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AGE AND GROWTH RATE ESTIMATION OF GREY MANGROVE *AVICENNIA MARINA* (FORSK.) VIERH FROM PAKISTAN

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Abstract

This study focused on the determination of age and radial growth in grey mangrove *Avicennia marina* (Forsk.) Vierh. The growth rate was measured by using two different methods. Firstly, the dendrometer technique was employed in which a dendrometer was fixed properly on the main tree trunk in order to determine the monthly radial growth; secondly, the manual measurements were taken from the healthy branches, the upper and the lower portions of the main trunk. The major purpose of this study was to evaluate the applicability of stem diameter change measurements in detecting the growth rate of the trees. In both the measurement techniques, the radial growth of main trunk as well as the branches significantly increased with the passage of time. The results of the dendrometer method showed the maximum growth rate (9.54±0.95cm) in the month of July, whereas it was minimum (0.58±0.058cm) in the month of October. It was found that the growth rate was higher in the upper branches, whilst it was lesser in the lower part of the main trunk. Age and the growth rate of *Avicennia marina* were estimated by applying the standard dendrochronological techniques, with dendrometer, manual measurement and cross- sectioning plants of the known ages. The maximum age of 32±1.42 years was recorded from the Port Qasim whereas the minimum (10±0.57 years) was recorded from the Korangi Crossing. The average growth rate ranged between 0.98±0.04 to 1.40±0.16 year/cm. Appearance and the successive development of cambium, characteristics of the initiation of growth rings were also investigated. *Avicennia marina* plants were grown by seeds in natural habitat as well as in the greenhouse. The cross sections were taken at the regular intervals to observe the appearance of growth rings. It was demonstrated that *Avicennia marina* has exhibited non-annual growth rings. It was concluded that the classical dendrochronological methods alone could not be applicable to this mangrove species.

Introduction

The plant growth generally depends on a multitude of environmental factors including soil, geology of the site, exposure, fire, competition and human factors etc. These factors influence the ring width of trees in various ways. The tree rings showed identifiable structural changes within the wood which usually appear as bands of different colors and shades to the naked eye (Heinrich & John, 2006). Regardless of a seasonal climate, growth rings were not always anatomically distinct in the tropics (Verheyden *et al.*, 2004a). The annual growth rings were of great importance for studying the forest ecology. They show variation in response to events in the form of narrow and wide rings and such recorded information was available in the trees. In contrast to the trees of temperate regions, only few tropical trees usually show annual growth rings.

Mangroves are the most productive tropical and sub-tropical wetlands on earth, the communities of plants and animals adapted to the saline and fresh water environments. These forests are the source of highly valued commercial products and fishery resources and also as sites for developing a burgeoning eco-tourism (Kathiresan & Bingham, 2001). Although, the mangrove plants are known to tolerate the extreme environmental conditions, yet they are rapidly disappearing throughout the world. With consistent degradation and destruction of these forests, there is a critical need to understand them in a better way. The most dominant mangrove species of Pakistan, *Avicennia marina* also tolerates a wide range of soil and water salinity levels, related to different inundation frequencies and evaporation of the water from the substrates (Matthijs *et al*., 1999; Dahdouh-Guebas *et al.*, 2004; Ye *et al*., 2005; Naidoo, 2006; Sobrado & Ewe, 2006). *Avicenna marina* has conspicuous tree rings. According to Saifullah *et al*., (2004) the mangrove forest cover is gradually declining day by day along the coast of Pakistan. However, little is known regarding the growth of this species and no comprehensive study has been conducted regarding the growth rate, age and periodic intervals for the formation of the growth rings in the mangroves of Pakistan.

Radial growth is a fundamental measurement to understand the tree biology, physiology, forest ecology, conservation and management of valuable forests. Dendrometer bands were employed to continuously record the stem radial variations. It is impossible to position the measuring tape at exactly the same place on a tree stem for repeated measurements and resulting in the placement errors (Bower & Blocker, 1966; Cameron & Lea, 1980). Dendrometer bands are commonly used to make short and long terms repeated measurements of tree-stem growth. Dendrometer supporting frames appear to be suitable for the stem variation measurements (Michelakis & Barbopoulou, 2002). It has been observed that the tree stem diameter altere because of the cambial growth and changes in the water content and water tension (Sevanto, 2003).The measurement accuracy required in any study depends on several factors. Dendrometer is a suitable device for growth measurements and the measurement of variation in the diameter of the whole stems (Sevanto, 2003). The growth data for stems of transplant are also needed to relate variation in cambial growth as well as the stem shrinkage and the growth expansion to the changing environmental factors.

In the most studies the measurements of diameter were made at the widely spaced intervals of time, making the precise observation of radial changes impossible. Fritts & Fritts, (1955) made a dendrograph capable of accurately recording the changes in radius measuring as small as 0.0025mm. This instrument was suitable for observing radial changes in the slow growing hardwoods and was used in several studies of radial growth in relation to environmental variation in trees and in the young seedlings (Fritts, 1954-55). However, no attempts have so far been made to examine monthly variability of radial growth or to investigate the growth variation in various parts of stem of mangroves or other tree species in Pakistan.

With these considerations in mind, the present study was aimed to examine,

i. The variation of radial growth in branches, upper main stem and lower main stem via dendrometer bands and manual measurements.
ii. The seasonal changes in radial growth in main stem by applying the dendrometer technique.
iii. To determine the age and the growth rate of mangrove species, *Avicennia marina* using tree rings in combination with other techniques.
iv. To investigate the formation of number of rings per year.

The present study suggested that as far as mangrove growth was concerned, this might not be an easy task due to non-annual nature of the rings, its continued cutting and disturbances in the forests**.** It is fully hoped that the present study will provide meaningful and valuable basic informations about the radial growth and dendrochronological potential of the mangrove species. These results will directly be used to understand the ecology and the dynamics of this tree and will help to conserve and manage these forests.

Materials and Methods

Sandspit mangrove swamp located in the sea coast of Karachi was selected to apply the dendrometer bands and aluminium foil method, because it is protected by World Wildlife Fund (WWF) Pakistan. This area is mainly covered with thick forest of mangrove species *Avicennia marina* (Forsk.)Vierh and easy to accessible. It is relatively free from human disturbances including cutting and damage of trees. One year study was conducted during April 2007 to March 2008. Combination of various methodologies were used. Firstly, the dendrometer technique was applied on twenty randomly selected plants for measuring the stem diameter changes if any in *Avicennia marina.*

The dendrometer bands (Fig. 1), imported from U.S.A were wrapped around the selected trees. The circumference growth of the *Avicennia* trees was directly measured. Hall's, (1944) method of using a Vernier Scale was used to achieve the greater measurement accuracy among measurements (0.25 mm or 0.01 inch). The monthly band observations were recorded for a period of one year. To quantify the relationships between growth rate and time the "Curve Fit Package" was applied followed by the method of Benjamin & Eagles (1997). In the second part, the other twenty plants were selected at the same site to assess the difference in growth in branches, on the upper portion of the main stem and the lower portion (above the tidal zone) of the main stem. To avoid human error aluminum strips were cut and wrapped around the branches, upper part and lower part of the trees. The monthly observations were recorded using measuring tape up to one year time period from the aluminum strips, so that each month growth was recorded from exactly at the same place.

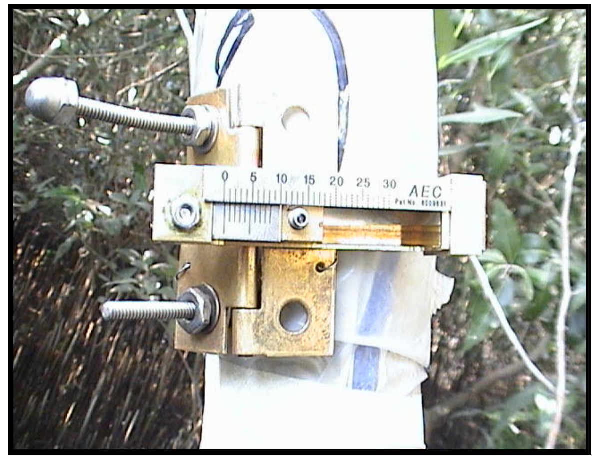

Fig. 1. Installing the Dendrometer Band in Sandspit Mangrove forest.

In the third part of study, the dendrochronological methods were applied as outlined by Stockes & Smiley (1968); Fritts (1976); Ahmed (1984). The dominant trees were sampled from six different sites i.e., Sandspit, Port Qasim, Kemari, Korangi Crossing, Ketti Bunder and Sonmiani. All the sites are located within the natural distribution of the species. Cores were obtained from 60 cm above the ground surface from the point, where the tree diameter was taken. Two cores per tree were taken using a hand operated Swedish increment corer**.** Standard dendrochronological procedures (Ahmed, 1984; Norton & Ogden, 1987) were employed to collect, prepare and polish the wood samples for analyses. The smooth surfaces of the cores were scanned by binocular.

The formation of well defined number of rings per year was determined by another method. The series of sections of the seedlings with known ages were cut and studied at the three months regular intervals. The age was estimated by adding six rings in total number of rings on the point where the cores were taken. Finally, the age was estimated by the results of growth meter bands, manual measurements of upper, middle and lower branches, by core sampling and by the section cutting of known age seedlings. Data obtained by Dendrometer were subjected to repeated measures analysis using the software SPSS Version10.. The negative exponential curve was fitted to express the relationship between radial growth rate of *Avicennia marina* with time by using the following equation,

$$\mathbf{y} = \mathbf{ae^{b/x}}$$

$$y = 0.0045 \exp^{(-4.44/x)}$$

where y= exponential growth, x=time, a and b are constants. Regression analyses were performed to examine the strength of the relationship between diameter breast height (dbh), age and growth rate.

Results and Discussion

Dendrometer results of repeated measures design and the follow-up, Post hoc test and Duncan's multiple range tests are given in Tables 1-3. Mean values of radial growth, Dbh and age of *Avicennia marina* calculated by manual measurement are given in Table 4. The results of the coring technique, the mean values of Dbh, age and growth rate are reported in Table 5.

The results of this study have revealed that the variations in the radial measurements by dendrometer were recorded to be higher during summer, beginning from April (Fig. 2). There was a continuous increment in circumference throughout the year, but the conspicuous variation was observed during May to July. The maximum circumference increment of 0.95±0.08 cm/year was found in July, while minimum 0.58 ±0.058cm was recorded in October, 2007 (Fig. 3). The growth of mangrove trees in this study showed some seasonal trend, with well-pronounced growth during April to July, corresponding to monsoon season. Trees from the tropics showed this pattern as reported by (Enquist & Leffler, 2001). It has been demonstrated that the annual growth of tropical trees was dependent on annual/ monthly variations in precipitation and not on temperature (Enquist & Leffler, 2001). The results suggested that the growth of *Avicennia marina* was larger in the rainy season (May to July), because during this season, salinity in the soil of mangrove forests was lower due to input of excess amount of fresh water from inland. Aksornkoae (1975) reported the better growth response of *Avicennia marina* in the low salinity areas. According to Clarke & Hannon (1971), low salinity may produce a higher growth rate of mangrove trees; besides low salinity, there might be other reasons i.e., tide level, air temperature, predator density, competition intensity, nutrient availability on which could enhance the growth of mangrove trees.

Table 1. Between-treatments for ANOVA of repeated measures of growth data.

Source	Type III sum of squares	df	Mean square	F-value	Significance level
Intercept	29110.44	1	29110.44	739.57	0.001**
Treatment	1653.58	2	826.79	21.00	0.01**
Error	236.16	6	39.36		

Table 2. Post hoc tests among the three different parts of stem.

(I) Treatments	(J) Treatments	Mean difference (I-J)	Std. error	Significance level
Branch	Upper stem	-2.60	1.32	0.09
	Lower stem	-8.37	1.32	0.001***
Upper stem	Branch	2.60	1.32	0.09
	Lower stem	-5.77	1.32	0.005***
Lower stem	Branch	8.37	1.32	0.001
	Upper stem	5.77	1.32	0.005***

The results of the second part of the study (Fig. 4) explained the phenomena of higher radial growth in branches compared with lower and upper parts of the stem while the upper stem showed higher growth in June. However, in July and September similar growth rate was recorded. The lower part of the stem showed least growth throughout the year, but in April this part showed enhanced growth compared to upper part whereas in March and February both exhibited equal level of growth.

The results of tests about the significance of difference in months and treatments are outlined in Table 5. Relationship between months and stem heights showed significant difference ($F=739.57$, $p<0.001$; and $F=21$, $p<0.01$, respectively) in the radial growth. Table 2 presented the post hoc tests providing details of the differences pertaining to different parts of the stem. The results showed that the growth in branches and the lower part of the stem is significantly different. However, the differences of growth in the branches and upper part of the stem was non-significant. The resulting homogeneous subsets from Duncan's multiple range tests were presented in Table 3. On the basis of the homogeneity the three stem heights were sub-divided into two subsets, the branches and the upper parts of the stem were grouped in subset 1, while the lower part forms separate subset, the two subsets were being significantly different.

In mangrove trees due to variation in salinity, tide and light physiological processes may be more rapidly altered compared to other terrestrial plants. The study reported that *Avicennia marina* showed radial increment throughout the year and the growth begins to increase from May and the maximum growth rate was attained in July (Fig. 2) because the flowering months of *A. marina* were April to early June while it produced seeds in late June up to August. During this period, plant entailed more nutrition to shelter and enhance the maturity of seeds. The present study anticipated that the branches showed high growth and produced higher number of leaves to produce more food. Leaves were the food factory of a plant and these were directly in contact with the branches. The maximum food was stored in branches and then transported into the different parts of the stem. The minimum amount of food was reached in the lower part of the stem. The total increase in stem width was expected to influence by various other factors because in the study areas many trunks or main stems were found hollow or rotten due to some fungal or insect disease. By keeping these points in mind it might be concluded that due to the availability of high amount of food branches grow faster. It was likely that the growth in *Avicennia marina* followed the same pattern of the transporting food, as higher the availability of food higher was the growth rate.

Table 3. The Duncan Homogeneous Subsets of three different parts of stem.

Treatments	Subset	
	1	2
Branch	11.02	-
Upper stem	13.62	-
Lower stem	-	19.4
Significance	0.096 NS	1.0 NS

Table 4. Mean of dbh, age and growth rate of mangrove species *Avicennia marina* estimated by dendrometer bands.

No. of trees	Mean radial growth	DBH (cm)	No. of rings/year
1	3.07 ± 0.02	10.50	2
2	2.83 ± 0.03	8.91	2
3	2.74 ± 0.01	9.61	2
4	2.61 ± 0.02	11.59	2
5	3.07 ± 0.03	9.23	2
6	2.66 ± 0.00	9.74	2
7	2.47 ± 0.00	9.14	2
8	3.14 ± 0.03	9.87	2
9	2.08 ± 0.00	11.24	3
10	2.11 ± 0.01	12.00	3

Note: ± standard error of mean

Table 5. Mean ± SE of dbh, age and growth rate of dominant mangrove species *Avicennia marina* estimated by coring technique.

Sites	Dbh range (cm)	Age range	Growth rate year/cm
Sands Pit	12.73–18.24	12–20	1.157 ± 0.05
Port Qasim	10.70–30.89	11–32	1.22 ± 0.04
Korangi Crossing	8.28–12.16	10–15	1.40 ± 0.16
Kemari	18.15–32.80	18–23	1.19 ± 0.12
Sonmiani	19.49–25.03	14–23	1.15 ± 0.17
Ketti Bunder	7.64–19.84	12–17	0.98 ± 0.04

Note: ± = Standard error

Seasonal variability in the growth of *Avicennia marina* is presented in Fig 3. The results of the dendrometer bands showed that tree growth was significantly related to the environmental factors during June and July. It was suggested that the summer climate was closely correlated to the tree growth. Some anomalies were difficult to explain and need to be further studied in future. The negative exponential curve provided a "good fit" of the equation with a high value of r=0.976. This curve depicted the rapid growth in early phase but subsequently the radial growth leveled off with time. This curve defined the growth in *Avicennia marina* throughout the year with monthly variation. The growth increased rapidly from April up to September and thereafter it slowed down rapidly (Fig. 4).

Table 4 presented the mean values of Dbh, age and growth rate of *Avicennia marina,* estimated by dendrometer bands. The number of rings per year was calculated by dividing the average radius of the tree with the mean radial growth. The results indicated that out of 10 trees 2 formed three rings per year as estimated by the other methods during the study. The contradiction in determined average number of rings (2±0.13 per year) may be due to the human error at the time of taken measurement because the results of the sections cutting of known age samples clearly indicated three rings were formed during a whole year. However**,** the number of samples were low and it was suggested to increase the samples size to reach a more accurate estimate in future. Dendrochronological attempt was also made to describe the age and growth rate structure of *Avicennia marina* at each sampling site. However, due to the insufficient number (less than six) of wood samples in some stands, overall results of linear regression were presented.

The results of estimation of age and growth rate of *Avicennia marina*, are presented in Table 5. The results indicate that the age and dbh varied greatly from tree to tree and site to site even in the same sized trees in mangrove forests**.** The fringing mangrove at Port Qasim displayed the maximum age (32 years) and a diameter of 23.57cm dbh, while trees having 10.86 cm dbh showed minimum age of 10 years at Korangi crossing. Table 5 also showed increasing age was associated with increasing diameter. The overall data of these two variables showed highly significant relation ($r=0.66$ and $p<0.001$) (Fig. 5).

However, owing to the wide variance, prediction of age from diameter would be unreliable**.** No data of age was available in Pakistan regarding this or any other mangrove species. Only a few age/diameter estimates**,** using modern dendrochronological technique have been published for some conifer trees in Northern areas of Pakistan (Ahmed, 1988; Ahmed & Sarangzai, 1991). Gymnospermic trees produced distinct annual rings, while ring formation in case of *Avicennia marina* was different where more than one ring was formed in a year. The Port Qasim trees attained the maximum age because this site is located on the northwest edge of the Indus delta at a distance of 35 km from Karachi city. This was usually undisturbed area with regard to deforestation; therefore, this site was expected to have older trees compared to other sites. However, Korangi Crossing with a certain degree of dwarf growth generally used for socio-economic values like grazing, fuel for local people, fodder for animals, which may explain the relatively young aged trees.

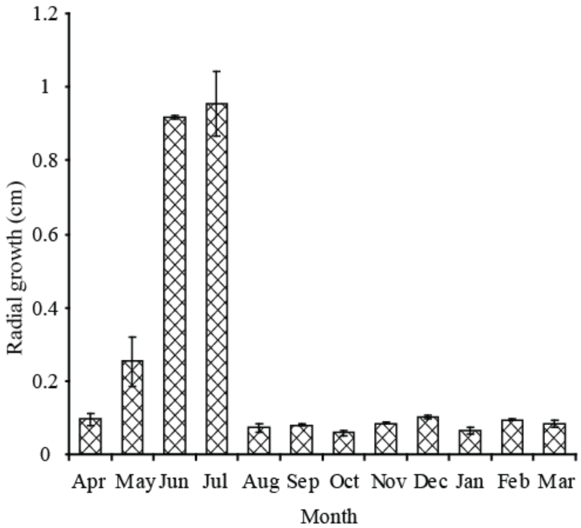

Fig. 2. Mean difference of circumference through dendrometer in Sandspit mangrove forest.

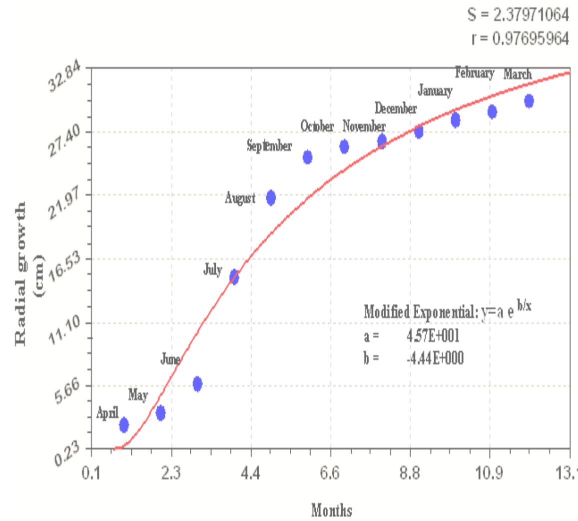

Fig. 3. Relationship between time and growth rate of *Avicennia marina by* dendrometer bands.

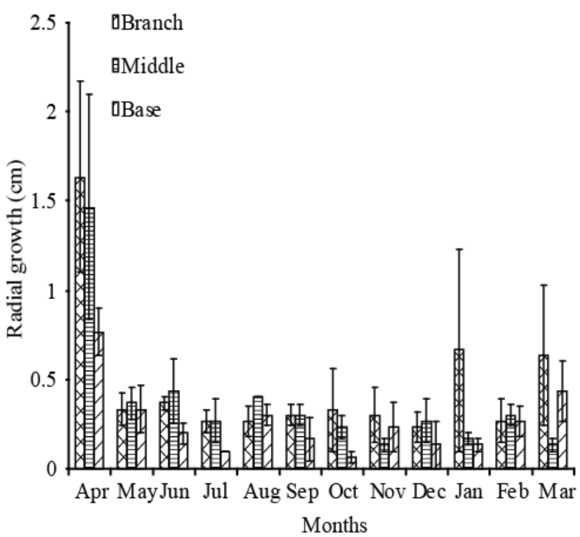

Fig. 4. Mean difference of radial growth measured by manual measurement at Sandspit mangrove forest.

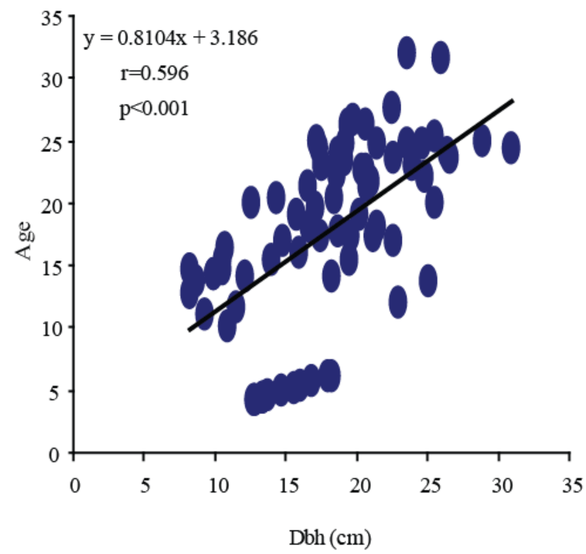

Fig. 5. Regression between overall dbh and age of all sites.

Growth rate in mangroves also varied greatly among the same sized trees even in a small area**.** Table 5 also showed growth rates in various mangrove forests**.** The growth rate ranged from 0.65 to 2.04 years/cm. However**,** mangrove trees growing in Korangi crossing showed slowest mean growth rate (1.40±0.16 years/cm) while fastest growth rate (0.98±0.04 years/cm) was recorded from Ketti Bunder which was about 170 km from Karachi. It was situated on one of the mouth of the river Indus. According to Schmitz *et al*., (2007a), the formation of growth layers seemed to be influenced by local environmental factors such as soil water salinity rather than seasonal climate. The effect of salinity has also been reported by various researchers (Lin & Sternberg, 1992; Tuffers *et al*., 2001 and Ball, 2002). The results of the present study also agreed with these workers and it was suggested that the maximum growth rate at Ketti Bunder was presumably due to low salinity (30.45±0.15) and lesser degree of pollution, whereas the average minimum growth rate at Korangi Crossing was possibly due to higher salinity (43.83±0.41ppt) and pollution due to discharge of the effluents by the industries situated in the vicinity (Fig. 6).

The sections and cores obtained from Korangi area also showed more complex structures or patch growth (Figs. 7 & 8) compared to other areas also possibly due to increased salinity (43.83 ±0.41) which imposed a greater stress on tree growth (Lin & Sternberg, 1993). In general**,** mangroves under study grew at 1.21±0.03 year/cm**.** Out of six sites, only one site (Korangi Crossing) showed significant correlation (p<0.1) between diameter and growth rate, however, other areas showed non-significant difference. Korangi lies in the industrial zone that has several tanneries releasing their effluents into sea, causing an alarming situation for the mangrove forest. This area was mostly surrounded by dwarf and stunted monospecific stands by *Avicennia marina* with patchy pattern and low density. There were considerable differences in environmental conditions explaining the patchy growth of *A. marina*. One of the possible reasons was the salinity fluctuations which posed a significant negative effects on photosynthesis and growth (Lin & Sternberg, 1993). Selvam *et al.*, (1991) stated that hypersalinity stunts tree growth in A. *marina* stands.

The overall results also indicated non-significant relation between Dbh and growth rate (Fig. 9). The absence of the relationship between the growth rate and basal diameter was also reported by Worbes *et al.*, (2003) and King *et al.*, (2005).

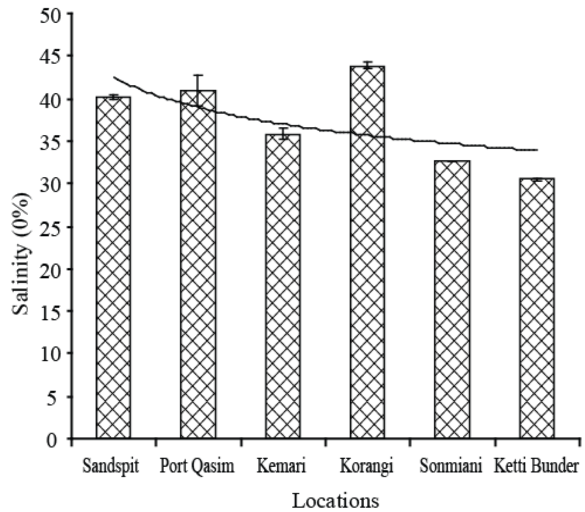

Fig. 6. Salinity levels of mangrove soils at different sites.

Fig. 7. Patchy pattern in the stem section of *A. marina*.

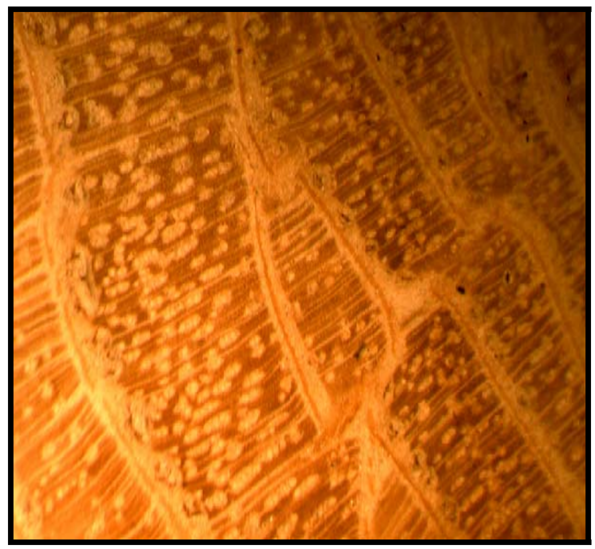

Fig. 8. Core showing the irregular growth.

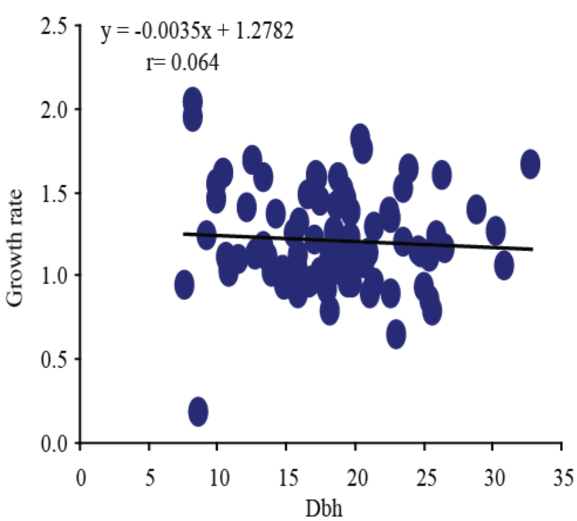

Fig. 9. Regression between overall dbh and growth rate of all sites.

According to them, no relation was found between radial increment and diameter, suggesting tree growth is determined by tree structural characters rather than by age. Like age, no data related to growth rates of mangrove species *Avicennia marina* are available in Pakistan for comparison. We tried to compare the growth rates of mangrove forests from the data of other countries, however, there were clear differences between the nature of the rings and climate of areas but comparison may provide an idea to understand the relationship between Dbh and growth rate. Verheyden, (2004b) presented <0.5-4.81mm per year growth rate for *Rhizophora mucronata*, while Thampanya (2006) reported higher growth rate of 3.8-5.7mm per year for *Avicennia* species from Thailand and Japan.

In many areas though significant relation was obtained between diameter and age, but no relation was found between diameter and growth rate. Therefore, like age, the growth rate was also not predictable from the diameter. In general, growth rate was the product of various factors (climatic and non-climatic, genetic, competition) and detailed investigations on the basis of which useful predictions and conclusion can be made and therefore, to be greatly expanded**.** Only a few studies have dealt with the formation of growth layers of *Avicennia*. Schmitz *et al.*, (2007b) showed the non-annual nature of the growth layers in *Avicennia marina* at Gazi Bay, whereas Gill (1971) observed two to six rings per year and showed a relationship between number of rings and diameter but not age. However, our results showed formation of three rings per year. Therefore, to estimate age of a tree, total number of rings should be divided by three and two years should be added (time taken by the plant reaching the place of sampling) to obtain total age. These estimates were supported by dendrometer bands, manual measurements, taking wood samples from the trees and cross sections from seedlings with known age.

Conclusions

It was concluded that the standard dendrochronological techniques could not be applied to mangrove species such as *Avicennia marina*. Though age of *Avicennia marina* could not be determined by simple ring count, nevertheless it was possible to estimate age by Dendrometer band, manual measurement of growth rate and by taking cores from trees.

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References

Ahmed, M. 1984. Ecological and dendrochronological studies on *Agathis australis* Salisb, Kauri. Ph.D. thesis. University of Auckland. New Zealand.

Ahmed, M. 1988. Population structure of some planted tree species in Quetta. *J. Pure and Appl. Sci.*, 7:25-29.

Ahmed, M. and A.M. Sarangzai. 1991. Dendrochronological approach to estimate age and growth rate of various species from Himalayan region of Pakistan. *Pak. J. Bot.*, 23: 78-89.

Aksornkoae. S. 1975. Structure, regeneration and productivity of mangrove in Thailand. pp: 109 Ph.D. Thesis, Michigan State University.

Ball, M.C. 2002. Interactive effects of salinity and irradiance on growth: implications for mangrove forest structure along salinity gradients. *Trees,* 16: 126-139.

Benjamin, S. and L.M. Eagles. 1997. A Curve Fitting Method and A Regression Method contributed. Faculty and Institute of Actuaries. Claims Reserving Manual v. 2.

Bower, D.R. and W.W. Blocker. 1966, Accuracy of bands and tape for measuring diameter Increments: *J. For*., 64: 21-22.

Cameron, R.J and R. Lea. 1980, Band dendrometers or diameter tapes: *J. For*., 78: 277-278.

Clarke, T.N. and N.J. Hannon. 1971. The mangrove swamp and salt marsh communities of the Sydney district. III. Plant growth in relation to salinity and waterlogging. *J. Ecol.*, 58: 351-369.

Dahdouh-Guebas, F., R. De Bondt, P.D. Abeysinghe, J.G. Kairo, S. Cannicci and L. Triest. 2004. Comparative study of the disjunct zonation pattern of the grey mangrove A*vicennia marina* (Forsk.) Vierh. in Gazi Bay (Kenya). *Bull Mar Sci*., 74: 237-252.

Enquist, B.J. and J. Leffler. 2001. Long term tree chronologies from sympatric tropical dry-forest trees: Individualistic response to climatic variation. *Journal of Trop Ecol.,* 17: 41-60.

Fritts, H. C. and E.C. Fritts.1955. A new dendrograph for recording radial changes of a tree. *Forest Science*, 1(4): 271-276.

Fritts, H.C. 1954-1955. An analysis of radial growth of Beech in a central Ohio forest during. *Ecology*, 39(4): 705-720.

Fritts, H.C. 1976. Tree Rings and Climate. Academic Press, London, New York and San Francisco: 567.

Gill, A.M. 1971. Endogenous control of growth-ring development in *Avicennia*. *For. Science*, 17(4): 462-465.

Hall, R.C. 194. A Vernier tree-growth band: *Journal of Forestry*, 42: 742-743.

Heinrich, I. and C.G.B John. 2006. Tree-ring anomalies in *Toona ciliata. IAWA Journal*, 27(2): 213-231.

Kathiresan, K. and B.L. Bingham. 2001. Biology of mangroves and mangrove ecosystems. *Advances in Marine Biology*, 40(81): 1-251.

King, DA., S.J. Davies, M.N. Nur Supardi and S. Tan. 2005. Tree growth is related to light interception and wood density in two mixed dipterocarp forests of Malaysia. *Functional Ecology,* 19: 445-453.

Lin, G. and L.S.L. Sternberg. 1992. Effect of growth form, salinity, nutrient and sulfi de on photosynthesis, carbon isotope discrimination and growth of Red Mangrove (*Rhizophora mangle* L.). *Aust. J. Plant Physiol.*, 19: 509-517.

Lin, G. and L.S.L. Sternberg. 1993. Effects of salinity fluctuation on photosynthetic gas exchange and plant growth of the red mangrove (*Rhizophora mangle* L.). *Journal of Experimental Botany*, 44(258): 9-16.

Matthijs, S., J. Tack, D. van Speybroeck and N. Koedam. 1999. Mangrove species zonation and soil redox state, sulphide concentration and salinity in Gazi Bay (Kenya), a preliminary study. *Mangroves and Salt Marshes*, 3: 243-249.

Michelakis, N. and E.A. Barbopoulou. 2002. Stem places and supporting frames suitability for "Dendrometers" installation on olive tree. Acta hort. (ishs) 586: 423-427.

Naidoo, G. 2006. Factors contributing to dwarfing in the mangrove. *Avicennia marina. Annals of Botany*, 97: 1095-1101.

Norton, D.A. and J. Ogden. 1987. Dendrochronology: a review with emphasis on New Zealand application. *New Zealand Journal of Ecology*, 10: 77-95.

Saifullah, S.M., S. Ismail, S.H. Khan and M. Saleem. 2004. Land Use- Iron pollution in a mangrove habitat of Karachi. *Indus Delta. Earth Interactions*, 8(17): 1-9.

Schmitz, N., A. Verheyden, J.G. Kairo, H. Beeckman and N. Koedam. 2007b. Successive cambia development in *Avicennia marina* (Forssk.) Vierh. is not climatically driven in the seasonal climate at Gazi Bay, Kenya. *Dendrochronologia.*, 25(2): 87-96.

Schmitz, N., S. Jansen, A. Verheyden, J.G. Kairo, H. Beeckman and N. Koedam. 2007a. Comparative anatomy of intervessel pits in two mangrove species growing along a natural salinity gradient in Gazi Bay, Kenya. *Annals of Botany*, 100: 271-281.

Selvam, V., R. Mohan, R. Ramasubramanian and J. Azariah. 1991. Plant communities and soil properties of three mangrove stands of Madras coast. *Indian J. Marine Sciences*, 20(1): 67-69.

Sevanto, S. 2003. Tree stem diameter changes measurements and sap flow in Scots Pine. Report series in Physics. University of Helsinki, Finland.

Sobrado, M.A and S.M.L. Ewe. 2006. Ecophysiological characteristics of *Avicennia germinans* and *Laguncularia racemosa* coexisting in a scrub mangrove forest at the Indian River Lagoon, Florida. *Trees*, 20:679-687.

Stockes, M.A. and T.L. Smiley. 1968. An Introduction to Tree-Ring Dating. Uni. Chicago Press, Chicago, 68.

Thampanya, U. 2006. Mangroves and sediment dynamics along the coasts of southern Thailand. Ph.D thesis, Wageningen University, The Netherlands.

Tuffers, A., G. Naidoo and D.J. von Willert. 2001. Low salinities adversely affect Photosynthetic performance of the mangrove, *Avicennia marina*. *Wetlands Ecology and Management,* 9: 225-232.

Verheyden, A., G. Helle, G.H. Schleser, F. Dehairs, H. Beeckman and N. Koedam. 2004a. Annual cyclicity in high-resolution stable carbon and oxygen isotope ratios in the wood of the mangrove tree *Rhizophora mucronata Plant Cell and Environment*, 27(1525-1536): 12

Verheyden, A., J.G. Kairo, H. Beeckman and N. Koedam. 2004b. Growth rings, growth ring formation and age determination in the mangrove, *Rhizophora mucronata*. *Annals of Botany*, 94: 59-66.

Worbes, M., R. Staschel, A. Roloff and W.J. Junk. 2003. Tree ring analysis reveals age structure, dynamics and wood production of a natural forest stand in Cameroon. *Forest Ecology and Management*, 173: 105-123.

Ye, Y., N.F.Y. Tam, C.Y. Lu and Y.S. Wong. 2005 Effects of salinity on germination, seedling growth and physiology of three salt-secreting mangrove species. *Aquatic Botany*, 83:193-205.

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