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Reliability of increment core growth ring counts as estimates of stand age in totara (*Podocarpus totara* D.Don)

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Abstract

Totara (*Podocarpus totara* D.Don) is an important indigenous timber tree in New Zealand. Old-growth stands have been depleted, but totara regeneration is a prominent feature of the rural pastoral landscape in many parts of the country. These young stands have not been well described or quantified. A method for determining their age is essential if their development and timber potential is to be understood. The reliability of a commonly used procedure for estimating tree age from growth-ring counts was investigated by sampling in totara stands of known age. Increment cores were taken from 11 planted stands ranging in age from 9 to 91 years. Of the 147 cores sampled, 122 (83%) were considered to be suitable for ring counting with the aid of a stereo-microscope. Estimates of age based on latewood band counts showed least bias in stands with diameter growth rates of approximately 5 mm yr^{-1}. There was a tendency towards underestimation in slower-growing stands because latewood bands were not formed every year. The age of seven well-stocked stands with mean diameter increment ranging between 2.8 and 4.8 mm yr^{-1} was underestimated by 7 – 19%. Cores obtained from faster-growing stands did not always exhibit distinct latewood bands and sometimes formed more than one growth ring per year. This led to overestimation of age. In three open-growing stands with diameter increment averaging 7.1 mm yr^{-1}, age was overestimated by an average of 10%. The latewood-band counting method is likely to underestimate age in regenerating totara stands where intense competition and slow growth rates can be expected. Avoidance of sampling suppressed trees and rejection of core samples with indistinct latewood bands should decrease error and allow estimates of stand age to lie within 10 – 15% of actual age.

Keywords: age; growth rings; increment cores; indigenous tree species; planted forest; *Podocarpus totara*; regeneration

Introduction

Regenerating stands of totara (*Podocarpus totara* D.Don) are a feature of the rural landscape in many parts of New Zealand (Bergin, 2000). These stands are often located in hill country cleared of the original forest within the past 150 years and converted into pasture. They have not been well-described or quantified and, until recently, they have not been considered as a potential wood resource. Totara is regarded as one of New Zealand's important native tree species (Bergin, 2003). Its timber is reported to be unequalled for ease of shaping, light weight and durability (Bergin & Gea, 2007). Most of the old-growth totara resource has been depleted and interest is now being expressed in market and non-market benefits associated with regenerating stands and planted woodlots (Moodie, 2010; Quinlan, 2010).

Accurate determination of the age of such stands is essential for the understanding of their development and potential response to silviculture (Bergin & Kimberley, 2010). In particular, more knowledge is required about the growth rates of totara on land

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that has been, and continues to be modified by the introduction of herbaceous plant species and grazing animals.

Determination of the number of growth rings representing annual formation of wood in the lower part of the tree stem has proved to be a useful indicator of the age of many temperate forest tree species (Fritts, 1976). Application of this method to totara has led to a range of opinion about the value of ring counts for determination of stand age. Garratt (1924) described the rings as distinct to the unaided eye, with a tendency to be close and uniform, and comprising very narrow bands of latewood with gradual transition from early wood. Hinds and Reid (1957) reported that rings in totara are poorly-defined, and that latewood forms slightly darker bands. Meylan and Butterfield (1978) found the growth rings of totara to be moderately distinct to distinct. Patel (1967) rated them as indistinct to distinct.

Further difficulties encountered in the counting of totara growth rings include uncertainty about their annual formation. Dunwiddie (1979) reported severe problems with ring wedging and lobate growth in both *Podocarpus totara* and *P. cunninghamii* (Hall's totara). Lloyd (1963) noted the presence of apparent false rings in five species of podocarp including *P. totara*. In a preliminary study of New Zealand timber tree species, Bell (1958) suggested that up to three rings may be formed in one year. Cameron (1959), when measuring growth ring widths in totara and other indigenous softwoods in North Auckland, acknowledged that false rings may have been counted, and that more than one ring could have been produced per year.

In contrast, Wells (1972) reported regular formation of annual rings in a study of Hall's totara growing in Central Otago, New Zealand. Because of difficulties with compressed ring sequences, McSweeney (1982) used basal discs from windthrown or logged totara trees in South Westland, New Zealand for ring counts rather than increment cores from living trees. After drying and sanding the discs, he found that growth rings were distinct. There was no evidence of discontinuous or false rings.

Other difficulties have included missing sections in core samples, extrapolation of sample data to all trees in a stand, and estimation of the time taken for trees to achieve core sampling height (Ogden, 1985). Problems associated with use of increment cores that bypass the chronological centre or pith of the tree have been highlighted by Norton et al. (1987). Various techniques, whereby age can be estimated from cores of totara and other New Zealand conifers, have been evaluated (e.g. Matsui, 2000; Duncan, 1989).

This study was carried out in order to determine the reliability of ring counts in increment cores for estimating tree age in totara stands. Planted stands of known age were used for this purpose. Small stands and shelterbelts of totara were planted in many parts of New Zealand during the past century and many were listed in a Forest Research Institute survey undertaken in the mid-1980s (Pardy et al., 1992). Whereas previous studies focussed on trees from old-growth forest, the present investigation used relatively young stands that would be comparable in age to totara regenerating on farmland. Other objectives of the study were: the refinement of existing techniques for use of core samples that have bypassed the pith; finding a suitable method for estimating the time taken for trees to reach coring height; identification of site and stand factors that influence the reliability of ring counts for assessing tree age; and evaluation of the applicability of these methods for determination of the age of young totara stands growing on farmland.

Materials and methods

Planted totara stands used for sampling

Eleven planted totara stands of known age that had been identified in a survey of New Zealand's indigenous trees (Pardy et al., 1992) were used for this study. Ten of these were located at seven sites in the North Island and one in the South Island (Figure 1). Site descriptions and stand histories recorded by Bergin and Kimberley (2003) are summarised in Appendix 1. Further stand and site details and climate information are given in Table 1.

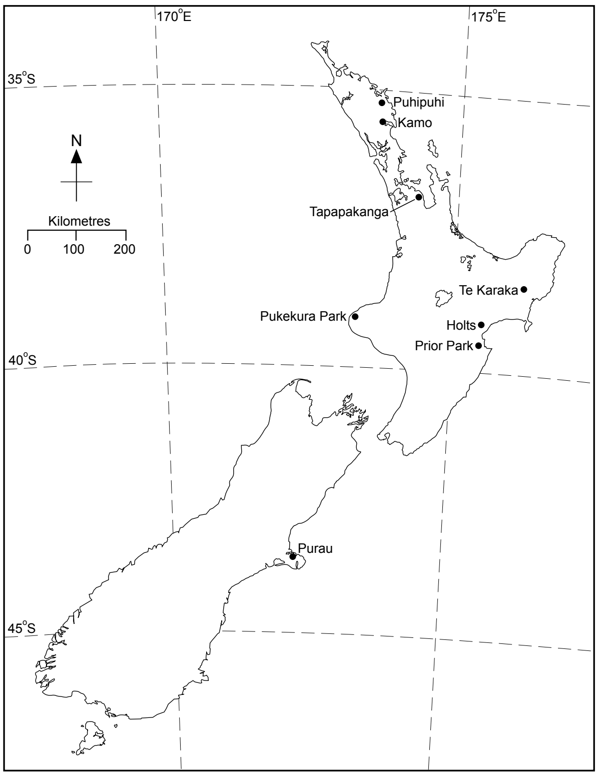

FIGURE 1: Location of eleven planted totara stands used for increment core sampling.

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TABLE 1: Stand, site and climate data for eleven totara plantions. For most sites, climate data were derived from records obtained at the nearest weather station (New Zealand Meteorological Service, 1983).

Location	Stand type	Age (yr)	Stocking (stems ha^{-1})	Mean DBH (cm)	MAI DBH (mm yr^{-1})	Mean height (m)	Elevation (m)	Aspect (º)	Slope (º)	Annual rainfall (mm)	Daily mean temperature (ºC)	No. of ground frosts yr^{-1}	Sunshine hours[2]
Well-stocked stands													
Tapapakanga[1], Firth of Thames	Plantation	9	2500	8.0	8.9	4.4	35	95	18	1296	14.0	3	na
Holt Forest, Waikoau, Hawke's Bay	Plantation	33	1975	15.4	4.7	9.3	240	275	5	1756	11.9	62	na
Te Karaka, Gisborne	Plantation	50	1100	19.6	3.9	12.0	80	135	20	1010	13.8	46	2172
Pukekura (Area 1), New Plymouth	Plantation	62	1078	35.6	5.7	18.6	49	220	10	1539	13.5	7	2114
Purau, Banks Peninsula[3]	Plantation	86	1100	27.7	3.2	11.2	20	270	15	666	11.6	89	1974
Prior Park, Wharerangi, Hawke's Bay	Plantation	88	1000	36.5	4.1	17.2	65	-	0	850	13.5	54	2245
Puhipuhi (1925 stems ha^{-1}),[4] Northland	Plantation	90	1925	25.9	2.9	20.0	260	-	0	1950	14.0	15	2045
Puhipuhi (1275 stems ha^{-1}),[4] Northland	Plantation	91	1275	35.0	3.9	22.9	260	-	0	1950	14.0	15	2045
Low-density stands													
Kamo, Whangarei, Northland	Shelterbelt	44	Single row	39.9	9.1	17.0	40	-	0	1600	15.4	7	1925
Pukekura (Area 6), New Plymouth	Mixed species; trees widely spaced	72	<500	52.9	7.3	17.7	49	220	10	1539	13.5	7	2114
Pukekura (Area 7), New Plymouth	Mixed species; trees widely spaced	83	<500	54.4	6.6	21.0	49	220	10	1539	13.5	7	2114

[1] *Climate information from Tapapakanga Regional Park Management Plan.*
[2] *Not available (na) from all weather stations.*
[3] *All sites in the North Island except Purau.*
[4] *Midway between Whangarei and Kawakawa.*

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Using the methods of Ellis and Hayes (1997), permanent sample plots were established in each stand to determine stocking density. Stem diameter at breast height (1.4 m; DBH) was recorded for each tree in each plot and the height of up to 10 trees per plot was measured using a hypsometer. Mean diameter increment was calculated for each plot.

Core sampling

Increment cores were taken from selected trees. The planned minimum of 10 sampled trees/plot could not be achieved where suitable trees were scarce or where owners or managers restricted the number of cores taken. The final number of cores represented 4 – 32 trees per plot (Table 2).

Trees to be sampled were selected to reflect the range of stem diameter of canopy trees in each plot. Using methods described by Norton (1998), a 20-, 30- or 35-cm long increment borer was used to extract a 5-mm diameter core from each tree. Cores were taken at breast height in all stands except Tapapakanga, where stem diameters were small and branching below breast height was frequent. Here cores were taken 50 cm above ground level. Obvious irregularities in stems or bark were avoided. Cores were taken from the uphill side of trees growing on sloping ground.

Core processing

Core samples were glued into shallow-grooved wooden blocks and prepared for microscopic examination by sanding, firstly with a belt sander to obtain a 4 – 5 mm wide flat surface, and then by use of progressively finer grades of sandpaper. A light covering of wood-polishing oil was rubbed into the surface to enhance the visibility of early and latewood bands.

Identification and counting of growth rings

Cores were examined with the aid of a stereo-microscope using magnifications of 5x and 10x under incident light from one direction. For the purposes of this study, a clearly-visible band of latewood was assumed to mark the termination of each annual growth period (Figure 2). Each band consisted of 2 – 3 rows of compressed tracheids with thickened cell walls. It formed a visual contrast with early wood in which the tracheids had thin walls and were circular in cross-section. False growth rings resulting from gradual changes in cell diameter and wall thickening (Figure 2) were ignored. Ring counting was done without knowledge of the true age of the trees sampled.

Cores were classified according to clarity of the latewood bands, using categories described by Meylan and Butterfield (1978):

1 = Bands indistinct
2 = Bands slightly distinct
3 = Bands moderately distinct
4 = Bands distinct
5 = Bands very distinct.

For simplicity, cores in Classes 4 and 5 were grouped together as "Distinct" and those in Classes 1, 2 and 3 as "Indistinct". Where clarity varied within a core, the dominant category was recorded.

TABLE 2: Numbers of increment cores sampled and latewood band Visibility Scores for eleven planted totara stands.

Location	Total no. of cores sampled	No. of cores use in study	Mean Visibility Score [1]	Number of cores with distinct latewood bands[2]	Proportion of distinct cores per stand (%)
Well-stocked stands					
Tapapakanga	12	12	1.0	0	0
Holt Forest	6	6	4.8	6	100
Te Karaka	18	16	4.1	12	67
Pukekura (Area 1)	10	10	3.4	5	50
Purau	14	11	3.2	4	29
Prior Park	6	5	3.0	2	33
Puhipuhi (1925 stems ha^{-1})	32	24	3.5	12	38
Puhipuhi (1275 stems ha^{-1})	31	22	2.7	6	19
Low-density stands					
Kamo	8	7	2.6	1	13
Pukekura (Area 6)	4	4	2.0	0	0
Pukekura (Area 7)	6	5	2.4	1	17

[1] *Latewood-band Visibility Score: 1 = Indistinct; 2 = Slightly distinct; 3 = Moderately distinct; 4 = Distinct; 5 = Very distinct (after Meylan & Butterfield, 1978).*
[2] *Latewood-band clarity based on Visibility Score amalgamation: Indistinct = Scores 1 + 2 + 3; Distinct = Scores 4 + 5.*

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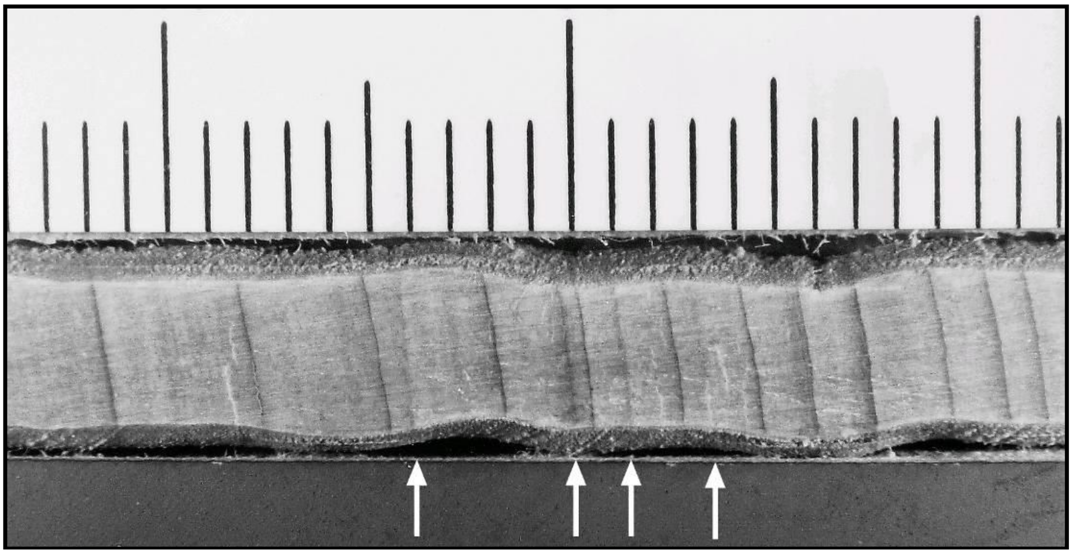

FIGURE 2: Latewood bands in an increment core sample taken at breast height from a totara stem. Twelve distinct bands are visible in this section of the core. Arrows indicate four indistinct bands considered to represent false growth rings. Scale: 1 mm between vertical lines.

Off-centre cores

Because the pith was not always in the centre of a stem, some core samples did not pass through the pith and, in consequence, the innermost latewood bands were missed. Various techniques have been proposed for estimating the number of rings missed by off-centre cores. A commonly used approach requires estimation of the closest distance between core and pith (the distance perpendicular to the core), and the average ring width (measured radially) in the inner part of the core. The number of missing rings is calculated by dividing the core-to-pith distance by the average ring width. Liu (1986) and Duncan (1989) described methods for obtaining the core-to-pith distance geometrically, using ring dimensions and angles obtained from the core. Visual methods offer a simpler approach. Applequist (1958) overlaid cores with a clear cellulose acetate sheet marked with patterns of concentric circles to obtain both the location of the pith and the average ring width. Norton et al. (1987) used a pair of compasses to trace the arcs of inner rings in order to establish the location of the pith.

A modification of the Applequist (1958) method was used in this study together with a simple geometric calculation. A transparent overlay marked with patterns of concentric circles of varying diameter was used to match the curvature of the latewood arc of the innermost ring on the sanded part of the core with the curvature of the best-fitting circle. The centre of this circle was taken to be the position of the pith (*Y* in Figure 3). The minimum core-to-pith distance (*a* in Figure 3) was then measured. The length of the portion of the core containing the 10 complete latewood bands nearest to the pith (*b* in the right-angle triangle *XYZ*, Figure 3) was then measured.

The number of bands in radius *YZ* must be n+10 where n is the number of missed bands. Assuming a constant growth rate over the period represented by *YZ* (length c in Figure 3), the ratio of a to c must equal the ratio of n to n+10, i.e.:

$$\frac{a}{c} = \frac{n}{n + 10}$$

The value of n can, therefore, be calculated from a and b using:

$$n = \frac{10a}{c - a}$$

$$= \frac{10a}{\sqrt{a^2 + b^2} - a}$$

An estimate of n was obtained using this method for each off-centre core and added to the number of complete bands identified in the core. Norton et al. (1987) cautioned that estimates such as this are likely to be reliable only if the core passes close to the pith. In this study, cores that had missed the pith by more than 40 mm were discarded. These usually represented large trees in older stands.

Correction for sampling at breast height

Growth rings formed before trees had attained breast height were not included in the core samples. In order to allow for age at breast height, it was assumed that trees had a height of 50 cm at time of planting and height growth rates of 10 cm in the first year and

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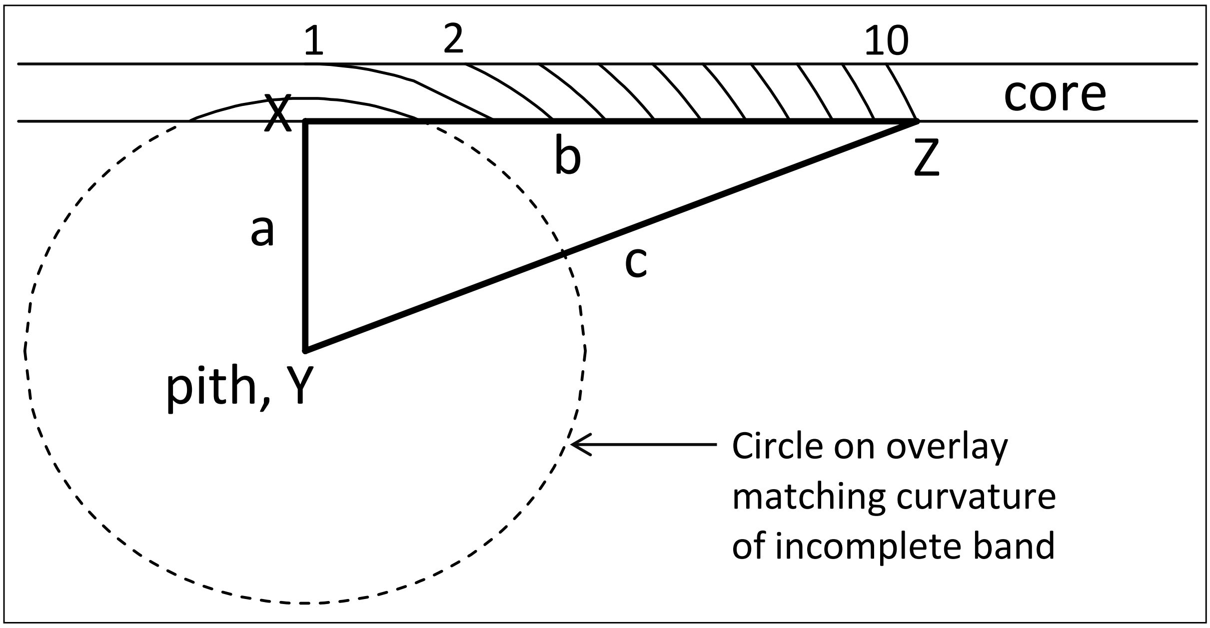

FIGURE 3: Illustration of the geometric method used to calculate the number of growth rings missed by a core sample.

20 cm per year thereafter (Beveridge et al., 1985). On this basis, trees would reach 1.4 m five years after planting. Tree age determined from the core count was, therefore, increased by 5 years for each sample.

Results

Stand and tree characteristics

The 11 planted totara stands were known to be 9 – 91 years old (Table 1 & Appendix 1). Eight were well-stocked (1000 – 2500 stems ha^{-1}). Two of the Pukekura stands contained other tree species, and totara trees were sparse and unevenly distributed. One stand (Kamo) had been planted as a shelterbelt. Mean stem diameter ranged from 8 cm in the youngest stand to 53 – 54 cm in the Pukekura "low-density" stands. Mean annual diameter increment (MAI) ranged between 3 mm yr^{-1} (the denser of the two Puhipuhi stands and the Purau stand) and 9 mm yr^{-1} (the youngest stand, Tapapakanga). Mean tree height in the oldest stand was 23 m. Potential growth and yield information based on measurements obtained from the eleven stands has been presented by Bergin and Kimberley (2003).

Visibility of latewood bands

Of the 147 cores sampled from the 11 stands, 122 (82%) were regarded as suitable for the counting of growth rings (Table 2). The rest were discarded for a number of reasons including the presence of knots or other irregularities that made ring counting difficult. Cores with clear latewood bands were obtained from all stands (Table 2). Bands were most distinct (mean Visibility Score > 4) in cores taken from Holt Forest and Te Karaka. Band clarity was poor (mean Visibility Score < 3) in cores from Tapapakanga, Kamo, Pukekura Area 6, Pukekura Area 7 and the 1275 stems per hectare stand at Puhipuhi. Samples from the three "low-density" stands had poor band clarity. These stands contained large-crowned, bushy totara trees in contrast to the other stands where trees had relatively small crowns. Mean annual diameter increment in the three "low-density" stands and the Tapapakanga stand exceeded 6 mm yr^{-1} (Table 1).

Some of the cores taken from fast-growing large-diameter trees showed wedging of rings and lobate growth. These features were similar to those reported in totara by Dunwiddie (1979). The percentage of cores with distinct bands of latewood varied between 0 and 100% in the well-stocked stands (Table 2). In the three "low density" stands 0 – 17% of cores were classed as distinct. Ring visibility was often most distinct in the innermost parts of the core. Cores taken at 50 cm height from nine-year-old trees at Tapapakanga had indistinct latewood bands (Table 2). Here there was a consistent pattern, only the 5 – 6 bands nearest to the pith being distinct. Data from this stand were excluded from further analysis. Some of the cores from slower-growing stands (Purau and Puhipuhi 1925 stems ha^{-1}) had well-defined rings (Table 2) but these were often very close together and difficult to count.

Table 3 indicates an overall tendency for underestimation of the number of annual rings per core in well-stocked stands. Here error and standard deviation decreased with increasing ring visibility. By contrast, in "low-density" stands, the number of annual rings was increasingly overestimated as latewood band visibility improved. This was presumably due to the presence of false rings. Lower error in cores

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TABLE 3: Effect of Visibility Class on error associated with estimation of totara stand age from latewood-band counts. Core samples were taken from ten planted stands (Tapapakanga excluded) and classified by the method of Meylan and Butterfield (1978).

Stand Type	Latewood band Visibility Class[1]	No. of cores per class	Underestimation (-) or overestimation (+) of stand age (%)	
			Mean	Standard deviation
Well-stocked stands	1	5	-13.7	14.1
	2	25	-14.5	12.0
	3	17	-10.8	9.0
	4	20	-10.1	8.5
	5	27	-10.3	9.5
Low-density stands	1	3	-1.3	32.1
	2	6	+10.9	17.1
	3	5	+18.6	22.7
	4	2	+20.2	13.2
	5	0	-	-

[1] *Latewood band Visibility Score: 1 = Indistinct, 2 = Slightly distinct, 3 = Moderately distinct, 4 = Distinct, 5 = Very distinct.*

with indistinct bands was presumably a consequence of the presence of less-distinct, disregarded bands which cancelled out the occurrence of false rings. The standard deviation for mean ring counts was much larger in the more open, faster-growing stands.

Adjustments for bypassing of pith

A total of 110 acceptable cores was obtained from 10 stands (Tapapakanga excluded). Of these, 18 included the chronological centre or pith of the tree and a further 48 passed within a distance from the pith (*a* in Figure 3) less than 5% of the estimated bark-to-pith radius and in only 13 cores was the distance from pith more than 10% of the radius. The average diameter per stand was smaller than that recorded for natural totara stands by Duncan (1989), varying between 8 and 36.5 cm in the denser plantations and between 40 and 55 cm in the three stands where tree spacing was greatest.

Stand age

Estimated mean age of the nine stands that contained at least one tree with distinct latewood bands in the sample core (Table 4) was lower than actual age by up to 19% in well-stocked stands. Values for six of the seven denser stands were within 12% of the known age. Underestimation suggests that distinct latewood bands may not be formed in every year. By contrast, age of the “low-density” Kamo and Pukekura Area 6 stands was overestimated, indicating that false rings had been counted. Only two cores from these stands were classed as Distinct. Comparison of estimated and actual stand age (Figure 4) indicated that latewood band counts, even when adjusted for core sampling height and bypassed pith, tended to underestimate stand age. In most cases the estimate was improved by rejection of cores with indistinct growth rings (Figure 5). Error was consistently lower for trees with diameter growth rates averaging 5 mm yr^{-1}. There was a tendency for age to be underestimated in slower-growing trees and overestimated where growth was faster (Figure 5).

Discussion

Counts of latewood bands in increment core samples can be used as a basis for estimation of stand age in young (< 100 year-old) planted totara stands if tree growth rate is taken into account. In slower-growing stands the method is likely to underestimate age (Figure 5). Underestimation in the seven denser stands by an average of 11.2% suggests that smaller trees do not form distinct bands of latewood every year. Norton and Ogden (1987) have shown that absence of rings and occurrence of partial rings are both associated with adverse environmental conditions. This is due either to confinement of radial growth to parts of the stem above core-sampling level, or to ring-wedging, which can result from development or death of major branches. In the current study, estimates of stand age were most accurate in trees with moderate growth rates of approximately 5 mm yr^{-1} MAI.

Major difficulties were encountered with samples from the low-density stands. Faster-growing trees may form more than one growth ring per year and the additional bands are difficult to discern.

In warmer lowland regions, totara often exhibits multiple growth flushes in one growing season. The effect of this on latewood band formation and the effect of mild winters when there is no abrupt cessation of growth require further study. Jane (1970) and Norton

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TABLE 4: Effect of rejection of increment cores with indistinct[1] latewood bands on estimation of age of totara stands.

Location	Actual stand age (yr)	Stand Age Parameters							
		All cores				Distinct cores only			
		Estimated stand age (yr)[2]	No. of cores in sample	Standard deviation	Error (%)	Estimated stand age (yr)[2]	No. of cores in sample	Standard deviation	Error (%)
Well-stocked stands									
Holt Forest	33	30.7	6	2.5	-7.0	30.7	6	2.5	-7.0
Te Karaka	50	40.4	16	4.0	-19.2	40.7	12	4.5	-18.6
Pukekura (Area 1)	62	54.6	10	6.1	-11.9	58.8	5	2.9	-5.2
Purau	86	76.3	11	6.4	-11.3	74.3	4	9.1	-13.6
Prior Park	88	80.0	5	8.0	-9.1	86.5	2	0.7	-1.7
Puhipuhi (1925 stems ha^{-1})	90	82.7	24	8.4	-8.1	83.1	12	7.0	-7.7
Puhipuhi (1275 stems ha^{-1})	91	79.3	22	11.2	-11.9	84.5	6	3.0	-6.1
Total			**94**		**-11.2**		**47**		**-9.5**
Low-density stands									
Kamo	44	55.0	7	6.0	+25.0	57.0	1	-	+29.5
Pukekura (Area 6)	72	62.5	4	15.0	+14.5	-	0	-	
Pukekura (Area 7)	83	95.0	5	9.1	-13.2	92.0	1	-	+10.8
Total			**16**		**+9.8**		**2**		**+17.3**

[1] *Latewood band clarity based on amalgamated Visibility Score: Indistinct = Scores 1 + 2 + 3; Distinct = Scores 4 + 5.*
[2] *Estimate adjusted for height at which cores were taken and for bypassed pith.*

and Ogden (1987) in their discussions about the effects of seasonal climate on growth ring formation included the occurrence of drought or sudden onset of low temperature but did not consider the consequences of mild winters. In the present study, estimation of age in faster-growing low-density stands located in the warmer, lowland regions (Taranaki and Northland) was difficult because indistinct rings were often common. Cores from higher-density stands in both these regions (Pukekura Area 1 & Puhipuhi) had a larger number of distinct rings. Stand characteristics as well as climatic factors are likely to affect the formation of distinct latewood bands.

Difficulty with identification of growth rings in the outermost parts of the stem has been reported for rimu (*Dacrydium cupressinum* Sol. ex Lamb) (Stewart & White, 1995). Clarity of latewood bands in indigenous conifer stems appears to increase with age, faint rings in outer sapwood becoming more distinct during

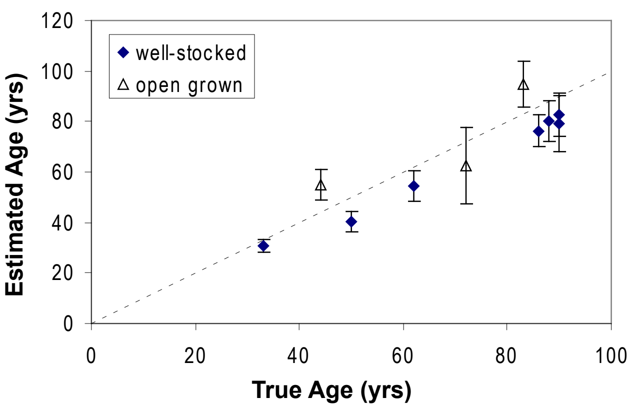

FIGURE 4: Comparison between estimated and actual age of ten planted stands of totara (Tapapakanga excluded). Error bars show standard deviations.

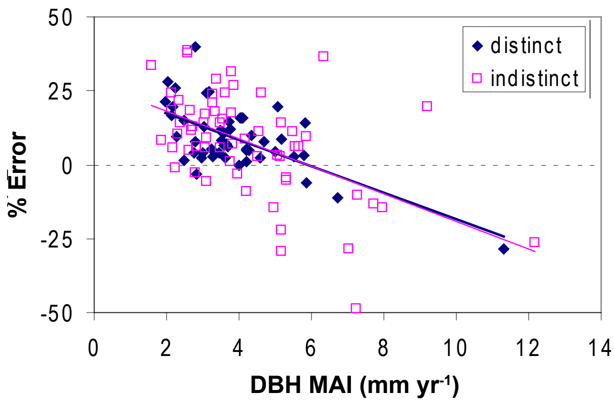

FIGURE 5: Relationship between error in age estimates derived from latewood band counts and tree growth rate in ten planted totara stands (Tapapakanga excluded).

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transition to heartwood. The reliability of latewood-band counts for assessment of stand age is likely to be compromised by difficulty in identifying clear bands in sapwood. This was particularly apparent in younger stands where stems were largely composed of sapwood (e.g. Tapapakanga).

Clear criteria will be required if observers are to adopt a consistent approach to the identification and counting of growth rings when estimating the age of totara trees. In regenerating stands where intense competition and slow growth rates can be expected, age estimates will be improved by avoidance of suppressed trees which are likely to exhibit closely spaced and incomplete latewood bands.

The standard deviation of estimated ages in the planted stands in this study averaged 8 years. This implies that a mean of 4 cores sampled in a stand would provide an estimate of ±8 years with 95% confidence, while a mean of 16 cores would provide an estimate with ±4 years. However, in natural stands there is an additional source of variation in tree ages due to the continuous period of recruitment typically found during the establishment phase. Therefore, larger sample sizes would be required in natural stands to achieve estimates of similar precision compared with planted stands.

Conclusions

Counting of the number of growth rings represented by clear bands of latewood in increment cores provides a reasonably consistent, repeatable basis for estimation of the age of totara in planted stands. The method described here tended to underestimate age in closed stands, and to overestimate the age of open-grown trees. Best mean estimates for most stands of 1000 – 2000 stems ha^{-1} were within 7 – 19% of the known number of years of growth and were obtained from increment cores taken from trees exhibiting mean annual diameter increment of 4 – 5 mm yr^{-1}.

Accuracy of the latewood-band counting method was improved by rejection of cores with irregularities such as knots, rot, loss of bark or loss of core sections. Only about half of the increment cores sampled in closed stands had bands of the clarity required for consistent results. Cores from open-grown trees tended to have less distinct bands. Unavoidable bypassing of pith during core sampling reduced accuracy, but this problem was overcome through use of a simple geometric calculation.

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APPENDIX 1: Site description and stand management history of totara stands sampled for this study. Source: Bergin and Kimberley (2003).

Location	Stand type
Tapapakanga, Firth of Thames	Totara provenance trial established 1987 on a single hectare of a moderately-sloping farmland site. Trial designed to monitor differences in growth and form of trees raised from seed collected at 36 different New Zealand locations (Bergin & Kimberley, 1992). The site has been maintained and monitored since planting.
Holt Forest, Waikoau, Hawke's Bay	Totara plantation of approximately 0.5 ha established 1963 on gentle slope cleared of bracken (*Pteridium esculentum* (G.Forst.) Cockayne) and blackberry (*Rubus fruticosus* L). Trees regularly hand-released from regrowth. All trees pruned to an average of 3.4 m.
Te Karaka, Gisborne	Totara plantation of 0.4 ha established 1947 on a site covered in kanuka (*Kunzea ericoides* (A.Rich.) Joy Thomps.) and manuka (*Leptospermum scoparium* J.R.Forst. & G.Forst.). Trees hand-released from grass during early years. Growth slow, possibly due to exposed nature of site and low rainfall.
Pukekura, New Plymouth	Three small stands of totara established 1936 on fertile sites. Planted in lines cut through bracken cover and hand-released during early years. Stands lightly thinned.
Purau, Banks Peninsula[1]	Small stand of totara planted 1910 on a pasture slope. Partial shelter provided by kanuka. Root systems trampled by cattle. Growth slow.
Prior Park, Wharerangi, Hawke's Bay	Totara plantation of 0.3 ha established 1908 on a river terrace. Good early survival. Continuous access for grazing stock.
Puhipuhi, Northland[2]	Two totara stands of less than 0.5 ha planted between 1904 and 1909 on flat fertile land dominated by grass and fern. Unfenced and subject to cattle grazing.
Kamo, Whangarei, Northland	Single row of totara trees planted 1955 as a shelterbelt. Grazing stock excluded during early years.

[1] *All sites in the North Island except Purau.*
[2] *Midway between Whangarei and Kawakawa.*

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