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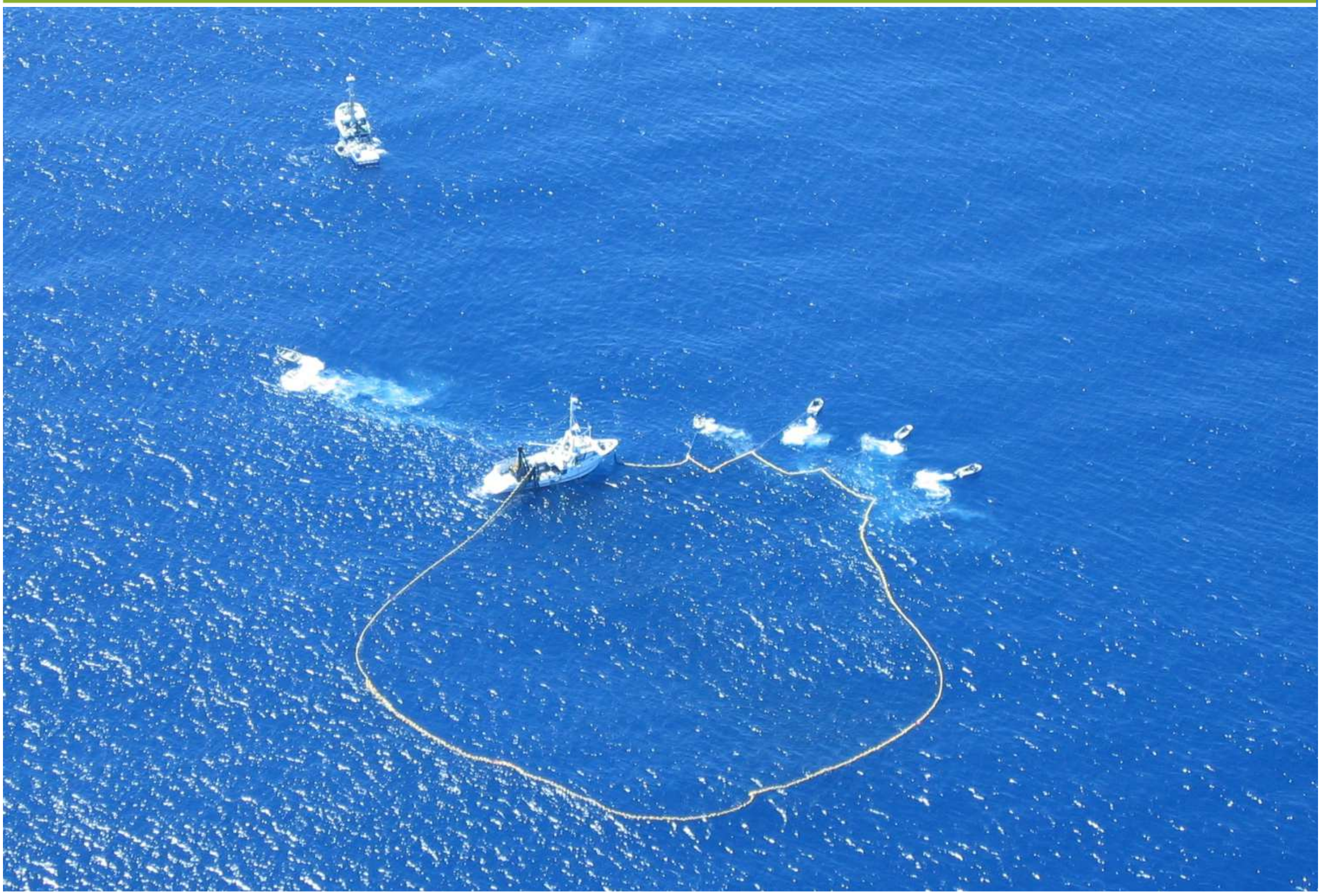
Archiving of hardparts for routine ageing and developing age-length keys for the Australian SBT surface fishery 2014-15



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Final Report project 2014/0814
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Executive summary

This report provides an update on the archiving of southern bluefin tuna (SBT) otoliths sampled in Australia and Indonesia over the last year (2014/15 fishing season), and the estimation of age and proportion-at-age of the Australian SBT surface (purse-seine) fishery for the 2013/14 fishing season.

Otoliths from 1479 SBT were received and archived into the CSIRO hardparts collection during the project. Of these, 133 were sampled from the Australian surface fishery (Port Lincoln, South Australia) and 1346 from the Indonesian longline fishery (Benoa, Bali). As noted previously, the current otolith sampling protocol in Port Lincoln 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 2013/14, 100 otoliths were selected and sent to Fish Ageing Services Pty Ltd. Age estimates were obtained for 99 SBT ranging from 1 to 5 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. The proportion at age estimates from this method suggest that in the 2013/14 season there was a higher proportion of age 2 fish (72%) and smaller proportion of age 3 fish (22%) in the catches than in any previous season. Moreover, the mean length of age 2-4 fish was estimated to be higher in 2013/14 than in past seasons, most notably for age 3.

The results of the project will be presented as working papers at the annual CCSBT Extended Scientific Committee (ESC) meetings in September 2015.

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 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 listed in the CCSBT data exchange requirements. SBTMAC has identified the development and maintenance of systems for sampling otoliths and routine ageing of all components of the commercial catch is an important research issue for the SBT fishery. CCSBT Scientific Meetings have also emphasised the importance of the long-term continuous monitoring of the Indonesian fishery, as an invaluable source of information on changes in the size and age composition of the spawning stock. The data resulting from this monitoring program are recognised as essential to understanding the impact of the Indonesian fishery on the SBT spawning ground, and in providing assessment inputs on the adult (spawner) component of the stock.

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 information.

3 Objectives

1. Continue to archive SBT hardparts into the already established collection, including 1000-1500 sets of otoliths from the SBT spawning ground and 300-600 sets of otoliths from the Great Australian Bight, and any otoliths collected through other resources during the course of the project.
2. Provide 100 SBT otoliths from the Australian surface fishery (2013/14 season) to 'Fish Ageing Services Pty Ltd' for sectioning and reading.
3. CSIRO to re-read 10% of otoliths (verification of ages).
4. Provide direct age estimates to the CCSBT via the data exchange process
5. Construct age-length keys and estimate the age distribution of SBT in the Australian fishery.
6. Prepare working paper(s) on the outcomes of the project to the CCSBT Scientific Committee (SC) meeting in 2015.

4 Methods

4.1 Otolith sampling and archiving 2014/15

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 Indonesian longline fishery

As in previous years, targeted sampling of SBT occurred at the Port of Benoa using the existing monitoring system (e.g. see Proctor et al., 2006). Landed SBT are graded into export and non-export quality based on flesh quality. Quality and grading is dependent on handling, length of trip and/or condition of fish at capture, rather than fish size (Davis and Farley 2001). Generally, only SBT graded as not suitable for export were available for monitoring. Fork length (FL) was measured to the nearest cm and otoliths removed using the “drilling technique” (Anon., 2002).

4.2 Direct ageing – surface fishery 2013/14

Of the 146 otoliths collected from the Australian surface fishery in the 2013/14 season (see Farley et al., 2014), 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 61-128 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

A subset of otoliths was 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).

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 (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 2012/13 (see Farley et al., 2014). Here we update the analysis to include data from the 2013/14 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

[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 2014/15

In 2014/15, a total of 133 sets of otolith were collected from the Australia surface fishery (Table 2). Seventeen tow cages were sampled with an average of 6.6 fish sampled per cage. The SBT sampled were between 61 and 128 cm fork length (FL) with a mode around 100-115 cm FL (Fig. 1).

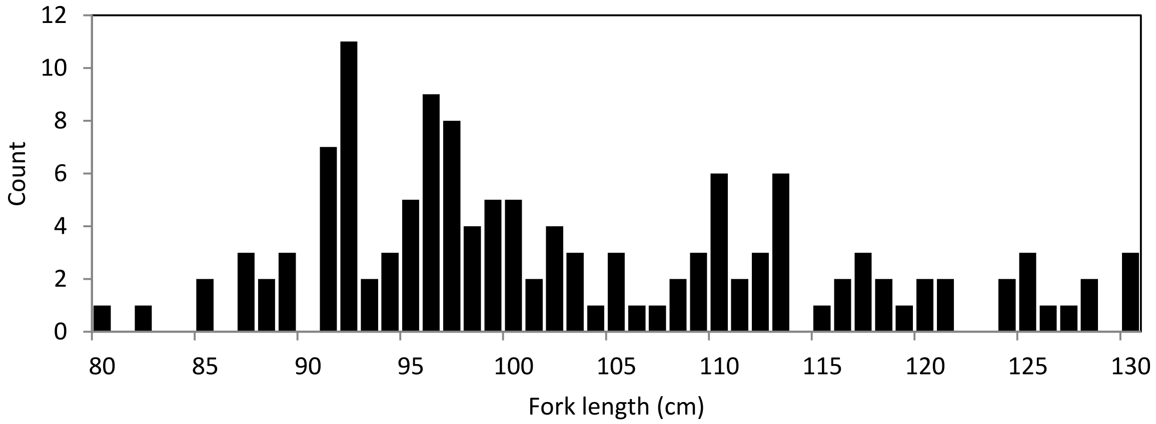
As noted in previous reports to AFMA (e.g. Farley et al., 2013), it is clear that the current sampling protocol in Port Lincoln does not provide either a fixed number of otoliths from each length class nor has it provided representative samples of otoliths in the past from all length classes in proportion to their abundance in the catch (see Farley et al., 2013). 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 2014/15 fishing season. Reliable estimates of catch-at-age are also dependent on measuring a representative sample of the catch.

A total of 1436 sets of otoliths were also collected from the Indonesian longline fishery (Table 2). SBT were between 117 and 201 cm fork FL with a small mode around 140-155 cm FL as well as a mode of larger fish at around 165-170 cm (Fig. 1).

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

Table 2. Number of SBT otoliths received by fishery in 2014/15. Note that it is currently unknown if small fish in the Indonesian sampled catch were caught on, or south of the, spawning ground

COUNTRY	FISHERY	REGION	NO. OTOLITHS	LENGTH RANGE (CM)	MEAN FL (CM)
Australia	Surface	Great Australian Bight	133	80-130	103.0
Indonesia	Longline	Spawning ground	1346	117-201	161.4
Total			1479		



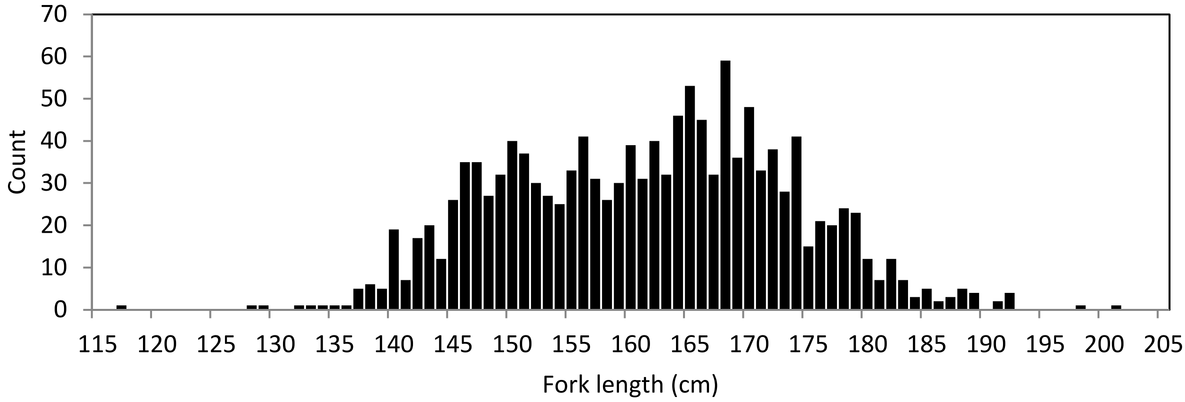


Figure 1. Length frequency of SBT with otoliths sampled from the Australian surface fishery (top; n=133) and the Indonesian longline fishery (bottom; n=1346) in the 2014/15 fishing season.

5.2 Direct ageing – surface fishery 2013/14

A final age estimate was given for 99 of the 100 SBT selected for ageing from the Australian surface fishery. Ages ranged from 1-5 years and the length to age relationship is given in Fig. 2. The coefficient of variation between readings was 2.85%. When successive readings of otoliths differed, they were only by ±1 (n=12) 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). The percent agreement between readers was 75% and 100% were within +/-1. The CV was 5.86%.

The direct age estimates obtained were provided to the CCSBT in April 2015 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.

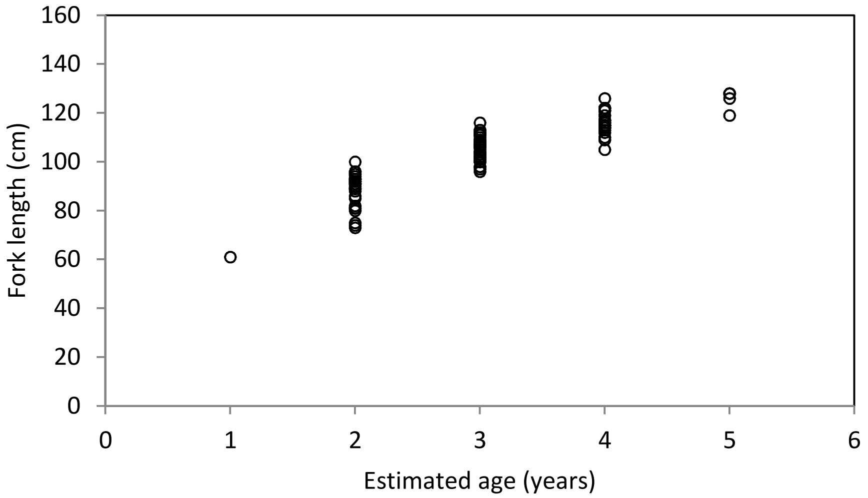


Figure 1. Length at age for SBT caught in the Australian surface fishery in the 2013/14 fishing season (n=99).

Table 3. Age-length-key for the 2013/14 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**	**TOTAL**
60	1					1
65						0
70		2				2
75		1				1
80		4				4
85		6				6
90		12				12
95		4	4			8
100		1	13			14
105			13	2		15
110			8	6		14
115			1	10	1	12
120				5	0	5
125				1	4	5
Total	1	13	42	20	7	99

5.3 Age distribution of the surface fishery 2001/02 to 2013/14

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, for the 2013/14 season, the proportion of fish estimated to be age 2 is much greater using the standard ALK (56%) and the M&B method with unknown growth (72%) than the M&B method with known growth (20%). Likewise, the proportion of age 3 fish is estimated to be much smaller with the ALK (37%) and M&B method with unknown growth (22%) than the M&B method with known growth (78%).

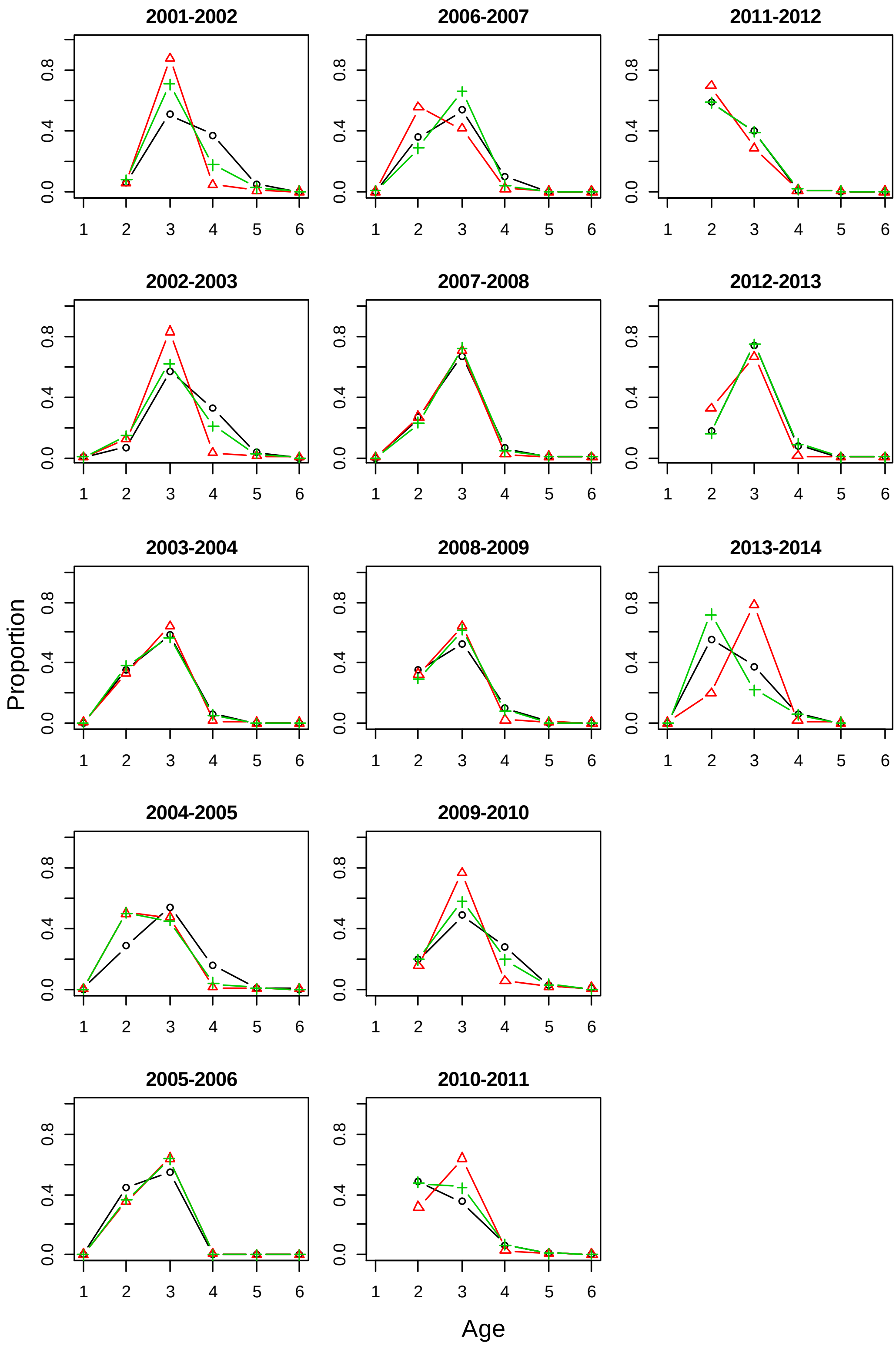


Figure 2. Estimated proportions of fish at age in each fishing season using i) the ALK method (black, open circles); ii) the M&B method with known growth (red, open triangles); iii) the M&B method with unknown growth (green, plus symbols).

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 more accurate. For the 2013/14 season, estimates from this method suggest there was a larger proportion of age 2 fish (72%) and smaller proportion of age 3 fish (22%) in the catches than in any previous season. Furthermore, the mean length at age estimates are higher than in past seasons, most notably for age 3 (Fig. 6).

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 often 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 2013/14 season, the CV of the estimates for ages 2 to 4 are 2%, 9% and 23% 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.

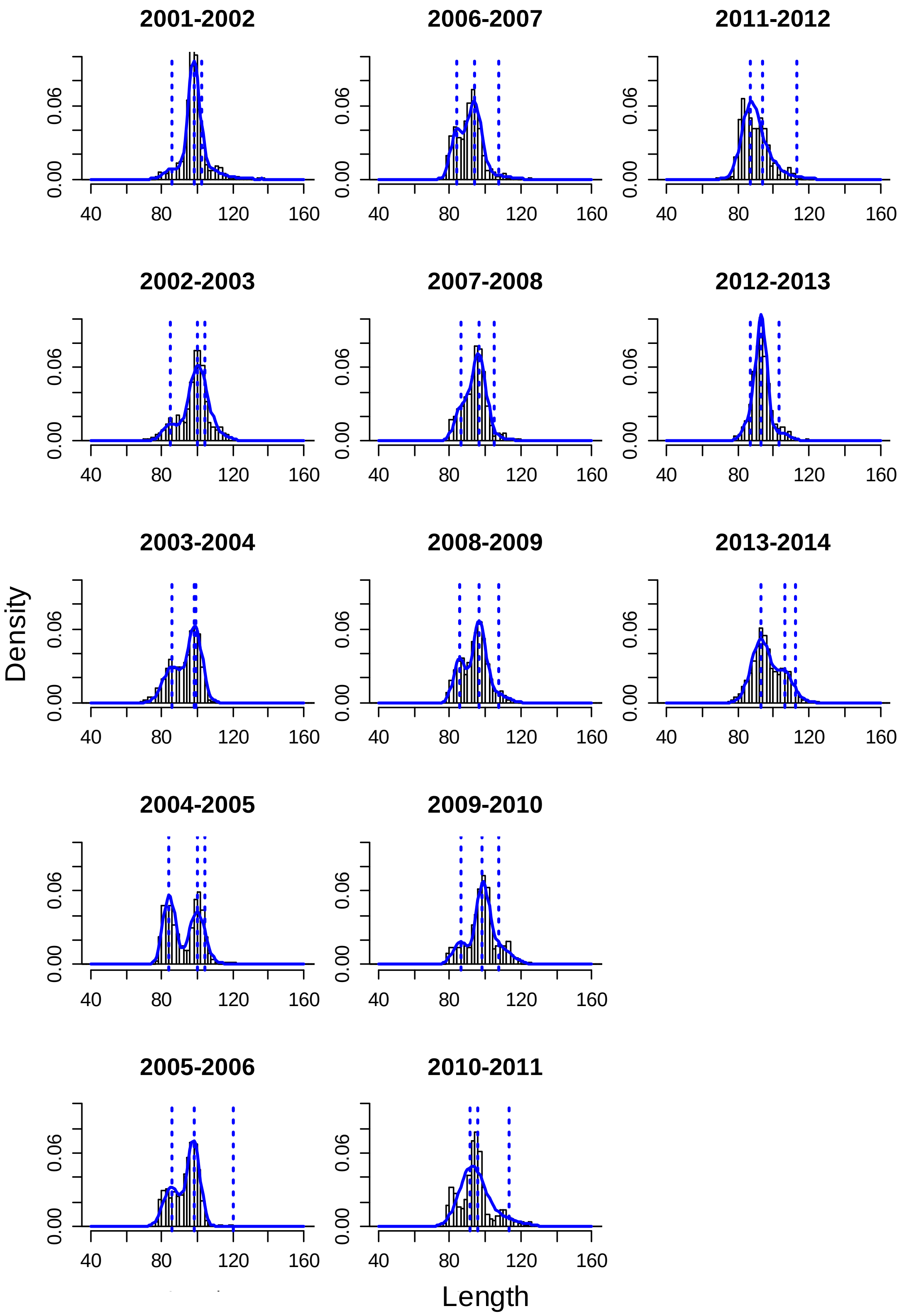


Figure 3. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and estimated mean lengths at age for ages 2-4 from the M&B method with unknown growth (solid blue curve and dashed blue vertical lines).

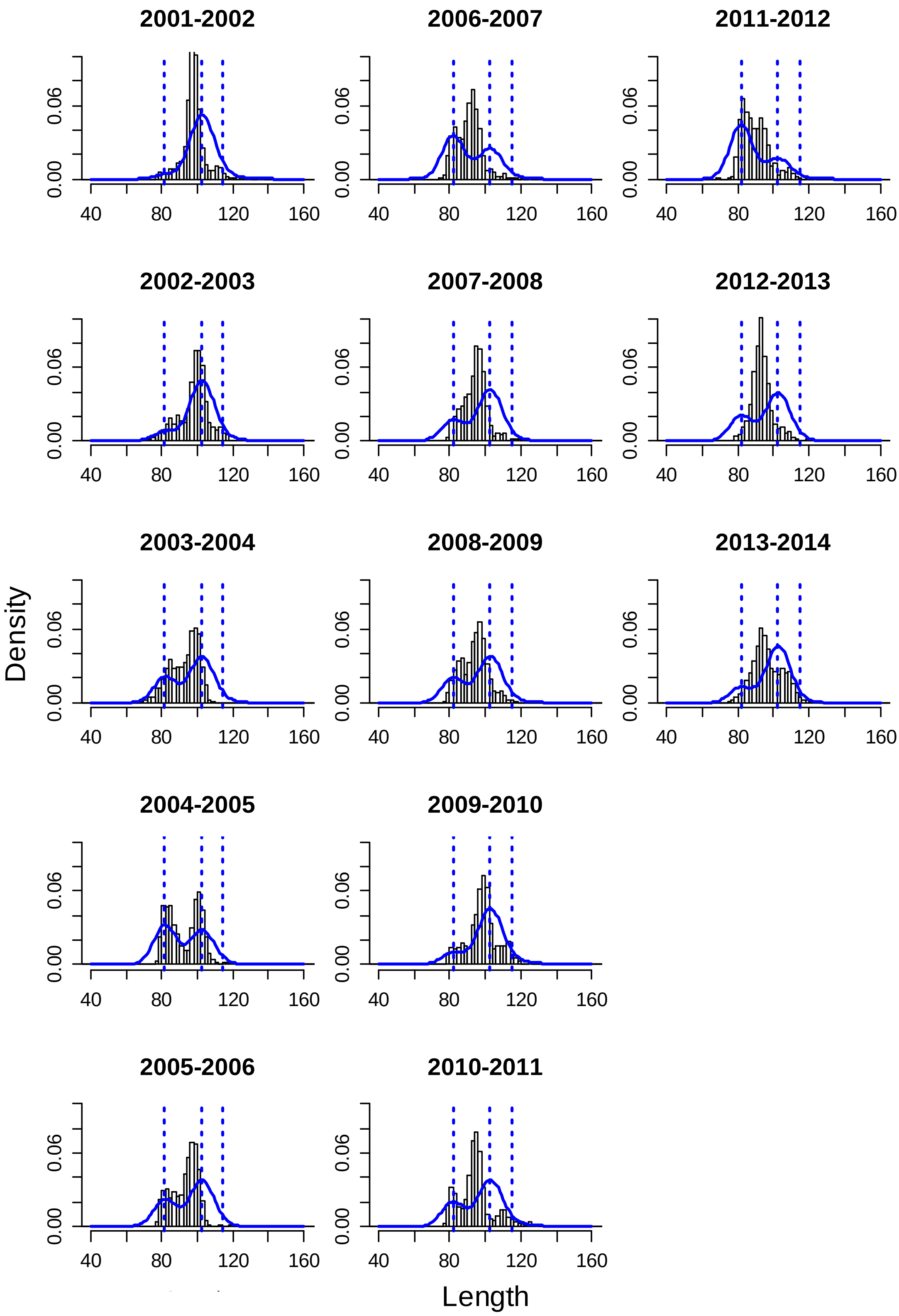


Figure 4. Length distribution of fish caught in the GAB in each fishing season, along with the estimated distribution and "known" mean lengths at age for ages 2-4 from the M&B method with known growth (solid blue curve and dashed blue vertical lines).

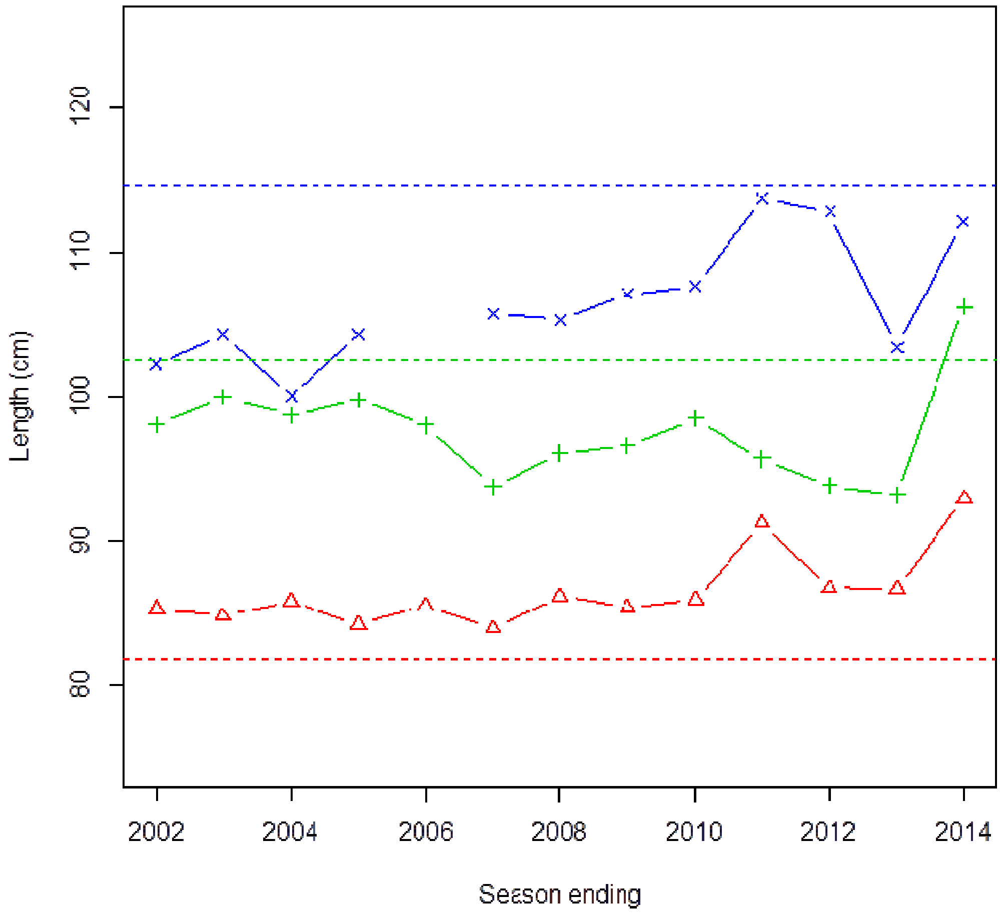


Figure 6. Mean length at age estimates using the M&B method with unknown growth (red triangle = age 2; green plus = age 3; blue cross = age 4). Note the age 4 estimate for 2006 is omitted because there were insufficient data to get a reliable estimate. For comparison, the horizontal dashed lines show 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 and Indonesia 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 reiterated the need to improve the representative nature of samples from all fisheries (Anon., 2012).

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 continued to archive otoliths sampled from SBT caught in Australian and Indonesian waters during the 2014/15 fishing seasons, and estimate the age of the SBT sampled in Australia in the 2013/14 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.

The proportion at age estimates from the M&B method with unknown growth suggest that in the 2013/14 season there was a higher proportion of age 2 fish (72%) and smaller proportion of age 3 fish (22%) in the catches than in any previous season. Furthermore, the mean length at age estimates for ages 2-4 are higher in 2013/14 than in past seasons, most notably for age 3.

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 2015. 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

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.

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
2013-2014	0.0003	0.1984	0.7799	0.0184	0.0030	NA	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.

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
2013-2014	0.0004	0.7200	0.2187	0.0580	0.0029	NA	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.

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
2013-2014	68.3	93.0	106.2	112.1	125.5	NA	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.

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
2013-2014	1.8	5.5	4.1	4.9	10.0	NA	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

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