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Early human impact in the forest ecotone of southern High Asia (Hindu Kush, Himalaya)

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ABSTRACT

The vegetation of the treeline ecotone of the southern declivity of arid High Asia (Hindu Kush, northern areas of Pakistan; Himalaya, northern central Nepal) is dominated by hedgehog-like open dwarf shrublands of thorny cushions. Since climatically sensitive ecotones are always also sensitive to human impact, the question arises whether the current lack of forests is a result of the Subboreal climate decline or of human impact. Due to inadequate knowledge of the pollen flora and of ecological indicator values of the plants, pollen analyses in High Asia have mainly been limited to the regional verification of globally known climatic impulses. However, the role of human impact on regional vegetation patterns has been widely neglected. We postulate that today's open dwarf shrublands replace woodlands and forests. Isolated vigorous juniper trees and successful reforestation appear to confirm our hypothesis. An abrupt decline of *Pinus* forests before 5700 and 5400 ka cal yr BP can be demonstrated. As the first indicator pollen of human impact appeared at both sites synchronous with the forest pollen decline, we infer human impact to be a more decisive cause for this environment change superimposing the effects of a climatic deterioration. The forests were displaced by open dwarf shrublands.

Introduction

Reconstructing environmental change during the Holocene in the mountains of the old world's desert belt is a highly controversial topic. Due to their remoteness the environmental setting is poorly known and the ecology is even less well understood. Therefore the current treelessness is uncontrovertibly accepted as natural. Most world vegetation maps (e.g. Prentice et al., 1992; Lauer et al., 1996) ignore the possibility of human-induced impacts in the subtropical mountains between the Atlas in the west and Southern Tibet in the east, despite the fact that there is a wealth of evidence of forest relicts, mostly of the Cupressaceae (Miehe et al., 2008; Farjon, 2005). Their indicator value for the potential natural vegetation has been largely ignored. The objectives of this paper therefore are to contribute to the question whether the current arid environments reflect a climatic forest decline (Herzschuh et al., 2006) as a matter of deterioration of tree growth conditions or whether humans re-enforced or initiated these environmental changes (Thelaus, 1992; Frenzel, 1994; Ren, 2000). The perception of human impact on the environment of the mountains under consideration is highly contradictory. This is because humans are known to have been present proven throughout the whole mountain range even from palaeolithic times (Corvinus, 1996, 2004; Aldenderfer, 2003; Brantingham et al., 2007, Bellezza, 2008). However, the connection is seldom made that primitive hunters, early livestock farmers or nomads, however small their numbers, may have represented a driving force that changed vast forest areas into grasslands. The present dwarf shrubland pastures are thus widely considered to be natural. This is despite the fact that precipitation data (Fig. 1) provide evidence of a forest climate (Henning, 1994; Miehe et al., 1996, 2001), as does the occurrence of isolated tree stands on normal sites in the middle of degraded rangelands (Miehe et al., 2003, 2008).

Our hypothesis is that livestock-dependent early societies changed vulnerable forest environments according to their needs into pastures. The palaeoecological challenge is that the climate-driven environmental changes of the Holocene are widely known by the use of multiple proxies but it is still difficult to detect a superimposed and mostly accelerating human impact if direct archaeological data are missing. Transfer functions fail to take the long lasting human influence into account, leading to a misinterpretation of the proxy data and distorted calculations of past climate (Yu et al., 2001; Herzschuh et al., 2006). Our approach therefore combines pollen analysis with floristic inventories and vegetation ecology to identify human impact indicators. Reconstructing past environments by means of pollen analysis is a largely useless effort with misleading results if knowledge of the ecological indicator values of plants, the present vegetation and its dynamics are lacking. Descriptive tools such as floristically complete vegetation records still prove to be an indispensable precondition to reading pollen records unless it is accepted that modelling replaces in depth ecological

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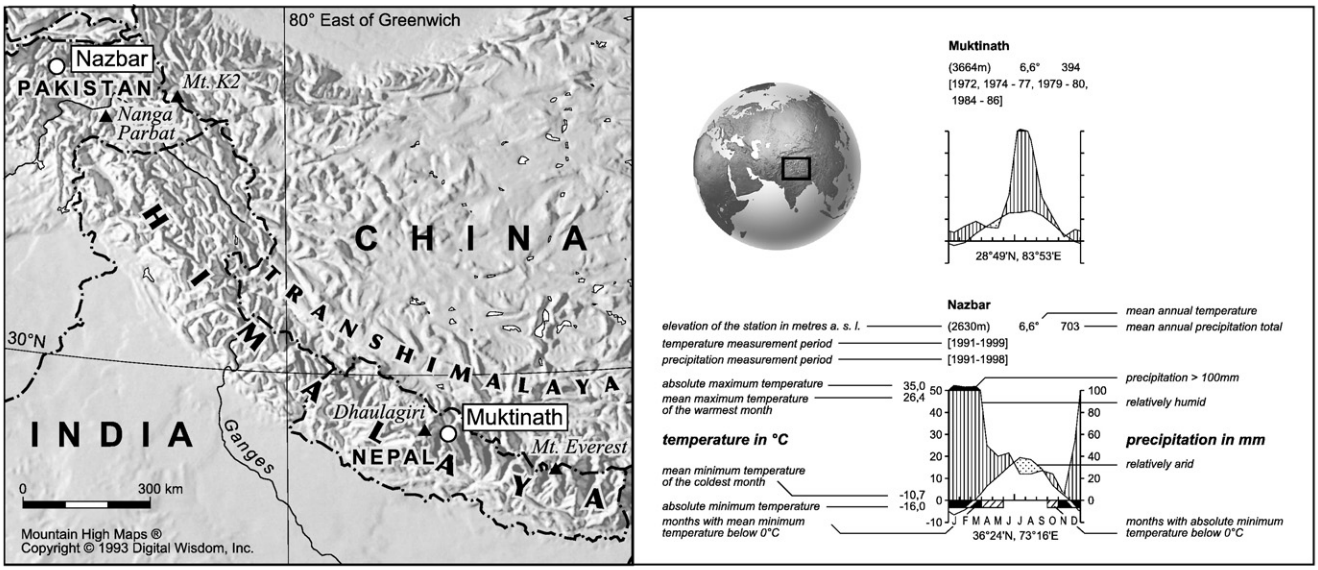

Figure 1. Locations of the pollen profile sites and related climatic diagrams (after data of Culture Area Karakorum Project, unpubl. and Climat. Rec. Nepal).

field experience. Thus using the "indicator–species approach" (Gaillard, 2007), our baseline assumption is that the actual and the past species' ecological indicator values (e.g. Behre, 1981, Ellenberg et al., 1991) are comparable. We therefore started with descriptive fieldwork techniques during the past 30 yr to record the vegetation patterns and understand the role of climate and humans for the establishment of the recent vegetation and to enlighten the ecological indicator value of plant species. As a result we present here the first ecological interpreted pollen diagram of High Asia stemming from the cooperation of a palynologist (Frank Schlütz) and two vegetation ecologists (Georg and Sabine Miehe) which enable us to detect early human impact.

Environmental setting

The treeline ecotone in arid High Asia

The two sites are located in the eastern Hindu Kush of the northern areas of Pakistan (Shukan) and the central Himalayas of northern Nepal (Jharkot) (Fig. 1). These sites are arranged along a 1300 km transect of the same ecosystem of open thorny dwarf shrublands ("Igelheiden", sensu Gams, 1956; see also Zohary, 1973; Kürschner, 1986). The mean annual precipitation ranges between approx. 400 and 700 mm (Fig. 1), thus exceeding the minimum of 200 to 250 mm/a for tree growth (Freitag, 1972, Henning, 1972, 1994). Snowfall of westerly disturbances in spring and autumn is the main form of precipitation in the Hindu Kush, whereas in the central Himalayas precipitation falls during the summer monsoon. Both sites have daily up-valley circulation connecting the remote side-valleys with more humid forest belts downstream. Hedgehog-like cushion-forming dwarf scrub 20 to 40 cm in height are the main woody constituents; the primary species are *Acantholimon kokandense*, *A. lycopodioides*, *Astragalus* Sect. *Aegacantha* in the Hindu Kush (Fig. 2) and *Caragana gerardiana* and *Sophora moorcroftiana* in northern Nepal (Figs. 4, 5). The suffruticose High Asian sage *Artemisia santolinifolia* and the dwarf shrubs of the bristly needled *Juniperus communis* are common in both sites. The dwarf shrubs form open stands and cover 30 to 60% of the slopes. Palatable graminoids and herbs are mostly browsed down to the ground or grow in the

Figure 2. Eastern Hindu Kush, northern areas of Pakistan, Nazbar: "Shukan". South-southeast facing open dwarf shrublands of *Artemisia santolinifolia* and *Acantholimon* hedgehog-like cushions and *Eremurus stenophyllus* pastures replacing forests. 36°23′N/73°07′E, 3400 m. Sept. 1990. Photo: G. Miehe.

Figure 3. North-central Himalayas of Nepal, Muktinath valley: "Jharkot": Terraced irrigated fields (1), irrigated poplar plantations (2) and village grazing areas with *Artemisia santolinifolia* open dwarf shrublands and *Caragana gerardiana* hedgehog cushions (3). Isolated sacred *Juniperus indica* trees (4), partly growing along irrigation channels along which also *Rosa* and *Berberis* shrubs aligned (5). Location of the pollen profile site (6). Archaeological sites with settlement excavations (7) and prehistorical caves (8). Dhaulagiri I (9). The broad arrow points to the gravel bed of the Kali Gandaki. 28°49′N/83°51′E; 3600 m. Towards the southwest (Dhaulagiri I), west and west-northwest. November 1976. Photo: G. Miehe.

protection of thorny shrubs. Only the unpalatable rhizomatous grass *Pennisetum flaccidum* is common and grows in the open at both sites. Common herbs include widespread annual weeds (e.g., *Polygonum plebejum*, *Potentilla bifurca*, *Malva pusilla*) and representatives of several functional groups, namely aromatic plants (Lamiaceae: *Elsholtzia*, *Nepeta*, *Thymus*), poisonous plants (e.g. *Arisaema flavum*, *Stellera chamaejasme*), rosette plants adapted to trampling (e.g. *Plantago* spp., *Tribulus terrestris*), as well as species with woolly, bristly hairs (e.g. Boraginaceae, *Cyananthus*, *Cousinia*). This spectrum of species obviously results from the selective grazing of livestock. Where the barren slopes are not affected by trampling carpets of Hepaticae (*Riccia*, *Marchantia*) seal the loamy soils and tiny ferns of *Botrychium lunaria* and *Ophioglossum vulgatum* become quite common. In the vicinity of both sites a few isolated but healthy dwarf juniper trees can be found (Shukan: *Juniperus excelsa* ssp. *polycarpos*, Jharkot: *Juniperus indica*). The pollen sites are located 500 m (Shukan) and 700 m (Jharkot) below the regional upper treelines (Miehe et al., 1996; Miehe, 1982). Inventories in both mountain areas since 1976 have revealed numerous isolated trees growing in shrubland pastures (Figs. 2–4; Miehe et al., 1996). The conclusion so far is that forests bordering the arid treeless core of High Asia have been largely extirpated and replaced by pastures with thorny shrubs and herbs avoided by livestock.

The extraction of timber is the main impact of the nearer past, enforced by the gathering of all remaining woody resources for fire wood, which has increased in the last 50 yr along with a higher population and tourism. In the Tibetan Himalaya firewood is stored as a matter of prestige on the flat roofs of the houses, showing the recently increased depletion of forest resources. Older people report that in the 1920s people hunted in (birch) forest above Muktinath — in a today treeless "alpine" environment. The decisive impact however is assumed to have been the initial clearing of forested land by farmers or nomads in order to improve grazing conditions and to obtain predator-free rangelands. Both sites are located along the same axis along which the "Neolithic Package" achievements of the Neolithic Revolution were diffused (cp. Diamond, 1997). It is thus highly probable that the grazing impact of wild herbivores was soon replaced by sheep, goat, cow and yak thousands of years ago.

The eastern Hindu Kush

The Hindu Kush site **Shukan** (3360 m, 36°23′ N/73°07′ E) is located in a small tongue basin of a side valley of the Nazbar River in the western upper catchment of the Gilgit River joining the Indus. The site is a heavily grazed Cyperaceae swamp adjacent to irrigated barley fields of a small seasonal summer settlement. Surrounding slopes are used for

Figure 4. Pastures with isolated forest relicts of *Cupressus torulosa* in open dwarf shrublands of *Caragana gerardiana* near the drought line of forests. Locations of Figure 5: (1), the arrow points to the site of the pollen profile. 28°53′N/83°47′E, 3250 m. Northern bank of the Cha Lungpa, looking towards southeast. Sept. 2001. Photo: G. Miehe.

summer grazing of sheep, goats, cows and donkeys (Fig. 2). Spiny unpalatable cushions of *Acantholimon kokandense* and *A. lycopodioides* cover up to 30% whereas other dwarf shrubs like *Ephedra gerardiana* and *Artemisia santolinifolia* are suppressed through heavy browsing and rarely flower under the presently increased grazing pressure. Shrubs of *Juniperus communis* are avoided by cattle and humans; they are quite common on the foot of the north-facing slope. The herb layer covers between 5 and 55% depending on the presence of unpalatable species. Highest values are attained where the long flowering stalks and large tufted rosettes of the geophytic *Eremurus stenophyllus* or the sclerophyllous tufts of *Festuca olgae* prevail. Dwarf and lopped trees of *Juniperus excelsa* ssp. *polycarpos* can rarely be found on more remote, sunny slopes mostly on exposed cliffs. Other trees and shrubs (*Salix hastata*, *Betula utilis*, *Sorbus tianschanica*) are restricted to wet sites at the bases of rockfalls or close to springs and rivers. *Hippophaë rhamnoides* and *Myricaria germanica* ssp. *alopecuroides* form common pioneer thickets in the braiding river beds. The nearest forest areas with *Cedrus deodara*, *Picea smithiana*, *Pinus wallichiana* and *Abies pindrow* are found on the upper slopes of the Indus Gorge 50 to 70 km southwards beyond the high ridges of the northwest Himalayas, but ca. 200 km away in terms of migration distance. Their altitudinal range is 2400 to 2900 m (*Cedrus*) 2800 to 3500 m (*Picea*), 2500 to 3500 m (*Pinus*), and 3000 to 3600 m (*Abies*), after Schickhoff (1995).The only known disjunct record of forest trees is located ca. 70 km northwest of Shukan at 3350 m with *Pinus wallichiana* partly with water surplus (see Table 2). Natural regeneration of *Pinus* is weak; *Juniperus communis* invades clearings in the *Pinus-Betula* forests.

The north-central Himalayas

The site **Jharkot** (3500 m, 28°49'N/83°51'E) is situated in the basin-like Muktinath valley, a side valley of the upper Kali Gandaki Gorge in the monsoonal rain shadow of the Himalayan main range north of Dhaulagiri I (Fig. 3). It is likewise a Cyperaceae swamp in wastelands surrounding a village with irrigated cultivation of barley, buckwheat and potatoes. The margin of the swamp has widespread salt indicators (*Glaux maritima*, *Triglochin* spp., *Pedicularis longiflora* v. *tubiformis*) and a suite of High Asian wasteland species (*Potentilla bifurca*, *Erodium stephanianum*, *Microgynoecium tibeticum*, *Malva pusilla*, *Mirabilis himalaica*, *Elsholtzia* spp.) and *Plantago* spp. as well as tall forbs typical of dung heaps (*Rumex nepalensis*, *Chenopodium album*, *Urtica* spp., *Hyoscyamus niger*, *Scopolia straminifolia*). The vegetation along irrigation canals and of stone walls around the fields is characterized by tall forbs of Apiaceae, *Thalictrum* spp., *Verbascum* sp., *Salvia hians*, *Cannabis sativa*, *Artemisia* spp. and *Cirsium* spp. with *Clematis tibetana* trailing from the walls. Numerous shrubs normally growing in forests (e.g., *Rosa sericea*, *Berberis* spp., *Lonicera* spp., *Cotoneaster tibetica*, *Spiraea arcuata*, *Berchemia edgeworthii*) are also part of the typical cultural landscape of the Tibetan oasis. The surrounding slopes have similar open dwarf shrublands of thorny cushions (Figs. 4, 5) like in the Hindu Kush, but Fabaceae (*Caragana gerardiana*, *Sophora moorcroftiana*) prevail, together with *Artemisia santolinifolia* and shrubs (*Abelia triflora*, *Viburnum cotinifolium*, *Leptodermis lanceolata*, *Aster albescens*, and the above mentioned forest species) (see Table 3) where boulders provide shelter from browsing. The herbaceous layer reflects the high selective grazing pressure as nearly all herbs and graminoids are avoided by livestock (*Thymus linearis*, *Heteropappus* spp., *Anaphalis* spp., *Vincetoxicum hirundinaria*, *Arisaema flavum*, *Stellera chamaejasme*, *Stipa inebrians*). With the exception of planted and irrigated poplars and willows, trees have not been detected. However, a few individuals of *Juniperus indica* in the religious protection of a nearby Buddhist temple testify to the forest potential of the present desert-like rangeland (Fig. 3: 4). The nearest forests are open stands of *Juniperus indica* and *Cupressus torulosa* only 8 km away in the Kali Gandaki valley. They are heavily lopped and continuously subjected to cutting for fuel wood or incense. Ten kilometers further down, *Pinus wallichiana* forms dense forests and further 30 km downwards there are cloud forests on the south side of the Himalayas, with *Tsuga dumosa*, *Quercus semecarpifolia* and *Alnus nepalensis*. Yet forests are not only found along with increasing rainfall towards the South but in the drier north as well. About 13 km northwest of Jharkot, open *Juniperus indica–Cupressus torulosa* forests occur on southern windward slopes (Fig. 4) and *Pinus wallichiana–Abies spectabilis* forests on sheltered north-facing slopes, while 18 km northwards in the arid part of the main valley *Pinus wallichiana* occurs in north-northwest exposures even with *Rhododendron lepidotum* in the undergrowth (see Table 3: record no. 9).

Materials and methods

Floristic records and vegetation monitoring

As a prerequisite for an in depth interpretation of pollen diagrams a quantitative approach with complete floristic records

Figure 5. Pastures of open dwarf shrublands of thorny cushions of *Caragana gerardiana* on wind-exposed gravel terrace of the Kali Gandaki. The cushions are wind-shaped and browsed. The open dwarf shrubland presumably replace open Cupressaceae forests. 28°52'N/83°46'E, 3150 m. Looking towards north-northwest. Sept. 1977. Photo: G. Miehe.

and vegetation surveys including flowering plants, ferns, fern allies, mosses and lichens was chosen. The vegetation records were executed with standard plot sizes (10×10 m) according to the Zürich/Montpellier approach (Mueller-Dombois and Ellenberg, 1974). Species composition, percentages of cover of each species, structure and especially diameter and size of phanerophytes were recorded. GPS position, altitude, slope exposure, slope inclination, geological substrate and habitat conditions (esp. water surplus or

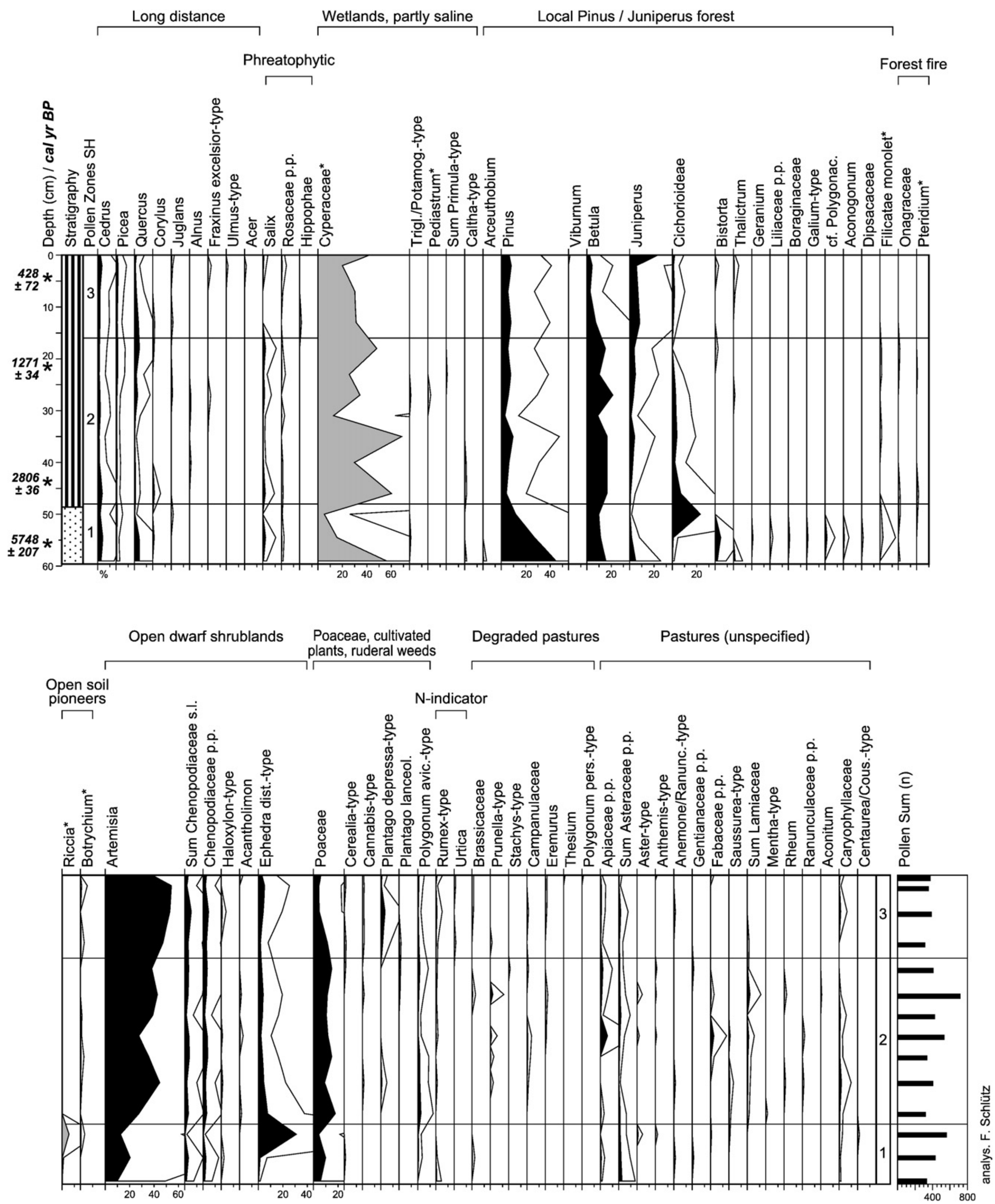

Figure 6. Pollen diagram Shukan, Hindu Kush (36°23′N/73°07′E, 3360 m). Palynological taxa arranged according to their ecological values (see text). Taxa of the pollen sum filled black, simple lines showing the fivefold exaggeration. Taxa with * not included into the pollen sum. Stratigraphy from top to base: Cyperaceae-turf, humous sandy gravel layer.

deficit) were documented as well. Special attention was given to all sites safe from grazing or trampling like steep cliffs and boulder slopes. Species were determined within the framework of the "Flora Karakorumensis Project" (Dr. B.W. Dickoré, Göttingen) for the Shukan site and with support through a larger number of plant taxonomists during the edition of the "Enumeration of Flowering Plants of Nepal" (Hara et al., 1978–82) for the Jharkot site. Plant names are given according to those floras. Semi-formal interviews about land use systems at present and in the past were held with local people with the help of translators.

Palynology

As the detection of the grazing impact of livestock is our main objective we took our cores from grazed swamps surrounded by pastures and not in lakes, due to the low dispersal distance of the insect-pollinated grazing weeds and the spores of ferns and mosses.

The two pollen profiles were taken in 1990 (Shukan) and 1995 (Jharkot). The 60 cm long profile Shukan consists of a humous sandy gravel layer at the base overlaid by Cyperaceae-turf (Fig. 6). The original dating was based on three conventional ^{14}C-dates (Hv) of bulk samples. The two younger ones yielded inverse ages and are here replaced by three AMS-datings of the pollen fraction (Morgenroth et al., 2000) measured in 2006 Erlangen (Erl., Table 1). The lower part of the 370 cm profile Jharkot (Fig. 7) is built by weak humus clayey material, a clayey detritus mud (64–110 cm) and a Cyperaceae-turf in the top. The upper part was dated by one conventional ^{14}C (79–82 cm, Hv.) and two AMS bulk samples (Beta Analytic) to be younger than 5380 cal yr BP, and the biostratigraphical results reveal that the profile covers about the whole Holocene. Calibrated ages of our data and data from literature were calculated with the online program CalPal (www.calpal-online.de, calibration set CalPal_2007_HULU, Weninger et al., 2004).

The pollen samples were prepared by standard methods using KOH, HF and acetolysis. Afterwards the suspensions were sieved in an ultrasonic bath (mesh 6 µm, 50 kHz) and stored in glycerine (Erdtman, 1960; Moore et al., 1999). For the standard analyses a 500 magnification was used, and for sub types of Poaceae and difficult cases a magnification of 1250 was used in addition to phase contrast and oil immersion. Charcoals have not been studied then in detail. The palynological taxa have been cross-checked with herbarium material of the Natural History Museum/London (BM) and our own project herbaria deposited at the University of Göttingen herbarium (GOET). Identification and nomenclature are also based on the literature (Beug and Miehe, 1999; Schlütz, 1999).

The calculation of pollen percentages is based on the sum of arboreal pollen (AP) and non-arboreal pollen (NAP), with Cyperaceae, water plants and spores not included. 140 different pollen and spore types are shown in the pollen diagrams. The authors decided to arrange the pollen diagrams in ecological groups (Figs. 6, 7). Based on vegetation inventories the palynomorphs are grouped due to their ecological indicator values. To the left palynomorphs of long distance transport, of groundwater depending woody plants (phreatophytic), of the surrounding wetlands and of the presumed primary forest ecosystem are given. After this sets of types attributed to different kinds of human impact follow. Thus the making of a human environment starts with fire indicators, followed by pioneer plants colonizing open soil surfaces, open dwarf shrubland pollen types, pollen types of cultivated plants, ruderal plants and livestock or grazing indicators. We intentionally used this "subjective" way of pollen data interpretation to illuminate what is obscure to so called "objective" statistical methods.

Table 1
Radiocarbon dates of the pollen profiles (Erlangen (Erl.), Hannover (Hv.) and Beta analytic (Beta)).

Profile	Depth (cm)	Lab. No.	Method	^{14}C yr BP	cal yr BP	Material
Shukan	3–6	Erl-9180	AMS	401 ± 42	428 ± 72	Pollen fraction
Shukan	20–22.5	Erl-9179	AMS	1350 ± 42	1271 ± 34	Pollen fraction
Shukan	42.5–45	Erl-9178	AMS	2685 ± 45	2806 ± 36	Pollen fraction
Shukan	53–60	Hv 17900	conv. 14C	4995 ± 190	5748 ± 207	Bulk
Jharkot	79–82	Hv 22983	conv. 14C	830 ± 140	791 ± 114	Bulk
Jharkot	122–131	Beta-156302	AMS	2870 ± 40	3002 ± 60	Bulk
Jharkot	162–171	Beta-154331	AMS	4620 ± 40	5380 ± 61	Bulk

Calibration was done with the online program CalPal (www.calpal-online.de, CalPal2007_HULU, Weninger et al., 2004). Error values refer to 1 Sigma (68% range).

Results

The eastern Hindu Kush, Shukan

The most striking feature of the local pollen zone **Shukan 1** (**SH 1**) is the drastic decrease of *Pinus* pollen from 45% down to a level typical for long distance transport like as *Cedrus*, *Picea*, *Quercus*, *Corylus* or *Juglans*. The high *Pinus* values coincide exclusively with pollen finds of Dipsacaceae (i.e. *Dipsacus inermis*), *Bistorta*, *Galium*-type (i.e. *Rubia chitralensis*), Liliaceae p.p., *Geranium* (i.e. *G. pratense*) and high values of fern spores (Filicatae monolet). This pollen assemblage largely corresponds with the composition of the nearest relictual patches of *Pinus wallichiana* forest (see Table 2). The high value of the monolet fern spores are important because those ferns are doubtless forest plants and their spores are short distance dispersed only, proving the local existence of a forest habitat until around 5700 cal yr BP. The collapse of a pine forest is evidenced through increased *Riccia*-spores: after the end of a crown-shaded microclimate and the removal of a cover of higher plants, open patches of soil are covered by those Hepaticae and *Botrychium* (*lunaria*) appears being typical for sun-exposed open soils. An identical succession (*Pinus* and Filicatae monolet followed by *Riccia*) is below demonstrated for the Himalayan site of Jharkot as well. *Ephedra* and Cichorioideae pollen show unique peaks in reaction to a drastic change of the vegetation structure. *Ephedra* shrubs are light-demanding and profit from the removal of shading pine crowns. The Cichorioideae include several disturbance indicators such as *Dubyaea* spp., *Cicerbita* sp., *Taraxacum* spp., *Crepis* spp., *Youngia* spp. growing near to forests and peak at the end of a *Pinus*-phase also at Jharkot (Fig. 7, end of JH 1).

Parallel to the decline of *Pinus*, pollen of *Juniperus* (the only constituent of the *Juniperus*-type here) and *Betula* show a slight decrease. It can be assumed that tree species of both genera were present in a *Pinus wallichiana* forests as they are today understory trees in the nearest relict forests (*Juniperus excelsa* ssp. *polycarpos*, *Betula utilis* spp. *jacquemontiana*). The collapse of the pine forest may have also affected the junipers and birches but both subsequently recovered. Our key question here is to what extent the end of pine forests was due to climatic changes and/or human activity. Fire most probably played a role as evidenced by the (weak) record of bracken (*Pteridium aquilinum*), a well known worldwide indicator of fire. Onagraceae-pollen (i.e. *Epilobium angustifolium*) although insect transported is present as well thus supporting the fire impact explanation. Livestock-keeping humans certainly do not profit from conifer forests as their grazing value is poor. In addition, we must consider that early livestock-keeping societies were seriously afflicted by predators such as wolves, leopards and bears. It seems likely, that already the early nomads actively destroyed the forests and hindered a re-establishing by their grazing herds.

The zone **SH 2** is defined by the replacement of the *Pinus* forest pollen assemblage by types of the present dwarf open shrublands of *Acantholimon* and *Artemisia*. Poaceae pollen doubles as soon as the *Pinus* forests were over. Lamiaceae (i.e. *Nepeta discolor*), Campanulaceae (i.e. *Asyneuma argutum*) and Fabaceae (i.e. *Cicer macranthum*, *Astragalus* spp.) as typical pasture components appear. Considering

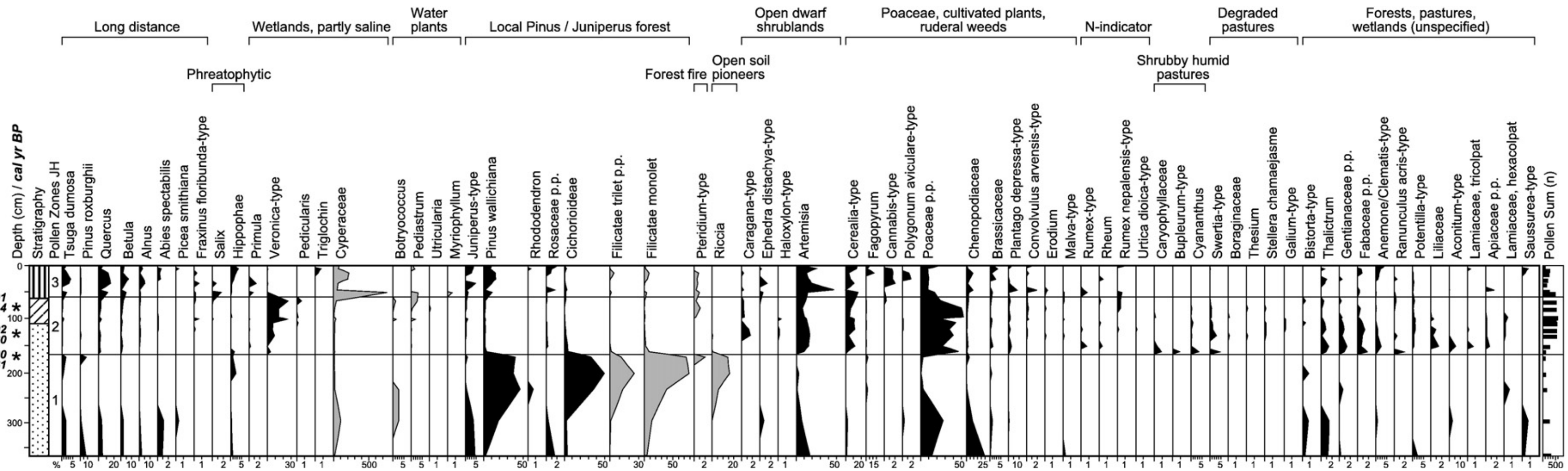

Figure 7. Pollen diagram Jharkot, central Himalaya (28°49'N/83°51'E, 3500 m). Palynological taxa arranged according to their ecological values (see text). Taxa of the pollen sum filled black, note different scales. Stratigraphy from top to base: Cyperaceae-turf, clayey detritus mud, humous clayey material.

Table 2
Vegetation records of relictual *Pinus* forests in the northeastern Hindu Kush.

	Record no.	1	2	3
Tree layer 1, 5–12 m	*Pinus wallichiana*	20	50	30
Tree layer 2, 5–190 m	*Betula utilis* ssp. *jacquemontii*	25	5	10
	Pinus wallichiana	5	25	
Tree layer 3/shrub layer 1, 2–4 m	*Betula utilis* ssp. *jacquemontii*	12		15
	Sorbus tianschanica	8		5
	Pinus wallichiana	+	+	+
Shrub layer 2, 0.2–0.8 m	*Juniperus communis*	20	10	8
	Cotoneaster integerrimus	+	+	
	Sorbus tianschanica	+	+	+
	Lonicera microphylla			+
	Rosa webbiana		+	+
	Pinus wallichiana		+	8
Herb layer, 05–0.25	*Stellaria graminea*	10	3	+
	Thalictrum foletidum	10	+	
	Thymus linearis	4	+	+
	Minuartia kashmirica	3		2
	Geranium pratense	+	+	
	Sorbus tianschanica juv.	+		+
	Poa pratensis ssp. *pratensis*	+	4	+
	Veronica biloba	+	+	
	Cicer microphyllum		r	+
	Arabidopsis mollissima		+	+
	Festuca hartmannii		+	+
	Potentilla chrysantha		r	+
	Orthilia secunda		1	1

Single records:
1 *Viola rupestris* +, *Arenaria orbiculare* +, *Cerastium thomsonii* +.
2 *Astragalus grahamianus* +, *Chenopodium foliosum* +, *Myosotis asiatica* +, *Polygonum plebejum* r, *Ribes orientale* +.
3 *Prunus jacquemontii* juv. +, *Scorzonera virgata* +, *Betula utilis* ssp. *jacquemontii* juv. +, *Juniperus excelsa* ssp. *polycarpos* juv. +, *Silene vulgaris* +, *Hieracium vulgatum* +, *Hylotelephium ewersii* +, *Nepeta discolor* +.
Site description: Phaiz Gah
1 36°33'N/73°41' E, 3.350 m, 30° NNE-exp. lower slope. Strong grazing, no wood-cutting.
2 36°33'N/73°35' E, 3.320 m, 25° N-exp. middle slope, weak grazing, no wood-cutting. *Juniperus communis* occupies clearings in the forest.
3 36°33'N/75°35' E, 3.320 m, 20° N-exp. middle slope, weak grazing, no wood-cutting.

the present relictual stands of *Betula* in the eastern Hindu Kush in water surplus positions the continued presence of *Betula* pollen can be attributed to stands near downstream of Shukan.

The question arises if desiccation (climate) or desertification (human impact) were the driving. We assume that the changes were driven by livestock-keeping humans as indicated by grazing weeds (*Acantholimon*, *Eremurus*) occurring for the first time together with a set of pollen indicating human presence (*Centaurea*/*Cousinia*, *Polygonum aviculare*, *Plantago depressa*-type, *Cannabis*) despite this unequivocal indication of human presence, grazing pressure remains relatively weak, because Poaceae attain higher values than in SH 1 and SH 3.

The period of **SH 3** covers about the last 1000 yr showing increased human impact, most probably through at least seasonal permanent presence of humans after the introduction of barley cultivation (Cerealia-type). This coincides with increased values of the *Plantago depressa*-type, the first occurrence of *Urtica* pollen, and increased *Rumex* values indicating more cattle dung. Grasses and birch have the lowest values. Grasses were widely replaced by *Artemisia* and the birches were cut for construction purposes and fuel. We assume that increased populations forced farmers to extend cultivation into the most remote valleys up to the highest sites suitable for crop cultivation, like Shukan. The most recent changes show a striking peak of juniper pollen. The field experience suggests that this indicates stronger grazing inducing the next step in degradation, the spreading of *Juniperus communis* shrubs. Those shrubs are an inedible grazing weed and favoured when competitive herbs and grasses are browsed. The most recent *Artemisia* decrease reflects the stronger grazing pressure as well.

North-central Himalaya, Jharkot

Reconstructing Holocene environments of the arid central Himalayas of northern Nepal is made easier by a wealth of archaeological data available from nearby excavation sites (Schuh, 1992–93; Schuh et al., 2006; Hüttel, 1994, 1997; Hüttel and Paap, 1998; Simons et al., 1994; Simons and Schön, 1998; v.d. Driesch et al., 2000; Knörzer, 2000). The vegetation ecology and human impact on the natural resources are also far better known than at the other sites (Miehe, 1982; Kriechbaum, 2002).

Similar to the Hindu Kush diagram the basal zone **JH 1** shows the presence of an inner-Himalayan moderately humid *Pinus wallichiana* forest with rhododendrons in the undergrowth and ferns in the herb layer. Forests of that humidity range are today commonly found 30 km to the south and require slightly higher annual rainfall of c. 450 to 500 mm, however, a NNW-exposed pine forest with *Rhododendron lepidotum* (Table 3: record no. 9) was found 18 km farther north. Even there was probably higher rainfall during JH 1 it is not necessarily needed to have at least *Rhododendron lepidotum* in the undergrowth. The pollen conservation during JH 1 however is poor and less oxidation resistant pollen may have been lost. The present swamp obviously did not exist. Nonetheless, the *Polypodium*- and *Pteris*-type including many forest ferns and the *Rhododendron* pollen, like the spores only short distance transported, reflect the existence of a moderately humid inner-Himalayan *Pinus wallichiana* forest during the mid-Holocene. *Juniperus indica* and *Abies spectabilis* as well as *Sorbus* (Rosaceae p.p.) are still present in the nearest recent *Pinus wallichiana* forest 12 km northwest. The breakdown of the pine forest was incisive and sudden. The AMS dating gives an age of about 5400 cal yr BP for its end. The forest loss was accompanied by disturbances indicated by *Riccia* and *Hippophaë*. *Riccia*-liverworts colonize soil surfaces when the cover of higher plants is removed. *Hippophaë thibetana* is a dwarf shrub pioneer on wet unstable sites mostly along streams eroding into moraines or on mass movements of sediments rich in clay. As the sediment and the pollen concentration (reflected by low pollen sums above and below change from JH 1 to JH 2) show no sudden change, we assume no hiatus in the profile. If there is any hidden gap in the sediment, the lost of forests would be somewhat younger than expected.

Possibly due to the loss of forests landslides occurred and became a predominantly factor of relief development since then (Baade and Mäusbacher, 2000). Two independent findings corroborate the authors' assumption that the mass movements followed a change in the forest cover by fire but did not cause the change. Firstly the disturbing impact on the forest releasing the landslide was fire, as *Pteridium aquilinum* spores occur for the first time and with highest values. And just 7 and 9 km south of Jharkot charcoals dated 5813 ± 115 cal yr BP and 6473 ± 118 cal yr BP (Saijo and Tanaka, 2002) indicate an earlier fire impact on forests until their lost at Jharkot. The ambiguity if forest fires are natural or caused by humans is less vague than in other sites because there is archaeological evidence of settlers in the area: bricks in cave settlements close to our site are nearly 7000 yr old (Simon, pers. comm. 2001; Schuh, 1992–93). This is concomitant with the oral tradition of the valley saying that the first settlers established in a forested area (Schuh, pers. comm. 1987). It is not unlikely that those early settlers burnt the easily flammable pine forests and started cultivation with buckwheat (i.e. *Fagopyrum*) on rain-fed unterraced fields like as practised even today in remote valleys of the Eastern Himalayas in Bhutan.

The pollen spectra of **JH 2** largely reflect already the present, treeless, desert-like environment dominated by open dwarf shrublands of *Artemisia santolinifolia* and *Caragana gerardiana*. The High Asian *Artemisia santolinifolia* sage remains widespread even today and bears evidence of the most widely distributed replacement vegetation of forest ecotones in High Asia. The possible anthropogenic nature of the environmental change from forests to a treeless landscape is corroborated by a large number of pollen types attributable to human impact. The first significant presence of Cerealia-type pollen along with a set of grazing indicators (e.g. *Cyananthus*, *Plantago depressa*-type) is followed by spectra indicating the development of wastelands around villages (e.g. *Convolvulus arvensis*, *Erodium stephanianum*, *Malva pusilla*) or heavily degraded common pastures (e.g. *Thymus linearis*, *Stellera chamaejasme*, *Thesium himalense*). The *Potentilla*-type can be placed in this assemblage as well regardless of whether it represents the salt-tolerant *Potentilla anserina* (of seasonally wet trampling places), *Potentilla bifurca* (wastelands near villages) or dwarf shrubs of *Potentilla fruticosa*, a constituent of shrubby replacement communities of semi-humid forests. Together with this set of pollen types, pollen of the *Caragana*-type appears for the first time. Belonging to insect-pollinated Fabaceae of dry slopes the pollen is only incidentally found in pollen diagrams (Beug and Miehe, 1999).

Table 3
Vegetation records of relictual *Pinus-Cupressus-Juniperus* forests in the Tibetan Himalaya nearest to the Jharkot site.

Record no.	1	2	3	4	5	6	7	8	9	10	11	12	13
Tree layer 8–12 m													
Pinus wallichiana	30			15	20	40	15	20	20				
Juniperus indica			+	15			4	3		15	3	5	
Cupressus torulosa							4	15	+	12			
Picea smithiana				20	15			10					
Betula utilis									8				
Shrub layer 0.3–3 m													
Cotoneaster tibeticus	15	12	10		+	2	1	1		10	+	2	1
Artemisia santolinifolia	8	10	15	12	10	30			+	2	4	10	
Caragana gerardiana	10	8	12	2			3	2		15	4	2	3
Juniperus indica	+		1	2	3	2	+	+	1	15		18	30
Aster albescens	12	10	8	2	1	+		1		1	1	+	
Cotoneaster microphyllus	2	4	10			+	1	+			+	+	
Juniperus communis	+		8	35	+	25	+	+		1	+		
Abelia triflora	2		3	1			1	+	4	+	+		
Berberis usteriana	1	+	10	2	+		1	10	+				
Viburnum cotinifolium	10	+	+	+	+			+	+				
Pinus wallichiana	+			1		1		+	+				
Caragana brevispina				12	2	+	1	10		1			
Berberis tsarica	1	2	2	1	1	+	+					+	
Lonicera myrtillus	1	8	2	+	10	12			+	10			
Ephedra gerardiana		+	30	+	+	2	+					+	
Rosa sericea							2	2		1	1	1	1
Potentilla arbuscula								+		8		10	8
Berchemia edgeworthii							10			8		+	
Cotoneaster ludlowii							1			2		+	
Juniperus squamata										15	+	8	12
Lonicera myrtilloides										+	+	1	8
Clematis tibetana											+	+	
Berberis mucrifolia											1	1	
Rabdosia rugosa							2					3	1
Rhododendron lepidotum								+	35				
Herb layer 0.01–0.3 m													
Leontopodium stracheyi	8	2	10		+	+	2	1	+	2	3	1	+
Anaphalis triplinervis	+	10	8	2		+	1	+			2	1	2
Thymus linearis		3		+	2	1		+		+	1	2	2
Danthonia cumminsii	+	+							5			+	+
Arisaema flavum	+									+		2	+
Thalictrum foetidum	+	+	+	1	1	1	1	1		1			
Silene moorcroftianum	+	+	+			+		+					
Dendranthema tenuiflorum	30					25		20					
Festuca gigantea	20	25	18	20	25	2							
Koeleria macrantha	25	20	12	15	2	1							
Elymus semicostatus	+	8	10	2	10	1							
Deyeuxia scabrescens	+	+	1		+								
Arabiodopsis himalaica			+	+	+								
Carex laeta		10	+			+				+	+		
Androsace strigillosa							1	1	2	1		+	1
Dendranthema nubigenum							+	+	+	+	1	+	
Stellera chamaejasme												+	+
Aster barbellatus							+			1			+
Polygonatum cirrhifolium									1			+	
Malaxis muscifera									+			+	

The pollen record demonstrates that the today dominating open dwarf shrublands of thorny cushions (Fig. 5) are present since at least 3000 yr. An increase in human impact is highly probable because the earliest period of settlement started around this time (Simons and Schön, 1998).

A further step towards today's environment is indicated by the appearance of tall forbs widely known from dung heaps and cattle resting places (*Urtica*, *Rumex nepalensis*). The pastures of the valley were certainly never better than during JH 2 as the percentages of grasses were never higher. The decrease of Poaceae pollen at the end of zone JH 2 marks the turn to a stronger degraded environment.

The most recent period (**JH 3**) covers roughly the last 500 yr including the Little Ice Age. As lower temperatures have been demonstrated from dendrochronological data (Bräuning and Mantwill, 2004) and certainly have affected high altitude agriculture we should consider superimposing effects of climate. Like in other regions of the southern Himalayas *Pteridium* indicates a continuous fire regime (Beug and Miehe, 1999; Schlütz and Zech, 2004). The local vegetation history depends highly on the water management of the Jharkot oasis. The Cyperaceae peak in the beginning of JH 3 may reflect irrigation, as Cyperaceae are here strictly confined to habitats fully depending on the irrigation system. A high anthropo-zoogenic impact by grazing is reflected by the decrease of the Poaceae representing the fodder resources of the surrounding slopes. The human impact is also evident from the increase of *Cannabis*, as *Cannabis sativa* is planted for human use. The most conspicuous event is a sharp drop of the cereal pollen coinciding with an *Artemisia* peak, whereas Poaceae remain low. Judging from present vegetation patterns we may conclude that irrigated corn fields were abandoned and invaded by *Artemisia santolinifolia*, while grazing pressure remained high. Perhaps irrigation canals were destroyed by landslides or war and the irrigated fields fell dry. Ancient irrigation terraces uniformly covered with dwarf shrubs of *Artemisia santolinifolia* are however a common pattern in the whole

Notes to Table 3
Cover-abundance in percent. + = <1%; *r* = only one record.
Single records:
1 *Poa jaunsarensis* +, *Agrostis munroana* 1.
7 *Trigonella gracilis* +, *Cymbopogon distans* 1, *Cymbopogon stracheyi* +, *Poa angustifolia*.
8 *Rhododendron lowndesii* +, *Leptodermis lanceolata* +, *Andropogon munroi* +, *Stipa sibirica* +.
9 *Spiraea arcuata* +, *Salix karelinii* +.
11 *Lonicera hypoleuca* 2, *Androsace muscoidea* 1.
12 *Arnebia euchroma* 1, *Verbascum thapsus* +, *Allium spicatum* +, *Arisaema jacquemontii* +, *Lasiocaryum densiflorum* +, *Heteropappus semiprostratus* +, *Ajuga lupulina* +, *Dicrano stigma lactucoides* +, *Dracocephalum heterophyllum* +.
13 *Saussurea fastuosa* +, *Gerbera nivea* 25, *Erigeron multiradiatus* +, *Monotropa hypopitys* +, *Anemone rupicola* 10, *Thalictrum platycarpum* +, *Hedysarum kumaonense* 2, *Youngia gracilipes* +, *Calamagrostis staintonii* +, *Cicerbita macrorhiza* 3, *Oreocome stelliphora* +, *Galium acutum* +, *Festuca wallichiana* +, *Clematis montana* +, *Kobresia nepalensis* +, *Pinus wallichiana juv.* +, *Pterocephalus hookeri* +, *Carex plectobasis* +.
Site description:
Site 1–6: Jomosum Chu, 28°46'N/83°46'E.
7, 8, 10: Longpoghyun Khola, 28°45'N/83°44'E.
11: Syang Khola 28°48'N/83°41'E.
12/13: Western slope of the Thak Khola, 28°52'N/83°46'E.
1: 3280 m, 38° N-exp., below limestone cliffs, scree. No grazing, little wood-cutting.
2: 3260 m, 38° N-exp. ridge, limestone scree and bedrock, grazing, wood-cutting.
3: 3260 m, 38° N-exp., moderate water surplus in flat gully.
4: 3190 m, 25° N-exp., middle slope, scree and moraine, weakly windward, selective wood-cutting (*Juniperus indica*), no grazing.
5: 3160 m, 25° N-exp., middle slope, scree and moraine, weakly windward, selective wood-cutting (*Juniperus indica*), no grazing.
6: 3080 m, 20° N-exp., lower slope, scree and moraine, near the drought line of *Pinus*, weakly windward. Grazing, wood-cutting.
7: 3480 m, 20° NNW-exp., moraine, near lower condensation level.
8 + 10: 2900 m, fully sun-exposed moraine, windward. Grazed.
9: 28°58'N/83°48'E 3760 m, 37° NNW-exp., moraine and scree, selective wood-cutting, no grazing.
11: 3250 m, 25° NNW-exp., middle slope with cliffs, moraine and scree, grazing, wood-cutting.
12: 3450 m, 20° E-exp., lower slope, scree, grazing.
13: 4500 m, 15° N-exp., slope shoulder, moraine, near the upper treeline, grazed.

rain shadow area of northern Nepal (Miehe, 1982) and southern Tibet and are evidence of the decreasing water resources of that part of the old world's desert belt (Zhu et al., 2008). This climatic trend of the youngest past may be reflected by appearance of *Triglochin* indicating salinisation.

Conclusions

Despite the present perception of the High Asian environment being naturally desert-like and arid with thorny open dwarf shrublands, two test sites have a forest climate with nearly double the rainfall known from the drought lines of forests (200 to 250 mm/a) and temperatures well above the known thresholds of tree growth (Körner, 1999; Henning, 1994; Domrös and Peng Gongbing, 1988). Moreover there is still an underdeveloped awareness of the importance of vigorous isolated trees in normal (not water surplus) habitats. The two regions, stretching over 1300 km from northern Pakistan to central Nepal have in common isolated juniper trees in inaccessible or religiously protected sites, showing the potential at least of *Juniperus* woodlands. Our approach therefore emphasizes the importance of in depth ecological knowledge of the present flora and vegetation to use non-lake pollen profiles as archives of local and regional landscape history. Paired with the knowledge of 30 yr of field experience the pollen data lead us to the conviction that there is a long lasting and much greater human impact on the environments of the arid mountains of southern High Asia than has been considered before. Our palaeoecological conclusions are supported by vegetation inventories and experimental grazing exclosures and successful non-irrigated reforestation (*Juniperus convallium*, *Cupressus gigantea*) in *Sophora*–*Artemisia* heathlands of Lhasa in a comparable environment (Miehe et al., 2003).

A significant environmental change set in with the decline of conifer forests in the Himalayas and in the Hindu Kush within a few hundred years between 5.7 (Shukan) and 5.4 (Jharkot) ka cal yr BP. Both sites have in common that the former presence of forests is indicated through pollen values of an amount surpassing the values originating from long distance transport and additionally by the presence of fern spores of short distance origin. At both sites *Riccia* covered the open soils after the conifers disappeared. There is only little evidence to argue in favour of orbital driven climatic changes at least not to an effect that forest died out. Nearby vigorous forests and climate data witness that forests could grow at our sites as soon as the high anthropo-zoogenic impact would be reduced. This is shown in the pollen diagrams by the coincidence of forest decrease with the appearance of pollen and spore types pointing to human impact and livestock grazing. The key issue however is that by vegetation analyses several palynomorphs have been identified as human disturbance indicators.

The forests never recovered again from the initial clearing. This underlines the vulnerability of the forest ecosystem against human influence. The hedgehog-like open dwarf shrublands of *Acantholimon*, *Caragana* and *Sophora* replaced forests. The vast areas covered today with these replacement communities (Schweinfurth, 1957; Dobremez, 1976; Miehe 1982; Zhang, 1988; Peer et al., 2001; Nüsser and Dickoré, 2002) suggest that our sites are not by chance exceptionally strongly degraded but are representative for the southern Asiatic part of the old world's desert belt. The two sites belong to the mountains where the "Neolithic Package" was dispersed (Diamond, 1997); a late intrusion of livestock therefore would not be probable. Yet the few spots in the study area where the history of humanity's first impact and the evolution of a cultural environment have been reconstructed show that human interference began at considerably different times (Kreutzmann, 1996; Beug and Miehe, 1999; Aldenderfer, 2003; Schlütz and Zech, 2004; Umer et al., 2007; Miehe et al., in press). As hominids already had the tool of fire for anywhere between 1.5 Ma (South Africa; Brain and Sillen, 1988) and 1.9 Ma (Omo, East Africa; Dechamps, 1984) and there is growing evidence from island palaeoecology that as soon as humans appear ecosystem dynamics are suddenly largely fire-driven (Kershaw, 1986; Burney, 1993; Ogden et al., 1998; Burney and Burney, 2003) we can expect that even remote and little populated mountain areas did not remain untouched. Livestock-breeding societies moreover had good reasons to burn forests because treeless rangelands are easier to manage. However there are only very few sites where archaeological findings in parallel with palaeoecological dates provide evidence of a "smoking gun" to prove human interference. As we have the certainty that wherever humans appear they changed their environments according to their needs the question "*cui bono*" (who profits?) may give adequate certainty of a circumstantial evidence in a palaeoecological case.

The answer to the question if the present treelessness of the treeline ecotone of arid High Asia is caused by climatic changes of the Holocene or human impact has at least three preconditions: (1) the knowledge of the regional flora, the plants' ecological indicator values and the vegetation dynamics, (2) the identification of palynomorphs especially those for human's presence and (3) choosing adequate non-lake pollen archives. As near the drought line of forests human impact can cause the same effect as a change to drier conditions, the in depth knowledge of human indicator pollen is a prerequisite to disentangle the ambiguity of climatic and cultural signals (e.g. Schlütz and Lehmkuhl, 2007) for dealing with the reconstruction of Holocene environmental changes.

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References

Aldenderfer, M.S., 2003. Moving up in the world. American Scientist 91, 542–549.
Baade, J., Mäusbacher, R., 2000. Environmental change and settlement history, preliminary results from the Mukthinath valley, Inner Himalaya, Nepal. Marburger Geographische Schriften 135, 40–52.
Behre, K.E., 1981. The interpretations of anthropogenic indicator in pollen diagrams. Pollen and Spores 23, 225–245.
Bellezza, J.V., 2008. Zhang Zhung. Foundation of civilization in Tibet. Österreichische Akademie der Wissenschaften, Philosophisch-Historische Klasse 368. Wien.
Beug, H.-J., Miehe, G., 1999. Vegetation history and human impact in the eastern central Himalaya (Langtang and Helambu, Nepal). Dissertationes Botanicae 318.
Bräuning, A., Mantwill, B., 2004. Summer temperatures and monsoon history on the Tibetan plateau during the last 400 years recorded by tree rings. Geophysical Research Letters 31, L24205.
Brain, C.K., Sillen, A., 1988. Evidence from the Swartkranscave for the earliest use of fire. Nature 336, 464–466.
Brantingham, J.P., Gao Xing, Olsen, J.W., Ma Haizhou, Rhode, D., Zhang Haiying, Madsen, D.B., 2007. A short chronology for the peopling of the Tibetan Plateau. Developments in Quaternary Science 9, 129–150.
Burney, D.A., 1993. Late Holocene environmental changes in arid southwestern Madagascar. Quaternary Research 40, 98–106.
Burney, L.P., Burney, D.A., 2003. Charcoal stratigraphies for Kaua'i and the timing of human arrival. Pacific Science 57, 211–226.
Corvinus, G., 1996. The prehistory of Nepal. Journal of the Nepal Research Centre 10, 1–25.
Corvinus, G., 2004. *Homo erectus* in East and Southeast Asia, and the questions of the age of the species and its association with stone artifacts, with special attention to handaxe-like tooly. Quaternary International 117, 141–151.
Dechamps, R., 1984. Evidence of bush fires during the Plio-Pleistocene in Africa (Omo and Sahabi) with the aid of fossil wood. Palaeoecology of Africa 16, 291–295.
Diamond, J., 1997. Guns, Germs and Steel. The Fate of Human Societies. Norton, New York.
Dobremez, J.F., 1976. Le Népal. Écologie et Biogéographie. CRNS, Paris.
Domrös, M., Peng Gongbing, 1988. The Climate of China. Springer, Berlin.
Driesch, v.d.A., Manhart, H., Schmitt, B., 2000. Archäozoologische Untersuchungen in der mittelalterlichen Siedlung von Khyinga-Khalun, Distrikt Mustang/Nepal. Beiträge zur Allgemeinen Vergleichenden Archäologie 20, 45–108.

Ellenberg, H., Weber, H.E., Düll, R., Wirth, V., Werner, W., Paulißen, D., 1991. Zeigerwerte von Pflanzen in Mitteleuropa. Scripta Geobotanica 18. Goltze, Göttingen.
Erdtman, G., 1960. The acetolysis method. Svensk Botanisk Tidskrift 54, 561–564.
Farjon, A., 2005. A Monograph of Cupressaceae and Sciadopitys. Royal Botanic Gardens, Kew.
Frenzel, B., 1994. Über Probleme der holozänen Vegetationsgeschichte Osttibets. Göttinger Geographische Abhandlungen 95, 143–166.
Freitag, H., 1972. Die natürliche Vegetation des südostspanischen Trockengebietes. Botanisches Jahrbuch 91, 147–308.
Gaillard, M.J., 2007. Pollen methods and studies/archaeological applications. In: Elias, S.A. (Ed.), Encyclopedia of Quaternary Science. Elsevier, Amsterdam, pp. 2570–2595.
Gams, H., 1956. Die Tragacantha-Igelheiden der Gebirge um das Kaspische, Schwarze und Mittelländische Meer. Veröffentlichungen des Geobotanischen Instituts, Stiftung Rübel 31, 217–243.
Hara, H., Chater, A.O., Williams, L.H.J., 1978–82. An Enumeration of the Flowering Plants of Nepal. British Museum (Natural History), London. 3 vols.
Henning, I., 1972. Die La Sal Mountains, Utah. Ein Beitrag zur Geoökologie der Colorado Plateau Provinz und zur vergleichenden Hochgebirgsgeographie. Abhandlungen Akademie der Wissenschaften und der Literatur Mainz. Mathematisch-Naturwissenschaftliche Klasse, Jahrgang 1975, 2.
Henning, I., 1994. Hydroklima und Klimavegetation der Kontinente. Münstersche Geographische Arbeiten 37.
Herzschuh, U., Kürschner, H., Mischke, S., 2006. Temperature variability and vertical vegetation belt shifts during the last ~50,000 yr in the Qilian Mountains (NE margin of the Tibetan Plateau, China). Quaternary Research 66, 133–146.
Hüttel, H.-G., 1994. Archäologische Siedlungsforschung im Hohen Himalaya. Die Ausgrabungen der KAVA im Muktinath-Tal/Nepal 1991–1992. Beiträge zur Allgemeinen Vergleichenden Archäologie 14, 47–163.
Hüttel, H.-G., 1997. Archäologische Siedlungsforschung im Hohen Himalaya. Die Ausgrabungen der KAVA im Muktinath-Tal/Nepal 1994–1995. Beiträge zur Allgemeinen Vergleichenden Archäologie 17, 7–64.
Hüttel, H.-G., Paap, I., 1998. On the chronology and periodization of Khyingia settlement mound. Beiträge zur Allgemeinen Vergleichenden Archäologie 18, 6–26.
Kershaw, A.P., 1986. Climatic change and Aboriginal burning in north-east Australia during the last two glacial/interglacial cycles. Nature 322, 47–49.
Knörzer, K.-H., 2000. 3000 years of agriculture in a valley of the High Himalayas. Vegetation History and Archaeobotany 9, 219–222.
Körner, C., 1999. Alpine Plant Life. Springer, Berlin.
Kreutzmann, H., 1996. Ethnizität im Entwicklungsprozess. Die Wakhi in Hochasien. Reimer, Berlin.
Kriechbaum, M., 2002. Flora, Vegetation und Landnutzung des Muktinath-Tales (Mustang, Nepal) als Beziehungsmuster von naturräumlicher Ausstattung und menschlicher Gestaltung im Zentralhimalaya. Dissertationes Botanicae 369.
Kürschner, H., 1986. Die syntaxonomische Stellung der subalpinen Dornpolsterformationen am Westrand SW-Asiens. Phytocoenologia 14, 381–397.
Lauer, W., Rafiqpoor, M.D., Frankenberg, P., 1996. Die Klimate der Erde. Eine Klassifikation auf ökophysiologischer Grundlage der realen Vegetation. Erdkunde 50, 275–300.
Miehe, G., 1982. Vegetationsgeographische Untersuchungen im Dhaulagiri- und Annapurna-Himalaya. Dissertationes Botanicae 66 (1), 2.
Miehe, G., Winiger, M., Böhner, J., Zhang Yili, 2001. The climatic diagram map of High Asia. Purpose and concepts. Erdkunde 56, 94–97.
Miehe, G., Miehe, S., Koch, K., Will, M., 2003. Sacred forests in Tibet: using Geographical Information Systems for forest rehabilitation. Mountain Research and Development 23, 324–328.
Miehe, G., Miehe, S., Kaiser, K., Reudenbach, C., Behrendes, L., La Duo, Schlütz, F., in press. How old is Pastoralism in Tibet? An ecological approach to the making of a Tibetan landscape. Palaeogeography, Palaeoclimatology, Palaeoecology.
Miehe, S., Cramer, T., Jacobsen, J.P., Winiger, M., 1996. Humidity conditions in the Western Karakorum as indicated by climatic data and corresponding distribution patterns of the montane and alpine vegetation. Erdkunde 50, 190–204.
Miehe, G., Miehe, S., Will, M., Opgenoorth, L., La Duo, Tsering Dorgeh, Liu, J.Q., 2008. An inventory of forest relics in the pastures of Southern Tibet (Xizang A.R., China). Plant Ecology 194, 157–177.
Moore, P.D., Webb, J.A., Collinson, M.E., 1999. Pollen Analysis. Blackwell Science, Oxford.
Morgenroth, G., Kerscher, H., Kretschmer, W., Klein, M., Reichel, M., Tully, T., Wrzosok, I., 2000. Improved sample preparation techniques at the Erlangen AMS-facility. Nuclear instruments methods in physics research/B 172 (1), 416–423.
Mueller-Dombois, D., Ellenberg, H., 1974. Aims and Methods of Vegetation Ecology. Wiley, New York.
Nüsser, M., Dickoré, W.B., 2002. A tangle in the triangle: vegetation map of the eastern Hindu Kush (Chitral, Northern Pakistan). Erdkunde 56, 37–59.
Ogden, J., Basher, L., McGlone, M., 1998. Fire, forest regenerations and links with early human habitations: evidence from New Zealand. Annals of Botany 81, 687–696.
Peer, T., Millinger, A., Gruber, J.P., Hussain Farrukh, 2001. Vegetation and altitudinal zonation in relation to the impact of grazing in the steppe lands of the Hindu Kush Range (N-Pakistan). Phytocoenologia 31, 477–498.
Prentice, C.I., Cramer, W., Harrison, S.P., Leemans, R., Monserud, R.A., Solomon, A.M., 1992. A global biome model based on plant physiology and dominance, soil properties and climate. Journal of Biogeography 19, 117–134.
Ren, G., 2000. Decline of the mid- to late Holocene forests in China: climatic change or human impact. Journal of Quaternary Science 15, 273–281.
Saijo, K., Tanaka, S., 2002. Paleosols of middle Holocene age in the Thakkhola basin, central Nepal, and their paleoclimatic significance. Journal of Asian Earth Sciences 21, 323–329.
Schickhoff, K., 1995. Verbreitung, Nutzung und Zerstörung der Höhenwälder im Karakorum und angrenzenden Hochgebirgsräumen Nordpakistans. Petermanns Geographische Mitteilungen 139, 67–85.
Schlütz, F., 1999. Palynologische Untersuchungen über die holozäne Vegetations-, Klima- und Siedlungsgeschichte in Hochasien und das Pleistozän in China. Dissertationes Botanices 315.
Schlütz, F., Lehmkuhl, F., 2007. Climatic change in the Russian Altai, southern Siberia, based on palynological and geomorphological results, with implications for climatic, teleconnections and human history since the middle Holocene. Vegetation History and Archaebotany 16, 101–118.
Schlütz, F., Zech, W., 2004. Palynological investigations on vegetation and climate change in the late Quaternary of Lake Rukche area, Gorkha Himal, Central Nepal. Vegetation History and Archaebotany 13, 81–90.
Schuh, D., 1992–93.Introduction. Ancient Nepal 130–133, c-m.
Schuh, D., Bielmeier, R., Cüppers, C., Schmidt, B., 2006. Forschungsbericht über die Exploration der Höhlen des Muktinath-Tales (1986–1987). Zentralasiatische Studien 35, 107–166.
Schweinfurth, H., 1957. Die horizontale und vertikale Verbreitung der Vegetation im Himalaya. Bonner Geographische Abhandlungen 20.
Simons, A., Schön, W., 1998. Cave systems and terrace settlements in Mustang Nepal. Settlement periods from prehistoric times up to the present day. Beiträge zur Allgemeinen Vergleichenden Archäologie 18, 27–47.
Simons, A., Schön, W., Shrestha, S.S., 1994. Preliminary report on the 1992 campaign of the team of the Institute of Prehistory, University of Cologne. Ancient Nepal 136, 51–75.
Thelaus, M., 1992. Some characteristics of the mire-developpement in Hongyuan County, eastern Tibet plateau. Proceed. 9th Intern. Peat Congress 1. Uppsala, pp. 334–351.
Umer, M., Lamb, H.F., Bonnefille, R., Lézine, A.M., Tiercelin, J.-J., Gibert, E., Cazet, J.P., Watrin, J., 2007. Late Pleistocene and Holocene vegetation history of the Bale Mountains, Ethiopia. Quaternary Science Review 26, 2229–2246.
Weninger, B., Jöris, O., Danzeglocke, U., 2004. Cologne Radiocarbon Calibration & Paleoclimate Package CalPal (www.calpal.de).
Yu, Ge, Tang, L.Y., Yang, X.D., Ke, X.K., Harrison, S.P., 2001. Modern pollen samples from alpine vegetation on the Tibetan Plateau. Global Ecology & Biogeography 10, 503–519.
Zhang, J.W., 1988. The vegetation of Xizang. Science Press, Beijing (in Chinese).
Zhu, L.P., Wu, Y.H., Wang, J.B., Lin, X., Ju, J.T., Xie, M.P., Li, M.H., Mäusbacher, R., Schwalb, A., Daut, G., 2008. Environmental changes since 8.4 ka reflected in the lacustrine core sediments from Nam Co, central Tibetan Plateau, China. The Holocene 18, 831–839.
Zohary, M., 1973. Geobotanical Foundations of the Middle East. Fischer, Stuttgart.

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