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

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CCSBT-ESC/1809/12

Prepared for the Extended Scientific Committee for the Twenty Third Meeting of the Scientific Committee, San Sebastian, Spain, 3-8 September, 2018

Citation

Farley J, Eveson P (2018). An update on Australian otolith and ovary collection activities, direct ageing and length at age keys for the Australian surface fishery. CCSBT-ESC/11809/12, Twenty Third Meeting of the Scientific Committee, 3-8 September, San Sebastian, Spain.



Acknowledgments

There are many people we would like to acknowledge for their support. Our thanks go to Seatec Pty Ltd for collecting otoliths as part of routine collecting from the South Australian tuna farms in Port Lincoln under AFMA supervision. Our appreciation also goes to Kyne Krusic-Golub (Fish Ageing Services) for sectioning and reading the otoliths, and Scott Cooper for database support. We also thank the boat owners and skippers, and processing factory staff, for allowing us to samples ovaries. This work was funded by AFMA and CSIRO Oceans and Atmosphere.

# Contents

# 1 Abstract

This report provides an update on (i) the southern bluefin tuna (SBT) otolith and ovary collection activities in Australia over the past year and (ii) estimates of proportion-at-age of the Australian surface (purse seine) fishery to include the 2016/17 fishing season.

Otoliths from 211 SBT caught in the Great Australian Bight (GAB) in 2018 were received and archived into the CSIRO hard-parts collection. A further 39 sets of SBT ovaries were collected from SBT caught by commercial longline operations off southeast Australia in July, bringing the total collected by Australia to 247. Histological analysis of the ovaries will be undertaken in preparation for the proposed maturity workshop in March-April 2019.

Age was estimated for 125 SBT from the 2016/17 fishing season and the proportions-at-age were estimated using standard age-length-keys and by applying the method developed by Morton and Bravington (2003) (M&B method) to the combined age-length data and length frequency data obtained from the catch sampling program. 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 Methods) should be more accurate. For the 2016/17 season, the proportion at age estimates from the M&B method with unknown growth are 63% age 2 and 33% age 3. These estimates suggest a larger proportion of age 2 and smaller proportion of age 3 fish in the catches in 2016/17 than in previous seasons, with the exception of 2013/14 and 2014/15.

# 2 Introduction

## Estimating proportion-at-age

Many stock assessments, including those for southern bluefin tuna (SBT), use age-based parameters within the models to estimate stock abundance, with annual catch in numbers at age (catch-at-age) from some fisheries as input data. 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 or infer age from length within the model. 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. 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 100-400 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%).

Since the 2002 fishing season, Australia has been obliged to provide annual length-at-age estimates for the surface (purse seine) fishery in the Great Australian Bight (GAB) to CCSBT. 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) measures the length of each fish and extracts the otoliths from these mortalities. 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. In recent years, however, the number of fish available for otolith sampling has declined primarily because of low mortalities in the cages during the towing operations (Farley et al., 2013).

## Maturity

There remains uncertainty about the size and age that SBT mature and the functional form of the maturity schedule. Up until 2013, the SBT operating model (OM) used a “knife-edge” maturity relationship, which specified that 0-9 year olds made no contribution to the spawning biomass or reproductive output of the population and 10+ year olds all contribute in proportion to their weight. In 2013, the method was updated to use the currently available estimates of maturity and additional information provided by the close-kin estimate to give a spawning potential by age (Anon 2013a). It was acknowledged, however, that there was no independent estimate of a maturity schedule for SBT (Anon 2013b). In 2014, a costed proposal for developing one (Farley et al., 2014) was supported by the ESC, and sample collection for maturity was listed as a high priority in the work plan for 2015 and ongoing. A sample size of 220 was proposed to be collected from statistical area 4 by Australia and Japan.

# 3 Otolith and ovary sampling 2018

A total of 174 sets of otolith were collected from the Australia surface fishery in the 2017/18 fishing season by Protec Marine Pty Ltd (Table 2). The fish were measured to the nearest cm (FL) and the otoliths removed and sent to CSIRO in Hobart. The size range of fish sampled was 75 to 130 cm FL (Fig. 1).

An additional 37 sets of otoliths were received from SBT sampled during CCSBT gene tagging fieldwork in the Great Australian Bight in February 2018 (Table 2; also see CCSBT-ESC/1908/07). As the tagging program was targeting two year-old fish, it provided an opportunity to collect otoliths from fish smaller than those generally sampled from the surface fishery. Otoliths were only collected from mortalities, which were recorded against CSIROs research mortality allowance approved by the CCSBT. The size range of fish sampled was 60-95 cm FL (Fig. 1).

A total of 39 ovaries were collected from SBT caught by a commercial longline operation off southeast Australia in July 2018. The ovaries (or part of one lobe) were removed and brought to the laboratory fresh. A subsample was taken from each ovary and fixed in 10% formalin for future histological analysis. A total of 247 ovaries, collected from fish ranging in size from 89-195 cm FL, have been collected since 2014 (Fig. 2) and should provide an adequate number of samples of the size range over which the transition to maturity occurs. Histological analysis of the ovaries will be undertaken over the next months in preparation for the proposed maturity workshop in Bali in March- April 2019 (see Anon 2017).

**Table 2. Number of SBT with otoliths collected from the Australian surface fishery and during gene-tagging operations in the 2018.**

| SOURCE | NO. OTOLITHS | LENGTH RANGE (CM) | MEAN FL (CM) |
|---|---|---|---|
| Australia surface fishery | 174 | 75-130 | 99.2 |
| Gene-tagging operations | 37 | 66-99 | 81.4 |

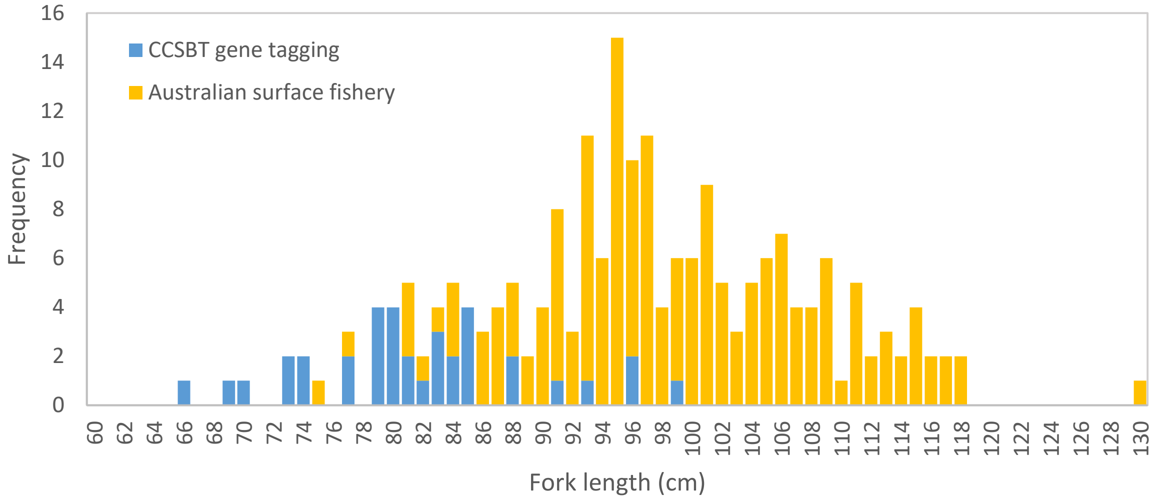


**Figure 1. Length frequency of SBT with otoliths sampled from the Australian surface fishery and during gene-tagging operations in the 2018.**

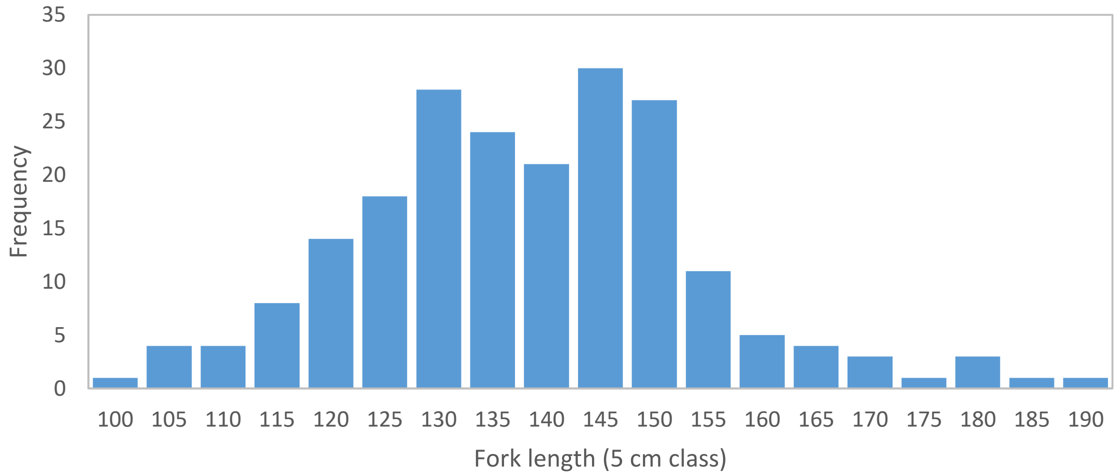


**Figure 2. Length frequency of SBT with ovaries sampled in Australia. The lower boundary length value of the bin is shown.**

# 4 Direct ageing

Of the 149 otoliths collected from the Australian surface fishery in the 2016/17 fishing season (see Farley and Eveson, 2017), 100 were selected for age determination. Otoliths were selected based on size of fish (length stratified sampling strategy rather than random sampling) to obtain as many age estimates from length classes where sample sizes were small. The fish selected for age estimation ranged in size from 81-122 cm fork length (FL).

One otolith from each fish was selected, weighed to the nearest 0.01 mg and sent to Fish Ageing Services Pty Ltd (FAS) in Victoria for sectioning and reading. The otoliths were prepared and read following Anon (2002). An ageing reference set (n=50 sectioned otoliths) was read by FAS prior to reading the 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, otolith weight or capture date.

An otolith reading confidence score was assigned to each otolith reading. The precision of readings was calculated using Average Percent Error (Beamish and Fournier, 1981).

A final age estimate was given all 100 SBT selected for ageing. Ages ranged from 2-6 years and the length to age relationship is given in Fig. 3. The average percent error between readings was 2.38% and the percent agreement was 86.0%. When successive readings differed, they were only by ±1 indicating a good level of precision. When readings differed, a final age was obtained by re-examining the otolith with the knowledge of the previous two age estimates as recommended by Anon. (2002).

Age estimates for all otolith collected during CCSBT gene tagging operations in 2017 were also obtained (n=25; see CCSBT-ESC/1908/07).

Table 3 shows the numbers of fish by age in each 5-cm length class from the surface fishery and gene tagging samples (n=125 total). 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 (see below), noting that for the M&B method the data are broken down by 1-cm, as opposed to 5-cm, length classes.

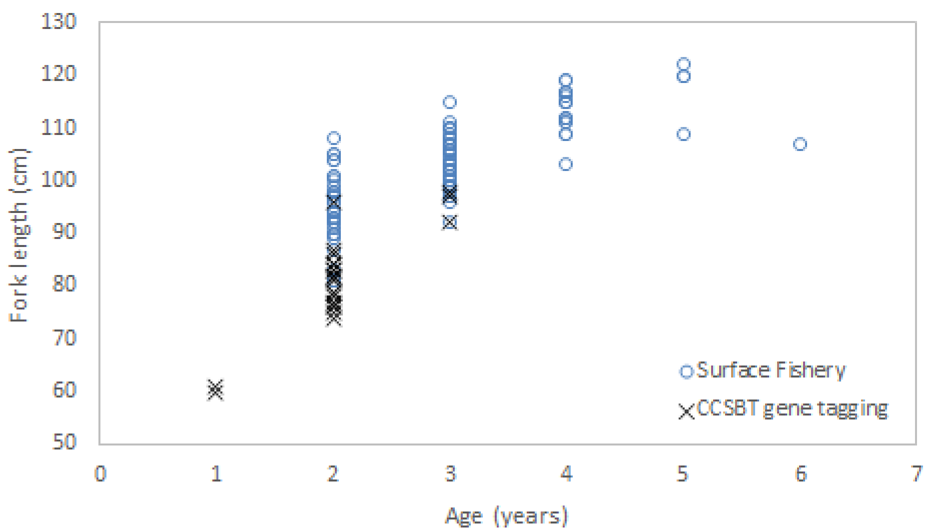


**Figure 3. Length at age for SBT caught in the Australian surface fishery and during gene tagging operations in the 2016/17 fishing season (n=125).**

**Table 3. Age-length-key for the 2016/17 fishing seasons based on length at age from SBT caught in the Australian surface fishery (n=100) and during CCSBT gene tagging operations (n=25). The lower length of each 5cm length bin is given in the first column and ages are shown across the top.**

| LENGTH (CM) | 1 | 2 | 3 | 4 | 5 | 6 | TOTAL |
|---|---|---|---|---|---|---|---|
| **60** | 2 | | | | | | 2 |
| **65** | | | | | | | |
| **70** | | 1 | | | | | 1 |
| **75** | | 8 | | | | | 8 |
| **80** | | 11 | | | | | 11 |
| **85** | | 4 | | | | | 4 |
| **90** | | 15 | 2 | | | | 17 |
| **95** | | 10 | 9 | | | | 19 |
| **100** | | 5 | 14 | 1 | | | 20 |
| **105** | | 3 | 13 | 2 | 1 | 1 | 20 |
| **110** | | | 5 | 5 | | | 10 |
| **115** | | | 1 | 9 | | | 10 |
| **120** | | | | | 3 | | 3 |
| **Total** | 2 | 57 | 44 | 17 | 4 | 1 | 125 |

# 5 Age distribution of the surface fishery catch

## Methods

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 (see Morton & Bravington, 2003, 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 2015/16 (see Farley and Eveson, 2017). Here we update the analysis to include data from the 2016/17 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.

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

| AGE | MEAN LENGTH (CM) | 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 for subsequent seasons), 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 $\pi_l$, the frequency of fish of length $l$ over all tow cages, to be

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

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

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[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.

[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.

proportions-at-age cannot be calculated. However, this is not always the case; e.g., for the 2010/11 season there were no fish belonging to length bin 85-90 cm in the age-length data despite ~7% of the observations from the length-frequency data being in this range. The consequences of this were discussed in Farley et al. (2012).

For the M&B method (with known or unknown growth), the age-at-length and length frequency data were binned into 1-cm length classes.

## Results

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 compared in Figure 4. The actual values are provided in Appendix A (Tables A1-A3). 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 most recent season (2016/17), the standard ALK and M&B method with unknown growth match quite closely, but the M&B method with known growth estimates a much lower proportion of age 2 fish and greater proportion of age 3 fish; a similar result was found in 2013/14 and 2014/15. However, in the previous season (2015/16), the two M&B methods (with known and unknown growth) match closely, but the standard ALK method estimates a considerably greater proportion of age 2 and lower proportion of age 3 fish.

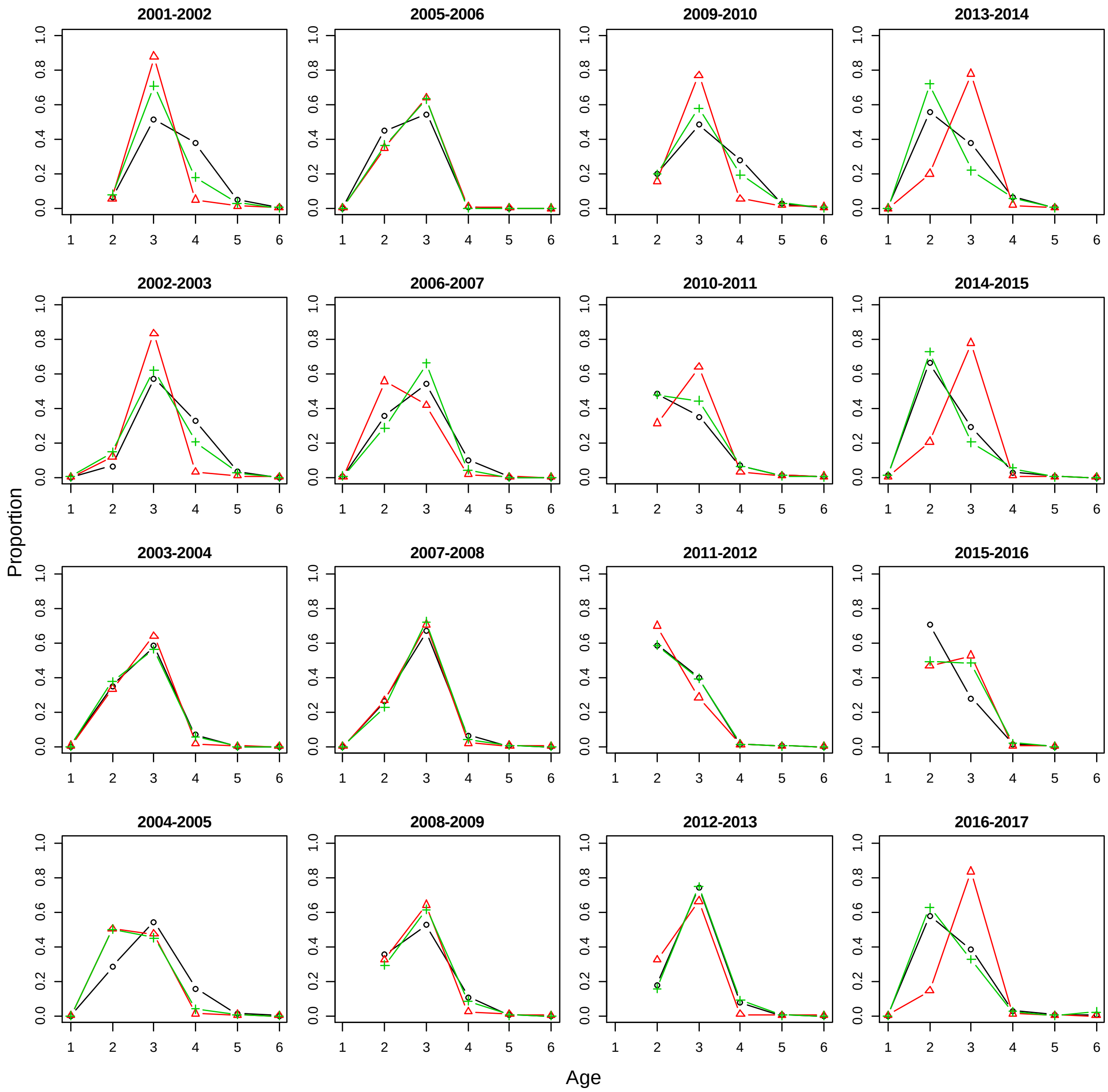


**Figure 4. Estimated proportions of fish at age in each fishing season using i) the ALK method (black, open circles); ii) the M&B method with known growth (red, open triangles); iii) the M&B method with unknown growth (green, plus symbols).**

The M&B method with unknown growth produces estimates that fit the length data very closely for all seasons (Fig. 5), with the exception of the 2010/11 season (as discussed in Farley et al. 2012). In comparison, the M&B method with known growth does not fit the length data nearly so well (Fig. 6). This is to be expected since the unknown growth method estimates the mean and SD in length at age based on the data (Tables A4 and A5 in Appendix A), and these estimates can be quite different than those derived from the growth model (Table 1). In particular, the mean length estimates from the M&B method for age 2 are larger in all seasons than the estimate from the growth model, and the age 3 and 4 estimates smaller (with one exception for age 3 in 2013/14) (Fig. 7).

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 most accurate. Using this method, the proportion at age estimates for the 2016/17 season are 63% age 2 and 33% age 3 (Table A3 in Appendix A). These estimates suggest a larger proportion of age 2 and smaller proportion of age 3 fish in the catches in 2016/17 than in most previous seasons, with the exception of 2013/14 and 2014/15. The mean length at age estimates for the 2015/16 season for ages 2, 3 and 4 are 93.4, 101.1 and 108.8 cm respectively (Table A4 in Appendix A).

The relatively small numbers of otoliths for fish of age 1 and age 5+, 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. 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 sometimes estimated to be very close to the mean length for age 3 (Fig. 5; Fig. 7). 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 were calculated by dividing the square root of the Hessian-based variance estimates by the estimates (Table A6 in Appendix A). 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. For the 2016/17 season, the CV of the estimates for ages 2-4 are 6%, 6% and 42% respectively. 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 42%) since these older age classes have less data available. As discussed in Farley et al. (2012), the 2010/11 season was an exception with much higher CVs for the age 2 and 3 estimates than in other seasons due to a contrast between the direct age data and length-frequency data for fish of ages 2 and 3 in this season.

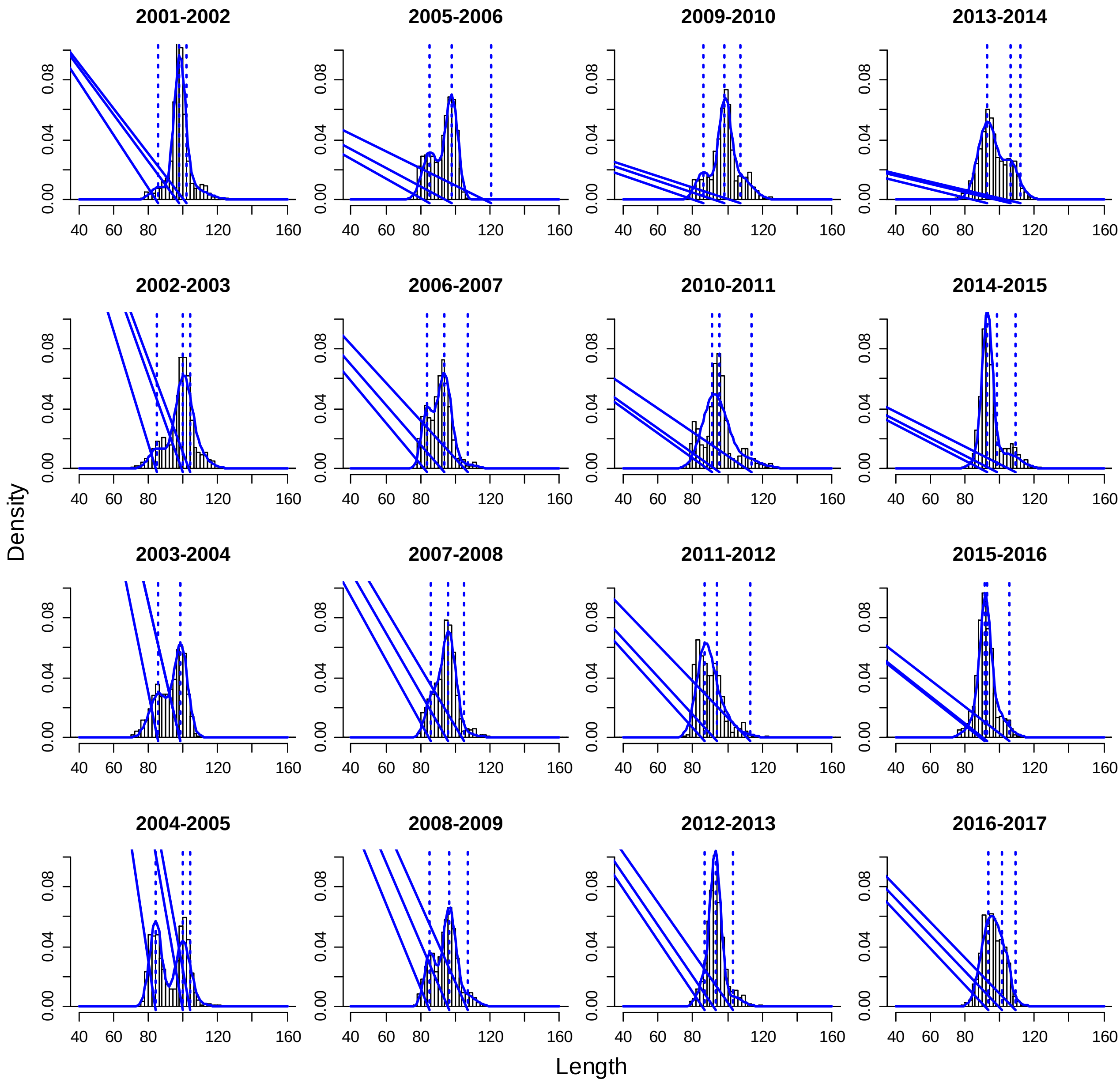


**Figure 5. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and estimated mean lengths at age for ages 2-4 from the M&B method with unknown growth (solid blue curve and dashed blu vertical lines).**

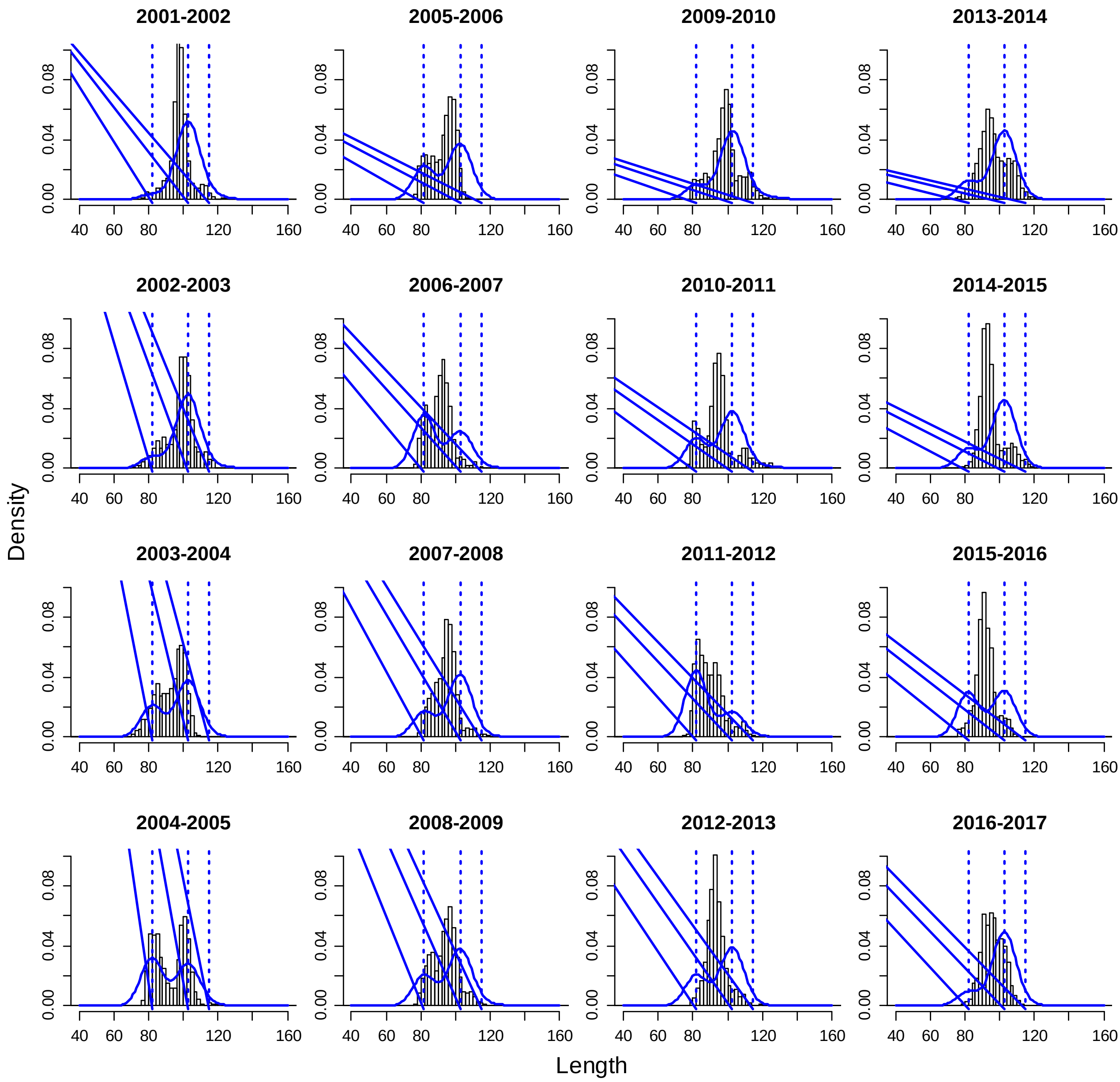


**Figure 6. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and "known" mean lengths at age for ages 2-4 from the M&B method with known growth (solid blue curve and dashed blue vertical lines).**

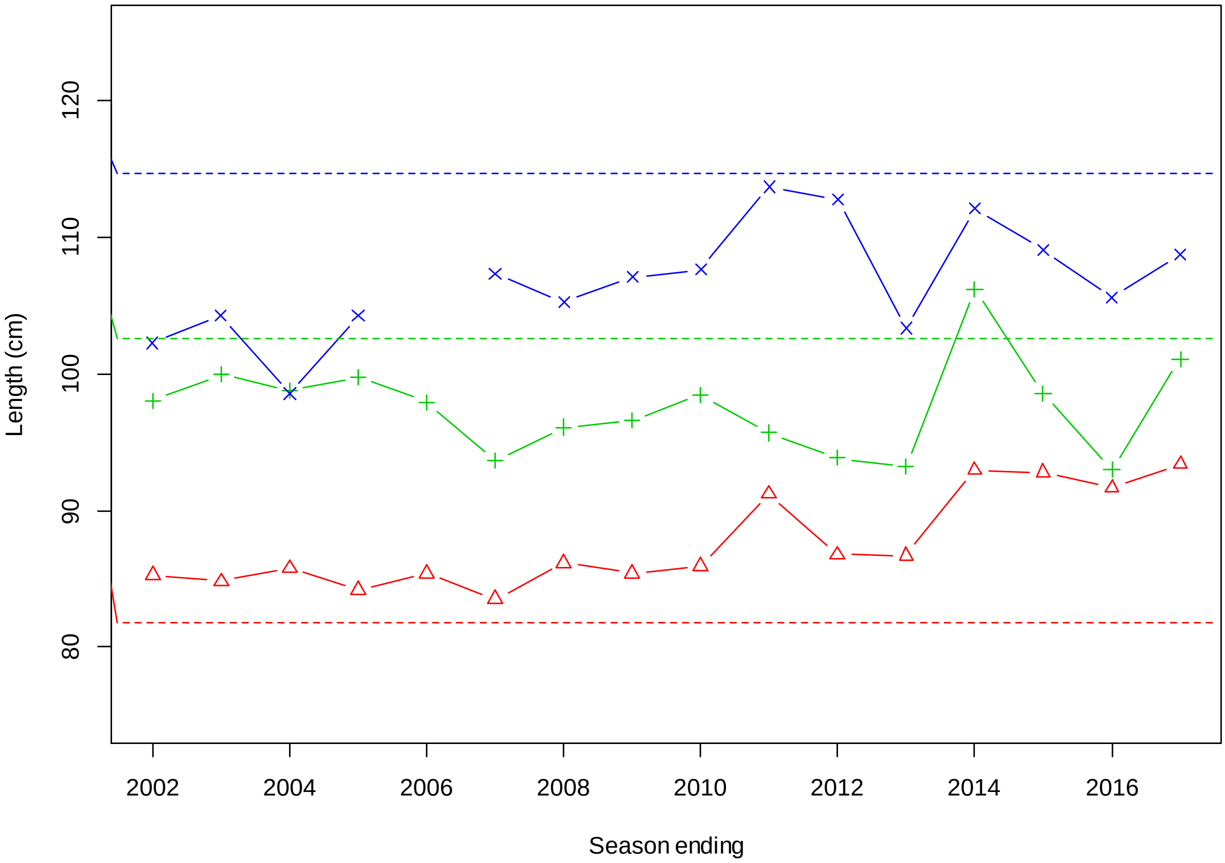


**Figure 7. Mean length at age estimates using the M&B method with unknown growth (red triangle = age 2; green plus = age 3; blue cross = age 4). Note the age 4 estimate for 2006 is omitted because there were insufficient data to get a reliable estimate. For comparison, the horizontal dashed lines show the mean length at age estimates for ages 2-4 used in the M&B method with known growth (derived from the 2000s growth model in Eveson 2011).**

As in previous reports, we again stress that the proportions at age derived here apply only to fish caught in the GAB 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).

# 6 Summary

Direct age estimates were obtained for 125 SBT caught in the GAB in 2016/17, and an additional 211 otoliths were collected in the GAB in 2017/18 for ageing next year. Ovaries were also collected from SBT caught off southeast Australia in July, bringing the total sampled to 247. Histological analysis of the ovaries will be undertaken in preparation for the proposed maturity workshop in March 2019.

For the 2016/17 season, the proportion at age estimates are 63% age 2 and 33% age 3. These estimates suggest a larger proportion of age 2 and smaller proportion of age 3 fish in the catches in 2016/17 than in most previous seasons, with the exception of 2013/14 and 2014/15. The mean length at age estimates for ages 2, 3 and 4 are 93.4, 101.1 and 108.8 cm respectively.

When combined with length-frequency data, the otolith sample sizes for age estimation of the Australian surface fishery (100 otoliths per fishing season; noting that an additional 25 otoliths were obtained this year from the gene tagging project) appear to 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 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 will be incorporated into the operating model. The direct ageing data set is a significant resource, which can be improved as more otoliths are collected and read (fish age estimated) from subsequent years.

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# Appendix A

Results from fitting the standard ALK method and the Morton & Bravington (M&B) method with known and unknown growth to the Australian surface fishery age-length and length-frequency data.

**Table A1: 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.**

| | AGE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SEASON | 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 |
| 2013-2014 | 0.0000 | 0.5559 | 0.3748 | 0.0659 | 0.0022 | NA | NA | NA |
| 2014-2015 | 0.0156 | 0.6605 | 0.2888 | 0.0297 | 0.0043 | 0.0001 | NA | NA |
| 2015-2016 | NA | 0.7070 | 0.2796 | 0.0127 | 0.0002 | NA | NA | NA |
| 2016-2017 | 0.0000 | 0.5763 | 0.3838 | 0.0294 | 0.0060 | 0.0045 | NA | NA |

**Table A2: 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.**

| | AGE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SEASON | 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 |
| 2013-2014 | 0.0003 | 0.1984 | 0.7799 | 0.0184 | 0.0030 | NA | NA | NA |
| 2014-2015 | 0.0012 | 0.2067 | 0.7792 | 0.0091 | 0.0032 | 0.0006 | NA | NA |
| 2015-2016 | NA | 0.4671 | 0.5266 | 0.0055 | 0.0008 | NA | NA | NA |
| 2016-2017 | 0.0007 | 0.1465 | 0.8365 | 0.0130 | 0.0027 | 0.0007 | NA | NA |

**Table A3: 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.**

| | AGE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SEASON | 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 |
| 2013-2014 | 0.0004 | 0.7200 | 0.2187 | 0.0580 | 0.0029 | NA | NA | NA |
| 2014-2015 | 0.0120 | 0.7292 | 0.2024 | 0.0525 | 0.0035 | 0.0004 | NA | NA |
| 2015-2016 | NA | 0.4941 | 0.4846 | 0.0203 | 0.0010 | NA | NA | NA |
| 2016-2017 | 0.0000 | 0.6258 | 0.3270 | 0.0231 | 0.0029 | 0.0211 | NA | NA |

**Table A4: 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.**

| | AGE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SEASON | 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 |
| 2013-2014 | 68.3 | 93.0 | 106.2 | 112.1 | 125.5 | NA | NA | NA |
| 2014-2015 | 83.8* | 92.8 | 98.6 | 109.1 | 121.1 | 127.5 | NA | NA |
| 2015-2016 | NA | 91.7 | 93.0 | 105.6 | 118.9 | 0.7NA | NA | NA |
| 2016-2017 | 60.5 | 93.4 | 101.1 | 108.8 | 112.1 | 104.8 | NA | NA |

# Estimate hit lower bound.

* Estimate hit upper bound.

**Table A5: 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.**

| | AGE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SEASON | 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 |
| 2013-2014 | 1.8 | 5.5 | 4.1 | 4.9 | 10.0 | NA | NA | NA |
| 2014-2015 | 2.2 | 3.0 | 8.6 | 5.6 | 5.3 | 0.2 | NA | NA |
| 2015-2016 | NA | 2.8 | 7.4 | 5.8 | 0.9 | NA | NA | NA |
| 2016-2017 | 0.7 | 4.8 | 4.2 | 4.7 | 8.2 | 1.2 | NA | NA |

**Table A6: 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.**

| | AGE | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SEASON | 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 | -- | -- | -- | -- |
| 2013-2014 | -- | 0.02 | 0.09 | 0.23 | -- | NA | NA | NA |
| 2014-2015 | 0.61 | 0.03 | 0.13 | 0.24 | -- | -- | NA | NA |
| 2015-2016 | NA | 0.06 | 0.06 | 0.42 | -- | NA | NA | NA |
| 2016-2017 | -- | 0.06 | 0.12 | 0.39 | -- | 0.68 | NA | NA |

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