CHAPTER V

The lake watershed

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5.1 Introduction

Watersheds are topographically delineated areas that are drained by stream systems, and are the bio-physical units for most hydro-ecological analysis. They are related with hydrologic ingredients such as precipitation, discharge, overland flow, stream flow and water transported sediments. These hydrological ingredients are useful in relating land use changes consequently affected by vegetation structure and composition. As a whole watershed study helps to identify the linkages between land use, environment and productivity that changes over time (Brooks and Peter 1995). It also supports information generation on stream biology, vegetation structure and the functional relationship of drainage with vegetation cover. Such studies can form a basis for formulating management strategies in the hills.

Human impacts on the Himalayan mountain ecosystems are pronounced in recent years. Anthropogenic pressure such as unplanned land-use, un-scientific cultivation, rampant grazing and trampling, and excessive natural resource exploitation has accelerated ecological degradation. These pressures caused decline in the vegetation cover that led to increased sediment load and nutrient enrichment in streams. Indiscriminate clearing of forests lead to severe degradation of forest soil and stream flow regimes (Hamilton and King 1983). Storm flow increases in streams following a rainfall event and becomes much faster in disturbed forests with grazing, croplands, and other land uses compared to undisturbed forests (Hamilton and Bruijnzeel 1997). About 25000 million mega gram of soil are being washed away world wide each year (Lazarus 1990). Stocking (1984) has emphasized the importance of vegetation in the abatement of soil erosion. Vegetation intercepts energy that protect the soil against rain beating effect and there is a continuous struggle between the vegetation cover and erosion (Ambasht 1996).

There is a little information available on the watersheds of the Himalaya. A multidisciplinary work in the Mamlay watershed of the south district of Sikkim explained why watershed should be taken as a functional unit for management (Sharma *et al.* 1998). Linkages of land utilization in watersheds and their cohesive impact in terms of soil erosion; nutrient loss and water balance should be understood for policy planning on the management of fragile mountain ecosystems. Lakes in the mountains are surrounded by watershed, and their life much depends on them. Lakes and their watersheds have strong linkages. Distribution of biological resources and maintenance of balanced watershed ecosystem is obligatory for longevity of lakes, as they cannot be separated from their drainage basins. Shapes of hydrographs reflect on how the drainage basins transform precipitation into runoff that embodies integrated influence (basin characteristics like geological features, soils, drainage basin morphology and vegetation) and changes the hydrological characteristics of closed basins. So a nested lake with surrounding watershed was undertaken for a detailed study on the land use/cover change detection, vegetation structure, overland flow, soil and nutrient loss, and precipitation partitioning pathways in a 12 km^2 Ramam watershed of the Khecheopalri lake. This watershed is characterized by elevation range from 1500 to 2375 m asl. The watershed area is mainly dominated by forest, but with a settlement of 35 households at the upper ridges (see Photoplate 4). These households practice agriculture, exploit natural resources and rear livestock. About 80 households from surrounding settlements also depend on natural resources of the lake watershed forest. Out of the 12 km^2 area only 91 ha actually drains directly into the lake (Fig. 3.1). The land area that drained into the lake comprised of forest (82.5 ha), cultivated land (7.5ha) and cardamom-based agroforestry (1ha).

5.2 Materials and methods

5.2.1 Land use/cover change

A land-use/cover map of the sacred Khecheopalari lake watershed was prepared from satellite images, IRS-1A/1B, LISS-II and IRS-1C, LISS-III, FCC of bands 2,3, and 4 at 1:50000 for the year 1988 and 1997 and Survey of India topographical maps. Intensive field investigations were carried out to check the land-use/cover classification.

5.2.2 Vegetation analysis

Extensive vegetation study was conducted during 1997-1999 and plants were identified following standard literature (Hooker 1857; Smith and Cane 1911; Polunin and Stainton 1984). The plants were categorized into various life forms (Raunkiaer 1934).

Tree structure analysis was done using 10 × 10 m plots (n=25) on randomly stratified selected sites for vegetation composition. The species occurring in each quadrats were listed and diameters at breast height (DBH) and base measured. The height of the tree was measured with the help of a clinometer. All the individuals were categorized into four groups (a) seedling (height up to 20 cm), (b) sapling (height >20 cm but DBH <

10 cm), (c) small trees (DBH > 10 cm but < 30 cm) and (d) big trees (DBH > 30 cm). Seedlings and saplings were considered as regenerating individuals. A/F (abundance: frequency) ratio was calculated following Curtis and Cottam (1956) in order to see the distribution pattern of species.

Ground vegetation of the watershed forest was studied by laying 1×1 m quadrats (n=75) on stratified random sites on seasonal basis during spring, rainy and winter seasons. On each sampling schedule plant species occurring in each quadrat were listed. Frequency and density were calculated for each species. Importance Value Index (IVI) was calculated by summing up relative dominance, relative frequency and relative density (Phillips 1959). All the ground vegetation was grouped into 'ten dominating species' with regards to IVI and rest as 'other species group'. Basal area was calculated following Mishra (1968). Species indices were calculated as follows: (a) Species richness (Margalef 1957) $(d) = (S-1)/ln\,(N)$; (b) Concentration of dominance (Simpson 1949) $(\lambda) = \sum (ni/N)^2$; (c) Diversity (Shannon 1948) $(H) = -\sum pi\ ln\,(pi)$; Equitability (Buzas and Gibson 1969) $E = e^{H}/S$ where, S = total number of species; N = total number of individual of all the species in all quadrats; pi = proportion value of i species; ni = total number of individual species in all quadrats.

Aboveground biomass of forest ground vegetation was harvested through quadrats of 50×50 cm (n=12) during Feburary, April, June, August, October and December. The aboveground biomass was separated into a few dominant species and other species group and oven dried at 80°C till constant weight. Net primary productivity was calculated by summing up the positive increments of biomass during sampling intervals in a year (Singh and Yadav 1974).

The woody biomass of tree species was estimated from 40×50 m (n=3) permanent plots. The trees that occurred in each quadrats were marked round the girth at the breast height and numbered. The annual increment of woody biomass was measured through diameter tape and was extrapolated using regression equations given by Sundriyal and Sharma (1996) as follows:

Species	Regression Equation	d.f	r	E
Quercus lamellosa	$y=\exp(-0.948+0.826\ln D^2H)$	27	0.947*	1.077
Castanopsis tribuloides	$y=\exp(0.807+0.595\ln D^2H)$	38	0.908*	1.049
Symplocos sp.	$y=\exp(0.520+0.594\ln D^2H)$	17	0.935*	1.066
Eurya acuminata	$y=\exp(1.165+0.514\ln D^2H)$	19	0.860*	1.073
Alnus nepalensis	$y=\exp(-2.847+0.839\ln D^2H)$	8	0.967*	1.030
Other species	$y=\exp(-0.427+0.719\ln D^2H$	24	0.915*	1.120

y=woody biomass (bole and branch) (kg); D=diameter at breast height (cm); H=tree height (m);; d.f.=degree of freedom; r=coefficient of correlation; and E=relative error calculated as antilog of the standard error of the natural logarithm of the value; *significant at $P<0.001$.

5.2.3 Overland flow, soil and nutrient estimation

Overland flow and soil losses were estimated from 12 experimental plots under different land-use/cover combinations in the lake watershed during 1997 and 1998 on three monsoon (pre-monsoon, mid-monsoon, and post-monsoon) seasons. Three rainfall events were considered for each monsoon period covering 18 events during two years of study. Overland flow and soil losses were estimated using natural shallow surface runoff channels and artificially delineated plots (Pandey *et al.* 1983; Singh *et al.*

1983; Rai and Sharma 1998a). The delineated plot size was 10×3 m^2 for estimation of overland flow and soil loss, and 3 plots were laid in each type of land-use/cover practice. These plots were bounded with aluminium sheets (6 cm inserted in the soil and remaining 15 cm exposed in air) on all sides to prevent water from entering from adjacent areas. The plots were located on slopes ranging from 20° to 35°. The organic debris loss was estimated from the overland flow. Net deposition of the sediment in the lake and bog was calculated using delivery ratio (Sharada *et al.* 1992).

The overland flow and soil losses along the slope were estimated from the collecting tank after each rainfall event. Soil samples were taken down to 30 cm depth adjacent to each of the delineated plots and were mixed together to form composite samples of the soil at each site. These samples were collected just before the rainy season at the time of plot delineation. The eroded soils were sampled in the form of sediment settled at the bottom of the collecting tank and as suspended clay material.

Sediment texture analysis of eroded soil was done using mesh sieve. Suspended clay material was separated by filtration using Whatman filter paper from the sample water. The soil for nutrient analyses comprised of both bed-load sediment and suspended clay material for eroded soils. The runoff water samples were analyzed for phosphate-phosphorus by stannous chloride method (Eaton *et al.* 1995) and total nitrogen by AOAC method (Cunniff 1995) and details of the method is given in Chapter VII. Soil nutrients of both parent and eroded sediment were analyzed as follows;

Total organic carbon was estimated using modified Walkley black method by the colorimetric determination adding potassium dichromate (Anderson and Ingram 1993). The amount of organic carbon in the sample can be determined by the amount of chromic produced and is computed in percent organic carbon by the given formula;

$$\text{Organic carbon (\%)} = \frac{K \times 0.1}{W \times 0.74}$$

where K = concentration on absorbance (mg)

W = weight of the sample (g)

Total phosphorus was estimated by colorimetric determination (Anderson and Ingram 1993) using molybdate reagent and the ascorbic acid of the digested sample and absorbance is read at 880 nm using UV-VIS spectrophotometer and computed by the given formula;

$$\text{Total phosphorus (\%)} = \frac{C \times B}{10 \times A \times W}$$

where A = aliquot taken for colour development

B = solution volume

C = concentration on absorbance (mg)

W = weight of the sample (g)

Total nitrogen was estimated by the modified Kjeldahl method (Anderson and Ingram 1993) and it is obtained by digesting the samples in the presence of sulfuric acid and catalysts (copper sulfate, mercuric oxide, selenium powder, and potassium sulfate) and computed using the formula given below;

$$\text{Total nitrogen (\%)} = \frac{A \times \text{solution volume (ml)}}{100 \times \text{aliquot (ml)} \times W}$$

where A = ml of M/140 HCl consumed in titration

W = weight of the sample (g)

5.2.4 Precipitation partitioning pathways

A total of nine stands comprising three each in forests, cardamom based agroforestry, and traditional crop based agroforestry systems were selected to investigate pathways of incident precipitation through the plant cover (Table 5.1). Incident precipitation was recorded during 18 rainfall events during 1997 and 1998. Partitioning of incident precipitation into throughfall, stemflow, canopy interception, floor leachate, floor interception, and biomass incorporation was made. Trees of dominant species were tagged for stemflow measurement in each of the systems. Stemflow was collected by attaching aluminium collars to three trees of different diameter classes in each stand. Within each plot three throughfall collectors and three-floor leachate collectors were established. Each throughfall collector was placed on the soil surface so that its upper rim was horizontal and was about 20 cm above the ground. Floor leachate collectors were covered by a 2 mm mesh nylon net. The litter carefully removed from below the collector was placed on the net. Floor leachate collectors were inserted into the soil surface such that the rim of the container was horizontal and level with the surface of the litter. Nine throughfall and floor leachate collectors were randomly located. Measurements were made during pre-, mid- and post-monsoon periods. Following each sampling, all throughfall and floor leachate collectors were randomly relocated. This technique produces more accurate estimates of annual volumes than fixed collectors (Kimmins 1973; Rai and Sharma 1998a). Throughfall and floor leachate volumes were calculated considering the width of the upper rim of the collecting vessel. Average stemflow was calculated with the basal area of the trees. Biomass incorporation was calculated on dry weight basis of woody biomass. Canopy interception was calculated by subtracting throughfall and stemflow values from the incident precipitation. Forest-floor interception was derived from the difference of the forest-floor leachate, overland flow and biomass incorporation with the added value of throughfall and stemflow. The experimental set up of work is shown in Plate 4.

5.3 Results

5.3.1 Land-use/cover change

The existing land-use/cover pattern of the Khecheopalri lake watershed in 1997 was dense mixed forest (22.53%), open mixed forest (40.69%), degraded forest (21.00%), cultivated land and settlements (13.44%), rock out crop (1.45%) and lake including bog (0.89%) (Table 5.2). Most of the lake watershed is under forest, with cultivation confined to the upper ridges (Fig. 5.1). The major land cover changes from 1963 to 1997 were the expansion of the bog area and agriculture land with settlements. The cultivated land area increased by 10.29%, most change occurring after 1988 (Table 5.2). Degraded forest increased by 13.42% during 1988-97. Dense mixed and open mixed forest cover decreased by 3.17% and 16.6%, respectively. The different land-use types in the watershed are forest, cardamom agroforestry, cropped area and bare land. In case of the lake area, major changes were recorded in the form of bog area expansion. In 1963 the bog was 3.4 ha that increased to 7.0 ha in 1997 (Fig. 5.2).

5.3.2 Forest structure, composition and productivity

5.3.2.1 Biological spectrum

A total of 112 plant species belonging to 58 families and 101 genera were recorded from the lake watershed forest. It constitutes 48 herbs, 37 tree species, 11 under-shrubs, 9 climbers, 6 shrubs and 1 epiphyte (Appendix 1). Most of the plants belonged to the family Araceae, Urticaceae and Polygonaceae. The biological spectrum showed 55% Phanerophytes, 20% Therophytes, 11% Cryptophytes, 8% Hemicryptophyte and 6% Chaemephyte (Fig.5.3).

5.3.2.2 Tree structure and its regeneration

On mean annual basis, 17 and 16 tree species with densities of 248 trees/ha and 224 trees/ha were recorded in the tree stratum during 1997 and 1998, respectively (Table 5.3). The highest density (76 and 88 trees/ha in 1997 and 1998, respectively) and IVI (111 and 143 in 1997 and 1998, respectively) were recorded for *Castanopsis tribuloides* which was followed by *Symplocos theifolia, Machilus edulis* and *Eurya acuminata.* The basal area for the stand was calculated to be 68 m^2/ha and 58 m^2/ha in 1997 and 1998, respectively (Table 5.3).

Out of 17 tree species, regenerating seedlings were recorded for 8-13 species and saplings for 4-11 species (Table 5.3). The species number increased but the density decreased in the case of saplings. The highest regeneration was observed in the sub-canopy species such as *Symplocos theifolia* (58-59% seeedlings and 61-64% saplings) followed by

Viburnum cordifolium (25-27% seedlings and 23-27% saplings). *Ficus nemoralis, Aporosa dioica, Artocarpus lakoocha* and *Alnus nepalensis* were found only in the regenerating stage and non of these reached the tree stage. The canopy species such as *Castanopsis* showed very poor regeneration with 9 plants/ha in seedling stage and 1 plant/ha in sapling stage. The middle canopy *Machilus* sp. showed fairly good regeneration but the seedlings and saplings showed decreasing trend in two years of study period.

The relationships between the tree DBH class and the density (trees/ha) and biomass (Mg/ha) for some species, other species and total species in stands are presented in Figures 5.4 and 5.5. The canopy species, *Castanopsis tribuloides,* was represented by almost all diameter classes. Sub-canopy species, *Symplocos theifolia* and *Eurya acuminata* were represented by lower diameter classes and stand biomass contribution was low (Fig. 5.5). Tree species in lower diameter (10-20 cm) and higher diameter classes (70-150 cm) were the most targeted size and some of the species completely lacked these sizes (Fig. 5.4). Density of trees of higher DBH classes declined. The tree population structure of the dominating canopy species and sub-canopy species, 'other species' and 'total species' were presented through four life stages (seedlings, saplings, small trees and big trees). *Castanopsis tribuloides* showed a very few regenerating seedlings and saplings, the small tree size number was also low but mostly represented by big trees. However, the middle canopy species *Machilus edulis* showed highest number of seedlings followed by saplings and number of small and big trees were much reduced to give uprightal pyramid. The sub-canopy species, *Symplocos theifolia* and *Eurya* *acuminata,* showed higher numbers of seedlings and saplings (Fig. 5.6). 'Other species' group also showed higher seedlings and saplings, the small size tree number was lowest.

5.3.2.3 Woody biomass and its productivity

The basal area showed a gradual increment (61 to 63 m^2/ha) during 1997 to 1999 (Table 5.4). The standing woody biomass of 336 Mg/ha was recorded in 1997, which increased to 346 Mg/ha and to 355 Mg/ha in 1998 and 1999, respectively. The highest biomass was contributed by *Castanopsis tribuloides* (123-128 Mg/ha) followed by *Beilschmiedia sikkimensis* (54-56 Mg/ha) and *Machilus edulis* (47-49 Mg/ha). Although the density of *Symplocos theifolia* (40 trees/ha) and *Eurya acuminata* (33 trees/ha) was found higher but their biomass was small (7.5-9.7 Mg/ha and 10-12 Mg/ha, respectively) because of lower diameter classes (Table 5.3). The woody biomass productivity was 9.5 Mg/ha/year.

5.3.3.4 Ground vegetation and its productivity

Species numbers recorded during spring, rainy and winter seasons, were 20, 22 and 24, respectively. On the basis of IVI, the dominant species were *Piper long* (56.01) and *Brachiaria eruciformis* (41.41) during spring, *Elatostema platyphyllum* (51.63) and *Pilea scripta* (49.81) during rainy and *Cyperus rotundus* (37.99) and *Selaginella* sp. (35.21) during winter season (Table 5.5). Plant density was higher in rainy season (85 plants/m^2) as compared to winter (80 plants/m^2) and the lowest recorded in the spring season (73 plants/m^2). Basal area of 9.97 cm^2/m^2, 7.65 cm^2/m^2 and 6.12 cm^2/m^2 were recorded during winter, rainy and spring seasons, respectively.

The species richness was highest in winter (3.01) followed by rainy (2.74) and lowest in spring (2.53), whereas the concentration of dominance showed the inverse relationship. Dominance was recorded highest in the rainy season (0.24) stating the dominance by a few species along with low (0.31) evenness index as compared with other seasons (Table 5.6).

Standing biomass of ground phytomass increased with the advancement of seasons and peaked during August and then declined in the subsequent months. The biomass ranged from 111 to 439 g/m^2. Average net primary productivity of ground phytomass was recorded 328 $g/m^2/yr$ in which *Brachiaria eruciformis* contributed highest (22.3%) followed by *Elatostema platyphyllum* (20.4%), *Pilea scripta* (17.7%), *Selaginella* sp. (10.0%) while rest 29.6% was contributed by other species (Table 5.7). The total net production from the forest of 91 ha area was estimated 299 Mg/year.

5.3.3 Overland flow, soil and nutrient loss

Overland flow was greatest over bare land (4.8%) and smallest in cardamom-based agroforestry (1.8%). Soil loss was highest on the cultivated area while it was lowest in the cardamom-based agroforestry system (Table 5.8). The runoff of organic debris was highest in the forest, followed by cardamom-based agroforestry, bare land and the least from cultivated area. Organic debris in forest runoff was mainly leaf litter. Sediment fractionation of eroded soil from different land-use ranged between 67-86% sand, 2-12% gravel, 3-14% silt and 1-7% clay (Table 5.8). Total area that drained in the lake was 91 ha, whose 68 ha area drained through two perennial streams (see Chapter VIII) and the remaining 23 ha area by overland flow directly to the lake. Soil loss from 23 ha area that drained in the lake was 112 Mg/yr.

Concentrations of nitrogen and organic carbon were higher in eroded soil than the parent soil in all the land-uses, while total phosphorus was mostly higher in parent than the eroded soil (Table 5.9). Analysis of variance of organic carbon and total nitrogen showed significant variation between land-uses and soil types, while in case of total phosphorus, significance between only soil types only was recorded (Table 5.9).

The highest inflow of nutrients was during rainy season from the inlet streams. The annual nutrient inflow to the lake from the inlet sources accounted 2.24 Mg of total nitrogen, 0.678 Mg of total phosphorus and 0.76 Mg of organic carbon (Table 5.10). The overland flow accounted 1.05 Mg of total nitrogen, 0.51 Mg of total phosphorus and 10.2 Mg of organic carbon. The outflow of nutrients from the system through outlet on annual basis was 1.88 Mg of total nitrogen, 0.88 Mg of total phosphorus and 4.08 Mg of organic carbon (Table 5.10).

5.3.4 Precipitation partitioning

Analysis of variance showed that throughfall, canopy interception, overland flow, floor interception and floor leachate varied significantly between the pre, mid and post monsoon periods. Stemflow did not show significant variation between rainfall timings. In case of overland flow significant variation between land-use was recorded (Table 5.11). Throughfall ranged from 54% in the cardamom-based agroforestry to 73% in natural forest. The partitioned throughfall positively correlated with the incident precipitation (r = 0.76; d.f. = 8; $P<0.01$). The stemflow was recorded highest in traditional agriculture-based agroforestry (6%) followed by natural forest (2%) and lowest in large cardamom based agroforestry (1%) of the total rainfall. Canopy interception accounted for 45% in cardamom-based agroforestry system followed by 31% in traditional agriculture-based agroforestry and 25% in natural forest (Table 5.11). About 62% of throughfall and stemflow was collected as leachate in large cardamom-based agroforestry system followed by 51% in traditional agriculture-based agroforestry and 31% in natural forest. Floor interception was highest (66%) in forest, followed by traditional crop based agroforestry (44%) and cardamom-based agroforestry (35%).

5.3.5 Faunal composition

Although the watershed forest is disturbed, a few terrestrial animals were sighted during our field visits and a few as reported by the local communities. Generally the remains of animals such as porcupines stings, snake covers, footprints of mammals and the sightings of the barking deer (*Mountiacus muntjak*), yellowthroated marten (*Martes flavigula*) commonly called "Malsapra" were often made from the watershed forest and bog. Altogether 18 mammalian species, 2 reptilian species and 15 bird species were recorded (Table 5.12). Indian pangolin, Sloth bear, Himalayan black bear and Long beared hedgehog was said to be in the area long back but were not mentioned to be found as reported during community interviews. *Ailurus fulgens* is a rare species also reported to be sighted by the village community long back only. Their absence from the watershed may be due to the degradation of dense mixed forest. A number of snakes both in the watershed forest and peatland were encountered which could not be identified. Although the animal life assessment was not the focus of the present study, the presence of these in the lake watershed has functional role to play in maintaining the biodiversity and food chain of the system.

5.4 Discussion

The conspicuous land-use/cover changes of the lake and its watershed in the past 35 years have led to the expansion of the bog area. Agriculture land expansion in the watershed caused major impact on the lake by increased sediment deposition related with bog formation. Population growth, tourism and fragmentation of farm owning families have led to expansion of agricultural land, which enhanced soil erosion and reduced soil fertility. Areas under dense and open mixed forests have decreased and degraded forest increased remarkably during 1988 to 1997. Nearly three fold increase in settlements and agriculture area has been recorded in the past 20 years. The conversion of dense forest to open mixed forest and then degraded forests has been mainly attributed to fuel wood, timber extraction, fodder collection and grazing.

The biological spectrum study represents phanerophytes as the dominating group indicating more arboreal and woody species. On the other hand higher percentage of therophytes showed that the vegetation have received disturbances or the man made stresses through agriculture, resource extraction and grazing pressure that lead to invasion by annual weeds. The cryptophytes, which contributes to 11%, was third highest life form and was recorded higher as compared to the Raunkier's normal spectrum. These forms showed that they could withstand grazing pressure through hidden subterranean perrenating buds.

The density of the trees has been found lower in range compared to other temperate forests of the world, which accounts to be 350-2080 trees/ha (Ralhan *et al.* 1982). The distribution pattern of the vegetation of the forest indicated that there is no regular distribution, except *Castanopsis tribuloides* and *Symplocos theifolia*, which showed more evenness. "Other species" group showed contagious distribution, which revealed that there is a strong competition among the species. Several workers including Greg-Smith (1957), Kershaw (1973) and Singh and Yadava (1974) have reported this type of general preponderance of contagious distribution on natural vegetation. The basal area of the present study site is on the higher range when compared with other temperate and tropical forests (Saxena 1979). This is due to the presence of old large tress of canopy species.

The forest is dominated by *Castanopsis tribuloides* in association with some secondary species. These secondary species have invaded the forest and spread as a result of anthropogenic pressure. Presently, the occurrence of some secondary species such as *Symplocos theifolia*, *Viburnum cordifolium* and *Eurya acuminata* are increasing. The density of the tree has substantially reduced compared with other temperate forest of the Himalayas (Saxena 1979; Rahlan *et al.* 1982; Sundriyal and Sharma 1996). Dominance of sub-canopy species in the lower diameter class states the dominance of these species in the near future. Some of the species such as *Alnus nepalensis*, *Artocarpus lakoocha* and *Aporosa dioica* were not in the tree stratum but are found only in the regenerating stage. The canopy species such as *Castanopsis* and *Magnolia* are regenerating inadequately while secondary species like *Symplocos, Eurya* and *Viburnum* sp. are regenerating most successfully. This was due to free grazing by animals in the watershed area and removal of small diameter class tree species for the purpose of fuelwood due to easy extraction by the children and women. *Eurya acuminata*, *Viburnum cordifolium* and *Symplocos theifolia* are also highly preferred and collected for fuelwood (as reported by the local community during participatory rural appraisal program).

Tree stage class presentation showed upright pyramids for most of the species, 'other species group' and 'total species'. However, the *Castanopsis tribuloides* showed inverted pyramids where regenerating seedlings and saplings were very few and only big trees remained. The regeneration is very poor in this climax canopy species. Small trees are very less and big trees are removed as it is priced for both timber and fuelwood. The presently dominating *Castanopsis* might become only a representative species soon and then disappear. It is envised that forest structure also would change. The canopy species *Quercus lamellosa* which is a well known climax dominating species in the region (Sundriyal and Sharma 1996) are very few in the number of standing trees and regeneration was totally absent. It is understood that *Quercus* is already squeezed and likely to disappear from the area. The sub-canopy species are likely to dominate most in near future as they showed balanced distribution of tree stage class in the form of upright pyramid. With the increasing biotic pressure the canopy species will be devoid of regeneration and expected that the forest will be dominated by the secondary species in the near future. The secondary species accumulate lower biomass compared to canopy species thus affecting the availability of fuelwood and timber for the ever-increasing population.

The woody biomass productivity of the tree species was 9.5 Mg/ha/yr. Biomass recorded in the present study was within the range of other temperate forests (Negi *et al.* 1983; Rawat and Singh 1988; Singh and Singh 1984). Some of the tree species like *Zanthoxylum acanthopodium* and *Machilus edulis* showed low biomass increment during the period of three years.

The species richness and diversity being higher in winter seasons was due to fair amount of rainfall in early winter season which might have favored the growth and propagation of certain plant species. The higher dominance in the rainy season was attributed to certain plant species contributing to higher IVI than other species whereas in other seasons the IVI values were evenly distributed. The productivity of the forest is found to be higher than that of the forests of Kumaon Himalaya (Melkania and Singh 1989) but the pressure of grazing and removal of fodder has increased recently (see Chapter IV). The reduced density of the trees, decrease in canopy species, pressure of grazing and trampling, and the considerable decrease in species diversity, few saplings from the disturbed forest along with the inevitable consequences of unstable rainfall has increased soil erosion and increased the recurrence of landslides.

The overland flow from the bare land was greatest compared to other land-uses. Soil loss from the open cropped area was maximum followed by bare land, forest, and minimum from large cardamom-based agroforestry. The overland flow and the soil loss in the large cardamom-based agroforestry system were less because of good tree canopy and under-storey thick large cardamom bush coverage. The low overland flow recorded in natural forest and cardamom-based agroforestry was comparable with values reported for the Central Himalayan forest and Mamlay watershed of the Sikkim Himalaya (Pathak *et al.* 1983; Negi *et al.* 1998; Rai and Sharma 1998a). On steep forested slopes in Australia, Bren and Turner (1979) found that the overland flow was only 0.005% of the rainfall. That was quite low compared to the present study, which may be due to the disturbed forest. Soil deposition in the lake was 141 Mg/yr besides 6.88 Mg/yr of organic carbon, 1.42 Mg/yr of total nitrogen and 0.31 Mg/yr of total phosphorus was recorded. Total soil loss from the lake watershed was 502 Mg/km^2/yr. This is lower than 616 Mg/km^2/yr from a watershed in south Sikkim (Rai and Sharma 1998b), however it was at the lower side of the range of 500-1000 Mg/km^2/yr reported for the Himalayan region by Milliman and Meade (1983).

The soil loss from the agricultural land was greatest followed by bare land, forest and cardamom agroforestry. Cultivated area occupied 13.4% of the total lake watershed and contributed 22.7% runoff, 42.5% soil loss, 33.2% organic carbon, 27.1% total nitrogen and 39.6% of total phosphorus. The agriculture practice although small in area contributed significant amount of soil and nutrient loss. Therefore, agriculture practice in the form of open cropped area in the lake watershed has to be minimized and should encourage agroforestry practices that showed lower rates of soil and nutrient loss. The forest cover although contributed insignificant amount of soil loss in mean annual basis as compared to other land uses but its degradation may have adverse effects. Around 164 kg/ha of soil loss was recorded from the disturbed forest, which is 6.56

times higher than the undisturbed forest when compared for six rainfall events. The importance of vegetation in the abatement of the soil erosion was well explained by Stocking (1984) and Ambasht (1996). The higher soil loss is due to the small diameter class trees, which are inefficient in binding the soil and also due to the pressure of resource extraction (see Chapter IV). Hence, the land use/cover change, which resulted in increase of agricultural land, conversion of dense mixed forest to open mixed and degraded forests, resource extraction practices, grazing and trampling all the major factors contributing for soil and nutrient loss in the watershed.

The throughfall, stemflow, and canopy interception results are similar to those of forests of the Central Himalaya and the Mamlay watershed in South Sikkim (Pathak *et al.* 1983; Negi *et al.* 1998; Rai and Sharma 1998a). Throughfall in natural forest was highest as a result of more canopy coverage. Throughfall of similar magnitude has been reported by several workers (Henderson *et al.* 1977; Rai and Sharma 1998a). Canopy interception was recorded highest in large cardamom-based agroforestry, which showed good tree canopy and under-storey cardamom coverage. Pathak *et al.* (1983) reported positive relationship of interception with canopy cover in the Oak forest of the central Himalaya. Waring *et al.* (1981) argued that the surface area of the forest is an important determinant in interception processes. Comparison between forest and agroforestry systems showed that totality of canopy and floor interception is very important determinant for water availability with respect to floor leachate. Floor interception of precipitation was directly related with the floor litter composition and quantity. The forest had more floor interception as a result of its thicker litter layer. Good vegetation cover will protect the soil against erosion (Ambasht 1996).

The above stated physical events have now assumed to have detrimental effects for the lake health and its longevity. The sediment and nutrient inputs from the disturbed watershed are filling up the lake gradually leading to elevation of surface and growth of vegetation. The vegetation in turn affects the flow regimes decreasing the frequency and depth of flooding, so that less sediment and nutrient is exported out from the system. Differences in the hydro-ecological attributes of the land-use/cover investigated in this study can form a background for soil and water conservation in the lake watershed. Our findings suggest that the dense mixed forest cover should be maintained on the ridges of the lake watershed to regulate stream flow. The conversion of forests to agriculture land has been quite conspicuous in the past few decades and it has to be reversed immediately ■

Table 5.1 Land use based stand characteristic for the hydro-ecological studies in the Khecheopalri lake watershed

Land-use	Altitude (m)	Slope (deg)	Tree height (m)	Basal cover (m^2/ha)	Canopy cover (m^2/ha)	Dominant tree species
Forest	1700-2375	25-35	16 ± 1	58	6805	*Castanopsis tribuloides, Symplocos theifolia, Machilus edulis, Eurya acuminata, Viburnum cordifolium*
Cardamom-based agroforestry	1700-1850	20-30	8.8 ± 1	92	1406	*Prunus cerasoides, Eurya acuminata, Alnus nepalensis, Ficus hookeri*
Traditional crop-based agroforestry	1775-2375	30-35	5.5 ± 4	35	727	*Prunus chinensis, Ficus nemoralis, Ficus hookeri, Prunus persica, Machilus edulis*
Bare land	1700-1900	25-35	-	-	-	-

Table 5.2 Comparison of land-use/cover change detection of Khecheopalri lake watershed. Total watershed area 1209 ha; - Land use not demarcated.

. Land-use/cover	Years							
	1963[a]		1976[a]		1988[b]		1997[b]	
	Area		Area		Area		Area	
	(ha)	(%)	(ha)	(%)	(ha)	(%)	(ha)	(%)
Dense mixed forest	1160	95.94	1145.0	94.70	310.80	25.70	272.20	22.53
[c]Open mixed forest	-	-	-	-	693.20	57.33	492.00	40.69
Degraded forest	-	-	-	-	91.70	7.58	254.00	21.00
Settlement and cropped area	38.20	3.15	53.20	4.40	100.00	8.27	162.50	13.44
Rock out crop	-	-	-	-	2.50	0.21	17.50	1.45
Lake water surface	7.40	0.61	6.80	0.56	6.60	0.54	3.79	0.31
Bog area	3.40	0.28	4.00	0.33	4.20	0.34	7.01	0.58

[a] Based on survey of India map; [b] Based on satellite imageries; [c] Large cardamom agroforestry has been included in open mixed forest category (69 ha).

Table 5.3 Density, basal area, importance value index (IVI) and the regeneration status of tree species in Khecheopalri lake watershed

Species	Density (tree/ha)		Basal area (m^2/ ha)		IVI		Regeneration: Seedlings (per ha)		Regeneration: Saplings (per ha)	
	1997	1998	1997	1998	1997	1998	1997	1998	1997	1998
Alnus nepalensis	-	-	-	-	-	-	-	16	-	-
Andromeda elliptica	4.0	4.0	0.5	0.3	4.5	4.6	-	8	-	7
Aporosa dioica	-	-	-	-	-	-	48	84	60	48
Artocarpus lakoocha	-	-	-	-	-	-	28	24	-	4
Beilschmiedia sikkimensis	4.0	8.0	2.0	2.4	6.8	12.5	-	31	80	68
Castanopsis hystrix	8.0	4.0	1.5	0.3	9.9	4.3	-	-	-	-
Castanopsis tribuloides	76.0	88.0	38	41.3	111	143	-	9	-	1
Cinnamomum obtusifolium	4.0	4.0	0.4	0.9	4.4	5.5	4	24	-	13
Engelhardtia spicata	8.0	8.0	1.1	1.8	9.4	11.0	-	-	-	-
Eurya acuminata	24.0	28.0	1.8	1.7	19.0	28.3	620	374	233	177
Ficus nemoralis	-	-	-	-	-	-	-	8	-	-
Juglans regia	4.0	4.0	1.8	1.3	6.5	6.0	-	-	-	-
Machilus edulis	16.0	16.0	6.8	3.1	25.0	21	-	-	-	-
Machilus sp.	8.0	-	1.7	-	10.0	-	172	91	48	44
Magnolia campbellii	4.0	4.0	1.1	0.8	5.4	5.2	-	12	-	4
Morus laevigata	8.0	4.0	2.0	0.4	8.5	4.6	-	-	-	-
Prunus sp.	8.0	-	1.0	-	9.2	-	-	-	-	-
Quercus lamellosa	-	4.0	-	0.5	-	4.7	-	-	-	-
Symingtonia populnea	12.0	8.0	4.0	1.5	13.0	10.0	-	-	-	-
Symplocos theifolia	48.0	24.0	2.4	0.8	43.0	22.0	2864	2828	1988	1740
Viburnum cordifolium	8.0	12.0	0.9	0.7	8.9	13.0	1240	1304	708	760
Zanthoxylum sp.	4.0	4.0	0.7	0.3	4.9	4.3	-	-	-	-
Total species	248	224	68	58	300	300	4976	4818	3117	2866

Table 5.4 Increment in woody biomass of tree species in Khecheopalri lake watershed

Species	Basal area (m^2/ha)			Biomass (Mg/ha)		
	1997	1998	1999	1997	1998	1999
Andromeda elliptica	0.5	0.5	0.5	2.9	3.02	3.3
Beilschmiedia sikkimensis	8.8	8.9	8.9	54	55.1	56
Artocarpus lakoocha	0.2	0.2	0.2	1.3	1.36	1.4
Castanopsis tribuloides	28	29	29	123	126	128
Engelhardtia spicata	0.4	0.4	0.4	3	3.17	3.3
Eurya acuminata	3	3	3.1	10	11.1	12
Juglans regia	3.2	3.3	3.4	25	26.3	27
Machilus edulis	7.1	7.2	7.3	47	47.9	49
Morus laevigata	0.9	0.9	0.9	7.2	7.43	7.6
Prunus sp.	1.2	1.2	1.2	9.3	9.6	10
Rhododendron arboreum	4.1	4.2	4.3	28	28.5	29
Schima wallichii	0.3	0.3	0.3	0.56	0.56	0.6
Evodia fraxinifolia	0.1	0.1	0.1	0.4	0.57	0.7
Cinnamomum obtusifolium	0.1	0.1	0.1	1.3	1.32	1.5
Symplocos theifolia	1.1	1.1	1.3	7.5	8.47	9.7
Castanopsis hystrix	0.7	0.7	0.8	5.6	5.67	6
Zanthoxylum acanthopodium	1.1	1.1	1.1	9.9	9.89	10
Total species	61	62	63	336	346	355

Table 5.5 Seasonal ground vegetation composition of the Khecheopalri lake watershed

Seasons/Species	Frequency (%)	Density (plants/m^2)	Basal area (cm^2/m^2)	Importance Value Index
Spring season				
Piper longum	68	16.00	1.13	56.01
Brachiaria eruciformis	64	17.84	0.14	41.42
Selaginella sp.	52	15.68	0.49	41.41
Cyperus rotundus	16	4.00	0.79	21.98
Cissus repanda	16	3.00	0.53	16.42
Oenanthe thomsonii	16	3.68	0.46	16.27
Viola canescens	28	2.00	0.25	13.29
Polygonum sp.	24	1.00	0.30	11.83
Nasturtium officinale	16	0.60	0.44	11.71
Centella asiatica	12	0.30	0.47	11.29
Other species	-	8.90	1.13	58.38
Total species	-	73.00	6.12	300.00
Rainy season				
Elatostema platyphyllum	68	18.52	1.34	51.63
Pilea scripta	72	17.72	1.25	49.81
Selaginella sp.	80	18.08	0.57	42.71
Brachiaria eruciformis	84	17.20	0.14	36.72
Viola canescens	36	5.48	0.69	21.75
Arisaema intermedium	12	0.20	1.41	20.82
Alocasia sp.	8	0.08	0.81	12.14
Urtica dioica	8	0.16	0.69	10.60
Tupistra nutans	12	0.40	0.31	6.68
Daphne involucrata	24	0.80	0.06	5.89
Other species	-	6.00	0.38	41.24
Total species	-	85.00	7.65	300.00

Winter season

Cyperus rotundus	20	13.88	1.74	37.99
Silaginella sp.	64	15.96	0.50	35.21
Brachiaria eruciformis	92	10.80	0.08	29.28
Viola canescens	40	4.00	1.26	24.20
Centella asiatica	24	7.00	0.88	21.45
Oenanthe thomsonii	20	3.80	1.07	18.81
Eupatorium cannabinum	20	4.80	0.94	18.72
Piper longum	36	0.84	0.70	14.07
Hydrocotyle javanica	24	6.30	0.20	13.79
Pilea scripta	28	4.60	0.12	11.70
Other species	-	8.02	2.47	75.47
Total species	-	80.00	9.97	300.00

Table 5.6 Species indices of ground vegetation of Khecheopalri lake watershed

Species indices/parameters	Seasons		
	Spring	Rainy	Winter
Number of species encountered	20	22	24
Species richness (Margalef's index)	2.53	2.74	3.01
Diversity index (Shannon's index)	2.16	1.95	2.57
Equitability index (Buzas & Gibson's index)	0.43	0.31	0.54
Dominance index (Simpson's index)	0.11	0.24	0.16

Table 5.7 Standing state of biomass in different months and net primary productivity of ground phytomass in Khecheopalri lake watershed

Species	Standing biomass (g/m^2)						Net productivity (g/m^2)
	Feb	Apr	Jun	Aug	Oct	Dec	
Brachiaria eruciformis	20	34	74	93	68	32	73 (22.3)
Elatostema platyphyllum	21	56	88	88	74	19	67 (20.4)
Pilea scripta	23	50	78	81	42	29	58 (17.7)
Selaginella sp.	16	31	42	49	33	24	33 (10.0)
Other species	31	77	128	128	45	84	97 (29.6)
Total species	111	248	410	439	262	188	328 (100)

Values in parenthesis are in per cent contribution of net productivity

Table 5.8 Rainfall, runoff and eroded soil characteristics of different land-uses of the Khecheopalri lake watershed

Runoff parameter	Forest	Cardamom agroforestry	Cropped area	Bare land
Overland flow (% of precipitation)	2.06	1.79	3.79	4.77
Runoff ($x10^5$ l/ha/yr)	6.7	5.8	12.4	15.6
Soil loss (kg/ha)*	25	15	405	156
Soil loss (Mg/ha/yr)	6.39	1.19	28.42	19.92
Sediment fractionation of eroded soil (%)				
Gravel (>2 mm)	12	7	2	12
Sand (2-0.04 mm)	74	84	86	67
Silt (0.04-0.09 mm)	9	3	11	14
Clay (<0.09 mm)	5	6	1	7
Eroded soil nutrient (kg/ha/yr)				
Organic carbon	328	38	969	739
Total nitrogen	41	5	91	122
Total phosphorus	13	2	51	39
Runoff water nutrient (kg/ha/yr)				
Total nitrogen	7.81	7.03	6.64	6.55
Phosphate-phosphorus	0.12	0.07	0.11	0.19
Runoff organic debris				
(g/l)*	1.96	1.75	1.28	1.29
(Mg/ha/yr)	1.31	1.13	1.59	2.01

*Mean of six rainfall events

Table 5.9 Nutrient concentration of parent and eroded soils under different land use in the Khecheopalri lake watershed. Values are mean (n=6) for composite sample

Land Use	Soil type[a]	Organic carbon (%)	Total nitrogen (%)	Total phosphorus (%)
Forest	PS	4.51	0.47	0.146
	ES	5.13	0.65	0.197
Cardamom agroforestry	PS	3.11	0.35	0.199
	ES	3.19	0.40	0.187
Open cropped area	PS	2.27	0.28	0.225
	ES	3.41	0.32	0.179
Bare land	PS	2.15	0.15	0.676
	ES	3.71	0.61	0.197
ANOVA *P* values [b]				
Land-use		0.005	0.050	NS
Soil type		0.050	0.005	0.050
Land-use × Soil type		NS	0.001	NS
$LSD_{(0.05)}$		-	0.070	-

[a] PS=Parent soil; ES= Eroded soil; [b] Beneath each column *P* values associated with analysis of variance are given with LSD values (P = 0.05) applicable for means of land use and soil type. NS is not significant

Table 5.10 Nutrient movement in the lake from the lake watershed.

	Spring	Rainy	Winter	Total
Inlets				
Nutrients (Mg/yr)				
Total nitrogen	0.009	2.23	0.003	2.24
Total phosphorus	0.002	0.675	0.001	0.678
Organic carbon	0.04	0.7	0.02	0.76
Overland flow				
Nutrients (Mg/yr)				
Total nitrogen	-	1.05	-	1.05
Total phosphorus	-	0.51	-	0.51
Organic carbon	-	10.2	-	10.2
Outlet				
Nutrients (Mg/yr)				
Total nitrogen	0.019	1.85	0.009	1.88
Total phosphorus	0.007	0.87	0.003	0.88
Organic carbon	0.14	3.94	0.0021	4.08

- No overland flow during spring and winter seasons

Table 5.11 Precipitation partitioning in three major land uses of the Khecheopalri lake watershed. Values in parenthesis are percentage

Partition components	Land-use											
	Forest				Cardamom agroforestry				Traditional crop based agroforestry			
	PM	M	POM	Total	PM	M	POM	Total	PM	M	POM	Total
Incident precipitation (mm)	1068	1998	572	3638	1068	1998	572	3638	1068	1998	572	3638
Through fall (mm)	566	1548	501	2615 (73)	525	1338	268	2131 (54)	452	1351	453	2256 (63)
Stem flow (mm)	31	72	7	109 (2)	10	30	8	47.4 (1)	11	309	7	327 (6)
Canopy interception (mm)	471	378	64	914 (25)	533	630	296	1460 (45)	606	338	112	1055 (31)
Overland flow (mm)	18	41	6	65	8	39	4	51	9	81	9	100
Floor interception (mm)	458	977	367	1804	17	676	76	769	5	1059	98	1162
Floor leachate (mm)	120	601	133	854	510	653	196	1359	449	520	353	1332
Biomass incorporation (mm)				0.63				0.52				0.10

Rainfall time: PM= Pre-monsoon; M= Monsoon; POM= Post- monsoon

ANOVA: Throughfall - Rainfall time $F_{3,8}$=63.5, P<0.005; Stemflow - Rainfall time $F_{3,8}$=1.72, NS; Canopy interception – Rainfall time $F_{3,8}$=16.5, P<0.005; Overland flow – Land-use $F_{3,20}$=3.2, P<0.05; Rainfall time $F_{3,20}$=9.8, P<0.005; Floor interception – Rainfall time $F_{3,8}$=10, P<0.005; Floor leachate – Rainfall time $F_{3,8}$=10.1, P<0.005. Land-use did not show significant variation for all parameters except overland flow

Table 5.12 Faunal composition of the Khecheopalri lake watershed

Scientific name	Family	Common/local name
Aves		
Gypaetus barbatus	Accipitridae	Lanmergeier
Megalaima frankhnii	Capitonidae	Golden throated Barbet
Cissa chinensis	Corvidae	Green Magpie
Cissa erythrorhyncha	Corvidae	Redbilled Magpie
Cissa fuvirostis	Corvidae	Yellow billed blue Magpie
Dendrocitha formosae	Corvidae	Himalayan tree pie
Dicrurus adsimilis	Dicruridae	Black Drongo
Mylcophonus caeruleus	Muscicapidae	Whistling thrush
Muscicapa westermnii	Muscicpidae	Little pied flycatcher
Minla strigula	Muscicpidae	Barthroated Siva
Heterophasia annectens	Muscicpidae	Sikkim chestnut trump sibea
Picus flavinucha	Picidae	Large yellow naped Woodpecker
Dendrocopus cathparius	Picidae	Crimson breasted pied
Dendrocarpus dinopium shril	Picidae	Golden backed three toed
Blythipicus pyrrotis	Picidae	Red earned Woodpecker
Reptiles		
Hemidactylus fluviviridis	Agamidae	House gecko
Calotes versicolor	Agamidae	Common garden lizard
Mammals		
Ailurus fulgens	Ailuridae	Red panda

Canis aureus	Canidae	Jackal (Siyal)
Vulpes vulpes	Canidae	Red fox
Macaca silenus	Cercopithecidae	Lion tailed macaque (Suhukabu)
Macac assamensis	Cercopithecidae	Assamese macaque (Suhu)
Mountiacus muntjak	Cervidae	Barking deer
Hystrix indica	Erethizontidae	Indian porcupine (Dumshi)
Felis marmorata	Felidae	Jungle cat (Sikmar)
Felis bengalensis	Felidae	Leopard cat
Paradoxorus hermaphroditus	Felidae	Common palm civet
Herpestes vitticolis	Herpistidae	Stripe necked mangoose
Martes flavigula	Musletidae	Yellow throated martin (Malsapra)
Ratufa indica	Sciuridae	Indian giant squirrel (Lotharkay)
Ratufa bicolor	Sciuridae	Malayan gaint squirrel
Funambulus pennanti	Sciuridae	Five striped palm squirrel
Suncus marinus	Soricidae	Grey musk shrew (Timzing)
Viverra zibetha	Viverridae	Large Indian civet

Local names given in parenthesis are either in Nepali, Lepcha or Bhutia.

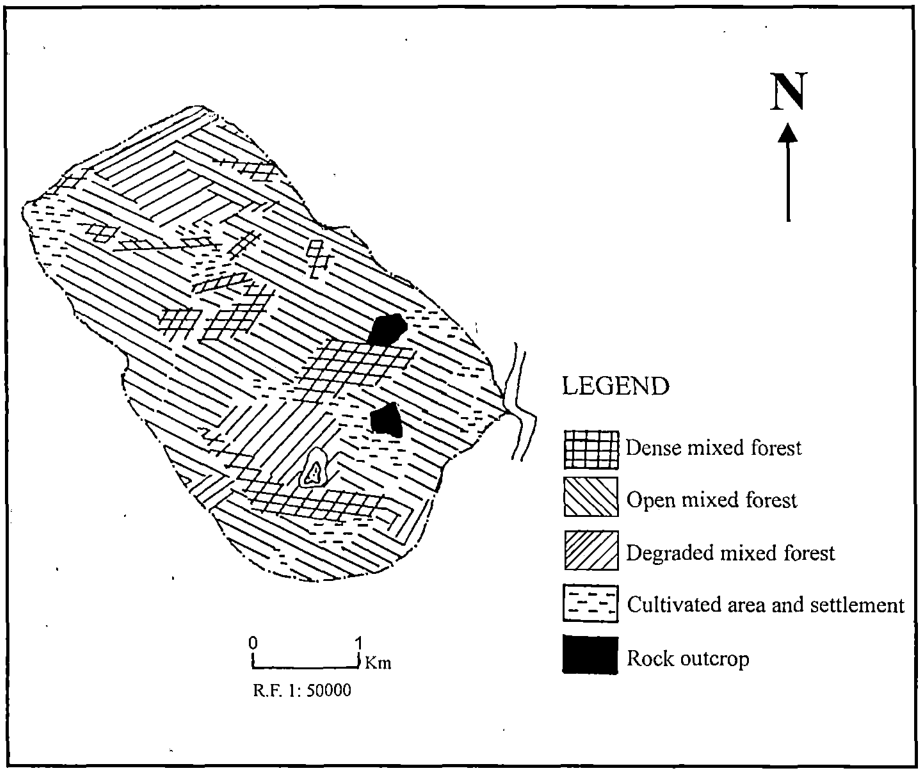

Fig. 5.1 Land use/cover map of Khecheopalri lake watershed for the year 1997.

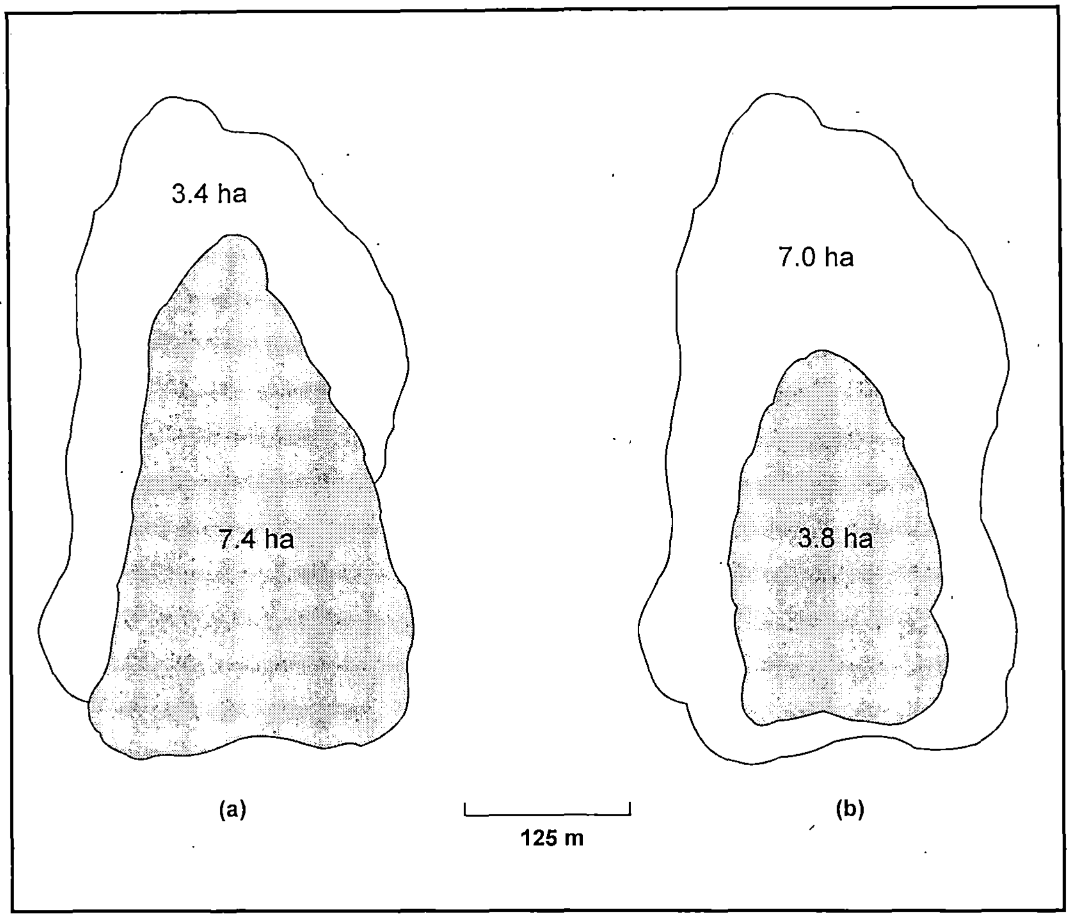

Fig. 5.2 Extent of open water surface (shaded) and peat land development in 1963 (a) and 1997 (b) of Khecheopalri lake

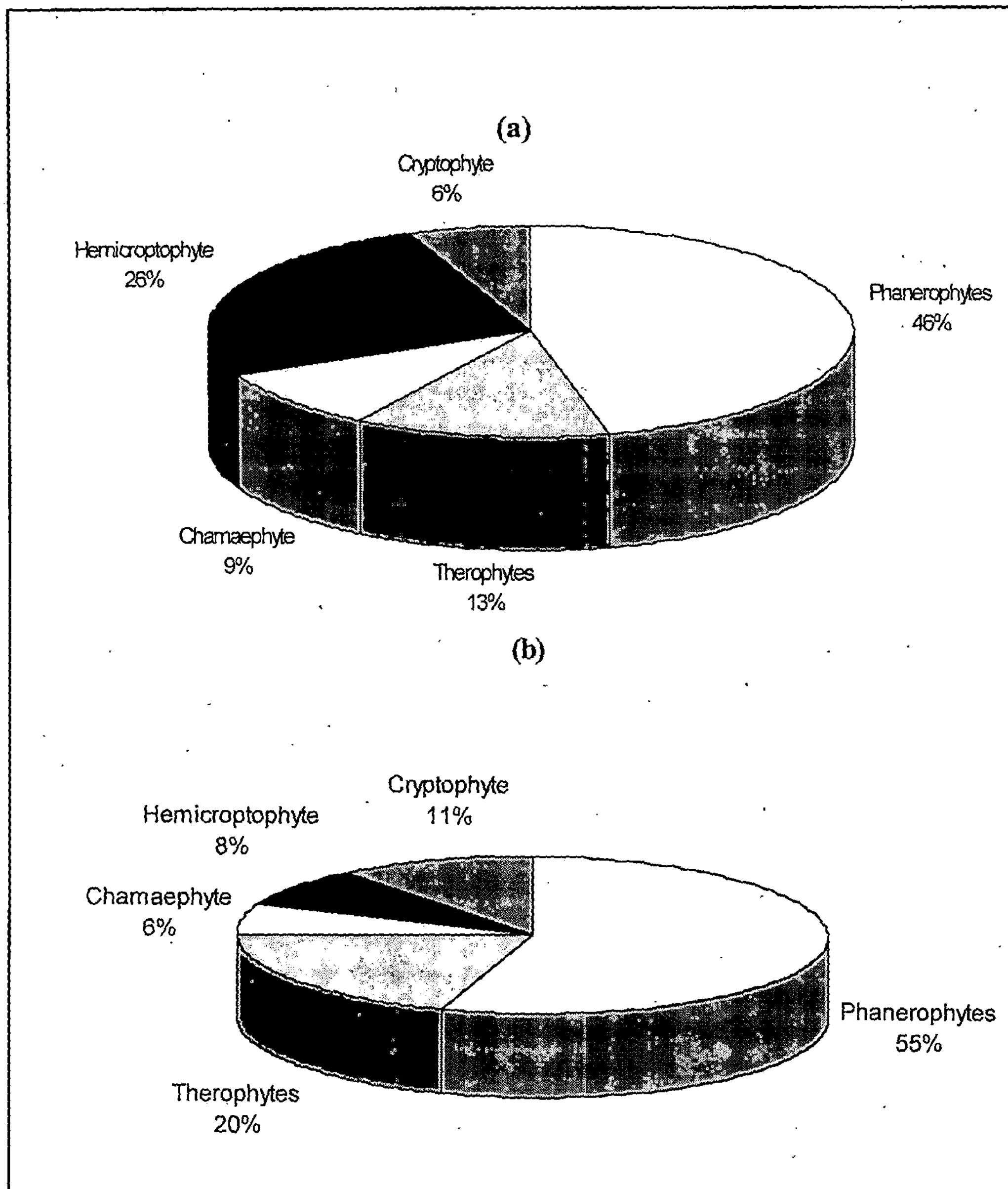

Fig. 5.3 Raunkiaer's normal spectrum (a) and biological spectrum of the Kecheopalri lake watershed (b)

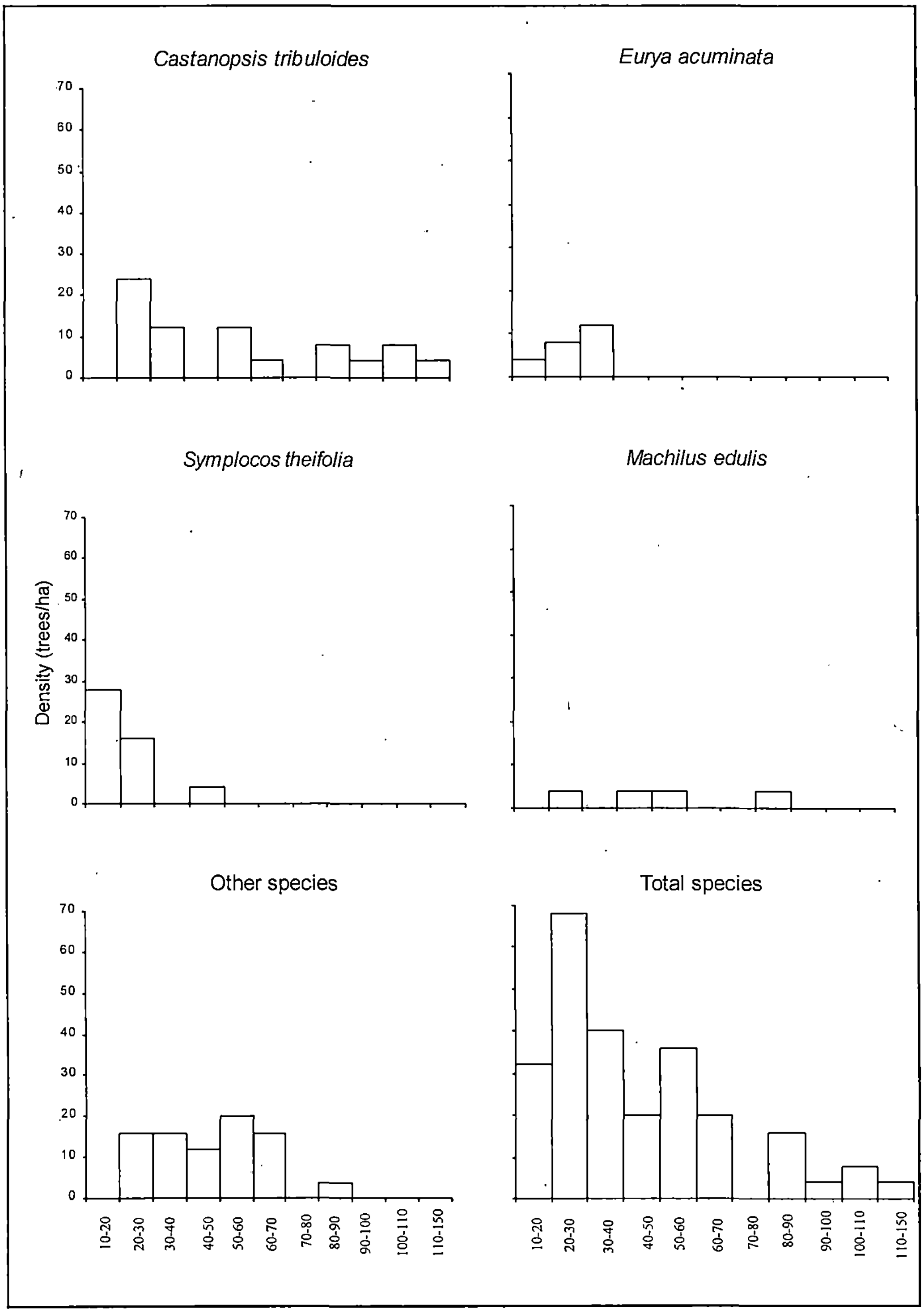

Fig. 5.4 Diameter class distribution of density of some important tree species, "Other species" and "Total species" in the Khecheopalri lake watershed forest.

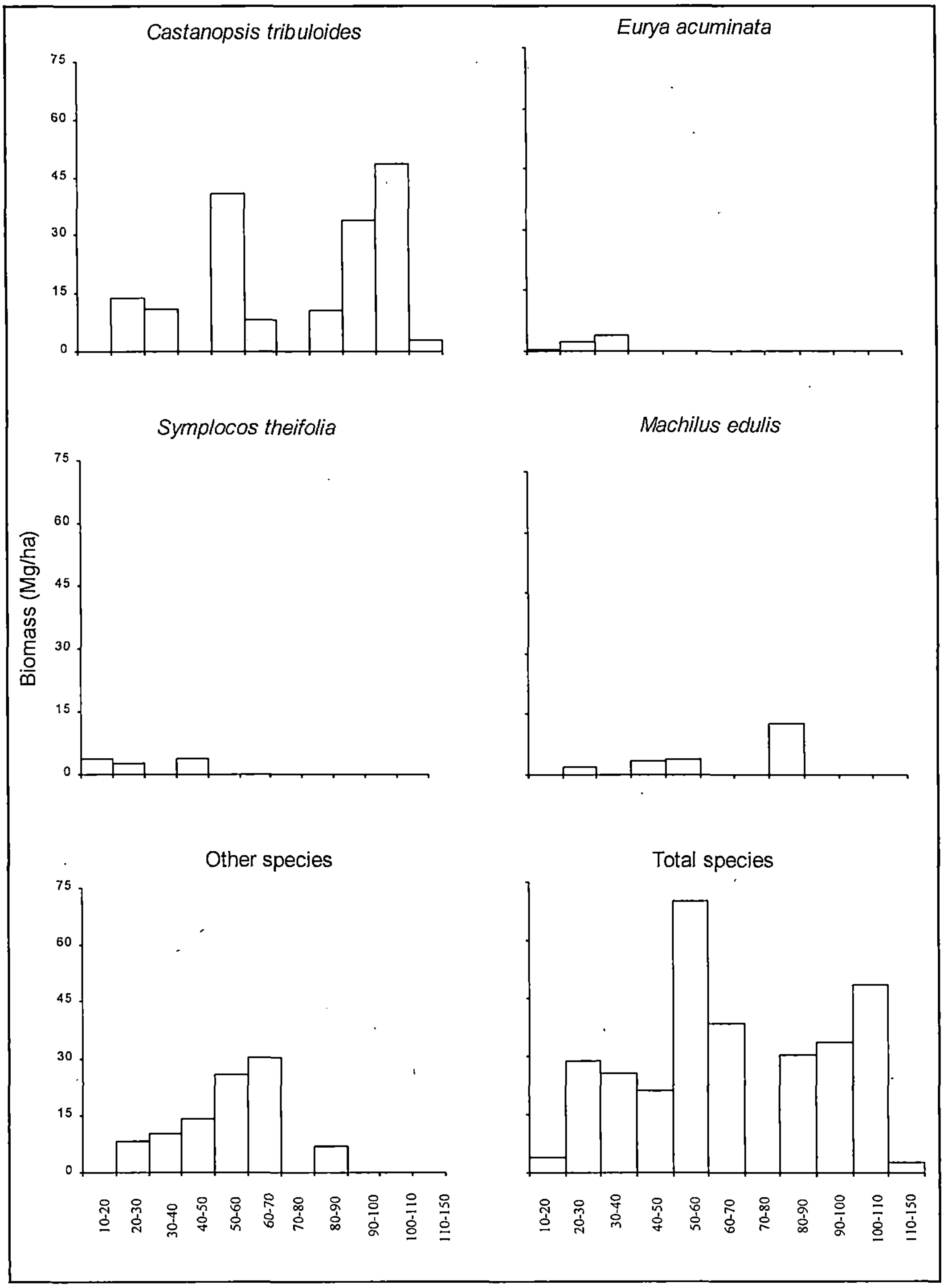

Fig. 5.5 Diameter class distribution of biomass of some important tree species, "Other species" and "Total species" in the Khecheopalri lake watershed forest.

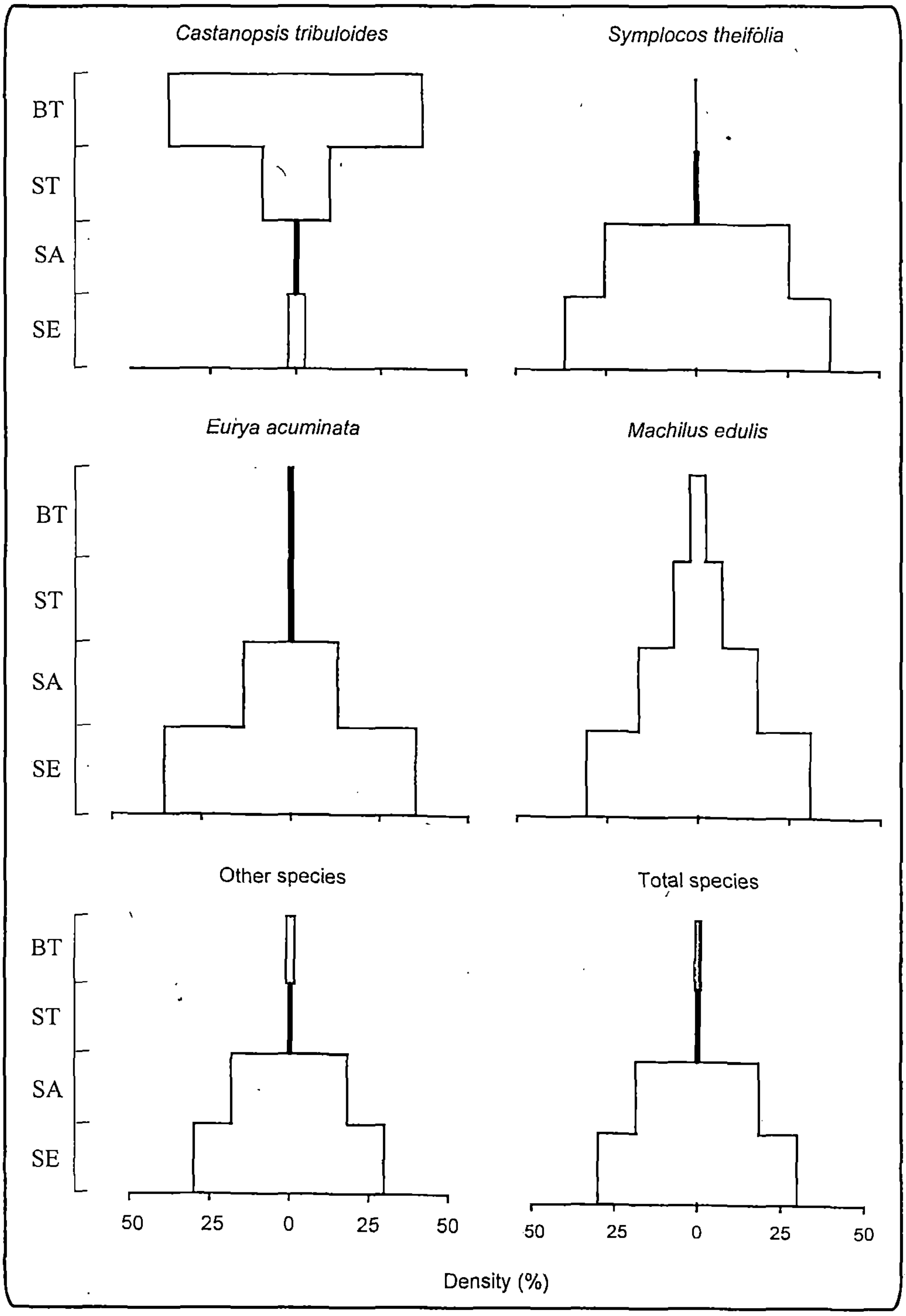

Fig. 5.6. Percent density of canopy (*Castanopsis tribuloides*), middle canopy (*Machilus edulis*), sub canopy (*Symplocos theifolia* and *Eurya acuminata*), "Other species" and "Total species"in different life stage classes (SE=Seedling height <20 cm, SA=Sapling height >20 cm butDBH<10 cm, ST = Small trees diameter >10 cm but <30 cm and BT=Big trees diameter >30 cm) in the lake watershed