New Zealand Journal of Botany, 1983, Vol. 21 : 121–126
0028–825X/83/2102–0121$2.50/0

A dendrometer band study of the seasonal pattern of radial increment in kauri (*Agathis australis*)

J. PALMER
J. OGDEN
Department of Botany, Auckland University
Private Bag, Auckland, New Zealand

Abstract Simple dendrometer bands were used to measure the radial increment of kauri (*Agathis australis* Salisb.) at 3 sites to the south and east of Auckland during the 1980–81 growing season. Diameter increment cores taken from some of the trees at the beginning and end of the study showed that the radial expansion measured by the bands correlated significantly ($P<0.001$) with the width of the annual ring formed over the same period. A reduction in tree growth rate during summer drought was recorded at 2 mid-altitude sites, but not near the altitudinal limit of kauri. These growth patterns were attributed to the different soil moisture conditions at the different sites.

Keywords dendrometer; kauri; *Agathis australis*; wood anatomy; ecology; New Zealand vegetation

INTRODUCTION

Dendrometers have been widely used to detect the seasonal growth patterns of trees because they provide an easy and convenient way for measuring changes in the diameters of tree trunks (Bormann & Kozlowski 1962). Several types of dendrometer are available, and reviewed by Fritts (1976). However, the only reported study in which band type dendrometers, measuring circumferential changes, have been used to study the growth of indigenous New Zealand trees in natural environments is that of Benecke & Havranek (1980) on *Nothofagus solandri* var. *cliffortioides*.

Dendrometer bands were placed on kauri (*Agathis australis* Salisb.) trees at 3 sites to the south and east of Auckland. One site (Kon 1) was located in the Hunua Range to the south of Auckland. The site vegetation included a group of kauris of mature form (mostly c. 50–80 cm diam.) covering about 1 ha on an old slip surface. There were 2 larger kauri trees on the outer margin of the slip, but otherwise the site was surrounded by tawa (*Beilschmiedia tawa*) – podocarp forest. The other 2 sites (Moe 1 and Moe 2) were on Mount Moehau, at the northern end of the Coromandel Peninsula, about 60 km east of Auckland. The lower of these 2 sites (Moe 2) was on a steep northerly slope similar to Kon 1, but carried fewer but larger kauri trees. The canopy was open and the understorey dominated by *Leptospermum ericoides* indicating disturbance (probably fire) last century. The vegetation of the higher site (Moe 1) comprised scattered kauris in mossy montane forest dominated by *Weinmannia silvicola* and *Dacrydium cuppressinum*. Kauri trees of all sizes occur in the area, although most of the larger trees (c. 1 m diam.) are prostrate. The date of fall of 8 of these trees was estimated by dendrochronological methods and the results suggested site disturbance by storms during the first half of last century (Palmer 1982). Only erect trees were banded. More precise site details and characteristics are outlined in Table 1 and given in greater detail in Palmer (1982). The dendrochronological characteristics of the Hunua Range site have been described by Dunwiddie (1979) and LaMarche et al. (1980). The general features of the Mt Moehau sites were described by Cranwell & Moore (1936) although some changes in the montane vegetation have occurred since then (Mason & Chambers 1950; Moore, L. B. pers. comm.). One of these sites (Moe 1) is of particular interest for the growth of kauri, because the species is here close to its highest altitudinal limit (810 m; Ecroyd 1982).

METHODS

The dendrometer type used was a band of aluminium held in place by a spring (Fig. 1). Increase in trunk diameter causes the band to move, and this movement is measured on a vernier scale. Dendrometers of this type are described by Hall (1944) and Liming (1957), but the design used was suggested by the Forest Research Institute, Rotorua (Mr A. Katz, pers. comm.). The bands were assembled in the field. Resin flowing down the trunk caused the band to stick but this was overcome by placing a strip of polythene sheet between the trunk and the band and leaving sufficient free polythene on the upper edge to fold over the band. This modification also protected the spring and scale

Received 15 October 1982; revision 17 January 1983

Table 1 Site descriptions and sample characteristics.

Site characteristics	Kon 1	Site name Moe 1	Moe 2
Location	Hunua Range	Mount Moehau	Mount Moehau
Latitude; Longitude	37°04′; 175°08′	36°32′; 175°25′	36°31′; 175°24′
Grid reference	N48; 708359	N39; 914986	N35; 900015
Altitude (m)	335	750	450
Topography (aspect)	Steep slope (NE)	Gentle slope or flat (NE)	Steep slope (NW)
Main canopy tree*	*Agathis australis*	*Weinmannia silvicola*	*Agathis/Weinmannia*
Total basal area (m^2/ha)	100	43	75
Total density (no/ha)	698	841	758
Number of banded trees	33	17	8
Diameter range of banded trees (cm)	18–172	14–71	41–139

*Stems of all species greater than 10 cm diam. at 1.2 m above ground level. Density and basal area values derived from point-centred quarter sampling (Cottam & Curtis 1956).

from mechanical damage and reduced spring corrosion. The vernier scale enabled measurement to an accurancy of 0.25 mm. Details of the method and an assessment of some possible sources of error, are given in Palmer (1982).

At the Hunua Range site, 33 kauris were banded from 16 to 20 June 1980, and on Mt Moehau 25 were banded from 28 to 30 August 1980 (Table 1). Increment cores, taken at the time of banding, confirmed that the next season's growth had not commenced at these dates. The bands were read at about 6-weekly intervals throughout the 1980 and 1981 growing season. All banded trees were greater than 10 cm diam. at 1.2 m above the ground. At the Mt Moehau sites, all erect kauri trees were banded, but at the Hunua Range site a stratified random sample, based on all of the 10 cm size class intervals represented, was taken; thus a range of tree sizes (and ages) was sampled (Table 1).

Two increment cores were taken from each tree when it was banded. These were mounted, surfaced, and used to determine mean radial growth rates. At the end of the study period, 2 more cores were taken from each of a random sample of 12 trees at the Hunua Range site. The paired cores from each tree were cross-matched and the width of the 1980–81 annual ring measured directly.

Climatic records, kept by the Auckland Regional Authority at Hunua (10 km from the study site) since 1962, were used to calculate mean monthly rainfall and temperature for July 1962 to June 1980 and for July 1980 to June 1981. The potential evapotranspiration (PE) rate was then calculated by following the procedure of Thornthwaite (1948) and tables given by Toebes (1968).

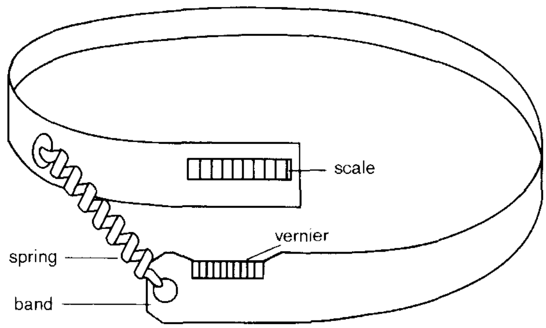

Fig. 1 Components of the dendrometer band.

RESULTS

Measurements by dendrometer bands include stem swelling caused by moisture changes in the bark and xylem as well as increases in diameter consequent upon cambial activity and cell expansion (Fritts et al. 1965). The possibility that the measurements recorded at the study sites reflect stem shrinkage and swelling rather than changes in growth rate cannot be ruled out. However, the close correlation (r = 0.9163; n = 12; $P < 0.001$) between the total radial increment measured by the bands, and the mean ring width (measured from cores, up-slope and down-slope aspects) indicates that total radial growth was accurately recorded (Fig. 2). The one instance in which the dendrometer reading was greater than the direct core measurement probably resulted from 2 upslope cores being taken as the downhill side of the tree was inaccessible. As in most gymnosperms the annual rings of kauri are normally wider on the down-slope side (Fritts 1976, p. 220).

Because of the small sample size, no statistically significant difference in diameter growth could be demonstrated among trees of different diameters (and ages) on any one site. Consequently the individual tree data were averaged to obtain the mean pattern of growth at each site (Fig. 3). Rapid

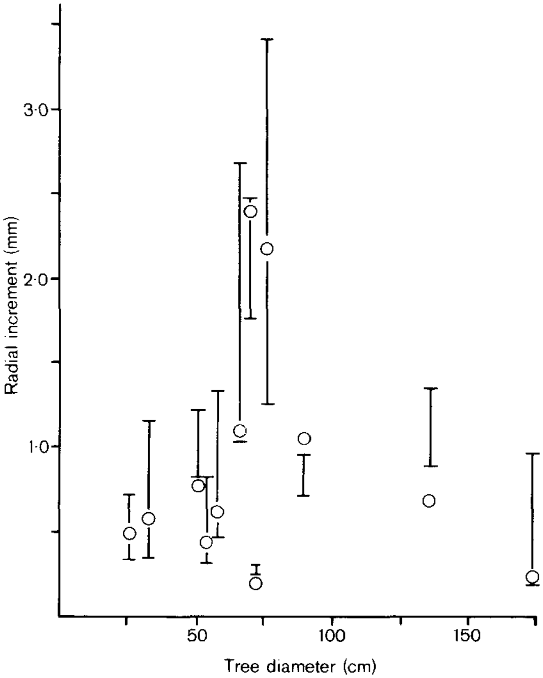

Fig. 2 Comparison of radial increment from dendrometer bands (open circles) with measurements from 2 cores per tree (vertical bars). The core measurements were thought to represent the maximum and minimum ring width increment.

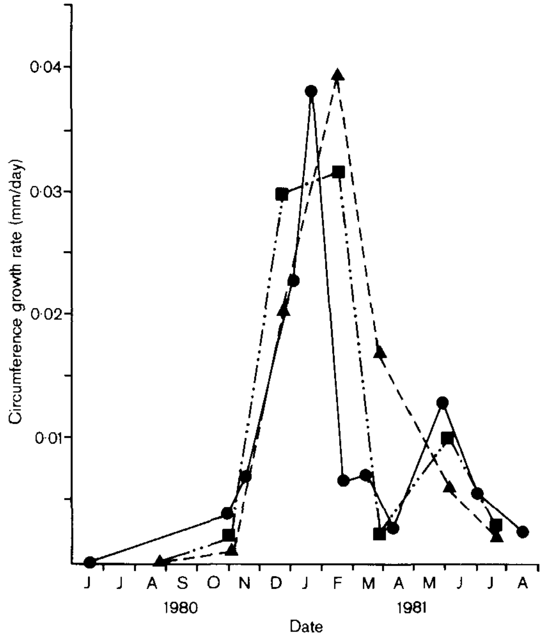

Fig. 3 Change in growth rate between sample periods. Kon 1 (circles); Moe 1 (triangles); Moe 2 (diamonds). Standard error bars omitted for clarity; see text.

Table 2 Radial growth of kauri (*Agathis australis*) at the 3 sites.

	Site names		
	Kon 1	Moe 1	Moe 2
Number of cores analysed	44	21	6
Maximum period analysed (maximum core span)	1619–1980	1733–1980	1810–1979
Mean period analysed (mean core span)	1815–1980	1857–1980	1855–1979
Mean annual ring width (mm)	1.937*	1.081	1.229
Standard error (mm)	0.098	0.080	0.097

*This mean value is significantly (P<0.001) greater than that at Moe 1.

circumference growth began in early November and peaked, at all sites, from December to February. At the 2 lower altitude sites there was a rapid decline in the growth rate during February, but some later recovery to a second peak during May. There was no evidence of a second peak at the higher altitude site. The cumulative growth curve was sigmoidal at all sites.

The growth rates determined from increment cores are given in Table 2. The mean rates are slightly below most of those published (see Ecroyd 1982); possibly this reflects the montane nature of the sites. Although growth at the high altitude site is generally less than at the lower altitudes, this was not so during the 1980–81 season; the high altitude trees grew relatively better than those at the lower sites. This is noteworthy in view of the supposedly degenerate state of the high altitude kauri stand on Mt Moehau (Ecroyd 1982).

The 1980–81 summer was dry, with below average rainfall being recorded in the Auckland region. In January, February, and March 1981, rainfall was

47% below normal*. A slight excess of evapo-transpiration over precipitation may be frequent in the Hunua Ranges in January but soil moisture deficits extended for 3 months during this study period. Recharge only occurred after exceptionally heavy rainfall in April (Fig. 4).

DISCUSSION

The results obtained by using simple dendrometers accurately reflect the radial increment associated with the formation of an annual ring. However, the dendrometer band measurements were generally slightly smaller than the mean of the ring width estimated from the 2 increment cores (Fig. 2). This may indicate an initial period of 'taking up the slack' before the bands registered growth. Growth was not uniform at all sites throughout the season, but the mid-summer growth check was not associated with the formation of a 'false ring' or wider than average latewood.

Previous studies on kauri diameter growth have suggested that growth occurs through most of the year, ceasing only in June, July, and August (I. Barton pers. comm.). A second, late season leaf and height growth flush has been recorded for kauri seedlings (R. C. Lloyd, in Ecroyd 1982) and occasionally for mature trees (I. Barton pers. comm.). The similar bimodal diameter growth patterns imply that some common variable affected growth at the lower altitude sites. This effect did not however extend to the higher altitude site where there was no indication of a second growth peak.

Water shortage during summer is known to be one of the most important environmental factors influencing cambial activity (Studhalter et al. 1963). Furthermore, if water stress is alleviated by late-season rainfall radial growth may resume until limited again by declining temperatures (Zahner 1968). The dry summer and associated soil moisture deficit in the Hunua Ranges seems a plausible reason for growth cessation. Both of the lower sites are at medium altitudes on steep, dry slopes. In contrast, the higher altitude site is mainly flat, boggy, and is situated on the leeward side of the summit of Mt Moehau (888 m). This summit is frequently enveloped in cloud (Cranwell & Moore 1936); condensation and 'fog drip' may contribute substantially to the total moisture available even in years of below average rainfall.

*Analysis of records from Station A64871 (Albert Park) given in Climatological Tables in Supplements to the New Zealand Gazette for the relevant months.

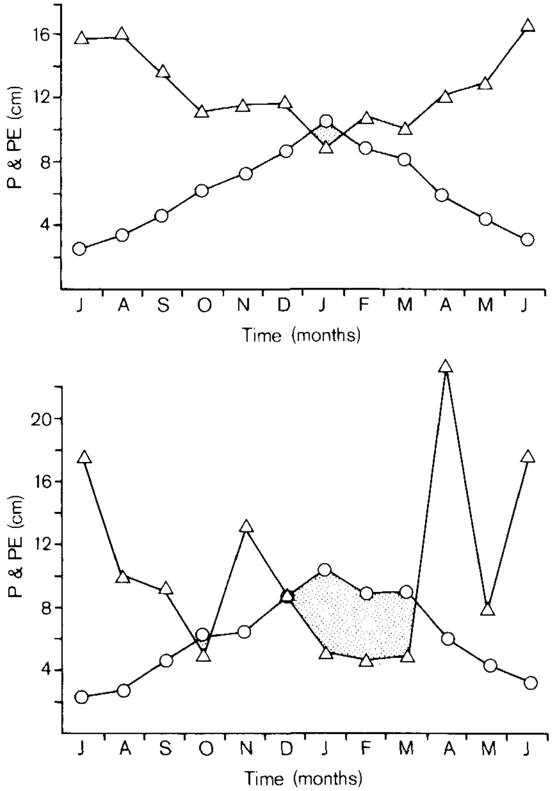

Fig. 4 Average precipitation (P; triangles) and potential evapo-transpiration (PE; circles) for: top, the period July 1962 to June 1980 and bottom, the period July 1980 to June 1981. When PE is greater than P (shaded) soil moisture is not being recharged sufficiently and moisture stress may occur.

The exceptionally good growth of kauri at the upper site in the warm sunny summer of 1980–81 may imply that, in common with other tree species growing near their altitudinal limits, low temperatures may limit growth more frequently than does soil moisture at high altitude sites.

ACKNOWLEDGMENTS

We thank Ian Barton and Andrew Dakin of the Auckland Regional Authority at Hunua for advice and field assistance. Richard Serra helped with technical aspects. Permission to work in the Hunua Ranges and on Mount Moehau was given respectively by the Auckland Regional Authority and the Auckland Conservancy of the New Zealand Forest Service. Various friends and colleagues accompanied J. P. on trips to the top of Mount Moehau.

REFERENCES

Benecke, U.; Havranek, W. M. 1980: Phenological growth characteristics of trees with increasing altitude, Craigieburn Range, New Zealand. *In:* Benecke, U.; Davis, M. R. *ed.* Mountain environments and subalpine tree growth. *New Zealand Forest Service Technical Paper No. 70.* Wellington, Government Printer, pp. 155 – 174.

Borman, F. H.; Kozlowski, T. T. 1962: Measurements of tree ring growth with dial gauge dendrometers and vernier tree ring bands. *Ecology 43* : 289 – 294.

Cottam, G.; Curtis, J. T. 1956: The use of distance measures in phytosociological sampling. *Ecology 37* : 451 – 460.

Cranwell, L. M.; Moore, L. B. 1936: The occurrence of karui in montane forest on Te Moehau. *New Zealand journal of science and technology 18* : 531 – 643.

Dunwiddie, P. W. 1979: Dendrochronological studies of indigenous New Zealand trees. *New Zealand journal of botany 17* : 251 – 266.

Ecroyd, C. E. 1982: Biological flora of New Zealand 8. *Agathis australis* (D. Don) Lindl. (Araucariaceae) kauri. *New Zealand journal of botany 20* : 17 – 36.

Fritts, H. C. 1976: Tree rings and climate. London, Academic Press.

Fritts, H. C.; Smith, D. G.; Stokes, M. A. 1965: The biological model for paleoclimatic interpretation of Mesa Verde tree-ring series. *American antiquity 31* : (2), (part 2) 101 – 121.

Hall, R. C. 1944: A vernier tree-growth band. *Journal of forestry 44* : 742 – 743.

Lamarche, V. C. Jr; Holmes, R. L.; Dunwiddie, P. W.; Drew, L. G. 1980: Tree ring chronologies of the Southern Hemisphere. Chronology Series 5, Vol. 3. Tucson Laboratory of Tree-Ring Research, University of Arizona, p. 77.

Liming, F. G. 1957: Homemade dendrometers. *Journal of forestry 55* : 575 – 577.

Mason, G. W.; Chambers, T. C. 1950: Vegetation of north-east Coromandel (Cape Colville Peninsula) with special reference to Mt Te Moehau. *Tane 3* : 69 – 71.

Palmer, J. G. 1982: A dendrochronological study of kauri (*Agathis australis* Salisb.) M.Sc Thesis. Auckland University.

Studhalter, R. A.; Glock, W. S.; Gaerter, S. R. 1963: Tree growth — some historical chapters in the study of diameter growth. *Botanical review 29* : 245 – 365.

Thornthwaite, C. W. 1948: An approach towards a national classification of climate. *Geographical review 38* : 55 – 94.

Toebes, C. 1968: Computation of the potential evapotranspiration by the Thornthwaite method. (Procedure No. 14) *Handbook of hydrological procedures.*

Zahner, R. 1968: Water deficits and the growth of trees. *In:* Kozlowski, T. T. *ed.* Water deficits and plant growth Vol. 2 New York, Academic Press, pp. 191 – 254.