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Potential Trees Species of North-East India for Dendroclimatological Studies

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ABSTRACT

Many tropical trees show distinct annual ring formation as in temperate conifers, and the growth of these annual rings is used as bio-indicators of environmental changes. Dendroclimatology is the science dealing with the reconstruction of a history of past climate through dendrochronological (tree ring) analysis and assessing the effect of climatic change on tree growth. Trees are living natural archives and their growth is largely impacted by various climatic and non-climatic events occurring in the surrounding environments. In Northeast India, several conifers and broad-leaf tree species such as *Abies densa, Larix griffithii, Pinus merkusii, Pinus kesiya, Pinus wallichiana, Quercus serrata, Toona ciliata* and *Tectona grandis* have been used for tree ring-based studies. Dendrochronological studies mainly focused on the reconstruction of climate history, climate-tree growth relationship, river flow history reconstruction, inter-annual density fluctuation, and for development of climate proxies. Among these, the oldest tree ring chronology of *Abies densa* of 490 years (1504 to 1994) was reported from Yumthang of Sikkim. Whereas the youngest chronology of *Toona ciliata* of 35 years (1984 to 2018) was from Chandel district of Manipur. The knowledge derived from the detailed study of these species will help forest managers and conservationists to manage the forest in a changing environment. This paper presented dendrochronological information of different trees of northeast India based on the published literature and their possible impact on climate reconstruction through dendroclimatology. However, further potential tree species forming tree rings need to be worked out for possible climate mitigation measures of tropical trees in northeast India.

Keywords Dendrochronology, Climate change, Tree species, Silvi-cultural characteristics, Tree ring with.

INTRODUCTION

Dendrochronology is a branch of science that studies the characteristics of the annual rings of trees and other woody plants and to relate them with the environmental conditions under which they were formed (Fritts and Swetnam 1989, Speer 2010). Whereas dendroclimatology is used to characterize tree rings to predict the historical environment in which trees

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occur (Pant 1979, Pompa and Hadad 2016, Upadhyay *et al*. 2021). Tree rings are recognized as natural archives that provide significant, high-resolution annual proxy data for paleoenvironmental research and climate reconstruction. A significant portion of tree-ring studies has been used to infer long-term climate histories beyond instrumental records. Bhattacharyya and Yadav (1999), Buckley *et al*. (2017), Dhyani *et al*. (2022), Upadhyay and Tripathi (2019), Thomte *et al*. (2023). In general, sensitive tree species are selected because they form tree rings with some variation, which allows synchronization of tree ring series from different trees at the same site. The selected tree species should be able to record different types of timing signals in their rings due to the variability of environmental conditions, especially climate (Speer 2010, Correa-Diaz *et al*. 2014).

The distribution ranges of tree species are known to better understand the relationship between growth and climate so that they can be appropriately managed and protected from the adverse effects of climate change (Gaire *et al*. 2020). In recent years, climate change has had significant impacts on the environment and its components. Over the past century, the average global temperature has raised by more than 1.3°F (Team 2008). According to the National Research Council Report (NRC) 2011, global temperature is projected to increase from 2°F to 11.5°F by 2100. Such changes in the climate may have profound impacts on the ecosystem and landscape. The north-eastern India (NEI) is one of the most vulnerable regions of the country, which includes the small states like Assam, Arunachal Pradesh, Tripura, Manipur, Mizoram, Meghalaya, Nagaland and Sikkim (Dash *et al*. 2012). According to Koppen's classification, this region has subtropical and humid climate (Oliver and Wilson 1987) except Arunachal Pradesh and Sikkim which are having alpine climate with cold, snowy winters and mild summers. The Ministry of Environment, Forest and Climate Change (MOEFCC), Indian has completed an assessment for future climate change of NEI through a Network for Climate Assessment (INCCA) and found that average annual precipitation is likely increase by 0.3% to 3% by 2030. The summer forecast predicts a temperature increase of 1.8°C to 2.1°C by the end of 2030 (INCCA 2010, Dash *et al*. 2012, Rao *et al*. 2020).

There are several approaches to understand the dynamics of climatic conditions and incorporate the relevant literature. Dendroclimatology is a widely accepted scientific tool, which uses various plant and tree species to study present climate and reconstruct past climate. Among all the tree species, conifers are best suited for determining climate response. Dendrochronological analysis can be performed on any tree or plant species that meet the requirements of producing distinguishable rings for many years, exhibiting ring characteristics that can be chronologically dated, and attaining sufficient age to provide the time control required for a particular study. Therefore, this study aims to identify and describe the major potential tree species of northeast India that have dendroclimatological potentials. This study is useful to provide a baseline information for targeting such trees which can be potentially used as indicator of past climate and to predict the growth trend of such trees in changing climate.

MATERIALS AND METHODS

Tree ring study sites distribution

This study covered entire northeast India for the dendrochronological studies of potential trees and stream flow reconstruction studies conducted in the region. Such studies were conducted in Arunachal Pradesh, Assam, Manipur, Mizoram, Meghalaya, and Sikkim excepting Tripura and Nagaland (Fig. 1).

Data collection

The primary data sources for this study are various research and review articles published till May 2023 from various search engines (like Web of Science, Scopus, Science Direct, Google Scholar, and Research Gate). The references of all collected articles were systematically reviewed (Moher *et al*. 2009). The scientific names of trees, their dendrochronological characteristics and the names of dendrochronologists were collected and interpreted. Finally, a bibliographic database was created and analyzed from the published research articles for the following information such as: Tree species studied, site characteristics (i.e. state, geographic coordinates, and elevation), and measured variables (tree ring width, earlywood

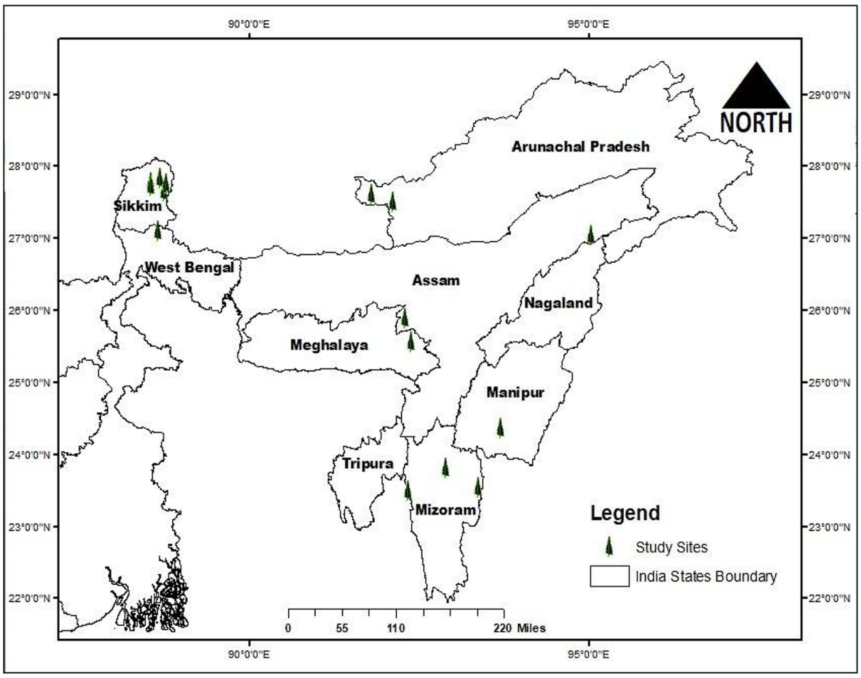

Fig. 1. The states wise distribution of sampling sites carried out for tree ring studies in Northeast India.

and latewood width, length of chronologies).

RESULTS AND DISCUSSION

In this study, all the Northeastern states have been considered except Nagaland and Tripura where no dendrochronological studies have been reported so far. Number of articles on dendrochronology were collected, reviewed and analyzed for their dendroclimatological potential. Our analysis suggest that the longest chronology developed for this region so far is from *Abies densa* Griff with a length of 490 years ranging from 1504 to 1994. The chronological length of tree species found in Northeast India are listed in Table 1.

The analysis of the review of surveyed articles showed that ~20 articles were directly related to dendrochronological studies. Whereas there were other articles including reviews which were indirectly supported by the dendro-related studies. We found that a total 9 species were used in dendrochronological studies in Northeast India (e.g., *A. densa, L. griffithii, T. dumosa, P. wallichiana, Q. serrata, T. ciliata, T. grandis, P. kesiya, .P. merkusii*). The details

Table 1. Species-wise chronological length.

Species	Chronology length	Duration	Sources
Abies densa Griff	490	1504-1994	Bhattacharyya & Chaudhary 2003
Tsuga dumosa (D. Don) Eichler	437	1575-2008	Borgaonkar *et al.* 2018
Pinus merkusii Jungh. & de Vriese	297	1703-1999	Shah & Bhattacharyya 2012
Pinus wallichiana A. B. Jacks	297	1704-2000	Shah & Bhattacharyya 2012
Larix griffithiana (Lindl. et gord) (Hort ex Carr.)	261	1628-2007	Shah *et al.* 2014
Quercus serrata Murra	47	1978-2017	Upadhyay *et al.* 2019
Pinus kesiya Royle ex Gordon	39	1980-2018	Thomte *et al.* 2022
Tectona grandis L.f.	37	1987-2017	Upadhyay *et al.* 2019
Toona ciliata	35	1984-2018	Monsang *et al.* 2023

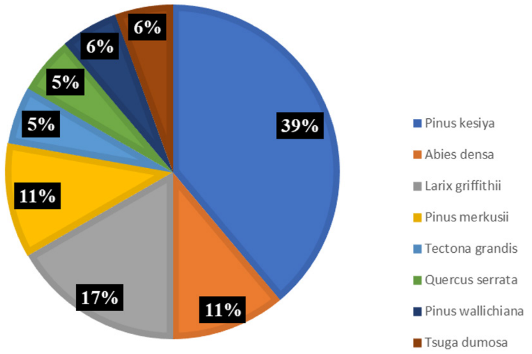

Fig. 2. Highly used tree species for dendrochronological studies.

are given in Table 2. The tree-ring-based studies in northeast India mainly focused on the reconstruction of climate history, the relationship between climate and tree growth, reconstruction of river flow history, inter-annual density variation, and development of climate proxies were based on these 9 tree species reported here so far. Among these, *Pinus kesiya* is most commonly used species for dendrochronological studies followed by *L. griffithii, A. densa,* and *P. merkusii* (Fig. 2).

Variables used in dendrochronological study

In NEI, most of the tree-ring studies are primarily focused on reconstructing climate history, relationships between climate and tree growth, river flow history reconstruction, and interannual density variation. For all this analysis, several tree-ring parameters (e.g. total tree ring width, TRW; earlywood width, EW; latewood width, LW; and adjusted latewood width, LW_{adj}) are important and have been used in the reconstruction studies so far (Fig. 3). In addition to these dendroclimatological parameters, among abiotic variables temperature and precipitation were most frequently used in dendroclimatological studies.

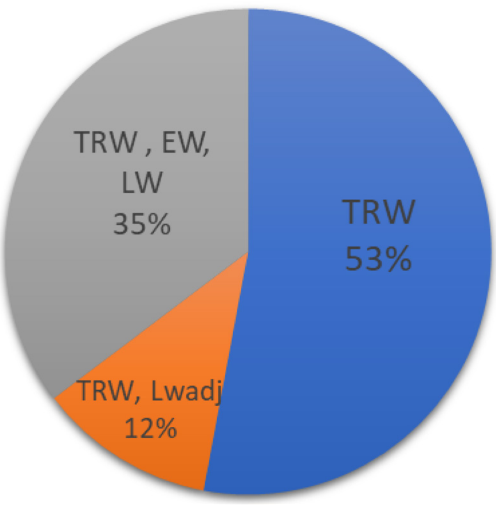

Fig. 3. Different variables used in tree ring studies.

Silvicultural characteristics of potential tree species for dendrochronology

Abies densa Griff (Himalayan Alpine Fir): A subalpine, broad-leaved conifer that grows 10 to 15 m tall and 1 to 2.5 m wide, and occurs at an elevation of 2800 - 3700 m (Gautam *et al*. 2020). This tree species is usually associated with *Rhododendron* and *Juniperus indica* and grows mainly on thin soil covering gneiss rocks. *Abies densa* trees grow only on moderate to steep slopes with shallow soil depth, which are not ideal growing conditions for other tree species. It is dominated by conifer in the upper belt of the central and eastern Himalayas from Nepal, Sikkim, Bhutan, and Adjacent Tibet to Burma (Shekhar and Bhattacharyya 2015, Gautam *et al*. 2020). This species was found to be suitable for dendrochronological and climate growth relationships (Bhattacharyya *et al.* 1992, Bhattacharyya and Chaudhary 2003).

Quercus serrata Murra (*Joilcham oak*) is a moderate to large-sized deciduous tree with a round crown in the open and a straight clean bole in the crop and it is a broad-leaved taxon (Upadhyay *et al*. 2019). The species grows quickly and is ideal for ornamental and shade plantation use (Troup 1921). The species has been found in the eastern Himalayas, the Khasi hills of Meghalaya, the Naga hills of Manipur, upper Burma and in China (from 914-2438 m amsl elevation). Though the dendroclimatic potential of *Q. serrata* has been well established in Northeast India particularly in Mizoram for the first time by Upadhyay *et al*. (2019). However, the authors further suggested that *T. grandis* and *P. kesiya* have higher dendrochronological potential as compared to *Q. serrata* in this region.

Table 2. A detailed list of the dendrochronological-related research and potential tree species in Northeast India.

Sl No.	Author	Family	Tree species	Tree ring chronology	Study area	Lat/long	Application area	Variables	State
1	Thomte *et al*. 2022	Pinaceae	*Pinus kesiya* Royle ex Gordon	1868-2018 (150)	Madan village, west Karbi angling district, Assam, North East India	25°52′47.99” N, 92°17′ 49.19” E	Dendroclimatology (soil moisture variability)	TRW	AS
2	Vandana Chaudhary & Bhattacharyya, 2000	Pinaceae	*Larix griffithii* Hook.f.	1891-1996 (105)	Sange, (West Kameng) Arunachal Pradesh	$27^0$29’58’’N $92^0$07’04’’E	Dendroclimatology	TRW	AP
3	Bhattacharyya & Chaudhary, 2003	Pinaceae	*Abies densa* Griff	(1504-1994) (490) (1688-1995) (307)	Yumthang T-Gompa	$27^0$49’36’’N $88^0$41’44’’E	Dendroclimatology	TRW	AP, SK
4	Shah *et al*. 2019	Pinaceae	*Pinus merkusii* Jungh. & de Vriese	1830-1999 (169)	Anzaw, (Mishmi hills) District of Arunachal Pradesh	27034’N and 29036’N and 95038’E and 97044’E	Dendrochronology (River flow reconstruction)	TRW	AP
5	Singh *et al*. 2016	Pinaceae	*Pinus kesiya* Royle ex Gordon	1958-2014 (56)	Khonghampat reserve forest	24°53’01.1” N 93°54’41.9” E	Dendroclimatology	TRW, IDF	MN
6	Thomte *et al*. 2020	Pinaceae	*Pinus kesiya* Royle ex Gordon	1980-2018 (39)	Sielmat, chrachandpur (Dist)	24°2’1’0” N 93°41’39” E	Dendroclimatology	TRW	MN
7	Thomte *et al*. 2022	Pinaceae	*Pinus kesiya* Royle ex Gordon	1980-2018 (39)	Sielmat, chrachandpur (Dist)	24°21’0” N Latitude, 93°41’39” E	Dendroclimatology	TRW, EW, and LW	MN
	Monsang *et al*. 2023	Meliaceae	*Toona ciliata*	1984-2018 (35)	Japhou forest community Chandel, Manipur	24.33° N 94.01° E	Dendrochronology	TRW	MN
8	Chaudhary &		*Pinus kesiya* Royle ex Gordon	1901-2000 (99)	(Shillong) Shyrawt reserved forest (SHY)	$25^0$35’11’’ N $91^0$56’08’’E			

Table 2. Continued.

SN	Author	Family	Tree species	Tree ring chronology	Study area	Lat/long	Application area	vari-ables	State
		Pinaceae					Dendrocli-matology	TRW	ML
	Bhat-tacharya								
	2002			1920-2000	Riat khwan reserved forest (RKF)	25^{0}34’45’’ N 91^{0}53’28’’E			
				(80)		25^{0}34’45’’N			
						91^{0}53’28’’E			
				1859-2000	Laitkor procted forest (LPF)	25^{0}32’51’’ N			
				(141)		91^{0}52’06’’E			
				1869-2000	Upper Shillong Forest				
				(131)	(USF)				
9	Shah	Pinaceae	*Pinus kesiya*		(Shillong plateau of khasi hills)	91◦47’E			ML
	&		Royle ex Gordon			91◦55’E			
	Bhat-tacharyya,			1859-2000 (142)	Laitkor proected forest (LPF)	35◦31’N			
	2012			1920-2000	Riat khwan reserved forest (RKF)	35◦39’N			
				(81)					
				1901-2000	Shyrwat reserve forest				
				(100)	(SHY)				
				1877-2000 (124)	Short-round protected forest (SRF)				
				1869-2000	Upper Shillong reserved forest				
				(132)	(USF)				AP
			Pinus merkusii		Mishmi hills				
			Jungh. & de Vriese	1703-1999 (297)	Dichu reserved forest	97◦00’ E			
		Pinaceae		1804-1999	(DIC)	97◦05’ E			
				(196)	Dong village	28◦13’ N			
				1778-1999	(DON)	28◦19’N			
				(222)	(Tilam top)				
					TIL				
			Pinus wallichi-ana		Ziro valley				
			A. B. Jacks.	1704-2000	Dobya village				
				297	(DOB)				
		Pinaceae							

Table 2. Continued.

SN	Author	Family	Tree species	Tree ring chronology	Study area	Lat/long	Application area	variables	State
				1792-2000	Hari village				
				(209)	(HAR)				
				1859-2000	Hong village	93◦85’E			
				(142)	(HON)	93◦89’ E			
						27◦53’N			
				1773-2000	Michi village	27◦68’N			
				(228)	(MIC)				AP
				1855-2000	(Rang village)				
				(146)	RAG				
10	Upadhyay *et al.* 2019	Lamiaceae	*Tectona grandis*	1987-2017	Turial riverine	23^{0}48’25.78”N	Dendrocli-matology	TRW, EWD, LWD	MZ
			L.f.	(37)		92^{0}53’06.47”E			
			Pinus kesiya			23^{0}32’19.33”N			
		Pinaceae	Royle ex Gordon	1978-2017 (40)	Ngur village	93^{0}22’24.67”E			
			Quercus serrata						
		Fagaceae	Murra	1971-2017 (47)	Vengther village	23^{0}29’17.41”N 92^{0}20’15.48”N			
11	Upadhyay *et al.* 2012	Lamiaceae	*Tectona grandis*	1970-2017	Turial riverine	23^{0}48’25.78”N	Dendrocli-matology	TRW, ED, and LD	MZ
			L.f.	(37)		92^{0}53’06.47”E			
12	Shah *et al.* 2014	Pinaceae	*Larix griffithiana* (Lindl. et gord) (Hort ex Carr.)	1733-1994 (261)	Lachen River (North Sik-kim)	27°45’44.6” N 88°33’06.9”E	Dendro-chronology (stream flow recon-struction)	TRW, EW, LW	SK
13	Shekhar & Bhattacharyya 2015	Pinaceae	*Abies densa* (Fir).	1628-2007 (379)	Zeme chuu at Lachen	27°45’44” N 88°33’ 06” E	Dendro-chronology (stream flow recon-struction)	TRW, EW, LW	SK
14	Yadava *et al.* 2015	Pinaceae	*Larix griffithiana* (Lindl. et gord) Hort ex Carr.).	1852-2006	Lachen, Lachung	27.717^{0}N	Dendrocli-matology	TRW, EW LW	SK
				154		88.560^{0}E			
						27^{0}38’23”N			
						88^{0}45’.22”E			
15	Borgaonkar *et al.* 2018	Pinaceae	*Tsuga dumosa* (D. Don) Eichler	1575-2008 (437)	Dambung (North Sik-kim)	27044’47”N 88^{0}46’38”E	Dendrocli-matology	TRW	SK

Larix griffithiana (Lindl. et Gord.) Hort ex Carr (Himalayan Larch) is a deciduous conifer. Distributed at an altitude of 2400-3650 m. It originates from eastern Nepal and extends through Darjeeling, Sikkim, Bhutan, and Arunachal Pradesh before reaching north Easter (NE) upper Burma and the Chumbi Valley in Tibet (Troup 1921, Sahni 1990). This tree thrives well on steep sloping morainic deposits with good drainage, reaching a height of 15-18 m with long pendulous branches and medium-sized girth. It grows mostly in patches as a pure forest or in mixtures with other conifers. Associated species of *Latrix graffitthiana* are mostly silver fir and rhododendron. From Northeast India, the dendroclimatic potential of L. *griffithiana* has been established and it has good prospects in understating fine resolution climatic changes from the NEI region using tree ring width data (Chaudhary and Bhattacharyya 2000, Yadava *et al*. 2015, Bhatta *et al*. 2018).

Pinus merkusii (Merkus Pine) is a two-needle pine, a medium- to large-sized tree, attaining height of 25-45 meters with a trunk diameter of up to 1 m distributed at an elevation of 800-2000 m. This pine grows from the southern Shan States of Myanmar through the hills of the Salween and Thaungin drainages. This pine can also be found in Thailand, Cochinchina, Sumatra, Java, Borneo, and the Philippines (Sahni 1990). In India, it is growing only in the Mishmi Hills of Arunachal Pradesh, Northeast India. The dendroclimatic potentiality of Merkus pine has been established earlier in India (Shah and Bhattacharyya 2012, Shah *et al*. 2019).

Pinus kesiya Royle ex Gordon (Khasi pine) is a three-needle pine species found in tropical montane forests in northern Thailand and the Philippines, and sub-tropical areas of north-eastern India (Singh *et a*l. 2016; Upadhyay *et al*. 2019). It is most common in sub-tropical forests in Khasi and Naga hills of Assam, and Manipur. This species is widely distributed at an elevation of 800-2000 meters amsl (Upadhyay *et al*. 2019, Thomte *et al*. 2020). This species is growing in association with broad-leaf taxa such as *Lithocarpus fenestrate, Quercus serrata, Schima wallichii,* and *Eugenia praecox* (Upadhyay *et al*. 2019, Thomte *et al.* 2023). In NEI, P. *kesiya* is a major potential species for dendrochronological studies and hence, it has been used by many researchers for tree ring analysis and establishing regional climatic reconstruction (Singh *et al.* 2016 , Thomte *et al*. 2022, Thomte *et al*. 2023).

Pinus Wallichiana (Blue Pine) mostly occurs at a higher altitude of an elevation ranging from 1800 to 3900 m amsl in the northwest Himalayas and up to Arunachal Pradesh in the East (Sahni 1990, Shah and Bhattacharyya 2009). This tree typically grows in glacier forelands and mountain screes and forming a pioneer species. In temperate forests, it grows together with Deodar (*Cedrus deodara*), Spruce (*Picea smithiana*), and Fir (*Abies pindrow*). This species crosses 3000 m amsl at the tree line in some locations with birch (*Betula utilis*) and juniper (*Juniperus macropoda*) (Champion and Seth 1968, Rashed 2022). This species has been reported as a highly promising species for dendrochronological studies (Shah and Bhattacharyya 2012, Gaire *et al*. 2019).

Tectona grandis (teak) is a deciduous tree native to South and Southeast Asia and it has been introduced to other tropical regions. Many researchers have conducted dendrochronological studies on teak covering almost its entire provenance range in South-East Asia (Shah and Mehrotra 2017) and found it to be a highly promising species for monsoon climate reconstruction (Bhattacharyya *et al*. 1992, DArrigo and Ummenhofer 2015, Upadhyay *et al*. 2021).

Tsuga dumosa (D. Don) Eichler is an economically and medicinally important conifer in the Pinaceae family. It is also known as “Hemlock spruce”. This species is found to be distributed at an elevation of 2100 -3600 m amsl. The species is associated with *Quercus semecarpifolia* in the lower belt, whereas with *P. wallichiana, Abies*, and *Picea* in the upper belt of Sagarmatha National Park (*Gaire et al*. 2019). Hemlock is a slow-growing, long-living, shade-tolerant species that is sensitive to prolonged drought (Havill *et al*. 2008). In addition, it is a highly promising tree species for dendrochronological studies in Northeast India and capturing late-summer temperature signals in the NEI region (Borgaonkar *et al*. 2018).

Toona Ciliata Roem belongs to family Meliaceae. It is a significant species of timber that can reach heights of about 25 to 35 m. This species is native to South China (Feng *et al.* 2015; Shah and Mehrotra, 2017, Li *et al*. 2018) and also sporadically found in the highlands of Central and Southern India, the Indus eastward in the tropical Himalayas, Laos, Myanmar, Pakistan, and the east coast of Australia (Kumar *et al*. 2012, Li *et al*. 2018). It is a common plant in India's sub-Himalayan tracts of Assam, Khasi Hills of Meghalaya, Manipur, Bihar, Madhya Pradesh, and the Western and Eastern Ghats (Shah and Mehrotra 2017). Toon does best in rich, well-drained soils and struggles in poor, sandy, and dense clayey soils (Tomazello *et al*. 2001). In NEI, T. Ciliata is one of the promising tree ring species for dendroclimatological studies (Shah and Mehrotra 2017, Monsang *et al*. 2023).

Climate response

The first dendroclimatic study on L. *griffthiana* and A. *densa* was attempted from Darjeeling, Sikkim, and Arunachal Pradesh in the North-Eastern region. The ring width chronology of A. *densa* showed a negative correlation with July-September temperature, whereas L. *griffthiana* showed a positive correlation with temperature in the same months (Chaudhary *et al.* 1999, Chaudhary and Bhattacharyya 2000; Bhattacharyya and Chaudhary 2003, Shah *et al.* 2014 Shekhar and Bhattacharyya 2015, Yadava *et al*. 2015). This reflects that the temperature acts as a stressor for the growth of the former species, whereas the same triggers the growth of the later species during the same months. Further, on Timberline of the eastern Himalayas, A. *densa* showed that the temperature has a significant impact on its growth during the months of July to September (Shah and Bhattacharyya 2012).

The majority of studies on *P. Kesiya* conducted in Meghalaya and Manipur on tree ring width chronology suggested a positive correlation with precipitation between December and March of the preceding year (Chaudhary and Bhattacharyya 2002, Gogoi *et al*. 2014, Upadhyay *et al*. 2019, Singh *et al*. 2016, Thomte *et al.* 2020, Thomte *et al*. 2022, Thomte *et al.* 2023). This showed that the winter shower of the rain triggers the growth of the species in NEI region.

Chronology A. *densa* was used to reconstruct the average temperature for the aforementioned months (Bhattacharyya and Chaudhary 2003, Shah and Bhattacharyya 2012), whereas the chronology of Khasi pine (P. *kesiya*), Merkus pine (P. *merkusii*), and blue pine (P. *wallichiana*) were used assess the spatiotemporal growth variations. The dendroclimatic analysis showed the species-dependent changes in the limiting climatic variables for radial stem growth. Pre-monsoon precipitation in the months of December to April was found to have a significant impact on Blue Pine's growth (Shah *et al*. 2009, Gaire *et al*. 2019).

CONCLUSION

This study suggests that most dendrochronological studies focused on a limited number of tree species (i.e. 9 tree species), for example, *A. densa, L. griffithii, P. Kesiya, P. Wallichiana, P. Merkusii, T. dumosa, T. grandis, T. ciliate, and Q. serrata* from few locations of NEI. The studies shown that the tree rings of conifers and deciduous trees at NEI were useful for developing climatic proxies, especially for reconstructing pre-monsoon temperature and precipitation. Therefore, it is suggested that more trees from different geographical regions need to be worked out for better analysis of regional climate pattern from dendrochronological observations. A network of climate-sensitive tree-ring chronologies of trees growing in contrasting climates of the northwestern and northeastern parts of the Himalayas and Peninsular India would be of great importance for establishing long-term, high-resolution climate reconstructions.

Moreover, tree rings contribute to the understanding of the detailed climate dynamics of the Indian subcontinent from a global perspective and their impacts during the Mediaeval Warm Period, the Little Ice Age, and the recent global warming. Most tree-ring analyses in India are based on ring width, while other tree-ring parameters are ignored. Recently, more emphasis is being laid on other tree-ring parameters such as density, isotopes, cell size and vascular area to understand past climatic changes and other aspects of environmental, ecological and geomorphological studies. Increasing land demand, for agriculture, and urbanization have led to rapid deforestation and the extinction of many ancient trees. To establish millennial tree-ring records, extensive efforts must be made in collecting tree-ring samples in new geographic areas and in selecting old trees. The need to obtain large numbers of samples from older trees could be substantiated by collecting samples from snags that often remain in forests after logging, from old wood used in the construction of houses, and from fossil wood. The knowledge gained from the detailed study of these species will help foresters and conservationists to manage the forest well and take the necessary measures to mitigate the potential impacts of climate change in the future.

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