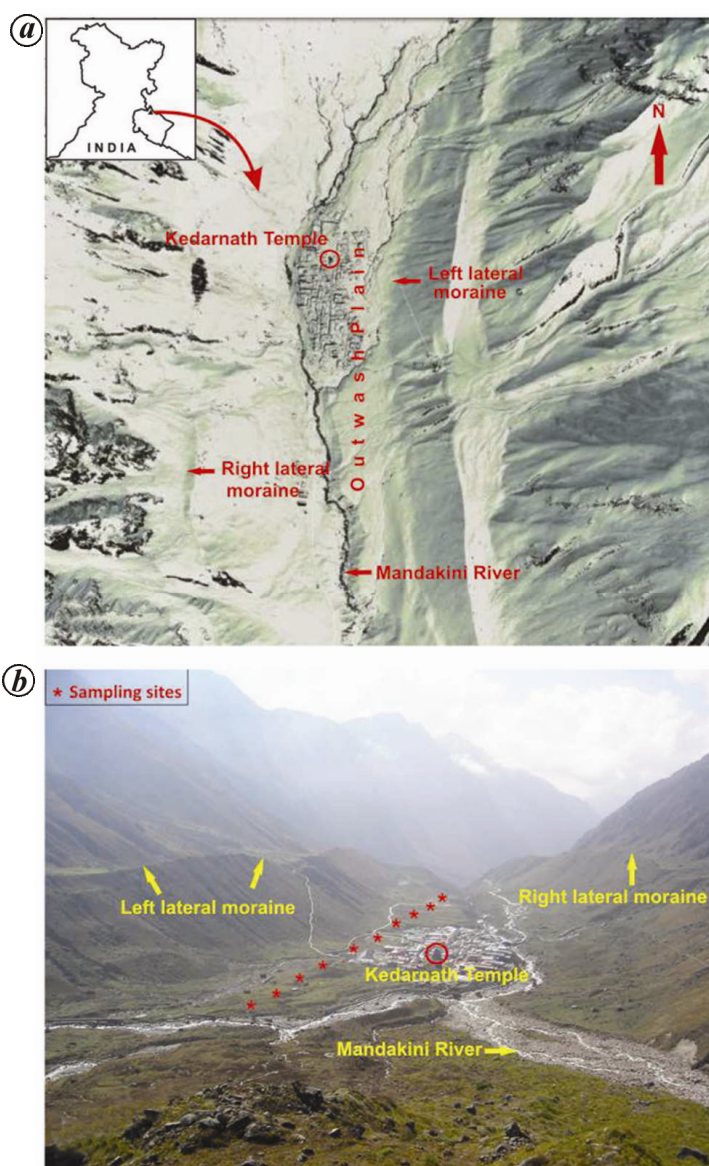


## Modern pollen rain in Kedarnath: implications for past vegetation and climate

Palynology, the study of pollen and spores, is widely recognized as an indispensable tool for climatic reconstructions, especially for the Quaternary Period (~2.6 million years). This is so because pollen and spores recovered from sediments deposited during this period can be easily related to different living plant groups, and therefore reflect the environmental and climatic conditions prevalent then. Moreover, pollen-spores are produced in abundance, and due to their minute size and chemically resistant nature, are readily preserved in the sedimentary records. Even a small amount of sediment can yield a wide variety of pollen-spores and can provide an optimal representation of vegetation growing in a particular region during a particular point of time<sup>1</sup>. Changes in the vegetational pattern in response to climatic fluctuations are thus well preserved in the pollen record of sediments<sup>2</sup>. However, for the correct interpretation of fossil pollen assemblages, a calibration set of modern pollen deposition (pollen rain) is required. The pollen rain records the dispersal and deposition of pollen from the surrounding vegetation on the exposed surfaces. Over the years, these surface pollen records have been successfully used to interpret past pollen assemblages with reference to vegetational shifts and climatic changes<sup>3–6</sup>, based on the principle that the relationship between the modern pollen assemblages and the extant vegetation from which they are derived, can be applied in the past as well. In India, good records of pollen rain are available from South India<sup>7</sup>, coastal regions<sup>8</sup>, Central India<sup>9</sup>, western desert<sup>10</sup>, Gangetic plains<sup>11</sup>, North East India<sup>12</sup>, and Outer and Lesser Himalayas<sup>13–15</sup> which have helped in the interpretation of past vegetation and climate in the respective areas. However, useful data from the higher altitudes, especially from the glaciated terrain are somewhat sketchy<sup>16–19</sup>. The present correspondence is part of an ongoing project aimed at deciphering vegetation and climate change in the Kedarnath region of NW Himalaya, Uttarakhand. The study is based on palynological analysis of surface sediments from the outwash plain of Chorabari Glacier, where the highly revered

Kedarnath shrine and a small township are located (Figure 1a). The study was undertaken to understand the relationship between modern pollen assemblages and the contemporary vegetation patterns, and would be useful for interpreting the fossil pollen records from older sediments in the Kedarnath area, in terms of the past vegetation succession and corresponding climatic fluctuations in the region.

The Chorabari Glacier is a valley glacier in the Garhwal Himalaya region (Uttarakhand), located at the western extremity of the central Himalaya between 30°44'50"–30°48'30"N and 79°1'16"–79°6'20"E. This glacier is the source of the Mandakini River, which eventually joins the Alaknanda River at Rudraprayag. The glacier during its retreat has carved out a typical U-shaped glacial valley. This valley encompasses the



**Figure 1.** a, Google image showing the area around Kedarnath. b, Field photograph of the area showing sampling sites in the outwash plain.

outwash plain of the Chorabari Glacier, which is well-developed and is about 1 km long and 0.5 km wide. The glacier is presently in a state of retreat and has shrunk both horizontally and vertically. Four episodes of recession can be traced by the marks of lateral moraines on the valley slopes<sup>20</sup>.

The climate of the region, owing to its high altitude, is generally temperate. The region is under the influence of the southwest summer monsoon and most of the rainfall is received during the months of June to September; with July and August receiving heavy rains. However, because of the local topographic setting, it invariably rains everyday during summer. During winter, cold waves in the form of western disturbances, accompanied by heavy snowfall, cause the temperature to fall appreciably. Snow accumulation in the valleys is considerable, which starts melting only after mid-May.

Ten samples (surface soils) were collected in a linear transect across the outwash plain of the Chorabari Glacier (Figure 1 b). Surface samples were collected from the alpine meadow using hand-pick and spatula. For the release of palynomorphs, the samples were treated with 10% aqueous K-OH solution to deflocculate the pollen/spores from the sediments. The samples were then treated with 40% HF solution to dissolve the silicates in the sediments. Thereafter, the standard technique of acetolysis using acetolysing mixture (9 : 1 of acetic anhydride and concentrated sulphuric acid respectively) was employed<sup>21</sup>.

The samples for microscopic examination were prepared in 50% glycerin solution. Pollen counting was carried out using an Olympus CX-41 light microscope under 40× magnification. Normally more than 400 pollen grains per sample were counted, which was taken as the total pollen count (TPC).

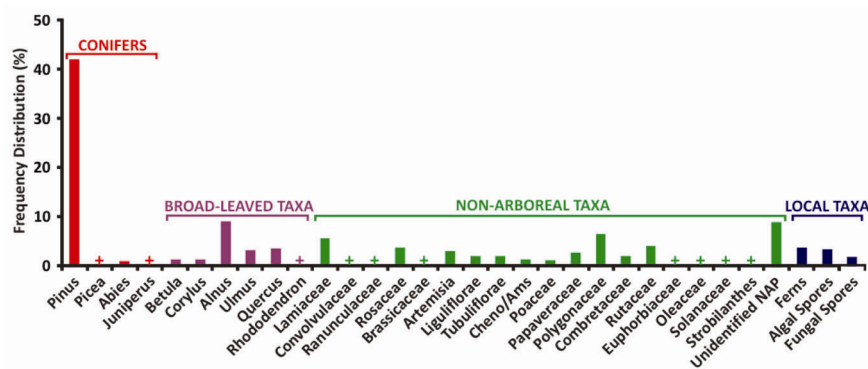
The vegetation around Kedarnath is influenced by topographic, climatic and edaphic factors. The major forest types occurring around the Kedarnath valley are composed of various broadleaved and conifer trees. Prominent high-altitude arboreal taxa include *Pinus wallichiana*, *Abies pindrow*, *Cedrus deodara*, *Alnus nepalensis*, *Betula utilis*, *Juglans regia*, *Juniperus communis*, *Myrica esculenta*, *Quercus leucotrichophora*, *Q. semicarpifolia*, *Rhododendron arboreum*, *Taxus baccata*, etc. among which *Pinus* and

*Quercus* dominate the vegetation<sup>22</sup>. The beginning of alpine vegetation is marked by timberline or tree-line, at an altitude of ~3500 m, above which there is complete absence of arboreal elements. Herbaceous taxa flourish in the alpine meadows and are represented by members of Liliaceae, Lamiaceae, Ranunculaceae, Convolvulaceae, Brassicaceae, Poaceae, Asteraceae (Liguliflorae/Tubuliflorae), Apiaceae, Polygonaceae, Chenopodiaceae, Ericaceae, Rutaceae, Papaveraceae, Saxifragaceae, Fabaceae, Primulaceae and Rosaceae. The alpine meadows are under anthropogenic impact as these are heavily grazed by sheep, goats, cows and buffaloes throughout summer. Moreover, due to the antiquity of the famous Kedarnath temple, the area has witnessed massive influx of religious tourists since time immemorial. As a result, trees in the vicinity of Kedarnath have been cut over hundreds of years for firewood, and presently only scattered remnants can be seen along the tree-line.

To understand the occurrence of various taxa of the surrounding vegetation in the pollen rain, palynological analysis of the 10 surface samples collected from the outwash plain of the Chorabari Glacier was carried out. The pollen assemblages reflect an overall dominance of arboreals, especially conifers, over the non-arboreals. Amongst the conifers, *Pinus* is the predominant taxa having the highest frequency (31–54%). Other conifers, such as *Abies* (0.4–2%) and *Picea* (0.2–2%) are recorded in low numbers. Among the broadleaved elements, *Quercus* (1–9%), *Alnus* (5–13%) and *Ulmus* (1–4%) are well represented. Other than these, *Betula* (0.2–3%) and *Corylus* (0.6–1%) are also present in moderate abun-

dance. *Rhododendron* is sporadic and *Juniperus* has marked its presence only in one sample. Non-arboreals (herbaceous taxa) are represented by the members of Lamiaceae, Convolvulaceae, Ranunculaceae, Rosaceae, Brassicaceae, Poaceae, Papaveraceae, Polygonaceae, Combretaceae, Rutaceae, Euphorbiaceae and Solanaceae along with other steppe elements, including *Artemisia*, Asteraceae and Chenopodiaceae/Amaranthaceae. The most frequently occurring non-arboreal taxa are Lamiaceae (2–9%), Rosaceae (1–6%), Polygonaceae (1–13%), Rutaceae (0.6–16%) and Papaveraceae (0.9–5%). Other than these, Ranunculaceae (0.4–2%), Convolvulaceae (0.4–2%), Poaceae (0.4–2%), Combretaceae (0.9–3%) and Euphorbiaceae (0.2–1%) are present in moderate abundance. Representation of Brassicaceae and Solanaceae is occasional, whereas Oleaceae and *Strobilanthes* have marked their presence only in one sample each. Amongst the steppe elements, *Artemisia* (1–8%), Chenopodiaceae/Amaranthaceae (0.4–2%) and sub-families of Asteraceae: Tubuliflorae (0.6–4%) and Liguliflorae (1–3%) are well represented. Ferns are represented in fair amounts (1–5%) along with fungal and algal remains (Figure 2).

The palynological data generated from all the samples in the outwash plain of Chorabari Glacier, Kedarnath, consistently show that the pollen rain is not compatible with the actual floristics of the area. Though the tree taxa are absent in the immediate vicinity of the sampling site, the pollen assemblages reflect an abundance of arboreal pollen over non-arboreal pollen. The samples are from an alpine meadow and this over-representation of arboreal pollen gives an erroneous impression that the area is covered



**Figure 2.** Composite pollen diagram showing the frequency distribution of different taxa from the outwash plain of Chorabari Glacier, Kedarnath (+ sign indicates values <1%).

with conifer forests. Among the arboreal pollen, *Pinus* shows absolute dominance (Figure 2). The overwhelming abundance of *Pinus* is because of its profuse pollen productivity and efficient wind dispersal<sup>23,24</sup>. *Abies* and *Picea* pollen are less represented due to their low productivity, bigger size and heavier nature, which inhibit their dispersal to long distances<sup>25</sup>. Broadleaved tree taxa, though important constituents of the temperate forests, seem to be rather under-represented. This is probably due to their lesser pollen productivity and low wind dispersal compared to the conifer pollen.

The ground vegetation of the outwash plain is exclusively vegetated by herbaceous taxa, which are ephemeral in nature, and sprout and flower for short durations when the snow melts. The ground vegetation is well represented by the presence of diverse non-arboreal pollen. Though quantitatively poor, the pollen assemblage has yielded a broad spectrum of herbaceous elements which reflect the alpine meadow vegetation at the study site. The apparently lesser representation of the non-arboreal taxa in the pollen record is due to the overwhelmingly high representation of the *Pinus* pollen and the relatively much lesser pollen production of the herbaceous taxa compared to the conifers. Certain elements like Liliaceae, Saxifragaceae, Fabaceae and Primulaceae, though part of the ground vegetation, are totally absent in the pollen record. Another conspicuous feature is the low percentage of Poaceae (grass) in the pollen spectra. The other reason for the low representation of non-arboreals could be their poor preservation potential, and the microbial and chemical degradation of the pollen grains might have been detrimental for the abundance of pollen of some plants. The good abundance of Polygonaceae and ferns is evidence of wet conditions from melt water streams criss-crossing the outwash plain.

The present study thus has important implications for understanding the relationship between the modern pollen assemblages and the vegetation from which they are derived. The representation of surrounding vegetation in the pollen record would provide a 'modern

analogue', which is a prerequisite for inferring past vegetation and climate.

Further palynological studies are now in progress around Kedarnath from older sediments deposited over the past thousands of years, in order to deduce past climatic fluctuations in the region. The studies would reveal the shifts in tree-line to lower/higher elevations as a consequence of advance/retreat of the glacier during different climatic phases. On proper calibration of the arboreal pollen/non-arboreal pollen ratio, the data reported here will be useful in interpreting the past vegetation succession with reference to the climatic shifts. The palynological studies also reveal the existence of luxuriant tree-line in the vicinity of Kedarnath in the past. However, the tree-line has been severely degraded due to intense anthropogenic pressure over the past hundreds of years. As of now, the tree-line is represented by scattered patches, which are poor remnants of the past lush vegetation. Based on the pollen evidence presented, it is suggested that restoration of tree-line in the area may also be taken up. Besides environmental benefits, the regeneration of temperate forests around Kedarnath would also have positive socio-economic implications.

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