REVIEW ARTICLE

Legendary Old Conifer Trees in Western Himalaya: Environmental Chronicles

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Abstract

The Himalayan mountain system is the abode of diverse tree species growing at different elevations from sub-tropical to sub-alpine regions. Many of the tree species growing in the Himalayan region are known to attain several centuries to millennial age. Trees growing in environments with seasonal climate produce annual growth rings, which represent yearly increment in radial growth. The physical and chemical properties of annual wood increments (ring-widths, wood density and isotopic composition) reflect the respective year's environmental conditions that affected tree growth and physiology. Various parameters of the annual wood increments are used to glean the yearly environmental variations. This makes the trees a unique natural archive of past environmental changes the tree faced over its life time. Tree-ring studies, so far carried out in India have shown over two millennia old trees of *Juniperus polycarpos* in cold arid Lahaul in the western Himalaya. Other conifer trees spanning over millennium age are of *Pinus gerardiana* and *Cedrus deodara* growing in extreme dry environments in the western Himalaya. As in the era of changing global climate the mean temperature of the Earth is continuously increasing and disturbing the regular pattern of climate variables. In the recent decades, the observed changes of climate variables are becoming the cause of societal challenges and responsible for the loss of lives and natural resources. In view of this, the precisely dated growth ring sequences in such old trees have been used to develop climate records (temperature/precipitation) for regions of the origin of tree-ring chronologies. The tree-ring derived climate records from the high-altitude regions of the Himalaya, where instrumental records are limited, are of significant value to understand natural climate variability and associated socioeconomic challenges in regional and global perspective.

Keywords: Climate, Conifer, Himalaya, Societal challenges, Tree-ring.

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Introduction

Growth ring forming trees, where annual radial wood increment could be precisely dated to the exact calendar year, so that growth ring parameters can be calibrated with weather records, are used to decipher past environmental conditions. The length of records developed using tree-ring parameters depends on the chronology length used, which largely depends on the availability of old trees. The Bristlecone pine (*Pinus longaeva* Engelm.) growing in east-central California's White Mountains, USA, is the world's oldest known living tree (Ferguson, 1968). The oldest named individual tree of Bristlecone pine, christened "Methuselah", first reported by Dr. Edmund Schulman (USA), was 4,800 years old (Ferguson, 1968). Another specimen of Bristlecone pine sampled by Schulman again in the White Mountains even aged 5,070 years, which is currently the oldest verified living tree in the world (Ferguson, 1968). The tree-ring chronology of living bristlecone pine linked with the growth ring sequences from dead woods have helped in developing an over 9,000 years long annually resolved chronology (Ferguson, 1968).

Trees in pristine forest stands attaining old age are crucial for extending the climate records back to centuries and even several millennia. The oldest trees are found usually in arid environments, where the resinous nature of conifer wood and low moisture content provide resistance against wood decay. The growth ring sequences of trees growing in climate stressed sites show high variations in ring-width (sensitive sites) due to the high interannual fluctuations in weather parameters. In contrast, trees growing over the sites having congenial climate do not show high variation in annual growth ring sequences and generally produce similar growth-rings (complacent sites). Hence, trees growing in sensitive sites are ideal candidates for environmental studies due to ease in high precision dating of growth ring sequences. In high altitude sub-alpine regions of the Himalaya, where the growing season is cool, tree growth is mostly limited by temperature. Many conifer species like Himalayan pencil cedar (*Juniperus polycarpos*), Neoza pine (*Pinus gerardiana*) and Himalayan cedar (*Cedrus deodara*) growing in harsh ecological conditions are found to attain very high age (Singh *et al.*, 2004, 2009; Singh and Yadav, 2007; Yadav, 2012; Yadav *et al.*, 2011; Yadava *et al.*, 2016; Misra *et al.*, 2020). Yadav *et al.* (2006) first reported a 1584-years (AD 420-2003) old tree of Himalayan pencil cedar from Lahaul-Spiti, Himachal Pradesh. Later in the same forest belt in Lahaul-Spiti, another old tree of Himalayan pencil cedar reaching 2023-years (16 BC-AD 2006) was discovered (Fig. 1), which still holds the oldest tree age record in

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India (Yadav, 2012). Similarly, ages of some other conifers in cold arid regions of the western Himalaya have been found to extend beyond one millennium. Such old trees are found growing over steep rocky slopes, where human approaches are very difficult. In many cases, we used ropes to approach the target trees for sampling (Fig. 2). The oldest trees found in Kinnaur, Himachal Pradesh region as reported by Yadav in 2012 are *P. gerardiana* (1556-years (AD 456-2011) (Fig. 3) and *C. deodara* (1089-years (AD 923-2011), Fig. 4) (Yadava *et al*., 2016). These studies endorsed that the Himalaya is the natural abode for legendary old trees, which have the phenomenal potential to provide valuable long-term environmental information archived in their growth ring sequences. Here, we present two case studies of the longest

Fig. 1: The oldest known Himalayan pencil cedar tree growing in Lahaul-Spiti, Himachal Pradesh, western Himalaya.

Fig. 3: Old Neoza pine stand in Kinnaur, Himachal Pradesh, western Himalaya. It is notable that the oldest known tree of neoza pines are met on such rocky locations where soil cover is very thin.

Fig. 2: Old age Neoza pine growing on steep rocky slope. An old Neoza pine tree in Kishtwar, Jammu and Kashmir being approached with the support of rope for sample collection.

Fig. 4: Old Himalayan cedar growing on rocky terrain. Umbrella shaped canopy, crown die-back and thick barks are important features of old trees.

temperature and precipitation records developed using ring-width parameters to show the potential utilities of old trees in understanding the long-term variability in climate.

Tree-ring Based Millennial Climate Records from the Himalaya

Basic to tree-ring based climatic studies is the fact that each consecutive annual growth ring in trees formed over their life span is precisely assigned to the calendar year in which the ring was formed (Stokes and Smiley, 1968; Fritts, 1976). Tree-ring samples in the form of increment cores or discs taken from a living tree have the chronology control provided by an outermost ring with a precisely known date that is the year when outermost ring was formed. In ward from this outermost ring of known age, successive inner annual growth layers are assigned sequentially to earlier years. A pattern of wide and narrow rings, which is common to all samples of a tree species collected from a homogeneous site, forms the basis for cross-dating among specimens. But in many cases mere counting of rings may not be always correct in assigning the calendar year to growth rings largely due to missing/false rings (Stokes and Smiley, 1968). Trees on arid sites having extremely slow growth rates are very likely to have frequent missing rings in certain parts of the radii. However, false (multiple) rings might also occur in certain years due to intra-annual variations in climate during the growth season. Such false rings are noted to be very common in juvenile trees, which experience short-term intra-annul environmental perturbations due to their shallow root system. Therefore, it is essentially required to find out the positions of missing/false rings for precise dating of growth ring sequences. The location of such missing/false rings in a specimen is verified by cross-dating its ring-with pattern with the pattern in other trees over a site. The tree-ring parameters (ring widths, density, stable isotopes) of dated growth ring sequences are measured and individual series merged to prepare the master chronology after removing the biological growth trend in the series (Fritts, 1976). In this way, tree-ring chronologies of various species have been prepared from the Himalayan region in India. The chronologies extending over the past thousand years are from *J. polycarpos* (2023-years, 16 BC-AD 2006; Yadav, 2012) from Lahaul, *P. gerardiana* (1556-years, AD 456-2011; Yadava *et al.*, 2016) and *C. deodara* (1089-years, AD 923-2011; Yadava *et al.*, 2016) from Kinnaur in the western Himalaya. A network of chronologies of these species developed from the homogeneous sites has been utilized to develop temperature and precipitation records for the region. The longest records of temperature and precipitation reconstructions so far available from the western Himalayan region are presented here.

Temperature Records

The globally increasing temperature in recent decades likely affect ecosystem services and are therefore of global concern. The IPCC-AR6 (2021) report highlighted that in comparison to any other 50 year period in last 2000 years, the global surface temperature has increased faster since 1970. Such warming and associated climate change poses disaster risk for the globe. However, ecosystem response to climate change could be region-specific due to strong regional variability in climate. In view of this, close networks of long-term climate records from different regions of the Earth are needed to understand long-term natural variability in climate. The available climate records from high altitude regions of the Himalaya are few, and in some cases go back to the last decade of the 19th century. Annually resolved tree rings provide valuable proxy to augment the observational records back to several centuries and millennia. To understand the long-term temperature variability, Yadav *et al.* (2011) first developed a millennium long mean summer temperature reconstruction from Lahaul-Spiti, Himachal Pradesh (Fig. 5). Lahaul-Spiti is a cold desert in the monsoon shadow zone of the western Himalaya. The Himalayan pencil cedar (*Juniperus polycarpos C. Koch*) from 30 high-elevation sites were used in this study. The Himalayan pencil cedar has the ability to survive in cold climatic conditions, and due to this unique nature, old age trees over 1500 years are very common in Lahaul-Spiti. A regional temperature series prepared by merging homogeneous instrumental temperature records from several weather stations in the western Himalaya was used in analysing the climate signal in tree-ring chronologies. Tree growth climate relationships revealed that the temperatures from May to August (May-August) of the growing season have significant negative correlations with radial growth of Himalayan pencil cedar, indicating that warm summers hamper tree growth. Using this relationship, May-August temperatures were reconstructed for the western Himalayan region extending back to the AD 940 (Yadav *et al.*, 2011, Fig. 5). The May-August temperature record showed centennial-scale variability, revealing extended periods of above average temperatures during the 11th–15th centuries. This warm period was consistent with the Medieval Climate Anomaly (MCA) (Lamb, 1965) and also showed resemblance with warmth on the southern Tibetan Plateau (Yang *et al.*, 2003) and the north-eastern Tibetan Plateau (Zhu *et al.*, 2008). The mean summer temperature reflected a decreasing trend since the 16th century with the coldest interval of the last millennium during the 18th–19th centuries for the western Himalayan region. The coldest interval of the last millennium reflects strong consistency with the glacial expansion in the western Himalaya. Further, the period from 1810-1909 was recorded as the coldest hundred years in the reconstruction. Tree-ring based temperature records from other regions in Central Asia also showed good agreement with the cold phases observed in the May-August temperature record for the western Himalaya.

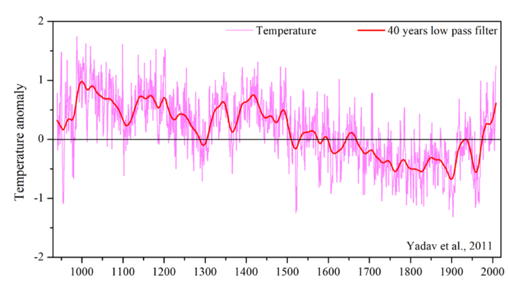

Fig. 5: Tree-ring based summer (May-August) temperature record (AD 940-2008) for the western Himalaya (Yadav *et al.*, 2011). Thick line represents 40-year low pass filter.

A northern Mongolia temperature reconstruction (D'Arrigo *et al.*, 2001) showed that the 19th century was the coldest of the last millennium, while strong consistency was also noted with temperature reconstructions from the Tien Shan (Esper *et al.*, 2003). The 20th century summer mean temperature showed a warming trend, though it was observed that the MCA was warmer than the 20th century (Yadav *et al.*, 2011). Such long-term temperature records from different regions of the Himalaya are useful for a better understanding of synoptic scale natural variability in temperature.

Precipitation Records

Precipitation is one of the most important variables of the climate system, which in combination with temperature, humidity, wind and solar insolation defines the actual climate of a particular region. Precipitation in the Himalayan region shows high spatial variability due to strong orographic forcing. The Himalayan region experienced several disasters either due to excessive precipitation causing floods or precipitation failures resulting in droughts. In the absence of long-term weather records the extremity and recurrence behaviour of such events is not known. High-resolution tree-ring-based precipitation records supplementing the weather records back to several centuries help in visualizing the natural variability and also identify forcing factors responsible for the extreme events.

Tree-ring records from the western Himalayan region have been used to develop over millennium-long precipitation records, especially for the winter and spring seasons. The cold arid region of upper Kinnaur in Himachal Pradesh receives about two thirds (~68%) of its annual precipitation through the mid-latitude westerlies during winter (December to February) and spring (March to May) seasons (Yadav 2011; Yadava *et al.*, 2016). The physiography of mountains in the cold arid region of Kinnaur, Himachal Pradesh provides an ideal habitat for *P. gerardiana* and *C. deodara*. On rocky steep slopes, beyond the reach of humans, very old age trees of these species are found (Singh *et al.*, 2009; Singh and Yadav, 2013; Yadav, 2013; Misra *et al.*, 2015). Large networks of chronologies were developed from moisture stressed sites in Kinnaur, Himachal Pradesh that revealed a direct and significant relationship with spring season (March to May (MAM)) precipitation (Yadava *et al.*, 2016). A March to May precipitation reconstruction extending from AD 1030-2011 was developed using a tree-ring chronology network of *Pinus gerardiana* and *Cedrus deodara* (Fig. 6). The reconstruction revealed extremely dry conditions during the

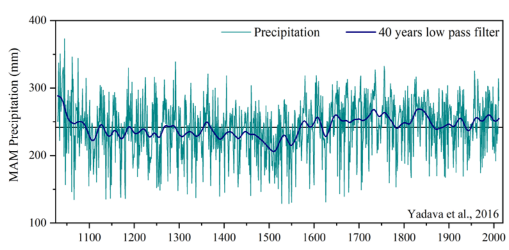

Fig. 6: Spring (March to May) precipitation reconstruction (AD 1030-2011) for the western Himalaya (Yadava *et al.*, 2016). Thick line represents 40-year low pass filter.

12th to mid-16th century and relatively wet conditions from the mid-16th century to 2011. Within the extended dry period (12th to mid-16th century), one of the driest phases was identified from AD 1490-1514. The precipitation during this period was about 15% lower than the long term mean. The reduction in spring precipitation during the late 15th to early 16th century was also consistent with other hydroclimatic records developed from the western Himalaya (Singh *et al.*, 2009; Yadav, 2011, 2013). The extreme drought event of the late 15th to early 16th century is also reflected in precipitation records developed from Jammu and Kashmir region (Singh *et al.*, 2021). Similarly, the 1970-71 drought was also widespread in large parts of the western Himalaya, Himachal Pradesh (Yadav, 2011, 2013; Yadav and Bhutiyani, 2013) and Jammu and Kashmir (Singh *et al.*, 2017, 2021; Yadav *et al.*, 2017). In Kinnaur region, about 67% of Himalayan cedar and 63% of Neoza pine trees had missing rings during 1970-1971 (Yadava *et al.*, 2016), indicating the severe impact of drought on tree growth. The high percentage of missing rings over Kinnaur in a drought year suggested the importance of soil moisture availability for the radial growth of trees. The wettest period of the past millennium was observed in the precipitation reconstruction during AD 1820–1844. The precipitation during this period was about 13% above the long term mean. However, an increasing trend in precipitation was noted since the mid-16th century, and according to Yadava *et al.* (2016), this pluvial condition showed consistency with the expansion of glaciers over the Karakoam (Hewitt, 1982) and lake level increase in arid Central Asia (Yang *et al.*, 2009). The pluvial conditions observed in the MAM reconstruction during the mid-16th century to 2011 also denotes resemblance with the Standardized Precipitation Index (SPI2-May) developed for the Kishtwar, Jammu and Kashmir regions (Yadav *et al.*, 2017). The SPI2-May reconstruction developed using Neoza pine and Himalayan cedar tree-ring chronologies (AD 1439-2014) indicated dry conditions from 1439 to 1660s and pluvial conditions from 1670s to 2014 in the Kishtwar region. Within the pluvial phase, the wettest period was noted in the last 31 years during AD 1984–2014. According to Yadav *et al.* (2017) this wetting coincides with glacial expansion in the Karakoram Himalaya and suggested a strengthening of westerlies in past few decades.

Societal Implication of Climate Change in Himalaya

Climate change plays an important role in shaping the ecosystems and societal well-being. Extreme weather events lead to reduced ecosystem productivity, possibly resulting in scarcity of food and livelihoods. Many of the ancient human civilizations are known to have been severely affected by climatic extremes, which severely limited the availability of life sustaining resources. Displacement, deurbanization of human settlements and collapse of the Indus Valley civilization have been linked with the deterioration of climatic conditions, such as weakening of the Indian summer monsoon (Staubwasser *et al*, 2003). Using tree-ring based records from the western Himalaya, we show that adverse climatic conditions that prevailed over decades to centuries severely affected the human societies in the historical past. The millennium long summer temperate reconstruction for the Lahaul-Spiti region showed strong consistency with glacio-archeological records developed by Saini *et al.* (2019) from

Lahaul Himalaya. Saini *et al*. (2019) identified settled colonization during the late 10th to early 19th centuries in the glacial moraine complex of Tharang, Miyar basin, at an elevation more than 3500 m asl in Lahaul. They marked settled agriculture at three sites namely Tharang, Phundag and Patam, largely due to warm temperatures and limited snowfall, allowing permanent settlements within the end-moraine complex. According to Saini *et al*. (2019), in Miyar basin, Lahaul Himalaya, glacial advances occurred in the late-18th and early-19th centuries, resulting in abandonment of settlements.

Similarly, the last millennium precipitation records developed from the western Himalaya (Yadava *et al*., 2016) showed several episodes of climatic challenges which strongly impacted the socioeconomic lives of the region. According to Yadava *et al*. (2016), low precipitation periods recorded in boreal spring precipitation showed strong consistency with Central Asian droughts (Hughes-Butler, 1907). In 1856, the reconstructed precipitation was 30% below the long-term mean and showed close linkage with famine in Toba and Kandahar, where wheat production was severely reduced due to droughts (Hughes-Butler, 1907). During the time of famine, the poverty was at its worst level and girls were said to be exchanged for goats (Hughes-Butler, 1907). Similarly, again in 1870 the food scarcity over Toba was found to be associated with the failure of precipitation, when the western Himalaya recorded precipitation was >20% lower compared to the long-term mean of the reconstructed boreal spring precipitation (Yadava *et al*., 2016). Even the failure of crop production was recorded in the Kumaon region because of the failure of winter and spring precipitation (Yadav *et al*., 2015). The centennial scale low precipitation period captured in the MAM precipitation reconstruction during the 12th to early 16th centuries also coincided with dry conditions in Central Asia (Yadava *et al*., 2016). The ruler of Kabul (Afghanistan) Zahiru'd-din Muhammad (Babur), wrote in his biography that in the early 16th century desert type conditions occurred, with strong winds over Kabul (Beveridge, 1921). Around twenty-five invasions over India from the Central Asian tribes occurred during the last millennium, when periods of prolonged droughts occurred in Central Asia from the early 12th to the early sixteenth centuries (Yadava *et al*., 2016). However, only six invasions occurred in the mid-18th century, when conditions were pluvial. According to Yadava *et al*. (2016), severe arid conditions over Afghanistan occurred since AD 1000, which persisted for more than three centuries. During this period the sultan of the Ghurid Empire in Afghanistan attacked India continuously in the late 12th century (Yadava *et al*., 2016), and nomads' migration also occurred towards south in search for pasture grounds (Faraser-Tytler and Kerr, 1967). Speleothem $\delta^{18}O$ based summer monsoon records revealed ample rainfall during the 12th century over India, when summer monsoon contributed 2/3rd of its annual precipitation (Sinha *et al*., 2011). Therefore, good agricultural production in monsoon-dominated regions of India was supported by sufficient precipitation, whereas the westerly dominated western Himalaya and Central Asia under the grip of long-term droughts experienced crunch in agricultural production. Scarcity of life sustaining resources in Central Asian regions is hypothesized to be an important reason to incite invasions of India during the Medieval period (Haig, 1928).

Conclusions

The Himalayan Mountain system provides a natural abode to old living trees. These old living trees archive the chronologically varying environmental features in their annual growth rings. Himalayan pencil cedar (2023-years, 16 BC-AD 2006) holds the record of oldest living tree in the western Himalaya. Other conifer species known to grow over millennium age in the western Himalaya are Neoza pine and Himalayan cedar. Annually resolved ring-width chronologies from such old trees are unique archives of environmental variables. Therefore the old living trees should be protected from anthropogenic encroachments and exploitations to preserve the trees living for longer period. The awareness of the society and/or communities living close to the pristine forest stand could be of a serious step towards saving the old living trees and forest in the remote Himalayas. Long-term climate records derived from such climatically sensitive tree-ring series have greatly helped in understanding natural variability in climate. Tree-ring derived climate series have portrayed inter-annual, decadal and centennial scale variability. It has been found that the human settlements in the high elevation regions of the western Himalaya were adversely affected by long-term climate extremes. Climatic adversities especially in Central Asia during the MCA caused severe scarcity of livelihood resources. Most of the invasions of India arising from Central Asian regions during the MCA were largely to acquire wealth and other livelihood resources. This finding endorses that competition to acquire resources has been the major cause of conflict in the historical past. Further, along with the study of tree-ring-width, other parameters such as stable isotope, wood density and anatomical features of the growth-ring sequences have immense potential to analyse the past and therefore very useful to understand the climatic variability and its societal challenges. However, protection of the old living trees and their natural habitat is a serious concern in the era of anthropogenic advancements and therefore, we strongly believe that there is an urgent need to take steps towards protecting their lives by collective approaches and responsibilities.

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