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# Vegetation history and monsoonal fluctuations during the last 12,500 years BP inferred from pollen record at Lower Subansiri Basin, Assam, Northeast India

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## ABSTRACT

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A 120 cm sediment profile from 4.5 m deep exposed section of Lower Subansiri River Basin has been pollen analyzed to trace palaeovegetation and climate in relation to monsoonal activity since 12,500 years BP. The study has depicted the existence of tropical mixed tree–savannah type to tropical mixed deciduous type forest under four climatic regimes, viz. cold and dry to warm and relatively dry since 12,500 years BP followed by a palynologically barren zone indicating strong fluvial activity. Four sets of monsoon fluctuations, i.e. relatively low to considerably decline in monsoonal activities have been estimated by using pollen marker taxa during the period. The marker taxa signifying high monsoonal activity are – Dipterocarpaceae, *Syzygium cumunii*, Arecaceae and Moraceae. *Melastoma malabathricum*, the only taxa which is marked as low monsoonal activity and dry depositional environment. The consistent occurrences of high land taxa are suggestive of long distance pollen transport from higher elevation via strong wind and water source.

**Key–words**—Lower Subansiri Basin, Monsoonal activity, Northeast India, Vegetation.

## निचली सुबांसिरी द्रोणी, असम, पूर्वोत्तर भारत के पराग अभिलेख से अनुमानित पिछले 12,500 वर्षों पूर्व के दौरान वनस्पति इतिहास एवं मानसूनी उतार-चढ़ाव

एस.के. बेरा एवं एस.के. बसुमतारी

## सारांश

निचली सुबांसिरी नदी द्रोणी के 4.5 मीटर गहरे खंड से अनावरित एक 120 से.मी. अवसाद परिच्छेदिका 12,500 वर्षों पूर्व से मानसूनी गतिविधियों के संबंध में पुरावनस्पति व जलवायु का पता लगाने को पराग विश्लेषित की गई है। अध्ययन ने प्रबल नदीय गतिविधि इंगित करते हुए परागाणविक रूप से अनुत्पादक मंडल के अनुगामी 12,500 वर्षों पूर्व से चार जलवायवी प्रवृत्तियों अर्थात शीत व शुष्क से कोष्ण एवं सापेक्षतया शुष्क के अंतर्गत उष्णकटिबंधीय मिश्रित वृक्ष-सवन्ना प्रकार से उष्णकटिबंधीय मिश्रित पतझड़ी प्रकार की मौजूदगी चित्रित की है। इस अवधि में पराग चिह्नक टैक्सा प्रयुक्त करते हुए मानसून उतार-चढ़ावों के 04 समुच्चय अर्थात निम्न के सापेक्षतया पर्याप्त रूप से घटती मानसूनी गतिविधियां अनुमानित की गई हैं। चिह्नक टैक्सा डिप्टेरोकार्पेसी, *सायज़ीजियम कम्युनिआई,* एरेकेसी व मोरेसी उच्च मानसूनी गतिविधियां व्यक्त कर रही है। *मेलास्टोमा मालाबाथ्रीकम,* एक मात्र टैक्सा है जो निम्न मानसूनी गतिविधि एवं शुष्क निक्षेपणीय पर्यावरण के रूप में चिह्नित है। उच्च भूमि टैक्सा की निर्बाध प्राप्ति तेज हवा व जल स्रोत के माध्यम से उच्च ऊंचाई से लंबी दूरी पराग परिवहन को सुझावित है।

**संकेत-शब्द**—निचली सुबांसिरी द्रोणी, मानसूनी गतिविधि, पूर्वोत्तर भारत, वनस्पति।

## INTRODUCTION

Detailed and systematic study of palynological record has provided valuable insights concerning the changing vegetation scenario and contemporaneous climatic changes in the Indian subcontinent during the Quaternary Period (Meher–Homji & Gupta, 1999). Hitherto, no adequate palynological information is available from northeast India. However, some preliminary works have been carried out in Assam (Gupta, 1971; Bhattacharya & Chanda, 1988, 1992; Bera, 2000, 2003; Bera *et al*., 2008), Manipur (Roy & Chanda, 1987; Nautiyal & Chauhan, 2009), Mizoram (Chauhan & Mandaokar, 2006; Mandaokar *et al*., 2008), Tripura (Goswami, 1981; Prasad, 1986, 1988; Prasad & Ramesh, 1983), Arunachal Pradesh (Bhattacharyya *et al*., 2007), Meghalaya (Gupta & Sharma, 1985; Basumatary & Bera, 2007, 2010). Nagaland (Bera *et al*., 2010) and Sikkim (Bhattacharya & Chanda, 1986; D' Costa & Mukharjee, 1986; Sharma & Chauhan, 2001; Chauhan & Sharma, 1996; Mehrotra *et al*., 2005).

However, the estimation of monsoonal activity by palynodata has been carried out by few workers in India (Swain *et al*., 1983; Prasad & Enzel, 2006; Demske *et al*., 2009). Study of the Indian monsoonal activity is critical for understanding regional and global variability as it drives major changes of the tropical Indian Ocean region (Gupta *et al*., 2003; Ely *et al*., 1993; Fleitmann *et al*., 2003; Goodbred & Kuehl, 2000). The changes in the monsoonal activity over South Asia affect the fluvial system and thus flora and fauna of the region (Gupta *et al*., 2006; Kumaran *et al*., 2005). Annual precipitation is an important parameter explaining the modern distribution of pollen taxa is clearly evidenced by distinct pollen assemblage, e.g. *Glochidion* pollen type, *Grewia*, *Schleichera oleosa*, *Trema orientalis*, *Lannea* type, *Maytenus* type, *Lagerstroemia* and Melastomaceae/Combretaceae are receiving annual rainfall 1200 to 2500 mm/yr, *Syzygium* type, *Trema orientalis*, *Olea dioica*, *Elaeocarpus*, *Securinega* type, *Tetrameles nudiflora*, *Mallotus* type, Moraceae/Urticaceae receiving 2800 to 4500 mm/yr and *Poeciloneuron* and *Syzygium* type are receiving exceeding 4500 mm/yr (Barboni & Bonnefille, 2001).

The present area of study located in Dhemaji District, situated in the northeastern corner of Assam, lies between lat. 27º27' and 27º57' N and long. 94º18' and 95º32' E respectively (Fig. 1). It is bounded in the north by Siang and Papumpare District of Arunachal Pradesh, in the east by the Arunachal Hills, in the west by Subansiri River, North Lakhimpur District and in the south by Brahmaputra River. The Subansiri River (Fig. 2a) is the largest tributary of the mighty Brahmaputra, a Trans–Himalayan river originating from the western part of Mount Pororu (5059 masl) in the Tibetan Himalaya (Goswami *et al*., 1990). The different geo–ecological zones transversed by the river have distinctive assemblage of topographical, geological, climatological and floral characteristics. After flowing for around 190 km through Tibet and 200 km through Arunachal Himalaya, it enters into the plains of Assam through a gorge near Gerukamukh which is situated in Dhemaji District and flows through North Lakhimpur District and then merges with mighty Brahmaputra River. The riverbed is composed of sand mixed with pebbles and boulders up to Chauldhoaghat (Goswami, 1997). The forest vegetation is tropical mixed deciduous type and the majority of the forest embraces semi–evergreen taxa and mixed deciduous taxa including riparian and swamp taxa (Champion & Seth, 1968). Floristically, due to the excessive deforestation, the forest areas are cleared and secondary monoculture forests have gradually been established. These forests mainly consist of *Shorea assamica*, *Mesua ferrea*, *Cinnamomum*

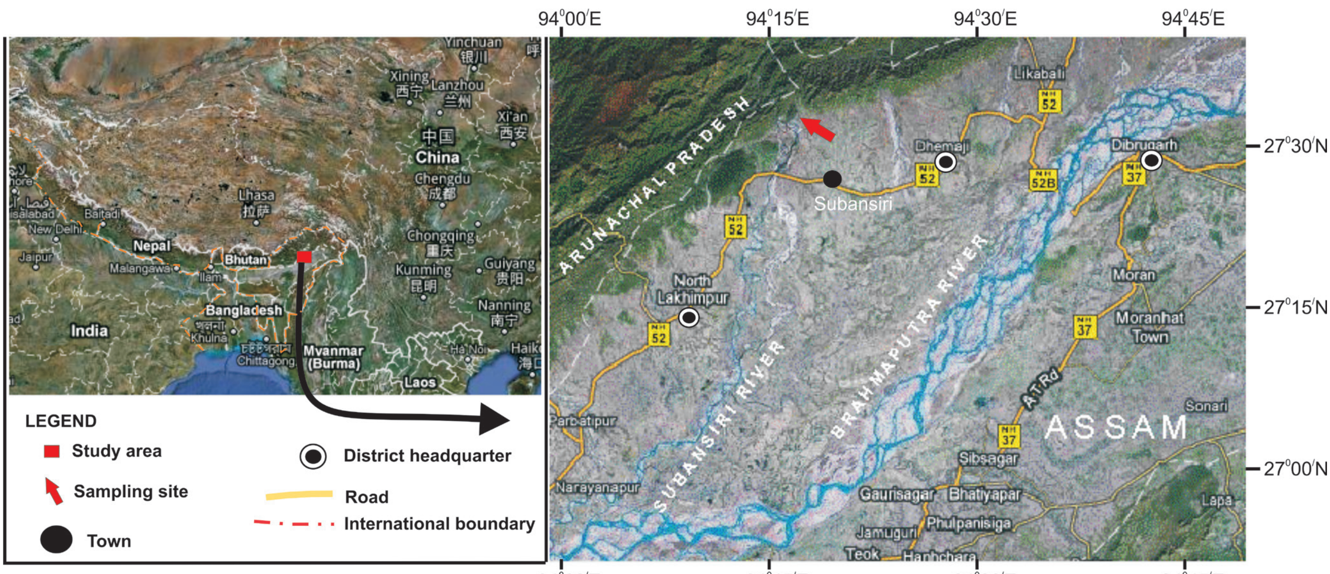


Fig. 1—Map showing the study area.

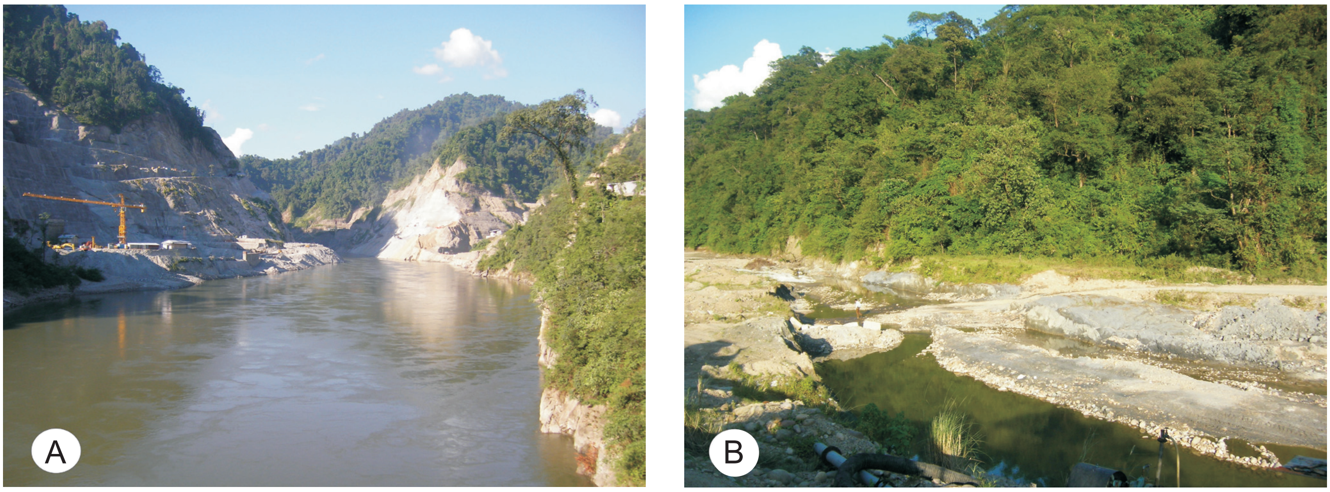


Fig. 2—(*a*) A view of Lower Subansiri River Basin, near NHPC Ltd., Assam. (*b*) A view of vegetation composition, Lower Subansiri River Basin, Assam.

*bejolghota*, *Dipterocarpus macrocarpus*, *Dillenia pentagyna*, *Lagerstroemia parviflora*, *Schima wallichii*, *Aporusa wallichii, Albizia lebbeck*, *Terminalia myriocarpa* and *Tetrameles nudiflora* (Fig. 2b). The main components of shrubby species are *Melastoma malabathricum*, *Holarrhena antidysenterica*, *Garcinia lancifolia* and *Acacia concinna*. Palms like *Areca*, *Caryota* and *Pinanga* are also conspicuous. Bamboos such as *Bambusa arundinaria, Dendrocalamus hamilitonii* and *Melocanna bambusoides* are common in and around of the study area. The ground flora in deciduous forest is very poor

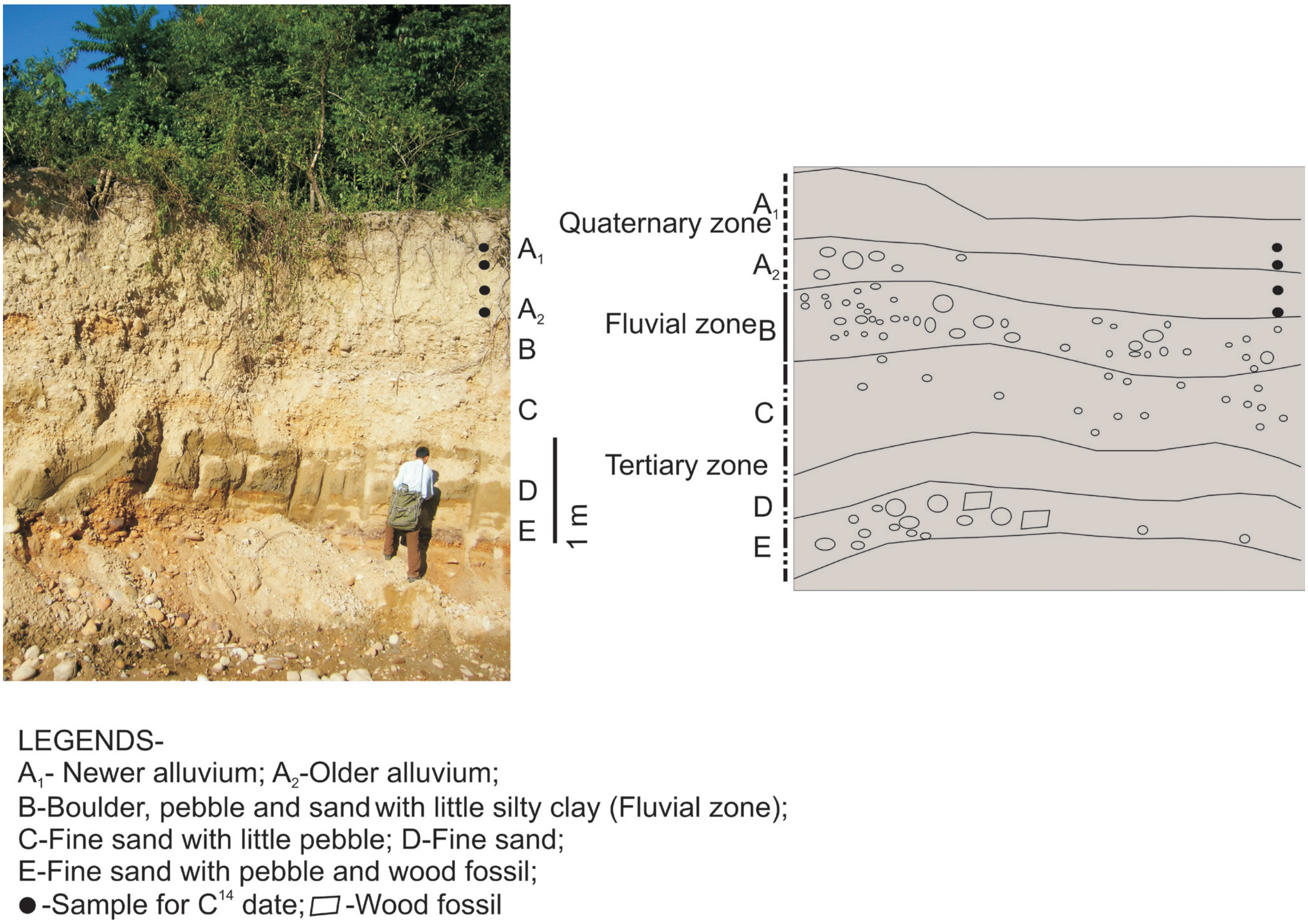


Fig. 3—Lithostratigraphy shown in photograph (left) and sketches (right) of Subansiri river section, Assam.

and seasonal. Ferns and fern–allies, liverworts and mosses are also seen on old tree trunks, rock, boulders, etc. along the water streams and shady places. The natural reserve forest is highly exposed to large scale deforestation primarily due to fulfil the needs of timber, firewood and ongoing construction of 2000 mw Lower Subansiri Dam by National Hydroelectric Power Corporation (NHPC Ltd). However, the over exploitation of natural forests are resulting in spreading of secondary degrade forest types which support inferior quality of trees and alien weeds.

The climate is generally hot and sultry during summer and moderate during winter. In general, temperature rises maximum upto 37º C during summers and minimum upto 2º C during winters. The relative humidity reaches high up to 90% during rainy season (Forest working plane, 2005, Dhemaji District, Assam). During the months of May to September, there is an average annual rainfall of 3,435 mm. Under the influence of south west monsoons, huge volumes of floodwater start spilling all along the 720 km length of embankments of the River Brahmaputra in Assam, India (Goswami, 1997).

The soil of the region is broadly classified into four groups, namely new alluvial, old alluvial, red loamy and lateritic soil. The new alluvial soil is found in the flood areas subjected to occasional flood and consequently receives annual silt deposit when the flood recedes. Geologically, older and newer alluvium soil covers the area. Piedmont deposits of older alluvium consist of boulders, cobbles, gravel, sand and silt. These are the main repository in the foothill zone. Flood plain area with newer alluvium consists of fluvially derived sediments including gravel, pebble, coarse to medium sand, silt and clay received from the rivers coming from the upper reaches are the main deposits next to the piedmont deposits. The old alluvial soils are developed at higher level and are not subjected to flooding. Red loamy soils have formed on hill slopes under high rainfall conditions. However, soil in the interior forest reserve is deep red clay with alkaline nature (Forest working plan, 2002, Dhemaji District, Assam). The detailed lithostratigraphic succession of the Subansiri River Section has been given (Fig. 3). The upper portion of lithocolumn ($A_1$, $A_2$ and B) belongs to the older alluvium and rest part (C, D and E) is under the Tipam Group (Middle–Late Miocene) as detected the scattered silicified fossil woods (Karunakaran, 1974). This study communicated the age–constrained pollen record from Lower Subansiri River Basin which is for the first time to trace palaeovegetation and palaeomonsoon activity along with palaeoflood in and around the study area.

## MATERIAL AND METHOD

A 4.5 m deep exposed Subansiri River Section was examined for interpretation of palaeovegetation, climate and monsoonal activity. The upper 1.7 m exposed section has been sampled at 10 cm intervals for palynological studies. However, below 2.8 m depth a Tertiary zone (Tipam Group, Middle–Late Miocene in age) was detected as evidenced by the scattered silicified fossil woods (Mehrotra *et al*., 2011). The collected soil samples were chemically processed using standard acetolysis method (Erdtman, 1953), 175–310 pollen grains per sample were identified and later counted. The four samples collected from the depths of 120, 100, 70 and 40 cm (base to top) of sedimentary soil profiles were carbon dated at Birbal Sahni Institute of Palaeobotany, Lucknow, India. The percentage of pollen taxa has been calculated with respect to the total pollen count. The pollen diagram is grouped on the basis of various characteristic plant taxa, viz. arboreal taxa (tree and shrub), nonarboreal taxa (terrestrial, marshy and aquatics) and high land taxa (conifers and other broad leaved taxa) respectively in the palynoassemblage (Pl. 1).

## RESULTS

Four pollen zones have been recognized in this pollen diagram based on the pollen assemblage recovered from the sedimentary soil profile. Each pollen zone is prefixed by S

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**PLATE 1**

Palynoassemblage recovered from sedimentary profile from Lower Subansiri River Basin, Assam. ⟶

1. Dipterocarpaceae
2. *Lagerstroemia* sp.
3. *Syzygium cumunii*
4. *Acacia catechu*
5. Moraceae
6. *Dillenia pentagyna*
7. *Salmalia malabaricum*
8. Arecaceae
9. Sapotaceae
10. *Mesua ferrea*
11. *Terminalia bellerica*
12. *Strobilenthes* sp.
13. *Melastoma malabathricum*
14. *Polygonum serrulatum*
15. *Impatiens* sp.
16. Tubuliflorae
17. *Artemisia* sp.
18. Chenopodiaceae
19. *Justicia simplex*
20. Cerealia
21. Poaceae
22. Cyperaceae
23. *Pinus* sp.
24. *Betula* sp.
25. *Alnus* sp.
26. *Nymphaea* sp.
27. *Typha* sp.
28. *Lycopodium* sp.
29. *Davallia* sp.
30. Microthyriacae


1
10 µm
2
5 µm
3
5 µm
4
5 µm
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20 µm

**PLATE 1**

after the name of the locality Subansiri from where the soil profile has been pollen analyzed (Faegri & Iversen, 1964). These pollen zones are described separately below (Fig. 4).

*Pollen zone S–I (120–100 cm)*—Grasses–Cyperaceae–Tubuliflorae–Solanaceae–Nymphaea–Salmalia–Sapotaceae assemblage: This pollen zone is extending from a depth of 120 cm (12,500±170 years BP) to 100 cm (7,960 ±170 years BP) has a time span of 4,540 years. The lithocolumn is characterized by silty clay with little sand and pebble. This pollen zone is characterized by the predominance of nonarboreal taxa (76.5%) over arboreal taxa (10.8%) and the high land taxa (12.7%) respectively. Among nonarboreal taxa, grasses (wild and cerealia type) are dominant (21.4% and 8.3%), Tubuliflorae (7.2%), Liguliflorae (5.6%), Malvaceae (3.0%), *Artemisia* (2.9%), Lamiaceae (2.1%), Euphorbiaceae (1.9%), Convolvulaceae (1.6%), Acanthaceae (1.1%), *Impatiens*, Chenopodiaceae/Amaranthaceae, Apiaceae, Caryophyllaceae and Brassicaceae are recorded as other prominent terrestrial nonarboreals at lower values. However, marshy taxa like Cyperaceae (8.8%), *Polygonum* (3.4%) and Onagraceae (3.2%) are encountered at moderate value. The prominent aquatic taxa like *Nymphoides* (1.3%), *Nymphaea* (1.1%), *Potamogeton* and *Typha* are recorded scarcely. Combretaceae (1.9%) associated with *Mesua ferrea* (1.3%) and *Schima* (1.1%) are represented as major tree taxa, however, Arecaceae, *Adina*, *Salmalia malabarica*, *Ilex*, Dipterocarpaceae, Moraceae and *Emblica officinalis* are sporadic. The shrubby elements such as Oleaceae, *Melastoma malabathricum* and Fabaceae are also encountered scarcely. The extra–regional taxa like *Pinus* (4.3%), *Betula* (2.9%), *Alnus* (2.6%) and *Quercus* (1.1%) are registered consistently in moderate value. However, *Corylus*, *Ulmus* and Ericaceae are sporadic.

*Pollen zone S–II (100–70 cm)*—Grasses–Bambusoideae–Caryophyllaceae–Impatiens–Onagraceae–Nymphaea–Potamogeton–Dipterocarpaceae–Terminalia–Lagerstroemia–Ilex–Careya assemblage: This pollen zone extending from a depth of 100 cm (7,960 ± 110 years BP) to 70 cm (6,421 ± 90 years BP) has a time span of 1,539 years. The lithocolumn is characterized by silty clay with little sand. This pollen zone is characterized by the dominance of nonarboreals (61.3%) over arboreals (24.1%) and the high land taxa (14.6%) respectively. Among nonarboreals, grasses (wild and cerealia type) are dominant (11.4% and 8.4%). Tubuliflorae (5.1%), Liguliflorae (4.0%), *Artemisia* (2.7%), Malvaceae (2.0%), Euphorbiaceae (1.1%), Lamiaceae, *Impatiens* and Convolvulaceae (1.0% each), Acanthaceae (0.8%), Chenopodiaceae/Amaranthaceae, Caryophyllaceae and Brassicaceae (0.7% each) and Apiaceae (0.4%) are recorded as other terrestrial nonarboreals at good to moderate values. Similarly, marshy taxa like Cyperaceae (6.8%), Onagraceae (3.8%) and *Poly-*

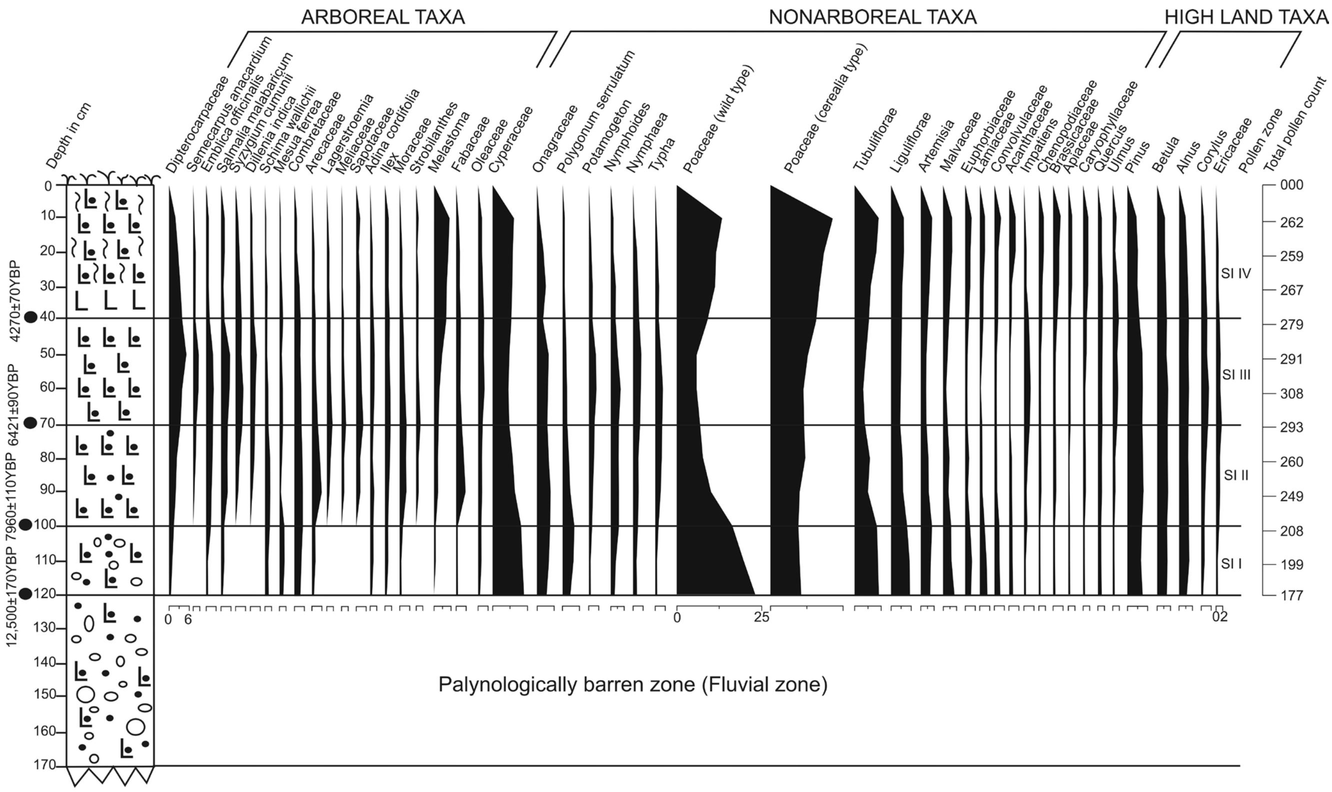


Fig. 4—Pollen diagram from Lower Subansiri River Basin, Assam (percentage calculated in term of total pollen count).

*gonum* (3.1%) are recorded at good values. Among the aquatic taxa, *Nymphoides* (2.4%), *Nymphaea* and *Typha* (1.5% each) and *Potamogeton* (1.2%) are moderately recorded. Among major trees, Combretaceae is represented as major constituent (2.4%) followed by Arecaceae (2.0%), Dipterocarpaceae (1.9%), *Emblica officinalis* (1.7%), Moraceae and *Salmalia malabaricum* (1.6% each), *Schima* (1.5%), *Ilex* (1.2%) and *Adina* (1.0%) respectively. However, *Mesua ferrea*, *Dillenia*, Sapotaceae, *Lagerstroemia*, *Syzygium*, Meliaceae and *Semecarpus* are sporadic. Fabaceae (1.9%) and Oleaceae (1.1%) are moderately recorded. *Melastoma malabathricum* and *Strobilenthes* are exhibited scarcely. The high land taxa like *Pinus* (4.6%), *Betula* (3.1%), *Alnus* (2.8%), *Corylus* (1.2%), *Quercus* and Ericaceae (1.1% each) are recorded moderately. *Ulmus* is sporadic.

*Pollen zone S–III (70–40 cm)*—Grasses–Tubuliflorae–Artemisia–Potamogeton–Dipterocarpaceae–Terminalia–Melastoma assemblage: This pollen zone extending from a depth of 70 cm (6,421 ± 90 years BP) to 40 cm (4,270 ± 70 years BP) has a time span of 2,151 years. The lithocolumn is characterized by 30 cm silty clay. This pollen zone is characterized by the predominance of nonarboreals (49.7%) over arboreals (33.7%) along with high land taxa (16.6%). Among nonarboreal taxa, grasses (wild and cerealia type) are dominated at the value of 6.2% and 9.5% respectively. Other terrestrial herbs like Tubuliflorae (3.0%), Liguliflorae (2.9%), *Artemisia* (1.9%), *Impatiens* (1.8%) and Malvaceae (1.2%) are recorded moderately. However, Caryophyllaceae, Convolvulaceae, Euphorbiaceae, Chenopodiaceae/Amaranthaceae, Brassicaceae, Apiaceae, Lamiaceae and Acanthaceae are recorded in sporadic frequency. Amongst, the marshy taxa, Cyperaceae (4.7%), Onagraceae (3.3%) and *Polygonum* (1.6%) are represented uniformly. The major aquatic taxa like, *Nymphoides* (2.5%), *Nymphaea* (2.2%), *Potamogeton* and *Typha* (2.0% each) are recorded consistently at moderate value. Dipterocarpaceae is represented as major tree constituent (4.2%) followed by *Salmalia malabaricum* (2.5%), *Emblica officinalis* (2.1%), *Syzygium* and *Dillenia* (2.0% each), Combretaceae (1.9%), Moraceae and Sapotaceae (1.7% each), *Ilex* (1.6%), *Semecarpus* (1.5%), Arecaceae and *Lagerstroemia* (1.3% each), *Adina* (1.2%) and Meliaceae (1.0%). *Mesua* and *Schima* are sporadic. *Melastoma malabathricum* is represented as lone shrubby element at the value of 1.8% accompanied by Oleaceae (1.7%), Fabaceae (1.5%) and *Strobilenthes* (1.0%) respectively in lower value. *Pinus* (4.5%), *Betula* (3.0%), *Alnus* (2.8%), *Corylus* (2.0%), *Ulmus* and Ericaceae (1.5% each) and *Quercus* (1.3%) are recovered moderately.

*Pollen zone S–IV (40–0 cm)*—Grasses–Xanthium–Brassicaceae–Solanaceae–Potamogeton–Dipterocarpaceae–Albizia–Syzygium–Melastoma assemblage: This pollen zone is dated back to 4,270 ± 70 years BP at the depth of 40 cm. This part of lithocolumn has 10 cm clay at the base overlain by 30 cm of silty clay with rootlets. This pollen zone is characterized by the predominance of nonarboreals (64.2%) over arboreals (23.1%) and the high land taxa (12.7%). Among nonarboreals, grasses (wild type and cerealia type) are domi-

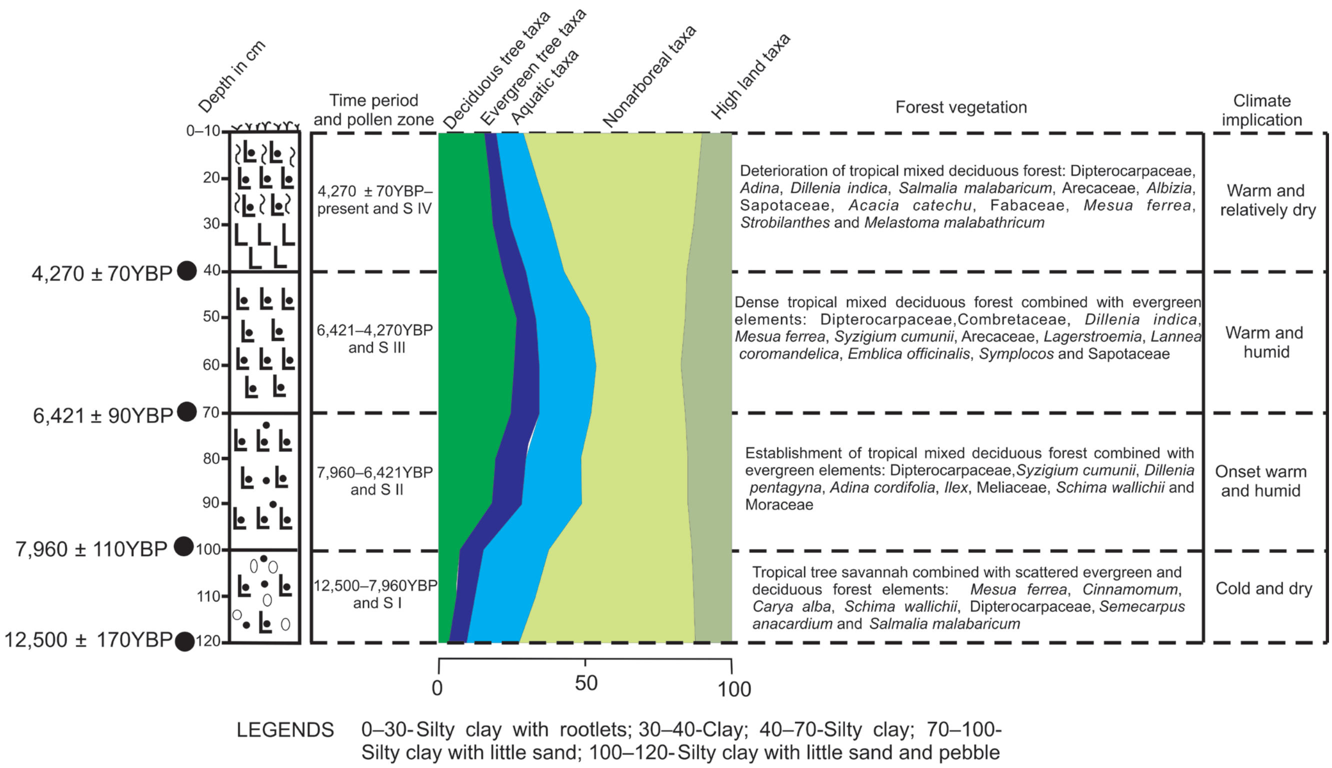


Fig. 5—Vegetation composition and climate implication of Lower Subansiri River Basin, Assam.

nant (11.3% and 14.5%) associated with Tubuliflorae (5.7%), Liguliflorae (3.6%), *Artemisia* (2.8%), Malvaceae (2.4%), Euphorbiaceae and Brassicaceae (1.5% each), Caryophyllaceae (1.4%), Lamiaceae, Convolvulaceae, Acanthaceae and Chenopodiaceae/Amaranthaceae (1.3% each) and Apiaceae (1.0%) are recovered moderately. *Impatiens* is sporadic. Marshy taxa like Cyperaceae (5.7%) and Onagraceae (1.8%) are recorded moderately. *Polygonum* is registered in sporadic frequency. Aquatics like *Nymphaea* (1.2%) and *Nymphoides* (1.1%) are encountered at lower value. However, *Potamogeton* and *Typha* are sporadic. Dipterocarpaceae is represented as major constituent (3.0%) followed by *Syzygium* (1.3%), Combretaceae and *Ilex* (1.2% each), *Salmalia malabaricum*, *Dillenia* and Sapotaceae (1.0% each). Other associated taxa like *Emblica officinalis*, Arecaceae, *Adina*, *Lagerstroemia*, Moraceae, *Schima* and *Mesua ferrea* are sporadic. *Melastoma malabathricum* is represented as lone shrubby element (4.0%) accompanied by Oleaceae (1.4%) and Fabaceae (1.1%) in low values. The high land taxa like *Pinus* (3.1%), *Betula* (2.5%), *Alnus* (2.4%), *Quercus*, *Ulmus* and *Corylus* (1.3% each) are recovered consistently at moderate values. Ericaceae is sporadic.

## DISCUSSION

The changing frequencies of various arboreal and nonarboreal palynomorph assemblage within soil profile with absolute radiocarbon dates collectively reflect the succession of forest vegetation and corresponding climates within fluctuating monsoonal activity in the study area over a long span of time. Changing assemblage of the aquatic plants at different levels in the pollen sequence significantly infers the lake–level fluctuations/hydrological status of lakes/swamps, which is very much affected by the rainfall regime. Furthermore, the appearance as well as marked alterations in the cerealia pollen along with cultural pollen taxa is taken for the precise understanding of incipient agricultural practice and its subsequent pace in a definite time frame.

During the first phase (12,500–7,960 years BP), the tree–savannah type of vegetation grew in the region under cold and dry climate as is evident by the higher value of terrestrial nonarboreal elements, viz. grasses, Tubuliflorae, Liguliflorae and Apiaceae along with scattered open mixed deciduous and semievergreen elements like Combretaceae, Lauraceae, *Salmalia malabaricum*, *Lagerstroemia* and *Ilex* together with stray presence of Dipterocarpaceae. The occurrence of *Potamogeton*, *Nymphaea* and *Nymphoides* suggests the existence of perennial waterlogged condition during this phase. The high land taxa comprised of conifers (*Pinus*) and broad leaved elements (*Alnus*, *Corylus* and *Ulmus*) are growing in higher reaches of Arunachal Himalaya proves wind activity. The stable presence of the taxa, viz. *Tsuga* and Ericaceae suggests water flowing conditions from high altitude during this period.

Subsequently during the second phase (7,960–6,421 years BP), the mixed deciduous forest got enriched with the

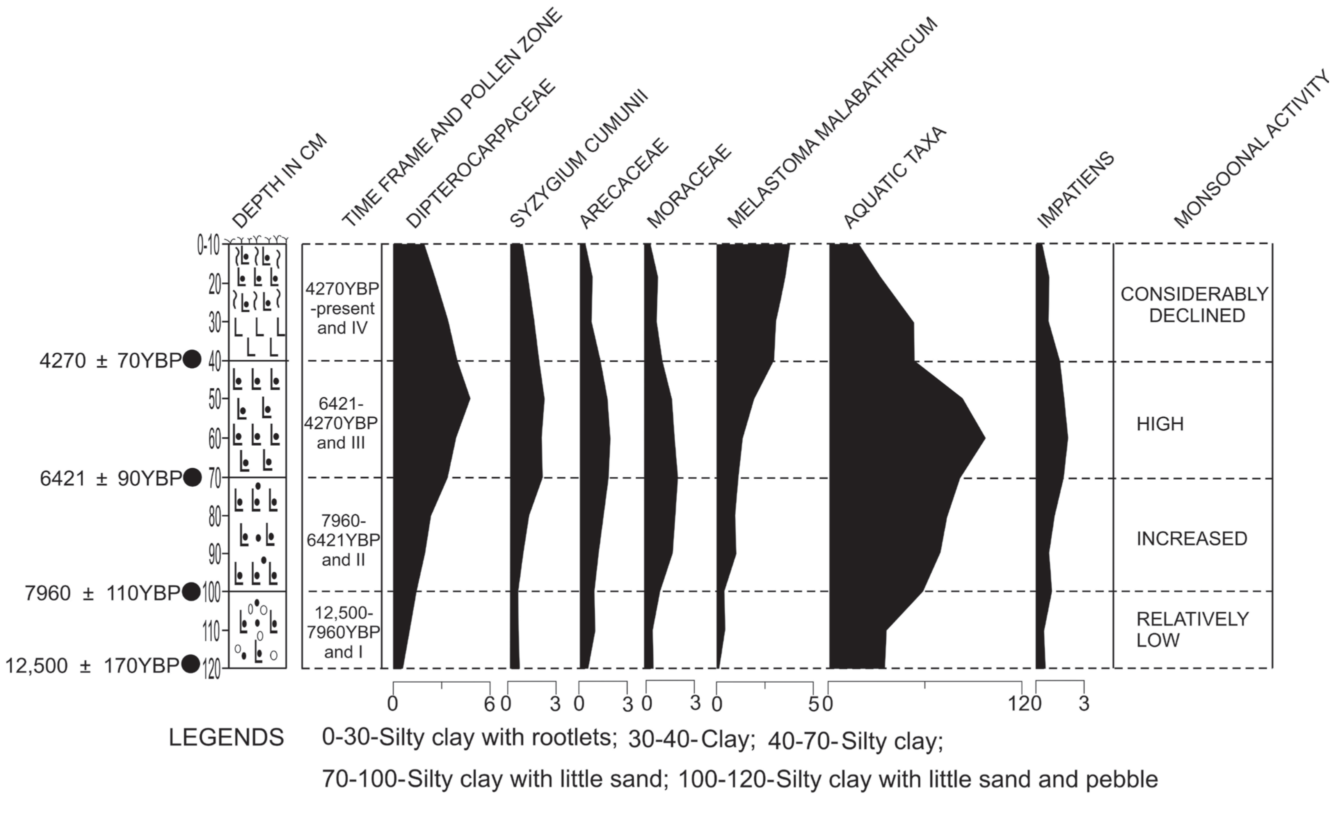


Fig. 6—Estimation of monsoonal activity fluctuation by using pollen marker taxa.

immigration of some more tropical deciduous arboreals like *Semecarpus anacardium*, *Emblica officinalis* and *Dillenia pentagyna*. Dipterocarpaceae got colonized as is evident by a relative rise in its frequency. Sharp declining trends in frequency of most of the terrestrial nonarboreal taxa have been observed. However, both marshy and aquatics especially Onagraceae, *Impatiens* and *Potamogeton* increased their value than the preceding phase. This vegetation change clearly depicts the formation of deciduous mixed forest along with vast stretches of swampy areas with wider perennial water logged conditions. The high land taxa (conifers and broad leave taxa) show continuously stable occurrence in the palynoassemblage in the sediment. The overall pollen assemblage suggests the onset of warm and humid climatic condition during this period. Pastoral activity is marked by the presence in traces of cerealia and culture pollen taxa in the palynoassemblage.

During the third phase (6,421–4,270 years BP), the mixed deciduous forest got more enriched with dense tropical mixed deciduous arboreals as compared to the preceding phase. The arboreal taxa are same as the preceding phase but with their higher density, viz. Dipterocarpaceae, *Syzygium cumunii*, Arecaceae and Moraceae. The semievergreen taxa such as *Mesua ferrea* and Combretaceae are consistent as the preceding phase. The high land taxa are registered in persistent frequency. The frequencies of aquatic taxa are increased than the preceding phase and supporting good southeast monsoon. The overall pollen assemblage is suggestive of the warm and humid climatic condition during this phase.

During the fourth phase (4,270 years BP onwards), mostly the semievergreen and deciduous arboreals such as *Mesua ferrea*, Dipterocarpaceae, Arecaceae and *Syzygium cumunii* have decreased whereas, the terrestrial nonarboreal taxa have increased as compared to those present during the preceding phase. The decreased values of most of the aquatic pollens indicate decreased water logged conditions as well as weakened southeast monsoon than the preceding phase. Sudden decline in Onagraceae and *Impatiens* are also indicator of low precipitation. The shrubby taxa *Melastoma malabathricum* shows its peak during this phase suggesting the declining monsoonal activity and dryness during the phase. The sudden increase of Cerealia, Brassicaceae, Chenopodiaceae, Apiaceae and *Xanthium* implies high pastoral activity by the new settlers in and around the study area. The consistent presence of high land taxa supports long distance pollen transport along with high wind activity. The overall scenario is suggestive of the deteriorated mixed deciduous forest under warm and relatively dry climatic condition during this phase (Fig. 5).

Based on the investigations in lakes Didwana, Sambhar and Lunkaransar (Singh *et al*., 1974, 1990), identified the following ecologically sensitive pollens, (i) *Artemisia*, an element of the > 50 cm annual rainfall regime, (ii) *Oldenlandia*, which is indicative of higher precipitation as it is found in sub humid and humid regions of NW India, (iii) *Typha*, a fresh water swamp taxon and (iv) *Syzygium cumunii*, indicative of > 850 mm average annual rainfall.

In this paper we have considered the marker pollen taxa to estimate monsoonal activity. The plant taxa Dipterocarpaceae, *Syzygium cumunii*, Arecaceae, Moraceae, *Impatiens* and aquatic taxa (*Nymphoides*, *Nymphaea*, *Potamogeton* and *Typha*) are considered as the high monsoonal marker pollen taxa and *Melastoma malabathricum* as the low monsoonal activity marker taxa to estimate the monsoonal activity (Singh *et al*., 1990; Barboni & Bonnefille, 2001), (Fig. 6). Results indicate that there was a fluctuation of monsoonal activity during the recent past. During the period 12,500 to 7,960 years BP, the monsoonal activity was relatively low as evidenced by low frequency of the high monsoonal activity marker taxa (Fig. 4). However, between 7,960 to 6,421 years BP, the monsoonal activity is increased than the preceding period as evidenced by increased frequency of marker pollen taxa in the pollen assemblage. From 6,421 to 4,270 years BP, the monsoonal activity is considerably higher than the preceding phase as marked by the high frequency of marker taxa, viz. Dipterocarpaceae, *Syzygium cumunii*, Arecaceae and Moraceae. Accordingly, during 4,270 years BP to present, the monsoonal activity relatively declined as suggested by the dominance of *Melastoma malabathricum* (sharply increased). The other marker taxa, viz. Dipterocarpaceae, *Syzygium cumunii*, Arecaceae and *Impatiens* also show lower percentage in the palynoassemblage thereby strongly supporting the weakened monsoonal activity.

It is quite important to note that since around 2,000 years BP, the monsoonal activity is strengthened in Indian Subcontinent, Arabian Sea and western Tibet (Phadtare, 2000). The carbon and oxygen isotopic records from the stalagmite in Xiangshui Cave, Guilin suggest that the Asian Monsoon was relatively stronger from 6,000 to 3,800 years BP and gradually weakening during the interval. However, since 3,800 years BP onwards, there is a relatively weak Asian Monsoon (Zhang *et al*., 2004). The South Asian monsoon in Holocene records reveal substantial regional differences (Staubwasser, 2006). More investigation with multiproxy palaeoclimate data are needed to find the precise and regional understanding of the palaeoclimate and vegetation in and around the study area.

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