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A 1584-year ring width chronology of juniper from Lahul, Himachal Pradesh: Prospects of developing millennia-long climate records

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We report here a 1584-year (AD 420–2003) long ring width chronology of Himalayan pencil cedar from cold arid region in Lahul, Himachal Pradesh. Ring width variations in trees at this site are found to be associated with variations in precipitation from previous growth years' September to concurrent May. Potential of this chronology in developing millennia-long hydrological records is recognized. Strong relationship between the present Himalayan pencil cedar chronology and two Himalayan cedar ring width chronologies prepared earlier from stands adjacent to the present site, demonstrates the utility of tree ring data network of these species in developing robust reconstructions needed for better insight into climate variability in longer perspective in the precipitation-deficient trans Himalayan region.

Keywords: Hydrological records, *Juniperus macropoda*, Lahul, precipitation variability, ring width chronology.

THE Himalayan mountain system, the highest one on earth, has strong influence on regional and extra-regional circulation system. High-elevation mountain heating, snow/glacier albedo and glacier melt freshwater flux into the ocean provide a strong land–ocean–atmosphere interactive system. In view of this, long-term high-resolution climate records for this data-scarce region are important to develop better insight into the climate change behaviour on regional and global scale.

The trans Himalayan region holds a potential treasure of high-resolution proxy records of climate like tree rings, lake deposits, ice cores, etc. Among these, tree rings are unique in terms of the existence of precise dating control to the level of calendar years. Various workers have earlier developed tree ring chronologies from India to reconstruct past climatic variability patterns prior to instrumental records for distinguishing natural and anthropogenic climate change[1–7]. However, the tree ring chronologies reported so far span few centuries, except for the lone record of millennium-long chronology of Himalayan cedar from western Himalaya[8].

Here we report the tree ring chronology of Himalayan pencil cedar (*Juniperus macropoda* Boiss.), which is the longest so far for the Indian region. Potential of this chronology prepared from moisture-stressed site in developing millennia-long hydrolological records is recognized. Such long-term records are essential to understand natural climate variability and for the validation of climate prediction models.

Himalayan pencil cedar is found[9] in the inner arid regions of northwest Himalaya to as far as Kumaon at altitudes from 1500 to 4300 m. It is a cold and drought-hardy tree growing in areas where rainfall is as low as around 30 cm. For the present study, tree ring samples of Himalayan pencil cedar were collected from dry moisture-stressed site near Keylong, Lahul and Spiti district, Himachal Pradesh (Figure 1). This area lying on the northern side of Pir Panjal range in Lahul and Spiti district, falls in the monsoon arid transition zone and is considered to be a potential indicator of the northern limits of the intensity of monsoon. The area is influenced by monsoon in summer and westerlies in winter. As the area falls in the rain-shadow zone of Himalaya, precipitation occurring in winter and spring is higher than in summer and autumn. Westerly depressions during winter and spring bring cloudy weather and light rains and often cause heavy snowfall at high elevations[10]. The above ecological settings in the region show that the tree-ring records from this region should provide valuable information on long-term precipitation record.

We collected tree-ring samples from old as well as relatively younger trees of Himalayan pencil cedar during May–June 2004. Trees were growing on moisture-stressed south and southeast slopes at altitudes ranging from 2600 to 3300 m asl near Keylong (Figure 1). Old trees were characterized by crown dieback and prominent strip barks (Figure 2). For sampling healthy, undisturbed, distantly growing trees were selected. Increment borers were used

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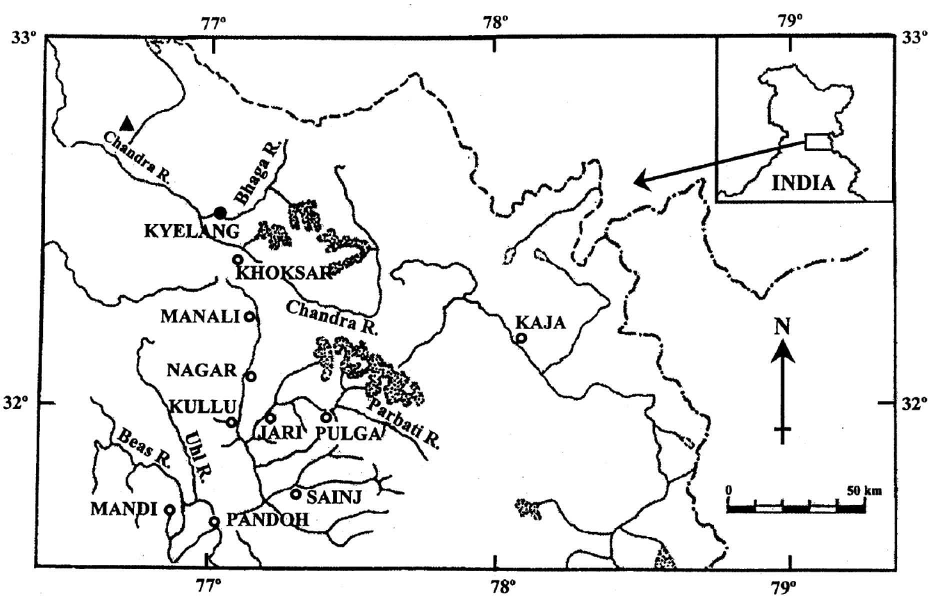

Figure 1. Map showing location of tree ring sampling site (dark filled triangle), and meteorological station (dark filled circle).

Figure 2. Old Himalayan pencil cedar with prominent crown dieback and strip barks.

to extract cores from opposite sides at breast height of the stem perpendicular to the slope direction. Disc samples from snags in the forest were also collected. The openness of stands maximizes the climate variance in the tree-ring sequences, as the effect of inter-tree competition among trees are negligible or greatly reduced. Missing rings were observed frequently, which could be due to climatic stress or wedging of rings. Disc samples provide ideal material to locate the missing rings due to wedging and in our case proved an asset in successful dating of tree core samples. Tree rings were dated employing usual dendrochronological techniques[11,12]. The ring widths of dated samples were measured with 0.01 mm accuracy using linear encoder coupled with personal computer. Dating of ring-width sequences was verified using computer-assisted COFECHA program[13], which identifies tree-ring width series segments that may have dating or measurement errors. Such samples showing dating irregularities were rechecked and errors corrected. The ring-width measurement series were standardized using straight line of either negative slope or no slope. However, in the case of nine samples where low frequency trend appeared to be different from common pattern in the rest of the trees, cubic smoothing spline with a 50% frequency-response cut-off width equal to two-thirds of the series to individual series was used. Ring-width measurement series were standardized after applying a power transformation technique to stabilize the variance[14]. Ring-width indices were obtained by calculating residuals of power-transformed ring width measurements and fitted values. After removing the autocorrelations using an autoregressive model selected on the basis of the minimum Akaike criterion, these indices were combined across all series in each year using biweight robust estimation of the mean to discount the influence of outliers. Standard, residual consisting of high-frequency variations and an arstan chronology composed of the residual incorporated with the pooled autoregression were prepared using the computer program ARSTAN.

For calibration of tree-ring data, weather records from stations close to the sampling sites are required. In the present case, the precipitation records of Keylong meteorological station (Figure 1) falling nearest to the sampling site were used. Though the data length ranges from 1904 to 1999, there were some data gaps. The weather data of Khoksar (1951–1969, with missing records from 1961 to 1965) and Srinagar (1893–2003) were used to estimate the missing values in Keylong precipitation records. However, temperature records from Srinagar valley were used, as no

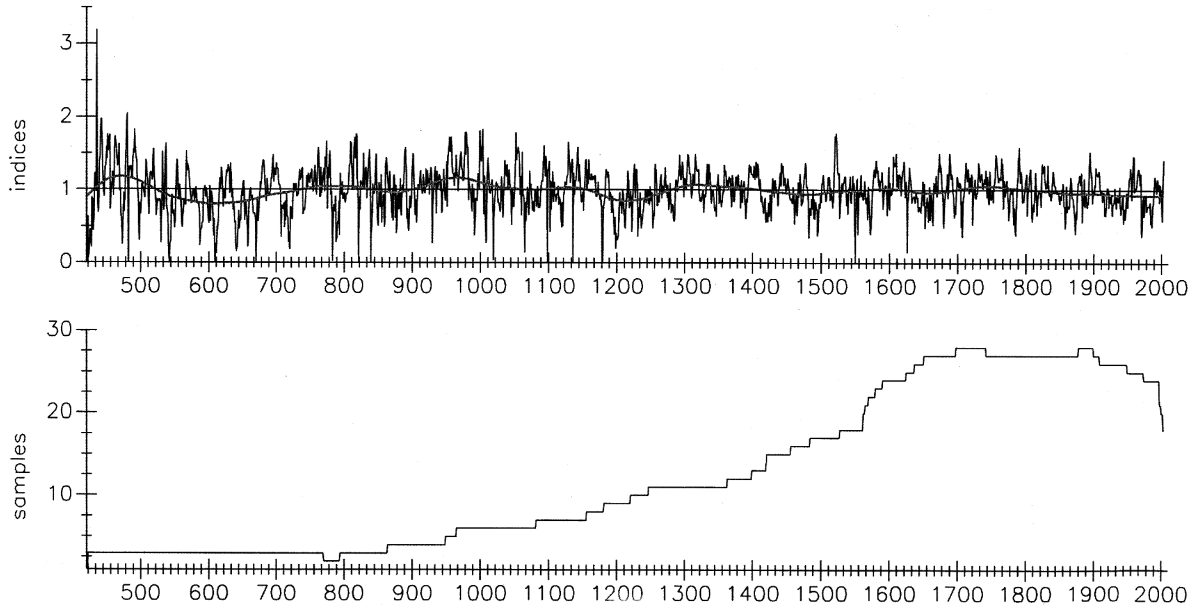

Figure 3. (Upper panel) Ring-width chronology of Himalayan pencil cedar (AD 420–2003). (Lower panel) Number of tree core samples used in the chronology.

Table 1. General chronology statistics of *Juniperus macropoda*

Year	1584 (AD 420–2003)
Tree/core	14/30
Mean	0.984
Standard deviation	0.31
Mean sensitivity	0.23
1st order autocorrelation	0.58
Common period analyses	
Period	496 (1500–1996)
Tree/core	7/14
Signal-to-noise ratio	10.15
Expressed population signal	0.91

other station data nearer to the sampling site were available. Response function analysis[12] was performed to understand tree growth–climate relationship.

We prepared 1584-year (AD 420–2003) chronology of Himalayan pencil cedar from Keylong (Figure 3). This provides the longest record of precisely dated tree-ring chronology from the Indian region. Prior to our present study, Bilham *et al.*[15] reported 1400 rings in one juniper disc sample collected from Hunza Valley, Karakoram, indicating the possibility of developing millennia-long chronology of this species from the northwestern Himalayan region. We hope it could be possible to extend back our present chronology by a couple of centuries more using old tree-ring materials from old houses and driftwoods. Ring-width chronology statistics such as mean sensitivity, and signal-to-noise ratio (Table 1) indicate the potential of the present chronology in climatic studies. However, threshold value of expressed population signal in the chronology (0.85) recommended by some workers[16] for suitability of the chronology for climatic studies was achieved with the replication of eight tree samples.

Response function analyses indicated that precipitation from previous growth years' September to concurrent May have direct relationship with tree growth (Figure 4). However, precipitation during monsoon months does not show significant relationship with radial growth of junipers in this area. Similar relationship was earlier noted between radial growth of Himalayan cedar chronologies prepared from moisture-stressed sites adjacent to the present juniper site and precipitation from Keylong[17]. Cross-correlation among Himalayan cedar chronologies prepared earlier from two moisture-stressed sites in Keylong[17] and the present Himalayan pencil cedar chronology was computed to see inter-species relationship and its applicability in reconstruction of hydrological parameters (Table 2). The relationship has been found to be stronger with the residual (with high frequency variations) ring-width chronologies in comparison to standard chronologies, with strong first-order autocorrelation (with low frequency variations).

Ring-width chronologies of juniper species from other Asian regions have been prepared from lower and upper forest borders. Similar to our chronology, the ring-width chronologies of *J. tibetica* prepared from moisture-stressed sites in Tibet are sensitive to precipitation[18,19] and have been suggested to be useful in developing reconstruction of Indian summer monsoon. However, the chronologies of this genus from upper forest borders in Karakoram, Pakistan and Tien-Shan, Kirghizia are sensitive to mean temperature[20–22]. For different climatic response of the chronologies of juniper available from different ecological

Table 2. Correlation between Himalayan cedar and Himalayan pencil cedar (standard and prewhitened) site chronologies from Lahul for common period AD 1500–2003

Chronology type		Species/site	
		Himalayan cedar/Madgram	Himalayan cedar/Ratoli
Standard	Himalayan pencil cedar/Shakoli	0.65 (0.0001)	0.63 (0.0001)
	Himalayan cedar/Ratoli	0.89 (0.0001)	1.00 (0.0)
Residual	Himalayan pencil cedar/Shakoli	0.72 (0.0001)	0.65 (0.0001)
	Himalayan cedar/Ratoli	0.91 (0.0001)	1.00 (0.0)

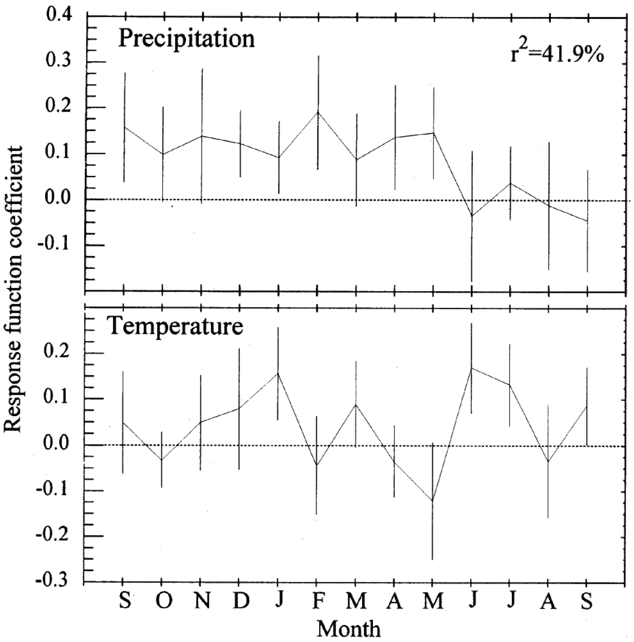

Figure 4. Response function analyses of residual chronology of Himalayan pencil cedar with monthly precipitation at Keylong (1904–99) and mean monthly temperature at Srinagar. Vertical bars are 95% confidence limits.

settings, we could not perform extra regional climatic signature analyses. However, we hope that the network of juniper data from lower forest borders could be useful in developing robust reconstructions of precipitation records.

Dendrochronological study of increment core and disc samples, collected from Himalayan pencil cedar growing in the arid region of Keylong, Lahul and Spiti district, Himachal Pradesh was carried out. The study revealed the existence of good cross-dating in ring-width patterns within and among trees. This helped in developing 1584-year long tree-ring width chronology, the longest so far from the Indian region. Strong relationship between ring-width chronology and precipitation indicated that such chronologies developed from moisture-stressed sites could be useful in developing precipitation reconstructions. Existence of significant relationship between Himalayan pencil cedar and Himalayan cedar chronologies from the same region further enhances the potential of developing robust reconstructions using tree-ring data network of the two species together. Such long-term hydrological records developed for the arid region using a network of multi-species, climate-responsive tree-ring chronologies should help in better understanding of variability in precipitation.

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Utilization of lime sludge waste from paper mills for fish culture

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Lime sludge (mud) waste from a paper mill at Jagiroad, Assam (Hindustan Paper Corporation Limited) can be used as a cheaper alternative source of liming for management of acidic water in the fish ponds of Assam. Lime sludge waste has no toxic substances, but contains 66.5% calcium carbonate. To maintain the alkalinity level of water, 1.5 times more lime sludge waste is required compared to pure lime. Parameters like pH, conductivity, free carbon dioxide, total hardness and dissolved oxygen are increased due to application of lime sludge waste from the paper mill, which are beneficial to the fish as well as fish food organisms. The heavy metals found in the lime sludge waste were below permissible level. Lime sludge has no adverse impact on growth and development of fish, rather it has some beneficial effect on production of fish.

Keywords: Fish production, lime sludge, paper mill, pond management.

ASSAM, situated in the northeastern region of the country, is endowed with vast and varied fishery resources in the form of ponds and tanks (2.5 m ha), floodplain wetlands (*beels*) and swamps (11.2 m ha), and the rivers Brahmaputra and Barak with their numerous tributaries (combined length 4820 km) covering about 334.5 m ha[1]. However, it is stated that the growth and development of fishes are not up to the mark due to acidic nature of water in most of the fisheries of the state. Therefore, it is difficult to achieve the target of fish production. Phytoplankton growth in acidic waters is often limited by inadequate carbon dioxide and bicarbonate ions. Some waters are so acidic that fishes do not survive or grow well. Muds in ponds also are acidic and strongly adsorb the phosphorus added in the fertilizer[2]. Soil pH in the range of 6.5 to 7.5 and water pH in the range of 6.5 to 9.0 are considered to be optimal for fish production[2]. Soils of the state are acidic[3], ranging from 4.6 to 6.8, which is below the optimal range. Thus, in order to achieve optimal fish production, the fish ponds of the state need adequate liming. Lime increases the pH of bottom muds and makes phosphorus readily available, besides increasing the pH and total hardness of pond water. However, addition of large quantities of lime increases the cost of fish production. For example, for correcting acidity of soil in the range of 6.0 to 6.5, a dose of 1000 kg/ha/yr of quick lime (CaO) is required[4], costing an additional financial burden of Rs 6000 (at current prices). Thus, application of lime in fish ponds becomes a costly but unavoidable management option for the poor and marginal fish farmers of the state. Therefore, it has become imperative to search for a cheaper alternative to pure lime for application in fish culture ponds. Limes sludge waste from the Hindustan Paper Corporation Limited (HPC) at Jagiroad, Morigaon district, Central Assam, can be used as alternative source of liming, as it contains high amount of lime[5].

The paper mill generates large quantities of lime sludge every day (940 tons/day). Disposal of this solid waste has become a problem, as it causes abnormal increase in soil alkalinity and damage to vegetation in the vicinity of the dumping ground. Utilization of this waste for fish culture will hopefully serve the dual purpose of pollution abatement as well as reducing the cost of fish culture operation in the state. However, before applying the waste into the fish ponds, it should be ascertained if it has any substance which is toxic to fishes or fish food organisms. Against this background, the present investigation has been carried out for extensive field and laboratory studies on utilization of lime sludge waste from the paper mill for fish culture.

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