Tree ring analysis in rimu (*Dacrydium cupressinum*): implications for studies of forest dynamics and sustained yield management

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Abstract

A preliminary analysis of tree ring series on rimu (Dacrydium cupressinum) discs indicated that inferences of past disturbance history based on ages derived from increment cores must be made with caution. On the discs examined, extreme wedging and lobate growth led to age underestimates of up to c.25% along different radii. In addition to age underestimation, there was a general trend of overestimation of diameter increment. This has implications for forest management because mean annual diameter increment is used to calculate volume increment, a key component in the determination of rotation length. If diameter increment is overestimated (and therefore volume increment as well), rotation length may be underestimated.

Introduction

The new Forests Amendment Act 1993 amending the Forests Act 1949 requires management of New Zealand's remaining indigenous forests for timber production to be on the basis of ecologically sustainable silviculture. This has triggered an urgent need for ecological research in indigenous forests to fill substantial gaps in our knowledge. One area of particular interest to forest managers is growth rate, because accurate diameter and volume increment data are critical for the determination of rotation length. These data can be collected by periodic remeasurement of trees on permanently marked plots or by the examination of past growth by measuring tree rings along a core extracted from a tree using an increment borer. Mean annual diameter increment can then be calculated by several methods: e.g.,

- from mean ring width along the entire core (tree radius)
- from mean ring width of the outermost 50 rings
- by dividing the tree's diameter by its age as determined from an increment core.

Errors are likely using increment cores however, because it is often difficult to core through the chronological centre of the tree, due to eccentric and variable growth. Several authors have devised methods to correct for these errors where the chronological centre has been missed or not reached (Norton, Palmer & Ogden, 1987, Duncan 1989). Of greater importance in tree ring studies is the degree to which age or growth derived from incre-

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ment cores is accurate in comparison to the actual age and growth patterns.

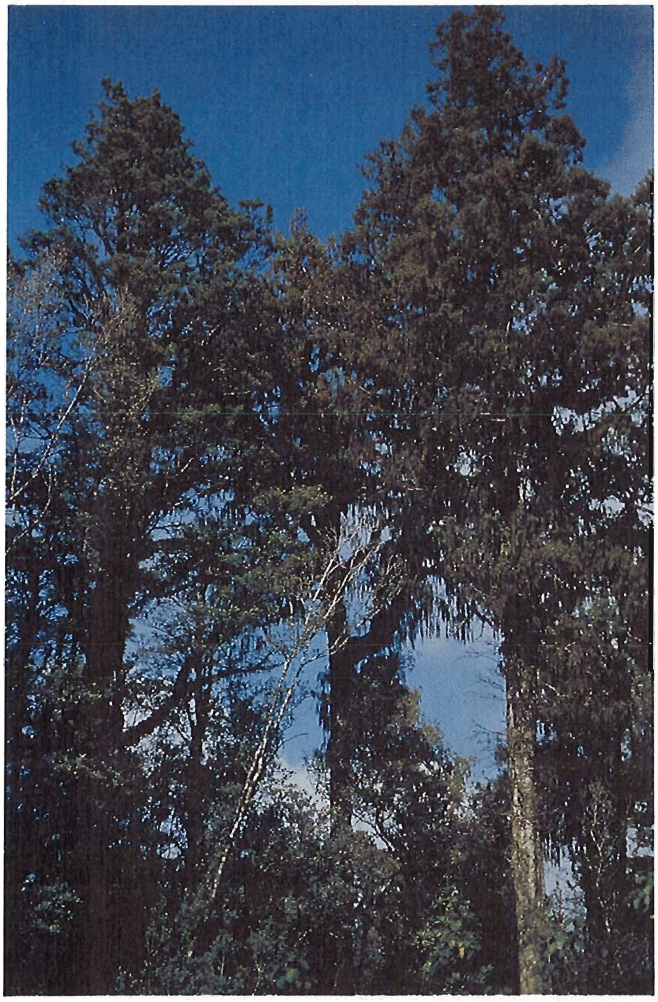
As part of a larger ecological study of stand structure of rimu on glacial moraines in Saltwater Forest, south Westland we were interested to know the accuracy of age and growth determinations made using increment cores. Rimu has been one of the most widely studied indigenous tree species, but is known to be one of the most difficult of all indigenous conifer species for tree-ring studies, as it exhibits extensive wedging around the circumference of the trunk (Franklin 1969, Norton, Palmer & Ogden 1987, Norton, Herbert & Beveridge 1988). However, it is also one of the most important species for sustained indigenous timber production in Westland (Richards 1994). Thus, a greater understanding of the likely errors associated with the measurement of rimu tree rings has relevance for management practice as well as general ecological research.

Our objectives of this study were:

- to evaluate the accuracy of increment coring as a means of age estimation in rimu;
- to identify problems associated with the use of increment cores for diameter increment calculation in rimu.

Methods

Twelve pairs of discs were cut from stems felled in Saltwater Forest during a harvesting operation by Timberlands West Coast Ltd. Each pair consisted of a disc from the base of the tree and a second from the base of the live crown.



Various logging techniques have been used in the past for timber extraction but now the forests at Saltwater and Okarito are the focus of sustained yield management. Photo: New Zealand Forest Service

Forests at Saltwater are dominated by rimu *(Dacrydium cupressinum)* on the right and miro *(Prumnopitys ferruginea)* on the left, that are often at least 600, and often greater than 700 years old. Because of the problems of underestimation associated with ageing from increment cores, many of the largest trees may be slower-growing and older than previously documented. Photo: Glenn Stewart

The discs were prepared for measurement by:

- levelling with an electric hand planer,
- sanding with a belter sander using progressively finer grades from 40 to 120 grit,
- sanding with a foot sander using progressively finer grades from 120 to 400 grit until the surface was polished and all annual rings visible.

Two pairs of discs that exhibited minimal wedging and lobate growth were selected for preliminary analysis. One of each disc pair was from the trunk base and the second at 10.5m and 19.6m, just below the live crown. Disc diameters were 46.2/38.0 cm, and 57.4/33.8 cm (base/base of the live crown, respectively).

Four radii were drawn on each disc to represent hypothetical increment cores. The radii ran to the chronological centre of each disc. Where possible, one radius was located in each quarter of the circumference, which was possible in most instances. Each radius was measured using TRIMS (Tree Ring Incremental Measuring System) dendrochronology software, a Henson Bench travelling stage and a binocular microscope. Unless otherwise stated, all ring widths were measured to 0.01 mm.

Next, beginning at the chronological centre, groups of 10 rings were traced around the full circumference of each disc and marked on each radius. It was assumed that growth rings were annual (Franklin 1969, i.e. no false rings) and that all years were represented on at least one of the radii of each disc. Franklin

(1969) noted that where rimu growth is slow, growth rings may be represented by continuous bands of latewood cells with no clear distinction between different years. Patel (1967) also noted that rimu growth rings were indistinct.

This method of tracing rings was employed because of extreme wedging out of annual rings at various points around the stem – i.e. rapid growth (wide rings) along some radii and extremely slow growth (narrow rings) along others. For example, on one disc 90 rings which formed 2.9 cm of wood on one radius formed only 1.5 cm of wood on an adjacent radius less than 90 degrees away. Both radii were located on lobes. In some instances it was necessary to trace every ring in a group of 10 to find the point at which rings wedged out. Ages of discs estimated in this way were considered to be as close as possible to the 'true' ages. These 'true' ages were then compared to the initial age determinations to establish the amount of error associated with age estimates based on single increment cores.

Using the decade markers as a guide, each radius was then remeasured using the same equipment as for the initial measurements. These 'true' ring widths were then compared to the initial measurements to establish the amount of error associated with growth measurements based on single increment cores.

As a second estimate of mean annual diameter increment the mean ring width for the outermost 50 rings was calculated. Finally, trunk diameters were divided by tree age as an approximate estimate of mean annual diameter increment. This method has been used by a number of workers (e.g., Duncan 1991, Cornere 1992).

Preliminary results

Cross matching to determine growth variability

As a preliminary step in the tree ring analysis we attempted to cross match the four radii on each disc to determine the variation in growth increment around the stem ('circuit uniformity'). Measurements made using the traced decade rings as a guide were compared to each other using the dendrochronological cross-matching programme COFECHA. The inner 200 rings were relatively concentric and possible to cross-match but thereafter difficulties were encountered even when attempting to cross-match two radii from the same disc, indicating that there is much within-tree variability of growth rings. Our original intention to compare growth at several points within the tree ('vertical uniformity' – cross matching discs from the base and base of live crown) was abandoned very early on for the same reasons. Further cross-matching was not attempted. However, mean radial increment calculated from the shortest radius ranged from 11.5 to 22.1% less than for the longest radius. On all four discs, the longest radius gave the highest mean annual diameter increment and it also provided the closest estimate of 'true' age.

For all discs, growth was asymmetric, wedging often extreme, and accurate ageing/measurement problematic. Investigations of the ring patterns of rimu and several other indigenous conifers have highlighted the difficulties of determining age of species exhibiting high rates of wedging associated with irregular or lobate growth (Duncan 1989, Dunwiddie 1979, Norton, Palmer & Ogden 1987, and Cornere 1992).

Use of the entire core for age and diameter growth estimation in rimu

Estimated ages from ring counts along the 16 radii were compared to the 'true' ages of the discs and expressed as a percentage error of the 'true' value. Age was underestimated for 14 of the 16 radii measured (Table 1). The mean age underestimates were 9.0%, 6.6%, 15.5% and 8.1% for each of the four discs, with an overall mean percentage error of 9.8%. Individual radii underestimated the 'true' age by up to 22.6%, although all discs had at least one radius accurate to within c. 3.5% of the 'true' age of the disc.

Estimated mean annual radial increments based on counts of the 16 radii were compared to the 'true' radial increment of the discs and expressed as a percentage error of the 'true' value (Table 2). Mean annual radial increment was overestimated on 14 of the 16 radii. Mean ring width determined from radial counts on the four discs ranged from 0.38 to 0.61 mm. 'True' mean ring width (remeasured after all rings were identified from tracing around the disc circumference) exhibited a similar range, from 0.34 to 0.59 mm. Mean ring width overestimates were 10.2, 5.6, 18.9, and 9.2% for each of the four discs, with an overall mean percentage error of 10.8%. Individual radii overestimated 'true' mean ring width by up to 29.3%, although all discs had at least one radius accurate to within c. 3.5%.

Use of the outermost 50 rings for age and diameter growth estimation in rimu

For the outermost 50 rings along each of the 16 radii, ring counting yielded mean annual diameter increment values ranging from 0.28-0.98 mm/yr with disc means of 0.46, 0.36, 0.76, and 0.54 mm/yr. Measurements based on 'true' age varied from 0.33 to 1.10 mm/yr with disc means ranging from 0.46 to 0.98. These values based on 'true' age are at least 0.3 mm/yr lower than those reported by Franklin (1973) for trees of similar diameter. This could reflect lower annual diameter increments for the trees we measured or, alternatively, overestimation associated with the inaccuracy of ring width measurement on increment cores.

Tree diameter divided by tree age for diameter growth estimation in rimu

Mean annual diameter increment determined by this method ranged from 0.84 to 1.17 mm/yr, but if 'true' ages were used these dropped to values ranging from 0.82 to 1.09 mm/yr. Calculation of increment by diameter/age calculation using initial age determinations overestimated actual mean annual diameter increment (Table 2) by up to 36.5% in the worst case. Increment cores were used to determine tree age in several nearby studies

Table 1: Errors in age estimation of rimu discs from counts along individual radii

	'True' age (yrs)	Radius 1 ring count	Radius 1 % error	Radius 2 ring count	Radius 2 % error	Radius 3 ring count	Radius 3 % error	Radius 4 ring count	Radius 4 % error
Log 1 base	565	543	–3.9*	475	–15.9	549	–2.8	490	–13.3
Log 2 base	525	568	8.2	501	–4.6	512	–2.5	474	–9.7
Log 1 crown	424	328	–22.6	368	–13.2	378	–10.8	427	0.7
Log 2 crown	366	322	–12.0	353	–3.6	354	–3.3	317	–13.4

* positive values indicate overestimates, negative values indicate underestimation.

Table 2: Mean ring widths (mm) of rimu based on measurement of radii (A) and on remeasurement after all rings were identified on all radii (B)

	Radius 1		Radius 2		Radius 3		Radius 4	
	mean ring width A	mean ring width B	mean ring width A	mean ring width B	mean ring width A	mean ring width B	mean ring width A	mean ring width B
Log 1 base	.451	.434	.402	.338	.381	.370	.420	.365
Log 2 base	.477	.516	.544	.526	.605	.590	.570	.514
Log 1 crown	.485	.375	.486	.422	.503	.448	.452	.455
Log 2 crown	.522	.459	.496	.478	.444	.429	.490	.423

and diameter increment can be calculated from their data. Mean annual diameter increment (± S.D.) for 449 rimu trees aged by Cornere (1992) on the adjacent terraces was 1.55 ± 0.69 mm/yr and for 110 rimu on moraines similar to where our discs were obtained was 1.44 ± 0.48 mm/yr (Stewart & White unpublished data). These values are considerably higher than our estimates derived from the discs and could reflect higher growth rates. However, they do not take into account age underestimation likely on increment cores and as a result of the inclusion of bark in the diameter/age calculation.

Implications

Calculation of diameter and volume increment

Although each measured radius was probably not independent (especially if from the same disc), overall mean annual diameter increments calculated from the 16 radii illustrate the general patterns outlined.

Mean annual diameter increment (mm/yr ± SE) estimates derived by five different methods were:

1) entire radius – initial ring measurements	= 0.97 ± 0.29
2) entire radius – 'true' ring measurements	= 0.89 ± 0.03
3) outermost 50 rings – initial ring measurements	= 0.53 ± 0.05
4) dbh/age	= 1.00 ± 0.24
5) dbh/'true' age for the four discs	= 0.82, 1.09, 0.90, 0.92

Because of problems associated with the recognition of all tree rings along individual radii, annual diameter increment was generally overestimated (Table 2,and see above), except for the calculations based on the outermost 50 rings. The calculation of diameter increment by dividing trunk diameter by age also resulted in overestimation, but if 'true' age was used, the small overestimation was within the error that could be attributed to the inclusion of bark.

If volume increment was determined using increment cores underestimating age would overestimate mean annual ring width and therefore overestimate volume increment. Although only four discs were measured, if age is consistently underestimated and growth increment overestimated from increment cores,then this has significant implications for sustained yield management in Saltwater Forest (if volume increment is calculated using increment core measurements). Volume increment is one of the factors used to determine rotation length – currently this is 500 years for rimu in Saltwater Forest. If annual ring width is less than currently believed and therefore volume increment is lower than predicted, production will not be sustainable unless rotation length is increased.

Although the longest radii, at least for rimu, appears most likely to give the most accurate age estimates, their use for the calculation of annual growth increment will usually result in overestimation. Growth is not uniform around the stem and the greatest ring width occurs along the longest radii (Franklin 1969). An alternative, and perhaps more robust method for estimation of mean annual increment may be to use trunk diameter divided by age. Several cores would still need to be taken from each tree to obtain an age estimate as close as possible to the 'true' age.

For the outermost 50 rings, diameter increment was underestimated, reflecting a decline in ring width with tree age and difficulty in the recognition of individual tree rings. We found the outer rings on the measured discs were consistently the most difficult to measure, being lighter (sapwood) and therefore less distinct. We regard this method as the most likely to give highly variable underestimates and/or overestimates of mean ring width. Furthermore, it would seem more relevant for forest management to know the annual growth increment over the entire trees' lifespan, rather than over just the last 50 years.

Periodic remeasurement of diameter on tagged trees is obviously the best method to obtain more accurate measures of diameter increment. However, for a slow-growing species such as rimu, that displays extremely irregular or lobate growth, the remeasurement interval required to obtain accurate data may well be many decades.

Studies of forest dynamics

Any inference of past disturbance history from rimu age distributions derived from increment cores must be made with caution because of the likely underestimates of tree age. Underestimates in this study for discs c.30-60 cm diameter ranged from 3 to 23%, but for larger-diameter stems (e.g., 80-100 cm dbh) greater underestimates are likely. Therefore, stand age structures based on age determinations from single increment cores from each tree (e.g., Six Dijkstra, Mead & James 1985, Cornere 1992, Rogers 1995) almost certainly represent minimum ages.

For rimu age determination it is therefore recommended that at least two increment cores be extracted from each tree, preferably along the longest radii. For terrace rimu stands in Saltwater Forest, Cornere (1992) plotted core length (expressed as % of longest radius) against % underestimate of true age to determine whether core length affected accuracy. He found a weak correlation ($r=0.41$, $n=60$, $p<0.001$) suggesting that longer cores were more likely to exhibit the most accurate age. Duncan (1989) noted a similar relationship for *Dacrycarpus dacrydioides* in south Westland. Although extracting a core from the longest radius may provide a good ring series there is no way of knowing, however, with any certainty whether the chronological centre will be reached because it is often not located at the geometric centre of the tree (Norton, Palmer & Ogden 1987).

Sudden increases in tree ring width can be used to date past disturbance events (e.g., Stewart & Rose 1990, Lusk & Ogden 1992). A rapid increase in diameter growth often occurs as trees are released from competition by disturbance-induced mortality of neighbouring trees. These 'growth releases' can provide insight into past forest regeneration processes. The huge variation in ring widths along different radii on the same disc identified in our study, however, indicates that an analysis of growth releases in rimu could be very misleading and of limited use in determining stand disturbance history.

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Mechanical site preparation using excavators

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ABSTRACT
The use of excavators for site preparation is becoming increasingly popular in New Zealand and overseas. Excavators can be fitted with a wide range of attachments and can fulfil multiple tasks within a forest.

This paper summarises recent LIRO studies of excavators used in a site preparation role in the forest industry.

Windrowing with an excavator fitted with a slash rake achieved 0.46 hectares per productive machine hour at a cost of $240 per hectare.

Spot cultivation by ripping and mounding with an excavator cost $434 per hectare at 0.29 hectares per productive machine hour.

The ROTREE spot cultivator-mounder working on sites with slopes of 0-15° covered 0.23-0.29 hectares per productive machine hour at a cost of $450-$540 per hectare.

Excavators can typically work on steeper slopes than other commonly used site preparation equipment and operate with less site impact.

Figure 1. Excavator with slash rake windrowing a site logged by contour tracking.

Introduction
Excavators as base machines for site preparation operations are common in North America, especially Canada, where there has been a rapid increase in the number of excavators used for site preparation in the last five years (Clark, 1993).

The use of excavators as a site preparation prime mover has also gained in popularity in New Zealand in the last three years.

Windrowing of heavy slash on rolling to steep terrain with excavators fitted with slash rakes and modified tracks (Hall, 1992) as an alternative to burning or line raking with tractor is now common practice in much of the South Island (Figure 1). Cultivation of cutover soils prior to planting is a common practice, especially in the compact pumice soils in the Bay of Plenty. *Pinus radiata* root growth becomes limited when soil strength exceeds 3 megapascals (Mason and Cullen, 1986). Many of the soils in the Bay of Plenty and in much of the rest of New Zealand exceed this level below a depth of 30-40 cm. The deep cultivation provided by ripping operations reduces the incidence of severe juvenile instability and sometimes increases tree growth, depending on the soil type.

Traditionally the cultivation of these sites has been carried out with a ripper-mounder unit mounted on a 150 kW tractor. Much

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