TERRESTRIALIZATION OF A PEAT LAKE IN THE SIKKIM HIMALAYA, INDIA

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SUMMARY

The present study was conducted in a 7.01 ha peatland, which is an inter-linking zone between the open water and upland forest of the sacred Khecheopalri Lake in the Sikkim Himalaya. Peat formation started around 3400 years ago with the oldest age near to the forest edge and recent formation towards the lake periphery. The study revealed that successional and terrestrialization processes were dominated by mosses and herbs at the lake edge and woody arboreal species near the forest edges. The spatial expansion and depth of the peat was greater in the disturbed site compared to the undisturbed site with a dominance of *Sphagnum* moss. Acidity and organic matter content were higher near the lake edge while total phosphorus and calcium followed the reverse trend having the highest values near the forest edge. The bulk density of the peat varied widely, with higher values near forest edges. Micro-relief topography and the concavity of the lake basin revealed slow transportation of peat to the lake bottom thus reducing the depth of the lake.

Keywords: Nutrients, peat stratigraphy, radio carbon dating, succession, watershed, India

INTRODUCTION

Peatlands are wetland ecosystems that develop when plant production is greater than decomposition. Specific geographical and geological characteristics (climate and atmospheric chemistry, watershed geology and hydrologic turnover) and openness of a site largely determine peatland development and its overall chemical composition (Heinselman, 1970). Peatlands exist throughout the world, particularly in northern temperate and boreal latitudes and are common features of glaciated landscapes (Curtis, 1959; Larsen, 1982). They cover about 3% of the earth's surface, or about 400 million hectares, mostly in the former Soviet Union, Canada, Indonesia and the United States (Joosten & Clarke, 2002). Peatland in India occupies 32,000 ha (Bord na Mona, 1985) but detailed information is not available except for some preliminary work carried out by Scott (1989). The present study was designed to investigate the peatland formation and its age, succession and terrestrialization, and nutrient dynamics of the sacred Khecheoplari Lake in the Sikkim Himalaya.

THE STUDY AREA

The present study was conducted in the sacred Khecheopalri Lake known as the "wish fulfilling lake" situated at $27^0 22' 24''$ N and $88^0 12' 30''$ E at an altitude of 1700 m above sea level in the western part of the Sikkim Himalaya. The lake represents the original 'neve' region of the ancient hanging glacier, the depression being formed by glacial scooping action (Raina, 1966) (Fig. 1). The lake has an open water area of 3.8 ha with 7.01 ha of peatland within an upland watershed of 12 km^2, of which 91 ha drains directly to the lake (Jain *et al.*, 2000). Geologically the rocks belong to the Darjeeling group comprised chiefly of high-grade gneisses containing quartz and feldspar with streaks of biotite (Geological Survey of India, 1984).

Table 1. Site characteristics of Khecheopalri peatland

Site	Aspect	Distance (m)	Depth (cm) Water	Depth (cm) Peat	Dominant species	Types of disturbance
I	NW	2	3	175	*Sphagnum nepalense, Brachiaria eruciformis , Arundo donax*	Tourism, Pilgrimage and settlement
		30	2	159	*Sphagnum nepalense, Polygonum* sp., *Arundo donax,*	
		60	20	102	*Acorus calamus, Juncus reflexa, Oenanthe thomsoni*	
II	SW	2	2	500	*Sphagnum nepalense, Acorus calamus, Brachiaria eruciformis Juncus reflexa*	Trampling, grazing, fuel-wood, timber collection, agricultural practices settlements and cowsheds
		30	4	385	*Sphagnum nepalense, Equisetum debele, Acorus calamus, Potentilla pedencularis*	
		60	12	320	*Acorus calamus, Sphagnum nepalense, Potentilla pedencularis*	
		90	132	170	*Cyperus rotundus, Hemiphragma heterophylla*	
III	NW	2	4	153	*Sphagnum palustre, Saccharum* sp., *Juncus reflexa*	Fuel-wood and timber collection
		30	8	146	*Saccharum* sp., *Diplazium umbrosum, Sphagnum palustre*	
		60	10	110	*Juncus reflexa, Equisetum sp., Oenanthe* sp. *Vaccinium* sp.	
		90	53	60	*Eupatorium* sp., *Symingtonia populnea, Alnus nepalensis*	
IV	SW	2	2	207	*Sphagnum nepalense., Arundo donax, Brachiaria eruciformis*	Fuel-wood and timber collection
		30	6	103	*Sphagnum palustre., Rhododendron lindleyi, Berberis wallichiana*	
		60	7	90	*Rhododendron lindleyi, Cyperus rotundus,,Anaphalis contorta*	

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

The soil is sandy loam in nature. Climate of the area is monsoonic and divisible into three seasons, rainy (June to October), winter (November to February), and spring (March to May). Mean annual precipitation was 3837 mm and temperature ranged from 4°C to 24°C during 1997-1998 (Jain *et al.*, 2000).

The watershed has mixed broad-leaved forests and agricultural land with 35 households residing in the top fringe and another 80 households in the vicinity. These people depend on the resources of the watershed forest. The lake water is not used for any other purposes except for rites and rituals. Fishing and boating are strictly prohibited. The lake is a resting-place for Trans-Himalayan migratory birds. There are some visible impacts of disturbance on the pristine nature of the lake and commercial and recreational tourism are high (18,713 in 1998) (Maharana *et al.*, 2000).

MATERIALS AND METHODS

Four sites were selected for the peatland study of which sites I and II have been disturbed and sites III and IV are relatively undisturbed (Fig. 1). A transect was laid out across each site perpendicular to the lake margin from the lake edge towards the forest edge and along which peat characteristics were determined at distances of 2, 30, 60 and 90 metres. Site characteristics are given in Table 1.

Stratigraphy (vertical strata) of the peatland was documented on the basis of visual colour differences, degree of decomposition, botanical composition and structure. The thickness of the peat strata was measured with a metal scale (Kratz & DeWitt, 1986). Peat bulk density was determined at one depth (50 cm). Per cent organic matter of oven-dried peat samples was determined by ignition at 450°C for 6 hours (Kratz & DeWitt, 1986). Radiocarbon dating was carried out at depths of 50, 100 and 150 cm on transect II. Samples of peat were removed through systematic excavation with a peat borer and were air dried and packed in aluminum foil before sending them to Birbal Sahni Institute of Paleobotany, Lucknow, India for ^{14}C radio carbon dating.

Cores for total nutrient analysis were taken in 1997 and 1998 from all of the sites at 0-50 and 50-100 cm depth intervals below the surface. Wet samples were transferred immediately to polyethylene bags to avoid excessive air contact. The samples were dried and sieved through a 2 mm mesh. Peat pH was determined using a digital pH meter and total nitrogen by a modified Kjeldahl method following Anderson &

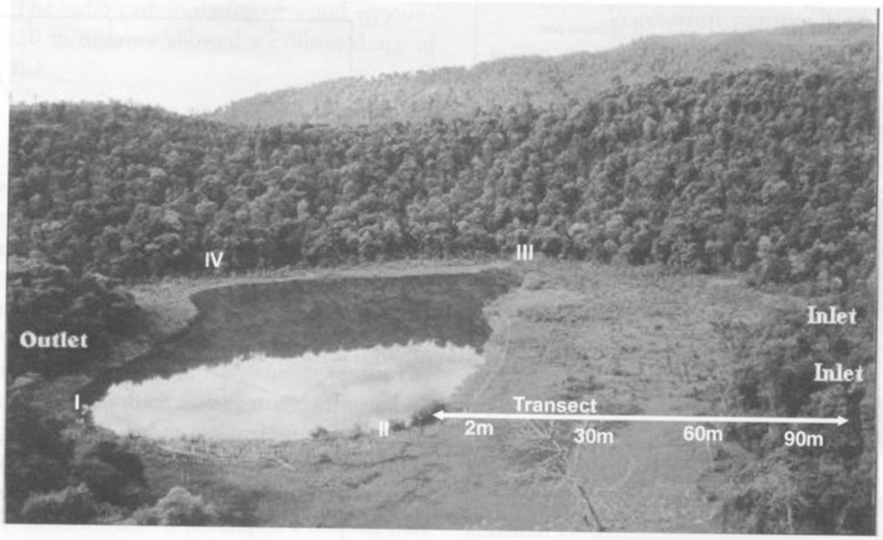

Fig. 1. Khecheopalri lake showing the peatland development around the Khecheopalri lake and the upland watershed. Different sites and locations taken for peatland studies are marked.

Ingram (1993). Total phosphorus was estimated by the chloro-stannous reduced molybdophosphoric blue colour method (Jackson, 1967) and total calcium was determined by titration following the method of Allen (1989).

The vegetation in the Khecheopalri peatland was extensively surveyed during 1997-99 and the plants were identified following standard literature (Hooker, 1857; Smith & Cane, 1911; Ganguly, 1972; Polunin & Stainton, 1984). Plant cover gradient of the peatland was estimated at four transects; considering four zones (2 , 30 , 60 and 90 m) at transects II and III and three zones (2 , 30 and 60 m) at transects I and IV from the lake edge towards the forest edge by random quadrats of 1×1m (n=48; 12 quadrats at each transect) for herbs, 5×5m (*n*=32; 8 quadrats at each transect) for shrubs and 10×10m (*n*=16; 3 quadrats each in transect I and IV and 5 quadrats each in transect II and III) for trees. Two quadrats were placed at 90m distance on both sides of the transect line adjacent to each other on transects II and III owing to the heterogeneity of tree species towards the forest.

Plant density (number of individuals of a species for unit area), frequency and basal area (average cross sectional area of the individual plants taken at or near the ground surface per unit area) of the ground vegetation of the peatland were studied seasonally (spring, rainy season and winter) during 1998 by placing random quadrats 1×1 m (n=75).

The exogenous supply of organic debris was estimated through the overland flow (Jain *et. al.*, 2000) and calculated with reference to the total runoff from the different land uses that drained the area using the delivery ratio (Sharada *et al.*, 1992; Jain *et al.*, 2000).

Analysis of variance (ANOVA) was carried out using a Microsoft Windows based statistical package (Systat, 1996).

RESULTS

Peat stratigraphy

Three relatively discrete strata are found in the Khecheopalri peatland.

1. Mat peat, which consists of poorly decomposed peat of *Sphagnum*, herbs, wood pieces and twigs. The organic matter varied from 45-93% with higher values at lake edges. The peat is light brown in color with identifiable interconnected plant remains. The mat varies in thickness from 89 to 218 cm from the lake edge to the forest edge in transect II as shown in Figure 2.
2. Debris peat that consists of moderately decomposed organic matter formed from the mat peat. Its organic content is 13-83% with a thickness ranging from 93 to 262 cm (Fig. 2).
3. Below the mat and debris peat is the gyttja layer of the lake bottom with an organic matter content of 30-70 %. The lake sediment material is dark brown to black and slimy, jelly-like without fibre content. The thickness increases from the forest edge towards the lake (5 to 97 cm) following the shape of

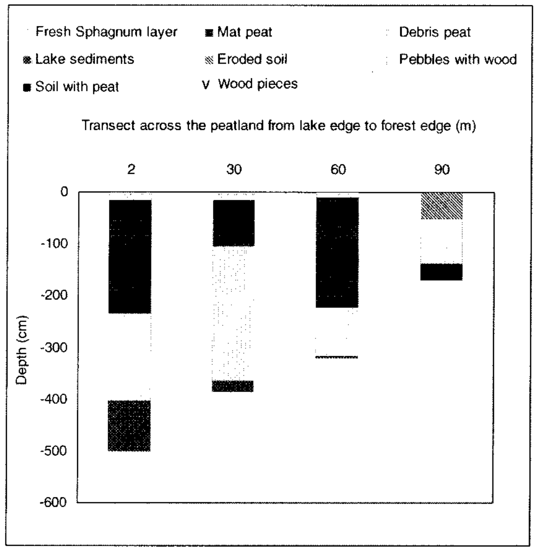

Fig. 2. Stratigraphic boundaries of the peat strata along transect from the lake edge to forest edge across the Khecheopalri peatland.

the concave basin (Fig. 2). At 90 m distance, near the forest edge, there is soil up to 50 cm depth that has been eroded from the watershed. Below this layer pebbles and wood pieces are encountered under which a mixture of peat and soil is found.

Bulk density varies widely (0.074-0.917 g cm^{-3}) with distance along transects II and III with lowest values towards the lake edge (Fig. 3), although it varies significantly with sites and distance. The organic matter contents of the peat samples show a reverse trend with gradual decrease from the lake periphery towards the forest margin (Fig. 3). Analysis of variance showed significant differences of organic matter content between sites, depth and distances along transect from lake edge to forest edge.

^{14}C Radio Carbon Dating

Peat formation started about 3400 years ago as indicated by the buried sample at 90 m distance along transect II. Depth wise age of peat increased from modern (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 2). The peat from 60 m distance at 50 and 100 cm depth was found to be greater in age than the peat between 2m and 30 m distance. However, at 60 m distance at 150 cm sample the mean calibrated age was found to be only 1312 but at a similar depth at 30 m distance it was 2860 (Table 2). The analysis of variance showed that ^{14}C age of peat varied significantly with the various peat depths (r^2 = 0.992, P<0.001) and showed strong positive correlation (0.988). The distance also varied significantly (r^2=0.992, P<0.001) but showed a negative correlation

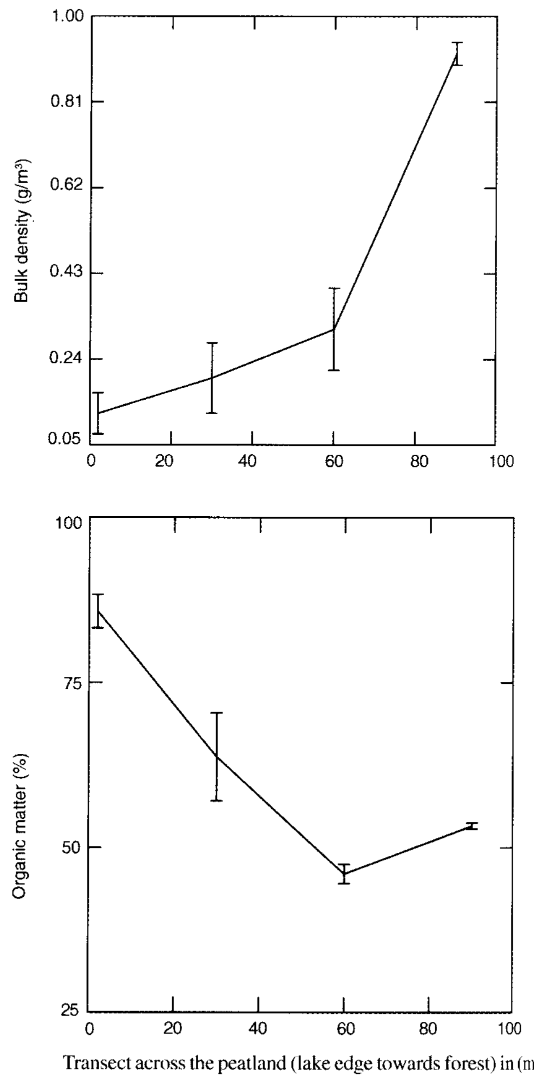

Fig. 3. Bulk density (a) and organic matter (b) along transect from the lake edge to forest edge across the Khecheopalri peatland.

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 F9, 48=14, P <0.001, LSD (0.05)=1*

(-0.326). The radio carbon dating of wood encountered at 120 m distance showed a calibrated age of 886-670 B.P.

Peatland formation

The history of peat formation at the sacred Khecheopalri, glaciated lake, dates back to 3400 years before present. The geological setting and land use transformation accelerated soil erosion processes that, with the movement of sediment and nutrients, resulted in the elevation of the periphery of the lake basin (Fig. 4). The high rainfall and favourable climate resulted in the development of a thick spongy mat dominated by *Sphagnum* moss with slightly elevated surface. This was invaded, at the peatland margins, by a number of plant species from the upland forest. Vegetation covers the open water surface where it developed a floating mat in a centripetal manner around the lake. From this floating mat the peat slipped down to the lake bottom (Fig. 4).

Vegetation composition

A list of plants found in the bog is presented in Appendix 1. Seasonal analysis of herbaceous vegetation showed only 20 plant species in the peatland during the spring season, which increased to 26 species in the rainy season and again reduced to 23 species in the winter season. The density (585 plants m^{-2}) and basal cover (28.96 cm^2 m^{-2}) were recorded highest in the rainy season (Table 3). The *Sphagnum* moss alone contributed around 48% and 37% of basal cover of all the species during rainy and winter seasons, respectively.

Succession and terrestrialization

The succession study showed that there was a sequential pattern of plant distribution in the peatland along transects from lake edge to forest edge. Highest basal coverage to 2 m distance from the lake was by mosses (87.9%) with some herbs (7%) and shrubs (6%). The per cent basal coverage of the mosses decreased to 65% at 30 m from the lake whereas the

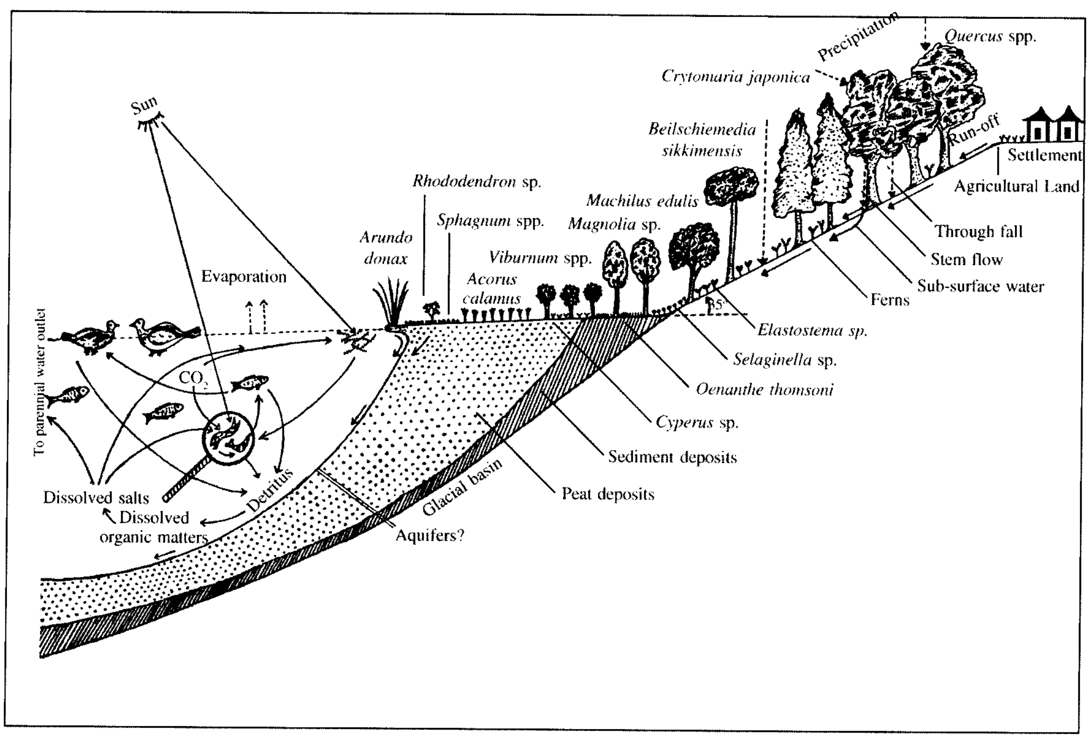

Fig. 4. Diagrammatic sketch of peatland formation in the Khecheopalri lake and its vertical transaction showing profilatic pattern of sedimentation processes, vegetation succession pattern and biotic interactions.

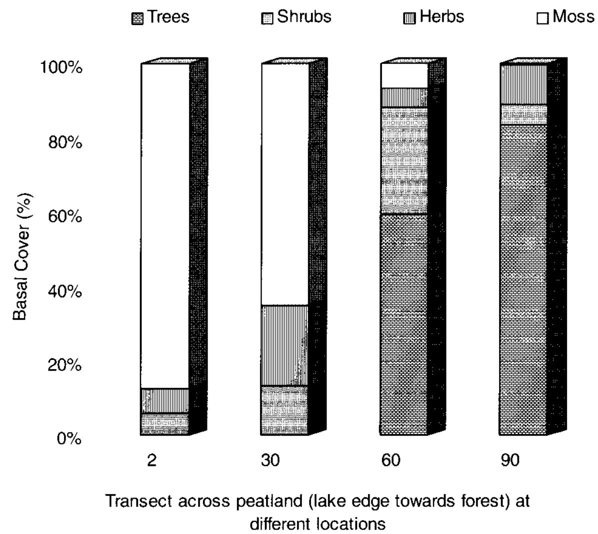

Fig. 5. Succession and terrestrialization of vegetation along transect from the lake edge to forest edge across the Khecheopalri peatland.

Table 2. Radiocarbon ages of Khecheopalri peatland.

Dated Material	Distance from lake (m)	Sample depth (cm)	Measured ^{14}C age	Calibrated age range (B.P.)
Peat	2	50	Modern	NA
Peat	2	100	220±70	284
Peat	30	50	Modern	NA
Peat	30	100	100±80	61-43
Peat	30	150	2770±90	2950-2770
Peat	60	50	550±80	640-511
Peat	60	100	760±70	725-655
Peat	60	150	1410±70	1346-1278
Peat	90	50	Modern	NA
Peat	90	80	2080±80	2140-1940
Peat	90	120	2970±100	3326-2959
Lake sediments	Lake periphery	700	37730±1300	NA
Charcoal[a]	120		260±80	430-0
Wood[b]	120	100	840±80	886-670

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

Table 3. Seasonal variation of frequency, density and basal cover of the herbaceous vegetation of the Khecheopalri peatland.

Species	Frequency (%)	Density (plant/m^2)	Basal cover (cm^2/m^2)
Spring			
Sphagnum palustre.	11	65.65	2.06
Sphagnum nepalense	33	196.95	6.18
Acorus calamus	28	12.60	9.90
Oenanthe thomsoni	52	21.64	2.72
Amaranthus sp.	60	27.48	0.86
Brachiaria eruciformis	44	18.88	0.15
Plantago erosa	28	1.80	0.90
Cyperus rotundus	20	5.36	1.05
Lycopodium cernum	24	2.40	0.31
Anaphalis contorta	16	4.00	0.50
Centella asiatica	16	7.00	0.06
Other species		6.60	0.91
Total species		370.36	25.6
Rainy			
Sphagnum palustre	24	111.25	3.49
Sphagnum nepalense	72	333.75	10.48
Brachiaria eruciformis	64	48.16	0.38
Amaranthus sp.	56	23.68	0.74
Plantago erosa	4	0.08	4.02
Acorus calamus	28	2.40	1.88
Fimbristylis sp.	40	12.00	0.85
Heidychium ellipticum	28	2.00	1.57
Commelina paludosa	44	11.08	0.30
Oenanthe thomsoni	24	6.36	0.79
Potentilla peduncularis	20	3.40	0.96
Other species		31.28	3.49
Total species		585.44	28.96
Winter			
Sphagnum palustre	18	83.17	2.53
Sphagnum nepalense	54	249.51	7.59
Brachiaria eruciformis	84	61.88	0.49
Acorus calamus	12	8.80	6.91
Cyperus rotundus	36	12.04	2.36
Oenanthe thomsoni	32	10.56	1.32
Fimbristylis sp.	40	8.56	0.56
Vaccinium nummularia	32	3.48	0.44
Juncus reflexa	40	2.64	0.09
Plantago erosa	12	0.80	1.50
Lycopodium cernuum	32	3.08	0.38
Other species		14.44	3.26
Total species		448.96	27.42

Table 4. 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 peatland 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
II	Forest land	7.5	5.90
	Cardamom agroforestry	-	-
	Agricultural land	3	3.82
	Total		9.72
III	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%)

herbs and shrubs increased by 21% and 13%, respectively (Fig. 5). A few trees (0.07%) were also found to be growing at this distance. Gradually, the wet and swampy condition changed to drier and mesic conditions at 60 m from the lake towards the forest where the percentage of herbs and mosses declined drastically to 5% and 6.5%, respectively. However, the contribution of shrubs increased to 29% and that of trees to 60%. At 90 m distance moss became negligible (0.28%) while herbs increased slightly to 11% and shrubs decreased to 5.4%. The maximum (84%) coverage here was of tree species (Fig. 5).

Nutrient dynamics

The total area of the lake watershed draining into the lake and peatland is 91 ha. The organic matter transported from the watershed is accounted for by 127 g m^{-2} yr^{-1} from agricultural land, 78.6 g m^{-2} yr^{-1} from forest, and 33.9 g m^{-2} yr^{-1} from cardamom based agroforestry systems. The highest deposition was from the forest with 64.8 Mg yr^{-1} followed by agricultural land 9.5 Mg yr^{-1}. The net organic deposition in the lake was 0.8 Mg ha^{-1} yr^{-1} (Table 4).

The nutrient contents of the peat samples are presented in Table 5. The pH of the peat materials was acidic, ranging from 4.01 to 5.85 and was higher at the forest edge. Analysis of variance of pH showed significant differences with sites, distance, depths and year. Total nitrogen varied significantly with sites, distance, depth, 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. Total phosphorus was low and ranged from 0.003% to 0.071% and increased with depth. Total phosphorus did not vary between sites and year but varied significantly between distance and depth. Calcium was low and ranged from 0.021%

Table 5. 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 peatland 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).

to 0.154% and showed increasing trend from the lake edge towards forest edge. Calcium varied significantly among sites, distance, depth and year (Table 5).

DISCUSSION

Peatland formation is intimately tied to geographical setting, hydrology, vegetation biomass and the succession and chemistry of an area thus involving both physical and biotic processes. Khecheopalri Lake had an open water area of 7.4 ha and peatland of 3.4 ha recorded in 1963 but this changed over 35 years with the open water area being reduced to 3.8 ha and peatland increased to 7 ha (Jain *et al.*, 2000). The peatland is covered with 85% of herbaceous vegetation and moss and 15% by shrubs and woody vegetation. Sediments are filling up the lake gradually through peatland increase and sliding 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 annually have found their way to the lake (Jain *et al.*, 2000). Peat bulk density was low at the lake edge and gradually increased along the transects and showed a positive correlation (0.701) with distance indicating that the peatland is entrapping the silt coming from the disturbed land use. However, during the rainy season when most of the precipitation (85%) fell the inflow to the lake was highest along with the higher nutrient load in lake water (Jain *et al.*, 1999).

Radiocarbon dating showed that the samples from the forest edge were older than the samples near the lake edges where the vegetation covers the open water surface. At 150 cm depth the calibrated age of peat was more at 30 m distance compared to 60 m. This distortion of data was the result of peat sliding down slope owing to concavity of the lake basin. Mat peat showed the greater accumulation time with increased distance from the lake edge and with depth. Kratz & DeWitt (1986) have reported similar results. In peatland the depth of the boundary between peat strata with the original basin showed a feeble positive correlation with depth (0.193) but a negative correlation (-0.178) with distance. The absence of a relationship between the depth of the peat strata and the distance from the lake edge is a result of the siltation process. Peat was not encountered at 90 m distance owing to soil erosion from the watershed. The radiocarbon age of wood and charcoal in the peatland provided evidence that terrestrialization commenced around 800 years ago while the oldest tree present at the peatland was around 400 years old.

The seasonal vegetation analysis revealed that rainfall favoured the growth of a number of species. In addition, grazing pressure affects the growth of vegetation on the peatland. Unpalatable species such as *Acorus calamus*, *Amaranthus* sp., *Lycopodium* sp, *Anaphalis contorta*, *Potentilla peduncularis* and less preferred species, including *Oenanthe thomsoni*, showed an increasing trend during the spring season with high pressure of grazing during this period. Some terrestrial plants such as *Rhododendron lindleyi*, *Sambucus adnata* were found growing in the peatland but were not recorded in the watershed forest, hence their source might be through birds, grazing animals or human activities (pilgrimage offerings).

Peat soils have many characteristics which distinguish them from mineral soils, including low bulk density (Boelter, 1974), high water holding capacity (Thorpe, 1968), and high organic matter content (Pollett, 1972). The results of this study showed that the 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 has low contents of total phosphorus and calcium (Richardson *et al.*, 1978; Lucas & Davis, 1961) and this was confirmed by the results of this study. Peat acidity and organic matter decreased with depth and distance from the lake periphery towards the forest margin and phosphorus and calcium showed increasing trends along with pH near the forest edge suggesting that peat deposition was arrested as a result of the accretion of sediments at this site from the disturbed watershed. The nutritive data in terms of plant growth from Table 5, when coupled with Malmstrom's guidelines (1956), suggest that peatland is deficient in phosphorus and calcium while nitrogen is slightly higher.

CONCLUSIONS

The geographic setting, watershed geology, climate and hydrological processes have led to the formation of peatland in the sacred Khecheopalri Lake. Succession and terrestrialization processes have already been encountered in the peatland with the invasion of woody arboreal species from the upland watershed. Peat was thicker at the sites where *Sphagnum* moss is dominant. Radiocarbon age of the peat revealed that the peat is increasing horizontally, covering the open water surface while peat slurry is being deposited at the lake bottom. The discovery of this unique peatland in the Himalayan belt opens a door for new ecological studies.

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Appendix 1

List of plants encountered, by life form, in the Khecheopalri peatland

Habit/Species	Vernacular name	Family	*Life-forms
Climbers			
Smilax aspera Linn.	'Kukurdaney'	Smilacaceae	Ph
S. rigida Wallich ex Kunth	-	Smilacaceae	Ph
Epiphytes			
Aeschynanthus sikkimensis Stapf.	-	Gesneriaceae	Ph
Bulbophyllum sp.	-	Orchidaceae	Ph
Rhaphidophora glauca Schott	'Kanchirna'	Araceae	Ph
Herbs			
Ageratum conyzoides Linn.	'Ilamay'	Asteraceae	Th
Amaranthus sp.	'Saag'	Amaranthaceae	Th
Anaphalis contorta Hook.f.	'Bukiphool'	Asteraceae	Th
Arisaema intermedium Blume	'Laruwa'	Araceae	Cr
A. costatum Martius ex. Schott.	'Bariko'	Araceae	Cr
Bidens pilosa Linn.	'Kuro'	Asteraceae	Th
Commelina paludosa Blume	'Kanay'	Commelinaceae	Ch
Corydalis juncea Wallich	-	Papaveraceae	Th
Cyanotis vaga Schuttes & Schuttes	-	Commelinaceae	Ch
Cynoglossum glochidiatum Wall.	-	Boraginaceae	Th
Cyperus rotundus Miq.	-	Cyperaceae	He
Drymaria cordata Willd.	'Abijalo'	Caryophyllaceae	Ch
Elatostema platyphyllum Wedd.	'Chiplay'	Urticaceae	Ch
Eupatorium cannabinum Linn.	'Banmara'	Asteraceae	Th
Eurya acuminata Royle	'Jhinguni'	Theaceae	Ph
Fimbristylis sp.	-	Cyperaceae	Th
Fragaria nubicola Lacaita	-	Rosaceae	He
Gnaphalium hypoleucum DC.	-	Asteraceae	Th
Gynura nepalensis DC.		Asteraceae	Th
Hedychium ellipticum Smith	'Jhankriphool'	Zingiberaceae	Cr
Hemiphragma heterophyllum Wall.	-	Scrophulariaceae	Ch

Hydrocotyle javanica Thunb.	'Golpata'	Apiaceae	He
Hypericum japonicum Thunb.	-	Hypericaceae	Th
Impatiens stenantha Hook. f.	-	Balsaminaceae	Th
Juncus sp.	-	Juncaceae	Th
Lindenbergia sp.	-	Scrophulariaceae	Ph
Lonicera glabrata Wall.	-	Caprifoliaceae	Ph
Lycopodium cernuum	'Nagbeli'	Lycopodiaceae	He
Mazus surculotus D. Don	'Kukur phool'	Scrophulariaceae	Th
Nasturtium officinale R. Br.	'Simrayo'	Brassicaceae	Th
Oenanthe thomsoni Clarke	-	Apiaceae	Ch
Pilea scripta Wedd.	'Chipley'	Urticaceae	Th
Plantago erosa Wall.	-	Plantaginaceae	Th
Persicaria capitata Gross	'Ratnaulo'	Polygonaceae	Th
Polygonum sp.	-	Polygonaceae	Th
Potentilla peduncularis D. Don	-	Rosaceae	Th
Rumex nepalensis Spreng	'Halhalay'	Polygonaceae	Th
Saccharum sp.	-	Poaceae	Th
Stellaria sp.	-	Caryophyllaceae	Ch
Tupistra nutans Wall.	'Nakima'	Liliaceae	Ch
Viola canescens Wall.	-	Violaceae	Th
Hydrophytes			
Aponogeton monostachyon Linn.	-	Naiadaceae	Cr
Ceratophyllum sp.	-	Ceratophyllaceae	-
Monochoria vaginalis C. Presl.	-	Pontederiaceae	Th
Scirpus sp.	-	Cyperaceae	Th
Semi-hydrophytes			
Acorus calamus Linn.	'Bojho'	Araceae	Cr
Alocasia sp.	'Ban Pindalu'	Araceae	Cr
Brachiaria eruciformis Griseb.	'Bonso ghans'	Poaceae	He
Sphagnum nepalense H. Suzuki.	-	Sphagnaceae	Ch
S. palustre Linn.	-	Sphagnaceae	Ch
Oxalis corniculata Linn.	'Amilo'	Oxalidaceae	Ch
Shrubs			
Arundo donax Benth.	'Narkat'	Poaceae	Ph
Berberis wallichiana DC.	'Chutro'	Berberidaceae	Ph

Hydrangea aspera D. Don	-	Hydrangeaceae	Ph
Mussaenda frondosa Wall.	'Dhobi'	Rubiaceae	Ph
Rhododendron lindleyi T. Moore	'Gurans'	Ericaceae	Ph
Sambucus adnata Walich ex DC.	-	Sambucaceae	Ph
Viburnum cordifolium Wall.	'Asare'	Sambucaceae	Ph
Trees			
Alnus nepalensis D. Don	'Uttis'	Betulaceae	Ph
Andromeda elliptica Sieb & Zucc.	'Angeri'	Ericaceae	Ph
Artocarpus lakoocha Roxb.	'Badar	Moraceae	Ph
Beilschmiedia sikkimensis King.	'Thulotarshing'	Lauraceae	Ph
Castanopsis tribuloides A. DC.	'Musray katus'	Fagaceae	Ph
Ficus benjamina Linn.	'Kabra'	Moraceae	Ph
Lyonia ovalifolia (Wallich) Drude	-	Ericaceae	Ph
Machilus edulis King.	'Phunsey'	Lauraceae	Ph
Magnolia campbellii Hook. f & Th.	'Gogey champ'	Magnoliaceae	Ph
Symingtonia populnea R. Br.	'Pipli'	Hamamelidaceae	Ph
Under shrubs			
Aconogonum molle *(D. Don) Hara*	'Thotney'	Polygonaceae	Ph
Agapetes serpens Sleumer	'Bandre-Khorsaney'	Vacciniaceae	Ph
Diplazium umbrosum Willd.	'Ningro'	Athyriaceae	He
Dryopteris sp.	'Unyo'	Dryopteridaceae	He
Equisetum sp.	'Kurkuray'	Equisetaceae	Th
Gaultheria sp.	-	Ericaceae	Ph
Melastoma normale D. Don	'Sindoore'	Melastomataceae	Ph
Osbeckia stellata *D. Don.*	'Chulesee'	Melastomataceae	Ph
Rubus ellipticus Wall.	'Aiselo'	Rubiaceae	Ph
R. paniculatus Roxb.	'Aiselo'	Rubiaceae	Ph
Solanum ferox Linn.	-	Solanaceae	Ph
Vaccinium nummularia C.B. Clarke	-	Ericaceae	Ph
V. vacciniaceum Sleumer	-	Ericaceae	Ph

*(Ph= phanerophyte, Th= therophyte, Ch= chamaephyte, He= hemicryptophyte, Cr= cryptophyte)