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A CORRELATION STUDY OF DENDROMETER BAND DATA AND PHENOLOGICAL EVENTS WITH TREE RING WIDTH MEASUREMENTS IN SOME TREES OF SRI LANKA

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ABSTRACT

Dendrometers provide an easy and reliable method of detecting growth patterns of trees by measuring changes in the diameters of tree trunks. A total of 163 trees, selected from 15 forest stations in the lowlands of Sri Lanka, were used in this study. In addition to the increase in circumference at breast height, other phenological events such as periods of leaf growth/ greening, flowering, seed ripening and fruiting were observed. The measured diameter increments were used for calculation of the number of growth periods as well as to calculate the periods of highest growth and their relationships with the observed phenological events. A correlation study was carried out with observed ring width measurements in tree cores obtained using a Swedish increment borer and wood slices. An important feature that emerged from this study was the similarities and differences among growth periods in the different tree species investigated as well as the differences in the duration of the growth periods.

For example, in *Swietenia macrophylla* and *Dipterocarpus spp* the growth periods extended throughout the year with only a few months of less vigorous growth, whereas in trees such as *Macaranga digyana*, the growth period was confined to only a few months of the year. Trees such as *Palaquium rubiginosum* and *Tectona grandis* showed only one prominent growth period for the year while most other tree species showed 2 to 3 growth periods. In *Horsfieldia irya* the maximum growth period corresponded with the period of initiation of flowering whereas in almost all tree species, the minimum growth corresponded with phenological events such as flowering. Trees within different climatic regimes such as thick dense forest and open woodlands responded differently.

It can be confidently assumed in tree-ring chronology that the observed phenological events are important in growth patterns and give important hints with reference to ring numbers in trees under tropical conditions. These observations are substantiated in this study through direct ring width and ring number establishment in cores and slices obtained from trees of known age.

INTRODUCTION

The ability to age trees is important in both ecology and forestry. The science of dating trees (dendrochronology) is well established in the case of temperate trees because chronological determinations are made simply by measuring and counting annual rings. Tropical tree chronology is, however, handicapped in this respect because most tropical trees do not form obvious annual rings or they form rings that are not related to annual events. In ecology as well as in forestry, the ability to age trees is important in utilizing both natural and man-made forests on a sustained yield basis. The determination of felling cycles and thinning regimes and the estimate of allowable cuts or exploitable volumes is based on age and growth rates. In population studies of ecosystem development and productivity, age determination is a basic prerequisite. A simplified method to age tropical trees has great economic potential for the proper utilization of tropical forests as well as in understanding the structure and function of tropical trees. In spite of the importance of techniques for obtaining tropical tree age and growth rates, only a few scattered studies on ring formation and age determination in tropical trees are available (Alvim, P. de T. and Alvim, R. 1978, Chowdhury, K.A. 1939, Alvim, P. de T. and Alvim, R. 1978).

It is very often found that age estimation in many rain forest trees using growth rings is unreliable because the majority of species do not show annual growth rings as in temperate zone trees. However, there is still a high proportion of tropical tree species which show clear demarcation of radial growth behaviour (Ogden, J. and West, C.J. 1981). A growth ring may be produced by the interactions of the periodical leaf fall, leaf production, flowering and fruiting with cambial activity. Therefore, with some knowledge of tree phenology and its relationship to subtle changes in climate, it may be possible to interpret correctly wood structure and age determination. In this study, phenological events such as leaf fall, flowering and fruiting are investigated along with direct growth variation in selected trees using dendrometers in addition to studying ring characteristics of trees of known age through wood slices and cores. The difference in growth rate as derived from dendrometer studies are used to differentiate the "annual ring" from the intra-annual bands even when these boundaries are ill defined. An attempt is made to observe the reflections in wood anatomy of periodic growth changes that occur in continuously growing trees.

MATERIALS AND METHODS

Localities

For these dendrometer studies, trees were selected from the lowlands of Sri Lanka (see Figure 1 and Table 1). Lowlands (0 to 3000 ft in elevation) are characterized by a hot humid climate. Floristically, they are dominated by lowland evergreen Dipterocarp forests and lowland evergreen forests of mixed families. The dominant arboreal taxa of Dipterocarpus forests are *Doona, Messua*, and *Dipterocarpus* species. The mixed forests are dominated by *Artocarpus, Euphoria, Filicium, Neolisea, Pometia, Mangifera*, and *Turpinia* (Koelmeyer, K.O., 1957, Rosayro de, limits are <13.0" to 16.2" and the annual precipitation is around 2,160 mm. The climate of the area is well documented at the climatic stations at Galle and Ratnapura. Dendrometer data were collected from the following reserves.

(a) Kottawa forest reserve - (6^0.06'N, 80^0.18'E, 8 miles NE to Galle) is a 25 acre patch of tropical rain forest that has been reserved from a forest that once had an extent of more than 5,000 acres.

(b) Ellakanda forest reserve - This is a tropical lowland forest (5^0.59'N, 80^0.36'E, 3.5 miles NE to Matara) which has an extent of 992 acres.

(c) Angunna Badulla Forest - (Badulla Kelle) (60^0.1'N, 80^0.32'E) is a lowland forest of 453 acres which is floristically less well known. Steep hills characterize the topography of the forest which has an elevation of 100 to 200 ft.

Table 1: Sampling stations and weather stations (see also Figure 1)

A_1	Mahakudugala		
A_2	Harasbadda	A_{13}	Wellana
A_3	Kandapola	A_{14}	Kiyanduwa
A_4	Pattipola	A_{15}	Kurunegala
A_5	Ohiya	B_1	Ellekanada
A_6	Middeniya	B_2	Angunna Badulla
A_7	Gonadeniya	B_3	Meddawatta
A_8	Uswewa	B_4	Kottawa Forest
A_9	Kalamatiya	C_1	Kurunegala
A_{10}	Rekawa	C_2	Nuwara Eliya
A_{11}	Welihena	C_3	Galle-Kottaw
A_{12}	Wilpita	C_4	Hambantota

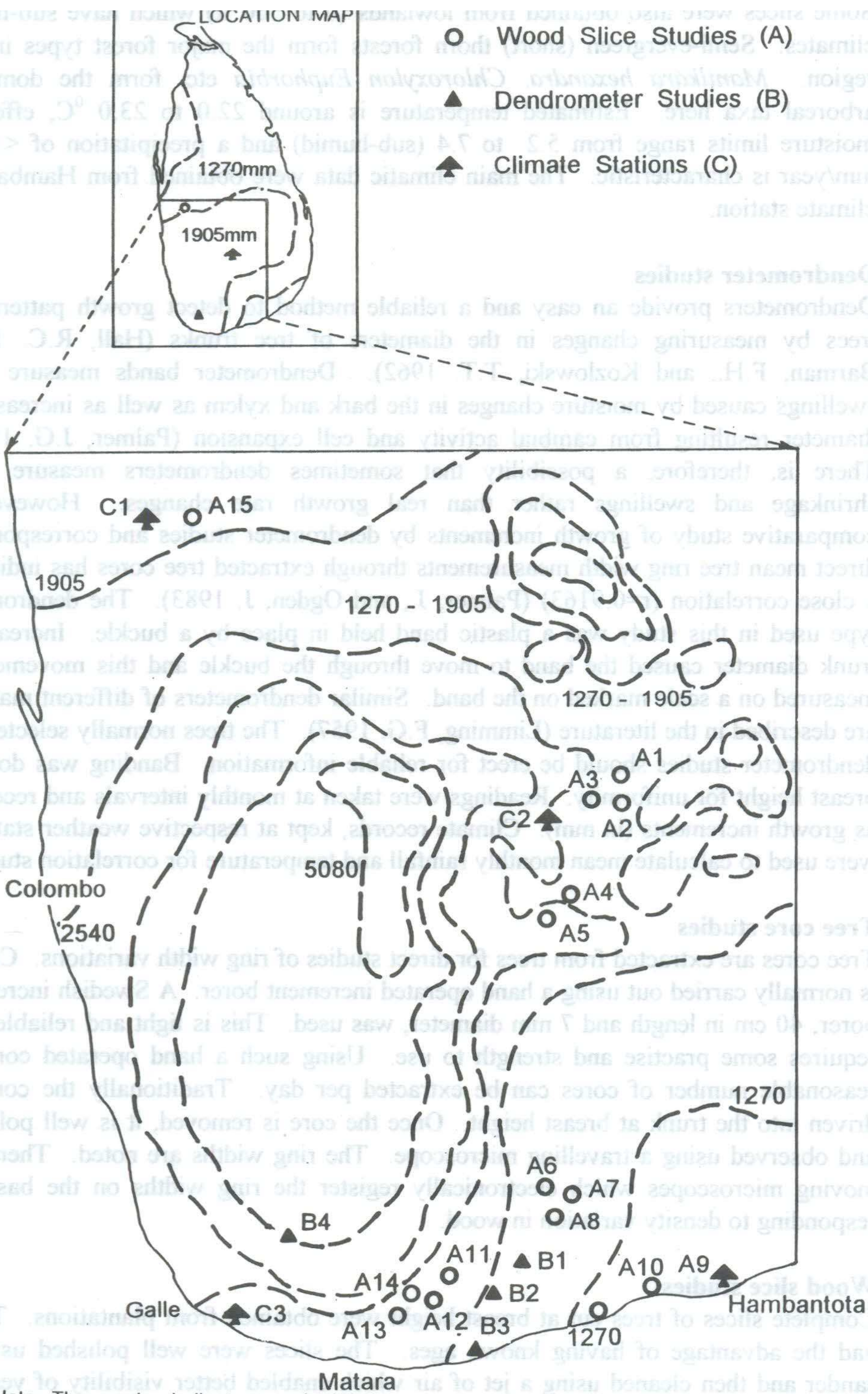
In the analysis of wood slices, sampling stations were selected from both lowland and upper montane areas (4,500 to 8,000 ft) of Sri Lanka. A mild and humid climate prevails in the upper montane areas. The major forest types are:

(a) Montane evergreen Dipterocarp forests where *Stemonoporus rigidus, Alphonsea coriacea*, and *Garcinia echinocarpa* are the dominant arboreal taxa

(b) Montane evergreen mixed forest where *Calophyllum walderi, Garcinia echinocarpa, Gordenia spp. Palagnium rubiginosum, Michelia milagirica, Elaeocarpus* and *Syzygium* are the dominant arboreal taxa

(c) Semi-evergreen (tall) forest where Chloroxylon, *Berrya, Vitex, Schleichera Hemicyclia, Premna, Grewia, Strychnos are the dominants.*

Average temperatures range between 22 and 23°C, effective moisture limits range from 8.0 to 10.2 (humid to sub-humid) and precipitation is <1,400 mm/year. Most climatic data were obtained from the climatic station at Nuwara Eliya.



Note: The number indicate annual rainfall data in mm.
The names of sampling stations are given in Table 1.

Some slices were also obtained from lowlands (0 to 500 ft) which have sub-humid climates. Semi-evergreen (short) thorn forests form the major forest types in this region. *Manilkara hexandra, Chloroxylon Euphorbia* etc. form the dominant arboreal taxa here. Estimated temperature is around 22.0 to 23.0 ^{0}C, effective moisture limits range from 5.2 to 7.4 (sub-humid) and a precipitation of <1,400 mm/year is characteristic. The main climatic data were obtained from Hambantota climate station.

Dendrometer studies

Dendrometers provide an easy and a reliable method to detect growth patterns of trees by measuring changes in the diameters of tree trunks (Hall, R.C. 1944, Barman, F.H., and Kozlowski, T.T. 1962). Dendrometer bands measure stem swellings caused by moisture changes in the bark and xylem as well as increases in diameter resulting from cambial activity and cell expansion (Palmer, J.G. 1982). There is, therefore, a possibility that sometimes dendrometers measure stem shrinkage and swellings rather than real growth rate changes. However, a comparative study of growth increments by dendrometer studies and corresponding direct mean tree ring width measurements through extracted tree cores has indicated a close correlation (r=0.9163) (Palmer, J., and Ogden, J. 1983). The dendrometer type used in this study was a plastic band held in place by a buckle. Increase in trunk diameter caused the band to move through the buckle and this movement is measured on a scale marked on the band. Similar dendrometers of different material are described in the literature (Limming, F.G. 1957). The trees normally selected for dendrometer studies should be erect for reliable information. Banding was done at breast height for uniformity. Readings were taken at monthly intervals and recorded as growth increments (in mm). Climate records, kept at respective weather stations, were used to calculate mean monthly rainfall and temperature for correlation studies.

Tree core studies

Tree cores are extracted from trees for direct studies of ring width variations. Coring is normally carried out using a hand operated increment borer. A Swedish increment borer, 40 cm in length and 7 mm diameter, was used. This is light and reliable, but requires some practise and strength to use. Using such a hand operated corer, a reasonable number of cores can be extracted per day. Traditionally the corer is driven into the trunk at breast height. Once the core is removed, it is well polished and observed using a travelling microscope. The ring widths are noted. There are moving microscopes which electronically register the ring widths on the basis of responding to density variation in wood.

Wood slice studies

Complete slices of trees cut at breast height were obtained from plantations. These had the advantage of having known ages. The slices were well polished using a sander and then cleaned using a jet of air which enabled better visibility of vessels. Strips were cut at a number of radii and then mounted onto the travelling microscope and the ring widths measured. Cross matching was performed for accurate dating etc. to avoid false rings.

RESULTS

Dendrometer

Table 2 gives a list of trees that were used for the estimation of monthly growth increments using dendrometer bands. Except for the trees selected from Meddawatta (Matara) others were from forest reserves. In total, 163 trees were used in this study. In addition to increase in circumference at breast height, other phenological events such as period of leaf growth/greening, flowering, seed ripening and fruiting were observed. The diameter increments were used for calculation of the number of growth periods. These observations are summarized in Table 3. Figures 2, 3, 4 and 5 illustrate mean monthly growth increments for each species obtained through dendrometer bands. These dendrometer band measurements were used to calculate the period of highest growth.

Direct ring width measurements

A list of trees for direct ring-width measurements is given in Table 4. The majority of these trees were obtained from plantations because information was available on their age - also slices of trunk could be easily obtained. Table 4 also gives a comparison of known age with the number of identifiable rings. The absolute ring width data were standardized by calculating the tree indices using a computer programme. Figure 6 gives the curve showing variations of absolute ring width during the period 1965-1987 in *Tectona grandis*. The smooth line in the figure is the fitted non-climatic trend, from which the expected ring widths were calculated. The tree indices curve plotted in the same figure was calculated by dividing the observed ring widths by the expected values.

Table 2: List of trees selected from the forest reserves for dendrometer studies

Locality	Tree Species	No of Trees Measured
Ellekanda forest	*Dipterocarpus zeylanicus*	*3*
	Araucaria can	*4*
	Pinus caribaea	*4*
	Albizzia moluccana	*4*
	Alstonia macrophylla	*4*
	Artocarpus nobilis	*3*
	Swietenia macrophylla	*3*
Kottawa forest	*Palaquium grande*	*3*
	Palaquium rubiginosum	*2*
	Garcinia cambogia	*2*
	Garcinia morella	*3*
	Calophyllum soulattri	*3*
	Artocarpus nobilis	*3*
	Mesua thwaitseii	*1*
	Dipterocarpus zeylanicu	*1*
	Doona congestiflora	*1*
	Mangifera zeylanic	*3*
	Semecarpus gardneri	*1*
	Campnosperma zeylanicum	*3*
	Chaetocarpus castanocarpus	*3*
	Macaranga digyana	*3*
	Kurrimia ceylanic	*3*
	Kurrimia sp.	*3*
	Horfieldia irya	*3*
	Carallia calycina	*2*
	Mastixia tetrandra	*1*
	Symplocos coronata	*3*
	Canthium dicococcum	*4*
	Pinus caribaea	*5*
	Araucaria can	*5*
	Digota	*3*
Angunna Badulla	*Dipterocarpus zeylanicus*	*3*
	Swietenia macrophylla	*5*
	Swietenia mahagoni	*4*
	Pinus caribaea	*10*
	Eucalyptus cam	*9*
	Araucaria can	*4*
Meddawatta	*Tectona gradis*	*4*
	Swietenia macrophylla	*7*
	Eucalyptus camaldulensis	*4*
	Alstonia macrophylla	*4*
	Azadirachta indica	*2*
	Melia	*2*
	Casuarina equisetifolia	*4*
	Filicium decipiens	*1*
	Eucalyptus oraliyan	*3*
	Tabebuia sp.	*4*

Table 3: Observed phenological data of the investigated tree species

No	Tree Species	Leaf Growth Greening	Leaf Fall	Flowering	Seed Ripening/ / Fruiting	No. of Growth Periods	Diameter Increase (Main growth period)od
1	*Dipterocarpus*	(0)Feb.-Mar. (0)Nov.-Jan.	-	(0)Sep.-Oct. Feb	(0)Oct.-Dec. Mar.-Apr.	1	Nov.-Sep. Nov-.Sep.
2	*Alstoni macrophylla*	(0)Contin.	Contin.	(0)Apr.-May Aug.-Sep.	(0)Jun.-Jul. Nov.-Dec.	2	1)Mar.-Jun. Jun.-Sep. 2)Jun.-Sep.
3	*Artocarpus nobilis*	(0)Aug.-Sep.	-	(0)Mar.-Jun.	(0)July	2	1)Mar.-Jun. Jul.-Jan. 2)Jul.-Jan.
4	*Palaquium grande*	(0)Jun.-Oct. Sep.-Oct. Mar.-Apr.	-	Mar.-Apr.	-		Oct.-Jun. Oct.-Jun.
5	*Palaquium rubiginosum*	(0)Dec. & June	-	-	-	1	Oct.-Dec. Oct.Dec.
6	*Garcinia cambogia*	(0)Mar.-Apr.	-	(0)April	(0)Apr.-Jun.	2	1)Jan.-Mar. May-Nov. 2)May-Nov.
7	*Garcinia morella*	(0)Aug.-Oct. Feb.-Mar.	-	-	-		1)Jul.-Dec. Jul-Dec. 2)Apr.-Jul.
8	*Calophyllum soulattri*	(0)Aug.-Sep	-	Jan.-Mar.	-	2	1)Mar.-Sep. Mar.Sep. 2)Oct.-Jun.
9	*Mesua thwaitseii*	(0)Nov.-Dec.	-	(0)April	-	2	1)Jul.-Nov. Jul.-Nov. 2)Mar.-May
10	*Doona congestiflora*	(0)Mar.-Apr.	-	(0)Aug.-Sep.	-	1	Jan.-Jul. Jan.-Jul.
11	*Mangifera zeylanica*	(0)Mar.-Apr. Oct.-Nov.	-	(0)Oct.-Dec. Feb.-Mar.	(0)Nov.Dec. Mar.-Ap..	2	1)Apr.-Jul. Jul.-Feb. 2)Jul.-Feb.
12	*Semecarpus gardneri*	(0)Mar.-Apr.	-	Dec.	-	2	1)Jul.-Sep. Jul.-Sep. 2)Oct.-Dec.
13	*Campnosperma zeylanicum*	(0)Dec.	-	Mar.-Apr.	-	2	1)Aug.-Sep. Aug.-Sep. 2)Mar.-May.
14	*Chaetocarpus castanocarpus*	(0)June	-	(0)Nov.-Apr. Dec.-Feb.	(0)Sep.-Oct.	2	1)Feb.-May. Jul.-Sep. 2)Jul.-Sep.
15	*Macaranga digyana*		-	Sept.	-	2	1)Feb.-May. Jul.-Sep. 2)Jul.-Sep.
16	*Kurrima ceylanica*	(0)Sep.-Oct.	-	Feb.-Mar. Oct.	-	2	1)Feb.-Jul. Feb.-Jul. 2)Aug.-Dec.
17	*Kurrimia sp.*	(0)Sep.-Oct. Feb.-May	-	(0)Jul.-Aug.	(0)Sep.-Dec.	2	1)Jun.-Mar. May-Nov. 2)May-Nov.
18	*Carallia calycina*	-	-	Jan.-Mar.	-	1	Mar.-Oct. Mar.-Oct.
19	*Horsfieldia irya*	(0)Feb.	-	(0)Jul.-Dec. Jan.-Feb.	Sep.-Dec.	2	Jul.-Nov. Jul.-Nov. Jan.-Apr.
20	*Mastixia tetrandra*	(0)Jul.-Aug.	-	-	-	2	Jan.-Apr. Jul.-Dec. Jul.-Dec.
21	*Symplocos coronata*	(0)April					
22	*Canthium dicococcum*	(0)Contin.	Contin.				
23	*Tectona grandis*	(0)Jun.-Sep.	Jan.-Feb.	Mar.-Aug.	Apr.-Dec.	1	Mar.-Nov. Mar.-Nov.
24	*Swietenia macrophylla*	(0)Feb.-Mar. Jun.-Jul.	-	May-Jul.	Jul.-Dec.	2	Apr.-Nov. Apr.-Nov. Jan.-Mar.
25	*Pinus caribaea*	(0)Mar.-Apr.	Nov.-Jan.	-	March	3	Sep.-Nov. Sep.-Jan. May-Apr. May-Jul.
26	*Araucaria cunninghamii*	(0)Feb.-Mar.	-	-	-	3	Sep.-Jan. Sep.-Jan. Feb.-Apr. May-Jul.
27	*Eucalyptus camaldulensis*	(0)Apr.-May	Dec.-Jan.	Jul.-Aug.	Aug.-Oct.	-	- -
28	*Melia dubia*	(0)May-Jun.	Jun.-Jul.	Feb.	-	1	Mar.-Nov. Mar.-Nov.
29	*Casuarina equisetifolia.*			Jan.-Mar. Aug.-Sep.	Mar.-Apr.	-	- -
30	*Eucalyptus oraliyana*	Apr.-May	-	May-Jun.	Jun.-Aug.	1	Apr.-Dec. Apr.-Dec.
31	*Azadirachta indica*	(0)Contin.	Contin.	(0)Aug.-Sep.	-	1	Mar.-Nov. Mar.-Nov.
32	*Filicium dicipiense*	-	-	-	-	-	- -

Contin. = throughout the year

Table 4: List of trees used in wood slice studies. The known ages and the determined ages are also given.

No Locality	Species	No of trees	Known age	Determined Ring Numbers
1. Uswewa	*Tectona grandis*	3	21	22
2. Gonadeniya	*Tectona grandis*	3	22	25
3. Middeniya	*Tectona grandis*	5	30	30
4. Kurunegala	*Tectona grandis*	3	24	25
5. Ellekanda Forest	*Swietenia macrophylla*	6	23	51
6. Dandeniya Forest	*Swietenia macrophylla*	2	15	34
7. Kottawa Forest	*Swietenia macrophylla*	1	56	
8. Welihena	*Pinus caribaea*	3	11	38
9. Wellana	*Pinus caribaea*	3	12	38
10.Kiyanduwa	*Pinus caribaea*	2	09	34
11.Wilpita	*Pinus caribaea*	3	13	32
	Hevea brasiliensis			
12.Mulatiyana	*Albizzia moluccana*	3	17	35
13.Kotapola	*Salmailia malabarica*	3	-	-
14.Ohiya	*Pinus patula*	3	-	-
Ohiya	*Tristinia comperta*	3	55-60	51
15.Mahaku-duglaa	*Eucalyptus robusta*	2	-	46
	Eucalyptus grandis	1	-	33
16.Harasbedda	*Eucalyptus robusta*	4		[illegible]

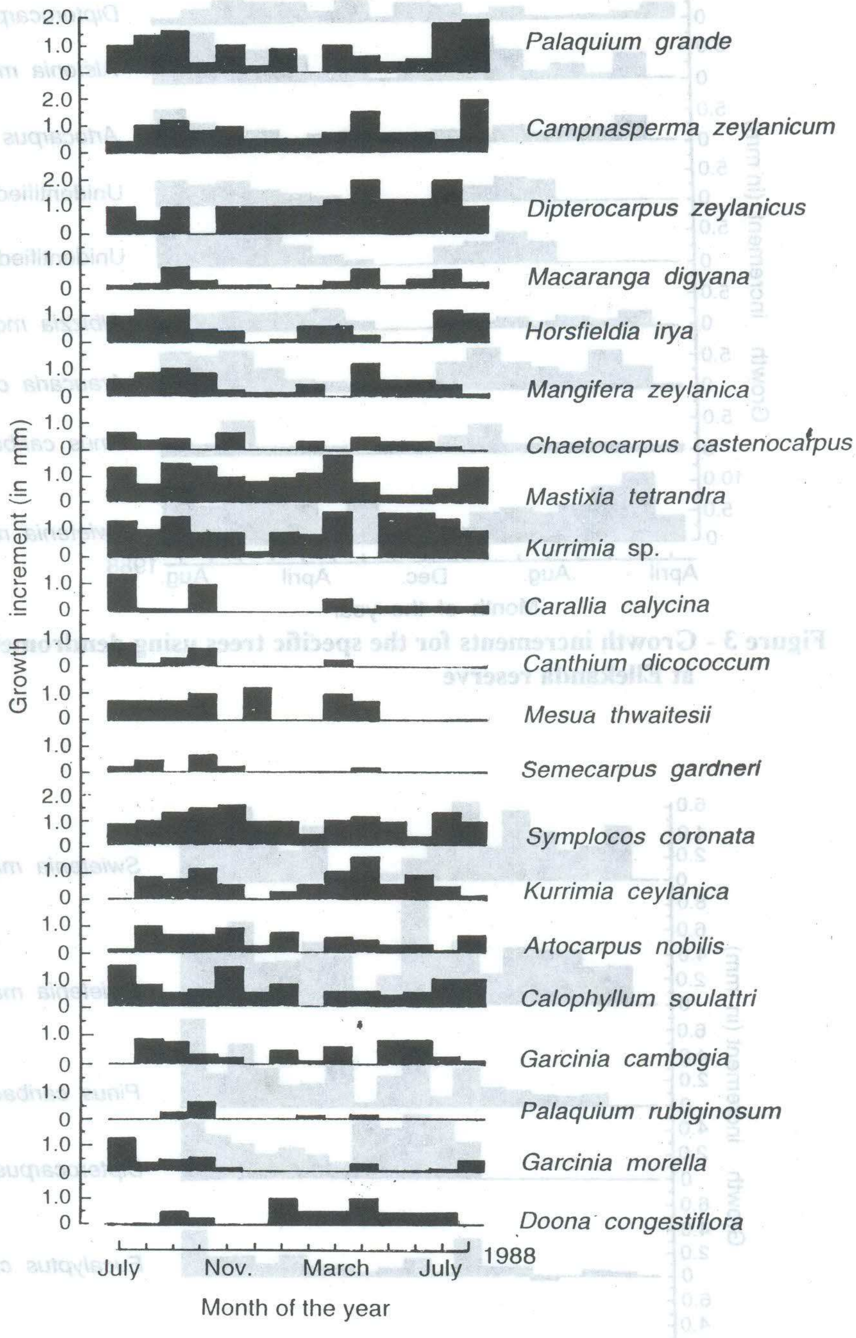


Figure 2 - Growth increments for the specific trees using dendrometer bands at Kottawa reserve

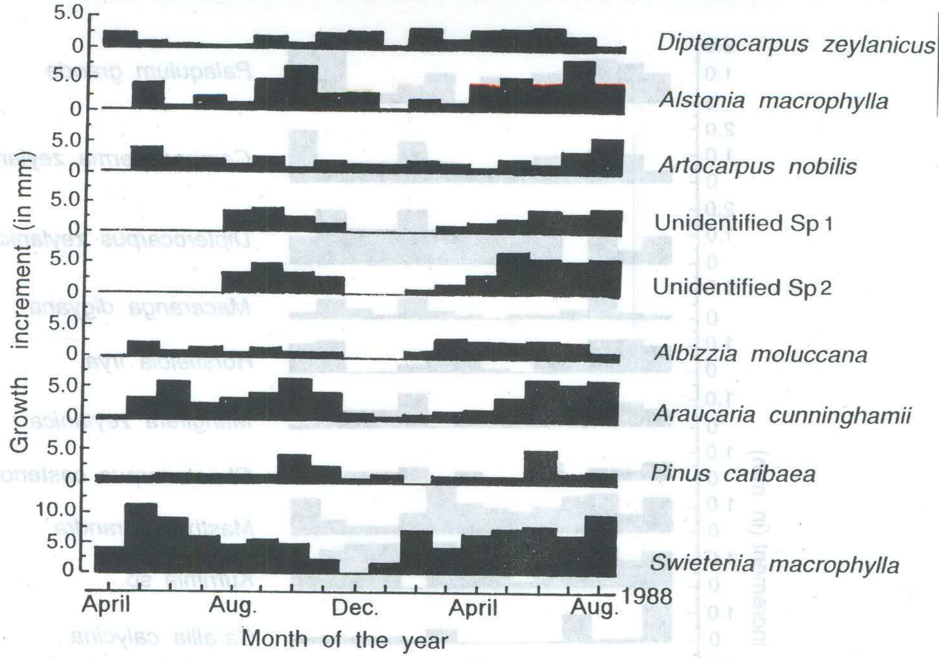


Figure 3 - Growth increments for the specific trees using dendrometer bands at Ellekanda reserve

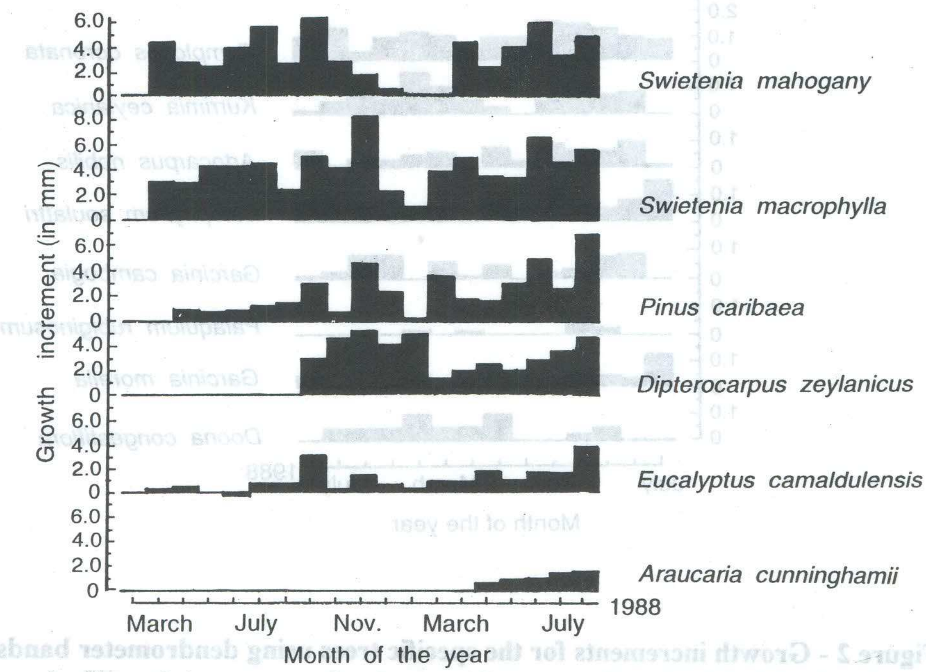


Figure 4 - Growth increments for the specific trees using dendrometer bands

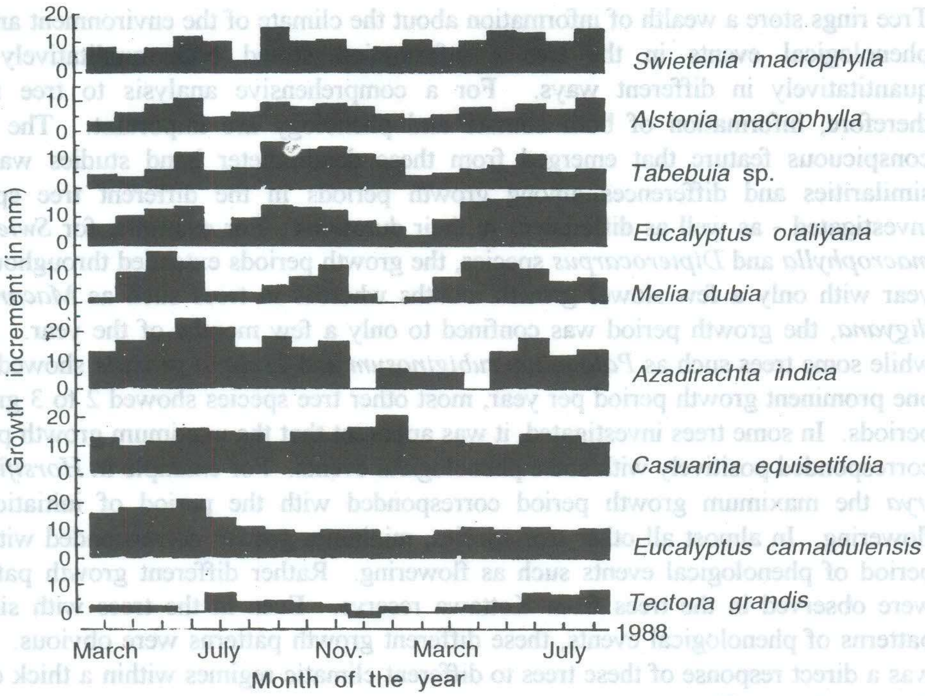


Figure 5 - Growth increments for the specific trees using dendrometer bands at Maddawatta, Matara

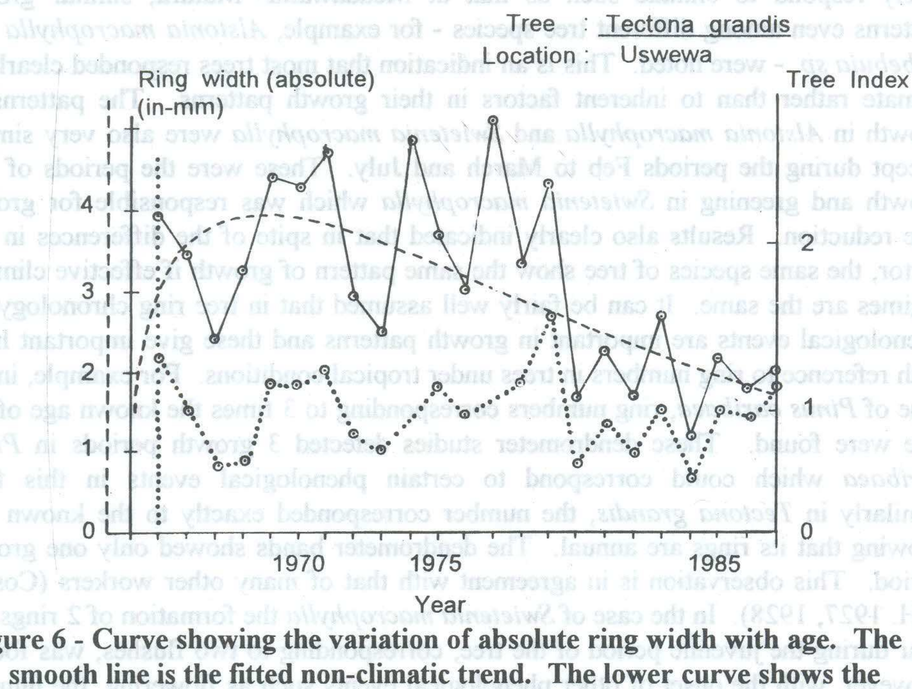


Figure 6 - Curve showing the variation of absolute ring width with age. The smooth line is the fitted non-climatic trend. The lower curve shows the variation of tree indices

DISCUSSION

Tree rings store a wealth of information about the climate of the environment and the phenological events in the tree - information stored both qualitatively and quantitatively in different ways. For a comprehensive analysis to tree rings, therefore, information of both climate and phenology are important. The most conspicuous feature that emerged from these dendrometer band studies was the similarities and differences among growth periods in the different tree species investigated - as well as differences in their durations. For example, for *Swietenia macrophylla* and *Dipterocarpus* species, the growth periods extended throughout the year with only a few slower growth months whereas in trees such as *Macaranga digyana*, the growth period was confined to only a few months of the year. Also, while some trees such as *Palaquium rubiginosum* and *Tectona grandis* showed only one prominent growth period per year, most other tree species showed 2 to 3 growth periods. In some trees investigated, it was apparent that the maximum growth period corresponded positively with some phenological events. For example in *Horstfieldia irya* the maximum growth period corresponded with the period of initiation of flowering. In almost all other tree species, minimum growth corresponded with the period of phenological events such as flowering. Rather different growth patterns were observed in the trees from Kottawa reserve. Even in the trees with similar patterns of phenological events, these different growth patterns were obvious. This was a direct response of these trees to different climatic regimes within a thick dense forest such as at Kottawa.

Among the tree species which were selected from open woodland, where trees could freely respond to climate such as that at Meddawatta- Matara, similar growth patterns even among different tree species - for example, *Alstonia macrophylla* and *Tabebuia sp*. - were noted. This is an indication that most trees responded clearly to climate rather than to inherent factors in their growth patterns. The patterns of growth in *Alstonia macrophylla* and *Swietenia macrophylla* were also very similar except during the periods Feb to March and July. These were the periods of leaf growth and greening in *Swietenia macrophylla* which was responsible for growth rate reduction. Results also clearly indicated that in spite of the differences in site factor, the same species of tree show the same pattern of growth if effective climatic regimes are the same. It can be fairly well assumed that in tree ring chronology the phenological events are important in growth patterns and these give important hints with reference to ring numbers in trees under tropical conditions. For example, in the case of *Pinus caribaea*, ring numbers corresponding to 3 times the known age of the tree were found. These dendrometer studies detected 3 growth periods in *Pinus caribaea* which could correspond to certain phenological events in this tree. Similarly in *Tectona grandis*, the number corresponded exactly to the known age showing that its rings are annual. The dendrometer bands showed only one growth period. This observation is in agreement with that of many other workers (Coster, C.H. 1927, 1928). In the case of *Swietenia macrophylla* the formation of 2 rings per year during the juvenile period of the tree, corresponding to two flushes, was found.

our comparison of determined ring numbers with the known ages. These data have been summarized in Table 4.

For this study the determination of the growth and age of some trees in tropical Sri Lanka was carried out by:

I. Periodical measurements (monthly) of the circumference of trees using dendrometers.

II. Observation of phenological events in the trees

III. Counting rings in trees of known ages

In view of the enormous range of growth factors and rates manifested in tropical trees, to develop a precise and practical method of aging samples of tropical trees needs further study.

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