

Holocene climatic fluctuations from Lower Brahmaputra flood plain of Assam, northeast India

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Pollen analysis of a 3.2-m deep sedimentary profile cored from the Dabaka Swamp, Nagaon District, Lower Brahmaputra flood plain, Assam has revealed persistent fluvial activity during 14,120–12,700 cal years BP which may be attributed to the paucity of pollen and spores with encounterance of fluvial marker taxa like *Ludwigia octovalvis* and *Botryococcus*. Later, fluvial activity was succeeded by the tropical tree savanna under cool and dry climate between 12,700 and 11,600 cal years BP corresponding to that of global Younger Dryas. Between 11,600 and 8310 cal years BP, relatively less cool and dry climate prevailed with inception of tropical mixed deciduous taxa like *Shorea robusta* and *Lagerstroemia parviflora*. This phase is further followed by a fluvial activity between 8310 and 7100 cal years BP as evidenced by trace values of pollen and spores. Fluvial activity was further succeeded by enrichment of tropical mixed deciduous forest under warm and humid climatic regime between 7100 and 1550 cal years BP which is well-matched with the peak period of the Holocene climatic optimum. However, during 1550–768 cal years BP, final settlement of tropical mixed deciduous forest occurred under increased warm and humid climate followed by deterioration in tropical mixed deciduous forest under warm and relatively dry climatic regime since 768 cal years BP onwards due to acceleration in human settlement as evidenced by Cerealia. Increase in *Melastoma*, *Ziziphus* and *Areca catechu* imply forest clearance at this phase. The occurrence of degraded pollen-spore along with adequate fungal elements especially, *Xylaria*, *Nigrospora* and Microthyriaceous fruiting body is suggestive of aerobic microbial digenesis of rich organic debris during sedimentation.

1. Introduction

Assam, situated in northeastern India under the foothills of the eastern Himalayas is one of the richest biodiversity zones in the world. Its flora include tropical evergreen, deciduous forests, riverine grasslands, bamboo orchards and numerous wetland ecosystems; many are now protected as national parks and reserved forests. Holocene (Late Quaternary) development and history of tropical mixed deciduous forests distributed in Lower Brahmaputra flood plain of Assam have not received much attention, except few scattered

publications from Upper Assam, Mikir Hills and Lower Assam (Bhattacharya and Chanda 1982, 1992; Bhattacharya *et al* 1986; Bera 2003; Bera and Dixit 2010; Dixit and Bera 2011). Here, based on pollen proxy records, an attempt has been made to deduce the seral stages involved in the development of tropical mixed deciduous forest under different climatic regimes since Holocene through the investigation of a sedimentary profile cored from Dabaka Swamp (lat. 26°07'4.4"N, long. 92°48'8.4"E), Nagaon District, Assam (figure 1). The unique tropical mixed deciduous forest in and around the study area is predominated by admixture of

Keywords. Climate change; Holocene; pollen proxy; Assam.

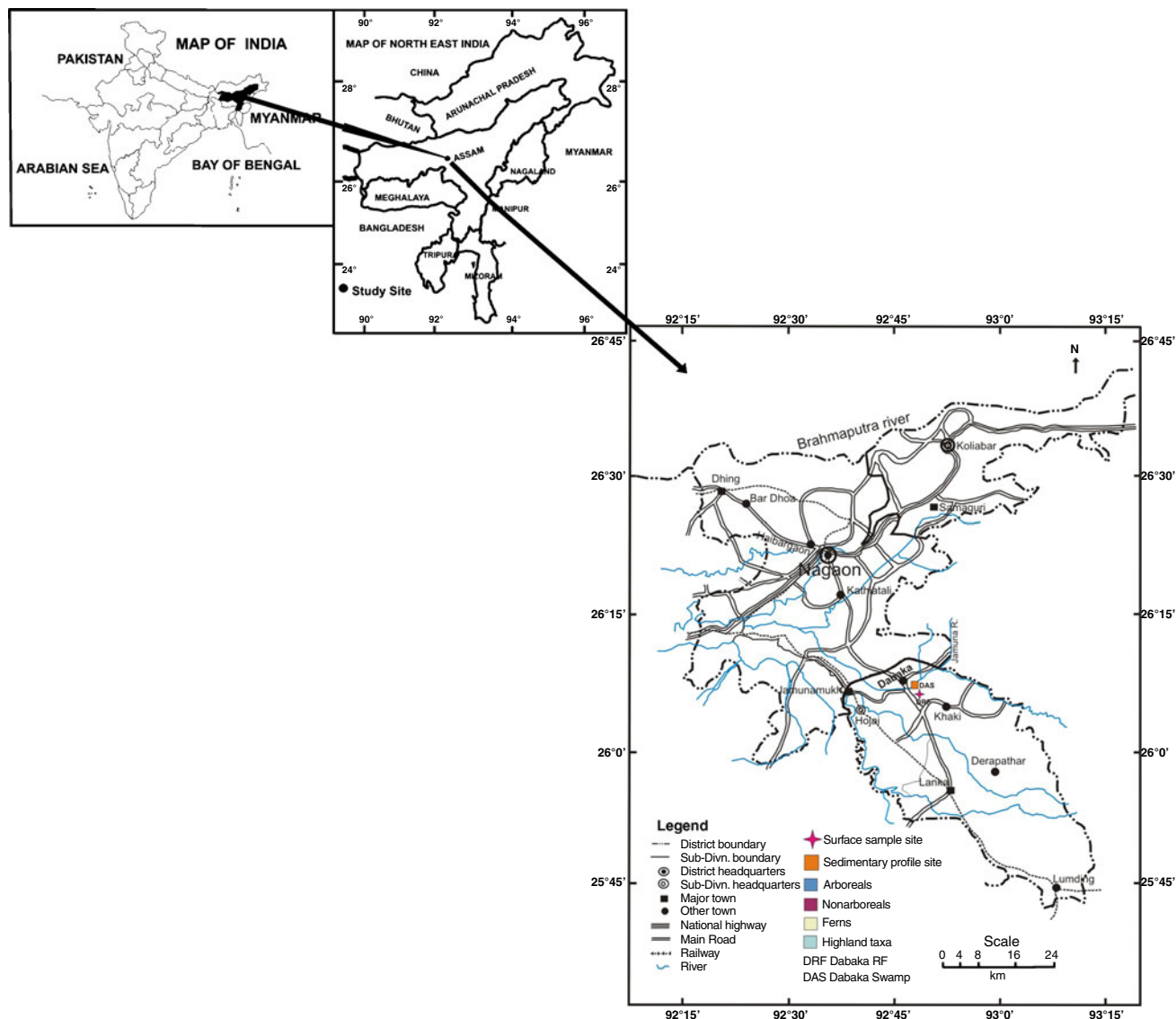


Figure 1. Location map showing sampling site.

deciduous and semi-evergreen elements. This is the first comprehensive study regarding origin and development of tropical mixed deciduous forest *vis à vis* climatic changes since Holocene in north-east India. The first phase of the present communication broadly incorporates vegetation types, nature of soil and climate followed by methodology of palynological samples. However, the subsequent phase includes palynological assessment of subsurface soil and moss cushions in order to construct modern pollen/vegetation relationship which could be used as background information for interpretation of pollen diagram. The pollen diagram is constructed based on palynoassemblage recovered from each palynozone to decipher past vegetation and climate change. The present paper also aims at finding signals of global climatic events such as Younger Dryas, Hypsithermal Period, Medieval Warm Period and Little Ice Age (LIA) in this

climatically sensitive region. According to some researchers, it is clear that the climate Holocene is unstable (Bond *et al* 1997; Mayewski *et al* 2004). However, the regulation of climate change, regional characteristics, abrupt change and its relation to human activities are also not clear (Street-Perrott and Perrott 1990; Lamb *et al* 1995). However, it is strongly suggested from our study that acceleration in human activities is one of the factors for the abrupt change in climate from increased warm and humid to warm and relatively dry since 768 cal years BP.

2. Study site

Dabaka Swamp belongs to the Dabaka Reserve Forest and is situated at about 29 km south of Nagaon District surrounded by dense tropical

mixed deciduous forest. The swamp comprises Cyperaceae (sedges), Poaceae (wild grass), Cerealia (crop plant), Brassicaceae, *Plantago erosa*, Onagraceae, *Polygonum serrulatum*, *P. plebeium*, Ranunculaceae, *Costus speciosus*, *Colocasia esculenta*, *Rumex acetosella* and *Impatiens balsamina* as the major plant taxa at the marginal area. Aquatic vegetation in the swamp consists of both Angiosperms and few Pteridophytes namely *Nymphoides indica*, *Potamogeton pectinatus*, *Nymphaea nouchali*, *Typha latifolia*, *Trapa bispinosa*, *Lemna minor*, *Eichhornia crassipes*, *Utricularia flexuosa*, *U. exoleta*, *Spirodela polyrhiza*, *Wolffia arrhiza*, *Nelumbo nucifera*, *Myriophyllum indicum*, *Ceratopteris thalictroides*, *Marsilea minuta*, *Pistia stratiotes*, *Salvinia oblongifolia* and *Azolla pinnata*, respectively. However, *Cyathea gigantea*, *Adiantum philippense*, *Polypodium heracleum*, *Selaginella biformis*, *S. ciliaris*, *Angiopteris evecta*, *Dryopteris filix-mas*, *Pteris stenophylla* and *Blechnum orientale* are common Pteridophytic taxa growing luxuriantly along the periphery of the swamp.

Surrounding mixed deciduous forest of the swamp comprise diversified forest elements namely *Terminalia bellirica*, *Dillenia pentagyna*, *Syzygium cumini*, *Shorea robusta*, *Sterculia villosa*, *Artocarpus integrifolia*, *Gmelina arborea*, *Lannea coromandelica*, *Adina cordifolia*, *Salmalia malabaricum*, *Tectona grandis*, *Lagerstroemia parviflora*, *Emblia officinalis*, *Semecarpus anacardium*, *Amoora wallichii*, *Acacia catechu*, *Albizia lebeck*, *A. odoratissima*, *Dalbergia sissoo*, *Ficus benghalensis*, *F. hispida*, *F. heterophylla* and few species of Arecaceae. However, *Artocarpus chaplasha*, *Elaeocarpus rugosus*, *Dipterocarpus macrocarpus*, *Amoora wallichii*, *Sapindus rarak*, *Tetrameles nudiflora*, *Schima wallichii*, *Terminalia myriocarpa*, *Spondias mangifera*, *Ilex sulcata*, *Symplocos racemosa*, *Duabanga sonneratioides*, *Lagerstroemia flos-reginae*, *Garcinia cowa*, *Barringtonia acutangula* and *Holarrhena pubescens* occur frequently in this forest as semi-evergreen plant associates. Grasses of the following genera are characteristic of the riparian areas, *Saccharum*, *Anthisteria*, *Phragmites*, *Erianthus* and *Arundo* cover extensive tracts along the swamp. Unique combination of bamboos, viz., *Dendrocalamus hamiltonii*, *D. gigantea*, *Bambusa bambos*, *B. balcooa*, *B. nutans*, *B. pallida*, *Chimonobambusa khasiana*, *Teinostachyum dullooa*, *Pseudostachyum polymorphum* and *Melocanna bambusoides* are scatteredly growing at places around the swamp.

3. Geology and climate

Nagaon District is covered by recent alluvium throughout its stretches. The drainage pattern in the valley is of antecedent type. The tortuous

courses of the Brahmaputra river and its tributaries often changes not only due to lateral erosion because of the low gradient of the rivers but also due to periodic, local and sudden changes in the basement levels due to earthquakes. The soil in the study area is characterized by recent deposition of alluvium, moderately deep to very deep with grey to molted grey colour. It is mostly composed of sandy to silty loams and slightly acidic in nature. On the riverbanks, it is less acidic and sometimes neutral or slightly alkaline. The soil lack in profile development and is deficient in phosphoric acid, nitrogen and humus (Karunakaran 1974). The climate in the district is moderate during the winter and in summer, it is hot. Rainfall makes its first appearance in the month of April with occasional and irregular light showers and at times heavy downpour followed by cyclonic storms. The irregular rainfall continues up to the end of May. About 80% rainfall is from southwest monsoon. The maximum temperature is 30.4°C during July and August, whereas, minimum temperature dips to 7°C in the month of January at places.

4. Material and methods

Materials for the present study include both surface and sedimentary profile samples. A set of surface samples including moss cushion (MC) and subsurface soil (SS) numbering DA-1 to DA-10 were procured in a transect along south to north from within the forest across edge to open land. The surface samples DA-1 to DA-5 are procured from within forest, DA-6 to DA-7 from forest edge and DA-8 to DA-10 from open land, respectively.

A 3.2-m deep sedimentary profile, comprises 32 samples for pollen analysis and out of 32, seven samples were chosen for radiocarbon dates. The C14 dating was carried out at the radiocarbon lab of Birbal Sahni Institute of Palaeobotany, Lucknow. The sediment was manually cleaned, sieved and subjected to hydrochloric acid to remove any carbonate component. After repeated rinsing and pH-checking, the sediment was combusted in continuous flow of oxygen. The resulting carbon dioxide was collected and converted to acetylene and then benzene using standard catalyst and procedures. The counting was done in a liquid scintillation counter (Quantulus 1220). Based on the seven C14 dates, i.e., 14,120 cal years BP at 320 cm, 12,700 cal years BP at 290 cm, 11,600 cal years BP at 230 cm, 8310 cal years BP at 160 cm, 7100 cal years BP at 130 cm, 1550 cal years BP at 80 cm and 768 cal years BP at 35 cm, the sedimentation rate is determined to 0.85 mm/yr. Sediments were chemically processed using standard acetylation method (Erdtman 1954) and 290–411 pollen

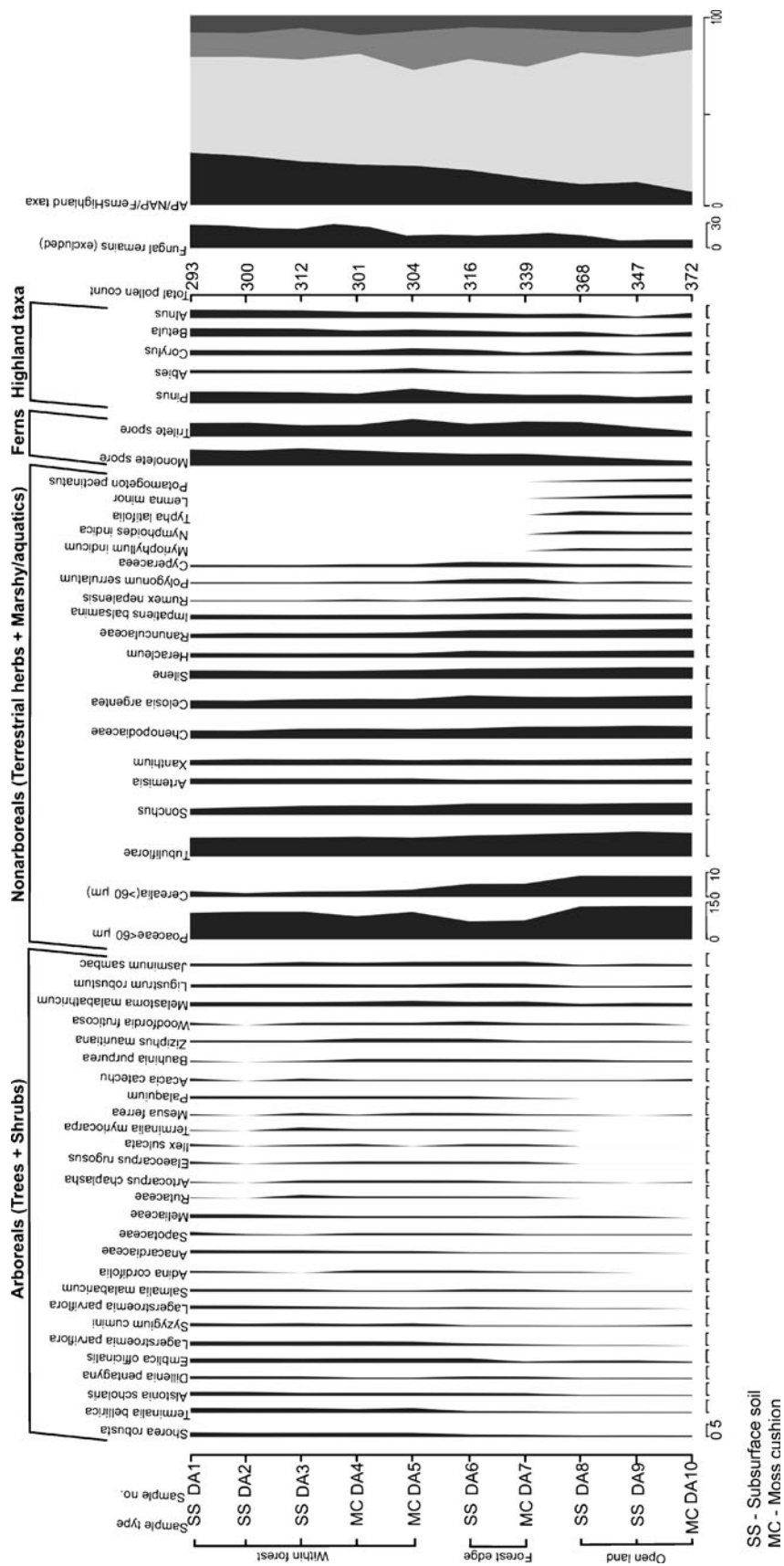


Figure 2. Pollen spectra in and around Dabaka Swamp, Nagaon District, Assam.

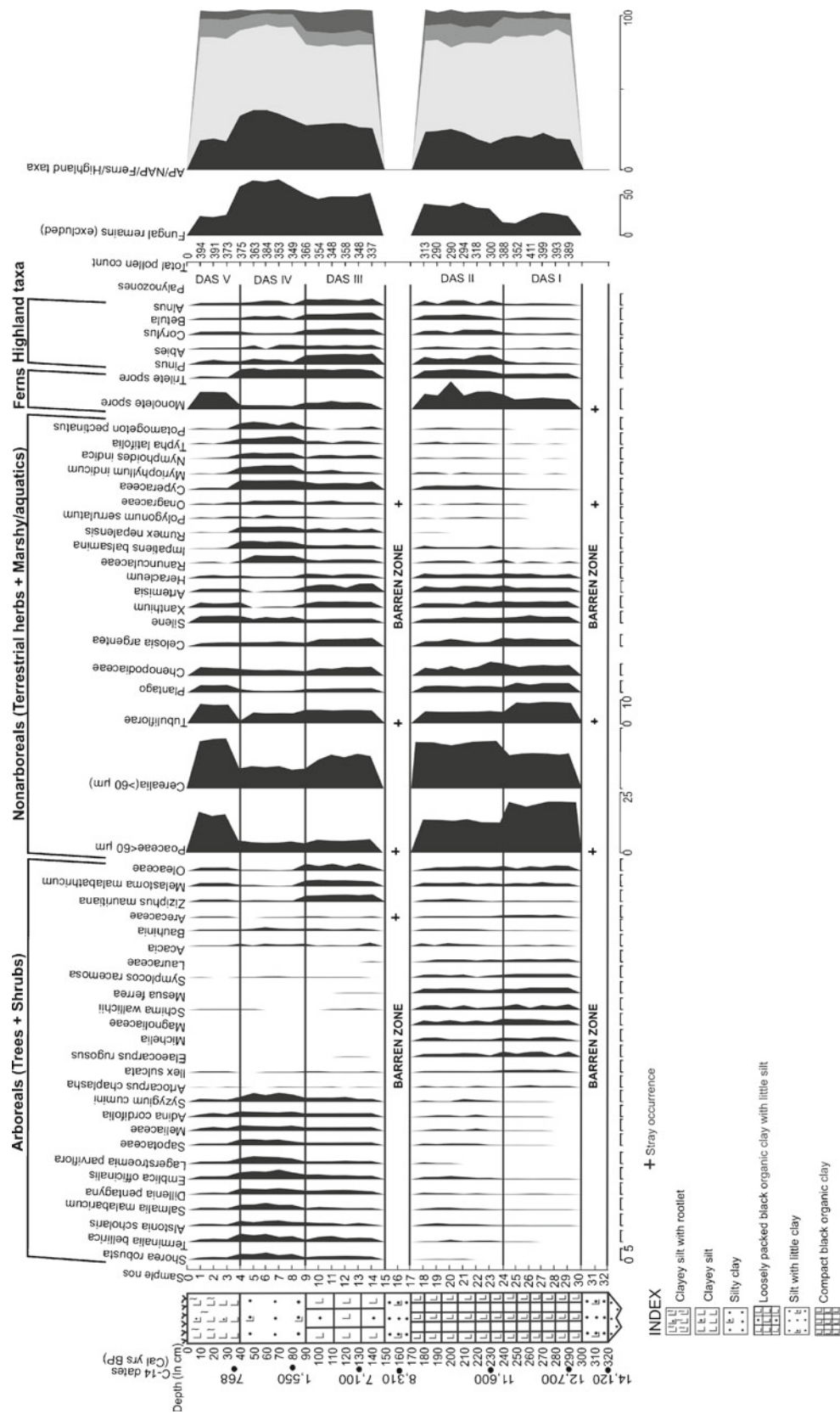
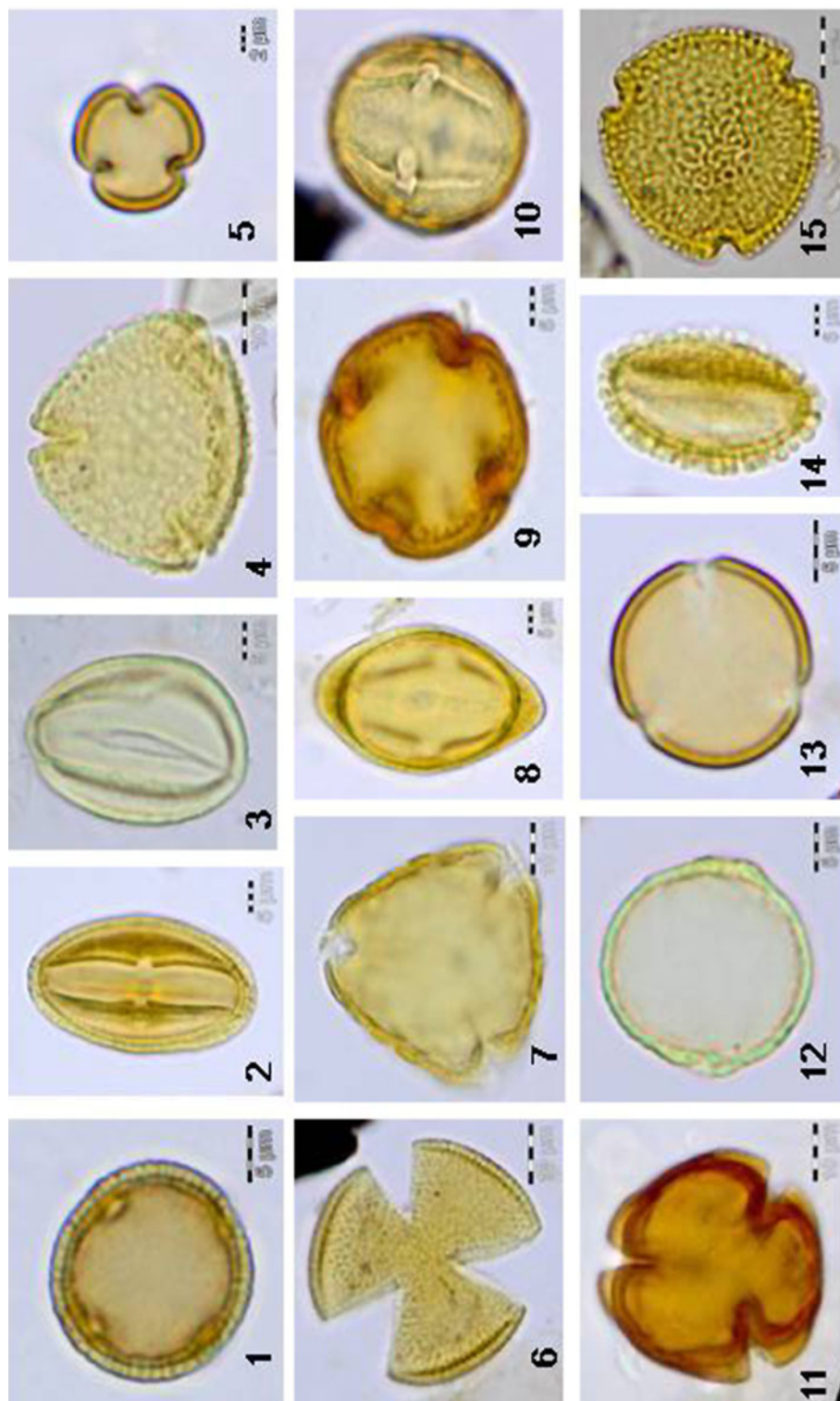


Figure 3. Pollen diagram from Dabaka Swamp, Nagaon District, Assam.



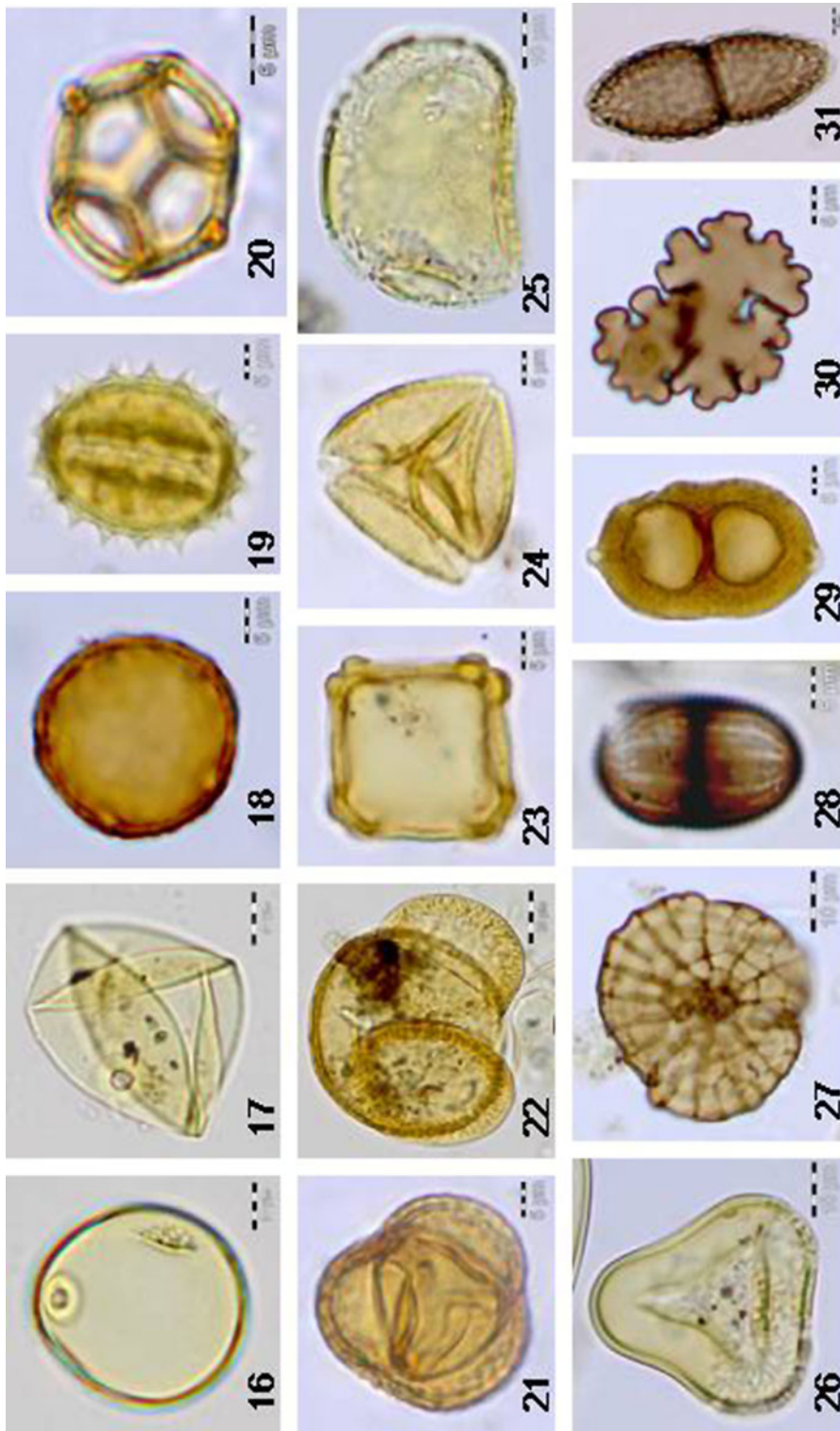


Figure 4. Palynoassemblage recovered from sediments of Lower Brahmaputra valley, Assam. 1. *Emblica officinalis*, 2. *Semecarpus anacardium*, 3. *Lannea coromandelica*, 4. *Symplocos racemosa*, 5. *Elaeocarpus rugosus*, 6. *Shorea robusta*, 7. *Schima wallichii*, 8. *Lagerstroemia parviflora*, 9. *Meliaceae*, 10. *Sapotaceae*, 11. *Mesua ferrea*, 12. *Artocarpus chaplasha*, 13. *Dillenia pentagyna*, 14. *Ilex sulcata*, 15. *Ligustrum robustum*, 16. *Poaceae* <60 µm, 17. *Cerealia*, 18. *Plantago erosa*, 19. *Tubuliflorae*, 20. *Liguliflorae*, 21. *Xanthium strumarium*, 22. *Pinus* sp., 23. *Alnus* sp., 24. *Nymphoides indica*, 25. Degraded trilete spore, 26. Degraded monolete spore, 27. *Microthyriaceae*, 28. *Cookeina* sp., 29. *Prosopium* sp., 30. *Entophlyctis* sp., 31. *Diplodia* sp.

Table 1. *Stratigraphy of soil profile.*

Column depth (in cm)	Lithology
320–300	Silt with little clay
300–170	Compact black organic clay
170–150	Silt with little clay
150–90	Loosely packed black organic clay with little silt
90–40	Silty clay
40–20	Clayey silt
20–0	Clayey silt with rootlet

grains per sample were counted. Grasses in the text are categorized into Poaceae with pollen $<60\ \mu\text{m}$ and Cerealia with pollen $>60\ \mu\text{m}$. Pollen spectra and diagram were made using Coral Draw-12. Plant elements in the study have been categorized into arboreals (trees and shrubs), nonarboreals (terrestrial herbs and marshy/aquatics), ferns and highland taxa. Fungal remains were excluded from the pollen sum to interpret the pollen spectra and diagram (figures 2 and 3). Photodocumentation of palynomorphs were done using Olympus BX 61 Microscope with BT-25 camera (figure 4). The sediment composition of the core exhibits the presence of clay, silt and organic matter in variable fractions. The depthwise lithostratigraphical details of the core are given in table 1.

5. Description of pollen spectra

For inferring palaeovegetation and palaeoclimate, it is a pre-requisite to establish modern/pollen vegetation relationship in and around the study sites. Therefore, a total of 10 surface samples were procured in and around the study area to analyze differential pollen dispersal and sedimentation. Detail palynoassemblage recovered from surface sediments within forest across forest edge to open land area are described below.

5.1 Pollen spectra (within forest)

Sample nos – DA-1–3 (SS) and DA-4–5 (MC): Palynological studies of SS and MC show that an average value of nonarboreal taxa (50.07%) is predominant over arboreal taxa (23.68%), ferns (14.08%) and highland taxa (12.20%). Among nonarboreals, grasses include Poaceae $<60\ \mu\text{m}$ (12.14%) and Cerealia $>60\ \mu\text{m}$ (2.77%) with a combined value of 14.91%. Other major terrestrial herbs are represented as Tubuliflorae

(8.68%), Chenopodiaceae (4.50%), *Celosia argentea* (3.37%), *Sonchus* (3.24%), *Silene* (3.05%), *Artemisia* (2.19%), *Xanthium* (2.18%) and *Heracleum* (1.66%) in moderately good values. Marshy taxa include Ranunculaceae and *Impatiens balsamina* (1.99% each) and Cyperaceae (1.13%) in lower values. However, *Rumex nepalensis* and *Polygonum serrulatum* are sporadic. Aquatic taxa are represented sporadically by *Myriophyllum indicum*, *Nymphaea nouchali*, *Typha latifolia*, *Lemna minor* and *Potamogeton pectinatus*. Among ferns, monolete (7.53%) and trilete spores (6.55%) are encountered in high values.

Among arboreals, major tree species are represented by *Shorea robusta* (1.66%), *Emblia officinalis* (1.52%), *Lagerstroemia parviflora* and *Terminalia bellirica* (1.26% each), *Alstonia scholaris* (1.13%), Anacardiaceae (1.06%), Meliaceae and *Syzygium cumini* (1.00% each) in lower values. *Salmalia malabaricum*, *Dillenia pentagyna*, Sapotaceae, *Adina cordifolia*, Rutaceae, *Palaquium* and *Acacia* are sporadic in the assemblage. Semi-evergreen tree taxa are also sporadically represented as *Ilex sulcata*, *Terminalia myriocarpa*, *Mesua ferrea*, *Elaeocarpus rugosus* and *Artocarpus chaplasha*. Major shrubs include *Ligustrum* (2.45%) in moderate value while others, *Melastoma malabathricum* (1.66%), *Jasminum* (1.19%) and *Ligustrum* (1.15%) are found in lower values along with sporadic *Ziziphus mauritiana*, *Bauhinia purpurea* and *Woodfordia fruticosa*. Highland taxa are represented by *Pinus* (4.12%), *Alnus* (2.72%) and *Betula* (2.45%) at moderately good values followed by low values of *Corylus* (1.79%) and *Abies* (1.13%). Fungal remains are encountered in fairly good values and are represented by *Alternaria*, *Xylaria*, *Curvularia*, *Diplodia*, *Nigrospora*, ascospore of *Cookeina* and Microthyriaceae.

5.2 Pollen spectra (forest edge)

Sample nos – DA-6 (SS) and DA-7 (MC): Palynological studies of SS and MC show that an average value of nonarboreal taxa to the tune of 60.69% which is dominated over arboreals (16.26%), ferns (14.61%) and highland taxa (8.44%). Among nonarboreals, grasses include Poaceae $<60\ \mu\text{m}$ (9.65%) and Cerealia $>60\ \mu\text{m}$ (5.91%) with a combined value of 15.56% followed by other terrestrial herbs such as Tubuliflorae (9.76%), Chenopodiaceae (5.48%), *Sonchus* (4.43%), *Celosia argentea* (4.27%), *Silene* (3.82%), *Heracleum* (2.45%), *Artemisia* (2.29%) and *Xanthium* (2.14%) at moderately good values. Marshy taxa include Ranunculaceae (3.20%) and *Impatiens balsamina* (2.44%)

at moderate values along with low values of Cyperaceae and *Polygonum serrulatum* (1.82% each), *Rumex nepalensis* (1.21%). Among ferns, monolete (7.34%) and trilete spores (7.27%) are encountered in good values in the assemblage.

Among arboreals, tree species include *Shorea robusta*, *Embllica officinalis*, *Alstonia scholaris* and *Dillenia pentagyna* in trace values but slightly improved as compared to other deciduous taxa such as *Lagerstroemia parviflora*, *Terminalia bellirica*, Anacardiaceae, Meliaceae, *Syzygium cumini*, *Salmalia malabaricum*, Sapotaceae, *Adina cordifolia*, *Palaquium*, *Acacia*. Semi-evergreen tree taxa are sporadically represented by *Ilex sulcata*, *Terminalia myriocarpa*, *Mesua ferrea*, *Elaeocarpus rugosus* and *Artocarpus chaplasha*. Major shrubs include *Melastoma malabathricum* (1.69%), *Ligustrum robustum* (1.38%) and *Jasminum sambac* (1.37%) in lower values. Whereas, *Bauhinia purpurea*, *Ziziphus mauritiana* and *Woodfordia fruticosa* are sporadic. Highland taxa are represented by *Pinus* (3.67%) in moderate value along with low occurrence of *Alnus* and *Betula* (1.69% each) and *Corylus* (1.39%) whereas, *Abies* is sporadic. Fungal remains are encountered in moderate values.

5.3 Pollen spectra (open land)

Sample nos – DA-8-9 (SS) and DA-10 (MC): Paly-nological studies of SS and MC show that an average value of nonarboreal taxa (75.07%) is dominant over arboreal taxa (9.99%), ferns (8.01%) and highland taxa (6.93%). Among nonarboreals, grasses include both Poaceae <60 µm (14.37%) and Cerealia > 60 µm (9.63%) at a combined value of 24.00% followed by other terrestrial herbs such as Tubuliflorae (11.86%), Chenopodiaceae (6.17%), *Sonchus* (4.79%), *Celosia argentea* (4.60%), *Silene* (4.23%), *Heracleum* (2.58%), *Xanthium* (2.39%) and *Artemisia* (2.30%) in high values. Marshy taxa include Ranunculaceae (3.49%), *Impatiens balsamina* (2.30%) in moderate values along with trace occurrence of Cyperaceae (1.11%). Other marshy taxa such as *Rumex nepalensis* and *Polygonum serrulatum* are sporadic. The representation of aquatic taxa including *Myriophyllum indicum*, *Typha latifolia* and *Potamogeton pectinatus* (1.01% each) is feeble, whereas, *Nymphoides* is sporadic. Among ferns, both monolete (3.59%) and trilete spores (4.42%) are encountered at moderately good values.

Among arboreals, tree taxa such as *Shorea robusta*, *Embllica officinalis*, *Alstonia scholaris*, *Dillenia pentagyna*, *Lagerstroemia parviflora*, *Terminalia bellirica*, Meliaceae, *Syzygium cumini*, *Salmalia malabaricum*, Sapotaceae, *Adina cordifolia*, Rutaceae, *Palaquium* and *Acacia* are poorly

represented along with trace occurrence of semi-evergreen tree taxa such as *Artocarpus chaplasha*, *Terminalia myriocarpa*, *Mesua ferrea*, *Ilex sulcata* and *Elaeocarpus rugosus*. *Melastoma malabathricum* is the lone shrub represented within 1.11%. However, *Ligustrum robustum*, *Jasminum sambac*, *Ziziphus mauritiana*, *Bauhinia purpurea* and *Woodfordia fruticosa* mark their sporadic presence. The major highland taxa are represented by *Pinus* (3.12%) in moderate value along with low values of *Alnus* (1.36%), *Betula* (1.27%) and *Corylus* (1.18%). *Abies* is represented sporadically. Fungal remains are encountered in relatively low value as compared to prior two cases.

6. Description of pollen diagram

For a better understanding of the succession of vegetation and climate, five pollen zones, viz., DAS I, DAS II, DAS III and DAS IV with the prefix DAS representing Dabaka Swamp (Faegri and Iverson 1989) have been recognised in this pollen sequence barring two barren zones between 320–300 cm and 170–150 cm owing to fluvial activity. These pollen zones are described below separately.

Barren zone (320–300 cm; 14,120–12,700 cal years BP): Grasses–Tubuliflorae–Onagraceae–Ferns–*Botryococcus*: This pollen zone is devoid of any arboreal pollen excepting trace pollen of Cerealia, Poaceae <60 µm, Tubuliflorae and Onagraceae with *Botryococcus* as algal remains.

Pollen zone DAS I (300–240 cm; 12,700–11,600 cal years BP): Grasses–Tubuliflorae–*Plantago*–*Celosia*–*Xanthium*–Magnoliaceae–*Mesua*–*Schima*–*Symplocos*–Lauraceae–Ferns assemblage: This phase is characterized by the predominance of nonarboreals at the average value of 66.05% over arboreals (19.94%), ferns (10.14%) and highland taxa (3.87%). Among nonarboreals, grasses both Poaceae <60 µm (21.70%) and Cerealia > 60 µm (13.26%) attaining a value of up to 34.96% are predominated over other terrestrial herbs such as Tubuliflorae (8.66%), Chenopodiaceae (4.50%), *Plantago* (4.11%), *Silene* (3.04%), *Celosia argentea* (2.78%), *Xanthium* (2.65%) and *Artemisia* (2.02%) in moderately high values along with low value of *Heracleum* (1.72%). Marshy taxa such as Cyperaceae, Ranunculaceae, *Impatiens*, *Rumex nepalensis* and *Polygonum serrulatum* are sporadically found. Aquatic taxa such as *Myriophyllum indicum*, *Nymphoides indica*, *Typha latifolia* and *Potamogeton pectinatus* are also sporadically encountered. Among ferns, monolete

(8.25%) and trilete spores (1.89%) are encountered with high to low values, respectively. Along with regional ferns some temperate fern allies such as *Gleichenia gigantea*, *Davallia sinensis*, *Osmunda regalis*, *Pteridium aquilinum* and *Pteris pentaphylla* are also encountered in trace values in the assemblage. Among arboreals, semi-evergreen tree taxa such as Magnoliaceae (2.54%) and *Mesua ferrea* (2.38%) are found in moderate values followed by low values of *Elaeocarpus rugosus* (1.88%), *Schima wallichii* (1.66%), *Symplocos racemosa* (1.37%), *Michelia champaca* (1.20%), Lauraceae (1.07%), *Ilex sulcata* (1.03%) and *Artocarpus chaplasha* (1.02%) along with sporadic deciduous taxa such as *Syzygium cumini*, *Terminalia bellirica*, *Alstonia scholaris*, *Salmalia malabaricum*, *Dillenia pentagyna*, *Embllica officinalis*, *Adina cordifolia*, Sapotaceae, Meliaceae, *Acacia* and *Bauhinia*. Among major shrubs, *Melastoma malabathricum* is found with moderate value of 2.04% followed by low value of Oleaceae (1.63%) whereas, *Ziziphus mauritiana* is observed sporadically. Highland taxa such as *Pinus*, *Abies*, *Corylus*, *Betula* and *Alnus* are found within a moderate frequency of 3.87%.

Pollen zone DAS II (240–170 cm; 11,600–8310 cal years BP): Grasses–Cyperaceae–*Plantago*–*Celosia*–Oleaceae–Magnoliaceae–*Mesua*–*Syzygium*–*Embllica*–Ferns–Highland taxa assemblage: This phase is characterized by the predominance of nonarboreals at the average value of 61.55% over arboreals (19.10%), ferns (10.38%) and highland taxa (8.97%). Among nonarboreals, grasses both Cerealia >60 µm (20.70%) and Poaceae < 60 µm (14.06%) attaining a value of up to 34.76% are predominated over other terrestrial herbs such as Tubuliflorae (5.88%), Chenopodiaceae (3.77%), *Plantago* (2.77%), *Silene* and *Xanthium* (2.38% each), *Celosia argentea* (2.27%) and *Artemisia* (1.99%) at moderately high values along with low *Heracleum* (1.54%). Among marshy taxa, except Cyperaceae (1.77%) other taxa such as Ranunculaceae, *Impatiens balsamina*, *Rumex nepalensis* and *Polygonum serrulatum* are sporadic. Aquatic taxa such as *Myriophyllum indicum*, *Nymphoides indica*, *Typha latifolia* and *Potamogeton pectinatus* are also encountered sporadically. Among ferns, monolete and trilete spores are encountered within moderately high frequency of 6.61% and 3.37%, respectively. Among arboreals, semi-evergreen tree taxa such as *Mesua ferrea* (1.89%), Magnoliaceae (1.66%), *Elaeocarpus rugosus* (1.33%), *Schima wallichii* (1.22%), *Symplocos racemosa* (1.06%) and *Artocarpus chaplasha* (1.00%) are found in low values whereas, *Ilex sulcata* is sporadic along

with occurrence of deciduous taxa such as *Syzygium cumini* and *Embllica officinalis* (1.02% each) in lower values. Rest of the semi-evergreen tree taxa such as Lauraceae and *Michelia* occurs in low values than preceding phase along with slight increment in deciduous taxa such as *Terminalia bellirica*, *Alstonia scholaris*, *Salmalia malabaricum*, *Dillenia pentagyna*, Sapotaceae, *Adina cordifolia*, Meliaceae, *Acacia*, Arecaceae and *Bauhinia*. *Shorea robusta* and *Lagerstroemia parviflora* are found in sporadic values. Among major shrubs, Oleaceae (1.72%) and *Melastoma malabathricum* (1.23%) are observed in low values whereas, *Ziziphus mauritiana* is observed sporadically. Highland taxa such as *Pinus*, *Abies*, *Corylus*, *Betula* and *Alnus* are found within a frequency of 8.97%.

Barren zone (170–150 cm; 8310–7100 cal years BP): Grasses–Tubuliflorae–Arecaceae–Onagraceae–*Botryococcus*: This zone is devoid of any arboreal pollen except trace pollen of grass, Tubuliflorae, Arecaceae and Onagraceae with *Botryococcus* as algal remains.

Pollen zone DAS III (150–90 cm; 7100–1550 cal years BP): Grasses–Cyperaceae–*Shorea*–*Dillenia*–*Terminalia*–*Lagerstroemia*–*Ziziphus*–*Melastoma*–*Impatiens*–Ranunculaceae–*Nymphoides*–*Typha*–Ferns–Highland taxa assemblage: This phase is characterized by the predominance of nonarboreals at the average value of 52.30% over arboreals (26.94%), ferns (7.81%) and highland taxa (12.95%). The major nonarboreals are represented by grasses with both Cerealia >60 µm (12.99%) and Poaceae <60 µm (5.59%) attaining a value of up to 18.58%. Other terrestrial herbs are represented by Tubuliflorae (6.07%), Chenopodiaceae (3.83%) and *Xanthium* (2.66%) in moderately high values followed by low occurrence of *Celosia argentea* (1.90%), *Artemisia* (1.84%), *Silene* (1.71%), *Plantago* (1.47%) and *Heracleum* (1.08%). Among marshy taxa, Cyperaceae (2.94%) is moderate in occurrence followed by *Impatiens balsamina* and *Rumex nepalensis* (1.65% each) and Ranunculaceae (1.52%) in low values whereas, *Polygonum serrulatum* is found sporadic. Among aquatic taxa, *Nymphoides indica* (1.24%), *Typha latifolia* (1.18%) and *Myriophyllum indicum* (1.04%) are found in low values but in relatively improved values than preceding phase. *Potamogeton pectinatus* is observed sporadically. Among ferns, monolete and trilete spores are observed within moderate frequency of 3.74% and 4.07% respectively. Among arboreals, tree taxa such as *Syzygium cumini* (1.84%), *Embllica officinalis* and *Dillenia pentagyna* (1.70%)

each), *Terminalia bellirica* (1.52%), *Shorea robusta* (1.47%), Sapotaceae and Meliaceae (1.42% each) and *Lagerstroemia parviflora* (1.19%) are encountered in low values, rest of the tree taxa such as *Alstonia scholaris*, *Adina cordifolia*, *Salmalia malabaricum*, *Acacia* and *Bauhinia* are sporadic along with trace semi-evergreen tree taxa such as *Ilex sulcata*, *Elaeocarpus rugosus*, *Artocarpus chaplasha* and *Schima wallichii*. Among major shrubs, Oleaceae (3.03%), *Ziziphus mauritiana* (2.99%) and *Melastoma malabathricum* (2.74%) are found in moderate values. Highland taxa such as *Pinus*, *Abies*, *Corylus*, *Betula* and *Alnus* are found within a high frequency of 12.95%.

Pollen zone DAS IV (90–40 cm; 1550–768 cal years BP): Grasses–Cyperaceae–*Salmalia*–Sapotaceae–Meliaceae–*Impatiens*–Ranunculaceae–*Rumex*–*Polygonum*–*Myriophyllum*–*Potamogeton*–Ferns–Highland taxa assemblage: This phase is characterized by the predominance of nonarboreals at an average value of 51.46% over arboreals (33.84%), ferns (5.47%) and highland taxa (9.23%). The major nonarboreals are represented by grasses with Cerealia >60 μm (8.28%) and Poaceae <60 μm (4.10%) attaining up to 12.38%. Other terrestrial herbs such as Tubuliflorae (4.21%), Chenopodiaceae (2.02%) and *Silene* (1.97%) are found in moderate values whereas, *Celosia argentea* (1.43%) occur in lower value, rest of the terrestrial herbs such as *Artemisia*, *Xanthium*, *Plantago* and *Heracleum* are sporadic. Among marshy taxa, Cyperaceae (3.95%), *Impatiens balsamina* (3.46%), Ranunculaceae (3.07%), *Rumex nepalensis* (2.58%) are found in moderate values followed by low occurrence of *Polygonum serrulatum* (1.27%). Among aquatic taxa, *Myriophyllum indicum* (3.51%), *Nymphoides indica* (3.02%), *Typha latifolia* (2.92%) and *Potamogeton pectinatus* (2.52%) occur in high values. Among ferns, monolete are observed with low value of 1.19% while, trilete spores are more frequent with 4.28%. Among arboreals, *Syzygium cumini* (3.47%), *Emblica officinalis* (3.24%), *Lagerstroemia parviflora* (3.22%), *Terminalia bellirica* (3.05%), *Shorea robusta* (2.91%), *Dillenia pentagyna* (2.80%), Sapotaceae (2.68%), *Salmalia malabaricum* (2.51%) and Meliaceae (1.92%) are found in moderate values while, *Alstonia scholaris* (1.70%) and *Bauhinia* (1.21%) occur in low values, rest of the tree taxa such as *Acacia* along with semi-evergreen taxa such as *Schima wallichii*, *Ilex sulcata*, *Artocarpus chaplasha* and *Symplocos racemosa* are sporadic. Among major shrubs, Oleaceae, *Ziziphus mauritiana* and *Melastoma malabathricum* are observed sporadically. Highland

taxa such as *Pinus*, *Abies*, *Corylus*, *Betula* and *Alnus* are found within a high frequency of 9.23%.

Pollen zone DAS V (40–0 cm; 768 cal years BP onwards): Grasses–Tubuliflorae–*Xanthium*–*Shorea*–*Terminalia*–*Melastoma*–Oleaceae–*Ziziphus*–Ferns–Highland taxa assemblage: This phase is characterized by the predominance of nonarboreals at the average value of 65.90% over arboreals (17.95%), ferns (8.97%) and highland taxa (7.18%). Among nonarboreals, grasses both Cerealia > 60 μm (20.22%) and Poaceae <60 μm (16.75%) attaining a value of up to 36.97% are dominated over other terrestrial herbs such as Tubuliflorae (7.23%), Chenopodiaceae (3.89%), *Plantago* (3.02%), *Silene* (2.77%) and *Xanthium* (2.33%) in moderately high values with *Artemisia* (1.64%), *Celosia argentea* (1.56%) and *Heracleum* (1.47%) in low values. Among marshy taxa, except low frequency of Cyperaceae (1.03%), all other taxa such as *Impatiens balsamina*, Ranunculaceae, *Rumex nepalensis* and *Polygonum serrulatum* are sporadically encountered. Aquatic taxa, viz., *Myriophyllum indicum*, *Nymphoides indica*, *Typha latifolia* and *Potamogeton pectinatus* are also sporadically visible in the assemblage. Ferns are encountered with a good value of 8.97%. Among arboreals, *Shorea robusta* and *Terminalia bellirica* are observed with 1.38% each, followed by *Emblica officinalis* (1.30%), *Syzygium cumini* (1.29%), Meliaceae, *Lagerstroemia parviflora* and *Adina cordifolia* (1.04% each) with low values. Rest of the tree taxa such as *Dillenia pentagyna*, Sapotaceae, *Salmalia malabaricum*, Meliaceae, *Alstonia scholaris*, *Acacia* and *Bauhinia* are sporadically encountered along with semi-evergreen tree taxa such as *Ilex sulcata*, *Schima wallichii* and *Symplocos racemosa*. Among major shrubs, Oleaceae (1.81%), *Melastoma malabathricum* (1.56%) and *Ziziphus mauritiana* (1.04%) are found in low values. Highland taxa such as *Pinus*, *Abies*, *Corylus*, *Betula* and *Alnus* are found within good frequency of 7.18%.

7. Discussion and conclusions

- Pollen studies of surface samples have reflected the existence of factual forest composition of arboreals as long as the study is confined to the woods but their frequency proportionately dwindles in the samples away from the forest. The special feature of this study indicates underrepresentation of *Shorea robusta* as a dominant ingredient of the forest and could be attributed to poor preservation of its pollen in the sediment despite its high pollen productivity (Bera 1990). However, the erratic representation of other

arboreals could be inferred to low pollen productivity owing to prevalence of entomophily (e.g., *Salmalia* and *Dillenia* sp.). Pollen rain in forest edge and open-land area show relative reduction in arboreals in contrast to the woods. However, grasses and other heathland taxa attain higher frequency than those of forest. Ferns are represented in constant values both inside, and on the outskirts of the forest.

- Thus, the pollen proxy record from sedimentary profile has demonstrated five phases of origin and development of tropical mixed deciduous forest under contemporaneous climatic variabilities in Lower Brahmaputra flood plain of Assam since Holocene. During 14,120–12,700 cal years BP, this region experienced fluvial activity as evident by trace pollen and spores supported by *Ludwigia octovalvis*, Tubuliflorae, grasses and *Botryococcus* though in low value. This fluvial activity was further succeeded by tropical tree savanna type of vegetation under cool and dry climatic regime during 12,700–11,600 cal years BP owing to dominance of grasses with interspersed *Syzygium*, *Salmalia* and *Dillenia* type of deciduous taxa along with semi-evergreen taxa such as *Mesua*, Magnoliaceae, *Elaeocarpus*, *Schima*, *Michelia* and *Symplocos*. The study matches the prevalent savanna ecosystem of northern South America as recorded by pollen record (11,570 years BP) indicating dry climatic condition since late glacial time (Behling and Hooghiemstra 1998). Also, the climatic regime at this phase is well-matched with the global Younger Dryas climatic event (Berger 1990).

During 11,600–8310 cal years BP, inception of tropical mixed deciduous taxa occurred with invasion of deciduous tree taxa such as *Syzygium*, *Embllica*, *Alstonia*, *Salmalia*, Sapotaceae, *Acacia* and *Dillenia* along with reduction in semi-evergreen tree taxa under relatively less cool and dry climatic regime corresponding to that of northern South American Younger Dryas (10,680–7200 years BP) climatic situations based on pollen record. *Shorea* and *Lagerstroemia* incepted for the first time in the assemblage at this time. This phase is further followed by a fluvial activity from 8310–7100 cal years BP owing to paucity of pollen and spores. This fluvial activity was further succeeded by enrichment of tropical mixed deciduous forest with invasion of deciduous taxa along with increment of marshy/aquatic, trilete fern and adequate fungal taxa under warm and humid climate influenced by active southwest monsoon from 7100–1550 cal years BP. Thus, this finding matches with the results according to which global temperatures appear to peak around 7000–6000 years ago, in a period called Hypsithermal.

Further, between 1550 and 768 cal years BP, final settlement of tropical mixed deciduous forest occurred with predominance of *Shorea robusta*, *Syzygium*, *Terminalia*, *Embllica* and *Acacia* with invasion of sal-associated taxa namely *Lagerstroemia*, *Lannea*, *Bauhinia*, *Alstonia*, Anacardiaceae, Sapotaceae and Arecaceae. Rich *Impatiens* indicate peak monsoonal signal at this time phase under increased warm and humid climatic regime corresponding to the Medieval Warm Period (Anderson *et al* 2002). With the inception of relatively drier climate owing to reduction in monsoon precipitation, around 768 cal years BP onwards, the gradual reduction in typical mixed deciduous elements was noticed. The result achieved from Arunachal Pradesh, northeast Himalaya showing climatic shifts from warm and humid to cool and dry around AD 1400 based on pollen records under the impact of LIA must have affected this region too owing to relatively drier climatic regime (Bhattacharyya *et al* 2007). This period of harsh climate partly falls within the temporal range of LIA, which is recorded at a global level between AD 1450 and 1850 (Lamb 1977; Bradley 1985; Grove 1988).

This dryness may also be attributed to the clearance of forest by anthropogenic activities such as jhuming, lumbering and pasturing in Lower Brahmaputra reserve forest area which presently poses a serious threat to biodiversity conservation. Increase in Cerealia with other prominent culture pollen such as Tubuliflorae, *Plantago*, Brassicaceae and *Artemisia* hints persistent pastoral activity. It is important to note that the coincidence of the advent of monsoon rainfall becomes a crucial and decisive factor for the regeneration and proliferation of the main constituent of tropical mixed deciduous in the Indian subcontinent.

Fossil pollen data show clear changes in natural vegetation during the Holocene that are affected by the summer monsoon including tropical seasonal rain forest, subtropical forest, temperate deciduous forest, tropical deciduous forest, conifer-deciduous mixed forest, temperate steppe and highland meadow/steppe. Despite various vegetation and climatic phases at different time intervals since Holocene, our results show that timely arrival of monsoon since around 6000 years BP is parallel to the gradual enrichment of tropical mixed deciduous taxa and thus final establishment of tropical mixed deciduous forest during 1550 to 768 cal years BP followed by warm and relatively dry climate owing to less monsoon precipitation and anthropogenic impact. This result somehow at broader scale matches with the study of monsoon influenced regions of China since Holocene based on pollen studies, where Early to Middle Holocene witnessed high humidity followed by dryness

since Late Holocene (Zhao *et al* 2009). Keeping all these views in mind, this paper aims to caution that great care is needed while interpreting the pollen diagram from the tropical mixed deciduous forest especially in a flood plain area such as Brahmaputra valley of Assam since the Quaternary period.

Acknowledgements

We are highly grateful to Dr Naresh Chandra Mehrotra, Director, BSIP, Lucknow for providing necessary facilities and encouragement for conducting the work. Thanks are due to anonymous reviewers and the Associate Editor, Dr Shankar for providing suggestions to improve the paper.

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