Growth and climate relationship in teak trees from Conolly's plot, South India

Teak (*Tectona grandis* L.f.) has been proven to be of great dendroclimatic potential in several areas of its natural distribution in India[1–3]. Growth rings are a useful tool for the determination of age and growth rate of the trees in wood production of managed stands. Several dendroecological and dendroclimatological studies have been carried out on tree species from upper tree-line in different mountain regions[4–6]. Many trees in the tropical forests of the Indian subcontinent are known to produce growth rings[7]. Teak tree is widely distributed in the peninsular and Central India, and has been studied from a dendrochronological point of view at several sites, viz. from dry deciduous forest in Korzi, Andhra Pradesh[8], and Upper Narmada river basin in Central India[3]. Teak tree-ring chronologies from Central India, show good association with moisture index rather than rainfall[9]. Moreover, teak trees from Indonesia, Thailand and Java have also been demonstrated to be a potential source of high-resolution reconstruction of monsoon-related parameters such as rainfall, drought frequency and El-Niño Southern Oscillation, etc.[2,10–13]. Besides, mean monsoon precipitation of June–September has been reconstructed back to AD 1835, based on ring-width data of teak[14]. However, an attempt has been made here to explore the dendroclimatological potential of teak (*T. grandis*) from peninsular India, and to understand any significant relationship existing between climatic variables and ring-width index of teak. For detailed climatic studies of this region, tree-ring analysis needs to be extended to other geographical regions to understand which climatic variables are significant in limiting the growth of teak over the region.

Teak samples for the present study have been collected from an area (11°16′–11°21′N lat.; 76°15′–76°20′E long.), located in the southern part of peninsular India (Figure 1). Monthly rainfall of Kerala subdivision and temperature data of Kozhikode and Palmer Drought Severity Index (PDSI) around the tree-ring sites were used in the dendroclimatic analysis. On the basis of the climate data, the mean monthly temperature varies in the range 25.8–29.5°C throughout the

year. June is the wettest, January and February are the driest, and March and April are the hottest of the year.

Two tree-ring cores per tree were taken using increment borer at breast height of the stem from healthy, straight trees. The aim was always to get the centre of the tree, i.e. pith. The selection of trees was based on examination of local conditions, such as soil texture on a slope, and minimal competition from neighbouring trees[15]. We have collected 33 tree-ring core samples from 17 living teak trees. All core samples were processed in the laboratory using standard dendrochronological techniques[15]. Skeleton plot method was used to assign the exact calendar year of growth to each ring[16]. The ring-widths of dated samples were measured with an accuracy of 10^{-3} cm under a high-magnification stereo-zoom microscope system. Dating of ring-width sequence was verified using the computer program COFECHA[17], which identifies tree-ring data segment-wise that may have either dating or measurements errors. Samples showing dating irregularities were rechecked and the errors corrected. The ring-width measurement series were standardized to remove the age-related and biological growth trend using the software ARSTAN[18]. Detrending for all series was done using cubic spline smoothing method with stiffness of 2/3 of each tree-ring series (with 50% frequency response cut-off). Standardized, individual ring-width series were averaged using the biweight robust procedure in the preparation of the mean chronology. After detrending, the chronology was computed using the biweight robust mean value function to remove effects of stand disturbances; in the residual version, chronology has been prewhitened by autoregressive modelling. The resulting prewhitened chronology was then added by reincorporating the pooled model of autoregression which contains the persistence common signal and synchronous among a large portion of series from the site[19]. The resulting tree-ring chronology represents growth variation caused by common environmental forcing.

Ring-width chronology statistics such as mean sensitivity (0.24), common vari-

ance (0.28), expressed population signal (0.87) and signal-to-noise ratio (6.7) indicate a strong environmental influence on tree growth[20]. However, we have presented the results of the residual version of the chronology (i.e. after autoregression). In this analysis, the updated global monthly PDSI dataset was obtained from the National Centres for Environmental Prediction, USA[21]. PDSI is a proxy for soil moisture and stream flow[21]. It is based on temperature and precipitation data for global land areas, on a 2.5° × 2.5° grid. It was averaged over the 9°–11°N lat.; 75°–77°E long. area (Figure 1).

The relationship between climate and tree growth was examined for the whole available climate data period and also for different time-spans, 1871–1900, 1900–2003 and 1871–2003 for precipitation and PDSI; 1901–1930, 1931–2003 and 1901–2003 for temperature and corresponding lengths of the tree-ring index, to observe the temporal stability in tree growth and climate relationship (Tables 1–3). In the present study, we have prepared the seasonal climatic variables (viz. previous monsoon (-JJAS) and post-monsoon (-ON), winter (DJF), pre-monsoon (MAM), monsoon (JJAS), post-monsoon (ON) and annual) to pool the common climatic signal in tree growth by combining monthly climatic dataset of rainfall and temperature as well as PDSI.
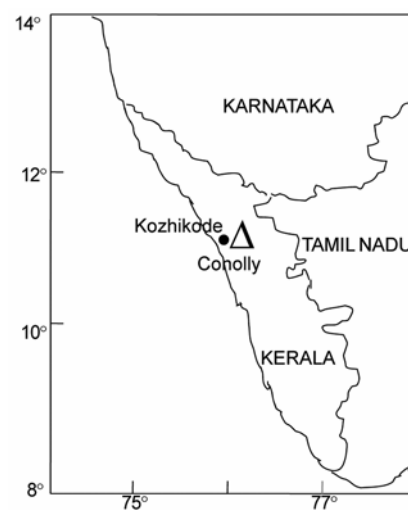

Figure 1. Location of tree-ring sampling site (Δ) and meteorological station (•) used in the study.

Table 1. Correlation analysis of raw ring-width and tree-ring index with rainfall during different seasons and periods

Site	1871–1900							1900–2003							1871–2003						
	Season							Season							Season						
CON	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
R								+			+			+							
I								+			+								+		

Table 2. Correlation analysis of raw ring-width and tree-ring index with PDSI during different seasons and periods

Site	1871–1900							1900–2003							1871–2003						
	Season							Season							Season						
CON	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
R						+		+	+	+	+	+		+							
I						+		+	+		+				+	+		+			

Table 3. Correlation analysis of raw ring-width and tree-ring index with temperature during different seasons and periods

Site	1901–1930							1931–2003							1901–2003						
	Season							Season							Season						
CON	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
R					+			•	•	•	•	•	•	•	•	•	•	•	•	•	•
I					+																

+, Significant at $P < 0.05$; •, Significant at $P < 0.05$.
1, Previous year monsoon (-JJAS); 2, Previous year post-monsoon (-ON); 3, Winter (DJF); 4, Pre-monsoon (MAM); 5, Monsoon (JJAS); 6, Post-monsoon (ON); 7, Annual; R, Raw-ring width; I, Ring-width index; CON, Conolly.

The tree growth–climate relationship based on correlation analysis, raw ring-width data and tree-ring index shows significant positive association with PDSI and rainfall during the previous year monsoon (-JJAS). PDSI and rainfall reveal significantly positive relationship with both raw-ring width data and tree-ring index during pre-monsoon (MAM) (Tables 1 and 2), for the period 1900–2003. During 1871–2003, only tree-ring index shows significant positive association with PDSI and rainfall of pre-monsoon month (MAM). This is supported by another study[22], where pre-monsoon showers were recorded to play an important role in breaking cambial dormancy. However, PDSI of previous year post monsoon (-ON) shows significant positive association with both data during 1900–2003 (Table 2). Other studies from peninsular India also reveal that teak trees show positive response to post-monsoon of previous year[23]. During 1871–2003, tree-ring index chronology also revealed significant positive rela-

tionship with PDSI during the previous year monsoon and post-monsoon (Table 2). The increased soil moisture at the beginning of the dry season also favours the physiological processes of tree during subsequent growing season[2,15]. Moisture availability at the root zone before the growing season is favourable in the tree growth process. Stored energy of the previous growth year and water availability at the beginning of the growing period are also important for the development of teak tree vessels[23].

In the case of temperature, the seasons (-JJAS, -ON, DJF, MAM, JJAS, ON and annual) showed highly significant negative correlation with raw ring-width data for the period 1931–2003 and 1901–2003 (Table 3). But there was no significant relationship of tree-ring index with any of the seasons (Table 3). Higher temperature accelerates evaporation and evapotranspiration resulting in anomalous moisture stress condition for the growth of the trees. Therefore, the negative response of temperature as observed in the

analysis. During 1901–1930, the seasonal (JJAS) temperature of the current year was positively and significantly correlated with ring-width index and raw ring-width data at Conolly's site. This may be due to the presence of more moisture at the beginning. However, Conolly's plot might have been artificially protected against insect defoliation. In addition, trees between these periods have suffered physiological disturbance due to plantations. These early rings provide the least reliable climatic information because of very short periods.

However, for further analysis, the relationship between raw ring-width data and seasonal climate data was re-examined using bootstrapped correlation analysis, Dendro-Clim2002 (ref. 24). Seasons from the preceding and current growth years were used in the analysis. Correlation analysis indicates a consistent relationship over time between ring-width data and seasonal climatic variable during 1900–2003. All values are significant at

$P < 0.05$ (Figure 2). During 1900–2003, the tree-ring growth is limited by moisture fluctuation of pre-monsoon months (MAM) and previous year monsoon (JJAS) as well as annual (Tables 1 and 2). During 1871–1900, ring-width index and raw ring-width data show that the PDSI during October and November (northeast monsoon) of the current year reveals significantly positive association (Table 2). PDSI revealed better performance compared to rainfall; this is supported by another study[25] which demonstrated the signal of summer month moisture index (April–September) in regional teak tree-ring chronology from Central India. Variation in tree-ring chronology, rainfall and PDSI is shown in Figure 3. The smoothed lines show low-pass filter obtained from cubic spline smoothing with cut-off low frequency of 30 years. Tree-ring index coincides with PDSI during the period 1880–2003, as evidenced in an earlier study[25]. In teak, local climate effects may be more significant than regional signals. However, land-surface conditions and local/regional circulation anomalies may also contribute to drought[26]. Higher growth has been observed during 1920–1930 due to moisture availability (lower panel, Figure 3). However, multi-decadal variability in PDSI exhibits a similar pattern to tree-ring chronology (Figure 3). We found that teak trees in this area are moisture-sensitive. The differences in the frequency domain must be recognized when comparing these data with other series of tree-ring data from this region, though the relationships between these records vary over time (Figure 3). Overall PDSI has shown significant positive relationship with teak tree-growth rather than rainfall over the region during different seasons, showing strong association with the recent period (1900–2003) than earlier, and indicating that the growth is more dependent on climate during the recent period. The reason for this increasing relationship is not known, but any one or a combination of several factors might be involved. This may be due to long-term climate change (e.g. rainfall, temperature), which causes the tree to change its response behaviour. However, before coming to any definite conclusion, we have to furnish a good network of teak tree-ring index chronologies and climate data from this region.

The data generated in the present study from Conolly's plot are not sufficient to understand the climatic behaviour over the past few centuries. The long-term high-resolution proxy records from different sites of peninsular India may help in understanding long-term monsoon variability over longer time-spans. A wide network of tree-ring data from this region might be useful to study past environmental history.
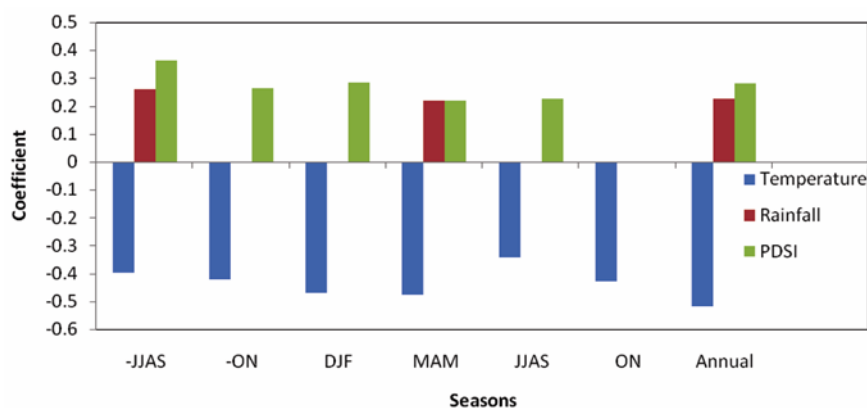

Figure 2. Bootstrap correlation between raw ring-width data and temperature, rainfall and PDSI during 1900–2003. All values are significant at $P < 0.05$.
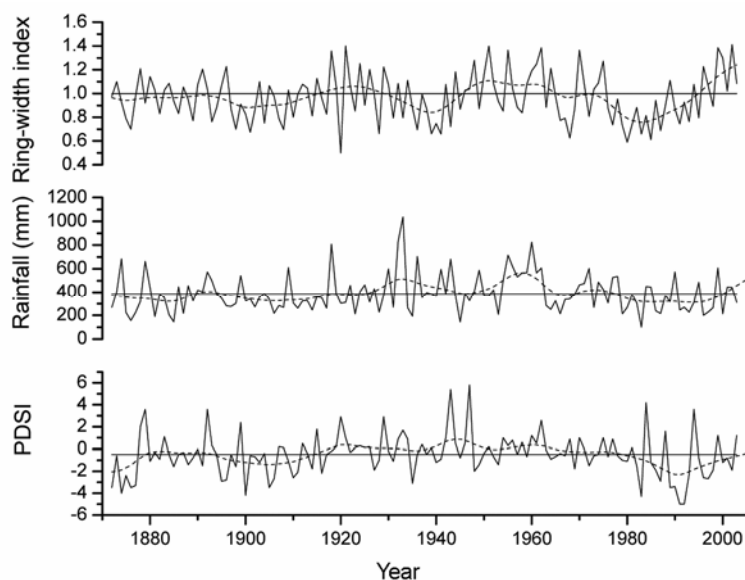

Figure 3. Variation in tree-ring chronology and rainfall (MAM) and PDSI (MAM) during 1872–2003. The smoothed lines are 30 years cubic spline fit.

1. Bhattacharyya, A., Yadav, R. R., Borgaonkar, H. P. and Pant, G. B., *Curr. Sci.*, 1992, **62**, 736–741.
2. Pant, G. B. and Borgaonkar, H. P., In *Environmental Management* (eds Singh, L. R. *et al.*), Allahabad Geographical Society, Allahabad, 1983, pp. 153–158.
3. Wood, M. L., M Sc thesis, University of Arizona, USA, 1996.
4. Wilson, R. J. S. and Luckman, B. H., *Holocene*, 2003, **13**(6), 851–861.
5. Laroque, S. J. and Smith, D. J., *Dendrochronologia*, 2005, **22**, 93–106.
6. Esper, J., Schweingruber, F. H. and Winiger, M., *Holocene*, 2002, **12**(3), 267–277.
7. Gamble, J. S., *A Manual of Indian Timbers*, Sampsonlow, Marston and Company, London, 1902, p. 868.
8. Yadav, R. R. and Bhattacharyya, A., *Proc. Indian Acad. Sci.*, *Sect. B*, 1996, **62**(3), 233–238.
9. Ram, S., Borgaonkar, H. P. and Sikder, A. B., *J. Earth Syst. Sci.*, 2008, **117**(5), 637–645.
10. Murphy, J. O. and Whetton, P. H., *Proc. Koninkl. Nederl. Akad. Wetensch.*, *Ser. B*, 1989, **92**, 241–257.
11. Pumijumnong, N., Eckstein, D. and Sass, U., *IAWA*, 1995, **16**(4), 385–392.
12. Borgaonkar, H. P., Pumijumnong, N., Buckley, B. M., Taesumrith, O. and

Chutiwat, S., *Palaeobotanist*, 2001, **50**, 27–34.

13. D'Arrigo, R. D. *et al.*, *Geophys. Res. Lett.*, 2006, **33**, L04709.
14. Shah, S. K., Bhattacharyya, A. and Chaudhury, V., *Dendrochronologia*, 2007, **25**, 57–64.
15. Fritts, H. C., *Tree-Rings and Climate*, Cambridge University Press, Cambridge, 1976.
16. Stokes, M. A. and Smiley, T. L., *An Introduction to Tree-Ring Dating*, University of Chicago Press, Chicago, 1968, p. 73.
17. Holmes, R. L., *Tree-Ring Bull.*, 1983, **43**, 69–78.
18. Cook, E. R., Briffa, K. R., Shhiyatov, S. and Mazepa, V., In *Methods of Dendrochronology: Applications in the Environmental Science* (eds Cook, E. R. and Kairiukstis, L. A.), Kluwer, Dordrecht, 1990, pp. 104–162.
19. Cook, E. R., Dissertation, University of Arizona, USA, 1985.
20. Cook, E. R. and Kairiukstis, L. A. (eds), *Methods of Dendrochronology: Applications in the Environmental Sciences*, Kluwer, Dordrecht, 1990, p. 394.
21. Dai, A. G., Trenberth, K. E. and Quian, T., *J. Hydrometeorol.*, 2004, **5**, 1117–1130.
22. Priya, P. B. and Bhat, K. M., *IAWA*, 1999, **20**, 181–192.
23. Bhattacharyya, A., Eckstein, D., Shah, S. K. and Chaudhary, V., *Curr. Sci.*, 2007, **93**, 1159–1164.
24. Biondi, F. and Waikul, K., *Comput. Geosci.*, 2002, **30**, 303–311.
25. Ram, S., Borgaonkar, H. P. and Sikder, A. B., *Quaternary Int.*, 2010, **212**, 70–75.
26. Namias, J., *J. Climate Appl. Meteorol.*, 1983, **22**, 30–39.

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Factors influencing shoaling preference in *Puntius sarana subnasutus*

Shoaling is a common phenomenon among fishes, and over half of the estimated 28,000 species of fishes[1] form shoals at some point during their life[2]. The decision of an individual to join a group may depend on a range of factors, such as group size[3], body size[4], colour[5], species[6], familiarity[7] and kinship[8]. Grouping based on such attributes is thought to reduce predation risk by minimizing phenotypic oddity or through coordinating antipredator behaviour and reducing competition within group members[9].

For effective grouping, individuals need to be able to recognize group members that possess suitable phenotypic cues. In freshwater fishes, social recognition is known to be achieved using a combination of visual and chemical cues[10]. Here, we evaluate the influence of kinship and body size of individuals on the shoal choice of *Puntius sarana subnasutus* by giving an opportunity to single individuals to shoal either with similar-sized full sibs or with phenotypically dissimilar, larger non-sibs. We examined the decision of individuals when preference to larger shoal conflicted with inclination for assorting based on kinship and phenotypic similarity.

P. sarana subnasutus were collected from canals associated with paddy fields at Irinjalakuda (10°25′–10°18′47″N lat. and 76°17′19″–76°12′48″E long.), Thrissur District, Kerala, India, during January–March 2008. Using Gonadotropin-releasing hormone (GnRH) analogue Ovaprim, gravid pairs were induced to breed and eight-month-old (standard length = 7.7 ± 2.15 cm and body mass = 11 ± 2 mg) sub-adults of the same breeding pair were selected as the sibling group. Individuals of the same age and size group selected from the young ones of another breeding pair formed the non-sibling group. *P. sarana subnasutus*, less than one-year-old (standard length = 16.3 ± 2 cm and body mass = 26.75 ± 4.12 mg), collected from the canal, formed the larger non-siblings group.

Shoaling preferences were tested in 70 l aquaria (85 cm × 32 cm × 32 cm), which was divided into two stimulus compartments (measuring 16 × 32 × 32 cm each) on the right and left, and a central compartment (measuring 53 × 32 × 32 cm). The test fish were introduced individually into the central compartment in a presentation cage. Ten minutes were given to the fish for assessment of stimulus shoal and thereafter, the movements of the fish were recorded for 6 min using a stopwatch.

We conducted three types of choice experiments and the basic protocol was the same in all of them. To test the influence of kinship on shoal preference (experiment 1), two stimulus shoals – one with siblings and the other with non-siblings of similar body size and equal number (10 versus 10; 1 : 1 ratio) were presented in the side chambers. In experiments 2 and 3, the number of individuals in stimulus shoals was altered in the following numerical combinations: 10 versus 10, 9 versus 11, 7 versus 13, and 4 versus 16 (ratios 1 : 1, 1 : 1.2, 1 : 1.9 and 1 : 4 respectively)[7]. In experiment 2, we tested the preference of the fish to larger shoals by providing similar-sized sibling stimulus shoal on either side. To determine the trade-off point of sibling preference against shoal size and larger body size (experiment 3), the test fish was given two different stimuli; one with similar-sized siblings and the other with larger non-siblings. The data were analysed using non-parametric two-tailed t-test (SPSS 11.0.1 statistical package).

In the first experiment, the test fish displayed an overall significant preference for stimulus shoals composed of siblings ($t = 7.041$; $n = 20$; $P < 0.0001$). When the test fish was presented to sibling stimulus shoals in the above-mentioned combinations, the fish preferred to remain with the larger group. The fish did not exhibit any preference for a particular stimulus shoal when the ratio was 1 : 1 and 1 : 1.2 (10 versus 10; $t = 1.928$, $n = 20$, $P = 0.0614$, and 9 versus 11; $t = 1.5025$, $n = 20$, $P = 0.413$). However, at higher ratios (1 : 1.9 and 1 : 4), the fish exhibited a significant preference for larger shoals (7 versus 13;