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The modern pollen–vegetation relationship in Jammu, India: a comparative appraisal

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ABSTRACT. An understanding of the relationship between modern pollen and vegetation is a prerequisite for reconstruction of vegetation and climate change from fossil pollen records. We conducted palynological studies of thirty-five surface soil samples from the Jammu region of India, which revealed that *Pinus*, among the conifers (regional needle-leaved taxa), is over-represented in the pollen assemblage due to its high production and effective dispersal of pollen. Other coniferous and broadleaved (regional and/or extra-regional) taxa have comparatively lower values in the pollen assemblages, similar to the representation of subtropical deciduous forest elements (regional), as well as shrubby (regional and/or extra-regional) taxa. This inconsistency in the pollen assemblage could be due to long-distance transport of the former by wind and/or water from the higher reaches of the Himalayas, and also because the latter have an entomogamous pollination syndrome and are not high pollen producers. The recovered pollen assemblage presents a distorted picture of the extant vegetation; hence, caution should be exercised in interpreting fossil pollen records from the study area. Principal component analysis (PCA) shows variability in the distribution of pollen from different sites in the Jammu region, perhaps the result of transport (by wind and/or water), altitude and/or edaphic factors of the Himalayan terrain. The study should improve our understanding of the modern pollen-vegetation relationship and aid further calibration and interpretation of fossil pollen records.

KEYWORDS: Palynology, surface soil, vegetation and climate change, PCA, Jammu (India)

INTRODUCTION

An adequate understanding of the relationship between modern pollen assemblages and extant vegetation is needed for the confident use of fossil pollen records for reconstruction of vegetation and climate change (Moore and Webb, 1978; Faegri and Iversen, 1989; Birks and Berglund, 2018; Quamar and Kar, 2020 and references cited therein). However, the Fagerland effect (non-linearity of the modern pollen-vegetation relationship, i.e. there is no one-to-one relationship between modern pollen and extant vegetation; Fagerland, 1952) twists the basic assumption of that relationship. Furthermore, the uncertainties related with pollen production, dispersal and preservation of taxa of angiosperms and gymnosperms, the structure of the surrounding vegetation, and taxonomic resolution of pollen (Faegri and Iversen, 1964; Quamar and Bera, 2014a–c; Gaceur et al., 2017; Broothaerts et al., 2018; Bajpai and Kar, 2018; Quamar, 2020; Quamar and Kar, 2020 and references therein) add to the complexity of the problem. That non-linearity, taphonomic issues, and differential pollen production result in pollen percentages that are ambiguously related to the abundance of the corresponding plant species in the vegetation. Understanding that relationship and the accompanying uncertainties are key to interpreting the fossil pollen data, and can improve the quality of reconstructions and interpretations of past vegetation, landscape and climate (Chen et al., 2017). Much research on that relationship has been done on the Indian subcontinent in the most recent

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years (Quamar and Bera, 2014a, 2017; Quamar, 2017; Quamar and Kar, 2020 and references cited therein), but fewer such studies have been done in the Jammu region (Vishnu-Mittre and Robert, 1971; Sharma et al., 2001; Quamar and Srivastava, 2013; Quamar et al., 2018a, b; Quamar, 2020). To address this, we analysed the pollen of 35 surface soil samples in order to establish the relationship between extant vegetation and the modern pollen assemblage, and to provide data on the modern pollen-vegetation relationship useful for improving the interpretation of fossil pollen records from the Indian subcontinent on different spatio-temporal scales. The selected sites have not been previously studied in terms of modern pollen dispersal or palaeoclimate reconstruction. A modern analogue of the pollen-vegetation relationship should help us understand the dynamics of vegetation and climate in and around the study area. We compare our present inferences on the pollen-vegetation relationship from Ranbir Singh Pura, Bajalta and Samba in the Jammu region with recently published records from the same region (Akhnoor in Jammu District: Quamar, 2020; Udhampur District and Reasi District: Quamar et al., 2018a, b, respectively).

STUDY AREA, GEOLOGY AND SOIL

Ranbir Singh (R.S.) Pura Sector (32°36′51.52″N, 74°38′58.15″E; 281 m a.s.l.) is located about 45 km southwest of Jammu Township, and Bajalta village is situated about 18 km northwest of Jammu Township (32°45.621′N, 74°57.026′E; 390 m a.s.l.) in Jammu District. Samba District (32°33′15.44″N, 75°06′55.70″E; 384 m a.s.l.) is about 47 km southeast of Jammu Township in the Jammu region (Figs 1 and 2). The landscape of the Jammu region is mainly plain to the south of the Siwalik hills. The lesser Himalayan Mountains are found northwards up to the Pir Panjal range. An intricate mosaic of mountain ranges and hills lies around the study areas, with river terraces, valleys and gorges (Mir, 2003). Silt deposits dominate in the northeast (Ravi Basin) and the northwest (Chenab Basin) of the Jammu foothills, which suggests transport (Wiggs, 1997; Ganjoo and Kumar, 2012) under reduced flow along river channels/banks (Chakrapani, 2005). These alluvial soils have little clay content, and stony and sandy soils are the chief soil types around the study areas (Mir, 2003), supporting cultivation of crops there.

VEGETATION

The plant life around the Jammu region is generally rather diverse, comprising 506 species of angiosperms, gymnosperms and pteridophytes (Pandita et al., 2014), including 86 herbaceous species and 62 genera of 29 tree and shrub families. Of the recorded species, 19 species of Fabaceae, 8 species of Malvaceae, 5 species each of Rosaceae and Rutaceae, and 6 species each of Moraceae and Euphorbiaceae have been identified. Seventeen families are monogeneric and monospecific: Phyllanthaceae, Salicaceae, Vitaceae, Arecaceae, Musaceae, Bignoniaceae, Capparaceae, Oleaceae, Boraginaceae, Lamiaceae, Cucurbitaceae, Puniaceae, Caricaceae, Asclepidiaceae, Moringaceae, Verbinaceae and Rubiaceae. Subtropical pine forests, lower Siwalik Chirpine (*Pinus roxburghii*) forests, subtropical dry evergreen forests, Himalayan moist temperature forests, Himalayan dry temperature forests, and sub-alpine and moist-alpine forests form the vegetation of the Jammu region. Subtropical dry mixed deciduous forests represent the vegetation type of the Jammu plains. Shrub-forest dominates the submontane and semimontane zones of the study areas. In the outer hills the flora differs entirely from the middle mountains, sub-mountainous and semi-mountainous zones with Deodar (*Cedrus libani*) as the dominant tree species (Champion and Seth, 1968; Sharma and Kachroo, 1981; Singh et al., 2002; Mir, 2003). Table 1 shows the accompanying species of the forests in and around the Jammu region (Quamar, 2020).

CLIMATE

The Jammu region has a monsoon-influenced subtropical humid climate (Cwa) (Köppen, 1936). The southwest monsoon (a component of Indian Summer Monsoon; ISM) brings rains during the months of June–September in the foothills and the Siwalik Range of the Jammu region. The area receives some precipitation during the winter months of December, January and February due to the Western Disturbances (WDs). The nearest climate research unit timeseries (CRU TS; 4.01, 0.5 × 0.5 gridded

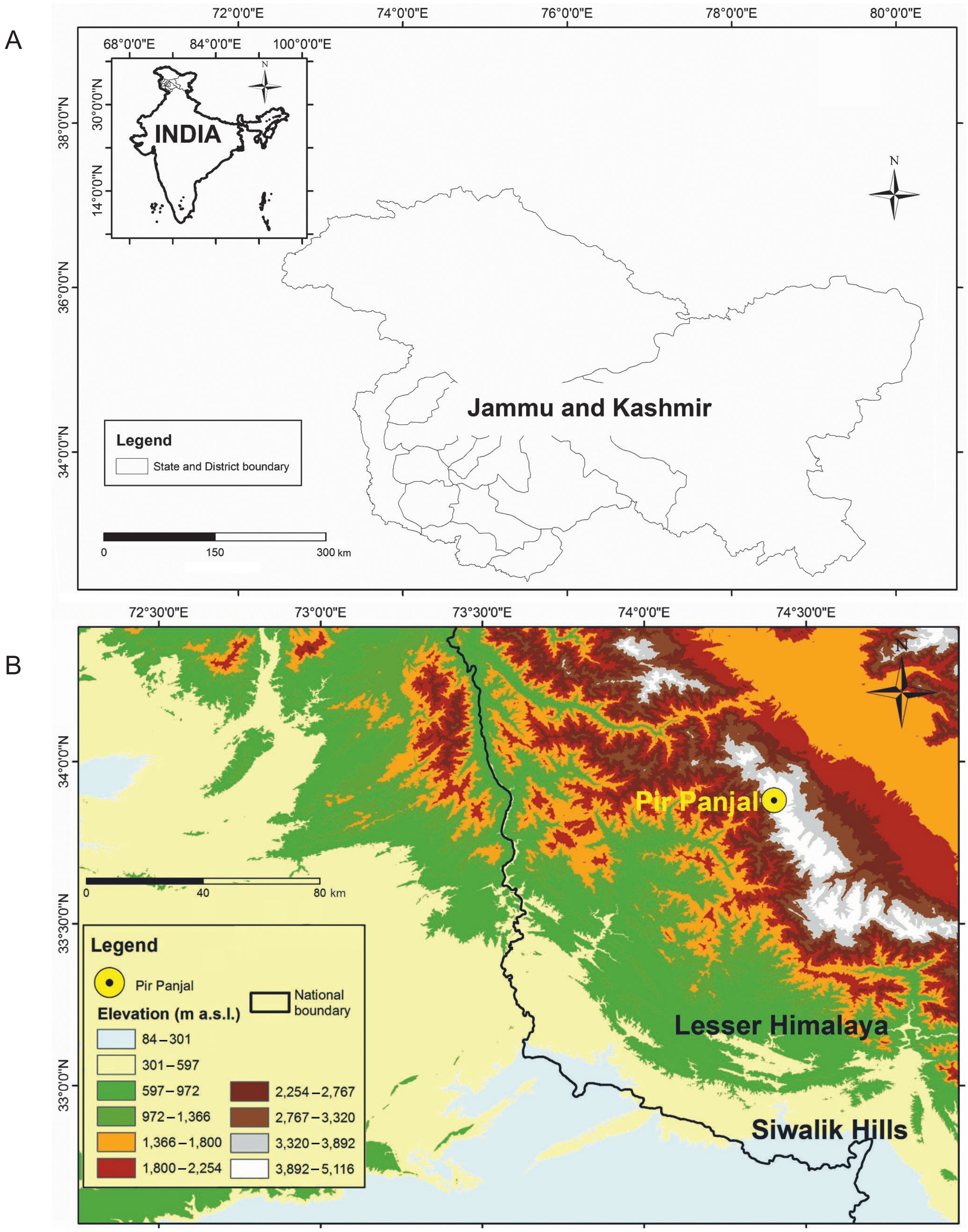


Fig. 1. **A**. Geographic map of India showing Jammu and Kashmir State. **B**. Shutter radar topographic mission (SRTM) digital elevation map (DEM) of Jammu District (Jammu and Kashmir State, India), showing Pir Panjal range (yellow circle), Siwalik Hills and Lesser Himalaya. Source of Figure 1: created using ArcGIS 10.3.

climate data points, 1901–2016) shows mean monthly precipitation and temperature around the study areas of Jammu region (Harris et al., 2014) (Fig. 3; Supplementary file 1[1]). Mean annual temperature (MAT) is 23.73°C for Jammu District and 21.55°C for Samba District of the Jammu region. Mean annual precipitation (MAP) is 755.28 mm for Jammu District and 899.75 mm for Samba District. Wind speed also plays a pivotal role around the study areas.

[1] Supplementary file 1: Temperature and precipitation records (monthly) during 1901–2016 from the study areas

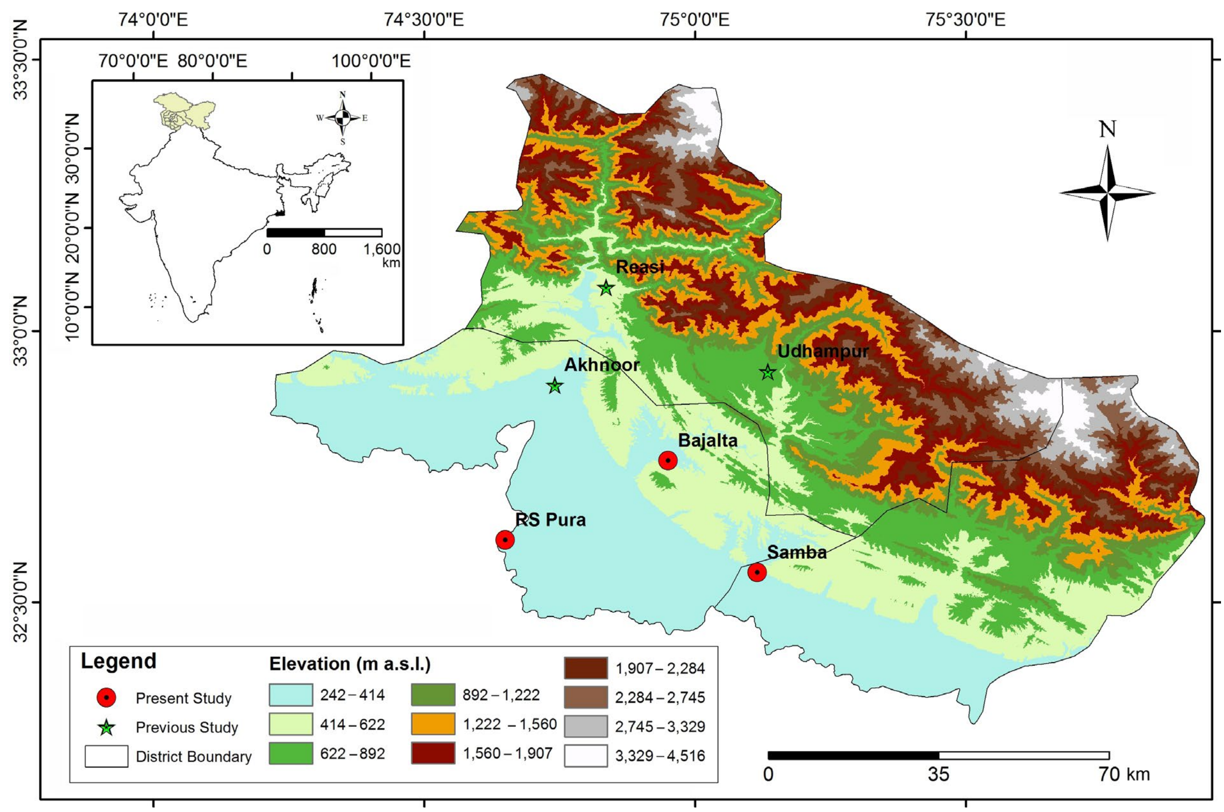


Fig. 2. Geographic map of India showing Jammu and Kashmir State (inset left). Shutter radar topographic mission (SRTM) digital elevation map (DEM) of Jammu District (Jammu and Kashmir State, India) showing the present study sites (R.S. Pura, Bajalta village in Jammu District, Samba District; red circles). Akhnoor (Jammu District), Udhampur and Reasi districts are given on the map to show the location of the recently published records (star) that are compared with the present study. Source of Figure 2: created using ArcGIS 10.3.

Table 1. Vegetation (regional taxa as well as extra-regional taxa) of the Jammu region, Jammu and Kashmir, India

Arboreal taxa (trees and shrubs)		Non-arboreal taxa (herbaceous taxa)
Subtropical forest elements (Regional tree taxa)	Temperate forest and alpine elements (Extra-regional tree and shrubby taxa)	Terrestrial herbs: Poaceae (Grasses)
Conifers: *Pinus* sp. (*Pinus roxburghii*) Broad-leaved taxa: *Ulmus* sp., *Juglans* sp., *Quercus* sp. Sub-tropical deciduous tree taxa: *Mallotus* sp., *Fraxinus* sp., *Shorea* sp., *Bombax* sp., *Syzygium* sp., Mimosaceae, *Emblica officinalis*, *Terminalia* spp., *Ficus* spp., *Grewia* sp., *Tamarindus* sp., *Mitragyna parvifolia*, *Lannea coromandelic*, *Acacia catechu*, *Butea monosperma*, *Mallotus philippensis*, *Albizzia* sp., *Eucalyptus* sp., *Bombax ceiba*, *Dalbergia sissoo*, *Morus alba*, *Cedrela toona*, *Melia azedarach*, *Bauhinia variegata*, *Flacourtia indica*, *Azadirachta indica*, *Ailanthus excelsa*, *Acacia modesta*, *Cassia fistula*, *Phoenix sylvestris*, *Olea* sp., *Sapindus* sp. Sub-tropical deciduous shrubby taxa: Acanthaceae, *Rungia* sp., *Ziziphus* sp., *Strobilanthes* sp.	Conifers: *Pinus* spp. (*Pinus gerardiana*, *P. wallichiana*), *Cedrus* sp., *Abies* sp., *Picea* sp., *Larix* sp., *Podocarpus* sp., *Juniperus* sp., *Tsuga* sp. Broad-leaved taxa: *Alnus* sp., *Betula* sp., *Carpinus* sp., *Corylus* sp., *Acer* sp., *Ilex* sp., *Salix* sp., *Aesculus* sp., *Celtis* sp., *Rhododendron* sp., *Skimmia* sp. Alpine scrub/Shrub: *Ephedra* sp. Tropical, sub-tropical and warm temperate (Shrubby taxa): *Dodonea* sp., *Croton* sp.	Cultural pollen taxa: Cerealia, Amaranthaceae, Caryophyllaceae, Brassicaceae, *Artemisia* sp., *Alternanthera* sp., *Cannabis sativa*, *Plantago* sp., Urticaceae, *Rumex hastatus* Heathland taxa: Asteroideae/Tubuliflorae and Cichorioideae/Liguliflorae (Asteraceae family), Malvaceae, *Xanthium* sp., *Justicia* sp., *Aconitum* sp., *Oldenlandia* sp., Mimosaceae, Boraginaceae, *Potentilla* sp., *Ricinus communis*, *Vitex negundo*, *Lantana camara*, *Parthenium hysterophorus*, *Datura metel*, *Murraya koenigi*, *Nerium indicum*, *Agave americana*, *Colebrookia oppositifolia*, *Euphorbia* sp., *Punica granatum*, *Ipomoea* sp., *Jasminum officinale*, *Cynodon dactylon*, *Saccharum munja*, *Dioscorea* sp., *Abrus precatorius*, *Vetiveria zizanoides* Marshy/Wetland taxa: Cyperaceae (Sedges), *Polygonum plebeium*, *P. serrulatum*, *Pimpinella* sp., *Polygala* sp., *Hygrophila* sp., *Chrozophora* sp., *Solanum* sp. Aquatic taxa: *Potamogeton* sp., *Lemna* sp., *Typha* sp., *Utricularia* sp., *Nymphoides* sp. (Nymphaeaceae) Algae: *Zygnema* sp., *Spirogyra* sp., *Botryococcus* sp., *Pediastrum* sp., *Pseudoschizaea* sp. Pteridophytic taxa: *Dryopteris* sp., *Adiantum* sp., *Diplazium* sp., *Selaginella* sp., *Lycopodium* sp.

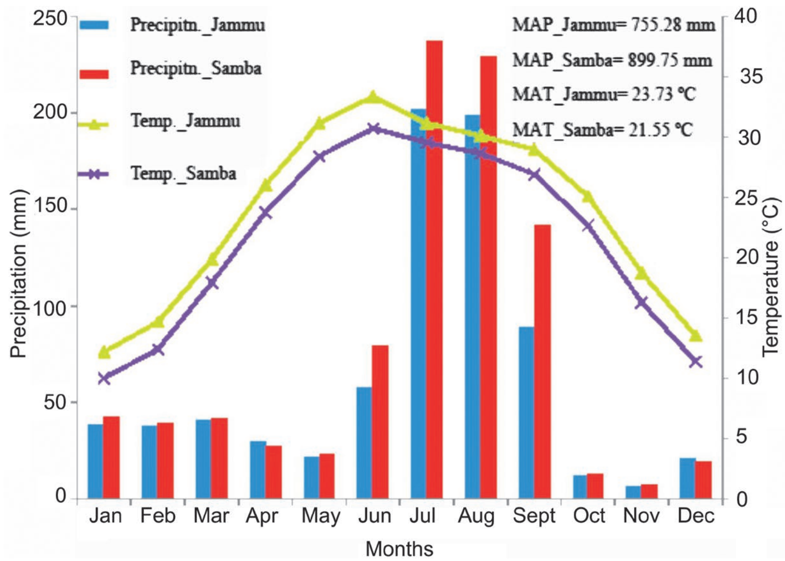


Fig. 3. Nearest Climate Research Unit Timeseries (CRU TS) 4.01, 0.5 × 0.5 gridded climate data point, 1901–2016, showing mean monthly precipitation and temperature around the study areas in the Jammu region of Jammu and Kashmir, India. These data are 116-year climate averages for the period 1901–2016; MAP – mean annual precipitation; MAT – mean annual temperature

MATERIALS AND METHODS

We collected 35 modern soil samples along a linear transect at varying intervals of ~150–300 m from open areas of R.S. Pura and Bajalta village (Jammu District) and Samba District of the Jammu region (Jammu and Kashmir), India, in February 2015. The samples were collected manually with a spatula into ziplock polythene bags, when it had been raining for the previous few days. The surface samples were taken down to 0.5 cm depth after removing any grass from the sampling sites.

Extraction of palynomorphs from the modern surface soil samples followed the standard preparation procedures devised by Erdtman (1943). In the chemical treatments, 10 g each of the 35 samples were boiled with 10% KOH to remove humus. Then the samples were treated with 40% HF and an acetolysis mixture (9:1 mixture of acetic anhydride $C_4H_6O_3$ and concentrated sulphuric acid H_2SO_4) to remove the silica, pollen kit, protoplasm and other cellulosic material. Five ml of 50% glycerine solution was added to the treated residue for microscopic examination and further storage, and 2 ml phenol was also added to avoid any post-maceration microbial contamination.

The palynomorphs were counted under a transmitted light microscope (Olympus BX50) with a 40× objective at the Quaternary Palynology Laboratory of the Birbal Sahni Institute of Palaeosciences (BSIP), Lucknow, India. Pollen and spores were identified by comparing their morphological characters with pollen and spores in published literature (Nair, 1965; Gupta and Sharma, 1987; Nayar, 1990; Quamar and Srivastava, 2013; Quamar, 2019; Quamar and Stivrins, 2021) and the pollen reference collection at the sporothek of the BSIP Herbarium. The samples were not very productive, though we tried to reach total pollen counts of ~300 per sample. Pollen percentages were, however, calculated using the total pollen sum of the terrestrial plant pollen. We excluded pollen of aquatic plants, marshy (wetland) taxa, as well as spores of algae, ferns and fungi, from the total pollen sum, but calculated their percentages using the total pollen sum. The pollen spectra (Figs 4–6) were combined into histograms (Supplementary File 2) using TILIA software (Grimm, 1990). Taxa in the pollen spectra were grouped as trees, shrubs, terrestrial herbs, marshy (wetland) taxa, aquatics, algal remains, pteridophytic taxa and fungal spores.

To assess the differences in pollen counts between study sites, we applied principal component analysis (PCA), using CANOCO ver. 5.0. PCA is an unconstrained method for reducing the dimensionality of large datasets, giving increasing interpretability and also minimizing information loss (Jolliffe and Cadima, 2016). PCA reduces the eigen value/eigenvector problem in data analysis. For the present study, we chose PCA as a vital predictive technique to differentiate the pollen distributions over varying geographical sites with different environmental constraints.

RESULTS

FROM OPEN AREAS OF R.S. PURA, JAMMU DISTRICT

The fifteen surface samples collected from open areas of the R.S. Pura Sector of Jammu District (Fig. 2) showed higher frequency of conifers (needle-leaved taxa) than of broadleaved taxa among the arboreal pollen (AP) taxa. The non-arboreal pollen (NAP) taxa reached fairly high values in the total pollen rain (Fig. 4; Supplementary file 2[2]). Table 2 presents detailed palynological results from this area. In PCA, 68% of the total variance of the data on dominant

[2] Supplementary file 2: Raw data (pollen counts) from R.S. Pura and Bajalta areas of the Jammu District, as well as from the Samba District of Jammu region

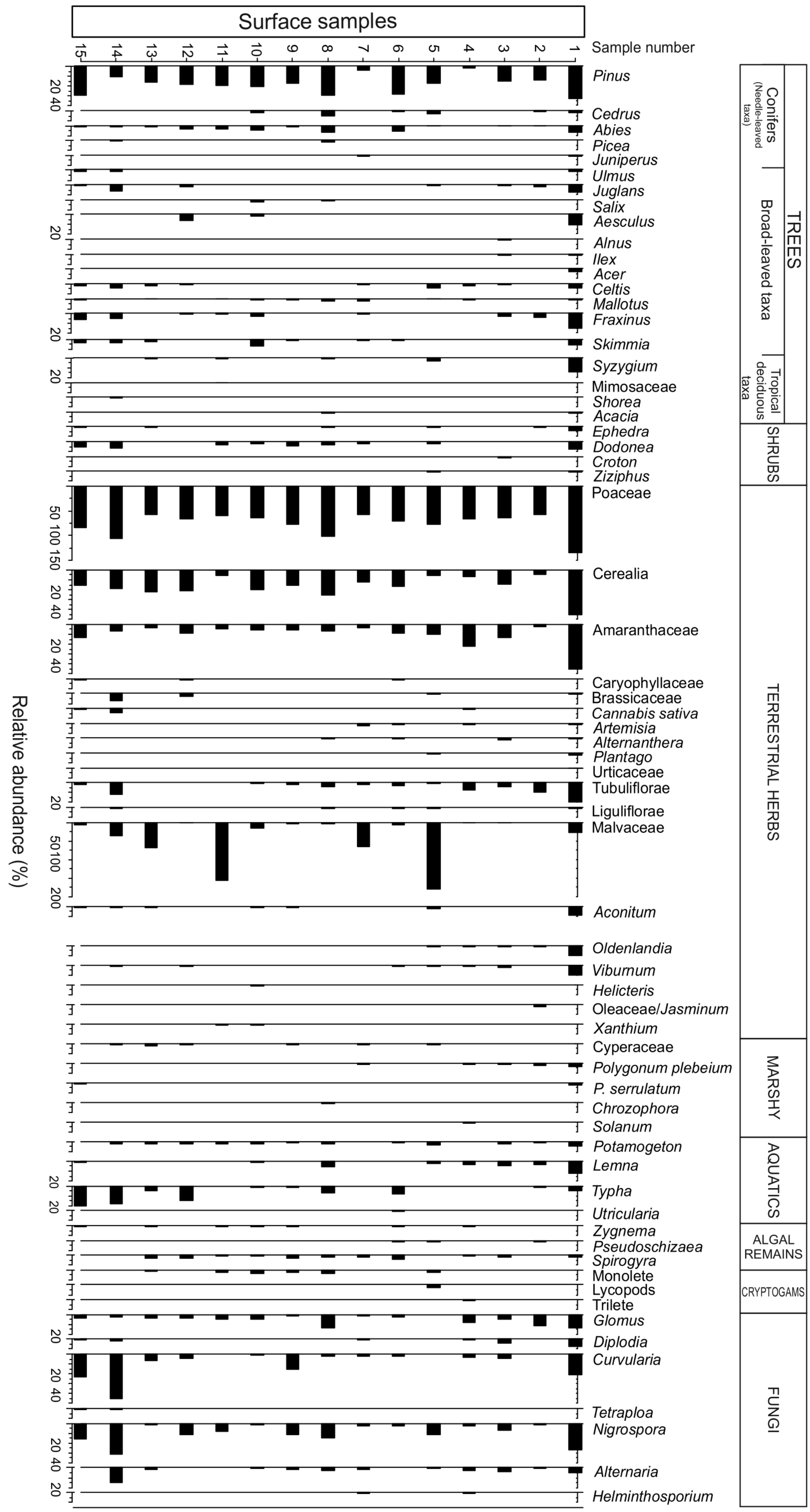


Fig. 4. Modern pollen spectra from open areas of R.S. Pura, Jammu District, Jammu and Kashmir, India

Table 2. Palynological results from the Jammu region; see Materials and Methods for explanation of percentages

Open areas of R.S. Pura, Jammu District	Open areas of Bajalta village, Jammu District	Open areas of Samba District
Conifers (10.32%): *Pinus* sp. (mean 8.49%), *Cedrus* sp., *Abies* sp., *Picea* sp., *Juniperus* sp. (mean 1.82%), sporadic. Broadleaved taxa, e.g. *Ulmus* sp., *Juglans* sp., *Salix* sp., *Aesculus* sp., *Alnus* sp., *Ilex* sp., *Acer* sp., *Celtis* sp., *Mallotus* sp., *Fraxinus* sp., *Skimmia* sp. (mean 3.45%). *Syzygium* sp., Mimosaceae (Mimosoideae), *Shorea* sp., *Acacia* sp. (tropical deciduous taxa) (mean <0.5%). Shrubby taxa, e.g. *Ephedra* sp., *Dodonea* sp., *Croton* sp., *Zizyphus* sp. (1.17%). Poaceae (mean 35.16%). Cerealia (mean 7.37%); other cultural taxa, (Amaranthaceae, Caryophyllaceae, Brassicaceae, *Cannabis sativa*, *Artemisia* sp., *Alternanthera* sp., *Plantago* sp., Urticaceae (mean 12.88%). Malvaceae, Asteroideae/Tubuliflorae, Cichorioideae/Liguliflorae (members of sub-families of Asteraceae), *Aconitum* sp., *Oldenlandia* sp., *Helicteris* sp., *Jasminum* sp. (Oleaceae), *Xanthium* sp., other prominent terrestrial herbaceous taxa (mean 18.88%). Marshy/wetland taxa (mean ~1%), aquatic taxa (mean 4.07%). Algal remains (mean 1.25%). Pteridophytic taxa comprising monolete and trilete fern spores and lycopods (mean 0.50%). *Glomus* sp. *Diplodia* sp., *Curvularia* sp., *Tetraploa* sp., *Nigrospora* sp., *Alternaria* sp., *Helminthosporium* sp. (mean 11.38%).	Conifers (mean 16.35%): *Pinus* sp. (mean 14.74%); *Cedrus* sp., *Juniperus* sp. (mean 1.61%), sporadic. Broadleaved taxa, e.g. *Juglans* sp., *Betula* sp., *Rhododendron* sp., *Celtis* sp., *Fraxinus* sp. (mean 1.03%), found in all samples. *Syzygium* sp., sole representative of tropical deciduous taxa (mean <0.5%). *Ephedra* sp., *Dodonea* sp., members of Acanthaceae, *Zizyphus* sp., shrubby taxa (mean ~1%), rare. Poaceae (mean 40.35%), Cerealia (mean 6.71%); other cultural taxa (Amaranthaceae, Caryophyllaceae, also *Artemisia* sp., *Alternanthera* sp. (mean 10.98%). Other prominent terrestrial herbaceous taxa, e.g. Asteroideae/Tubuliflorae (members of sub-family of Asteraceae), Malvaceae, Rosaceae, *Xanthium* sp. (mean 13.42%). Marshy/wetland taxa (mean 2.33%), aquatic taxa (mean 1.58%), sporadic. Algal remains, pteridophytic taxa comprising trilete fern spore and lycopods (mean <0.5% each), sparse. *Glomus* sp., *Diplodia* sp., *Curvularia* sp., *Tetraploa* sp., *Cookeina* sp., *Nigrospora* sp., *Alternaria* sp., *Helminthosporium* sp. (mean 15.32%).	Conifers (mean 10.17%): *Pinus* sp. (mean 10.08%); *Cedrus* sp., *Picea* sp., *Larix* sp., *Juniperus* sp. (mean 1%), sporadic. Broadleaved taxa, e.g. *Ulmus* sp., *Juglans* sp., *Alnus* sp., *Celtis* sp., *Aesculus* sp., *Fraxinus* sp., *Acer* sp., *Mallotus* sp. (mean 1.67%), sparse. *Syzygium* sp., the sole tropical deciduous taxon (0.09%), sporadic. Shrubby taxa, e.g. *Croton* sp., *Dodonea* sp. (mean <0.5%). Poaceae (mean 30.41%), Cerealia (mean 3.40%); other cultural taxa (Amaranthaceae, Caryophyllaceae, Brassicaceae, also *Cannabis sativa*, *Artemisia* sp.) (mean 5.05%). Malvaceae, Asteroideae/Tubuliflorae (members of sub-family of Asteraceae), *Aconitum* sp., *Oldenlandia* sp., *Viburnum* sp., *Xanthium* sp., other terrestrial herbaceous taxa, (mean 23.03%). *Polygonum plebeium*, the sole representative of marshy/wetland taxa (mean <0.05%), aquatic taxa (mean <0.5%). algal remains (mean <0.5%), rare. Pteridophytic taxa comprising monolete and trilete fern spores and lycopods (mean 0.52%), rare. *Glomus* sp., *Diplodia* sp., *Nigrospora* sp., *Curvularia* sp., *Tetraploa* sp., *Cookeina* sp., *Nigrospora* sp., *Alternaria* sp., *Helminthosporium* sp. (mean 27.85%).

and subdominant taxa at the R.S. Pura site was explained, but principal components 1 and 2 could explain only 46% of it (Fig. 7).

FROM OPEN AREAS OF BAJALTA VILLAGE, JAMMU DISTRICT

The ten surface samples collected from open areas of Bajalta village, Jammu District (Fig. 2), showed higher frequency of conifers than of broadleaved among the arboreal pollen (AP) taxa. Non-arboreal pollen (NAP) taxa were less abundant in the total pollen rain (Fig. 5; Supplementary file 2). Table 2 presents detailed palynological results from this area. PCA explained 82% of the variance for the Bajalta site; principal components 1 and 2 explained about 60% of the total variance of the pollen taxa (Fig. 8).

FROM OPEN AREAS OF SAMBA DISTRICT

The ten surface samples collected from open areas of Samba District (Fig. 2) showed higher frequency of conifers than of broadleaved taxa among the arboreal pollen (AP) taxa. Non-arboreal pollen (NAP) taxa were abundant in the total pollen rain (Fig. 6; Supplementary file 2). Table 2 presents detailed palynological results from this area. PCA explained 86% of the total variance for the Samba site, with principal components 1 and 2 explaining ~65% of the total variance in the pollen percentages and distribution (Fig. 9).

DISCUSSION

INFERENCES ON THE MODERN POLLEN RAIN–VEGETATION RELATIONSHIP

Among the conifers, *Pinus* (saccate grain, regional taxon) showed high frequency in the pollen assemblages. This can be attributed to its high pollen productivity and pollen dispersal (Andersen, 1970; Bhattacharayya, 1989; Traverse, 2007; Pidek et al., 2010; Ertl et al. 2012; Kar et al., 2015, 2016; Quamar et al., 2018a, b; Bajpai and Kar, 2018; Quamar, 2020;

Quamar and Kar, 2020 and references therein). The high sporopollenin content of the exine of *Pinus* pollen also helps make it resistant to oxidation and microbial attack (Havinga, 1967, 1984), allowing good preservation of it in the substrate. Pollen grains of *Pinus* have air bladders, and the taxon is anemophilous. The sacci increase the buoyancy of the pollen grains, favouring transport by wind, water (Suc and Drivaliari, 1991) and surface runoff (Frazer et al., 2020). The longer buoyancy time of the pollen grains (Pocknall, 1980) and their high fall speed (0.031 m/s) (Xu et al., 2012) when their sacci become saturated with water allow them to be deposited differentially. Hopkins (1950) suggested that differential flotation, particularly between coniferous pollen and other taxa, could be due to weak differences in the density and surface/volume ratio of the grains (Flenley, 1971; Davis and Brubaker, 1973). The other coniferous temperate forest elements (extra-regional taxa), such as *Cedrus* sp., *Abies* sp., *Picea* sp., *Larix* sp., and *Juniperus* sp., have much lower values in the pollen spectra and are barely recorded. This behaviour of their pollen can be attributed to lower pollen productivity and pollen dispersal efficiency (Kar et al., 2015, 2016; Quamar et al., 2018a, b; Bajpai and Kar, 20018) and preservation potential (Quamar, 2020). The record of pollen of *Cedrus* sp., *Abies* sp.,and *Picea* sp. (saccate grains), as well as *Larix* sp. and *Juniperus* sp. (non-saccate grains, extra-regional taxa/temperate forest elements) from the study areas could reflect transport of their pollen through wind and/or water from the higher reaches of the Himalayas. *Ulmus*, *Juglans* and *Mallotus* are regional broadleaved taxa (Tab. 1) that were scarce in the pollen spectra, recorded at lower values. The other broadleaved taxa (extra-regional temperate elements), such as *Alnus*, *Betula*, *Salix*, *Aesculus*, *Ilex*, *Acer*, *Celtis*, *Mallotus*, *Fraxinus*, *Rhododendron* and *Skimmia*, were scattered in the pollen spectra at lower frequency than the conifers, especially *Pinus*, perhaps due to transport by wind and/or water from higher reaches of the Himalayas. Tropical deciduous forest elements (regional taxa), such as *Syzygium*, members of the subfamily Mimosoideae, *Shorea* and *Acacia*, appeared sporadically in the pollen spectra; this seems related to their entomophilous habit. The complete absence of other tropical deciduous forest elements (regional taxa), such as *Terminalia*, *Emblica officinalis*, *Grewia*, *Mitragyna parvifolia*, *Mangifera indica, Madhuca indica*, *Lannea coromandelica*, *Bombax ceiba*, *Azadirachta indica*, *Melia azedarach*, *Eucalyptus*, *Ficus*, *Mallotus philippensis*, *Albizzia*, *Schleichera*, *Dalbergia sissoo, Morus alba, Butea monosperma*, *Tamarindus*, *Flacourtia*, *Cassia fistula*, *Sapindus* and others from the pollen assemblages, could be ascribed to entomogamy and low pollen production (Cannel and Smith, 1984; Duan et al., 2009; Cariñanos et al., 2014; Quamar, 2020; Quamar and Bera, 2014a, b; Quamar and Kar, 2020; Quamar et al., 2018a, b and relevant references therein).

Ephedra sp., *Dodonea* sp., *Croton* sp., members of Acanthaceae, and *Zizyphus* sp. are prominent shrubby taxa that were sporadic in the pollen record. *Ephedra*, an anemophilous taxon, was sparse, perhaps due to its poor pollen dispersal and low preservation. The low pollen production or entomogamy could also be cited as reasons for the low representation of other shrubby taxa. *Ephedra* is an alpine scrub, whereas *Dodonea* and *Croton* are found in tropical, subtropical and warm-temperate areas of the Indian subcontinent. *Ziziphus* and members of the family Acanthaceae are common tropical deciduous forest elements (shrubby taxa) found around the study areas in the Jammu region. Poaceae and Amaranthaceae, being anemophilous taxa, form significant shares of the modern pollen assemblages of the study areas, followed by Cerealia. Caryophyllaceae, Brassicaceae, *Artemisia*, *Alternanthera*, *Cannabis sativa*, *Plantago* and members of Urticaceae have meagre shares in the modern pollen assemblages. The pollen record of Cerealia and other cultural plant taxa, such as Amaranthaceae, Brassicaceae, Caryophyllaceae, *Artemisia* sp., *Alternanthera* sp., *Cannabis sativa*, *Plantago* and members of Urticaceae, is indicative of agricultural practice, as well as other human activities in and around the study areas. Asteroideae/Tubuliflorae (a subfamily of Asteraceae) showed high values, which could indicate pastoral activity around these areas of the Jammu region (Mazier et al., 2006). Caryophyllaceae and *Artemisia* also point to grazing of open landscape types around the study areas (Van Joolen, 2003). Members of Malvaceae have overall good representation in the pollen spectra, which could indicate fair pollen preservation, despite entomogamy. Cichorioideae/Liguliflorae, *Aconitum* (Ranunculaceae), *Oldenlandia*, *Viburnum*, *Helicteris*, *Jasminum* (Oleaceae), Rosaceae and

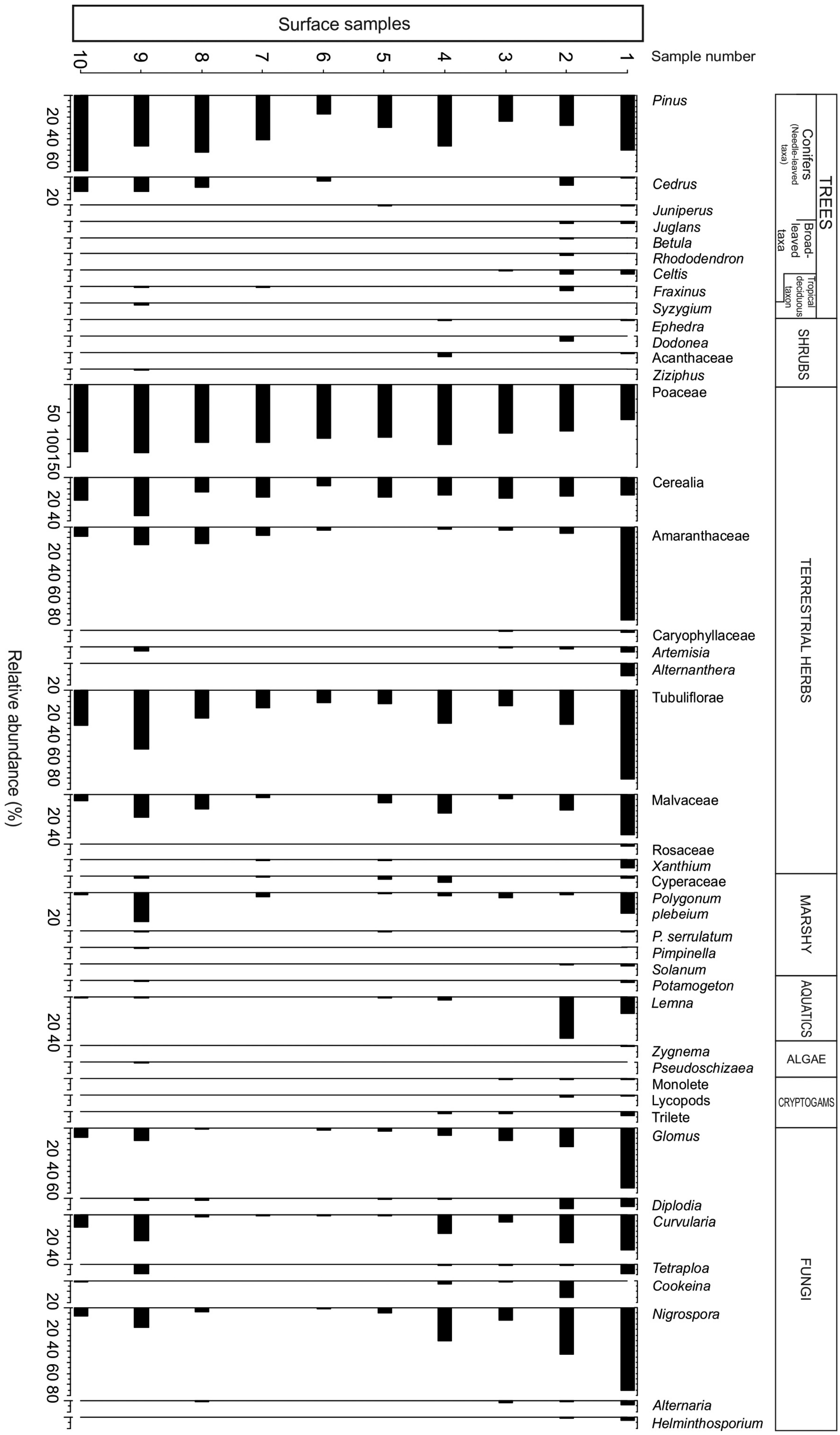


Fig. 5. Modern pollen spectra of from open areas of Bajalta village, Jammu District, Jammu and Kashmir, India

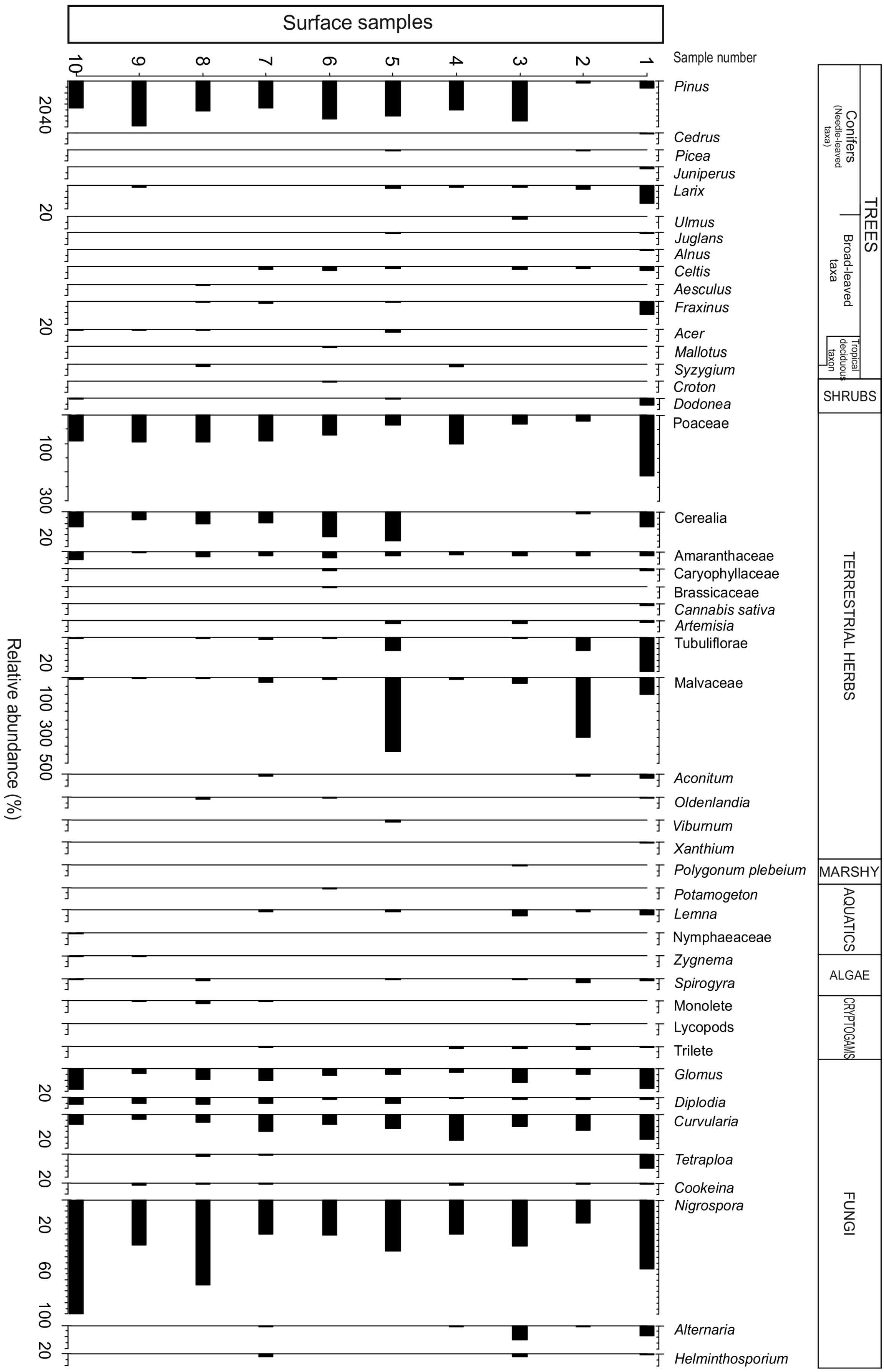


Fig. 6. Modern pollen spectra from open areas of Samba District, Jammu region, Jammu and Kashmir, India

Xanthium were sporadically recovered; this could be due to entomogamy of these terrestrial herbaceous taxa (Vincens et al., 1997; Quamar et al., 2018a, b; Quamar, 2020; Quamar and Kar, 2020). Low dispersal efficiency, as well as poor preservation of their pollen in the studied substrate could also be cited as reasons for the irregularity of their representation in the assemblages. Nor can we rule out oxidation and high pH of the studied natural pollen trapping media/substrates, coupled with microbial degradation of the pollen (Quamar and Bera, 2014a, b, 2017; Quamar and Kar, 2020 and references cited therein). The record of marshy (wetland) taxa, such as Cyperaceae, *Polygonum plebeium*, *Polygonum serrulatum*, *Chrozophora*, *Pimpinella*, and *Solanum*, indicates wet conditions around the sampling sites. We also found aquatic taxa, such as *Potamogeton* sp., *Lemna* sp., *Typha* sp., members of the family Nymphaeaceae and *Utricularia* sp., as well as algal spores, including zygospores of *Zygnema* and *Spirogyra*, and *Pseudoschizaea*; they may have originated from waterbodies and/or aquatic environments around the sampling areas (Pišút et al., 2010). Monolete and trilete fern spores and lycopods could indicate high water availability and the presence of mesic habitats (Kato, 1993). The high percentages of *Glomus* may indicate local soil erosion (Medeanic and Silva, 2010). The presence of *Glomus*, *Diplodia*, *Curvularia*, *Tetraploa*, *Nigrospora*, *Cookeina*, *Alternaria* and *Helminthosporium* reflects warm and humid climate around the study areas (Quamar, 2015).

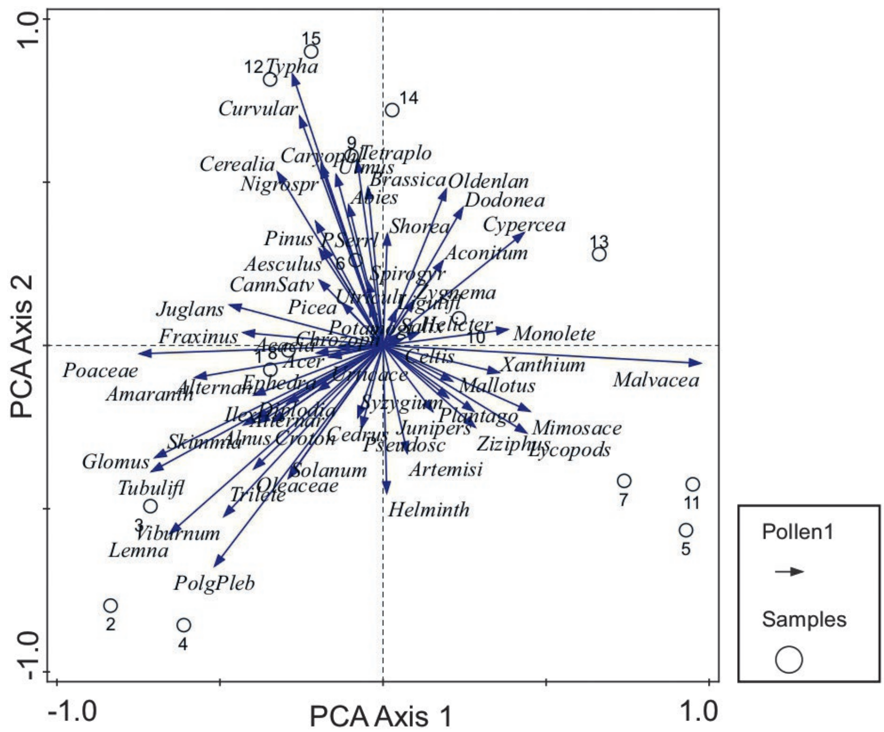
In the present study, principal component analysis (PCA) was used for the unconstrained ordination axes, corresponding to the directions of the greatest variability within the data set. Canoco 5 allows the ordination method to indicate the variance through PC1 and PC2, and in this study the pollen relation was determined using PCA. The total variance explained by PCA was 68%, while PC1 and PC2 explained 46%. In PCA of the data from the R.S. Pura site, most of the variance (60–70%) was attributed to *Typha*, *Ulmus*, *Tetraploa* and *Curvularia*. The lower variance for this site is accounted for by *Shorea*, *Oldenlandia*, Cyperaceae, Monolete, *Zygnema* and a few others (variance only 30–40%). For Poaceae, Amaranthaceae, *Alternaria*, *Lemna*, trilete spores, *Polygonum plebeium*, *Glomus* and many others the variance ranged from −60% to −10% (Fig. 7). The mixed nature of variance for the taxa suggests that the data for this site are related to its environmental setting.

At the Bajalta site, the total variance explained by PCA was 82%; PC1 and PC2 could explain 60% of the variation in the pollen assemblage. The distance between the symbols in the pollen composition approximates dissimilarity as measured by their Euclidean distance. For the Bajalta site, principal components 1 and 2 showed 60–70% variance for *Cookenia*, *Rhododendron*, *Lemna*, Lycopods, *Dodonea*, *Nigrospora* and a few others, indicating dominance of indigenous taxa around the depositional site. *Solanum*, Malvaceae, *Glomus*, *Helminthosporium*, *Artemisia*, Rosaceae and a few others gave negative variance of −50% to −70%, indicating dominance of local vegetation, mainly herbs and lower plants rather than tree taxa (Fig. 8). Thus, PCA suggests that the depositional site was controlled by local environmental conditions rather than long-distance transport.

For the Samba site, 86% of the total variance of the pollen assemblage was explained. PC1 and PC2 explained 65% percent of it. Principal components 1 and 2 showed that *Ulmus*, *Polygonum plebeium*, *Lemna*, *Artemisia*, trilete spores and *Alternaria* accounted for 70–85% of the variance, suggesting altitudinal control of the taxa, with moist conditions. *Pinus*, *Glomus*, *Curvularia*, Poaceae and *Nigrospora* accounted for 50–70% of the variance, reflecting cool and dry conditions and local erosion around the depositional setting. Monolete, *Diplodia*, *Zygnema*, *Nymphaea*, *Acer*, and many others showed −30 to −50% variance, reflecting humid conditions around the sampling area. *Picea*, *Juglans*, *Alnus*, *Juniperus*, *Viburnum*, lycopods and a few others indicate altitudinal variance in PCA for this site (Fig. 9). Generally, the data for the depositional site clearly indicates an altitudinal regime with moist conditions.

AGRICULTURAL PRACTICE AROUND THE STUDY AREA

Agricultural practice around the study areas is suggested by the records of pollen of Cerealia (>40 µm diameter) and other cultural plant taxa. Between-site differences in the counts of Cerealia pollen and other cultural plant taxa reflect corresponding differences in the intensity of agricultural practice and other human activities around the study areas.



Summary Table:				
Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.2970	0.1669	0.1404	0.0793
Explained variation (cumulative)	29.70	46.39	60.42	68.35

Fig. 7. Results of PCA analysis of surface soil samples in relation to the pollen assemblages and extant vegetation of R.S. Pura, Jammu District, Jammu region

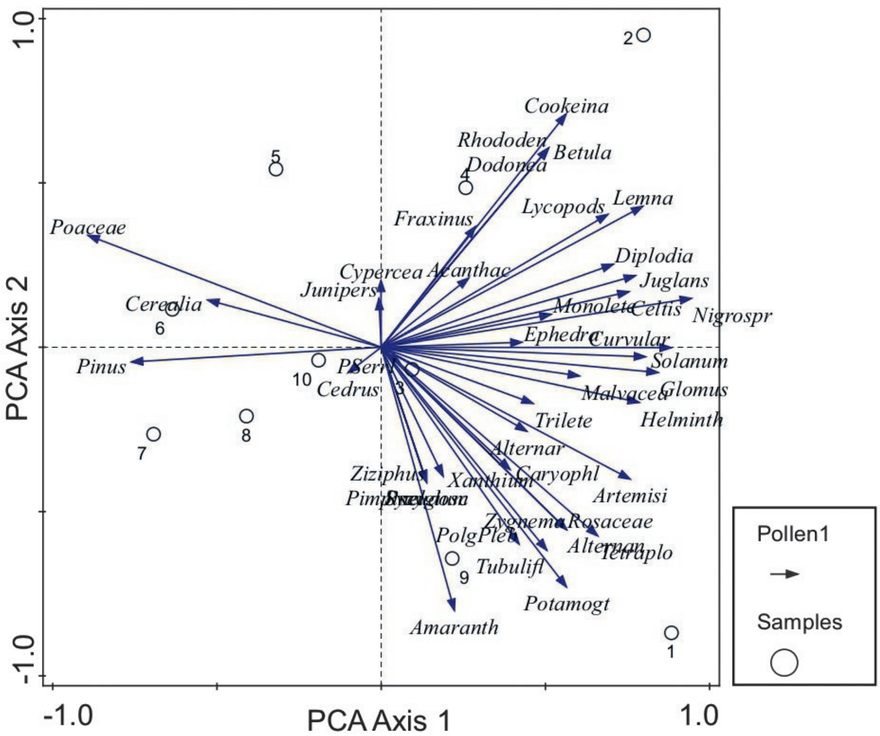
In addition to Cerealia we also recorded Amaranthaceae, Caryophyllaceae, Brassicaceae, *Cannabis sativa*, *Artemisia*, *Alternanthera*, *Plantago* and Urticaceae around the R.S. Pura Sector of Jammu District; Amaranthaceae, Caryophyllaceae, *Artemisia*, and *Alternanthera* were recovered around the Bajalta area of Jammu District; around the Samba District of the Jammu region we recorded Amaranthaceae, Caryophyllaceae, Brassicaceae, *Cannabis sativa* and *Artemisia*.

The record of Poaceae pollen could be related to opening of the forest (perhaps reflecting human activity; Moss et al., 2005). When found in high numbers, it suggests an undisturbed depositional environment around the study areas (Brown, 1985; Catto, 1985; Fall, 1987; Bush, 2000; Behling and Negrelle, 2001).

COMPARISON WITH RESULTS FROM OTHER STUDIES OF THE JAMMU REGION

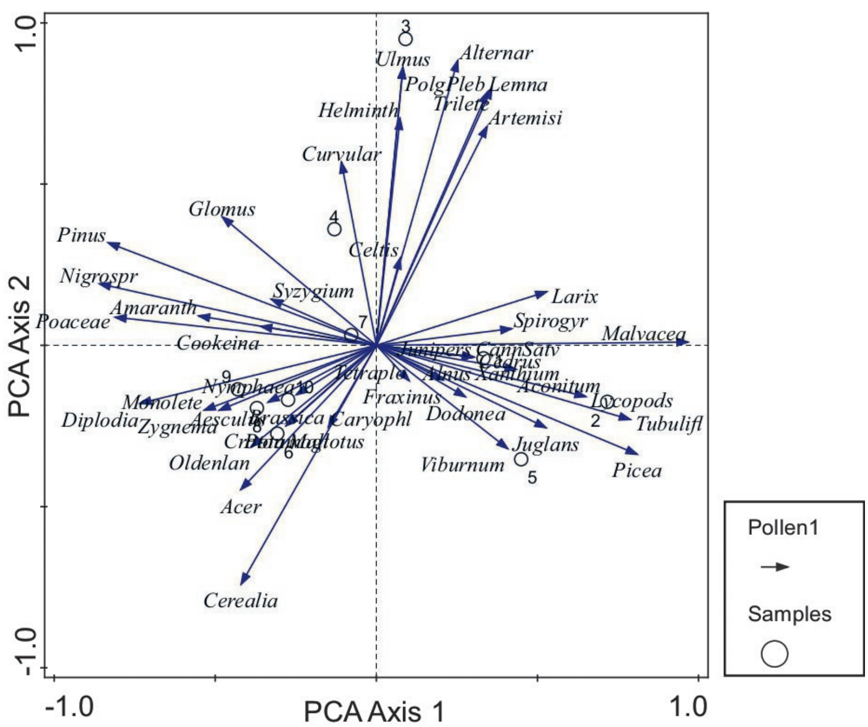
Akhnoor (Jammu District)

Inferences about the modern pollen and vegetation from a study done in Akhnoor, Jammu District (Quamar, 2020), where the samples (moss polsters) were collected from the edge of forested areas, agree with our finding of high representation of *Pinus* and lower values of other coniferous (extra-regional) taxa. Broadleaved regional subtropical and/or extra-regional (temperate) taxa were sporadic and found at very low frequency; they may have been transported by wind and/or water from upland areas or the higher reaches of the Himalayas. Among the broadleaved subtropical (regional) taxa, *Mallotus* was well represented in the pollen assemblages of the Akhnoor samples (but had lower values in the samples from R.S. Pura, Jammu District, and Samba District, and was absent from the samples from Bajalta village, Jammu District), perhaps due to their local presence and high pollen dispersal and preservation. *Carpinus*, a temperate (extra-regional) broadleaved taxon, was also over-represented in the pollen spectra of Akhnoor (but was absent from the samples from R.S. Pura, Bajalta village, Jammu District, and Samba District), perhaps due to transport by wind and/or water from nearby higher reaches of the Himalayas, as well as good preservation of their pollen in the studied substrate from Akhnoor. Subtropical deciduous forest elements were either sporadic



Summary Table:				
Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.4396	0.1625	0.1392	0.0780
Explained variation (cumulative)	43.96	60.21	74.13	81.93

Fig. 8. Results of PCA analysis of surface soil samples in relation to the pollen assemblages and extant vegetation of the Bajalta area of Jammu District, Jammu region



Summary Table:				
Statistic	Axis 1	Axis 2	Axis 3	Axis 4
Eigenvalues	0.4726	0.1776	0.1243	0.0881
Explained variation (cumulative)	47.26	65.02	77.45	86.25

Fig. 9. Results of PCA analysis of surface soil samples in relation to the pollen assemblages and extant vegetation of Samba District, Jammu region

or palynologically silent (present in the extant vegetation but absent in the recovered pollen assemblages) in the samples from open areas of R.S. Pura, Bajalta village (Jammu District) and Samba District, as well as from Akhnoor. This discrepancy in their representation in the pollen spectra from these areas can be explained by the fact that they are not wind-pollinated (rather entomogamy) and also not high pollen producers. The palynological results for the shrubby taxa were similar in all the studied areas. Among the herbaceous taxa, Poaceae showed lower values in the Akhnoor samples than in the present study. The values of Cerealia and other cultural plant taxa as well as other terrestrial herbaceous taxa, marshy/wetland taxa, aquatic taxa, algal remains, pteridophytic taxa, and fungal spores were more or less similar between Akhnoor and the present study. Similar inferences were drawn from these areas.

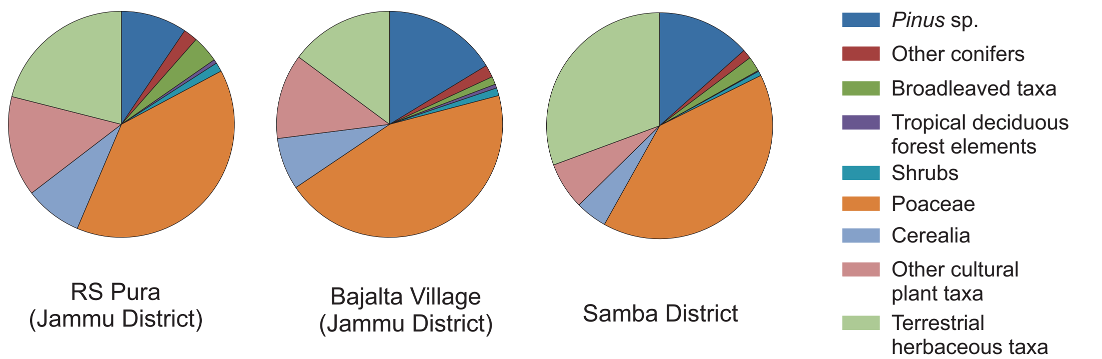
Udhampur

A study of the modern pollen rain–vegetation relationship in Udhampur District (Quamar et al., 2018a), where the samples (moss cushions) were collected from open areas of the forest, showed high frequency of *Pinus*, as in the present study. Among the conifers, *Tsuga* (extra-regional temperate taxon) was recorded in Udhampur but not in the present study, showing comparatively low values in the pollen spectra; its pollen productivity is lower than *Pinus*, and its pollen dispersal and preservation is low. *Quercus* is a regional broadleaved taxon recorded from Udhampur but not in the present study. Other broadleaved (extra-regional temperate) taxa, such as *Carpinus Corylus* and *Elaeocarpus*, were recorded sporadically and at low frequency in Udhampur but not in the present study. Their pollen productivity is low as compared to *Pinus* sp. This distribution could be explained by their lower pollen productivity than *Pinus*, poor pollen dispersal and poor pollen preservation in the substrate, and transport by wind and/or water from nearby higher reaches of the Himalayas. *Skimmia* and *Indigofera* are shrubby taxa recorded sporadically from Udhampur but not in the present study, perhaps due to poor pollen dispersal and poor preservation, low pollen production or entomogamy. Among the herbs, Poaceae, Cerealia and other cultural plant taxa, as well as other terrestrial herbaceous taxa, marshy/wetland taxa, aquatic taxa, algal remains, pteridophytic taxa and fungal spores, reached more or less the same values in Udhampur and the present study.

Reasi

In a study of the dispersal of modern pollen in Reasi District (Quamar et al., 2018b), where samples (moss polsters) were collected from open areas of the forest along the Reasi–Katra Route, *Pinus* occurred at high frequency and dominated the pollen rain around the study area; the same was true in the present study. The conifers *Podocarpus* and *Tsuga* (extra-regional temperate taxa) were recorded in Reasi at low values but were not encountered in the present study. *Quercus* (regional broadleaved taxon) as well as *Carpinus*, *Corylus*, and *Elaeocarpus* (extra-regional temperate broadleaved taxa) were recorded at various low frequencies in Reasi but not in the present study; these taxa show low pollen productivity, poor pollen dispersal, and poor preservation in the pollen-trapping media/substrates used. Besides low pollen productivity, low pollen dispersal and poor preservation of the pollen of extra-regional temperate conifers, as well as broadleaved taxa, their transport by wind and/or water from nearby upland areas cannot be ruled out and may be the main reason for their lower values in, or absence from, the pollen assemblages of Reasi and the present study, due to their entomophily. The pollen values for Poaceae, Cerealia and other cultural plant taxa, such as members of Amaranthaceae, Caryophyllaceae, Brassicaceae, *Artemisia* and *Cannabis sativa*, as well as Asteroideae/Tubuliflorae, Cichorioideae/Liguliflorae (Asteraceae), Malvaceae, *Xanthium*, *Justicia*, *Oldenlandia*, *Aconitum*, *Valeriana* and Rosaceae (cf. *Potentilla*), prominent terrestrial herbaceous taxa, were more or less the same for Reasi and the present study. Marshy/wetland taxa, aquatic taxa, algal remains, pteridophytic taxa, and fungal spores trended almost the same for Reasi and for the present study.

Summing up, it can be stated that (1) *Pinus* (regional conifers) dominated the pollen assemblages of both study areas; (2) other conifers (regional and/or extra-regional taxa) showed lower values than *Pinus* did; (3) subtropical deciduous (regional) taxa were sporadic or palynologically silent; (4) broadleaved and shrubby regional and/or extra-regional taxa also showed lower values or were palynologically silent; (5) Poaceae (grasses), Cerealia and



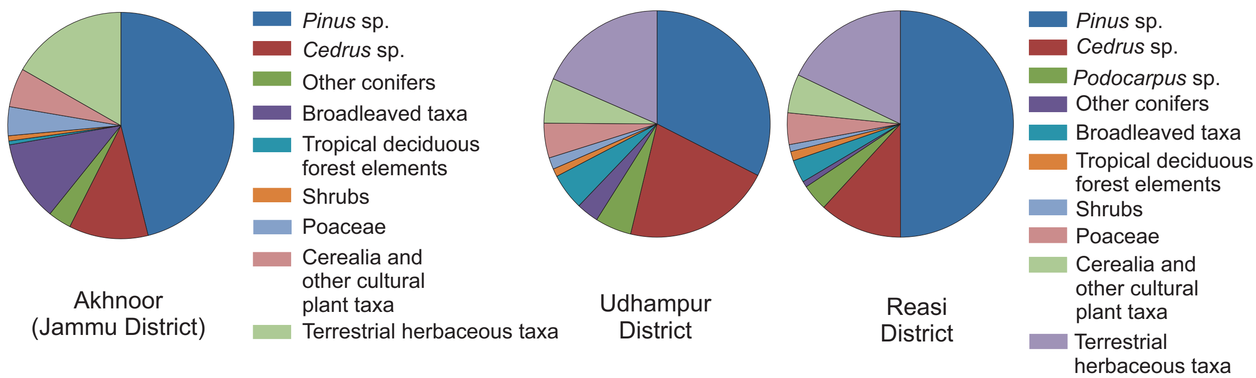


Fig. 10. Pie charts in the first row show the relative abundance of the chief contributors to the forest constituents in the modern pollen assemblages around the study areas. Pie charts in the second row show the relative abundance of the chief contributors to the forest elements in the modern pollen rain from Akhnoor (Jammu District), as well as from Udhampur District and Reasi District

other cultural plant taxa had more or less similar shares in the pollen assemblages from all studied areas; (6) other terrestrial taxa were rare and less abundant, except for Asteroideae/Tubuliflorae and to some extent Malvaceae; and (7) wetland (marshy) and aquatic taxa, algal, pteridophytic and fungal spores showed similar lower values in the pollen assemblages of all studied areas.

Pie charts (Fig. 10) show the chief contributors to the forest elements of the modern pollen assemblages of R.S. Pura and Bajalta village in Jammu District, and Samba District in the Jammu region (in the first row). They are also compared with the modern pollen assemblages from Akhnoor in Jammu District, as well as Udhampur District and Reasi District (in the second row).

The extended R-value model approach (Parsons and Prentice, 1981; Prentice and Parsons, 1983; Sugita, 1993, 1994) should be applied to achieve the best approximation of a "pollen sample's view" of the landscape (Prentice and Webb, 1986; Sugita, 1994; Calcote, 1995). The modelling approach corrects the non-linearities (Fagerland effect: Fagerland, 1952) that arise from the use of pollen percentage data. Also, the relevant pollen source area and the distance-weighted plant abundance can be defined, which helps improve the pollen representation (pollen production and dispersal) as well as transport and preservation, and ultimately this can better clarify the modern pollen rain–vegetation relationship of an area.

FACTORS AFFECTING THE MODERN POLLEN–VEGETATION RELATIONSHIP

Insights gained from establishing the relationship between modern pollen assemblages and extant vegetation can help in reconstructing past vegetation and the associated palaeoclimate. In this study we generated a comparative data set in order to estimate the extent to which various plant taxa/groups of the present-day vegetation are represented in modern pollen assemblages. The relationship between modern pollen assemblages and extant vegetation is affected by various factors, including pollen productivity and dispersal mechanisms (Ma et al., 2008).

Besides the variation in the pollen productivity, dispersal, transport and preservation potential of an individual taxon, which causes a non-linear relationship (Fagerland effect: Fagerland, 1952), climatic factors (e.g. temperature, precipitation/rainfall, relative humidity, air pressure, wind speed, wind direction, human disturbances affecting the source vegetation: Sugita, 2007a, b), a long-term sampling strategy (to control for differences in flowering periodicity), differences in pollen transport distance, soil pH, and the characteristics of the natural pollen-trapping media/substrates (soil surface samples, moss cushions, surface sediment from lakes, especially larger lakes) can affect the pollen rain–vegetation relationship observed in an area. Moss polsters, in fact, best reproduce the overall extant vegetation scenario in any area (Quamar and Bera, 2017) by providing an acidic and (often) waterlogged substrate conducive for good preservation of pollen grains and spores, ultimately representing the local contemporary vegetation faithfully (Wilmshurst and McGlone, 2005). Moss polsters also reflect pollen deposition over periods ranging from a year to fifteen years (Crowder and Cuddy, 1973; Caseldine, 1981; Bradshaw, 1981; Cundill, 1991). Surface soils collect pollen for a few to many years, depending on the sedimentation rate, but the exact period a soil sample covers is difficult to determine. In addition, due to mechanical and chemical corrosion, fragile grains with thin exine may be destroyed in soils (Wilmshurst and McGlone, 2005); that is why many plants are always under-represented or less represented in soil samples. Surface sediments from the central part of larger lakes have a larger pollen source area; their pollen assemblages contain more regional pollen and also are not distorted by the local pollen, consequently enabling better interpretation of regional vegetation (Qin et al., 2015).

CONCLUSIONS

1. The pollen assemblages showed over-representation of *Pinus*.

2. The over-representation of *Pinus*, as well as under-representation and/or absence of other coniferous, broadleaved (regional and/or extra-regional) taxa, together with the record of transported/extra-regional taxa in the pollen assemblages, distorts the real picture of extant vegetation. Ultimately the pollen assemblages do not fully correspond to the extant vegetation.

3. Subtropical deciduous (regional) and shrubby taxa (regional and/or extra-regional) taxa were also under-represented in the pollen assemblages, presenting a false picture of the extant vegetation.

4. Pollen of the terrestrial herbaceous taxa Poaceae, Cerealia, Asteroideae/Tubuliflorae, and Malvaceae, though showing high values, represented only part of the extant ground vegetation.

5. PCA showed that different environmental, altitudinal and local climatic factors control the pollen assemblage, as supported by the significant variance of PCA 1 and 2.

The present study should facilitate the confident use of fossil pollen data for reconstruction of vegetation dynamics and the associated climate in the study area and in similar areas on the Indian subcontinent.

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