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Mid-Holocene vegetation shifts and climate change in the temperate belt of Garhwal Himalaya

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ABSTRACT

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Pollen analysis of 3.06 m deep sediment core from the temperate lake-Nachiketa Tal, has brought out the vegetation shifts and climatic oscillations in the temperate region of Garhwal Himalaya since Mid-Holocene. The pollen sequence depicts that between 5,304 and 3,912 yr BP the mixed conifer forests dominated by *Pinus* cf. *wallichiana* together with *Cedrus* and *Abies* occupied most of the landscape under a regime of a cold and dry climate. The record of pollen of aquatic element, *Potomogeton* and freshwater alga-*Botryococcus* implies the existence of the lake. The broad-leaved forests mainly constituted of oak (*Quercus* cf. *semecarpifolia*) occurred sparsely in the moist and shady situations. Between 3,912 and 2,975 yr BP the mixed conifer forests got transformed into mixed oak-broad-leaved forests as evidenced from the much expansion of *Quercus* and improvement of its close allies *Alnus*, *Betula*, *Carpinus*, *Juglans*, *Salix*, etc. This change in the vegetation pattern suggests that a warm and humid climate prevailed in the region. Around 2,975 to 1,872 yr BP the abrupt decline in *Quercus* and its broad-leaved associates and a corresponding spurt in *Pinus* cf. *wallichiana* reflect the re-establishment of pine dominated conifer forests with reversal of cool and dry climate. Subsequent expansion of *Quercus* and broad-leaved taxa around 1,872 to 767 yr BP and declining trend of conifers took place with the prevalence of warm and moderately humid climate. The sporadic encounter of Cerealia pollen during this phase indicates that the area was under cereal-based agricultural practice. Since 767 yr BP onwards a warm and less humid climate prevailed than before and consequently relatively less-diversified mixed broad-leaved oak forests continued to thrive in the region, with relatively reduced frequencies of *Quercus* and other thermophillous broad-leaved elements.

Key-words—Palaeovegetation, Palaeoclimate, Mid-Holocene, Nachiketa Tal, Garhwal Himalaya.

गढ़वाल हिमालय के शीतोष्ण कटिबंध में मध्य होलोसीन वनस्पति विस्थापन एवं जलवायु परिवर्तन

अंजलि त्रिवेदी, बी.एस. कोटलिया एवं एल.एम. जोशी

सारांश

शीतोष्ण झील-नचिकेता ताल से प्राप्त 3.06 मी. गहरे अवसाद क्रोड के पराग विश्लेषण ने मध्य होलोसीन से गढ़वाल हिमालय के शीतोष्ण क्षेत्र में वनस्पति विस्थापन एवं जलवायु उतार-चढ़ाव प्रस्तुत किया है। पराग अनुक्रम चित्रित करता है कि 5,304 व 3,912 वर्ष पूर्व के मध्य शीत एवं शुष्क जलवायु प्रवृत्ति के अंतर्गत अधिकांश दृश्यभूमि *देवदार* व *बलूत* सहित *पाइनस* के तुलनीय *वाल्लिचिएना* के साथ-साथ मिश्रित शंकु वनों से प्रभावी थी। जलीय तत्व, *पोटोमोगेटन* व अलवणजल एल्गा-*बॉट्रियोकोक्कस* के पराग का अभिलेख झील का अस्तित्व इंगित करता है। बांज (*क्वेरकस* के तुलनीय *सेमेकार्थिफोलिआ*) के मुख्यतः गठित चौड़ी-पत्ती वन आर्द्र व छायादार स्थितियों में विरल रूप से उगे।3,912 व 2,975 वर्ष पूर्व के मध्य, *क्वेरकस* के अति विस्तार एवं विकास तथा इसके निकट संबंधी *एल्नस, बेतुला, कार्पिनस, जग्लेन्स, सेलिक्स,* इत्यादि से प्राप्त यथा प्रमाणित मिश्रित शंकु वन मिश्रित बांज-चौड़ी पत्ती जंगलों में तब्दील हो गए। वनस्पति प्रतिरूप में यह बदलाव सुझाता है कि प्रदेश में कोष्ण व आर्द्र जलवायु प्रबल थी।2,975 से 1,872 वर्ष पूर्व के लगभग *क्वेरकस* व इसके चौड़ी-पत्ती सहयोगी एवं *पाइनस* के तुलनीय *वाल्लिचिएना* में एक अनुरूपी उत्क्षेप में यकायक कमी शीत व शुष्क जलवायु के उलटाव के साथ चीड़ प्रभावी शंकु वनों की पुनर्स्थापना निरूपित करती है। उत्तरवर्ती, 1,872 से 767 वर्ष पूर्व के लगभग *क्वेरकस* व चौड़ी पत्ती टैक्सा के बढ़ाव तथा कोष्ण व सामान्यतः आर्द्र जलवायु की प्रबलता के साथ शंकु की घटती प्रवृत्ति दिखी। इस प्रावस्था के दौरान धान्य पराग का कदाचनिक समागम इंगित करता है कि क्षेत्र में धान्य आधारित खेती होती थी। प्रदेश में767 वर्ष पूर्व से कोष्ण व अल्प आर्द्र जलवायु प्रबल थी तथा परिणामतः *क्वेरकस* व अन्य तापरागी चौड़ी-पत्ती तत्वों की सापेक्षतया घटती आवृत्ति सहित प्रदेश में संगत रूप से अल्प-विविधरूपायित मिश्रित चौड़ी-पत्ती बांज वन पनपते रहे।

संकेत-शब्द—पुरावनस्पति, पुराजलवायु, मध्य होलोसीन, नचिकेता ताल, गढ़वाल हिमालय।

INTRODUCTION

Considerable data have been generated on the vegetation succession, climate change and lake level fluctuation during the Quaternary Period on broader time scale from the subtropical and temperate belts from the different sectors of the Himalaya comprising the regions of the Kumaon (Vishnu-Mittre *et al*., 1967; Gupta, 1977; Chauhan & Sharma, 1996; Kotlia *et al*., 1997, 2010) from western Himalaya and Himachal Pradesh (Sharma & Singh, 1974a, b; Sharma & Chauhan, 1988; Chauhan, 2006; Chauhan *et al*., 2000; Bhattacharyya, 1988) and Jammu & Kashmir (Vishnu-Mittre & Sharma, 1966; Sharma & Singh, 1968; Singh, 1964; Gupta *et al*., 1984; Sharma *et al*., 1985; Trivedi & Chauhan, 2008, 2009) from northwest Himalaya, based on the pollen evidence from the lacustrine deposits. However, the Garhwal region with a large number of potential lakes/bogs for the Quaternary palaeoclimatic studies have hitherto not got adequate attention on this aspect, barring the sketchy proxy records retrieved from the subtropical lakes, viz. Dewar Tal (Chauhan & Sharma, 2000) and temperate belt Deoria Tal (Sharma *et al*., 1996; Sharma & Gupta, 1997) and Sat Tal (Chauhan *et al*., 1997), depicting the changing vegetation scenarios, contemporaneous climatic shifts and impact of human activity during the Late Holocene. In the present paper, an attempt has been made to extend such studies in the temperate belt of this region in order to bring out more proxy signals on the vegetation shifts and climatic oscillations since the Mid-Holocene period through the pollen analytical investigation of 3.06 m thick sediment core from Nachiketa Tal, lying at an elevation of ca. 25502 amsl.

Nachiketa Tal is located about 29 km north of Uttarkashi Town and about 4 km from Chaurangi Khal in the temperate belt of Garhwal Himalaya between 30º & 31ºN and 78º and 31º N and 78º & 79º E at an elevation of 2550 m amsl amidst the dense oak forest (Fig. 1). The lake is elliptical in outline, measuring about 150 m in length and 40 m in breath with irregular margin. The lake remains covered with thick sheet of ice during the cold months of January and February.

CLIMATE

The climate of this region is temperate and typical montane type with well defined rainy, winter and summer seasons. The maximum annual mean temperature ranges from 15ºC to 25ºC, but during winter it descends to 5ºC and occasionally it descends below 0ºC, during the cold months of January and February. Average annual rainfall is about 2,000 mm. During the months of severe cold the precipitation is in the form of snow. All the surrounding mountains remain snow clad during the winter.

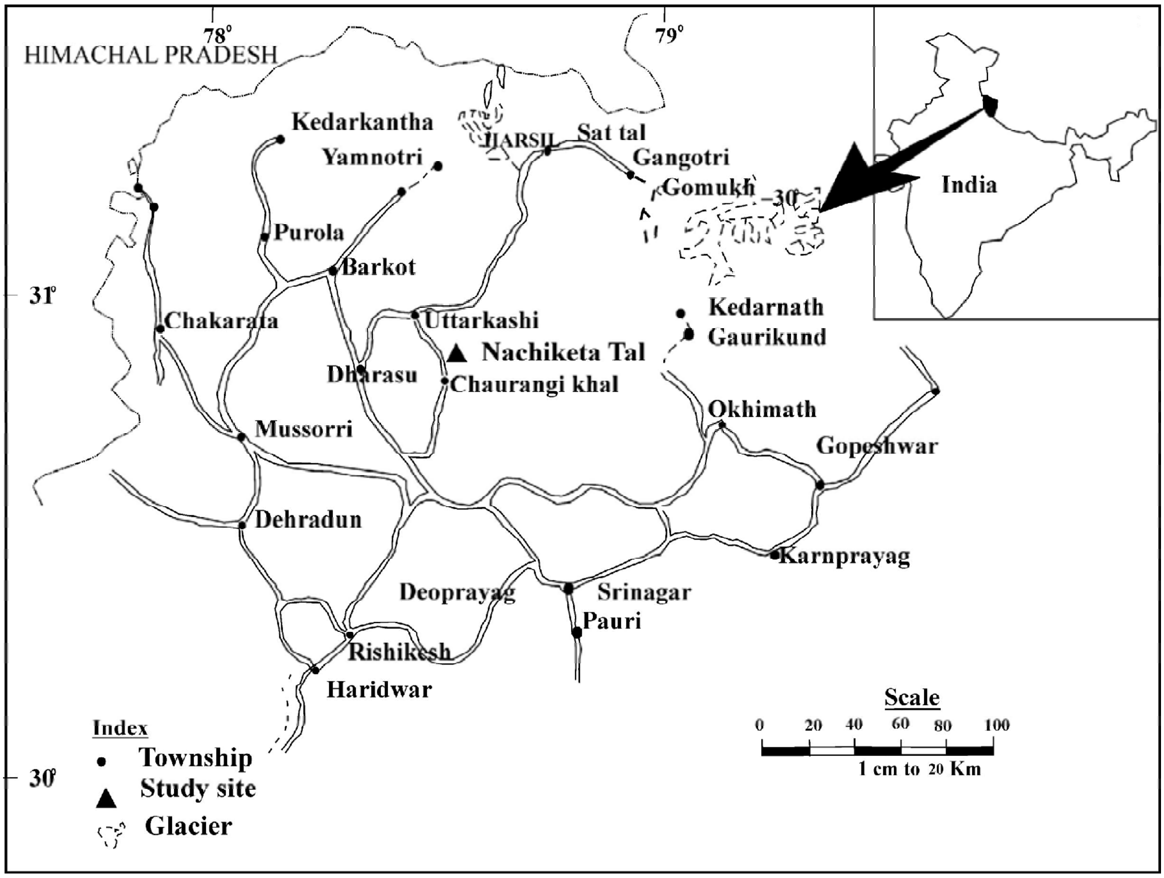

Fig. 1—Map showing the site of investigation in Uttarkashi District, Garhwal Himalaya.

VEGETATION

The hill slopes contiguous to the lake are largely covered with oak forest dominated by *Quercus semecarpifolia*. The other prominent broad-leaved of oak such as associated *Rhododendron arboreum, Aesculus indica, Alnus nepalensis, Acer caesium, Fraxinus excelsior, Ulmus wallichiana, Myrsine africana, Salix elegans, Pyrus malus,* etc. also occur frequently in the forest. Other arboreals such as *Myrica esculanta, Lyonia ovalifolia, Symplocos* sp. and *Engelhardtia bellutianum* have sporadic distribution in the forest. The shrubby vegetation comprises *Berberis asiatica, B. chirta, Rosa moschata, Rubus ellipticus, Lonicera obavata, Crataegus cranulata, Zanthoxylum alatum, Viburnum cotonifolium, V. fruticosa,* etc.

The herbaceous vegetation on the forest floor is quite luxuriant and constituted of *Anaphalis adnata, Primula* sp., *Potentilla fulgens, Pedicularis* sp., *Berginia ligulata, Swertia chirta, Geranium nepalense, Agremonia* sp., *Aster* sp., *Pedicularis* sp., *Sedum trifidum, Saxifraga diversifolia, Thalictrum chelidonii, Galium suga, Jasminum humile, Rumex nepalensis, Artemisia* sp., etc.

The higher reaches support conifer forest composed of *Pinus wallichiana, Cedrus deodara* and *Abies spectabilis,* whereas chirpine forests (*Pinus roxburghii*) occur gregariously on the lower adjoining hill slopes to the lake and are almost devoid of other undergrowths, besides the grasses.

MATERIAL AND METHODS

A 3.06 m sediment core was collected from the centre of the lake below 2.6 m water column using SPIZZ German core. In all, 30 samples were picked up from this core at 10 cm intervals for pollen analysis. Besides, three bulk three samples were also taken at broader intervals for radiometric dating.

The sediment composition of the core collected is uniformly black organic mud with scattered rootlets in the upper part up to the depth of 50 cm. Out of three samples for radiometric dating only one sample at the depth of 109 cm could be date to 1,855 yr BP, whereas upper most sample at 10 cm depth proved to be modern. The available ^{14}C date of 1,855 yr BP has been used to calculate the sedimentation rate, which is 17 years/cm. This sedimentation rate has facilitated the extrapolation of more dates, i.e. 5,204 yr BP at 306 cm depth; 3,912 yr BP at 230 cm depth; 2,875 yr BP at 170 cm depth and 767 yr BP at 10 cm depth for the precise temporal delineation of vegetation changes and climatic events in the chronological sequence from in the region since Mid-Holocene.

The AMS ages determined for this sediment core are set out in the Fig. 2.

The standard technique of pollen analysis (Erdtman, 1943) through the use of 10% aqueous KOH, 40% HF solutions and acetolysing mixture (9:1, acetic anhydride and concentrated sulphuric acid) was followed to extract the pollen and spores from the sediments. Samples for microscopic examination were prepared in 50% glycerine solution.

Sample No.	Depth	AMS Age
NKT-I	10 cm	Modern
NKT-II	109 cm	1,855 yr BP

Fig. 2—AMS ages for sediment core.

POLLEN ANALYSIS

All the samples analysed from this sediment core were found very productive in pollen and spores (Pl. 1). The pollen sums vary from 300 to 500, which include only the terrestrial pollen. The pollen of aquatic plants and fern spores were excluded from the pollen sum due to their origin from local provenance. However, their frequency percentages have been calculated from the pollen sums for their representation in the pollen diagram. The plant taxa recovered have been broadly grouped as trees, shrubs, herbs, fern spores and algal remains and they are arranged in the same sequence in the pollen diagram. Further, the tree taxa are put in order of their altitudinal distribution.

Description of pollen diagram

The pollen diagram prepared from the Nachiketa Tal has been divided into five distinct pollen zones (NKT-I, NKT-II, NKT-III, NKT-IV and NKT-V), taking into account the fluctuating trend of prominent arboreals and non-arboreals. The pollen zones are prefixed with the initials 'NKT' after the name of study site-Nachiketa Tal and are numbered from bottom to top (Fig. 3).

Pollen Zone NKT-I (306-230 cm): *Pinus cf. wallichiana-Picea-Abies-Cedrus-Carpinus-Poaceae-Rosaceae-Cheno/Am-Polygonum serrulatum-Fern assemblage*

This pollen zone covers a time interval of 5,304 to 3,912 yr BP. The lower part of it is marked by the low pollen content, comprising few grains of Poaceae and *Pinus*, however, the upper half depicts the high frequency of *Pinus* cf. *wallichiana* (31.83-38%) followed by *Abies* (5-7.2%) and *Cedrus* (1.56-8.8%). *Quercus* (1.9-9.36%) and *Ulmus* (3.2-4.68%) are relatively better represented in contrast to other broad-leaved taxa, viz. *Betula* (1.27-1.56%) and *Corylus* (1.9-1.56%). Among the non-arboreal taxa, Poaceae (15.88-21%) is present in high frequency followed by *Thalictrum* (7.2-13.9%), Chenopodiaceae/Amaranthaceae (0.8-3.9%), whereas Ranunculaceae (1.27%) is met with in low frequency. Marshy vegetation is marked by the moderate values of Cyperaceae (2.54-3.12%) and *Polygonum serrulatum* (0.5-1%). *Potamogeton* (3.2-5.46%), the sole representative of aquatic vegetation is met with consistently in high frequencies. Freshwater alga-*Botryococcus* (3.2%) is recovered in one sample only. Fern spores monolete (64-130%) are abundant as compared to trilete spores (3.18-4.68%), which are in low frequency.

Pollen Zone NKT-II (230-170 cm): *Quercus-Pinus cf. wallichiana-Alnus-Cedrus-Juglans-Rosaceae-Poaceae-Cheno/Am-Polygonum serrulatum-Fern assemblage*

This pollen zone with the time bracket of 3,912 to 2,975 yr BP exhibits the much enhanced frequencies of *Quercus* (24.9-37.5%). Likewise, *Betula* (1.02-3.12%), *Alnus* (1.98-2.54%) and *Ulmus* (1.5-3.64%) are also better represented. *Juglans* (2.49-4.3%), *Rhododendron* (1.02-2%), *Salix* (1.02-2.54%) and *Symplocos* (0.76-1.66%) turn up for the first time with increasing trend. However, Meliaceae (2%) is recorded in one sample only. Among the conifers, *Pinus* cf. *wallichiana* (1.5-18.48%) as well as *Cedrus* (3-1%), *Abies* (2.64-8.84%) and *Picea* (0.51-1.04%) portray a sharp decline. Shrubby elements such as *Strobilanthes* (2%), Oleaceae (0.89-1.75%), Rosaceae (1.8-5.2%) and Rutaceae (2% only in a sample) appear for the first time in this zone with moderate values. Among non-arboreal taxa, Poaceae (5.81-13.55%) exhibits much reduced values with declining trend. *Artemisia* (1.5-5.2%), Caryophyllaceae (maximum up to 1.5-10.79%) and Ranunculaceae (3.12-4.1%) reappear with increasing trend in the upper half of this pollen zone. *Polygonum serrulatum* (2.56-6.49%) has relatively low frequency compared to the preceding zone together with Cyperaceae (0.5-1.66%), which becomes much sporadic with moderate values. *Potamogeton* (0.83-1.8%) has reduced values than in the preceding pollen zone, whereas *Typha* (4%) and *Utricularia* (0.5%) are retrieved for the first time, though sporadically. Monolete fern spores (48.12-15.8%) decline much in the upper part in this zone. On the other hand trilete fern spores (1-3.38%) remain sporadic as seen in Pollen Zone NKT-I.

Pollen Zone NKT-III (170-110 cm): *Pinus cf. wallichiana-Quercus-Abies-Poaceae-Polygonum serrulatum-Fern assemblage*

This pollen zone encompassing the time span of 2,875 to 1,872 yr BP demonstrates much enhancement in *Pinus* cf. *wallichiana* (3.12-60%). Similarly the other conifers such as *Picea* (0.51-1.04%), *Abies* (2.64-8.84%) and *Cedrus* (5.5-8.82%) also show increasing trend with moderate values. On the other hand, *Quercus* (30-15%) exhibits a sharp declining trend. The other broad-leaved associates such as *Alnus* (4.72% only in a sample), *Betula* (0.694-2.56%), *Ulmus* (0.5-1.38%) and *Juglans* (0.5-1%) also are marked by their reduced frequencies than in the Pollen Zone NKT-II. Shrubby elements such as Rutaceae (2.56%), Rosaceae (4.69%) and *Cotoneaster* (0.85%) are recovered very scantily. Poaceae (5-15.26%) is characterized by the slightly increased values among the non-arboreals.

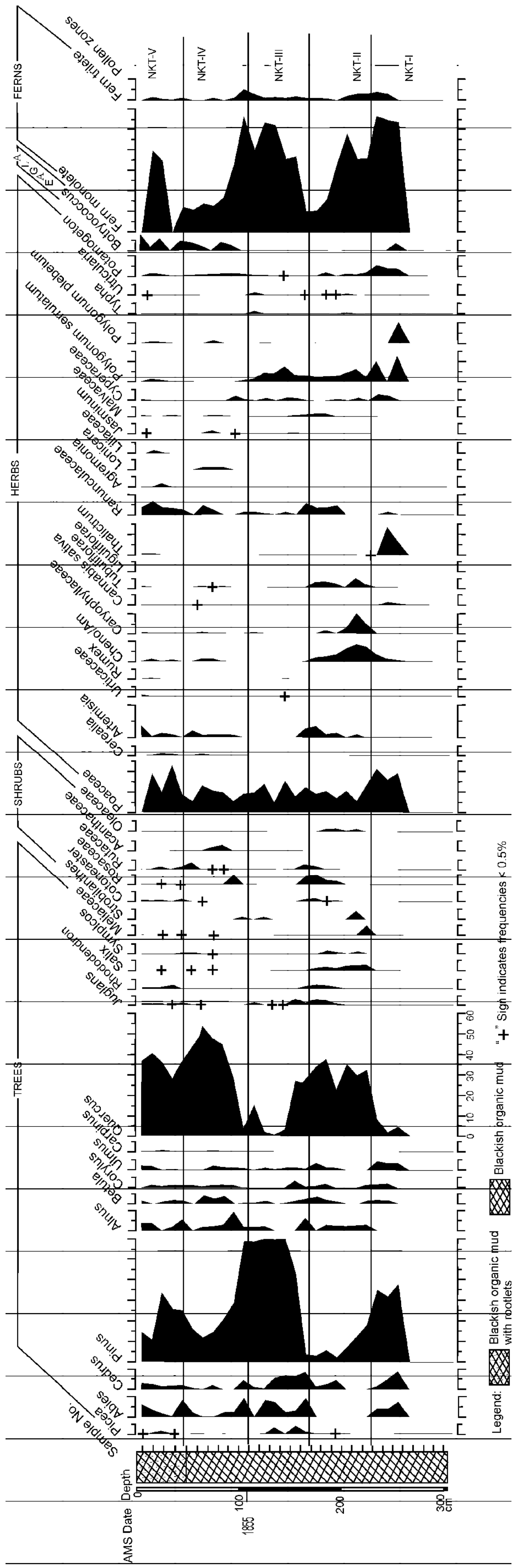

Fig. 3—Pollen diagram from Nachiketa Tal, Uttarkashi District, Garhwal Himalaya.

The rest of the herbaceous elements, viz. *Artemisia* (4.69%), Ranunculaceae (1.38-5.55%) and Malvaceae (0.85%) are scarcely present. Marshy taxon *Polygonum serrulatum* (2.48-6.94%) is met with consistently much increased frequencies than in the preceding pollen zone, whereas Cyperaceae (1.24-1.38%) is static as before. *Potamogeton* (0.5% in one sample only), *Typha* (1%) and *Utricularia* (6.75%) are encountered occasionally. Fern monolete (0.58-44%) has excessively increased frequencies in contrast to the Pollen Zone NKT-III and trilete (1.28-2.48%) are recorded in low frequencies and do not show any marked change.

Pollen Zone NKT-IV (110-45 cm): *Quercus-Pinus cf. wallichiana-Abies-Betula-Poaceae-Ranunculaceae-Botryococcus-Fern assemblage*

This Pollen zone with the temporal range of 1,872 to 767 yr BP reveals the consistently much high frequency of *Quercus* (4.19-56.8%) with increasing trend. Similarly, *Alnus* (1.39-9.22%), *Betula* (0.7-3.96%), *Ulmus* (1.3-2.3%) and *Corylus* (0.8-1.53%) are also recorded in the improved values than to seen in the preceding pollen zone. The other broad-leaved taxa, *Juglans* (0.4-1.8%), *Salix*, *Symplocos* (1.5% in one sample each) and Meliaceae (0.5% in one sample only) are very scanty. On the other hand, *Pinus* cf. *wallichiana* (11.4-64.3%) portrays a sharp decreasing trend followed by *Abies* (8.2-1.8%) and *Cedrus* (0.8-4.3%), which are extremely low. The shrubby elements, Rutaceae (0.66-3.8%) and Rosaceae (0.38-0.7%), *Strobilanthes* (1.39%) and *Cotoneaster* (0.4% in one sample only) are recorded in variable frequencies. Acanthaceae shows the increased frequencies than in the preceding pollen zone. Among the non-arboreal taxa, Poaceae (5.5-13%), despite of its high frequencies, remains more or less static as before. However, *Artemisia* (1.5-2.9%), Ranunculaceae (1.2-4.87%), Chenopodiaceae/Amaranthaceae (0.81-1.5%) and Tubuliflorae (0.41-0.66%) has slightly increase values. *Lonicera* (1.21-1.33%) and *Jasminum* (0.5%) turn up sporadically for the first time. Marshy taxa, *Polygonum serrulatum* (0.4-1.8%), *Polygonum plebeium* (1.3% in one sample only) and Cyperaceae (0.4-2.3%) become more sporadic in this zone. Fern monolete spores (11-67.8%) decline abruptly, after a short rise in the beginning of this zone. The trilete spores (0.68%-1.7%), in general, are recorded in reduced frequencies. The freshwater alga-*Botryococcus* (2-4.41%) reappears with increased values, after a lapse in pollen zones NKT-II & NKT III, whereas *Potamogeton* (0.7-1.2%) is scarcely present.

Pollen Zone NKT-V (45-0 cm): *Quercus-Pinus cf. wallichiana-Cedrus-Abies-Alnus-Poaceae-Artemisia-Ranunculaceae-Botryococcus-Fern assemblage*

This pollen zone with the temporal interval of 767 yr BP to Present also is characterized by the better representation of *Quercus* (10.3-32.8%), however, with slightly reduced values than Pollen Zone NKT-IV. The broad-leaved associates such as *Alnus* (2-3.5%), *Betula* (1-1.5%) and *Corylus* (0.98-1.5%) demonstrate slightly reduced values, whereas *Juglans* (0.5-1.06% each), *Salix*, Meliaceae (0.49-0.5% each) and *Carpinus* (0.49-0.35%) are sporadic. *Pinus* cf. *wallichiana* (28-41.4%), *Picea* (0.35-1.38%), *Abies* (1-5.6%) and *Cedrus* (1.47-3.15%) are show increasing trend in contrast to Pollen Zone NKT-IV. The shrubby elements, *Cotoneaster* (1-1.47%), Rosaceae (0.49-0.69%) and Rutaceae (0.35-1.96%) are scarce compared to the Pollen Zone-III, though scantily. Among the non-arboreals, Poaceae (3.54-28.5%) dominates, exhibiting increased values in this zone together with *Artemisia* (1.5-5.6%) and Ranunculaceae (3-6.21%). Chenopodiaceae/Amaranthaceae (0.49-1.38%) do not show any change. Cerealia (1.5-2.5%) is met with in increased values than in the preceding pollen zone. However, *Thalictrum* (0.69-1.06%), *Rumex* (0.69%) and Urticaceae (0.7%) are meagrely presented. Marshy element, Cyperaceae (0.71%) is feeble present together with *Polygonum plebeium* (0.69%). *Polygonum serrulatum* (1.38%) is met with slightly improved frequencies, though sporadically. Among the aquatics, *Potamogeton* (0.35-6.21%) do not show any marked changes compared to preceding zone, whereas *Utricularia* (0.35%) reappears after a lapse in the Pollen Zone NKT-IV, though meagrely. However, the freshwater alga-*Botryococcus* (1.38-9.65%) attains somewhat increased values. Fern producing monolete spores (35.3-40.07%) are marked by an increasing trend with high frequency than before. On the other hand, trilete spores (0.35-1.96%) are infrequent.

DISCUSSION

The changes in Quaternary palynofloras are typically ascribed to the changing climatic patterns that affected the entire earth (Wrigth & Frey, 1965). The pollen diagram of this profile reveals a good floristic diversity. However, the diagram is mainly dominated by *Quercus*, *Pinus*, Poaceae, Cyperaceae and algal spores. As discussed earlier, the contrasting climatic requirements of *Quercus* and *Pinus* and high fluctuations in their percentages justify using the Q/P ratio as an important parameter for climate interpretation (Fig. 3). Inferred climate trends are also based on local hydrological conditions deduced from percentages of Cyperaceae pollen, fern spores, aquatic plants and algal spores.

The pollen analytical investigation of 3.06 m deep sedimentary profile from Nachiketa Tal located in the temperate zone of Garhwal Himalaya have provided some interesting inferences concerning the vegetation shifts and climatic variability in the region since Mid- Holocene Period. The pollen sequence has deciphered that around, 5,304 to 3,912 yr BP (Pollen Zone NKT-I), the temperate belt of this region supported mixed Pine-Oak forests in which *Pinus* cf. *wallichiana* was the major component, however oak woods were confined in pockets and depressions, where moist and shady condition prevailed. The other high altitudinal conifers such as *Abies* and *Cedrus* also flourished well in the region, whereas the close associates of oak, viz. *Ulmus* and *Betula* occurred sparingly. The overall vegetation mosaic reflects that this region was under a cold and dry climatic condition owing to reduced monsoon precipitation. The herbaceous flora on the forest floor was largely constituted of grasses (Poaceae) along with Chenopodiaceae/Amaranthaceae, *Thalictrum* and Ranunculaceae. Ferns grew in isolated patches in shady and damp situations in the proximity of the lake. The record of aquatic element-*Potamogeton* with moderate values together with alga-*Botryococcus* suggests the existence of the lake of moderate dimension during this period.

Between 3,912 to 2,875 yr BP (Pollen Zone NKT-II) the drastic improvement in *Quercus* and a simultaneous reduction in *Pinus* cf. *wallichiana* and other high altitudinal taxa, viz. *Cedrus* and *Abies* suggest the replacement of pine-oak broad-leaved forests by mixed oak-broad-leaved forests. This is also indicated by the increase in Q/P ratio. The mixed oak-broad-leaved forests became diversified in composition as clearly manifested by the invasion of a large number of other associated broad-leaved taxa such as *Juglans, Rhododendron, Salix, Symplocos* and Meliaceae for the first time together with the shrubby elements, Rosaceae and Rutaceae. This significant change in the vegetation scenario occurred in response to onset of a warm and humid climate attributable to prevalence of active monsoon precipitation. The beginning of this phase coincides with the Period of Climatic Optimum, which has been globally recorded between 9,000 to 3,000 yr BP (Bradley, 1999). This is also substantiated by the decline in grasses (Poaceae), paving the way for the proliferation of oak forests. Similarly, the low value of the local wetland members, sedges (Cyperaceae), *Polygonum serrulatum* and *Polygonum plebeium* further indicates that the marshy ground was virtually submerged under high water. Fern continued to flourish well in moist and damp habitats as witnessed in the preceding phase.

Around 2,875to 1,872 yr BP (Pollen Zone NKT-III) the expansion in *Pinus* cf. *wallichiana* together with moderate increase in other temperate conifers such as *Cedrus*, *Abies* and *Picea*. On the other hand, *Quercus* declined sharply and its broad-leaved-associates, viz. *Juglans*, *Alnus*, *Betula*, *Ulmus*, etc. turned more sporadic than before. This apparent change in the overall vegetation pattern elucidates that the *Pinus* cf. *wallichiana* dominated conifer forest succeeded the mixed oak- broad-leaved forests as a consequence of change in climate condition which became cold and dry with the commencement of this phase of reduced monsoon precipitation. This is also well corroborated by the decreased Q/P ratio. The herbaceous vegetation on the forest floor was largely constituted of grasses only since pine and conifer forests altogether are devoid of other herbaceous undergrowths. The lake got shallower as reflected by scanty presence of aquatic elements, viz. *Potamogeton* and *Utricularia* and total absence of *Botyrococcus* as compared to witnessed in the preceding phase. However, the widening of the swampy condition along the lake margin took place owing to prevailing harsh climate as clearly indicated by the much increase in *Polygonum serrulatum*.

Between 1,872 and 767 yr BP (Pollen Zone NKT-IV) amelioration in climate is reflected which most likely became warm and humid. This is well manifested by the sudden improvement in *Quercus, Salix, Symplocos* and Meliaceae as well as substantial decline in *Pinus* cf. *wallichiana* and other conifers, viz. *Cedrus*, *Abies* and *Picea* during this phase. Replacement of mixed pine forest by mixed oak-broad-leaved forest further supports the amelioration in climate. The improvement in shrubby elements such as Rosaceae, Rutaceae and Acanthaceae also occurred on account of amelioration in climate. The better representation of aquatic elements such as *Typha* and reappearance of freshwater alga- *Botryococcus* and reduction in sedges are indicative of the rise in lake water-level with low marshy condition along the lake margin due to increased precipitation during this period. The first encounter of cerealia pollen and the improvement seen in other culture pollen taxa such as Chenopodiaceae/Amaranthaceae, *Artemisia*, Caryophyllaceae, Urticaceae, etc. demonstrate that during this phase the adjoining area around the lake site was under agricultural practice and the impact of intensive biotic pressure.

PLATE 1 ⟶

1. *Abies*
2. *Cedrus*
3. *Pinus*
4, 5. *Quercus*
6. *Symplocos*
7. *Betula*
8. *Corylus*
9. *Alnus*
10, 16. Meliaceae
11. *Juglans*
12. *Ulmus*
13. *Rhododendron*
14. *Convolvulus*
15. *Strobilanthes*
17. *Cannabis sativa*
18. Brassicaceae
19. *Artemisia*
20. Cheno/Am
21. Poaceae
22. Cerealia
23. Caryophyllaceae
24. Tubuliflorae
25, 26 *Polygonum serrulatum*
27. Cyperaceae
28. *Utricularia*
29. Fern trilete
30. Fern monolete
31. *Botryococcus*
32. *Potamogeton*


1
2
3
50 µm
4
10 µm
5
10 µm
6
20 µm
7
20 µm
8
20 µm
9
20 µm
10
20 µm
11
12
20 µm
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20 µm
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20 µm
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2 µm
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20 µm
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20 µm
21
5 µm
22
23
20 µm
24
2 µm
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26
27
2 µm
28
20 µm
29
5 µm
30
31
20 µm
32
20 µm

PLATE 1

Since 767 yrs BP onwards (Pollen Zone NKT-V), the landscape continued to be occupied by the mixed oak-broad-leaved forests. However, the forests got less diversified than earlier as envisaged by the relatively reduced frequencies of *Quercus*. Similarly the other broad-leaved taxa and shrubby elements also declined with the onset of this phase. Contrary to this the moderate expansion of *Pinus* cf. *wallichiana* and other conifer also occurred by this time. The overall vegetation mosaic portrays that the region experienced a warm and less humid climate as a consequence of moderate monsoon precipitation. However, the selective felling or clearance of oak forests by the local inhabitants to meet out their various requirements cannot be ruled out. During this period, the lake probably turned smaller and shallower in dimension and the marshy margin got wider all along the lake in response to the reduction in the monsoon precipitation. This is well testified by the fact that important aquatic elements, viz. *Potamogeton* and freshwater alga-*Botryococcus* show decreased frequencies than witnessed in the preceding phase. Concurrently, the acceleration of the agriculture practice in the region also took place probably to cope with the food security of escalating human population in the region during the recent past. This is well documented by the frequent recovery of Cerealia and other culture pollen taxa right from the onset of this phase.

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