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An update on Australian otolith collection activities, direct ageing and length at age keys for the Australian surface fishery

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Important disclaimer

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Contents

1 Abstract

Australia continued to collect and archive otoliths from SBT caught by the Australian surface fishery during the 2013/14 fishing season. Age was also estimated for 95 SBT caught by the surface fishery in the previous fishing season (2012/13), and the proportions-at-age of SBT caught in the fishery was estimated using three methods - the standard age-length-key (ALK), the method of Morton and Bravington (hereafter referred to as the M&B method) with known growth, and the M&B method with unknown growth. The estimated proportions at age were compared with previous seasons. Provided that the length frequency data are representative of fish caught in the surface fishery, and given our goal of estimating proportions at age in the *catches* (not in the *population*), the M&B estimator with "unknown growth" (see section 4.3) should be more accurate. The results from applying the M&B method with unknown growth suggested there was a much higher proportion of age 2 and smaller proportion of age 3 fish for the 2010/11 and 2011/12 seasons than in previous seasons. However, this was no longer the case in 2012/13, with the estimated proportion of fish at ages 2 and 3 (0.16 and 0.75 respectively) returning to levels more commonly seen in the past. The work continues to highlight the need for further discussion within the CCSBT regarding the technical details of how the direct age data could be incorporated into the stock assessment model in the future.

2 Introduction

Most stock assessments, including those for southern bluefin tuna (SBT), use age-based models to estimate stock abundance. Such models require estimates of the annual catch in numbers at age (catch-at-age) for each fishery as an input. For many fisheries, however, the only direct information available is the size distribution of the catch (catch-at-length) and total number caught. Although length provides some information on the age structure of the catch, since age and length are related, there is a need to convert catch-at-length into catch-at-age. Many simulation studies have shown that using direct age data as opposed to size data in age-structured assessment models is more likely to give unbiased estimates of stock status (Ono et al. 2014). Direct ageing from hard parts (otoliths) identifies different age groups among similarly sized fish and is generally considered a fundamental requirement of fisheries monitoring, particularly for long-lived species such as SBT.

The most common way of using direct age data in assessments has been the construction of age-length-keys from which proportions at age in the catch can be estimated. Morton and Bravington (2003) developed more efficient parametric methods to estimate proportions-at-age for SBT and recommended between 100-200 otoliths from the Australian surface fishery would be sufficient to provide acceptable levels of precision (CVs under 20%). Since 2002, we have been archiving between 200-400 otoliths annually, but only ageing (reading) 100. The additional otoliths provide a reserve which can be aged if we find that the CVs of the proportion-at-age estimates based on 100 samples are too high (i.e., greater than 20%).

Australia has been obliged to provide annual length-at-age estimates for the surface fishery from the 2002 fishing season to CCSBT. The 2011 CCSBT-ESC listed as a priority item consideration of new data sources in the operating model with particular reference to direct ageing data (Anon, 2011). In 2012, as part of the review of the Scientific Research Program, the CCSBT ESC reiterated the central role and importance of these direct age data and the need to improve the representative nature of samples from all fisheries (Anon, 2012). Support was also noted for a new inter-laboratory comparison of direct ageing methods.

The current paper provides an update on SBT otolith sampling in Australia for 2013/14, and age estimation of a subsample of otoliths from the 2012/13 fishing seasons to meet our CCSBT commitment. Updated estimates of proportion-at-age of the surface fishery are provided.

3 Methods

3.1 Otolith sampling in 2013/14

Developing an otolith sampling scheme from the surface fishery sector is challenging because of the farming (aquaculture) component in Port Lincoln. The challenge is that fish can grow between their time of capture in the wild and the time when they are harvested after having been retained in farms during the grow-out phase. It is also important to note that the period when fish for farming are captured corresponds to a season when juvenile SBT are growing rapidly. Thus, otoliths collected from fish at the time of harvest, at the completion of the grow-out phase, will not provide the best length-at-age data for developing age-length keys for the fishery. In response to these issues, Australia has developed a sampling program based on fish that die either during towing operations or during the first two weeks after fish are transferred from towing cage into farm cages.

The current protocol requires that all farm operators provide a sample of 10 fish that have died either in towing operations or within the first weeks after fish have been transferred to stationary farm cages. A company contracted to the Australian Fisheries Management Authority (AFMA), Protec Marine Pty Ltd, measures the length of each fish and extracts the otoliths from these mortalities. The otoliths and length data are sent to CSIRO for archiving. In the past, there have been between ~25 and 40 tow cages a year, giving a total of 250-400 otoliths collected from this sector each season. However, in 2012/13 low mortalities in the cages during the towing operations resulted in only 96 SBT being sampled for otoliths (Farley et al. 2013).

3.2 Direct ageing for 2012/13

Of the 96 otoliths collected from the Australian surface fishery in the 2012/13 season (see Farley et al., 2013), 95 were suitable for age determination which is below the minimum 100-200 required based on the work by Morton and Bravington (2003). The fish selected for age estimation ranged in size from 61-128 cm fork length (FL). One otolith from each pair was selected and weighed to the nearest 0.1mg if undamaged. Otolith weight was then compared to fork length to check that the capture data associated with each otolith was correct. Gunn et al. (2008) showed that the relationship between otolith weight and fork length was curvilinear (R^2 = 0.903), and thus if any outliers were detected, they could be removed. Outlying data points were not found in the data.

Otoliths were prepared and read by 'Fish Ageing Services Pty Ltd' (FAS) in Victoria using the techniques described by Anon (2002). The SBT otolith reader at the FAS was previously associated with the Central Ageing Facility (CAF), and has read SBT otoliths since 1998.

All otoliths were embedded by FAS in clear casting polyester resin. Four serial transverse sections were cut from each otolith with one section including the primordium. The preparation of multiple sections for most otoliths had the advantage of increasing the likelihood of at least one section being clear enough to interpret. All sections were mounted on glass slides with resin and polished to 400 µm following the protocols given in Anon (2002).

Opaque (dark) and translucent (light) zones were visible along the ventral 'long' arm of each otolith section, and the number of opaque zones was counted. An ageing reference set (n=50 sectioned otoliths) was read by FAS prior to reading each season's otoliths for calibration purposes.

The selected otoliths were then read at least two times by FAS without reference to the previous reading, size of fish or capture date. An otolith reading confidence score was assigned to each otolith reading:

0. No pattern obvious

1. Pattern present – no meaning

2. Pattern present – unsure with age estimate

3. Good pattern present – slightly unsure in some areas

4. Good pattern – confident with age estimate

5. No doubt

A subset of otoliths was then read once by a secondary otolith reader (from CSIRO) who was trained in SBT otolith reading in 1996 and has read SBT otoliths routinely since that time. All readings were conducted without reference to the size of the fish, date of capture, otolith weight or to previous readings.

The precision of readings was assessed using the coefficient of variation (CV) (Chang, 1982; Campana et al., 1995).

A potential problem in assigning age for SBT is that the theoretical birth date is January 1 (middle of the spawning season; see CCSBT-ESC-0509-Info) and opaque increments are formed during winter (May and October) (Gunn et al., 2008). Using the number of increments as an estimate of age can be misleading if SBT are caught during the winter. However, SBT in the GAB are caught during summer (November to April), so there is less confusion about assigning an age from increment counts. For example, SBT with 2 increments in their otoliths were classed as 2 year-olds. Thus, SBT of the same age, caught in the same fishing season, were spawned in the same spawning season.

3.3 Age distribution of the surface fishery

The most common way of estimating proportions at age in a given year, using age-at-length samples and a length distribution sample in the same year, is via an age-length key (ALK). The length frequency data are multiplied by the proportion of fish in each age class at a given length to give numbers (or proportions) at age. In mathematical terms, the proportion of fish of age *a*, p_a, is estimated as follows:

$$\hat{p}_a = \sum_l \frac{N_l}{N} \frac{n_{al}}{n_l}$$

where N_l is the number of fish in the length sample of length *l*, n_{al} is the number of fish in the age-length sample of age *a* and length *l*, $N = \sum_l N_l$ and $n_l = \sum_a n_{al}$.

A drawback of the ALK method is that it makes no use of the information about likely age contained in the length frequency data alone—thus it is inefficient, with variance up to 50% higher than necessary (Morton & Bravington 2003, see Table 2). This is especially true for fisheries that catch young fast-growing fish, such as the Australian SBT surface fishery, where length is quite informative about age. As an alternative to the ALK, Morton and Bravington (2003) developed a parametric method which makes more efficient use of the information in both the length frequency and direct age data. The basis for the method is maximization of the following log-likelihood within each year:

$$\Lambda = \sum_l \left\{ N_l \log\left(\sum_a p_a p_{l|a} \right) + \sum_a n_{al} \log\left(p_a p_{l|a} \right) \right\}$$

where N_l, n_{al} and p_a are defined as above for the ALK, and $p_{l|a}$ is the probability that a fish of age *a* will have length l. Recall that the proportions at age (p_a) are what we are interested in estimating.

Here we assume $p_{l|a}$ follows a normal distribution with mean and variance that are either (a) known *a priori*, or (b) unknown and needing to be estimated together with the proportions at age. The former “known growth” approach is slightly more efficient if accurate estimates are available and if growth is consistent across cohorts; the latter “unknown growth” approach is robust to changes in growth and almost as efficient, so it is generally to be preferred. Variances for the proportion at age estimates can be obtained from the Hessian using standard likelihood theory.

Previously we applied the standard ALK method and the method of Morton and Bravington (hereafter referred to as the M&B method) to the age-length and length-frequency data from the Australian surface fishery in seasons 2001/02 through 2011/12 (see Farley et al., 2013). Here we update the analysis to include data from the 2012/13 season. For the M&B method, we applied both the known and unknown growth approaches for comparison. In the known growth case, mean and standard deviation (SD) in length at age were assumed equal to the values in Table 1. These values were derived using the growth curve for the 2000s reported in Table 3 of Eveson (2011) and assuming the mid-point of the surface catches to be 1 February. The SDs include individual variation in growth, measurement error, and growth within the fishing season, taken as 1 December to 1 April (see Polacheck et al. 2002, p.44-48, for more information on calculating variance in expected length at age). In the unknown growth case, we found it was necessary to set lower and upper bounds on the mean length at age parameters, or else unrealistic estimates could be obtained for data-limited age classes (discussed in greater detail later). We chose fairly generous bounds equal to the mean length at age ±2 standard deviations (SDs), as calculated from the otolith age-length data. Note that in past years we have used the mean and SD values from Table 1 (derived from the growth model). The results are generally not sensitive to which option is chosen, but this year we were unable to obtain variance estimates for the proportions at age in the 2012/13 season using the values from Table 1 (the problem being caused by having one fish in each of age-classes 7 and 8 in the otolith data for this season – see Table 2).

Table 1. Mean and standard deviation (SD) in length at age derived from the growth model for the 2000s.

AGE	MEAN	SD
1	55.0	5.7
2	81.9	6.3
3	102.6	6.8
4	114.7	7.3
5	124.8	7.8
6	133.4	8.2
7	140.7	8.5
8	146.8	8.8

Length samples are taken from the tow cages each year (previously 40 fish were sampled per cage but this was increased to 100 fish per cage in the 2012/13 season), and the data scaled up by the number of fish in each tow cage to estimate the length frequency distribution of the entire catch. For the M&B method, it is important to estimate the "effective sample size"[1] of the length data in order to correctly weight the relative information of direct age data versus length data in the likelihood, and also to estimate variances correctly. This entails a re-scaling of the length frequencies derived from the scaled-up tow cage samples, as described in Basson et al. (2005). Specifically, if T is the number of tow cages in a particular season, c_i is the number of fish in tow cage i, m_i is the total number of fish sampled from tow cage i, and m_{il} is the number of fish of length l in the sample from tow cage i, then we estimate π_l, the frequency of fish of length l over all tow cages, to be

[1] The length samples taken from the tow cages do not constitute independent random draws from the entire catch (since the lengths of fish within a tow cage are not representative of the entire catch). The effective sample size refers to the sample size that leads to the equivalent variance as the tow cage samples had in fact been independent random draws.

$$\hat{\pi}_l = \sum_i c_i^* \frac{m_{il}}{m_i}$$

where

$$m_i = \sum_l m_{il}$$

and

$$c_i^* = \frac{c_i}{\sum_{j=1}^{T} c_j}.$$

The variance of $\hat{\pi}_l$ is estimated by

$$\mathrm{V}[\hat{\pi}_l] = \sum_i \frac{c_i^{*2}}{m_i}$$

Finally, we estimate the effective sample size of fish of length *l* to be

$$\tilde{N}_l = \frac{\hat{\pi}_l}{\mathrm{V}[\hat{\pi}_l]}.$$

These are the numbers we used as the N_l's for both the ALK and M&B methods.[2]

For the ALK method, the age-at-length and length frequency data were binned into 5-cm length classes. Generally, enough otoliths are available so that there are very few "missing rows" in the ALK for any year when 5-cm length bins are used; i.e., there are very few length bins for which the proportions-at-age cannot be calculated. However, this is not always the case, as the results for the 2010/11 season has shown (Farley et al., 2012). For the M&B method, the data were binned into 1-cm length classes.

4 Results and Discussion

4.1 Otolith sampling in 2013/14

A total of 146 sets of otolith were collected from the Australian surface fishery this year. The sampled fish were between 61 and 128cm fork length (FL) with a mode around 100-115 cm FL (Fig. 1).

It is clear that the current sampling protocol does not provide either a fixed number of otoliths from each length class nor has it provided representative samples of otoliths from all length classes in proportion to their abundance in the catch from the surface fishery. In previous seasons, this has often resulted in an apparent disproportionate number of large fish sampled compared to the size distribution of SBT from the surface fishery (based on CCSBT CatchAtLength data). The exact reason for the disparity is unclear, but could be the result of selection biases in the choice of dead fish to retain for otolith sampling or due to size related differences in towing and early farming related mortality rates. It could also be due to biases in the estimated size distributions of fish in the tow cages. The resulting age-length keys have "missing rows" where there are no or very few age estimates for the smaller length classes. The missing rows could lead to highly uncertain (less robust) age-length-keys and highlights the issue of representative otolith sampling for

[2] For the ALK method, which only makes use of the proportion of fish of a given length class and not the absolute numbers, it should not matter whether we use the scaled-up tow cage numbers or the re-scaled effective sample sizes, but for consistency we use the same numbers for all methods.

the fishery. It is unknown if sufficient fish were sampled within each length class to estimate the age distribution of the surface fishery catch in the 2013/14 fishing season. Reliable estimates of catch-at-age are also dependent on measuring a representative sample of the catch.

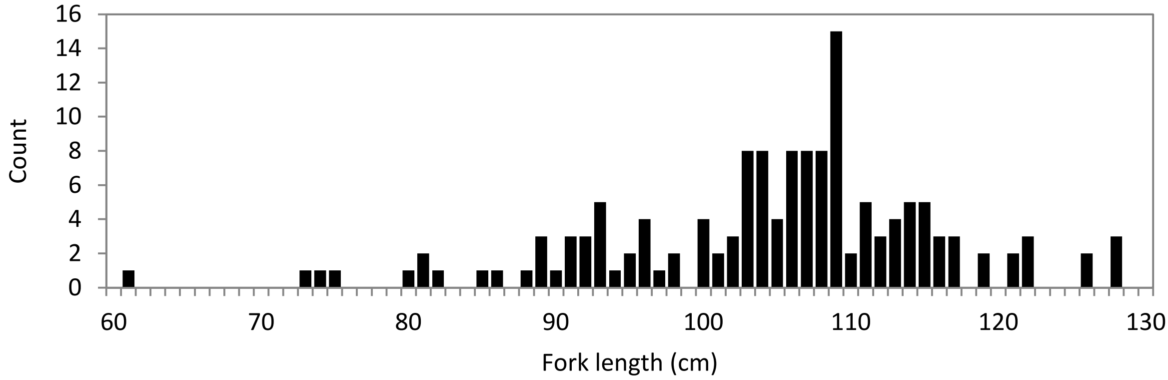

Figure 1. Length frequency of SBT with otoliths sampled from the Australian surface fishery in the 2013/14 fishing season (n=146).

4.2 Age estimates for 2012/13

A final age estimate was given to all 95 SBT selected for ageing. Ages ranged from 2-8 years and the length to age relationships is given in Fig. 2. The coefficient of variation between readings was 5.07%. When successive readings of otoliths differed, they were only by ±1 (n=22) or ±2 (n=1) indicating a good level of precision. For these fish, a final age was obtained by re-examining the otolith with the knowledge of the previous two age estimates as recommended by Anon (2002).

Table 2 shows the numbers of fish by age in each 5-cm length class for the fishing seasons. These data are used in both the standard ALK and M&B methods of estimating the proportions of fish at age in the surface fishery, noting that for the M&B method the data are broken down by 1-cm, as opposed to 5-cm, length classes.

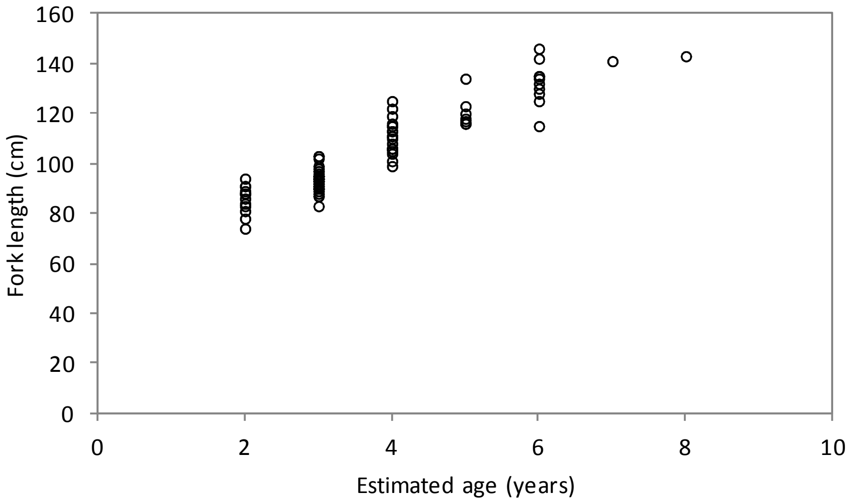

Figure 2. Length at age for SBT caught in the Australian surface fishery in the 2012/13 fishing season (n=95).

Table 2. Age-length-key for the 2012/13 fishing seasons for the Australian surface fishery. The lower length of each 5cm length bin is given in the first column and ages are shown across the top.

2012/13	2	3	4	5	6	7	8	Total
70	1							1
75	1							1
80	3	1						4
85	5	4						9
90	3	23						26
95		11	1					12
100		3	2					5
105			6					6
110			5					5
115			4	4	1			9
120			1	2				3
125			1		2			3
130				1	3			4
135					3			3
140					1	1	1	3
145					1			1
Total	13	42	20	7	11	1	1	95

4.3 Age distribution of the surface fishery 2001/02 to 2012/13

The proportions at age estimated from the standard ALK method, the M&B method with known growth, and the M&B method with unknown growth are given in Table 3, Table 4 and Table 5 respectively. For easier comparison, the results are also plotted in Figure 3. For many seasons there is reasonably good agreement between the various methods, but for others the estimated proportions at ages 2-4 are considerably different. For example, in the 2009/10 season ages 3 and 4 are different, while in 2010/11 ages 2 and 3 are different. The M&B results differ significantly from the standard ALK results in seasons where the age-length data and length-frequency data suggest different proportions of fish in each age class, since the M&B method takes the length-frequency data into account whereas the ALK method uses only the age-length data.

The results from the ALK method for the 2010/11 season highlight the problem when the age-length data does not adequately cover the length range found in the length-frequency data (Farley et al. 2012). Specifically, there are no fish belonging to length bin 85-90 cm in the age-length data, despite approximately 7% of the observations from the length-frequency data being in this range. As such, these fish do not get attributed to any age class and the estimated proportions-at-age for the 2010/11 season using the ALK method only sum to 92%. The proportions could be scaled up to equal 1, but this is not a very satisfactory solution because we know the majority of fish of lengths 85-90 cm would belong to ages 2 and 3 in some proportion. The M&B method does not suffer from this problem because it uses the information about age from the length-frequency data as well in order to fill in these “gaps” in the age-length key.

The M&B method with unknown growth produces estimates that fit the length data very closely for all seasons (Figure 4), with the exception of the 2010/11 season (see below). In comparison, the M&B method with known growth does not fit the length data nearly so well (Figure 5). This is to be expected since the unknown growth method estimates the mean (Table 6) and SD (Table 7) in length at age based on the data, and these estimates can be quite different than those derived from the growth model (Table 1).

The growth model was estimated based on age-length data and tag-recapture data for fish born in the 2000s. It does not include the length-frequency data due to concerns about size-selective fishing (Polacheck et al. 2002, Appendix 3), and is not specific to fish in the GAB nor to seasons. Provided that the length-frequency data are representative of fish caught in the surface fishery, and given our goal of estimating proportions at age in the *catches* (not in the *population*), the M&B estimator with unknown growth should be more accurate.

The proportion at age estimates from the M&B method with unknown growth suggest that in the 2010/11 and 2011/12 seasons there was a higher proportion of age 2 fish and smaller proportion of age 3 fish than in previous seasons. However, in the 2012/13 season, this was no longer the case, with the estimated proportion of fish at ages 2 and 3 (0.16 and 0.75 respectively) returning to levels more commonly seen in the past.

The lack of a close fit to the length-frequency data for the 2010/11 season using the M&B method with unknown growth is most likely due to the mean lengths of age 2 and 3 fish in the direct age-length data being much larger than the modes for age 2 and 3 fish in the length-frequency data. For example, the mean length of age 2 fish from the direct aging data is 91.4 cm whereas the mode that presumably corresponds to age 2 fish in the length-frequency data is around 82 cm (Figure 4). The reason for this discrepancy is unclear, but it is unlikely to be due to incorrect age estimation by FAS as the CV between independent readers was consistently low and no bias detected.

The relatively small numbers of otoliths for fish of age 1 and older than age 4, as well as the low proportion of fish corresponding to these age classes in the length-frequency data, can lead to difficulties in estimating mean length for these ages. Without constraints, it is hard to estimate 'sensible' mean lengths at age for these age classes. Even with the generous bound constraints that we imposed, some estimates still hit the bounds (Table 6). Since the proportion at age estimates are so close to 0 for these age classes, the consequences of incorrectly estimating their mean length should be small. Of some concern, however, are the mean length estimates for age 4 fish, which are often estimated to be very close to (and in 2003/04 smaller than) the mean length for age 3 (Table 6; Figure 4).

It is possible to impose tighter bounds on the mean length at age parameters, but doing so simply results in the age 4 estimates falling on the lower bound, so it is not a very satisfactory solution. A possibility for future consideration is to incorporate *a prior* distributions on the mean length at age parameters—this would provide an intermediate approach to the known and unknown growth methods currently available.

CVs of the estimated proportions at age using the M&B method with unknown growth are provided in Table 8. They were calculated by dividing the square root of the Hessian-based variance estimates by the estimates. Where the estimated proportion at age was less than 0.01 (i.e., for age 1 and most of ages 5 and above), we have opted not to show the CV because dividing by such a small number can lead to a very large and misleading CV. In general, the proportion at age estimates are quite precise for ages 2 and 3 (CVs < ~10%), but less so for age 4 and 5 (ranging from 14% to 39%) since these older age classes have less data available. However, for the 2010/11 season, the age 2 and 3 estimates have much higher CVs than previous seasons (22% and 23% respectively). As discussed above, there is a contrast between the 2010/11 direct age data and length-frequency data for fish of ages 2 and 3, which results in larger uncertainty in the estimated proportions at age for these age classes. The age 3 estimate for 2011/12 and the age 2 estimate for 2012/13 also have higher CVs than most seasons; this may in part be due to the lack of separation in the length modes for age classes 2 and 3 in these seasons, which makes the length frequency data less informative for age estimation.

We stress that the proportions at age derived as part of this project apply only to fish caught in the GAB in the surface fishery. They are unlikely to apply to the population of fish found in the GAB due to the size-selective nature of the surface fishery, and they are less likely to apply to the global population since data collected in the GAB are not representative of fish found in other regions (for example, age-1 fish found off Western Australia are smaller on average than age-1 fish found in the GAB at the same time, likely due to a later spawning event (Polacheck et al. 2002).

Table 3: Proportions at age for each fishing season estimated using the standard ALK method. (Four decimal places are shown to retain the small but non-zero proportions for ages 1 and >4). NA = not applicable.

SEASON	AGE 1	2	3	4	5	6	7	8
2001-2002	NA	0.0626	0.5130	0.3742	0.0457	0.0039	0.0006	NA
2002-2003	0.0013	0.0652	0.5726	0.3256	0.0350	0.0002	0.0001	0.0000
2003-2004	0.0000	0.3515	0.5817	0.0665	0.0003	0.0000	0.0000	NA
2004-2005	0.0000	0.2853	0.5448	0.1572	0.0122	0.0003	0.0001	0.0000
2005-2006	0.0000	0.4505	0.5448	0.0044	0.0002	0.0001	NA	NA
2006-2007	0.0023	0.3571	0.5405	0.0996	0.0004	0.0001	0.0000	NA
2007-2008	0.0000	0.2637	0.6698	0.0624	0.0036	0.0005	NA	NA
2008-2009	NA	0.3531	0.5273	0.1065	0.0052	0.0000	NA	NA
2009-2010	NA	0.1961	0.4871	0.2798	0.0253	0.0024	NA	NA
2010-2011	NA	0.4864	0.3519	0.0667	0.0124	0.0029	0.0000	NA
2011-2012	NA	0.5886	0.3970	0.0118	0.0022	0.0000	0.0000	NA
2012-2013	NA	0.1749	0.7441	0.0786	0.0020	0.0004	0.0000	0.0000

Table 4: Proportions at age for each fishing seasons estimated using the M&B method with known mean and variance in length at age. NA = not applicable.

SEASON	AGE 1	2	3	4	5	6	7	8
2001-2002	NA	0.0575	0.8812	0.0470	0.0108	0.0023	0.0012	NA
2002-2003	0.0013	0.1212	0.8333	0.0318	0.0091	0.0021	0.0005	0.0007
2003-2004	0.0048	0.3336	0.6394	0.0176	0.0036	0.0010	0.0001	NA
2004-2005	0.0016	0.5028	0.4759	0.0129	0.0042	0.0009	0.0012	0.0006
2005-2006	0.0014	0.3502	0.6379	0.0096	0.0008	0.0002	NA	NA
2006-2007	0.0022	0.5585	0.4179	0.0181	0.0026	0.0005	0.0002	NA
2007-2008	0.0006	0.2681	0.7065	0.0197	0.0040	0.0011	NA	NA
2008-2009	NA	0.3247	0.6413	0.0235	0.0086	0.0018	NA	NA
2009-2010	NA	0.1556	0.7692	0.0513	0.0165	0.0074	NA	NA
2010-2011	NA	0.3148	0.6384	0.0313	0.0094	0.0059	0.0003	NA
2011-2012	NA	0.6988	0.2857	0.0114	0.0029	0.0009	0.0003	NA
2012-2013	NA	0.3241	0.6632	0.0088	0.0018	0.0018	0.0002	0.0002

Table 5: Proportions at age for each fishing seasons estimated using the M&B method with unknown mean and variance in length at age. NA = not applicable.

SEASON	AGE 1	2	3	4	5	6	7	8
2001-2002	NA	0.0803	0.7093	0.1780	0.0279	0.0040	0.0006	NA
2002-2003	0.0016	0.1465	0.6200	0.2061	0.0256	0.0002	0.0001	0.0000
2003-2004	0.0004	0.3783	0.5647	0.0565	0.0001	0.0000	0.0000	NA
2004-2005	0.0000	0.5025	0.4526	0.0393	0.0053	0.0003	0.0000	0.0000
2005-2006	0.0000	0.3664	0.6322	0.0010	0.0002	0.0001	NA	NA
2006-2007	0.0078	0.2876	0.6621	0.0422	0.0003	0.0001	0.0000	NA
2007-2008	0.0000	0.2287	0.7228	0.0438	0.0042	0.0005	NA	NA
2008-2009	NA	0.2930	0.6170	0.0864	0.0035	0.0000	NA	NA
2009-2010	NA	0.1969	0.5783	0.1939	0.0290	0.0019	NA	NA
2010-2011	NA	0.4775	0.4438	0.0659	0.0100	0.0028	0.0000	NA
2011-2012	NA	0.5885	0.3943	0.0151	0.0022	0.0000	0.0000	NA
2012-2013	NA	0.1568	0.7500	0.0902	0.0022	0.0008	0.0000	0.0000

Table 6: The estimated mean length at age (in cm) for each fishing season using the M&B method with unknown mean and variance in length at age. NA = not applicable.

SEASON	AGE 1	2	3	4	5	6	7	8
2001-2002	NA	85.3	98.0	102.3	113.8	119.7	136.3	NA
2002-2003	72.2	84.8	100.0	104.3	113.1	129.7	132.6	141.6
2003-2004	66.2	85.8	98.8	98.6	113.1#	128.3#	122.7	NA
2004-2005	44.5#	84.2	99.8	104.3	111.5	120.0#	137.7	137.5
2005-2006	69.2*	85.4	97.9	120.4	130.7	132.8	NA	NA
2006-2007	82.2	83.5	93.7	107.4	129.2	129.8	141.7	NA
2007-2008	57.3	86.2	96.1	105.3	111.4	133.0	NA	NA
2008-2009	NA	85.4	96.6	107.1	117.2	125.4	NA	NA
2009-2010	NA	86.0	98.5	107.6	116.9	126.1	NA	NA
2010-2011	NA	91.2	95.7	113.7	124.6	125.7	143.5	NA
2011-2012	NA	86.8	93.8	112.8	115.3	137.8	126.2	NA
2012-2013	NA	86.7	93.2	103.4	118.0	119.4	140.8	143.4

[#] Estimate hit lower bound.

* Estimate hit upper bound.

Table 7: The estimated standard deviation in length at age (in cm) for each fishing season using the M&B method with unknown mean and variance in length at age. NA = not applicable.

SEASON	AGE 1	2	3	4	5	6	7	8
2001-2002	NA	4.2	3.2	7.3	7.4	7.6	0.2	NA
2002-2003	2.9	4.4	4.8	6.9	6.6	4.6	2.2	2.1
2003-2004	3.5	5.2	3.9	6.4	5.1	4.4	5.6	NA
2004-2005	4.0	3.5	4.3	6.8	7.9	8.8	6.4	7.9
2005-2006	3.1	4.6	3.6	7.6	4.1	2.8	NA	NA
2006-2007	3.2	3.1	4.2	5.9	2.7	3.0	0.0	NA
2007-2008	0.6	3.6	4.2	7.1	8.9	1.7	NA	NA
2008-2009	NA	3.3	3.8	4.9	3.6	2.3	NA	NA
2009-2010	NA	4.3	3.6	5.3	4.3	3.6	NA	NA
2010-2011	NA	6.4	8.0	5.3	3.5	4.7	0.0	NA
2011-2012	NA	4.8	7.5	4.7	6.3	1.9	6.8	NA
2012-2013	NA	3.8	3.0	5.4	3.5	3.9	0.1	0.0

Table 8: Coefficients of variation (CVs) of the estimated proportions at age for each fishing season using the M&B method with unknown mean and variance in length at age. A dash (--) indicates where the estimated proportion at age was less than 0.01. NA = not applicable.

SEASON	AGE 1	2	3	4	5	6	7	8
2001-2002	NA	0.13	0.03	0.14	0.25	--	--	NA
2002-2003	--	0.10	0.06	0.18	0.39	--	--	--
2003-2004	--	0.05	0.04	0.31	--	--	--	NA
2004-2005	--	0.03	0.04	0.36	--	--	--	--
2005-2006	--	0.06	0.03	--	--	--	NA	NA
2006-2007	--	0.07	0.03	0.18	--	--	--	NA
2007-2008	--	0.10	0.04	0.31	--	--	NA	NA
2008-2009	NA	0.07	0.04	0.19	--	--	NA	NA
2009-2010	NA	0.09	0.05	0.14	0.37	--	NA	NA
2010-2011	NA	0.22	0.23	0.18	0.32	--	--	NA
2011-2012	NA	0.12	0.17	0.34	--	--	--	NA
2012-2013	NA	0.19	0.04	0.08	--	--	--	--

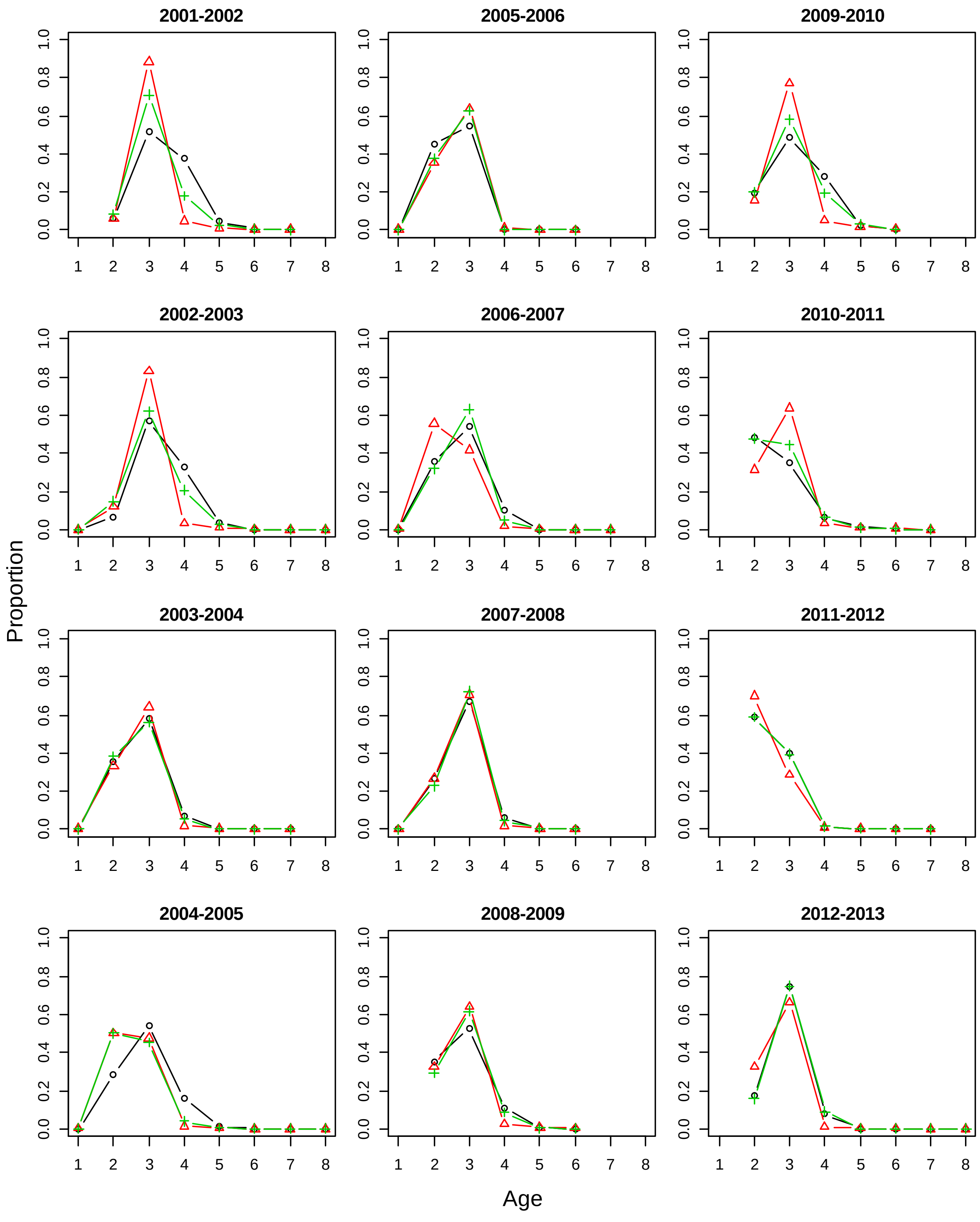

Figure 3. Estimated proportions of fish at age in each fishing season using i) the ALK method (black, open circles); ii) the M&B method with known growth (red, open triangles); iii) the M&B method with unknown growth (green, plus symbols).

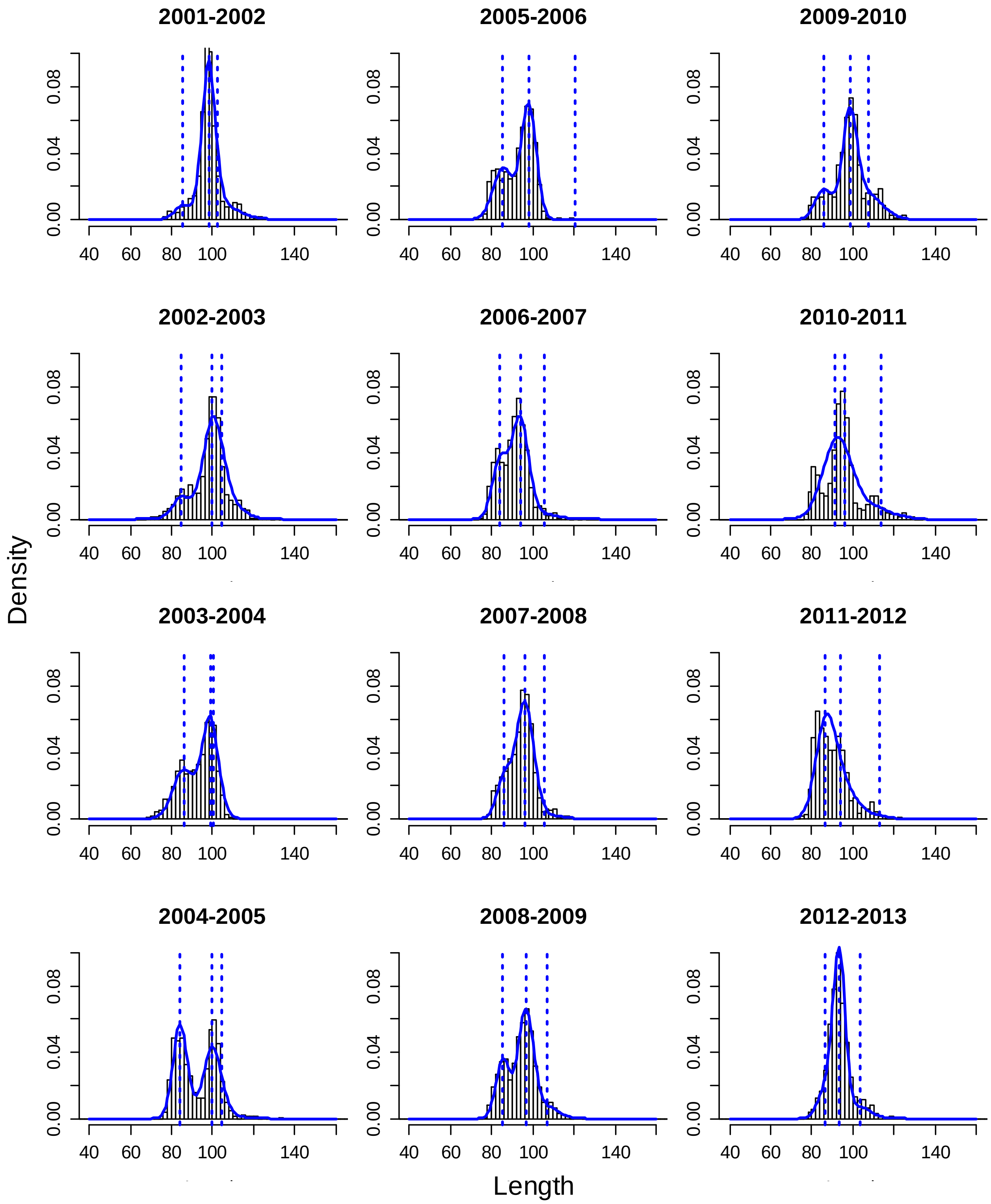

Figure 4. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and estimated mean lengths at age for ages 2-4 from the M&B method with unknown growth (solid blue curve and dashed blue vertical lines).

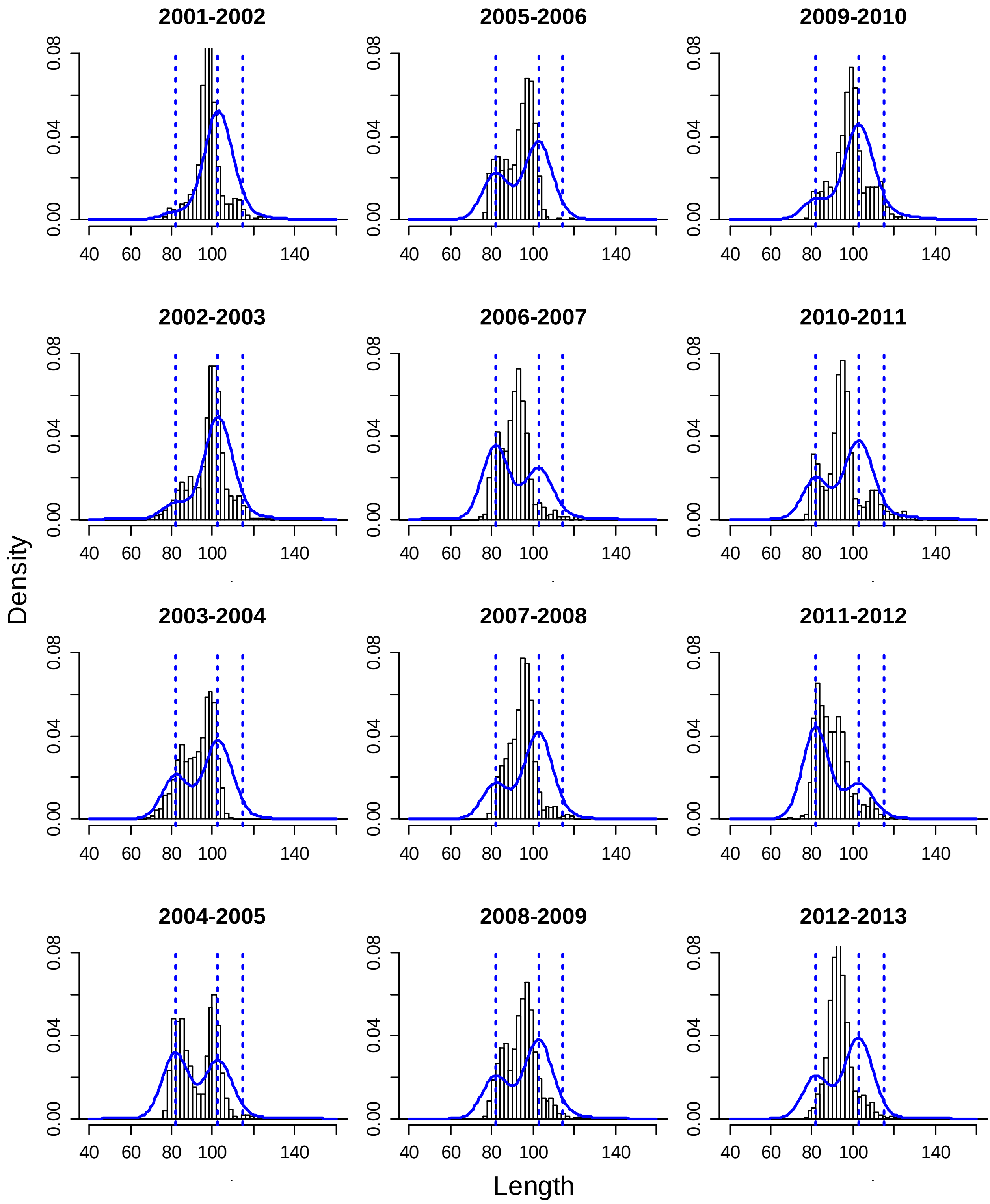

Figure 5. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and "known" mean lengths at age for ages 2-4 from the M&B method with known growth (solid blue curve and dashed blue vertical lines).

5 Conclusions

The proportion at age estimates from the M&B method with unknown growth suggest there was a much higher proportion of age 2 and smaller proportion of age 3 fish in the 2010/11 and 2011/12 seasons than in previous seasons (with the exception of 2004/05). However, this was no longer the case in the 2012/13 season, with the estimated proportion of fish at ages 2 and 3 (0.16 and 0.75 respectively) returning to levels more commonly seen in the past. The proportion at age estimates are quite precise for ages 2 and 3 (CVs generally less than 10%), although there have been some exceptions in recent seasons. In particular, the CVs of the age 2 and 3 estimates for the 2010/11 season were higher than usual due to a contrast between the direct age-length data and the length-frequency data. The age 3 estimate for 2011/12 and age 2 estimate for 2012/13 also have higher CVs than most seasons, which may in part be due to the lack of separation in the length modes for age classes 2 and 3 in these seasons. Finally, the proportion at age estimates for ages 4 and 5 are not as precise (CVs ranging from 14% to 39%) since these older age classes have less data available.

At this stage we consider that the otolith sample sizes for age estimation (100 otoliths per fishing season) provide acceptably low CVs for ages 2 and 3. Whether the higher CVs for age classes 4 and 5 are adequate can only be evaluated once the direct age data are used in the SBT operating model. If it is important, then there will be a need to re-evaluate the sampling design for otoliths including (a) number sampled per length class and (b) the number of otoliths that need to be read. The estimated proportions at age will also only be representative of the catch if the size frequency distribution of the fish sampled is representative.

This work again highlights the need for continued discussion within the CCSBT regarding development of protocols for obtaining representative samples of length at age from all fisheries, and the technical details of how the direct age data could be incorporated into the operating model in the future. Preece et al. (2012) provided information on the inclusion of the direct age data in the operating models. The CCSBT ESC restated the importance of collecting size and age data by area for all fisheries (Anon, 2012).

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