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Vegetation and climate dynamics in Khyber Pakhtunkhwa (NW Pakistan), inferred from the pollen record of the Kabal Valley in Swat District during the last 3300 years

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ABSTRACT. We present a pollen-based palaeoenvironmental reconstruction of the past 3300 years in the Kabal Valley of Swat District in the Hindu Kush mountains of Khyber Pakhtunkhwa Province, north-western Pakistan. We studied the pollen record from 38 samples taken from a 150 cm long radiocarbon-dated sediment core in order to analyse the vegetation history of the area. Only the upper 76 cm of the core, with 20 samples recording the last 3300 years, had sufficiently preserved pollen. Conifers such as *Pinus, Picea, Abies, Cedrus* and *Taxus*, and herbs belonging to Poaceae, Cyperaceae and Amaranthaceae were found consistently throughout the period, at varying abundance. The vegetation reconstruction revealed that Cyperaceae and Poaceae dominated the conifers from 3300 to 300 cal yr BP. The decrease in herbaceous vegetation (mainly Poaceae) from 2400 to 1500 cal yr BP, and its increase from 1500 to 1200 cal yr BP, indicate contraction followed by expansion of grassland in the Kabal Valley of Swat, pointing to corresponding dry-cool and wet-warm periods. Herbs were abundant in most samples from 900 to 300 cal yr BP. This change from conifer forest to open grassland can be attributed to the more pronounced impact of widespread deforestation, agricultural activity and a drier summer climate. Evergreen trees and shrubs such as Oleaceae, Myrtaceae, Moraceae species, *Juglans* and *Dodonaea* dominated and were constant from 2400 cal yr BP to the present. Conifers such as *Pinus*, *Taxus*, *Picea*, *Abies* and *Cedrus* were frequent in the study area from 300 cal yr BP to the present. Today these conifers occur mostly in mixed coniferous forests at higher elevation in the alpine area.

KEY WORDS: Holocene, vegetation dynamics, pollen record, Kabal Valley, Swat district, Khyber Pakhtunkhwa Province, Pakistan, Hindu Kush Himalaya, conifers, herbs

INTRODUCTION

Little information is available about the past vegetation and climate changes in Pakistan. Pakistan is affected by the Indian monsoon system and is subject to changes in vegetation cover, ongoing desertification and climate change (Claussen et al. 2003). Important progress in research on the Holocene climate in monsoon regions has been made during the last few decades, based on evidence from cave deposits, speleothems, lake sediments, peat deposits and loess–palaeosoil sequences (An et al. 2000, Hong et al. 2005, 2010, Wang et al. 2010, Chen et al. 2014). Despite the availability of information from numerous geological studies conducted in Pakistan (Waagen 1882, 1885, Noetling 1901, Balme 1970, Pakistani–Japanese Research Group 1985, Wardlaw & Pogue 1995, Mertmann 2003, Sultan 2004, Alam

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2008), there have been only a few palaeoecological studies, for example from the Karachi coast near the Arabian Sea (von Rad et al. 1995, Schulz et al. 1996, Ivory & Lézine 2009) and from the salt range of Pakistan (Schneebeli-Hermann et al. 2014). To infer the vegetation history and palaeoclimate during the last glacial–interglacial cycle in onshore areas, a study was conducted in southern Pakistan near the Arabian Sea coast by the cooperative German–Pakistan project PAKOMIN (Pakistan Oxygen Minimum; von Rad et al. 1995, Schulz et al. 1996). The aim was to analyse pollen and spore abundance and changes in floral diversity along a continuous, high-resolution, undisturbed gravity core derived from the present-day oxygen minimum zone (OMZ) of the Indus continental shelf (Ansari & Vink 2006). This joint project provided the first uninterrupted 30 000-year vegetation and palaeoclimate record of the southern Pakistan hinterland near the Arabian Sea. That analysis and interpretation of the core revealed (1) greater glacial aridity than during the following postglacial period up to the present day, (2) a downslope retreat of the Himalayan subalpine and deciduous tree zone during the Last Glacial Maximum (LGM) to the Younger Dryas cold interval, and (3) a marked change to early Holocene humid conditions.

Apart from these few studies, conducted mostly on the extreme southern side of Pakistan near or on the shore of the Arabian Sea (0 m a.s.l.), the first study from northern Pakistan focused primarily on the Neogene mammal fauna, which includes a family of hominoids, the Ramapithecidae (Badgley & Behrensmeyer 1980). In a second study, an attempt was made to trace early human impacts in the upper forest ecotone of Hindu Kush Himalaya (36°23′N/73°07′E) at the Shukan site (Miehe et al. 2009). The present work is only the third palaeoecological study of the area. Our research area lies in South Asia, whose pollen database is yet to appear (not available as of the date of this paper). The sampling sites covered in the East Asian Pollen Database (EAPD) include China, Mongolia, the Russian Far East, Vietnam, Cambodia and Thailand (Harrison et al. 1995, Zhuo et al. 2014). So far there is no published work on the vegetation history of the north-western part of Pakistan, which is situated in one of the world's most important mountain systems, the Hindu Kush. This study reports the first records from the north-western side of the lower Hindu Kush, and is aimed at reconstructing the vegetation history of the Kabal Valley in Swat District (750 m a.s.l.) of Pakistan's Khyber Pakhtunkhwa Province.

For the Swat District and surrounding areas, several studies have contributed knowledge of woodland types from the low-elevation subtropics to the high mountains (Beg & Khan 1984, Hussain et al. 1992, Hussain et al. 1995, Ahmed et al. 2010, Rashid et al. 2011, Sher & Al Yemeni 2011, Qasim et al. 2011, Ilyas et al. 2012, Khan 2012, Akhtar & Bergmeier 2015). The Swat District's wide altitudinal range encompasses different climate and vegetation zones, with montane forest and alpine vegetation above the tree line (Fig. 1b); this makes the Swat Valley a most suitable area for reconstructing the vegetation dynamics of the past and particularly for studying the influence of climate change on vegetation. The Kabal part of the Swat Valley is surrounded by mountains; most likely the majority of pollen and spores comes from the vegetation growing in the adjacent mountain system (Fig. 1b). Hence the pollen assemblage in this part of the Swat Valley probably originates from plants inhabiting a broad spectrum of altitude. Changes in the past climate must have had a marked effect on the altitudinal occurrence of taxa, and these changes should be represented in the pollen record. Hence, the natural vegetation found to have grown on the mountains around Kabal village in the Swat Valley should be a good indicator of past climatic conditions.

The recession of glaciers in the Himalayas is proceeding faster than in any other part of the world; at the current rate they are very likely to disappear by the year 2035 (Husnain et al. 2005). This recession has been observed more often in the Western Himalayas, as the contribution of snow to the runoff of major rivers on the western side is 60–70%, compared to only 10% on the eastern side (IPCC 2001). The high mountain region (7000–8000 m a.s.l.) in the Himalayas and Hindu Kush mostly receives winter rains, while the low-elevation region (300–500 m a.s.l) mostly receives summer rains (Hussain et al. 2005). Winter precipitation lasts from December to March, due to western disturbances passing along the path between 30°N and 60°N, whereas monsoon precipitation in the summer is caused by lows and depressions developing in the Arabian Sea and Bay of

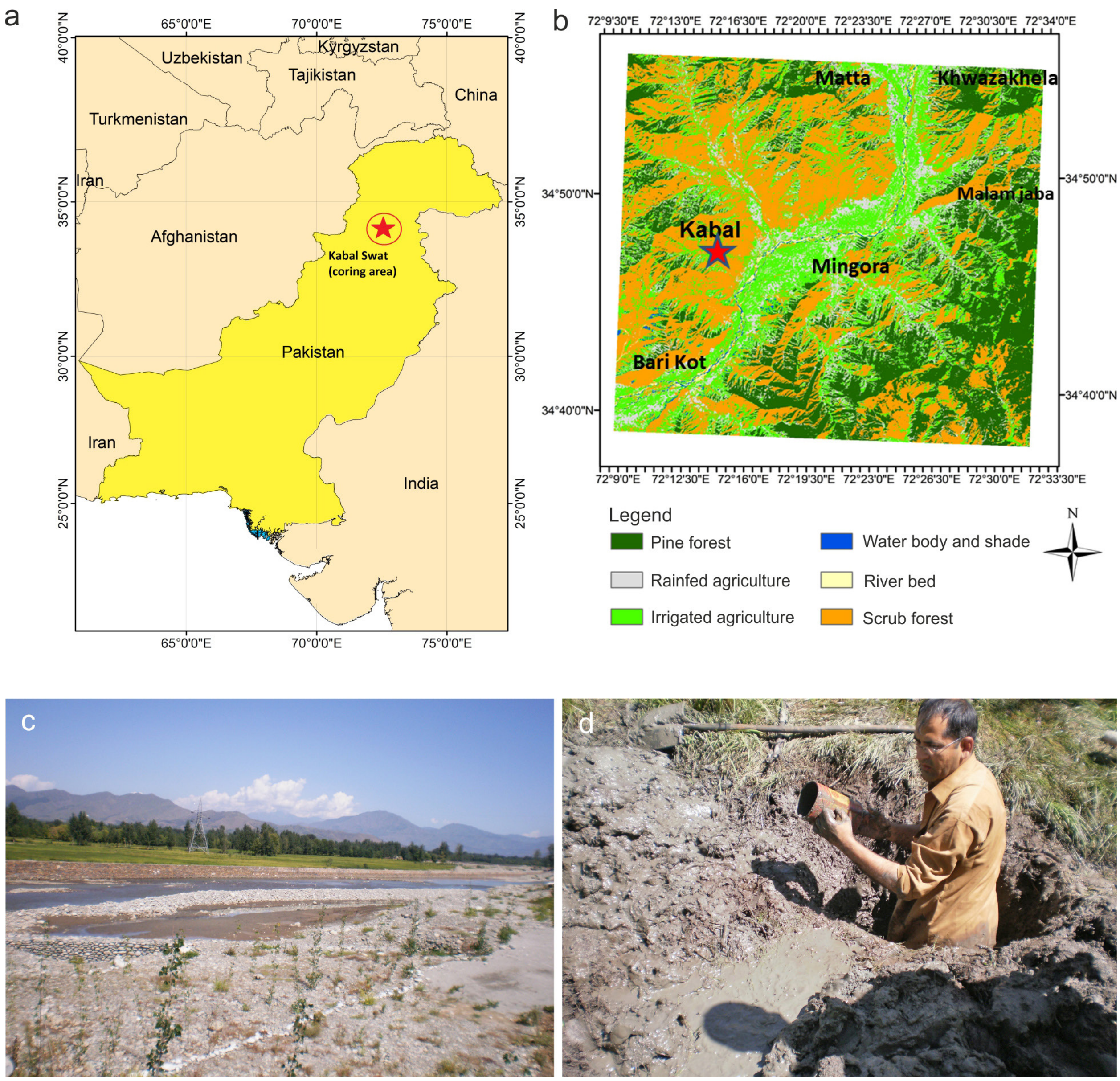

Fig. 1. **a** – map of Pakistan (shown in yellow) and neighbouring countries of the region. The coring site is located in north-western Pakistan in Kabal village (star) in the Swat Valley; **b** – map (50 × 50 km) of the study area, showing the geographical distribution of the main vegetation types and the altitudinal distribution of the vegetation, including the upper tree line. Elevations of the area surrounding the Swat River: Bari Kot (750 m a.s.l.), Mingora (800 m a.s.l.), Kabal (950 m a.s.l.), Matta (1200 m a.s.l.), Khwaza Khela (1200 m a.s.l.), Malam Jabba (3000 m a.s.l.); **c** – Swat River 10 km west of the coring site in Kabal village, flowing from the northern mountains to the southern plain of Pakistan (Photo by author); **d** – author at the coring site (34°66′N 72°13′E, elevation: 750 m a.s.l.) (Photo by Dr Qadeem Khan)

Bengal from July to September (Hussain et al. 2005). In terms of climate and flora, the eastern part of the Hindu Kush is more similar to the Himalayas, so most biogeographers call it Hindu Kush Himalaya (Khan et al. 2012). The Hindu Kush forests that come under the influence of the monsoon are represented by *Pinus wallichiana*, *Pinus roxburghii*, *Cedrus deodara*, *Picea smithiana* and *Abies pindrow*, and the important indicator species of the Himalayan range are *Abies pindrow*, *Pinus wallichiana*, *Fragaria nubicola*, and *Rhododendron*, *Viola* and *Clematis* species (Khan et al. 2012). In terms of species composition and richness, the vegetation of the western and northern parts of the Himalayas is similar to that of the Hindu Kush and the monsoon belt of the Karakorum, perhaps owing to similarity of geology, physiography and climate. Characteristic species of this transitional belt of the Western Himalaya, Southern Karakorum and Eastern Hindu Kush are *Cedrus deodara*, *Picea smithiana*, *Ephedra gerardiana*, *Thymus linearis* and *Cotoneaster microphyllus* (Khan et al. 2012, Ali & Qaiser 2009).

In June and July, the equatorial trough of the Intertropical Convergence Zone (ITCZ) moves northward. As it crosses the equator the trade winds swing around, becoming the south-west monsoon into Asia. Monsoons are most intense in Asia, which has the largest land mass, building up an intense low-pressure system each summer (Sarfaraz 2007). The Himalayas cause the ITCZ to move much further north than anywhere else in the world. As the air flows northward it picks up moisture from the Indian Ocean, in consequence of which the monsoon brings torrential rain to Asia in July and August. Monsoons in the subtropical Hindu Kush and Himalayas are the result of the seasonally reversing tropical winds, bringing the dry and wet seasons. Monsoon rains on these mountains have fostered a rich flora, famous for its unique endemic (and threatened) biodiversity, forests, wildlife, and immense unexplored genetic resources, thanks to which the Western Himalayan moist temperate Ecoregion has been designated a "Global 200" Priority Ecoregion for Global Conservation (Ahmad et al. 2014).

In this paper we present an assessment of the vegetation history of the Kabal Valley in Swat District spanning the last 3300 years of the late Holocene, based on the pollen record. The aim is to fill the research gap in the palaeoecology of the Hindu Kush Himalayan mountains by tracing the composition of species in the surrounding vegetation during the late Holocene. As the first study in the Hindu Kush Himalayan phytogeographic region, the paper offers preliminary insights into the past vegetation dynamics of the Swat Valley and surrounding northern areas. At present, the conifers on the surrounding mid-altitude mountains (1500–3000 m a.s.l) include *Pinus* and *Picea* species, while the high-altitude mountains (3000–5000 m a.s.l.) have *Cedrus* species (Jan et al. 2015, Siddiqui et al. 1999). An important task is to trace the history and temporal dynamics of these conifers on the surrounding Hindu Kush mountains of the Swat Valley.

SETTING

Pakistan is located in South-western Asia and extends north-east to south-west (37–23°N, 60–75°E) (Fig. 1a). Khyber Pakhtunkhwa, one of Pakistan's four provinces, is located in the north-west part of the country (31°49′–35°50′N, 70°55′–71°47′E), covering an area of 74 521 km^2. In this north-western province, the Swat Valley lies between the Hindu Kush of Afghanistan to the west, the Indian Himalayas to the east, and the Karakorum Mountains towards the north which separate Pakistan from the Tibetan Plateau of China. The exact point of our coring site (Fig. 1b) is in the western part of Swat District in the village of Kabal (34°66′N; 72°13′E) at 750 m a.s.l. The Kabal Valley (34°66′N; 72°17′E) is in Swat District between the Hindu Kush foothills and the Himalayas in Khyber Pakhtunkhwa Province. Kabal village covers 400 km^2, at 700–2500 m a.s.l. (Fig. 1c). As part of the high-altitude Hindu Kush Himalayan region, the Swat District features a diverse set of biophysical, ecological and socio-economic characteristics (Qasim et al. 2011). Our research area (Kabal village in Swat Valley) is encircled by the Hindu Kush mountain systems. The mountains of the Swat Valley and adjoining areas consist of rock units representing the Kohistan Arc sequence, Tethys oceanic lithosphere and Indo-Pakistan plate sequence. The Kohistan Arc sequence consists essentially of Late Jurassic–Cretaceous and Tertiary plutonic and metamorphic plutonic, volcanic and sedimentary rock (Arif et al. 2011, Akhtar & Bergmeier 2015). The Swat area consists of Precambrian–Cambrian basement (Arif et al. 2011). The basement rock in Swat is overlain by Phanerozoic metasedimentary rocks of the Alpurai group (DiPietro 1991, DiPietro & Lawrence 1991, DiPietro et al. 1993, Arif et al. 2011). The Eastern Hindu Kush forms a triangular ecotone which delimits the Irano-Turanian, Sino-Himalayan and Central Asiatic floristic regions (Noroozi et al. 2008).

CLIMATE

Pakistan lies just above the Tropic of Cancer in the western part of the monsoon climate zone. The country's subtropical climate experiences extreme temperature variation. Pakistan has five major mountain systems – the Hindu Kush, Himalayas, Karakorum, Kirthar and Suleiman ranges – located in different bioclimatic zones, a circumstance which contributes to high plant biodiversity. The study area may well be impacted by the rain shadow effect, being surrounded by Karakorum to the north, the Himalayas to the east, and the Hindu Kush to the west, but no information is available to confirm that. Pakistan has four well-marked seasons: cold (November–February), hot (March to mid-June), monsoon (mid-June to mid-September) and post-monsoon (mid-September to October). The summer season is extremely hot, with 25–50% relative humidity (Pakistan Meteorological Department technical report no. PMD-22/2009). The monsoon rainfall occurs in summer (July–August), and the winter rainfall (December–January) is brought by western systems. Except for the southern slopes of the Himalayas and the submontane region, where annual rainfall ranges from 760 to 2000 mm, most of the country is arid to semi-arid; 75% of the country receives less than 250 mm rainfall, while 20% of the country receives only 125 mm (Pakistan Meteorological Department technical report no. PMD-22/2009, Qamar et al. 2009, Salma et al. 2012). The temperature varies from a low of –6°C in winter (mid-December) in the north to a high of 50°C in summer (mid-June) in the centre and south of the country. A six-decade study (1931–1960 and 1961–1990) of average climate conditions of Pakistan revealed cooling over northern and south-eastern Pakistan, due to increased monsoon rainfall and cloud cover (Kruss et al. 1992). An analysis of a reconstructed time series of temperature from 1876 to 1993 showed high variability of temperature and pointed to a warming trend since the beginning of the 20th century, with a total change of 0.2°C (Singh & Sontakke 1996). According to the Pakistan Meteorological Department, average annual rainfall has been decreasing at a rate of –1.18 mm/decade throughout the country, which may be attributed to drought conditions during 1998–2001. Details of the general climate of the area and surrounding high- and low-elevation areas are given in Table 1, based on 30-year (1981–2010) average daily maximum/minimum temperature and rainfall data obtained from the Peshawar Regional Meteorological Center (Meteorological Department of Pakistan. ISO 9001: 2008. http://www.pmd.gov.pk/).

VEGETATION

The present-day vegetation and climate of Kabal and surrounding areas of the Qalagai Hills in Swat is of temperate mountain type (Beg & Khan 1984, Ilyas et al. 2012, 2013). Because of the marked differences in edaphic, physiographic and local climatic conditions on different slopes at different elevations, the slopes support different plant associations (Ahmad 1986, Ilyas et al. 2012). Almost 40% of Pakistan's natural forests are located in Khyber Pakhtunkhwa Province (Ahmed & Mahmood 1998, Akhtar & Bergmeier 2015). The present-day forested areas of the Kabal Valley in Swat District are located in the Hindu Kush, west of the Pakistani Himalayas, and their growth is under the influence of the monsoon. Representative species include the conifers *Abies pindrow, Cedrus deodara*, *Picea smithiana*, *Pinus roxburghii* and *Pinus wallichiana*. The eastern part of the Hindu Kush towards the Hazara Division is more similar to the Himalayas in terms of the climate and flora. The Kabal Valley experiences overgrazing, deforestation, logging, and clearing of land for terrace cultivation, which are the major threats responsible for the overall degradation of forests in this zone (Hussain et al. 1997, Sher et al. 2010, Sher & AlYemeni 2011). Natural coniferous forests of *Pinus*, *Abies*, *Cedrus* and *Picea* are also under heavy

Table 1. Meteorological data for areas south and north of the Kabal Valley in Swat District, KP, Pakistan (ARF – annual rainfall, RH – relative humidity, MAT – mean annual temperature, LMM – lower montane Malakand, UMM – upper montane Malam Jabba. Temperature was recorded at 0300 GMT, and rainfall was measured at 0800 GMT)

	Coordinates	Elevation m a.s.l.	ARF mm	RH %	MAT °C
1. Plain zone					
Charsadda	34°80′N; 71°43′E	276	>127	45–50	>20
Mardan	34°12′N; 72°20′E	285	>127	45–50	>20
2. LMM zone					
Malakand	34°33′N; 71°55′E	500	>889	55–60	>20
Batkhela	34°10′N; 71°53′E	650	>889	55–60	>20
3. Swat zone					
Kabal village	34°66′N; 72°13′E	750	>1016	60–65	>15
Fiza gut Hill	34°79′N; 72°38′E	1150	>1016	60–65	>15
4. UMM zone					
Malam Jabba	34°81′N; 72°57′E	2600	>1016	60–65	>15

social and economic (logging) pressure (Siddiqui et al. 1999). A variety of trees, shrubs and herbs grow in these forests today, including *Abies pindrow, Picea smithiana, Pinus roxburghii, Pinus wallichiana, Cedrus deodara, Dalbergia sissoo, Quercus semecarpifolia, Platanus orientalis Aesculus indica, Ailanthus altissima*, *Diospyros kaki*, *Juglans regia, Juniperus* sp., *Datura stramonium, Dodonaea viscosa, Euphorbia wallichii, Indigofera heterantha, Otostegia limbata, Polygonum plebeium, Amaranthus viridis, Artemisia scoparia, Chenopodium album, Cynodon dactylon* and others (Jan et al. 2015).

MATERIALS AND METHODS

SITE SELECTION FOR CORING

Most parts of Khyber Pakhtunkhwa Province have almost no suitable terrestrial sites or environmental archives for palaeoecological studies, probably due to the dry, warm climatic conditions. As a result of climatic impacts, the elevational gradient and the surrounding topography, sediments accumulated at the Kabal site long before the early Holocene. The coring site in Kabal village (34°66′N, 72°13′E) was selected after an exhaustive survey spanning the month of September 2012. A comparatively undisturbed, semi-swamp-like terrestrial coring site away from the rice fields (Fig. 1d), two kilometers west of the Swat River (Fig. 1c), was finally selected. Manual application of a Russian corer (two persons drilling and one standing above) could only penetrate the accumulated sediment to a final depth of 150 cm in three increments of 50 cm. The cores were transferred to split PVC tubes and covered with plastic foil after coring, then transported to Göttingen University, Germany, and stored in a cold room (4°C).

RADIOCARBON DATING

For radiocarbon dating, four samples were dated by accelerator mass spectrometry (AMS) radiocarbon dating in the Cosmogenic Nuclide Laboratory at the Department of Geosciences, National Taiwan University (NTUAMS). Three bulk sediment samples taken at depths of 55, 82 and 148 cm along the core and a fourth wood charcoal sample at 116.5 cm were used for dating. A linear age-depth model (Fig. 2) was fitted with the CLAM package of R software (R Foundation for Statistical Computing 2013), using linear interpolation. Ages were calculated every 1 cm, from 0 cm (top) to 148 cm (bottom), weighted by the calibrated probabilities (weights =1) and calculations at 95% confidence ranges with 1000 iterations and 1.93 (-log) goodness-of-fit.

SAMPLE PROCESSING AND DATA ANALYSIS

For extraction of pollen and spores, 38 sediment samples (each 0.5 cm^3) were taken from the core every 4 cm, starting from the surface at 0 cm down to 148 cm. Sample processing followed standard pollen analysis methods (Faegri & Iversen 1989). The samples were kept in hydrofluoric acid (HF) for three days due to their high silicate content. One *Lycopodium clavatum* marker tablet containing 18 583 ± 762 spores was added to each sample for calculation of the pollen concentration and influx values. The extracted pollen samples were mounted in glycerol for pollen identification and counting. The pollen grains and spores were identified by light microscopy at 400× and 1000×, based on the large reference collections of the Department of Palynology and Climate Dynamics, University of Göttingen, and supported by the morphological descriptions in different atlases (Fujiki et al. 2005, Tissot et al. 1994, Nayar 1990) and other relevant publications (Huang 1972, Seetharam 1985, Bonnefille et al. 1999). Samples were counted to a minimum of 300 pollen grains. We excluded 18 samples (80–148 cm) from the data analysis because they contained no pollen grains. Due to very low pollen concentrations and insufficient preservation of grains

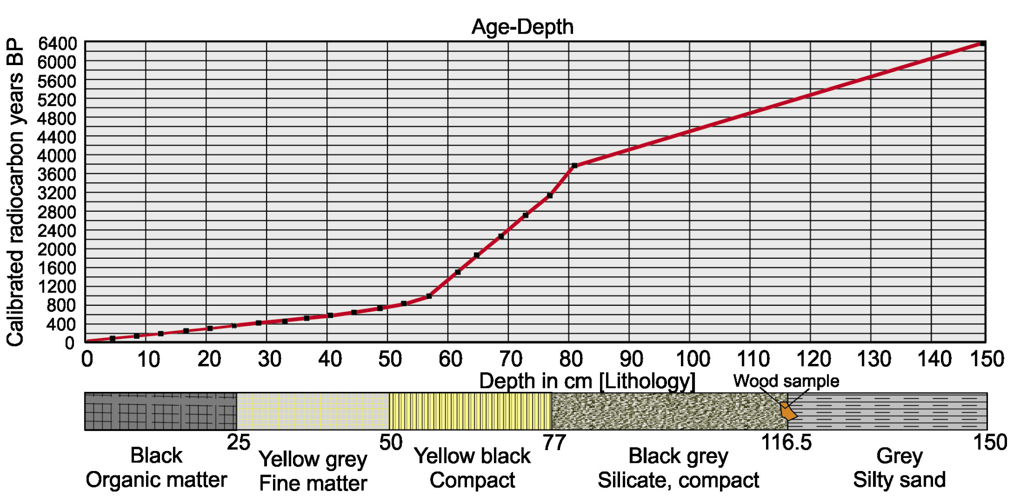

Fig. 2. Age-depth relationship (linear interpolation, calibrated years BP/core depth in cm) based on a total of 20 samples shown as black dots on the red line. Three of these 20 samples (from 55, 82 and 148 cm depth along core) and a fourth sample of charcoal taken at 116.5 cm were radiocarbon-dated

from 64 cm downwards, fewer pollen grains could be counted: 246 pollen grains from the sample at 64 cm, 198 at 68 cm, 202 at 72 cm, and 134 at 76 cm. Table 2 gives the ecological grouping of the pollen and spore types identified in samples from the Kabal Valley core.

POLLEN DIAGRAM

The pollen percentage diagram was compiled with TILIA 1.7.16 (Grimm 2011); it illustrates the most abundant and ecologically important taxa. Pollen taxa were assigned to their respective vegetation groups (conifers, trees/shrubs, herbs). The pollen diagram is based on pollen totals, which include all pollen taxa, excluding fern, moss and fungal spores and also unidentified taxa. All samples from 76 cm downward without pollen grains were omitted from the pollen diagram. The CONISS (constrained cluster analysis by sum-of-squares) method was used for identification of the pollen zones.

MULTIVARIATE DATA ANALYSIS

Multivariate data analysis of the pollen percentage data employed Canoco 5 for Windows (ter Braak & Smilauer 2012). To decrease the effect of rare taxa. pollen taxa present at frequency >1% in at least two samples were included in the analysis. To assess the vegetation and climate dynamics of the area during the entire period, less frequent taxa from all age zones

Table 2. Ecological grouping of the pollen and spore types identified in samples from the Kabal Valley core, Swat District, Pakistan

GRASSLAND SPECIES		
	Species	Ecological group
1	Acanthaceae	Upland Herb
2	*Artemisia*	Upland Herb
3	Bignoniaceae	Tree/Shrub
4	Boraginaceae	Upland Herb
5	Brassicaceae	Upland Herb
6	Euphorbiaceae	Upland Herb
7	Fabaceae	Upland Herb
8	Lamiaceae	Upland Herb
9	Scrophulariaceae	Upland Herb
10	Poaceae	Upland Herb
11	Ericaceae	Tree/Shrub

SUBMONTANE FOREST		
	Species	Ecological group
1	Meliaceae	Tree/Shrub
2	Verbenaceae	Upland Herb
3	Rutaceae	Tree/Shrub
4	*Eucalyptus*	Tree/Shrub
5	*Salix*	Tree/Shrub
6	*Platanus orientalis*	Tree/Shrub
7	Anacardiaceae	Tree/Shrub
8	Chloranthaceae	Tree/Shrub
9	*Populus*	Tree/Shrub
10	*Myrica*	Tree/Shrub
11	Arecaceae	Tree/Shrub
12	Commelinaceae	Upland Herb
13	Convolvulaceae	Upland Herb
14	Cyperaceae	Upland Herb
15	*Oxalis*	Upland Herb
16	Gentianaceae	Upland Herb
17	Ephedraceae	Upland Herb
18	Celastraceae	Tree/Shrub
19	Lilaceae	Upland Herb
20	Apocynaceae	Upland Herb

MONTANE FOREST		
	Species	Ecological group
1	Aquifoliaceae Ilex	Tree/Shrub
2	Araliaceae	Upland Herb
3	Balsaminaceae	Upland Herb
4	Cupressaceae	Tree/Shrub
5	Moraceae	Tree/Shrub
6	Oleaceae	Tree/Shrub
7	*Plantago*	Upland Herb
8	Rosaceae	Upland Herb
9	Rubiaceae	Upland Herb
10	*Dodonaea*	Tree/Shrub

SUBALPINE CONIFEROUS FOREST		
	Species	Ecological group
1	*Pinus*	Tree/Shrub
2	*Picea*	Tree/Shrub
3	*Abies*	Tree/Shrub
4	*Cedrus*	Tree/Shrub
5	*Taxus*	Tree/Shrub
6	*Betula*	Tree/Shrub
7	Ranunculaceae	Upland Herb
8	*Quercus*	Tree/Shrub
9	*Juglans*	Tree/Shrub
10	*Alnus*	Tree/Shrub

Subalpine Coniferous forest		
	Species	Ecological group
1	*Pinus*	Tree/Shrub
2	*Picea*	Tree/Shrub
3	*Abies*	Tree/Shrub
4	*Cedrus*	Tree/Shrub
5	*Taxus*	Tree/Shrub
6	*Betula*	Tree/Shrub
7	Ranunculaceae	Upland Herb
8	*Quercus*	Tree/Shrub
9	*Juglans*	Tree/Shrub
10	*Alnus*	Tree/Shrub

SUBTROPICAL VEGETATION		
	Species	Ecological group
1	Amaranthaceae	Upland Herb
2	*Polygonum*	Upland Herb
3	Solanaceae	Upland Herb
4	Caryophyllaceae	Upland Herb
5	*Cannabis sativa*	Upland Herb
6	Cucurbitaceae	Upland Herb
7	*Berberis*	Tree/Shrub
8	*Ailanthus altissima*	Tree/Shrub

SPORES		
	Species	Ecological group
1	Fungal spores	Upland Herb
2	Fern spores	Upland Herb

were ignored in PCA to facilitate assignment of the dominant herbs, shrubs, trees and conifers to the different age zones. Detrended correspondence analysis (DCA) revealed a gradient length of 1.921 and the response data were not compositional, so a linear model was fitted to the data. We applied principle component analysis (PCA), as recommended by Leps and Smilauer (2003), for datasets with short environmental gradients. The species data were standardized and log-transformed. The ordination diagram was centered by species, and the scaling focuses on distance between groups (conifers, trees/shrubs, herbs).

RESULTS

STRATIGRAPHY AND CHRONOLOGY

The hand-operated Russian corer penetrated the sediment down to 150 cm depth; at 148 cm core depth the measured age was 8103 ± 107 cal yr BP. From the lowest 150 cm upwards to 100 cm the core was a uniform yellowish grey, consisted of silty sand, had no sharp or gradual boundary and contained almost no organic matter. The silty material from 100 cm upwards to 77 cm was dark blackish grey in color and composed mainly of silicate material. The clayey, silty sediment from 77 cm upwards to 55 cm was yellowish black and was more compact than the upper part. There were fewer plant remains and lower organic content at 77–55 cm than in the lower part of the core at 100–77 cm. The upper 55–0 cm showed a uniform stratigraphic structure, having no lateral or vertical adjacent units and no sharp boundary. From 48 cm upwards to 25 cm the sediment was yellowish grey and its morphology indicated higher content of fine-fraction decomposed organic matter, with few plant roots or other remains. The top 25 cm of the profile was mainly black to grayish black and was very rich in organic matter, with no stratification. Here the sediment consisted of loosely bound granules, leaving pores for pollen relocation and biological activity, and it contained abundant root growths, with occasional charcoal particles. The texture of that section of the sediment was clayey.

The chronology of the core is based on four radiocarbon dates (Tab. 3). The deepest sample at 148 cm dates to the early middle Holocene (8103 ± 107 cal yr BP). The age-depth model (Fig. 2) revealed an almost linear relationship (R^2 = 0.921) between core depth and calibrated age. The surface of the Kabal Valley core (0 cm) is of modern age, as pollen of present-day conifers such as *Pinus, Picea* and *Abies* are abundant in the uppermost sample.

POLLEN DIAGRAM

The pollen percentage diagram (Fig. 3) shows the pollen taxa assigned to the different vegetation groups. Our published study of a pollen rain transect of this area (Jan et al. 2015) indicated that the source of the pollen is local (originating from vegetation on a 5 km^2 mountain area around the coring site) and represented predominantly by *Pinus, Picea, Cedrus, Abies*, Cyperaceae and Poaceae species.

POLLEN ZONE DESCRIPTIONS

ZONE KS-1 (76–70 cm, 3300–2400 cal yr BP). Herb pollen grains predominate and include Cyperaceae (7–10%), Poaceae (7–9%), Amaranthaceae (4–6%), *Artemisia* (0–4%) and Lamiaceae (0–3%). Conifer pollen is less frequent and includes *Picea* (4–6%), *Pinus* (2–6%), *Abies* (1–4%), *Cedrus* (2–3%) and Cupressaceae (0–3%). Other arboreal and shrub pollen types are Bignoniaceae (0–4%), Chloranthaceae (1–3%) and Moraceae (2–3%). The zone is characterized by low pollen concentrations ranging from 8314 to a maximum 20 435 grains/cm^3. The average value of pollen influx is 187 pollen/cm^2/yr, with a sedimentation rate of 0.009 cm/yr (Fig. 4).

ZONE KS-2 (70–55 cm, 2400–900 cal yr BP). This period is also dominated by herb pollen grains, including Poaceae (8–15%) and Cyperaceae (2–9%) at varying abundance, as well as *Artemisia* (4–6%), Acanthaceae (1–4%) and Amaranthaceae (3–6%). The abundance of Poaceae pollen is unchanged from 2400 to

Table 3. Radiocarbon dates for the Kabal Valley core sample record. OM – organic matter

Sample Id	Lab code	Depth (cm)	Material	C^{13}/C^{12} ratio	^{14}C Age (yr BP)	Age (cal yr BP)
SK-055	NTUAMS-333	55	Wood	0.0103	781 ± 5	883
SK-82	NTUAMS-578	82	Bulk OM	0.0101	3461 ± 25	3756
SK-116	NTUAMS-334	116	Charcoal	0.0101	4932 ± 35	5664
SK-148	NTUAMS-579	148	Bulk OM	0.009	7266 ± 112	8103

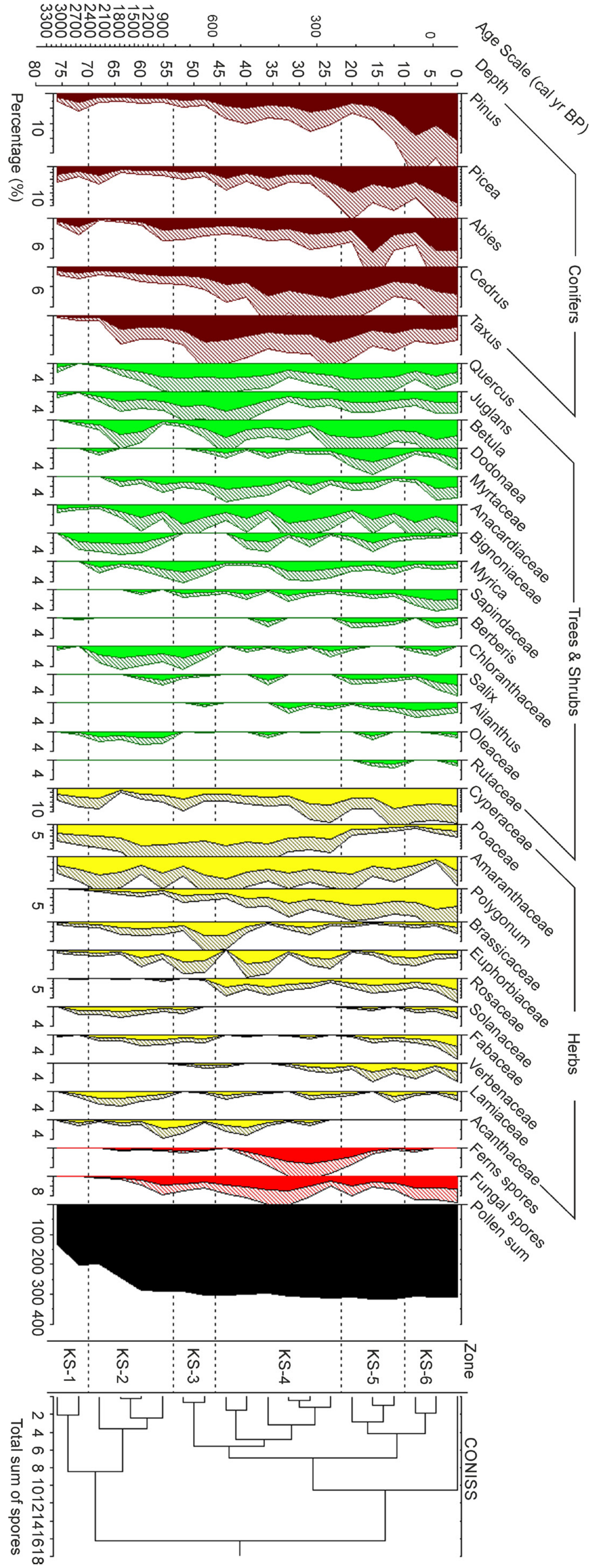

Fig. 3. Pollen diagram of the Kabal core from the Swat Valley in the Hindu Kush (Khyber Pakhtunkhwa Province, north-western Pakistan). Cluster analysis based on the percentage data for the most important taxa grouped as conifers, trees/shrubs, herbs, and spores. The age scale is based on calibrated years before the present

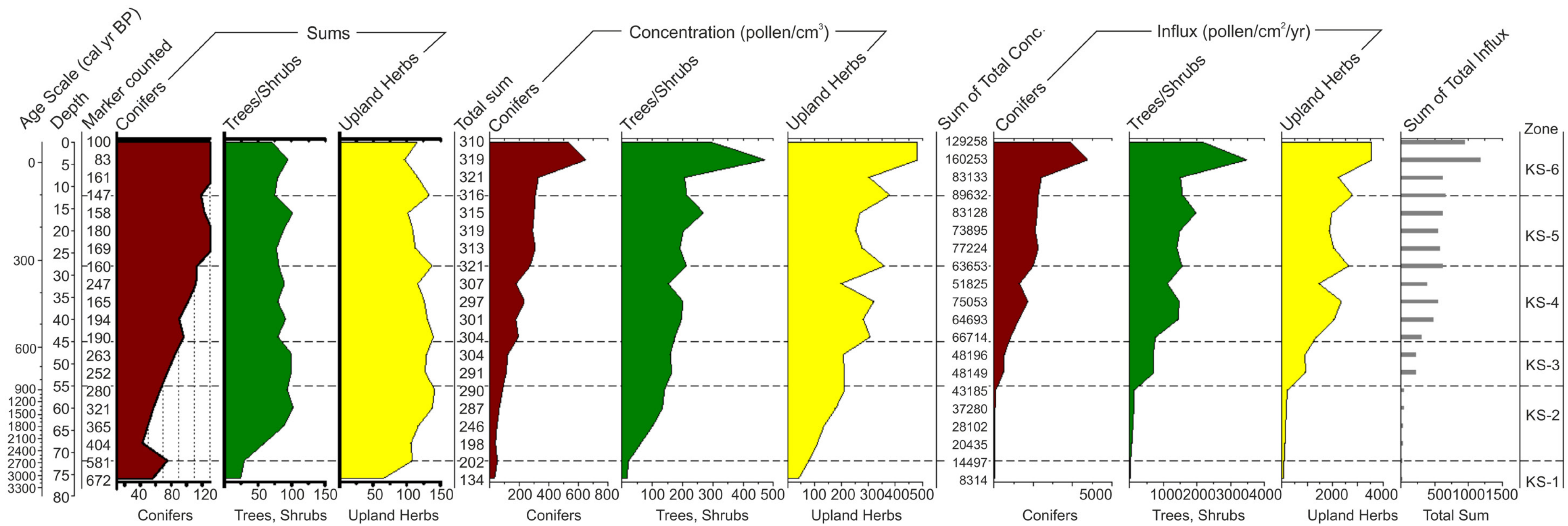

Fig. 4. Percentage sums of ecological groups – conifers, trees/shrubs (TRSH), upland herbs (UPHE) – and records of pollen concentrations (pollen/cm³) and pollen influx (pollen/cm²/yr). The pollen sums from the last three samples were 198, 202 and 134 respectively

1500 cal yr BP but increases notably from 1500 to 900 cal yr BP. Other taxa found include the conifers *Taxus* (1–6%), *Picea* (2–5%) and *Abies* (0–4%), and the tree/shrub species *Quercus* (1–5%), *Juglans* (2–4%), Bignoniaceae (2–4%), Chloranthaceae (3–5%) and *Myrica* (1–3%). There are more fungal spores in this zone than in the previous zone. This period also shows low pollen concentrations (up to 43 185 grains/cm^3) and low average pollen influx (397 pollen/cm^2/yr). The sedimentation rate is 0.009 cm/yr.

ZONE KS-3 (55–46 cm, 900–600 cal yr BP). The herb pollen of this zone includes Poaceae (11–14%), Cyperaceae (5–9%), Amaranthaceae (3–6%), Brassicaceae (2–6%), Rosaceae (1–5%), *Artemisia* (2–5%), Acanthaceae (1–4%), Euphorbiaceae (1–3%) and *Polygonum* (1–3%). Conifers include *Taxus* (5–10%), *Pinus* (2–6%), *Picea* (3–6%), *Cedrus* (3–6%) and *Abies* (3–4%). The tree and shrub pollen include *Juglans* (4–7%), *Quercus* (5–6%), Chloranthaceae (0–4%), Anacardiaceae (1–4%), Myrtaceae (2–4%), *Myrica* (1–4%), *Betula* (0–3%), *Platanus orientalis* (0–3%) and Ericaceae (1–3%). Pollen concentration is higher (maximum 66 713 grains/cm^3), as is average pollen influx (2917 pollen/cm^2/yr). The sedimentation rate is 0.004 cm/yr.

ZONE KS-4 (46–23 cm, 600–300 cal yr BP). This period is still dominated by pollen of herbs such as Poaceae (7–12%) and Cyperaceae (5–11%), but conifers such as *Cedrus* (5–10%), *Pinus* (5–9%), *Taxus* (6–8%), *Picea* (4–6%) and *Abies* (3–5%) are also abundant. Other herbs include *Artemisia* (1–4%), Brassicaceae (0–5%), Euphorbiaceae (1–4%), *Polygonum* (2–7%), Amaranthaceae (3–6%) and Rosaceae (3–5%). The tree and shrub pollen includes *Juglans* (2–7%), *Quercus* (3–5%), Myrtaceae (2–4%), Anacardiaceae (1–4%) and *Myrica* (1–4%). The pollen concentrations in the samples from this period range from 66 713 to 83 652 grains/cm^3), and average pollen influx is 6146 pollen/cm^2/yr. The sedimentation rate is 0.007 cm/yr.

ZONE KS-5 (23–12 cm, 300–100 cal yr BP). This zone represents a time span of 200 calibrated years. The pollen of the herbs found in this zone includes Cyperaceae (7–14%), Poaceae (2–8%), *Artemisia* (1–3%), Verbenaceae (1–3%), Amaranthaceae (3–5%), *Polygonum* (5–7%) and Rosaceae (1–4%). Conifers include *Taxus* (5–9%), *Picea* (8–14%), *Abies* (4–11%), *Cedrus* (5–11%) and *Pinus* (7–10%). Tree pollen includes *Quercus* (4–6%), *Juglans* (2–4%), *Betula* (2–3%) and *Platanus orientalis* (0–3%). Shrubs include Bignoniaceae (1–3%), *Dodonaea* (1–4%) and *Myrica* (1–3%). This period is characterized by high pollen concentrations ranging from 77 223 to a maximum 89 632 grains cm^3, and average pollen influx is 6586 pollen/cm^2/yr. The sedimentation rate is 0.007 cm/yr.

ZONE KS-6 (12–0 cm, 100–62 cal yr BP). This is the top zone, representing the most recent pollen spectra of the research area. Conifers are the most abundant taxa and include *Pinus* (12–19%), *Picea* (8–12%), *Abies* (4–9%), *Cedrus* (6–7%) and *Taxus* (3–4%). The tree species include *Quercus* (2–4%), Chloranthaceae (1–4%), *Juglans* (2–3%), Myrtaceae (1–3%), *Betula* (2–3%) and Anacardiaceae (2–3%). Shrubs are represented by Sapindaceae (2–3%) and Meliaceae (1–4%). The herb pollen found in this zone includes Cyperaceae (8–12%), Fabaceae (1–3%), Verbenaceae (1–3%), *Artemisia* (1–4%), Amaranthaceae (1–3%) and Polygonum (5–7%). The maximum pollen concentration is 129 258 grains/cm^3, and maximum pollen influx is 9497 pollen/cm^2/yr. The sedimentation rate is 0.007 cm/yr.

MULTIVARIATE DATA ANALYSIS

The PCA ordination diagram (Fig. 5) shows a clear division of trees/shrubs in the lower left and herbs in the lower right quadrants, while conifers are in the upper left quadrant. All taxa were included in the analysis but the diagram shows only 18 taxa which were present at average frequency of at least 5% in each of the respective six pollen zones. The lower right quadrant shows that herbs belonging to Poaceae, Cyperaceae, Brassicaceae, Fabaceae, Amaranthaceae and Asteraceae (*Artemisia*) are concentrated mostly between 900 and 300 cal yr BP, represented by their respective zones (KS-3, KS-4). The lower left quadrant shows that shrubs/trees belonging to Oleaceae, Myrtaceae, Bignoniaceae, *Juglans, Dodonaea* and *Sapindaceae* are consistently present from 2400 cal yr BP to the present, represented by zones KS-2 to KS-6. The upper left quadrant shows that conifers including *Pinus*, *Taxus*, *Picea*, *Abies* and *Cedrus* are predominant at 300–100 cal yr BP (KS-5), 2400–900 cal yr BP (KS-2), and in the most recent zone (100 cal yr BP to 2012; KS-6) as reported by Jan et al. (2015).

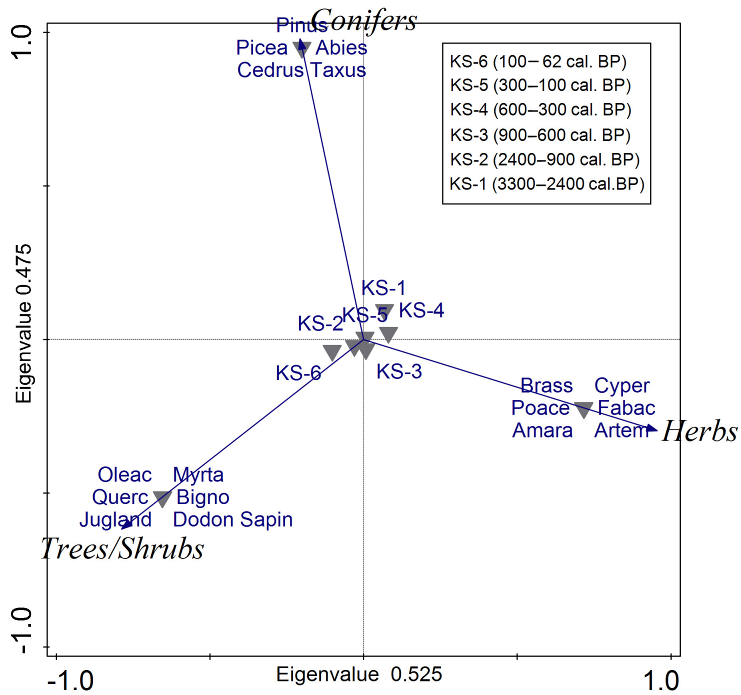

Fig. 5. Results of PCA of square-root-transformed pollen percentage data from the Kabal Valley (Swat District) in Khyber Pakhtunkhwa Province, Pakistan. KS-1 – oldest pollen zone of the core (76–70 cm, 3300–2400 cal yr BP), KS-2 – second age interval (70–55 cm, 2400–900 cal yr BP), KS-3 – third age interval (55–46 cm, 900–600 cal yr BP), KS-4 – fourth age interval (46–23 cm, 600–300 cal yr BP), KS-5 – fifth age interval (23–12 cm, 300–100 cal yr BP), KS-6 – sixth age interval (12–0 cm, 100–62 cal yr BP)

DISCUSSION

The pollen diagram and our multivariate data analysis revealed changes in the vegetation of the Kabal area in Pakistan's Swat Valley during the last 3300 years. Two of the four radiocarbon-dated bulk samples taken from the core represented dates of 5660 cal yr BP (116 cm depth) and 8100 cal yr BP (148 cm depth), but the samples contained little or no pollen from 76 cm downwards, probably due to local climatic effects in the sediment archive, corrosion in the sediment archive, or drier climatic conditions, so we relied on the samples from increments down to 76 cm, which recorded the vegetation history back to 3300 cal yr BP only.

From 3300 to 2400 cal yr BP, the higher presence of Poaceae and Cyperaceae in the pollen record reflects a fairly open landscape and swampy conditions, respectively, during the early late Holocene, as compared to the modern-day vegetation in the surroundings of the core (Jan et al. 2015). The presence of pollen of alpine coniferous vegetation, mainly *Picea*, *Pinus*, *Abies* and *Cedrus*, as well as mixed forest vegetation, can be attributed to the coniferous forests that have grown on the surrounding mountains for the last 8000 years. The presence of pollen from herbs such as Amaranthaceae and *Artemisia* indicates the semi-arid conditions of the lower plains. The very low pollen concentrations (up to 20 400 grains/cm^3) and low pollen influx (190 pollen/cm^2/yr) point to the sparseness of the vegetation cover under those semi-arid conditions. Due to the low sedimentation rate (0.009 cm/yr), less material was transported towards that slightly depressed site, probably due to lower erosion rates or lower precipitation. Conifer pollen can be transported over a long distance, but the abundant presence of both *Pinus* and *Picea* pollen, up to 6% each in samples of this age, indicates that both of these conifers were on the surrounding mountains within a few kilometers of the sampling site. The absence of any previous published information on the palaeoecology of the Hindu Kush that would enable the history of conifers to be traced back to the early Holocene or late Pleistocene leaves a gap that necessitates further studies. Among the present-day conifers, however, competitive forest trees such as *Pinus wallichiana*, *Abies pindrow* and *Picea smithiana* are dominant at nemoral through boreal levels in the surrounding Hindu Kush (Akhtar & Bergmeier 2015).

From 2400 to 900 cal yr BP, *Taxus*, *Quercus*, *Juglans*, *Betula* and fungal spores increased, while Cyperaceae, Bignoniaceae, Solanaceae and Lamiaceae decreased in the surrounding vegetation. As evident from the pollen diagram, the decline of Poaceae between 2400 and 1500 cal yr BP was followed by a slight increase between 1500 and 1200 cal yr BP; this attests to the contraction and expansion of the grassland surrounding the coring site, indicating dry-cool and wet-warm periods, respectively. The southern High Asian forest ecotone of the Hindu Kush Himalaya forests in the south of Gilgit-Baltistan were represented by *Cedrus deodara, Picea smithiana, Pinus wallichiana* and *Abies pindrow* at elevations ranging from 2400 to 3600 m a.s.l. (Miehe et al. 2009). The higher number of fungal remains as compared to the earlier period (3300–2400 cal yr BP) points to a dry period and grazing activity, the latter of which is supported by the presence of animal remains in the sample. Change in the vegetation has been cited as an important factor in cultural changes in the Harappan Civilization of the Hindu Kush Himalayas of north-western South Asia from 2500 to 1900 cal yr BP (Madellaa & Fuller 2006, Miehe et al. 2009). This period is also characterized by low pollen concentrations (up to 43 200 grains cm^{-3}) and low average pollen influx (400 pollen/cm^2/yr) reflecting sparse vegetation cover. Moreover, the low sedimentation rate (0.009 cm/yr) points to lower precipitation at higher elevation on the mountains surrounding the coring site.

From 900 to 600 cal yr BP, the presence of *Pinus*, *Picea*, *Cedrus* and *Abies* in the vegetation indicates that the lower Hindu Kush was covered by coniferous forests, accompanied by *Juglans*, *Quercus* and *Betula*. The constant abundance of Poaceae along with the increase of Cyperaceae, Amaranthaceae and Brassicaceae reflects an open landscape, with coniferous forests growing on the nearby highlands. This change can be attributed to the drier cool climate and to increased agricultural activity. The increase in pollen concentration (66 700 grains cm^{-3}) and lower average pollen influx (2900 pollen/cm^2/yr) and sedimentation rate (0.004 cm/yr) show the stability of local vegetation cover during this period. Our findings are in line with those of Miehe et al. (2009), who reported that the abundance of Poaceae increased on open shrubland, overrepresented mainly by *Artemisia* and *Euphorbia* in the upper high-elevation Shukran Valley of Gilgit-Baltistan.

During 600–300 cal yr BP there was an increase in Cyperaceae and *Polygonum* along with *Cedrus*, fungal and fern spores, whereas the pollen of Poaceae, *Eucalyptus* and *Juglans* decreased. The increase in *Cedrus* along with non-pollen palynomorphs indicates the spread of coniferous forests in wet cold conditions on the surrounding Hindu Kush. Small trees such as *Berberis* and *Salix* appeared for the first time, due to the moist and cold conditions prevailing in the study area. The higher pollen concentrations and pollen influx reveal the spread of abundantly pollen-producing conifers on the surrounding high mountains, but the vegetation cover weakened downwards toward the valley, resulting in increased sedimentation due to an increase of eroded material transported from the upper mountains towards the depressed coring site. The abundance of fungal spores in the assemblage may have been caused by erosion or other factors such as decomposition or human impacts.

From 300 to 100 cal yr BP, the constant presence of Cyperaceae, *Berberis* and conifers, the increase of tree/shrub species and the simultaneous decrease in recorded pollen of Poaceae, Brassicaceae and ferns indicate a drastic decrease in herbaceous vegetation. Presumably the area of open vegetation contracted due to the expansion of forests with tree/shrub taxa such as *Juglans*, *Betula, Dodonaea*, *Polygonum* and Rosaceae. The spread of trees and shrubs on the surrounding mountains resulted in high pollen concentrations and high pollen influx. *Berberis lyceum* is a shrub found mostly in the foothills of the present-day Hindu Kush. We conclude that wet, cooler conditions prevailed during this phase.

The top three samples (12–0 cm) of the core provide sufficient data regarding the changes in vegetation and climate during the last 100 years. Coniferous forests spread in the area, dominated by *Pinus*, *Picea*, *Abies* and *Cedrus* species, along with herbs such as *Polygonum*, Amaranthaceae, Fabaceae and Verbenaceae. The synchronous presence of coniferous and mixed forest indicates wet cool climate. This period shows the maximum pollen concentrations (83 130–129 260 grains cm^{-3}), pollen influx (9500 pollen/cm^2/yr) and sedimentation rate (0.007 cm/yr), pointing to increased human activity and land erosion. The pollen record of the last 100 years (till 2012) reflects an overall vegetation spectrum closely resembling the present-day vegetation of nearby Miandam Hill, as reported by Akhtar & Bergmeier (2015).

This similarity of vegetation means that the annual average values of the different climatic variables have remained the same in this particular Hindu Kush phytogeographic zone of Swat District. Forest cover was reported to have increased in the Swat District during the fourteen years from 1996 to 2000 (Government of Khyber Pakhtunkhwa 2008) but, contrary to that assertion, significant deforestation has occurred, due to large-scale exploitation of forest resources, partly illegal agricultural expansion, and fuel wood collection in deprived rural areas of Swat (Ali et al. 2006, Shabaz & Ali 2006, Qasim et al. 2011).

The PCA ordination diagram (Fig. 5) separates the conifers, trees/shrubs and herbs found along the entire core (20 samples) during the last 3300 years. Herbs belonging to Poaceae, Cyperaceae, Brassicaceae, Fabaceae, Amaranthaceae and Asteraceae (*Artemisia*) were mostly abundant from 900 to 300 cal yr BP. The occurrence of abundant herbs during this period has been attributed to a more pronounced impact of widespread deforestation, agricultural activity and drier summers (Pignatti 1997). From 2400 cal yr BP to 2012, evergreen trees and shrubs dominate the pollen assemblage, notably Oleaceae, Myrtaceae, Bignoniaceae, *Juglans*, *Dodonaea* and Sapindaceae, which are consistently present at the warmer end of the gradient (lower part of PCA diagram). Multivariate analysis revealed that conifer taxa were abundant in the area from 2500 to 1100 cal yr BP. However, *Pinus*, *Taxus*, *Picea*, *Abie*s and *Cedrus* were most abundant from 300 to 100 cal yr BP, followed in magnitude by their abundance during 2400–900 cal yr BP and thirdly during the most recent 100 years (1912 to the coring year, 2012). These conifers occur at higher altitudes in the alpine zone of the Hindu Kush, representing cool climate.

COMPARISON WITH REGIONAL PRECIPITATION AND TEMPERATURE RECORDS

We compared the pollen sums of conifers, trees/shrubs and upland herbs at the study site with published palaeoclimate data (Asad et al. 2017, Christiansen & Ljungqvist 2012, Cook et al. 2013, Frank et al. 2007, Moberg et al. 2005, Thompson et al. 2000, Treydte et al. 2006, Wilson et al. 2016, Yadava et al. 2016, Yang et al. 2014), in order to evaluate the impact of regional and large-scale climate trends (Fig. 6). As no climate records from 3000 to 2000 yr BP are available, it is difficult to bridge the reconstructed vegetation with the associated palaeoclimate during this period. However, the available records allow comparison of the vegetation and climate trends of the past 2000 years. These reconstructed series include annual precipitation over the past millennium in the Karakoram region (Treydte et al. 2006), boreal spring (March–May) precipitation in Western Himalaya (Yadava et al. 2016), West Qinlin Mountains precipitation (Yang et al. 2014), ice core records from Dasuopu, Tibet (Thompson et al. 2000), and temperature records from Karakoram (April–July) (Asad et al. 2017), Nepal (Cook et al. 2003), High Asia (Cook et al. 2013) and other Northern Hemisphere sites (Moberg et al. 2005, Frank et al. 2007, Christiansen & Ljungqvist 2012, Wilson et al. 2016).

These palaeoclimatic records reveal a period of drought and low temperatures on a regional scale from 2000 to 1400 yr BP. Our reconstruction of the Swat Valley vegetation of this period shows that grassland herbs, particularly Poaceae species, dominated the surrounding mountains. *Juglans* and *Quercus* species were present at low abundance on the surrounding mountains. Due to cool climatic conditions, conifers such as *Pinus* and *Picea* were also infrequent in the Hindu Kush. These taxa most likely shifted to lower elevations, where their ecological demands regarding precipitation and temperature were met. Comparisons of the reconstructed Swat Valley vegetation with existing palaeoclimate data indicate that the vegetation in the Hindu Kush changed as a function of precipitation and temperature in the area, as recorded in Karakoram, West Qinlin, Dasuopu and Tibet. From 1300 to 500 yr BP and from 1850 AD to recent times (1950) the temperature of the Karakoram, High Asia and Northern Hemisphere increased, bringing with it an increasing trend of the abundance of conifers (*Pinus, Piceae, Abies, Cedrus*) and upland herbs (Cyperaceae, Polygonaceae, Amaranthaceae), as well as low abundance of other trees and shrubs. During periods of warmer temperatures without higher precipitation, the climate seems to have promoted the spread of trees and shrubs (e.g. ca 900 and ca 600 cal yr BP). In contrast, the spread of conifer vegetation in the Hindu Kush appears closely related

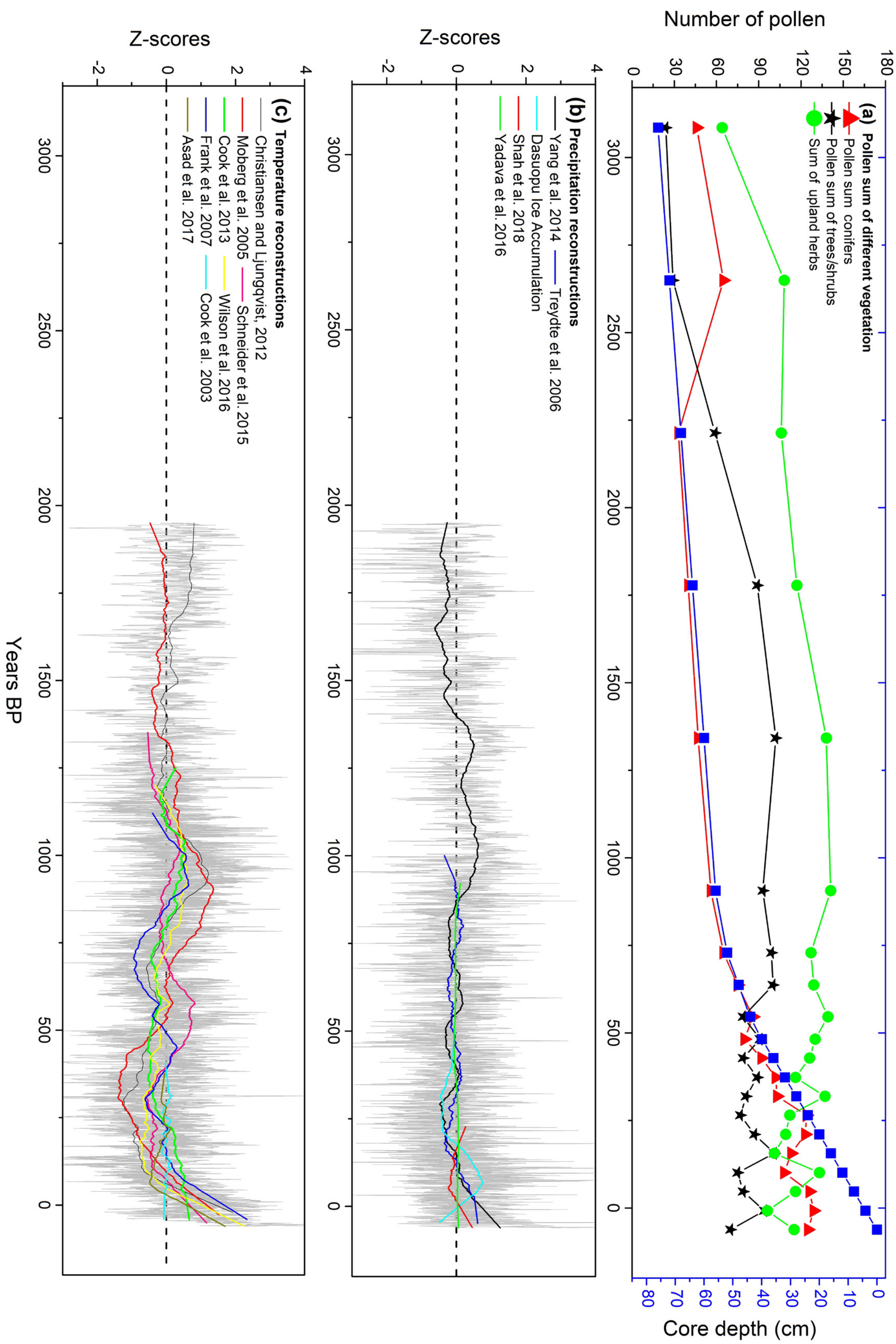

Fig. 6. Comparison of vegetation reconstruction (pollen sums of conifers, trees/shrubs, upland herbs; this study) with precipitation, ice core accumulation and temperature variation for different regions in the Northern Hemisphere. **a** – total pollen sum, **b** – precipitation reconstructions from Karakoram (Treydte et al. 2006), Western Himalaya, (Yadava et al. 2016), West Qinlin Mountains (Yang et al. 2014) and ice core record from Dasuopu, Tibet (Thompson et al. 2000), **c** – temperature records from Karakoram (Asad et al. 2017), Nepal (Cook et al. 2003), High Asia (Cook et al. 2013) and Northern Hemisphere reconstructions (Moberg et al. 2005, Frank et al. 2007, Christiansen and Ljungqvist 2012, Wilson et al. 2016)

to the combined effect of increased temperature and precipitation during the past 150 years. While *Taxus* seems to be able to endure relatively dry periods, all other conifer species reach abundance only under significantly warmer and wetter conditions. The upland herb vegetation seems to have been rather resilient to the varying climate conditions of the past 2000 years, their abundance having been influenced more by the replacement of conifer forest as well as other trees and shrubs under warmer and wetter climate conditions in the 19th and 20th centuries.

CONCLUSIONS

The Kabal Valley of Swat District is situated at the transition between three of the world's important mountain systems: the Hindu Kush of Afghanistan to the west, Indian Himalayas to the east, and Karakorum Mountains below the Tibetan Plateau of China to the north. Our pollen record from this area uncovers new and interesting aspects of the vegetation and climate history of the Hindu Kush in Pakistan during the last 3300 years. Our study revealed shifts in the upper vegetation zones of the Kabal Valley of Swat District during the late Holocene. From 3300 to 2400 cal yr BP, semi-arid herbaceous vegetation represented by Cyperaceae and Poaceae species was dominant in the valley, later replaced by mixed coniferous forests of *Taxus, Pinus, Juglans*, Poaceae and Cyperaceae from 2400 to 900 cal yr BP, suggesting comparatively moderate climatic variability during the late Holocene. The decrease in herbaceous vegetation, mainly Poaceae, from 2400 to 1500 cal yr BP, and again its increase from 1500 to 1200 cal yr BP, indicates contraction and expansion of grassland in the Kabal Valley, pointing to the respective dry cool and wet warm periods. Herbs belonging to Poaceae, Cyperaceae, Brassicaceae, Fabaceae, Amaranthaceae and Asteraceae (*Artemisia*) were abundant from 900 to 300 cal yr BP. This can be attributed to a more pronounced impact of widespread deforestation, agricultural activity and drier summers. Evergreen trees and shrubs dominated the pollen assemblages, notably Oleaceae, Myrtaceae, Moraceae, *Juglans* and *Dodonaea*, which have been constant from 2400 cal yr BP to the present. Conifers such as *Pinus*, *Taxus*, *Picea*, *Abies* and *Cedrus*, which reflect the major vegetation of the study area, have been most abundant from 300 cal yr BP to the present (i.e. 2012). These conifers occur mostly in mixed coniferous forests at higher elevation in the alpine area today. Finally, our comparison of the pollen-based reconstruction of the Swat Valley vegetation with regional and large-scale climate trends has shown that the combination of increased precipitation and increased temperature since the 19th century has been particularly responsible for major changes in the vegetation. We can expect that further warming and increased precipitation will have a significant impact on the regional vegetation and landscape. Additional high-resolution Holocene pollen records of the Hindu Kush are needed for a more detailed comparison with other South and Central Asian palaeoarchives, which could yield more precise and practical knowledge applicable to management and conservation.

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