



Ring width variation in *Pinus merkusii* Jungh. & de Vriese: An endemic pine of Arunachal Pradesh

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Abstract

Ring width variation was carried out on six straight trees of *Pinus merkusii* collected from Anjaw District of Arunachal Pradesh. The main aim of the present study was to evolve a sampling procedure for comparison of ring width variation amongst trees. Despite of straight trees, some eccentric cross-sectional discs with wide rings on lower side were observed. There was a statistically significant variation in ring width around the circumference at breast height. A non-significant variation between the mean of two opposite directions versus mean of eight cardinal directions suggested that any two opposite directions can be selected for comparison of ring width amongst Merkus pine. The radial variation in ring width at breast height and successive heights showed maximum ring width near the pith with irregular decrease towards the bark. There was a negative and highly significant correlation between ring width and age ($r = -0.689^{**}$). Ring number 15 can be considered as a boundary between juvenile wood (Rings 1-15) and mature wood (Rings 16-bark). There was irregular increase and decrease in ring width variation in selected rings from base to top in both vertical and oblique sequences in all trees.

Keywords: *Pinus merkusii*, ring width, juvenile wood, circumference, sampling, radial variation, axial variation

Introduction

Annual rings are the reliable sources of climatic proxy information^[1]. They are the important tools to understand the tree growth and their reactions to various environmental conditions during or before the formation of wood^[2]. Hence, annual rings form the basis of dendrochronology, dendroclimatology dendroecology and wood anatomy. They are also considered as valuable instruments in forest management and product manufacturing^[3]. Annual rings in conifers are formed due to active and dormant state of cambium which leads to formation of large sized thin walled tracheids in early wood and small sized thick walled tracheids in latewood. Both the early wood and latewood constitute the total ring width. Ring width is a predictor of density and mechanical strength^[4]. It is related to produced wood volume and end product uniformity^[5]. It is also related to cell number and cell size^[6]. A perusal of literature reveals that tracheid numbers are more closely related to ring width^[7] than tracheid size^[8,9].

Pinus merkusii is one of the most important species of natural pine forests of South-east Asia. It is widely distributed in Thailand, Laos, Cambodia, Vietnam, Indonesia and Philippines Islands of Luzon and Mindoro. In India, it occurs in eastern parts of Anjaw district of Arunachal Pradesh neighbouring to India-Myanmar pine forests ecoregion. It is the dominant species in this region and forms either pure stands or associated with other conifers species like *Pinus armandii* and *Taxus wallichiana*.

An examination of literatures reveals that tree rings chronology in response to rainfall and temperature have been studied in other countries by numbers of workers^[10,11,12,13,14]. Despite of being endemic pine species of Arunachal Pradesh,

no attempt has been made to study its ring width variation. The present study has been taken up to evolve an efficient sampling procedure for comparison of ring width values within and between trees with the following objectives (a) to study ring width variation around the circumference, along the radius from pith to bark and along the height from base to top of the tree and (b) to see the effect of age on ring width and (c) to demarcate the boundary between juvenile wood and mature wood.

Material and Methods

The samples for the present study were collected from pine forests of Dong village, Anjaw district of Arunachal Pradesh at the time of road construction by Border Road Organization under border area development programme. The geographical coordinate of the site taken with the GPS were 28°10' N and 97°02' E. Six straight trees of merkus pine with uniform crown and no visible defect were selected randomly from felling site. The age of the trees varied from 25-91 years with average height 23.4 ± 8.89 mm and diameter at breast height 54.83 ± 19.22 cm respectively. Complete cross-sectional discs of about 5 cm. thickness were sawn at breast height and at regular interval of 3m along the height. The north side of each tree was marked before felling. A total of 42 cross-sectional discs were taken for present investigation.

Sample processing and measurement

The cross sectional discs were smoothed to end grain with the help of an electric planer and were photographed (Fig. 1). The cross-sectional discs of breast height were marked into eight

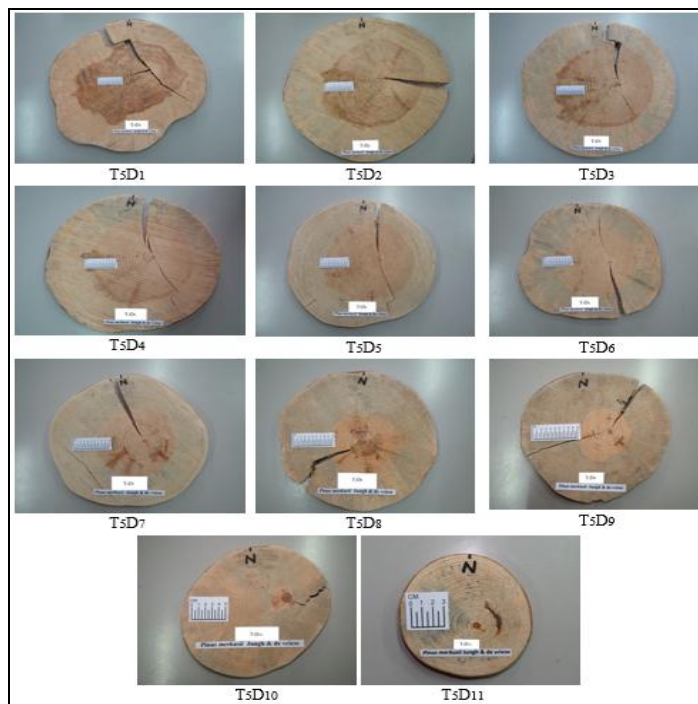


Fig.1: Cross-sectional discs of *Pinus merkusii* Jhunch & de Vriese

Cardinal directions namely North, South, East, West, North East, North West, South East and South West. Some of the rings were marked around the circumference to facilitate counting of rings easily. Radial wedges sawn out from eight cardinal directions were soaked in water to attain fully saturated condition. A total of 336 rings (42 rings x 8 directions) were randomly selected from 48 wedges (6 trees x 8 directions) around the circumference. Two opposite directions were selected at breast height and successive heights for study of radial variation in ring width. Few rings were selected randomly from each tree to study axial variation. Ring width was measured with the help of an ocular micrometer fitted in one of the eye pieces of stereomicroscope at 20x.

Statistical analysis

The data were subjected to statistical analysis by using SPSS 18.0 software package.

Results

Circumferential variation in ring width.

Analysis of variance presented in Table 1 showed statistically significant variations in ring width among eight cardinal directions around the circumference in individual trees and pooled data. Further, analysis of variance between directional combinations was carried out by using the formulae [15]. The results given on Table 2 showed statistically non-significant variation between two opposite directions versus means of eight cardinal directions around the circumference for all selected trees and pooled data.

Table 1: Analysis of variance for ring width among eight cardinal directions at breast- height in *Pinus merkusii*

Tree no.	Source of variation	Degree of freedom	Sum of square	Mean square	F ratio
Tree 1	Directions	7	48.155	6.879	3.32**
	Rings	6	50.175	8.362	4.043**
	Error	42	86.873	2.068	
	Total	56	1409.87		
Tree 2	Directions	7	52.82	7.546	3.54**
	Rings	6	11.63	1.938	0.91 ^{ns}
	Error	42	89.48	2.131	
	Total	56	1211.64		
Tree 3	Directions	7	58.56	8.36	2.98*
	Rings	6	390.30	65.05	23.17**
	Error	42	117.91	2.81	
	Total	56	2593.44		
Tree 4	Directions	7	125.33	17.905	12.904**
	Rings	6	70.40	11.734	8.457**
	Error	42	58.276	1.388	
	Total	56	2249.904		
Tree 5	Directions	7	108.58	15.512	10.697**

	Rings	6	240.55	40.093	27.646**
	Error	42	60.908	1.450	
	Total	56	1947.089		
Tree 6	Directions	7	100.40	14.344	9.321**
	Rings	6	265.67	44.279	28.774**
	Error	42	64.632	1.539	
Pooled	Total	56	1796.752		
	Directions	7	56.999	8.143	2.544*
	Rings	41	1159.311	28.276	8.876**
	Error	287	914.943	3.188	
	Total	326	11208.708		

The levels of significance used are:

ns = non-significant

* = 5 percent at $p < 0.05$ level i.e. significant.

** = 1 percent at $p < 0.01$ level i.e. highly significant

Table 2: Analysis of variance for ring width values between various directional combinations at breast -height in *Pinus merkusii*

Tree No.	Source of variation	Degree of freedom	Sum of square	Mean square	F ratio
Tree 1	N+S vs \bar{X}	1	9.130	9.130	4.414 ^{ns}
	E + W vs \bar{X}	1	2.367	2.367	1.144 ^{ns}
	NE + SW vs \bar{X}	1	0.349	0.349	0.169 ^{ns}
	NW +SE vs \bar{X}	1	15.950	15.950	7.713 ^{ns}
Tree 2	N+S vs \bar{X}	1	1.229	1.229	0.609 ^{ns}
	E + W vs \bar{X}	1	13.29	13.29	6.239 ^{ns}
	NE + SW vs \bar{X}	1	1.956	1.956	0.918 ^{ns}
	NW +SE vs \bar{X}	1	1.255	1.255	0.589 ^{ns}
Tree 3	N+S vs \bar{X}	1	0.013	0.013	0.004 ^{ns}
	E + W vs \bar{X}	1	8.19	8.19	2.917 ^{ns}
	NE + SW vs \bar{X}	1	3.68	3.68	1.286 ^{ns}
	NW +SE vs \bar{X}	1	0.682	0.682	0.243 ^{ns}
Tree 4	N+S vs \bar{X}	1	8.614	8.614	6.206 ^{ns}
	E + W vs \bar{X}	1	0.36	0.36	0.26 ^{ns}
	NE + SW vs \bar{X}	1	10.309	10.309	7.427 ^{ns}
	NW +SE vs \bar{X}	1	0.779	0.779	0.561 ^{ns}
Tree 5	N+S vs \bar{X}	1	2.152	2.152	1.48 ^{ns}
	E + W vs \bar{X}	1	0.343	0.343	0.23 ^{ns}
	NE + SW vs \bar{X}	1	4.84	4.84	3.34 ^{ns}
	NW +SE vs \bar{X}	1	1.746	1.746	1.20 ^{ns}
Tree 6	N+S vs \bar{X}	1	7.273	7.273	4.726 ^{ns}
	E + W vs \bar{X}	1	8.682	8.682	5.64 ^{ns}
	NE + SW vs \bar{X}	1	1.990	1.990	1.29 ^{ns}
	NW +SE vs \bar{X}	1	2.757	2.757	1.791 ^{ns}
Pooled	N+S vs \bar{X}	1	0.128	0.128	0.040 ^{ns}
	E + W vs \bar{X}	1	1.049	1.049	0.329 ^{ns}
	NE + SW vs \bar{X}	1	0.0012	0.0012	0.0004 ^{ns}
	NW +SE vs \bar{X}	1	0.0818	0.0818	0.0256 ^{ns}

N, S, E, W, SE, NW, SW and NE - Eight cardinal directions viz. North, South, East, West, Southeast, Northwest, Southeast and Northeast.

\bar{x} = Mean of cardinal directions

vs =versus; ns= non-significant

Radial variation in ring width from pith to bark at breast height and successive heights.

Based on the results of circumferential variation in ring width, two opposite directions namely North and South were taken. The results of Tree 5 presented in Figs. 2-3 showed irregular decrease in ring width variation from pith to bark. Similar results were obtained for remaining trees. The ring width was maximum near the pith and thereafter decreased irregularly towards the bark.

Linear correlation and regression were performed to see the effect of age on ring width. A negative and statistically highly significant relationship between age and ring width was seen

in Tree No. 2-6 and pooled data except Tree 1 (Table 3). The scattered diagram plotted between age and ring width showed steep decrease in ring width up to 15th ring from pith and afterwards gradual decrease towards the bark. Therefore, Ring number 15 was considered a boundary between juvenile wood and mature wood (Fig. 4).

Axial variation in ring width from base to top

There was irregular increase in ring width variation in selected rings of Tree1-4 and decrease in Tree 5-6 from base to top in vertical sequence (Fig.5). Whereas, there was irregular increase in ring width in oblique sequence in all trees (Fig.6).

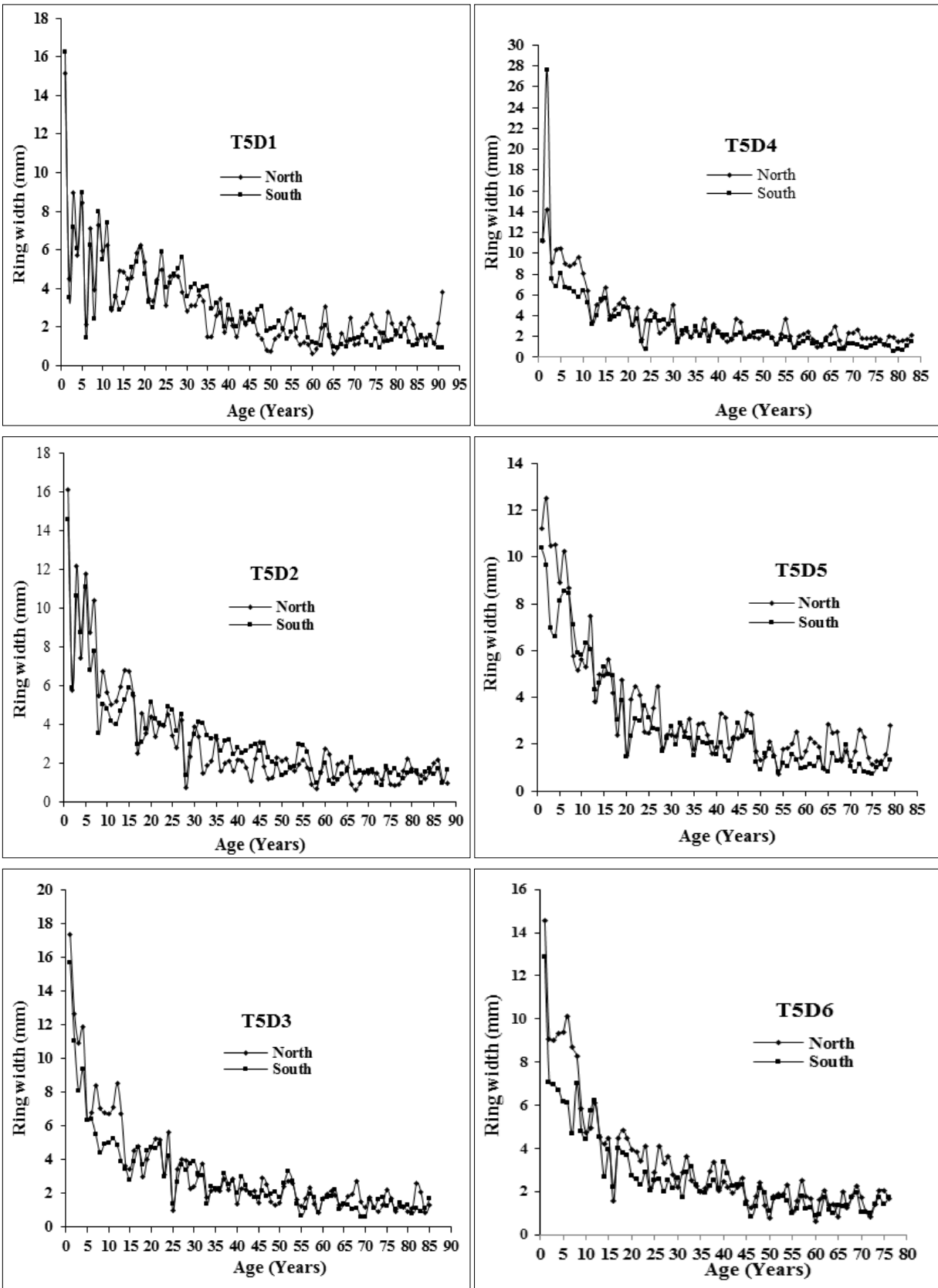


Fig 2: Radial patterns of ring width variation at breast-height and successive heights

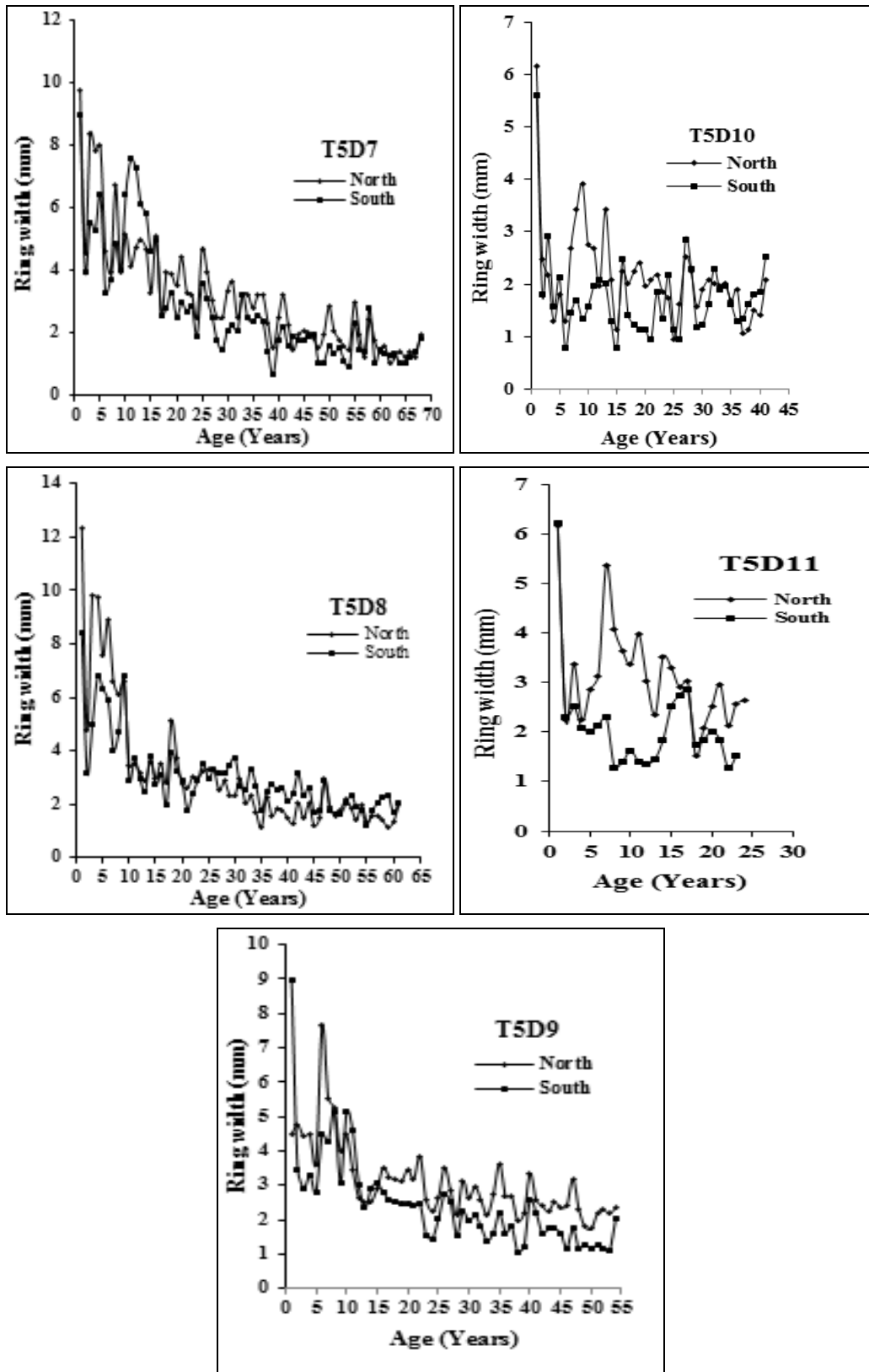


Fig 3: Radial patterns of ring width variation at breast-height and successive heights

Table 3: Effect of age on ring width in *Pinus merkusii*.

Tree No.	Correlation coefficient (r)	Coefficient of determination (r ²)	Regression constant (B ₀)	Regression coefficient (B ₁)	Standard error (Sb ₁)
Tree-1	- 0.195 ^{ns}	0.038	5.761	-0.426	0.391
Tree-2	- 0.655**	0.429	6.905	-1.089	0.233
Tree-3	- 0.661**	0.437	16.216	-3.511	0.830
Tree-4	- 0.659**	0.435	9.927	-2.169	0.505
Tree-5	- 0.820**	0.672	9.959	-1.954	0.145
Tree-6	- 0.808**	0.652	12.783	-2.589	0.202
Pooled	- 0.689**	0.475	6.183	-0.067	0.004

The levels of significance used are:

ns = non- significant

* =5 percent at p<0.05 level i.e. significant.

** =1 percent at p<0.01 level i.e. highly significant

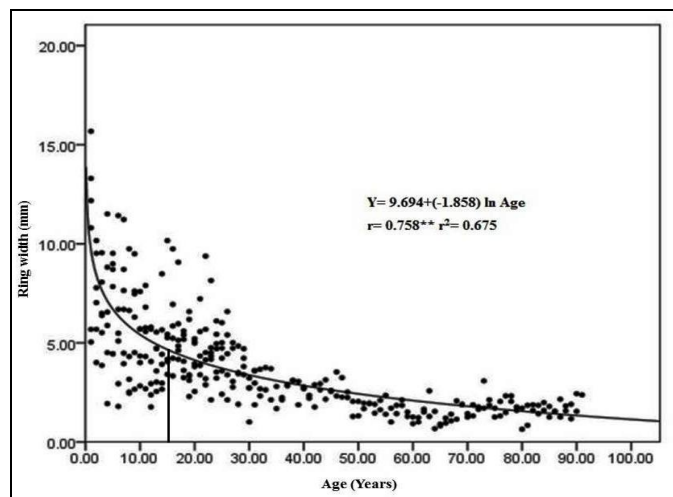


Fig 4: Relationship between age and ring width

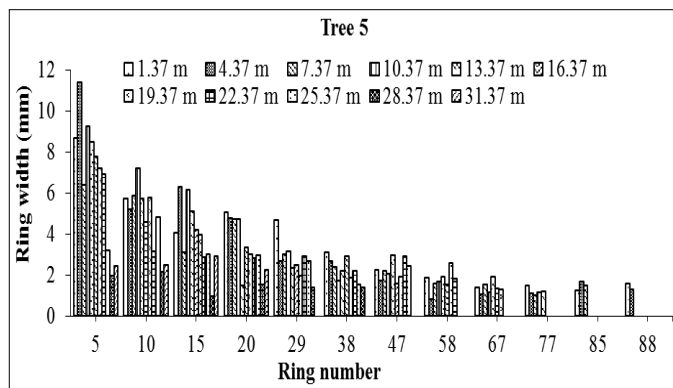


Fig 5: Axial variation of ring width in vertical sequence

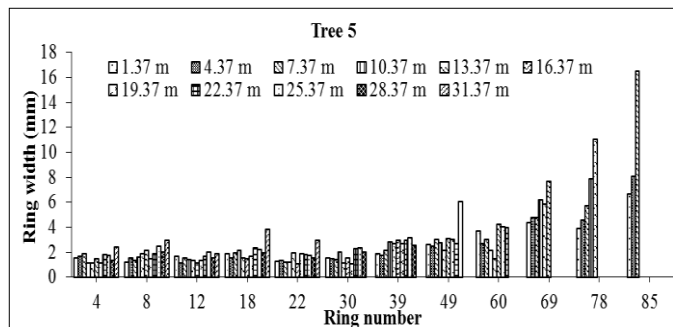


Fig 6: Axial variation of ring width in oblique sequence

Discussion

Ring width is highly variable and presents sum of cells formed by cambium during growing season. The wind is the cause of eccentricity around the stem which resulted differences in ring width between east and west sides in conifers [16]. The differences in ring width on the southern and northern facing slopes and the variation in ring width is totally dependent upon elevation, slope exposure and topography etc. [17]. Though the sample were taken from straight trees but some eccentric cross sectional discs were observed in Tree 1, 3, 4 5 and 6. The rings were wider on the north side which may be due to direction of prevailing wind from south side. Circumferential variation in ring width was studied to find out the least number of directions essential for comparison of ring width values within and between trees. In present investigation, a statistically significant variation around the circumference was observed in all selected trees and pooled data. A non-significant observation was observed between the mean of two opposite directions versus the mean of all directions. Similar results were obtained in other conifers [16, 18, 19]. Hence, any two opposite directions can be recommended for further study in ring width variation in *Pinus merkusii*.

Radial patterns of ring width variation are important (a) to study the level of variation along the radius (b) to study the effect of age on ring width and (c) to demarcate the boundary between juvenile and mature wood. Most of the workers have observed irregular radial pattern of ring width variation [19, 20, 21, 22, 23]. In the present investigation, radial variation in ring width was studied in two opposite directions namely North and South at breast height and successive heights. A few rings near the pith had maximum ring width and afterwards ring width decreased irregularly at different heights in *Pinus merkusii*. The maximum ring width near the pith may be due to more cambial activity during early years of tree growth and irregular variation in ring width may be due to drastic changes in cambial phenology due to environmental and physiological conditions of the trees. The present findings are in agreement with the finding of other conifers species like *Pinus radiata* [24], *Pinus banksiana* [22], *Pinus eladantica* [25] and *Thuja occidentalis* [26]. The negative relationship between age and ring width in *Pinus merkusii* confirms the findings of other researchers [23, 27, 28].

The boundary between juvenile and mature wood also varies among species. Ring no. 10 was considered as a demarcation

between juvenile wood and mature wood [23, 24], 12-15 years [28, 29] and 15-20 years [30]. In the present study, the logarithmic regression model is highly significant ($r = 0.758^{**}$ at $p < 0.001$ level). The ring width decreased steeply up to 15 years and decreased gradually afterwards. Hence, rings 1-15 as juvenile wood (Zone-I) and rings 16 - bark as mature wood (Zone-II) are considered for the present study. In the present investigation, ring width increased irregularly in both vertical (except Tree 5&6) and oblique sequences. It is contrary to the findings of other investigators [21, 22, 26, 31] who reported decrease in ring width from bottom to top in conifers. There is simultaneous formation of juvenile and mature wood by the cambium in trees. The juvenile wood present at the top is formed by immature cambium and has large proportion of early wood than late wood which may be the reason for wider rings at the top than base of the trees.

Conclusion

Sampling from any two directions should be adopted for comparison of ring width

Ring width exists statistically significant variation among eight cardinal directions around the circumference whereas, the mean ring width of two opposite directions versus mean of eight cardinal directions exhibits non-significant differences. It decreases irregularly from pith to bark at all heights and has negative but significant relationship with age.

References

1. Fritts HC. Tree Rings and Climate, Academic Press, London, 1976.
2. Bräuning A, De Ridder M, Zafirov N, Garcia GI, Dimitrov DP, Gartner H. Tree ring features: indicators of extreme event impacts. IAWA journal. 2016; 37(2):206-231.
3. Alteyrac J, Cloutier A, Ung CH, Zhang SY. Mechanical properties in relation to selected wood characteristics of black spruce. Wood Fib Sci. 2006; 38:229-237.
4. Adamopoulos S, Milios E, Doganos D, Bistinas I. Ring width, latewood proportion and dry density in stems of *Pinus brutia* Ten. Eur J Wood Prod. 2009; 67:471-477.
5. Koga S, Zhang SY. Inter-tree and intra-tree variations in ring width and wood density components in balsam fir (*Abies balsamea*). Wood Sci. Tech. 2004; 38(2):149-162.
6. Vaganov EA, Hughes MK, Shashkin AV. Growth Dynamics of conifers tree rings: Images of past and future environments. Springer, New York, 2006.
7. Rossi S, Deslauriers A, Griçar J, Seo JW, Rathgeber CB, Anfodillo T, et al. Critical temperatures for xylogenesis in conifers of cold climates. Global Eco Biogeo. 2008; 17(6):696-707.
8. Mäkinen H, Nojd P, Saranpaa P. Seasonal changes in stem radius and production of new tracheids in Norway spruce. Tree Physiology. 2003; 23(14):959-968.
9. Deslauriers A, Rossi S, Anfodillo T, Saracino A. Cambial phenology, wood formation and temperature thresholds in two contrasting years at high altitude in southern Italy. Tree Physiology. 2008; 28(6):863-871.
10. Buckley BM, Barbeti M, Watanasak RD Arrigo, Boonchirdchoo S, Saratunon S. Dendrochronological investigations in Thailand. IAWA Journal. 1995; 16:393-409.
11. Buckley BM, Cook BI, Bhattacharya A, Dukpa D, Choudhary V. Global surface temperature signals in pine ring width chronologies from southern monsoon Asia. Geophys Res Lett. 2005; 32:L20704, doi: 10.1029/2005GL023745
12. Buckley BM, Duangsathaporn K, Palakit K, Butler S, Syhapanya S, Xaybouangem N. Analyses of growth rings of *Pinus merkusii* from Lao PDR. For Eco Mgmt. 2007; 253:120-127.
13. Duangsathaporn K, Palakit K. Climatic signals derived from the growth variation and cycles of *Pinus merkusii* in Easternmost Thailand. Thai J For. 2013; 32(1):9-23.
14. Pumijumong N, Wanyaphet T. Seasonal cambial activity and tree ring formation of *Pinus merkusii* and *Pinus kesiya* in northern Thailand in dependence on climate. Forest Ecol Mgmt. 2006; 226:279-289.
15. Freese F. Elementary statistical methods for forests. Agri Handbook 317, USDA, Forest Service, Washington, 1974
16. Bannan MW, Bindra M. The influence of wind on ring width and cell length in conifers stems. Can J Bot. 1970; 48(2):255-259.
17. Lei AS. Tree size and ring width of three conifers in Southern Nevada. USDA For Serv Proc RMRS, 1999, 94-98.
18. Andrew IA, Burley J. Variation in wood properties of *Pinus kesiya* Royle ex Gordon (syn. *P. khasya* Royle; *P. insularis* Endlicher); Six trees of Assam Provenance grown in Zambia. Wood Sci. Tech. 1970; 4(3):195-212.
19. Bala M. Ring width variation at breast-height in *Cedrus deodara* (Roxb.) Loud. J Indian Acad Wood Sci. 1991; 22(1):45-51.
20. Knapic S, Perreira H. Within-tree variation of heart wood and ring width in Maritime pine (*Pinus pinaster* Ait.). For Eco Mgmt. 2005, 81-89.
21. Jyske T, Makinen H, Saranpaa P. Wood density within Norway spruce stems. Silva Fenn. 2008; 42(3):439-455.
22. Park YI, Koubaa A, Brais S, Mazerolle MJ. Effects of cambial age and stem height on wood density and growth of jack pine grown in boreal forest stands. Wood and Fibr Sci. 2009; 41(4):346-358.
23. Gogoi BR, Sharma M, Sharma CL. Ring width variations of Khasi pine (*Pinus kesiya* Royle ex Gordon) at breast height. J Ind Acad Wood Sci. 2014; 11(1):87-92.
24. Cown DJ, Ball RD. Wood densitometry of 10 *Pinus radiata* Families at seven contrasting sites: Influence of tree age, site, and genotype. NZ Jour For Sci. 2001; 31(1):88-100.
25. Kiaei M, Khademi-Eslam H, Hemmasi AH, Samariha A. Ring width, physical and mechanical properties of eldar pine (case study on Marzanabad site). Cellul Chem Technol. 2012; 46(1-2):125-135.
26. Bouslimi B, Kaubaa A, Bergeron Y. Anatomical properties in *Thuja occidentalis* variation and relationship to biological Processes. IAWA Journal. 2014; 35(4):363-384.
27. Missanjo M, Matsumara J. Radial variation in tracheid length and growth ring width of *Pinus kesiya* Royle ex Gordon in Malawi. Int Jour Res Agri For. 2016; 3(1):13-21.

28. Boruszewski P, Jankowska A, Kurowska A. Comparison of structure of juvenile and mature wood of *Larix decidua* Mill. From fast-growing plantation in Poland. *Bioresources*. 2017; 12(1):1813-1825.
29. Sadegh AN, Kiaei M. Formation of juvenile/mature wood in *Pinus eldrica* medw and related wood properties. *World App Sci Jour*. 2011; 12(4):460-464.
30. Zhu J, Nakano T, Hirakawa Y. Effect of radial growth rate on selected indices for juvenile and mature wood of Japanese larch. *Jour Wood Sci*. 2000; 46:471-422.
31. Yu M, Cheng X, He Z, Wu T, Yin Z. longitudinal variation of ring width, wood density and basal area increment in 26year old Loblolly pine (*Pinus taeda*) Trees. *Tree Ring Research*, 2014, 137-144.