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Record of vegetation, climate change, human impact and retting of hemp in Garhwal Himalaya (India) during the past 4600 years

Dieter Demske,[1] Pavel E Tarasov,[1] Christian Leipe,[1,2] Bahadur S Kotlia,[3] Lalit M Joshi[3] and Tengwen Long[1,2]

Abstract

This study is focused on a 3.55-m-long sediment core retrieved from Badanital (i.e. the BT core) in 2008. Badanital (30°29′50″N, 78°55′26″E, 2083 m a.s.l.) is a small lake located in the upper catchment area of the Ganges in Garhwal Himalaya, northern India. The lake and the regional broad-leaved semi-evergreen forests are under the influence of the Indian Summer Monsoon (ISM) and westerly associated cyclones. Palynological investigation of the BT core revealed past vegetation changes reflecting both climate and human impact during the last 4600 years. Maximum spread of oaks occurred during *c.* AD 550–1100 and *c.* AD 1400–1630, that is, the intervals which partly overlap with the ‘Medieval Warm Period’ and the ‘Little Ice Age’, respectively. Three intervals of decreased oak pollen percentages are attributed to (1) continuously drier and cooler climatic conditions and fire activity (*c.* 2600–500 BC), (2) severe reduction in oak forests followed by secondary succession of alder woods (*c.* AD 1150–1270) and (3) pre-modern settlement activities since the British imperial occupation (after *c.* AD 1700). We argue that the high percentages (i.e. up to 28%) of *Humulus*/*Cannabis* type and *Cannabis* type pollen point to intense local retting of hemp *c.* 500 BC–AD 1050. Based on our age model, *Cannabis* fibre production at Badanital is contemporaneous with archaeological records of ancient hemp products from different parts of Eurasia suggesting possible linkages to early trade and knowledge exchange routes connecting India and the Himalaya with Central and East Asia and possibly Europe.

Keywords

age model, *Cannabis*, human impact, late Holocene, non-pollen palynomorphs, pollen, retting of hemp, vegetation

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Introduction

Garhwal and Kumaun Himalayas are densely forested regions of northern India (Forest Survey of India, 2013). The temperate and moist mountain climate, controlled by monsoonal precipitation, promotes evergreen broad-leaved oak forests, which dominate in the western Himalaya between 1500 and 3300 m a.s.l. (e.g. Champion and Seth, 1968; Schweinfurth, 1957; Singh and Singh, 1987). Published pollen records from Garhwal and Kumaun Himalayas indicate regionally variable climatic impacts on vegetation during the Holocene (Bhattacharyya and Chauhan, 1977; Bhattacharyya et al., 2011; Gupta, 1977, 2008; Phadtare, 2000; Phadtare and Pant, 2006; Sharma and Gupta, 1997; Trivedi et al., 2011). Isotopic records from northern Indian speleothems suggest that major climatic inferences linked to the Indian Summer Monsoon (ISM) occurred from 2250 to 1250 BC, and more recently during the ‘Medieval Warm Period (MWP)’ and the ‘Little Ice Age (LIA)’ (Kotlia et al., 2015; Phadtare and Pant, 2006; Sanwal et al., 2013). Furthermore, several pollen records show considerable impact by humans, likely through agricultural expansion, on the local vegetation after *c.* 1650 BC (Sharma and Gupta, 1997; Trivedi et al., 2011).

A favourable climate and rich forest resources (Singh and Rawat, 2012a, 2012b; Singh and Singh, 1987) provided good support to the Neolithic hunter-gatherer populations in Garhwal Himalaya. Reduced precipitation after *c.* 2250 BC caused a transformation of the agriculture-based Harappan Civilization, which flourished in the Greater Indus Valley since approximately 3250 BC, ultimately leading to a migration of post-urban Harappan populations towards the Ganges valley and the foothills of the western Himalaya (Fuller and Madella, 2001; Giosan et al., 2012; Leipe et al., 2014a; Staubwasser et al., 2003). A further decrease in precipitation culminated around 1250 BC and is associated with the continuous disappearance of traces of the Harappan Civilization from the archaeological record (Leipe et al., 2014a). Today in Garhwal Himalaya, agriculture takes place at 1000–2200 m a.s.l., supplemented by semi-nomadic pastoralism at the

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[1] Section Paleontology, Institute of Geological Sciences, Free University of Berlin, Germany
[2] Eurasia Department, German Archaeological Institute, Germany
[3] Department of Geology, Kumaun University, India

Corresponding author:
Pavel E Tarasov, Section Paleontology, Institute of Geological Sciences, Free University of Berlin, Malteserstr. 74-100, Building D, 12249 Berlin, Germany.
Email: ptarasov@zedat.fu-berlin.de; paveltarasov@mail.ru

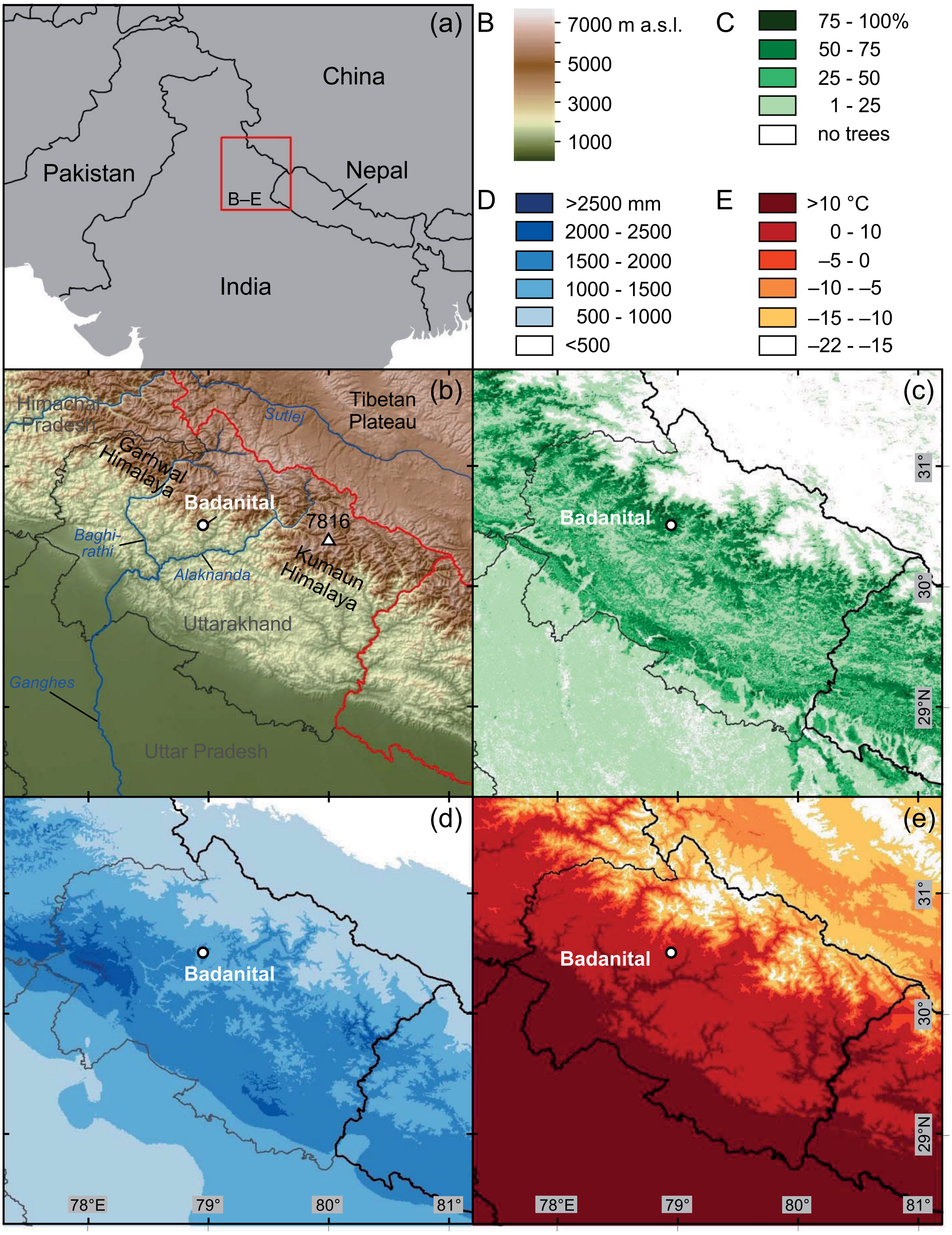

Figure 1. Map compilation showing (a) the location of the study region in NW India; (b) the topographic situation (Jarvis et al., 2008) of Badanital in Garhwal Himalaya; (c) MODIS total tree cover in percent (Hansen et al., 2002); (d) mean annual precipitation in millimetre (Hijmans et al., 2005) and (e) mean temperature of the coldest month (January) in °C (Hijmans et al., 2005) in the study region.

higher altitudes from 1800 m up to 4500 m a.s.l. (Sharma et al., 2009; Singh and Rawat, 2012a; Singh and Singh, 1986).

The small lake Badanital is situated near the upper limit of agricultural activities in Garhwal Himalaya. Previous work on a 3.55-m sediment core from Badanital (further named the BT core) was conducted for reconstructing late-Holocene climatic changes based on geochemical parameters (Kotlia and Joshi, 2013). This paper aims to reconstruct past changes in vegetation distribution with reference to climatic and environmental forces and human activities using the palynological archive from the same core. A second goal is to discuss the evidence of local hemp retting in context of regional hemp exploitation and possible linkages to Eurasian trade networks.

Modern settings

Study area

Badanital (30°29′50″N, 78°5526″E, 2083 m a.s.l.; Figure 1a and b), sometimes referred to as Badhani Taal, is located in the outer western Himalaya and belongs to the Rudraprayag district of Garhwal Himalaya in Uttarakhand. The lake is 120 m long, 55 m wide, 2 m deep and has no surface outflow (Kotlia and Joshi, 2013). The watershed catchment area drains into the Lastar Gad, a southward flowing tributary of the Mandakini River, which joins the Alaknanda near Rudraprayag at 610 m a.s.l. Further downstream, the confluence of Alaknanda and Baghirathi marks the beginning of the Ganges.

Tectonic movements in the study area are associated with proximity to the Jutogh Thrust. Negi (1991) and Kotlia and Joshi (2013) suggested that the lake was formed following a tectonic event. Triggered by events of excessive precipitation, landslides are also common in the disaster-prone district of Rudraprayag (Bookhagen et al., 2005; Rautela et al., 2014).

Climate

The region is influenced by the ISM and the westerlies (Scherler et al., 2010). At 1500–3000 m a.s.l., a warm–humid temperate mountain climate predominates, but microclimate conditions strongly depend on topography. The ISM brings up to 75–80% of the annual precipitation from June to September (Kotlia and Joshi, 2013) to the study region. Winters are cool and dry, though moderate-to-high snowfall associated with westerly disturbances are frequent from December to February. Meteorological data from Mandal, Chamoli District (1998–2007) demonstrate a mean annual precipitation of 2044 mm and strong year-to-year variability (Gairola et al., 2010; Sharma et al., 2009). The high-resolution surface climate dataset (Hijmans et al., 2005) illustrates regional variations in annual precipitation (Figure 1d) and mean temperature of the coldest month (Figure 1e) with, respectively, *c.* 1500 mm and *c.* 6°C at Badanital. In general, the Himalayas are subject to high flash rates of lightening associated with the movement of monsoonal air masses (Murugavel et al., 2014).

Modern vegetation

The major forest type of Garhwal and Kumaun Himalayas is hemi-sclerophyllous broad-leaved evergreen forest dominated by oaks (Singh and Singh, 1987). Between 1400/1800 and 2200/2400 m a.s.l., the vegetation communities comprise evergreen *Quercus leucotrichophora*, *Quercus floribunda* and associated taxa including *Abies pindrow*, *Rhododendron arboreum*, *Lyonia ovalifolia*, *Pyrus pashia*, *Litsea lanuginosa*, *Carpinus viminea*, *Alnus nepalensis* and *Betula alnoides* (Table S1, available online). These lower Himalayan mountain ranges are characterized by a high total tree cover (Hansen et al., 2002; Figure 1c). Within a radius of 1 km around Badanital, tree cover ranges between 10% and 74%. Oak-dominated forests occupy slopes around Badanital, while open grassland, swampy marshes and human-disturbed forest vegetation occur near the lake (Negi, 1991).

Major forest trees at 2400–3300 m a.s.l. include *Quercus semecarpifolia*, *Acer* spp. and *Pinus wallichiana*. Subalpine communities with *Betula utilis*, *Rhododendron*, *Abies spectabilis* or *Q. semecarpifolia* grow in a timberline zone at 2800–3600 m a.s.l. (Gairola et al., 2010; Rawal and Pangtey, 1994).

Between 1500 and 2200 m a.s.l., *A. nepalensis* grows naturally in oak forests (e.g. Sharma et al., 2009; Singh and Rawat, 2012b), but small patches of pure stands also occupy disturbed grounds along stream beds and around lakes (e.g. Osmaston, 1922; Singh and Singh, 1987). At lower altitudes of the western Himalaya, *Pinus roxburghii* forms subtropical forests ascending up to 1600–1800 m a.s.l., and as a component of dry oak forests commonly expands into disturbed and exploited forests (e.g. Osmaston, 1922; Singh and Singh, 1987). Hence, both *A. nepalensis* and *P. roxburghii* are primarily natural elements of western Himalayan forests, which may spread as pioneer trees (Hussain et al., 2008; Ohsawa et al., 1986). Similarly, *Ficus* (Moraceae) is common in open forest and on disturbed ruderal sites (Gairola et al., 2010; Singh and Rawat, 2012a).

Human impact

During the past centuries, forest resources of the central and western Himalaya have been strongly exploited for local and commercial purposes, including iron smelting, magnesite and limestone mining and road construction (Singh and Singh, 1987; Upreti et al., 1985). Today, local agro-pastoralists based in small villages at 1000–2200 m a.s.l. (Sharma et al., 2009; Singh and Rawat, 2012a, 2012b) contribute to exploitation and degradation of forests by collecting fuel wood, cutting trees for domestic uses and through sapling suppression from herd animal browsing (Sharma et al., 2009).

In remote mountain areas of Garhwal and Kumaun Himalayas and in western Nepal, hemp is locally cultivated for traditional multi-purpose use (Clarke, 2007a; Shah, 1997, 2004). In the eastern Himalaya, shifting cultivation or slash and burn agriculture, locally called 'jhuming', was commonly performed on land previously used by semi-nomadic people and accompanied by populations reliant upon settled agriculture (Singh and Singh, 1987).

Material and methods

Core and sample processing

The investigated BT core has a total length of 3.55 m and was retrieved using a piston corer in January 2008 (Kotlia and Joshi, 2013). The lithological description of the core is summarized in Table 1. Contiguous subsamples were taken in 1 cm slices and dried at 30°C for storage and transportation. Quantitative samples of 2–2.5 mg dry weight were processed using standard steps (Faegri and Iversen, 1989), including application of hydrochloric acid, potassium hydroxide, hydrofluoric acid, acetolysis and ultrasonic sieving through 7-μm meshes. *Lycopodium* marker spores were added, allowing for calculation of pollen and spore concentrations (Maher, 1981; Stockmarr, 1971). Coarse particles were removed by decanting, and the presence of mineral particles was noted for lithological description. The prepared samples were stored and mounted in water-free glycerol in order to prevent swelling of palynomorphs. Microscope analysis was performed on a Zeiss Axiophot at magnifications of 400× and 640× using transmission light, switching to phase contrast or Nomarski differential interference contrast when needed. At least 300 pollen grains (on average *c.* 400) per sample were counted.

The preservation of pollen and most of non-pollen palynomorphs was good. Algal coenobia of *Pediastrum* were rare and weakly preserved, suggesting partial loss during the drying process. The basic pollen sum includes terrestrial arboreal pollen (AP) and non-arboreal pollen (NAP) taxa excluding counts of aquatic taxa and non-pollen palynomorphs. Percentages were calculated on the basic sum, in case of the two excluded groups including their partial sum. The subdivision into pollen zones was based on square-root transformed percentages of terrestrial taxa using stratigraphically constrained cluster analysis by the method of incremental sum of squares (Grimm, 1987). Diagrams were created with the Tilia software package including Tilia 2.0.b.4, TiliaGraph 2.0.b.5 and TiliaGraphView 1.0.7.2 (Grimm, 1990, 2000).

Determination of palynomorphs

Pollen types were distinguished based on morphological criteria following standard references (Beug, 2004; Faegri and Iversen, 1989; Gupta and Sharma, 1986; Moore et al., 1991; Nakagawa et al., 1996; Sorsa and Huttunen, 1975; Wang et al., 1997; Zanni and Ravazzi, 2007). Pollen grains of grasses were differentiated into Poaceae wild grass type <40 μm, wild grass type >40 μm and cereal type (40–60 μm). The latter was distinguished from the wild grass type on the basis of annulus characteristics (Beug, 2004). Because of overlaps in morphological characteristics, the cereal type may still include pollen of some wild grass species (Beug, 2004; Gupta, 1977). The Moraceae type includes 2–5 porate pollen grains described for *Morus* or *Ficus* (Beug, 2004; Moore et al., 1991), but possibly also some badly preserved grains of Cannabaceae.

Pollen of *Cannabis* (hemp) type was differentiated from *Humulus*/*Cannabis* type based on morphological characteristics

Table 1. Lithological description of the BT sediment core from Badanital summarized for this study. Core segments are divided at 90, 190 and 290 cm. The column of carbonaceous mud shows multiple layers with embedded coarse sand (up to 2 mm) and fine to medium gravel (up to 1 cm size) including sub-rounded to sub-angular pebble.

Core depth	Sediment	Embedded material
0–250 cm	Black carbonaceous mud, sticky, cohesive, micro-laminated, moderate admixture of plant fragments (above 190 cm: very clayey with some silt; 190–250 cm: occasional silty layers)	50 and 110 cm: occasional gravel 140–141 cm: wood particles 149–155 cm: medium pebble 161–162 cm: wood particles 234–237 cm: fine pebble 242–243 cm: fine pebble 247–250 cm: wood particles
250–335 cm	Black carbonaceous mud, silty clay, occasional rock fragments and admixed woody material (250–283 cm: moderately clayey with silt and sand; 283–310 cm: clayey with some silt; 310–335 cm: very clayey with much silt and sand)	250–254 cm: coarse sand 256–259 cm: fine pebble 259–262 cm: coarse sand 268–273 cm: occasional gravel 273–278 cm: fine pebble 278–283 cm: coarse sand 310–326 cm: occasional gravel, coarse sand 328–335 cm: fine and medium pebble, coarse sand
335–355 cm	Brownish-grey to reddish-brown clayey mud, much silt and sand, low organic content (347–355 cm: sandy clay)	335–339 cm: occasional gravel, coarse sand 339–347 cm: fine gravel and coarse sand 354–355 cm: fine to medium gravel and pebble

(Figure 2). While both types show typical down-bending of the tectum forming a sunken pore characteristic for Cannabaceae (Faegri and Iversen, 1989; Moore et al., 1991), pollen assigned to *Cannabis* type has larger size (>27.5 µm) and distinctly protruding pores (e.g. Dörfler, 1990; French and Moore, 1986; Punt and Malotaux, 1984). Confusion with large *Humulus* (hop) pollen grains can be excluded, as associated taxa including *Humulus scandens* and *Humulus yunnanensis* occur only in eastern Eurasia (China, Korea, Japan) and in Yunnan (China), respectively (Small, 1978). Palynomorphs assigned to *Humulus*/*Cannabis* morphological type have smaller (<27.5 µm) or crumpled grains, with pore protrusion being weak, concealed or non-decisive. Despite some morphological uncertainty, occurrence of hop pollen in the BT core is unlikely. Cultivated hops were introduced to northern India in the 19th century and are not regarded as native species (e.g. Shah et al., 2012). Modern records of wild *Humulus lupulus* in Himachal Pradesh and Uttar Pradesh (Bisht et al., 1998) might represent plants escaped from cultivation.

Pollen grains belonging to the genus *Pinus* were differentiated into *Pinus* subgen. *Diploxylon* and subgen. *Haploxylon* (Nakagawa et al., 1996; Zanni and Ravazzi, 2007), which are associated with the regionally common species of *P. roxburghii* and *P. wallichiana* (Price et al., 1998), respectively. Grains which could not be identified on subgenus level were summarized as *Pinus* undiff.

The recorded non-pollen palynomorphs (NPP) represent hornworts and liverworts (mosses *s.l.*), fern plants and allies, non-siliceous algae and rotifers (resting eggs of *Filinia* and *Anuraeopsis*). Besides grass epidermis fragments (Ralska-Jasiewiczowa and van Geel, 1992), the counted phytoclasts include charred particles (>50 µm), which were characterized by thoroughly black appearance in differentiation against brownish plant fragments and dark translucent mineral grains with a crystalline structure. Fungi were recorded as ascospores of various coprophilous taxa (van Geel et al., 2003) and chlamydospores from vasculo-arbuscular endomycorrhizal *Glomus* (van Geel et al., 1989).

Radiocarbon dating and age modelling

Nine samples of bulk sediment rich in organics were selected for AMS radiocarbon dating (Table 2). All conventional ^{14}C ages were calibrated using OxCal v.4.2 software package (Bronk Ramsey, 2001). A Poisson process deposition model (Bronk Ramsey, 2008) was introduced to establish the age-depth relationship of the BT core using ^{14}C dating results and depths of the nine samples, as well as the main lithological boundaries, as key inputs. This model allows a non-uniform sedimentation rate throughout the analysed sequence. It is also found to be effective in synthesizing all available age information and in dealing with complex multi-modal age distribution after calibration (e.g. Huang et al., 2014). The model was set with a critical value of 60% and 95%, respectively, for the agreement index and the convergence index. All dates leading to indices lower than the critical values were removed from the final model (Bronk Ramsey, 1995).

Results

Chronology

The uppermost date (UCIAMS-61369 at 0–1 cm depth, Table 2) showed an unusually high $F^{14}C$ value (with a calculated radiocarbon age of −755±20 ^{14}C BP) and was reported as a post-bomb date (cf. Reimer et al., 2004). Bomb13NH2 curve was adopted for calibration of the date (Hua et al., 2013), which yielded a median calibrated age of AD 1999 (Table 2). This result confirmed a modern age of the sediment surface and allowed the assumption that the zero depth of the sequence can be associated with the coring time (i.e. AD 2008).

The other eight dates were calibrated using the IntCal13 curve (Reimer et al., 2013). Some dates in the upper part of the BT core do not show a clear trend of increasing age with depth (Table 2). This can be ascribed to input of older organic material caused by soil erosion (e.g. Stanley and Chen, 2000), as indicated by *Glomus* spores. The Poisson process model confirmed incompatibility of the four dates from 4 to 140 cm depth (i.e. agreement index was lower than the critical value of 60%) to the overall age-depth relationship and removed them from the final model (Figure 3). Figure 3 and Table 3 demonstrate well-constrained ages and relatively narrow uncertainty ranges in the upper half of the BT core above 209 cm. The modelled ages of the lower part of the core (below 250 cm) are less robust (Table 3) and should be treated with caution.

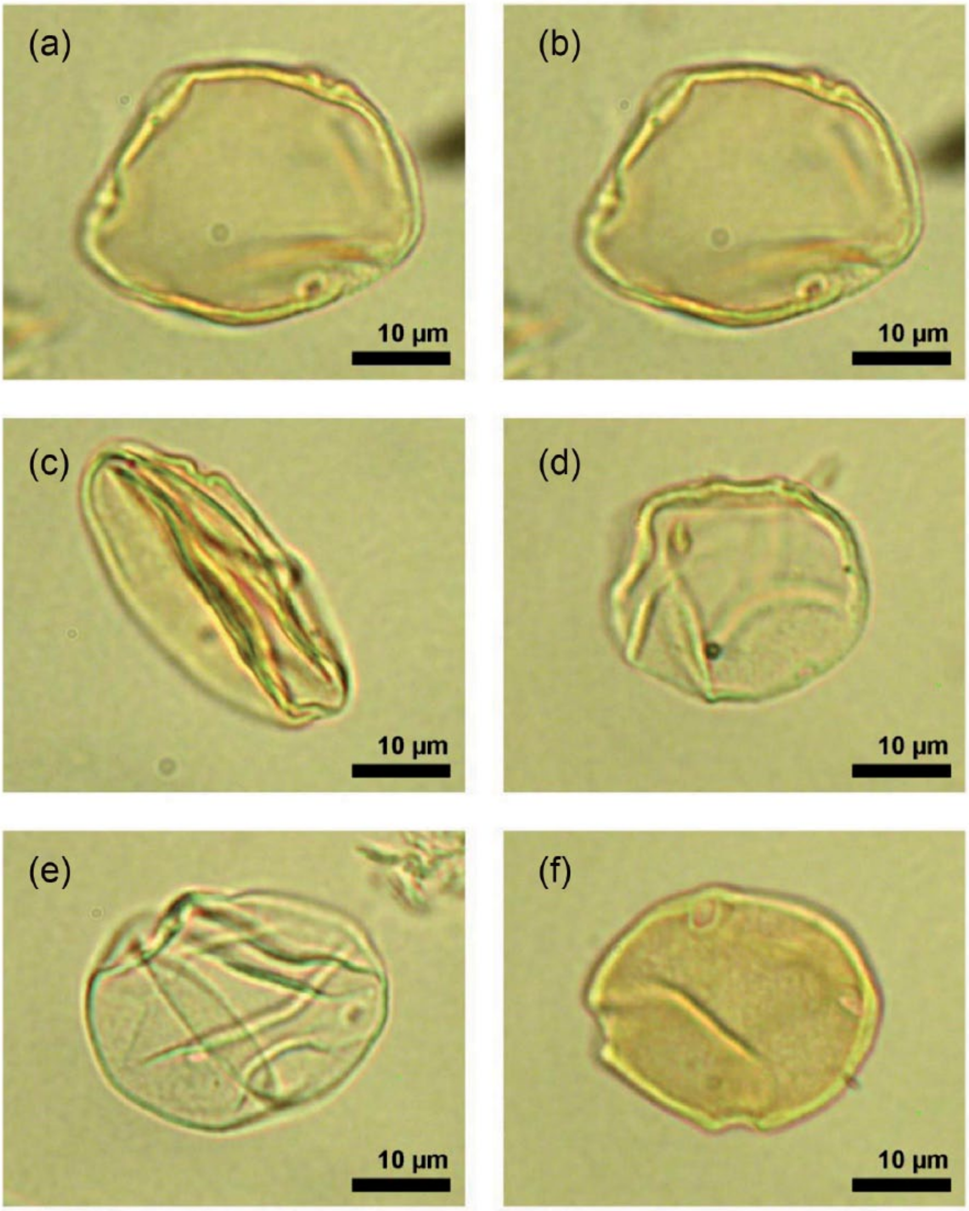

Figure 2. Pollen types of Cannabaceae and Moraceae recorded in the sediment core from Badanital (sample from 259 to 260 cm depth). (a, b) *Cannabis* type characterized by large size (>27.5 µm), sunken pores, steeply rising annulus and hollow rim within annulus (slightly different focus); (c) *Humulus/Cannabis* type, crumpled pollen grain with weakly rising annulus; (d) *Humulus/Cannabis* type, slightly crumpled grain of small size (<27.5 µm); (e) *Humulus/Cannabis* type, slightly degraded and (f) Moraceae type, four-porate grain.

Table 2. Radiocarbon AMS dating results obtained on bulk sediments from the Badanital core along with the respective calibrated ages expressed as 95% probability ranges and median point estimates (following, for example, Feranec and Kozlowski, 2016; Rull et al., 2015; Scott et al., 2007).

Laboratory code	Core depth (cm)	Radiocarbon date (^{14}C yr BP)	Calibrated age, 95% range (yr AD/BC)	Calibrated age, median (yr AD/BC)
UCIAMS-61369	0–1	Post-bomb $F^{14}C$ = 1.1 ± 0.00273	AD 1957–2000	AD 1999
Poz-43654	4–5	615 ± 30	AD 1295–1401	AD 1349
Poz-43736	34–35	470 ± 30	AD 1410–1457	AD 1435
UCIAMS-61370	67–68	495 ± 20	AD 1411–1443	AD 1427
Poz-43655	99–100	650 ± 25	AD 1282–1393	AD 1355
UCIAMS-61377	137–138	565 ± 15	AD 1318–1415	AD 1349
UCIAMS-61371	206–207	920 ± 20	AD 1039–1161	AD 1095
Poz-43656	263–264	2450 ± 30	754–411 BC	577 BC
Poz-43657	322–323	3815 ± 35	2452–2140 BC	2257 BC

The radiocarbon datings (^{14}C yr BP) were calibrated using OxCal v.4.2 software. The uppermost date (UCIAMS-61369) is reported with its $F^{14}C$ value (according to Reimer et al., 2004) and calibrated with Bomb13NH2 calibration curve (Hua et al., 2013). All other dates are reported with their radiocarbon age calibrated using IntCal13 (Reimer et al., 2013).

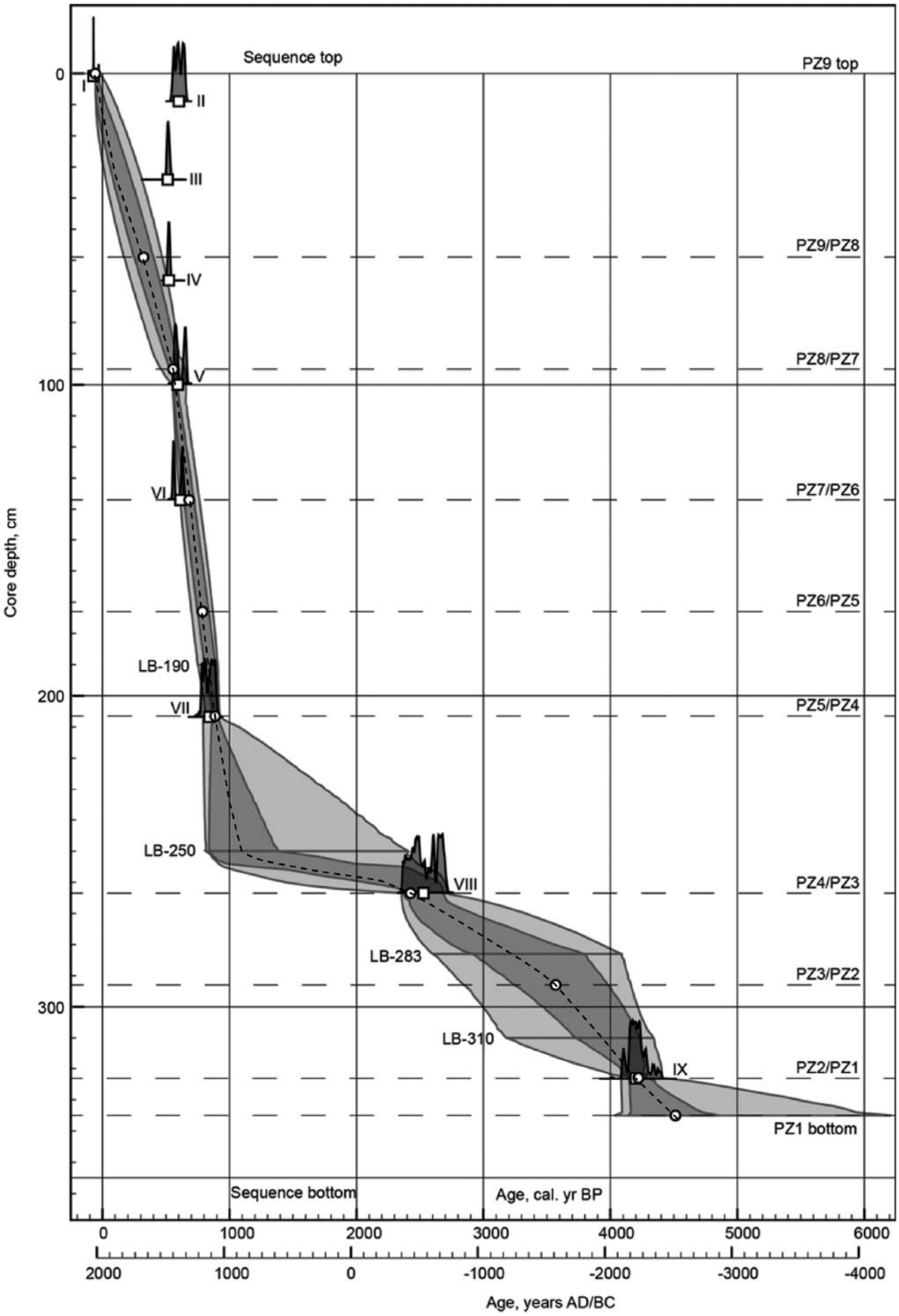

Figure 3. Age-depth model constructed for the Badanital core. The wider and lighter shade represents 95% probability distribution range, while the narrower and darker shade represents 68% probability distribution range. Open circles indicate the modelled age medians of pollen zone boundaries. Four key lithological boundaries (LB) of the BT core (see Table 1 for details) are also shown. Calibrated age distributions of the nine radiocarbon dates are plotted, with their calibrated medians shown in open squares. I = UCIAMS-61369, II = Poz-43654, III = Poz-43736, IV = UCIAMS-61370, V = Poz-43655, VI = UCIAMS-61377, VII = UCIAMS-61371, VIII = Poz-43656, IX = Poz-43657 (see Table 2 for details).

Pollen zones

The pollen and NPP records (Figures 4 and 5) of the BT core are summarized in this section. Samples from the basal clayey layer (355–335 cm) with a very low pollen content and poor age control are not presented here.

Pollen zone (PZ) 1 (335–323 cm; *c*. 2560–2270 BC) is characterized by high percentages of *Alnus* and *Quercus*, but also *Betula*, Rosaceae and *Abies*. Taxa prevailing at lower elevations are represented by *P.* subgen. *Diploxylon*, *Phyllanthus* type and Ericaceae. The NAP types contribute less than 35%.

Table 3. The modelled age-depth relationship for pollen zone boundaries in the BT core.

Pollen zone boundary	Core depth (cm)	95% range (yr AD/BC)	68% range (yr AD/BC)	Median (yr AD/BC)
PZ 9/PZ 8	59	AD 1480–1780	AD 1550–1700	AD 1626
PZ 8/PZ 7	95	AD 1303–1489	AD 1366–1422	AD 1394
PZ 7/PZ 6	137	AD 1185–1340	AD 1229–1309	AD 1267
PZ 6/PZ 5	173	AD 1081–1249	AD 1114–1201	AD 1160
PZ 5/PZ 4	209	AD 928–1157	AD 1024–1089	AD 1053
PZ 4/PZ 3	262	762 BC– AD 126	730–385 BC	479 BC
PZ 3/PZ 2	293	2212–898 BC	2029–1291 BC	1617 BC
PZ 2/PZ 1	323	2457–2141 BC	2337–2200 BC	2268 BC
PZ 1 bottom	335	4265–2084 BC	2912–2189 BC	2562 BC

PZ 2 (323–293 cm; *c*. 2270–1620 BC) shows decreasing AP taxa percentages, including *Alnus*, *P.* subgen. *Diploxylon* and *Abies*. Moraceae type, *Prunus*/*Sorbus* type and Poaceae undiff. are more abundant in the upper part.

PZ 3 (293–262 cm; *c*. 1620–480 BC) reveals very low AP taxa percentages. Percentages of NAP (Caryophyllaceae, *Persicaria* and Poaceae undiff.) reach absolute maxima and *Humulus*/*Cannabis* type increases in abundance.

PZ 4 (262–209 cm; *c*. 480 BC–AD 1050) demonstrates maximum percentages of *Quercus* and *P.* subgen. *Diploxylon*, while *Alnus* and Moraceae type percentages remain relatively low. The contribution of NAP decreases moderately towards the upper zone boundary. Continuous presence of *Cannabis* type and high frequencies of *Humulus/Cannabis* type are noticeable.

PZ 5 (209–173 cm; *c*. AD 1050–1160) shows a gradual increase in *Alnus* and a sharp decline in *Quercus* percentages. A minor peak of Chenopodiaceae and decreasing contribution of *Humulus*/*Cannabis* type are noteworthy.

PZ 6 (173–137 cm; *c*. AD 1160–1270) reveals peak of *Alnus* (up to 60%) and low NAP percentages. Towards the upper zone boundary, the frequencies of Rosaceae and *Abies* increase.

PZ 7 (137–95 cm; *c*. AD 1270–1400) evidences a relatively stable contribution of AP with prevailing *Alnus* and *Quercus* accompanied by increased percentages of Rosaceae. Among the NAP *Polygonum* type, *Artemisia* and pollen of Poaceae wild grass type >40µ are abundant.

PZ 8 (59–95 cm; AD 1400–1630) records a maximum of *Quercus* pollen, relatively high frequencies of *Betula* and Rosaceae type and a decreasing contribution of *P.* subgen. *Diploxylon* pollen. The NAP percentages decrease significantly towards the upper zone boundary.

PZ 9 (59–0 cm; since AD 1630) is dominated by Chenopodiaceae, *Artemisia* and Poaceae. Although NAP values exceed 50%, *Quercus*, *Alnus* and Rosaceae remain important AP types. Percentages of *Alnus* and *P.* subgen. *Diploxylon* increase towards the core top.

Major changes in the non-pollen palynomorphs follow the above sequence. Zones 1–3 reveal high abundance of fern spores and well-represented aquatic taxa (including *Nelumbo*). Resting eggs of rotifers are rare in zones 1–3, but more frequent in zone 4. Algal remains are present throughout, but the abundance of *Botryococcus* is higher in zones 1–2 and 8–9. Distinct maxima of charred phytoclasts are recorded in zones 1–2, in contrast to moderately varying abundance in zones 5–9. Ascospores of coprophilous fungi are frequent in zones 4, 7 and 9, but nearly absent in zones 1–3 and 8. *Glomus* chlamydospores show increased abundance in zones 7–9.

Interpretation and discussion

In this study, we focus on changes in the forest cover caused by climatic and anthropogenic factors. The record reveals an interval with high percentages of *Cannabis* pollen, therefore we also discuss the use of hemp fibres in the Himalayan region and possible linkages to Eurasian trade networks.

Forest development

The pollen record reveals the regional forest history since *c*. 2560 BC. Since the lake catchment and pollen source areas are relatively small, the reconstruction represents a confined part of Garhwal Himalaya. By *c*. 2560–2270 BC (PZ 1), forest around Badanital was dominated by oaks and alders with an admixture of diverse evergreen (e.g. Myrtaceae, *Grewia*, *Strobilanthes* type, *Symplocos*) and deciduous taxa (Rosaceae, *Betula*, *Carpinus*, *Juglans*, *Ulmus*, *Acer*), including various shrubs (*Corylus*, *Myrica*, *Lonicera*) and ferns (Polypodiales, *Pteris* type, *Pteridium*). Abundant alder trees indicate soil disturbance, possibly reflecting increased fluvial activities at riverside habitats, as suggested by the varying content of mineral matter in the sediments. The dense forest cover including warm-temperate and subtropical taxa points to warm and humid climatic conditions. The presence of *Nelumbo* (water lotus), which at lower altitudes of Nainital persisted throughout the Holocene (Gupta, 1977), also points to warmer conditions.

Declining contribution of alder woods and the spread of grasses indicate a severely disturbed forest cover after *c*. 2270 BC. Increasing abundance of Moraceae type (including *Morus*, *Ficus*) also indicates greater forest openness or patchiness. The decline of oak, alder and pine forests and spread of open vegetation communities (Poaceae, *Persicaria* and Caryophyllaceae) culminated between *c*. 1620–480 BC (PZ 3).

The reduction in forest vegetation can be ascribed to a climatic deterioration after 2300 BC. Corresponding vegetation changes ascribed to the 4.2 ka event and a transition to cooler and drier conditions were reconstructed from pollen records across Garhwal and Kumaun Himalayas (Gupta, 2008; Phadtare, 2000; Sharma and Gupta, 1997; Trivedi et al., 2011). The late-Holocene weakening of the ISM and North Atlantic centennial-scale cooling episodes strongly affected environments in the Himalayas (e.g. Leipe et al., 2014a, 2014b). This climatic development culminated in a dry interval around 3.2 ka (Kotlia et al., 2015) leading to severe forest reduction in Garhwal Himalaya as evidenced by PZ 3 (Figure 4).

Forest disturbance was aggravated by local fires as indicated by the record of large-sized (>50 µm) charred phytoclasts (Figure 5). The regional occurrence of fires during the second millennium BC may be explained by drier climatic conditions and increased lightning frequency under the weakened ISM. Charcoal was noted also in other pollen sequences from Garhwal and Kumaun Himalayas (Gupta, 1977), but, at least in part, ascribed to human impact (Sharma and Gupta, 1997).

After *c*. 480 BC, oak forests recovered forming stable communities with a low contribution of alders under improving climatic conditions. The optimum development of dense oak forests occurred about 480 BC–AD 1050 (PZ 4). This interval overlaps in time with the 'MWP' in the West Himalayas dated to *c*. AD 830–1160 (Sanwal et al., 2013) or to *c*. AD 750–1450 (Kotlia et al.,

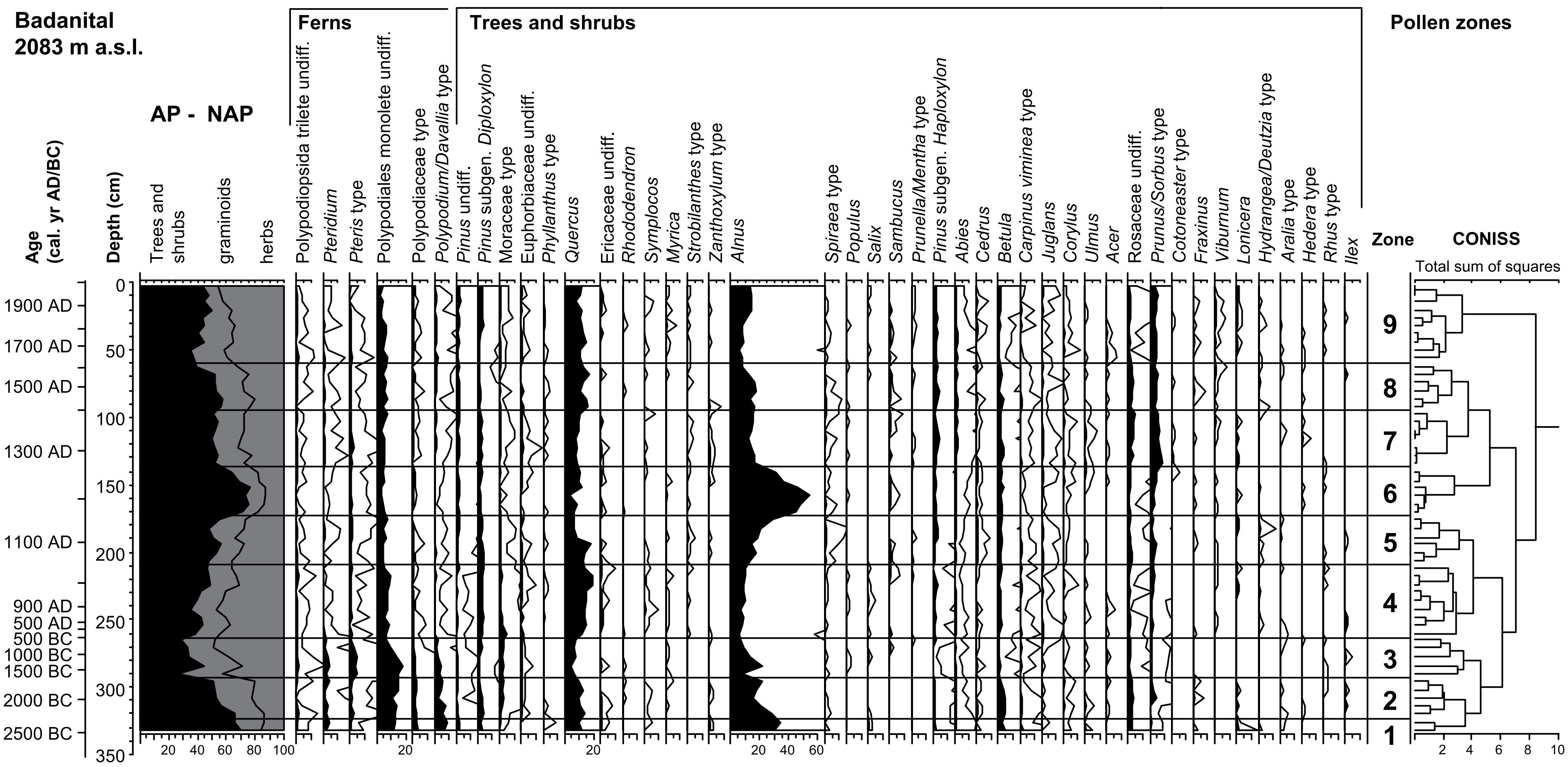

Figure 4. Percentage diagram of the Badanital record showing arboreal pollen taxa, fern spores and the CONISS cluster diagram. Fern spore percentages do not influence CONISS results. Lines represent a 10-fold exaggeration.

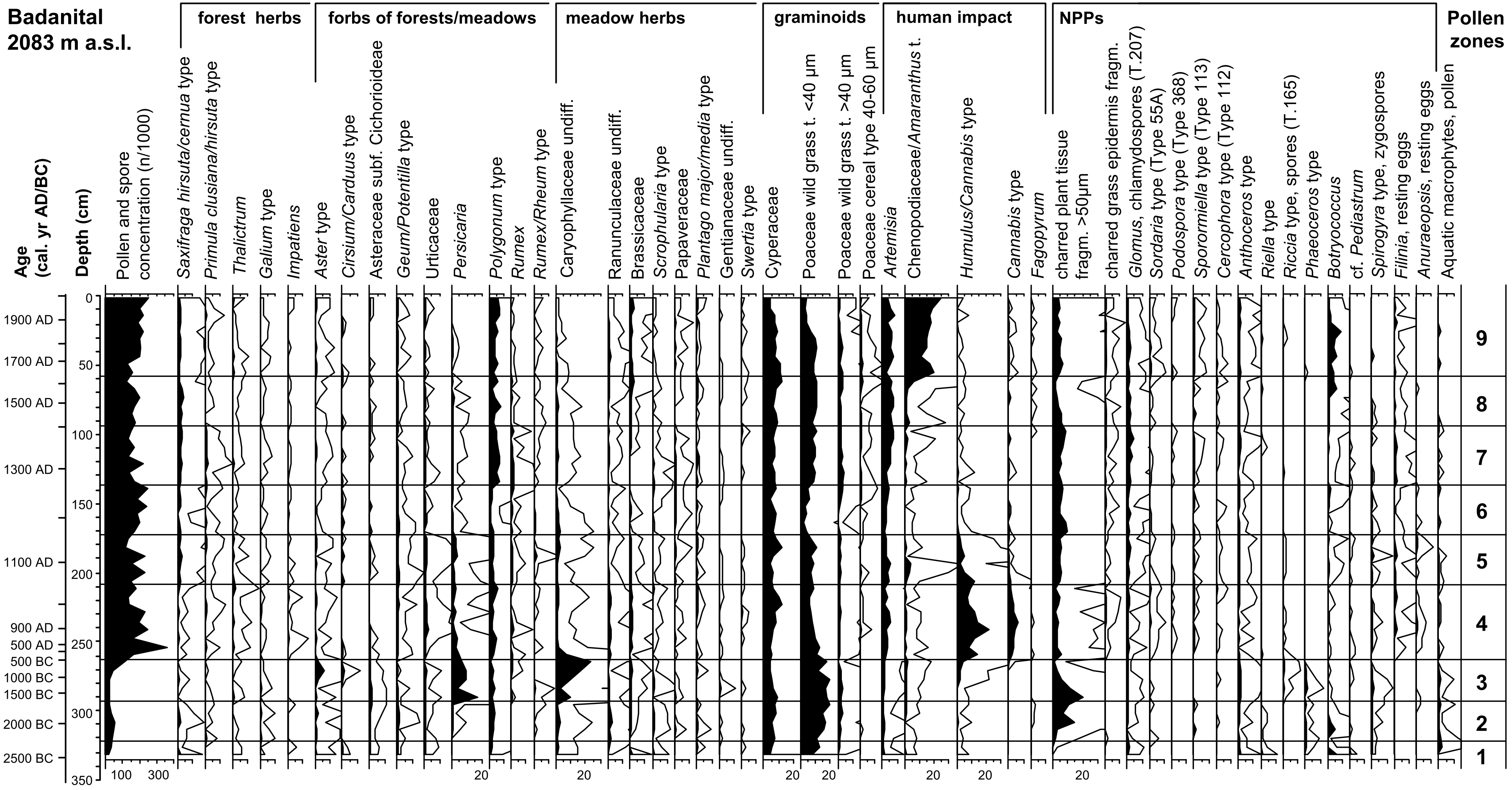

Figure 5. Percentage diagram of the Badanital record showing non-arboreal pollen taxa and non-pollen palynomorphs. Lines represent a 10-fold exaggeration. Note that concentration values in the diagram, next to the depth axis, represent total number of pollen and spore grains per cubic cm (n) divided by 1000, e.g. 300 = 300,000 grain/cm3.

2015). Vegetation changes reflecting climatic warming are also recorded at several sites in Garhwal and Kumaun Himalayas (Phadtare and Pant, 2006; Trivedi et al., 2011) and adjacent Himachal Himalaya (Chauhan, 2006). Slightly increased frequencies of coprophilous fungi spores indicate moderate grazing activities around Badanital. The pollen record of *Cannabis* type and *Humulus/Cannabis* type (PZ 4) suggests considerable human impact on the lake ecosystem during this time interval.

A severe reduction in oak forests accompanied by a spread of alder, other deciduous trees (*Juglans*, *Betula*), shrubs (*Spiraea* type, Hydrangeaceae) and *Pinus* subgen. *Haploxylon* started during PZ 5. Additionally, a spread in *Abies*, a mid to high mountain forest element, is indicated. The enormous expansion of alder woods recorded in PZ 6 (*c*. AD 1160–1270) points to heavy disturbance of forest habitats, which might be caused by various environmental factors including soil erosion, climatic deterioration and/or human impact. Erosion as the major factor can be excluded, because the recorded input of coarse mineral grains (Table 1) follows the *Alnus* pollen maximum. An interval of dry climate dated to AD 1250–1450 (Sanwal et al., 2013) could possibly influence the forest development and human activities, but a severe drought at this time is unlikely and does not appear in the regional vegetation and moisture reconstructions (Leipe et al., 2014a, 2014b). Hence, the changes in vegetation reconstructed between *c*. AD 1050 and 1270 (PZ 5 and 6) can be explained by initial anthropogenic disturbance (e.g. cutting of trees, pasture or small-scale agriculture), subsequent abandonment of the area and successional development of alder vegetation.

After *c*. AD 1270 (PZ 7–9), the vegetation cover was relatively stable. In general, open oak forests with a still considerable contribution of alder and a variety of Rosaceae (*Pyrus*, *Prunus*, *Sorbus*, *Rubus*, *Cotoneaster*) covered the area under warm and humid climatic conditions. During *c*. AD 1390–1630 (PZ 8), oak forests again expanded. Furthermore, the reduced contribution of *P.* subgen. *Diploxylon* pollen points to some decrease in warm-temperate *Pinus* species (e.g. *P. roxburghii*) growing at lower altitudes. As indicators of grazing and human impact are weak, the spread of oak forests (likely *Q. semecarpifolia*) is attributed to cooler climatic conditions during the 'LIA' interval (Bookhagen and Burbank, 2006; Sanwal et al., 2013; Sharma and Owen, 1996). For the study region, different 'LIA' time ranges including *c*. AD 1440–1880 (Sanwal et al., 2013), *c*. AD 1450–1750 (Kotlia et al., 2013) and AD 1510–1790 (Kotlia and Joshi, 2013) have been suggested. Corresponding changes in regional vegetation ascribed to the 'LIA' are reported from other sites in the western Himalaya (Chauhan, 2006; Phadtare and Pant, 2006). Severe reduction in forest and a parallel spread of Chenopodiaceae around Badanital documents settlement activities during the past *c*. 300 years.

Vegetation disturbance and human impact

Generally, weak representation of pollen types indicating human impact between *c*. 2560 and 480 BC (PZ 1–3) supports the interpretation that predominantly natural factors were driving regional vegetation development. However, human-induced environmental changes in the wider study region may be expected after *c*. 2000 BC when late- and post-Harappan migrants reached the more humid areas of the western Himalayan foothills and the Yamuna–Ganges interfluve (Fuller, 2006; Giosan et al., 2012; Leipe et al., 2014a). In the early first millennium BC, people of the Painted Grey Ware (PGW) culture brought large-scale cultivation to the upper Jamuna–Ganges valley (Lal, 1992), in part linked to Early Iron Age sites on the central Gangetic plains (Singh, 2008; Tewari, 2003). Wood remains of Himalayan *P. roxburghii* were found at Jakhera/Atranjikhera on the Gangetic plains, possibly pointing to the penetration of PGW culture people into Garhwal Himalaya along the Ganges and/or across convenient passes (Lal, 1992; Tewari, 2003). There are also a few archaeological records documenting human activities in the study region prior to *c*. 500 BC. In the region of Kumaun Himalaya, an iron smelting site at Uleni (Almora district) was dated to *c*. 1022–826 BC (Singh, 2008), and in Tehri Garhwal, a contemporary PGW site was discovered (Lal, 1992). The only evidence for human deforestation activities may come from increased concentrations of charred plant fragments recorded in PZ 2 and 3 (*c*. 2270–480 BC). However, such interpretation remains highly hypothetical, since increased fire activity could have been also naturally induced by lightning.

Between 480 BC and AD 1050 (PZ 4), moderate grazing activities are indicated by the record of ascospores from fungi growing on animal dung (Figure 5). Low pollen percentages of Urticaceae, Brassicaceae and *Artemisia* also suggest occasional browsing of the area by people and the use of forests as seasonal grazing grounds. The record of individual pollen grains of *Fagopyrum* (buckwheat), however, does not provide conclusive evidence for cultivation of this grain crop. Low abundance of Chenopodiaceae pollen (in comparison to the uppermost PZ 9) does not indicate a local sedentary human population in the forests around Badanital. In contrast to moderate disturbance of terrestrial vegetation indicated by increased herb pollen concentration, the lake itself was subject to considerable human impact. The high pollen concentrations of *Cannabis* type and *Humulus*/*Cannabis* type suggest that local populations used Badanital for water retting of hemp.

Around AD 1050–1100 (lower PZ 5), moderate disturbances in oak forests were likely associated with a short settlement phase, which is indicated by increased pollen frequencies of ruderal Chenopodiaceae. Scarce occurrence of dung fungi points to weak grazing activities, suggesting dense forest cover and limited grazing grounds around the lake. The subsequent decline in oak forest recorded in the upper PZ 5 (*c*. AD 1100–1160) possibly reflects forest clearing by pastoralists in an attempt to gain more grazing land. In historical context, the oak forest destruction phase at Badanital dates to the late Buddhist–Hindu period in northern India. At the same time, the decrease in pollen associated with *Cannabis* and the increase in *Alnus* pollen during PZ 5 point to a continuous reduction in hemp processing and a successional growth of alder on the disturbed forest sites, respectively.

Our record suggests that human impact was absent around the lake during PZ 6 (*c*. AD 1160–1270). This is indicated by maximum spread of pioneer alder communities during the first half (*c*. AD 1160–1200), which were gradually replaced by regenerating oak during the second half (*c*. AD 1200–1270). In addition, pollen related to retting reaches low concentrations suggesting that hemp processing was given up. The phase of abandonment at Badanital during this interval corresponds to a historical period marked by conflict, which faced Mongol attacks, taxation and confiscations by early dynasties of the Delhi Sultanate, and resulting rebellions (Walsh, 2006).

The vegetation development between AD 1270 and 1390 (PZ 7) is characterized by stable, though rather open oak forests. A slight increase in *Pteridium*, *Rumex* and *Polygonum* type and *Artemisia* percentages (Figure 5) may be attributed to weak disturbances caused by humans. Increased abundance of *Glomus* and hornwort mosses (*Anthoceros* type) indicates soil disturbances, while spores of coprophilous fungi point to moderate seasonal grazing activities around Badanital. Increased frequencies of Poaceae pollen >40 µm suggest enhanced agricultural activities in the broader region, but do not provide conclusive evidence for grain cultivation.

The spread of oak forests and low frequencies of charred plant fragments between *c*. AD 1390 and 1630 (PZ 8) correspond to reduced vegetation disturbance, low human impact and weak grazing activities. One speculative reason for this abandonment of the area could be annual taxes based on crops introduced by the Mughal Empire (AD 1526–1707). This so-called tax-farming finally contributed to the break-down of the Mughal fiscal system (Walsh, 2006).

Large-scale deforestation during the past *c*. 300 years coincides with a rapid expansion of ruderal vegetation, dominated by Chenopodiaceae communities, the presence of cultivated plants (cereals, buckwheat and hemp) and a spread of Brassicaceae, *Polygonum* and *Artemisia*. The foundation (and/or expansion) of Badhani village likely occurred before commencement of the British imperial period (AD 1757–1947). An increase in the abundance of charred particles, hornwort spores and coprophilous fungi points to moderate vegetation disturbances. Hence, human activities likely represent similar strategies to those used in the region today, with herders migrating to higher altitudes in the summer months.

A spread of alder and pine forests likely coincides with the First War of Indian Independence (AD 1857–1858), followed by direct rule of the British Crown (Walsh, 2006). It is likely that the commercialization of agriculture, combined with low competitiveness of mountain peasants, caused abandonment of agricultural land and forest recovery at Badanital.

Evidence of hemp exploitation and retting from northern India and Eurasia

The palynological sequence from Badanital revealed an interval of high percentages of *Cannabis* type and *Humulus*/*Cannabis* type. In pollen records from European lakes, percentage values of 20–30% for both types (variations between 8–10% and 80–90%) are interpreted as an indicator of water retting of hemp (Edwards and Whittington, 1990, 1992; Kittel et al., 2014; Lavrieux et al., 2013; Mercuri et al., 2002; Schofield and Waller, 2005). Retting is a microbial process facilitating the release of bast fibres from bundled hemp stalks submersed in adequately shallow water (Clarke, 2007a; Dörfler, 1990; French and Moore, 1986). Dated to AD 900–1860, the exceptional record of both hemp pollen and sedimentary cannabinol from Lake Aydat (Massif Central, France) clearly documents the local practice of retting (Lavrieux et al., 2013). Remarkably, the pollen percentages in the Aydat and Badanital records are similarly high. Considering continuous representation of *Cannabis* type (up to 8%) and maximum percentages of *Humulus*/*Cannabis* type (above 8%), the confidential interval of intense retting at Badanital can be dated from *c*. 480 BC to AD 1050. High loss on ignition (LOI) values reported in the corresponding BT core section (Kotlia and Joshi, 2013) point to increased amounts of organic matter and corroborate an external input by retting activities. Between *c*. 1300 BC and AD 1150 values of 3–28% are recorded, though dominated by *Humulus*/*Cannabis* type pollen (2–20%). Excluding past growth of *Humulus* in the study area, the initial increase in frequencies of *Humulus*/*Cannabis* type after *c*. 1300 BC could point to a spread of wild hemp plants, early hemp cultivation and/or the beginning of retting at Badanital.

In southwest Asia, the use of fibres in general dates back well before 7000–6000 BC (Fuller, 2008). It is likely that *Cannabis* entered India via Himalayan trade routes about 3000 years ago (Fleming and Clarke, 1998). Archaeological records suggest an early use of hemp and various fibre plants in northern India during the first millennium BC or even earlier. At Senuwar in the middle Ganges region, fossil remains of *Linum usitatissimum* point to the use of flax fibres *c*. 1300–600 BC, whereas findings of *Cannabis* seeds are considered weak evidence for its use as a fibre crop (Fuller, 2008). At Narhan in Uttar Pradesh, flax seeds and fibres of ramie (*Boehmeria*, Urticaceae) were dated to *c*. 1300–800 BC (Fuller, 2008). At this time, the PGW culture people inhabiting river-banks used ramie-fibre nets for fishing (Lal, 1992). Literary records (e.g. the Atharveda texts) suggest the use of *Cannabis* in India since about 1200–1000 BC (Booth, 2003; Touw, 1981).

Intense retting of hemp at Badanital took place between *c*. 480 BC and AD 1050. According to archaeological evidence, this time interval corresponds to intensified human mobility, interaction and trade across northern India along the major rivers. During *c*. 600–300 BC, the Uttarapatha was a major trading network along the Indo-Gangetic plain connecting the northwestern India ports on the Bay of Bengal with northern side routes towards the upper and middle Ganges region (Singh, 2008). In the Mauryan Empire (322–185 BC), the Ganges valley was a ‘hub for trade routes’, while immigration areas of the Yuezhi tribes (200 BC–AD 300) can be considered as a ‘crucible of trade’ (Walsh, 2006). The Kushan Empire (AD 78–144) controlled Indian routes connected to the Silk Road network (Walsh, 2006) during the early first millennium AD. During the reign of the Gupta empire (AD 320–550), fibre products of silk, cotton, flax and hemp were widely distributed in India (Randhawa, 1980). During the 7th–11th century AD, hemp products were available as mats, cloth and textiles including imports from the Tang dynasty in China (Randhawa, 1980). Historical records of the 9th–11th century AD report on hemp fields and hempen yarns produced in India (Walsh, 2006). Traditional processing of hemp fibres, including the retting technique, is still widely distributed in the Kumaun and Garhwal Himalayas (Kuddus et al., 2013; Mathur and Joshi, 2013; Pant and Samant, 2010; Shah, 1997, 2004; Shah and Joshi, 1971) and in Nepal (Clarke, 2007a).

Early cultivation of hemp at Badanital could be linked to records of hemp seeds in the burial caves of Mebrak in Nepal Himalaya located at 3000–3500 m a.s.l. Since *c*. 1000 BC, the Kali Gandhaki gorge was an important trade route connecting the Tibetan Plateau with the lower Ganges valley, thus linking India with Xinjiang and Central Asia (Alt et al., 2003; Knörzer, 2000). At the Jhong site, macrobotanical remains of several grain crops were found, including seeds of *Cannabis* dated between 400 BC and AD 200 (Knörzer, 2000). The fossil hemp at the Jhong site is thought to be imported, because evidence for present-day traditional cultivation in the area is lacking (Knörzer, 2000). The nearby Muktinath site of the Himalayan mummies revealed finely woven textiles made of cotton, wool and linen or other plant fibres including mixed fabrics and a pair of trousers, which point to advanced techniques of textile processing between 400 BC and AD 50 (Alt et al., 2003).

The fossil hemp seeds from the Mebrak sites corroborate increased frequencies of *Humulus*/*Cannabis* type and appearance of *Cannabis* type pollen at Badanital. This may tentatively suggest that hemp was widely known and locally used across the West and Central Himalayas since *c*. 500 BC. The assumed import of hemp to the Kali Gandhaki sites (Knörzer, 2000) could point to regional trade and connections with the north, but possibly also with the Garhwal Himalaya.

The decline of hemp fibre production at Badanital occurred within a few decades. One possible explanation is that hemp production was subject to the competitive import of silk and hemp from China during the Tang dynasty (Randhawa, 1980). Furthermore, retting of hemp eventually deteriorates limnic environments, poisons fish and prevents the lake to be used as a potable water source (Edwards and Whittington, 1990). This scenario, however, remains purely hypothetical and cannot be accepted without further proof. Hence, we suggest that the disappearance of the short-lasting settlement at Badanital and the end of retting activities may have been caused by a combination of environmental and socioeconomic factors, which forced people to abandon the area.

The presented record from Badanital raises more general questions concerning the primary origin of retting techniques applied to hemp. Only a few Asian pollen records potentially point to early retting sites. In eastern Asia, palynological evidence is severely hampered by the fact that *Humulus scandens* and *Cannabis* pollen have similar size ranges. At the Seonam-dong site in South Korea up to 25% and 50% of *Humulus*/*Cannabis* pollen were assigned to the use of hemp as an agricultural crop during 3150–400 BC and AD 200–950, respectively (Park et al., 2013). High percentages of *Humulus* type pollen, possibly including *Cannabis*, were noted at the Banpo site (Shaanxi Province) dated to 4115–3535 BC, associated with cloth imprints in ceramic (Fleming and Clarke, 1998; Li, 1974). A sedimentary sequence from the Yangtze lowlands in eastern China revealed high frequencies of Moraceae type pollen since *c*. 3000 BC (Innes et al., 2014). However, the wide pollen category comprising Moraceae s.l. allowed for different interpretations, either reflecting secondary trees of Moraceae in open woodlands or retting of *Cannabis* for fibres (Innes et al., 2014). Except these references, we are not aware of further pollen sites potentially documenting retting of hemp in China or Korea.

As the chronological and regional evaluation of retting activities and ancient hemp fibre products in Asia are beyond the scope of this paper, we refer the reader to more comprehensive studies (e.g. Clarke and Merlin, 2013; Fleming and Clarke, 1998; Lu and Clarke, 1995; Merlin, 2003; Touw, 1981). Because the records of hemp from Badanital and Nepal may suggest early linkages to East and Central Asian trade routes, some selected examples with direct evidence of ancient cloth and textiles are pointed out below. In Korea traces of hemp thread, chord and cloth are reported from the Goongsan and a Gojoseon site dated to *c*. 3000 BC and 2333–108 BC, respectively (Clarke, 2006). In China, weaving of hemp cloth dates back to the Shang dynasty in the second millennium BC (Booth, 2003; Li, 1974). Funerary hemp textiles associated with the Shang dynasty were detected at the Anyang and Changsha cemeteries (*c*. 1520–1030/685 BC) (Fleming and Clarke, 1998; Merlin, 2003). In Shaanxi province, a fragment of tightly woven hemp cloth was found in a grave of the late Western Zhou dynasty (Li, 1974; Merlin, 2003), and in Henan province, a pair of hemp trousers were excavated from a royal Guo tomb of the Western Zhou (1046–771 BC) (Beck et al., 2014). The Yanghai Tombs in Xinjiang revealed *Cannabis* seeds, which were dated to *c*. 750–550 BC and tentatively assigned to *C. indica* (Jiang et al., 2006; Mukherjee et al., 2008; Russo et al., 2008). Furthermore, *Cannabis* fibres were detected in decorative tails of horse figurines from the Astana graves in Xinjiang dated between the 3rd and 9th century AD (Chen et al., 2014).

European records for hemp fibre use are not as old as those from Asia. In southern Italy, retting of hemp was established during the first century AD (Mercuri et al., 2002). The oldest Scandinavian record of hemp retting from Sweden is of a similar age (Larsson and Lagerås, 2015). In Denmark, the water retting technique was known at least since 800 BC, being initially applied to flax and by AD 375–1000 also to hemp (Andresen and Karg, 2011). Possibly, the oldest European record of woven hemp cloth from the Celtic grave at Hochdorf, near Stuttgart, Germany, is dated to *c*. 550 BC (Körber-Grohne, 1985, 1987), hence predating pollen evidence for retting sites in Europe (Dörfler, 1990; Larsson and Lagerås, 2015; Mercuri et al., 2002; Rösch, 1999). However, the Hochdorf cloth was shown to be made from unretted or not fully processed hemp fibres (Banck-Burgess, 1999; Körber-Grohne, 1985). Remarkably, fibres directly peeled from the stalks are sometimes also used in modern traditional processing of hemp in Nepal, Vietnam, Korea and China (Clarke, 1995, 2006, 2007a, 2007b) and similar techniques are known in Europe (Ottich, 2006).

General knowledge on ancient use of hemp fibres, whether unretted or retted, for making textiles is still fragmentary. The cultural diffusion of hemp towards Europe probably progressed along westward routes from Central Asia or further south from southwest Asia eventually reaching the Mediterranean (Dörfler, 1990; Fleming and Clarke 1998; Mercuri et al., 2002; Merlin, 2003). Badanital possibly represents the earliest retting site for hemp in India and might provide a missing link in the Eurasian history of ancient retting techniques.

Conclusion

The palynological sequence from Badanital documents the 4600-year-long vegetation history of Garhwal Himalaya. The most severe forest disturbances between *c*. 2270 and 480 BC are attributed to climatic deterioration and natural fires. Another phase of deforestation is linked to the settlement and human activities over the past three centuries. Under moderate human impact on vegetation, a dense forest developed during *c*. AD 480–1050. A decline of oak forests, secondary succession of alders (*c*. AD 1160–1270) and subsequent regeneration of oak forest were associated with a dry interval and abandonment of the area. During *c*. AD 1390–1630, oak forests were able to spread again, as human impact was weak.

The pollen record from Badanital also provides evidence for local use of hemp implying cultivation of hemp since *c*. 1300/1000 BC and water retting between 480 BC and AD 1050/1160. Thus, Badanital represents the first Indian and one of the oldest Eurasian records documenting local water retting of hemp. Relating pollen evidence from Badanital to historical accounts and archaeological sites, Garhwal Himalaya was likely linked to a network of trade routes across the Indo-Gangetic plain, first along the Uttarapatha routes and later connected to the Silk Road trade network via the Himalayan Kali Gandhaki route in Nepal.

Considering the still fragmentary knowledge on ancient Eurasian retting sites and textiles, the pollen record from Badanital should provide incentives for further palynological studies contributing to the history of hemp. Geochemical analyses of sedimentary cannabinol as a biomarker would be most important in areas of eastern Asia, where taxonomic differentiation using pollen analysis seems to be problematic. Furthermore, existing archaeological records of hempen products leave open several questions concerning the ancient use of hemp fibres and the temporal/spatial diffusion of water retting technique across Eurasia.

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