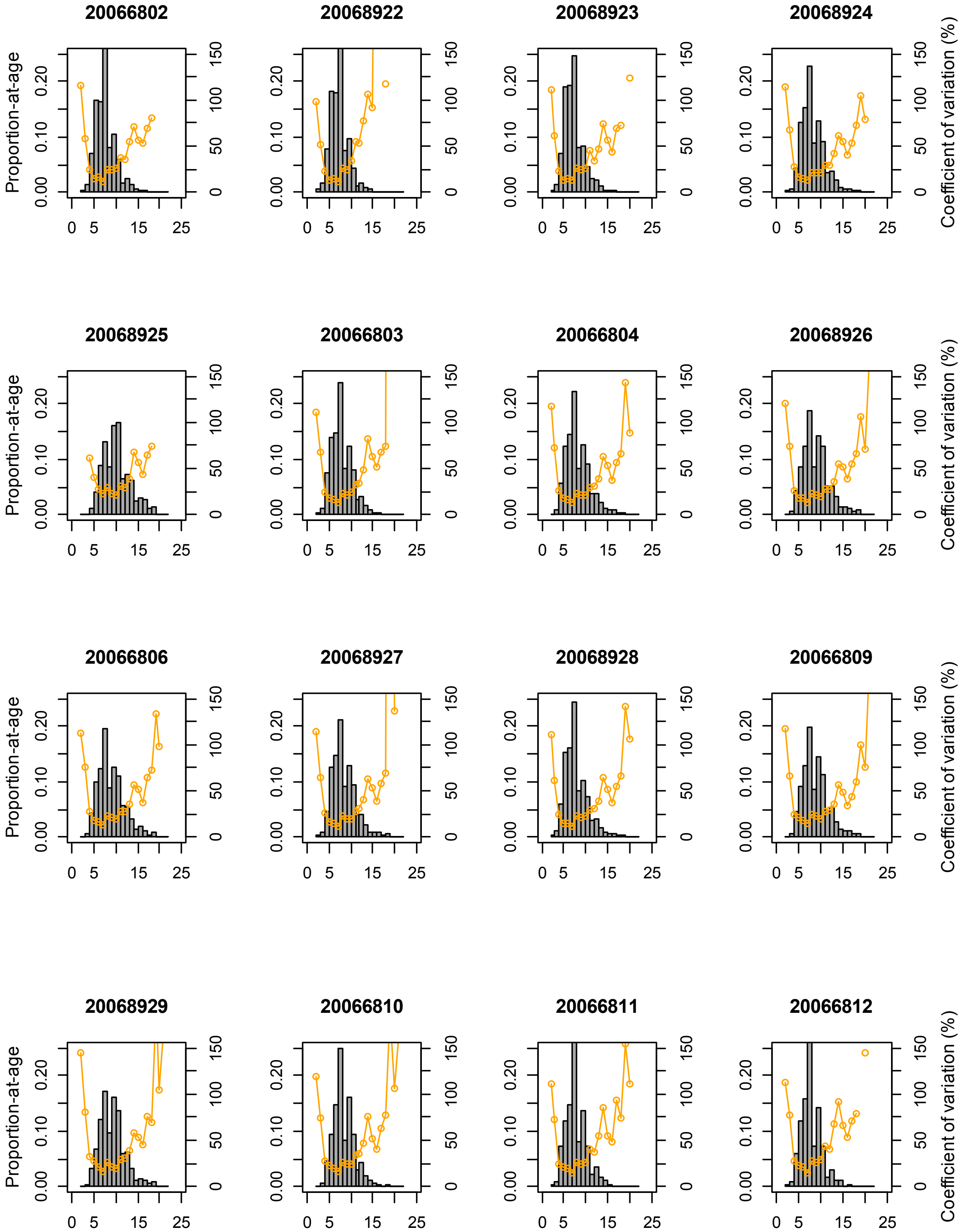


Figure A1: Estimated scaled proportions-at-length by landing for all fish combined (males and females) for the EMA 1 fishery in the 2006–07 fishing year with bootstrapped coefficient of variation for each length class.



20066802
20068922
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20068925
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20068929
20066810
20066811
20066812
Proportion-at-age
Coefficient of variation (%)

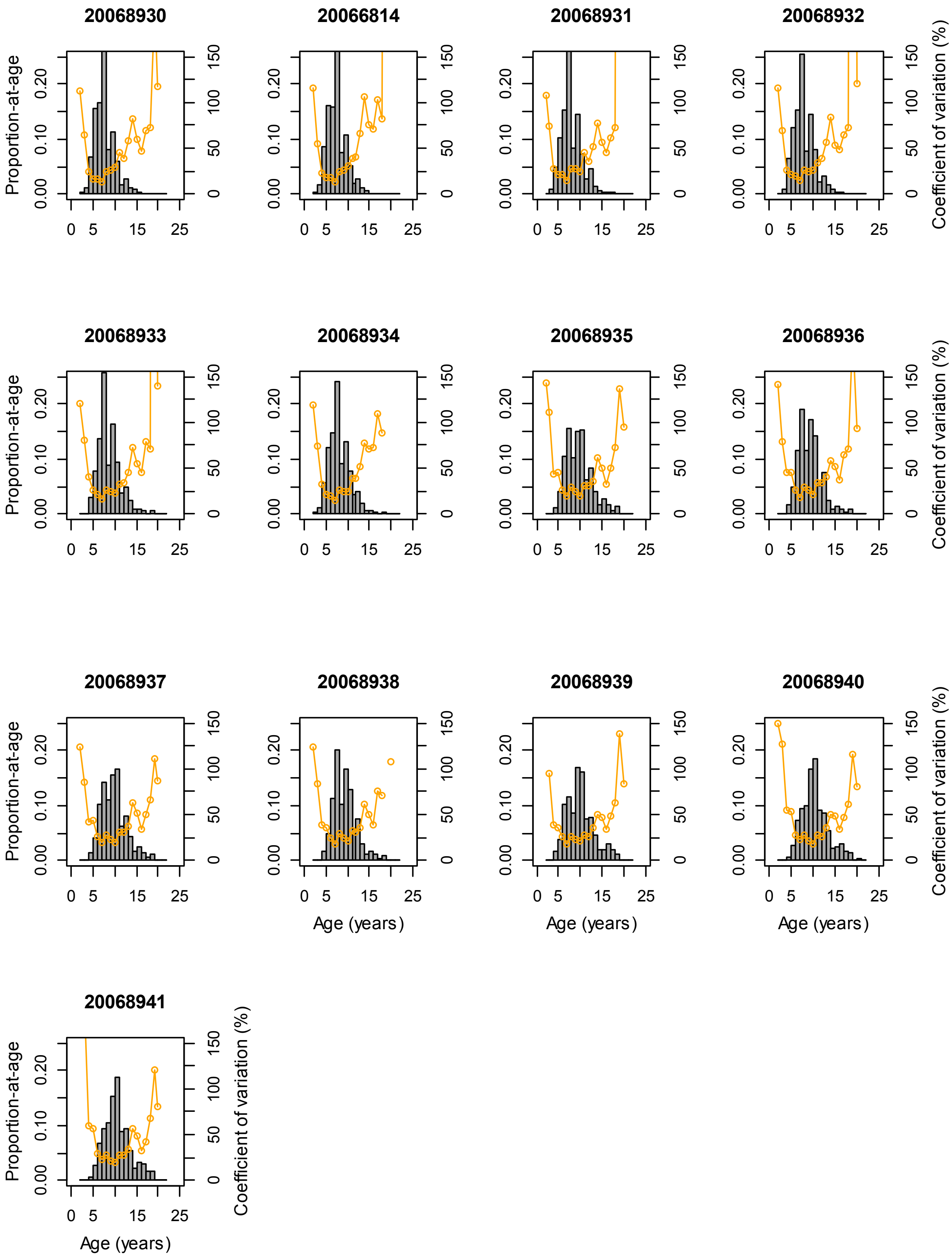

Figure A2: **Estimated scaled proportions-at-age by landing for all fish combined (males and females) for the EMA 1 fishery in the 2006–07 fishing year with bootstrapped coefficient of variation for each length class.**

Appendix B: Scaled length distributions

Table B1: Estimated scaled numbers-at-length (NAL), bootstrapped coefficients of variation (CV), and bootstrapped mean-weighted coefficients of variation (MWCV) calculated from the data collected during the 2006–07 fishing season and scaled to the total reported catch landed.

	Males		Females		All	
Length	NAL	CV (%)	NAL	CV (%)	NAL	CV (%)
≤ 26	–	–	–	–	–	–
27	291	139	–	–	291	139
28	291	139	–	–	291	139
29	999	97	645	98	1 645	84
30	1 515	87	999	101	2 514	85
31	3 358	49	1 193	91	4 552	49
32	8 331	43	3 975	50	12 306	39
33	17 008	34	13 083	32	30 091	31
34	51 720	31	29 801	34	81 521	30
35	98 147	23	76 564	25	174 711	23
36	157 922	21	128 698	22	286 620	21
37	175 783	18	146 636	19	322 419	17
38	200 392	14	167 535	16	367 927	14
39	251 192	14	226 104	14	477 296	13
40	353 411	11	311 940	10	665 352	10
41	403 941	11	417 968	10	821 909	10
42	496 427	7	550 542	8	1 046 969	7
43	377 441	5	485 982	7	863 423	5
44	285 833	8	407 063	10	692 897	8
45	208 141	11	291 318	12	499 459	11
46	152 259	14	221 249	14	373 507	13
47	96 702	15	136 027	16	232 729	14
48	49 613	22	77 458	17	127 071	17
49	15 612	31	30 871	21	46 483	21
50	7 888	29	10 637	30	18 525	25
51	1 547	61	1 757	52	3 305	44
52	401	100	882	66	1 283	54
53	–	–	188	136	188	136
54	–	–	188	141	188	141
≥ 55	–	–	–	–	–	–
Total	3 416 165		3 739 303		7 155 472	
MWCV (%)		12.0		12.0		11.2

Appendix C: Scaled age distributions

Table C1: Estimated scaled numbers-at-age (NAA), bootstrapped coefficients of variation (CV), and bootstrapped mean-weighted coefficients of variation (MWCV) calculated from the data collected during the 2006–07 fishing season, scaled to the total reported catch. The undetermined numbers at age are for all fish of lengths 53 or 54 cm and for male fish of length 27 cm, for which there was no age-length key.

	Males		Females		All	
Age	NAA	CV (%)	NAA	CV (%)	NAA	CV (%)
2	291	209	16 753	105	17 045	104
3	29 505	94	30 177	78	59 681	63
4	295 920	29	63 397	63	359 318	27
5	519 488	25	279 742	32	799 231	22
6	506 522	27	506 199	27	1 012 721	20
7	514 275	23	1 082 946	18	1 597 220	15
8	257 326	36	371 126	33	628 452	26
9	490 473	25	468 229	37	958 702	21
10	369 317	30	314 709	30	684 026	22
11	130 388	37	139 181	43	269 569	28
12	76 013	51	250 121	39	326 134	31
13	106 081	52	58 898	54	164 979	40
14	46 439	84	30 847	70	77 286	56
15	401	144	68 048	61	68 449	60
16	33 516	56	24 567	48	58 082	39
17	26 463	58	3 171	57	29 634	52
18	10 057	98	26 314	85	36 371	67
19	1 702	80	135	115	1 837	75
20	1 702	92	3 222	96	4 924	73
21	–	–	176	145	176	145
22	–	–	967	109	967	109
Undetermined	291	117	376	118	667	88
Total	3 416 170		3 739 301		7 155 471	
MWCV (%)		30.6		31.7		23.4

Appendix D: Age-length keys

Table D1: Age-length key used to convert the scaled length distributions to age distributions; data collected during the 2006–07 fishing year in EMA 1. Each row gives the proportion at age of each length class. The total number of observations in each length class is also provided.

Males

	Age (years)																										
Length	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	≥ 25	*n*
≤ 26	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
27	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
28	–	–	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
29	–	–	–	0.63	0.25	–	0.13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	8
30	–	–	–	0.17	0.17	0.33	0.33	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
31	–	–	–	–	0.67	0.33	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
32	–	–	–	–	–	0.57	0.29	0.14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7
33	–	–	–	–	–	0.29	0.43	0.14	0.14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7
34	–	–	–	–	0.10	0.30	0.30	0.20	0.10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
35	–	–	–	–	–	–	0.50	0.33	0.17	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
36	–	–	–	–	–	0.50	0.25	0.17	–	0.08	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	12
37	–	–	–	–	–	0.20	0.20	0.30	0.10	0.10	–	0.10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
38	–	–	–	0.14	0.43	0.29	–	–	0.14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7
39	–	–	–	–	0.63	0.25	–	0.13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	8
40	–	–	–	–	–	0.50	0.38	–	–	–	0.13	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	8
41	–	–	–	–	–	0.09	0.09	0.36	0.09	0.09	0.09	–	0.09	–	0.09	–	–	–	–	–	–	–	–	–	–	–	11
42	–	–	–	–	0.09	0.09	–	0.36	0.18	0.18	–	–	–	0.09	–	–	–	–	–	–	–	–	–	–	–	–	11
43	–	–	–	–	–	–	0.43	–	–	0.29	0.29	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7
44	–	–	–	–	–	–	0.09	–	0.09	0.45	0.18	0.09	–	0.09	–	–	–	–	–	–	–	–	–	–	–	–	11
45	–	–	–	–	–	–	–	0.14	0.14	0.14	0.57	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7
46	–	–	–	–	–	–	–	–	–	0.43	–	0.43	–	0.14	–	–	–	–	–	–	–	–	–	–	–	–	7
47	–	–	–	–	–	–	–	–	–	–	0.10	0.20	0.20	0.10	–	–	0.20	0.10	0.10	–	–	–	–	–	–	–	10
48	–	–	–	–	–	–	–	–	–	–	–	–	0.29	–	0.14	–	0.29	0.29	–	–	–	–	–	–	–	–	7
49	–	–	–	–	–	–	–	–	0.29	–	–	0.14	0.29	0.14	–	–	–	0.14	–	–	–	–	–	–	–	–	7
50	–	–	–	–	–	–	–	–	–	–	–	–	0.17	0.17	0.33	–	–	–	–	0.17	0.17	–	–	–	–	–	6
51	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.25	0.25	0.25	0.25	–	–	–	–	–	4
52	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1.00	–	–	–	–	–	–	–	–	–	–	1
≥ 53	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0

Table D1: Continued.

Females

Length	Age (years) 0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	≥ 25	*n*
≤ 26	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0
27	–	–	–	–	–	1.00	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
28	–	–	–	0.33	–	0.67	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3
29	–	–	–	0.50	0.50	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2
30	–	–	–	0.57	0.29	0.14	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	7
31	–	–	–	–	0.60	0.20	–	0.20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5
32	–	–	–	0.10	–	0.50	0.30	0.10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
33	–	–	–	0.10	0.10	0.70	–	0.10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
34	–	–	–	0.17	–	0.17	0.17	0.33	0.17	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
35	–	–	–	–	0.09	0.55	0.18	0.18	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	11
36	–	–	–	–	–	–	0.33	0.50	0.17	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
37	–	–	–	–	–	0.25	0.12	0.62	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	8
38	–	–	0.10	–	–	0.30	–	0.40	0.20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
39	–	–	–	0.10	0.10	0.20	0.30	0.20	0.10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
40	–	–	–	–	0.10	0.10	0.20	0.30	–	0.20	0.10	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
41	–	–	–	–	–	–	0.33	0.50	–	0.17	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
42	–	–	–	–	–	–	–	0.67	–	0.33	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	6
43	–	–	–	–	–	–	0.20	0.20	0.20	0.10	–	0.10	0.20	–	–	–	–	–	–	–	–	–	–	–	–	–	10
44	–	–	–	–	–	0.14	0.14	–	0.29	0.14	0.14	–	0.14	–	–	–	–	–	–	–	–	–	–	–	–	–	7
45	–	–	–	–	–	–	–	–	0.18	0.09	0.36	0.18	0.18	–	–	–	–	–	–	–	–	–	–	–	–	–	11
46	–	–	–	–	–	–	–	0.10	0.10	–	0.30	0.10	0.10	–	–	0.20	–	–	0.10	–	–	–	–	–	–	–	10
47	–	–	–	–	–	–	–	–	–	0.14	0.29	–	–	0.29	0.14	0.14	–	–	–	–	–	–	–	–	–	–	7
48	–	–	–	–	–	–	–	–	–	–	0.10	0.20	0.20	0.20	0.10	–	0.20	–	–	–	–	–	–	–	–	–	10
49	–	–	–	–	–	–	–	–	–	–	0.20	–	0.10	0.10	0.10	0.10	0.20	–	0.10	–	0.10	–	–	–	–	–	10
50	–	–	–	–	–	–	–	–	–	–	–	–	0.09	0.09	–	0.09	0.27	0.27	0.09	–	–	–	0.09	–	–	–	11
51	–	–	–	–	–	–	–	–	–	–	0.15	–	0.08	0.08	0.23	0.08	–	0.15	0.08	0.08	0.08	–	–	–	–	–	13
52	–	–	–	–	–	–	–	–	–	–	–	–	–	0.40	0.20	0.20	–	–	–	–	–	0.20	–	–	–	–	5
≥53	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0