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Pollen deposition pattern in the tropical deciduous Sal (*Shorea robusta*) forests in northeastern Madhya Pradesh

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This paper deals with the study of modern pollen-vegetation relationship, based on the pollen analytical investigation on 23 surface samples from the tropical deciduous Sal (*Shorea robusta*) forests in district Sidhi, Madhya Pradesh. The study reveals the dominance of non-arboreal and low representation of arboreal pollen. Among the tree taxa, Sal (*Shorea robusta*), the principal constituent of modern forest floristic (90%), is not represented proportionally in the pollen rain and only an average of 12% pollen of it is deposited in the sediments. It declines to a value of 6.5% at the edge of forest and remains as low as 1.5% in the adjoining open area. This irregular representation of Sal pollen in the sediments could be inferred to their poor preservation, irrespective of it being an enormous pollen producer. The consistent record of pollen of *Madhuca indica* in moderate values corresponds more or less closely with its frequent presence in the forest. However, the other associates of Sal such as *Emblica officinalis*, *Adina cordifolia*, *Lagerstroemia*, *Terminalia*, *Anogeissus*, *Boswellia serrata*, *Syzygium* etc. are not represented in accordance to their actual composition owing to their low pollen productivity, since majority of them exhibit a strong tendency of entomogamy.

The good representation of grasses, sedges, Cheno/Am, Asteraceae, etc. shows a more or less close coherence with their actual composition on the forest floor as well as in the open area. However, the consistently high frequencies of cerealia and *Xanthium* pollen are indicative for the proximity of cultivated land/pasture to the study sites.

Key-words— Pollen deposition, Pollen spectra, Sal forests, Northeastern Madhya Pradesh.

INTRODUCTION

VALUABLE information on modern pollen-vegetation relationship has been provided for the tropical evergreen and deciduous forests distributed in South India and Sri Lanka (Bonnefille *et al.*, 1999; Anupama *et al.*, 2000; Barboni & Bonnefille, 2001), foot-hills of Himalaya (Sharma, 1985; Gupta & Yadava, 1992) and tropical deciduous scrub vegetation in Rajasthan desert (Singh *et al.*, 1973). All these studies have generated significant comparative database on this aspect for the factual appraisal of the pollen sequences from their respective regions in terms of past vegetation dynamics during the Quaternary Period. However, Madhya Pradesh which alone possesses approximately 26% of the total forest of the country with great potentiality for Quaternary palaeofloristic studies has not yet received enough attention to understand the pollen deposition pattern in the Sal forest (Chauhan, 1994). This pollen rain study has also provided a valuable analogue for the precise reconstruction of the palaeovegetation scenarios from the tropical regions during the Holocene (Bera, 1990; Chauhan, 1995, 2000, 2002, 2004, 2005; Chauhan *et al.*, 2001; Shaw *et al.*, 2007; Yadav *et al.*, 2006). The present paper is an attempt to produce more data from other areas in order to achieve greater precision regarding the representation of Sal and its other associates in the modern pollen rain, their pollen dispersal efficiency and factors affecting the preservation of pollen/spores in the sediments through the pollen analysis of surface samples (moss cushions and surface soils) from the forest areas at Chuniapat and Jhandaya Hill and open area at Pondi, district Sidhi in the northeastern Madhya Pradesh (Fig.1).

CLIMATE

District Sidhi experiences seasonal climatic fluctuations. Summer season is marked by high temperature with average annual minimum and maximum of 24° C and 30° C, respectively. However, temperature seldom shoots up to 42° C during the month of May. Winter temperature falls to an average of 7° C, but it further descends to as low as 1° C during extreme cold months of December and January. The average annual precipitation is approximately 1180 mm. Most of the rain falls during the months of July and August.

MATERIAL AND METHOD

In all, 23 surface samples (moss cushions and surface soils) were collected in linear transects from edge to within the forest at Chuniapat (C_{16} from the edge of forest and C_{17-19} from the forest area) and Jhandaya Hill (J_{41-42} from the edge of forest and J_{43-49} from the forest area) and open area at Pondi (P_{31}-P_{40}) in district Sidhi at 100m interval each. While collecting the samples it was surmised that a major fraction of pollen gets deposited within the distance of about 100m or so immediately after their discharge from the parent plants as the dense canopied forest inhibit their easy and longer exit, contrary to that of the open cultivated area (Luna *et al.*, 2002), where distance of 200 m from the source has been observed to be a normal range for the deposition of a bulk of pollen load after

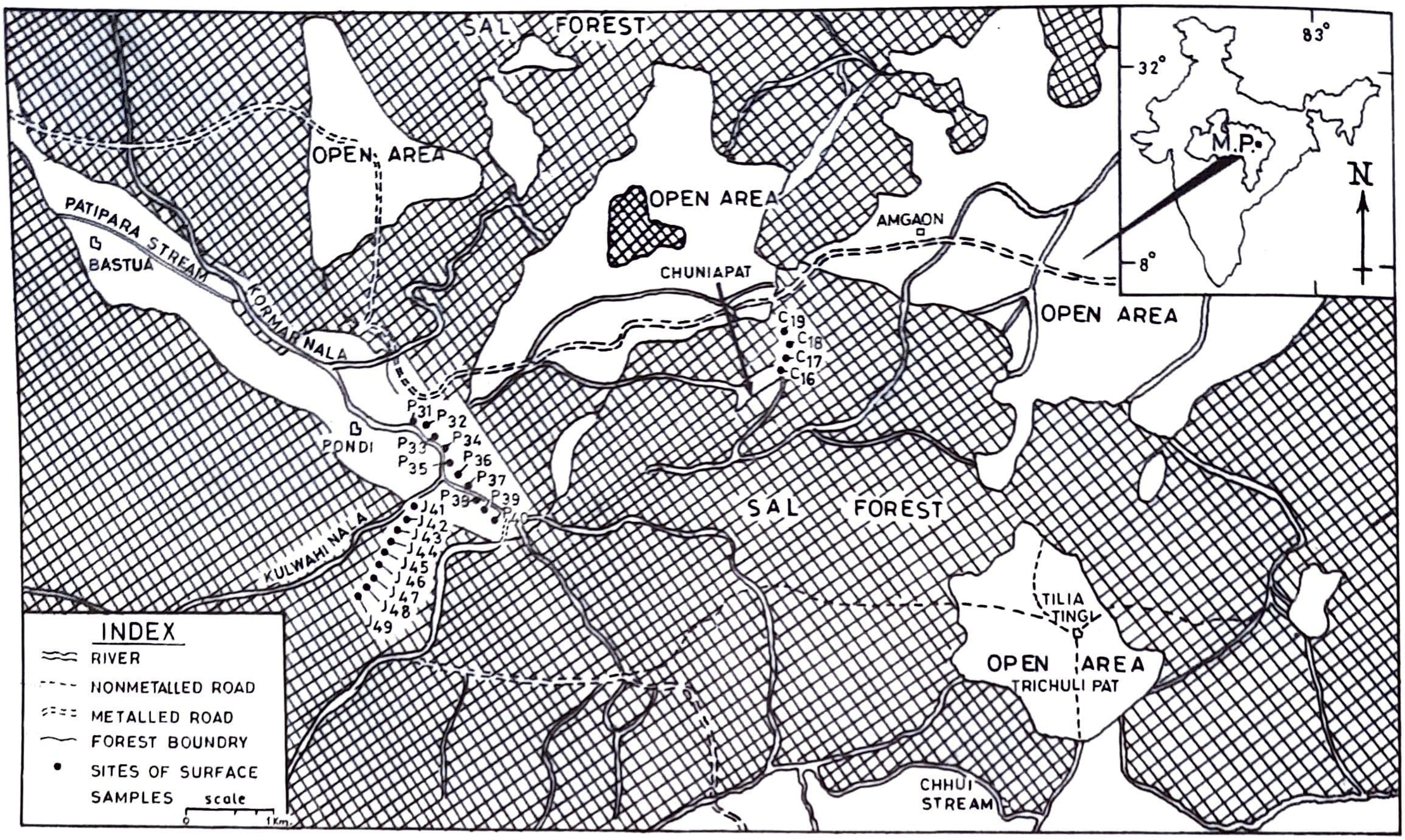

Fig. 1. Map of Sidhi District (M.P) showing the sites of surface samples

dispersal.The sampling strategy was planned in transects to understand the average representation of the prominent forest constituents/plant groups of the regional vegetation in the pollen rain across the forest and open area. Besides, the sampling was done during the peak flowering of Sal and other associated trees so that a factual evaluation of pollen rain in relation to modern floristic in the region could be made. This comparative database on pollen-vegetation relationship serves as a modern analogue for the precise appraisal of fossil pollen spectra in terms of past vegetation and climate in the area of investigation.

Samples were treated with 10% aqueous KOH and 40% HF solutions in order to remove humus and silica present in the sediments, respectively. Thereafter, the conventional procedure of acetolysis (Erdtman, 1943) using acetolysing mixture (9:1 ratio of acetic anhydride and concentrated sulphuric acid) was followed. Finally, the samples were prepared in 50% glycerin solution for microscopic examination. The identification of the dispersed pollen in the sediments was executed by comparing them with the reference slides available in the sporothek of BSIP Herbarium, photos and descriptions in the published literature (Chauhan & Bera, 1990; Nayar 1990).

POLLEN ANALYSIS

The pollen sums range from 182 to 384, depending upon pollen productivity of samples. The percentage frequencies of the recovered pollen taxa have been calculated in terms of total land plant pollen including fern spores too. The plant taxa grouped as herbs, shrubs, pteridophytes, trees and drifted taxa are arranged in the same sequence in the pollen spectra. Poaceae pollen have been categorized as < 40μm and > 40μm based on grain size, to segregate the wild and cultivated (cerealia) types, respectively. The pollen frequencies of less than 0.5% are indicated by '+' sign in the pollen spectra. The physiography, floristic and pollen rain composition of all the three areas of investigation are dealt separately as below:

1. Chuniapat

This site lies about 5 km east of Pondi Forest Rest House between 81° 17' Long. and 23° 45' Lat. Topographically, the entire area is marked by a number of small hills with gentle slopes and flat tops. The hills, running from east to west, vary in elevation from 468m to 678m. The area receives fairly good rainfall, which favours profuse growth of Sal forests. Moist condition is more prevalent in valleys and ravines.

Floristically, most of the region possesses dense tropical deciduous Sal (*Shorea robusta*) forests (Champion & Seth, 1968). Besides Sal, *Madhuca indica*, *Anogeissus latifolia*, *Terminalia chebula*, *T. arjuna*, *Milliusa tomentosa*, *Careya arborea*, *Buchanania lanzan*, *Emblica officinalis*, *Lagerstroemia parviflora* and *Mitragyna parvifolia* also occur abundantly. The pure or mixed stands of *Dendrocalamus strictus* can be seen in deep ravines. Meagre shrubby vegetation includes the species of *Carissa opaca*, *Woodfordia fruticosa*, *Strobilanthes* sp., *Melastoma malabathricum*, *Nyctanthes arbor-tristis*, etc.

Grewia hirsuta, *Desmodium* spp., *Crotalaria albida*, *Vernonia diversens*, *Leucas mollissima*, *Plectranthus mollis*, *Drysophylla crucida*, *Panicum notatum*, *Colebrookea oppositifolia*, etc. constitute the herbaceous flora on the forest floor. The epiphytic orchid, *Vanda tesellata* and the parasitic *Dendropthoe falcata* are widespread on a number of common trees.

Pollen rain: Four surface samples (moss cushions) numbering C_{16} to C_{19} were pollen analysed from this area, over a distance of about 300m. Sample C_{16} is from the edge of forest, whereas samples C_{17} to C_{19} are from the forest area (Fig. 2).

Pollen spectrum (C_{16}) from the edge of forest exhibits moderate values of arboreals. *Terminalia* (7%), *Madhuca indica* (5%) and *Shorea robusta* (4%) are the major tree taxa. The other taxa such as *Lagerstroemia*, *Adina cordifolia*, Sapotaceae (1-5% each), *Anogeissus*, *Diospyros*, *Mitragyna*, *Casuarina equisetifolia*, Anacardiaceae and Rutaceae (1.5% each) are encountered in low frequencies. Fabaceae and *Ricinus communis* (under 2% each) are the only representatives of shrubby vegetation.

The non-arboreals, Poaceae (40%), Tubuliflorae (10%) and Cyperaceae (6%) are better represented as compared to *Blepharis*, Caryophyllaceae (2% each), Lamiaceae, Malvaceae and Loranthaceae (1.5% each). Trilete fern spores (20%) are recorded frequently.

Pollen spectra (C_{17} to C_{19}) from inside the forest bring out better representation of both arboreals and non-arboreals in contrast to at the edge of forest. *Shorea robusta* (7-11%) and *Madhuca indica* (6%) show consistently good values. Similarly, *Lannea coromandelica*, *Anogeissus* (1-5% each), *Boswellia serrata* (1-3%), *Emblica officinalis* (1-2%) and *Lagerstroemia* (1-1.5%) are also recorded in low values. *Buchanania*, Anacardiaceae (1-2% each), *Butea monosperma* and Myrtaceae (1.5% each) are encountered sporadically. Fabaceae and Oleaceae (2% each) represent the shrubby vegetation. The pollen of Himalayan elements, *Pinus* and *Alnus* (1% each) are recorded in extremely low values.

Among the herbaceous taxa, Poaceae (32-40%), Tubuliflorae (2-11%) and Cyperaceae (5-6%) are the prominent constituents. Caryophyllaceae, *Blepharis* (2-3% each), Lamiaceae and Loranthaceae (3% each) are also recorded in good frequencies. Fern spores (monolete 2% and trilete 2-5%) are present in reduced frequencies.

2. Jhandaya Hill

This site is situated approximately 1 km south of Pondi Forest Rest House between 81° 45' Long. and 23° 51' 62" Lat. Most of the area here is comprised of undulating plains and a number of flat-topped small hills with gentle slopes. However, in some places the hill slopes are steep too. The hills, running from east to west, vary in elevation from 468m to 678m. Kulwahi nala drains along the edge of the hillock studded to the flat area. The forests are not luxuriant because of presence of a large number of boulders.

The forest vegetation is dominated by *Shorea robusta* (Sal). The usual associates of Sal are almost alike as mentioned above. However, *Boswellia serrata* occurs profusely, particularly on the bouldery hill slopes. The riverine elements such as *Syzygium cumini*, *Lagerstroemia* together with *Melastoma malabathricum* thrive well along the bank of Kulwahi river. The shrubby elements viz., *Woodfordia fruticosa*, *Ziziphus mauritiana*, *Strobilanthes* spp., etc. occur sparsely in the forest. *Dendrocalamus strictus* grows luxuriantly in the moist or damp situations.

Pollen rain: Nine surface samples (moss cushions) numbering J_{41} to J_{49} were analysed in transect from north to south across the forest at Jhandaya Hill (Fig. 3), covering a distance of approximately 800m in transect. Samples J_{41} and J_{42} are from the edge of forest, whereas the remaining samples i.e.

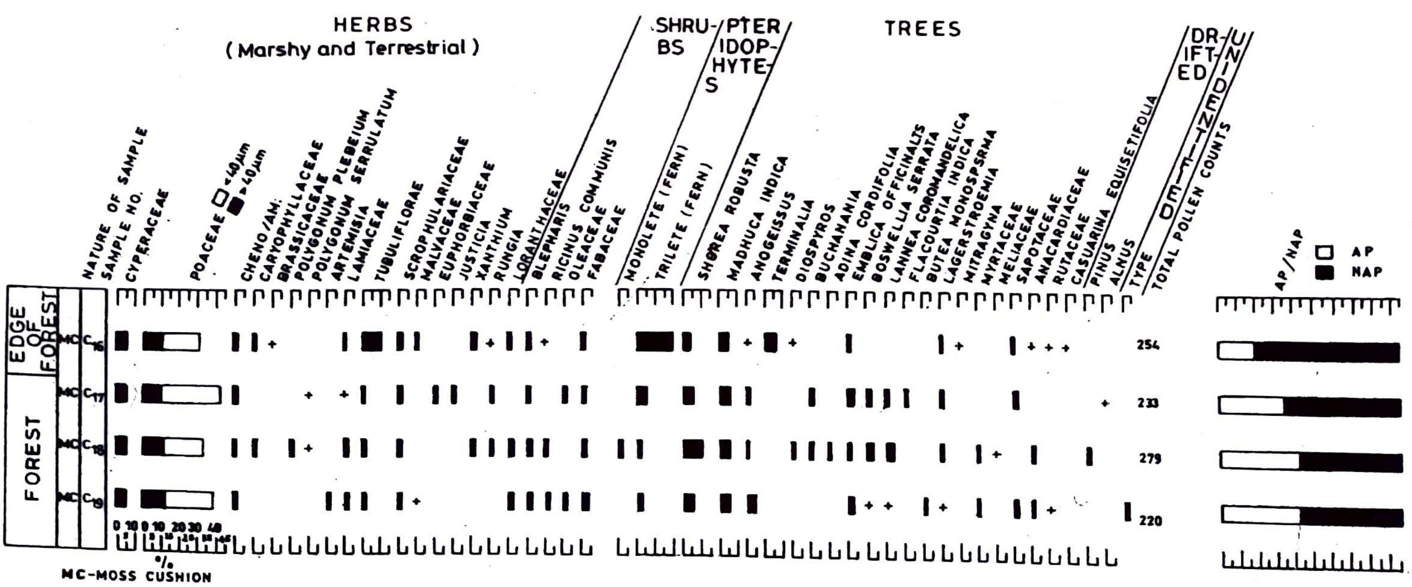

Fig. 2. Pollen spectra from Chuniapat, Sidhi (M.P.)

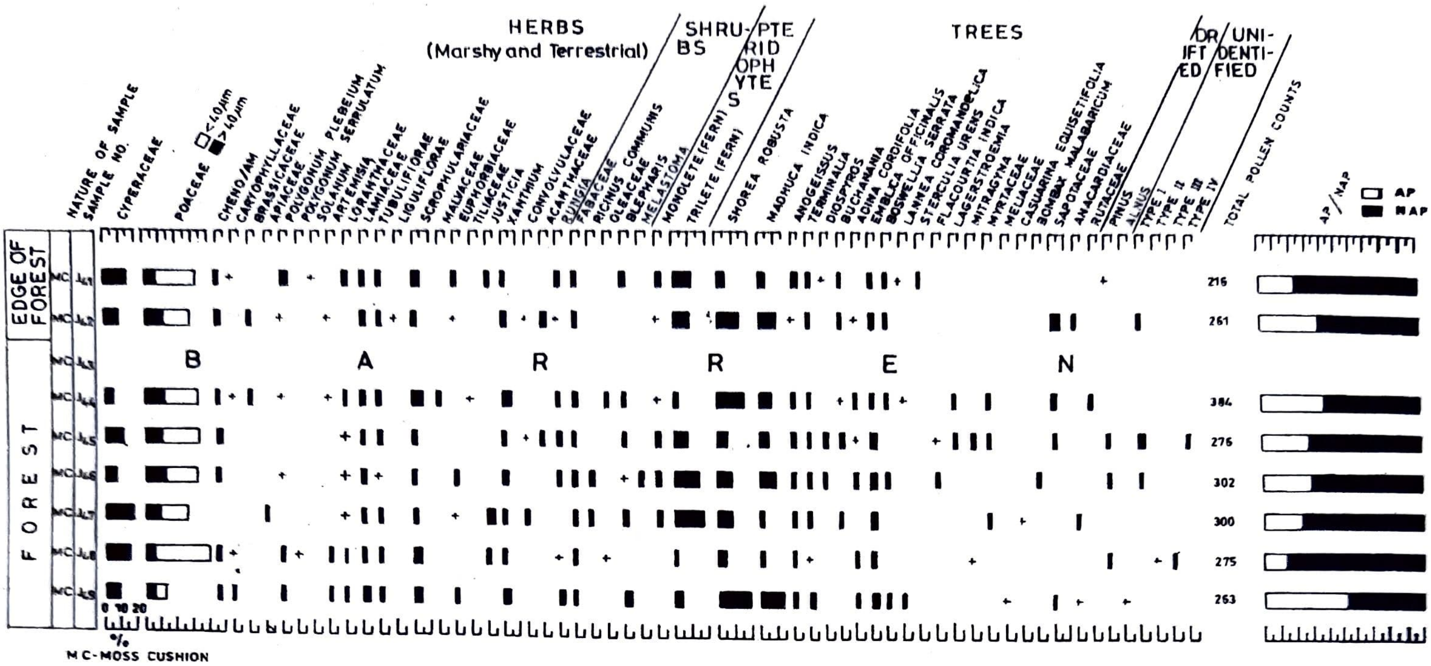

Fig. 3. Pollen spectra from Jhandaya Hill, Sidhi (M.P.)

J_{43} to J_{49} are from the forest area.

Pollen spectra (J_{41} and J_{42}) from the edge of forest depict a good representation of both arboreals and non-arboreals. The tree taxa, viz., *Shorea robusta* (5-17%) followed by *Madhuca indica* (4-10%), *Anogeissus* (1-4%), *Emblica officinalis* (2-3%) and *Terminalia* (1.5-2%) show high frequencies in contrast to other sporadically represented taxa such as *Buchanania*, *Boswellia serrata* (2% each), *Diospyros*, *Lannea coromandelica* and *Sterculia urens* (1% each). Fabaceae (3%) is the only representative of shrubby vegetation. Drifted pollen of *Pinus* are scantily present.

The non-arboreals, viz., Poaceae (28-31%), Cyperaceae (10-15%), Scrophulariaceae (2-3%), Cheno/Am, *Xanthium* (1.5-3% each), Lamiaceae and Tubuliflorae (2% each) are recorded consistently. Loranthaceae (3%) is recorded in moderate values, though sporadically. Trilete fern spores (2-14%) are better represented than monolete spores (1-2%).

Pollen spectra (J_{43} to J_{49}) from the forest area demonstrate increased frequencies of arboreals. *Shorea robusta* (5-20 %), *Madhuca indica* (2-14%) and *Emblica officinalis* (2-4%) show higher frequencies as compared to at the edge of the forest. *Anogeissus*, *Terminalia* (1.5-2% each), *Buchanania*, *Adina cordifolia* and *Boswellia serrata* (1-2% each) do not show any marked change in their frequencies. *Lannea coromandelica*, *Flacourtia indica* and Myrtaceae (1-2% each) are sporadically present. *Pinus* (1.5%) and *Alnus* (under 1%) are encountered sporadically in the samples.

Poaceae (13-40%) and Cyperaceae (7-18 %) have improved values than at the edge of forest. The other herbaceous taxa such as Scrophulariaceae (1-7%), *Xanthium* (1-5%), *Blepharis* (1-3%), Lamiaceae and Loranthaceae (1-2% each) are recorded consistently in all the samples. Apiaceae, *Solanum* (1-2% each), Malvaceae and Convolvulaceae (1% each) are extremely sporadic.

3. Pondi

This locality lies about 70 km south of Sidhi Town between 81° 45' Long. and 23° 51' 62" Lat. Topographically, Pondi is a flat area and surrounded by the hillocks. However, the vast plain area here is being used as fallow land as well as pasture.

Forest is altogether absent at Pondi proper owing to intensive agricultural practice and biotic pressure. Nevertheless, the heath land adjacent to the cultivated fields has scattered trees of *Butea monosperma*, *Mangifera indica*, *Azadirachta indica*, *Shorea robusta* and *Acacia catechu*. Besides, *Syzygium cumini*, *Mallotus philippinensis*, *Melastoma malabathricum* and members of Meliaceae are common along the bank of Kormar nala, which drains through vast plains. The surrounding hills support dense Sal forests.

Adhatoda vasica, *Vitex negundo*, *Carissa opaca*, *Ricinus communis*, *Ziziphus* spp., *Woodfordia fruticosa*, etc. comprise the shrubby vegetation. Grasses and sedges together with *Mazus japonicus*, *Micromeria biflora*, *Blepharis indica*, *Euphorbia hirta*, etc. are the major constituents of herbaceous complex.

Pollen rain: Ten surface samples (moss cushions and surface soils, numbering from P_{31} to P_{40}) were analysed across the open area at Pondi, covering a distance of about 900m (Fig. 4). The pollen assemblage, in general, shows the high frequencies of non-arboreals and poor representation of arboreals, viz., *Shorea robusta* (1-2%), *Anogeissus*, *Terminalia* and Myrtaceae (0.5-2% each). *Buchanania*, *Boswellia serrata*, *Lagerstroemia*, *Adina cordifolia* and *Bombax malabaricum* (2% each) are met with scantily. The shrubby vegetation is marked by the high values of Fabaceae (1.5-5%) in most of the samples, whereas *Strobilanthes* (2%), *Ziziphus* and Lythraceae (1% each) are quite low and sporadic. *Pinus* (1.5%) is recorded sporadically.

Poaceae (15-50%), Cyperaceae (23-35%) and Tubuliflorae (2-15%) are the major constituents of ground flora. *Xanthium* (1-15%), Cheno/Am (2.5-5%), Scrophulariaceae (1.5-5%), *Artemisia* (1-3%) and *Justicia* (2-2.5%) are also encountered frequently in some of the samples. Fern spores (monolete 0.5-2% and trilete 1.5-7%) are encountered continuously in moderate values.

DISCUSSION

The pollen-vegetation relationship study is one of the most indispensable aspects prior to the investigation of sedimentary profiles from any area since it provides potentially valuable analogue for proper evaluation of the vegetation changes involved during the Quaternary Period in a definite time frame. This comparative database is generated through the analysis of surface samples from different provenances, so that precise information on the representation of various plant taxa in the pollen rain could be obtained. The pollen assemblage, in general, has deciphered the dominance of non-arboreal pollen (NAP) and comparatively low representation of arboreal pollen (AP). Interestingly, among the tree taxa, *Shorea robusta* (Sal), which constitutes approximately 60-90% of the total forest floristic, is represented by an average of 12% pollen deposited in the forest area with the highest frequency of 20% pollen recorded at Jhandaya Hill. It declines considerably at the edge of forest, where only an average of 6.5% pollen is recorded. Further, It has also been observed that *Shorea robusta* pollen remains extremely low (1.5%) in the adjoining open area at Pondi, merely at a distance of about 200m from the dense Sal forest at Jhandaya Hill. The earlier work conducted during peak flowering period (Chauhan, 1994) has revealed that *Shorea robusta* (Sal) is an enormous pollen producer, despite being an entomogamous plant. Hence, from the above mentioned account it is obvious that the irregular or under-representation of this important forest ingredient in the modern pollen rain could be attributed to the poor preservation of its pollen in the sediments. The low sporopollenin content of pollen wall and high pH of the soil might have been a limiting factor for scarcity of Sal pollen in the sediments (Gupta & Yadav, 1992). Besides, the sharp decline in the frequencies of *Shorea robusta* pollen at the edge of forest and in the adjoining open area also denotes its poor dispersal efficiency. Similarly, the moss cushions analysed from the Sal dominated area in Tarai-Bhabar, close to the foot-hills of Kumaon (Gupta & Yadav, 1992) and Garhwal (Sharma, 1985) Himalayas have also exhibited the presence of pollen in traces (2%) or its total absence. Among the associates of Sal, *Madhuca indica* is consistently better represented both in the forest and open area in contrast to other tree taxa. The inhabitants conserve these plants for their fleshy flowers, since they are an important means of their subsistence. The good preservation of its pollen in the sediments cannot be denied.

Barring *Shorea robusta* and *Madhuca indica*, the other important forest constituents such as *Terminalia*, *Lannea coromandelica*, *Anogeissus*, Myrtaceae cf. *Syzygium*,

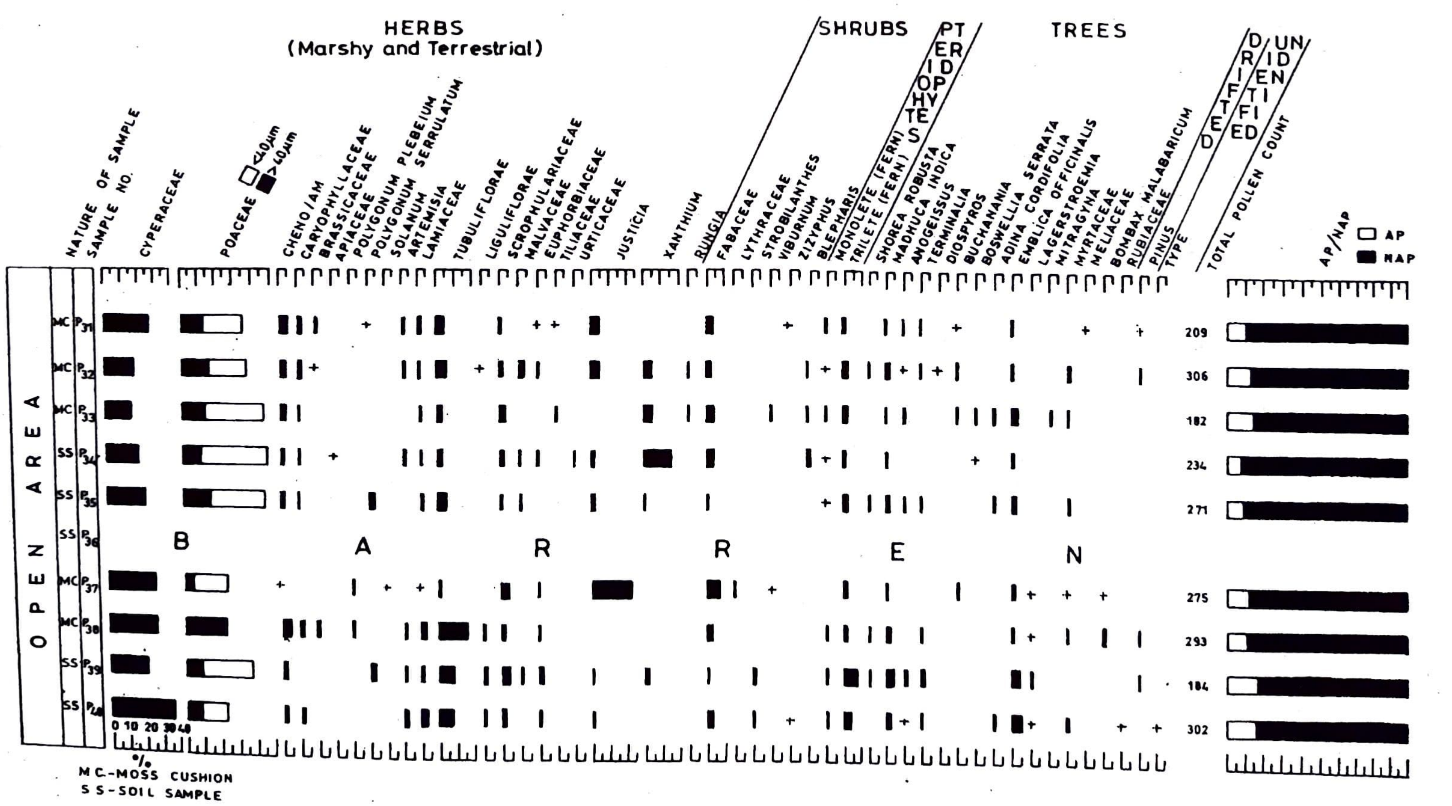

Fig. 4. Pollen spectra from Pondi, Sidhi (M.P.)

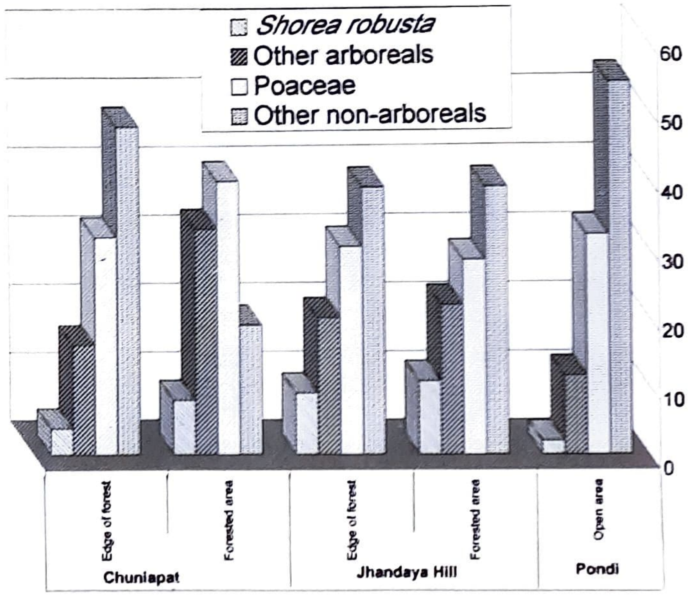

Fig. 5. Composite pollen spectra from Sal forests in district Sidhi (M.P.)

Lagerstroemia, *Emblica officinalis*, *Adina cordifolia*, *Diospyros*, etc. occurring in appreciable proportion in the forest, are encountered sporadically with extremely low frequencies. The under-representation of all these taxa could be inferred to their low pollen productivity owing to their entomogamous mode of pollination. In addition, the microbial degradation and the partial preservation of the pollen in the sediments cannot be ruled out. Similar observations have also been made on the investigation of surface sediments from the tropical deciduous forests in Africa (Vincens *et al.*, 1997) and South Indian mountains (Anupama *et al.*, 2000; Barboni & Bonnefille, 2001). Further, it has been noticed that the pollen of certain tree taxa such as *Boswellia serrata*, *Butea monosperma*, *Flacourtia indica*, etc. are either recovered in traces or remain totally absent. Apart from the above mentioned tree species, *Manilkara hexandra*, *Mimusops elangi*, *Dalbergia sissoo*, *Schleichera oleosa*, *Pterocarpus marsupium*, *Kydia calycina*, etc. are very common in the forest, but could not be traced in the pollen rain. Partly, this discrepancy may be inferred to the fact that the pollen grains of most of the taxa are not discernible beyond family level owing to much overlapping of morphological characters with the closely related species or genera.

Among the non-arboreals, Poaceae followed by Cyperaceae has consistently much higher frequencies in transects from all sites. However, they attain the maximum values in open area, which could be attributed to their profuse growth as well as scanty presence of arboreal taxa. The overall representation of these taxa in the pollen spectra depicts a close coherence with their composition in the ground flora. Likewise, Scrophulariaceae, Lamiaceae, Chenopodiaceae/ Amaranthaceae, etc. are also characterised by their good frequencies. The consistent presence of cerealia pollen in moderate frequencies (8%) at Chuniapat and Jhandaya Hill indicates the proximity of agricultural land to the forest. However, the increased values of cerealia pollen (12%) together with *Xanthium* and Urticaceae in the pollen spectra from open area at Pondi signify the intensive cultivation and increasing human activities in the area of investigation. On the other hand, the record of pollen of Asteraceae (Tubuliflorae and Liguliflorae) in enhanced frequencies, particularly in the pollen spectra from the open area at Pondi in contrast to forest could be inferred to intensive pastoral activities. Most of the plants belonging to this family escape from grazing (Mooney, 1997; Mazier *et al.*, 2006) as they are less palatable to cattle and goats. The frequent recovery of monolete and trilete spores suggests the prevalence of moist and shady conditions on the forest floor, which favour profuse growth of ferns and their allies. However, the considerable reduction in their values in open area at Pondi reflects the meagre presence of ferns.

The moderate to low values of Loranthaceae pollen in the spectra from the forest area at Chuniapat and Jhandaya Hill truly reveal good growth of *Dendropthoe falcata* or other members of this family on *Madhuca indica*, *Butea monosperma*, *Mallotus philippinensis* and *Diospyros melanoxylon* trees, which are their common host in the forest. Their presence also denotes a high moisture content in the atmosphere of the above mentioned areas as compared to open area at Pondi.

The presence of stray pollen of subtropical and temperate elements such as *Pinus* and *Alnus* implies their exclusive wind transportation from Himalayan region.

Thus, from the above discussed account, it is conspicuous that the pollen/spore deposition pattern in the surface sediments/moss cushions does not wholly demonstrate the actual floristic composition of the region. Hence, the derived comparative database on the pollen-vegetation relationship and all limiting factors deduced from the pollen analysis should be taken into consideration with great care, while assessing pollen assemblage recovered in the sedimentary deposits in terms of past vegetation and climate.

CONCLUSIONS

The comparative assessment of AP and NAP ratio in the surface samples from forest area with special reference to depositional pattern of *Shorea robusta* pollen, in general, reveals that the arboreals constitute an average of 31% of the pollen rain, of which Sal (*Shorea robusta*) has an average of 12% pollen alone (Fig.5). The rest of the trees are represented by average 18-19% pollen only. The extremely low pollen of associates of Sal, viz., *Terminalia*, *Lagerstroemia*, *Emblica officinalis*, *Diospyros*, Mytaceae cf. *Syzygium*, etc. despite their frequent presence in the forest, could be inferred to their low pollen productivity and partial preservation in the sediments. However, the consistent representation of *Madhuca indica* with good frequencies shows a coherence with its actual composition in the forest. The non-arboreals form a major fraction of the pollen rain, attaining average high value of 69%. Thus, while interpreting the pollen diagrams from the tropical deciduous Sal forests from central India as well as equivalent floristic regions, this comparative database should be taken as modern analogue for the precise reconstruction of palaeovegetation scenarios during the Quaternary Period. The physiognomic aspect of the forests whether they are dry or moist types, can be determined from the available information on the climatic requirements of the retrieved plant taxa or the floristic assemblage in the sediments. On the other hand, in the surface samples analysed from the adjoining open area, located barely at a distance of 200m from the edge of dense tropical deciduous Sal forests, there is an abrupt reduction in the values of trees pollen to an average of 12%. This poor representation of tree pollen could be inferred to their low dispersal efficiency. Furthermore, Sal pollen is recorded with an average value of merely 1.5%. The remaining major fraction of pollen rain represents the non-arboreal vegetation with very high value of 88.5%. Hence, if we get more or less similar analogous values of arboreal/non-arboreal pollen in any sediment profiles, it may be presumed that the study site would have been situated in an open area in the proximity of dense Sal forest in the past. Apart from the aforesaid account, it has been observed that Poaceae exhibits a sharp increase in its value to an average of 39% in contrast to 30% as recorded in the forest area. Likewise, the other non-arboreals also bring out a similar converging trend. The consistent presence of pollen of cerealia and cultural/ruderal taxa such as Cheno/Am, Brassicaceae, Caryophyllaceae together with heath land taxa such as Asteraceae, etc. in appreciable numbers at Pondi is indicative of increasing pastoral and other human activities.

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