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Archiving of hardparts for routine ageing and developing age-length keys for the Australian SBT surface fishery 2015-16

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Executive summary

This report provides an update on the archiving of southern bluefin tuna (SBT) otoliths sampled in Australia over the last year (2015/16 fishing season), and the estimation of age and proportion-at-age of the Australian SBT surface (purse-seine) fishery for the 2014/15 fishing season.

Otoliths from 171 SBT were received and archived into the CSIRO hardparts collection during the project. Of these, 137 were sampled from the Australian surface fishery (Port Lincoln, South Australia) and 34 from CCSBT gene-tagging fieldwork operations in the Great Australian Bight. As noted previously, the current otolith sampling protocol for the surface fishery does not provide either a fixed number of otoliths from each length class or representative samples of otoliths from all length classes in proportion to their abundance in the catch. This has led to less robust age-length keys and highlights the need to develop sampling protocols that provide a more representative sample of the size at age for the full size range of the catch for the purpose of constructing annual age-length keys.

To estimate the age of SBT caught in the Australian surface fishery in 2014/15, 100 otoliths were selected and sent to Fish Ageing Services Pty Ltd. Age estimates ranged from 1 to 6 years. 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 sampling the catch. 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 most accurate. For the 2014/15 season, the proportion at age estimates from the M&B method with unknown growth are 73% age 2 and 20% age 3. These estimates are very similar to the 2013/14 season, but suggest a larger proportion of age 2 and smaller proportion of age 3 fish in the catches than in any of the previous seasons.

The results of the project will be presented as working papers at the annual CCSBT Extended Scientific Committee (ESC) meetings in September 2016.

1 Background

Age-based models are commonly used to assess fish stocks, including southern bluefin tuna (SBT). 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 of fish 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. 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. There is an explicit expectation that the Commission for the Conservation of southern bluefin tuna (CCSBT) will move to direct age based methods for converting catch-at-length into catch-at-age in the SBT stock assessment rather than the current "cohort-slicing" approach, which has recognised deficiencies (Anon., 2012).

In the 1980s and 1990s, hardparts (e.g., otoliths, vertebrae and scales) were sampled from southern bluefin tuna (SBT) caught on Australian and Japanese fishing grounds in the southern oceans. By 1993, otoliths were also being sampled from SBT caught by Indonesian longline vessels on the spawning ground in the north-east Indian Ocean. These otoliths were catalogued and stored in the CSIRO hardparts archive, in preparation for future analysis. CSIRO then developed techniques to accurately estimate the age of SBT using the archived otoliths (Gunn et al., 1996). From this and subsequent work, it was found that SBT is a relatively long-lived and late maturing species, and that the age composition of SBT varies considerably by geographic region (Farley and Davis, 1998; Farley et al., 2007; Gunn et al., 2008).

In 2003, the CCSBT agreed that all SBT fisheries should collect and analyse hardparts (otoliths) to characterise the age distribution of their catch. In 2004, the CCSBT members confirmed “that reading and analysis of the otoliths collected was a priority to provide direct ageing data for assessments, and were encouraged to move towards annual interpretation of collected otoliths as a regular input to indicators and assessments.” This resulted in SBTMAC assigning a high research priority to such a system.

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 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). Interest was noted for a second inter-laboratory comparison of direct ageing methods and a costed proposal was presented to the ESC in 2014 (Anon., 2014).

2 Need

In order to assess the state of any fish stock it is vital that the age structure of that stock is known. This is particularly true for a long-lived, late-maturing species like SBT. Although the length of a small fish is generally a reasonably good indication of its age, the length of a bigger and possibly full-grown fish is not a good indicator of age. This is why it becomes important to obtain direct age data for a sample of the catch. In the case of small fish it is still important because (a) there may be changes in growth between cohorts or years, and (b) there will always be some overlap in the size/age distribution (fish of the same length can be of different ages, even when they are small). Routine ageing is required because of the natural variability and dynamic nature of fish growth.

The CCSBT agreed that all fisheries should collect and analyse otoliths, and the provision of direct ageing data for all countries is again listed in the CCSBT data exchange requirements for 2014. There is, therefore, an ongoing need for SBT otoliths to be catalogued into the collection so that the material is available for age estimation. As a member of the CCSBT, Australia is under an obligation to provide this direct age information.

3 Objectives

1. Provide 100 SBT otoliths from the Australian surface fishery (2014/15 season) to 'Fish Ageing Services Pty Ltd' for sectioning and reading.
2. Provide direct age estimates to the CCSBT via the data exchange process.
3. Construct age-length keys and estimate the age distribution of SBT in the Australian fishery.
4. Prepare working paper(s) on the outcomes of the project to the CCSBT Scientific Committee (SC) meeting in 2016.

4 Methods

4.1 Otolith sampling and archiving 2015/16

4.1.1 Australian surface fishery

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. 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 during the towing operations (Farley et al., 2013). The otoliths and length data are sent to CSIRO for archiving.

4.1.2 Gene-tagging field operations

SBT were also sampled during CCSBT gene-tagging fieldwork operations in the Great Australian Bight in February 2016 (Preece et al., 2015). As the tagging program was targeting two year-old fish, it provided an opportunity to collect otoliths from fish smaller than those sampled from the surface fishery. Otoliths were only collected from mortalities, which were recorded against CSIROs research mortality allowance approved by the CCSBT.

4.2 Direct ageing – surface fishery 2014/15

Of the 133 otoliths collected from the Australian surface fishery in the 2014/15 season (see Farley et al., 2015), 100 were selected for age determination. The number of otoliths selected was based on the work by Morton and Bravington (2003) who estimated that between 100-200 otoliths from the surface fishery would be sufficient to provide acceptable precision (CVs under 20%). 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. That is, all otoliths that had been collected from small and large fish were selected for ageing, as well as a fixed number of otoliths from each of the remaining 1 cm length classes (randomly selected within a length class). This was the best way of obtaining as many age estimates from length classes where sample sizes were small, while providing enough estimates for each season. The fish selected for age estimation ranged in size from 80-130 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. FAS is a fee-for-service ageing laboratory established in early 2009. The SBT otolith reader at the FAS was previously associated with the Central Ageing Facility (CAF), and has read SBT otoliths since 1999. The technique to read SBT otoliths developed by CSIRO was transferred to the CAF prior to and during the CCSBT's Age Estimation Workshop in 2002 (Anon., 2002). The sister otolith, if present, remained in the hardparts collection.

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 the 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

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 calculated using Average Percent Error (Beamish and Fournier, 1981).

4.3 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 (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 2013/14 (see Farley et al., 2015). Here we update the analysis to include data from the 2014/15 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 π_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

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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.

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

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; 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.

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[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.

5 Results and Discussion

5.1 Otolith sampling and archiving 2015/16

A total of 137 sets of otolith were collected from the Australia surface fishery in the 2015/16 season (Table 2). The sampled fish were 78 to 122 cm in length, with two modes around 90-95 cm and 102-108 cm (Fig. 1). Of the fish sampled, 120 were from 17 tow cages giving an average of 7.06 fish sampled per cage. The tow cage was not recorded for the remaining 17 fish sampled.

As noted in previous reports to AFMA (e.g. Farley et al., 2013), it is clear that the current sampling protocol for the surface fishery does not provide either a fixed number of otoliths from each length class nor has it provided representative samples of otoliths in the past from all length classes in proportion to their abundance in the catch. This has generally resulted in an apparent disproportionate number of large fish being sampled compared to the estimated size distribution of SBT from the surface fishery, as has been reported previously (see Stanley and Polacheck, 2003; 2004; Farley et al., 2010; 2013), although this year a larger proportion of small fish (<105 cm) were sampled compared to last year. The resulting age-length keys have “missing rows” where there are no or very few age estimates for the smaller 1-cm length classes. The missing rows could lead to highly uncertain (less robust) age-length-keys and highlights the issue of representative otolith sampling for 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 201/16 fishing season. Reliable estimates of catch-at-age are also dependent on measuring a representative sample of the catch.

This year, the date that the fish died was not recorded for the majority (73.3%).

An additional 34 sets of otoliths were collected during the gene-tagging fieldwork operations (Table 2). The sampled fish were 60 to 95 cm in length, the majority from a mode between 76 and 80 cm (Fig. 1). Some of these otoliths will be required for developing the age-length key for the 2015/16 season.

All otoliths received were cleaned and archived into the hardparts collection.

Table 2. Number of SBT otoliths received by fishery in 2015/16.

SOURCE	REGION	NO. OTOLITHS	LENGTH RANGE (CM)	MEAN FL (CM)
Australia surface fishery	Great Australian Bight	137	78-122	100.95
Gene-tagging operations	Great Australian Bight	34	60-95	79.0
Total		171		

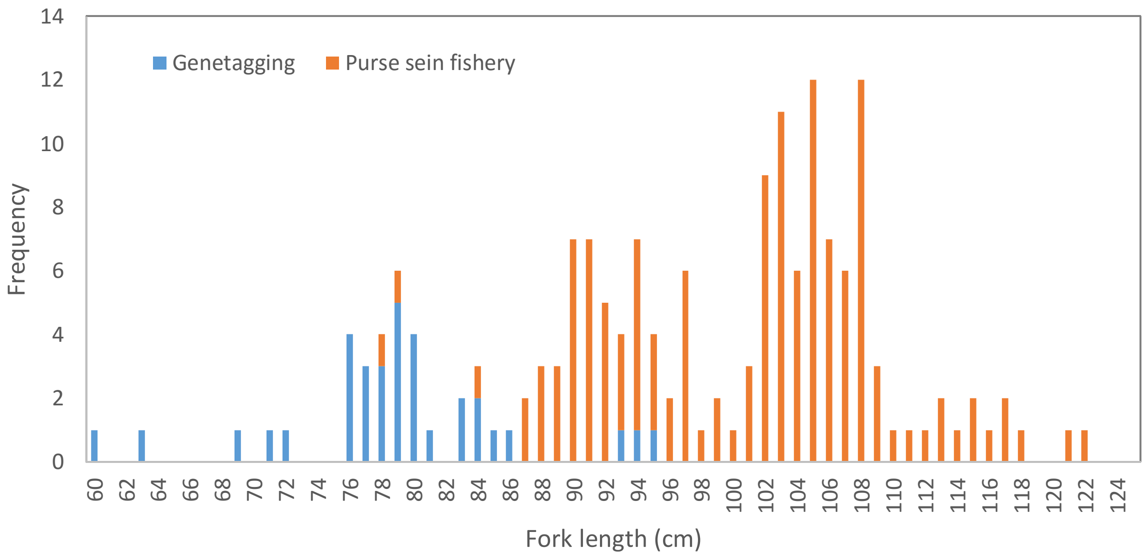

Figure 1. Length frequency of SBT with otoliths sampled from the Australian surface fishery and during gene-tagging operations in the 2015/16 fishing season.

5.2 Direct ageing – surface fishery 2014/15

A final age estimate was given all 100 SBT selected for ageing from the Australian surface fishery. Ages ranged from 1-6 years and the length to age relationship is given in Fig. 2. The average percent error between readings was 4.18% and the percent agreement was 74.0%. 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).

The direct age estimates obtained were provided to the CCSBT in April 2016 as part of the data exchange process.

Table 3 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.

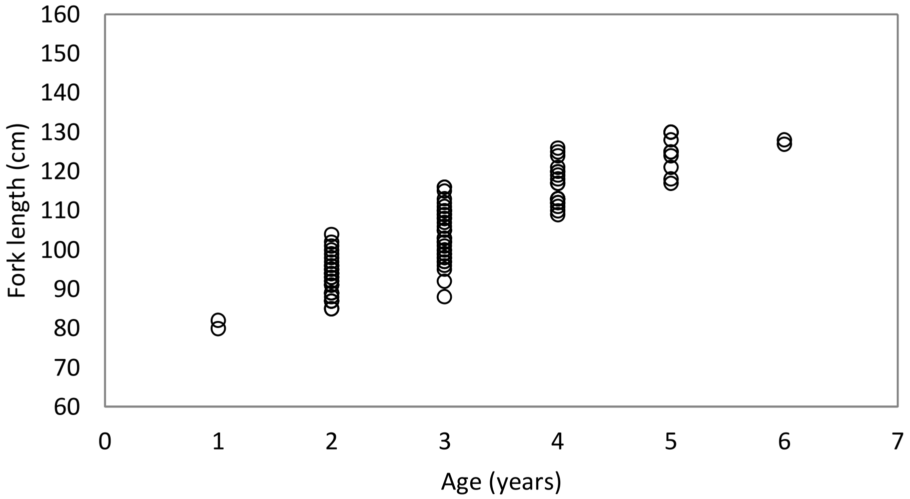

Figure 2. Length at age for SBT caught in the Australian surface fishery in the 2014/15 fishing season (n=100).

Table 3. Age-length-key for the 2014/15 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.

	AGE						
LENGTH (CM)	1	2	3	4	5	6	TOTAL
80	2						2
85		9	1				10
90		10	1				11
95		7	8				15
100		4	9				13
105			9	1			10
110			6	8			14
115			3	4	2		9
120				4	2		6
125				2	3	2	7
130					3		3
Total	2	30	37	19	10	2	100

5.3 Age distribution of the surface fishery 2001/02 to 2014/15

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 3. 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 two most recent seasons (2013/14 and 2014/15), the proportion of fish estimated to be age 2 is much greater using the standard ALK and the M&B method with unknown growth than the M&B method with known growth. Likewise, the proportion of age 3 fish is estimated to be much smaller with the ALK and M&B method with unknown growth than the M&B method with known growth.

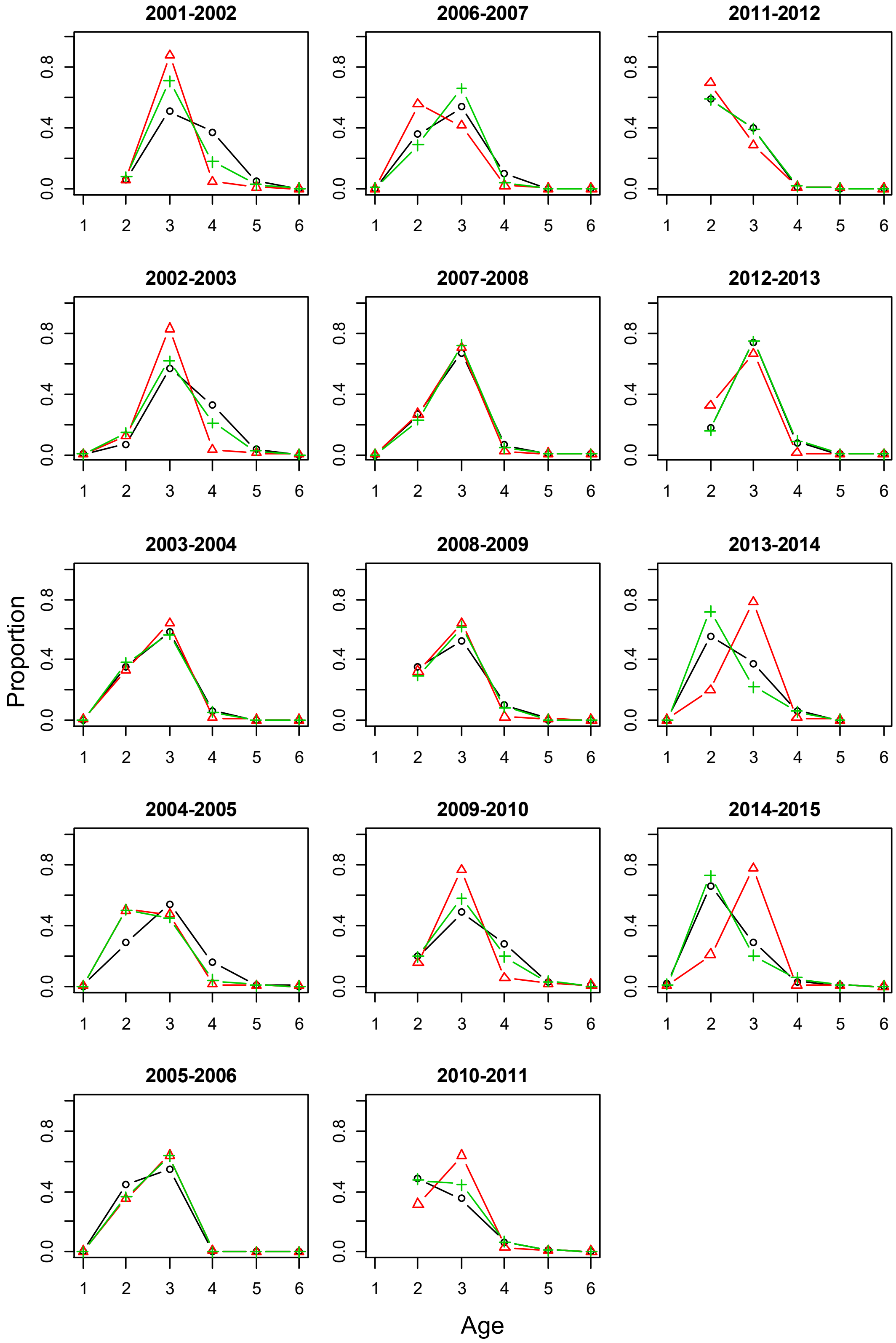

Figure 3. Estimated proportions of fish at age in each fishing season using i) the ALK method (black, open circles); ii) the M&B method with known growth (red, open triangles); iii) the M&B method with unknown growth (green, plus symbols).

The M&B method with unknown growth produces estimates that fit the length data very closely for all seasons (Fig. 4), 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. 5). 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. 6).

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 Great Australian Bight (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 2014/15 season are 73% age 2 and 20% age 3. These estimates are very similar to the 2013/14 season, but suggest a larger proportion of age 2 and smaller proportion of age 3 fish in the catches than in any of the previous seasons. The mean length at age estimates for the 2014/15 season for ages 2-4 are 93, 99 and 109 cm respectively.

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. 4; Fig. 6). 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 2014/15 season, the CV of the estimates for ages 2-4 are 3%, 13% and 24% 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 39%) 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 previous seasons due to a contrast between the direct age data and length-frequency data for fish of ages 2 and 3 in this season.

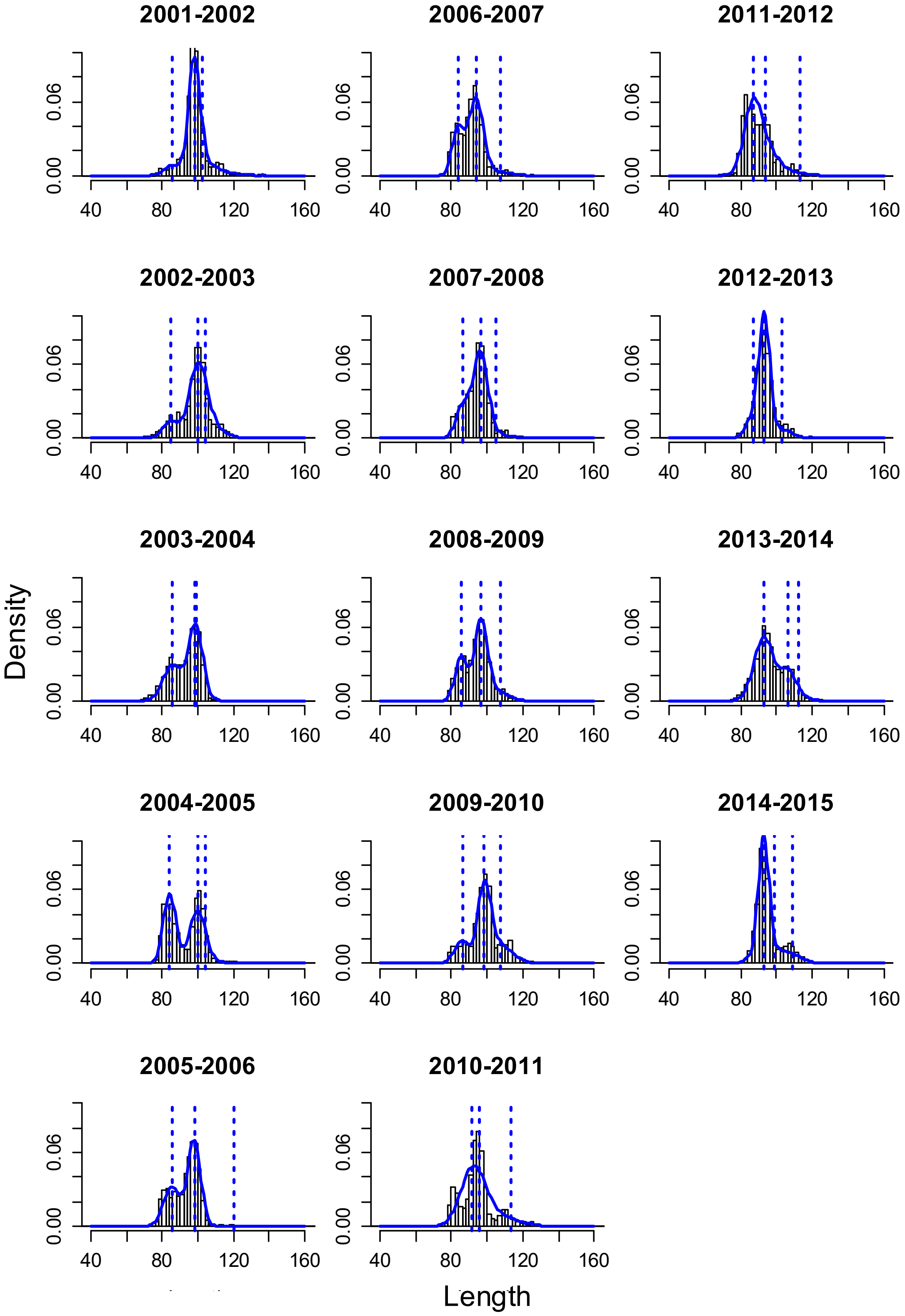

Figure 4. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and estimated mean lengths at age for ages 2-4 from the M&B method with unknown growth (solid blue curve and dashed blue vertical lines).

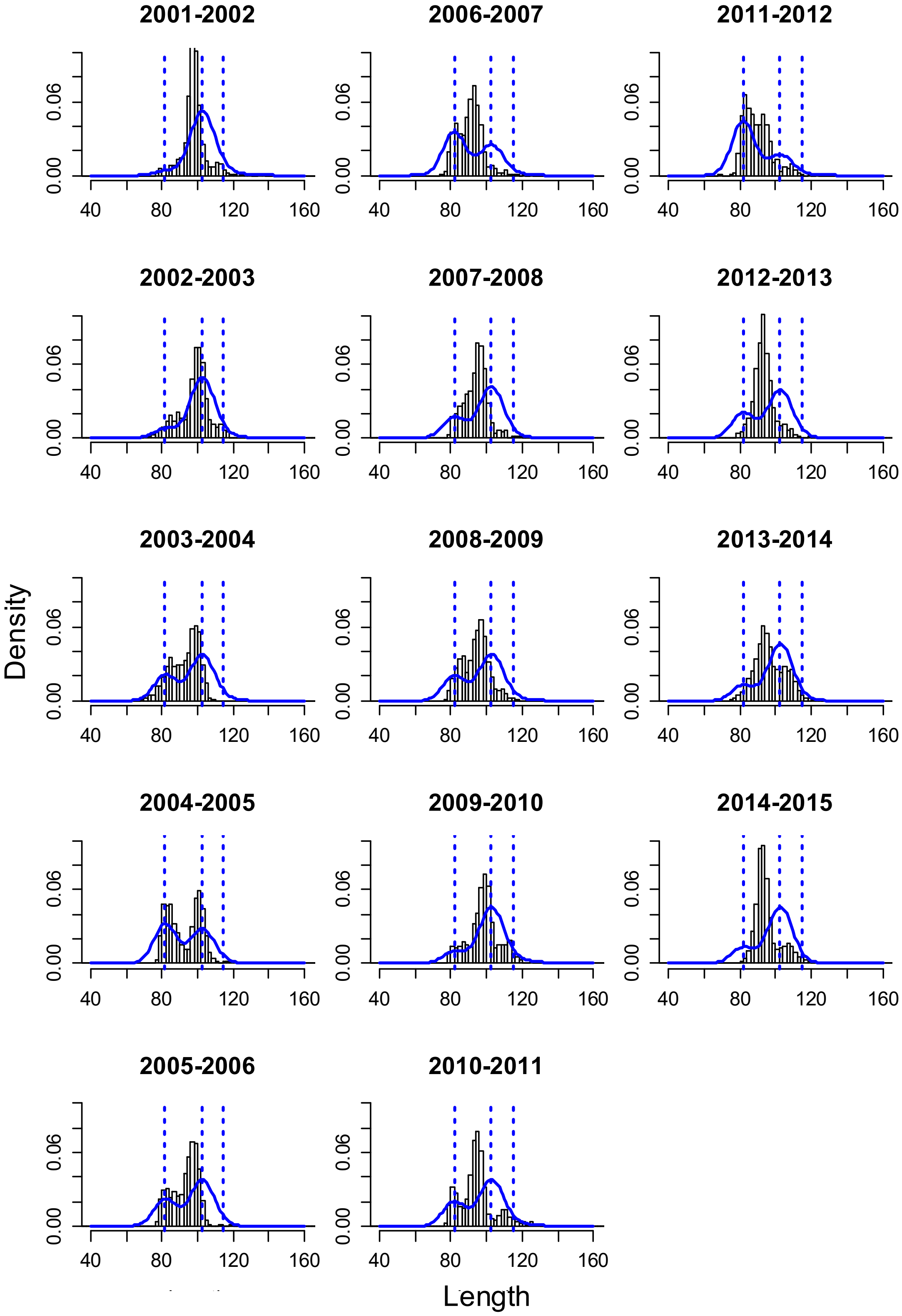

Figure 5. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and "known" mean lengths at age for ages 2-4 from the M&B method with known growth (solid blue curve and dashed blue vertical lines).

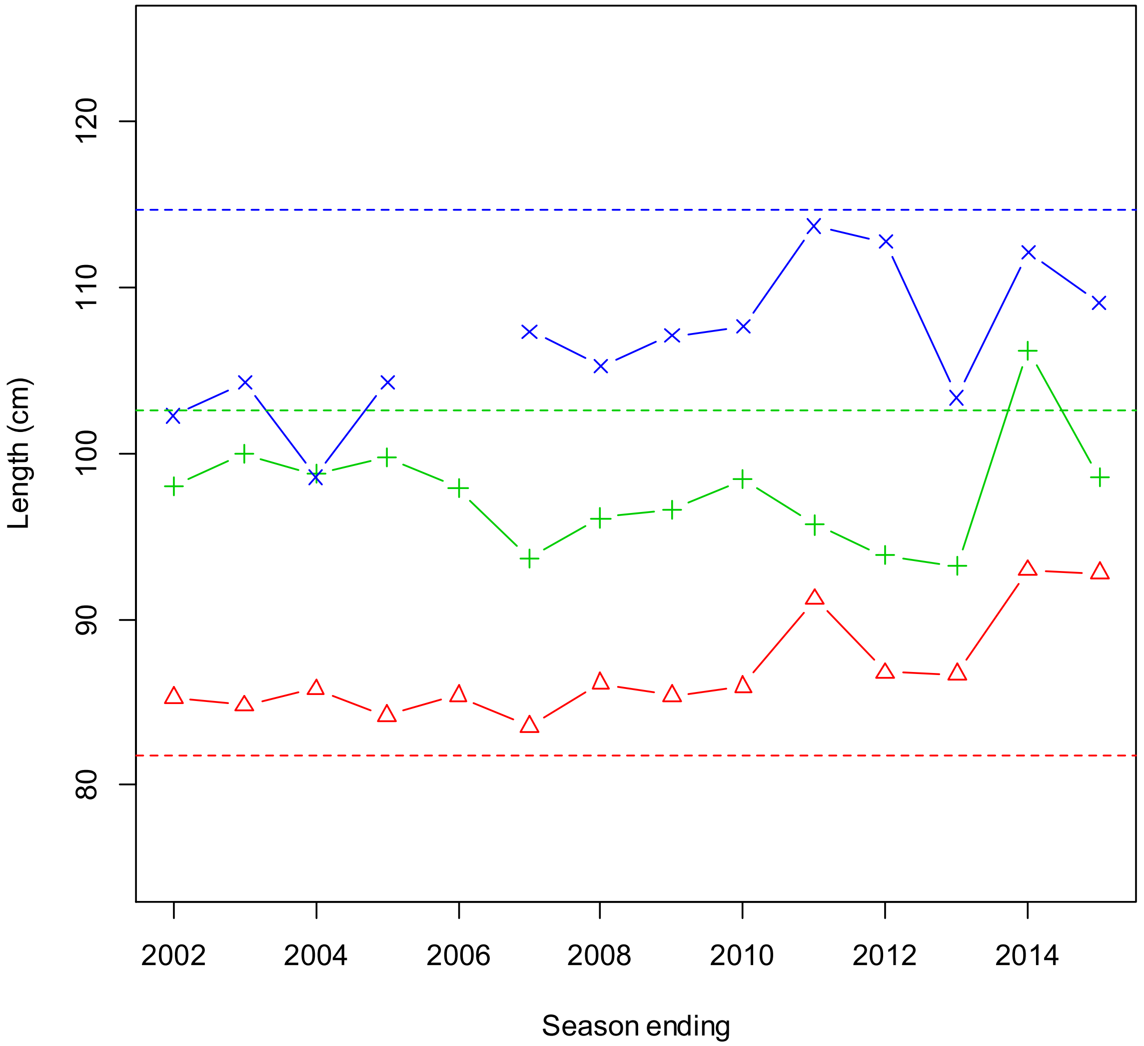

Figure 6. Mean length at age estimates using the M&B method with unknown growth (red triangle = age 2; green plus = age 3; blue cross = age 4). Note the age 4 estimate for 2006 is omitted because there were insufficient data to get a reliable estimate. For comparison, the horizontal dashed lines show 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 Benefits-Management Outcomes

The collection and archiving of SBT hard parts from Australia continued to benefit a number of research projects including the current direct age work, updating growth parameters, and work using otolith chemistry to resolve the question of summer residency of juvenile SBT in the GAB versus the Indian Ocean.

The project improved the scientific understanding of the age structure of SBT caught in the Australian surface fishery, and fulfilled Australia's commitments to the CCSBT. Direct age data for use in the SBT stock assessment and in the evaluation of the performance of a management procedure (through the conditioning of the operating model) should, over time, lead to a more robust stock assessment and basis for management advice, thus improving AFMA's ability to meets its objectives with respect to SBT.

As noted in previous reports, representative catch-at-age estimates require representative size frequency samples from the surface fishery catch, and all attempts should be made to obtain such samples. The difficulties associated with otolith collection are recognised, but again, attempts should be made to collect as representative a sample as possible. This is particularly important given the evidence of changes in growth rates in the past, and the likely continued changes if the stock abundance increases. The CCSBT has continued to reiterate the need to improve the representative nature of samples from all fisheries.

The current work continues to highlight the need for discussion within the CCSBT regarding the technical details of how the direct age data will be incorporated into the stock assessment model. Preece et al. (2012) provided information to the 2012 CCSBT ESC meeting on the inclusion of the direct age data in the operating models, and suggested that the implementation would be relatively straightforward. The CCSBT ESC restated the importance of collecting size and age data by area for all fisheries, and the need for discussion on its inclusion in the operating model (Anon., 2012).

It is important to note that the real benefit of the direct age data is the continuous time series of data. The continued reading of otoliths and associated analysis of length frequency data for the subsequent years is thus recommended and has been recognised by the CCSBT as a high priority for future research and monitoring.

7 Conclusions

The project met all of its agreed objectives. We archived otoliths collected from SBT caught in Australian waters during the 2015/16 fishing season, and estimated the age of SBT sampled in Australia in the previous (2014/15) season. The direct age data were provided to the CCSBT as part of the data exchange process in April. Using these data, we estimated proportions at age in the catch of the Australian surface fishery.

For the 2014/15 season, the proportion at age estimates from the M&B method with unknown growth are 73% age 2 and 20% age 3. These estimates are very similar to the 2013/14 season, but suggest a larger proportion of age 2 and smaller proportion of age 3 fish in the catches than in any of the previous seasons. The mean length at age estimates for ages 2-4 are 93, 99 and 109 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) 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 results of the project will be presented as working papers at the annual CCSBT-ESC meeting in 2016. 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.

8 References

Anonymous (2002). A manual for age determination of southern bluefin *Thunnus maccoyii*. Otolith sampling, preparation and interpretation. The direct age estimation workshop of the CCSBT, 11-14 June 2002, Queenscliff, Australia, 39 pp.

Anonymous (2011). Report of the sixteenth meeting of the Scientific Committee, Commission for the Conservation of Southern Bluefin Tuna, 19 – 28 July, Bali, Indonesia. Available at http://www.ccsbt.org/site/reports_past_meetings.php.

Anonymous (2012). Report of the seventeenth meeting of the Scientific Committee. Commission for the Conservation of Southern Bluefin Tuna, 27-31 August, Tokyo, Japan. Available at http://www.ccsbt.org/site/reports_past_meetings.php.

Anonymous (2014). Report of the nineteenth meeting of the Scientific Committee. Commission for the Conservation of Southern Bluefin Tuna, 6 September, Auckland, New Zealand. Available at http://www.ccsbt.org/site/reports_past_meetings.php.

Basson, M., Bravington, M., Peel, S., & Farley, J. (2005). Estimates of proportions at age in the Australian surface fishery catch from otolith ageing and size frequency data. CCSBT-ESC/0509/19.

Beamish, R.J. & Fournier, D.A. (1981). A method for comparing the precision of a set of age determinations. Canadian Journal of Fisheries and Aquatic Sciences 38: 982-983.

Eveson, P. (2011) Updated growth estimates for the 1990s and 200s, and new age-length cut-points for the operating model and management procedures. CCSBT-ESC/1107/9.

Farley, J.H. & Davis, T.L.O. (1998). Reproductive dynamics of southern bluefin tuna, *Thunnus maccoyii*. Fish. Bull. 96, 223–236.

Farley, J.H., Davis, T.L.O., Gunn, J.S., Clear, N.P. & Preece, A.L. (2007). Demographic patterns of southern bluefin tuna, *Thunnus maccoyii*, as inferred from direct aging data. Fish. Res. 83: 151–161.

Farley, J., Eveson, P. & Preece, A. (2010). Archiving of hardparts for routine ageing and developing age-length keys for the Australian SBT surface fishery 2007-8 - 2009-10. AFMA Final Report project R2007/813.

Farley, J., Eveson, P. & Clear, N. (2012). An update on Australian otolith collection activities, direct ageing and length at age in the Australian surface fishery. CCSBT ESC-1208-18.

Farley, J., Eveson, P. & Clear, N. (2013). Archiving of hardparts for routine ageing and developing age-length keys for the Australian SBT surface fishery 2010/11 - 2012/13. AFMA final report for project R2009/837.

Farley, J., Eveson, P. & Clear, N. (2015). Archiving of hardparts for routine ageing and developing age-length keys for the Australian SBT surface and Indonesian longline fisheries 2014/15. AFMA final report for project R2014/0814.

Gunn, J.S., Clear, N.P., Carter, T.I., Rees, A.J., Stanley, C., Farley, J.H., & Kalish, J.M. (2008). The direct estimation of age in southern bluefin tuna. Age and growth in southern bluefin tuna, *Thunnus maccoyii* (Castelnau): Direct estimation from otoliths, scales and vertebrae. Fisheries Research 92:207-220.

Gunn, J.S., Clear, N.P., Rees, A.J., Stanley, C., Farley, J.H. & Carter, T. (1996). The direct estimation of age in southern bluefin tuna. Final report for Fisheries Research Development Corporation project 1992/42, Canberra, Australia.

Morton, R. & Bravington, M. (2003). Estimation of age profiles of southern bluefin tuna. CCSBT-ESC/0309/32.

Polacheck, T., Laslett, G.M., and Eveson, J.P. (2002). An integrated analysis of growth rates of southern bluefin tuna for use in estimating the catch at age matrix in the stock assessment. Final report. FRDC Project No. 1999-104.

Preece, A., Eveson, P., Farley, J., Hillary, R., Basson, M. & Davies, C. (2012). Potential inclusion of direct ageing data in the SBT operating model. CCSBT-ESC/1208/22.

Preece A., Eveson P., Davies C., Grewe P., Hillary R. & Bravington M. (2015). Report on gene-tagging design study. CCSBT-ESC/1509/18.

Stanley, C. & Polacheck, T. (2003). An update on Australian otolith collection activities: 2002/03. CCSBT-ESC/0309/21.

Stanley, C. & Polacheck, T. (2004). An update on Australian otolith collection activities: 2003/04. CCSBT-ESC/0409/13.

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	0.2971	0.0043	0.0001	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

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

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

[#] 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

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

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