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Mid-Holocene vegetation and climatic changes in southwestern Garo Hills, Meghalaya, northeast India based on pollen records

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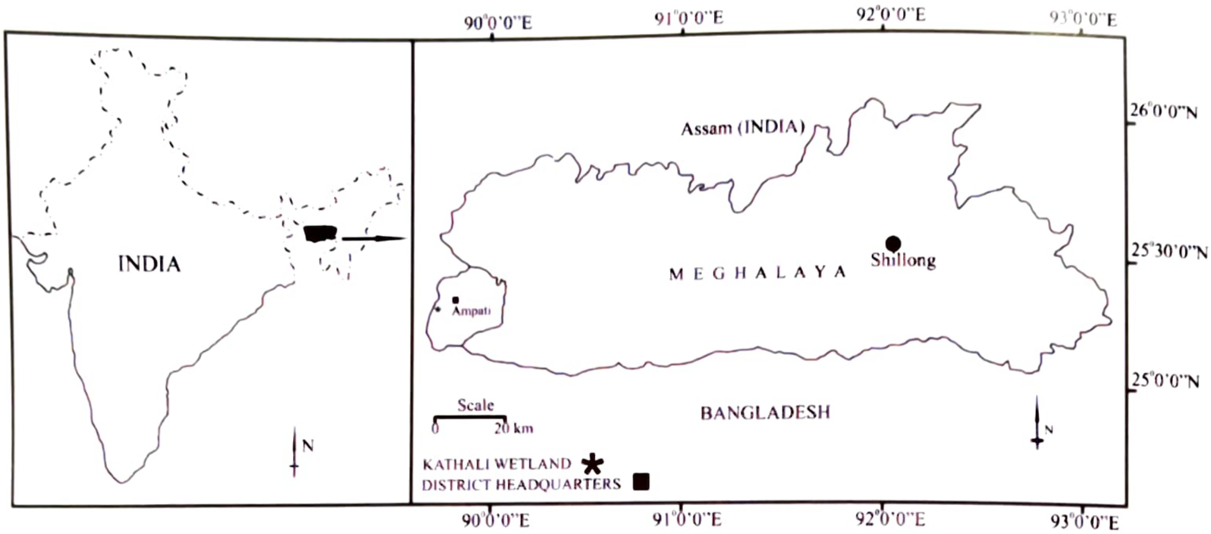
ABSTRACT

This paper presents a palynological observation on 180 cm deep sedimentary soil profile procured from the Kathali wetland of southwestern Garo Hills to reconstruct the palaeovegetation and climatic changes in the region. Three climatic phases have been recognized based on the major arboreal pollen taxa. In the first phase (4,620 to 1,030 cal yr BP), the tropical mixed deciduous forest was flourishing composed of *Shorea robusta*, *Schima*, *Duabanga* and *Bombax* under warm and humid climatic conditions. The presence of evergreen taxa, *Elaeocarpus* and *Mesua*, along with *Nepenthes* and *Impatiens* pollen, is strongly indicative of the high monsoonal activity in the region. The second phase (1,030 to 560 cal yr BP) was observed to be similar as the first phase with comparatively low values of arboreal taxa under relatively less warm and humid climatic condition. The debut of cereal pollen, along with the other cultural pollen taxa especially *Brassica* and Solanaceae, signals anthropogenic activities in this region. Lastly, in the third phase, around 560 cal yr BP to present, low values of arboreal taxa was noticed. The absence of *Mesua* and *Nepenthes* pollen in relation to the increased values of cereal and other cultural pollen in this phase suggests the deterioration of forest in relation to the expansion of anthropogenic activities in the region. The increased values of marshy taxa and decline in the frequencies of aquatic taxa were also observed, which indicates the comparatively poor water logged conditions in and around the study region.

Key words: Holocene, Kathali wetland, Meghalaya, Monsoonal activity, Palaeovegetation, Pollen assemblage.

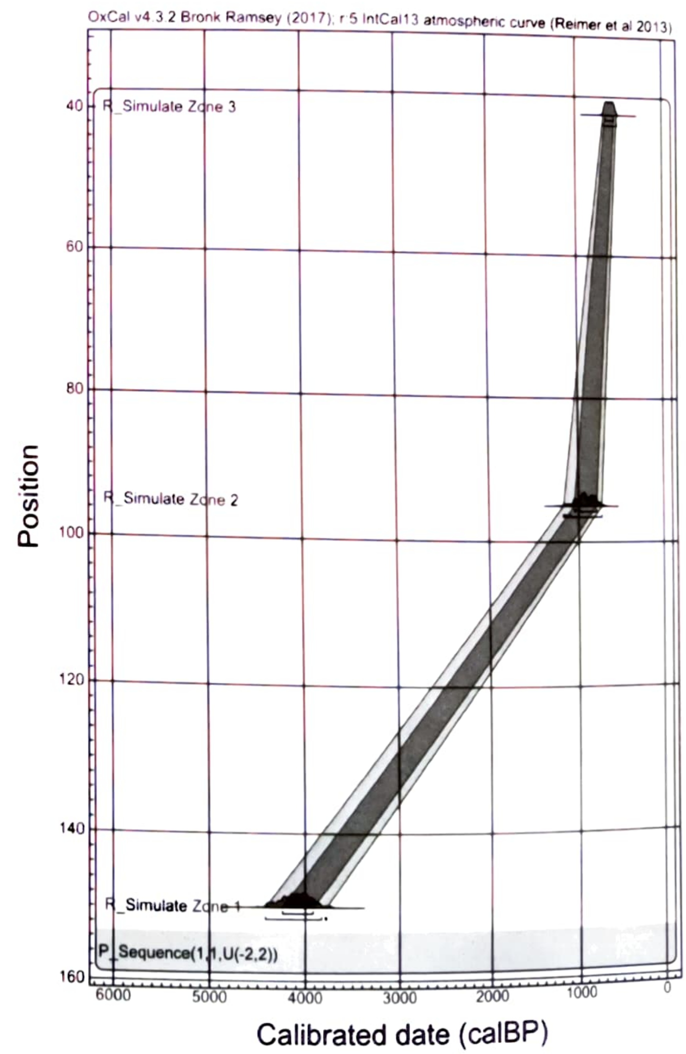
INTRODUCTION

The palaeoenvironment scenario of northeast India is a least understood domain, especially of the Meghalaya region, particularly with regards to the beginning of late Pleistocene to late Holocene, which is crucial period, in which incipient agriculture first emerged. The southwest Garo Hills are lying in the southwestern part of Meghalaya State, situated adjacent to Bangladesh (Text-Figure 1). Because of its unique geographical location, which combines foothills and flood plain areas, it bears strong potential for palaeoclimatic and palaeovegetation studies. Pollen analysis is recognized as a powerful tool for deciphering the regional responses of vegetation to climatic changes and anthropogenic influences during the Holocene (Dixit & Bera 2013). To date, many workers have focused on past vegetation and climatic investigations in the



Text-Figure 1. Location map showing the study area.

northeast region of India (Bera 2003, Dixit & Bera 2011, 2012, Bhatacharyya et al. 2014, Ghosh et al. 2014), these palyno-investigations portray valuable insights concerning the vegetation alteration scenarios and contemporaneous climatic changes since the Quaternary period. However, hitherto, palynological information available for the Indo-Burma region, especially in context to Meghalaya State, is sparse. Further, a few published records on vegetation succession and past climatic changes in Meghalaya include Garobadha and Singrimari swamps of west Garo Hills (Basumatary & Bera 2010, 2012). Basumatary et al. (2015) conducted a detailed study dealing with relationship of surface pollen and extant vegetation in and around Kathali wetland in order to develop modern pollen analogues for precise palaeoclimatic interpretation. However, to date, no literature is available from the wetlands of southwestern Garo Hills, in order to trace vegetation and climate history. In this communication, it is proposed to develop a pollen database from a sedimentary soil profile from Kathali wetland of south-west Garo Hills has been made which may help to reconstruct the development of tropical mixed deciduous forests distributed in this region since the Mid-Holocene. Correlation with other sites of Indo-Burma biodiversity hotspot is also discussed while drawing the inferences from the generated palynodata.



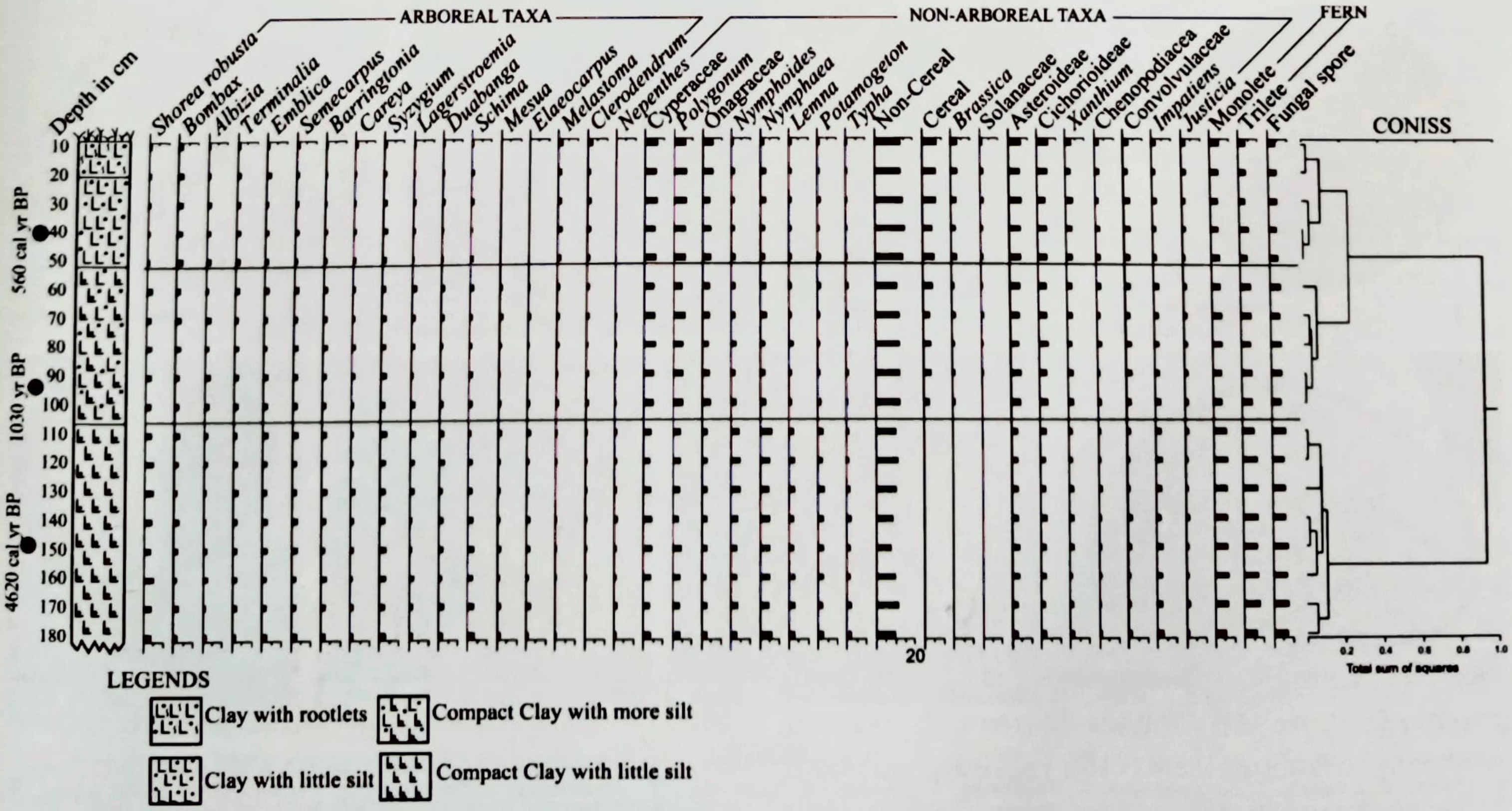
Text-Figure 2. Bayesian age–depth model of the Kathali wetland sequence.

The Holocene is significant in many respects, particularly in terms of human development and

PLATE 1

A. A view of Kathali wetland, B. Sediment coring and measurement activities at Kathali wetland.

establishment of centers of civilizations. The changes in climate during this epoch have made significant impacts on landscape, vegetation and climate worldwide; however, the rate of change has accelerated dramatically during the last hundred years, largely due to human impact. Because of the gradual or abrupt climatic changes during the Holocene, many civilizations evolved, developed and perished. Various records of multiple societal collapses during the last 6000 years are also available, both on local and regional scales, synchronous with the abrupt shifts to drier and/or colder climatic regimes (McGhee 1981, Weiss et al. 1993, Hodell et al. 1999). Thus, attempts have also been made to trace the impact of anthropogenic activities on the vegetation and inception of agricultural practices and its subsequent pace in southwest Garo Hills District since the Mid-Holocene.



Text-Figure 3. Pollen diagram of 180 cm deep sedimentary core from Kathali wetland, Meghalaya.

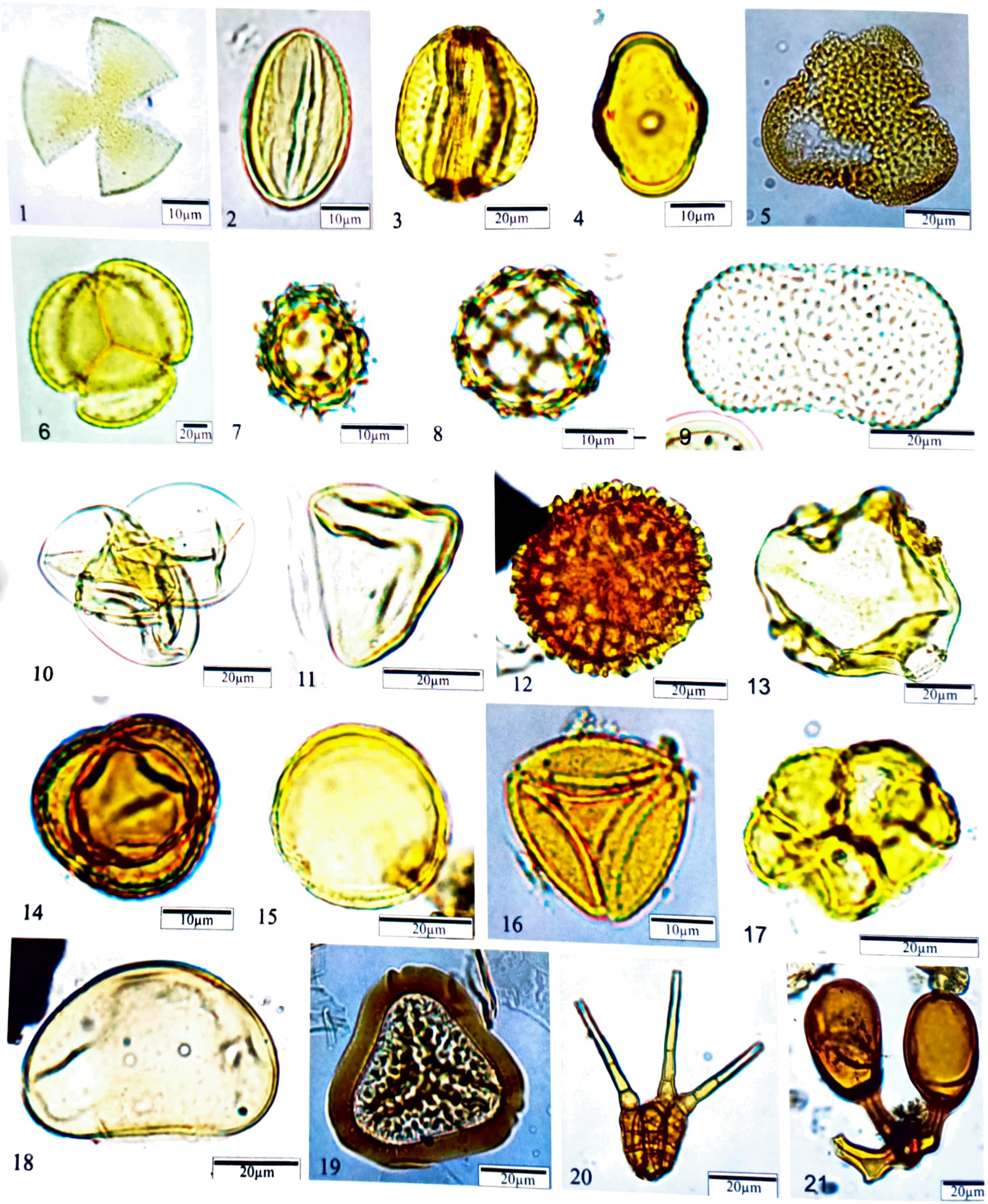


PLATE 2

1. *Shorea*, 2. *Lannea*, 3. *Barringtonia*, 4. *Duabanga*, 5. *Bombax*, 6. *Nepenthes*, 7. Asteroideae (Asteraceae), 8. Cichorioideae (Asteraceae), 9. *Impatiens*, 10. Cereal, 11. Cyperaceae, 12. *Polygonum*, 13. Onagraceae, 14. *Xanthium*, 15. *Nymphaea*, 16. *Nymphoides*, 17. *Typha*, 18. Monolete fern spore, 19. Trilete fern spore, 20. *Tetraploa*, 21. *Glomus*.

STUDY SITE AND VEGETATION

The Kathali wetland (27°12" N and 94°02" E) is located in the newly formed southwest Garo Hills District of Meghalaya State, which lies in close proximity to the Bangladesh. During summer the wetland becomes wider due to heavy rainfall and during winter it becomes smaller due to low rainfall. In general, the vegetation of the studied region comprises of tropical mixed deciduous forest, enriched with core arboreal taxa such as: *Shorea robusta, Salmalia malabaricum, Terminalia bellirica, Dillenia pentagyna, Semecarpus anacardium* and *Emblica officinalis* (Rao & Haridasan 1982).

The wetland vegetation is very rich and largely comprises of grasses, Cyperaceae, Polygonaceae, Onagraceae and Ranunculaceae, in the margin areas (Plate 1A). The aquatic taxa, namely *Nymphoides indica, Euryale ferox, Nymphaea nouchali, Lemna minor* and *Utricularia flexuosa* are growing luxuriantly in the center of the wetland. Besides, aquatic angiosperms and some pteridophytic elements such as *Ceratopteris thalictroides, Marsilea minuta, Isoetes coromandelina, Pistia stratiotes* and *Azolla pinnata* are also luxuriantly growing within the swamp. However, other terrestrial ferns namely *Dryopteris flex-max, Lycopodium clavatum, Adiantum phillippense, Angiopteris evecta, Blechnum orientale* and *Equisetum diffusum* are growing at the periphery of the wetland along with other terrestrial herbs. Scattered deciduous forest occur around the wetland composing of *Shorea robusta, Terminalia bellirica, Albizia lebbeck, Bombax ceiba, Emblica officinalis, Dillenia pentagyna, Careya arborea* and *Semecarpus anacardium*. Few evergreen taxa like *Schima wallichi, Duabanga grandiflora* and *Artocarpus chaplasha* are also growing in association with major deciduous elements in the vicinity of the forest.

CLIMATE AND SOIL

The climate of the area is controlled by the southwest monsoon. During summer, it is hot and humid. The maximum temperature during summer raises up to 35^{0}C and during winter, the minimum temperature dips down to 3^{0}C. The relative humidity ranges from 75–98%. The annual rainfall in the region ranges from 1,494 to 2,552 mm. The soil of the wetland is alluvial, fine loamy in nature and the forest soil is fine loam, sandy in nature and rich in humus.

MATERIAL AND METHODS

Field work

A 1.8 m deep sedimentary soil profile was collected by trenching from the southwestern flank of the Kathali wetland (Plate 1B). The soil samples from the sedimentary section were procured at 10 cm interval from bottom to top, thus, comprising a total number of 18 soil samples. For the sedimentary profile we use the acronym 'KW' after Kathali wetland.

Chronology of Profile

Out of 18, five soil samples rich in carbon content were chosen for radiocarbon dating from the depths of 150, 120, 95, 70 and 40 cm of KW sequence. The ^{14}C dating was carried out at the radiocarbon laboratory of BSIP (Laboratory/Sample code used is BS/KW). The sediment was manually cleaned, sieved and subjected to hydrochloric acid to remove carbonate component, if any. After repeated rinsing, pH-checking and drying, the sediment was combusted in the continuous flow of oxygen. The resulting carbon dioxide was collected and converted to acetylene and then to benzene using the standard catalysts and procedures. The counting was done in a liquid scintillation counter (Model: Quantulus 1220). Of the five bulk samples, three samples rich in carbon content have been radiocarbon dated in 'KW' sequence to 4,100±110 yrs BP at 150 cm, 1,100±90 yrs BP at 95 cm and 530±70 yrs BP at 40 cm. These radiocarbon dates were converted into Calendric age/date (cal BP i.e., 4,620 cal yr BP, 1,030 cal yr BP and 560 cal yr BP, respectively) using OxCal v.4.3.2 package (Ramsey 2008) with the standard IntCal 13 calibration curve (Reimer et al. 2013). The radiocarbon dates have been rounded to the nearest 5 years. The depthwise ^{14}C dates of the core are given in Text-Figure 3. A Poisson process deposition model (Bayesian age-depth modeling) (Ramsey 2017) was introduced to establish the age-depth relationship. The model showed all agreement indexes and convergence indexes higher than the critical values, thus all ^{14}C dates and interpolated dates remain in the model. The final age-depth model is presented with 68% and 95% probability range (darker and lighter shades) respectively for the age of every depth (Text-Figure 2).

In the KW sequence the estimated sedimentation rate (SR) for the first phase (bottom of the sequence) between 4,620 and 1,030 cal yr BP is 0.015 cm/yr. For the period between 1,030 and 560 cal yr BP (middle of the sequence), estimated SR falls to 0.011 cm/yr. After 560 cal yr BP, estimated SR rises drastically, suggesting an average SR until present around 0.071 cm/yr.

Laboratory work

The soil samples were processed employing the standard acetolysis method (Erdtman 1943). The samples were treated with 10% aqueous KOH solution to deflocculate the pollen/spore from the sediments followed by 40% HF treatment to dissolve silica content. Thereafter, the conventional procedure of acetolysis was followed using acetolysis mixture (9:1 anhydrous acetic anhydride and conc. H_2SO_4). Finally, the material was kept in 50% glycerin solution with a drop of phenol to avoid microbial decomposition. A total pollen sum of 300 to 345 was counted from each sample to make the pollen diagram. Grasses in the text were categorized into Poaceae <45μm (non-cereal) and Poaceae >45μm (cereal) (Joly et al. 2007). The pollen diagram was made using TILIA (Tilia v. 2.0) with further modifications in CoralDraw-12 software programme (Text-Figure 3). For the precise identification of fossil palynomorphs in the sediments, the reference pollen slides available at the BSIP herbarium as well as pollen photographs in the published literature (Erdtman 1952, Nayar 1990, Fujiki et al. 2005) were consulted. The counting with photo-documentation of palynomorphs was done using an Olympus BX-50 Microscope (under 40x magnification) with attached DP-25 Olympus camera (Plate 2). The pollen taxa were categorized as arboreal taxa, non-arboreals, ferns and fungal remains excluding the high land taxa in the palynoassemblage. Pollen frequencies were made based on the total sum of palynomorphs. The three pollen zones have been recognized based on the frequency fluctuations of arboreal and non-arboreal pollen taxa. The pollen zones are numbered KW-I –III from the bottom to top.

RESULTS

Pollen zone –KW-I (180-110 cm; 4,620 to 1,030 cal yr BP): *Shorea-Bombax-Mesua-Nepenthes-Nymphaea*-Grasses assemblage: This pollen zone is characterized by the dominance of non-arboreal taxa (64.2%) over arboreal taxa (17.9%). The ferns and fungal remains are also recorded at average values of 8.1% and 4.2% respectively. Among non-arboreal taxa, the grasses are dominant at average value of 9.8%. The other associated herbaceous taxa such as Asteroideae, Cichorioideae, *Impatiens* and *Justicia* are encountered within the values of 1-4%. The marshy and aquatic taxa, namely Cyperaceae, Onagraceae, *Nymphaea* and *Potamogeton* are represented between 1-4.5%. Among the arboreal taxa, *Shorea*, *Bombax*, *Syzygium* along with evergreen taxa chiefly *Mesua* and *Elaeocarpus* are recorded between 1-4.5%. The shrubby elements, *Melastoma* and *Clerodendrum* are represented sporadically. The *Nepenthes* pollen is continuously exhibited represented at the value of 1% in the palynoassemblage.

Pollen zone –K-II (110-50 cm; 1,030 to 560 cal yr BP): *Shorea-Semecarpus-Duabanga-Schima*-Grasses-cereal-Cyperaceae-*Nymphaea* assemblage: This pollen zone is characterized by the dominance of non-arboreal taxa at average value of 54.3% over arboreal taxa (26.0%). Ferns and fungal remains are also recorded at the average values of 9.8% and 5.3% respectively. Among the non-arboreal taxa, the grasses are dominant at the average value of 12% and the other associated herbaceous taxa such as Asteroideae, Cichorioideae, Chenopodiaceae and Convolvulaceae are encountered within the value of 1-5%. Among the marshy and aquatic taxa, Cyperaceae, Onagraceae, *Nymphaea* and *Potamogeton* are represented between 1-5.5%. Among the arboreal taxa *Shorea*, *Semecarpus*, *Lagerstroemia* along with evergreen taxa chiefly *Mesua* and *Elaeocarpus* are recorded between 1-3%. The shrubby elements, *Melastoma* and *Clerodendrum* are continuously exhibited in trace values in the palynoassemblage. *Nepenthes* pollen is also exhibited in sporadic values.

Pollen zone –K-III (50-0 cm; 560 cal yr BP to present): *Bombax-Terminalia-Albizia-Syzigium*-Grasses-cereal-*Brassica*-Onagraceae assemblage: This pollen zone is characterized by the dominance of non-arboreal taxa at average values of 48.0% over the arboreals (31.8%). The ferns and fungal remains are also recorded at average values of 13.1% and 6.9%, respectively. Among non-arboreal taxa, the grasses are dominant at average values of 15%. Other associated herbaceous taxa such as Asteroideae, Cichorioideae, Convolvulaceae and *Justicia* are represented within the values of 1.4-7%. The marshy taxa such as Cyperaceae, Onagraceae and Polygonaceae are encountered within the values of 3.7-6.4%. Among the aquatic taxa, *Nymphaea* and *Nymphoides* are also continuously exhibited (0.5-3%) in the palynoassemblage. Among the arboreal taxa, *Shorea*, *Terminalia*, *Emblica*, *Barringtonia* and *Careya* are regularly represented in the palynoassemblage. The evergreen taxa namely *Mesua* and *Elaeocarpus* along with *Nepenthes* pollen are absent.

DISCUSSION

The pollen proxy record from the sedimentary profile has demonstrated three phases of development of tropical mixed deciduous forest under contemporaneous climatic alterations in the southwest Garo Hills District since the Mid-Holocene. During 4,320-1,030 cal yr BP, this region experienced forest proliferation followed by gradual settlement, composed of chief arboreal ingredients namely *Shorea robusta*, *Syzygium*, *Semecarpus*, *Bombax*, *Albizia* and *Schima* under warm and humid climatic conditions with the influence of active SW monsoon. The evergreen taxa chiefly *Mesua*, *Duabanga* and *Elaeocarpus* along with *Nepenthes* pollen in the palynoassemblage were observed and suggestive of high rainfall activity in the region. Thus this climate regime is analogous to the finding which show high summer monsoon precipitation with increased humidity around 1500 years BP recorded from central Nepal, based on the studies of speleothem of cave deposit (Denniston & Gonzalez 2000). The presence of riparian taxa chiefly, *Duabanga*, *Barringtonia*, *Syzygium* and *Impatiens* pollen in the assemblage is indicative of presence of a perennial river and streamlets in the region during the first phase. The abundance of cereal pollen, Tubuliflorae, Liguliflorae, Convolvulaceae and *Justicia* is indicative of presence of the open land patches in and around the region. The abundance of aquatic taxa such as *Nymphaea*, *Trapa*, and *Lemna* pollen is indicative of occurrence of wider perennial water logged conditions in response to the high monsoonal activity in the region. The ferns and fungal spores such as *Lycopodium*, *Dryopteris*, *Polypodium*, Microthyriaceae and *Glomus* strongly suggest presence of warm and humid climatic conditions during the first phase. 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 some important tree elements in tropical deciduous forests in the Indian subcontinent. Thus, the warm and humid climatic conditions prevailing in the northeastern region, with timely arrival of adequate rainfall, play an important role in making favourable conditions for the germination of seeds of many plants (like *Shorea*, *Emblica*, *Dillenia*, *Bombax*, and *Lagerstroemia*) immediately after its shedding (Meher-Homji 1996). This is also of particular significance in view of the limited viability period of the seeds of these important plants.

In the second phase, around 1,030 to 560 cal yr BP, the forest was similar to the first phase with comparatively decreased values of arboreal taxa. The decrease values of evergreen taxa mainly *Mesua*, *Elaeocarpus* and *Schima* along with *Nepenthes* pollen indicates the commencement of deterioration of forest in and around the region. However, the increased values of non-arboreal taxa such as Poaceae, Asteroideae, Cichorioideae and *Justicia* is indicative of the expansion of the open land vegetation in the region. The relatively decreased values of core aquatic taxa, namely *Nymphaea*, *Nymphoides* and *Potamogeton* in relation to the increased values of marshy taxa, *Polygonum*, Cyperaceae and Onagraceae was observed, which is suggestive of relatively low rainfall activity than the preceding phase in the region. The overall palynodata is suggestive of the relatively less warm and humid climatic conditions in the region. The appearance of cereal and other cultural pollen, namely *Brassica* and

Solanaceae signals human activities in the region during this period. The comparative dryness may also be attributed to clearance of forest through anthropogenic activities like jhuming, lumbering and pasturing in the Garo Hills reserve forest area, which presently pose a serious threat to biodiversity conservation. Increase in cereals along with other culture pollen taxa like Asteroideae, *Brassica*, Caryophyllaceae, and *Xanthium* hints persistent pastoral activity. The occurrence of degraded pollen-spores along with adequate fungal elements especially *Xylaria, Nigrospora* and Microthyriaceous fruiting body is suggestive of aerobic microbial digenesis of rich organic debris during sedimentation.

Lastly, in the third phase, around 560 cal yr BP to present, the forest vegetation deteriorated at a faster pace as evident by the absence or low values of arboreal taxa. The absence of *Nepenthes* pollen is a striking feature in this phase, which clearly indicates forest deterioration in the region, owing to its sensitivity towards forest disturbance and human activity. The marshy taxa such as Cyperaceae, Polygonaceae, and Onagraceae were found in comparatively higher values than in the second phase (KW-II) which shows relatively low perennial water logged conditions in the region during the third phase. The abundance of cereal and cultural pollen is indicative of high anthropogenic activities in the region. These pollen results correspond to the research findings, where the first indication that humans have affected the vegetation at northern Scandinavian mountain was observed in the palynological record at around 700 cal yr BP (Staland et al. 2010). Increase in the pollen of Poaceae and *Rumex* spp., at this time, in combination with Asteraceae, Chenopodiaceae, *Epilobium, Urtica, Hordeum* and *Plantago* pollen, indicate both disturbance of vegetation and a higher degree of available nutrients than were previously present. These features are indicative of anthropogenic changes, associated with settlements or herds of domestic animals (Räsänen 2001, Schofield et al. 2007). The palynological results achieved during this time frame also coheres from Arunachal Pradesh, northeast Himalaya, showing climatic shifts from warm and humid to cool and dry around 1400 AD based on pollen records under the impact of Little Ice Age (LIA) and must have affected this region too owing to relatively less warm and humid climatic regime (Bhattacharyya et al. 2007). This period of relatively discordant climate partly falls within the temporal range of LIA, which is recorded at a global level between 1450 AD and 1850 AD (Bradley 1985). Thus, this result also corresponds to the palaeoclimatic data of Manipur, northeast India, which show expansion of open-vegetation and contemporary reduction of trees since 560 cal yr BP owing to reduction in monsoon precipitation (Tripathi et al. 2017). The agriculture/pastoral activity involves relationships with animals and plants, the remains of these organisms provide the most direct evidence (Fuller et al. 2009); however, our palynological data provide a clue of agricultural pace during the Mid-Holocene, based on the selective marker pollen types (like cereal: *Brassica*, Solanaceae and Caryophyllaceae).

CONCLUSIONS

The palynological investigations from a lacustrine sedimentary profile in southwestern Garo Hills District of Meghalaya State show presence of warm and humid climate between 4,620 and 1,030 cal yr BP (KW-I), indicating consolidation of tropical mixed deciduous forest. Grasses and other cultural taxa immensely decreased at this phase indicating poor pastoral activities at this time interval. Marshy taxa like *Impatiens, Polygonum,* Onagraceae and Cyperaceae, as well as aquatic taxa namely *Lemna, Typha* and *Nymphaea* were recorded in improved conditions resulting in wider lake water conditions in association with marshy lands, as found today. Fungal remains, especially Microthyriaceous fruiting bodies along with *Diplodia, Cookeina, Pleospora, Xylaria, Alternaria* and *Nigrospora* support high humidity, followed by two pollen zones of relatively less warm and humid climate (KW-II and KW-III) between 1,030 to 560 and 560 to present, as evident by the decline of major tree elements such as *Shorea, Syzygium, Bombax, Terminalia*, and others, along with decline in aquatic taxa such as *Lemna, Typha, Potamogeton, Nymphaea* and *Nymphoides*. The region experienced a less warm and humid climate since 560 cal yr BP as a consequence of reduction in monsoon precipitation and a rise in pastoral activities (human settlement). The first appearance of cereals, Solanaceae and *Brassica* is well noted. Thus, inception and pace of cereal based agriculture practice was quite interestingly captured in the KW sequence, which rose exponentially in the later phases (KW-II and KW-III pollen zones).

The increase of secondary forest elements (shrubs), viz., *Melastoma* and *Clerodendrum*, caused a loss of biodiversity in the southwest Garo Hills, as noted in a sedimentary core from Kamrup District of Assam (Dixit & Bera 2013). Correlation of our study at local and regional levels could provide insights on the effects of southwest monsoon precipitation over a wide range of the Indian Peninsula. More sedimentary cores/trenches from nearby sites could be palynologically tested for strengthening the database of regional climatic scenarios that can improve the climatic models used to assess the trends of climatic changes in the future.

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