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A study on the micro-environment, litter accumulation on forest floor and available nutrients in the soils of broadleaved, mixed pine and pine forests at two distinct altitudes in Meghalaya, North East India

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The present study deals with the micro-environment, litter accumulation and status of available nutrients in the major forest types (broadleaved, mixed pine and pine forests) at two distinct altitudes in Meghalaya, North East India. The representative forest stands were selected at two markedly distinct altitudes at Umroi (ranging from 1100 to 1200 m asl) and Upper Shillong (ranging from 1900 to 2000 m asl). The findings depict that the temperature (ambient and soil) was markedly high at Umroi, and greater values were recorded during pre-monsoon season in all the cases. Relative humidity was high in Upper Shillong, and values decreased from broadleaved to pine forest at both altitudes. Light interception was decreased from broadleaved to pine forest and higher values were recorded in the representative forests at Upper Shillong. Litter accumulation on the forest floor decreased from broadleaved to pine forest, and higher values were obtained at Upper Shillong, with a maximum in the broadleaved forest during pre-monsoon season. Soil moisture was higher in the topsoil than sub-soil, and values decreased from broadleaved to pine forest. The forest stands at Upper Shillong showed markedly high values and lower values were recorded during pre-monsoon season. Soil pH was acidic in nature. Organic carbon, total Kjeldahl nitrogen and available phosphorus were high in the topsoil, with some exceptions in the case of available phosphorus due to leaching, irrespective of seasonal variation. The concentration of these nutrients decreased from broadleaved to pine forest and higher values were obtained for post-monsoon season in the respective forest type. Peak values were recorded at Upper Shillong during post-monsoon season. From the findings it has been concluded that forest-floor characteristics, micro-environment and nutrients status are highly linked with the nature of vegetation and altitude. It was also observed that polyculture helped soil fertility in terms of available nutrients. The results on C : N ratio depict that pine forests (monoculture) at both the altitudes are nutrient-poor.

Keywords: Available nutrients, litter accumulation, micro-environment, Northeast India, nutrient status.

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THE North East (NE) India is known for its high plant diversity and is regarded as a hot spot of biodiversity[1]; it is an extension of the eastern Himalayan complex. About 50% species of Indian flora is confined to this part of the country[2]. Highly undulating topography leads to marked variation in edapho-climatic conditions, and has resulted in great variation in altitude irrespective of distance. This condition leads to alteration in vegetation composition. Change in species composition is one of the major causes for determination of forest types and varied forest-floor characteristics, micro-environment and available nutrients in different types of forests, as chemical composition of the soil is largely governed by the nature of vegetation. Polyculture facilitates litter decomposition, leading to high soil fertility[3].

Disturbance is one of the major factors, which determines plant communities in natural ecosystems[4]. The present study was carried out in Meghalaya (25°2′–26°7′N lat. and 89°49′–92°50′E long.). Anthropogenic activities, viz. extraction of timber, collection of fuelwood and cattle grazing, have led to massive destruction of forests in some areas, resulting in change in vegetation landscape. Because of this, pine has gradually replaced broadleaved species in the disturbed sites. The major vegetation in Meghalaya falls under broadleaved (tropical and subtropical evergreen and semi-evergreen forests and moist deciduous forest), broadleaved with pine, and pine forests; these cover about 48.3%, 4.5% and 7.1% of the total geographical area of the state respectively[5]. Pine forests are confined between 800 and 2000 m asl[5].

Umroi is located at 25°40′N lat. and 91°54′E long. and situated in the Ri-Bhoi District, Meghalaya. The area receives annual rainfall of 1850 mm. The altitude varies from 1000 to 1100 m asl. Umroi is 27 km towards the northeast direction from Shillong[3].

Upper Shillong is located at 25°32′N lat. and 91°54′E long. and situated in East Khasi hills District, Meghalaya. The area experiences annual rainfall of 2880 mm. The altitude varies from 1900 and 2000 m asl. Upper Shillong is 12 km south of Shillong, the state capital[3].

For detailed study one stand each of subtropical broadleaved, mixed pine and pine forests was selected at two altitudes. The study was carried out to know how colonization of pine leads to changes in forest-floor characteristics (litter accumulation), micro-environment and status of available nutrients in the soil, and how such changes are taking place with variation in altitude.

The field survey and collection of soil samples (in triplicate) were done during pre-monsoon (April–May) and post-monsoon (September–October) seasons from the top layer nutrient uptake zone (0–15 cm) and sub-layer (15–30 cm), in 2006. During the study period, sites were visited 10 times and a total of 30 samples (three samples in triplicate) were collected from each soil layer (depth). The micro-environmental conditions such as ambient and soil temperature, humidity, light intensity and litter accumulation on the forest floor were measured during the time of each sampling. Accumulation of litter was determined by collecting litter samples from the forest floor using quadrat (0.5 × 0.5 m size) method.

The soil samples were analysed for total Kjeldahl nitrogen (TKN), available phosphorus (molybdenum blue method) and organic carbon (Walkley and Black method). Soil moisture content was determined gravimetrically by drying 10 g of field-moist sample at 105°C for 24 h in a hot-air oven. Soil pH was measured electrometrically by a digital pH meter using 1 : 2.5 suspension of soil and water. The C : N ratio was also calculated. Standard methods were adopted for analysis of soil following prescribed books[6,7].

The soil temperature was highly influenced by ambient temperature, and it was increased from broadleaved to pine forest at both the places (Table 1), and it was markedly low in the forest stands at Upper Shillong. Pre-monsoon season had more values in each type of forest at the two places. Relative humidity and light interception decreased from broad-leaved to pine forest at both altitudes and higher values were obtained at Upper Shillong. The relative humidity was higher during post-monsoon season.

Litter accumulation on the forest floor decreased from broadleaved to pine forest, and the values were higher during pre-monsoon season. The litter accumulation was markedly high in the forest stands at Upper Shillong (Table 2).

Table 1. Forest micro-environment in broadleaved, mixed pine and pine forests

	Air temperature (°C)		Soil temperature (°C)		Relative humidity (%)		
Forest stand	Pre-monsoon season	Post-monsoon season	Pre-monsoon season	Post-monsoon season	Pre-monsoon season	Post-monsoon season	Light interception (%)
Broadleaved-I	27.4 ± 1.5	25.5 ± 1.1	21.5 ± 0.4	22.4 ± 1.4	53 ± 2.5	59 ± 4.1	83 ± 7.4
Mixed pine-I	30.5 ± 1.6	27.0 ± 1.8	22.3 ± 1.1	23.7 ± 1.7	50 ± 2.9	56 ± 2.6	71 ± 4.8
Pine-I	34.2 ± 1.0	29.9 ± 1.6	24.9 ± 1.0	24.7 ± 1.2	37 ± 2.4	52 ± 2.5	53 ± 5.9
Broadleaved-II	15.6 ± 0.7	13.2 ± 1.3	12.8 ± 0.6	10.2 ± 0.6	90 ± 3.7	96 ± 4.1	94 ± 8.4
Mixed pine-II	19.4 ± 1.2	16.3 ± 1.8	14.3 ± 1.5	12.1 ± 0.8	82 ± 1.9	92 ± 3.6	80 ± 6.5
Pine-II	21.6 ± 1.4	17.9 ± 0.9	17.7 ± 1.2	13.8 ± 1.0	73 ± 2.4	81 ± 2.8	58 ± 7.4

±, Standard error.

Soil moisture content was markedly higher in forests of Upper Shillong than Umroi. Topsoil had more moisture content than the sub-soil, and greater values were recorded during post-monsoon season. There was a marked variation in values from the topsoil to the sub-soil in the forests at Upper Shillong. Soil pH was in acidic range and the acidity decreased from the topsoil to sub-soil during pre-monsoon season; however, it increased from the topsoil to sub-soil during post-monsoon season. Soil pH ranged from 4.6 to 5.7 in the topsoil and from 4.8 to 6.1 in the sub-soil. Site-specific results indicated that Umroi had soil pH range 4.6–5.8; however, it was recorded between 4.9 and 6.1 at Upper Shillong. Topsoil had higher organic C and TKN in all types of forests during both the seasons. However, available phosphorus content was high in the sub-soil during post-monsoon season, with some exceptions. The organic C, TKN and available phosphorus decreased from broadleaved to pine forest. The values were markedly higher in the representative forests at Upper Shillong. The C : N ratio increased from broadleaved to pine forests; higher values were recorded in the sub-soil. Normally, low C : N ratio was noticed during post-monsoon season. The soil characteristics in different types of forests at Umroi had higher values than those at Upper Shillong (Tables 3 and 4).

The findings show that micro-environment and litter accumulation on the forest floor are directly influenced by seasonality and altitude. The temperature (air and soil) and relative humidity are highly linked with season and altitude. Low temperature at Upper Shillong supported high relative humidity. The change of vegetation from polyculture to monoculture and dominance of pine in mixed pine and pine forest indicate increased degree of disturbance that may lead to open canopy, resulting in a decrease in light interception from broadleaved to pine forest. High litter accumulation on the forest floor at Upper Shillong may be due to: (i) low rate of decomposition, and (ii) dominance of broadleaved species. A similar result was obtained by earlier workers[3,8].

The status of available nutrients in the soil is largely governed by the nature of vegetation and polyculture leads to the release of more nutrients in the soil than monoculture[3]. Release of nutrients from litter through decomposition process is recognized as an important part of the nutrient cycle, whereby essential mineral elements tied up in the plant biomass are made available for further plant growth[9]. Low temperature adversely affected microbial activity in the forests at Upper Shillong (high altitude). As a result, litter accumulation on the forest floor was markedly high. Litter layer plays an important role in forest growth in the soils[10], and leaf-litter accumulation enhances soil chemicals[11].

Table 2. Litter accumulation on forest floor in broadleaved, mixed pine and pine forests

Forest stand	Litter accumulation (kg ha^{-1}) Pre-monsoon season	Post-monsoon season
Broadleaved-I	7970 ± 59	5830 ± 893
Mixed pine-I	5650 ± 82	4270 ± 74
Pine-I	3050 ± 59	2830 ± 56
Broadleaved-II	10290 ± 73	8660 ± 84
Mixed pine-II	8780 ± 86	7560 ± 75
Pine-II	5640 ± 70	3370 ± 89

± , Standard error.

Table 3. Soil moisture content, pH and available nutrients in broadleaved, mixed pine and pine forests at Umroi

		Values (seasonal) under different forest types					
		Pre-monsoon			Post-monsoon		
Soil characteristics	Soil depth (cm)	Broadleaved-I	Mixed pine-I	Pine-I	Broadleaved-I	Mixed pine-I	Pine-I
Soil moisture content (%)	0–15	30 ± 2.1	25 ± 1.7	21 ± 2.3	44 ± 3.4	39 ± 2.9	35 ± 2.5
	15–30	24 ± 1.3	19 ± 2.2	15 ± 0.9	27 ± 1.7	30 ± 2.3	31 ± 2.6
Soil pH	0–15	4.6 ± 0.12	5.1 ± 0.14	5.2 ± 0.16	5.7 ± 0.21	5.8 ± 0.17	5.5 ± 0.16
	15–30	4.8 ± 0.08	5.5 ± 0.10	5.7 ± 0.11	5.2 ± 0.12	5.1 ± 0.11	5.3 ± 0.15
Organic carbon (%)	0–15	3.4 ± 0.10	3.2 ± 0.09	2.7 ± 0.11	2.9 ± 0.11	2.6 ± 0.13	2.4 ± 0.12
	15–30	2.6 ± 0.13	2.4 ± 0.11	2.1 ± 0.12	2.3 ± 0.15	1.9 ± 0.09	1.6 ± 0.09
Total Kjeldahl nitrogen (%)	0–15	0.28 ± 0.02	0.24 ± 0.01	0.18 ± 0.01	0.26 ± 0.02	0.21 ± 0.02	0.19 ± 0.03
	15–30	0.20 ± 0.01	0.17 ± 0.02	0.12 ± 0.02	0.19 ± 0.03	0.14 ± 0.03	0.10 ± 0.01
C/N ratio	0–15	12.14 ± 0.4	13.33 ± 0.6	15.00 ± 0.5	11.15 ± 0.5	12.38 ± 0.9	13.16 ± 1.0
	15–30	13.00 ± 0.3	14.12 ± 0.8	17.5 ± 1.2	11.58 ± 0.16	13.57 ± 0.9	16.00 ± 0.7
Available $P \times 10^{-2}$ (%)	0–15	0.26 ± 0.04	0.20 ± 0.05	0.14 ± 0.03	0.30 ± 0.05	0.30 ± 0.07	0.28 ± 0.06
	15–30	0.24 ± 0.05	0.20 ± 0.04	0.10 ± 0.03	0.32 ± 0.04	0.36 ± 0.03	0.23 ± 0.02

±, Standard error.

Table 4. Soil moisture content, pH and available nutrients in broadleaved, mixed pine and pine forests at Upper Shillong

		Values (seasonal) under different forest types					
		Pre-monsoon			Post-monsoon		
Soil characteristics	Soil depth (cm)	Broadleaved-II	Mixed pine-II	Pine-II	Broadleaved-II	Mixed pine-II	Pine-II
Soil moisture content (%)	0–15	57 ± 3.0	48 ± 1.9	46 ± 2.1	74 ± 3.8	72 ± 4.8	60 ± 3.4
	15–30	45 ± 2.4	37 ± 1.6	32 ± 1.1	55 ± 1.5	49 ± 2.1	45 ± 1.5
Soil pH	0–15	5.1 ± 0.13	4.9 ± 0.15	5.4 ± 0.15	5.5 ± 0.09	5.3 ± 0.1.0	5.7 ± 0.10
	15–30	5.6 ± 0.19	5.5 ± 0.15	6.1 ± 0.13	5.2 ± 0.09	5.0 ± 0.08	5.4 ± 0.11
Organic carbon (%)	0–15	4.9 ± 0.15	4.6 ± 0.12	4.3 ± 0.12	5.2 ± 0.17	4.9 ± 0.16	4.5 ± 0.15
	15–30	3.6 ± 0.15	2.9 ± 0.16	2.6 ± 0.12	3.5 ± 0.08	3.1 ± 0.14	2.7 ± 0.15
Total Kjeldahl nitrogen (%)	0–15	0.51 ± 0.02	0.44 ± 0.01	0.35 ± 0.01	0.58 ± 0.02	0.52 ± 0.01	0.39 ± 0.02
	15–30	0.32 ± 0.01	0.23 ± 0.01	0.20 ± 0.02	0.34 ± 0.02	0.27 ± 0.04	0.21 ± 0.03
C/N ratio	0–15	9.61 ± 0.8	10.45 ± 0.5	12.29 ± 1.1	8.96 ± 0.9	9.40 ± 0.7	11.54 ± 1.0
	15–30	11.25 ± 0.9	12.61 ± 0.5	13.00 ± 0.7	10.30 ± 0.8	11.48 ± 0.7	12.89 ± 1.1
Available $P \times 10^{-2}$ (%)	0–15	0.34 ± 0.02	0.30 ± 0.05	0.25 ± 0.03	0.42 ± 0.06	0.42 ± 0.05	0.30 ± 0.06
	15–30	0.17 ± 0.03	0.25 ± 0.04	0.20 ± 0.02	0.46 ± 0.05	0.45 ± 0.04	0.32 ± 0.05

±, Standard error.

Microbial activity and growth are highly influenced by soil pH[12]. The pH range of 4.3–6.0 as noticed during the present study indicates high microbial biomass, and it was more favourable in the forests at Upper Shillong. This finding is in conformity with earlier work carried out in NE India[13], where it was reported that the pH range 4.5–6.0 supports optimum bacterial and fungal growth[13]. Availability of organic C is important in controlling nutrient cycling and soil biological activity. Higher organic carbon value in the topsoil indicated high rate of litter decomposition. As a result, values for total nitrogen and available phosphorus were markedly high. High moisture content during post-monsoon season supported decomposition of litter that leads to increase in the release of nutrients, resulting in more fertile soil. Greater organic C content in the soil at Upper Shillong indicated more microbial biomass, which may be due to increased moisture content. Fine particles (clay) helped in the retention of more organic C and TKN in the soil of Upper Shillong than sandy soil of Umroi. Increased TKN in broadleaved forest depicted high rate of litter decomposition; the decomposition rate is more rapid in nitrogen-rich sites. A similar trend in results has also been established in past studies at other places[13–15]. Greater release of nutrients in broadleaved forest indicated enhanced rate of decomposition of mixed litter, which could be attributed to its diverse chemical composition compared to single-species litter. Chemical composition of leaf litter determines the rate of decomposition[16], and nutrient supply to the soil due to decomposition of litter is enhanced from monoculture to polyculture[17,18]. Release of nutrients in the soil is inversely proportional to the C : N ratio. Increased C : N ratio from broadleaved to pine forest indicated that the soil in the former case is nutrient-rich, and in latter nutrient-poor. High C : N ratio indicated low nitrogen content and/or high organic C content in the soil[13].

Low available phosphorus in the topsoil during post-monsoon season may due to: (i) luxuriant growth of herbaceous species and tree seedlings that leads to more uptake of phosphorus, and (ii) reduced mineralization and/or increased nutrient loss from the topsoil through leaching and run-off[3,19].

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Reproductive ecology of *Cycas beddomei* Dyer (Cycadaceae), an endemic and critically endangered species of southern Eastern Ghats

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***Cycas beddomei* is an endemic and critically endangered, tropical, dry deciduous, dioecious gymnosperm confined to India. Coning and leaf flushing events occur during April–June. The plant is typically anemophilous and it is highly effective for optimal seed set. In both the sexes, during maturation process the cones show weak thermogenesis and emit mild foetid odour, which apparently do not have any significant role in pollination. *Alphitobius* beetles use male cones for feeding and breeding during which they get coated with pollen. These beetles in search of other male cones visit female cones by mistake and effect pollination. The female cones offer only warmth to the beetles during night. The beetles diapause on male plants or in the soil until the next coning season. Leaf flushing episode occurs immediately after the maturation of cones in both sexes, to gain the lost energy and also to supply photosynthate for the growing seeds in female plants. The squirrels, *Funambulus palmarum* and *Ratufa indica* act as seed dispersal agents. A beetle species uses the seeds for breeding and causes seed infestation to a great extent. The adults that emerge from the seeds diapause in the soil until the next seed season to repeat the next breeding cycle. The study suggests that the restricted participation of plants in the annual coning event, restricted seed dispersal, seed infestation and other factors relating to natural regeneration contribute to the endemic and endangered status of the plant.**

Keywords: *Alphitobius* sp., anemophily, *Cycas beddomei*, leaf phenology, seed infestation.

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LITTLE is known about the pollination systems and pollinators of the ancient group of cycads, as only a few have been studied[1]. Detailed pollination studies are available for only four of the world's eleven cycad genera. Hall *et al.*[2] reviewed the experimental studies of pollination in all cycads so far carried out by different workers and concluded that these cycads are primarily entomophilous: *Zamia furfuracea* by *Rhopalotria*, *Zamia pumila* by *Rhopalotria*, *Pharaxonotha*, *Encephalartos cycadifolius* by *Metacucujus*, *Encephalartos villosus* by *Parthetes*, *Macrozamia macdonnellii* by *Cycadothrips*, *Macrozamia communis* by *Tranes*, *Bowenia spectablis* by *Miltotranes* and *Lepidozamia peroffskyana* by *Tranes*. The family Cycadaceae represents a single genus *Cycas*, the sole living *Cycas* group occurring in Asia. It consists of about 100 species, out of which 40 are Indo-Chinese, 27 are Australian and the distribution of the remaining species has not been clearly documented. *Cycas* occurs in the Malaysian region, Japan, India and Sri Lanka, extending to Micronesia and Polynesia, Madagascar and East Africa[3]. In *Cycas*, pollination mechanisms have been discussed by different workers. In *Cycas circinalis*, the pollen is transferred to female cones by the wind, while pollen is transferred from female cones to ovules by both wind and water[4]. In *C. panzhihuaensis*, the first phase of pollen transfer from male to female cones occurs by wind, and the second phase from female cones to ovules by insects[5]. Wind is the major pollination agent in *C. seemanni*[6]. In *C. rumphii* and *C. thouarsii*, the strong odour and thermogenesis in male and female cones serve as a mechanism to attract insects for pollination[7]. Norstog