AN EVALUATION OF ERRORS IN TREE AGE ESTIMATES BASED ON INCREMENT CORES IN KAHIKATEA (*DACRYCARPUS DACRYDIOIDES*).

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ABSTRACT

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Twelve kahikatea (*Dacrycarpus dacrydioides*) discs were used to assess the likely errors associated with estimating tree age from growth ring counts in increment cores. Two major sources of error were examined: (1) Failure of the increment core to pass through the tree's chronological centre. A geometric model is developed for estimating the distance to the chronological centre in cores where the arcs of the inner rings are visible. The mean percentage error from 84 cores that passed within 50 mm of the chronological centre was ±35% corresponding to a mean absolute error of ±21 years. The majority of this error is due to growth rate differences between the missing radius and the measured part of the core. (2) Missing rings. The average age underestimate from 48 cores due to missing rings was 13%. A significant correlation between radius length and age under estimate (r = 0.81) suggests that sampling along the longest radii will reduce this error. The average age underestimate due to missing rings from cores located along the longest radii of the twelve samples was 3%.

KEYWORDS: *Dacrycarpus dacrydioides* - kahikatea - dendroecology - tree age estimate - growth ring - dendrochronology.

INTRODUCTION

Tree-ring counts from increment cores are widely used in ecological studies as a non-destructive means of estimating tree ages. Three problems arise when using growth rings from increment cores to estimate tree age (Norton *et al.* 1987):

1. For a variety of reasons increment cores often fail to reach the chronological centre of the tree, and age must be extrapolated for the missing portion of the radius (see Norton *et al.* (1987) for terminology).

2. Missing rings are common in many New Zealand trees with frequent "wedging out" of groups of rings along some radii (i.e. growth rings are absent around a portion of the circumference).

3. Sampling is rarely at ground level, and the time taken by the tree to reach the sampling height has to be estimated.

By examining kahikatea (*Dacrycarpus dacrydioides*) discs of known age this paper investigates the first two of these problems.

Estimation of the age of the missing radius involves three steps:

1. Estimating the position of the chronological centre, and obtaining an estimate of the length of the missing radius.

2. Estimating the mean ring width in the missing radius.

3. Dividing the estimated length by the estimated mean ring width to obtain an estimate of age in the missing radius.

The tree's geometric centre is often used as an estimate of the position of the chronological centre in order to obtain the length of the missing radius (Wardle 1963, Clayton-Greene 1977, Allen 1988). A previous study (Norton *et al.* 1987) has investigated the errors associated with this method in 4 New Zealand tree species (*Agathis australis, Libocedrus bidwillii, Nothofagus solandri,* and

Prumnopitys taxifolia). In the present study a geometric model is developed for estimating the length of the missing radius in cores where the arcs of the inner growth rings are visible (Fig. 1). The errors associated with the application of this model to kahikatea trees are investigated.

Missing rings due to ring wedging have been identified in a number of New Zealand tree species (Dunwiddie 1979, Norton *et al.* 1987) and are thought to be a result of the development and death of major branches, and consequent variations in food and growth regulator supplies (Fritts *et al.* 1965). A number of authors have commented on the difficulties in ageing discs of species that exhibit a high rate of ring wedging often associated with irregular or lobate diameter growth (Dunwiddie 1979, Norton *et al.* 1987, Norton & Ogden 1987). Errors in age estimates are likely to be accentuated if based on increment cores, since missing rings on single radii can be as high as 10% of the total number of rings present (Norton & Ogden 1987). The present study investigates the likely errors caused by missing rings in increment cores from kahikatea trees.

A GEOMETRIC MODEL FOR ESTIMATING THE MISSING RADIUS

Increment cores often pass close enough to the chronological centre that the arcs of the inner rings are visible. Applequist (1958) used a device called a "pith locator" to estimate the distance to the chronological centre based on the curvature of these inner rings. Norton *et al.* (1987) suggest a similar method of tracing the arcs, fitting circles to them using a compass, and then measuring the length of the missing radius. Alternatively the length of the missing radius (r) can be related to the height (h) and length (L) of an arc (Fig. 1) by Equation 1:

$$r = \frac{L^2}{8h} + \frac{h}{2}$$

Equation 1.

This model assumes concentric growth from the chronological centre to the increment core. Dunwiddie (1979) notes that lobate growth in young trees of kahikatea is not excessive, and growth close to the chronological centre may be approximately concentric. For cores passing close to the centre this assumption may therefore be valid.

Liu (1986) proposed a similar model for estimating the lengths of missing radii based on measurements of growth rings at the tree circumference and the diameter of the increment core. Liu's (1986) model assumes concentric growth for the entire age of the tree, an assumption which appears invalid for most New Zealand tree species (Norton *et al.* 1987).

MATERIALS AND METHODS

APPLICABILITY OF THE GEOMETRIC MODEL

Discs from the bases of twelve kahikatea trees were sanded using successively finer grades of sandpaper until the growth rings were clearly visible. Seven lines representing theoretical increment cores were drawn on each disc. The lines were drawn from randomly located points on the disc's circumference to points 5, 10, 15, 20, 30, 40 and 50 mm from the tree's chronological centre (distance m in Fig. 1). A second line, parallel to the first, was drawn at a further 5 mm from the tree's chronological centre (the diameter of commercially available increment cores). These lines represent increment cores that have missed the chronological centre by 5, 10, 15, 20, 30, 40 and 50 mm respectively. Unless stated otherwise all lengths were measured to ±0.1 mm using vernier callipers. Lengths less than 30 mm were measured, and growth rings counted under reflected light using 0.6x binocular magnification. Growth ring formation was assumed to be annual.

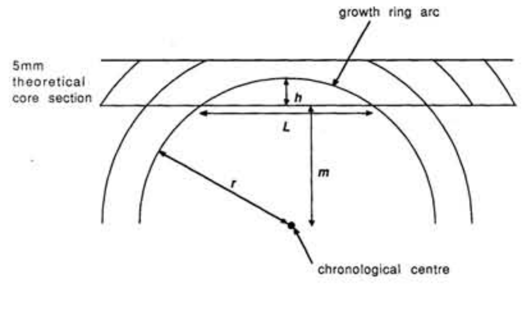

Figure 1. Diagram of a theoretical core section showing the height (h) and length (L) of an inner growth ring arc, the missing radius (r), and the distance by which the core misses the chronological centre (m).

In all cases more than one arc was visible in the 5 mm section representing the increment core. The arc selected for measurement was chosen using the following guidelines (in order of precedence):

1. The arc was free of any ring wedging within the 5 mm core section.

2. The arc was the largest visible in the 5 mm core section. This minimises the error in deriving the estimated missing radius due to measurement errors in h and L.

The lengths h, L and the true length of the missing radius were measured and an estimate of the length of the missing radius was derived using Equation 1.

The number of rings in the missing radius were counted and the mean ring width determined. The mean ring widths of the innermost 20 and 50 growth rings in each theoretical core (starting from the measured arc) were used as estimates of mean ring width in the missing radius (cf. Norton *et al.* 1987). The lengths used for the calculation of mean ring widths (d in Fig. 2) were corrected to compensate for the offsetting of the theoretical core from the tree centre using Equation 2:

$$d_{\text{corrected}} = \sqrt{\left(\frac{L^2}{8h} - \frac{h}{2}\right)^2 + \left(d + \frac{L}{2}\right)^2} - \left(\frac{L^2}{8h} + \frac{h}{2}\right)$$

Equation 2.

Estimates of the number of growth rings in the missing radius were obtained by dividing the estimated length of the missing radius by the mean ring widths obtained from the 20 or 50 innermost growth rings.

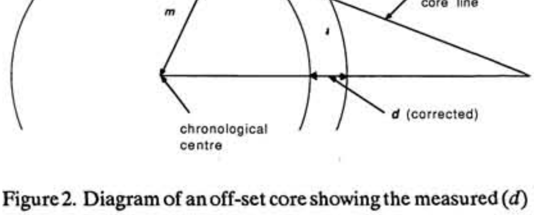

Figure 2. Diagram of an off-set core showing the measured (d) and the corrected ($d_{\text{corrected}}$) distances used for calculating mean ringwidth, and the distance by which the core misses the chronological centre (m).

ESTIMATION OF MISSING RINGS

The high degree of ring wedging and lobate growth in the twelve sampled discs made accurate determination of the true age difficult. An estimate of the true age of each disc was obtained by counting rings along a radius from the chronological centre. When it was apparent that the radius was missing rings, a growth ring circumference was followed around until counting could be continued on another radius that included the missing rings. This procedure was continued to the disc circumference thus giving an estimate of the true age.

Four locations, representing increment core sampling points were subjectively located on the circumference of each of the sanded discs. The points were located in an attempt to simulate likely field sampling positions using the following guidelines:

1. All of the discs exhibited lobate growth, often with deep fluting, giving an irregular circumference. Points were located on the ends of the largest lobes.

2. An attempt was made to place one point in each quarter of the circumference (this was not always practical).

Lines representing theoretical increment cores were drawn from the chronological centre to the four points on the disc's circumference. In all cases the longest radius was included as a theoretical core. The growth rings along each line were counted under reflected light using 0.6x magnification, and the core's length was measured to ±1 mm using a steel ruler.

RESULTS

APPLICABILITY OF THE GEOMETRIC MODEL

Comparisons between the estimated and true missing radius length, mean ring width and age of the missing radius were made in three ways (cf. Norton *et al.* 1987): (1) the absolute differences between estimated and true values were determined and the values averaged to give a mean for each method; (2) the absolute differences were expressed as a percentage error of the true value and averaged to give a mean percentage error for each method; (3) the number of over- and underestimates were tallied for each method, and significant deviations from expected frequencies were determined using a Chi-square test. In some age estimates the estimated age equalled exactly the true age; the error of ±0% was added into the average of the class but the core is not represented as either an over- or under-estimate in the tables.

Results from the estimation of the missing radii lengths are summarised in Table 1. The mean percentage error from all cores is ±21% and individual errors ranged from -40.5 to 111.5%. The absolute error increased with increasing distance from the chronological centre. Some of the error in the estimated radius length is due to measurement error in the lengths *h* and *L*. In all estimates *h* was >2 mm and *L* was >10 mm. With a measurement accuracy of ±0.1 mm the maximum error in the estimated radius due to measurement errors in *h* and *L* is less than 7% (unpub. data). Larger errors occur as a result of non-concentric growth. There was no significant trend to over- or under-estimate missing radius length.

Results from the estimation of mean ring widths are summarised in Table 2. The method of estimating mean ring width appears to make little difference, since the mean percentage errors of the 20 and 50 innermost ring estimates are 43 and 47% respectively. The ranges of individual errors for the two methods are -52.0 to 213.4% and -53.6 to 268.6% respectively. Errors due to measurement and the assumption of concentric growth in deriving the corrected lengths are likely to be small. The majority of error is caused by differences between the actual growth rates in the missing radius and the actual growth rate in the measured part of the core. Significantly more mean ring widths were over-estimated ($P < 0.05$). In most cases the discs showed suppressed early growth, with narrow rings followed by growth release. The 20 and 50 innermost rings often occurred within the period of release resulting in an overestimate of mean ring width.

The results of estimation of missing radii age are summarised in Table 3 for the two methods of mean ring width estimation. The absolute error in age estimate tends to be smaller in cores that pass closer to the chronological centre. Significantly more ages were under-estimated ($P < 0.05$) as a result of the tendency to over-estimate mean ring width.

ESTIMATION OF MISSING RINGS

The true age of the sampled discs ranged from 390 to 555 years with a mean of 455 years. The difference between the number of growth rings counted along each of the four core lines and the samples true age was expressed as a percentage under-estimate of the true age. For each sample the lengths of the core lines were expressed as a percentage of the longest radius of the sample. Core length expressed as a percentage of the longest radius was plotted against percentage age under-estimate (Fig. 3) and the two were found to be significantly correlated ($r = 0.81, n = 48$). For a given sample, cores measured on longer radii

Distance from chronological centre (mm).	Mean absolute error ± S D (mm).	Mean percentage error ± S D	Number of over/under estimates.
5	1.4 ± 0.9	15.9 ± 9.6	7/5
10	2.9 ± 3.5	19.7 ± 23.3	6/6
15	3.6 ± 2.7	19.4 ± 14.9	6/6
20	4.0 ± 3.2	16.4 ± 13.3	3/9
30	6.2 ± 4.1	18.3 ± 11.3	7/5
40	13.7 ± 17.3	30.5 ± 36.5	5/7
50	14.0 ± 7.2	25.8 ± 12.5	3/9
	6.5 ± 8.7	20.8 ± 20.1	37/47 ($X^2 = 1.19, P < 0.5$)

Table 1. Summary of the results of estimation of the missing radius length.

	Mean ring width ± S D (mm).	Mean percentage error ± S D.	Number of over/under estimates.
Missing radius	0.540 ± 0.177		
20 inner rings	0.651 ± 0.282	43.3 ± 45.8	53/31 (X^2 = 5.76, $P < 0.05$)
50 inner rings	0.669 ± 0.268	47.4 ± 56.7	61/23 (X^2 = 17.19, $P < 0.01$)

Table 2. Summary of the results of estimation of mean ring width.

tend to give better estimates of true age. The mean age under-estimate of all cores was 13.3 ± 9.6%, while the mean age under-estimate of the longest radius in each sample was 3.4 ± 2.2%. The largest individual age underestimate due to missing rings was 39.5%.

DISCUSSION

This method of estimating the age of the missing radius has a mean percentage error of ±35%. This represents a ±21 year age estimate error. For the sampled discs with a mean age of 455

Distance from chronological centre (mm).	Mean absolute error ± S D (years).	Mean percentage error ± S D	Number of over/under estimates.
20 INNER RINGS			
5	5.3 ± 3.7	30.1 ± 23.5	6/5
10	8.1 ± 8.8	21.8 ± 12.8	4/7
15	13.9 ± 11.9	32.3 ± 23.9	5/7
20	16.0 ± 8.3	32.2 ± 13.5	3/9
30	21.6 ± 15.9	33.6 ± 21.3	2/9
40	45.8 ± 56.4	58.9 ± 83.8	4/8
50	37.4 ± 23.7	41.2 ± 25.6	4/8
	21.2 ± 27.7	35.4 ± 37.4	28/53 (X^2 = 6.37, $P < 0.05$)
50 INNER RINGS			
5	6.8 ± 5.0	34.8 ± 20.6	6/6
10	7.3 ± 9.5	18.1 ± 16.2	2/10
15	10.3 ± 13.8	21.1 ± 20.8	2/10
20	15.7 ± 13.3	28.9 ± 20.4	4/8
30	20.4 ± 15.4	30.1 ± 21.9	2/10
40	54.2 ± 66.1	67.6 ± 95.9	5/7
50	37.3 ± 31.8	41.8 ± 39.9	5/7
	21.7 ± 32.9	34.6 ± 43.7	26/58 (X^2 = 12.19, $P < 0.01$)

Table 3. Summary of the results of estimation of missing radii age.

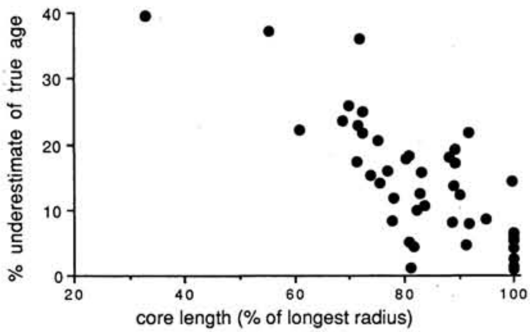

Figure 3. Plot of core length (expressed as a percentage of the longest radius) against core age (expressed as a percentage underestimate of true age) for 48 theoretical cores. $r = 0.81$.

years this represents an error of ±5% in the total age estimate.

Comparisons with the method of Norton *et al.* (1987) who used the geometric centre are difficult, as the errors in that study are given only as a percentage of total tree age. Average tree ages are not given, making it impossible to derive a comparative measure of the error in missing radius estimate independent of the tree age. The two methods also differ in their application. The geometric centre is used as an estimate of the position of the chronological centre when an increment core fails to reach the centre, because the corer is too short or because of a rotten tree centre (e.g., Clayton-Greene 1977, Allen 1988). When an increment core passes to the side of the chronological centre and the inner growth rings arcs are visible these can be used to estimate the position of the chronological centre (Applequist 1958, Clayton-Greene 1977, Norton *et al.* 1987). It would be expected that this latter method would provide better estimates of missing radius length, since the position of the chronological centre is estimated from direct evidence (the inner growth ring arcs) rather than the assumption that it is located at the geometric centre. The majority of error in the estimation of the length of the missing radius (Table 1) is due to non-concentric growth close to the tree centre. Other tree species will vary in this respect. Eccentric or lobate growth when trees are young is likely to increase the errors in age estimates.

On average the majority of the error in age estimates was due to error in the estimation of mean ring width in the missing radius. In the sampled discs there was a tendency to over-estimate mean ring width and so under-estimate age, due to a period of suppressed early growth. In trees that show a period of rapid initial growth followed by suppression, the tendency will be to over-estimate age. In general the sign of this error is unpredictable (Norton *et al.* 1987) and depends on individual tree growth patterns, the distance of the core from the tree centre, and the portion of the core used for ring width estimation.

The errors in age estimates (Table 3) ignore the effects of missing rings. In cores where rings are missing due to ring wedging age will be under-estimated. This is the case even when a core passes through the chronological centre. The mean error in age estimates due to missing rings was 13%. However, by taking four increment cores and using only the core with the greatest number of growth rings, the mean under-estimate in the true age of the samples is reduced to 3%. The significant correlation between radius length and error in age estimate in the kahikatea samples suggests that field sampling along the longest radii will reduce errors due to missing rings.

The total error in age estimates based on increment cores is due to a combination of errors associated with estimating age in the missing radius and errors associated with missing rings. By combining the two values the results suggest that in the sampled discs the average error in age estimate in cores measured along the longest radius, and passing within 50 mm of the tree's chronological centre is less than 10%.

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