Impact of modern pollen rain studies from South and Little Andaman Islands, India, to interpret present and past vegetation

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Studies on modern pollen deposition are important for understanding the relationship between pollen assemblages and the vegetation from which they are derived. In the present study, 30 surface samples collected from different sites of South and Little Andaman Islands were palynologically analysed to determine the composition of pollen deposited on the surface sediments. Samples from South Andaman Island reveal an overall dominance of core mangrove pollen, which is compatible with the present-day vegetation in the area. The Little Andaman pollen record shows a dominance of peripheral mangroves from inhabitated areas and reflects the degradation of core mangroves due to anthropogenic activities.

Keywords: Mangroves, palynological analysis, pollen rain, South and Little Andaman Islands.

MILLIONS of tonnes of pollen grains are produced every year by flowering plants, the major percentage of which gets deposited on the ground surface. Where the pollen grains and spores get accumulated in the sediments, they preserve the record of past vegetation over time[1]. Studies on modern pollen deposition were initiated to facilitate the interpretation of fossil assemblages to reconstruct the past vegetation[2–6]. Over the years, palynology (the study of pollen and spores) has proved to be a potent tool for vegetational and climatic reconstruction, especially for the Quaternary period (≃ 2.6 M yrs). Due to their minute size and resistant exine, the pollen/spores are better preserved in the sediments compared to other plant parts. Thus, they provide an optimum representation of contemporaneous flora growing in a particular region during a specific time. Modern 'pollen rain', i.e. the deposition of modern pollen grains on the surface sediments provides the modern analogue, which is a pre-requisite for inferring past climate and vegetation. In India, though a lot of palaeoclimatic studies have been done using pollen/spores as proxy, only scattered information is available on modern pollen rain from the foothills of the Himalayas[7,8]; Rajasthan[9]; western Uttar Pradesh[10]; northeastern Madhya Pradesh[11] and South India[12,13]. So far, no information is available on recent pollen rain from the Andaman and Nicobar Islands. The present communication is an attempt to study the composition of pollen deposited in the surface sediments of Little Andaman and South Andaman Islands, which would help in inferring past climate change and vegetation succession in and around the study area.

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A total of 30 surface samples were collected in linear transects from different sites of South Andaman, viz. Ross Island ($R_{1–3}$), Jetty ($J_{4–6}$), Corbyns Cove ($C_{7–9}$), Chiriyatapu ($Ch_{10–12}$) and Jolly Buoy Island ($Jb_{13–15}$), and from Little Andaman, viz. Jackson Creek ($Jc_{16–18}$), Dugong Creek ($Dc_{19–21}$), V.K. Puram ($V_{22–24}$), R.K. Puram ($R_{25–27}$) and Netaji Nagar ($N_{28–30}$) at an interval of 100 m each (Figure 1).

Samples were treated with 10% aqueous KOH solution and 40% HF solution to deflocculate the pollen/spores and to dissolve the silica content of the sediments. Thereafter, the standard technique of acetolysis using acetolysing mixture (9 : 1 of acetic anhydride and concentrated sulphuric acid respectively) was employed. The samples for microscopic examination were prepared in 50% glycerin solution. Pollen counting was carried out

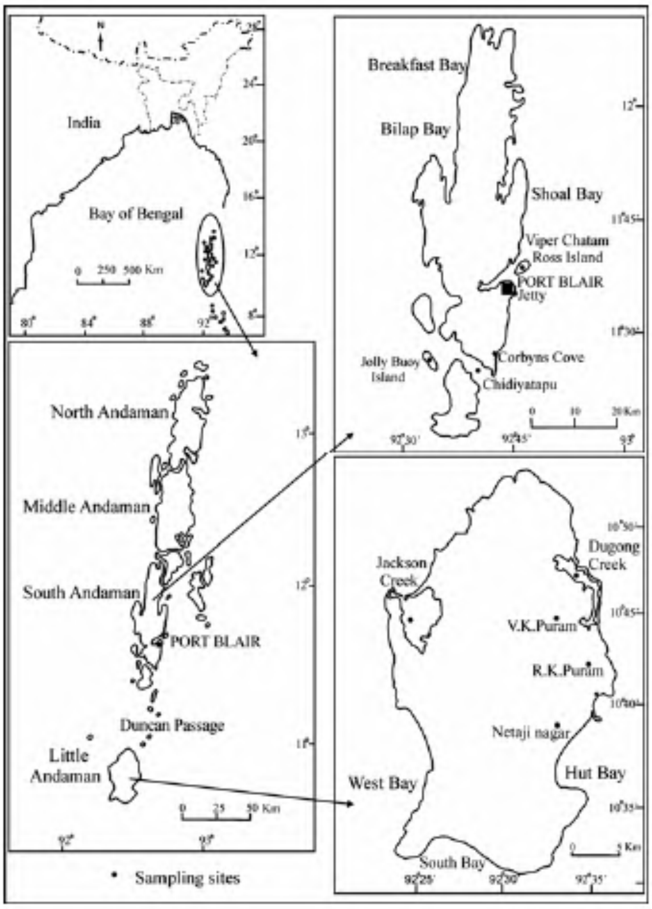

Figure 1. Map showing the location of sampling sites in South and Little Andaman Islands.

using an Olympus BX-61 light microscope under 40× magnification. The percentage frequencies of the recovered pollen taxa have been calculated in terms of total land plant pollen, including fern spores. The plant taxa have been grouped as core mangroves, peripheral mangroves, hinterland taxa, aquatic taxa and pteridophytes.

In the Andaman Group, there are four major islands (North Andaman, Middle Andaman, South Andaman and Little Andaman) and about 278 minor islands. Of these, South Andaman (10°30′–13°42′N lat.; 92°14′–94°14′E long.) is characterized by undulating hilly topography and lies 315 m amsl. The climate is equatorial humid tropical, characterized by high temperature (23–30°C) and high relative humidity (71–85%). December is the coolest month and May is the warmest month. Average annual rainfall is 3000 mm, distributed over 8–9 months (May–January)[14]. Little Andaman Island (10°30′–10°55′N lat.; 92°23′–92°36′E long.) is separated from South Andaman in the north by the Duncan Passage. The Little Andaman Island covers an area of 731.4 km^2 and encompasses tidal flats, mangrove swamps, beaches, coastal plains and two major creeks, i.e. Dugong Creek in the northeast and Jackson Creek in the northwest. The island is low-lying all along the east coast, whereas small undulating hills occupy the central parts, while the intertidal belts are characterized by recent coral-reef formations. The Islands possess equatorial humid tropical climate with high temperature (23–30°C) and high relative humidity (71–85%) throughout the year. The average annual precipitation is 3000–3500 mm/yr.

Mangrove vegetation forms the dominant forests in the islands, mostly fringing along the creeks, backwaters and muddy as well as flat rocky shores. The vegetation of South Andaman is predominanted by core mangroves such as *Rhizophora apiculata*, *Rhizophora mucronata*, *Excoecaria agallocha*, *Bruguiera gymnorrhiza*, *Nypa fruticans* and *Heritiera littoralis*. *Acanthus ebracteatus*, *Acanthus ilicifolius* and *Acanthus volubilis* form thick patches, which occur in large populations fringing all along the tidal creeks. *Avicennia officinalis*, *Avicennia marina*, *Sonneratia alba*, *Sonneratia apetala*, *Sonneratia caseolaris* and *Sonneratia griffithii* are other species that are present towards the sea and also along the rocky shores. *Lumnitzera littorea*, *E. agallocha*, *Xylocarpus granatum*, *Xylocarpus moluecensis*, *Bruguieria parviflora*, *Ceriops tagal*, *Rhizophora stylosa* and *Scyphiphora* could be seen frequently. *Aegiceras corniculatum* shows restricted distribution, while *Aegialitis rotundifolia* and *Kandelia candel* are rare. Among other associate species, which are not true mangroves but are found in the same habitats, *Acrostichum aureum*, *Acrostichum speciosum*, *Cerbera floribunda*, *Dolichandrone spathacea*, *Licuala spinosa*, *Caesalpinia bonduc*, *Intsia bijuga*, *Terminalia catappa*, *Derris scandens*, *Pongamia pinnata*, *Barringtonia asiatica*, *Hibiscus tiliaceous*, *Thespesia populnea*, *Pandanus tectorius*, *Clerodendron inerme* and *Vitex negundo* are prominent. *Phoenix paludosa* and *Cynometra ramiflora* form the borders of the mangroves, whereas *Pandanus leram* and *Guettarda speciosa* are the other prominent constituents of tidal-zone vegetation.

From Ross Island, three surface soil samples ($R_{1–3}$) were analysed. Pollen assemblages of these samples reflect an overall dominance of core mangroves over the peripheral mangroves. Amongst core mangroves, the prominent taxa with highest frequencies were *Aegiceras corniculatum* (10–14.5%), *R. mucronata* (7–16%), *Acanthus ilicifolius* (6–11%), *Lumnitzera racemosa* (4–8.5%) and *X. granatum* (5–6%). Other taxa such as *A. officinalis* (1–7%), *E. agallocha* (2–5.5%) and *Bruguiera* (1–4.5%) were also recorded in low values, whereas *Sonneratia* (1.10%) was represented in only one sample. Amongst peripheral mangroves, *Casuarina* (5–13%) and *P. pinnata* (5–8.5%) were represented in high values (Figure 2). The other taxa such as *Syzygium* (1–4.5%), *Phoenix* (1–3.5%) and *Barringtonia racemosa* (1–3%) were characterized by low values, whereas *Terminalia* (3.2%) was encountered in one sample. Among the herbaceous taxa, Poaceae (10–12%) and Chenopodiaceae (5–14.5%) were prominent. Monolete (6–7%) and trilete (3–6.5%) spores were also represented in good frequencies. *Potamogeton* was the only representative among freshwater taxa (1.41%).

The pollen spectra from Jetty ($J_{4–6}$) exhibited high frequency of *P. paludosa* with a wide range (27–42.5%), followed by *Barringtonia* (7–15.5%). The other peripheral mangroves such as *Terminalia* (3–11.5%) and *Pongamia* (3–5.5%) attained moderate values. *Excoecaria* (8–15.5%) was the only taxa represented by moderate values among core mangroves, whereas *Xylocarpus* and *Aegiceras* were poorly represented. Poaceae (21–28.5%) was the major constituent of ground flora, and Chenopodiaceae showed low frequency. Monolete and trilete spores (3–4%) were also encountered in low values.

The pollen spectra from Corbyns Cove ($C_{7–9}$) revealed moderate values of core mangroves. An overwhelming majority of core mangroves was actually contributed by *R. mucronata* (12–21.5%) followed by *Lumnitzera* (2–14.5%) and *Acanthas ilicifolius* (5–11%). Other taxa such as *E. agallocha* (7–7.5%), *Bruguiera* (3–7%), *Sonneratia* (5.75%), *X. granatum* and *Aegiceras corniculatum* (5% each) were also well-represented. Amongst the mangrove associates, *Terminalia* (12–16.5%) and *Casuarina* (7–9.5%) were better represented compared to *B. racemosa* (5–8%), *Phoenix* (4–8%) and *Syzygium* (2–4%). The non-arboreal vegetation was represented by good frequencies of Poaceae (5–11%) and Chenopodiaceae (6–8%), whereas *Typha* (1–3.5%) exhibited low values among freshwater taxa. Monolete (2–8.5%) and trilete (1–7%) spores were also encountered in good numbers.

The pollen assemblage of Chidiyatapu ($Ch_{10–12}$), in general, showed moderate frequencies of core and peripheral mangroves. Among core mangroves, *R. mucronata* (14–21%), *Acanthus ilicifolius* (5–9.5%), *Aegiceras cor-*

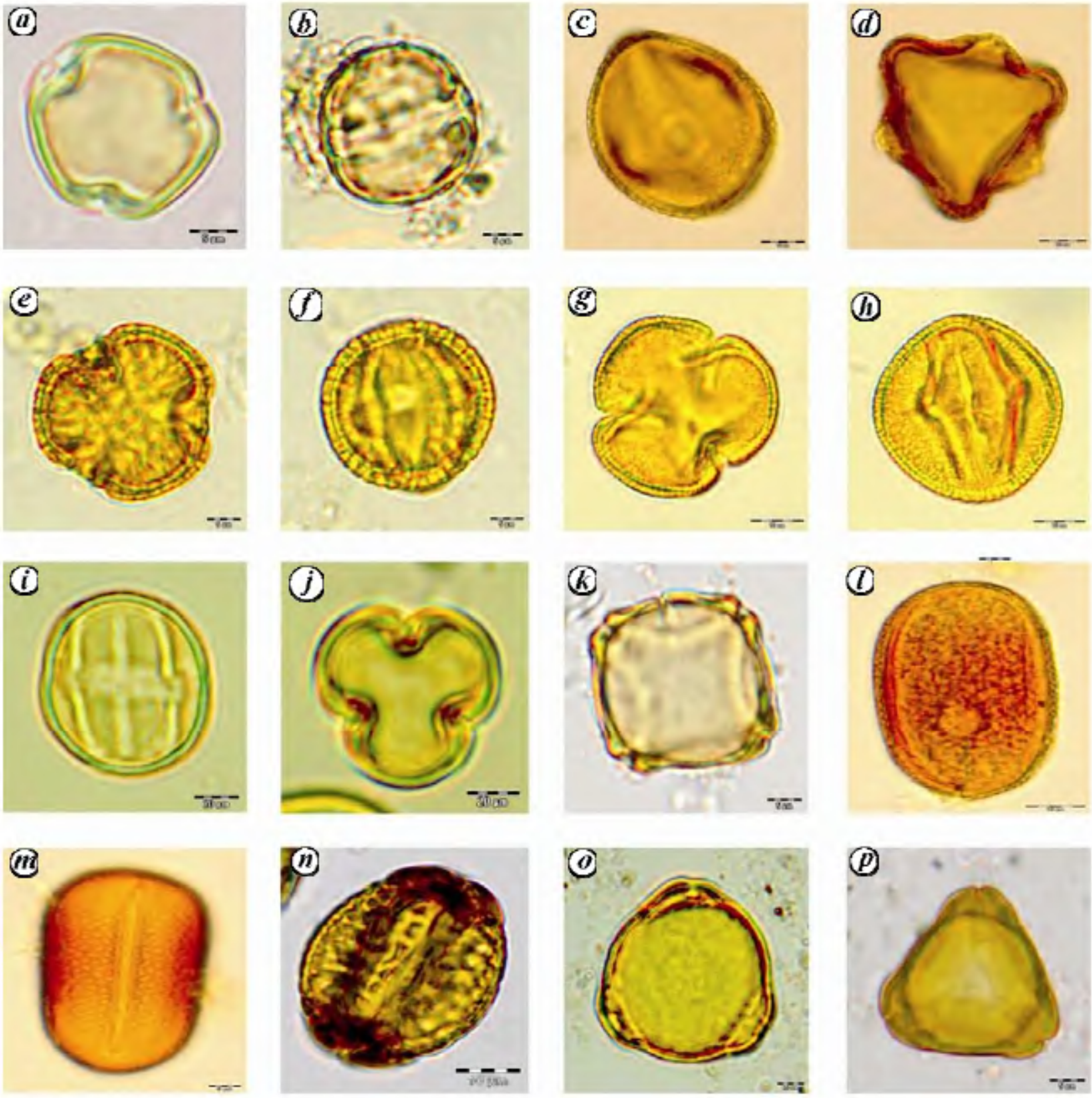

Figure 2. Pollen of core and peripheral mangroves recovered from surface samples of South and Little Andaman Islands. ***a***, ***b***, *Rhizophora mucronata*; ***c***, ***d***, *Sonneratia apetala*; ***e***, ***f***, *Avicennia marina*; ***g***, ***h***, *Excoecaria agallocha*; ***i***, ***j***, *Aegiceras corniculatum*; ***k***, *Xylocarpus granatum*; ***l***, ***m***, *Acanthus ilicifolius*; ***n***, *Barringtonia racemosa*; ***o***, *Casuarina equisetifolia* and ***p***, *Syzygium*.

niculatum (3–11%) and *Xylocarpus* (3–9.5%) were recorded in high values. Pollen grains of *Lumnitzera* (7.69%), *E. agallocha* (5.73%), *Bruguiera* (4.9%) and *Sonneratia* were represented in moderate frequencies. *Terminalia* (6–9.5%), *Casuarina* and *Syzygium* (4–9.5% each) were the most dominating pollen grains in the surface sediments that comprise of the mangrove associates. The pollen grains of *Barringtonia*, *Phoenix* and *Pandanus* were represented in low values. Chenopodiaceae (8–12.5%) and Poaceae (7–11.5%) were the major constituents of herbaceous taxa. Freshwater taxa, viz. *Potamogeton* (1.53%) and *Typha* (1–3.5%) were represented in low frequencies. Monolete (4–8.5%) and trilete (3–9%) ferns were also recorded in good numbers.

The pollen spectrum obtained from Jolly Buoy Island ($Jb_{13–15}$) was dominated by *Phoenix* (16–28.5%) and *Barringtonia* (11–19%). Other taxa, such as *Terminalia* and *Pongamia* were under-represented in the pollen assemblages. Although Poaceae was abundant in the samples, its frequency widely varies (16–33.5%), followed by Chenopodiaceae (3–11.5%). Among core mangroves, *Avicennia* (7–13.5%) was dominant, whereas other taxa, viz. *Rhizophora* and *Excoecaria* (4–11% each) and *Aegiceras* (4–9.5%) were represented by moderate fre-

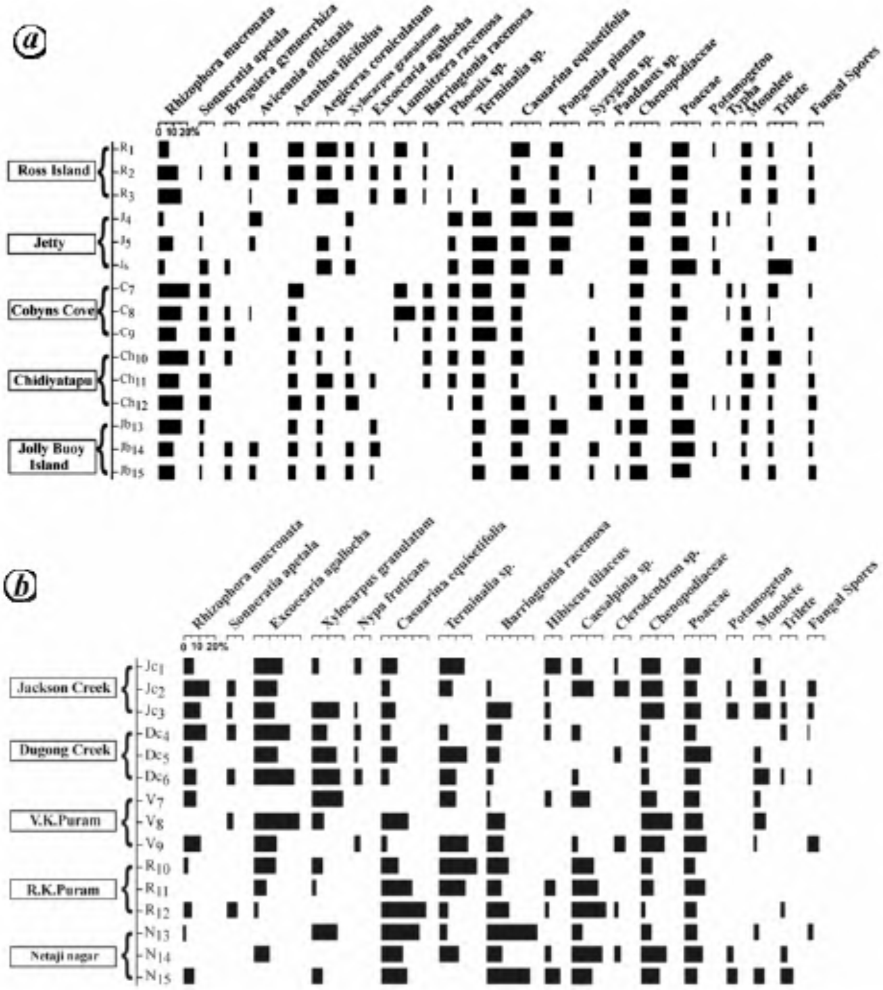

Figure 3. Pollen spectra from (***a***) South Andaman Island and (***b***) Little Andaman Island.

quencies. Pollen grains of *Xylocarpus* and *Lumnitzera* were recorded in low values. Poaceae (16–33.5%) and Chenopodiaceae (3–11.5%) were recorded in all the samples. Fern spores (monolete and trilete) were also encountered in all the samples. The results of the pollen analyses of South Andaman are presented in a pollen diagram (Figure 3 *a*).

In Little Andaman, *R. apiculata, R. mucronata*, *B. gymnorrhiza* and *N. fruticans* were the most dominant mangrove species. Species of *E. agallocha*, *X. gratanum*, *X. mekongensis*, *B. parviflora*, *C. tagal*, *S. caseolaris* and *H. littoralis* were frequent. *Acrostichum* occurred more frequently towards the land. The other significant associate members were *Casuarina equisetifolia*, *P. pinnata*, *Syzygium claviflorum*, *Thespesia populnea*, *B. racemosa*, *Acrostichum aureum, Calophyllum inophyllum, T. catappa*, *Cycas rumphii* and *H. tiliaceus*. Species of *Sarccolobus carinatus*, *Derris scandens*, *Dalbergia monosperma* and *Flagellaria indica* were the prominent climbers, whereas *Hoya parasitica*, *Drynaria quercifolia* and many orchids were the epiphytes growing on the trunks or branches of mangroves and littoral trees. Prostrate grasses such as *Cynodon dactylon*, *Ischaemum muticum*, *Thuarea* and *Cyperus* commonly occurred on the beaches[15].

From Jackson Creek, three surface samples ($Jc_{16–18}$) were collected. The study has revealed an overall dominance of peripheral mangroves over the core mangroves. The core mangroves were represented by moderately high values of *E. agallocha* (13–19%), *X. granatum* (4–18%) and *R. mucronata* (6–16.5%). Other core taxa such as *S. apetala* (3–5.5%) and *Nypa* (1–4%) were represented in low values. Amongst the peripheral mangroves, *Terminalia* (8–15.5%), *Caesalpinia* (6–13.5%) and *Barringtonia* (2–16%) were most dominantly represented in the spectra. Other taxa such as *Hibiscus* (2–10.5%), *Casuarina* (5–10.5%) and *Clerodendron* (2–9.5%) were represented in moderate values. Poacaeae and Chenopodiaceae (Cheno/Ams) were other elements of ground flora that are comparatively well-represented. Aquatic vegetation was represented only by *Potamogeton* (2–7%). Fern spores were recorded in good numbers, mostly by monoletes compared to triletes.

Three surface soil samples ($Dc_{19–21}$) were collected from the mangrove forest of Dugong Creek. The pollen assemblage, in general, depicted high frequencies of core mangroves, viz. *E. agallocha* (15–26%), *X. granatum* (9–18%) and *R. mucronata* (5–14.5%). Other taxa such as *S. apetala* (5–6%) and *Nypa* (2–5%) were recorded in low values. Mangrove associates were marked by high values of *Terminalia* (4–17%), *Casuarina* (5–10%) and *Barringtonia* (4–9.5%). Other taxa were represented in variable frequencies, such as *Caesalpinia* (4–6%), *Clerodendron* (4.25%) and *Hibiscus* (3.80%). Poaceae showed dominance over the Cheno/Ams. Fern spores were recorded in moderate values.

The pollen spectrum of V. K. Puram ($V_{22–24}$) was characterized by an abundance of high pollen frequencies of *Casuarina* (11–20%), *Barringtonia* (5–24%) and *Terminalia* (7–12%). The other mangrove associates such as *Hibiscus* and *Caesalpinia* were represented by low percentages. Among the core mangroves, *Excoecaria* (7–18%) and *Xylocarpus* (3–13.5%) were abundant in the samples, whereas pollen grains of *Rhizophora* were rarely represented (4.5%). Among the herbaceous taxa, the most common types were Poaceae and Chenopodiaceae. Fern spores were present in significant percentages.

In the pollen spectra from R.K. Puram ($R_{25–27}$), the pollen frequencies of peripheral mangroves were high, characterized by significant percentages of *Terminalia* (17–23.5%), *Barringtonia* (12–27%), *Hibiscus* (4–15%) and *Casuarina* (5–11.5%), whereas *Clerodendron* and *Caesalpinia* were recorded in low values. *E. agallocha* (9–20.5%) was represented by high values among core mangroves, whereas *X. granatum* (4.2%) was present only in one sample. Herbaceous taxa were recorded in moderate percentages and monolete ferns (3–7%) were well-represented.

The pollen spectra of Netaji Nagar ($N_{28–30}$) reflected the dominance of peripheral mangroves such as *Barringtonia* (9–32.5%), followed by *Casuarina* (13–24.5%) and *Caesalpinia* (6–20%) which showed relatively high values, while *Terminalia* (4–12%), *Hibiscus* (3–10%) and *Clerodendron* (3.92%) were recorded in low frequencies. Among core mangroves, the dominance of *Xylocarpus* (6–16.5%) and co-dominance of *Excoecaria* (9.84%) was recorded, whereas *Rhizophora* (1–6.5%) was present in low frequencies. Poaceae and Cheno/Ams were frequent and attained values ranging from 6 to 16%. Aquatic vegetation was represented by *Potamogeton* (3–6.5%). Ferns were moderately recorded in the spectra. The percentage frequencies of different pollen from Little Andaman have been plotted in a pollen diagram (Figure 3 *b*).

The results from the pollen analyses of surface sediments conducted in South Andaman reveal an overall dominance of core mangroves over the peripheral mangroves. The pollen spectra from all the transects reflect the existing local and nearby vegetation. Among core mangroves, *Rhizophora*, *Aegiceras* and *Acanthus* pollen were represented in high frequencies. Other important taxa, such as *Bruguiera*, *Sonneratia* and *Xylocarpus* are occurred in appreciable proportion in South Andaman, but were represented with low frequencies in the pollen record. The under-representation of these taxa could be due to their low pollen productivity or partial preservation of pollen in the sediments. Among peripheral mangroves, *Phoenix* showed the highest frequencies in transects from Jetty and Jolly Buoy Island. Likewise, *Casuarina*, *Barringtonia* and *Terminalia* were also characterized by their good representation. The pollen assemblage reflected the dominance of Poaceae over the Cheno/Ams in the ground flora. The consistent recovery of monolete and trilete spores in good amounts, attributed to ferns, depicts the prevalence of moist and shady conditions with abundant rainfall.

The pollen analyses of surface samples from all the transects in Little Andaman Island show that the pollen/spore deposition is compatible with the actual floristics of the area. However, mangrove pollen are dominated by the peripheral mangroves, even though this area is close to the present-day core mangrove cover. Among mangrove associates, *Barringtonia*, *Terminalia* and *Casuarina* were represented in high frequencies from all the transects, specially from V.K. Puram, R.K. Puram and Netaji Nagar. The above three areas were poorly represented by core mangroves. As these areas are inhabitated villages, the core mangroves have been deforested, which is also evident from the modern pollen–vegetation relationship. On the other hand, Jackson and Dugong Creeks are the uninhabited swamps where *Rhizophora*, *Excoecaria*, *Bruguiera*, *Ceriops*, *Nypa*, *Sonneratia* and *Xylocarpus* were the important mangrove constituents. Pollen analytical investigations from the above two areas also represent the consistent representation of *Rhizophora*, *Excoecaria* and *Xylocarpus* with high frequencies and show a coherence with the present vegetation. The pollen of *Sonneratia* and *Nypa* were lowly represented, despite their frequent presence in the forest, which could be attributed to their low pollen productivity and poor preservation in the sediments. Herbaceous taxa were moderately present throughout the pollen spectra in accordance with the actual vegetation on the forest floor.

The present study would develop an understanding of the representation of present vegetation in the pollen record, which would be helpful in tracing the past vegetational changes vis-à-vis climatic fluctuations in and around the study area. The Andaman and Nicobar Islands are important for high species and ecosystem diversity; however, the region is extremely ecologically sensitive. The islands are also one of the few places in India where mangroves are relatively undisturbed compared to other densely populated areas on the mainland; but this is presently under threat due to increasing anthropogenic impact. Palynological studies have been initiated in the area from sediment profiles deposited over thousands of years, to decipher the changes in the vegetation, with special reference to mangroves. The studies would throw light on the existence of mangroves, in the not-so-distant past, from areas where they have presently disappeared/degraded because of encroachment. Such areas are potential places where regeneration/restoration of mangroves can be taken up. Many areas of the Andaman and Nicobar Islands were devastated by the tsunami of December 2004; however, places having mangrove cover remained unscathed. Other than environmental benefits, the regeneration of mangroves in populated areas would have socio-economic implications and would also provide a buffer to check the wrath of tsunamis[16].

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Effect of sub-lethal concentrations of insect growth regulator, lufenuron on larval growth and development of *Aedes aegypti*

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The effect of sub-lethal concentrations (LC_{20} = 0.0002 and 0.001 ppm, and LC_{40} = 0.002 and 0.02 ppm for II and IV instar larvae respectively) of a dispersible concentrate formulation of the insect growth regulator, lufenuron on larval growth and development of *Aedes aegypti* was studied. When II and IV instar larvae were subjected to the above-mentioned sub-lethal concentrations of lufenuron through the culture medium, there was a significant increase in the time taken for pupation (17.2 ± 0.74 and 11.4 ± 0.8 days for II and IV instar LC_{20}-treated larvae respectively, and 19 ± 0.89 and 14.6 ± 1.0 days for II and IV instar LC_{40}-treated larvae respectively). Also, there was increase in the time taken for adult emergence 3.8 ± 0.83 and 5.4 ± 0.83 days from pupation of LC_{40}-treated II and IV instar larvae respectively). There was 28.1 ± 2.06% and 43.59 ± 0.87% reduction in pupation in LC_{20} of lufenuron-treated II and IV instar *A. aegypti* larvae respectively. Also, with LC_{20} of lufenuron-treated II and IV instar larvae there was 43.54 ± 5.12% and 43.59 ± 0.87% reduction in adult emergence respectively. Further, it was observed that II instar larvae treated with LC_{20} of lufenuron developed into 25.8 ± 2.08% deformed adults. In LC_{40}-treated II instar larvae there was 33.72 ± 2.38% reduction in pupation and 63.44 ± 4.76% reduction in adult emergence. Also, it was observed that there was 54.84 ± 3.9% and 61.3 ± 5.2% reduction in pupation and adult emergence respectively, in IV instar larvae treated with LC_{40} of lufenuron. The reduction in pupation of the IV instar larvae treated with LC_{40} of lufenuron was due to failure of the larvae to undergo pupation. These studies are fundamental to the use of lufenuron in *A. aegypti* management.

Keywords: *Aedes aegypti*, larval growth and development, lufenuron, sub-lethal concentration.

AEDES AEGYPTI is the main vector of dengue, yellow fever and chikungunya viruses in many parts of the world affecting millions of people worldwide each year. The only effective vector intervention involves well-organized larval control measures[1,2]. To control mosquitoes, organophosphate pesticides such as malathion, temephos and pyre-

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