Journal of the Palaeontological Society of India
Volume 62(2), December 31, 2017: 237-244

ISSN 0552-9360

MODERN PALYNOLOGICAL CENSUS OF DUNAGIRI VALLEY: DISTRIBUTION AND ITS RELATIONSHIP WITH PAST VEGETATION AND CLIMATE

ANJALI TRIVEDI[1], **VINIT KUMAR**[2], **AJAI MISHRA**[3] and **REKHA TRIPATHI**[3]

[1]BIRBAL SAHNI INSTITUTE OF PALAEOSCIENCES, LUCKNOW-226007, INDIA
[2]WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN-248001, INDIA
[3]CAS IN GEOLOGY, UNIVERSITY OF LUCKNOW, LUCKNOW-226007, INDIA
E-mail: atrivedee@gmail.com; anjali_trivedi@bsip.res.in

ABSTRACT

Preliminary study of 9 surface moss and sediment samples from different altitudinal edaphic and ecological zones of Chamoli District reveals the modern pollen rain-vegetation relationship, based on pollen. The pollen assemblage shows the dominance of conifers with excessively high frequencies of *Pinus* cf. *wallichiana*, whereas *Cedrus deodara*, *Abies, Picea* are recorded consistently with moderate values. The overall good representation of all these taxa depicts the profuse presence of coniferous forests on the adjoining lower hill slopes. The steady presence of thermophillous broad-leaved elements viz., *Betula utilis, Alnus*, *Juglans* and *Corylus* in low frequencies along with stray pollen *Quercus* cf. *semecarpifolia*, *Salix*, *Ulmus*, etc. reflects their occurrence in restricted pockets in the region. The poor presentation of all these taxa could also be attributed to their low pollen productivity owing to entomophilous mode of pollination as well as their sparse presence in the local flora. The partial preservation of their pollen in the sediments cannot be denied. The grass pollen together with good representation of sedges, Chenopodiaceae, Caryophyllaceae, Brassicaceae, Asteraceae and *Artemisia* in the pollen rain substantiate their actual presence in the herbaceous complex.

Key words: Pollen, Garhwal Himalaya, Pollen spectra, Dunagiri Glacier, India

INTRODUCTION

The census of the pollen and spores of modern environment by their pollen shower is an indispensable tool for interpreting qualitative and quantitative Quaternary pollen records and vis a vis reconstruction of palaeovegetation distribution (Overpeck *et al*., 1985; Bradley, 1985; Anderson *et al*., 1989; Mayewski *et al*., 2004). The pollen census reveals various aspects: pollen production, diffusion, deposition and conservation. Studies of the relationship between pollen deposition and local vegetation can contribute significantly to the interpretation of fossil pollen diagrams (Birks, 1994; Hicks and Sunnari, 2005; Gerasimidis *et al.,* 2008) and to make vegetation based reconstruction of past climate (Tarasov *et al*., 1999; Seppä *et al*., 2004). The pollen production and dispersal characteristics of plants and accumulation in sediment are also important factors to understand and determine the corrections for the late Quaternary pollen spectra (Davis, 1963, 2000; Andersen, 1970, 1973; Hjelmroos and Franzen, 1994; Bunting *et al*., 2004). The alpines are among the sentient ecology that respond easily against any changes in climatic and other biotic activities. Very few late Quaternary studies have been carried out the alpine and sub-alpine regions of Garhwal Himalaya (Ranhotra and Battachharya, 2013). The Modern pollen analogue is scarce from glaciated region of Garhwal Himalaya, excepting a solitary report from Tipra Bank Glacier (Bhattacharyya and Chauhan, 1997). In this context, the present study based on the investigation of surface samples from Dunagiri Glacier has been pursued in order to understand the pollen deposition pattern of various plant species in relation to their factual presence in the modern vegetation in the region. This will serve as modern analogue for the precise appraisal of pollen sequences of past in terms of vegetation and climate change as well as to decipher the glacial and interglacial stages and shifting of tree line during the Quaternary (Pleistocene -Holocene). The present study reflects pollen precipitation in alpine and sub alpine, region of Garhwal Himalaya and their surrounding vegetation across elevation gradient.

The pollen spectra of surface samples are employed as background to prepare flawless paleogeographical and paleoecological reconstructions as there is no any other technique to reconstructing straightway. Each pollen zone has specific vegetation composition with ratio denoting to specific ecological niche is correlated to a specific kind of spectrum (Janssen, 1967; Overpeck *et al*., 1985; Bunting *et al*., 2004; Davis and Aderson, 1988; Wilmshurst and Mcglone, 2005; Xu *et al*., 2005; Gosling *et al*., 2009).

STUDY AREA

Geomorphology and Climate

Dunagiri Glacier, one of the important glaciers of the Dhauliganga (basin) system of glaciers where more than ~135 glaciers of different sizes lie in deep and narrow valleys. Dunagiri is an 4.5 km long, northward-flowing, single valley type glacier terminating at an altitude of 4200 m asl (snout) with its headwall occurring just below the Dunagiri peak (6489m asl) (Kumar *et al*., 2016). A stream originating from the glacier enrage in to Dhauliganga near the Jumma Village. (Fig.1). Dunagiri Glacier is broad in the accumulation zone with several transverse crevasses (Fig. 2). There is a steep highly crevassed ice fall at around 4850 m asl thereafter; the glacier is straight with not much change in width. The glacier is dissected in innumerable serac faces and crevasses. The glacier in its present form is bounded by the left and right lateral moraines and a circular terminal moraine.

The study area falls under cold and dry climate. Monsoon winds have strong influence on rainfall patterns. The north facing

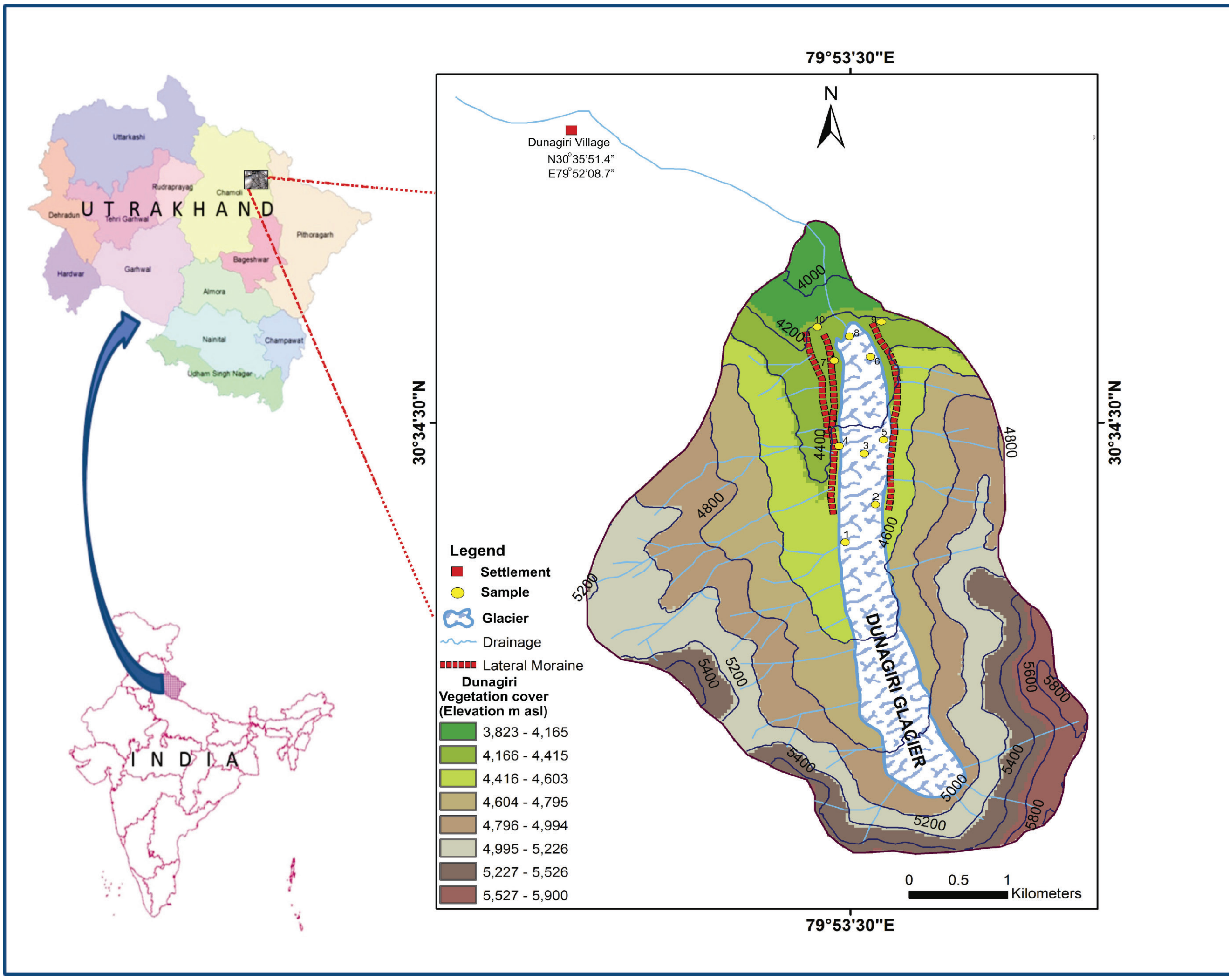


Fig. 1. Geomorphological map of Dunagiri Glacier, Garhwal showing site of surface samples.

parts are moist as compared to southern parts. Winter rain occurs occasionally in January. The entire region experiences snowfall in winter. The metrological Data is available of nearest Chamoli District of Uttarakand. The higher reaches (more than 4500 m) remain snow bound round the year. The mean maximum summer temperature is 25.6 °C and mean minimum winter temperature ranges from 2.3°C to 17.9°C. The glaciers and bare land cover about 26 and 46 percent area of reserve.

Vegetation

Dunagiri Glacier is characterized by the temperate to alpine type of vegetation (Champion and Seth, 1968). The north facing slopes are thickly roofed with vegetation in contrast to the south facing slopes. At about altitude of 2,500m asl the broad leaved-conifer woodland is chiefly characterised by the species of *Pinus* cf. *wallichiana orylus colurna, Alnus nepalensis, Juglans regia, Ulmus wallichiana, Layonia ovalifolia. Coronus capitata, Berberis asiatica, Berberis chitria, Daphne cannabina, Desmodium gangenticum, Eupatorium adenophorum, Indigofera dosua, Plectranthus japonicus, Rubus paniculatus*, and *Viburnum coriaceum* are the common shrubs growing mainly along ~~on~~ the stream banks or ridge sides. The ground flora mainly comprises *Geum elatum, Ainsliaea aptera, Ajuga parviflora, Anaphalis busua, Carex condensate, Conyza japonica, Desmodium polycarpum, Galium rotundifolium, Gerbera macrophylla, Oplismenus compositus, Ranunculus diffusus, Scutellaria angulosa, Viola canescens* etc.

At high elevations, the plant community slowly switched by species of *Pinus wallichiana, Quercus semecarpifolia, Taxus baccata* and *Cedrus deodara* up to 3,000m asl. The ground flora flourishes lavishly in the region and encompasses mainly *Polygonum emodi, Gnaphalium hypoleucum, Primula denticulate,* Poaceae, *Poa annua, Artemisia nilogririca*, etc.

In the upper temperate belt i.e. up to the elevation of 3,500 m asl the woodland comprising *Abies spectabilis, Quercus semecarpifolia, Betula utilis,* and *Rhododendron campanulatum* occur in pockets. Most of the constituents of these forests are gnarled and stunted. The lateral moraines support *Abies-Betula-Rhododendron* type vegetation (Fig. 2). The profuse herbaceous flora largely comprises grasses, *Artemisia parviflora*, *Potentilla atrosanguinea*, *Meconopsis aculeata*, *Geranium nepalense*, *Thalictrum foliosum*, *Impatiens thomsonii*, *Polygonum filicaule*, *Ranunculus hirtellus*, *Primula denticulata*, *Viola biflora*, etc. The herbaceous vegetation is interspersed with patchy scrubs, which are constituted of *Cotoneaster microphylla*, *Rosa macrophylla*, *Crataegus crenulata*, etc. However, in certain shady depressions and moist hill slopes *Impatiens balsamina*, *Polygonum filicaule* and *P. cognatum*, occur gregariously.

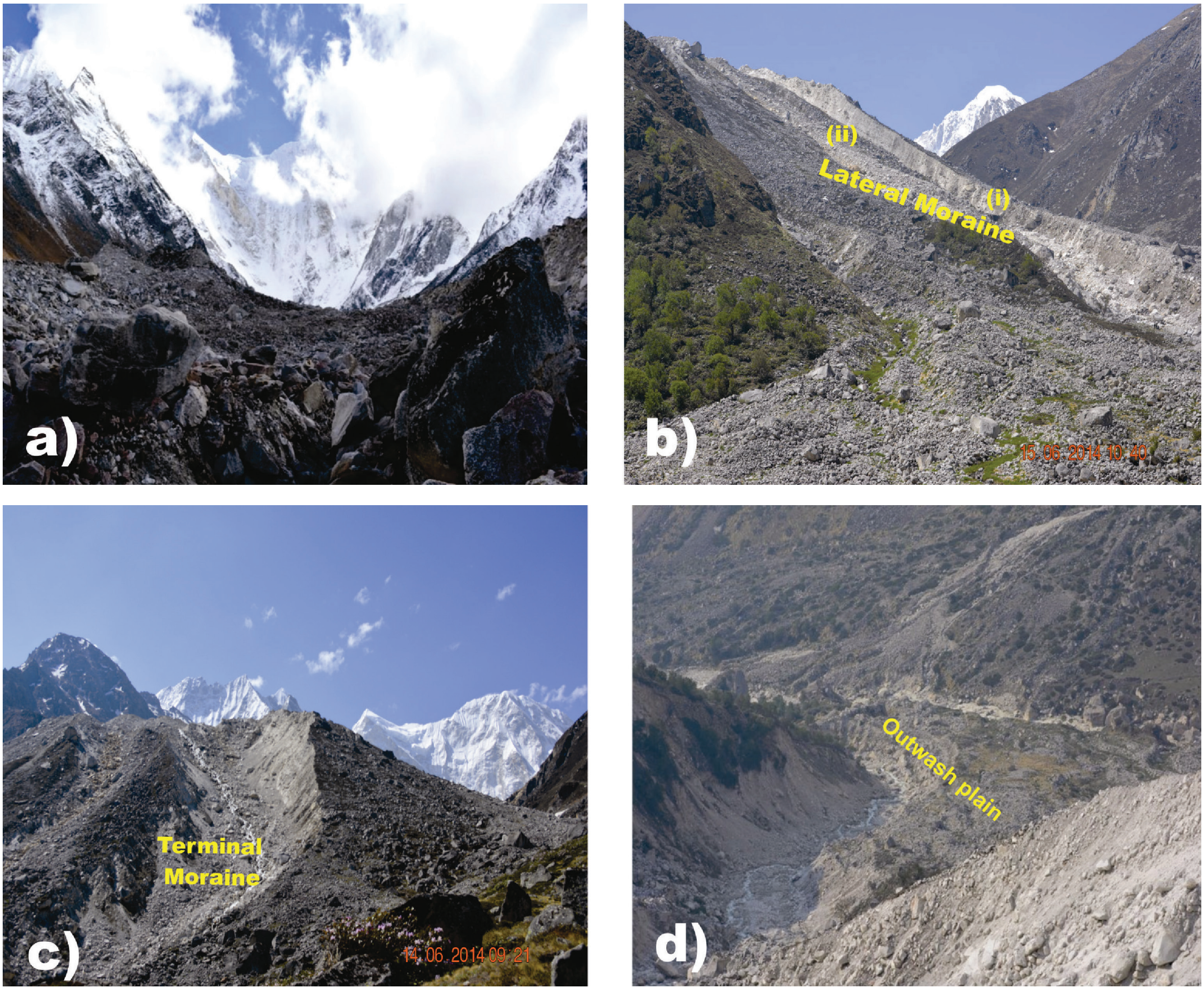


Fig. 2. Geomorphology of the Dunagiri Glacier, Garhwal.

Above 3,700m asl the plant community is overtopped by *Betula-Rhododendron-Juniperus* scrub sub-alpine forest before merging into alpine meadows. It seems to be able to grow in moist as well as dry sites, where it is greatly dependent on melting snow. At higher altitude, above the timberline, vegetation turns steadily into alpine sparse vegetation consisting mainly *Polygonum filicaule, Ranunculus hirtellus,* Polygonaceae, Cyperacceae, Poaceae, Asteraceae, Ericaceae, Ranunculaceae, Lamiaceae and ferns etc. Herbs grow on dispersed highlands and carpets of mountain as well as crustose and foliose lichens spread on the rocks.

In Garhwal Himalaya, the alpine vegetation cover is also affected by deforestation for day to day needs of nearby villagers and grazing by livestock.

MATERIAL AND METHODS

The extensive field survey was done. Nine modern pollen samples (Table-1) and qualitative vegetation data were collected at different elevational intervals along a transect from the Dunagiri Glacier region near the snout to moraine/till deposition in the May-June 2015 from the altitude 4373m to 3763m above asl.

Fifty gram of sample was heated in 10% aqueous KOH solution to segregate pollen/ spores from the sediments and to eliminate the humus. Thereafter, it was treated with 40% HF solution in order to dissolve the silica content. The sample was treated with glacial acetic acid to dehydrate before acetolysing (Erdtman, 1943) it using acetolysing mixture (9:1, ratio of acetic anhydride and concentrated sulphuric acid). The sample was again washed with water thrice. Finally, the sample was prepared in 50% glycerin solution for microscopic examination. The pollen sums vary from 200 to 300 depending upon the pollen potential of the samples and include only the terrestrial pollen. The pollen of aquatic plants and fern spores were excluded from the pollen sums due to their origin from local sources. The pollen taxa recovered are grouped as trees, shrubs, herbs, ferns, algal remains, fungi and drifted pollen and are arranged in the same manner in the pollen spectra.

Table. 1. Information on the modern pollen sampling sites from the Dunagiri Glacier.

Sample number	Location	Sample position	Altitude (m a.s.l.)	Latitude/ Longitude	Description
DG-1	Dunagiri Glacier	Glacial region	4373	30°34′32.5” N 79°53′29.7” E	Near Dunagiri snout
DG-2	Dunagiri Glacier	Glacial region	4339	30°34′34.01” N 79°53′19.34” E	Left lateral moraine of Dunagiri glacier
DG-3	Dunagiri Glacier	Glacial region	4345	30°34′38.60” N 79°53′19.41” E	Downstream from the snout
DG-4	Dunagiri Glacier	Glacial region	4272	30°35′02.3” N 79°53′21.0” E	Near Dunagiri terminal moraine
DG-5	Dunagiri Valley	Periglacial region	4073	30°35′20.12” N 79°53′11.57” E	Left lateral moraine near campsite
DG-6	Dunagiri Valley	Periglacial region	3791	30°35′40.45” N 79°53′10.49” E	Moss cushion
DG-7	Dunagiri Valley	Periglacial region	3785	30°35′42.49” N 79°53′6.43” E	Moss cushion
DG-8	Dunagiri Valley	Dunagiri valley	3770	30°35′38.57” N 79°52′59.45” E	Around Dunagiri glacier area
DG-9	Dunagiri Valley	-	3763	30°35′46.23” N 79°52′49.25” E	Near Dunagiri campsite

MODERN POLLEN COMPOSITION

Alpine zone

Pollen assemblage from alpine region (sample no. DG-1 to DG-4) portrays an overall dominance of arboreal taxa over non-arboreals (Fig. 3, Plate.1) with high frequencies of coniferous elements. Among the coniferous taxa *Pinus* cf. *wallichiana* (54-65%), attains highest frequencies followed by *Abies* (5-10.8%), *Picea* (2.5-5%), *Cedrus* (4.5-6.9%), *Ephedra* (0.8- 2%) and *Juniperus* (1.2-1.9%). The broad-leaved taxa are represented in fluctuating frequencies in the samples of which *Betula* (3-5%), *Alnus* (1-2.5%) are well represented, whereas *Rhododendron*. (0.39-3%), *Corylus* (1-1.3%), Rosaceae (0.8-1%), Oleaceae (0.77-1.2%), *Juglans* (0.8-1.19%), *Querecus* cf. *semicarpifolia*, *Ulmus, Salix* and *Rhus* (0.40% each) are low and scarce.

Non-arboreals are truly portrayed by taxa growing in the region. Among them, Poaceae (2-4%), Apiaceae (1-4.5%), *Artemisia* sp. (3-6.6%), Tubuliflorae (2.8-6%), Lamiaceae (1-3%) and Chenopodiaceae (1.7-2%) are the major taxa. Liguliflorae (0.79-1.5%), Caryophyllaceae (0.77-1%), Convolulaceae (0.4-1.6%), Cyperaceae (0.8-1.7%), *Polygonum serrulatum* (0.4-1.8%), *P. plebeium* (0.5-1%), Urticaceae (0.4-1.6%), Ranunculaceae (0.39%) are in low values. Ferns (0.5-2%) together with fungal spores maintain constantly low values.

Sub-alpine region

The pollen assemblage from the subalpine region (sample no DG5- DG-9) shows an overall dominance of arboreals over non-arboreals. The pollen assemblage is marked by predominance of conifers as documented by huge values of *Pinus* cf. *wallichiana* (45-60%). Other conifers, viz. *Abies* (4-7.7%), *Picea* (3.2-5%) and *Cedrus deodara* (2-2.6%) are also present in good amount. The alpine scrubs are represented by *Juniperus* (1-3.3%) and *Ephedra* (0.4-2.5%) with deviating low frequencies. Among temperate broad-leaved taxa, *Betula* (2.5-6.7%), *Corylus* (1-2.5%) and *Alnus* (1-2.6%) portray in good amount however, *Juglans*, *Ulmus* (0.5-1% each), *Salix* (0.36-1%), *Rhododendron* (0.4-1%), Rosaceae, Oleaceae (0.77-1.2% each) and *Quercus semecarpifolia* (0.5%) are present in low values. Among the non-arboreals, *Artemisia* (3-6.6%), Tubuliflorae (0.8-4.31%), Lamiaceae (0.77-4.3%), Chenopodiaceae (1.7-3), *Polygonum serrulatum* (0.5-5.2%); and *P. plebeium* (1.2-2.3%) are represented by high values. Poaceae (0.5-1%), Liguliflorae (0.79-1.5%), Caryophyllaceae (0.5-1%), Convolvulaceae (0.39%), Cyperaceae (0.8-1.7%), Apiaceae, Urticaceae (0.4-1% each) and Ranunculaceae (0.5%) are low in values and infrequent. The ferns (0.5-2%) are recovered steadily along with fungal spores.

DISCUSSION

Modern Pollen vegetation relationship from Dunagiri Glacier region

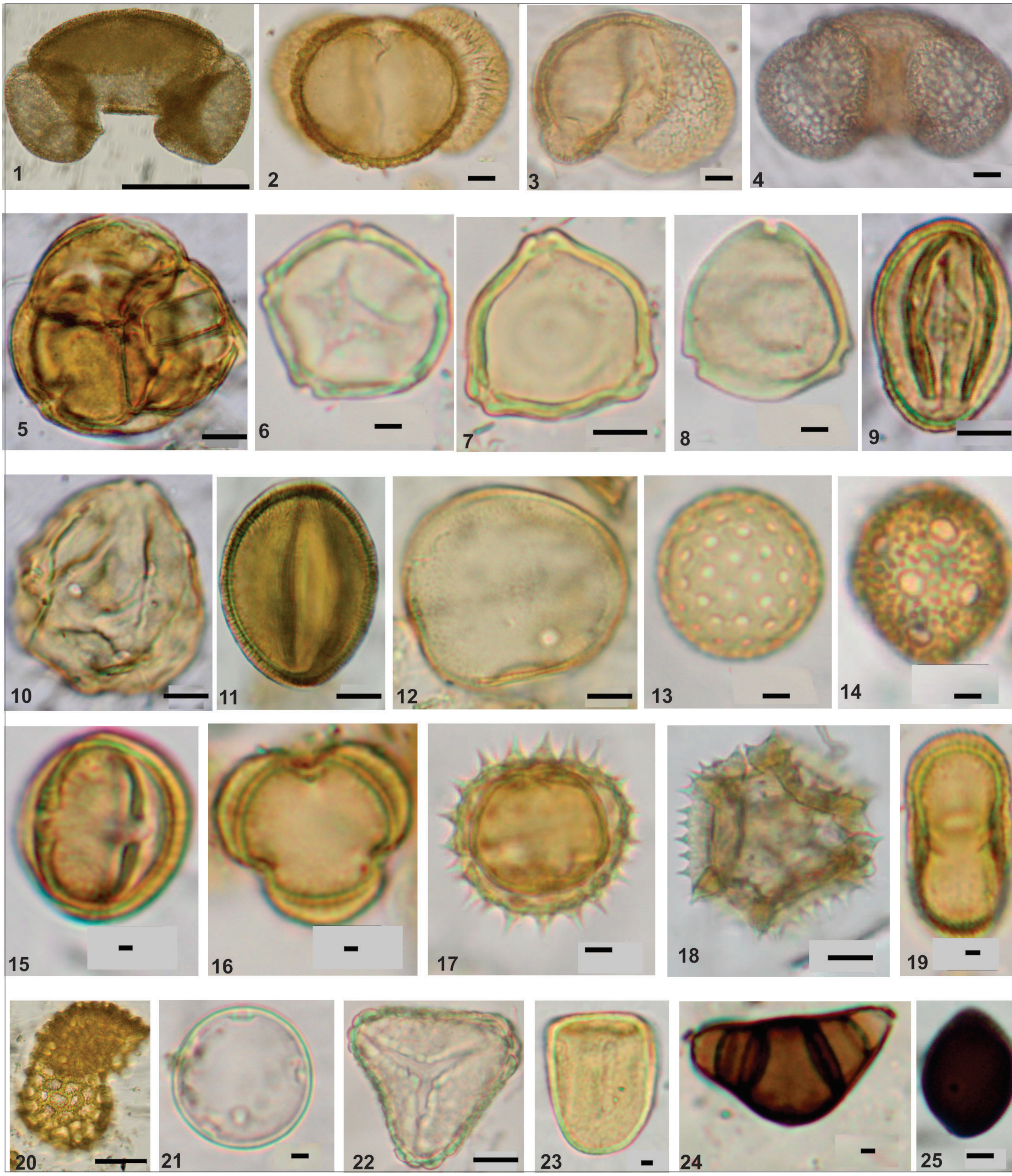
The pollen data recovered in the sediment samples of the Dunagiri alpine and subalpine region bestow the first data on recent pollen deposition and used as a frame, for interpretation of palynological studies in progress.

The surface soil and moss cushions are commonly used as a collecting and preserving medium for modern pollen deposition from surrounding vegetation to discover the association between pollen, vegetation and climate. The studied area of Dunagiri Glacier region falls under cool and arid climate of the Garhwal Himalaya. The study of surface samples from the region has helped us to understand the relationship between the modern pollen assemblage and the surrounding vegetation type. The results match with the similar work has been done in same region (Rahotra *et al*., 2013; Kar *et al*., 2015; Kar *et al*., 2016) and besides globally (Islebe and Hooghiemstra, 1995; Ohnemach and Straka, 1983; Fang *et al*., 2015). Though

EXPLANATION OF PLATE I

1. ***Abies***, 2. ***Cedrus deodara***, 3. ***Picea***, 4. ***Pinus*** 5. ***Rhododendron***,, 6. ***Alnus***, 7. ***Betula***, 8. ***Corylus***, 9. ***Querecus***, 10. ***Juglans***, 11. Convolvulaceae, 12. Poaceae, 13. Chenopodiaceae, 14. Caryophyllaceae, 15. & 16. ***Artemisia***, 17. Tubuliflorae, 18. Liguliflorae, 19. ***Polygonum plebeium***, 20. ***Polygonum serrulaum***, 21. Urticaceae, 22. Fern trilete spore; 23. Cyperaceae, 24. ***Curvularia***, 25. Fungal ascospore.

Plate I



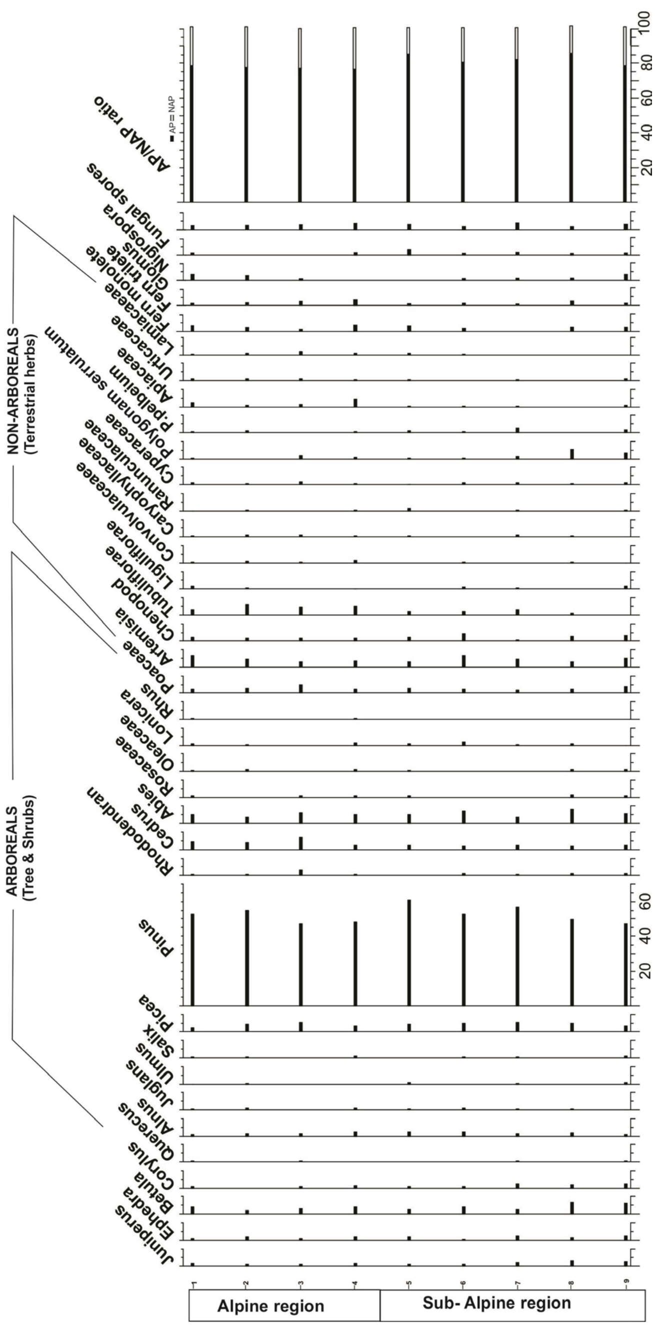


Fig. 3. Pollen spectra from Dunagiri Glacier, Garhwal.

the studied area have almost negligible arboreal, except some temperate broad-leaved trees, there is still over-representation of arboreals specially *Pinus wallichiana*. The over-representation of *Pinus* could be attributed to its abundant pollen production and good preservation of its pollen in the sediments. In addition, light weight and winged pollen grains of *Pinus* cf. *wallichiana* can be transported over long distances by upthermic winds from the adjoining lower elevation (temperate belt) with pure and luxuriant blue pine (*Pinus wallichiana*) forests (Vishnu–Mittre and Sharma, 1966, Cormor *et al*., 2004). Other conifers like *Abies, Picea* and *Cedrus deodara* are represented in low frequencies probably their large size and low production as compared to *Pinus* cf. *wallichiana*. The under- representation of temperate broad-leaved taxa like *Querecus* cf. *semicarpifolia*, *Alnus Corylus, Betula*, etc. could also be due to their anemophillous nature and poor preservation of pollen in the soil. Thus, the present study has revealed that the modern pollen assemblage portrays false image and not resemble to the present day vegetation of the area. Dominance of *Pinus* pollen has also been observed in Pindari Glacier, Kumaon Himalaya (Bera *et al.,* 2011), Jammu region (Sharma *et al*., 2001, Quamar and Srivastava, 2013) and Tipra Bank Glacier (Bhattacharyya and Chauhan, 1997); Gangotri Glacier, Garhwal Himalaya (Ranhotra and Battacharyya, 2013). Similar inferences concerning the representation of conifers and broad-leaved elements have been drawn through the analysis of surface and subsurface sediments from Naychhudwari bog (Chauhan, 2006) and Sithikhar bog (Chauhan *et al*., 2000) from the alpine belt of Himachal Pradesh. The under-representation of non-arboreals is due to less pollen productivity and poor pollen preservation in the sediment. The consistent presence of *Ephedra* in the pollen spectra from sub-alpine to alpine belts denotes its frequent presence in the dry mountain slopes, exclusively in the alpine zone.

Artemisia, Chenopodiaceae, Rosaceae, Asteraceae and grasses, the major meadow elements, are recovered frequent in all the samples, corresponding their actual representation to larger extent in the herbaceous complex of the region. The Low frequency of ferns with algal and fungal spores and absence of marshy and aquatic also supports dry environment.

CONCLUSION

The palynological studies from the surface samples of Dunagiri Glacier region does not reflect the true picture of present day vegetation, although the permutation and combination of the pollen data set would be valuable for drawing the Quaternary vegetational history and changing pattern of palaeoclimate. Dunagiri Valley has bare vegetation with very few broad-leaved elements, though the dominance of tree taxa denoting the generous pollen production and efficient wind dispersal from extra-regional sources.

The some important reasons for pollen/vegetation abnormalities are i) Differential pollen production of different species. ii) physical properties of pollen grains are different to supports transport distance and iii) topography vegetation cover and atmospheric condition also play important role iv) entomophillous nature of most the of the broad-leaved forest taxa vi) alkaline soil which is not amiable for pollen and spores preservation.

Noteworthy that the interference of human for utilization of various plants for medicinal purposes as well as extortionate grazing pressure in alpine region has led to severe change in vegetation composition of species during last few decades. This is also aggravated by increment in global heat increased up to 0.06 ^{o}C over the past century (Houghton *et al*., 1996) and result the change in diversity pattern (Pauli *et al*., 2012)

ACKNOWLEDGEMENT

Authors are thankful to Prof. Sunil Bajpai, Director, Birbal Sahni Institute of Palaeosciences, Lucknow for permission and providing facilities and consistent support to accomplish this work. Financial support by the Department of Science and Technology (DST), Government of India, New Delhi for the Sponsored Project (SR/DGH/GL-3/2008) is highly acknowledged.

REFERENCES

Andersen, S. 1970. The relative pollen productivity and pollen representation of north European trees, and correction factors for tree pollen spectra. *Dan. Geol. Unders. II, RSkke*, **96**: 1-96.

Anderson, P. M., Bartlein, P. J., Brubaker, L. B., Gajewski, K. and Ritchie, J. C. 1989. Modern analogues of late-Quaternary pollen spectra from the western interior of North America. *Journal of Biogeography*, **18**: 573-596.

Andersen, S. T. 1973. The deferential pollen productivity of trees and its significance for the interpretation of a pollen diagram from a forested region. In: Birks, H.J.B., West, R.G. (Eds.), Quaternary Plant Ecology. Blackwell, Oxford, pp. 109-16.

Bera, S. K., Ali, S. N., Bali, R. and Agarwal, K. K. 2011. Impact of Pollen Rain from the Vegetation of Alpine-Subalpine Belt as a Reliable Measure for Palaeoclimatic Interpretation: A Case Study from Pindari Glacier, Kumaun Himalaya, India. *International Journal of Earth Sciences and Engineering*, **04**(06): 1010-1019.

Bhattacharyya, A. and Chauhan, M. S. 1997. Vegetational and climatic changes during recent past around Tipra Bank Glacier, Garhwal Himalaya. *Current Science*, **72**(6): 408-412.

Birks, J. B. J. 1994. The importance of pollen and diatom taxonomic precision in quantitative environmental reconstruction. *Review of Palaeobotany and Palynology*, **83**: 107-117.

Bradley, R. S. 1985. Quaternary Palaeoclimatology: Methods of Palaeoclimatic Reconstruction. Boston, Allen and Unwin, London.

Bunting, M. J., Gaillard, M. J., Sugita, S., Middleton, R. and Broström, A. 2004. Vegetation structure and pollen source area. *The Holocene*, **14**(5): 651-660.

Connor, S. E., Thomas, I., Kvavadze, E. V., Arabuli, G. J., Avakov, G. S., and Sagona, A. 2004. A survey of modern pollen and vegetation along an altitudinal transect in southern Georgia, Caucasus region. *Review of Palaeobotany and Palynology*, **129**: 229–250.

Champion, H. G. and Seth, S. K. 1968. A Revised Survey of Forest Types of India, Government of India Press, New Delhi, pp. 404.

Chauhan, M.S. 2006. Late Holocene vegetation and climate in the alpine belt of Himachal Pradesh. *Current Science*, **91**(11): 1572-1578.

Chauhan, M. S., Mazari, R. K. and Rajagopalan, G. 2000. Vegetation and climate in upper Spiti region, Himachal Pradesh during late Holocene. *Current Science*, **79** (3): 373-377.

Davis, M. B. 1963. On the theory of pollen analysis. *American Journal of Science*, **261**: 897-912.

Davis, M. B. 2000. Palynology after Y2K-understanding the source area of pollen in sediments. *Annual Review of Earth and Planetary Sciences*, **28**(1): 1-18.

Davis, O. K. and Anderson R. S. 1988. Pollen in Packrat (Neotoma) Middens: Pollen Transport and the relationship of pollen to vegetation: reply. *Palynology*, **12**(1):226-229

Erdtman, G. 1943. An Introduction to Pollen Analysis. Chronica Botanica, Waltham, Mass., USA.

Fang Y., Ma, C., Mao Limi., Zhu, Cheng, Zhang, W. 2015. Surface pollen spectra from Shennongjia Mountains, central China: An interpretation aid to Quaternary pollen deposits. Review of Palaeobotany and Palynology, **214**: 40-50.

Gerasimidis, A., Panajiotidis, S. and Athanasiadis, N. 2008. Five decades of rapid forest spread in the Pieria Mountains (N. Greece) reconstructed by means of high-resolution pollen analysis and aerial photographs. Vegetation History and Archaeobotany, **17**(6): 639-652.

Gosling, W. D., Mayle, F. E., Tate, N. J. and Killeen, T. J. 2009. Differentiation between Neotropical rainforest, dry forest, and savannah ecosystems by their modern pollen spectra and implications for the fossil pollen record. *Review of Palaeobotany and Palynology*, **153**(1-2):70-85.

Hicks, S. and Sunnari A. 2005. Adding precision to the spatial factor of vegetation reconstructed from pollen assemblages. *Plant Biosystems*, **139**:127–134.

Hjelmroos, M. and Franzen, L. G. 1994. Implications of recent long-distance pollen transport events for the interpretation of fossil pollen records in Fennoscandia. *Review of Palaeobotany and Palynology*, **82**(1): 175-189.

Houghton, J. T., Filho, L. G., Callander, B. A. Harris, N., Kattenberg, A and Maskell, K. *Climatic change* 1995: The science of climatic change, Cambridge University Press, Cambridge. 1996.

Janssen, C. R. 1967. A comparison between the recent regional pollen rain and the sub recent vegetation in four major vegetation types in Minnesota (U. S. A.). *Review of Palaeobotany and Palynology*, **2**: 331-342.

Islebe, G. A. and Hooghiemstra, H. 1995. Recent pollen spectra of highland Guatmala. *Journal of Biogeography*, **22**(6):1091-1099.

Kar, R., Bajpai, R. and Singh, A. D. 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.

Kar R., Bajpai, R. and Mishra, K. 2016. Modern pollen rain in Kedarnath: implications for past vegetation and climate. *Current Science*, **110** (3) 10 : 296:298.

Kumar, V., Mehta, M., Mishra, A. and Trivedi, A. 2016. Temporal fluctuations and frontal area change of Bangni and Dunagiri glaciers from 1962 to 2013, Dhauliganga Basin, central Himalaya, India. Journal of Geomorphology, doi: 10.1016/j.geomorph.2016.12.012.

Pauli, H., *et al*. 2012. Recent plant diversity changes on Europe's mountain summits. *Science*, **336**: 353– 355.

Mayewski, P. A., Rohling, E. E., Stager, J. C., Karlén, W., Maasch, K. A., Meeker, L. D. and Lee-Thorp, J. 2004. Holocene climate variability. *Quaternary research*, **62**(3): 243-255.

Overpeck, J. T., Webb, T. I. I. I. and Prentice, I. C. 1985. Quantitative interpretation of fossil pollen spectra: dissimilarity coefficients and the method of modern analogs. *Quaternary Research*, **23**(1): 87-108.

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

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

Seppä, H., Birks, H. J. B., Odland, A., Poska, A. and Veski, S. 2004. A modern pollen–climate calibration set from northern Europe: developing and testing a tool for palaeoclimatological reconstructions. *Journal of Biogeography*, **31**(2): 251-267.

Sharma, C., Trivedi, A. and Malik, M. A. 2001. Modern pollen/spore rain in Surinsar and Mansar lakes, Jammu. *Geophytology*, **31**(1&2):9-17.

Tarasov, P. E., Guiot, J., Cheddadi, R., Andreev, A. A., Bezusko, L. G., Blyakharchuk, T. A. and Zernitskaya, V. P. 1999. Climate in northern Eurasia 6000 years ago reconstructed from pollen data. Earth and Planetary Science Letters, **171**(4): 635-645.

Vishnu-Mittre and Sharma, B. D. 1966. Studies of post glacial vegetation history from Kashmir valley-I, Haigam Lake. *Palaeobotanist*, **15**: 185-212.

Wright Jr., H. E. 1967. The use of surface samples in Quaternary pollen analysis. Review of Palaeobotany and Palynology, **2**: 321-330.

Wilmshurst, J. M. and Mcglone, M. S. 2005.Origin of pollen and spores in surface lake sediments: Comparison of modern palynomorph assemblages in moss cushions, surface soils and surface lake sediments. *Review of Palaeobotany & Palynology*, **136**(1-2):1-15.

Xu, Q. H., Li, Y. C., Yang, X. L., Xiao, J. L., Liang, W. D. and Peng, Y. J. 2005. Source and distribution of pollen in the surface sediment of Daihai lake, inner Mongolia. *Quaternary International*, **136**: 33-45.

Manuscript received January 2017

Revised Manuscript accepted April 2017