CSIRO
MARINE RESEARCH

Estimates of proportions at age in the Australian surface fishery catch from otolith ageing and size frequency data

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Abstract

Southern bluefin tuna caught by Australia’s surface fishery in the Great Australian Bight were aged by examining transverse sections of their sagittal otoliths. Age was assigned to 417 fish caught over three fishing seasons (2001-2, 2002-03 and 2003-04). Proportions at age in the catch were estimated by applying the approaches developed by Morton and Bravington (2003; CCSBT-ESC/0309/32) to the age data and the size frequency distributions obtained from sampling the catch. A standard age-length-key was also used for comparison. Differences between the approaches and results are discussed.

Introduction

Southern bluefin tuna (SBT) is a relatively long-lived and late maturing species. Their growth rate is most rapid during the first years of life, and age at 50% maturity is not reached until about age 12 (Davis et al., 2001; Schaefer 2001). The oldest SBT sampled is approximately 41 years of age (Gunn et al., In press). Differences are known to occur in the size and age composition of SBT by geographic region. Estimating the age distribution of the commercial catch is, therefore, of great importance for stock assessments and, by implication, for management. The CCSBT has recognised this importance and has agreed that all SBT fisheries should collect and analyse hardparts (otoliths) to characterise the age distribution of their catch.

Otoliths have been sampled from SBT caught in Australian fisheries since the 1960s. However, since the 1999/00 season, otoliths have been routinely collected each year under AFMA supervision from the South Australian tuna farms (mortalities) in Port Lincoln. Otoliths have also been collected from incidental mortalities during CCSBT tagging operations in Western Australia and South Australia since 2001-02, and opportunistically by CSIRO off the east coast of NSW.

CSIRO has developed and validated techniques to accurately estimate the age of SBT using otoliths (Gunn et al., in press; Clear et al., 2000). The key object of the current work was to use these techniques to estimate the age of a subsample of SBT caught in the Australian surface fishery in the Great Australian Bight (GAB), and to construct age-length keys (ALKs) for the fishery to meet our CCSBT commitment. Although the CCSBT's immediate request was to estimate the age of SBT sampled from the 2001-2 season, the ultimate goal is to estimate the age of SBT from the Australian catch annually. Since the number of otoliths collected during 2001-2 was relatively low and very few small or large fish were sampled, we included samples from the 2002-3 and 2003-4 seasons. This allowed for a more robust analysis and construction of ALKs for the fishery. We have also implemented the more efficient approach to age estimation described in Morton & Bravington (2003), combining the otolith with length data assuming a parametric form for the length-at-age relationship.

Purpose of estimating the age distribution

Before describing the methods and results in detail, it is worth emphasizing a basic but often overlooked point about estimated age distributions. There are two quite different ways of using estimated age distributions inside a stock assessment procedure: first, in determining which animals to remove from the modelled population when projecting next year’s abundance-at-age; and second, as something to compare with a predicted age distribution when constructing the "objective function". The purpose to which an estimate will be put should be carefully considered before deciding how to construct the estimate.

Clearly, if every fish in every towcage was measured, then we would have a perfectly accurate estimate of the catch length frequency, i.e. with zero variance. This would be true even if there was only one towcage and it contained only one fish. In that case, though, we would obviously have no reason to trust that the length of that single fish accurately represented the entire length distribution of catchable fish[2] in the GAB. For inferences about the latter, a better estimate might be obtained by treating the entire sample of measured fish as a multinomial sample from the population. In fact, even this will generally give a spuriously precise answer, because it neglects any overdispersion arising from genuine differences between the complete length frequencies in different towcages; we only have a finite number of towcages to represent "the population'', as well as only having a small subsample from each one. Some fairly sophisticated analysis beyond the scope of this paper would be required to do a proper job of accounting for tow cage effects in estimation of *catchable population* length frequency, but the basic point is that variance in the population length frequency estimate will be a lot larger than variance in the catch length frequency estimate, even if the two point estimates turn out to be the same. The essential point here is whether to treat the towcages as *fixed properties* or as things that could have turned out differently by chance. The former is appropriate for making inferences about what the actual catch was; the latter is appropriate for making inferences about fish in the GAB (i.e. uncaught as well as caught fish).

The *principal* impact of "estimator purpose" is on what variance to associate with an estimate. However, it turns out that the (optimal) point estimator changes too, because the appropriate weighting to give to samples from different towcages is affected.

In this paper, we have assumed (largely for ease of calculation) that the aim is to infer age distribution *in the actual catch*, and have calculated variances and weighting schemes accordingly. This means that the estimates we present here—or more particularly their variances—should *not* be treated as something to be compared with a predicted distribution as part of an "objective function" within a stock assessment. Our point estimate is probably not too bad for that purpose (though suboptimal), because sampling is fairly well balanced in the GAB, but the variance we give is inappropriate for that purpose.

Methods

Otolith sampling and selection

Sagittae otoliths for age determination were selected from those already collected and archived into the CSIRO hardparts collection. The otoliths selected were sampled from SBT caught in Australian's surface fishery in the GAB in the 2001-02 (n=125), 2002-03 (n=122) and 2003-04 (n=171) fishing seasons. A fishing season runs from Nov/Dec to April of the following year. Otoliths were selected based on size of fish. All otoliths sampled from small and large fish were selected from each fishing season, and a fixed number of otoliths (either 10 or 20) were chosen from each of the remaining 5 cm length classes (Table 1). This was the

[2] "Length (or age) distribution of catchable fish" means the length (or age) distribution of fish, multiplied by selectivity and/or availability as appropriate. Selectivity is dealt with elsewhere in the stock assessment and is irrelevant to the discussion of estimator purpose.

best method of obtaining as many age estimates from length classes where sample sizes were small, while providing enough estimates for each season. Morton and Bravington (2003) reported that between 100-200 otoliths from the surface fishery should be sufficient to provide acceptable precision (CVs under 20%).

Otoliths were weighed to the nearest 0.0001 g provided they were not chipped or damaged. The relationship between otolith weight and fish length was examined to ensure that the otolith and the data that accompanied the otolith were consistent. Otoliths were then packaged and sent to the Central Ageing Facility (CAF) in Victoria for sectioning and reading (age estimation). 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 primary otolith reader (CAF) counted the number of alternating opaque and translucent increments in each otolith twice and a final count was assigned. To examine the consistency of readings, a subsample of 10% of the otoliths were read twice by a secondary otolith reader (at CSIRO). The Average Percentage Error (APE) method of Beamish and Fournier (1981) was used to measure the intra-reader consistency in otolith readings (replicate readings by the primary reader) as well as inter-reader consistency (final age estimate by primary and secondary reader). All readings were conducted without reference to the size of the fish, date of capture, or to previous readings.

A problem in assigning age for SBT is that theoretical birthdate is January 1 (middle of the spawning season; see CCSBT-ESC/0509/Info) and opaque increments are formed during winter (May and October) (Clear et al., 2000, Gunn et al., In Press). Using the number of increments as an estimate of age can be misleading if SBT are caught during the winter. However, SBT in the GAB are caught during summer (November to April), so there is less confusion about assigning an age from increment counts. For example, SBT with 2 increments in their otoliths were classed as 2 year-olds. Thus, SBT of the same age, caught in the same fishing season, were spawned in the same spawning season.

Length-frequency sampling

In the GAB, length samples are made for each towcage separately. Since there is a possibility that mean length is correlated with number of fish in the towcage (e.g. because a towcage of given size can either hold fewer big fish or more small fish), it is desirable to weight the samples to reflect numbers in each towcage. In addition, in order to estimate variances correctly, and also to correctly weight the relative information of direct age data versus length data, it is necessary to get right the "effective sample size" of the length data; that is, it must be possible to treat the length "sample" as made up of independent draws from the underlying age or length frequency. This entails a re-scaling of the towcage-weighted length frequency. If c_i is the number of fish in towcage i, and π_ℓ is the frequency of length ℓ, then we calculate

$$c_i^* = \frac{c_i}{\sum_j c_j}$$

$$\hat{\pi}_\ell = \sum_i c_i^* \frac{n_{i\ell}}{n_i}$$

$$\mathbb{V}\left[\hat{\pi}_\ell\right] \approx v_\ell \stackrel{def}{=} \sum_i \frac{c_i^{*2}}{n_i}$$

and then calculate

$$\hat{n}_\ell \stackrel{def}{=} \hat{\pi}_\ell / v_\ell$$

which can be treated as a multinomial sample with the "right'' amount of variance. We neglect any finite-sample-correction, since typical a length sample will be 40 fish from a cage of 10000.

For the otolith data, we have simply aggregated all available otoliths in a year; since the otoliths that are actually read are subsampled by length and only used to infer age-at-length (rather than a complete age frequency), there is no reason to worry about towcage or tagging-data effects[3].

Inferring the age distribution

The simplest approach for obtaining estimates of proportions at age is the standard non-parametric age-length key (ALK) approach. The length frequency vector for year t, weighted and re-scaled as just described, is simply multiplied by the matrix of the proportion of fish in each age class at a given length to give numbers (or proportions) at age. Enough otoliths are available so that there are very few "missing rows" in the ALK for any year, i.e. few length classes for which no proportions-at-age can be calculated.

One downside of the ALK is that no use is made of the information about likely age contained in the length frequency alone—thus it is inefficient, with variance up to 50% higher than necessary (Morton & Bravington 2003, table 2). This is especially true for young-fish fisheries such as the Australian SBT surface fishery, where length is quite informative about age (Morton & Bravington 2003, section 2.1). 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 the age data; a similar approach can be found in Martin & Cook (1990). Here we use two versions of Morton & Bravington's estimator, assuming that the mean and variance of length at age are either (a) known *a priori*, or (b) unknown and needing to be estimated together with the proportions at age. The former is slightly more efficient if accurate estimates are available *and* if growth is consistent across cohorts; the latter is robust to changes in growth and almost as efficient, so it is generally to be preferred.

The basis for both versions is maximization of the following log-likelihood within each year:

$$\Lambda = \sum_s \left\{ N_s \log\left(\sum_a p_a p_{s|a} \right) + \sum_a n_{as} \log\left(p_a p_{s|a} \right) \right\}$$

where N_s is the number of sampled fish of size s, n_{as} is the number of sampled fish of age a and size s, p_a is the proportion of fish at age a (i.e. what we want to estimate), and $p_{s|a}$ is the probability that a fish aged a will be of length s. In version (a), $p_{s|a}$ is calculated from a Normal distribution with known mean and variance that depend on a, whereas in version (b) the parameters of the Normal are estimated along with the p_a. The R routine "optim" was used to fit the models.

Variances for the M&B estimates can be obtained from the Hessian. We have not calculated variances for the ALK estimates; Morton & Bravington (2003, section 6.2.3) do give a

[3] Apart from within-season growth, which we have ignored for the moment.

formula but note that the estimate of variance has high sampling variability, and the M&B estimates are preferable to ALK estimates in any case.

Results and Discussion

Age estimates

Age was estimated for 417 SBT ranging in size from 47-162 cm FL (Fig. 1). Only one otolith could not be read as it was too opaque to distinguish the annual increments. Of the otoliths read, the second age estimate of the primary reader agreed with the original estimate in 62% of cases and 98% were within one year of the original. The average percent error between readings by the primary reader was 4.18%, and between the two readers was 3.36% (n=40). These precision estimates are considered good, and the low levels of error suggest consistent interpretation of age in blind tests.

The standard ALKs for the three seasons are given in Table 1. These were applied to the length frequency distributions for each season, obtained as described above (i.e. the same length frequency distributions that were used with the M&B estimator; see Figure 2.)

Proportions at age

Results for the standard ALK approach is shown in Table 2 and illustrated in Figure 4. For comparison the cohort-sliced proportions at age are shown in Figure 3. Results from the M&B estimator (unknown growth) are shown in Table 3 through to Table 6 and Figure 5. First we note that estimated proportions at age are somewhat different from the standard ALK proportions at age (e.g. when comparing figures). Some of the differences are large enough that they could have an effect when used in an assessment context.

The relatively small numbers of otoliths for individuals older than age 5, as well as the low proportion of large fish in the size frequency distribution suggests that it would be better to estimate a mixture of fewer distributions (e.g. 4 or 5 components). Difficulties can arise with estimates of mean length when there is limited data for some length ranges – notably for larger fish. This is a well-known problem with fitting mixture distributions to data. This problem occurs with the 2003/4 data which includes a reasonable number of otoliths in the age 5 category (22 out of the 171), at lengths between 111 and 140cm, but the size frequency distribution has very few individuals above 110cm (Table 5). Without constraints on the mean size at age, or informative starting values, it is hard to estimate a 'sensible' mean size at age for these older age classes, particularly when too many components are being fitted. There are several approaches that could be used to overcome this, including:

a) Using informative starting values (though this does not always resolve the problem)
b) Fixing mean length at age parameters for ages 5 and above, based on information from other years or other sources
c) Imposing a monotonic increase constraint on mean lengths at age (or some form of growth curve)
d) Fitting a smaller number of age classes in the mixture

In this case, approach (a) worked with respect to estimated mean lengths, but then lead to a close to singular Hessian which also meant that it was not possible to calculate the variances of the estimates. This underlines the need for further work to develop an approach which is robust to such situations. This should not, however, be a cause for concern since the younger age classes which are most important for this dataset appears to be well estimated, and the issue with older age classes is a technical one which can be resolved.

It would be worth exploring a formulation which takes cohort effects explicitly into account. Note that if there are substantial differences between the growth of different cohorts, it would be acceptable for an age 4 mean length in season t (say) to be LESS than the age 3 mean length in season t, but it would have to be greater than the age 3 mean length in season t-1.

The standard deviations imply CVs of less than 10% for proportions at age 3, and CVs of less than 20% for ages 2 and 4, with the exception of the 2003/4 season age 4 estimate which is likely to be related to the difficulties in estimating the mean lengths at age for the larger fish in this season.

We note that application of the M&B estimator with "known growth", and means and variances of length given age taken from a growth study based on data pre-2000 (Polacheck et. al. 2003) did not lead to estimated proportions at age that were believable when compared to the standard ALK and the M&B estimator with unknown growth. The growth parameters we assumed (from are 1990's) were not consistent with the observed mean lengths-at-age in the GAB in recent years. Even apparently small differences in mean length at age appear to have a potentially large effect on estimated proportions at age. (Note: We have not yet repeated this with updated estimates based on data from the 2000's given in Eveson et. al. 2005).

Discussion

The purpose to which an age composition estimate is to be put is important in deciding how to construct the estimator, and especially for deciding how to compute a variance. The task of constructing an optimal estimate of population age distribution, taking into account cage-to-cage variability and limited sampling, is tricky, and we are developing methods for doing this. Meanwhile, we reiterate that the variances given here do *not* describe the uncertainty about the age distribution of catchable SBT in the GAB, which would be much larger; they simply describe our uncertainty about the age distribution of the actual catch, under the assumptions of representative independent sampling within each towcage.

There are technical issues with respect to the number of age classes being estimated and ensuring that the estimated mean lengths at age are biologically plausible, which we'll continue to pursue and attempt to resolve.

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Tables

Table 1. Age length keys by fishing season (2001/02, 2002/03 and 2003/04) for the GAB surface fishery. The upper length of each 5cm length bin is given in the first column (the lowest length bin is also a 5cm bin), and ages are shown across the top.

2001/02	1	2	3	4	5	6	7	8	Total
70		1							1
75		2	1						3
80		1	1						2
85		1							1
90			3						3
95		2	11	5					18
100			11	7	1				19
105			9	11					20
110			3	18					21
115			3	10	5				18
120				2	3	2			7
125					3				3
130					3	1			4
135					1		2		3
140						1			1
Total		7	42	53	16	4	2		124

2002/03	1	2	3	4	5	6	7	8	Total
65	1								1
70	1								1
75		2							2
80			1						1
85		4	4						8
90		4	7						11
95			3	3					6
100			7	3					10
105			6	3	1				10
110			3	6	1				10
115			2	7	1				10
120				8	2				10
125			1	3	6				10
130					11	1			12
135					1	3	2		6
140				1	1	3	1	2	8
145					1	1		1	3
150						2		1	3
Total	2	10	34	34	25	10	3	4	122

2003/04	1	2	3	4	5	6	7	8	Total
50	1								1
55	9								9
60	9								9
65	8	1							9
70	1	2							3
75		8							8
80		9							9
85		5	1						6
90		5	4	1					10
95		3	7						10
100		2	8						10
105			7	3					10
110			5	5					10
115			2	6	2				10
120				8	2				10
125			1	5	4				10
130				7	3	1			11
135				1	8	5			14
140					3		1		4
145						6			6
150						1			1
155									0
160							1		1
Total	28	35	35	36	22	13	2	0	171

Table 2: ALK. Proportions at age for the three fishing seasons using the standard “age-length key” method (as described in Morton and Bravington, 2003). (Four decimal places are shown to retain the small but non-zero proportions for ages 1 and >4)

Season	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
2001-2002		0.0203	0.4776	0.3789	0.0416	0.0009	0.0009	
2002-2003	0.0007	0.0597	0.5134	0.3155	0.0420	0.0000	0.0000	0.0000
2003-2004	0.0000	0.3302	0.5564	0.0661	0.0003	0.0000	0.0000	

Table 3: M&B Estimator. Estimated proportions at age for the three fishing seasons using the "parametric estimator: unknown growth" method as described in Morton and Bravington (2003). The means and standard deviations of length given age were also estimated within the optimisation. (Four decimal places are shown to retain the small but non-zero proportions for ages 1 and >4)

Seasons	1	2	3	4	5	6	7	8
2001-2002		0.0803	0.7093	0.1780	0.0279	0.0040	0.0006	
2002-2003	0.0016	0.1465	0.6200	0.2061	0.0257	0.0002	0.0001	0.0000
2003-2004	0.0005	0.3814	0.5469	0.0659	0.0053	0.0000	0.0000	

Table 4: The standard deviation of the estimated proportions at age for the three fishing seasons.

Seasons	1	2	3	4	5	6	7	8
2001-2002		0.0105	0.0224	0.0243	0.0070	0.0025	0.0006	
2002-2003	0.0029	0.0147	0.0362	0.0380	0.0100	0.0002	0.0001	0.0000
2003-2004	0.0000	0.0211	0.0335	0.0355	0.0042	0.0000	0.0000	

Table 5: The estimated mean length given age (assuming this is normally distributed) for the three fishing seasons using the "parametric estimator: unknown growth" method described in Morton and Bravington (2003). Problems with the estimates for ages 5 and older in 2003/4 are discussed in the text.

Seasons	1	2	3	4	5	6	7	8
2001-2002		85.28	98.04	102.29	113.82	119.70	136.27	
2002-2003	72.24	84.82	99.98	104.30	113.05	129.73	132.65	141.62
2003-2004	69.33	85.80	98.70	99.57	98.47	114.29	124.91	

Table 6: The standard deviations of the length given age (assuming this is normally distributed) for the three fishing seasons using the "parametric estimator: unknown growth" method as described in Morton and Bravington (2003).

Seasons	1	2	3	4	5	6	7	8
2001-2002		4.22	3.24	7.32	7.36	7.62	0.19	
2002-2003	2.86	4.44	4.77	6.88	6.63	4.59	2.24	2.12
2003-2004	5.12	5.21	3.91	5.22	6.06	5.99	5.67	

Figures

Figure 1. Length at age for SBT (n=417) caught by Australia's surface fishery in the Great Australian Bight over three fishing seasons (2001-2, 2002-03 and 2003-04).

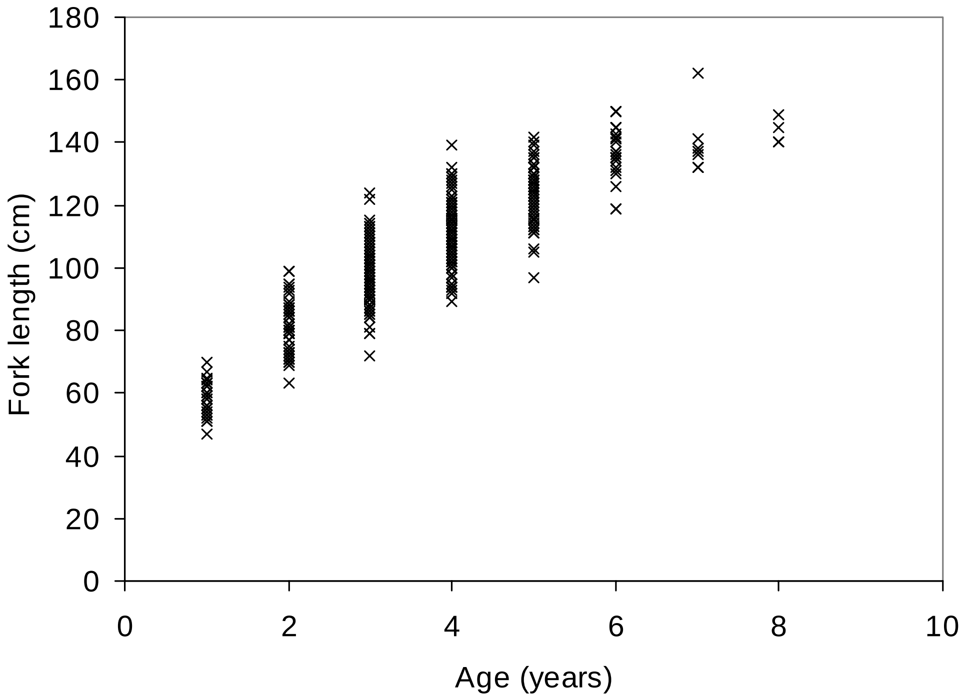

Figure 2: The frequency per fishing season of each length class for the catch and otolith data sets (a fishing season is from November to April). Length frequencies were weighted by number caught in each tow cage..

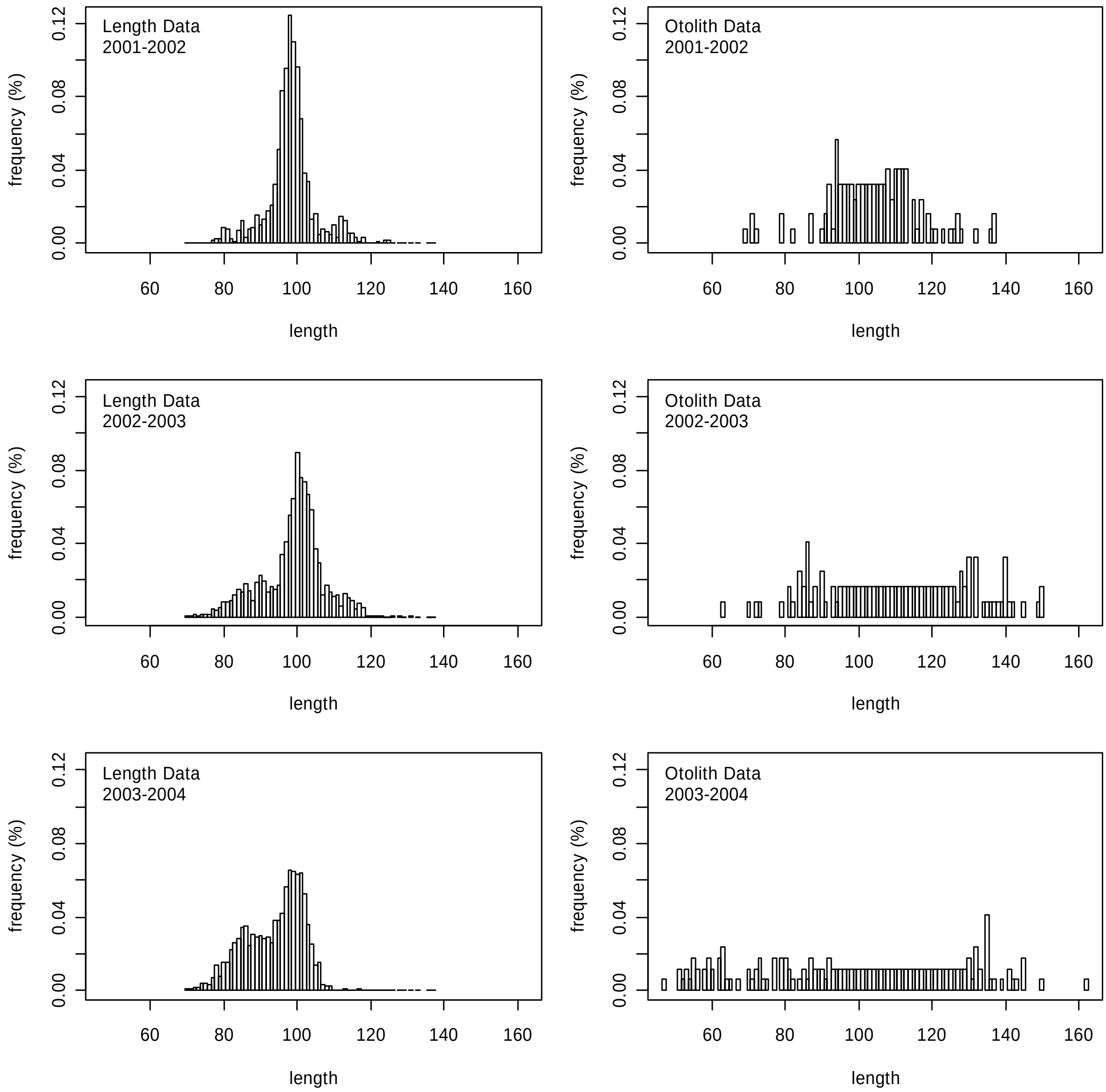

Figure 3 Proportions at age from cohort-slicing for comparison. Taken from the 2005 data exchange (filename: AusSurfaceFishery_CAAbySeason_2002-2004.xls)

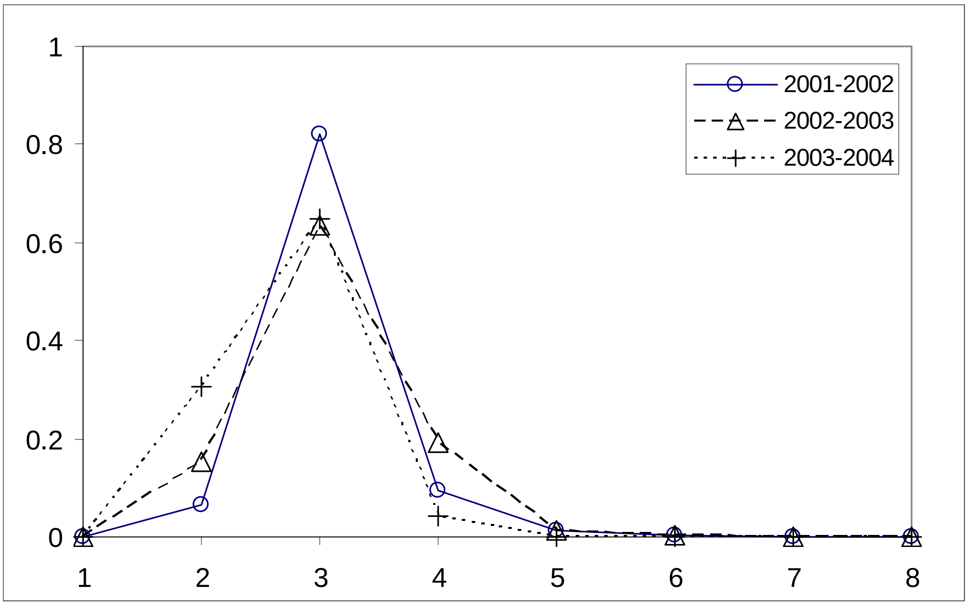

Figure 4. The estimated proportions at age for the given fishing seasons. Proportions were estimated using the “age-length key” method as described in Morton and Bravington (2003).

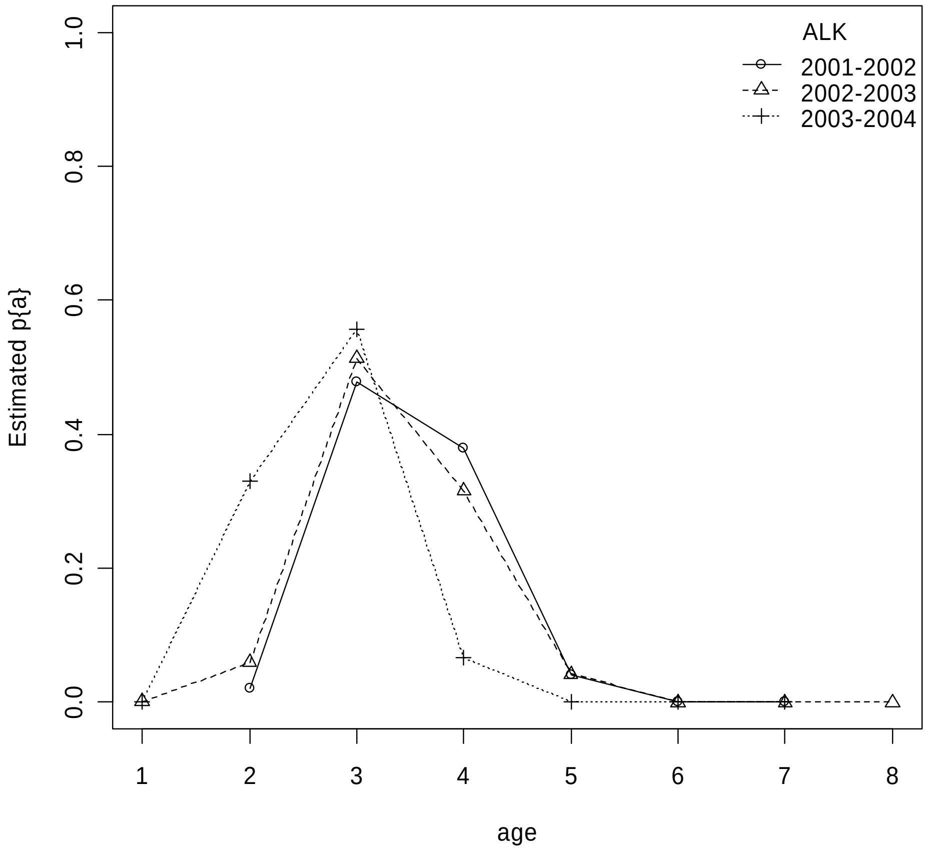

Figure 5. The estimated proportions at age for the given fishing seasons. Proportions were estimated using the "parametric estimator: unknown growth" method as described in Morton and Bravington (2003). The proportions at size given age were also estimated within the optimisation.