*Tropical Ecology* **59**(2): 339–350, 2018
ISSN 0564-3295

www.tropecol.com

# Over-representation of some taxa in surface pollen analysis misleads the interpretation of fossil pollen spectra in terms of extant vegetation

IPSITA ROY[1], PARMINDER S. RANHOTRA[1*], MAYANK SHEKHAR[1], A. BHATTACHARYYA[1], ASHISH K. PAL[1], Y. K. SHARMA[2], S. P. SINGH[3] & UTSA SINGH[1]

*[1]Birbal Sahni Institute of Palaeosciences, Lucknow (UP), India.*
*[2]Department of Botany, University of Lucknow, Lucknow (UP), India.*
*[3]Central Himalayan Environment Association, Nainital, Uttarakhand, India*

**Abstract:** Pollen grains of 21 surface samples (moss cushions) from two forest types, chirpine (*Pinus roxburghii*) dominated mixed forest at Mahidanda (MAD) and oak (*Quercus* spp.) dominated broadleaved forest at Nachiketa (NAT) (Uttarakhand, Western Himalaya) were analyzed for the pollen-vegetation relationship. At both sites samples consisted of pollen of local species (species occurring within the study forest, referred to as autochthonous pollen) and those of extra-local species (occurring outside the study forest, referred to as allochthonous pollen). The study reveals that pine pollen were highly represented at both the sites due to its profuse pollen production and long distance transport by valley winds. However, in the oak forest, there was a good representation of pollen from diverse broadleaved taxa like, *Alnus, Quercus* and *Rhododendron.* It has been noted that the proportion of oak pollen in surface samples is lower in comparison to earlier analysis from the same site. This might indicate the decline of oak and increase of fire resistant pine over time. The presence of pollen of species belonging to timberline and subalpine forests viz., *Abies, Picea, Cedrus* and *Betula* in both sites might indicate the role of valley wind in transporting the pollen grains from far off areas. It shows that the interpretation of past vegetation based on surface pollen analysis should be done with caution, as it may include pollen of species which do not occur there and species with a greater production and dispersal of pollen are over represented.

**Key words:** Conifer and broadleaved forests, modern pollen-vegetation relationship, Uttarkashi, Uttarakhand, Western Himalaya.

**Guest editor:** S.P. Singh

## Introduction

Recent global warming has had much impact on the vegetation pattern in terms of changing limit of the forest zonation in the Himalayas. To understand the temporal vegetation changes pollen studies are quite useful, but for that it is necessary to have modern pollen database. Chirpine (*P. roxburghii*) and banj oak (*Q. leucotrichophora*) are two major forest species of mid-elevational belt in the central Himalayan region. One of the major forestry issues in the region for quite some time has been the changes in the relative importance of these forests forming species (Singh & Singh 1992). Often chirpine is said to be expanding at the expense of banj oak because of frequent fires and lopping of oak branches for various purpose by local people. Modern pollen dispersal studies have been used to interpret changes in vegetation on the basis of fossil pollen spectra and climate (Bush & Rivera 1998; Crowley *et al.* 1994; Herzschuh *et al.* 2010; Li *et al.* 2005; Rull 2006; Yang *et al.* 2016), to find out the

[*]*Corresponding Author*; e-mail: ranhotra.p@gmail.com

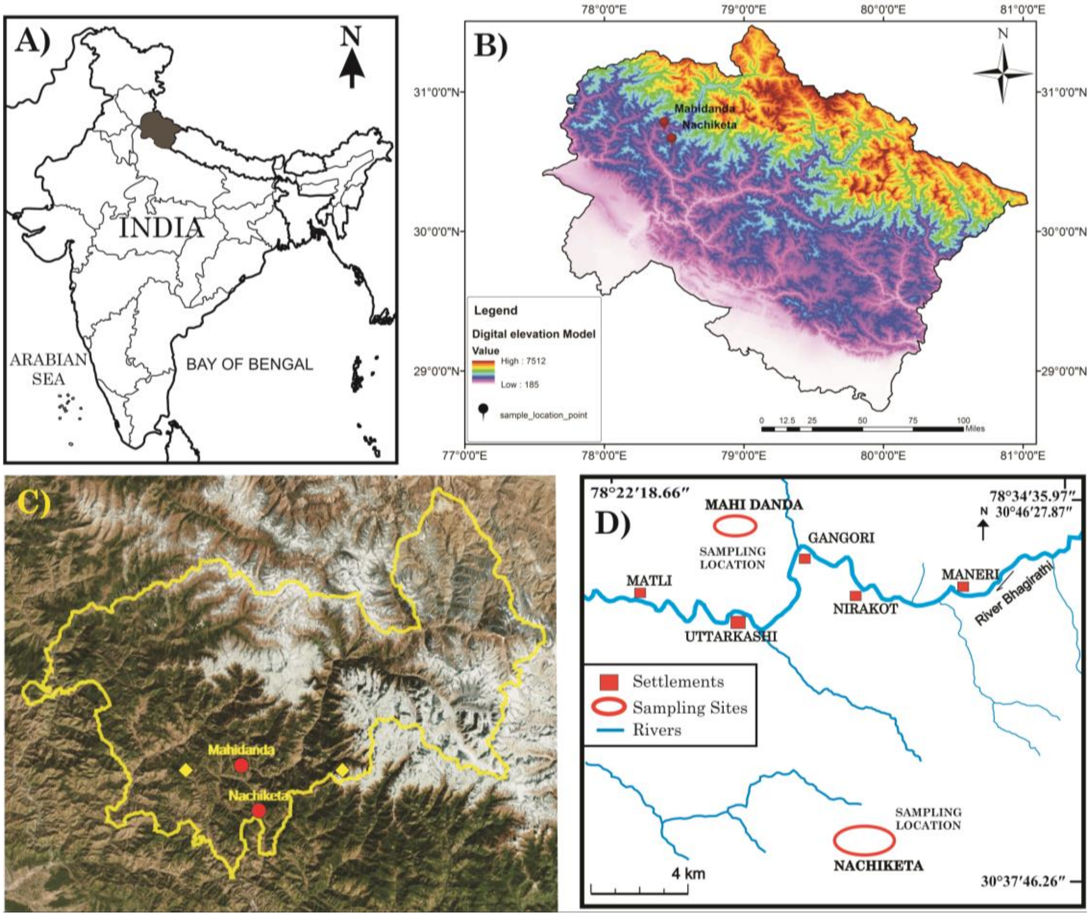


**Fig. 1.** (A) Map of India showing the Uttarakhand province, (B) Digital elevation map (DEM) of Uttarakhand showing the two study area Nachiketa and Mahidanda, (C) DEM of Uttarkashi district with the location of study sites (solid red circles) and the nearest CRU data grid points (yellow diamonds) for climate, (D) Sketch map of the area showing the locations of the two study sites, Uttarkashi town, surrounding settlements and other features.

relationship between pollen source area and plant abundance (Bunting *et al*. 2004; Sugita 1993), and to reconstruct the past land-cover and land-use changes (Gaillard *et al*. 2008, 2010; Mazier *et al*. 2015). There are a good number of modern pollen dispersal studies from different parts of Himalayas: moist, Indian summer monsoon (ISM) dominated eastern Himalayan and adjoining parts (Bera 2000); from the intense ISM - weak Westerly (ISM-W) dominant regions of western Himalaya (Chauhan & Sharma 1993; Gupta & Yadav 1992; Sharma 1985), Pindari Glacier area (Bera *et al*. 2011), Gangotri Glacier valley (Ranhotra & Bhattacharyya 2013), Chaurabari glacial area (Kar *et al*. 2016); Chota Shigri Glacier area (Bera & Gupta 1989), Rohtang area (Bhattacharyya 1989a), Lahaul-Spiti (Bhattacharyya 1989b; Kar *et al*. 2015) of Himachal Pradesh and primarily the Westerly dominant North-west region viz. Kashmir (Vishnu-Mittre 1966; Vishnu-Mittre & Robert 1971; Vishnu-Mittre & Sharma 1966). These studies provide modern pollen analogues from diverse environments of moist to dry vegetation/forest types on regional scale from east to the north-west Himalaya. Strong localized valley winds due to the steep pressure and temperature gradient within the short latitudinal distance play a major role in the transportation and influx of the pollen from one vegetation and climate regime to the other (Oliver & Fairbridge 2005). Thus, the modern pollen datasets from the Himalayan region need much attention for development of a good quality proxy for the reconstruction of past vegetation. For a better understanding of the regional pollen dispersal scenario and its relationship with the existing vegetation and climate, there is a need to

**Table 1.** The temperature (°C) and precipitation (mm) data of Uttarkashi town from the year 2009 to 2016.

| | |
|---|---|
| Mean annual temperature (MAT) | 21.8 |
| Average temperature of summer months (JJAS)* | 27 |
| Average temperature of winter months (DJF)** | 13.5 |
| Mean temperature of hottest month (June) | 30–31 |
| Mean temperature of coldest month (January) | 12 |
| Mean Annual precipitation (MAP) | ~1,500 |
| Precipitation during summer months (JJAS) | ~1,300 |
| Precipitation during winter months (DJF) | ~80 |

*June, July, August, September; **December, January, February
(Source: www.worldweatheronline.com)

**Table 2**. The temperature (°C) and precipitation (mm) data from the Climatic Research Unit (CRU-TS 3.22) of the University of East Anglia for Nachiketa and Mahidanda from the year 1901 to 2014.

| | Nachiketa (NAT) | Mahidanda (MAD) |
|---|---|---|
| Mean Annual Temperature (MAT) | 13.5 | 19.5 |
| Highest temperature (June) | 19.6 | 26.4 |
| Lowest temperature (January) | 5.2 | 10.1 |
| Mean Annual Precipitation (MAP) | ~1,100 | ~900 |

gather more modern pollen datasets on the close spatial and altitudinal scale from the various climatic zones and forest types of the Himalaya.

This paper aims to understand pollen vegetation relationship in chirpine - banj oak forest zone of Bhagirathi valley. It sheds light on the factors which influence pollen assemblages and temporal changes in the importance of chirpine and banj oak. This work will also add to the database in the catalogue of modern pollen-vegetation relationships in the Western Himalaya, which could be used to interpret spatio-temporal fossil pollen spectra in terms of extant vegetation and climate.

## Study sites

For understanding the scenario of pollen diversity in pine - oak zone, two sites, Nachiketa (NAT) and Mahidanda (MAD) near Uttarkashi Township in the Bhagirathi valley of the Garhwal Himalaya were selected (Fig. 1). NAT site (30°38'N; 78°28'E), is presently characterized by a small lake, named Nachiketa Tal, and evergreen oak forest (~2,200–2,500 m asl) consisting of *Quercus floribunda, Q. leucotrichophora, Rhododendron arboreum, Alnus nepalensis, Juglans regia,* and *Carpinus viminea* (Fig. 2). Chirpine (*Pinus roxburghii*), dominates on the comparatively drier open slopes, at relatively lower elevations around the NAT site (Fig. 2d).

The other study site, MAD (30°45'N; 78°25'E) is situated at ~2,000–2,100 m altitudes (Fig. 3). It is dominated by chirpine forest interspersed with trees of bluepine (*P. wallichiana*), *Quercus* and *Alnus*. Moist areas at both the sites support the growth of ferns and members of few Cyperaceae. The surrounding area is anthropogenically affected by the localized cultivation, cattle-grazing, and deforestation at some places.

The last eight years' (2009 to 2016) temperature and precipitation data from Uttarkashi town (source: https://www.worldweatheronline.com/uttarkashi-weather-averages/uttarakhand/in.aspx) provide an idea of the climate of both sites (Table 1). Further, the temperature and precipitation data have also been obtained from the Climatic Research Unit (CRU) of the University of East Anglia [CRU TS v.3.22; (05 × 05 degree) grid; available at http://www.cru.uea.ac.uk/cru/data/hrg/)] for the period 1901–2014 CE (Harris & Jones 2015, Table 2). The variations in the temperature and precipitation amongst the NAT, MAD and Uttarkashi area might be due to differences in their altitudes as well as valley orientation controlling the monsoonal precipitation.

## Method

Amongst the available natural pollen and spore traps viz., moss cushions, surface sediment, spider webs, cracks/hollows in tree stem and boulders etc., the moss cushions are the best natural pollen traps for the modern pollen dispersal studies. In total, 21 samples of moss cushions growing on the boulders were collected from the NAT and MAD localities and analyzed for the pollen dispersal. Of these 16 samples were from the NAT (Table 3) site (from ~2,200 to 2,500 m altitudes) (Fig. 2a,b) and five from MAD site (from 2,030 to 2,070 m altitude) (Table 4).

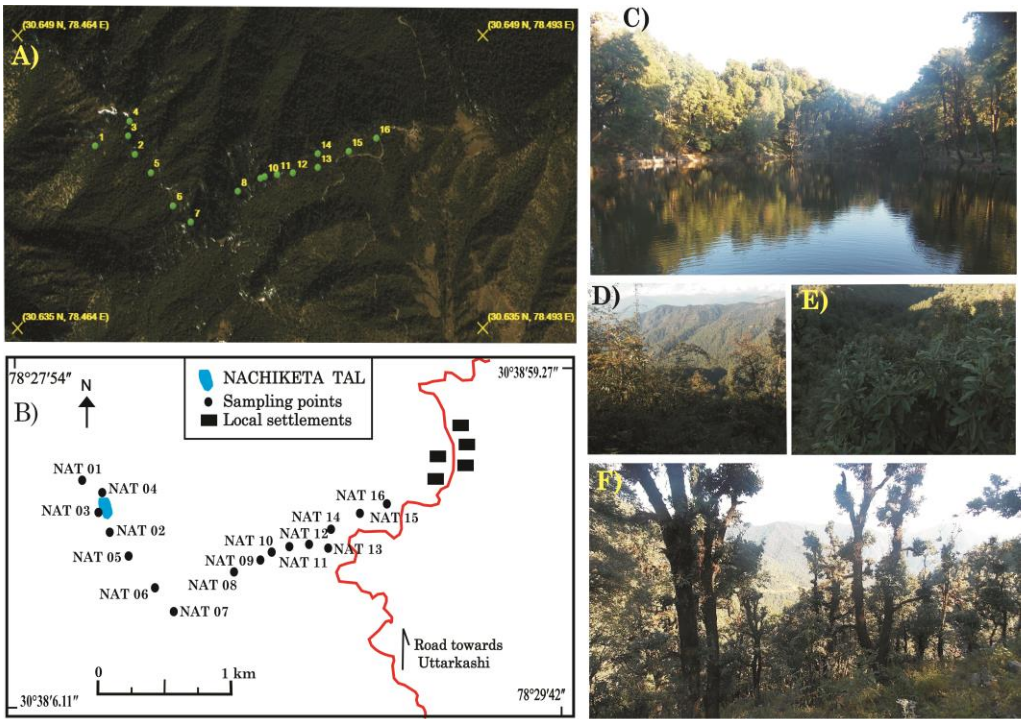


**Fig. 2.** (A) Google earth view of Nachiketa area showing the sampling points, (B) Sketch of Nachiketa area showing the location of Nachiketa Tal, sampling points and surrounding settlements, (C) View of Nachiketa Tal surrounded by broadleaved vegetation, (D) View of distant slopes with the pine growth, the source of *Pinus* pollen to the source area, (E-F) View of forest with growth of *Rhododendron* (E) and *Quercus* (F).

**Table 3.** Details of the surface samples collected from the Nachiketa (NAT) area near Uttarkashi, Western Himalaya.

| Code | Lat. (N) | Long. (E) | Altitude (m asl) |
|---|---|---|---|
| NAT 06 | 30°38' 27.0" | 78° 28' 25.4" | 2492 |
| NAT 07 | 30°38' 24.1" | 78° 28' 29.4" | 2478 |
| NAT 05 | 30°38' 32.1" | 78° 28' 20.4" | 2477 |
| NAT 01 | 30°38' 37.3" | 78° 28' 07.9" | 2444 |
| NAT 04 | 30°38' 41.6" | 78° 28' 15.7" | 2442 |
| NAT 02 | 30°38' 35.9" | 78° 28' 16.8" | 2440 |
| NAT 03 | 30°38' 39.0" | 78° 28' 15.3" | 2439 |
| NAT 08 | 30°38' 29.5" | 78° 28' 39.9" | 2420 |
| NAT 10 | 30°38' 32.0" | 78° 28' 45.9" | 2419 |
| NAT 09 | 30°38' 31.8" | 78° 28' 45.0" | 2416 |
| NAT 11 | 30°38' 32.4" | 78° 28' 48.7" | 2388 |
| NAT 12 | 30°38' 24.0" | 78° 28' 48.0" | 2385 |
| NAT 16 | 30°38' 40.7" | 78° 29' 44.5" | 2306 |
| NAT 15 | 30°38' 37.8" | 78° 29' 10.5" | 2295 |
| NAT 14 | 30°38' 36.0" | 78° 28' 57.8" | 2294 |
| NAT 13 | 30°38' 33.6" | 78° 28' 57.8" | 2255 |

**Table 4.** Details of the surface samples collected from the Mahidanda (MAD) area near Uttarkashi, Western Himalaya.

| Code | Lat. (N) | Long. (E) | Altitude (m asl) |
|---|---|---|---|
| MAD 01 | 30°45' 37.37" | 78° 25' 35.08" | 2070 |
| MAD 02 | 30°45' 36.22" | 78° 25' 36.15" | 2060 |
| MAD 03 | 30°45' 35.12" | 78° 25' 37.12" | 2050 |
| MAD 04 | 30°45' 36.2" | 78° 25' 37.92" | 2040 |
| MAD 05 | 30°45' 38.22" | 78° 25' 38.45" | 2034 |

Forests of NAT site are dominated by broadleaved forest with *Quercus leucotricophora* and *Q. floribunda* as main constituents mixed with *Rhododendron arboreum, Alnus, Juglans, Corylus, Carpinus* etc. At MAD site, *Pinus roxburghii* (Conifer) grows on valley slopes with few broadleaved taxa.

For the extraction of pollen and spores the moss samples were processed (acid-base treatment) as per the standard technique (Erdtman 1943). 10 g dry mass of the moss cushions was treated with 10% potassium hydroxide solution to remove the extraneous organic matter, followed by the digestion of

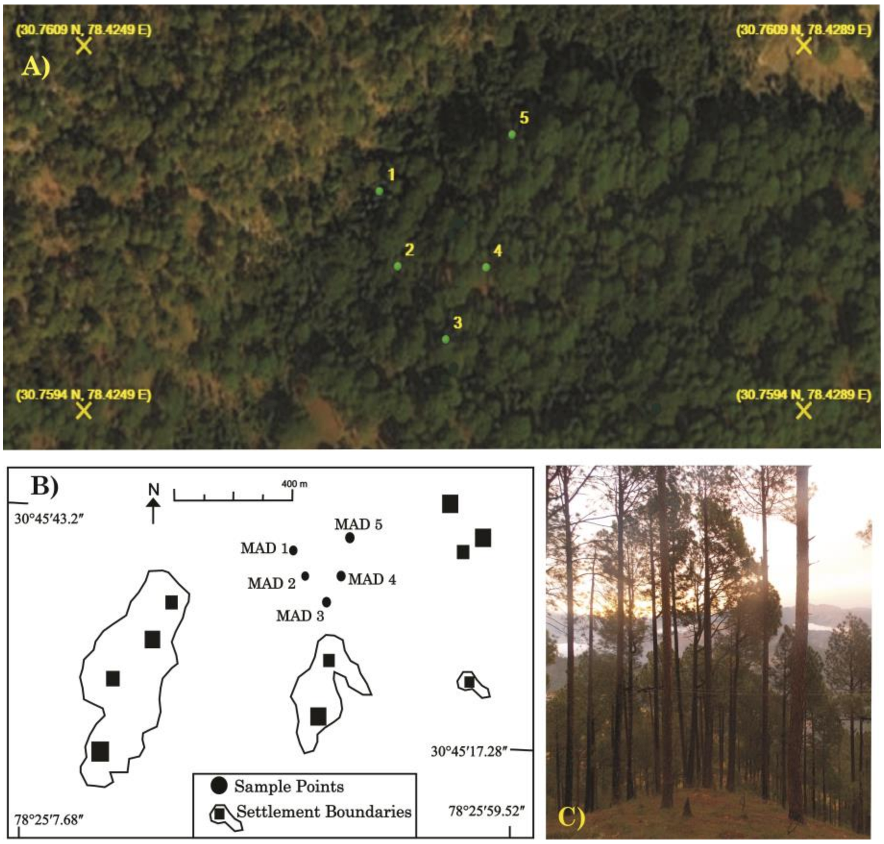


**Fig. 3.** (A) Google earth view of Mahidanda forest showing the location of sampling points, (B) Sketch map of Mahidanda showing the location of sampling points and surrounding settlements, (C) View of forest slopes with the growth of *Pinus roxburghii*.

silica using 40% hydrofluoric acid. The cellulose content was removed by acetolysis process (treatment with acetic anhydride and conc. sulphuric acid in 9:1 ratio). The samples were finally washed four times with distilled water to make clear of acid content by centrifugation process (2000 rpm for 10 minutes). The extracted samples were stored in glycerol and phenol to prevent them from drying and inhibit the growth of microbes.

The macerals were studied with light compound microscope (Leica DM 2500) under 20× and 40× magnification for the identification, counting and micrography of the recovered pollen and spores. For pollen and spores identification, the available pollen keys (Faegri & Iverson 1989; Gupta & Sharma 1986; Moore *et al.* 1991) and pollen reference slides available at Birbal Sahni Institute of Palaeosciences, Lucknow, were used. Between 350 and 800 pollen and spores per sample were counted, and they were taken as Total Pollen Counts (TPC). Pollen diagrams (Figs. 4, 5) representing the pollen frequency spectra of the samples were prepared using Tilia software version TILIA 1.7 (Grimm 2011). Two pollen diagrams were plotted; the first one represented the pollen frequency of individual taxa for each sample, arranged according to their altitudinal distribution (Fig. 4). The calculation of pollen frequency of each pollen taxon is based on the Pollen Sum (PS) which excludes the count of fern spores (monoletes and triletes) from the TPC. This was done to avoid the under representation of ground or herbaceous pollen taxa in the frequency calculation, as some samples collected near the ferns represent very high counts of the fern spores which may overshadow the actual representation of other non-arboreal taxa in the frequency. The frequency of fern spores, shown in the pollen diagrams, has been calculated on the TPC. In the altitudinal pollen diagram (Fig. 4), the variations in pollen frequency throughout the diagram were demarcated as per altitude for which determination was done by cluster analysis using constrained incremental sum of squares (CONISS) method available in Tilia 1.7 software (Grimm 1987, 2011). For assessing the ecological similarities of the


**Fig. 4.** Modern altitudinal pollen spectra. Each sample pollen spectrum is arranged according to the altitude. NAT represents samples of Nachiketa and MAD represents samples of Mahidanda.

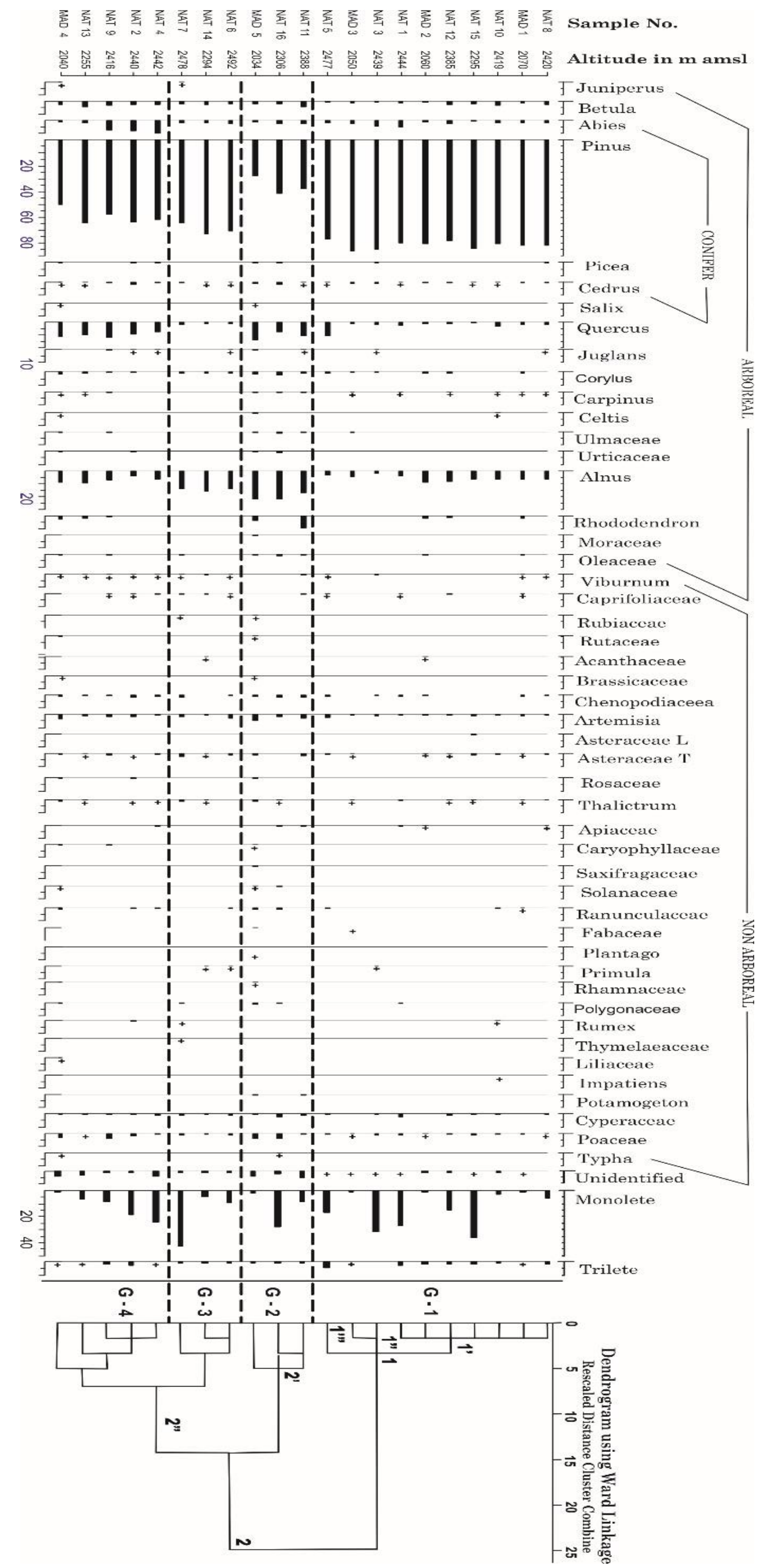

**Fig. 5.** Modern hierarchical pollen diagram with sample pollen spectra grouped according to the similarity in the pollen assemblage irrespective of the altitude.

sampling locations within the altitudinal range, the samples were analyzed for their similarity index through hierarchical relationship using the SPSS 21 software. This analysis also excludes the fern spore (monoletes and triletes) counts as explained above. The second pollen diagram (Fig. 5) thus shows the grouping of the samples in which the pollen spectra of each sample are arranged according to their similarity index irrespective of the altitude and site. In both pollen diagrams, the taxa were arranged as arboreal and non-arboreal from left to right corner and the frequency of taxon less than 1% was marked by '+' sign.

To find any change in the pollen spectra since last several years due to the increased anthropogenic impact on the forests, the pollen frequency of an exploratory earlier pollen vegetation study (Gupta & Sharma 1993) from this region was compared with this study. This comparison thus assessed the changes of 2.5 decades.

## Results

The surface samples yielded a good number of pollen grains of arboreal and non-arboreal taxa in which former were distinctly dominant over the latter. In both sites, some reported pollen taxa are transported from the high altitude areas including treelines viz., *Abies, Cedrus* and *Betula*. They could be referred to as external or allochthonous pollen, in contrast to pollen of species of the two study sites, which could be called internal or autochthonous pollen. Both the pollen spectra (Figs. 4, 5) prepared, thus helped to measure the pollen influx of internal and external plants, for developing the pollen-vegetation relationship and for understanding the comprehensive ecological scenario.

### *Pollen assemblage zones*

*I. Altitudinal zones:*

Variations in the frequency distribution of pollen and spores have been noticed throughout the altitudinal range, based on which the pollen spectra have been divided into three Altitudinal Zones (AZ-1 to AZ-3) using the constrained cluster analysis pollen diagram (Fig. 4).

**AZ-1 –** represents the surface samples near the Nachiketa Tal (NAT) within the altitudinal range of 2,492–2,416 m asl. Amongst dominant arboreal taxa, *Pinus* had the highest frequency (58–85%). The extra-local species pollen recorded were *Abies* (~2–10%), *Cedrus* (1–2%) and *Picea* (rare). The broadleaved taxa observed in pollen samples were *Alnus* (1.8–14.4%) and *Quercus* (1.5–12%). Pollen of *Betula*, though occurring in treeline areas were also present (0.7–3.1%). The other broadleaved taxa such as *Corylus, Carpinus, Juglans, Ulmus,* and *Celtis* recorded infrequently. *Rhododendron* pollen were present in only one sample at the bottom of this zone. The pollen of non-arboreal taxa were less common, but fern spores with monoletes (7–43%) and triletes (~5%) were common. Pollen of Chenopodiaceae (1.5%), *Artemisia* (0.3–2.7%) and Asteraceae-Tubuliflorae (T) type (2.7%) were also encountered in samples. From moist areas, pollen of Cyperaceae (0.2–2.3%) were present throughout, with sporadic presence of Ranunculaceae, *Thalictrum*, Polygonaceae, etc. Poaceae (0.3–4.1%) also had sporadic-to-fair representation in this zone.

**AZ-2 –** In the samples of this altitudinal zone (2,388–2,070 m) the frequency of pine pollen (40–84%) was as high as in AZ-1. Compared to AZ-1, *Abies* (0.4–3%) became sparser and *Picea* became negligible. Among broadleaved species *Alnus* (6–22.4%) showed a noticeable increase, *Quercus* (1–12%) and *Betula* (2.2–4.7%) did not show any noticeable change, *Juglans* became almost absent, and *Rhododendron* (Ericaceae) was more prominent (10.1%) in one sample. Chenopodiaceae, Asteraceae, and *Artemisia* also remained almost unchanged compared to AZ-1. Monolete spores (4.3–35.9%) were frequent while the frequency of trilete spores was low ~0.3–1.8%. Pollen of Cyperaceae (0.2–2.5%), Poaceae (0.4–4%) and other species of ground vegetation were infrequent.

**AZ-3 –** In samples from the altitudes 2,060–2,030 m which were from the chirpine forest of Mahidanda (MAD) site, *Pinus* (30–87%) was clearly dominant, while treeline species *Abies* and *Betula* declined further and became rare. *Quercus* (1.1–14%) was prominent only in the samples collected from valley depressions with comparatively lower altitudes. *Alnus* (4.8–23.1%) occurred almost in same frequencies as it did in AZ-2 and *Rhododendron* (2–4%) appeared in all samples but in lower frequencies. Fern spores (Monolete 1–2.2% and Trilete ~1.6%) and pollen of Poaceae (0.2–4%) and Cyperaceae were infrequent. Pollen of Chenopodiaceae (1.4%), *Artemisia* (0.6–4.7%), Brassicaceae (~0.2%) and Asteraceae-T (0.2–1.7%) too poorly represented.

*II.Ecological Groups:*

The ecological similarities between the samples of the two study sites have been analyzed through the hierarchical analysis. It groups the ecologically

**Table 5.** The pollen percentage variability of few important taxa in the hierarchical pollen diagram.

| Groups | G-1 | G-2 | G-3 | G-4 |
|---|---|---|---|---|
| *Pinus* | 81 | 36 | 70 | 60 |
| *Abies* | 3 | 3 | 3 | 6 |
| *Quercus* | 3 | 11 | 1 | 10 |
| *Alnus* | 2–8 | 20 | 14 | 10 |
| *Betula* | 2 | 2 | 2 | 3 |
| *Rhododendron* | 1–2 | <1 | nil | 2–3 |
| *Artemisia* | 0.8 | 3 | 1.6 | 1.6 |
| Chenopodiaceae | <0.5 | 1 | 0.6 | 0.7 |
| Asteraceae | 1.5 | 1 | 1 | 1 |
| Cyperaceae | 1–2 | 1–2 | 0.5 | 0.6 |
| Poacaeae | 2–3 | 3–4 | 1–2 | 3 |
| Apiaceae | <0.5 | 0.2 | Nil | <0.5 |
| Polygonaceae | <0.5 | 0.5 | <0.5 | <0.5 |
| Ranunculaceae | <0.5 | 0.9 | <0.5 | <0.5 |

similar samples irrespective of the altitudes. In the hierarchical analysis samples are divided into four Groups (G-1 to G-4). In the G-1, samples from the altitudinal gradient of ~2,477 to 2,034 m asl shows abundance of *Pinus* (~81%) which contrasts with the low presence of *Quercus* (3%) and *Alnus* (2–8%). The G-2 includes samples taken from altitudes of 2,388, 2,031 and 2,306 m asl. This group contrasts with minimum pollen frequency of *Pinus* (36%). Among broadleaved taxa, *Alnus* (20.17%) is dominant followed by *Quercus* (10.5%). G-3 samples from the altitudes of 2,294, 2,478 and 2,492 m asl exhibits high values of *Pinus* (70%) followed by the *Alnus* (14%). *Quercus* (1.1%) is sharply less in frequency. The G-4 from the altitudes 2,033–2,442 m asl shows *Pinus* ~60% and *Quercus* ~10%. *Abies* (6%) and *Betula* (3.06%) have maximum values in this group as compared to the above groups. Details of taxa represented in each group are shown in Fig. 5 and Table 5.

## Discussion

### *Pollen deposition scenario*

An overview of pollen spectra (Fig. 4) reveals that pollen assemblages could be classified as local (autochthonous) arboreal, local non-arboreal and external (allochthonous). Among local arboreal, *Pinus* pollen were generally dominant while *Alnus* and *Quercus* were prominent, but poor second/third. Allochthonous pollen grains were of *Abies, Betula* and *Cedrus,* growing in high elevation areas including treelines. The valley winds are likely to be a major transporting agent of pollen. Relatively high frequency of *Abies* pollen in the samples of zone AZ-1 is likely to be due to the close proximity to the *Abies* forests.

Grouping of the samples (Fig. 5) based on correspondence in their pollen assemblages provides a comprehensive scenario of the ecological similarities amongst the samples irrespective of altitude. The pollen variations can also be related with the vegetation distribution at these altitudes. Group 1, clustering 10 samples from the two sites (NAT and MAD) shows dominance of *Pinus* pollen. High pine pollen frequency in samples collected from MAD site dominated by pine trees is expected, whereas, its high representation in some NAT samples, despite its low presence in vegetation indicates their transportation by wind from external sources. Thus, chirpine's presence could be overestimated by pollen studies in certain situations, because of its high pollen production and an efficient wind dispersal (Vishnu-Mittre & Robert 1971; Vishnu-Mittre & Sharma 1966). The Group 2 samples with high frequencies of *Alnus* and *Quercus* fairly represented the broadleaved forest, as the samples of this group are collected from sites dominated by broadleaved taxa growing along the moist depressions. The Group 3 was again dominated by the pollen of *Pinus* followed by those of *Alnus,* indicating the close proximity of *Alnus* and also an efficient dispersal of *Pinus* pollen through wind. The Group 4, apart from the dominance of *Pinus* pollen, also had *Quercus* and *Alnus* pollen in good numbers.

The ground or non-arboreal taxa are less represented in pollen samples and cannot provide an accurate picture of their presence or abundance. However, good amount of fern spores in several samples could be linked well to the abundance of ferns in moist patches.

Previous studies from several sites above the growth limit of *Pinus* in the higher Himalayas (Bera *et al.* 2011; Kar *et al.* 2015, 2016; Ranhotra & Bhattacharyya 2013; Quamar & Srivastava 2013), also reported *Pinus* pollen in good frequencies. From the Bara Shigri glacial samples Bhattacharyya (1989b) reported high amount of *Pinus* pollen much away from the source of provenance. The valley wind dynamics (Egger *et al.* 2002; Maharjan & Regmi 2015; Schmidli & Rotunno 2012) and topography of the valley could play an important role in pollen transport (Chauhan & Sharma 1993; Sharma 1985; Quamar *et al.* 2017). In the present study, only a few samples collected from the oak forest showed a good pollen representation of *Quercus* and *Alnus* (Fig. 5). However, in some such samples *Alnus* pollen were relatively over represented, possibly because of their greater wind dispersal than *Quercus* pollen. *Rhododendron* had good pollen frequencies in few samples collected near its trees and sporadic to absent in the samples away from them. Poor pollen production and entomophilous dispersal nature of *Rhododendron* pollen (Hirao *et al*. 2006; Orwa *et al*. 2009) might explain its under representation.

We have compared our data to that of an earlier study conducted some 25 years ago from the Nachiketa site using moss cushions (Gupta & Sharma 1993). *Pinus* is seen to increase from 20–40% in 1993 to 30–80% in the present study that is its pollen frequency has almost doubled in about two and one-half decades. On the other hand, banj oak pollen has decreased to 12% in the present study from the earlier 15–45%. Increase in chirpine at the expense of banj oak is a common feature in middle ranges of Central Himalayas because of the frequent man-made fires and lopping of banj oak branches for fodder and firewood (Singh & Singh 1992). Chirpine being fire tolerant takes advantage of fire. The depletion of *Quercus* spp. has also been discussed by others (Khali & Bhatt 2014; Singh & Rawat 2012) as the wood of oak species is used as firewood, leaves as fodder for cattle and forest floor litter as fertilizer.

## Conclusion

Surface pollen studies could be used to monitor changes in species composition of forests under the influence of human disturbance and climate change. However, corrective measures would be required because species like chirpine are likely to be over represented in pollen samples because of relatively greater pollen production and an effective pollen transport by wind. In mountains, species of different climatic conditions can occur within a small area because of rapid elevational difference. Therefore, a pollen assemblage may include species which do not occur together. However, comparison between different datasets of different time-span on a site can effectively document the changes in species composition.

## Acknowledgements

Authors are thankful to the Director, BSIP, Lucknow, for providing the administrative and infrastructure support to carry out this research work and also for permission to publish the results (BSIP/40/2017-18). We are grateful to the Forest Department officials - PCCF, Uttarakhand Forest Department, DFO-Uttarkashi, Mrs. Meenakshi Joshi (IFS) and other staff members for their kind permission, support and help during the field work for the collection of samples. One of the authors, Ipsita Roy gratefully acknowledges the DST-INSPIRE fellowship (IF150998) for the financial assistance during the tenure of this work.

## References

Bera, S. K. & H. P. Gupta. 1989. Correlation between pollen spectra and vegetation of Chhota Shigri Glacier in Himachal Pradesh, India. *Palaeobotanist* **38:** 404–410.

Bera, S. K. 2000. Modern pollen deposition in Mikir Hills, Assam. *Palaeobotanist* **49**: 325–328.

Bera, S. K., S. N. Ali, R. Bali & K. K. Agarwal. 2011. Impact of pollen rain from the vegetation of alpine-subalpine belt as a reliable measure for palaeo-climatic interpretation: a case study from Pindari Glacier, Kumaun Himalaya, India. *International Journal of Earth Sciences and Engineering* **4**: 1010–1019.

Bhattacharyya, A. 1989a. Modern pollen spectra from Rohtang range, Himachal Pradesh. *Journal of Palynology* **25**: 121–131.

Bhattacharyya, A. 1989b. Modern pollen spectra of BadaShigri Glacier, Greater Himalayan Range, Lahaul-Spiti District, Himachal Pradesh. *Science Culture* **55**: 246–248.

Bunting, M. J., M. J. Gaillard, S. Sugita, R. Middleton & A. Broström. 2004. Vegetation structure and pollen source area. *The Holocene* **14**: 651–660.

Bush, M. & R. Rivera. 1998. Pollen dispersal and representation in a neotropical rain forest. *Global Ecology and Biogeography* **7**: 379–392.

Chauhan, M. S. & C. Sharma. 1993. Modern pollen deposition in sub-tropical zone of Kumaon Himalaya, India. *Geophytology* **23**: 147–153.

Crowley, G. M., J. Grindrod & A. P. Kershaw. 1994. Modern pollen deposition in the tropical lowlands of northeast Queensland, Australia. *Review of Palaeobotany and Palynology* **83**: 299–327.

Egger, J., S. Bajrachaya, R. Heinrich, P. Kolb, S. Lämmlein, M. Mech, J. Reuder, W. Schäper, P. Shakya, J. Schween & H. Wendt. 2002. Diurnal winds in the Himalayan Kali Gandaki valley. Part III: Remotely piloted aircraft soundings. *Monthly Weather Review* **130**: 2042–2058.

Erdtman, G. l943. *An Introduction to Pollen Analysis*. Waltham, Massachusetts.

Faegri, K. & J. Iverson. 1989. *Text Book of Pollen Analysis*. John Wiley & Sons Ltd., New York.

Gaillard, M. J., S. Sugita, J. Bunting, J. Dearing & F. Bittmann. 2008. Human impact on terrestrial ecosystems, pollen calibration and quantitative reconstruction of past land-cover. *Vegetation History and Archaeobotany* **17**: 415–418.

Gaillard, M. J., S. Sugita, F. Mazier, A. K. Trondman, A. Brostrom, T. Hickler, J. O. Kaplan, E. Kjellström, U. Kokfel, P. Kunes & C. Lemmen. 2010. Holocene land-cover reconstructions for studies on land cover-climate feedbacks. *Climate of the Past* **6**: 483–499.

Grimm, E. C. 1987. CONISS, A FORTRAN 77 program for stratigraphically constraint cluster analysis by the method of incremental sum of squares. *Computers and Geosciences* **13**: 13–35.

Grimm, E. C. 2011. *TILIA 1.7. 16.* Illinois State Museum. Research and Collection Center. Springfield, USA.

Gupta, A. & C. Sharma. 1993. Recent pollen spectra from Nachiketa Tal, Garhwal Himalaya. *Geophytology* **23**: 155–157.

Gupta, H. P. & C. Sharma. 1986. *Pollen Flora of North-west Himalaya.* Indian Association of Palyno-stratigraphers, Lucknow.

Gupta, H. P. & R. R. Yadav. 1992. Interplay between pollen rain and vegetation of Tarai-Bhabar in Kumaon Division, UP, India. *Geophytology* **21**: 183–189.

Harris, I. C. & P. D. Jones. 2015. CRU TS3.23: Climatic Research Unit (CRU) Time-series (ts) version 3.23 of high resolution gridded data of month-by-month variation in climate (Jan. 1901–Dec. 2014). *Centre for Environmental Data Analysis, University of East Anglia Climatic Research Unit*; doi:10.5285/4c7fdfa6-f176-4c58-acee-683d5e9d2ed5.

Herzschuh, U., H. J. B. Birks, S. Mischke, C. Zhang & J. Böhner. 2010. A modern pollen–climate calibration set based on lake sediments from the Tibetan Plateau and its application to a Late Quaternary pollen record from the Qilian Mountains. *Journal of Biogeography* **37**: 752–766.

Hirao, A. S., Y. Kameyama, M. Ohara, Y. Isagi & G. Kudo. 2006. Seasonal changes in pollinator activity influence pollen dispersal and seed production of the alpine shrub *Rhododendron aureum* (Ericaceae). *Molecular Ecology* **15**: 1165–1173.

Kar, R., R. Bajpai & K. Mishra. 2016. Modern pollen rain in Kedarnath: implications for past vegetation and climate.*Current Science* **110**: 296–298.

Kar, R., R. Bajpai & A. D. Singh. 2015. Modern pollen assemblages from Hamtah and Chhatru glaciers, Lahaul-Spiti, India: Implications for pollen-vegetation relationship in an alpine arid region of western Himalaya. *Quaternary International* **371**: 102–110.

Khali, M. & V. P. Bhatt. 2014. Community structure of montane forest along the altitudinal gradient in Garhwal Himalaya, India. *Journal of Ecology and the Natural Environment* **6**: 205–214.

Li, Y. C., Q. H. Xu, X. L. Yang, H. Chen & X. M. Lu. 2005. Pollen-vegetation relationship and pollen preservation on the Northeastern Qinghai-Tibetan Plateau. *Grana* **44**: 160–171.

Maharjan, S. & R. P. Regmi. 2015. Diurnal wind Characteristics in and around Chisapani confluence of Karnali river in Mid-Western Nepal. *Journal of Institute of Science and Technology* **20**: 1–5.

Mazier, F., A. Brostrom, P. Bragée, D. Fredh, L. Stenberg, G. Thiere, S. Sugita & D. Hammarlund. 2015. Two hundred years of land-use change in the South Swedish Uplands: comparison of historical map-based estimates with a pollen-based reconstruction using the landscape reconstruction algorithm. *Vegetation History and Archaeobotany* **24**: 1–16.

Moore, P. D., J. A. Webb & M. E. Collison. 1991. *Pollen Analysis*. Blackwell Scientific Publications, Oxford, UK.

Oliver, J. E. & R. W. Fairbridge. 2005. Mountain and Valley winds. *In:* J. E. Oliver (ed.) *Encyclopedia of World Climatology*. Springer, Dordrecht.

Orwa, C., A. Mutua, R. Kindt, R. Jamnadass & A. Simons. 2009. Agroforestree Database: a tree species reference and selection guide version 4.0. World Agroforestry Centre ICRAF, Nairobi, KE. (http://www.worldagroforestry.org/sites/treedbs/tree databases.asp).

Quamar, M. F. & J. Srivastava. 2013. Modern pollen rain in relation to vegetation in Jammu, Jammu and Kashmir, India. *Journal of Palynology* **49**: 19–30.

Quamar, M. F., S. N. Ali, S. K. Pandita & Y. Singh. 2017. Modern pollen rain from Udhampur (Jammu and Kashmir), India: insights into pollen production, dispersal, transport and preservation. *Palynology* **42**: 1–11.

Ranhotra, P. S. & A. Bhattacharyya. 2013. Modern vegetational distribution and pollen dispersal study within Gangotri glacier valley, Garhwal Himalaya. *Journal Geological Society of India* **82**: 133–142.

Rull, V. 2006. A high mountain pollen-altitude calibration set for palaeoclimatic use in the tropical Andes. *The Holocene* **16**: 105–117.

Schmidli, J. & R. Rotunno. 2012. Influence of the valley surroundings on valley wind dynamics. *Journal of the Atmospheric Sciences* **69**: 561–577.

Sharma, C. 1985. Recent pollen spectra from Garhwal Himalaya. *Geophytology* **13**: 87–97.

Singh, G. & G. S. Rawat. 2012. Depletion of oak (*Quercus* spp.) forests in the western Himalaya: Grazing, fuelwood and fodder collection. pp. 29–42. *In:* C. A. Okia (ed.) *Global Perspectives on Sustainable Forest Management.* In Tech, Rijeka, Croatia.

Singh, J. S. & S. P. Singh. 1992. *Forest of Himalaya*. Gyanodaya Prakashan, Nainital, India.

Sugita, S. 1993. A model of pollen source area for an entire lake surface. *Quaternary Research* **39**: 239–244.

Vishnu-Mittre & D. R. Robert. 1971. Studies of pollen content of moss cushions in relation to forest composition in the Kashmir valley. *Geophytology* **1**: 84–96.

Vishnu-Mittre & D. B. Sharma. 1966. Studies of post glacial vegetation history from Kashmir Valley-I, Haigatu lake. *Palaeobotanist* **15**: 185–212.

Vishnu-Mittre. 1966. Some aspects of concerning pollen analytical investigations in the Kashmir valley. *Palaeobotanist* **15**: 157–175.

Yang, Z., Y. Zhang, H. Ren, S. Yan, Z. Kong, K. Ma & J. Ni. 2016. Altitudinal changes of surface pollen and vegetation on the north slope of the middle Tianshan Mountains, China. *Journal of Arid Land* **8**: 799–810.

(Received on 04.07.2018 and accepted after revisions, on 04.08.2018)