A Climatological Signal Analysis of Pinus kesiya Tree Ring Parameters from Northeast India

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ABSTRACT:

Global temperatures have increased by an unprecedented amount since 1850, with the 30 years between 1983 and 2012 being the warmest in the previous 1400 years (IPCC, 2014). According to the most recent IPCC report (sixth assessment report), from the middle of the 19th century, the last four decades have been consistently warmer with a faster rise in temperature over land than in oceans (IPCC, 2021). According to predictions for the 21st century, temperatures will rise along with an increase in the frequency and severity of weather extremes such drought, heat waves, and heavy precipitation (Dai, 2013; IPCC, 2014; Trenberth et al., 2014). Records from the western Himalaya region of India indicated a tendency toward increasing maximum and minimum temperatures during the time period.

KEYWORD: Climatological Signal, Pinus kesiya, Vulnerability, tele-connections, Climate Reconstruction

INTRODUCTION

Climate change and forests

Storing over half of the carbon on Earth. and generate almost 50% of the primary production's net output (Bonan, 2008; Shevliakova et al.,2013). Additionally, forests make up 80% of the world's plant biomass (Kindermann et al., These woods are increasingly in danger from human-caused disturbances as of 2008. accompanied by a shift in climate. Growing conditions have changed due to global warming. There have been reports of plant seasons (Fiwa et al., 2014; Gruber et al., 2011; Linderholm, 2006; Yohe & Parmesan, 2003). There is evidence that forests are changing where they are found. due to climate change, ranging towards higher latitudes and elevations (Chen, 2012; Gaire) According to Allen et al.'s (2010) evaluation of the pertinent literature, there may be an intensification of the world's forests. Death as a result of rising weather extremes like drought and heat waves. Severe Droughts have had a lasting and pervasive residual effect on forest ecosystems. During several years of slowed recovery and diminished tree growth (Anderegg, 2015). In addition, conflicting findings in the literature (caused in part by differing techniques) may cause the vulnerability of forests to such Extremes are common, especially in wet areas (Allen et al., 2015).

Dendrochronology

Dendrochronology is a branch of science that examines annual growth layers, sometimes known as tree rings, in woody plants (Smith & Lewis, 2006). Coniferous trees create seasonal growth layers with alternating bands of light and dark color. Earlywood refers to the lighter band of cells with thin walls and wide lumens, whereas latewood refers to the darker band of cells with thicker walls and narrow lumens (Fritts, 1976). Earlywood and latewood are two types of seasonal wood that are generated at the beginning and end of the vegetative period, respectively. They come together to form a single tree ring or annual growth increment. The growth pattern of trees on a location reflects the influence of a common environmental component, such as climate (Fritts, 1976; Smith & Lewis, 2006). A variety of techniques can be used to extract the environmental circumstances that trees have thus recorded, with the measurement of tree-ring width being the most popular (Fritts, 1976; Speer, 2010). For instance, when a tree does not receive enough moisture or when the temperature is too low, narrow rings develop. Wide rings are a defining trait of trees that grow in environments that are favorable for their development.

Goals and queries:

To develop tree-ring chronologies of P. kesiya from new sites and resample from previously studied localities in order to enhance their spatial and temporal extent. To develop the first partial tree-ring width chronologies (earlywood, latewood and adjusted latewood chronology) of P. kesiya and establish their climatic responses. To reconstruct past climate variables beyond the available instrumental records. To evaluate tele-connections with global atmospheric and oceanic circulation.

REVIEW OF LITERATURE

Distribution of Pinus kesiya

The three-needle pine Pinus kesiya Royle ex. Gordon (Khasi pine) is one of the important tropical pine species occurring within 12° to 30° N latitude in Southeast Asia (Armitage & Burley, 1980; Farjon & Filer, 2013; Hansen et al., 2003; Wright & Isaza, 1997) (Fig. 2.1). It is native to Northeast India, Myanmar, China, Thailand, Laos, Cambodia, Vietnam and Philippines (Armitage & Burley, 1980; Farjon, 2010). P. kesiya occurs as pure stands, in pine savannas and in mixed forests with broadleaves (Farjon, 2010). In Northeast India, it is found mostly in the Khasi Hills of Meghalaya, Naga Hills of Nagaland and in the hills of Manipur (Sahni, 1990). In the Khasi Hills of Northeast India, it occurs at elevations between 800–2000 m a.s.l. and flourishes at an elevational range of 1200–1400 m a.s.l. (Sahni, 1990). It has been reported as far north as Yachuli village in Arunachal Pradesh, Northeast India (Rai, 2018). Across its entire range in Southeast Asia, it is mainly found in the altitudinal range from 350–2900 m a.s.l., and primarily above 1000 m a.s.l. (Armitage & Burley, 1980). It grows well in moist conditions with moderate to high rainfall and at an elevation of 600–1800 m a.s.l. (Hansen et al., 2003). P. kesiya prefers well-drained soils and are unable to tolerate extremes of heat and cold (Krishnamurthi, 1969). New shoots appear in February– March and male and female cones also develop simultaneously or follow soon after (Singh & Venugopal, 2011; Troup, 1921). Annually, P. kesiya trees produce three. flushes of new needles and branches in February, June and October (Das & Ramakrishnan, 1986; Singh & Venugopal, 2011).

Dendrochronology in Northeast India

The majority of tree-ring studies in Northeast India (including Sikkim and SubHimalayan West Bengal) were largely concentrated over the Eastern Himalaya region of Sikkim, Sub-Himalayan West Bengal and Arunachal Pradesh (Fig. 2.2; Shah et al., 2014). More recently, attention has been gradually shifting towards the tropical and sub-tropical forests of the region (Shah & Mehrotra, 2017; Singh et al., 2016; Upadhyay et al., 2019, 2021). The studies from this region considering only P. kesiya (Chaudhary & Bhattacharyya, 2002; Singh & Venugopal, 2011; Singh et al., 2016) have already been discussed in section 2.2. The available literature on tree-ring-based studies from the Northeastern region of India are highlighted in the following sections.

Tree-growth and climate

Chaudhary et al. (1999) conducted preliminary tree-ring studies from various conifer taxa in the Eastern Himalaya, Northeast India. Three tree-ring chronologies from Abies densa, one each from Sikkim, Sub-Himalayan West Bengal and Arunachal Pradesh were successfully developed. In addition, two chronologies of Larix griffithiana were also developed from Arunachal Pradesh and Sikkim. The A. densa chronology from Sikkim was the longest, extending to 1503 CE. Response function analysis revealed the potential of the species as a surrogate for temperature records.

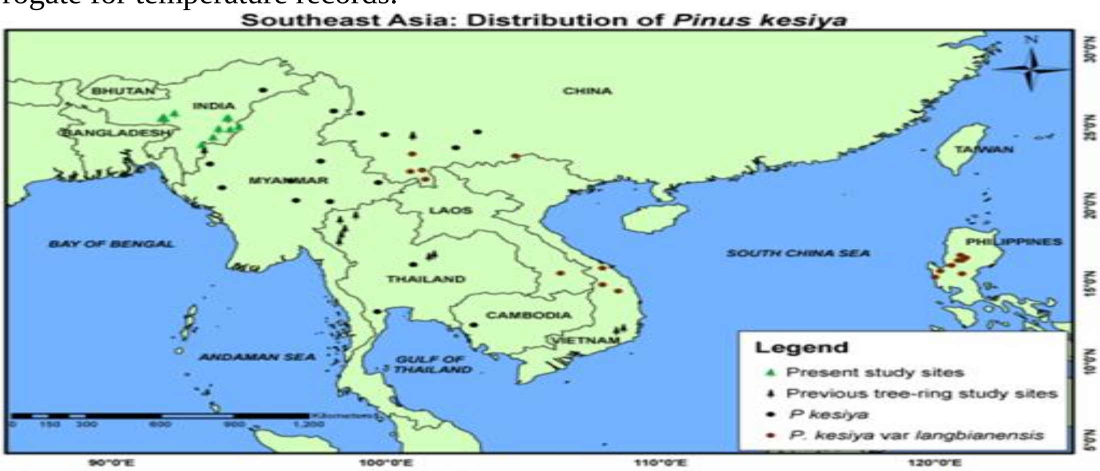

Fig. 2.1 Distribution of *Pinus kesiya* in South-Southeast Asia after Farjon and Filer (2013)

Tree-ring width of Pinus wallichiana growing in Ziro valley, Arunachal Pradesh across five sites were analyzed for its dendroclimatic potential (Shah et al., 2009). The coherence or (lack thereof) between sites were determined with the help of correlation matrix, hierarchical cluster analysis (HCA) and principal component analysis (PCA). The multiple site chronologies were transformed into a new set of uncorrelated variables or principal components (PC) by means of principal component analysis (PCA). This resulted in three chronologies represented by the first principal component (PC1) and two chronologies by the second principal component (PC2) that make up 33.2% and 25.8% of the explained variance respectively. The clustering of sites based on the HCA mirrored that of the PCA and to a lesser extent, the correlation matrix. Both PC1 and PC2 were strongly and significantly correlated with DecemberApril precipitation. The growth of three Pinus species from Northeast India and their response to climate was assessed by Shah and Bhattacharyya (2012). They used Pearson correlation and a suite of multivariate statistical techniques — Principal Component Analysis (PCA), UPGMA Agglomerative Hierarchical clustering, and Non-Metric Multidimensional Scaling (NMDS) to determine the clustering between sites and species. The results of these methods yielded a grouping broadly based on each species i.e., P. kesiya, P. merkusii and P. wallichiana. The PC scores of each individual clusters derived from PCA were then used to examine climate and tree-growth relationship. The response function and correlation analysis enumerated that climate parameters during one or more months of the winter and early growing season regulated the growth of the three Pinus species from Northeast India.

Sub-fossil wood

Shah and Bhattacharyya (2009) developed two floating ring width chronologies from sub-fossil wood of P. wallichiana found in Ziro Valley, Arunachal Pradesh. A total of 22 radii from 6 stem discs was used to construct a 331-year chronology from the Tarin site. Another chronology of 83 years was developed from 4 radii of one stem disc recovered from Siro village site, Arunachal Pradesh. As the existing master chronology began from the year 1704 CE (Shah et al., 2009), the age of the outer most ring was assumed to be older than 1704 CE. The age of the subfossil wood was therefore estimated by C-14 dating of the innermost rings of the stem disc, one from each site.

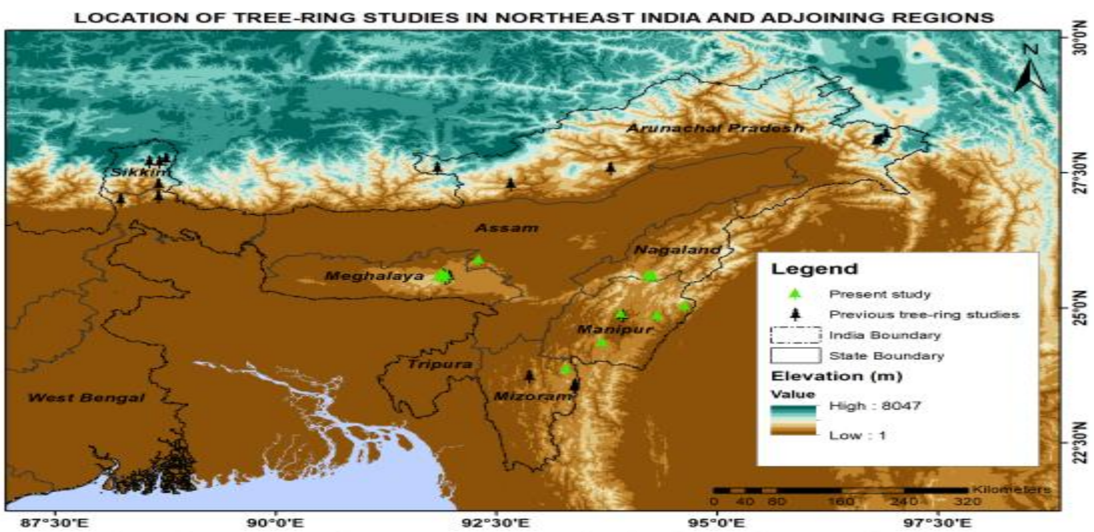

Fig. 2.2 Sites of present and past tree-ring studies in the northeast and adjoining regions of India

Previous dendrochronological studies based on partial ring width (earlywood and latewood)

The annual tree-ring width (or total ring width) of trees integrates the environmental conditions during an entire growing season and may also be modulated by the conditions of the preceding year (Fritts, 1976). The earlywood (EW) and latewood (LW) are seasonal components of the total ring width and are likely to contain seasonal climate signals since they are formed during different periods of the growing season. In general, the variations in precipitation, temperature and photoperiod primarily induce the transition from EW to LW (Antonova & Stasova, 1993, 1997; Fritts, 1976; Larson, 1969; Renninger et al., 2006). Initial investigations of the seasonal signals in EW and LW were conducted in conifers since the EW-LW transition was generally distinct. An increasing number of studies related to EW and

LW features from broad-leaved taxa have also been analyzed (e.g., García González & Eckstein, 2003; Hafner et al., 2015; Rozas & García-González, 2012; Tardif & Conciatori, 2006). In the following sections, an attempt was made to synthesize the available literature on dendrochronological studies of EW and LW of different conifer taxa from around the world with emphasis on the extraction of separate climatic signals in EW and LW (Fig 2.3). Only the studies dealing with visual methods of identification of EW and LW boundaries were retained, and the studies based on automated methods such as in Xray densitometry were excluded.

ANALYSES OF TREE-RING CHRONOLOGY

Tree-rings of P. kesiya have clear annual ring boundaries that are abrupt and can be easily recognized. The demarcation between earlywood (EW) and latewood (LW) are distinct in most cases. Although false rings are common (Fig. 3.4), they can usually be distinguished from a true ring. Simple correlation analysis of the multiple ring width components of P. kesiya for each site indicated that the EW accounts for most of the variation in total ring width (TRW) (average correlation > 0.9; Fig. 4.1). The EW and LW were also highly correlated for each site with the exception of DER (Fig. 4.2). The longest chronology (164 years) was established from the site LKF in Shillong, Meghalaya spanning the period 1855–2018 CE. The SIE chronology of 39 years from Churachandpur, Manipur, was the shortest (1980 to 2018 CE).

CLIMATE RECONSTRUCTION

Based on the chronology statistics and correlation analysis discussed in Chapter 4, the TRW parameter was selected to reconstruct drought (scPDSI) for the spring/premonsoon season (February–May). A spatial reconstruction of drought was targeted based on 95 scPDSI grids distributed at a spatial resolution of 0.5° x 0.5° over the entire northeastern region of India. The calibration time period was then selected to estimate each PCR model used to reconstruct spatial February–May scPDSI (hereafter FMAMscPDSI). Since a common time period for estimating the covariance matrix is required in principal component analysis, it was determined on the basis of the earliest last year of the time series used. In this case, the network of 12 tree-ring TRW chronologies was used as the basis to select the year 2018 as the last year of the calibration period that is common for all chronologies. The calibration period of 1971–2018 (48 years) constituting 70 % of the instrumental data was selected for the calibration analysis in this study. The scPDSI data that is available before 1971 was withheld from the calibration period in order to test the scPDSI estimated by the TRW chronologies for validation skill. Consequently, the validation period selected for PPR model is 1951– 1970 (20 years), i.e., ~30 % of the instrumental data. The overlapping subset of TRW chronologies falling within a search radius of 500 km was used to estimate the nestedPCR model of each of the 95 grid points to produce the spatial FMAM-scPDSI reconstruction. A minimum of one TRW chronology was set to produce each grid point on the basis of the field correlation. Only the significantly correlated chronologies ($p < 0.10$) were retained as a predictor in the PCR model (Cook et al., 1999). An additional criteria of minimum sample size was set to 5 samples for each TRW chronology in order to sort out weakly replicated series and less reliable inner portions of the chronologies. Consequently, the earliest start year was truncated to 1872 CE as opposed to 1855 CE in the oldest chronology. The scPDSI for the spring season (February–May) was thus reconstructed for all 95 grids of Northeast India.

SUMMARY AND CONCLUSIONS

The major objectives of this study are to develop a network of new tree ring chronologies of Pinus kesiya from Northeast India by measuring multiple tree-ring parameters, to evaluate the climate response of the different tree-ring parameter from each site using correlation analysis, to reconstruct climate beyond instrumental records and to assess teleconnections with global climate indices.

Conclusions

A dendrochronological study was carried out in the tropical/sub-tropical region of Northeast India. The evergreen conifer Pinus kesiya growing in the hills of Northeast India was used to develop tree-ring chronologies based on multiple growth parameters consisting of annual or total ring width, partial ring (earlywood and latewood) width and the adjusted latewood index. Tree core samples were collected from 15 sites distributed across the states of Assam, Meghalaya, Nagaland, Manipur and Mizoram in Northeast India. From a total collection of 861 tree core samples, 831 samples were successfully crossdated. The existing chronology of P. kesiya in Northeast India has been updated and the network extended with the addition of 9 new sites and 6 new chronologies developed from the region. Altogether 47 chronologies based on multiple tree-ring parameters were developed. These include 12 total ring width chronologies, 24 partial ring width chronologies (12 earlywood chronologies and 12 latewood chronologies) and 11 adjusted latewood chronologies.

The climate signals in multiple tree-ring width parameters were evaluated by computing the climate response based on Pearson's correlation analysis for both daily and monthly climate (rainfall and temperature). A largely synchronous pattern of positive (negative) significant response of radial growth to rainfall (temperature) during winter (pre-monsoon and early monsoon) season was observed for most of the sites in the case of the total ring width and earlywood chronologies. Although an early/late summer season rainfall signal were found in most of the adjusted latewood chronologies, these were largely secondary in significance. A majority of the adjusted latewood chronologies demonstrated that latewood growth was primarily governed by winter season rainfall. The temperature signals in the adjusted latewood chronologies indicated a delayed response towards late per-monsoon/spring season to mid-summer season relative to the other two parameters. The climate response of the adjusted latewood chronologies was less consistent between sites compared to the total ring width and earlywood chronologies. The recent decline in summer monsoon rainfall, frequent droughts and rising temperatures already observed in Northeast India may progressively constrain the growth and productivity of P. kesiya in the region under future climate warming. The consistent positive (negative) growth response to rainfall (temperature) observed in all parameters reflected that radial growth of P. kesiya was constrained by moisture variability and this was confirmed by the significant correlation of the total ring width with pre-monsoon/spring drought (scPDSI). On the basis of this strong relationship between total ring width and scPDSI, spring drought variability for the past 149 years since 1872 CE was reconstructed for Northeast India. The reconstruction captured past widespread drought events in the Indian sub-continent. While the reconstruction was more consistent with dry episodes, it was observed that not all droughts in the pre-monsoon season were followed by drought during the summer monsoon season. This is the first tree-ring based drought reconstruction from Northeast India. Available drought reconstructions for similar seasons from Myanmar and Nepal compared favorably with the present reconstruction. Spatial field correlations of the actual and reconstructed scPDSI confirmed that most of Northeast India south of 26°N latitude including central and south Assam are well represented in the reconstruction. Significant correlations with climate oscillations, particularly the AMO and PDO point to possible links between pre-monsoon drought variability in the region and global oceanic-atmospheric circulation systems.

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