The oldest Birch tree in the Western Himalaya depicting signature of major climatic events of the recent era in its tree rings

Over half a millennium old, precisely dated broadleaved trees are rare across the mountain ranges of the world, including the Himalaya. In dendrochronology, oak is widely used in Europe and North America, but in the Himalaya most of its species are not datable. Except for its two deciduous species, *Quercus griffithii* and *Quercus serrata*[1], most of the Himalayan oaks are diffuse–porous woods and absence of other anatomical features delineating tree ring boundary. In the Indian Himalaya, birch (*Betula utilis*), popularly known as 'Bhojpatra', is a typical alpine tree-line species which has been established as a suitable broadleaved tree for dendrochronology[2–4]. Interestingly, it is a 'diffuse–porous' tree and the ring boundary is delineated by a light line of terminal parenchyma[5]. The species epithet, *utilis* literally means various uses and justifies the importance of this tree. As a sacred tree, it is used in various religious rituals. Historically, its bark was used as a paper substitute for writing texts in Sanskrit and is in use even now. It was the only source of writing manuscripts in Kashmir before Emperor Akbar introduced paper in the 16th century. It is documented that well-known early Sanskrit writers like Kalidasa (4th century CE), Sushruta (3rd century CE) and Varahamihira (6th century CE) used the bark of this tree in writing their manuscripts[6].

Birch is well recognized as an indicator species for studying tree-line dynamics[3,5,7–9] and changing position of glacier snouts[5]. Earlier tree-ring analyses from Bhojbasa close to Gangotri glacier in Uttarakhand, India revealed that birch tree can reach ages up to four hundred years in the Himalaya[5].

Here, we report an old living birch tree from the Western Himalaya and argue that it may be the oldest, not only in the Himalaya but also in the globe. In addition, the potential of this tree in climate and ecological studies in the Himalayan region is discussed.

Species of birch grow across the higher reaches of the Himalaya and other mountains as well as in high-latitude areas[10]. *Betula utilis* has a wide distribution, from Afghanistan and northern Pakistan in the west and along the Himalaya in India and through the western Chinese Heng Duan mountains in northwestern Yunnan, to Sichuan in east and Hebei Province in northern China (Figure 1 *a*). It grows between altitudes 2500 and 4300 m amsl. At lower altitudes, it is distributed sporadically. Towards higher altitudes, it forms dense and gregarious stands either as pure forest or mixed with *Rhododendron campanulatum* or *Abies*, and also with juniper and *Salix* spp.

The sampling site located in Darma valley, Kumaun region, Western Himalaya. It shares borders with Tibet, China in the north and Nepal in the east (Figure 1 *b*). The site from where the samples were collected is characterized by open birch forest, growing at 2800–3900 m on the north slope of Mt Panchachuli. The trees have gregarious stands of either pure patches of *B. utilis* or mixed with *A. spectabilis* along the slope of moraines (Figure 2 *a*). In a comparatively flat area, a tree with huge girth (10.4 m) and heavy branches is located near a temple in Tidang, Darma Valley (Figure 2 *b*). It escaped logging because it is protected as a sacred tree. The tree-ring samples in the form of tree cores were collected at breast height (~1.3 m) from this tree

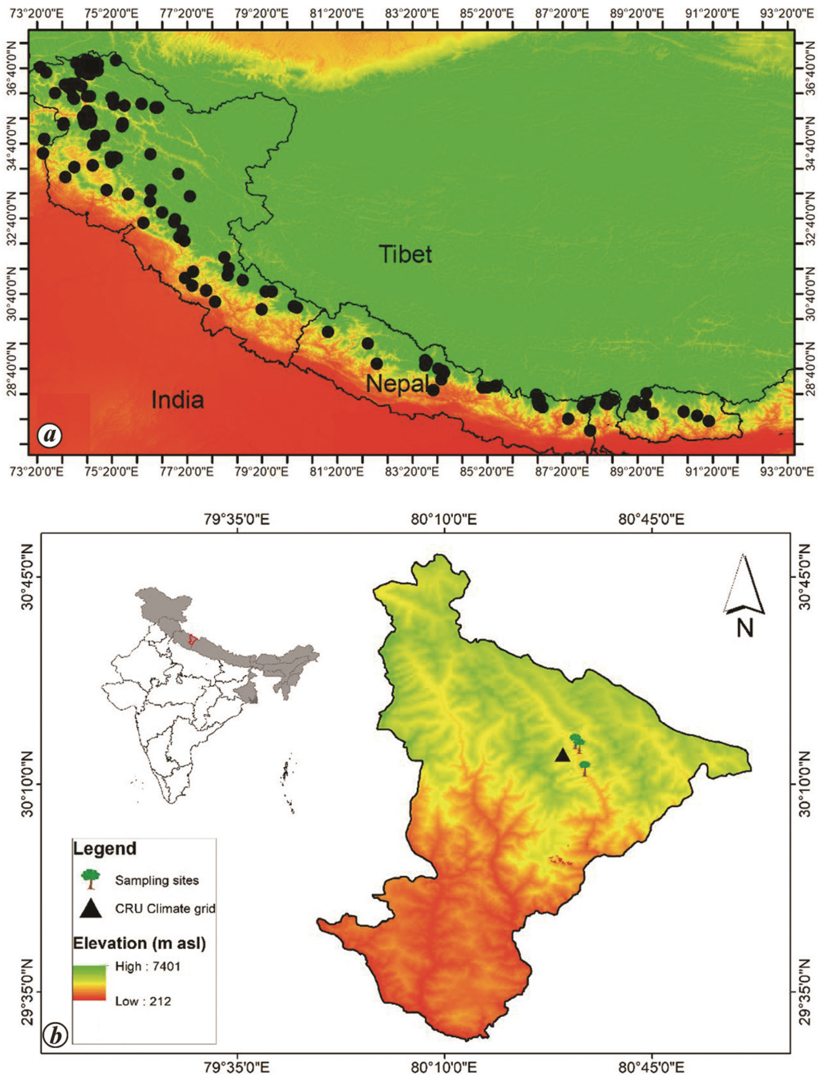

Figure 1. ***a***, Distribution of *Betula utilis* in the Himalaya and adjoining regions (Data source.gbif.org). ***b***, Location map showing sampling sites.

(Figure 2 *c*) using an increment borer, and also from other birch trees growing in the glacier valleys from Baling, Tidang and Sipu. A total of 137 tree core samples from 72 trees were collected from these sites. Climate data for this remotely located study area are not available. Therefore, for comparison of tree-ring width data with climate parameters, data of nearest grid points of Climate Research Unit (CRU T S 4.03) were used for the period AD 1902–2017. Also, we used the long reconstructed Asian temperature data for the region during the period AD 1331–1989 (ref. 11). We assessed temporal changes in temperature with periods of tree growth suppression and release during three major phases of the recent era, viz. Medieval Warm Period (MWP), Little Ice Age (LIA) and warming during recent years.

The collected tree cores of birch were mounted and processed using standard procedures of tree-ring analysis. Counting of the rings under stereo zoom microscope requires careful examination as tree-ring boundaries are faint. Moreover, there are missing rings in many of these cores. Each ring of these cores was dated to the calendar year of its formation using the cross-dating technique[12]. Ring widths of each dated core were measured under increment measuring stage with 0.001 mm precision coupled with a microcomputer. Later, these measurements and dates were checked using the computer program COFECHA[13]. Cores having errors were re-examined to evaluate the source of errors and corrections made. Ring-width series were standardized using the program ARSTAN[14], which removes growth trends related to age and stand dynamics while retaining the maximum common signal. In the present study, we applied 30-year smoothing spline for standardization to remove the high-frequency signals and retain only the low-frequency signals[15]. Cubic smoothing spline curves are efficient to remove non-climatic noise, such as long-term trends and effects of localized disturbance events that characterize natural forest dynamics[15]. Ring-width indices were obtained by calculating residuals of power-transformed ring-width measurements and fitted values. These indices were combined in all the series in each year using biweight robust estimation of the mean. The final chronology was 687 years long, spanning the period 1331–2017 CE (Figure 3). The chronology statistics exhibited high mean sensitivity, and signal-to-noise ratio indicated its dendroclimatic potentiality (Table 1).

An informed idea of life span of birch trees from the Himalaya and its adjoining regions can be generated from the length of this chronology and those from earlier studies in Nepal and India (Table 2). Therefore, the studied birch tree emerges as an oldest dated broad-leaved tree from the Himalaya, covering a time span of AD 1331–2017.

Birch trees attaining such an old age with a long tree sequence are rare. Because of its survival under harsh environmental conditions become critical after attaining certain age. Trees confined at higher altitudes frequently encounter strong winds and natural hazards. Furthermore, the large-scale exploitation of trees for timber, fuel and other multifarious uses may be responsible for their failure to survive for long. In comparison to the chronologies of birch published so far from different parts of the world, the present chronology (over 600 years) is the longest. There is a possibility to extend this chronology since we could not collect samples from this tree that reach up to the centre or pith. With further careful search, we can identify older trees from the present study area. Such long-lived

Table 1. Summary statistics of birch tree-ring chronology

Time period	AD 1331–2017
Common period among all trees	AD 1787–2017
Number of cores/trees	137/72
Mean sensitivity	0.29
Standard deviation	0.32
First order autocorrelation	0.49
Signal-to-noise ratio	14.76
Expressed population signal	0.92

Table 2. Reported age structure of *Betula utilis* across the Himalayan region

Reference	Study area	Time span (AD)	Chronology length
Present study	Darma Valley, India	1331–2017	687
5	Gangotri, India	1751–2002	452
8	Nepal	–	Approx. 450
18	Nepal	1831–2012	182
17	Nepal	1655–1998	344
7	Nepal	1552–2009	458

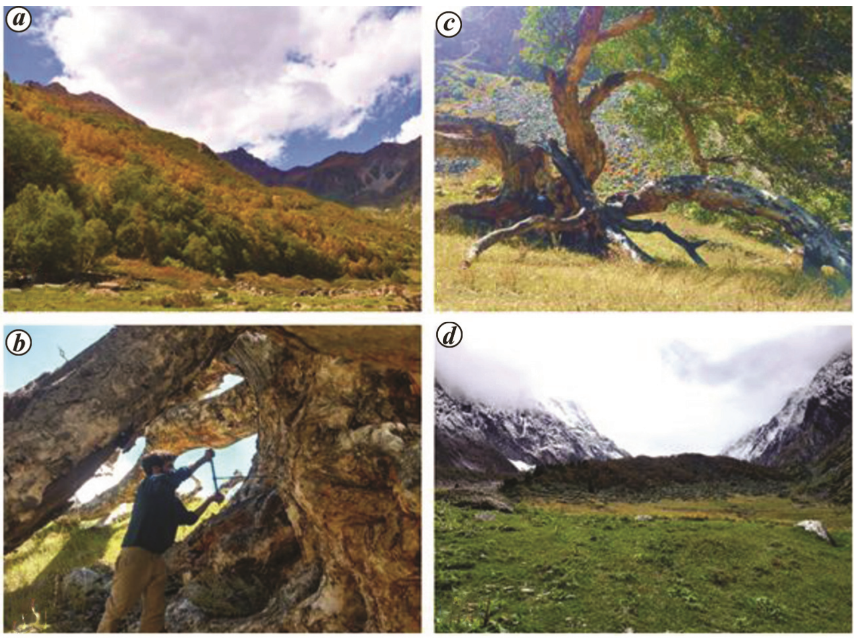

Figure 2. Details of sampling site in Darma Valley, Western Himalaya: ***a***, Pure patch of *Betula utilis* with *Abies spectabilis* in Sepu. ***b***, Coring from the oldest *Betula utilis* tree. ***c***, Oldest *B. utilis* tree in Tedang. ***d***, Upward migration of birch at Baling, near Chipa glacier.

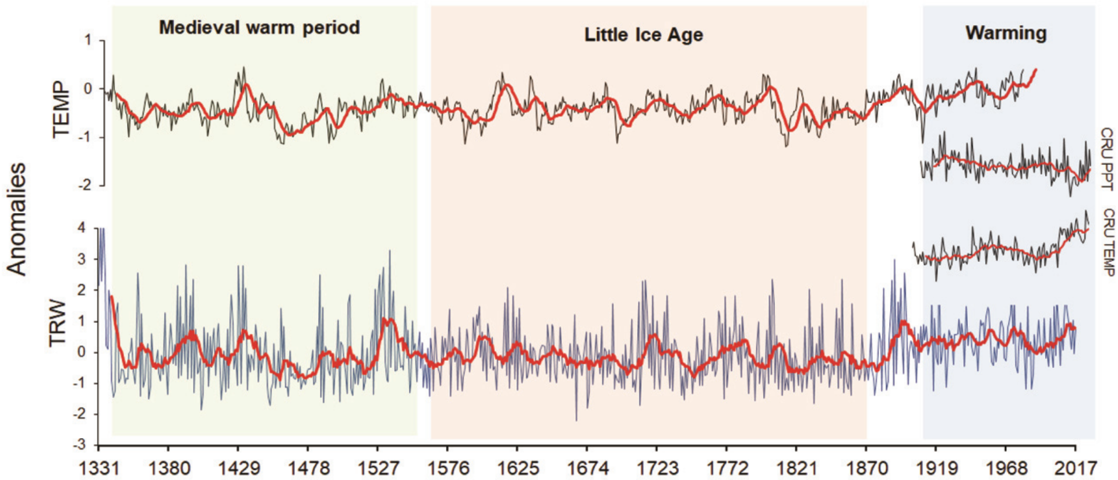

Figure 3. Simple matching of tree ring width chronology (TRW) with Asian regional temperature (TEMP) data showing increased/slow temperature related to higher/low tree growth during the Medieval Warm Period, Little Ice Age and recent warming.

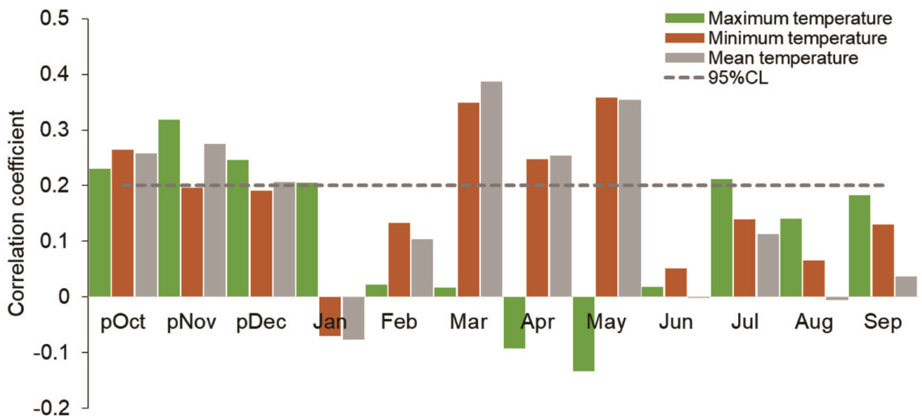

Figure 4. Correlation between birch chronology with monthly mean (grey bar), maximum (green bar) and minimum temperature (brown bar). Dotted line indicates 95% significance confidence level (CL).

trees are important for palaeoclimatic studies. Birch is sensitive to climate and mass balance variations of glaciers, as its growth is strongly influenced by the cold wind blowing from the adjacent glaciers[5]. The existence of trees older than 600 years suggests that this site was free of ice since then. Moreover, global warming might play an important role in upward migration of birch forest at this site. Presence of young trees and saplings much above the location of these aged birch trees suggests upward migration of birch in the Himalaya in recent years (Figure 2 *a* and *d*).

The tree growth/climate analysis showed that birch has a significant positive correlation with mean temperature (pOct–pDec, $r = 0.34$, $p < 0.01$, March–May, $r = 0.48$, $p < 0.01$), maximum temperature (pOct–pJan, $r = 0.37$, $p < 0.01$, March–May, $r = 0.40$, $p < 0.01$) and minimum temperature (pOct–pDec, $r = 0.25$, $p < 0.01$) during winter months. In case of precipitation, we did not record any significant response (Figure 4).

The temperature sensitivity of this tree was also proved by the existence of a significant positive correlation ($r = 0.22$, $P < 0.01$) between birch chronology and Asian annual temperature during the period AD 1331–1989. A glance at the tree-ring chronology of this old birch tree and its correlation with temporal temperature sequence shows that this tree has captured signals of the major global glacial/climatic events of the past millennium, i.e. warming of the MWP, LIA cooling and warming in the recent period (Figure 3). This study also reveals that LIA was not a persistent cool phase, but was interrupted by short warm phases as indicated by the presence of several short phases of growth surges[5]. The presence of more short surges of growth during the 17th century also supports that the latter phase of LIA was substantially weak in the Himalayan region[16]. Ongoing detailed tree-ring analysis of birch would provide a comprehensive climatic vis-à-vis glacier scenario of this region.

This study on the existence of a 600-year-old birch tree close to the Panchachuli glacier, Western Himalaya is significant. Tree ring of birch close to a monsoon-fed glacier could be a highly potential proxy to understand the role of the Indian summer monsoon and regional glacier behaviour. A detailed study is in progress on the role of regional climate factors/glacier mass balance in determining the growth of birch along its distribution around the Himalaya and Tibetan

Plateau. This would fill the gap of existing glacier chronologies spatio-temporally for a better understanding of the role of climate on glacier dynamics and other related events that have major implications in various societal aspects related to water resource management. Such an old birch tree remains under threat of natural calamities and human disturbance, and therefore needs proper protection. One way could be to declare it as a natural heritage tree.

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