Growth rate convergence in teak (*Tectona grandis* L.)

Teak (*Tectona grandis* L.) possesses distinct annual growth rings in a cross-section[1], hereafter referred to as 'rings'. Width of each ring reflects the quantum of radial growth accrued by the tree in a year[2]. These ring widths are used to analyse the intra-population variation and the patterns of growth rates through time[3,4]. We report here our attempt to determine the variation in the growth pattern of teak trees that have attained different radial sizes.

Field data on rings of 168 teak trees from three sites, viz. Virnoli [1958 (year of planting); *n* (number of trees samples) = 72], Bhagavati (1961; $n = 48$) and Barchi (1953; $n = 48$) were collected between March and April 1999 during the process of establishment of seed production area for teak. These plantations are located within a radius of 20 km from Dandeli (Haliyal Forest Division), Karnataka, India.

Heartwood ring widths were measured using a ruler with a precision of 1 mm. Four measurements were taken radially from the pith outwards in four directions approximately at 90° from each other at stump height of each tree. False rings were easily avoided by considering only those rings that formed a complete circle[4]. Measurements were taken in units, hereafter called measurement units (MUs), with each MU consisting of five rings. The first set of five rings beginning from the pith formed the first MU (MU1); the next set of five rings beginning from MU1 formed the second MU (MU2) and so on. Since each ring represents one year of growth, each of the MUs comprising five rings represents five years of growth. Whenever the total number of heartwood rings was not in multiples of five, measurements were taken up to the maximum possible extent as units of five rings and the remaining number of rings was counted and their widths measured. Since rings in the sapwood were not easily discernible, total sapwood width was measured. Thus, data were obtained on the total radius of the tree in four directions (width of the bark was excluded from the measurements). The average radial width (average of the four directions) of each MU for each of the trees, was computed and used during the analysis.

It is known that variations in growth are best expressed during the juvenile stage. Since juvenility in teak trees is known to extend up to about 20 years[5,6], analysis on growth pattern was restricted to four MUs. Also, a minimum of four MUs was available for all the trees across the three sites. Frequency distribution of 168 trees based on radius from pith to the end of MU4, followed normal distribution (Figure 1). From this frequency, trees were categorized into four size cohorts namely those with very small (C1), small (C2), medium (C3) and large (C4) radius (refer Figure 1). The average growth rate, measured as cm/MU, of trees in each of the cohorts at every MU was plotted. Data from the individual sites and data that were pooled from all the sites were separately analysed. Interpretations related to growth patterns made from the pooled data were found to be more meaningful due to two reasons: (i) it would form a good representation of the study area, and (ii) the year of planting varies between the plots and, by pooling the data any hidden interaction between stage of growth and prevailing environmental condition in any plot will be negated by the other plots that would be facing different conditions while passing through that particular stage of growth.

The growth rates of tree cohorts at different MUs for the pooled data (Figure 2) show that the cohort with large radius (C4) had the highest growth rate and the cohort with very small radius (C1) had the lowest growth rate at MU1; the intermediary cohorts (C2 and C3) show a similar trend and were positioned between C1 and C4. The relative positions of the cohorts remained the same at MU2 and MU3. A comparison between cohorts showed that the growth rates were significantly different at each of the first three MUs (Student's *t* test; $p < 0.05$). Two interesting patterns could be seen: (i) cohorts with higher growth rates during their initial stages reduced their growth rates towards the end of their juvenile period while those with lower growth rates in their initial stages increased their growth rates, and (ii) all the cohorts converged towards a common growth rate at the end of the juvenile phase. Analysis of data from the individual sites also showed convergence during the same time. These results indicate that irrespective of initial differences, growth rates converge towards the end of the juvenile phase in teak.

The contribution of growth during each of the MUs on the total growth was tested through correlations. Also, the influence of growth during a particular MU on the growths during other MUs was tested. Table 1 reveals that growth during each of MU1, MU2 and MU3 was positively correlated with that of total growth till 20 years whereas growth during MU4 was not correlated with the same. Interestingly, growth rate during MU1 and MU2 was negatively and sig-

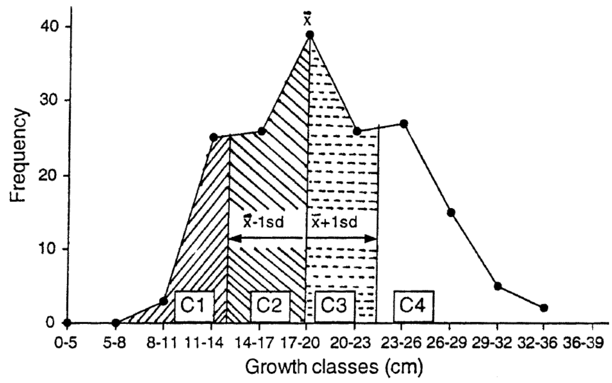

Figure 1. Frequency distribution of 168 trees based on the radius from pith to the end of MU4. C1, C2, C3 and C4 indicate cohorts with trees of very small, small, medium and large radius respectively. The mean radius (up to MU4) of trees at Virnoli, Bhagavati, Barchi and for the pooled data are 21.74 ± 4.53 cm, 20.28 ± 6.06 cm, 16.79 ± 3.78 cm and 19.91 ± 5.23 cm respectively.

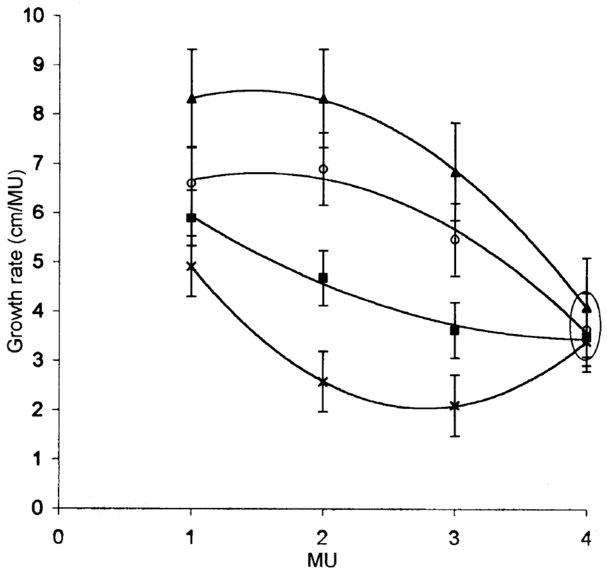

Figure 2. Growth rates of radial cohorts in different measurement units (MU) from the pooled data (points within the circle are not significantly different, the cohorts C1 (×), C2 (■), C3 (O) and C4 (▲) contain 35, 55, 46 and 32 trees respectively).

Table 1. Correlation matrix between growths in different measurement units (MU) and total growth from the pooled data

	MU1 (1–5 years)	MU2 (6–10 years)	MU3 (11–15 years)	MU4 (16–20 years)
MU1				
MU2	0.27*			
MU3	0.05	0.53*		
MU4	– 0.16*	– 0.26*	– 0.04	
Total growth (1–20 years)	0.53*	0.78*	0.75*	0.15

*Indicates $p < 0.05$.

nificantly correlated with that of MU4, suggesting that 'growth rate compensation' was occurring towards the end of the juvenile phase of the trees. If this compensation were to continue for a long period it could be expected that growth beyond MU4 would be larger for trees in C1 and C2 than for trees in C3 and C4. In this context, one way ANOVA was performed to test the differences in the average growth of trees beyond MU4 in different tree cohorts in all the three sites. Data from the three sites could not be pooled as tree age and cohort size varied among sites. Results showed that the differences in growth beyond MU4 among the cohorts were non-significant. This indicates that growth rate compensation may not extend beyond the juvenile stage of the tree. It also suggests that growth rates of similar aged trees are relatively constant across cohorts beyond their juvenile stage. Relatively constant diameter increment for all diameter size classes in managed hardwood stands has been reported[7]. Similarly, studies on Norway spruce have shown that mean annual diameter increment and tree diameter are poorly correlated[8]. It is obvious that at some point of time if radial growth rates have to be constant across trees of different diameters, there should be a point when their growth rates would converge irrespective of the initial growth differences. This study shows that growth rate convergence coincides with the end of juvenile growth phase for teak trees.

1. Tewari, D. N., *Monograph of Teak*, International Book Distributors, Dehra Dun, 1992.
2. Chowdhury, K. A., *Indian Forest Rec. (n.s) Utilization*, 1939, **2**, 1–39.
3. Assmann, E., *Principles of Forest Yield Study*, Pergamon Press, New York, 1970.
4. Bhattacharya, A., Yadav, R. R., Borgaonkar, H. P. and Pant, G. B., *Curr. Sci.*, 1992, **62**, 736–741.
5. Lamprecht, H., *Silviculture in the Tropics*, Deutsche Gesellschaft fur Technische Zusammenarbeit Germany, 1989.
6. Bhat, K. M., Priya, P. B. and Rugmini, P., *Wood Sci. Technol.*, 2001, **34**, 517–532.
7. Eyre, F. H. and Zillgitt, W. M., USDA Tech. Bull. No. 1076, 1953, 124 p.
8. Lundqvist, L., *Scand. J. For. Sci.*, 1993, **8**, 510–517.

ACKNOWLEDGEMENTS. We thank the Director and Group Coordinator (Research) of Institute of Wood Science and Technology, Bangalore, Dr R. V. Rao and Dr T. S. Rathore for their support. We also thank Prof. K. N. Ganeshaiah and Dr K. Chandrashekara for their valuable suggestions and inputs in data analysis and manuscript preparation. We are grateful to Dr N. Karaba, Dr G. Joshi, Dr G. Jagadeesh, Mr G. Ravi Kumar, Mr S. K. Dwivedi and Smt B. Raji for their meaningful discussions. We are also grateful to the two anonymous reviewers for their suggestions. Financial assistance from the World Bank Aided F.R.E.E. Project is acknowledged.

Received 16 May 2002; revised accepted 13 August 2002

A. N. ARUN KUMAR[‡]
Y. B. SRINIVASA*[,‡]
S. S. CHAUHAN[†]

Institute of Wood Science and Technology, 18th Cross, Malleswaram, Bangalore 560 003, India
[†]*School of Forestry, University of Canterbury, P.B. 4800, Christchurch, New Zealand*
**For correspondence*
e-mail: yb@iwst.res.in
[‡]*The authors have contributed equally.*