pilgrimage centres that attract a large number of people from across the country and abroad. Improved road safety conditions in the region would boost tourism, which is one of the major sources of revenue for the Himalayan States and thus contribute to the welfare of the masses.

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The past 26,000 years evolutionary history of Keoladeo National Park (Ghana), Rajasthan

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Pollen analysis of a 4.4 m trench dug out from the Keoladeo National Park (Bharatpur district, Rajasthan) situated on the western edge of the Gangetic Plains has revealed that around 26,000 yrs BP, the area was a thick forest dominated by *Holoptelea* under moist climate and good monsoon, reflecting an interstadial period. The next phase between 20,000 and 14,000 yrs BP had witnessed a barren zone with no trace of any pollen deposition. This could be attributed to poor preservation of pollen during the course of sedimentation, most likely due to the drying of the lake during the Last Glacial Maximum period. This was followed by favourable humid conditions and good vegetation cover in the region. Gradually this huge lake turned into a wetland.

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RAJASTHAN in western India is known for its vast stretch of desert. Initiation of desert conditions and temporal change in its geographical coverage has always invited the attention of geologists, palaeoclimatologists, ecologists and geomorphologists. Quaternary vegetation succession and corresponding climatic fluctuations in the region are known through various studies[1–10].

Most of the work carried out in the region covers the western part of the Rajasthan desert. Eastern Rajasthan has not received due attention for similar Quaternary palaeoclimatic studies despite the fact that there exist a number of potential lake sites. The present communication provides palaeoclimatic proxy data and vegetation succession in the region reflecting climatic changes covering the past 26,000 yrs or so, inferred through the investigated sediment profile from the Bharatpur Bird Sanctuary (Keoladeo National Park) wetland – a World Heritage Site, which lies at the western edge of the Gangetic Plains. The Keoladeo National Park (27°7′6″–27°6′2″N and 77°29′5″–77°33′9″E) is about 2 km southeast of Bharatpur, 50 km west of Agra and 150 km south of Delhi (Figure 1). The wetland or the natural sanctuary depression covers about 29 sq. km area, of which 11 sq. km is marshy land and the rest is scrubby with a thick growth of grass.

The wetland of the sanctuary turned completely dry during 1999–2002, probably for the first time in its history, because of successive monsoon failure. This made it feasible to dig out a 4.4 m deep trench at the selected site for palynological investigations.

Vegetation of Rajasthan[11–17] covering Bharatpur and its nearby forested Park region[18–20], has been thoroughly worked out. The Park is a protected forest area and the vegetation comprises mostly scrub woodland, littered with shrubby thickets, climbers and medium-sized arboreal elements to make it a savannah-type open grassland. The luxuriance of the wetland vegetation is reflected through copious growth of free-floating, rooted amphibious and marshy taxa[21]. About 400 species of flowering plants are recorded from the Bharatpur region, of which nearly one-fourth inhabits the wetland area[22].

The Bharatpur region experiences moderate climatic conditions typical to the upper Gangetic Plains. The temperature varies from 5 to 45°C – the minimum in December–January and maximum in May–June. Onset of monsoon brings down the summer temperature to as low as 27°C, which generally continues till October. Average rainfall in the area calculated for the past 100 yrs is 655 mm, showing gradual decline as demonstrated by the annual rainfall witnessed during the last one decade which now stands only at 496 mm.

A 4.4 m deep trench was dug out from the completely desiccated main wetland (Figure 2) in order to expose the sediment profile. In all 44 samples were collected from

the trench at an interval of 10 cm each for pollen analysis. In addition, eight samples for radiocarbon dating were also collected from suitable horizons of the sediment profile. Beyond 4.4 m depth, sample collection was not possible as water started oozing out.

The collected samples were treated with 10% aqueous KOH solution to deflocculate the pollen/spores from the sediments, followed by 40% HF treatment to dissolve silica content. Thereafter, the conventional procedure of acetolysis[23,24] was followed using acetolysis mixture (9 : 1 acetic anhydride and concentrated sulphuric acid). Finally, the material was kept in 50% glycerine solution for microscopic examination. A few drops of phenol was also added to the glycerine solution to protect the processed material from microbial contamination.

The investigated profile is delineated into six distinct litho zones. The thickest top zone is black clay, below which is the thinnest sandy zone followed by yellowish silty clay, brownish clay, yellowish-brown silty clay and then the bottom zone comprised of sandy material (Table 1).

Among the eight samples collected for radiocarbon dating, only three have yielded radiocarbon dates. The sample from the top has proven to be modern. Details of radiocarbon dates are given in Table 2.

Based on the available three radiocarbon dates from different depths of the wetland profile, two sedimentation rates have been calibrated from the lower and upper horizons, i.e. 1 cm/63 yrs for 2.50–4.40 m depth and 1 cm/2 yrs for 0.55–1.55 m depth. These sedimentation rates have been utilized to extrapolate the age of well-demarcated pollen zones identified in the pollen diagram and to decipher vegetational change and corresponding climatic shifts in the specific time-frame. The calibrated dates at different profile depths are 26,460 yrs BP at 4.4 m depth, 20,160 yrs BP at 3.20 m depth, 13,860 yrs BP at 2.20 m depth, 2610 yrs BP 1.6 m depth and 2550 yrs BP at 1.30 m depth. This may not be precise and ^{14}C dates on closer intervals may be needed; however these are not available.

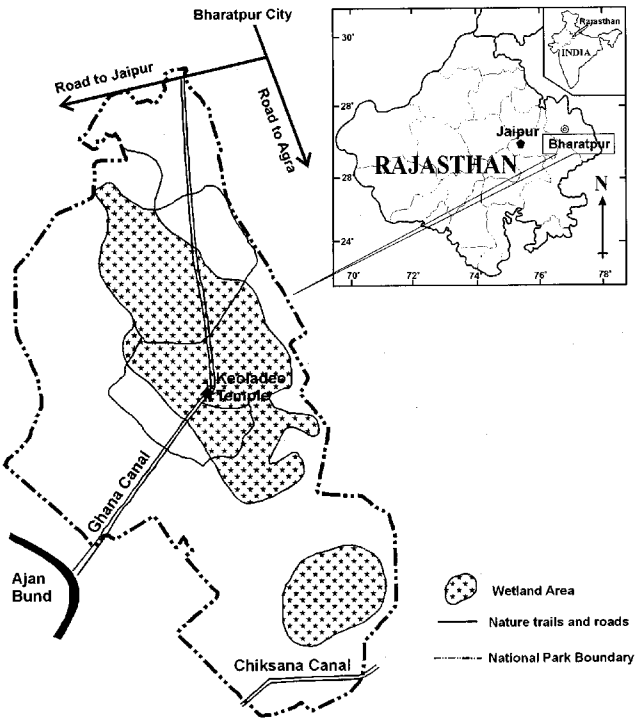

Figure 1. Map of Keoladeo National Park (Ghana), Bharatpur, Rajasthan.

The constructed pollen sequence from Ghana wetland is delineated into five distinct pollen zones, viz. BP-I to BP-V on the basis of fluctuations witnessed in the representation of prominent arboreal and non-arboreal taxa. The prefix BP stands for Bharatpur and the zones are numbered I–V from the bottom upwards.

Pollen sum is based on total terrestrial pollen, excluding those of aquatics and spores of ferns, moss, fungi and algae. Most of the analysed samples in the profile were found palynologically productive. However, some of the samples were barren and with few pollen and spores. Pollen sum ranges from 150 to 250, except in some samples where total count is either more than 250 or less than 150, depending upon the recovery of palynomorphs.

The low pollen count in some of the samples can possibly be attributed either to the scanty vegetation cover or poor pollen preservation. The encountered plant taxa have been grouped in the pollen diagram as trees, shrubs, herbs, aquatics, ferns, bryophytes, fungi and algae.

Pollen zone BP-I (4.40–3.20 m): *Holoptelea*–Myrtaceae–Sapotaceae-Urticaceae–grasses–Cheno/Am assemblage. This zone covering the timespan of 26,460 to 20,160 yrs BP shows high values of *Holoptelea* (20–80%) followed by other tree taxa such as Myrtaceae (2–15%) represented consistently in good frequencies. Sapotaceae (2–10.5%) and Rubiaceae (2–4%) are also recovered, but sporadically and in moderate values. However, arboreals like *Azadirachta*, Bombacaceae, Caesalpiniaceae, Capparidaceae,

Table 1. Profile of sampled zone

Depth (cm)	Lithology
0–180	Black clay
180–200	Slightly sandy
200–250	Yellowish silty clay
250–270	Brownish clay
270–290	Yellowish-brown silty clay
290–440	Sandy material

Table 2. Radiocarbon dates

Sample (depth in cm)	Laboratory reference number	^{14}C dates yrs BP
0–10	BS-2170	Modern
50–60	BS-2187	2400 ± 120
150–160	BS-2186	2600 ± 100
250–260	BS-2169	15,990 ± 960
350–360	–	No date
390–400	–	No date

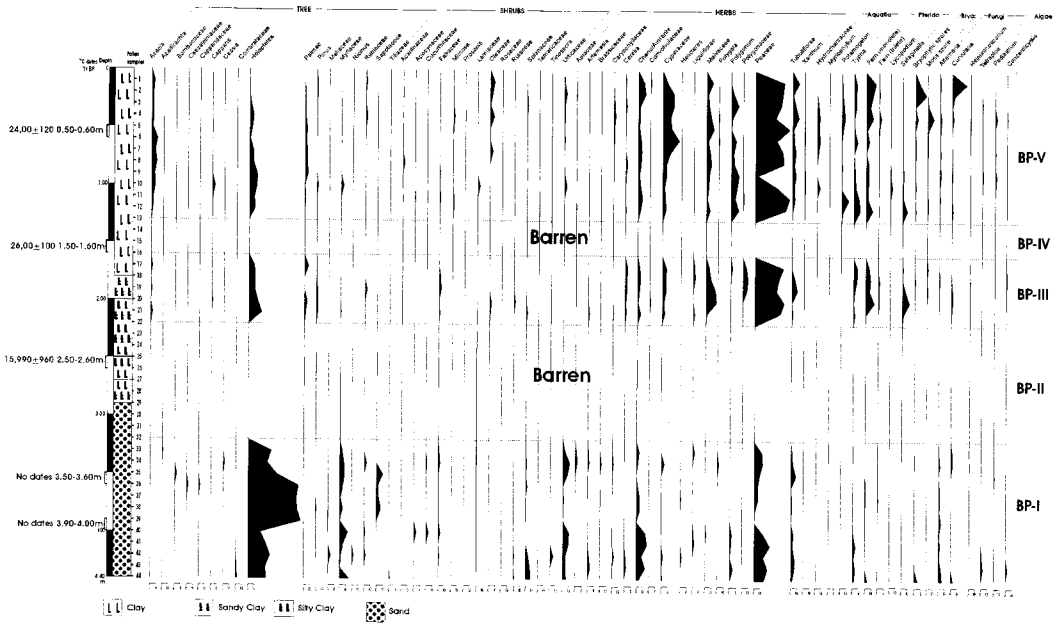

Figure 2. Pollen diagram from Keoladeo National Park, Bharatpur, Rajasthan. (Percentage calculated in terms of total terrestrial pollen.)

Cassia, Combretaceae, Meliaceae, *Ricinus* and Tiliaceae (1%) are encountered in extremely low numbers.

Among the shrubby elements, Urticaceae (1–11%), Solanaceae (2–7.5%) and *Tinospora* (1–9.5%) are represented in moderate values though sporadic. Fabaceae, Oleaceae and Rutaceae are recorded occasionally.

Non-arboreals such as Poaceae and Cheno/Am are represented as major constituents and Tubuliflorae is marked by its consistent presence though in moderate to low frequencies. Other herbaceous taxa, viz. *Artemisia*, Brassicaceae, Caryophyllaceae, Cerealia, Helicteres, Liguiliflorae and Rumex (1–4%) are also present but meagre.

Marshy elements such as Cyperaceae and *Polygonum* (2–5% each) are found in moderate to low values, whereas Apiaceae (2.5–3%) and *Polygala* (2%) are scanty. *Typha* (1–4%) is present consistently in the lower part only. *Hydrocharis* and *Myriophyllum*, together with freshwater alga, *Pediastrum* (1% each) are characterized by their stray occurrences.

Ferns (monolete 1–4% and trilete 1%) are scanty. Fungal spores comprising *Alternaria* (1–6%), *Helminthosporium* (1–5%) and *Torula* (1%) are marked by their variable frequencies.

Pollen zone BP-II (3.2–2.2 m): This zone, ^{14}C dated to 15,990 ± 960 yrs BP (2.55 m depth) and covering a timespan of 20,160 to 13,860 yrs BP, is marked as the barren zone with no trace of any pollen deposition. This could be attributed to poor preservation of pollen during the course of sedimentation most likely due to drying of the lake during the Last Glacial Maximum (LGM).

Pollen zone BP-III (2.2–1.6 m): Poaceae–Holoptelea–Malvaceae–fern assemblage. This zone covering the time period between 13,860 to 2610 yrs BP, is characterized by a sharp decline in *Holoptelea* (9–20%) followed by Myrtaceae (1%) and total disappearance of Sapotaceae. However, Palmae (2–7%) and *Acacia* (2–3%), appear for the first time and in good frequency in this zone along with sporadically represented *Capparis* and Rubiaceae.

Shrubby vegetation comprising Fabaceae and Oleaceae (2–3% each), Rutaceae and Solanaceae (2% each) are also less compared to zone BP-I.

Among the non-arboreals, Malvaceae (2–17%), Cheno/Am (1–6%) and Cerealia (2–4%) are present consistently in moderate values in the middle of the zone. However, *Artemisia*, Caryophyllaceae, Convolvulaceae, Liguiliflorae and Tubuiliflorae are scanty.

Marshy elements such as Cyperaceae (3.8%), Polygonaceae (6–8%) and *Polygonum plebeium* (1–4%) are better represented than in zone BP-I. *Typha* (1–6%) is the prominent representative of aquatic vegetation, whereas Hydrocharitaceae (0.5%) is scanty.

Ferns (monolete 1–13% and trilete 1–2%) are recovered with increased frequencies in this zone. Bryophytic, moss and fungal spores tend to become low in number.

Pollen zone BP-IV (1.6–1.3 m): Barren zone. This zone covering a short time period from 2610 to 2550 yrs BP, exhibits sharp decline in vegetation with poor recovery of pollen. This zone is designated as the barren zone.

Pollen zone BP-V (1.3–0.0 m): Poaceae–Cyperaceae–Polygonum–Cheno/Am–Malvaceae–Holoptelea–Acacia assemblage. This zone with a ^{14}C date of 2400 ± 120 yrs BP (0.55 m), covers 2550 yrs BP to the modern time period. Among the arboreals, *Holoptelea* (1–12%) and *Acacia* (2–10%) are represented consistently and in good

frequencies. Palmae (1–5%) too is present consistently, but in moderate frequency. *Capparis, Mimosa* and Rubiaceae are encountered occasionally (1–4%). Capparidaceae, Sapotaceae and Myrtaceae are recorded sporadically.

Among the shrubby elements, Oleaceae (1–6.5%) and Urticaceae (1–4%) are sporadic with moderate frequencies, whereas Acanthaceae (1–3%) is present occasionally. Fabaceae, *Prosopis*, Lamiaceae, Rutaceae, Solanaceae, Tamaricaceae and *Tinospora* are scanty (1%).

Among the non-arboreals, Poaceae (34–55%) is well represented. Cheno/Am (2–12%), Cyperaceae (3–17.5%), Malvaceae (1–12%), *Polygonum plebeium* (1–13%), Tubuiliflorae (1–10%) are present consistently and in good frequencies. Cerealia (1–3%) and Caryophyllaceae (0.5–3%) are recorded sporadically, whereas *Justicia* and Polygonaceae are encountered rarely.

Aquatic element Potamogeton (1–11%) and Typha (1–10%) are well-represented, Hydrocharitaceae (2–5%) is moderate and *Myriophyllum* scanty.

Ferns (monolete 1–15%, trilete 1–4.5%), bryophytic (1–17%), and moss (1–9%) spores are present consistently.

Based on the investigated lake site, it was possible to reconstruct the vegetation history as well as to deduce the corresponding climatic inferences of the region. The environmental changes based on palaeovegetation succession and stratigraphic analysis of the investigated lake deposits, covers a time-span of ±26,460 yrs BP to the Present. In the first phase between 26,460 and 20,160 yrs BP (pollen zone BP-I), the high percentage of *Holoptelea* has revealed that the region was dominated by thick forest of *Holoptelea* associated with arboreal elements like Myrtaceae and Urticaceae and the ground covered mainly with grasses, Cheno/Ams, Asteraceae and Fabaceae.

The reconstructed vegetation scenario depicts that the region during this period enjoyed thick forest under moist climate and good monsoon. The deduced observation corroborates well with the interstadial phase witnessed through earlier palynological studies for the Kathmandu valley[25]. Stable isotope data available from calcrete records for Thar Desert have also indicated good monsoonal phase between 25,000 and 60,000 yrs BP[26] as well as geomorphological studies carved out for the Khudala site in the Thar Desert depicting channel-activated phase during the period 30,000–70,000 yrs BP[27].

The second phase (pollen zone BP-II) culminated with the onset of the LGM (20,000–14,000 yrs BP) according to extrapolated dates based on the available ^{14}C date of 15,990 ± 960 yrs BP. This phase demonstrates no trace of vegetation evidenced by palynologically barren sediment horizon, indicating to inhospitable climatic conditions in the region. According to Wasson *et al.*[6], pollen and other plant remains get preserved in the sediments only when there is open water in the lake basin. Pollen is not preserved, or poorly preserved, when the lake is in desiccated phase.

In the next phase, deglaciation had started and the climatic conditions turned humid again with less dry conditions in the lake as is evidenced by scanty presence of some arboreals and domination of non-arboreal taxa. In the fourth phase completely dry conditions are witnessed again though for a short period between 2610 and 2550 yrs BP, as no traces of pollen are seen in this phase.

During the last phase, commencing from 2550 yrs BP and upwards, decline in arboreal vegetation is seen barring the much reduced presence of arboreal elements, viz. *Holoptelea*, *Acacia*, *Palmae*, *Capparis* and Rubiaceae. Simultaneously grasses flourished along with other non-arboreal taxa such as Caryophyllaceae, Cheno/Ama, Malvaceae and Tubuliflorae. Presence of aquatics, viz. Hydrodictiaceae, *Potamogeton* and *Typha* in sporadic numbers portrays reduction in rainfall. Marshy vegetation comprising Cyperaceae, *Polygonum* and Polygonaceae is indicative of siltation, that the lake probably turned into a marshy lowland. It can therefore, be concluded that the history of the Bharatpur wetland can be traced back at least to about 26,000 yrs, when it was a lake, and during the course of time the harsh climatic conditions ultimately turned it into the present marshy wetland.

The required high resolution climatic reconstruction was not feasible from the present investigated profile due to inadequate carbon content in the samples gathered from lower horizons of the lithocolumn for ^{14}C dating. Nevertheless, OSL dating of the samples is being done at PRL, Ahmedabad.

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