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The Early Holocene vegetation and climate in Naradu Glacier Valley of Kinnaur District, Himachal Pradesh

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ABSTRACT

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The pollen record recovered from a 2.5 m thick glacio-lacustrine deposit at 4,125 m a.m.s.l in the Naradu Glacier Valley, Kinnaur District reveals the Early Holocene vegetation and climatic history of the region for about 1,650 years. The high percentage of pollen of extra local elements, both conifers and broad-leaved taxa along with good amount pollen of local trees, shrubs and herbs indicate that tree line ecotone zone might have been closer to the site due to improved climatic conditions compared to present. This is attributed to the effect of the strengthening of SW monsoon in India. However, an increase in local steppe elements around 10,640 yrs B.P. (12,720 Cal yrs B.P.) and 8,990 yrs B.P. (10,190 Cal yrs B.P.) suggests that the climate was comparatively less moist. This phase around 12,720 Cal yrs B.P. could possibly be linked to the Younger Dryas, a well-known global event.

Key-words—Pollen analysis, Naradu Glacier lake, Early Holocene, Younger Dryas, Himachal Pradesh.

हिमाचल प्रदेश में किन्नौर जिले की नराडु हिमनद घाटी की प्रारंभिक होलोसीन वनस्पतिजात एवं जलवायु

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सारांश

किन्नौर जिले की नराडु हिमनद घाटी में समुद्र तल की औसत माध्यम ऊँचाई 4125 मी. पर निक्षेपित 2.5 मी. मोटी हिमसरोवरी से प्राप्त परागकण अभिलेख से इस क्षेत्र का लगभग 1,650 वर्षों का प्रारंभिक होलोसीन वनस्पतिजात एवं जलवायु इतिहास प्रकट होता है। अन्य स्थानीय तत्वों के परागकण की उच्च प्रतिशतता, स्थानीय वृक्षों, झाड़ियों एवं शाक की प्रचुर परागकण मात्रा सहित शंकुवृक्ष व चौड़ी-पत्ती वाले दोनों वर्गकों से इंगित होता है कि पेड़ कतार संक्रमिका क्षेत्र वर्तमान की तुलना में विकसित जलवायवी स्थितियों के कारण स्थल से निकट रहे होंगे। यह भारत में दक्षिण-पूर्व मानसून की मजबूती का प्रभाव देता है। फिर भी, 10,640 वर्ष पूर्व (12,720 अंशाकित वर्ष पूर्व) तथा 8,990 वर्ष पूर्व (10,190 अंशाकित वर्ष पूर्व) के लगभग स्थानीय स्टेप तत्वों में वृद्धि प्रस्तावित करती है कि जलवायु तुलनात्मक अल्प आर्द्र थी। लगभग 12,720 अंशाकित वर्ष पूर्व के इस चरण का संबंध संभवतः, सुविख्यात भू-मंडलीय घटना तरूण ड्रयाज से रहा होगा।

संकेत-शब्द—परागकण विश्लेषण, नराडु हिमनद झील, प्रारंभिक होलोसीन, तरूण ड्रयाज, हिमाचल प्रदेश।

INTRODUCTION

KINNAUR, Himachal Pradesh, northwestern part of the Himalaya is well known for its varied Quaternary sediments, which are represented by glacial, fluvio-glacial, fluvial, lacustrine and unconsolidated to semi-consolidated scree fan/talus deposits. These deposits are distributed in the inner reaches as basinal/ valley fills and along the foot of the mountains (Sharma, 1976). Some palynological data is available from the western Himalaya (Bhattacharyya, 1988; Bhattacharyya & Chauhan, 1997; Chauhan *et al.*, 1997; Kotlia *et al.*, 1997, 2000; Phadtare, 2000; Ranhotra *et al.*, 2001; Sharma & Chauhan, 1988) but very little is known from the alpine regions of Kinnaur. The glacio-lacustrine sediments at Kinnaur are suitable archive for pollen analyses to reconstruct the past vegetation and climate of this region.

The present paper deals with the pollen analysis to understand the vegetation vis-à-vis climate during Early Holocene from a 2.5 m thick glacio-lacustrine deposit exposed at an altitude of 4,125 m a.m.s.l in the Naradu Valley, Himachal Pradesh (Fig. 1).

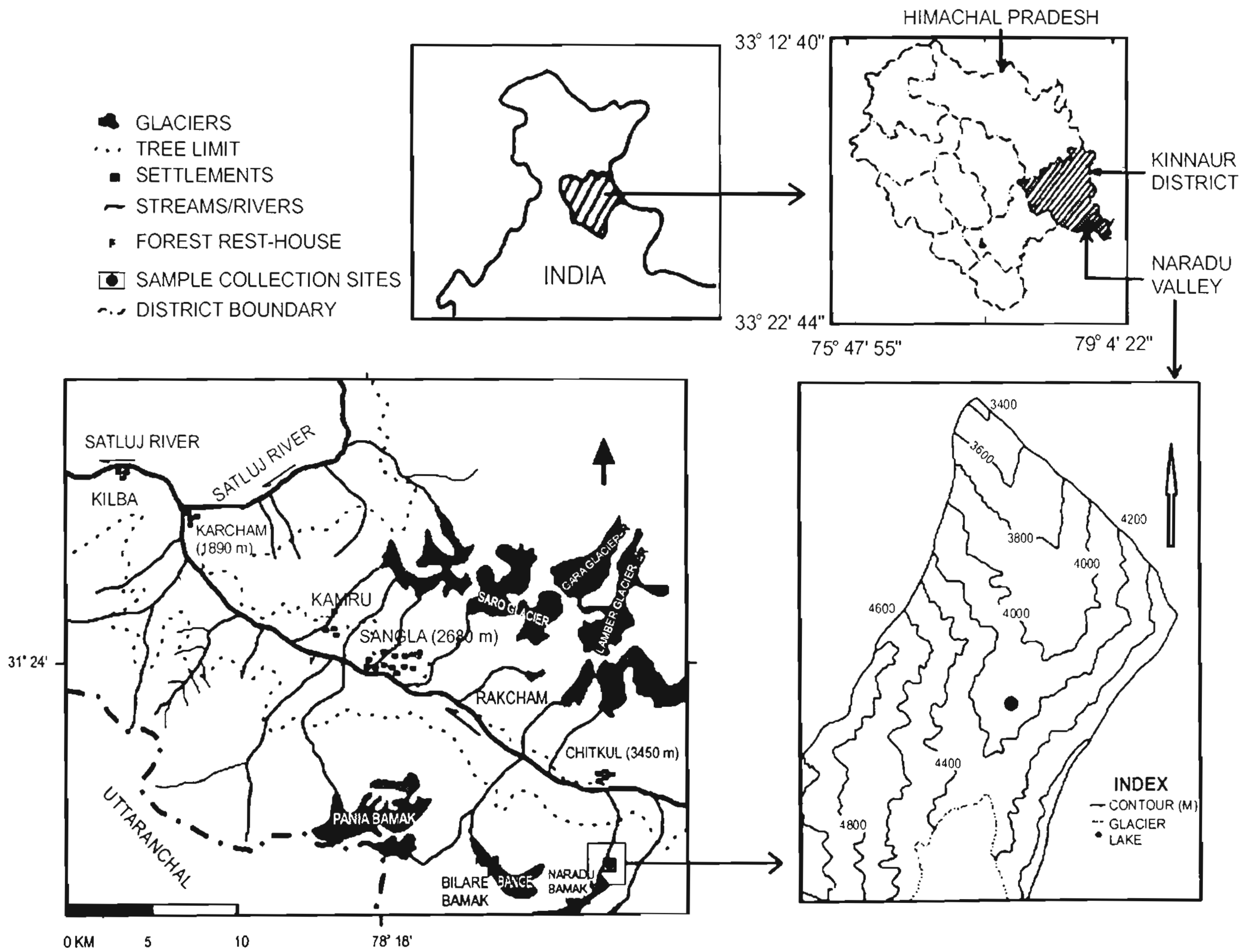

Fig. 1—Location map of study area showing the site of palaeolake sediments exposed at 4,125 m a.m.s.l. in periglacial area of Naradu Glacier.

AREA OF STUDY

The SW-NE trending Naradu Glacier Valley is situated in the Sangla Tehsil of Kinnaur District, Himachal Pradesh. The Naradu Glacier is north facing with the present snout position being located at 4,325 m a.m.s.l. The total area of the valley covers about 23.12 sq. km. It is narrow in outline and ascends from the height of 3450 m a.m.s.l at Chitkul – a small village at the road head that connects it with Sangla town. Naradu Garang, originating from the melt-waters of the glacier, forms the main perennial drainage that bisects the valley before meeting the trunk stream Baspa, a tributary of the Sutlej River (Fig. 1).

The Naradu Glacier is located in a critical zone in the confluence of warm-moist monsoonal circulation and cold-dry airflows. It is influenced both by the Asian summer and winter monsoon and by the Westerlies.

The Quaternary deposits are represented by glacial to fluvio-glacial sediments sporadically distributed throughout the valley. The lateral and end moraines are well preserved near the mouth of the glacier valley, which is narrow at an altitude of 4,100 m a.m.s.l and opens into a broad U-shaped valley at an altitude of 4,000 m a.m.s.l where the lateral and end moraines coalesce.

The lake deposits, which are well exposed in the higher reaches (above 4,100 m a.m.s.l) closer to the right lateral moraines, reflect a less well-ordered lake system in dead ice filled basin. These deposits consist of the following two facies; alternating sequences of diamict, sand and gravel some of which are weakly cross bedded, and rhythmically bedded sand and/or silt and clay or varves, displaying proximal-distal fining trends. The upper most sediment of the lake is massive gravel rich diamict. The diamict facie shows weak sorting. Texturally the finer fraction of lake sediment is silty sand. The silty sand is moderately to poorly sorted, finely to symmetrically skewed and mesokurtic to leptokurtic.

The entire thickness of the periglacial lacustrine sediment, exposed at the site, is nearly 4 to 5 m, but the palynological study is based on the analyses of samples collected from the finer fraction, which is barely 2.40 m thick and forms only a part of the whole deposit (Fig. 2). This finer fraction of the sequence consists of clay/silt with occasional 5 to 20 cm thick layers of fine sand. Also two "frozen" layers have been encountered, one at the base of the profile at the depth of 240 cm and other one from 100 to 145 cm depth (Figs 2 & 3). These are the frozen grounds and the presence of ice crystals within these layers of the lake sediments have been used as direct evidence to identify the permafrost belt in Naradu Glacier Valley. The samples were collected at certain depths from fine sand and clay/silt zones only, both for pollen and radiocarbon dating.

Fig. 2—Profile of the palaeolake sediments exposed along the right bank of Naradu Garang.

MODERN VEGETATION AND CLIMATE

The distance from the tree line to this palaeo-lake site is approximately 4 km and the whole area is characterised by alpine meadows, which are represented predominantly by herbaceous elements and scattered small trees and bushes. The later are represented mainly by stunted *Juniperus, Ephedra* and *Artemisia*. The herbaceous taxa consist mostly of Asteraceae, Primulaceae, Crassulaceae, Scrophulariaceae, Ranunculaceae, Saxifragaceae, Brassicaceae, Caryophyllaceae and Chenopodiaceae. *Betula utilis* (Birch or Bhojpatra) forms the tree line at the altitude of 3800 m. Just below the birch belt is the sub-alpine conifer and broad-leaved forest, which are characterised mainly by Fir, Pine, Spruce, Oak, *Acer caesium*, *Ulmus wallichiana*, *Juglan* sp., *Celtis australis, Carpinus viminea,* etc.

Climate data only for two years 1990-91 have been recorded from the Automatic Weather Station, which has been installed recently under DST sponsored project close to the site. These data reveal that July is the warmest month with temperature ranging from 14°C to 18°C. The coldest month is February having temperature –18°C to –20°C. High wind speed 1-20 km/hour with average being 5.5 km/hour blows generally 25° to 45° N. Precipitation especially during July and August is high due to intense southwest monsoon and it varies greatly within short distances. It is around 1775 mm close to the site and above 4200 m, it is in the form of snow but exact amount is not known.

MATERIAL, METHODS AND RADIOCARBON DATES

The study is based on the analyses of glacio-lacustrine sediments collected from a 2.5 m thick profile (Fig. 3). This deposit mainly consists of clay/silt with occasional lenses of sand. These clay/silt deposits are interbedded with 5 to 20 cm thick layers of sand. The lake deposit is capped by 3 to 5 m thick gravel with accumulation of sand indicating period of relatively quiescent sedimentation as gravelly and sandy deposits represent two different regimes of fluvial system.

The samples for palynological analysis were collected at the interval of 5 cm from the layers of clay/silt and sand. These samples were macerated using standard procedure of acetolysis (Erdtman, 1943). The position of the samples analysed for pollen and radiocarbon dates have been shown in the litholog along with the pollen diagram (Fig. 3). About 200-300 pollen/spores per sample were counted. This was taken as "Total Pollen Count", which includes both "local elements" and "extra local elements". The taxa, belonging to extra local elements are growing in the lower valley and their pollen grains are carried to the site by the upthermic wind. *Betula, Juniperus* and other shrubs and herbs that grow mostly close to the site, are deposited in the lake sediments, which are considered here the local pollen taxa. In the percentage calculation of pollen taxa, the pollen number of extra local elements was excluded from the total pollen count to make "Pollen Sum" of each sample. Percentage frequency of pollen taxa of each local element is determined in terms of Pollen Sum; whereas to avoid the over representation of extra local pollen taxa, their percentages are calculated on total pollen count and plotted in the diagram. The pollen taxa, which are sporadic to less than one percent are represented by plus sign.

Two radiocarbon dates viz., (BS- 2007) 8,990 ± 410 yrs B.P. (10,190 Cal yrs B.P.) and (BS-1947) 10,640 ± 880 yrs B.P. (12,720 Cal yrs B.P.) at the depth 35-40 cm and 230-235 cm respectively suggest that sediments were deposited probably during the transition of Pleistocene to Holocene or the early part of the Holocene. The two radiocarbon dates are calibrated to calendar years using radiocarbon calibration program (Stuiver & Reimer, 1993). It is evident from these two dates that the rate of sedimentation is high and the 2.5 m lake sediments were deposited during slightly more than 1500 years. To mark some important changes in the pollen assemblages, the ages at some depths are interpolated based on linear regression of these two ^{14}C dates. Based on the assumption of a linear sedimentation rate, the three interpolated ages are: 10,466 ± 830 yrs B.P. (12,136 Cal yrs B.P.), 9,900 ± 669 yrs B.P. (11,460 Cal yrs B.P.) and 9,511 ± 558 yrs B.P. (10,920 Cal yrs B.P.) at the depths of 210, 145 and 100 cm respectively.

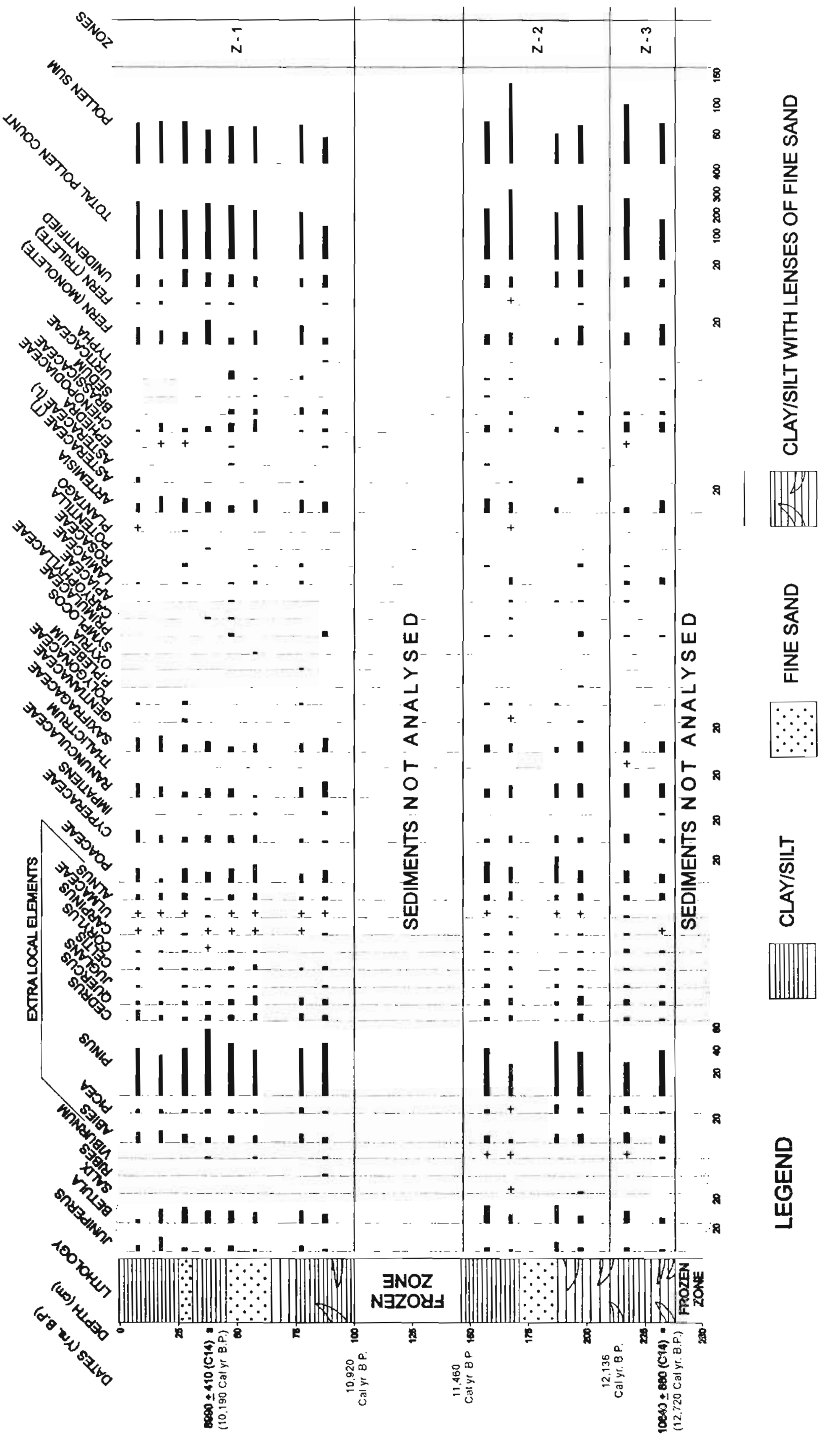

Fig. 3—Pollen diagram from Naradu Glacier area, Kinnaur, Himachal Pradesh.

EARLY HOLOCENE VEGETATIONAL AND CLIMATE HISTORY

The pollen diagram (Fig. 3) shows a good representation of both extra local pollen as well as local arboreal and non-arboreal pollen taxa. The pollen diagram has been divided into three zones i.e., Pollen zone 1-3 based on the variation of some key pollen taxa. Due to large sample-interval in the pollen diagram, the precise demarcation of the boundary of these zones has not been possible. These zones are described below.

Pollen Zone-3—This zone (at the bottom) includes two samples, which are from depth 2.40 to 2.10 m and having dates around 10,640-10,466 yrs B.P. (12,720 to 12,136 Cal yrs B.P.). Among pollen of non-arboreal taxa, Chenopodiaceae (9%), *Artemisia* (4-10%), Ranunculaceae (10-11%), Saxifragaceae (8%), fern (11-18%), Cyperaceae (3-9%) and Poaceae (8-12%) represent high concentration. The dominating arboreal taxa include conifers in which *Pinus* (28-37%) is represented by higher values over other conifers. The other taxa are *Betula* (4-11%), *Juniperus* (1-4%), *Quercus* (3-4%), *Alnus* (4-6%), *Celtis* (2%), etc.

Pollen Zone-2—This zone represents the interval from 2.10 to 1 m and is assumed an age interval from 10,466 to 9,900 yrs B.P. (12,136 to 11,460 Cal yrs B.P.). In comparison to zone-3, here Chenopodiaceae (2-5%) shows decline in its frequency. There is wide range in Ranunculaceae (6-13%) and Saxifragaceae (5-10%). Among other taxa, Poaceae (8-27%) represents sharp increase with maximum values at the base of this zone. Cyperaceae (4-7%) and *Artemisia* (4-10%) do not show much change, whereas ferns (7-16%) show little variation. Amongst arboreal taxa, *Pinus* (28-47%), *Juniperus* (2-9%), *Betula* (6-15%), *Alnus* (4-9%), *Quercus* (3-7%) and *Celtis* (2-5%) show an increase in their values in comparison to Pollen Zone-3. This zone is also marked by the appearance of *Salix* (2%).

Pollen Zone-1—This zone from the depth 1 m to top of the profile, dated around 9,500 yrs B.P. (10,900 Cal yrs, B.P.) onwards, shows an increase of Chenopodiaceae (2-10%) in some of the samples in relation to the previous zone, but the value is low (2%) in two samples just above the frozen layer. *Artemisia* (6-13%) is also towards higher side and *Ephedra* (1-2%) represents meagrely. Ranunculaceae (2-12%) shows a little decline while Saxifragaceae varies between 5-12%. Cyperaceae (3-11%) and fern spores (2-21%) show some increase. However, there is decline in Poaceae (4-16%) by few percent. *Pinus* (36-57%) shows some increase in this zone but one sample in the middle of the profile is represented by 57%. *Juniperus* (2-12%) registered little change, but *Betula* (3-13%), *Alnus* (2-7%), *Celtis* (1-3%) and *Quercus* (2-6%) exhibit a minor decline in comparison to the Pollen Zone-2.

The available data on modern pollen/vegetation relationship of the high altitude region of the western Himalaya (Bhattacharyya, 1989a, b) has been taken as a guideline to interpret these pollen spectra (i.e., percent representation of individual pollen taxa plotted per sample) in terms of the past vegetation. The comparison between modern and fossil pollen sedimentation at the present site shows that the higher amount of pollen of sub alpine/temperate elements i.e., taxa of lower elevations has masked the pollen population of local taxa in all samples. Good representation of extra local elements in the past also suggests that there is possibility of the upward movement of the forest elements closer to the site under ameliorating conditions of climate. On the contrary, low concentration of extra local elements represents cooler and drier conditions when the glacier snout and corresponding tree line might have also descended to lower elevations. The overall good amount of extra local elements together with the local taxa recorded in the Naradu Valley, suggest that the area was close to tree line or just above it during the Early Holocene.

At the beginning of the post-glacial period (in Zone-3) i.e., around 10,640 yrs B.P. (12,720 Cal yrs B.P.), the comparatively high values of Chenopodiaceae, *Artemisia* and corresponding low values of conifers and broad leaved taxa suggest comparatively cooler and less moist climate than the following period. Subsequently, from about 10,466 yrs B.P. (12,136 Cal yrs B.P.) in Zone-2, the climate turned to be warm and moist as indicated by the low values of Chenopodiaceae and simultaneous increase of conifers, *Betula, Alnus* and *Salix*. This amelioration in climate is also supported by some increase in Ranunculaceae, Saxifragaceae and Poaceae. Later on, around 9,500 yrs B.P. (10,900 Cal yrs B.P.) in the Zone-1, increase in Chenopodiaceae, decline of Poaceae, Cyperaceae, Ranunculaceae, Saxifragaceae and broad-leaved taxa and appearance of *Ephedra*, which was sporadic in lower zones suggest that the area had relatively drier conditions than the Zone 2.

DISCUSSION AND CONCLUSION

The pollen record recovered from the 2.5 m thick lacustrine section provided a broad idea of the vegetation and climate during the Early Holocene. Though the pollen data in this study provide information for only a short time span (1,650 yrs), it holds great significance as there are not much data available covering this period by dated sediments from periglacial regions of the Himalaya. The high amount of pollen of extra local elements, especially *Pinus,* from the lower elevations along with a good amount of local trees/shrubs and herbs suggest that the site was not only closer to the tree line but the area itself had good coverage of alpine taxa. These, in turn are suggestive of upward movement of the forest cover and the area possibly experienced warm and moist climatic conditions similar to those of the present. The presence of Poaceae, Ranunculaceae, Saxifragaceae and other herbaceous taxa also indicates the spreading of these local elements along the margin of the lake. The ferns colonising the vast area of the region through out the Early Holocene also indicate moist climate. Evidence of wet climatic conditions during this time span has also emerged from other studies. The high influx of sediments of the Ganges–Brahmaputra under higher river discharge also supports increase of monsoon during the Early Holocene (Goodbred & Kuehl, 2000). Northern and equatorial Africa also experienced increased monsoon during this period (Beuning *et al.*, 1997; Gasse, 2000; Russell *et al.*, 2003; Talbot *et al.*, 1984). This wet phase is believed to be the result of enhanced monsoon circulation driven by precessional orbital forcing coupled with oceanic and vegetation feedbacks that amplified land-sea contrast (Clausen *et al.*, 1999; Kutzback *et al.*, 1985; Overpeck *et al.*, 1996). However, the moist phases in Kinnaur were interrupted by two short phases when climate seems to be less moist as indicated by some increase in steppe elements (Chenopodiaceae, *Artemisia, Ephedra*) and low values of sub-alpine to temperate elements recorded in the sediments. This is also further corroborated with the presence of two frozen layers in the profile: one in the middle around 11,460 to 10,900 Cal yrs B.P. and the other at the bottom around 12,720 Cal yrs B.P. Both the layers precede the corresponding sediments of pollen spectra, which indicate comparatively less moist climatic condition. One dry phase around 12,720 Cal yrs B.P. might be contemporaneous to the Younger Dryas episode, which is well recognised in many parts of the globe (Birks & Birks, 1980; Bradley, 1999; Lamb, 1977) and also within India from Rajasthan (Kar *et al.*, 2001), Ganga Plain (Sharma *et al.*, 2004), Bay of Bengal (Chauhan & Suneethi, 2001; Chauhan *et al.*, 2004) and Himalayan region (Juyal *et al.*, 2004; Sinha *et al.*, 2005). However, due to uncertainties and large error range exhibited in radiocarbon dates of the present sediment profile it could not be interpreted precisely whether this dry spell due to impact of Younger Dryas or not. The other period having comparatively arid condition during the Early Holocene has been noted around 10,190 Cal yrs B.P.

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