Growth-ring analysis of Indian tropical trees: dendroclimatic potential

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Tree ring analysis of four tropical taxa, viz. *Tectona grandis*, *Cedrela toona*, *Michelia champaca* and *M. nilagirica* is reported. The former two have clear, datable and climatic sensitive growth rings and have therefore a potential value. The other two are unsuitable as tree-rings are not datable to the calendar year of their formation. They lack cross-matching even within the radii of a tree. Moreover, non-synchronous growth during the sampling year has been reported in these trees growing in the same site, suggesting that no common environmental variable acts as a limiting factor in the growth of *Michelia sp.*

TREE ring analysis in tropical woods was not considered important earlier since annual growth rings were believed not to be formed in these trees due to lack of seasonality in the tropical climate. Even in species where the rings were discernible, age determination by counting their growth rings was considered unreliable[1,2].

Brandis[3] pointed out growth rings in several Indian tropical trees in relation to mensuration studies and reported annual growth rings in teak. According to Fernandez[4], more than one ring is formed every year in this tree. Gamble[5] referred to growth rings in a large number of tropical trees as annual rings. Many subsequent studies reported the formation of false rings to be common in tropical trees precluding growth rings in these trees as annual.

After Chowdhury's initial work[6] on growth ring formation in relation to climate no work appeared from India until recently when growth-rings of tropical trees were recognised as an important source of proxy climate data[7-10]. Here we report the tree ring analysis of *Tectona grandis* L. f., *Cedrela toona* Roxb., *Michelia champaca* L. and *M. nilagirica* Zenk.

Tree-ring samples were collected from the tropical evergreen forests of Western Ghats in 1986 and the tropical montane forests of South India during November–December, 1987. To achieve maximum circuit uniformity samples were collected above breast height to minimize the effect of buttressing. Twentytwo disc samples of teak were collected from the Dahanu Forest Division (Thane, Maharashtra) during the period of logging. These samples were from well-diversified areas along the ranges of Western Ghats between Vada and Dahanu. Ten discs were from West sloping hills while the remaining were from east sloping side. The discs as well as 10 cores from 8 trees of *Cedrela toona* were collected from evergreen forests of Koppa division (Chikmagalur District of Karnataka). In case of *Michelia* spp. only increment cores were collected of which 10 cores were from 5 trees of *M. champaca* in Koppa and 22 cores from 11 trees of *M. nilagirica* of which 6 were growing in Doddabetta and 5 in Lovedale in Tamil Nadu.

The increment cores were mounted in wooden frames. The transverse section of discs and cores were surfaced such that each ring could be easily identified. Skeleton plot technique[11] was applied to date the samples. Ring width of each dated sample was measured using the Bannister Incremental measuring machine at IITM, Pune.

Growth-rings in tropical trees

In tropical trees, except ring-porous woods, growth rings are not always apparent. Several studies emphasized on wood anatomical changes in association with phenological changes for demarcating the growth rings[6,12-20].

The growth-ring characters of four taxa, *Tectona grandis* L. f., *Cedrela toona* Roxb., *Michelia champaca* L. and *M. nilagirica* Zenk have been discussed here from the dendrochronological point of view.

Tectona grandis L. f.

The wood is ring porous to semi-ring porous. Rings are very clear and distinguished by the pore size. These are usually annual but false rings also occur in saplings and mature trees[4,6]. It was earlier reported that false rings were formed in several teak trees due to severe physiological disturbance and insect defoliation. However, the latter has been found to be related mostly to the place of seed origin. Trees originating from seeds of Java were more susceptible to insect defoliators and produce false rings whereas trees of Indian seed origin did not[6]. Missing rings reported in teak saplings were believed to be due to physiological disturbances[6].

In our teak collection false rings occurred in a few samples, but these were easily traceable when measured in two or three different directions along the diameter of each sample. Cross-matching of the samples suggested the formation of two groups, one for samples from west facing the slope and the other from east facing the slope. Figures 1 and 2 show the nature of variations in the ring width of *Tectona grandis* of Dahanu corresponding to the western and eastern slope respectively. The smooth lines in both figures are the standard suitable filters[21]. The biological trend is removed by dividing the ring-width values with the corresponding smooth values giving dimensionless index values representing the tree-growth variation mostly due to environmental changes. Table 1 gives the detailed statistics of each of the samples. It is seen that most ring-width series show high values of first-order autocorrelation indicating the presence of trend or more low-frequency variance except in the case of sample numbers tkd 10C, 15A and 15B, where the comparatively low mean sensitivity values indicate less high-frequency variance in teak. The chronology developed from good cross-matched samples going back to 1764 A.D. is shown in Figure 3.

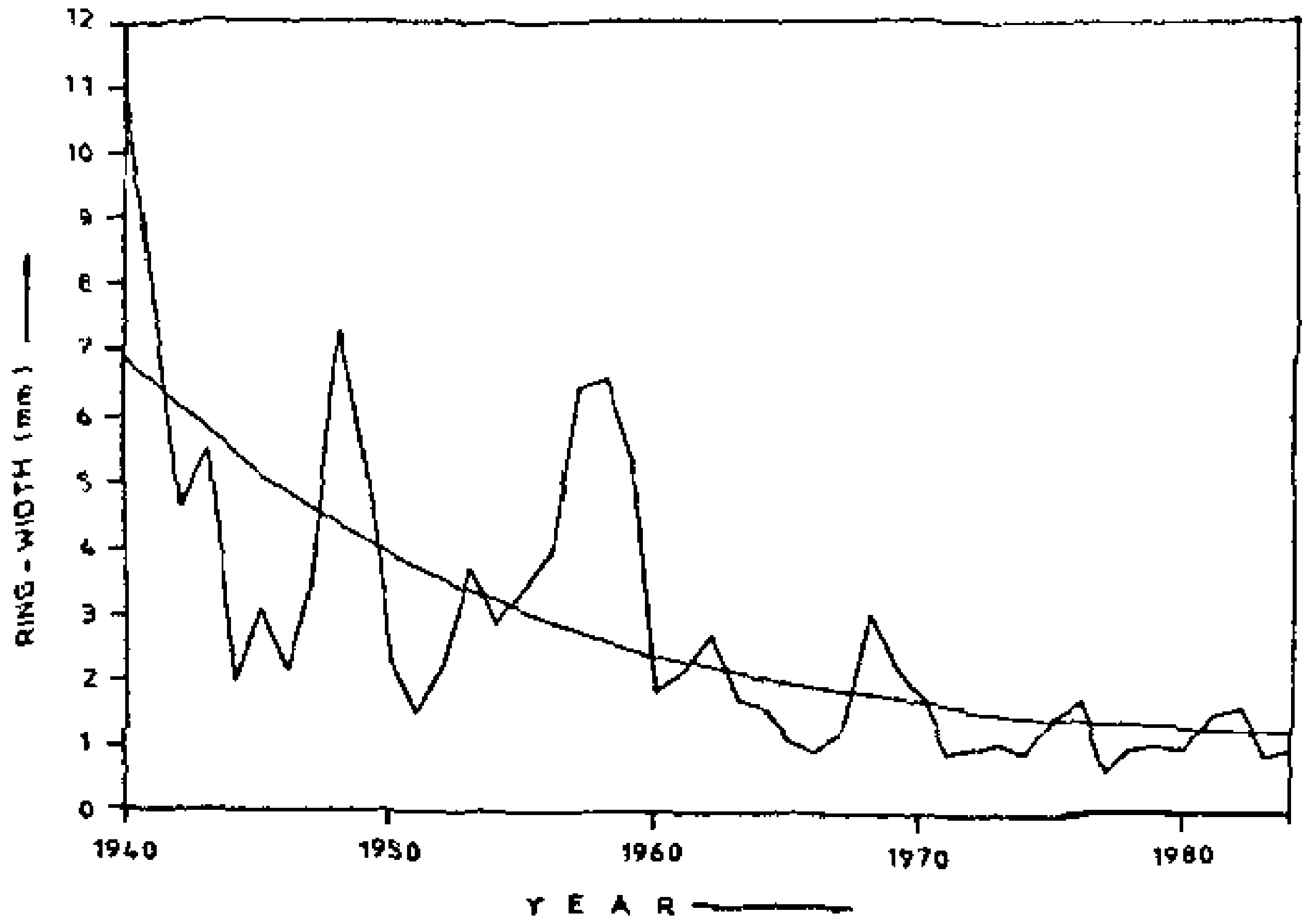

Figure 1. Ring-width curve of teak (*Tectona grandis*) growing on western slope in Dahanu, Maharashtra.

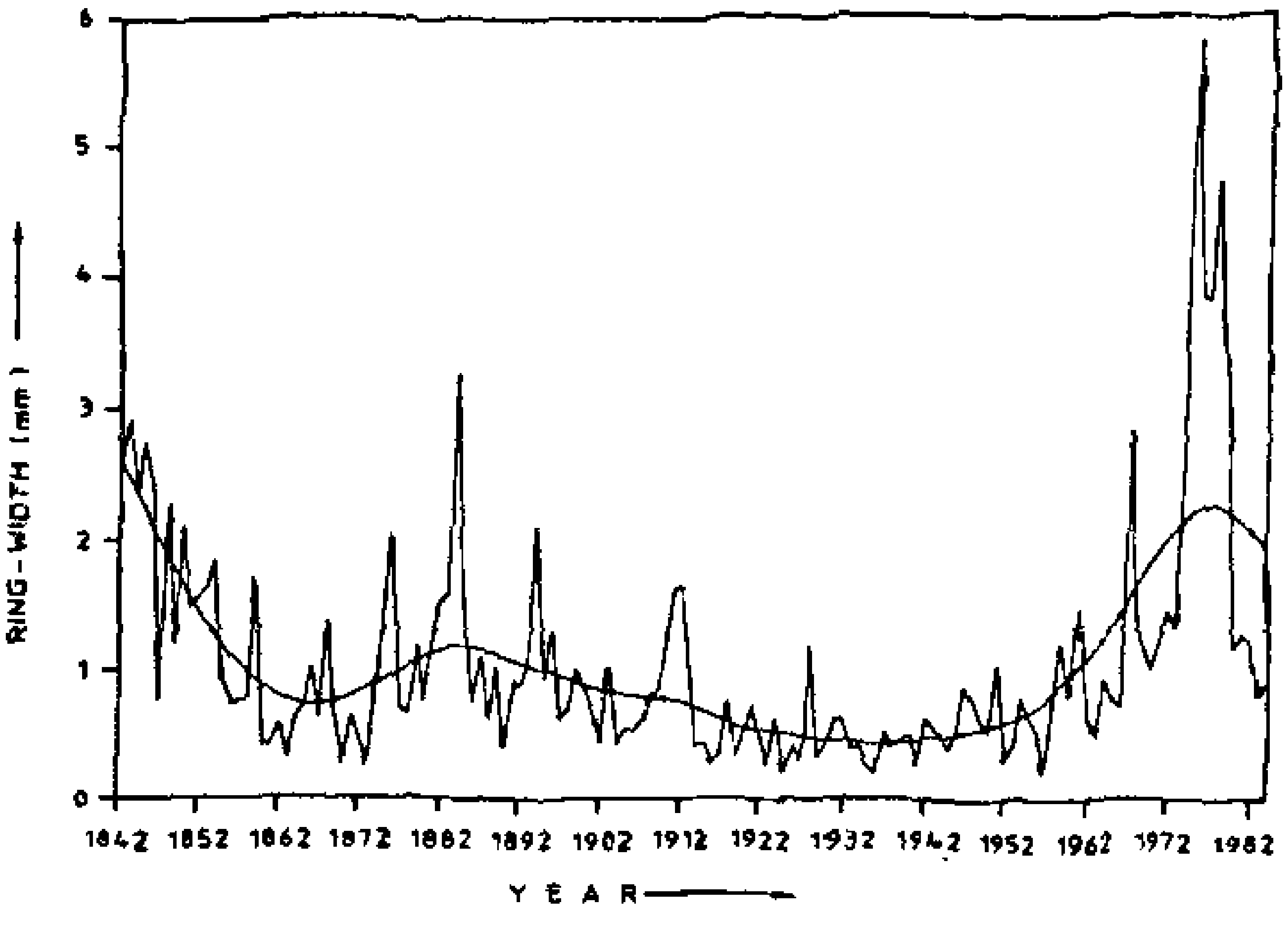

Figure 2. Ring-width curve of teak (*T. grandis*) growing on the eastern slope in Dahanu, Maharashtra.

Cedrela toona Roxb.

This is ring-porous or semi-ring porous. Growth rings are very clear and usually delimited by large pores and initial parenchyma. False rings are also formed

Table 1. Statistics of teak (Dahanu) ring-width series and their indices

Sample No.	Period	No. of years	Mean RW/Index	Std. dev. RW/Index	Mean sensitivity RW/Index	Lag-1 Auto-correlation RW/Index
TKD1A	1940–1984	45	2.813/0.989	2.272/0.494	0.362/0.363	0.759/0.566
TKD1B	1935–1984	50	2.082/0.970	2.171/0.492	0.392/0.385	0.848/0.446
TKD2A	1935–1984	50	1.939/1.000	1.489/0.714	0.446/0.447	0.684/0.588
TKD3A	1938–1985	48	1.659/0.994	1.130/0.446	0.380/0.376	0.692/0.494
TKD4B	1933–1983	51	4.183/0.961	3.375/0.671	0.371/0.370	0.756/0.713
TKD5A	1937–1985	49	2.728/0.988	1.882/0.580	0.445/0.443	0.754/0.663
TKD9A	1928–1985	58	2.808/0.985	2.114/0.436	0.442/0.417	0.633/0.170
TKD10A	1764–1984	221	1.216/0.990	1.381/0.520	0.420/0.418	0.730/0.212
TKA10C	1820–1984	165	1.000/0.987	0.801/0.570	0.432/0.431	0.414/0.132
TKD15A	1910–1984	75	1.835/0.983	1.183/0.500	0.464/0.460	0.404/0.002
TKD15B	1910–1984	75	2.380/1.045	1.455/0.745	0.441/0.455	0.360/0.091
TKD16A	1842–1984	143	1.035/0.987	0.870/0.485	0.438/0.441	0.685/0.234
TKD16B	1842–1985	144	1.258/0.988	0.789/0.463	0.415/0.415	0.551/0.237
TKD17A	1840–1984	145	1.168/1.001	0.806/0.503	0.330/0.331	0.698/0.539

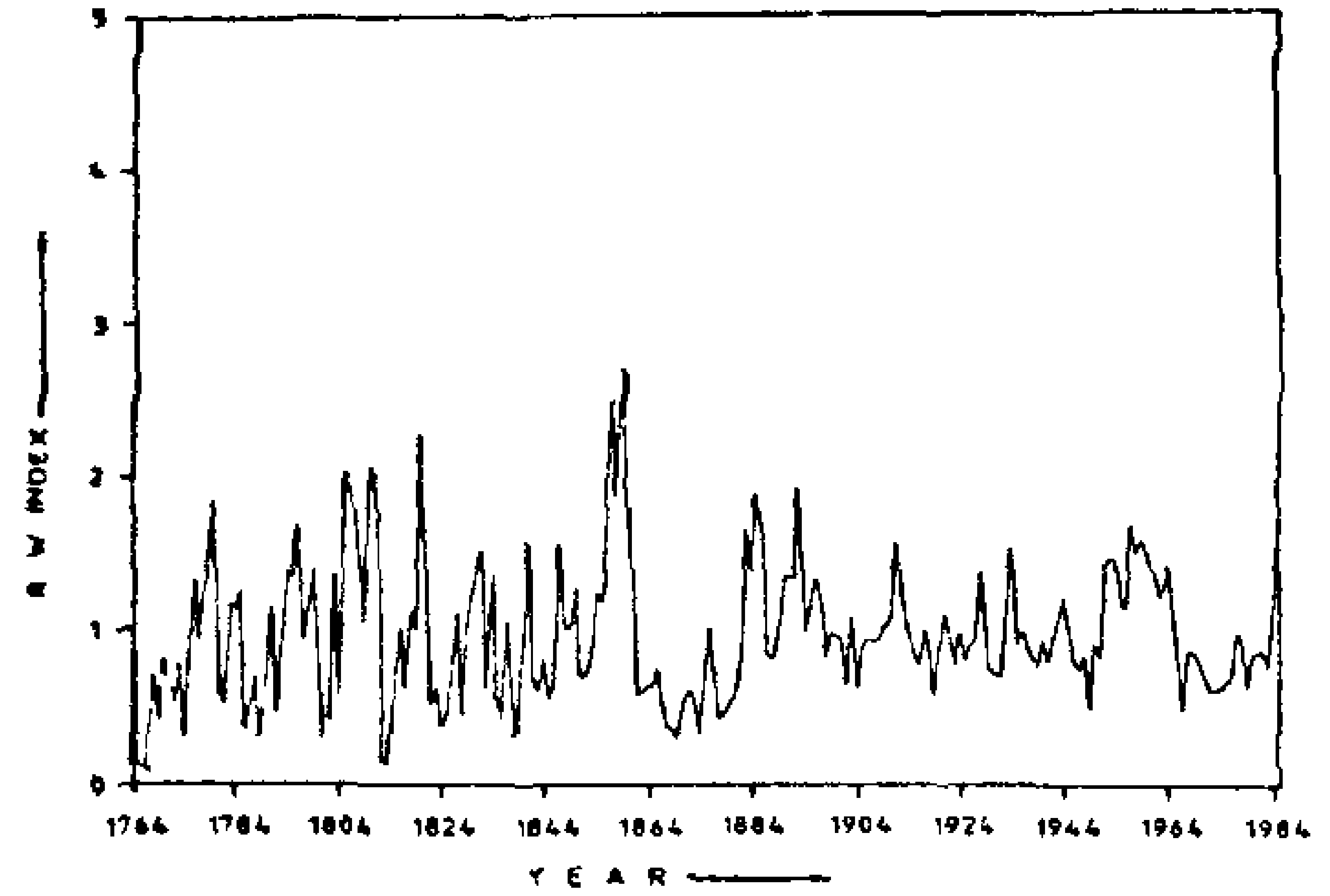

Figure 3. Teak (*T. grandis*) ring-width index chronology from Dahanu, Maharashtra.

occasionally by lines of concentric parenchymatous cells within early wood cells. These lines are similar to the initial parenchyma type but the associated vessels in early wood zone and preceding late wood zone do not show marked variations in size as in annual growth rings. These rings were dated to the calendar year of their formation using skeleton plot method of cross dating in which matching of ring width pattern is seen among the specimens. In the skeleton plot, the width of each annual ring of a core is compared with that of the preceding and subsequent rings. Any change in the ring from broad to narrow or vice versa is plotted against the position of narrow ring counted from the innermost ring on the graph paper by a vertical line. The narrower the ring the longer is the line. A good cross-dating has been observed among skeleton plots of the cores. A master plot extending back from 1800 A.D. to 1987 A.D. has been made plotting only common narrow rings of these plots (figure 4). The individual cores were dated later by matching with the master plot. This study shows that specimens of *C. toona* studied here have no absent rings but false rings are very common. The latter can be easily distinguished through cross-dating as these are not synchronous in cores. Figure 5 shows variation in ring-width of one of the samples of *Cedrela toona* of Koppa region. The smooth curve is the filter used to remove the biological trend. Table 2 gives detailed statistics of each sample of *C. toona* included in the analysis. More low-frequency variance can also be seen in *C. toona* as indicated by moderately high values of first-order autocorrelation and low values of mean sensitivity. Ring-width index chronology of *C. toona* for the site is obtained from 5 samples going back to 1800 A.D. (Figure 6).

Michelia champaca L. and *M. nilagirica* Zenk

In both the species, wood is diffuse porous and does not show any distinct zone of early and late wood. Concentric parenchyma bands demarcate the boundary of the successive growth rings. The tree cores of both species analysed have a variable degree of parenchyma formation during 1987, the year of sampling. Many cores from trees of the same site did not show any parenchyma line in the last-formed ring whereas others had a fully developed parenchyma line. This feature seems to be due to the non-synchronic growth pattern. It was earlier noticed in *M. champaca* that, two bands of parenchyma were intercepted by a few rows of fibres. The first band is usually continuous throughout the disc while the last band of the season was incomplete[13,14,22].

Tree growth and climate

Precipitation is the decisive factor for diversity in the tropical forests of India. To understand its role in tree growth, the relative width of growth rings was correlated with the annual rainfall of sampling sites. The narrow growth rings in teak have been found to match with the low rainfall years. Earlier tree ring studies of teak from Thane region showed that rainfall of October (of the previous year) was very significantly related to teak growth. This indicates that the moisture balance of the soil before the beginning of the next growing season is important for teak growth. Similar observation was also made from teak growing in

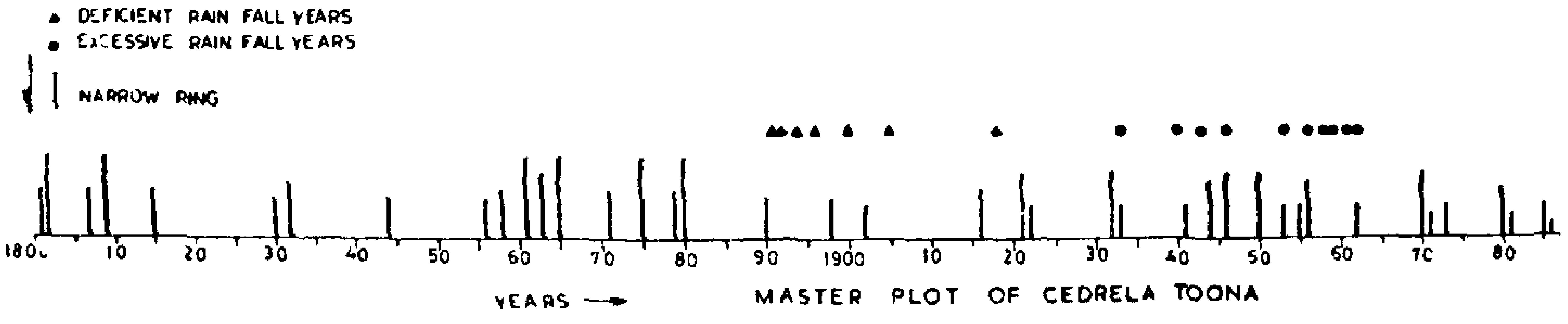

Figure 4. Master ring-width plot of *Cedrela toona* from Koppa, Karnataka. The excess and deficient rainfall years have also been marked on the plot to indicate the tree growth relationship with rainfall.

Table 2. Statistics of *Cedrela toona* (Koppa) ring-width series and their indices

Sample No.	Period	No. of *years*	Mean *RW/Index*	Std. dev. *RW/Index*	Mean sensitivity *RW/Index*	Lag-1 Auto-correlation *RW/Index*
KOP0A3	1841–1985	145	2.602/1.003	1.479/0.439	0.344/0.344	0.638/0.458
KOP0B3	1866–1983	118	3.542/1.000	1.677/0.447	0.417/0.417	0.344/0.254
KOP0A5	1912–1958	47	3.876/0.989	2.154/0.464	0.386/0.385	0.656/0.491
KOP0A6	1916–1986	71	1.775/0.937	2.140/0.826	0.534/0.538	0.500/0.399
KOP008	1800–1985	186	2.029/1.000	1.995/0.734	0.385/0.384	0.734/0.425

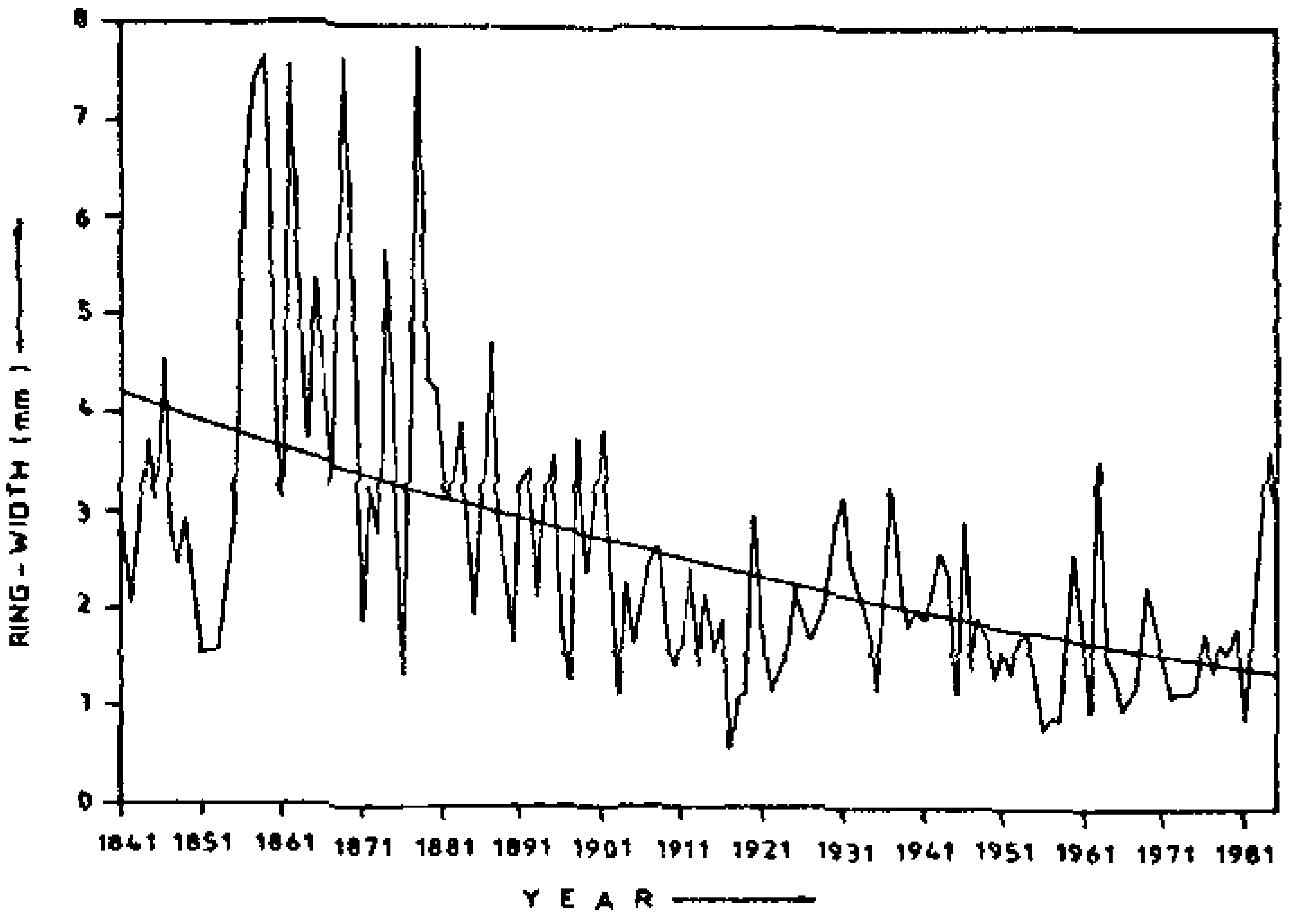

Figure 5. Ring width curve of *C. toona* growing in Koppa, Karnataka.

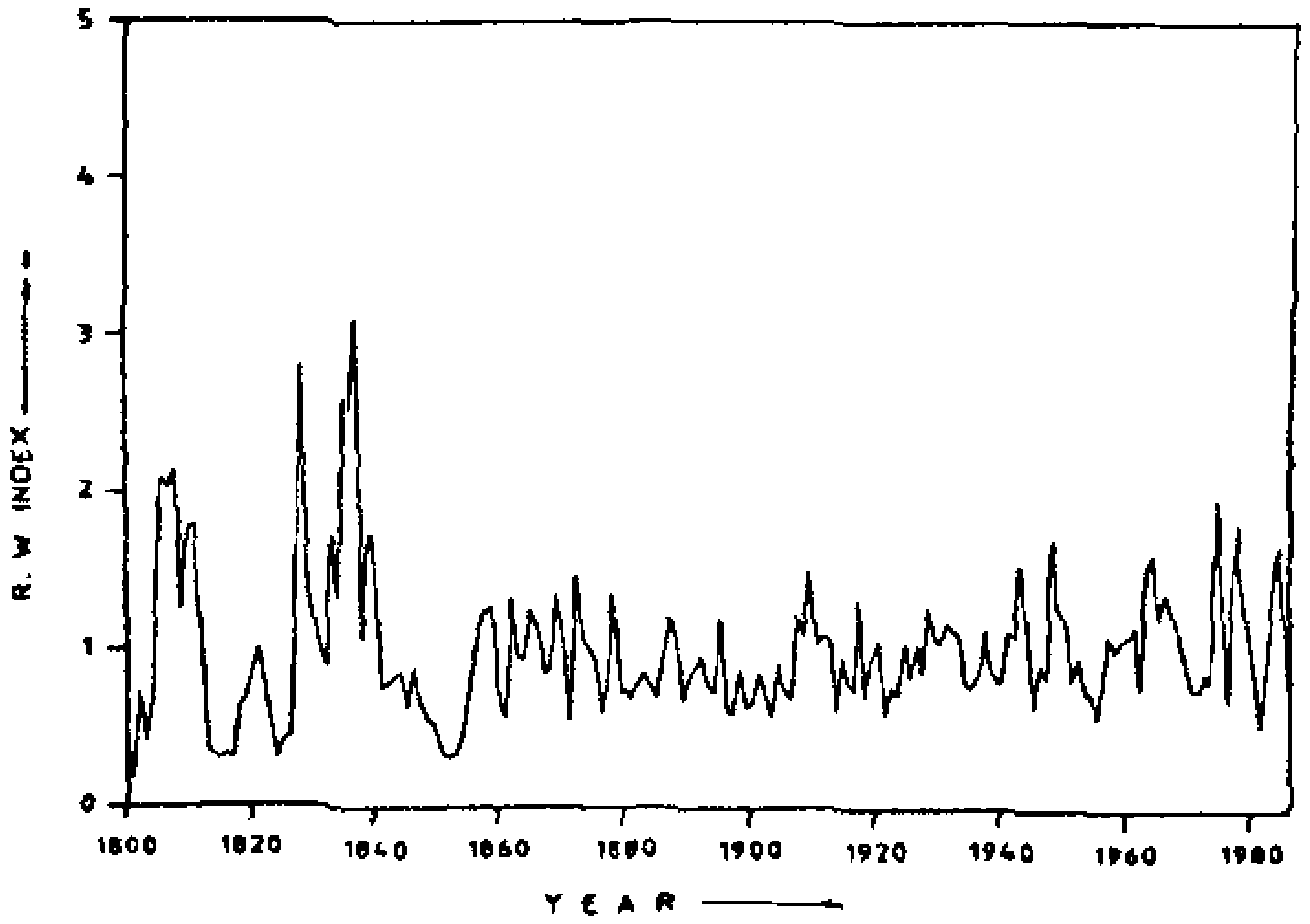

Figure 6. Ring width index chronology of *C. toona* from Koppa, Karnataka.

Central Java, where growth in teak was found influenced by rain at the end of the previous year's rainy season and during the usual onset month of the current year's rainy season[23]. Ramesh *et al.*[9] found that the stable isotope ratio (*D/H*) of annual rings contains considerable potential for monsoon rainfall reconstruction.

Figure 7 gives the teak tree ring chronology of the region and monsoon rainfall at Dahanu. Their simple correlation is greater than 0.5 which is significant at 0.1% level. The previous year's monsoonal rainfall of the region is also equally significant for tree-growth. The spell of good precipitation years reflects the normal growth of teak. As shown in Figure 7 the period 1950–60 with a spell of higher rainfall corresponds to

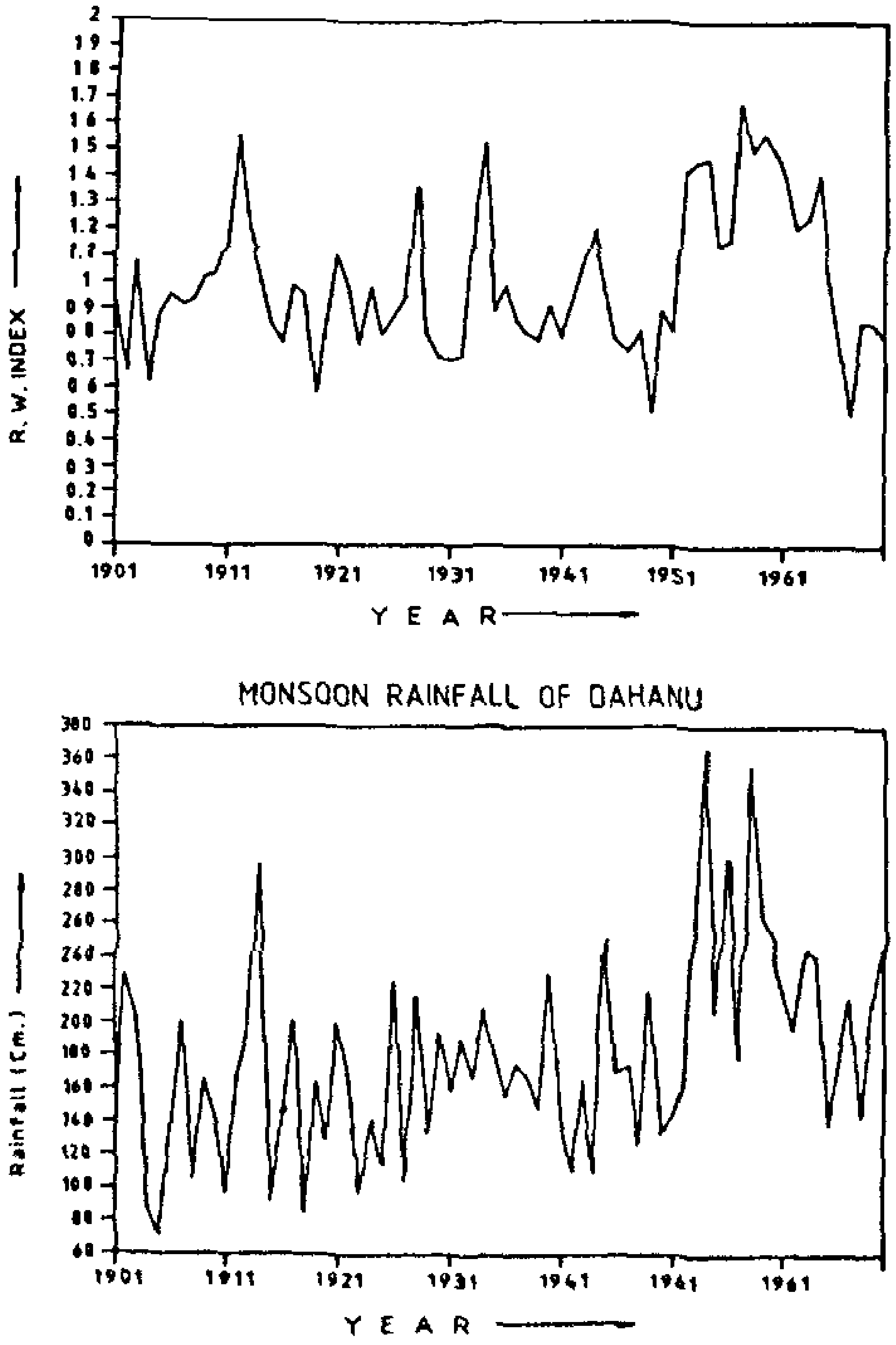

Figure 7. Ring width index chronology of teak from Dahanu and monsoon rainfall at Dahanu together to show the correlation between tree growth and monsoon

normal or above-normal growth of teak, whereas the period 1933–49 which is a comparatively low precipitation period shows below normal growth of teak. This can be explained on the basis of the carryover effect of moisture balance which acts as a booster for the next growing season. On the other side, continuous low rainfall years carry over the lack of moisture, not sufficient for normal growth resulting in the group of narrow rings.

In *Cedrela toona*, the excess and deficient rainfall years of southern Karnataka determined earlier[24] were marked in the master plot to visualize reduction in tree growths during those regional abnormal climatic years (Figure 4). Preliminary growth–climate relationship of this tree indicates that narrow growth rings are formed during both high and extremely deficient rainfall years. Similar observation in tree growth was also noted in relation to annual rainfall data from Chikmaglur which is the closest and the most suitable meteorological station in the region. Figure 8 shows the *C. toona* tree-ring chronology of this region and the annual rainfall at Chikmaglur. A significant reduction in tree growth indicated by the narrow rings might be due to low photosynthetic activity caused by deficit soil water in less rainfall years during peak monsoon period (June, July and August) when growth is supposed to be fast. Moreover, this tree has a shallow root system and grows in this region on flat sticky red soil where due to low water infiltration and poor drainage, excessive moisture may reduce soil oxygen and inhibit root growth.

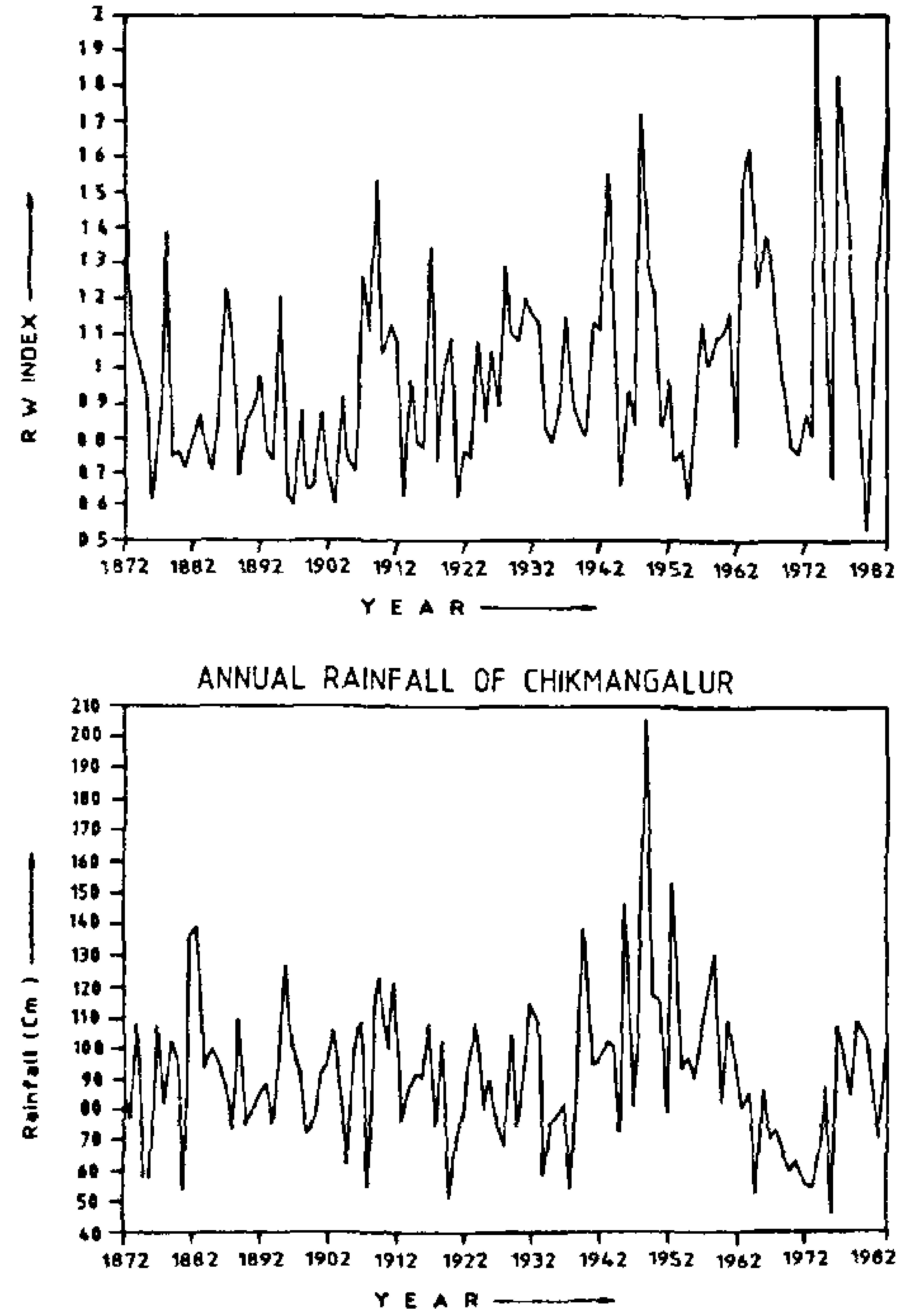

Figure 8. Ring width index chronology of *C. toona* from Koppa and annual rainfall of Chikmagalur, Karnataka, shown together to show the correlation between tree-growth and annual rainfall.

Conclusion

The present study reveals that two species, *Tectona grandis* and *Cedrela toona* growing in tropical forests of peninsular India have good potential for dendroclimatic analysis, especially to reconstruct past vagaries of monsoon. Teak has been found to be good potential for drought reconstruction. It grows very old indicating possibility of getting longer chronology for climate reconstruction. *C. toona* seems to be promising for flood reconstruction. In evergreen forests this has poor growth when rainfall is more than average in wet season. The potentiality of other trees in tropical forests for tree ring analysis would be dependent primarily on the nature of their growth rings, especially if they are datable. Even if one or two potential species are found for dendroclimatic study from each of the diversified tropical forests it would be of great significance in the study of various aspects of climatic changes from the vast part of the Indian subcontinent.

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Archaean greenstone belts of the eastern Baltic and the southern Indian shields — a comparative study

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A comparative study of the Archaean greenstone belts of the same time span (3.3 Ga to 2.5 Ga) in the Dharwar craton of southern India and the eastern Baltic shield of Karelia, USSR, shows some significant differences in their evolutionary trend. Whereas detrital sedimentary rocks occur throughout the stratigraphic succession in the southern Indian shield, they are restricted to the upper part of the sequence in the eastern Baltic shield. Chemogenic sediments (banded iron- and manganese-formations and carbonate rocks), dominant constituents in the Dharwar belts are poorly developed in the Baltic shield. Stromatolites are absent in the Baltic greenstone belts, but occur in profusion in the Dharwar belts. Bimodal/polymodal volcanic assemblages, together with immature sediments in the Baltic shield, point to an island arc setting, whereas association of both mature and immature sediments with bimodal volcanics in the Dharwar belts favours a back-arc environment.

POST-accretionary early history of the earth is preserved in the Archaean (> 2500 m.y.) geological record. Greenstone–granite and gneiss–granulite provinces constitute the Archaean terranes. Study of these rock formations tells us about the nature and evolution of the early crust hydrosphere, atmosphere and biosphere. The tectonic environment in which the Archaean greenstone belts developed and the trend of evolution they followed constitute some of the major aspects of study of the earth's history during the Archaean.

Greenstone belts evolved throughout the Archaean and Proterozoic times[1]. The Archaean belts have been classified into early (> 3300 m.y.), middle (3300 m.y. to 2900 m.y.) and late (2900 m.y. to 2500 m.y.) greenstone belts[2]. Each of these classes is characterized by distinctive tectonic, environmental, volcanic, sedimentational and biological signatures, implying a secular change in characters. However, as recent studies emphasize, greenstone belts evolved contemporaneously could be characterized by widely different evolutionary trends, depending on the sedimentary-tectonic environment in which they developed. The Archaean greenstone belts and the gneiss–granulite belts of the eastern Baltic shield in Russia and the Dharwar craton in southern India which evolved during the same time (3100 m.y. to 2600 m.y. ago) provide an opportunity for understanding this aspect.

Greenstone belts of the eastern Baltic shield

The oldest rocks in the eastern Baltic shield and in the Dharwar craton are > 3.1 to 3.2-Ga-old gneisses acting as a basement or a nucleus on which or bordering which the greenstone belts developed[3-8]. In the Karelian province of the Baltic shield, successively younger greenstone belts (Figure 1) developed from east to west between 3.1 and 2.6 Ga (refs. 5,9). Bimodal mafic-felsic as well as polymodal calc-alkaline volcanic associations are equally well developed in the Baltic shield greenstone belts[10]. Peridotitic and basaltic komatiites frequently occur in the lower part of the volcanosedimentary sequence. In some belts (Hautavaara, Oster, Parandovo) the lower part of the section is represented by andesite and dacite lavas and tuffs. Sedimentary rocks are subordinate, chiefly represented by immature polymictic conglomerates and graywackes. Banded iron formations are restricted to the

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