CHAPTER VI

The peatland

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6.1 Introduction

Peatlands are the wetland ecosystems that develop when plant production is greater than decomposition. Partially decomposed materials gradually accumulate to develop a peat. The peat deposits are composed largely of moss stems and leaves or partially decomposed remains of vascular plants. Specific geographic and geologic characteristic (climate and atmospheric chemistry, watershed geology and hydrologic turnover) and openness of a site largely determines the peatland development and its overall chemical properties. They are best developed in the temperate glaciated regions where the precipitation is abundant throughout the year, atmospheric humidity is high, soil temperature is low, evaporation is reduced, runoff water is minimized and the abundant growth of the plants are possible (Welch 1952; Proctor 1995; Moore and Bellamy 1974; Bradbury and Grace 1983). Peatlands are although resistant to microclimatic change and remains unchanged for thousand of years. They are useful in various ways but fill the lakes with organic sediments produced at the bottom. They may be termed as minerotrophic, ombrotrophic or transition peatlands depending on the mineral content and inflow-outflow systems (Kulzynski 1949; Walter 1973; Moore and Bellamy 1974). Bog is a term that should be reserved for the acid nutrient-poor peat forming ecosystem that are dependent entirely on the hydrology of a system. The floating mats of vegetation colonize the lake surface and form a platform in which the bog vegetation develops and a moss of *Sphagnum* dominates the bog.

Voluminous literature that deals on the formation of peat are available with more focus on the geologic, topographic, climatic and biotic controls of an area (Heinselman 1970). However, the ultimate result is the terrestrialization of the peat where large number of species invades to develop a mesic condition. Contrary to it, the process of 'paulidification' may occur by the invasion of the bog vegetation to upland forest (Klinger 1996a).

Peatlands exist throughout the world, particularly in northern temperate and boreal latitudes and is common feature of glaciated landscapes (Curtis 1959; Larsen 1982). They cover about 1% of the earth's surface, or about 150 million hectares, mostly in the former Soviet Union, Canada, and the United States (Moore and Bellamy 1973). Canada alone has approximately 110-130 million hectares of peatland that gives the largest peat resources of the world (Zoltai 1988). Peatlands have developed in northern latitudes around the world since the retreats of Pleistocene glaciation and particularly since the onset of relatively cool moist climates about two to three thousand years ago (Heinselman 1963, 1970, 1975). Pollen trapped in peat during the process of development of peatlands provides a record of climatic and vegetational change of the respective period. Post glacial archeological information has been uncovered from accumulated peat where dead body of people have been found buried and preserved intact for around 2,000 years in European bogs (Godwin 1981). Peatland studies have drawn worldwide interest because of its economic importance as a fuel, soil conditioner, unique biota and successional patterns.

Peatland area is recorded to be 32,000 ha in India (Bord na Mona 1984). Peatland studies in India is new to ecological science, however listings of peat forming areas in India was already made by Scott (1989). Report on the formation of peatland in the Himalayan region is not available except the Khecheopalri lake under present study. It is situated in the temperate zone at an altitude of 1700 m. This peatland is in a transition phase and possesses characters of more of a bog than fen. The lake had an open water area of 7.4 ha and peatland of 3.4 ha in 1963. Area under peatland reversed in a span of 45 years with an open water of 3.8 ha and 7 ha peatland (Jain *et al.* 2000; Chapter V). The peatland is covered with 85% of herbaceous vegetation including moss and 15% by shrubs and woody vegetation.

This chapter deals with the determination of peatland age and its formation, and vegetation succession, terrestrialization and nutrient dynamics of peat. A thrust was given on the role of peatland as an inter-linking system between the watershed and the lake. The role of peatland on filtering of sediment transported by overland flow from the disturbed watershed has also been dealt.

6.2 Materials and methods

Four sites have been selected for the detailed study of peatland considering site I and II as disturbed sites and Site III and IV as relatively undisturbed sites (see Fig. 7.1). Site characteristics about peatland with total peat depth, water depth encountered and dominant vegetation cover of the four sites have been given in Table 5.1.

6.2.1 Peat stratigraphy

Stratigraphy (vertical strata) of peatland was documented on the basis of visual color differences, degree of decomposition, botanical composition and structure at a distance of 2 m, 30 m, 60 m and 90 m along a transect from the lake edge to the bog forest edge by measuring the thickness of the peat strata with a metal scale (Kratz and DeWitt 1986). Peat bulk density was determined along the distance at one depth (50 cm). Percent organic matter of oven-dried peat samples was determined by ignition at 450 °C for 6 hours (Kratz and DeWitt 1986).

6.2.2 Age determination

The age of the peatland was tested by estimating vertical accumulation rates at 4 locations (2 m, 30 m, 60 m and 90 m) in a transect from lake periphery to bog forest edge in three depths i.e. 50 cm, 100 cm and 150 cm. Lake sediment was collected at 700 cm. Samples of peat were removed through systematic excavation using gloves and samples were air dried and packed in aluminium foils Radiocarbon was dated in Birbal Sahni Institute of Paleobotany, Lucknow, India.

6.2.3 Vegetation analysis

The vegetation in the Khecheopalri bog was extensively surveyed during 1997-99. The plants were identified following standard literature (Hooker 1857; Smith and cane 1911; Polunin and Stainton 1984; Ganguley 1972) and classified on the basis of life forms (Raunkiaer 1934).

Per cent basal cover of the bog was estimated at four peripheral zones at (2 m, 30 m, 60 m and 90 m) along a transect from the lake edge towards the bog forest edge by random quadrats of 1×1 m (n=48) for herbs, 5×5 m (n=32) for shrubs and 10×10 m (n=16) for trees. For stree species the basal area was measured at breast height (1.3 m above the ground) whereas for the shrubs and herbs basal area was measured at the ground level. The basal area was expressed on unit area basis and then the per cent for each plant types were calculated.

The vegetation analysis was done at the four sites selected for the study. Species composition was done in stratified random quadrats for herbs 1×1 m (n=75), shrubs 5×5 m (n=45) and trees 10×10 m (n=25) plots. Ground vegetation of the bog in general was studied in stratified random quadrats 1×1 m (n=75) during March (spring), July (rainy) and December (winter). Total numbers of individuals of each species were recorded. Density, frequency and importance value index (IVI) of each species was calculated following Phillips (1949).

Species indices was calculated following Margalef's (1957) for species richness, Shannon's (1948) for species diversity, Buzas and Gibson's (1969) for equitability and Simpson's (1949) for concentration of dominance (see Chapter V).

6.2.4 Biomass production and organic matter deposition

Herbaceous standing biomass was estimated using 50×50 cm quadrat (n=17) at the four sites. The harvested samples were separated into different species and dried in a hot air oven at 80°C to constant weight and weighed. The exogenous supply of organic debris was estimated through the overland flow (see chapter V) and calculated using the value of total runoff from the different land use that drained the area using a delivery ratio (Sharda *et al.* 1992; Jain *et al.* 2000).

6.2.5 Nutrient dynamics

Cores were taken annually from the four sites (1997-98) at 0-50 cm and 50-100 cm depth intervals below the peat surface at distance of 2 m, 30 m, 60 m, and 90 m along a transect from the lake edge to bog forest edge for evaluating the horizontal continuity of the peat strata and the strata boundary. Wet samples were transfered immediately to polyethylene bags to avoid excessive air contact.

The peat samples were dried and sieved with 2 mm mesh for total nutrient analysis. Peat pH was determined using digital pH meter and total nitrogen by modified Kjeldahl method following Anderson and Ingram (1993). Total phosphorus was estimated by chlorostannous reduced molybdophosphoric blue color method (Jackson 1967) and calcium was estimated using titration method following Allen (1989). Analysis of variance (ANOVA) was done using window based statistical package (Systat 1996).

6.3 Results

6.3.1 Peatland formation and carbon dating

Khecheopalri, a glaciated lake, has the history of peat formation back to 3400 years. The geological setting and disturbed land use practices from the upland watershed led to the accelerated soil erosion process with the movement of the sediment and water-laden nutrients that resulted into the elevation of the periphery of the lake basin (Fig. 6.1). Further accumulation of the silt deposits from the disturbed land use blocked the inundation regimes coming from the watershed. The favored climate resulted in the invasion by number of plants species from the upland forest. The herbs and sedges provided the substratum for the moss to develop, which formed a thick spongy mat with slightly elevated surface, which further affected the inundation regimes thus decreasing the depth and frequency of flooding resulting in seepage (Fig. 6.1). So the less organic matter is exported out and deposited as peat. With the surplus water along with the sediment from the watershed, and the peat accumulation through herbs and *Sphagnum,* the vegetation covers the open water surface and it developed a floating mat in the centripetal manner around the lake. It produces a sound while walking which is often cited as a "quacking bog" ('Schwingmoor' in German). From this floating mat the peat slipped down to lake bottom (Fig. 6.1).

6.3.1.1 Peat stratigraphy

Two relatively discrete peat strata were found in the Khecheopalri peatland with the lake sediments below. Mat peat, which consisted of poorly decomposed peat of *Sphagnum,* herbs, wood pieces and twigs. The organic matter varied from 45-93% with higher values at the lake edge. The peat was light brown in color with identifiable interconnected plant remains and could be lifted vertically. The mat peat varied in thickness from 89 to 218 cm at different distances from 60 m from bog forest edge to 2 m at lake edge (Fig. 6.2). The mat peat showed the alternating bands reflecting dry and wet climatic phases with oxidation favored by dryness and new brown layer accumulating upon return of wetter conditions. The debris peat consisted of the moderately decomposed material which was formed from the mat peat and the organic matter content of 13-83% with the thickness ranging from 93 to 262 cm was recorded (Fig. 6.2). The debris peat was recorded highest at 30 m distance from the lake. Below the mat and debris peat was the lake sediment layer, that was deposited at the lake bottom consisting of 30-70 % organic matter. The material was dark brown to black, slimy and jelly like with almost no fiber content. It slowly increased from the bog forest edge towards the lake (5 to 97 cm) giving the shape of the concave basin (Fig. 6.2). The stratum near the bog forest margin at 90 m distance was replaced by the eroded soil from the watershed upto 50 cm depth. Below this depth pebbles and wood pieces were encountered. Further below a mixture of peat and soil was encountered which has resulted from siltation that occurred from upland watershed and also leading to soil deposition by landslides from uplands.

The bulk density varied widely (0.074-0.917 g/cm^3) with distance showing low values towards the lake edge (Fig. 6.3). It varied significantly with sites and distance. The organic matter contents of the peat samples showed a gradual decrease from the lake periphery towards the forest margin. Analysis of variance showed significant differences of organic matter content between sites, depth and distances (Fig. 6.3).

6.3.1.2 Age determination

The depth wise accumulation of the peat also showed increased radiocarbon dates stating that the stratigraphic boundaries are present within the peat stratum. It is generally concave structure but with the pronounced difference in micro-relief coupled with the peat slide down along the concavity, resulted in certain distortion of the data. Peat formation started about 3000 year ago as indicated by buried sample from landslip at 90 m distance. Age of peat depth-wise depicted modern to 550 ^{14}C age for 50 cm depth, 100-760 ^{14}C age for 100 cm depth and 1410-2770 ^{14}C age for 150 cm (Table 6.2). The peat data from 50 and 100 cm depth of 60 m distance was found older than the peat between 2-30 m from the lake periphery. Depth-wise age of peat also showed increasing trend till 100 cm depth. However at 60 m distance at 150 cm calibrated age was 1312 but at similar depth at 30 m distance it was 2860 (Table 6.2). The analysis of variance showed that ^{14}C age of peat varied significantly with the depth ($r^2 = 0.992$, $P<0.001$) showed strong positive correlation (0.988) however, the distance although varied significantly ($r^2=0.992$, $P<0.001$) but showed a negative correlation (-0.326). The dating of wood encountered at 90 m distance showed the calibrated age of 886-670 B.P. stating that the terrestrialization had started around 800 years back and the oldest tree to be present at the bog edge is around 400 years old.

6.3.2 Terrestrialization

Basal coverage study showed that there was a sequential pattern of plant distribution on the peatland (see Photoplate 5). Highest coverage at 2 m distance was by mosses (87.9%) with some herbs (7%) and shrubs (6%). *Sphagnum nepalense* and *Sphagnum palustre* dominated among the mosses. Per cent basal coverage of the mosses decreased to 65% at 30 m distance whereas the herbs and shrubs increased by 21% and 13%, respectively (Fig. 6.4). The *Brachiaria* sp, *Amaranthus* sp., *Fimbristylis* sp., *Oenanthe* sp. and *Juncus* sp. mostly dominated among the herbs and *Arundo* sp. and *Rhododendron* sp. among the shrubs. A few trees (0.07%) were found to be growing at 30 m distance. Gradually the wet and swampy condition changed to drier and mesic conditions at 60 m distance where the percentage of herbs and mosses declined drastically with 5%

and 6.5%, respectively. However contribution by shrub increased to 29% and that of trees to 60%. The dominating shrub species at this site were *Rhododendron lindleyi*, *Sambucus adnata* and *Viburmun cordifolium*. At 90 m distance moss became negligible (0.28%) while the herbs increased slightly to 11% and the shrubs decreased to 5.4%. The maximum (84%) coverage here was of the tree species (Fig. 6.4). The dominating tree species were *Magnolia* sp., *Acer* sp., *Machilus* sp. and *Castanopsis* sp.

6.3.2.1 Biological spectrum

A total of 86 plant species belonging to 47 families and 82 genera was recorded in the peatland during the study period (Appendix 2). It constituted 42 herbs, 13 under-shrubs, 10 trees, 7 shrubs, 6 semi-hydrophytes, 4 hydrophytes, 2 climbers and 2 epiphytes. Majority of the plant species belonged to families such as Polygonaceae, Ericaceae, Araceae and Asteraceae. The biological spectrum study showed the dominance by phanerophytes (46%) followed by hemicryptophyte (26%), therophyte (13%), chaemephyte (9%) and cryptophyte (6%) (Fig. 6.5).

6.3.2.2 Vegetation composition and biomass

The herb density was found to be highest with the presence of *Sphagnum* moss as the dominating plant at all the sites upto 30 cm distance (see Photoplate 5). Site III was highly diverse in vegetation composition. The density of the herb was recorded highest at the site II with 456 plants/m^2 and highest basal area (140 cm^2/m^2) followed by the site I showing 453 plants/m^2 and 57 cm^2/m^2 basal area (Table 6.3). The highest basal area at the site II was due to the dominance by *Acorus calamus*. The species richness and the species diversity were recorded higher at site III with greater dominance by a few species such as *Acorus calamus* and *Sphagnum* spp. at the site II. *Arundo donax* was the major shrub species and *Polygonum* sp. was dominating herb at the site I. Site IV was dominated by *Brachiaria eruciformis*. The shrub density varied from 2944 plants/ha from site II to 4192 plants/ha at site III. Site III showed high density with low basal area (2.1 m^2/ha) dominated by *Saccharum* sp. The highest basal area (6 m^2/ha) was recorded at site IV for the shrub species which was due to dominance by *Rhododendron* sp. The tree density varied from 36 trees/ha to 256 trees/ha at site IV and III, respectively. But the trees were small in size. The species richness and diversity were higher for all plant habits at site III, species were evenly distributed at site IV for herbs and site I for shrubs (Table 6.3).

Seasonal analysis of vegetation showed only 20 plant species in the bog during spring season, whereas it increased to 26 species in the rainy season and again reduced to 23 species in the winter season. The highest density was always recorded for *Sphagnum* spp. at all the seasons. *Amaranthus* sp. was next dominant species in the spring season with 27 plants/m^2, whereas in rainy and winter seasons *Brachiaria eruciformis* was the second dominant species. The density of the plants contributed by the 10 dominant species with regards to IVI was 530 plants/m^2 whereas the other species contributed only 55 plants/m^2 in the rainy season. The basal area for the 10 dominating species was higher in winter season (23 cm^2/m^2) and spring season (25 cm^2/m^2) with *Acorus calamus* alone contributing, respectively 6.9 cm^2/m^2 and 9.9 cm^2/m^2 (Table 6.4).

The species richness values indicated that it was highest in the rainy season (2.61) with lowest diversity (1.09) and evenness (0.11) indicating that the diversity was not only dependent on number of species rather strongly influenced by equitability of distribution. The higher dominance (0.59) was recorded in the rainy season attributing to the dominance by *Sphagnum* spp. (Table 6.5). In spring and winter season the diversity was higher with more evenness and dominance index.

6.3.3 Peat standing biomass and the exogenous supply

The peatland of Khecheopalri was dominated by *Sphagnum* and vascular herbacious vegetation comprising 85% biomass and remaining 15% contributed by shrubs and woody species. Out of 85%, the *Sphagnum* dominated site accounted 27%, *Acorus* dominated site 24%, followed by other species dominated site 15%, *Brachiaria* dominated site 13% and least from *Polygonum* dominated site with 6% (Table 6.6). The highest standing biomass (960 g/m^2) was recorded for *Acorus* sp. followed by *Sphagnum* spp. (533 g/m^2). The highest standing biomass at site II was 14.9 Mg followed by site I with 7.9 Mg.

The total area of the lake watershed draining into the lake and bog is 91 ha (Fig. 3.1). The organic matter transported from various land uses of the watershed accounted 127 $g/m^2/yr$ from agricultural land, 78.6 $g/m^2/yr$ from forests, and 33.9 $g/m^2/yr$ from cardamom agroforestry (Table 6.7). The highest deposition (64.8 Mg/yr) was recorded from the forest followed by agricultural land (9.5 Mg/yr). The net organic deposition in the lake was 0.8 Mg/ha/yr.

6.3.4 Nutrient dynamics

The nutrient contents of the bog samples are presented in Table 6.8. The pH of the peat materials was acidic that ranged from 4.01 to 5.85 being higher at bog forest edge and showed an increasing trend along the transect with depth in two years. Analysis of variance of pH showed significant differences with sites, distance, depths and year. Total nitrogen varied significantly with sites, depth, distance and year with concentration being generally higher in the upper layer (0-50 cm) compared to the lower depth (50-100 cm). It ranged from 0.73 to 1.42% in different depths and distances from the lake. Total phosphorus was low and ranged from 0.003 to 0.071% and increased with depth. Total phosphorus did not vary among sites and year but varied significantly between distance and depth. Calcium was low and ranged from 0.021 to 0.154% and showed increasing trend from the lake edge towards bog forest edge. Calcium varied significantly among sites, distance, depth and year (Table 6.8).

6.4 Discussion

Peatland formation is intimately tied to geographical setting, hydrology, plant biomass and its succession, and chemistry of an area thus involving the physical and biotic processes. Sediment and nutrients are filling up the lake gradually through peatland increment and sliding down of peat. Around 141 Mg of sediments along with 1.42 Mg of total nitrogen, 0.31 Mg of total phosphorus and 6.88 Mg of organic carbon have annually found their way to the lake (Jain *et al.* 2000 and also see chapter V). The bulk density was found low at the lake edge and gradually increased along the transect and showed a positive correlation (0.701) with distance supporting that the peatlands are entrapping the silt coming from the disturbed land use. However, during the rainy season when most of the precipitation (85%) was received, the inflow to the lake was highest along with the higher nutrient load in the lake water (Jain *et al.* 1999 and also see Chapter VII). Although the peatland is acting as a filtering interface its role is limited during rainy season because of the magnitude and rainfall received during this period.

Deeper the original basin, the thicker the mat peat recorded near the lake edges. It increased vertically as well as horizontally in the centripetal manner around open water. The lake sediments and the peat at periphery favored the growth of the herbs and sedges that provided the substratum for the growth of *Sphagnum* moss. Mat peat showed greater accumulation time with the greater distance from the lake edge and with depth. Kratz and DeWitt (1986) also reported similar results. In peatland the depth of the boundary between peat strata with the depth of original basin showed a feeble positive correlation with depth (0.193) and negative correlation (-0.178) with distance. The absence of the relationship between the depth of the peat strata and the distance at the lake edge has been due to siltation. Around 33% of the bog area increased in the past four and half decades. The open water area was 7.4 ha in 1963 that decreased to 3.8 ha in 1997, and peatland increased from 3.4 ha to 7 ha (Jain *et al.* 2000; see Chapter V). This indicated that the peat formation took place since long time back but its horizontal increment has been a very recent phenomenon. Radiocarbon dating showed that the samples from the bog forest edge were older than the samples near the lake edges. Except at 30 m distance at 150 cm depth it showed higher dates with higher debris peat than at 60 m and 90 m which was due to sliding down of peat slurry due to micro–relief topography and the trampling by the livestock. Peat stratigraphy was not encountered at 90 m distance resulting from soil erosion of the watershed and also paulidification that might have occurred. If the soil erosion and the livestock grazing continues in the peatland, then with current rate of land-use cover change may limit the longevity of the lake to 35 years more when most of the lake water may be horizontally covered by vegetation.

The phanerophytes dominated the bog explaining the invasion by woody and arboreal species. The hemicryptophyte was much higher when compared with normal biological spectrum. This could be due to the perennating buds being present under the peat soil surface and protecting them from browsing by grazing animals. The third higher group was therophyte, which was due to relatively drier condition of the bog during winter and the stress by the livestock grazing that led to invasion by annual weeds.

The successional pattern of the vegetation revealed that the moss and herbs dominated near the lake edge. Peat concentration was found higher at the lake edges due to dominance of *Sphagnum* spp. and other bog flora. Woody arboreal species invaded the bog forest edge especially at the site where uplands was dominated by forest (see Photoplate 5). It reduced the rate of evaporation showing higher water depth suggesting arrested bog growth at the edges and the paulidification was not taking place. Site wise vegetation composition revealed that site III showed highest diversity in terms of plant communities as this site was dominated by forests in the upland watershed. The terrestrial and arboreal shrub and tree species were recorded higher mostly at this site and led to rapid terrestrialization with low peat deposits. Site I and II which are the disturbed sites had the highest peat depth recorded which was mostly contributed by the dominance of *Sphagnum* and the herbs. The standing biomass of the herbaceous vegetation was also found higher at these sites. The site IV had less peat deposits due to the presence of outlet although the density of the herbs and shrubs were fairly good.

The standing biomass contributed by moss and herbs accounted to be slightly lower in range as than the range of 360 g/m^2 to 1,945 g/m^2 reported from Iowa Prairie glacial marshes (van der Valk and Davis 1978). *Acorus calamus* grows well in the bog and contributed highest standing biomass. Its basal area was recorded highest during spring and winter seasons stating that the photosynthates from herbage biomass gets translocated in the basal part after the maturity. The higher species richness during rainy season was due to higher species number and density of plants.

The seasonal vegetation analysis revealed the pressure of grazing in the peatland. The unpalatable species (*Acorus calamus, Amaranthus* sp., *Lycopodium* sp, *Anaphalis* sp, *Potentilla pedencularis*) and less preferred species (*Centella* sp., *Oenanthae thomsonii*) increased during the spring season showing high pressure of grazing during these periods. The invasion by new species such as *Gaultheria* sp., *Eupatorium* sp. and *Polygonum* sp. were also recorded in the bog during the three years of study period. Some of the terrestrial plants such as *Rhododendron lindleyi* and *Sumbucus* sp. were found growing in the bog but not recorded in the watershed forest. Hence their means of arrival in the lake area might be through birds, grazing animals, wind, or through human activities (religious offerings).

The organic soil of peat have many characteristics which distinguish them from mineral soils such as low bulk density (Boelter 1974), high water holding capacity (Thorpe 1968), and high organic matter content (Pollett 1972). Our results showed that peat contained high organic matter and had low bulk density. The nutrient content of the peat is often an indicator (especially if the peat is drained) of its nutritive value for plant growth (Stanek 1975). Highly acidic peat show low contents of the total phosphorus and calcium (Richardson *et al.* 1978; Lucas and Davis 1961) and reported that highly acidic peat often contained as little as 0.01% phosphorus. Our results showed similar trends, the peat was highly acidic containing very low phosphorus and calcium. Peat acidity and organic matter decreased with depth and distance from the lake periphery towards the bog forest margin, and phosphorus and calcium increased along with pH near the bog forest edge. Peat deposition was retarded due to the accretion of sediments at this site from the disturbed watershed. The nutritive data in terms of plant growth given in Table 6.7 when coupled with Malmstrom's guidelines (1956) suggest that peatland is deficient in phosphorus and calcium and nitrogen was found slightly higher.

The geographic setting, watershed geology, climate and hydrologic processes had led to the formation of peatland in the Khecheopalri lake. The terrestrialization and plant succession have already been encountered in the bog with the invasion by woody arboreal species from the upland watershed. The area of the peat has been found more in the disturbed sites compared to the undisturbed sites stating that disturbances has led to enhancement of peatland. Radiocarbon age of the peat revealed that the peat is increasing horizontally covering the open water surface and the peat slurry is getting deposited at the lake bottom due to micro-relief topography thus threatening the lake longevity. The peatland formation in Khecheopalri lake is unique. Its role in filtering the sediments and nutrients from the watershed overland flow was interesting. Most of the sediment accretion was observed on the bog forest edge ■

Table 6.1 Physical characteristics of Khecheopalri peatland

Site	Aspect	Distance (m)	Depth (cm)		Dominating species
			Water	Peat	
I	NW	2	3	175	*Sphagnum* spp., *Brachiaria eruciformis* , *Arundo donax*
		30	2	159	*Sphagnum* spp., *Polygonum* sp., *Arundo donax, Polygonum* sp.
		60	20	102	*Acorus calamus, Juncus reflexa, Oenanthe thomsonii,*
II	SW	2	2	500	*Sphagnum* spp., *Acorus* sp. *Brachiaria* sp., *Juncus* sp.
		30	4	385	*Sphagnum* spp., *Eqisetum debele, Acorus slamus*, *Potentilla* sp.
		60	12	320	*Acorus calamus, Sphagnum* spp., *Potentilla* sp., *polygonum* sp.
		90	132	170	*Cyperus rotundus*, *Magnolia* sp., *Hemiphragma* sp.
III	NW	2	4	153	*Sphagnum* spp., *Saccharum* sp., *Juncus* sp.
		30	8	146	*Saccharum* spp., *Diplazium umbrosum, Sphagnum* spp.
		60	10	110	*Juncus* sp., *Equisetum sp., Oenanthe* sp. *Vaccinium* spp.,
		90	53	60	*Eupatorium* sp., *Symingtonia* sp., *Magnolia* sp., *Alnus* sp.
IV	SW	2	2	207	*Sphagnum* spp., .*Arundo donax*, *Brachiaria* sp., *Fimbristylis* sp.
		30	6	103	*Sphagnum* spp., *Rhododendron lindleyi Berberis wallichiana,*
		60	7	90	*Rhododendron lindleyi*, *Cyperus rotundus,,Anaphalis* sp.

Site I & IV do not have bog at 90 m distance

Table 6.2 Radiocarbon ages of Khecheopalri peatland.

Lab No	Dated Material	Distance from lake (m)	Sample depth (cm)	Measured ^{14}C age	Calibrated age range (B.P.)
BS-1535	Peat	2	50	Modern	NA
BS-1537	Peat	2	100	220±70	284
BS-1528	Peat	30	50	Modern	NA
BS-1527	Peat	30	100	100±80	61-43
BS-1507	Peat	30	150	2770±90	2950-2770
BS-1517	Peat	60	50	550±80	640-511
BS-1538	Peat	60	100	760±70	725-655
BS-1533	Peat	60	150	1410±70	1346-1278
BS-1545	Peat	90	50	Modern	NA
BS-1503	Peat	90	80	2080±80	2140-1940
BS-1508	Peat	90	120	2970±100	3326-2959
BS-1493	Lake sediments	Lake periphery	700	37730±1300	NA
BS-1419	Charcoal[a]	120		260±80	430-0
BS-1540	Wood[b]	120	100	840±80	886-670

a = old burnt tree; b = wood piece collected from peat depth.

Table 6.3 Vegetation analysis of Khecheopalri peatland

Vegetation types	Sites			
	I	II	III	IV
Herbs				
Number of species	16	19	20	13
Density (plants/m^2)	453	456	349	421
Basal area (cm^2/m^2)	57	140	49	44
Species richness	1.6	1.9	2.1	1.3
Species diversity	1.24	1.05	1.27	1.14
Eveness index	0.22	0.14	0.18	0.24
Dominance index	0.009	0.22	0.01	0.009
Shrubs				
Number of species	8	9	9	8
Density (plants/ha)	3200	2944	4192	3872
Basal area (m^2/ha)	4.5	4.9	2.1	6.0
Species richness	1.32	0.53	1.44	1.28
Species diversity	2.02	0.198	2.03	1.88
Eveness index	0.94	0.37	0.85	0.82
Dominance index	0.07	0.07	0.06	0.06
***Trees**				
Number of species	5	3	8	3
Density (trees/ha)	100	92	256	36
Basal area (m^2/ha)	1.7	1.3	3.1	0.6
Species richness	1.24	0.64	0.69	0.91
Species diversity	1.51	1.07	1.61	1.06
Eveness index	0.91	0.97	0.63	0.96
Dominance index	0.2	0.21	0.13	0.67

* Trees mostly occuring at the bog forest edge

Table 6.4 Seasonal variation of frequency, density, basal area and IVI of the herbaceous vegetation of the Khecheopalri peatland.

Species	Frequency (%)	Density (Plants/m^2)	Basal area (cm^2/m^2)	IVI
Spring				
Sphagnum spp.	44	262.6	8.25	113.00
Acorus calamus	28	12.60	9.90	48.20
Oenanthe thomsonii	52	21.64	2.72	27.80
Amaranthus sp.	60	27.48	0.86	23.80
Brachiaria eruciformis	44	18.88	0.15	15.20
Plantago erosa	28	1.80	0.90	10.10
Cyperus rotundus	20	5.36	1.05	9.90
Lycopodium cernum	24	2.40	0.31	7.06
Anaphalis contorta	16	4.00	0.50	6.51
Centella asiatica	16	7.00	0.06	5.58
Other species		6.60	0.91	33.20
Total species		370.36	25.6	300
Rainy				
Sphagnum spp.	96	445	13.98	139.00
Brachiaria eruciformis	64	48.16	0.38	19.50
Amaranthus sp.	56	23.68	0.74	15.30
Plantago erosa	4	0.08	4.02	14.50
Acorus calamus	28	2.40	1.88	11.20
Fimbristylis sp.	40	12.00	0.85	11.20
Heidychium ellipticum	28	2.00	1.57	10.10
Commelina paludosa	44	11.08	0.30	9.76
Oenanthe thomsonii	24	6.36	0.79	7.54
Potentilla peduncularis	20	3.40	0.96	7.00
Other species		31.28	3.49	54.70
Total species		585.44	28.96	300

Winter

Sphagnum spp.	72	322.68	10.13	121.00
Brachiaria eruciformis	84	61.88	0.49	30.20
Acorus calamus	12	8.80	6.91	29.20
Cyperus rotundus	36	12.04	2.36	17.50
Oenanthe thomsonii	32	10.56	1.32	12.70
Fimbristylis sp.	40	8.56	0.56	10.90
Vaccinium nummularia	32	3.48	0.44	7.92
Juncus reflexa	40	2.64	0.09	7.85
Plantago erosa	12	0.80	1.50	7.73
Lycopodium cernuum	32	3.08	0.38	7.63
Other species		14.44	3.26	47.1
Total species		448.96	27.42	300

Table 6.5 Species indices of the herbacious vegetation of the Khecheopalri peatland

Parameters	Spring	Rainy	Winter
Number of species encountered	20	26	23
Density (plants/m^2)	370	585	449
Basal coverage (cm^2/m^2)	25.6	28.9	27.4
Species richness (Margalef's index)	2.08	2.61	2.36
Diversity index (Shannon's index)	1.21	1.09	1.13
Equitability index (Buzas and Gibson's index)	0.17	0.11	0.13
Dominance index (Simpson's index)	0.51	0.59	0.54

Table 6.6 Herbacious biomass in the Khecheopalri peatland.

Site	Species	Area (ha)	Standing Biomass (Mg)
I	*Brachiaria* sp.	0.17	0.69
	Sphagnum sp.	0.5	2.67
	Acorus sp.	0.34	3.30
	Polygonum sp.	0.23	0.58
	Other species	0.19	0.72
	Total species		7.96
II	*Brachiaria* sp.	0.22	0.89
	Sphagnum sp.	0.54	2.88
	Acorus sp.	1.0	9.60
	Polygonum sp.	0.2	0.50
	Other species	0.27	1.03
	Total species		14.9
III	*Brachiaria* sp.	0.12	0.49
	Sphagnum sp.	0.34	2.13
	Acorus sp.	0.34	3.26
	Polygonum sp.	-	-
	Other species	0.38	1.44
	Total species		7.32
IV	*Brachiaria* sp.	0.41	1.66
	Sphagnum sp.	0.45	2.40
	Acorus sp.	-	-
	Polygonum sp.	-	-
	Other species	0.2	0.76
	Total species		4.82
	Total bog	5.96	35.00

Total area of the bog is 7.01 ha of which 1.05 (15%) not considered as it was dominated by shrubs and tree seedlings. Standing biomass of *Brachiaria* sp. 405 g/m^2; *Sphagnum* spp. 533 g/m^2; *Acorus* sp. 960 g/m^2; *Polygonum* sp. 250 g/m^2 and Other species 380 g/m^2.

Table 6.7 Exogenous deposition of organic debris from the drainage area of the lake watershed to the peatland.

Site	Land use/cover	Area (ha)	*Organic debris carried to bog through run-off (Mg/year)
I	Forest land	5	3.93
	Cardamom agroforestry	0.1	0.03
	Agricultural land	4	5.09
	Total		9.05
11	Forest land	7.5	5.90
	Cardamom agroforestry	-	-
	Agricultural land	3	3.82
	Total		9.72
111	Forest land	40	31.44
	Cardamom agroforestry	-	-
	Agricultural land	0.5	0.64
	Total		32.08
IV	Forest land	30	23.58
	Cardamom agroforestry	0.9	0.31
	Agricultural land	-	-
	Total		23.89
	Total lake watershed	91	74.74

*Calculation based on delivery ratio: cardamom agroforestry (30%); forests (60%) and agricultural land (80%)

Table 6.8 Nutrient concentration of peatland at two depths of four sites along the distance from lake periphery to forest edge. Values are means of 1997 and 1998 (n=6).

Site	Depth (cm)	Distance (m) 2				30				60				90			
		pH	TN	TP	Ca	pH	TN	TP	Ca	pH	TN	TP	Ca	pH	TN	TP	Ca
I	0-50	4.41	0.83	0.017	0.056	4.07	1.42	0.008	0.064	5.35	1.15	0.008	0.064	-	-	-	-
	50-100	4.79	0.87	0.019	0.072	4.51	1.50	0.046	0.077	5.13	1.26	0.070	0.081	-	-	-	-
II	0-50	4.01	1.19	0.018	0.071	4.91	1.42	0.016	0.077	4.83	1.31	0.029	0.076	4.96	1.15	0.050	0.132
	50-100	4.28	0.95	0.019	0.073	5.11	1.37	0.028	0.078	5.29	0.91	0.047	0.080	5.24	1.13	0.045	0.139
III	0-50	4.58	1.05	0.013	0.062	4.56	1.21	0.017	0.081	5.79	0.85	0.026	0.081	5.42	1.17	0.071	0.152
	50-100	4.71	0.87	0.023	0.065	4.96	0.82	0.036	0.086	5.71	1.11	0.043	0.087	5.85	1.08	0.064	0.154
IV	0-50	4.05	1.29	0.003	0.021	4.57	0.77	0.004	0.022	5.34	0.73	0.025	0.023	-	-	-	-
	50-100	4.45	0.89	0.005	0.022	4.79	0.65	0.005	0.025	5.62	0.68	0.025	0.024	-	-	-	-

TN = total nitrogen (%); TP = total phosphorus (%); and Ca = Calcium (%); dash = no bog at this distance.

ANOVA: pH - Site $F_{3,96}$=19.28, P<0.001; Distance $F_{2,96}$=14.34, P<0.001; Depth $F_{1,96}$=83.37, P<0.001; Year $F_{1,96}$=171.9, P<0.001; LSD $_{(0.05)}$=0.08. Total nitrogen - Site $F_{3,96}$=59.95, P<0.001; Distance $F_{2,96}$=19.73, P<0.001; Depth $F_{1,96}$=66.55, P<0.001; Year $F_{1,96}$=88.63, P<0.001;LSD$_{(0.05)}$=0.04. Total phosphorus - Site not significant; Distance $F_{2,96}$=11.72, P<0.001; Depth $F_{1,96}$=6.37, P<0.05; Year not significant; LSD$_{(0.05)}$=0.007. Calcium - Site $F_{3,96}$=422, P<0.001; Distance $F_{2,96}$=88.49, P<0.001; Depth $F_{1,96}$=18.78, P<0.001; Year $F_{1,96}$=36.02, P<0.001;LSD$_{(0.05)}$=0.003. Interactions were mostly significant in all the cases (ANOVA calculated upto 60 m distance)

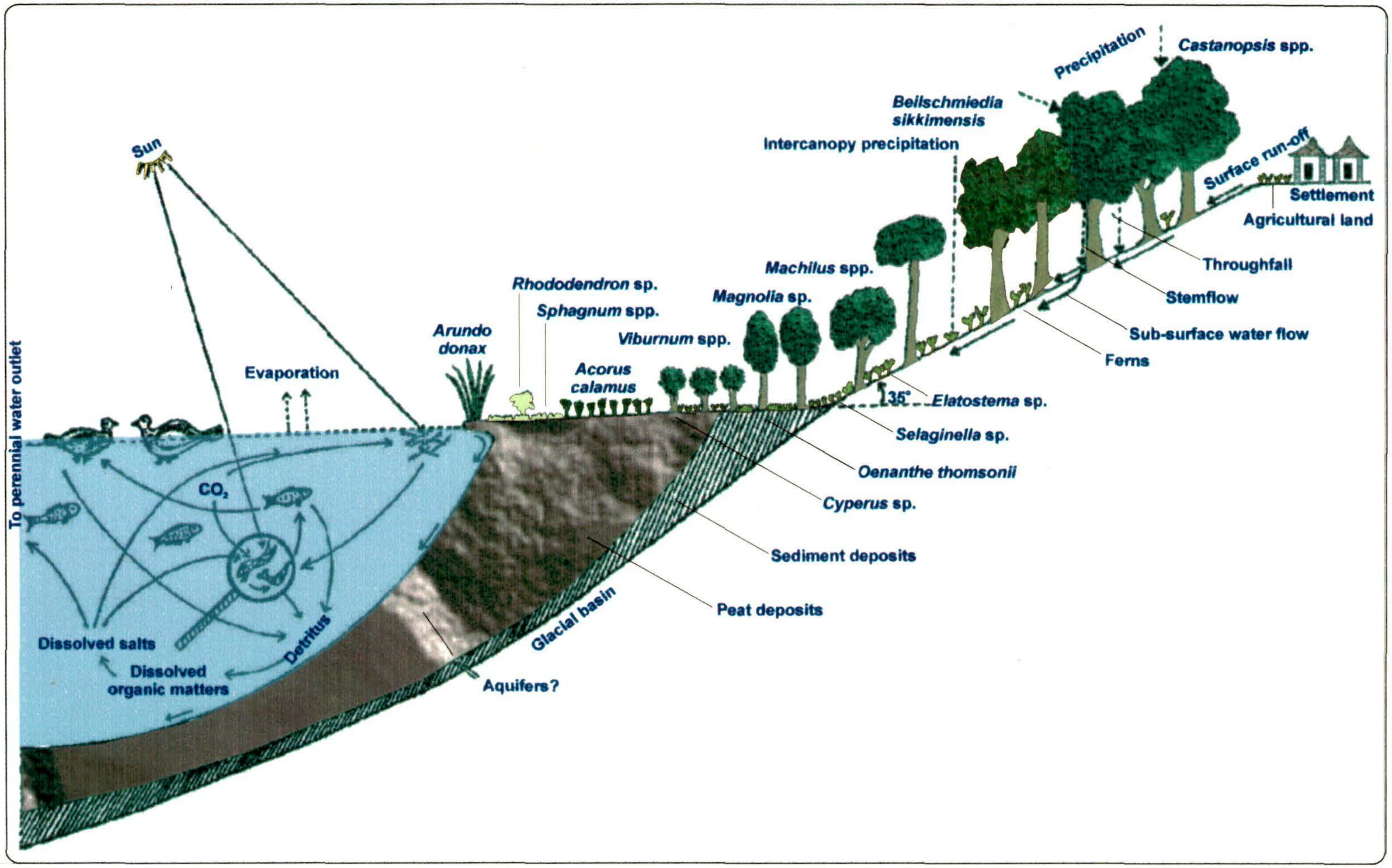

Fig. 6.1 Diagramatic sketch of peatland formation and its vertical transection of Khecheopalri lake showing profilatic pattern of sedimentation process, vegetation succession pattern and biotic interactions

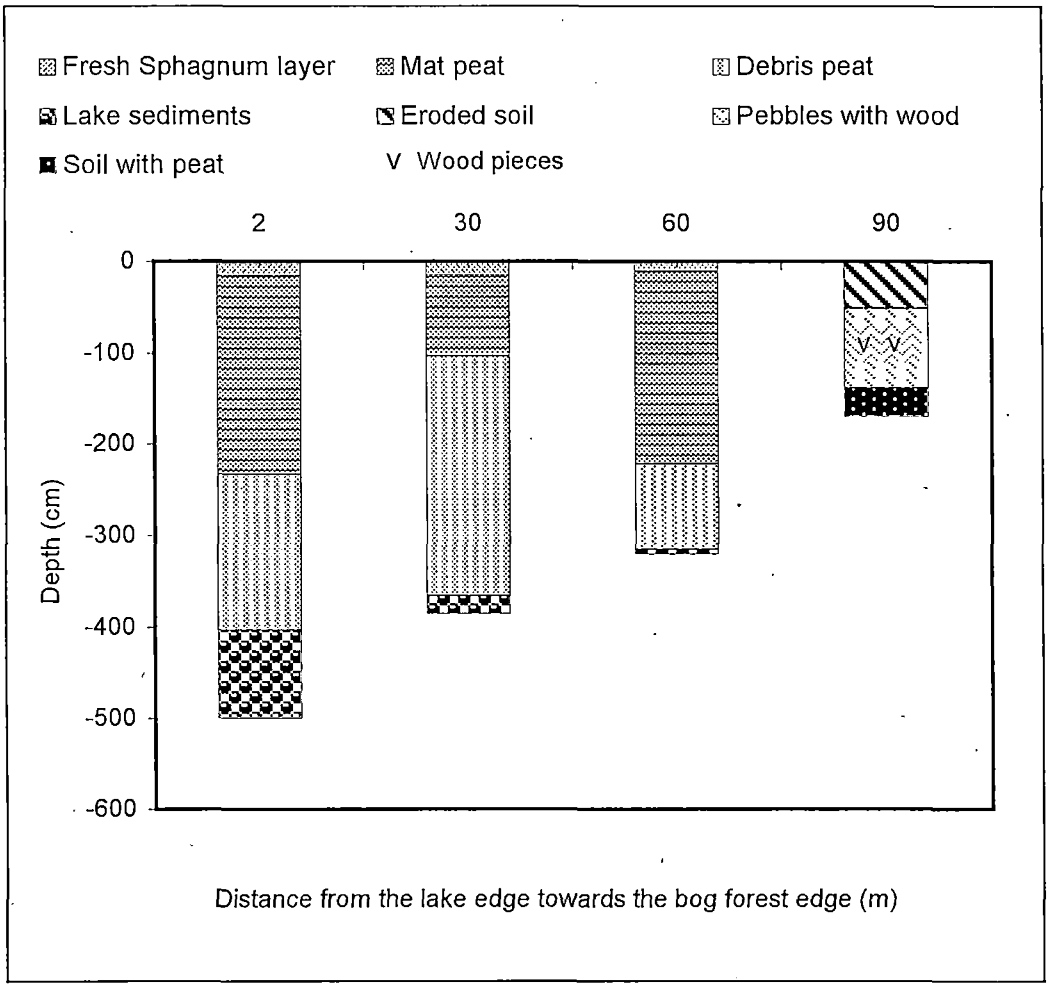

Fig., 6.2 Stratigraphic boundaries of the peat strata along a transect from the Khecheopalri peatland

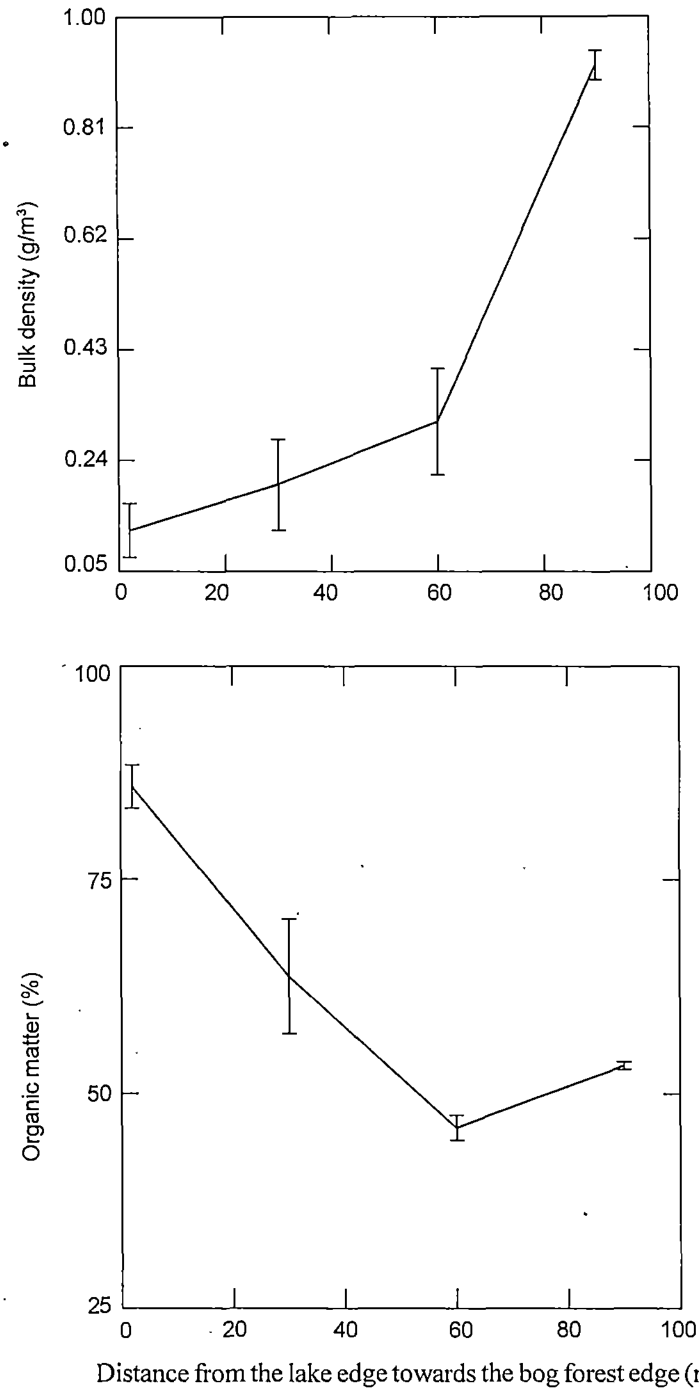

Fig. 6.3 Bulk density and organic matter along a bog transect in the Khecheopalri lake **ANOVA**- Bulk density Site $F_{3,24}$=368, P<0.001; Distance $F_{3,24}$=372, P<0.001; Site x Distance$F_{9,24}$=182, P<0.001; LSD $_{(0.05)}$=0.02. Organic matter Site $F_{3,48}$=347, P<0.001; Distance $F_{3,48}$=1488, P<=0.001; Depth $F_{1,48}$=740, P< 0.001; Site x Distance $F_{9,48}$=182.5, P<0.001; Site X Depth interaction not significant, Site x distance x Depth $F_{9,48}$=14, P <0.001, LSD $_{(0.05)}$=1

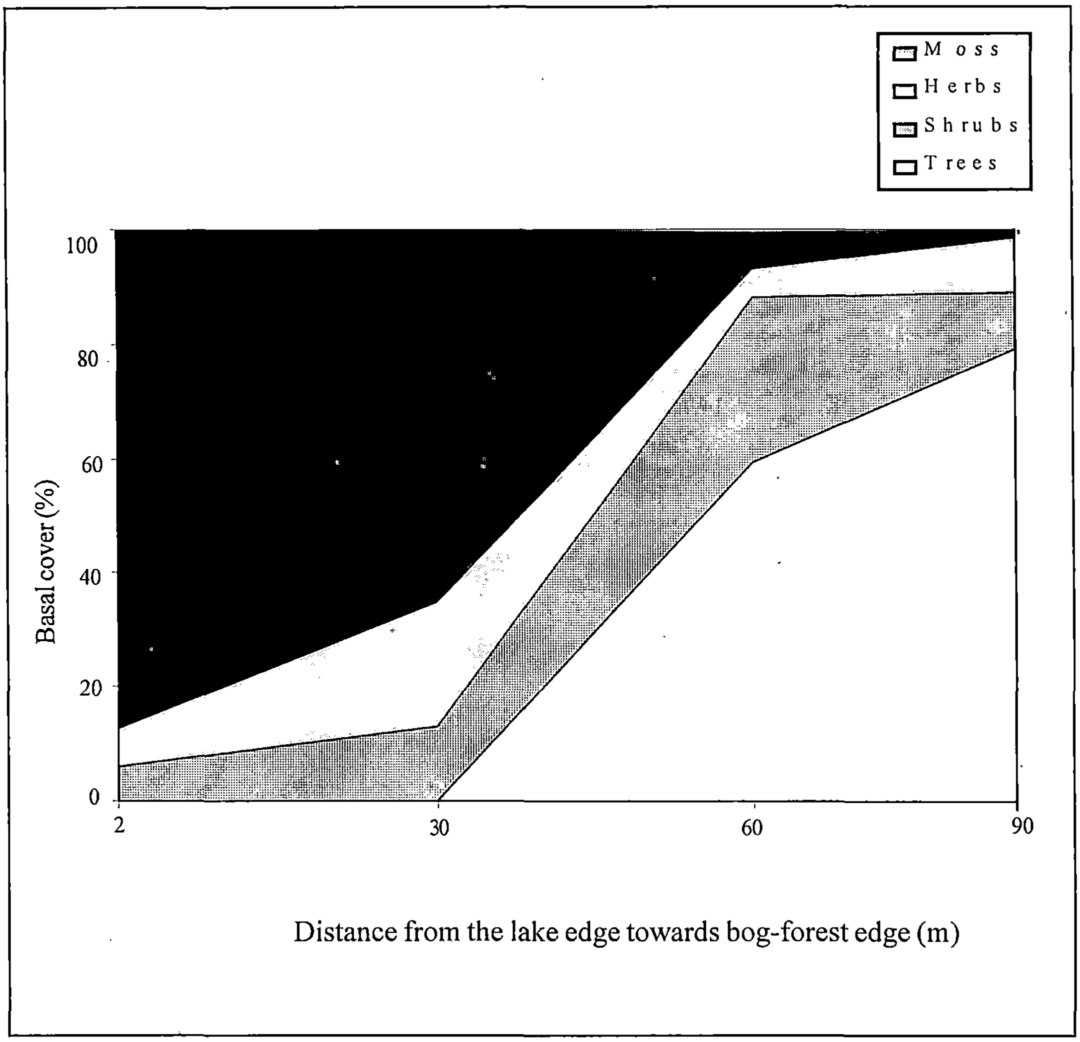

Fig. 6.4 Diagramatic representation of the basal coverage of different plant habits in Khecheopalri peatland.

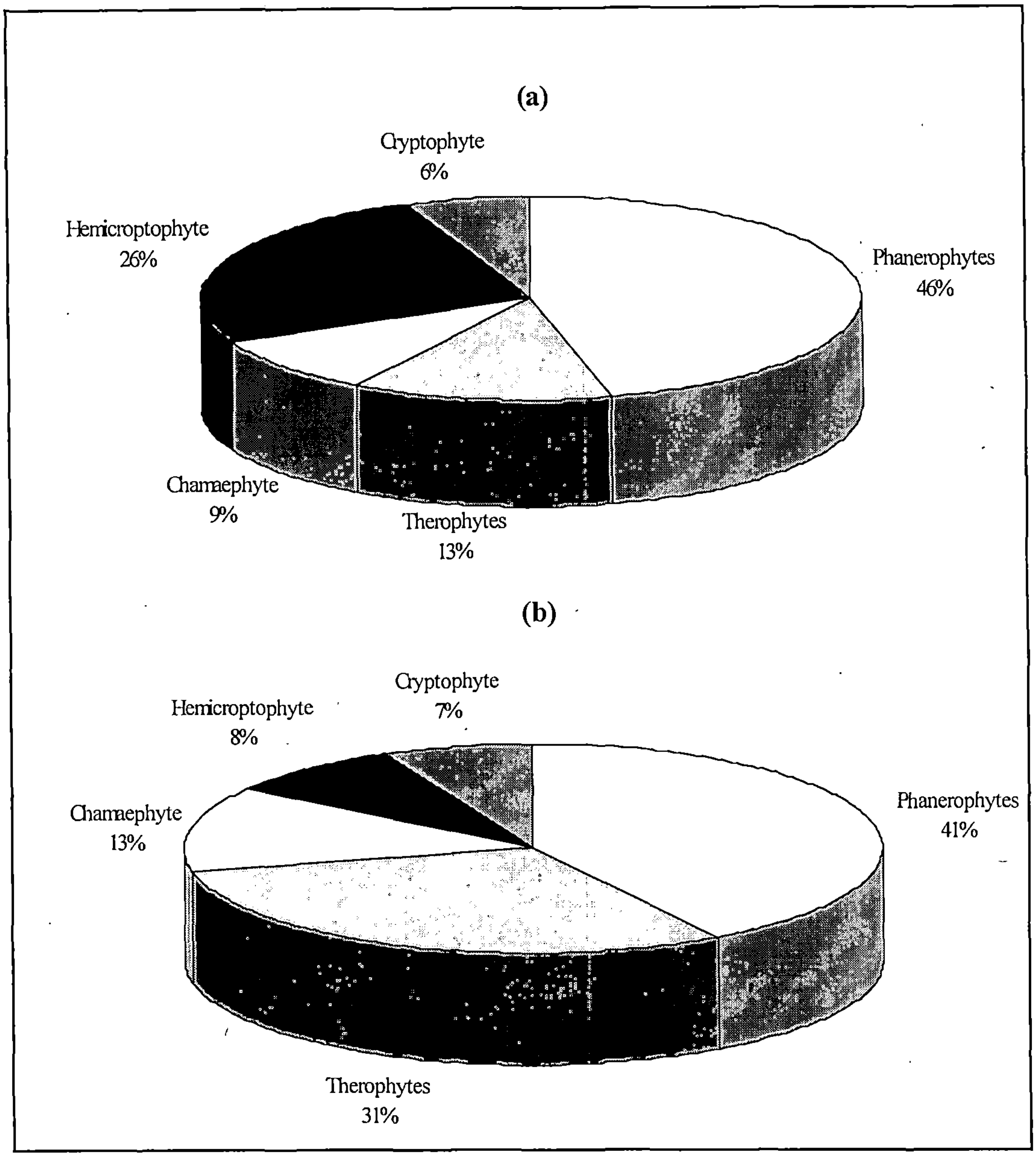

Fig. 6.5 Raunkiaer's normal spectrum (a) and biological spectrum of the Kecheopalri lake bog (b)