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Response between tree–rings of *Pinus kesiya* and daily climate–A study from Manipur, Northeast India

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ABSTRACT

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A 39 years (1980–2018 C.E.) long tree–ring width chronology of Khasi Pine (*Pinus kesiya*) was developed using 36 tree cores collected from Manipur, Northeast India. The significant dendrochronological potential of this tree was achieved from this region, based on tree–ring chronology statistics. A linear response between ring–width chronology of *P. kesiya* and daily gridded climate (mean temperature and rainfall) records has been established. A significant negative association has been observed between daily mean temperature and tree growth during March 24 to May 27, whereas, rainfall showed positive response from February 24 to March 25. This study is a maiden attempt from India to analyze the response of tree ring growth to the daily climatic records. Further studies with a larger number of samples of *P. kesiya* are recommended from this region to strengthen the chronology statistics and to extend the chronology time span.

Key–words—Khasi Pine, Tree growth, Daily gridded climate, Sub–tropical region.

पाइनस केसिया के वृक्ष–वलयों के बीच अनुक्रिया तथा दैनिक जलवायु – मणिपुर, पूर्वोत्तर भारत से अध्ययन

लैम्गिनसैंग थॉम्टे, संतोष के. शाह, निवेदिता मेहरोत्रा, अबनी के. भगबती एवं अनूप सैकिया

सारांश

मणिपुर, पूर्वोत्तर भारत से संगृहीत 36 वृक्ष क्रोड प्रयुक्त करते हुए खासी चीड़ (*पाइनस केसिया*) का 39 वर्षीय (1980–2018 ईसवीं) दीर्घ वृक्ष–वलय चौड़ाई कालानुक्रमण विकसित किया गया। वृक्ष–वलय कालानुक्रमण सांख्यिकी पर आधारित इस अंचल से इस वृक्ष की सार्थक वृक्षकालानुक्रमी क्षमता पूर्ण की गई। *पी. केसिया* का वलय–चौड़ाई कालानुक्रमण एवं दैनिक समेकित (ग्रिडेड) जलवायु (माध्य तापमान व वर्षा) अभिलेखों में रैखिक अनुक्रिया दृढ़ की जा चुकी है। दैनिक माध्य तापमान और वृक्ष वृद्धि के बीच 24 मार्च से 27 मई के दौरान सार्थक नकारात्मक साहचर्य प्रेक्षित किया गया है जबकि 24 फरवरी से 25 मार्च तक वर्षा ने सकारात्मक अनुक्रिया दर्शायी। वृक्ष–वलय वृद्धि से दैनिक जलवायवी अभिलेखों की अनुक्रिया को विश्लेषित करने का भारत में यह अध्ययन का यह प्रथम प्रयास है। कालानुक्रम सांख्यिकी को सुदृढ़ करने और कालानुक्रमण अवधि विस्तृत करने को इस अंचल से *पी. केसिया* की बड़ी संख्या में नमूनों के साथ अध्ययनों की संस्तुति की जाती है।

सूचक शब्द—खासी चीड़, वृक्ष–वृद्धि, दैनिक समेकित जलवायु, उप–उष्णकटिबंधीय अंचल।

INTRODUCTION

THE response of climate on radial growth of both conifer and broad–leaved taxa has been studied in various geographical regions of India using tree–ring analysis, based on standard Dendrochronological techniques (Bhattacharyya & Yadav, 1999; Bhattacharyya & Shah, 2009; Shah *et al.*, 2014b; Pandey *et al.*, 2016). The relationship between tree and climate are prerequisite towards long term past climate reconstruction. To achieve this, monthly or seasonal climate data are widely used in various dendroclimatic studies and the relationship is mostly established using response function and correlation function analysis (Fritts, 1976). However, using monthly data, some climate signals are inevitably lost. This is mainly because months are invented categories not based on any of the laws of nature (Jevšenak & Levanič, 2018). Growth is a continuous process and should not be limited by artificially set monthly time frame (Jevšenak & Levanič, 2018). Moreover, the response of trees to intermittent high temperature and rainfall events could be masked out by the low temporal resolution of the climate variable. Such deficiencies can be rectified to a large extent with the help of daily climate data and it also allows for a statistical determination of an exact time frame linking the climate variable of interest with tree growth. There are some studies around the globe in which, climate–growth correlation has been calculated using daily climate data (Beck *et al.*, 2013; Liang *et al.*, 2013; Castagneri *et al.*, 2015; Jevšenak & Levanič, 2018), to simulate tree–ring chronologies (Touchan *et al.*, 2012) and to improve daily scale reconstructions of rainfall events using tree–ring records (Chun *et al.*, 2017).

Among the various tree–ring studies carried out in India, the Northeastern region of India has lower number of studies in comparison to Northwest and western Himalaya (Shah *et al.*, 2014b). These studies are mostly available from few geographical regions of Northeast India i.e., Arunachal Pradesh (Chaudhary & Bhattacharyya, 2000; Bhattacharyya & Chaudhary, 2003; Bhattacharyya *et al.*, 2008; Shah *et al.*, 2009; Shah & Bhattacharyya, 2009, 2012; Shah *et al.*, 2019), Sikkim and Darjeeling Himalaya (Bhattacharyya & Chaudhary, 2003; Shah *et al.*, 2014a, Yadava *et al.*, 2015; Shah & Mehrotra, 2017; Borgaonkar *et al.*, 2018), Meghalaya (Chaudhary & Bhattacharyya, 2002; Shah & Bhattacharyya, 2012) and Mizoram (Upadhyay *et al.*, 2019). In addition, a single dendrochronological study is reported from the state of Manipur carried out by Singh *et al.* (2016). In all these studies,

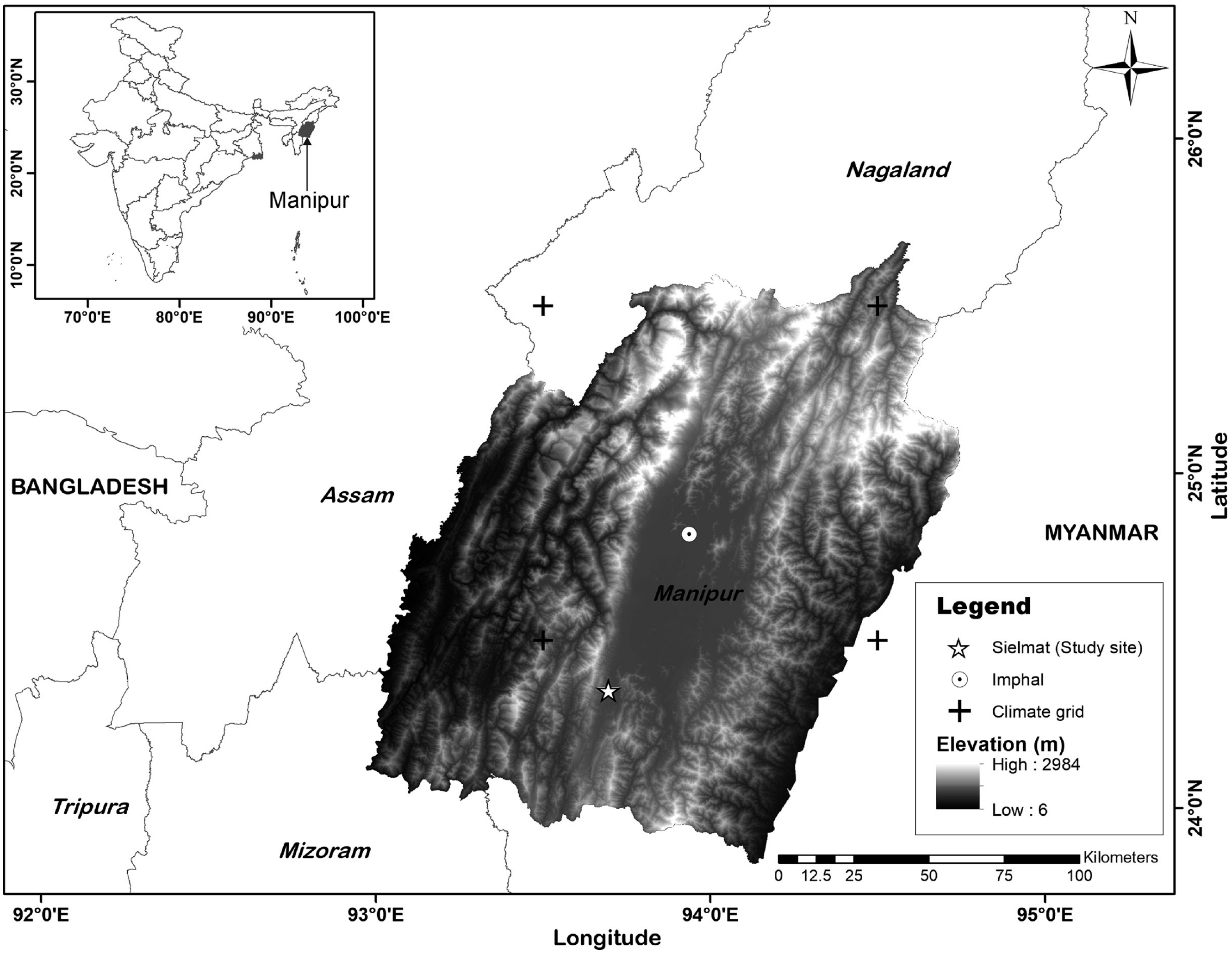

Fig. 1—Map showing tree core sampling site along with daily climate grid points from Indian Meteorological Department (IMD).

monthly precipitation and temperature are used to derive their response on tree growth. Thus, in the present study we made a maiden attempt to understand the response of daily climate on radial growth of Khasi Pine (*Pinus kesiya* Royle ex Gordon) in Manipur, Northeast India.

P. kesiya is a three needle pine, native to Cambodia, China, India, Laos, Myanmar, Philippines, Thailand and Vietnam (Armitage *et al.*, 1980). In India it grows mostly in Khasi Hills, Naga Hills and Manipur (Sahni, 1990). It occurs at elevations between 800 to 2000 m asl in Khasi Hills and thrives well at elevation range of 1200 to 1400 m asl (Sahni, 1990). For its proper growth it requires moist conditions having an annual rainfall of 200 cm with well–drained soils, while extreme heat or cold conditions have a detrimental effect on the tree (Krishnamurthi, 1969). The tree–ring studies on this species have been carried out in India (Chaudhary & Bhattacharyya, 2002; Singh & Venugopal, 2011; Shah & Bhattacharyya, 2012; Singh *et al.*, 2016, Upadhyay *et al.*, 2019) and Thailand (Buckley *et al.*, 1995; Pumijumnong & Wanyaphet, 2006; Pumijumnong & Eckstein, 2011). The dendrochronological importance of this species is well established and we further make an attempt to investigate its relationship with climate variations in the Manipur region. The main objectives of the present study are–(i) to understand the dendrochronological potential of *P. kesiya* from the new geographical region of India and (ii) to establish response between tree–rings of *P. kesiya* and daily climate (mean temperature and rainfall).

Study site

The present study has been carried out in Sielmat (24°21'0" N Latitude, 93°41'39" E Longitude, elevation 855 m asl), which is located in Churachandpur District of South Manipur, Northeast India (Fig. 1). This sampling site is situated ~60 km Southwest from Imphal, the capital of Manipur. Climatically, Churachandpur District has a moderate sub–tropical to temperate monsoon climate varying from place to place depending on the density of rainfall and elevation. In the present study, the nearest climate station with continuous record closest to the tree core–sampling site is located at Imphal Airport Meteorological Station, Imphal. This station records monthly mean temperature and total monthly precipitation for 1955–2012 C.E. This dataset has been analyzed in Singh *et al.* (2016) and showed that the station recorded June as the wettest month with total precipitation reaching over 256 mm. The months of May to September receive over 2/3rd of the annual precipitation (1400 mm) and considered as very humid season. The hottest month recorded is September (24.7 °C) and January the coolest (12.8 °C) (Singh *et al.*, 2016).

MATERIALS AND METHODS

Sampling and chronology development

A total of 40 tree cores from 20 trees of *P. kesiya* growing in Sielmat locality was collected using Swedish increment borer. These trees were mostly growing on well–drained soils with gentles slopes. All the samples were brought to the laboratory and processed using standard method of dendrochronology (Fritts, 1976; Speer, 2010). In the laboratory, each tree core was air–dried, glued to a wooden mount and then polished using different grades of sand paper to observe the growth rings under a stereozoom microscope. The rings of each tree core were counted and calendar dates were assigned using crossdating technique. The crossdating was carried out using skeleton plotting method (Stokes & Smiley, 1968). The ring–width of each sample was measured using Velmex tree–ring measurement system with 0.001 mm precision. The computer program COFECHA (Holmes, 1983; Grissino–Mayer, 2001) was used to check for errors in dating.

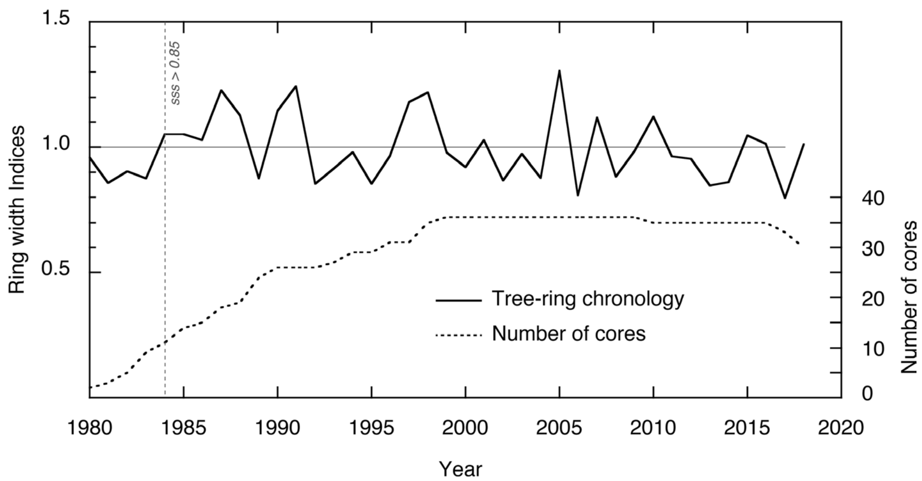

Fig. 2—Residual tree–ring chronology of *P. kesiya* from Sielmat, Manipur, Northeast India spanning from 1980 to 2018 C.E.

The series, which showed error in dating, was either removed or corrected.

The correctly dated tree–ring series were standardized in order to remove the biological growth trends and stand dynamics resulting from age and competition among trees and to preserve the common climatic signals (Cook, 1985). The Friedman super smoother was selected for detrending with the sensitivity set to the moderate flexibility alpha value of 5 (Friedman, 1984). The ring width values of each year are divided by their corresponding fitted curve values to produce detrended ring width indices. The detrended indices of all the series are averaged to develop standard version of tree–ring chronology by using bi–weight robust mean that reduces the effect of outliers (Cook *et al.*, 1990). Similarly, another set of chronology i.e., residual tree–ring chronology was developed where autoregressive modelling was applied to remove the presence of auto–correlation in the standard chronology. The first order auto–correlation was removed in order to remove the effect of previous year growth on current year. Generally, the sample size declines in the early portion of a tree–ring chronology. Thus we used the subsample signal strength (SSS) criteria (Wigley *et al.*, 1984) with a threshold value of 0.85 to determine the most reliable time span of the chronology. The various chronology statistics for both standard and residual chronology were calculated. Further, Pearson correlation analysis, signal to noise ratio was used for the common period to show the degree of association between the tree–ring series.

Climate data and analysis

The tree–ring chronology developed using *P. kesiya* tree cores from Sielmat was further processed to derive influence of climate on its growth. To fulfill the objectives of our present study we procured daily gridded mean temperature and rainfall datasets from the Indian Meteorological Department (IMD), which are available for 1951–2017 C.E. and 1951–2015 C.E., respectively. These daily gridded datasets are spatially distributed in resolution of 1°x1° latitude and longitude. For present study, both temperature and rainfall daily data from four nearest grids (93.5° E/24.5° N, 94.5° E/24.5° N, 93.5° N/25.5° E, 94.5° N/25.5° E) surrounding the sampling sites were extracted (Fig. 1). These four grid datasets are averaged to prepare regional daily temperature and rainfall and further correlated with tree–ring chronology of *P. kesiya*. The

Table 1—Tree–ring chronology statistics of *Pinus kesiya* from Sielmat, Manipur, Northeast India.

	Standard chronology	**Residual chronology**
Series inter–correlation	0.452	
Mean segment length (Years)	30	
Time span of the chronology (Years)	1980–2018 (39)	
Trees / Cores	20 / 36	
Mean sensitivity	0.205	0.179
Standard deviation	0.207	0.140
1st order autocorrelation	0.268	–0.172
Common time period analysis		
Time span	1990–2016	
Trees / Cores	15 / 25	
All series Rbar	0.303	0.201
Within tree Rbar	0.451	0.377
Between tree Rbar	0.298	0.195
Signal to noise ratio	10.893	6.308
Subsample Signal Strength (SSS)	0.916	0.863
Year with SSS > 0.85	1984	
Variance explained in first PC	35.8	24.9

correlation was carried out in R programming environment (R Core Team, 2019) using package *dendroTools* (Jevšenak & Levanič, 2018). This R package allows the comparison of tree–ring variables with daily climatic data by way of sliding a moving window through the daily data of interest and averaging the sum of the data within each window (Jevšenak & Levanič, 2018). The computed averages are then used to derive correlation with tree–ring chronology. The *dendroTools* package takes into account all possible window widths for a specific dendroclimatic window of 12–month period starting January 1 to December 31 in order to identify the optimal sequence of consecutive days, which contains maximum climate signal in the ring width series. In present study, a linear relationship was established using pearson's correlation between the residual tree–ring chronology of *P. kesiya* and daily climate (mean temperature and rainfall) datasets.

RESULTS

Chronology assessment

The wood and ring features of the *P. kesiya* samples collected from Sielmat showed clear zonation between earlywood and latewood. We also observed false rings in both earlywood and latewood portion, which might be due to the changes in soil moisture conditions of the forest. Based on the result of COFECHA, thirty–six successfully cross–dated series were included in the final datasets. The four series, which were poorly correlated with the master site series, were removed from further analysis. The successfully cross–dated tree–ring series has high correlation with the master site series with mean inter–correlation of 0.45. This high value of mean inter–correlation showed higher degree of commonality exists in the individual series contributing to the site chronology. Based on the successfully cross–dated tree–ring series, we prepared tree–ring chronology of *P. kesiya* from Sielmat, which is 39 years and extends from 1980 to 2018 C.E. (Fig. 2).

The standard tree–ring chronology of *P. kesiya* has a first–order autocorrelation of 0.268, which showed that there is an influence of previous year climate on the current year growth. This high first–order autocorrelation was removed in residual version of the tree–ring chronology (Table 1). The mean sensitivity and standard deviation recorded in standard chronology of *P. kesiya* are 0.205 and 0.207, respectively. Both these statistical parameter decreases in the residual chronology (Table 1). For further analysis we have selected residual version of tree–ring chronology of *P. kesiya* in which first order auto–correlation was removed. The correlation between trees, within trees and all series for the residual chronology are 0.377, 0.195 and 0.201, respectively (Table 1). Similarly, other statistical parameters calculated for the common period i.e., signal–to–noise ratio and variance explained by the first principal component are 6.3 and 24.9%, respectively. The SSS value crossed the threshold limit of 0.85 back to 1984 (Wigley *et al.*, 1984).

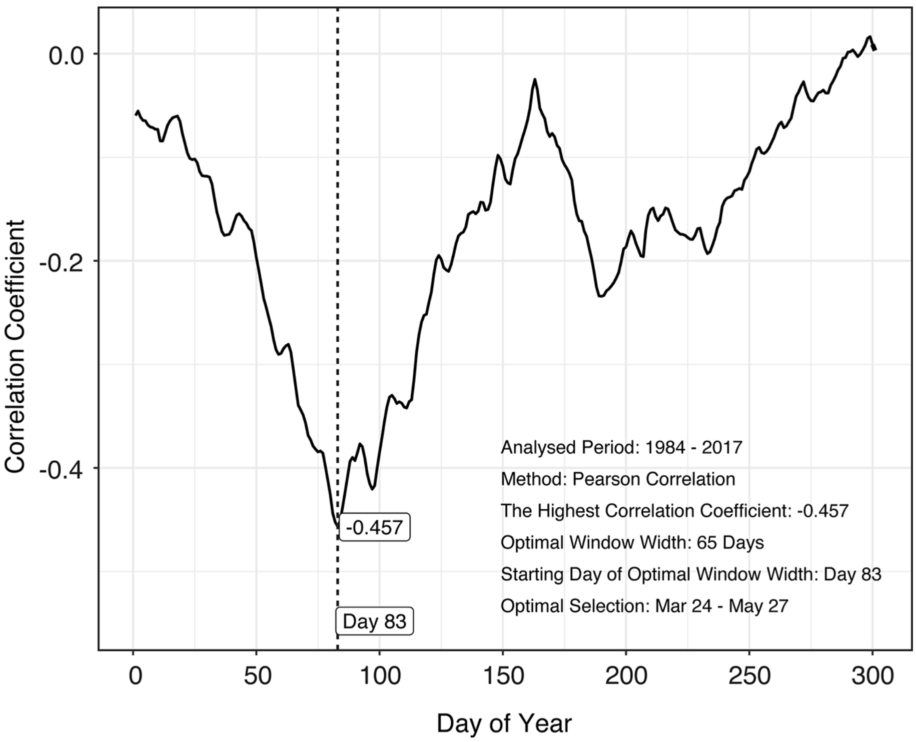

Fig. 3—The maximized correlation coefficient observed with daily mean temperature data for tree–growth of *P. kesiya.*

DISCUSSION

A tree–ring chronology with a low autocorrelation, a high mean sensitivity and a high standard deviation usually is of good potential for dendroclimatological studies. The presence of auto–correlation in our tree–ring chronology showed the current year's growth is correlated with the preceding year's growth, which is caused by influence of previous year's climate on current year's growth. The mean sensitivity is a measure of the relative differences from one annual ring to the next, with values ranging from 0 to 1 (Speer, 2010). The standard deviation is a measure of variations in both low–frequency and high–frequency variances and measures the positive and negative departures from the mean. The moderate values of these statistical parameters are considered normal, as also previously observed in various studies of *P. kesiya* (Chaudhary & Bhattacharyya, 2002; Pumijumnong & Wanyaphet, 2006; Shah & Bhattacharyya, 2012; Upadhyay *et al.*, 2019). The additional chronology statistics calculated for the common period (1990–2016 C.E.), which includes maximum number of tree–ring series also showed a high degree of dendroclimatic potential of this species from the region. The higher percentage of variance explained in first principal component showed common climatic factors influence the growth of trees, which are growing in this region of Manipur. However, the signal to noise ratio is not very high which shows the various exogenous factor such as anthropogenic activities and other environmental conditions might disturb the climatic signal preserved in these trees which are still young and experiencing rigorous growth. Based on the SSS value crossing the threshold of 0.85 from 1984, *P. kesiya* has acceptable common signal strength captured by adequate sample depth (Wigley *et al.*, 1984) from 1984 to 2018 in the present study.

The correlation between residual tree–ring chronology and daily mean temperature for time period covering 1984–2017, showed highest negative correlation coefficient,–0.457 with a window width of 65 days, starting on day of year 83 of the current growing season. Thus the ring width of *P. kesiya* therefore contains the optimal temperature signal from March 24 (day of year 83) to May 27 (day of year 147) (Fig. 3). Similarly, the correlation of residual tree–ring chronology with daily rainfall data for time period covering 1984–2015, showed highest positive correlation coefficient, 0.459 with a window width of 30 days, starting on day of year 55 of the current growing season. Thus the ring width of *P. kesiya* contains the optimal rainfall signal from February 24 (day of year 55) to March 25 (day of year 90) (Fig. 4). The relationship of daily mean temperature and rainfall with radial growth of *P. kesiya* depicted a reverse response to each other during pre–monsoon period. This response showed that the availability of soil moisture during pre–monsoon season is an important factor for regulating the annual growth of *P. kesiya* in Sielmat, Manipur, Northeast India. These climatic

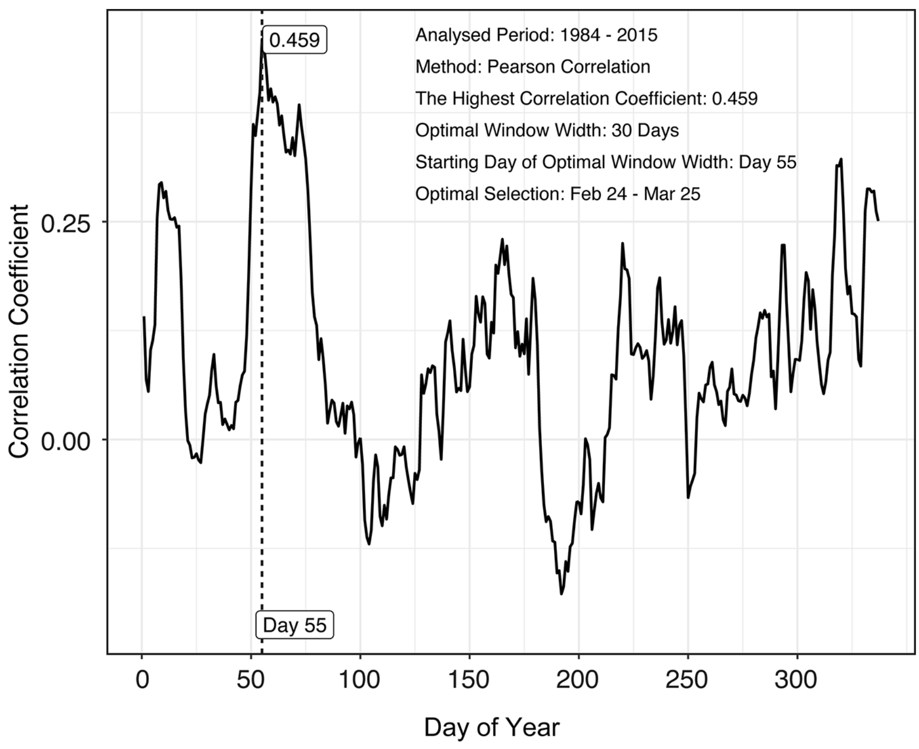

Fig. 4—The maximized correlation coefficient observed with daily rainfall data for tree–growth of *P. kesiya.*

responses of high temperatures and low precipitation during pre–monsoon, might promote high evapotranspiration rates and lower soil moisture content creating moisture–stressed conditions for the trees thereby limiting growth. A similar result was also reported from Northern Thailand where the cambial activity of *P. kesiya* is strongly determined by soil moisture (Pumijumnong & Wanyaphet, 2006). The pre–monsoon season is characterized by rising temperature and relatively dry conditions interspersed by intermittent precipitation with generally clear skies. Northeast India receives 25% of its annual precipitation during this season, more than half of which is contributed by thunderstorms (Mahanta *et al.*, 2013). The pre–monsoon season is also the hottest season of the year when the maximum temperatures are recorded in India (Kothawale *et al.*, 2010).

The response of daily climate observed in radial growth of *P. kesiya* from Sielmat, Manipur is consistent with other tree–ring studies on *P. kesiya* carried out from other areas with monthly climatic records. The present result is consistent with the peak period of cambial activity of *P. kesiya* observed during March and April in Meghalaya (Singh & Venugopal, 2011). The activation of the cambium of *P. kesiya* growing in Meghalaya was attributed to a gradual increase in temperature towards the end of February (Singh & Venugopal, 2011). The study by Singh *et al.*, (2016), which is the only other tree–ring study in Manipur, also found significant negative correlations of *P. kesiya* tree–ring chronology with the mean temperature of April–June. However, they have not observed any significant correlations with precipitation for the same species. Chaudhary and Bhattacharyya (2002) also reported significant positive correlations of tree growth with the precipitation in March for *P. kesiya* in two sites from Shillong, Meghalaya. Similarly, Shah and Bhattacharyya (2012) also reported negative response for the growth of *P. kesiya* with mean temperature of May and June. The study carried out by Pumijumnong and Eckstein (2011) corroborated with our results, where they noted significant positive correlations with March–April precipitation and significant negative correlations with March to May mean temperature for *P. kesiya* and *P. merkusii* from Northwestern Thailand.

CONCLUSIONS

The successful crossdating of tree–ring series of *P. kesiya* in the present study records the dendroclimatic potential of these trees collected from the South Manipur, Northeast India. The response of daily climate (mean temperature and rainfall) on radial growth of *P. kesiya* has been successfully established which has not been carried out previously in the Indian region. Based on the response of daily climate, growth of *P. kesiya* in the study area is strongly determined by soil moisture during pre–monsoon season. The present study however, needs exploration of more sites and collection of additional samples for developing longer tree–ring chronologies in order to obtain a much more definitive scenario of the climatic conditions regulating tree growth of *P. kesiya*. But the present analysis opens the arena towards the study of daily climatic response in relation to the growth of annual ring producing tree taxa in various geographical regions of India.

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